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INTRODUCTORY SURVEY OF RADAR
PART II

A non-technical account of selected airborne equipments

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INTRODUCTORY SURVEY OF RADAR

PART II

A NON-TECHNICAL ACCOUNT OF SELECTED AIRBORNE EQUIPMENT

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AIRCRAFT INTERCEPTION

INTRODUCTION

1. Aircraft interception equipment, commonly known as AI, is used to detect and intercept aircraft at night or under conditions of bad visibility. The basic principles of operation are similar to those employed in other radar apparatus. Short radio frequency pulses are transmitted from an aerial mounted on the aircraft, and reflections are returned from objects within range, including other aircraft. The returning echoes are received, and the range and direction of the reflecting object can be found by interpreting the picture on the cathode ray tube.

2. The earlier airborne radar devices had a maximum range of two to three miles, but in later designs this range has been increased to about six miles. It can be shown that this rather limited range makes it unlikely that a fighter will be able to detect an enemy aircraft unless the position of the latter is already known with some certainty. Usually the enemy is first picked up by a powerful ground station, which can also locate the fighter. This is the function of GCI stations. (Ground Controlled Interception). The ground controller can give flying directions, course and altitude, to the pilot and bring him on the track of the enemy, so that AI contact may be established. Up to the present time most of the interceptions have been carried out with the help of ground control. Sometimes, however, fighters patrol in a region where enemy activity is probable, and rely on their own radar to find a target; this is known as "freelancing." The control of large numbers of fighters by GCI stations is a difficult problem, but as airborne radar design improves maximum ranges will increase and freelancing will be more profitable. The night fighter will then be less dependent on ground control.

3. AI equipment requires an operator, and it is, therefore, installed in two-seater fighters. Beaufighters, Havocs and Mosquitoes are used. The ground controller tells the pilot where to fly, and continues to vector him over the radio telephone until his own operator picks up a "contact." The operator then controls the interception by giving the pilot oral instructions over the aircraft intercommunication system. The pilot may request the operator to bring him in from above or from below, according to weather conditions. On moonlit nights with a carpet of white cloud, the visibility will be better from above the enemy, but on moonless nights visibility may be down to a few hundred feet, and will be better from below. When the fighter is behind the enemy and the range is down to 1,000 feet or less, the pilot keeps a sharp lookout for the other aircraft. When he obtains a "visual" he identifies, and goes in to attack. Two points here are noteworthy. First, airborne radar is not yet accurate enough for blind firing. Second, radio identification of aircraft (*see* IFF, Chapter 6) is not sufficiently certain for the fighter pilot to attack without visual recognition. The second point is important because visual identification at night is difficult, and often takes some time, so that the enemy may find out that he is being followed and take evasive action.

The different marks of AI

4. *Mk. IV* is the first type of AI described, as the earlier marks were experimental in nature and large scale production was not carried out. Mk. IV, on the other hand, has had considerable operational success, and was still being manufactured and used at the time of writing (September, 1943). It was first flown by the R.A.F. about December, 1940.

5. *Mk. V* which was introduced slightly later, was a design developed from Mk. IV. Its use provides an exception to the statement that the operator controls the interception by giving the pilot oral instructions. The Mk. V operator was responsible for working the set, but the pilot was equipped with a cathode ray tube indicator of his own, so that he was not dependent on oral information. Very few Squadrons were fitted with AI Mk. V.

6. *Mk. VI* differed from the others in being the only equipment which could be used in single seater fighters. A pilot's indicator was fitted, and no operator was required. Experience showed, however, that an operator could be a great help to a pilot during an interception. The apparatus itself was more complex and had less range than Mark IV. Only a few aircraft were fitted with Mark VI.

7. *Mk. IV, V and VI* transmitted on 1½ metres, but all later designs used centimetre wavelengths. The improved performance obtained by this reduction in wavelength was so great that earlier 1½ metre systems are obsolescent. The advantages of centimetre transmitters will be discussed later. Mk. VII which works on 9 cm., was the first of the new designs. It was introduced to the Services in January, 1942 for defence against low-flying aircraft. Only about 50 aircraft were fitted to tide over the interval while the Mk. VIII was finalised. The 9 cm. AI Mark VIII became operational in December, 1942. An American

AI equipment known as SCR.720 or AI Mk. X was sent to this country, and was flown by the R.A.F. This also used a wavelength of 9 cm., and a short account of the display system used is given later.

AI MK. IV

General principles of operation

8. The AI Mk. IV aerial polar diagrams are given in fig. 1, and the aerials are shown in fig. 2. A transmitting aerial is fixed to the nose of the aircraft so that radiation is sent out mainly in the forward direction as shown in fig. 1 (A). The transmitter field extends to either side, and above and below the aircraft, but there is little radiation in a backward direction.

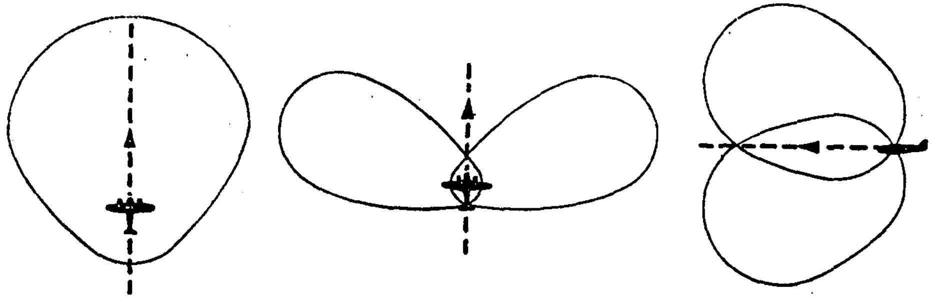
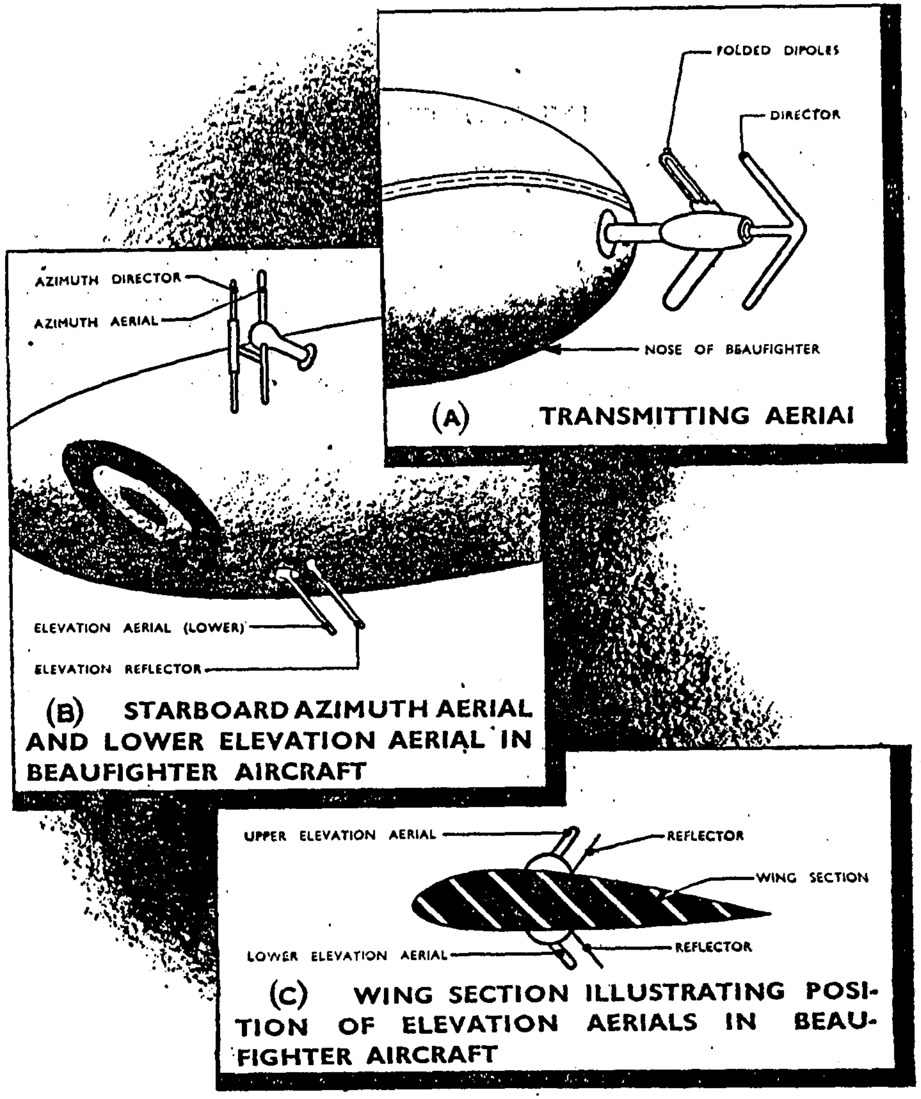

(A) Transmitter aerial (B) Azimuth receiver aerial (C) Elevation receiver aerial

Fig. 1.—AI Mk. IV., typical aerial polar diagrams

9. In Beaufighter installations the azimuth aerials are mounted on the leading edge of the wings. These aerials are directional. The port aerial favours the reception of signals originating from targets to the left of the line of flight, while the starboard aerial favours those coming in from the right of the line of flight. This is brought about by the screening action of the body of the aircraft, and by fitting the aerials with directors to increase their natural directional properties. The polar diagram of the azimuth receiving aerials is shown in fig. 1 (B).

10. The elevation aerials, which are also directional, are placed above and below the starboard wing, and have reflectors fitted behind them. The metal wing acts as a screen so that the upper aerial can best receive signals from above the fighter, and the lower one can best receive those coming in from below, *see* fig. 1 (C). It is important to realise that the direction-finding properties of the equipment are derived from the receiving aerials only.



(A) TRANSMITTING AERIAL

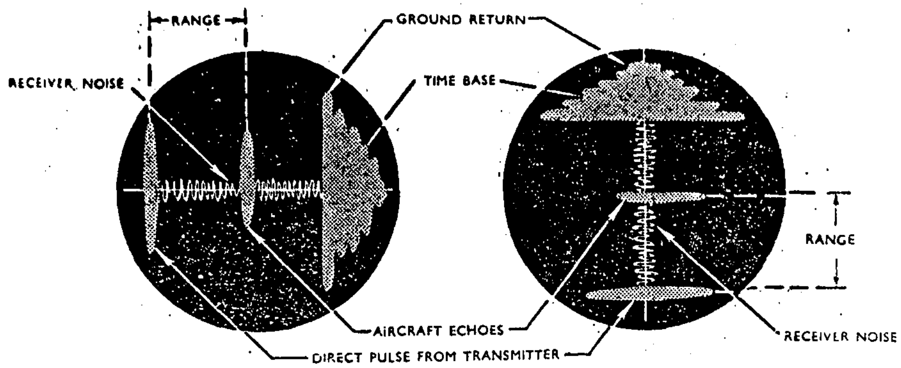
(B) STARBOARD AZIMUTH AERIAL AND LOWER ELEVATION AERIAL IN BEAUFIGHTER AIRCRAFT

(C) WING SECTION ILLUSTRATING POSITION OF ELEVATION AERIALS IN BEAUFIGHTER AIRCRAFT

Fig. 2.—AI Mk. IV., aerials

11. The operator is provided with two cathode ray tubes. The elevation tube, on the left, has a horizontal trace beginning at the left-hand side of the tube. The right-hand tube is for azimuth, and the trace starts at the bottom. Typical indications are shown in fig. 3.

12. Suppose that there is a target two miles from the fighter, above and to starboard. The return echo will be received on both azimuth aerials, but the starboard aerial will produce a larger signal than the port one. It is arranged that the starboard signal appears only on the right-hand side of the azimuth trace, whereas the signal from the port aerial appears only on the left-hand side. By comparing the amplitudes of the *blips* on the ziamuth tube the operator determines the bearing of the target.



Elevation tube Azimuth tube

Fig. 3.—AI Mk. IV., typical indications

13. In a similar manner the signals from the upper and lower elevation traces appear above and below the trace on the elevation tube only. When the blips on each tube are equal the enemy is dead ahead of the fighter. The range is read off in the usual manner as illustrated in fig. 3.

Minimum range

14. At the beginning of the trace there appears a large blip produced by the direct pulse from the transmitter. This is known as *transmitter break through* and is so strong that it would upset the functioning of the receiving channel. The latter is, therefore, suppressed, or automatically rendered insensitive, until the transmitter pulse is just finishing. If the receiver is made sensitive too soon, echoes from short range targets are masked by the powerful direct pulse which tends to extend a short distance along the trace. But if it is made sensitive too late, targets at short range will obviously not be seen at all. Hence, to get a good minimum range the receiver must be " opened up " or made sensitive at just the right moment, that is when the direct pulse is just dying away. To bring about this condition the operator has a control, which, on Mk. IV, is marked OSCILLATOR BIAS. It is normally set so that the back edge of the direct pulse is just showing. The operator usually experiments with this control to find the best setting by flying close behind an aircraft during the day.

15. Assuming the oscillator bias control to be correctly set, the minimum range of Mk. IV is about 400 feet. The question of suppressing the receiving channel while the transmitter is active has been mentioned here, because it is a general principle which is applicable to all the AI receivers from Mk. IV to Mk. VIII. In each equipment there is a control analogous to the oscillator bias, which is set during flight to give the best minimum range.

Maximum range

16. In additon to echoes from aircraft a large echo is produced by ground reflection. This is called *ground return*, and it appears on the tube as an extensive echo rather like a Christmas tree in shape. The leading edge of the ground return is at a range corresponding to the height of the aircraft above the land over which it is flying. Unfortunately the ground return is very strong indeed compared with aircraft returns, and consequently there is no chance of detecting aircraft at ranges greater than the height of the fighter aircraft. This is the most serious limitation on the performance of AI Mk. IV. Note, therefore, that above 18,000 feet the maximum range of the equipment is of the order of 3½ miles, but below this height the maximum range is limited to the height of the fighter. This is illustrated in fig. 9.

17. Sea returns are somewhat less extensive than ground returns, and, in favourable circumstances, targets at ranges greater than the height may be detected.

Sensitivity of direction finding

18. In carrying out an interception it is not necessary for the operator to make an accurate estimation of the angular position of the target. Instead he instructs the pilot to turn until the azimuth signals are equal, and then the elevation signals are equalised by climbing or diving as the case may be. The sensitivity of AI Mk. IV is then such that a target displacement of 5 deg. from the line of flight may be observed.

Facilities for identification of friend or foe

19. Aircraft fitted with AI Mk. IV may carry a small interrogator transmitter which is used when the operator wishes to find out whether a target he has contacted is friendly or otherwise (*see* IFF, chapter 6). Many friendly aircraft which are used at night carry an IFF responder. When the operator presses his interrogator button the auxiliary transmitter sends out pulses which trigger off the responder on a friendly

aircraft. The pulse from the responder appears with the target blip on the trace. Since echo and responder signal have to cover the same range they appear at the same point on the traces. The echo, however, lasts only for about a microsecond whereas the IFF response may be either 7 or 20 microseconds according to the code which is being used. These are known as the *short* and *long* responses respectively. It is arranged that the IFF responder only operates at intervals of about 3 seconds so that the IFF signal appears and disappears on the tube. The responder may be adjusted to give out different sequences of short and long pulses according to a pre-arranged code. The appearance of a short IFF response is shown in fig. 4, but the intermittent nature of the response is not apparent from the diagram.

Elevation tube

IFF. response, a wide echo appears on the trailing edge of the target echo

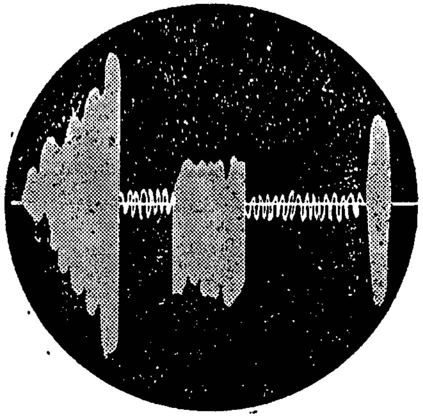


Fig. 4.—AI Mk. IV., IFF response

Homing beacons

20. By operating a switch the timebase range can be increased to 60 miles for a homing beacon. This may be triggered off by the Mk. IV transmitter itself, (*see* Beacons, chapter 6). At extreme ranges the beacon signal is usually most easily picked up on the lower elevation trace. When the signal has become sufficiently strong, homing is carried out in the usual manner using the azimuth tube.

AI beam approach (AIBA)

21. When the pilot has come to within 8 to 10 miles of base the operator may pick up a beam-approach beacon (BABS) which should enable him to bring the aircraft in along the lines of the runway. The beacon is triggered off by the Mk. IV transmitter, and is at the far end of the runway. It radiates a *dot* signal to one side of the runway and a *dash* signal to the other side. These signals are of 0·2 sec. and 1·2 sec. duration respectively. To the left of the runway the dot signal has a greater amplitude than the dash, while to the right of the runway the opposite holds good. In line with the runway the two signals have equal amplitude and they merge to form one continuous signal.

A—Aircraft too much to port. Dot signal jumps out to greater amplitude for 0·2 seconds every second every 1·2 seconds

B—Aircraft too much to starboard. Dash signal. Signal diminishes in amplitude for 0·2 second every 1·2 seconds

Fig. 5.—AI Mk. IV., indications from beam approach beacon in azimuth tube

22. These signals are received on either of the AI Mk. IV traces. Consider the right-hand azimuth trace. When in line with the runway the BABS signal will be dead steady. If the aircraft is too far to port it will be in the *dot* region and the signal will tend to shoot out to the right for 0·2 sec. every 1·2 secs. as indicated by the dotted line in fig. 5. If the aircraft is too far to starboard, it will be in the *dash* region and the signal will tend to shoot back towards the timebase. The range is read in the usual manner (*see* chapter 6 on Beacons and fig. 17 (A) and 17 (B).

23. The above-mentioned equipment enables a pilot to make a beam approach in conditions of bad visibility, but it is not accurate enough for carrying out a blind landing. The ground must be visible for the final touch-down.

24. The general performance of AI Mk. IV, and the facilities available to the operator have been described, but, before concluding, there is one technical point which should be mentioned. As the signals from each of the four receiving aerials are applied to four deflecting plates of the cathode ray tubes, it might be thought that four receiving channels would be required. This is avoided, however, by a switching arrangement

shown in fig. 6. The signals from each aerial are received in turn and switched on to the appropriate plate of the tube. This is done by two rotary switches, each with four fixed contacts and one moving contact. These connect the receiver to each aerial in turn, and at the same time switch the output to the correct plate. The switch revolves 25 times per second so that the indications on the tube appear continuous.

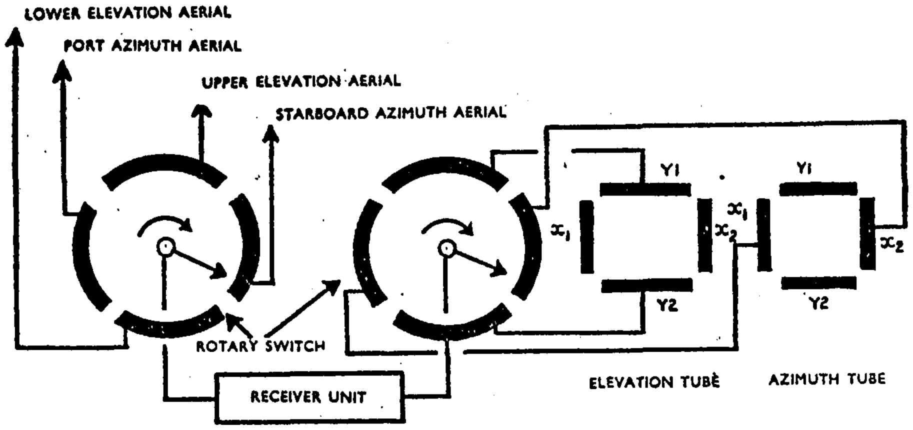


Fig. 6.—AI Mk. IV., schematic diagram of the aerial switching

Leading particulars

25. The following are the leading particulars of AI Mk. IV ARI. 5003:—

Wavelength, 1·5 metres; approximately 193 Mc/s.
Pulse recurrence frequency, 750 p.p.s.
Pulse width, 2·8 microseconds.
Peak pulse power, 10 kW.
Aerial systems; half wave dipoles, vertical polarisation
  Maximum range, over 18,000 feet, 3½ miles.
  Minimum range, 400 feet.
  Sharpness of DF at dead ahead, ±5 deg.
Facilities for IFF, Homing beacon and Beam approach
Units:

Modulator, type 20. Produces 7 kV pulse.
Transmitter, type T.3065. Output valves VT90
Receiver, type R.3102A. Two RF Stages. 3 IF Stages. IF frequency, 45 Mc/s.
Indicator, type 48. Two tubes, azimuth and elevation, exponential timebases.
Power supply, 500 watt, 1,600 cycle,
80-volt engine-driven alternator, with control panel, type 3.
Weight, 118lb.

AI MK. V

General principles of operation

26. AI Mk. V was designed so that the operator need not instruct the pilot orally during the interception. The pilot is provided with an indicating tube of his own, and on this the information is displayed in a manner which can be easily read. The transmitting and receiving aerial systems are similar to those described for Mk. IV and the direction-finding properties of the equipment are due to the orientation of the receiving aerials as before. The observer's display, however, is slightly different.

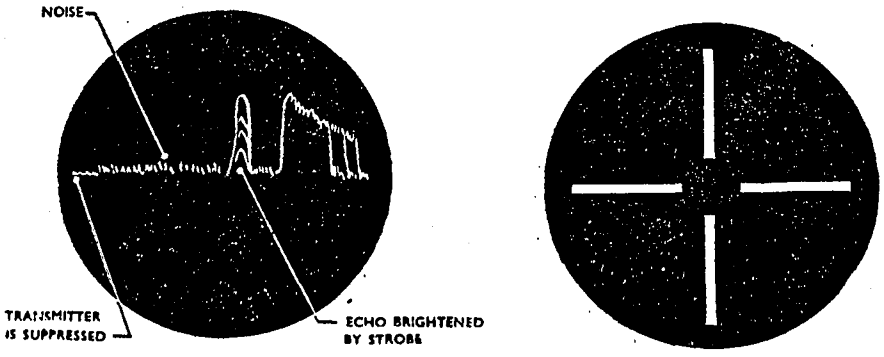
27. In operating AI Mk. IV the observer must interpret his picture and tell the pilot what to do. This introduces a time delay which must be cut to a minimum if a dodging target is to be successfully followed. There are several sources of error; the operator may mis-interpret the picture; he may give a wrong instruction; the pilot may fail to hear the observer's message, and a repeat may be necessary. AI Mk. V is designed to try to overcome some of these difficulties by providing a pilot's indicator. An operator is still required to work the equipment but the information is relayed electrically to the pilot.

28. The desirability of a pilot's indicator is a highly controversial question. There are a few disadvantages, for example, the pilot must divide his attention between looking out into the darkness for the enemy and watching the tube. Up to the present, the method of giving oral instructions, and leaving the pilot free to look out for the enemy, seems to be most successful.

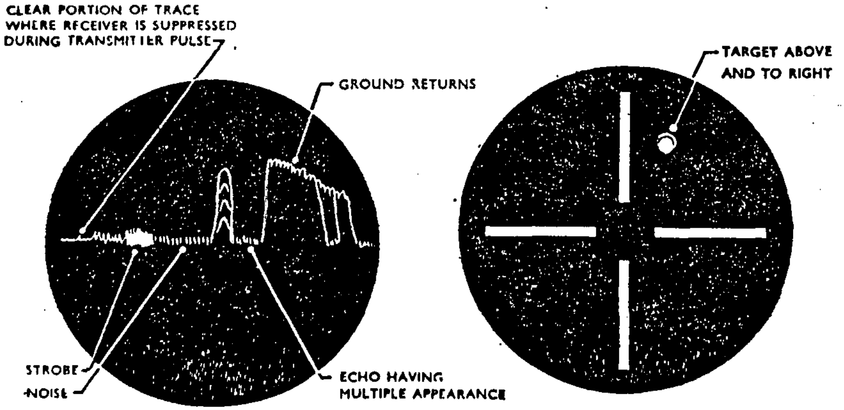
29. Mk. V equipment has been fitted to a small number of aircraft only, and is obsolete. The display system, however, is of interest, because a pilot's indicator with a similar presentation may yet be used in future Marks of AI.

30. The operator's display system consists of two tubes. The left-hand tube bears a horizontal range trace, fig. 7 (A). Before establishing a contact, receiver noise and ground returns are seen on this trace. During the time when the transmitter is firing the receiver is suppressed

so that no direct pulse is visible at the beginning of the timebase. A small portion of the trace, equal in length to one-third of a mile, is exceptionally bright. This bright patch is known as the *strobe*, and by turning the *strobe control* it can be moved along the timebase to any desired position. The observer's right-hand tube indicates direction—azimuth and elevation—by the movement of a spot. It is marked with cross lines as shown in fig. 7 (B), and is known as *spot indicator*. Before contact is established this tube is switched off, only the left-hand tube being used for searching.



(A) Operation range tube (B) Operator's direction-finding tube (Switched off)



(C) Operator's range tube target strobed (D) Operator's direction finding tube (Switched on after contact)

Fig. 7.—AI Mk. V., observer's cathode ray tubes

31. The operator first watches the range tube until an echo appears. The echo has a multiple appearance because the signals from each one of the four receiving aerials are superimposed on the tube. The operator turns the strobe control until the bright patch coincides with the echo, he then switches on the right-hand tube, and a single spot appears on it. The position of the spot indicates the position in azimuth and elevation of the target echo which has been strobed. Fig. 7 (C) shows the condition when the echo has been strobed, and fig. 7 (D) the condition when the spot has moved to a position in the right-hand upper quadrant, showing that the target is to starboard and above the fighter.

The pilot's indicator

32. The markings on the face of the pilot's tube are shown in fig. 8. During the searching process the tube is blank, indicating that no contact is available. When contact is established, and the operator switches on his own spot indicator, a spot also appears on the pilot's tube giving simultaneous directional information. Moreover, when the range of the target aircraft has decreased to 7,500 feet, short horizontal lines called *wings* appear on each side of the spot on the pilot's tube. They grow longer as the range between target and fighter diminishes until at 2,500 feet they just span the central U-shaped marking. At this point the pilot should throttle back until the fighter is flying at the same speed as the target. Some time is required for a night fighter to lose speed and unless this precaution is taken the fighter may overshoot the target. At 1,000 feet the wings reach the two vertical lines called the *goal posts*. When the spot is just level with the top of the U, the fighter is in the best position for attack. Finally the wings exceed the " goal posts " by ½ inch, which position corresponds to a minimum range of 500 feet.

Homing facilities

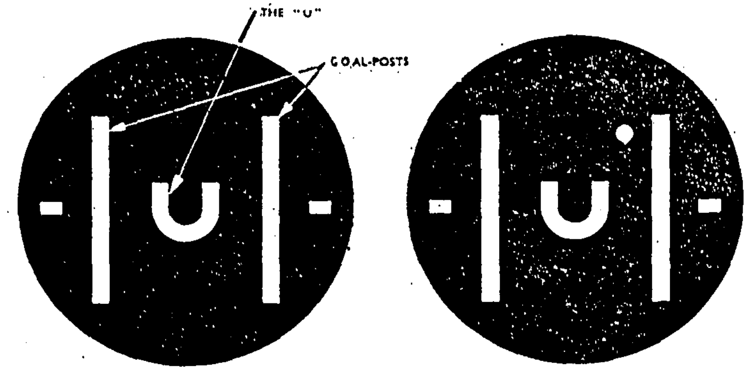
33. For homing on a ground beacon, a switch for increasing the range scale on the operator's tube is fitted. The beacon signal, which appears beyond the ground returns, is selected by the strobe and the directional information concerning it appears on the pilot's indicator, as in the case of an aircraft interception, but only in the azimuthal plane. The aircraft is homed on to the beacon in the same way as on the interception range, but in this case the wings appear at 11 miles, span the U at 4½ miles, and reach the " goal posts " at 1 mile.

34. To sum up, the properties of a pilot's indicating tube are as follows :—

(1) Azimuth and elevation are shown by the horizontal and vertical movement of a spot.

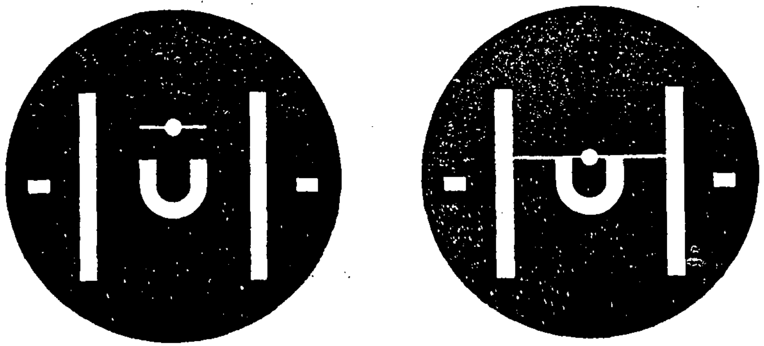
(2) Ranges are shown by a horizontal line through the spot, the line begins to grow at 7,500 feet and spans the tube at 500 feet, minimum range.

(3) No spot indicates no contact.



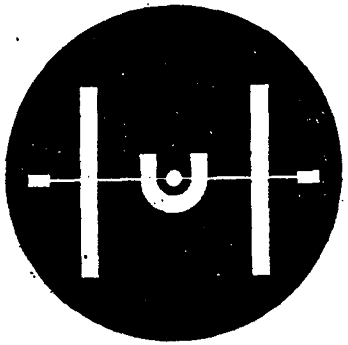
(A) No signal before contact

(B) Spot indication appears at contact target above and to right. Range greater than 7,500 ft.



(C) Target above and dead ahead. Range 2,500 ft.

(D) Target slightly above and dead ahead. Range 1,000 ft.



(E) Target line ahead at minimum range 500 ft.

Fig. 8.—AI Mk. V and AI Mk. VI, screen indications, pilot's tube

Other facilities

35. IFF and beam approach facilities are available exactly as in AI Mk. IV. The operator's range trace is used for both.

Performance

36. As regards maximum and minimum range Mk. V is similar in performance to Mk. IV.

Leading particulars

37. The leading particulars of AI Mk. V (ARI.5005) are as follows:—

Wavelength, 1·5 metres approximately. 193 Mc/s. approximately.
Pulse recurrence frequency, 670 p.p.s.
Pulse width, 2·8 microseconds.
Peak pulse power, 10 kW.
Aerial systems, half wave dipoles as in Mk. IV
Maximum range over 18,000 feet, 3½ miles.
Minimum range, 400 to 500 feet.
Sharpness of DF at dead ahead, 5 degrees.
Facilities for IFF, homing beacon, beam approach.
Pilot's indicator
Units:
Modulator, type 29 produces 5 kV pulse.
Output stage consists of four V.T. 75A valves in parallel.
Transmitter, type T.3100. Two VT90 valves in push-pull.
Receiver, type R.3085: 2 RF stages, 4 IF stages; IF frequency 27 Mc/s. Automatic gain control. Strobe circuit.
Indicator, type 41. Exponential range scan. Spot indicator tube.
Pilot's indicator, type 42. Spot indicator with range wings.
Control unit, type 87, Pilot's control unit.
Power supply. 80-volt, 500 watt, 1,600 c/s, engine-driven alternator with control panel, type 3.
Weight 135 lb.

AI MK. VI

General principles of operation

38. AI Mk. VI is noteworthy as being the only equipment designed for use in single-seater fighters, the main feature being that no operator is required. When the pilot has switched on and made a few preliminary

adjustments, no controls should require attention during an interception. Information is displayed on a pilot's indicating tube which is exactly the same as that described for Mk. V.

39. AI Mk. VI has been very little used. It has been fitted to a few Defiants and Hurricanes. For the present the two-seater centimetre equipments hold the field and the few Mk. VI installations can be regarded as little more than experimental.

Method of operation

40. The basic principles of the display system can be most readily grasped by thinking of the equipment as a form of Mk. V wherein the operator's task is performed automatically. Let us review the duties of a Mk. V operator. He must first switch on and adjust the tube controls; he then proceeds as follows:—

(1) An echo is detected and strobed.

(2) The spot is switched on to the pilot's tube to indicate a contact.

(3) The echo is strobed continuously until minimum range is reached.

41. With the Mk. VI the pilot himself switches on the set and adjusts the tube brightness and background controls. As there is no operator's range tube, the strobe pulse cannot be seen. Such a pulse is however developed by the strobe unit, and it is easier to describe what happens if one imagines an extra range tube fitted to show the strobe and the echoes. Such a tube is added when the equipment is fitted in a two-seater aircraft accommodating an operator.

42. The AI Mk. VI strobe movement is entirely automatic. During the searching process the strobe starts at zero range and drifts along the timebase, taking about four seconds to cover a range of six miles. If no blip is encountered it returns to the beginning of the timebase and repeats the process until it encounters a blip when it stops drifting and *sticks* to it. The bright spot then appears automatically on the pilot's tube showing the direction in azimuth and elevation of the target. As the target range diminishes the strobe range diminishes also, until minimum range is reached. Wings grow on the pilot's tube as previously described.

43. Precautions must be taken to prevent the automatic strobe sticking to the ground return, as if this happened the spot would fly down to the bottom of the pilot's tube, thus indicating a target vertically below the fighter. The ground return, however, is rather extensive compared with narrow echoes from aircraft. The strobe circuit is designed so that the ground return is rejected on account of its greater width. On. encountering the ground return the strobe starts drifting again from the beginning of the trace.

44. The direct pulse from the transmitter must be eliminated by suppressing the receiver for the short time while the transmitter is firing. Otherwise the automatic strobe will stick to the direct pulse. The receiver suppression control is usually adjusted when flying above 5,000 feet so that the pulse echo at minimum range disappears. This need be done only at the beginning of a flight.

45. A press switch called the *panacea button* is also fitted for the following purposes.

(1) If a spot has appeared on the pilot's tube, indicating a target, the pilot may wish to reject it to search for another. He then pushes the panacea button, and the strobe pulse begins to search again. Should there be no other target within maximum range the strobe will return to the original one and the spot will reappear on the tube.

(2) Normally when seaching there is no spot visible on the tube and the pilot has therefore no indication of the state of serviceability of the apparatus. He may then hold the panacea button in. The spot should then appear with the wings expanding and contracting regularly. This shows that the strobe is searching and the equipment is functioning properly.

Performance

46. AI Mk. VI has not been produced in quantity. This may be due in part to the development of centimetre equipment about the time when the equipment was introduced. But a few disadvantages of the automatic strobe are rather important:—

(1) It is difficult to get the automatic strobe to stick to a weak echo. In practice this makes the maximum range poorer than that of AI Mk. IV—probably about 2½ to 3 miles.

(2) It is difficult to get the spot to move rapidly enough to deal with a dodging target.

(3) The strobe circuits are complex and servicing is more difficult.

(4) As already mentioned, the pilot has the difficult task of watching the tube and looking out into the darkness to catch sight of the enemy. To become expert in the use of the pilot's indicator requires considerable skill and practice.

47. The spot indication with range wings is, however, a method of display which is easily interpreted and is therefore suitable for a pilot's indicator. It is a method which may possibly be used in future Marks of AI.

48. There is no provision made for receiving IFF or beacons on AI Mk. VI equipment which is fitted with a pilot's indicator only.

Leading particulars

49. Leading particulars of AI Mk. V (ARI.5006) are as follows :—

Wavelength 1·5 metres approximately.
Frequency band 193 Mc/s.
Pulse recurrence frequency, 670 p.p.s.
Pulse width, 2 microseconds.
Peak pulse power, 10 kW.

Aerial systems, half wave dipoles as in Mk. IV.
Maximum range 2½ to 3 miles.
Minimum range 500 feet.
Sharpness of DF at dead ahead, 5 degrees.
No facilities for beacons or IFF on pilot's indicator.
No operator required.

Units
Modulator type 16, produces a 2-microsecond pulse, output stage consists of 4 VT75A valves; delay network used for shaping modulator pulse.
Transmitter, type T.3074. Two type VT90 valves in push-pull.
Receiver, type R.3075
(a) Receiver unit, type 36 : 2 RF stages, 4 IF stages, IF frequency 20 Mc/s, automatic gain control.
(b) Automatic strobe unit, type 2.
Indicating unit, type 30, pilot's indicator.
Indicating unit, type 32, observer's indicating unit (if fitted).
Control unit, type 67, main switch, panacea button.
Control unit, type 96, tube controls.
Power supply 500 watts, 80 volts, 1,600 c/s engine-driven alternator and control panel, type 4.
Weight 134 lb.

AI MKS. VII AND VIII

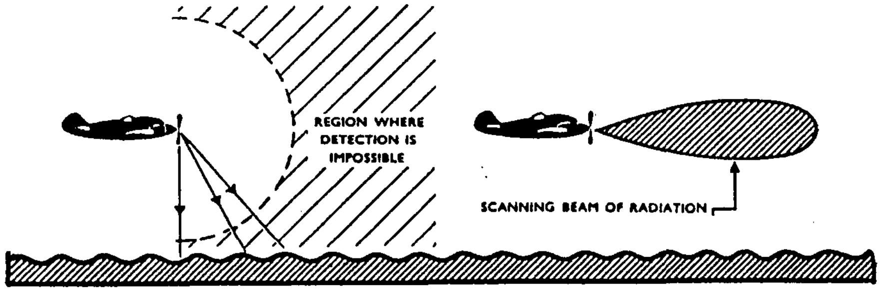
General principles of operation

50. The most outstanding feature of recent designs of AI equipments is the use of very short wavelengths of the order of 9 centimetres. Before the introduction of centimetre radiation, wavelengths were of the order of 1½ metres and it was quite impossible to obtain a narrow beam without using an aerial array too large to install in an aeroplane. The transmitter was designed to send out a very broad beam, and much of the radiation struck the ground. The target response was therefore obstructed by the ground return whenever the range of the target was greater than the height of the fighter. The earlier marks of AI equipment were therefore unsuitable for intercepting low-flying aircraft, as the maximum operational range was strictly limited to the height at which the fighter was patrolling.

51. When a 9 cm. transmitter is used a 12-degree beam can be produced by quite a small aerial system so that there is no reflection from the ground when the beam is horizontal or pointing upwards, *see* (fig. 9). The maximum range of the apparatus for the detection of aircraft is then independent of the height above ground. This is, of course, of the greatest importance.

AI Mk. VII

52. After AI Mk. IV had been used with considerable success against fairly high-flying enemy aircraft, it became clear that a more highly-beamed device was desirable for interceptions at low altitudes. Fortunately a transmitting valve called a magnetron had been developed which gave out considerable power at very high frequencies. In the spring of 1941 an experimental AI was flown in which a magnetron transmitter was fitted. The test flights were successful, and it was thought that a dangerous delay might occur if production was held up while the design was being finalised. A small number of equipments were therefore manufactured for immediate use. This interim equipment was called AI Mk. VII, and, because it was produced quickly, certain facilities had to be omitted ; for example, no provision was made for receiving beacons or for IFF.



(A) Ordinary AI (B) AI on 9 cm. wavelength

Fig. 9.—Comparison of ordinary AI with 9 cm. AI

53. Four half-squadrons of Beaufighters were fitted with AI Mk. VII, and these achieved a large number of operation successes during the year 1942. Mk. VII was then replaced by Mk. VIII and Mk. VIII A. As Mk. VIII is a more developed form of Mk. VII it is unnecessary to describe the latter, but the following details are noted for comparison.

Leading particulars

54. AI Mk. VII (ARI5049).

Wavelength 9·1 cm., 3,300 Mc/s.

Frequency band S.

Pulse recurrence frequency, 2,500 p.p.s.

Pulse width, 1 microsecond.

Peak pulse power, 5 kW.

Aerial system. Vertical half wave dipole at focal point of paraboloid reflector.

Common transmitting and receiving aerial.

Spiral scan.

Maximum range, 3 miles.

Minimum range, 400-500 feet.

Sharpness of DF, 1·3 degrees at dead ahead.

No beacon or IFF facilities.

No pilot's indicator.

Units:

Modulator, output tetrode, CV44, producing a 5-amp pulse at 10 kV.

Transmitter, CV38, magnetron feeding into a coaxial line.

Mixer, CV43, soft rhumbatron switching valve, crystal mixer.

Receiver, CV37 reflector klystron local oscillator. 4 stages IF. IF frequency, 13 Mc/s. PRF controlled by a Hartley oscillator.

Indicating unit, radial time base. 2-mile and 5-mile ranges.

Power supply. 1,200 watt, 80 volt, 1,600 c/s, engine-driven alternator with control panel, type 5.

AI Mk. VIII

Aerial system

55. The aerial system of AI Mk. VIII consists of a small dipole fixed at the focus of a parabolic reflector about three feet in diameter, (*see* fig. 10). The narrow beam of radiation sent out is not quite parallel-sided, but diverges slightly, forming a beam of width 10 deg. . Radiation returning from a target is received on the same aerial so that reception is only possible inside the same beam as that which comprises the transmitted radiation. The receiver is, in fact, beamed as well as the transmitter. Obviously the beam must be moved about or the chance of detecting an enemy will be remote. The movement of the beam, which is called *scanning*, is effected by rotating and deflecting the parabolic mirror while the aerial remains fixed. The transmitting unit is mounted beside the scanner in the nose of the aircraft (Beaufighters and Mosquitoes being used). The magnetron output is fed to the aerial through a short length of coaxial cable. The nose of the aircraft is made of perspex, a material which is transparent to short wave radiation.

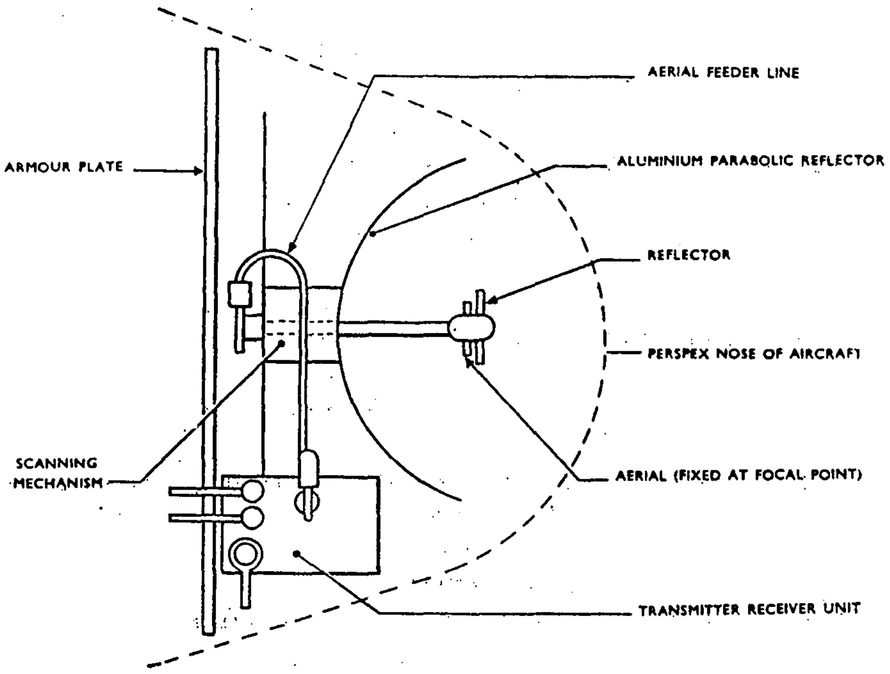


Fig. 10.—Scanning mechanism and aerial system mounted on nose of Beaufighter or Mosquito

Spiral scan

56. The slightly divergent beam is made to scan the space in front of the aircraft in a spiral, which is best described by assuming the aircraft to be fixed horizontally in front of a vertical screen. Consider what would appear on this screen if, instead of radio waves, one had a beam of light (fig. 11). Where the light strikes the screen there appears a circle of illumination whose size will depend on the angular width of the beam, about 12 deg.. Suppose that the scanner is started up, then

the circular spot traces a spiral pattern on the vertical screen. It begins at the centre, spirals out to the edge and then spirals back to the centre again, and so on. In the actual aircraft a complete cycle of this process takes about 1 second. The pitch of the spiral is such that no point on the screen is left un-illuminated. At the extreme edge of the spiral the angle which the beam makes with the line of flight of the aircraft is 45 deg., so that, in front of the aircraft the only region which is scanned is that situated within a cone of 45 deg. semi-angle. This is known as the *cone of search*, and no other region is " visible " with AI Mk. VIII.

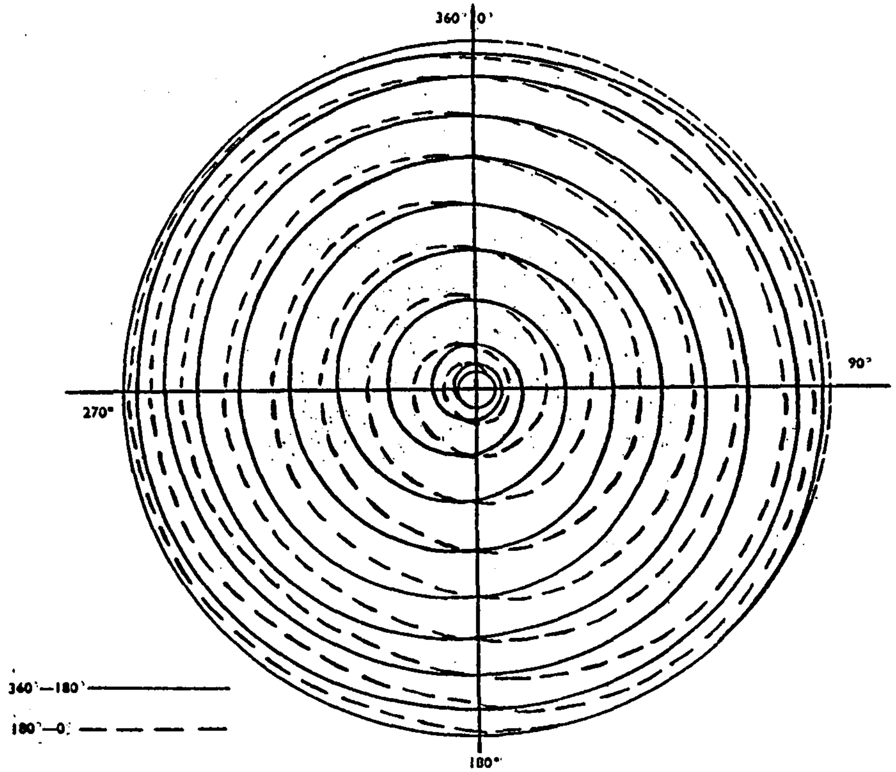


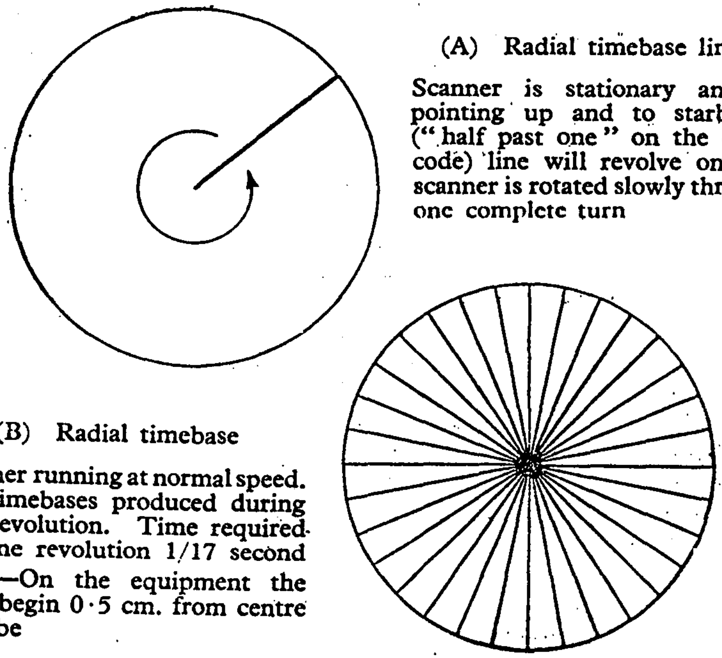
Fig. 11.—Scanning diagram

Radial timebase

57. Consider now the way in which the results are displayed on the cathode ray tube to the observer. Suppose that the scanner is not running and the tube brilliance is turned up more than is normally the practice during actual operation. A radial timebase line will appear, starting at the centre of the tube and proceeding outwards towards the edge. The direction of the line is determined by the direction in which the radial beam is pointing at that instant, *see* fig. 12(A). If the scanner is turned slowly so that the radiated beam traces out one turn of its spiral, the radial timebase line will make one revolution on the tube. If, however, the scanner runs at normal speed, one turn of the spiral is completed in so short a time that the tube appears to be filled with radial lines as shown in fig. 12(B). These lines are of course being traced in succession round the tube, but the movement is so rapid that only the complete picture is observed. Actually the beam completes one spiral in 1/17th of a second during which period 150 timebases are produced, so that the radial lines have a separation of about 2½ degrees on the tube face.

Range and direction finding properties

58. If the tube brilliance is turned down until the timebase lines have just vanished, as in the correct operational setting, and if a signal is received from a target, it is applied to the cathode ray grid so that the timebase is brightened up at a point corresponding to the range of the aircraft, then, as the beam of radiation sweeps over a target in front of the aircraft, bright spots on successive timebases will produce an arc of a circle on the tube, as shown in fig. 13. The distance of the arc from the tube centre indicates the range of the target.



(A) Radial timebase line

Scanner is stationary and is pointing up and to starboard (" half past one " on the clock code) line will revolve once if scanner is rotated slowly through one complete turn

(B) Radial timebase

Scanner running at normal speed. 150 timebases produced during one revolution. Time required for one revolution 1/17 second

Note—On the equipment the lines begin 0·5 cm. from centre of tube

Fig. 12.—AI Mk. VIII, radial time base development

59. The position of the arc on the tube face gives indication of the target's position on a clock code, so that the observer may inform the pilot in which direction to look for his target. Hence if the arc appears at " 12 o'clock " on the tube the target is at some point above the fighter. If it appears at " 3 o'clock " on the tube, the target is at the same height as the fighter and somewhere out to starboard, and so on. If the radiated beam is scanning the region in front of the aircraft steadily it will, of course, only hit the target at certain specified intervals, and for the rest of the time no radiation will be returned. One would therefore expect the aircraft response on the tube to appear fluctuating and not continuous; this is in fact the case.

60. Now consider how the tube response is affected by the angular deviation of the target from the centre-line of the aircraft, i.e. from the line of flight. If the target is out near the edge of the scan (say at about 35 deg. from the centre-line) the rather narrow beam will only hit it during a small portion of its complete revolution. The tube will then be brightened up only during a small portion of a revolution of the timebase, that is to say, an arc of small angular length will appear on the tube. If the target is kept at the same range but its angular displacement from the centre-line of the target is made less, then as the scan proceeds the beam will remain on the target for a longer time, that is, for a larger portion of a complete circle. The effect on the cathode ray tube will be to produce an arc of a greater angular length than before. When the target is dead ahead on the centre-line of the aircraft the scanning beam will remain on it for one complete turn every scanning cycle, so that the response on the cathode ray tube will be a complete circle. Hence the angular deviation " off centre " of the target is determined by an inspection of the completeness of the

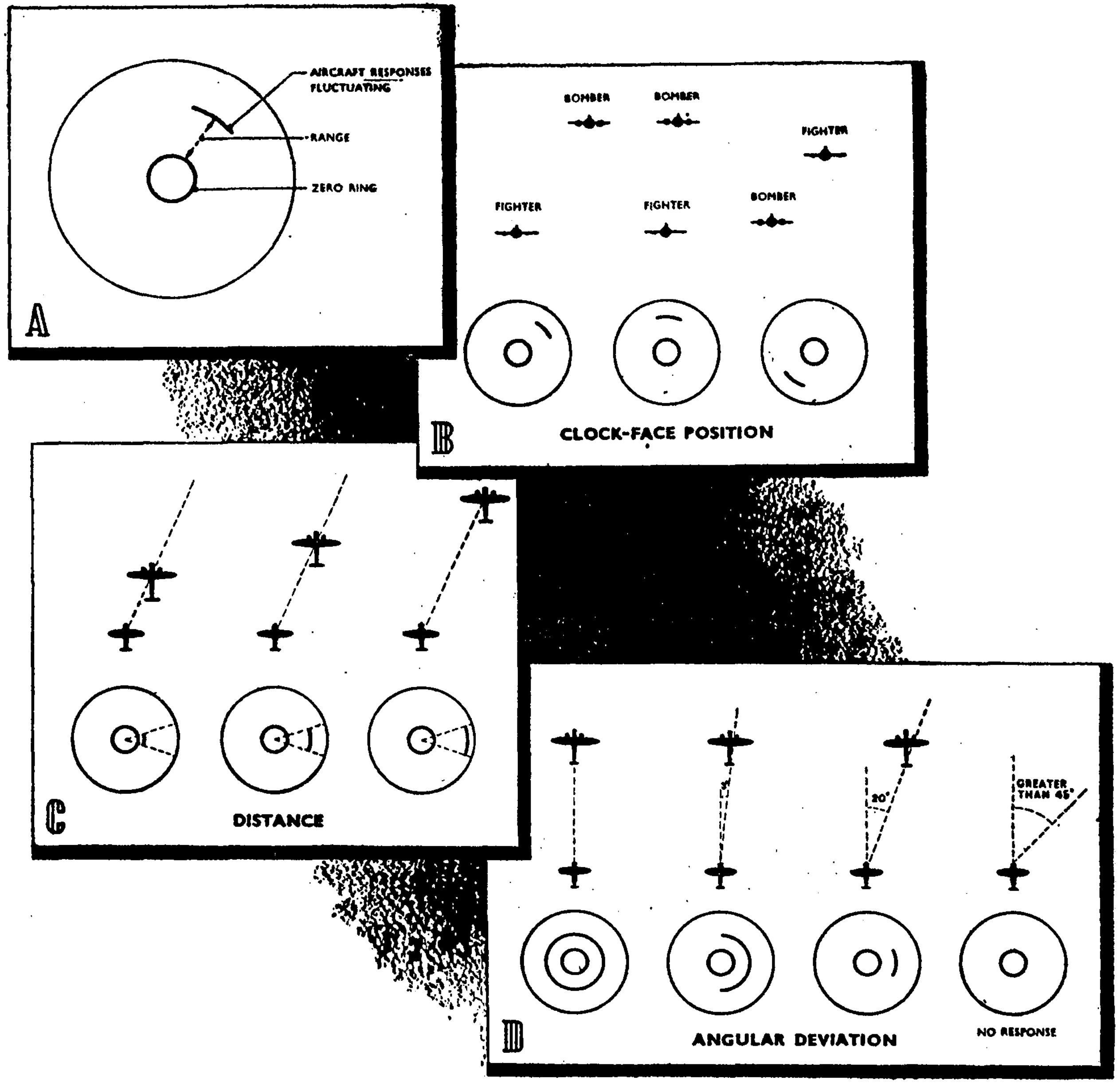


Fig. 13.—ARI. 5093 display system on AI

target arc on the cathode ray tube. The relationship between the position of the target and the appearance on the tube are shown in fig. 13(D).

61. The angular size of the arc on the tube and the angular deviation "off centre" are related as follows :—

	Arc	*Target position*
(Complete circle)	360 deg.	0 deg. off centre.
(Semi-circle)	180 deg.	3 deg. off centre.
	60 deg.	10 deg. off centre.
	30 deg.	20 deg. off centre.
	10 deg.	45 deg. off centre.
	No return	Greater than 45 deg. off centre.

Zero-circle and range marker rings

62. If the range scale on the radial timebase were to start at the centre of the tube, then the arc traced by a target at close range would be a very small circle and it would be difficult to see the details of this trace. It is therefore arranged that the timebase does not start at the centre but at a small distance from it, so that a point corresponding to zero range is represented by a small circle at the centre of the tube. Since the start of the timebase is always brightened up by the direct pulse from the transmitter, this zero ring always appears on the tube, and range is measured from it to the target arc, and not from the centre to the target arc (fig. 13(C)).

63. A range change switch is provided so that two ranges are available.

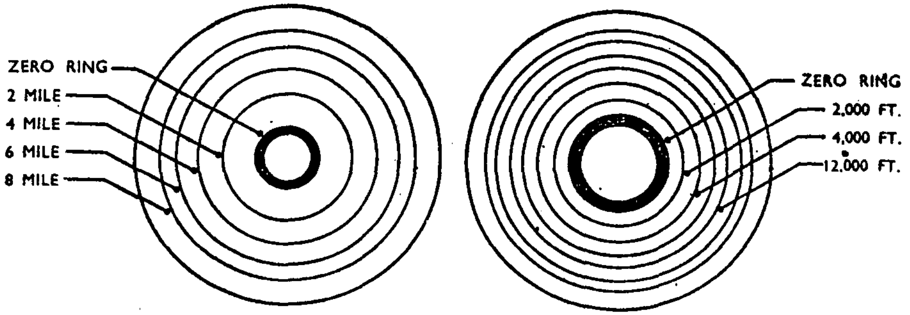
(a) (1) From zero to two miles, the latter being at the edge of the tube.

(2) (b) From zero to eight miles (at the edge of the tube).

If a switch on the indicator unit is pressed, a series of concentric range marker rings appear on the tube. These rings appear every 12,000 feet on the short range and every two miles on the long range (*see* fig. 14).

Ground returns

64. Responses are obtained on the cathode ray tube due to reflections from the ground, but these reflections do not as a rule interfere with the detection of aircraft. There are two kinds of ground returns which produce responses on the display tube, namely (1), ground and sea returns due to the main-beam of radiation striking the earth, and (2), the altitude ring due to stray radiation from the aerial system striking the earth.



Range marker rings on the 0 to 8 mile range

Range marker rings on the 0 to 12,000 feet range marker rings over 2,000 feet

Fig. 14—AI Mk. VIII, marker rings

65. In the earlier Marks of AI, the ground returns were a mass of echoes beginning at a range equal to the height of the fighter. In Mk. VIII, the radiation is concentrated into a beam and the ground returns appear when the moving beam strikes the earth at a point within the maximum range of the equipment. Fig. 15 (a) shows how this happens. As the beam passes over the surface of the earth it traces a path as shown by the line ABC. Therefore the range at which the echoes appear will decrease from a maximum at A to a minimum at B, increasing again to a maximum at C. During this period the timebase has moved from position O^1 A^1 to O^1 C^1, and this variation of range, in conjuction with the rotation of the timebase causes the echoes to appear on a horizontal band $A^1B^1C^1$ across the tube.

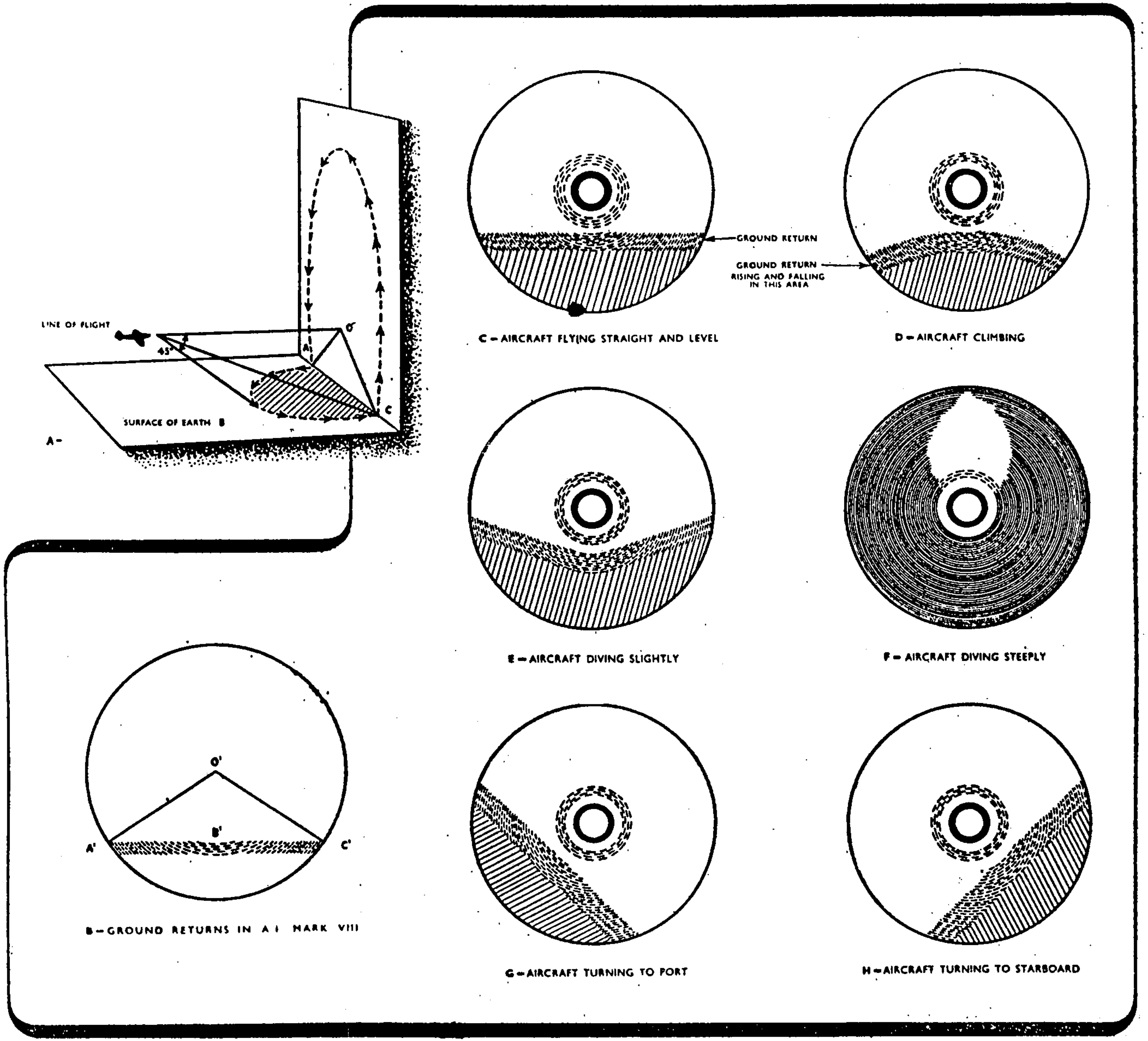
66. Since the beam spirals in and out continuously, the position of the line ABC on the earth's surface changes continuously, and in the innermost part of the spiral it is improbable that the beam will strike the ground within maximum range unless the aircraft is flying at a very low altitude. As the beam moves out there will be a time when it just strikes the earth at maximum range and echoes will appear at the bottom of the tube. Each successive spiral will cause another band of echoes, each one being formed higher up the tube until the outermost spiral has been reached. As the beam spirals inwards the band of echoes will appear successively lower and lower until they vanish. Hence the ground returns appear in the form of a fluctuating pattern of illumination which rises and falls from the bottom of the tube during each scanning cycle. The cycle is repeated about once a second, and the general configuration of the returns depends on whether the aircraft is diving, banking, or in level flight (figs. 15 (C) and 15 (H). Sea returns are much weaker than the corresponding ground returns and in general give no response at all

at maximum range, and weak response at shorter ranges. This is due to the mirror-like reflection of the radiation from the sea which prevents it being so completely scattered back to the aircraft. The returns depend to some extent on the roughness of the sea.

67. *The altitude ring* on the tube is represented by a circle of illumination at a distance corresponding to the height of the aircraft above ground. It is produced by stray radiation which leaks from the transmitting aerial straight to the ground below, is there reflected, and is received by the receiving aerial. This leakage radiation is transmitted and received all the time irrespective of where the main beam is pointing. It therefore occurs all round the scan and correspondingly is shown as a complete circle on the cathode ray tube. The altitude ring is produced because the radiation is not quite perfectly beamed, and if the design of the aerial system were improved, it would be eliminated. The ring gets weaker as the height of the aircraft increases, but at 5,000 feet it may be sufficiently intense to hide a target at the same range.

Performance

68. The average maximum range of AI Mk. VIII is about 5½ miles, but under favourable conditions contacts can be established at ranges up to 6½ miles. The maximum range is not limited by the height as in earlier forms of AI. Above 5,000 feet the ground echo rises only a small distance up the tube, and is not unduly troublesome during the searching process. When the fighter is below 5,000 feet any target flying above



B — GROUND RETURNS IN A I MARK VIII

C — AIRCRAFT FLYING STRAIGHT AND LEVEL

D — AIRCRAFT CLIMBING

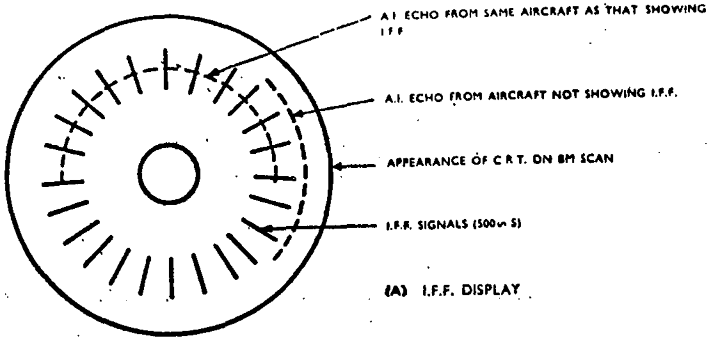
E — AIRCRAFT DIVING SLIGHTLY

F — AIRCRAFT DIVING STEEPLY

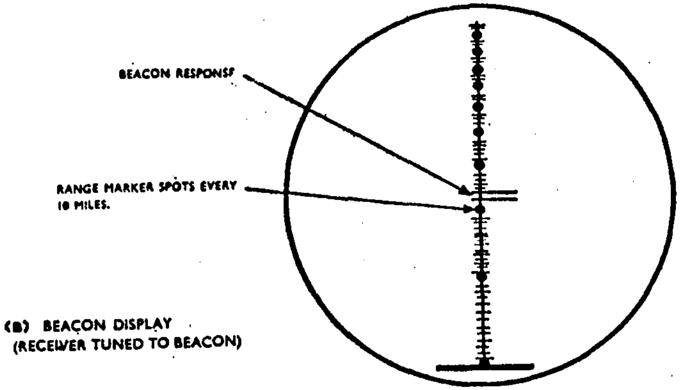
G — AIRCRAFT TURNING TO PORT

H — AIRCRAFT TURNING TO STARBOARD

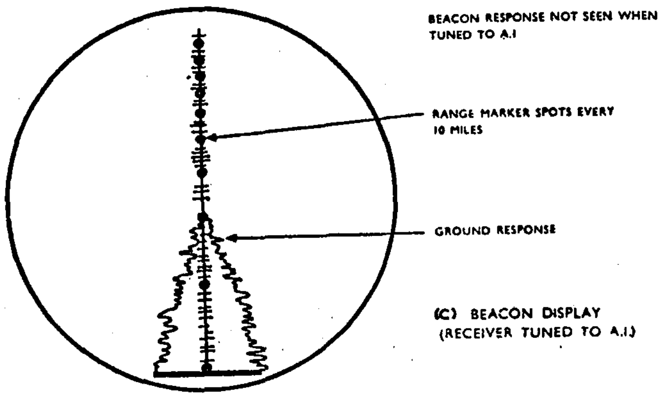
Fig. 15.—AI Mk. VIII, indications



(A) I.F.F. DISPLAY



(B) BEACON DISPLAY (RECEIVER TUNED TO BEACON)



(C) BEACON DISPLAY (RECEIVER TUNED TO A.I.)

Fig. 16.—AI Mk. VIII, IFF and beacon display

the fighter can still be detected at maximum range because it will be seen in the clear portion of the tube. In certain circumstances, however, when the target is lower than the fighter, the aircraft response merges with the ground return and cannot be distinguished from it. The minimum range is about 400-500 feet. As in Mk. IV the receiver is suppressed until the transmitter pulse is just finishing, otherwise the zero ring would be unduly bright and wide. When the fighter has closed in to 800 feet, the target arc on the tube begins to merge with the zero ring. By adjusting the receiver suppression control the zero ring may be dimmed slightly, so that the bright target arc is still visible although it may be superimposed on the zero ring. In this manner directions of targets as close as 400 feet can usually be ascertained. The receiver suppression control is usually set on a daylight flight to give good minimum range readings.

69. The sensitivity of AI Mk. VIII as regards direction-finding is very good, as is seen from the figures given to show the relationship between target arc and angle off centre. An angular deviation of the target from the line of centre of just over one degree can be detected on the tube as the return no longer forms a complete circle. This is very useful for following a dodging target because the observer can immediately detect the beginning of evasive action.

IFF facilities

70. When an operator wishes to identify an aircraft as friendly or otherwise he presses an interrogator switch on the indicating unit. If the target aircraft is friendly, and carries a Mk. III or IIIG IFF set, there immediately appears on the timebase, in addition to the normal signal, a very distinctive signal as shown in fig. 16 (A). The friendly signal consists of a series of radial lines corresponding to ¾ mile in length and appearing in every fifth timebase. The distance represented by these responses may be increased to 1½ miles for coding purposes or to six miles to indicate distress. In the case of the short IFF signal (¾ miles) the target response should be half way along the radial lines, and in the other cases at a distance from the inside edge equivalent to ⅜ mile. Even when the target is off centre and is indicated by an arc the friendly signal is a complete circle of IFF responses. Should there be two targets showing on the tube at different ranges, and only one friendly signal, the operator can tell which aircraft is showing the signal by noting the range of the two targets and the range corresponding to the beginning of the IFF signals. The friendly signals should begin at a range ⅜ mile less than that of the sending aircraft. Should there be two arcs at the same range, and one IFF signal, the observer cannot tell which is friendly,

but is very unlikely that two aircraft will remain at equal ranges for long. The IFF signal is not steady but flashes up periodically for about 0·2 sec. every 3 seconds. Certain sequences of long and short signals can be used as the basis of a code which can be changed when necessary.

71. The friendly signal is produced as follows. A small auxiliary transmitter and receiver unit is carried on the aircraft. This *interrogator*, also termed *Lucero*, sends out a 5-microsecond pulse on ordinary wavelengths (1·5 metres) at the beginning of every fifth timebase, if required. When the pulse reaches the IFF responder of a friendly aeroplane, a 5-microsecond pulse is immediately sent back. This signal is received and fed to the cathode ray tube so that it will appear at a distance from the zero ring which represents the range of the friendly aircraft. However, as the signals from the IFF responder are very much longer than ordinary AI signals, they occupy a longer portion of the radius. Because the pulses are sent out at every fifth timebase, only every fifth radial timebase will show a signal. Finally, since the interrogator aerial is non-directional, signals from the friendly aircraft will appear all the time, independent of the position of the scanner, and so will show up all the way round the tube.

Beacon operation and display

72. AI Mk. VIII provides homing beacon facilities at distances up to 90 miles from the ground station. This system operates on centimetre wavelengths and employs the usual beacon principles, namely, a pulse from the aircraft transmitter is received by the ground station and used to trigger a ground transmitter, which then radiates a coded response back to the aircraft. The return from the beacon is radiated on a frequency slightly different from that of the aircraft transmitter, so that when the receiver is tuned to the beacon, it does not at the same time receive ground returns, which are on the same frequency as that of the aircraft transmitter. The display system used in beacon operation employs a 90-mile vertical timebase with the origin at the lower end of the tube. The scale contracts exponentially towards the upper edge of the tube in order to give maximum accuracy at short distances. Marker dots are available at 10-mile intervals.

73. Transmission and reception of the beacon signals takes place via the rotating mirror system and the bearing of the beacon has to be obtained from mirror position. This is achieved by switching the receiver output signals on to the right- and left-hand side of the timebase according to whether the mirror is pointing to the right or left. A switch geared to the rotating mirror performs this function, and the switching must take place at the 12- and 6-o'clock positions of the scanner. The signals appear as blips on each side of the vertical timebase, and when these are equal the aircraft is heading towards the beacon. The direction finding properties are very sharp as on the AI ranges. Like echoes on the AI ranges, the beacon response is not in general steady, but appears and disappears in synchronism with the scanning cycle. Fig. 16 (B) shows the typical appearance of the Mk. VIII beacon display when the receiver is tuned to the beacon frequency; note that there are no ground returns visible. If the receiver is tuned to the AI transmitter frequency on this range, echoes from ground objects, coast lines, and ships up to 40 or 50 miles can be seen. This is sometimes useful for navigating. Fig. 16 (C) shows the display on the cathode ray tube when the receiver is tuned to the AI frequency.

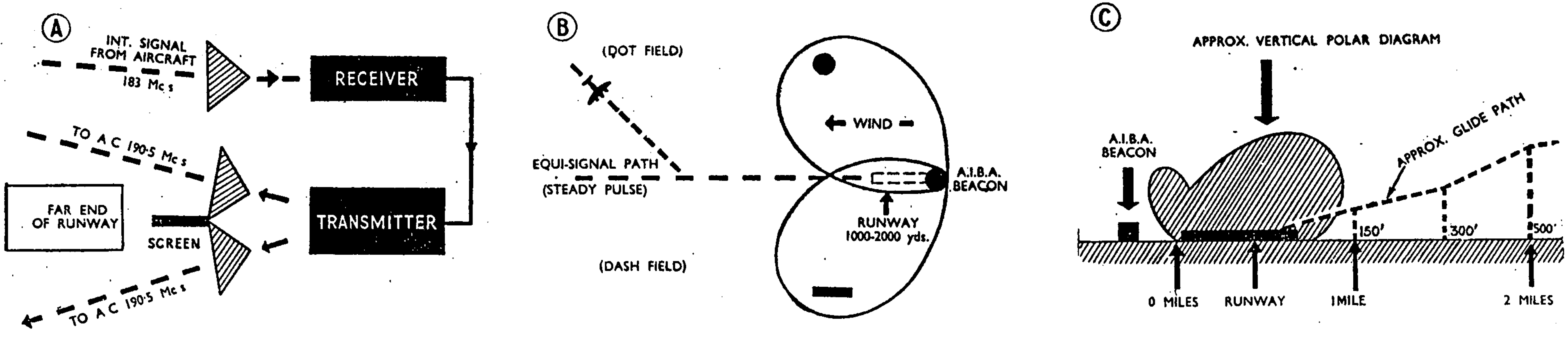
AI beam approach

74. When the aircraft has reached base with the help of the centimetre homing-beacon, it is possible to locate the line of the runway by flying in from a distance of eight miles and observing the beam approach beacon. This beacon works on ordinary 1½ metre wavelength and it is made to respond by the same auxiliary transmitter which interrogates friendly aircraft. By means of a switch on the indicating unit an eight-mile vertical timebase can be obtained on which the beam approach beacon signal appears as a horizontal deflection to the right-hand side only. It normally appears as a rather fat blip with a square top (fig. 17 (D)). Range marker dots are available at two-mile intervals.

75. The system is exactly similar to that described for AI Mk. VI. If the aircraft is directly in line with the runway the signal is steady; if too much to starboard the signal is long and fluctuates with its length decreasing (dash signal), if too much to port the signal is short and fluctuates with its length increasing (dot signal). By noting the amount which the signal fluctuates the angular deviation from true course can be estimated.

76. Unlike the system of homing in which the direction finding equipment is in the aircraft, it is quite possible to be in the equisignal zone for a short time and yet to be flying in the wrong direction, see fig. 17 (F). The beam approach beacon must, therefore, be used in conjunction with the homing beacon, and with the radio telephone link with base.

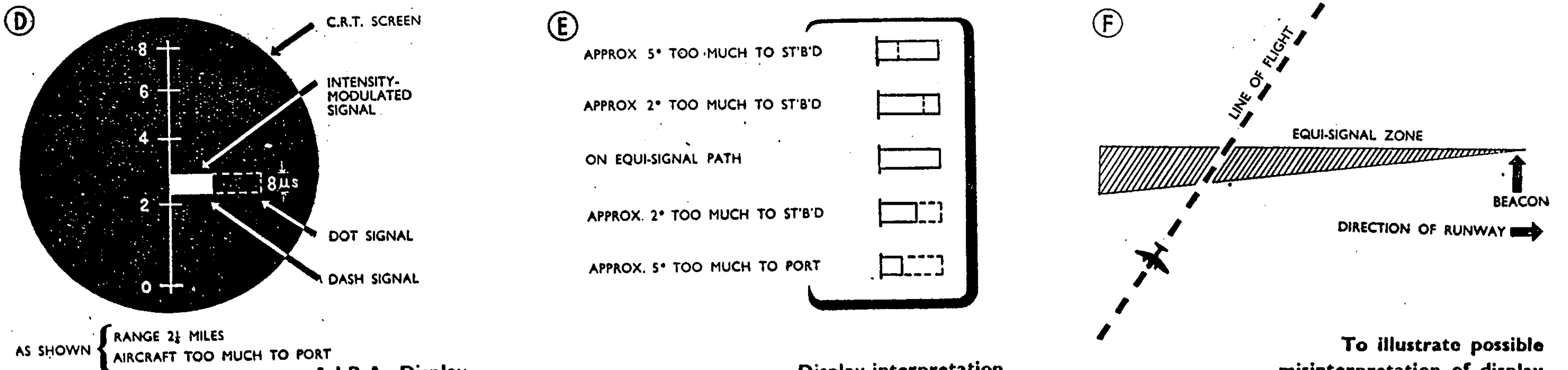
77. As the system does not indicate height it cannot be used for a completely blind landing. Further information regarding beacon and IFF coding, and details of beacon, IFF and blind approach systems is given in Chap. 6.



A.I.B.A. Aerials

A.I.B.A. Zones

Vertical Polar Diagram A.I.B.A.



A.I.B.A. Display

Display interpretation

To illustrate possible misinterpretation of display

Fig. 17.—AIBA display

78. *Leading particulars*

AI Mk. VIII, ARI. 5093

Wavelength: 9·1 cm., 3,300 Mc/s.

Frequency band: S.

Pulse recurrence frequency: 2,500 on AI ranges,
930 on beacon ranges.

Pulse width: 1 microsecond on AI ranges,
3 microseconds on beacon ranges.

Peak pulse power: 25 kW. (approx.).

Aerial system: Half-wave vertical dipole placed at the focal point of a 28 in. parabolic reflector. Common transmitting and receiving aerial. Spiral scan. Coverage 45 deg. in all directions from line ahead.

Maximum range: About 5½ miles dead ahead falling off to about 2 miles at 45 deg. off centre. (Limited to some extent by ground returns when target is below a low-flying fighter).

Minimum range: 400-500 feet.

Sharpness of D.F.: 1·3 deg. at dead ahead but less accurate as the angle of centre increases.

Facilities: Centimetre beacon facilities for homing up to 90 miles from base. IFF and AI/BA facilities. No pilot's indicator.

Units

Modulator: Type 53, hard valve modulator using three CV57 tetrodes in parallel in output stage, produces 35 amp. pulse at about 10 kV.

Transmitter: Type TR.3151, CV64 magnetron modulated at 13 kV.. Soft rhumbatron switching valve, CV43; crystal mixer.

Receiver: Type 50, reflector kylstron local oscillator, CV67. 4 IF stages. IF frequency, 13·5 Mc/s.

Indicating: Type 73, one tube, radial timebase. 2-mile and 8-mile ranges. 90-mile exponential beacon timebase. 8-mile AI/BA timebase.

Interrogator: Type TR.3152. Transmits on 183 Mc/s for Mk. III. IFF and AI/BA.

Power: Type 225.

Power supply: 1,200-watts, 80 volts, 1,600 c/s engine-driven alternator. 500 watts DC generator with control panel, type 5.

Weight: 212 lb. (This is the weight of the six main units only).

AI Mk. X (Modified American SCR-720)

General principles of operation

79. An equipment, known in America as SCR-720, was used operationally by Fighter Command. This apparatus may be regarded as the American equivalent to the British Mk. VIII, and is called AI Mk. X.

80. The main difference between Mk. VIII and Mk. X is that the latter employs a helical scanning system instead of a spiral movement of the beam. This necessitates a different display system for the operator. Two cathode ray tubes are used in the indicating unit, one being a range/azimuth tube, and the other an azimuth/elevation tube. From a technical point of view, a noteworthy feature of the apparatus is the use of a line modulator with a rotary spark gap.

Aerial system

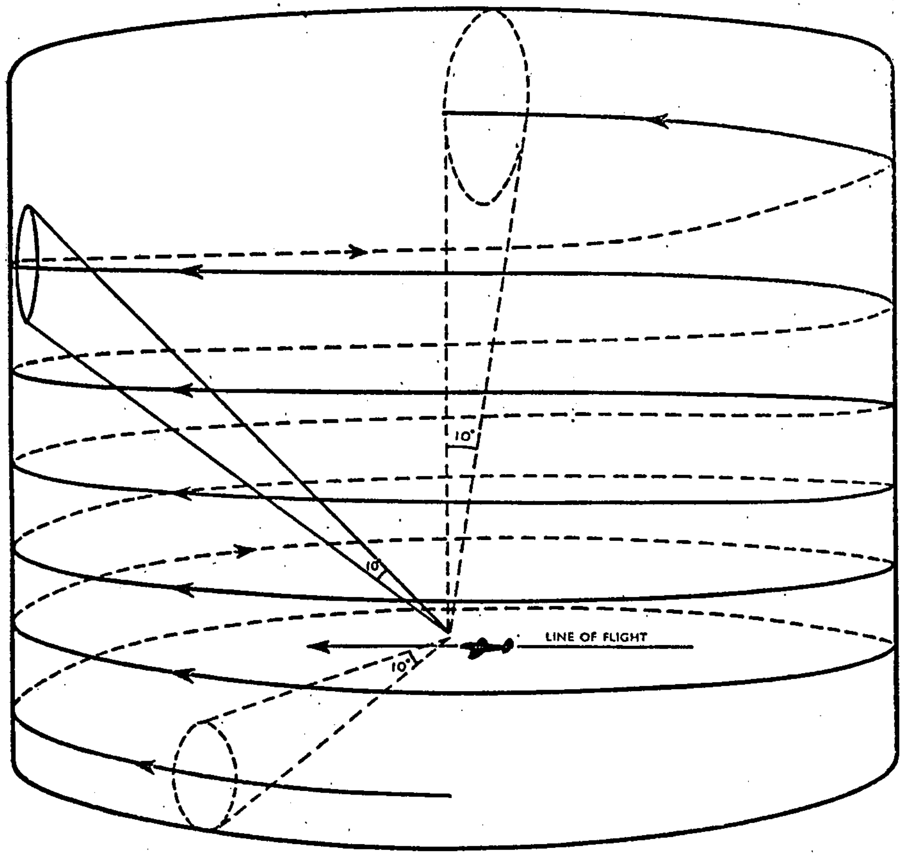
81. AI Mk. X is in many ways similar in design to Mk. VIII. The transmitting valve is a magnetron which radiates power on a wavelength of 9 cm. The output is fed to a small vertical dipole aerial fixed at the focal point of a parabolic mirror 29 inches in diameter. This system produces a narrow beam of radiation about 10 degrees wide, as in Mk. VIII. The aerial system is mounted inside the perspex nose of Mosquito aircraft, perspex being transparent to high frequency radiation. Echoes are received on the same aerial so that the receiver, as well as the transmitter, is beamed, and the direction-finding properties are, therefore, sharp.

82. The aerial is connected to the transmitter when the pulse is being sent out, but immediately afterwards, when echoes are returning, it is connected to the receiver. This is done automatically by a special switching valve called a soft rhumbatron. The transmitting unit is mounted in the nose of the aircraft, and a short coaxial line carries the transmitter output to the aerial. In Mosquito aircraft the pilot and operator sit side-by-side. The indicating unit is mounted in front of the operator just above the receiver which carries the tuning controls. The remainder of the units, which require no adjustment in flight, are mounted in the rear of the cockpit

Helical scan

83. The beam must be moved in a regular manner throughout the space in front of the aircraft so that contact with enemy may be established. This is done by means of an electrical scanning mechanism. Assume the aircraft to be fixed horizontally at the centre of a vertical cylinder as shown in fig. 18. Consider what would appear on the cylinder if instead of a beam of radiation there was a beam of light. The mirror and aerial system are mounted so that they can rotate about a vertical axis. If the beam is pointing dead ahead and producing a circle of illumination on the inside of the cylinder, then when the scanner is rotated one turn about a vertical axis the spot of light will trace out a circle on the cylinder. Now, the mirror and aerial system can also be rotated to some extent about a horizontal axis so that the beam can be tilted up to 40 degrees or down to 20 degrees from the horizontal. Suppose the mirror to be gradually tilting upwards as it rotates. The spot of light will now trace out a helix on the wall of the cylinder. The beam of radiation is not quite parallel-sided, but diverges slightly, forming a 10-degree beam. The tilting movement is slow compared with the speed of rotation, so that no part of the cylinder between the tilt limits

is left unilluminated. When the beam has spiralled up to an angle of 40 degrees the tilting movement is reversed, and the beam travels down to an angle of 20 degrees below the horizontal. The mirror then begins to tilt upwards again and the scanning cycle is repeated.



(6 turns of the Helix are shown. In the equipment there are 12 turns between —20 deg. to +40 deg).

Fig. 18—Helical scan

84. Whenever the mirror is pointing backwards, the cathode ray tube is blacked-out so that no signals are seen. Signals are received on the tube during the time when the scanner is rotating from port, through dead-ahead, to starboard; and during the backward half turn no signal appears on the tube. Nevertheless the echoes which appear on the tube are fairly steady, because once a signal has been applied to the screen of the cathode ray tubes it takes about three seconds to fade away. This phenomenon is termed *afterglow*.

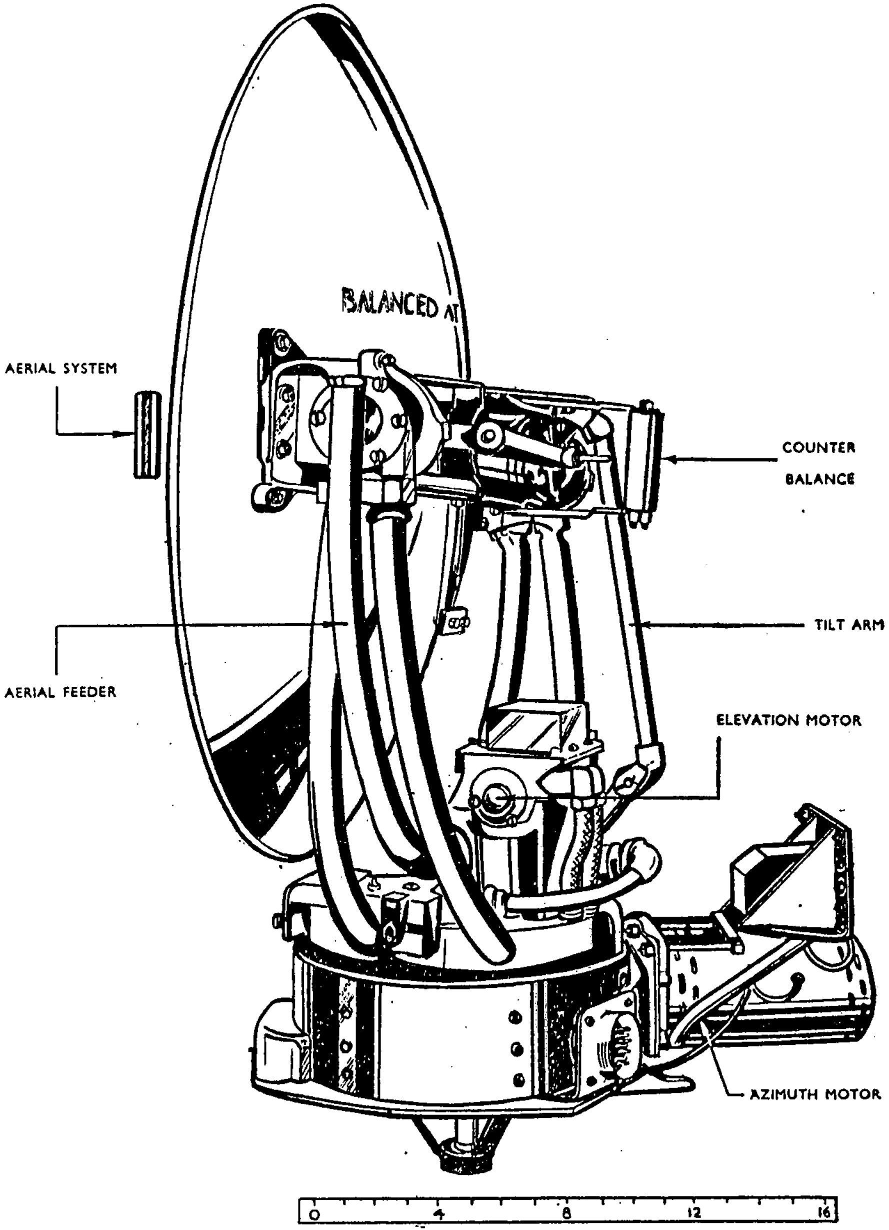
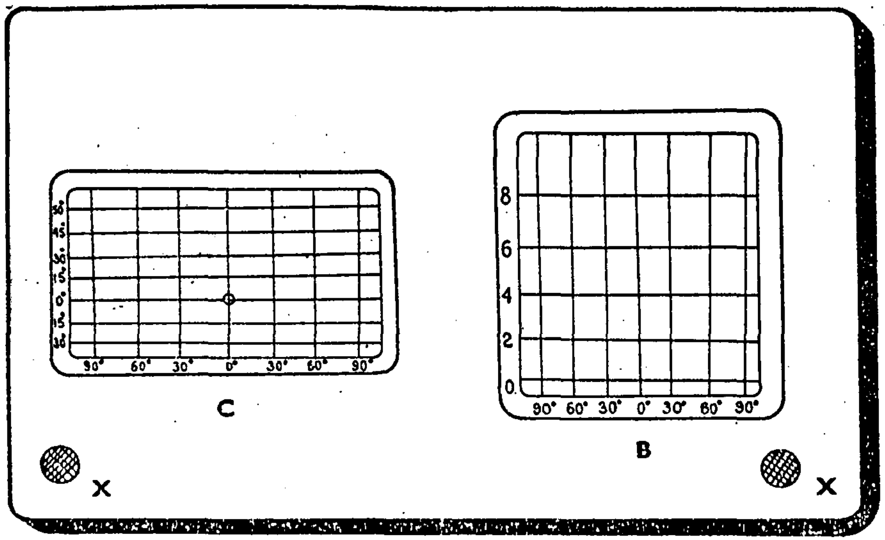
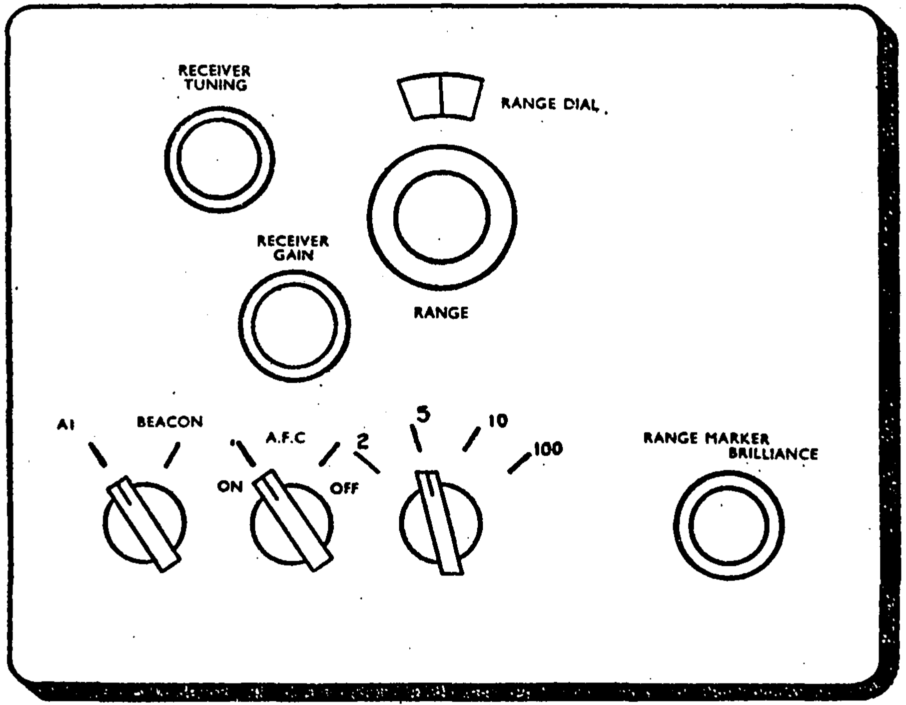


Fig. 19.—SCR-720, scanner



Indicating unit showing engraved scales (A)
B. Range azimuth tube, B-scope C. Azimuth elevation tube, C-scope
X. Brilliance controls



Receiver panel showing main controls only

Fig. 20—SCR-720, controls and display tubes

85. The upper and lower tilt limit of the mirror can be controlled by the operator. He can use a switch to select the following limits.

(1) —5 deg. all the time.
(2) —5 deg. to + 10 deg.
(3) —5 deg. to + 40 deg.
(4) + 10 deg. to + 40 deg.
(5) —20 deg. to + 40 deg.

The scanner is illustrated in fig. 19.

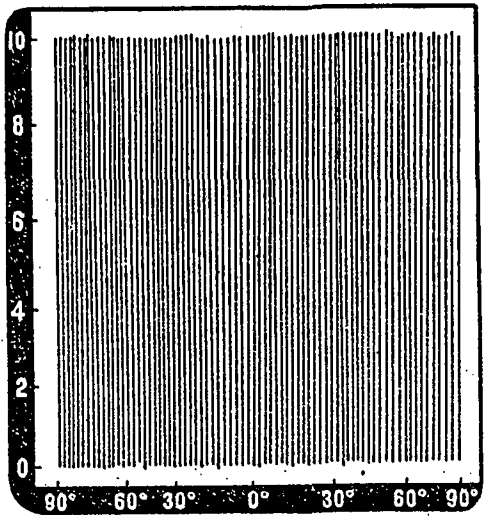
86. Suppose that the —20 deg. to +40 deg. tilt limits have been selected. All the space in front of the aircraft from 20 deg. below the line of flight to 40 deg. above it will be scanned. Hence the region of search in a sideways direction is greater for SCR-720 than in the case of AI Mk. VIII, where the beam spirals 45 deg. off centre in all directions. On the other hand, the beam in the case of SCR-720 is never directed more than 20 deg. downwards.

Display system

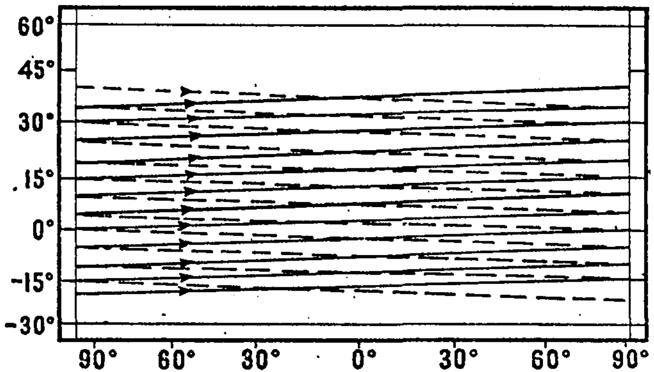
87. The operator has two tubes before him as shown in fig. 20(A). The right-hand one, which is the B-scope, measures range from bottom-to-top, and azimuth from the centre-line towards either side. The left-hand tube, known as the C-scope, indicates azimuth and elevation. The tube fronts are fitted with transparent masks with scales engraved on them as shown. Echoes appear as bright spots against a darker background.

88. Normally the brilliance control is turned down so that only echoes appear as bright spots on the tubes, but it is instructive to describe the pattern produced if the brilliance is turned up so that the scan lines are visible. Suppose that the 0- to 10-mile range is being used and the scanner is running between the —20 deg. to + 40 deg. tilt limits; on the range azimuth tube a series of vertical lines will be seen which are so close together that they tend to merge with each other. These are the range-timebase lines. Each line originates at the bottom of the

tube, which corresponds to zero range, and finishes at the top, which in this case corresponds to a range of 10 miles. Although the tube appears to be filled with these lines they are, of course, being traced in succession from left to right as the scanner moves from port through line-ahead to starboard. During the next half revolution of the scanner, when the mirror is towards the rear, no lines are traced; and then once again the picture is traced out from left to right as before. Because each line takes a few seconds to disappear the whole tube appears to be filled with timebase lines. The scanner runs at 6 revolutions per second, so it takes one-twelfth of a second to trace out one complete set of scan lines on the range/azimuth tube. Also, each scan line originates at the same time as a pulse is radiated from the aerial, and on the AI range 1,500 pulses are sent out in a second. Hence there are about 125 timebase lines on the range/azimuth tube (fig. 21(A)).



(A) B-scope: Range azimuth tube showing range timebase lines originating at the bottom of the tube.



(B) C-scope: azimuth elevation tube showing timebase lines. Tilt limits —20 deg. to +40 deg. solid lines are traced when mirror is tilting upwards. Dotted lines in downward sweep. Time for complete cycle is 4 seconds

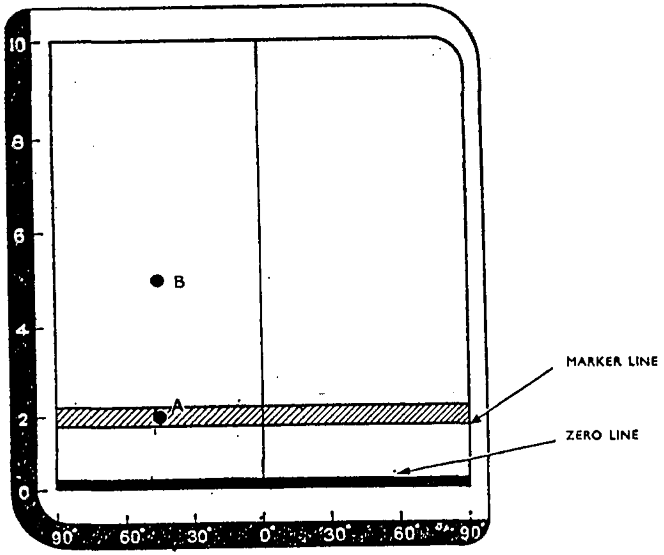
Fig. 21—SCR-720, timebase displays

89. If the azimuth/elevation or C-scope is examined while the brightness control is turned above normal, so that the scan lines are seen, the appearance of the tube will be as shown in fig. 21(B). The scanner tilts up relatively slowly compared with its speed of rotation so that it takes 2 seconds to tilt from —20 deg. to +40 deg. Twelve rotations will take place during that time, so that the spot traces out twelve parallel lines from left to right across the tube, each line sloping slightly upwards. During the next twelve revolutions, another set of lines will be produced in sequence, starting from the top of the cathode ray tube. These are shown as dotted lines in the illustration. Hence there are 24 scan lines on the C-scope during each complete scanning cycle when the stated tilt limits are being used.

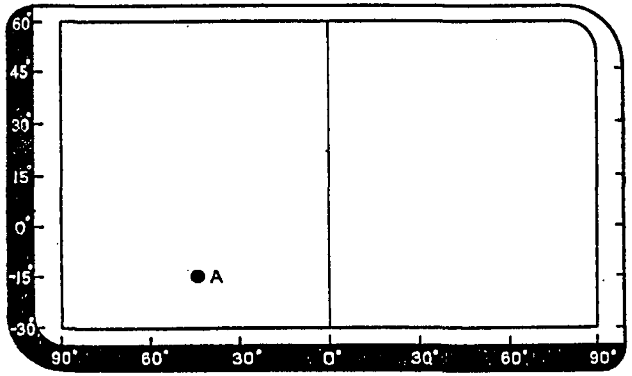
90. If narrower tilt limits were chosen, such as the —5 deg. to + 10 deg., then fewer horizontal scan lines would be seen. In this case, there will be 3 lines when the mirror is moving upwards, and 3 lines when it is moving down. The mirror will complete this cycle in one-quarter of the time required on the wider tilt limits.

91. Assuming that the wide tilt limits are again in use, that the apparatus is switched on to the 10-mile range, and that the cathode ray tube brilliance controls are turned down, as they are during operations, so that the timebases are invisible. Consider, first, the picture which will be seen on the B-scope. When a signal is received from a target it is applied to the cathode ray tube grid so that the timebase is brightened up at a point corresponding to the range of the target. Only a few timebases on the B-scope will be so brightened, these timebases occurring when the target is being illuminated by the beam of radiation. A short bright horizontal line will then appear on the tube. As the transmitted beam is narrow, only a few timebases are brightened, and the line will be very short, so that one may regard the target echoes as producing bright spots on the tube. The position of such a spot on the B-scope indicates the range and azimuth of the target according to the scale markings (fig. 22).

92. The direct pulse from the transmitter produces a bright spot at the beginning of each range timebase, thus producing a bright line along the bottom of the B scope in a position corresponding to zero range.



(A) B-scope: two targets at 45 deg. to port and ranges 2 and 5 miles



(B) C-scope: only signals within the shaded band on the B-scope appear in the C-scope. Target A is at an angle of—15 deg. with respect to the fighter. (The marker line appears on the tube, but not the shaded band)

Fig. 22—SCR-720, development of display

93. On the B-scope a narrow horizontal line will be observed which can be moved up and down the tube as a control marked RANGE on the receiver unit is turned manually. This control knob has a range scale attached to it. The range control is turned until the line on the cathode ray tube coincides with the leading edge of the bright target echo. The target range can then be read from the circular scale attached to the range marker control. In this way the range of an aircraft can be found more accurately than would be possible by using the scales attached to the cathode ray tube. The horizontal line on the B scope is called the range marker.

94. The display on the C-scope depends on the setting of the range marker on the B-scope. This range marker must be correctly operated before the C-scope tube can be used to give elevation reading, because only targets between certain ranges, determined by the setting of the range marker, appear on the C-scope. For example, if the range marker is set at 5 miles, only targets between 5 miles and 5 miles plus 1,500 feet appear on the C-scope. In other words, an echo does not appear on the C-scope until the range marker has been made to coincide with its leading edge on the B-scope. Once the marker has been set the echo will appear on the C-scope in a position such that its azimuth and elevation can be read off from the transparent scale in front of the tube.

95. During the searching process the operator watches the B-scope. Suppose two targets as in fig. 22(A), appear and these are at 45 deg. to port, but the ranges are different, 2 miles and 5 miles. The observer turns the range marker control until the marker line coincides with the target he is interested in—for example, the two-mile one. A bright spot is then visible on the C-scope and the elevation can be determined from it by noting the scale reading on the face of the tube. If further elevation readings are required as the fighter closes in, the operator must continue to set the range marker on to the echo on the B-scope as the range decreases. He may also strengthen the echo by selecting suitable tilt limits so that the sweep of the radiated beam up and down is more restricted. The beam will then cross the target more frequently, and the spot on the tube will be brightened. When searching at long ranges, narrow tilt limits will be best; but, when following at close ranges, if the target changes height rapidly, it may be necessary to change over quickly to wide tilt limits, otherwise the echo may be lost. When an interception is being carried out the operator should adjust the receiver gain control, the range marker, and the tilt limits switch as necessary.

96. The following ranges are available on the equipment.

Range	*Scanner speed* (*r.p.m.*)	*P.R.F* (*p.p.s.*)
0 — 2 mile	360	1,500
0 — 5 mile	360	1,500
0 — 10 mile	360	1,500
0 — 100 mile	100	375

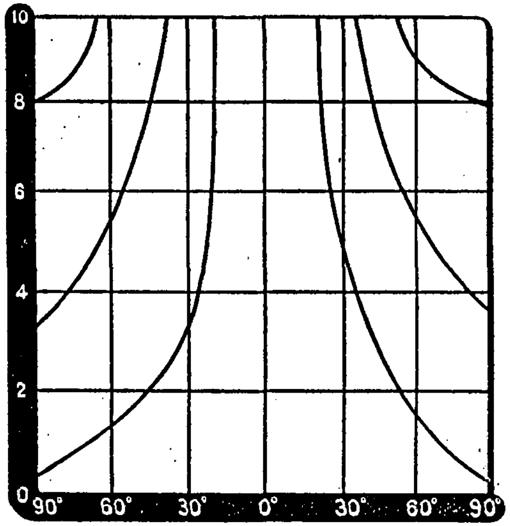
97. The range marker is used, as explained previously, on the three short ranges only; on the 100-mile range the elevation tube is not used, and no marker line is seen on the range tube.

Ground returns

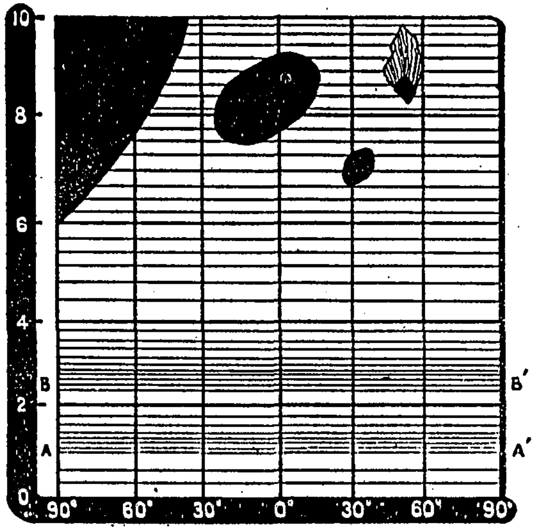
98. As in the case of AI Mk. VIII, responses are obtained on the range tube due to reflection from the ground, and there are two kinds of ground returns, namely,

(1) *Ground and sea returns due to the main beam of radiation striking the earth or sea.* Whenever the radiated beam strikes the ground within the maximum range, responses are seen on the B-scope, provided this is on the appropriate range setting. Stronger reflections are sent back from built-up areas, rocky hills or large metal structures. Coastlines can also be clearly seen. The ground returns are, of course, a disadvantage when trying to contact an enemy flying below the fighter, but in certain circumstances they can be used as a help in navigating. When the scanner is on the wider tilt limits and the beam is going down to 20 degrees below the horizontal, the part of the B-scope which is filled in with ground returns can, in fact, be regarded as being a somewhat distorted picture of the ground over which the aircraft is about to fly. When the aircraft is banked for turning, the ground responses are seen only on the side to which the aircraft is banked.

(2) *The altitude return due to radiation spilling over from the reflector* (*fig.* 23(*B*)). Altitude responses are seen with AI Mk. X in very much the same manner as in Mks. VII and VIII. They appear on the B-scope as a horizontal line, the lower edge of which is at a height above land or sea at which the fighter is flying. The width of the altitude response depends on the height and on the character of the land, but even under bad conditions the intensity of the altitude response is substantially less than that of an aircraft.



(A) B-scope: The curved lines indicate the track of responses emanating from stationary objects not dead ahead. Aircraft is flying straight and level.



(B) B-scope: Showing altitude return AA_1 and ground return BB_1. Also strong returns from rocky hills beyond six miles range. Aircraft flying at 5,000 ft.

Fig. 23.—SCR-720, typical display

Performance

99. The maximum range of the equipment is six to eight miles. This maximum range extends undiminished over a very wide field of view, from 75 deg. right to 75 deg. left, and from 50 deg. above to 20 deg. below. Beyond these limits the range falls fairly quickly; for example, at 90 deg. left or right the maximum range is two miles and the falling off in range at 75 deg. is due to the screening effect of the Mosquito engines. The minimum range is about 300 feet.

100. When flying over land below heights of 5,000 feet the maximum range is reduced by an amount depending to a large extent on the position of the target aircraft. If the target is above, the effect is small; while if the target is below, the maximum range will be of the order of four times the height of the fighter. When flying over sea the maximum range is considerably better than four times the height, and when the sea is very smooth it is virtually unlimited by the height.

101. Accuracy of direction-finding is about 5 deg. at any angle within the field of scan.

102. The high voltage parts of the apparatus are in pressurised containers and operate in a satisfactory manner at any height.

Comparison between AI Mk. X and AI Mk. VIII

103. The field of view is very much wider with Mk. X than it is with Mk. VIII. It might be thought from the theoretical description which has been given of the spiral scan that the field of view would extend to 5½ miles in any direction up to 45 deg. from the line of flight. For technical reasons, connected with the aerial system design, this does not occur in practice. In fact, if a Mk. VIII equipment has a maximum range of 5½ miles dead ahead, the range 40 deg. off line-ahead, this will usually drop to about 2½ miles. This means that the region searched out by the spiral scan is rather limited, and the ground stations must place the fighter accurately behind the enemy to ensure making contact. The extension of the field of view in AI Mk. X to 75 deg. to either side of line-ahead is of very great value when patrolling under GCI control, since contacts can be much more easily made. It is also of the utmost value when freelancing since for a given density of enemy aircraft a greater number of contacts can be obtained.

104. The range/azimuth display, using a long-afterglow tube, enables the operator to estimate the course of the target with respect to the fighter. On the B-scope a faint luminous trace is visible, with a light spot (the aircraft response) at one end, giving a clear indication of the relative course of the target. This is of great value to the operator.

105. When using AI Mk. VIII it is extremely difficult to estimate the relative course of the target, and operators do not attempt this. Instead they correct azimuth and height as quickly as possible, so that the fighter is on the same track as the target, and then they instruct the pilot so that the fighter continues to follow the same path as the target aircraft.

106. AI Mk. VIII has very accurate direction-finding properties to within 1 deg. at line-ahead but at greater angles off-centre the accuracy is much lower. It is, for example, difficult to estimate angles of 20 deg. or 30 deg. off line-of-flight by noting the completeness of the circular arc, and these angles cannot be read with anything like 1 deg. accuracy. In the case of AI Mk. X, the direction-finding is not so good at line-ahead, but is uniformly maintained over all angles. An angle of 45 deg. off-centre can be as accurately read (to 5 deg. as dead ahead), but for targets directly in front, changes of course cannot be detected quite so quickly as with Mk. VIII.

107. The theoretical advantages of AI Mk. X over AI Mk. VIII may be summed up as follows:—

(1) In following "jinking" targets the range/azimuth display enables the operator to follow the target's mean course.

(2) The wide coverage makes it unlikely that a contact will be lost quickly by a displacement in azimuth; and quick turns, which are difficult to carry out at night, need not be attempted.

(3) By watching the B-scope it is easy for the operator to estimate what rate of turning will be required to bring him behind the target, so that there is less tendency to "weave" due to over-correcting than there is with Mk. VIII.

(4) The range/azimuth display makes it easier to intercept targets approaching or crossing the path of the fighter. These interceptions are very difficult with Mk. VIII, due to the somewhat limited field of view. On the other hand, sudden changes in target height are rather easier to follow with AI Mk. VIII than with AI Mk. X.

Note.—The minimum ranges of AI Mk. VIII and Mk. X are similar.

108. The American equipment gives wider coverage, afterglow showing the track of the target, and giving good direction-finding at wide angles. In British equipment, on the other hand, the spiral scan gives very accurate direction-finding at dead ahead, and the apparatus is more easily operated because only the receiver gain control need be adjusted during an interception.

Beacon facilities

109. Ground beacons on centimetre wavelengths can be triggered off by the main transmitter, and can be observed like aircraft echoes on the range/azimuth tube. It is possible to use these homing facilities up to 100 miles from base as in Mk. VIII.

Beam approach and IFF

110. No provision is at present made on SCR-720 equipment for receiving identification signals from friendly aircraft, or for making a beam approach to the runway. Instead, an auxiliary equipment called SCR-729 may be installed, which has a transmitter of its own radiating on the 1½ metre band. This triggers IFF Mks. III and IIIG sets, and also triggers beam approach beacons.

111. The SCR-729 apparatus has an indicating tube of its own, which is a simple range tube, and the return signals are received on two directional aerials as in the case of AI Mk. IV or Lucero.

Leading particulars

AI Mk. X.ARI. 5570 (American SCR-720)

Wavelength: 9·1 cm., 3,300 Mc/s.

Frequency band: S.

Pulse recurrence frequency: 1,500 on AI range.
375 on beacon range.

Pulse width:	¾ microseconds on AI range. 2¼ microseconds on beacon range.
Peak pulse power:	70 kW. (approx.).
Aerial system:	Half-wave dipole, vertically polarised, at focal point of 29-inch parabolic reflector. Common transmitting and receiving aerial. Helical scan. Coverage, 75 deg. to each side of line-ahead, and from —30 deg. to +50 deg. in elevation.
Maximum range:	About 6 miles at all azimuths between 75 deg. port to 75 deg. starboard. (This is limited in cases where the target is below the fighter to about four times the height of the fighter).
Minimum range:	300 feet.
Sharpness of D/F	5 deg. at all azimuths.
Centimetre beacon facilities:	No IFF or AI/BA. SCR-729 used for IFF and AI/BA. Pilot's indicator not used by R.A.F.
Units:	
Modulator.	Rotary spark gap producing 4 kV pulse. Pressurised modulator.
Transmitter.	Magnetron. Pressurised container for RF unit.
Mixer.	Soft rhumbatron switch valve. Crystal mixer.
Receiver.	Reflector klystron local oscillator. 6 IF stages. IF frequency, 60 Mc/s. Automatic frequency control.
Indicating.	Two tubes, range azimuth, and azimuth elevation. Ranges: 2, 5, 10, 100 miles.
Power supply.	1,200 watt, 80-volt, 1,600-cycle, engine-driven alternator. Output transformed to 115 volts for American equipment. 1,500 watt, 24 volt DC generator with control panel, type 5.
Weight.	500 lb. including scanner, cables and mounting racks.

CHAPTER 2

H2S AND ASV

LIST OF CONTENTS

Modern H2S-ASV systems

ASV Mk. II

LIST OF ILLUSTRATIONS

Introduction

1. H2S is an airborne equipment working on a wavelength of 9·1 cm. It has a double function; to act as a navigational aid and as a blind-bombing device for aircraft of Bomber Command. It was first used operationally in the winter of 1942-1943.

2. During the early test flights with AI Mk.VII it was observed that echoes were returned not only from other aircraft but also from terrestrial objects, and that towns in particular gave quite large responses. This happened despite the fact that the scanning arrangements were not designed for the specific purpose of showing ground returns, and it was apparent that if an equipment were constructed with the primary object of scanning the ground beneath the aircraft, it should prove useful as an aid to bombing. Preliminary experiments carried out on these lines were successful and led finally to the development of the present H2S. The original equipment is now called H2S Mk. I, and although newer marks of H2S are now in service, they differ only in detail; in the elementary account there is no need to differentiate between them.

3. Operational aircraft of Coastal Command also required some form of radar apparatus to detect enemy submarines and surface vessels, and to locate convoys. A type of equipment known as Aircraft to Surface Vessel Equipment, or ASV, had been used for this purpose for some time. It had a wavelength of about 1·5 metres, and the very early apparatus, ASV Mk. I, had already been replaced by a more operationally-efficient version, ASV Mk. II. It was clear, however, that an equipment working on a much shorter wavelength would be more satisfactory, so that when H2S was finally developed for Bomber Command it was also installed in Coastal Command aircraft. The Coastal Command H2S differs slightly from that fitted into bombers, and it is generally called ASV Mk. III. Later Marks are also coming into service.

Information supplied by H2S Mk. II (ASV Mk. III)

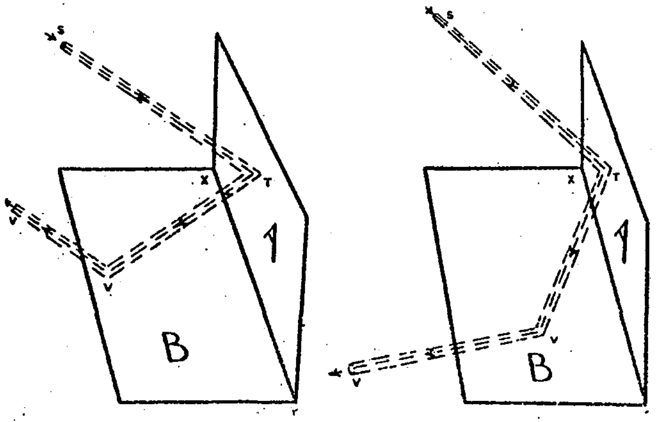
4. The later H2S and ASV equipment supplies a map of the ground beneath the aircraft. This map is displayed on the face of a cathode ray tube, and the point on the ground directly beneath the aircraft appears at the centre. Three scales are provided; a small scale map extending to a range of 100 miles, one of intermediate scale extending to 30 miles, and one of large scale, for blind bombing, extending to 10 miles. The map shows coastlines, towns, and surface craft at sea. In H2S equipment, the top of the map always corresponds to true North, and the course of the aircraft is shown by a bright line called a line-of-flight marker, which extends from the centre to the edge of the map. ASV Mk. III differs from H2S Mk. II in only one important detail: the top of the map

corresponds not to true North but to the direction in which the aircraft is heading, so that as the aircraft changes course the whole map rotates.

5. It is possible to measure the accurate bearing and range of a target from the aircraft. The range of distant targets can be found, with sufficient accuracy for navigational purposes, from the small and intermediate scale maps, while the large scale map gives more accurate ranges on the nearer targets, and can be used either for blind bombing or for obtaining the exact ground speed. It is also possible to measure the height of the aircraft above the ground with sufficient accuracy for bombing.

General principles

6. H2S and ASV work on the usual radar principle. A transmitter sends out short pulses of electromagnetic waves of wavelength 9·1 cm. and duration 1 microsecond. The recurrence frequency of these pulses is about 670 per second. Certain objects on the ground scatter the waves falling on them and return echoes to the aircraft. If the surface of the earth were everywhere quite flat, the waves would, of course, be reflected from it as from a mirror, and there would be no energy returned to the aircraft except from the point on the ground directly beneath it. The surface of the sea does indeed approximate to this condition and returns very few echoes. The surface of land, however, is rougher and more broken, and its irregularities give rise to hundreds of small random echoes, which appear for short spaces of time and quickly fade again as the aircraft changes its position. These echoes give a characteristic shimmering appearance to the map, so that it is possible for the operator to tell at a glance whether he is flying over land or over sea.



Reflection of narrow beam when plane of incidence is perpendicular to two reflecting planes

Reflection of narrow beam when plane of incidence is not perpendicular to reflecting planes

Fig. 1.—H2S beam reflections

7. Certain natural and man-made structures on the earth's surface give a different type of echo from that due to wave irregularities on the ground. This second type of echo is much stronger and more persistent, and is due to scattering from vertical or almost vertical surfaces. It is interesting to note the way in which it usually arises. Fig 1. shows two planes at right angles, the plane A being vertical and the plane B horizontal. Imagine a narrow beam ST of electromagnetic waves from a distant source falling on the plane A at the point T. The waves will be reflected downwards, and will strike the plane B at the point U, where they will be reflected a second time and will travel along the path UV. Now if the direction ST is perpendicular to the line XY where the two planes meet, it is easy to show, by the laws of reflection, that the final path UV after the double reflection is parallel to the original path ST. In other words the beam is returned to the distant source. When the direction of the incident beam is not perpendicular to the line XY, the waves will not be returned along this original path, but will be replaced in the way indicated in fig. 1 (B). Suppose then that the aircraft flies past a large square building, *see* fig. 2. When it is at the point A the radar pulses

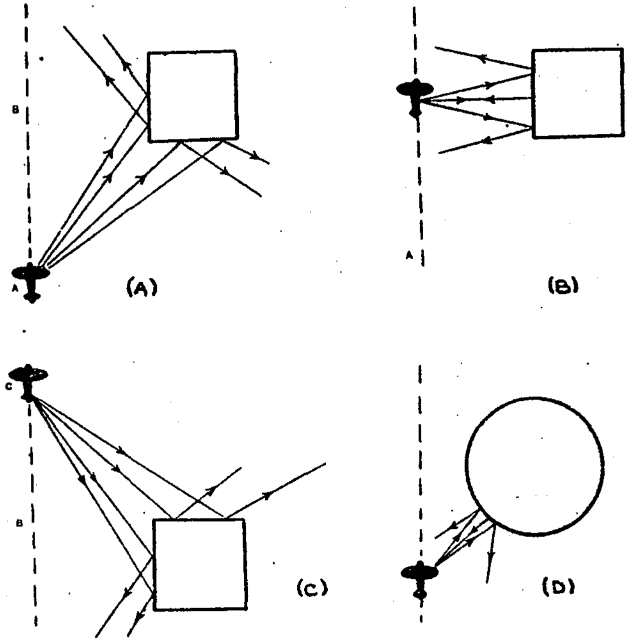


Fig. 2.—Reflection of radar waves from buildings

will be reflected as shown in fig. 2 (A); when the aircraft reaches the point B, opposite to the building, there will be a large return echo, and when the aircraft reaches C the reflected waves will travel away in the direction shown in fig. 2 (C). In other words a large echo will be returned only when the aircraft is exactly opposite to the building. With a circular building, however, *see* fig. 2 (D), there would always be some energy returned whatever the position of the aircraft relative to the building might be. A town will clearly give a strong response, since it has so many buildings that there will always be some vertical surfaces inclined at the correct angle to return the radiation. If three reflecting surfaces are mutually at right angles in the way indicated in fig. 3, it can be shown that incident radiation reflected from each of the three surfaces in turn always returns along its own path, no matter what its direction of incidence may be. Such a system of surfaces is often called a *corner reflector*, and will always return strong echoes. Buttresses and angles in the walls of buildings will therefore reflect well.

NOTE: Fig. 3 is to be interpreted as a hollow right-angled prism.

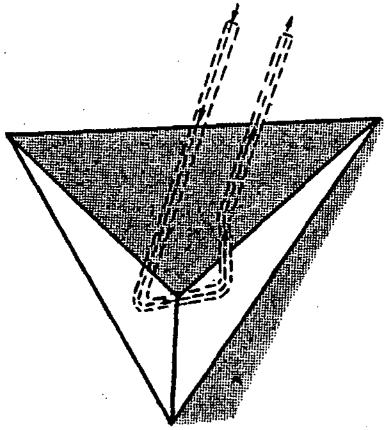


Fig. 3.—Corner reflector

8. It will be seen that echoes are returned principally from objects which have vertical or almost vertical surfaces and sharp edges, and particularly from those which rise sharply from the level surface of the earth. Such objects are buildings, clusters of buildings, cliffs at a coastline, islands, and ships. Hills which rise gradually give no definite response, although high and rocky mountains may be seen.

9. Although the reflecting properties of two or three planes at right angles plays an important part in producing the large responses from objects on the earth's surface, other factors are also probably present. For instance, in a town there will always be a large number of surfaces such as sloping roofs which are inclined at the correct angle to return radiation to the aircraft in a single reflection. There will also be many surfaces which will be too rough to reflect the incident waves but will scatter them in all directions, and some energy will be returned to the aircraft no matter what their inclination may be. The resultant echo will therefore be due to these effects added to the corner effect.

MODERN H2S-ASV SYSTEMS

The scanning unit

10. After having considered the way in which echoes are returned from objects on the ground it is necessary to see how the waves are transmitted and received by the aircraft.

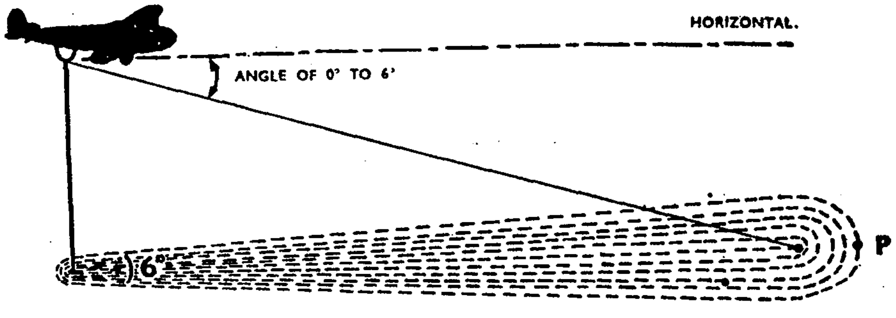
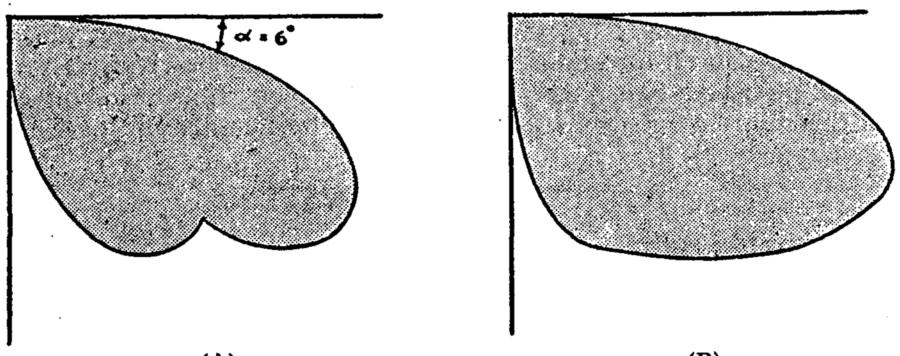


Fig. 4.—Strip of ground illuminated by H2S

11. The equipment uses a common transmitting and receiving aerial system housed in a perspex blister beneath the belly of the aircraft. The older aerial unit consists of a rectangular section of a paraboliodal mirror fed by a half-wave aerial at its focus. The aerial has a reflector and a director to direct the energy into the mirror. This system illuminates a strip of ground in the shape of a sector of a circle about 6 deg. wide extending from the point beneath the aircraft to a great distance as shown in fig. 4. The most remote point of illumination, P, is controlled by means of an adjustable " step " fixed into the top of the mirror, and by varying the position of this step the inclination of the beam can be varied. The usual inclination is about 6 deg. The polar diagram of this system is shown in fig. 5 (A). The newer equipments use a " Cosec θ " aerial system similar to that described in A.P.1093C, Chapter 2, and the mirror is fed by a waveguide. The principal advantage of the newer aerial lies in the improved polar diagram, *see* fig. 5 (B).

12. Whatever type of mirror system the equipment employs, the whole mirror rotates about a vertical axis at a rate of one revolution per second, so that it scans the ground or sea beneath the aircraft. Since the



(A)
Polar diagram used on earlier H2S equipments

(B)
Polar diagram with new scanner—better coverage

Fig. 5—H2S polar diagrams

illuminated strip of ground is 6 deg. wide, the beam will take 6/360 seconds or one-sixtieth of a second to sweep over any particular target. The pulse recurrence frequency is 670 per second, so that each echo will be returned $\frac{670}{60}$ times, or about 11 times during each revolution of the scanner.

The cathode ray tube and the production of the map

13. The map is essentially a PPI display on a 6 in. cathode ray tube, and although such a display has already been described it will be helpful to consider this particular display in greater detail.

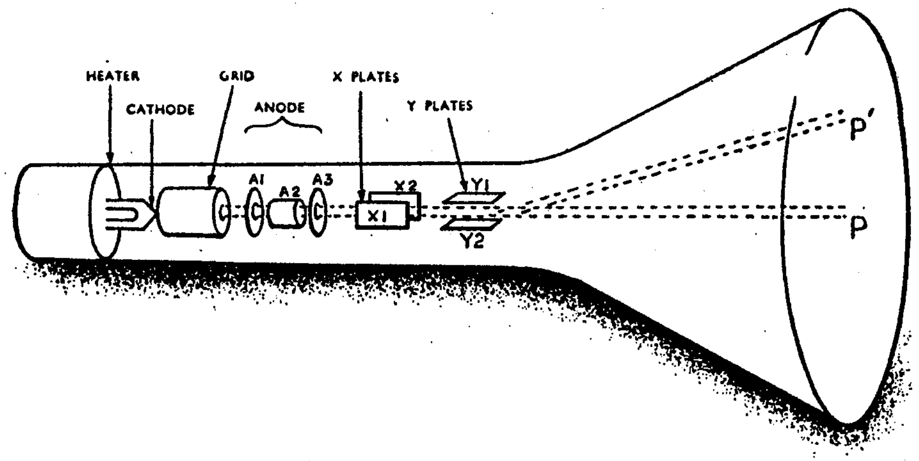


Fig. 6.—Cathode ray tube

14. Fig. 6 shows a typical cathode ray tube. Inside the glass envelope are the heater, the cathode, the grid, the anode, and the deflecting plates. The heater is simply a coil of wire whose function is to raise the temperature of the cathode. When the temperature of any conductor is raised sufficiently it emits large numbers of electrons. These electrons are minute particles much smaller than atoms, and each one carries a relatively high negative electric charge. The anode of the tube consists of three parts, A1, A2 and A3. The parts A1 and A3 are simply discs with small holes in their centres, while A2 is a cylindrical tube. If the three parts of the anode are raised to a much higher potential than the cathode the negative electrons emitted from the cathode are attracted towards the first plate A1, and many of them strike this plate and are absorbed into it. Some pass through the hole at the centre, however, through the tube A2, and through the hole at the centre of A3. They leave A3 with a very high velocity, and travel on to strike the face of the tube at P. The constant stream of electrons striking the tube face at P cause a coating of fluorescent material on the glass in this neighbourhood to glow with a green light. By varying the potential of the cylinder A2 relative to that of the discs A1 and A3 it is possible to focus the electron beam so that the patch of light at P is very small indeed. The grid which is situated between the cathode and the anode is usually maintained at a potential somewhat lower than the potential of the cathode, so that the electrons are discouraged from setting out on the first part of their journey, and it is not until they have left the grid behind that they really gain a high speed. By making the grid slightly too negative it is possible to cut off the electron stream altogether, as slight variation of the grid potential causes a marked change in the number of electrons which finally reach P. Thus, the brightness of the spot of light at P depends on the potential of the grid. The x and y plates are two pairs of parallel plates and are used to deflect the beam. If both x plates and both y plates are at the same potential the spot P will be in the centre of the tube. If, however, the potential of the upper y plate is higher than that of the lower one, the electrons will be attracted to the former and repelled from the latter as they pass, and the spot will move upwards to P^1. The distance from P to P^1 will depend on the difference in potential between the two plates. In the same way a difference in potential between the two x plates will deflect the beam in a horizontal elevation.

15. Fig. 7 (A) shows a view of the face of the tube with the x and y plates seen end-on. The two pairs of plates are mutally perpendicular. Suppose that the potentials of the x plates vary in the way shown in figs. 8 (A) and 8 (B). The plate x1 is first made positive in potential while x2 is made negative, so that the electron beam is deflected. Since the electrons will be attracted to x1 and repelled from x2 the spot of light

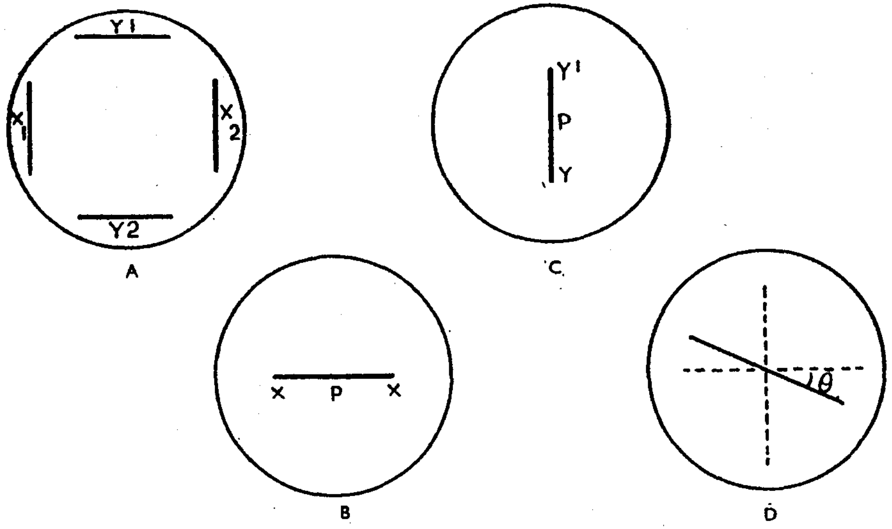


Fig. 7.—Development of PPI display

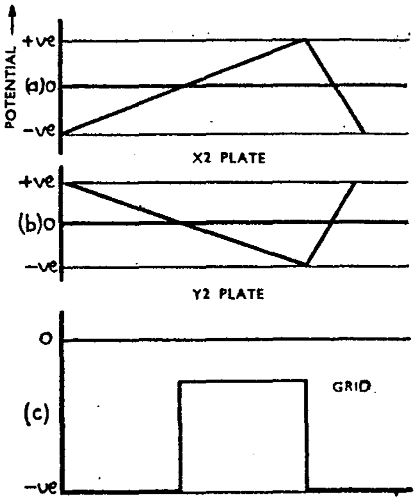


Fig. 8.—Potentials on a PPI tube

will move across the tube face to the point X. As time goes on the potential of x1 falls uniformly while that of x2 rises uniformly, so that the spot moves through P to X1. The potentials then reverse again so that the spot will fly back. If the potentials continue to vary in the sawtooth manner shown in fig. 8, this process will repeat itself again and again, and if it repeats itself sufficiently rapidly the movement of the spot will be no longer visible, but a continuous line or trace XPX1 will appear on the tube face. If the potential variation shown in fig. 8 had been applied to the y plates instead of the x plates, the trace would have been vertical.

16. Suppose that saw-toothed voltage waves are applied to both the x and y plates simultaneously. If these two waves have the same amplitude, the trace will be inclined at an angle of 45 deg. If, however, the amplitude on the y plates is greater than that on the x plates, the y deflection will be greater than the x deflection so that the timebase will be inclined at a different angle, θ in fig. 7 (D). Moreover, by varying the relative amplitudes of the waves applied to the two it will be possible to incline the trace at any desired angle.

17. In the H2S equipment two pairs of saw-tooth waves of frequency 670 cycles per second are applied, one to each pair of plates. These waves are supplied by an apparatus known as a *magslip,* described in para. 20, and their amplitudes are varied in such a way that at each successive journey the angle of inclination of the trace is slightly greater than it was during the previous journey, so that the trace appears to rotate. The magslip is geared to the scanner in such a way that each rotation of the scanner corresponds to one complete rotation of the trace. The potential of the grid of the tube is not uniform but is varied in the way indicated in fig. 8 (C). When the spot commences its journey from the left-hand side of the tube, its potential is so strongly negative that no electrons reach the tube face. It is only when the spot reaches the centre point P that the grid potential is raised sufficiently to allow the electron to pass, and immediately the spot reaches its farthest limit, X, the potential falls again and is kept strongly negative until the spot once more reaches P on its next journey. The result is that the first half of the trace and the flyback are blacked out, and all that appears on the tube is a radial line PQ (fig. 9). This radial line rotates in synchronism with the aerials.

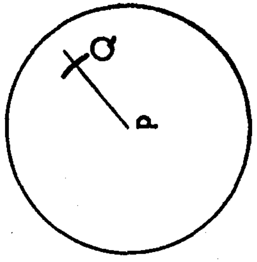


Fig. 9.—Appearance of echo on tube

18. The transmitter is so timed that a pulse of waves is sent out at the exact instant that the spot reaches P. The return signal is received some time later, and is applied to the grid of the tube so as to brighten up the trace. While the 6 deg. beam from the scanner sweeps past a target, it causes about 11 successive responses. Thus the return signal will brighten about 11 successive traces each time the aerials revolve. The appearance of the echo will therefore be a rather long, bright smear, similar to that shown at Q in fig. 9. The distance PQ is proportional to the time taken for the pulse to complete its double journey, or to the range of the target, while the direction PQ corresponds to the direction of the target for the aircraft. In this way the map appears on the face of the tube. The inner surface of the face of the tube is coated with a material which continues to glow for a short space of time after the trace has passed, so that the echo persists during the intervals between the successive sweeps of the trace. It is usual to adjust the potential of the grid so that the trace is not quite bright enough to be seen, and only becomes visible when the grid is made more positive by the signal. In this way only the echoes can be seen, and the trace itself is made quite invisible.

19. When a target is very distant its echo is usually considerably thinner than the echo from a nearer target. Thus on running up to a large town the appearance on the tube will be similar to that shown in fig. 10, and will vary as indicated by the echoes a, b and c. This is because the incident waves fall on the distant town from a direction almost parallel to the ground, and consequently only the front row of buildings returns echoes, while the buildings behind are shielded. As the aircraft approaches more closely, and its angle of elevation increases, the "thickness" of the town begins to show, and when the aircraft is almost overhead the town appears in its own shape.

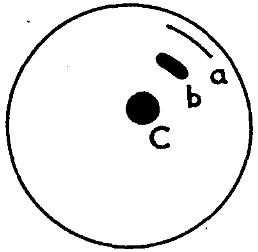


Fig. 10.—Appearance of town at different ranges

The magslip and line-of-flight marker

20. The magslip consists essentially of three coils arranged in the way shown in fig. 11. Two of these coils, the stator coils, are stationary and have their axes at right angles. The third, the rotor, has its axis in the same plane as the axes of the stators, but can rotate about an axle perpendicular to this plane. A saw-toothed voltage wave is applied to the terminals of the rotor coil, and an electromotive force is induced in each of the stators, so that similar saw-toothed voltage waves appear between their terminals. The relative amplitudes of these stator voltage waves depends, however, on the position of the rotor. The voltage waves from one stator are amplified and applied to the x plates of the PPI tube, while the waves from the other are amplified and applied to the y plates. Thus the direction of the trace on the tube, which depends on the relative amplitudes of the saw-toothed waves applied to the x and y plates, is controlled by the position of the rotor. As the rotor rotates with uniform velocity, the trace on the tube will also rotate with the same uniform velocity. The rotor is geared to the scanner, and establishes the necessary relationship between the direction of the trace and the direction in which the scanner is looking.

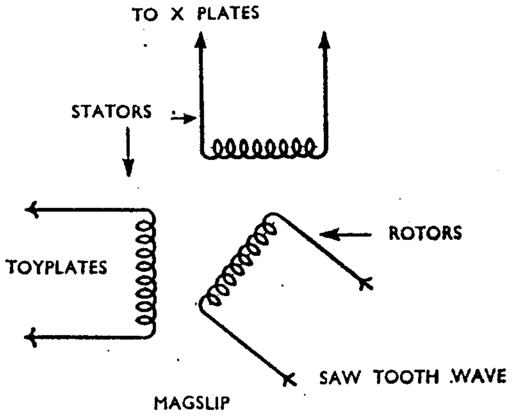


Fig. 11.—Magslip theory

21. In ASV Mk. III equipment the stator coils are fixed relative to the framework of the aircraft, and are so positioned that whenever the scanner looks along the direction in which the aircraft is heading—that is along the aircraft in the direction of a line drawn from tail to nose—the trace is directed from the centre to the top of the tube. Thus the top of the map always corresponds to the direction of flight in the way described previously.

22. In H2S equipments the stator coils are themselves mounted on a rotatable framework, and the position of this framework is controlled by the gyro-compass so that the coils retain this position relative to the

true North direction and not relative to the structure of the aircraft. The result is that directions on the map correspond to true geographical directions and do not depend in any way on the course on which the aircraft is flying. It is usual to arrange the orientation of the stator-coils in such a way that the top of the map on the tube always corresponds to true North.

23. In H2S apparatus it is necessary to show the line-of-flight of the aircraft on the map. This is accomplished by the line-of-flight marker, or *course marker*, which is operated from the scanner. Whenever the scanner is looking along the aircraft in the direction of flight it automatically closes a contact. This applies a high potential to the grid of the PPI tube so that the trace is brightened along its whole length from the centre to the edge of the tube. Each time the scanner sweeps round, one timebase is brightened in this way, so that the operator sees a bright radial line on the map and the direction of this line is his line-of-flight.

The distortion of the map

24. On the face of the PPI tube it is possible to show any one of the following four maps :—

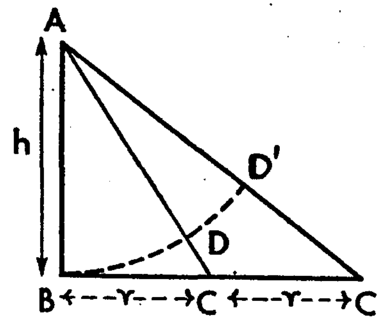
(1) The 10-mile scale where the radius of the PPI represents 10 miles.

(2) The 30-mile scale where the radius of the PPI represents 30 miles.

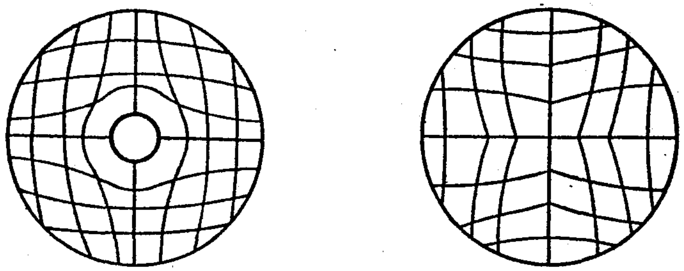
(3) The 50-mile scale where the radius of the PPI represents 50 miles.

(4) The 50-100 miles scale which is used entirely for locating beacons, and on which the time-base starts at a range of 50 miles and extends to 100 miles, so that points in the centre are at a range of 50 miles while points round the edge are at 100 miles range. This is really an extension of the 0-50 mile map.

25. The first three are the maps most often used, and they are subject to a peculiar kind of distortion. This distortion arises because the apparatus measures not the ground range but the slant range of a target, and its nature will be apparent from fig. 12(A). An aircraft is shown situated at the point A whose height above the ground is h; the point on the ground nearest to the aircraft is the point B directly below. No echo, except the echo of an airborne object, can appear on the display tube at a smaller range than this. Further, the point B will always give an echo no matter in what direction the aerials are pointing, because some radiation always travels vertically downwards. The result is that the point B appears as a ring of radius h at the centre of the map, and that no echoes can be seen inside this ring.



(A) How distortion arises



Outward distortion of map showing hole at centre
(B)

Inward distortion of map when hole is closed
(C)

Fig. 12.—H2S distortion

26. Consider the point C at a distance r from B. Its apparent range on the map will be the slant range AC. A second point C^1, whose ground range from B is just 2r will appear on the map at a range C^1. Now, although BC^1 is twice BC, it is easy to show that AC^1 is less than twice AC. In other words, if the map had no distortion the point C^1 would be twice as far from the centre as the point C, whereas in fact C^1 is less than this distance from the centre. It is hence possible to show that the distortion of the map is of a kind indicated in fig. 12(B). If the surface of the earth were covered with perfect squares, their appearance on the map would be similar to that shown in the sketch. This form of distortion is known as *outward distortion.* It becomes less marked at longer ranges, since as the range increases the slant distance, AC, and the distance measured along the ground, BC, become more nearly equal.

27. The distortion, particularly on the 10-mile map, has one good effect. Suppose that a bomber is directly over a town. All the echoes lie in a compact mass at the centre of the tube, and if there were no hole at the centre it would be difficult to distinguish one from another or to find the bearing of any particular one accurately. The effect of the distortion, however, is to scatter the echoes so that they appear farthest apart and the angular discrimination is greatly increased. This is useful in blind bombing.

28. For purposes other than bombing the hole at the centre of the map is a disadvantage, and in order to reduce the distortion and close the ring there is a control known as the 10-MILE ZERO KNOB. By turning this knob it is possible to change the time at which the trace commences its journey relative to the time of the transmitter pulse. By adjusting this control suitably the hole can be completely closed. The map will still be distorted, however, since the range of any point C, fig. 12(A) now appears to be the slant range AC minus the height AB, or the length DC, and this length is not proportional to the ground range BC. The second point C_1 at twice the range of C has an apparent range D_1C_1, and C^1D^1 is more than twice DC. The distortion in this case is an inward distortion, so that squares drawn on the ground have the appearance indicated in fig. 12(C). By suitably adjusting the zero control, the two distortions can almost be made to neutralise, and there is some position at which the radius of the hole is less than h, where the map is almost, though not quite, distortionless.

29. On the 30-mile scale the hole is approximately one-third of its size on the 10-mile scale, and the distortion is not serious. The diameter can be varied by a screwdriver control, but no knob is provided and the operator is generally expected to work with the control fixed. On the 50-mile scale the hole is very small and its radius cannot be varied.

Measurement of range

30. For ordinary navigational purposes the equipment need only supply approximate ranges on towns and coastlines. For blind bombing, however, it is necessary to measure range accurately.

31. The fact that the equipment measures slant range is unimportant for navigational purposes, since the error involved will be relatively small, and on the 0-30, 0-50, and 50-100 miles maps no correction need be applied. On the 0-10 miles scale, however, it is necessary to allow for the height of the aircraft, and a correction must be applied to convert the slant range into ground range. It is clear from fig. 12(A) that the ground range of the point C is

$$r = BC = \sqrt{AC^2 - h^2}$$

where AC is the slant range, so that it is a simple matter to find the value of r if both the slant range and the height are known. There is one difficulty, however. If r is not large in comparison with h, in other words if the aircraft is almost over the target, the ground range r will be changing rapidly as the aircraft flies up, but the slant range AC will be changing relatively slowly. This means that a small error in the measurement of AC will mean a large error in the measurement of r. It is therefore better to measure not the slant range AC but the difference DC between the slant range and the height, since a small percentage error in measuring this quantity will not cause such a large error in r. We then have

$$\begin{aligned} r^2 &= (h + DC)^2 - h^2 \\ &= 2h \times DC + DC^2 \end{aligned}$$

and if h is known, r can be found by measuring DC. The calculation is not made every time a range is taken, but is performed by graphical methods which will be described later. In measuring the ground speed it is necessary to take two ranges on a target with a fixed interval of time between the two, using a stop watch.

32. For purposes of range measurement the map is supplied with a range marker. This marker is produced by brightening each trace for a very short period of time, and appears as a bright ring, whose centre is the centre of the PPI tube. The time at which the brightening occurs relative to the transmitter pulse is controlled by a range knob, and by rotating this knob the radius of the bright circle can be varied. When the circle touches any required echo on the tube the range can be read off from a calibrated scale, more details of which appear in para. 39.

Measurement of height

33. The equipment measures the height of an aircraft by noting the range of the first ground return. It would be possible to do this by measuring the radius of the hole in the centre of the map, but it would not be easy to obtain very accurate results in this way, and in practice it is usual to measure height by means of a special *height tube* carried for the purpose. The height tube is a cathode ray tube whose time base is applied to the y plates only so that the trace is always vertical, and the signal is applied not to the grid as it was in the PPI tube, but

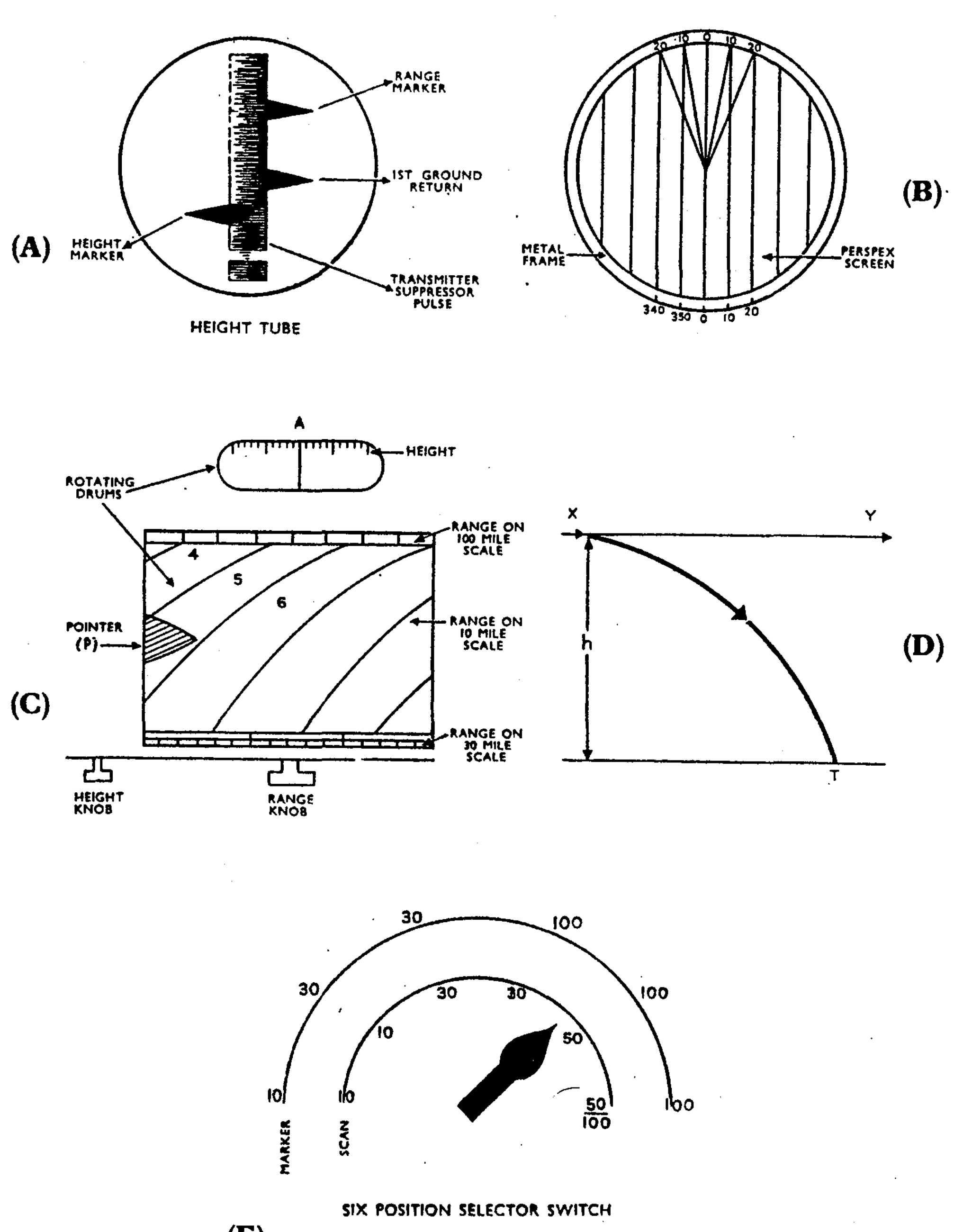


Fig. 13.—H2S display and controls

to the x plates, so that it appears as a horizontal deflection of the trace. Fig. 13(A) shows the appearance of the display. The blank space near to the bottom of the tube is caused by the transmitter suppressor pulse which cuts out the receiver to prevent damage while the transmitter is sending out its burst of waves. The deflection at the left-hand side of the trace is the height marker. The ground return appears as a persistent echo on the right-hand side of the trace. The range marker also appears on this tube as well as on the PPI tube.

34. The first ground return is the only important echo in the height tube, since all other echoes flash through so quickly as the scanner rotates that they can hardly be seen.

35. To find the height of the aircraft it is only necessary to turn a control knob until the height marker is opposite to the echo, and the height can be read off from a calibrated scan which is described in para. 39.

36. The range marker on this tube is simply a duplicate of the marker in the PPI tube. It is used here to check the height and range calibrations, and if the range and height markers are put opposite to one another the height and range should clearly have the same value, and the aircraft height is obtained.

Measurement of bearings

37. Accurate bearings are required on both Bomber Command and Coastal Command equipments. Bearings are measured in both cases by means of a perspex disc which is mounted in a circular metal frame in front of the tube. The frame and disc, which are shown in fig. 13(B), can be rotated about their centre point. The use of the device is self-explanatory; and it will measure bearings accurately to within ± 3 deg.

Use of the height and range controls

38. The unit containing the height and range indicators has a display similar to that shown in fig. 13(C). The displays themselves are marked on two drums, A and B, which rotate about vertical arcs. When the height control knob is turned it does three things:—

(1) It moves the height marker *on the height tube only*;

(2) It moves the point P up or down the left hand side of the drum B, and

(3) It rotates the drum A.

When the range control knob is rotated, it does two things:—

(1) It moves the range marker on *both the height tube and the range tube*, and

(2) It rotates the drum B.

39. On the 30- and 100-mile scales, where the slant range only is taken, the ranges are read off from fixed pointers at the centre of the display. The range on the 100-mile scale is marked along the top of the drum, and the range on the 30-mile scale is marked along the bottom. On the 10-mile scale, where it is necessary to allow for the height of the aircraft, the range is read from the tip of the pointer P. On the centre of the drum between the 100-mile and the 30-mile scales are drawn a number of lines of constant range, each line being marked with a number indicating the range in miles to which it corresponds. In reading the range of an echo on the 15-mile scale it is first necessary to find the height by moving the height marker to a position opposite to the first ground return on the height tube. The pointer P will move with the height marker, and its final position will be determined by the height of the aircraft. The next operation is to adjust the range marker on the PPI tube until it touches the inside edge of the echo. The drum B will now be in a position corresponding to the range reading, and the lines of constant range on the drum are so arranged that the particular curve which corresponds to the range of the target just touches the tip of the pointer P. Thus to find the ground range on the 15-mile scale it is necessary :—

(1) To move the height marker to the correct position on the height tube ;

(2) To move the range marker to the correct position on the range tube ; and, finally,

(3) To read off the range from the drum by noting the range curve which touches the tip of the pointer P.

Blind bombing procedure

40. To direct a bomb on to a target it is necessary to know the height and the ground speed of the aircraft and the range of the target. For high-altitude bombing it is also necessary to take into account the wind speed and the ballistic properties of the bomb, since different types of bomb have different wind resistances and fall with somewhat different trajectories. In the first instance, one can neglect the effect of wind resistance, however, and suppose that the bomb falls with uniform acceleration, so that its trajectory will be similar to that shown in fig. 13(D). The aircraft is at a height h above the ground and it releases a bomb at the point X. The bomb will continue to travel forward with the speed of the aircraft during its time of fall, and when it reaches the ground the aircraft will be at a point Y vertically above the target. The distance XY is determined by the speed of the aircraft and the time of bomb fall. Knowing these two quantities it is possible to calculate the point at which to release the bomb, and this calculation is performed automatically by the equipment. The equipment will determine :—

(1) The height of the aircraft, and hence the time of bomb fall ;

(2) The range of the target at any instant ; and

(3) The ground speed of the aircraft.

41. A number of red lines (not shown in the sketch) are drawn on the part of the range drum concerned with the 10-mile scale. These lines are marked 100, 150, 200, 250 and 300. The figures stand for the ground speeds of the aircraft. Having picked out the target and found the ground speeds accurately, the height pointer P is set correctly and the drum is turned until the red curve corresponding to the ground speed of the aircraft touches the pointer P. This puts the height marker on the PPI tube at the correct bombing range. As the aircraft approaches the target the echo will draw nearer to the preset range marker, and when it reaches the marker the operator knows that he is at the point X (fig. 13(D), and that it is time to release his bombs.

42. Very often, the target is so close beneath the aircraft at the point of bomb release that it may be barely visible among the large amount of clutter from the direct ground return. To overcome this difficulty there is a second set of red curves on the range drum. These curves are shown as dotted lines to differentiate them from the previous red curves which are drawn as full lines, and they are marked with the same numbers but are labelled “ 30 seconds.” To use these curves, the navigator sets up his height marker correctly as before and turns the drum B until the dotted curve corresponding to his ground speed touches the pointer P. This time, however, he has to wait for exactly 30 seconds after the target has touched the range marker before he releases the bombs. These 30-second curves are probably more useful than those previously described. In practice it is necessary to allow for wind resistance in calculating the point of bomb release, and for this purpose tables are provided. These tables tell the bomb aimer what length of time must be subtracted from the 30 seconds for an aircraft flying at any given height and speed in order to allow for the windage on any particular type of bomb.

The 6-position selector switch

43. One difficulty in switching from one scanning range to another is that of identification. Suppose that the observer is looking at a target

on the 50-mile scale map, and that he brings the range marker up to it and follows it. As he approaches the target he will wish to switch to the 30-mile scale, and when he does this the whole appearance of the map will change. Moreover, on the 30-mile scale the setting of the range marker is different from its setting on the 50-mile scale, and if he switches both scale and range marker over at the same time, the marker will move away from the echo, so that the identification of the target will be very difficult. In order to make the identification easier the scale and the range marker are switched by the selector switch shown in fig. 13 (E). There are six positions of this selector switch. In the extreme left-hand position, marked 10, 10, both the map and the range marker use the 10-mile scale switching so the next position changes range scale to 30 miles, but leaves the scale of the map as it was. The third position gives the 30-mile scale for both map and marker. The remaining 3 positions give similar combinations. When the operator wishes to switch from the 50-mile to the 30-mile map, therefore, he first moves the selector switch from position 5 to position 4. This changes the scale of the map but leaves the range scale unchanged so that the range marker still touches the target on the new map. It is then an easy matter to recognise the target, and the switch can be turned to position 3. The range marker will then move off the target, but this does not now matter since the echo has already been identified and the marker can easily be brought back by turning the range knob.

The fishpond unit

44. Bomber Command aircraft often carry an additional unit known as the *Fishpond unit.* This unit has a separate display tube which shows the H2S map on a much larger scale, so that the radius of the tube represents only 5 miles, and the hole in the centre of the map occupies a considerable area of the tube. Any other aircraft flying below the bomber will return an echo, and if its range is less than the height of the bomber, the operator will see its echo somewhere in the hole. The wireless operator usually uses the fishpond unit and watches the map so that he can give warning of the approach of enemy aircraft.

Lucero

45. Lucero is an apparatus used in conjunction with H2S and ASV Mk. III. Its function is to interrogate ground beacons and IFF equipment carried by other aircraft. It has a separate transmitter, receiver, and common aerial unit of its own, but its echoes are displayed on the H2S tube. A fuller description appears in chapter 6 which deals specifically with radar beacons.

Summary of data

46. *H2S*

Range on land:	40-50 miles.
Accuracy:	±2 per cent. on 100-mile and 30-mile scales. ± 100 yards on 10-mile scale.
Accuracy of bearing:	About ± 3 deg., though no great accuracy required.

H2S Mk. II with Lucero

Range on responder beacons:	About 90 miles at 4,000 ft. under favourable conditions. The extra 50-100 mile range scale is included for use with beacons.
Range on IFF sets:	60-80 miles.
Range on BABS:	Up to 14 miles at 1,000 ft. (*See beacons in Chap.* 6).
Accuracy of range on BABS:	± 200 yards at 6 miles.
Sector discrimination on BABS:	± 1 deg.

Transmitter

Peak pulse power:	About 50 kW.
Pulse length:	1 microsecond.
Pulse recurrence frequency:	6 per second.
Wavelength:	9·1 cms.

Aerial system

Scanner rotating at rate of 1 revolution per second. Details described in text above.

RECENT DEVELOPMENTS IN H2S DESIGN AND LATER MARKS OF ASV

47. The preceding description refers to H2S Mks. II, IIA and IIB, as installed in aircraft of the main bombing force. On reference to the summary of H2S equipments given in A.P.1093C, Chapter 4, it will be seen that other Marks of H2S were under development. Mks. IV, VI and VII are not dealt with here. Mk. V is an American equipment (AN/APS.15) which has been used for ASV, refer to ASV Mk. X—in

para. 69. In connection with recent improvements in design since the introduction of H2S Mk. II, the chief points of interest are as follows :—

(1) Scan distortion correction.
(2) Display of a track marker.
(3) Roll-stabilisation of the scanner.
(4) Increased discrimination by reducing the operational wavelength.

Scan distortion correction

48. The distortion of the map mentioned in para. 24 has been greatly reduced by a change in design of the indicating unit. The scan-corrected display is known as indicating unit type 184, and is fitted in H2S Mks. II C and III.

49. It was stated that by adjusting the 10-*mile zero knob* the hole in the map can be completely closed up, thus reducing the distortion to some extent but not completely eliminating it. When this is done, the distance of a target echo from the centre of the cathode ray tube is a reading of the slant range minus height of the target. But if the aircraft changes height, it is necessary to reset the 10-mile zero control whose function is to control the start of the trace relative to the time of triggering of the transmitter. It is possible, however, to arrange that the setting of the *height marker control* determines the start of the trace so that the hole in the centre of the map is completely closed provided the correct height is set in. This arrangement has been made in indicator unit, type 184. The operator does not need to re-set the 10-mile zero. Provided he sets in the correct height no hole will appear in the map, and an object on the ground beneath the aircraft always appears in the centre of the cathode ray tube.

50. In the earlier indicating units some distortion of the map occurs when the hole is completely closed, as shown in fig. 12(C). This takes place because the cathode ray tube is provided with a linear timebase, i.e. the electron beam moves outwards from the centre of the tube with uniform speed. In order that there should be no distortion at all the beam should be made to move rapidly away from the centre of the tube, and then move slowly as it approaches the circumference, thus expanding the central area of the map so that distances on it are exactly proportional to ground ranges. The manner in which the electron beam should move to produce a distortionless picture varies with the height of the aircraft, but this difficulty is overcome in indicator unit, type 184 by providing an additional control known as the *distortion corrector*. When this knob is set by the operator to the aircraft height the timebase is speeded up by the correct amount in the central part of the tube, and the map is expanded in that region so that the inward distortion is almost eliminated. Distances between any two points in the tube face are then very nearly proportional to ground range. Even when these special precautions have been taken the map scale is not quite perfect in the centre, because it is difficult to design electrical circuits which will make the electron beam move fast enough at the beginning of the timebase.

Display of track marker

51. In H2S Mk. II equipment the aircraft heading or course is indicated by a bright radial line which appears when the LINE-OF-FLIGHT switch is depressed. This line is designated the *course marker* in more recent equipments. If there is no wind, and if the pilot sets his course so that a target point is on the course marker, the aircraft eventually passes directly over the target, and the echo is seen to remain on the marker line as the range diminishes, until the crossing point is reached. If, however, a cross wind is blowing, the aircraft drifts and the echo is seen to drift off the course marker. In this case the course marker does not indicate the future track of the aircraft, i.e. the path on the map over which it will fly. On the other hand, if the aircraft course and airspeed are known, as well as the wind speed and direction, the track can easily be plotted; for, provided these quantities remain constant, the track is a straight line displaced from the course marker line by the angle of drift. In H2S Mks. II C and III equipments, which use indicating unit, type 184, the calculation is done automatically, and the track is displayed as a bright radial line on the cathode ray tube. The data mentioned above are fed into the Mk. XIV bombsight, which calculates the drift angle, and the information is fed out electrically and displayed on the H2S tube. Two marker lines are therefore available according to the position of a two way switch on the indicating unit which is marked COURSE and TRACK.

Roll-stabilisation of the scanner

52. When an aircraft is flying straight and level, the axis of rotation of the scanner is perpendicular to the earth's surface, and the centre point on the H2S map corresponds to a point vertically below the aircraft. If the aircraft banks, the axis of rotation of the scanner is tilted with respect to the earth's surface and a displacement of the H2S map results. This sliding of the display during evasive action on a bombing run makes accurate bombing difficult. To overcome this difficulty new scanners have been developed which are gyro-stabilised against roll. As soon as the scanner platform is displaced by about one deg. from the horizontal, a gyro comes into action to develop a restoring force. This

stabilisation remains effective for displacements up to 30 deg. to either side. The platform is not stabilised against pitch, or displacement of the scanner's axis as the aircraft climbs or dives, as this can usually be avoided during bombing operations. Stabilised scanner platforms are installed in H2S Mks. II C and III A, and also in other Marks.

Increased discrimination

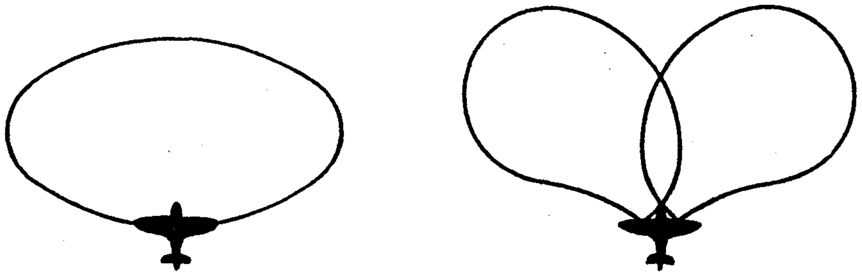
53. As shown in fig. 4 the strip of ground illuminated by the H2S, Mk. II scanner is roughly a sector of angle 6 deg. Suppose that the beam is sweeping over an isolated object such as a chimney. A 6-deg. arc is then seen on the H2S tube. If the beam width is reduced, a correspondingly smaller arc appears on the tube, until when an extremely narrow beam is used the echo of the chimney appears as a point of light on the tube. Hence in order to discriminate between objects on the ground that are fairly close together it is necessary to use as narrow a beam as possible.

54. There are two possible ways of increasing H2S discrimination by reducing the beam width. The first method is to increase the aperture of the aerial system by designing a larger scanning mirror. This means that a much larger perspex blister must be fitted to the aircraft. The second method is to increase the frequency of the transmitter, i.e. to make use of a shorter wavelength. In recent Marks of H2S, both methods are used. Mks. III and IV are X-band equipments radiating on a wavelength of 3 cm. By using an X-band transmitter, and an aerial system of about the same size as in earlier designs, the beam width can be reduced to about 3 degrees. H2S Mk. III C employs a 3 cm. transmitter with a 6-ft. aerial array, so that still better definition is obtained. Future equipments are designed with higher-powered transmitters to ensure adequate range, and with as narrow a beam width as possible to obtain high discrimination. A list of H2S equipments is given in A.P.1093C, Chapter 4.

ASV Mk. II

General principles

55. The older ASV equipment, ASV Mk. II, is obsolescent and has been replaced by the later marks. It works on the radar principle, having a transmitter which radiates pulses of RF waves of frequency 176 Mc/s and a receiver which detects and displays the return signals. Echoes are received from ships, submarines and coastlines.



A—P.D. of forward-looking transmitter A.S.V. Mk.II

B—P.D. of forward-looking receiver A.S.V. Mk. II

Fig. 14—ASV Mk. II polar-diagrams, forward-looking

56. The smaller types of Coastal Command aircraft, such as Beauforts and Hudsons, carry a transmitting aerial situated beneath the nose of the plane so that the polar diagram is similar to that shown in fig. 14(A). There are two receiving aerials, one beneath each wing, and echoes are received on each of these alternately. The polar diagram of the receiving aerials is shown in fig. 14(B) whence it is clear that one aerial looks rather to the starboard side and the other to the port side of the aircraft. The echoes are displayed on a cathode ray tube whose trace is vertical (fig. 15), and it is arranged that echoes from the starboard-looking aerial deflect the trace to the right while echoes from the port aerial deflect it to the left. Thus the echo of a target at a point T (fig. 14(B)), which is in front and to the starboard side of the aircraft, will appear on the tube as a double deflection of the trace, the right-hand deflection being greater than the left-hand one. From the appearance of the display the operator knows that to home on the target he must turn to the starboard until the two halves of the echo are equal in length, and that he will then be heading directly towards the target.

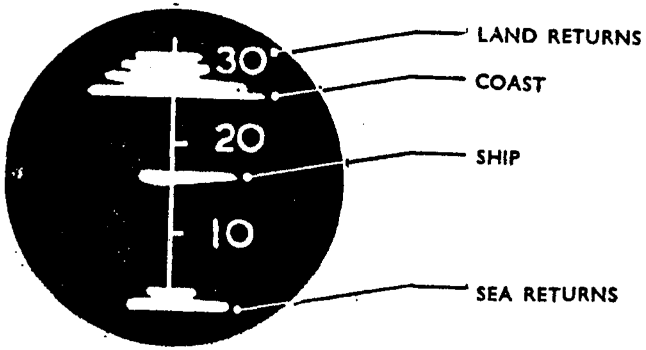
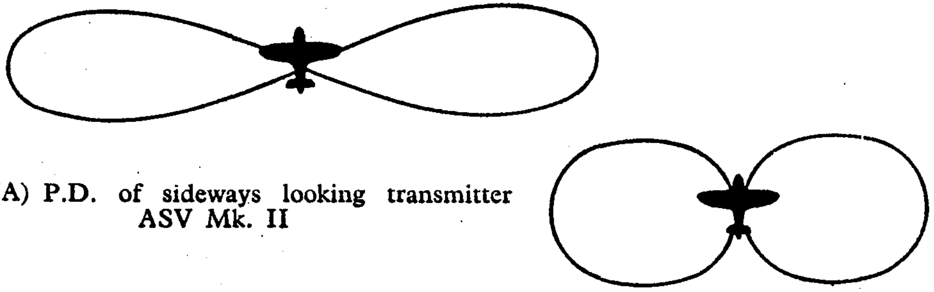


Fig. 15.—ASV Mk. II display tube, forward-looking

57. Larger aircraft, such as Whitleys, Wellingtons, Liberators, Sunderlands and Catalinas, have, in addition to the aerials already described, sideways-looking arrays. The sideways-looking transmitting array is a broadside array containing four stacks each of two aerials mounted above the body of the aircraft, and its polar diagram is shown in fig. 16(A). There are two receiving aerials, one mounted at either side of the body of the aircraft, so that they have polar diagrams similar to those shown in fig. 16(B). Again, the echoes are received by each aerial in turn, and an echo from the starboard receiving aerial deflects the trace to the right, while that from the port aerial deflects it to the left. The operator can use either these or the forward-looking aerial systems at will. The sideways-looking system is usually employed for searching, and the forward-looking system is for homing on to the target.



(A) P.D. of sideways looking transmitter ASV Mk. II

(B) P.D. of sideways looking receiver ASV Mk. II

Fig. 16—ASV Mk. II, polar diagrams, sideways-looking

58. By means of a range switch the velocity of the scan can be varied, and the time base on the tube can represent either 9, 36 or 90 nautical miles range. The range can be read directly from a scale marked in nautical miles.

59. The equipment will itself, with its own radar pulses, interrogate beacons, and beacon responses can be seen on the display tube.

60. **Performance**

Range on surface craft	up to 12 miles
Range on coastlines	50-70 miles
Range on responder beacons	80-90 miles
Range on BABS beacons	20 miles at 1,000 ft.

LATER MARKS OF ASV.

61. As explained in para. 1, when H2S Mk. II was finally developed for Bomber Command it was also installed in Coastal Command aircraft. Slight modifications were required, and the equipment was called ASV Mk. III. The chief modification effected was the fitting of a different reflector to the aerial system so that a beam more suitable for searching from low altitudes was produced. Many of the equipments were installed in Wellington aircraft for attacking surfaced submarines. For night attack the usual method is to home on the target using the radar equipment until the range is one mile, and then obtain a " visual " by switching on the Leigh light. The H2S drum for computing ground range, and the height marker, are no longer required. The bombing scales are therefore replaced by range scales reading nautical miles. The height marker is preset at one mile, and is made to appear on the PPI tube, thus providing a fixed one-mile marker ring which indicates when the Leigh light should be switched on.

62. Several new equipments are in operation, and more are under development. A full list is given in A.P.1093C, Chapter 4.

General trend of ASV design

Transmitter frequency

63. Beamwidth and discriminating power already discussed in connection with H2S are also of importance in ASV equipments, particularly when the reflecting object is small as in the case of a surfaced submarine in the end-on aspect. The echo cannot be picked out on the cathode ray tube unless discrimination is good so that it can be distinguished among the general clutter of sea returns. The use of the *Schnorkel* by enemy submarines has recently led to an increased demand for better discrimination. X-band as well as S-band transmitters are now being used for ASV. On X-band a narrow beam can be more readily obtained without unduly increasing the size of the aerial system. ASV Mks. VIII A (AN/APS.3) and X (AN/APS.15) are American X-band equipments which are in use. ASV Mk. XI (ASVX) is a British X-band equipment which was designed for the Naval Air Arm, while Mks. XIII and XIV are improved versions of ASVX.

Transmitter power

64. It is most important that ASV radar apparatus should have as good a maximum range as possible in order to increase the probability of locating enemy vessels when using a given number of patrolling aircraft. A powerful transmitter is essential for obtaining long range echoes, and for this reason every opportunity is taken to increase the power and efficiency of the magnetron transmitting valves used in recent

designs. The ASV Mk. III S-band transmitter has a power of roughly 50 kW, and in favourable circumstances surfaced submarines can be detected at a maximum range of 15 miles. A more recent S-band high-powered transmitter used in Mk. VI is rated at 200 kW., and maximum range is 25 to 30 miles.

65. The X-band magnetrons which are used at present are not capable of producing quite as much power as the new S-band types, but, as the X-band beams are usually narrower, the available energy is more concentrated. The X-band ranges are therefore comparable with those obtained by using more powerful S-band transmitting valves. Very good ranges have been obtained on ASV Mk. X (AN/APS.15) which employs an X-band magnetron developing about 40 kW. In favourable circumstances submarines have been detected at 35 miles with this apparatus and schnorkels have been seen at 12 miles. It must be appreciated that range figures vary a great deal with the conditions of the sea, and also according to the aspect of the vessel; for example, if a vessel is approached end-on the maximum range of detection will be reduced to about two-thirds of the value for the broadside aspect. The figures quoted for ranges above are for broadside aspects.

Beam shape

66. It was stated that ranges can be increased by concentrating the available energy from the transmitter into a narrow beam. The S-band designs of ASV, (Mks. III and VI), use scanning mirrors somewhat similar in design to the H2S reflector, which produces a beam narrow in azimuth but wide in elevation.

67. The beam does not resemble that of a searchlight, but is wedge shaped. The object of this design is the production of an illuminated strip on the ground or sea, so that all points within range of the transmitter will be illuminated once for each turn of the scanner, and a complete map obtained on the cathode ray tube. For ASV working it is not quite so important that complete coverage should be obtained for one individual turn of the scanner, and in some equipments the beam is produced by a parabolic reflector so that it is narrow in elevation as well as in azimuth. The energy is then more concentrated and maximum ranges are improved; and, as the aircraft usually fly low when searching, a fairly good coverage is still obtained with this type of beam. If the beam is narrow in elevation, it is usually necessary to provide some means of altering the tilt of the mirror in elevation so that the sea below the aircraft, and also out towards the horizon, can be satisfactorily covered. In other words, if the beam is concentrated in this way some kind of scanning action is desirable. This may be either manual or automatic. In some equipments for example, ASV Mk. V (American ASG1), and ASV Mk. V A (American AN/APS.2, a parabolic beam reflector is fitted, and by operating a tilt switch the beam may be set at any desired elevation. The best possible maximum range is therefore obtained, but the searching process is rendered a little more complex because the operator must adjust the scanner tilt control during search. ASV Mk. XI (ASVX designed for the Naval Air Arm) has a beam 5 deg. in horizontal cross-section and 8 deg. in the vertical plane, and the tilting of the scanner is automatic. When searching the scanner revolves once at +1·4 deg., followed by a revolution at —2·8 deg. and one at —7 deg., thus securing a coverage from one quarter of a mile out to fifty miles range and preserving the advantages of the concentrated beam.

Sector scan

68. Many ASV equipments use an all-round-looking scanner for search purposes, but sometimes facilities are provided for restricting the searching movement. The mirror may be made to swing to-and-fro in azimuth over any desired sector—an arrangement called *sector scanning*. If a weak echo is observed the beam can be oriented approximately in the direction of the target, and made to oscillate in azimuth so that only a small sector of the tube is in use. The beam then passes over the target vessel more frequently, and the echo may be improved. Sector scanning is useful when the operator is interested in searching in a specified direction.

69. ASV Mk. X (AN/APS.15) has a double sector-scan switch. The first selector switch determines the width of the sector swept out by the scanner in steps of 30 deg., and the second selector determines the azimuth of the central line of the sector relative to the aircraft heading. Sector scan facilities are provided on some of the more recent ASVX equipments. The sector width may be varied from 5 to 60 deg., provided that the extreme limits of the swing do not exceed 75 deg. port or starboard from the line-of-flight.

Attenuation of transmitted signal

70. For the detection of aircraft carrying ASV radar, enemy vessels have been equipped with a listening device consisting of an ultra-short-wave receiver for detecting the radar pulses. The strength of the received pulses increases as the aircraft approaches the vessel, and it is therefore possible to estimate the rate of approach. As a counter measure an attenuator can be fitted to the ASV equipment between the transmitter and the aerial system, as in ASV Mks. VI and VI A. As the aircraft approaches the target vessel the attenuator is adjusted so that the intensity of the radar beam is gradually reduced. This can be done without diminishing the echo too much because very much less transmitter power

is required at short ranges. The presence of the aircraft can still be detected by the listening device when the attenuator is used, but it is no longer possible to tell whether it is approaching or not. ASV Mk. VI A has an automatic attenuator requiring no adjustment by the operator.

Spiral scan for ASV

71. AI Mk. VIII (*see* Chapter 1), which employs a spiral scan with a cone of search of semi-angle 45 degrees, has been modified for use as ASV. The beamwidth is about 12 deg. both in azimuth and elevation and fairly good ranges are obtained. The ninety-mile and eight-mile range-deflection timebases are used instead of the AI radial timebase, and when the aircraft has been headed towards the target vessel the scanner is switched over to a conical scan of semi-angle 3 deg. An automatic device is fitted which gives audible or visual warning at a predetermined range. The modified AI equipment is known as ASV Mk. XII.

Stabilised scanners

72. Gyro-stabilised scanners, already mentioned in connection with H2S are fitted in some of the later marks of ASV. They are designed for use with X-band narrow beam transmitters because high discrimination cannot be obtained unless the scanner is stable. ASV Mk. XIIIA is an improved version of Mk. XI (Naval Air Arm ASVX) with a more powerful X-band transmitter and a roll-stabilised scanner; Mk. XIV is similar but has a scanner stabilised for both pitch and roll.

Lock follow with automatic bomb release

73. ASV Mk. VIA designed for Coastal Command has some new features. The transmitter is a high-powered (200 kW) S-band magnetron fitted with an automatic attenuator. When the operator has "locked" the scanner on to a target vessel, range and azimuth information are transmitted automatically and continuously to an indicating meter in the pilot's cockpit. A computer is installed and it is possible for the bomb-load to be released without using a Leigh light, provided that the attacking aircraft flies at constant speed and height.

74. The scanner produces a wedge-shaped beam rotating through 360 deg. for searching, but once an echo has been observed the scanner driving-motor is switched off when the scanner is pointing approximately at the target. The mirror is energised by two waveguides displaced slightly in azimuth from its focal point. The energy is fed from the transmitter through each waveguide in turn, the switch-over taking place many times per second. The beam therefore alternates rapidly between two positions 5 deg. apart in azimuth. This arrangement is called an *aizmuth split beam.* If the target is slightly displaced from the main axis of the mirror, the signals vary in amplitude according to the position of the beam; but, when the mirror is pointing directly at the target, steady signals are received all the time because the signal amplitudes are equal for both beam positions. Electrical circuits are arranged to lock the mirror on to the target vessel, and to keep the mirror pointing straight at the target. This is known as a *lock-follow* or *auto-follow* system.

75. A pilot's indicator is provided with two pointers, one to show target range from 0 to 12 nautical miles, and the other to indicate azimuth from 30 deg. port to 30 deg. starboard. Radar bearings and ranges are continuously and automatically transmitted to the pilot's meter, once the mirror has locked on to the target.

76. The Leigh light indicator has two pointers on it. The first of these indicates the bearing of the Leigh light, and the second indicates the bearing of the target obtained from the radar apparatus. The light can be kept in the correct direction ready for use by keeping the needles aligned.

(1) *Search.* During the searching process the mirror is spinning in the usual manner and the operator watches the tube for targets. If a target is located the aircraft is directed towards it.

(2) *Leigh light attack.* When the range is less than 10 miles the scanner is stopped with the mirror pointing approximately in the direction of the target. An "inching switch" is provided so that the mirror can be rotated by a small amount in either direction, until the echo comes up as a bright spot on the PPI tube and as a deflection signal on the height tube. A small bright spot called a strobe (*see* Chapter 1, AI Mk. V) is visible on the height tube trace, and the operator rotates the manual strobe control until the bright spot moves along the trace and comes directly on to the echo. This is known as *setting the strobe.* The auto-follow switch is then depressed and the scanner aligns on the target, and should remain aligned thereafter. When the auto-follow mechanism is switched on, the pilot's indicator is illuminated. As the range diminishes the strobe on the height tube trace remains coincident with the target echo, and range and azimuth are continuously displayed on the pilot's meter. The pilot flies so that the azimuth needle is kept central on the scale. Azimuth is also shown on the Leigh light meter so that the light can be aligned ready

to switch on. This is usually done at one-mile range. On the indicating unit there is a " velocity meter " which shows the rate at which the range is diminishing, i.e., the rate at which the echo and strobe are moving down the height tube trace. If, because of excessive sea returns or for any other reason, the strobe slips off the echo and remains stationary on the trace the auto-follow system will fail to operate. The velocity meter then reads zero. The operator should therefore watch the velocity meter during the run in, and if it slips back to zero he must reset the strobe and proceed as before.

(3) *Blind bombing*. Provided that the problem of identification can be overcome, blind bombing runs may be carried out with ASV Mk. VIA. The searching process and transmission to automatic follow are carried out as above. The attacking aircraft must fly at constant height and speed, and the pilot must avoid " weaving " when approaching the target vessel. The height is set on the computer by the operator at the beginning of the run. Three coloured lamps—green, amber, and red—flash on at intervals as the range diminishes so that the operator can tell that the computer is working. The red lamp lights up at about 4,000 ft. range and the bombs are released when it goes out. The release point depends on the ground speed and height. If the pilot decides at the last moment, not to attack, an over-riding switch in the cockpit can be placed in the " safe " position.

CHAPTER 3

RADAR AIDS TO GUNLAYING IN BOMBER AIRCRAFT

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Para.

General principles of AGLT

LIST OF ILLUSTRATIONS

Fig.

GENERAL PRINCIPLES OF AGLT

Introduction

1. AGLT (Airborne Gunlaying in Turrets), formerly called Village Inn, is an ultra short wave radar equipment installed in heavy bombers. Its primary function is to provide the rear gunner with accurate information about the position of an enemy fighter. The directional properties of the system are such that the gunner can open fire at an unseen target with an accuracy of about half a degree. Under conditions of good night visibility the equipment may be used in a less ambitious way—the gunner using radar to find the location of the attacking fighter, but relying on visual aid for firing the guns.

2. AGLT has two subsidiary functions. In the first place it warns the gunner and air-crew that an aircraft has been picked up in the AGLT beam. This is achieved by the injection of a warning note into the intercommunication system whenever an aircraft is within 4,000 feet of the bomber and inside the beam. The warning note is of the pipping type and varies with the range in the same way as that used in Monica.

3. The second subsidiary function of AGLT is connected with the operation of the Mk. II C gyro gunsight, which is used with AGLT. The gyro gunsight is a form of predictor which calculates the allowance that the gunner has to make in order to hit the target. The sight is automatic, but normally has to have the target range fed into it by an optical range finder which is operated by pedals. When AGLT is used the range correction is obtained from the radar equipment and the sight becomes fully automatic. It can be used in this way either by night or by day. This last function of AGLT may be summarised by stating that the equipment provides automatic range for the Mk. II C gyro gunsight.

Scanning system

4. AGLT is installed in powered gun turrets. The scanner is covered by a perspex dome and is mounted at the base of the turret as shown in fig. 1. It rotates in azimuth with the guns when the turret is turned. The scanner is connected to the gun elevating mechanism by a parallel linkage so that it follows the gun movement in elevation. The aerial is a small dipole mounted near the focal point of a 16-inch parabolic reflector. The dipole is mounted eccentrically and is spun by an electric motor at 2,000 r.p.m. This causes the axis of the beam to follow a conical scan with a vertical angle of 11 degrees. The aerial is fed from a 9·1 cm. magnetron transmitter through a coaxial cable, and half-microsecond pulses are radiated at a p.r.f. of 660 per second.

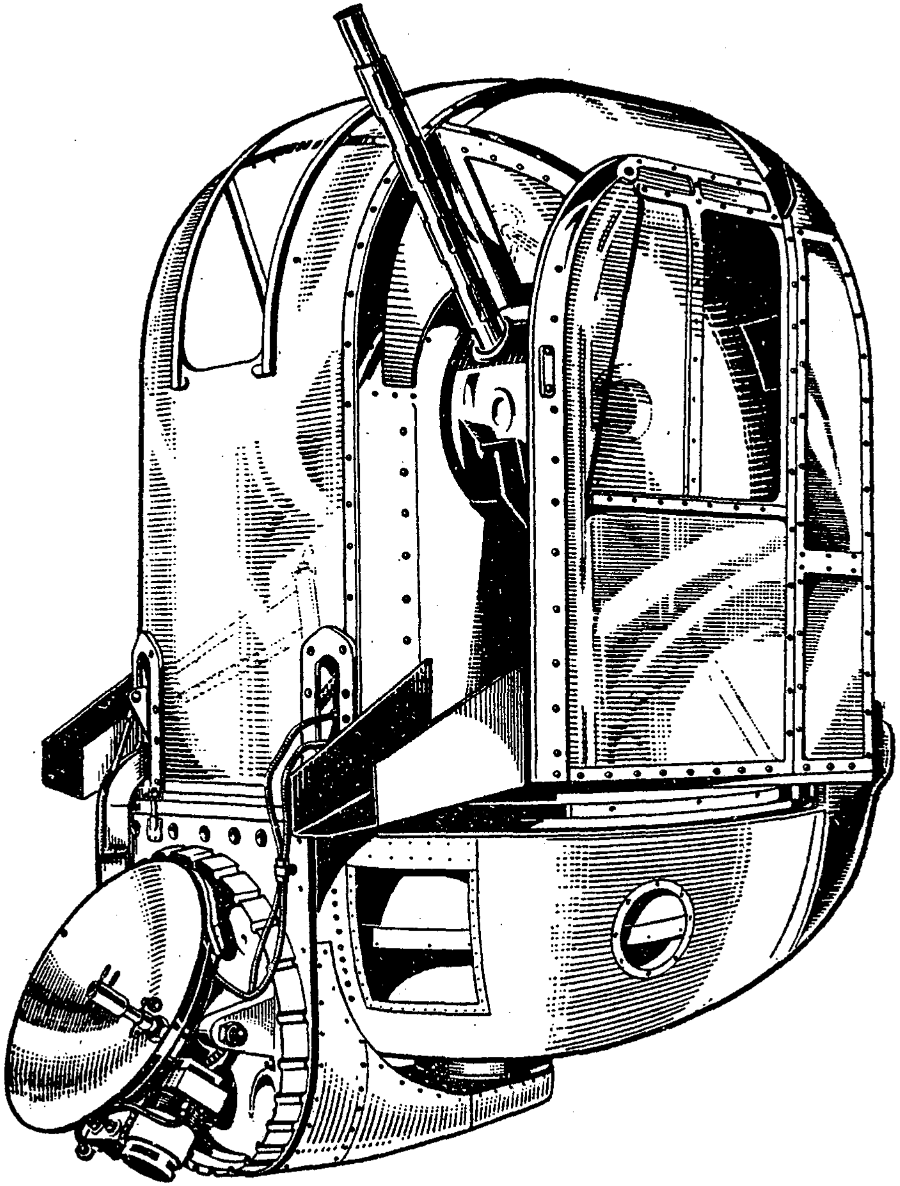


Fig. 1.—Rear gun turret with AGLT scanner

5. The beam is about 17 degrees wide at half-amplitude and one might therefore expect to be able to pick up an aircraft approximately within a 30-degree cone. In fact, the sensitivity is sufficient to enable aircraft to be picked up over a 35-deg. cone in most cases. Aircraft can be detected by the rear gunner over most of the rear hemisphere, since the axis of the beam can be scanned over ± 85 deg. in azimuth and ± 45 deg. in elevation. This form of search involves manual control of the turret and is tedious, but it need not be normally employed since most aircraft fitted with H2S are also fitted with Fishpond, which has a coverage over the whole of the lower hemisphere.

6. The maximum range of AGLT is artificially restricted to 4,000 feet. This range was chosen in order to limit the number of casual contacts from friendly bombers and to eliminate ground returns. The minimum range of the system is about 500 feet.

Display system

7. The direction of the enemy aircraft is indicated by the movement of a bright spot on a cathode ray tube. This form of display is sometimes known as a spot indicator. The displacement of a bright green spot from the centre point of the tube gives a measure of the bearing and elevation of the attacking aircraft. Usually the operator of a radar equipment looks directly at a cathode ray tube, but in this case the image of the spot is projected into the gunsight through an optical system containing mirrors and a convex lens. The display unit therefore consists of a cathode ray tube with an attached optical system. The complete unit, which is called the collimator, is shown in fig. 2. The collimator is mounted on the right-hand side of the gunsight with the axis of the tube vertical and the screen facing upwards. Fig. 3 is a sketch of the sight with the collimator attached.

8. The Mk. II C gyro gunsight is a reflector sight. The aiming point is seen by the gunner as a bright spot in the centre of a circle of diamonds as shown in fig. 4(a). The aiming point which is produced by reflection is called the graticule.

9. When a gun is provided with a fixed sight, the gunner must allow for the movement of a target by aiming in front of it; and must allow for the effect of gravity on the bullet by aiming slightly above the target. In firing from a moving aircraft other allowances must be made which are discussed later. The Mk. II C gunsight is, however, a predictor sight, the graticule moving about under the influence of a gyro and an electromagnetic system. The allowance is computed electrically and the graticule is automatically offset from the fixed aiming point by the correct amount. This simplifies gunlaying to a considerable extent.

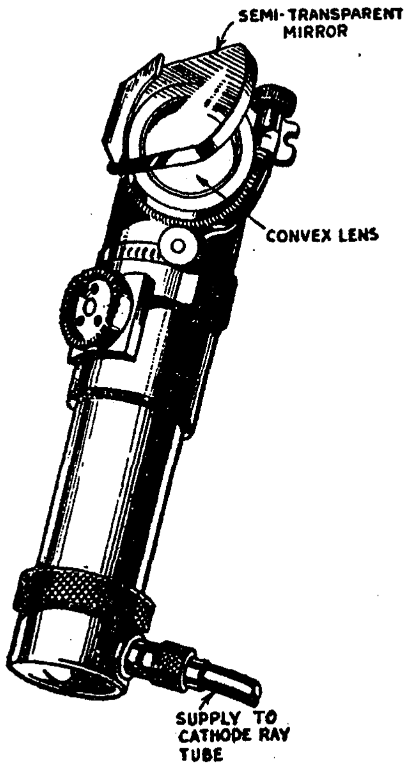


Fig. 2.—AGLT collimator

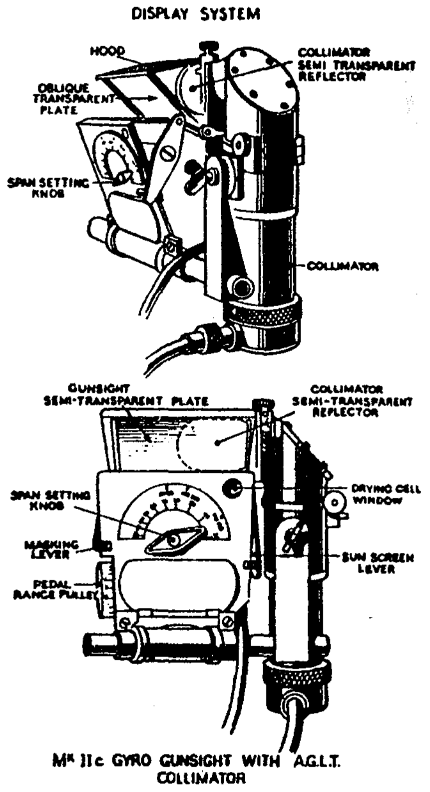


Fig. 3.—Gyro gunsight with AGLT collimator

When firing during the day, the gunner simply moves the guns to keep the aircraft encircled by the graticule with the central aiming point superimposed on the target. For night firing, the image of the AGLT green spot is observed in place of the target aircraft, and the guns are moved so that the green spot is central in the graticule, *see* fig. 4. In this way the gunner is able to keep his gunsight graticule lined up on an invisible target by regarding the image of the cathode ray tube spot as the target.

10. When operating, either during the day or at night, range is automatically fed into the gunsight computer from the AGLT receiver. The gunner therefore has no ranging difficulties when the sight is used in conjunction with radar equipment. It is convenient, however, for him to be aware of the approximate range of a target without having to look away from the gunsight, so that he may know when to open fire. In visual firing, the appearance of the target is sufficient for this purpose.

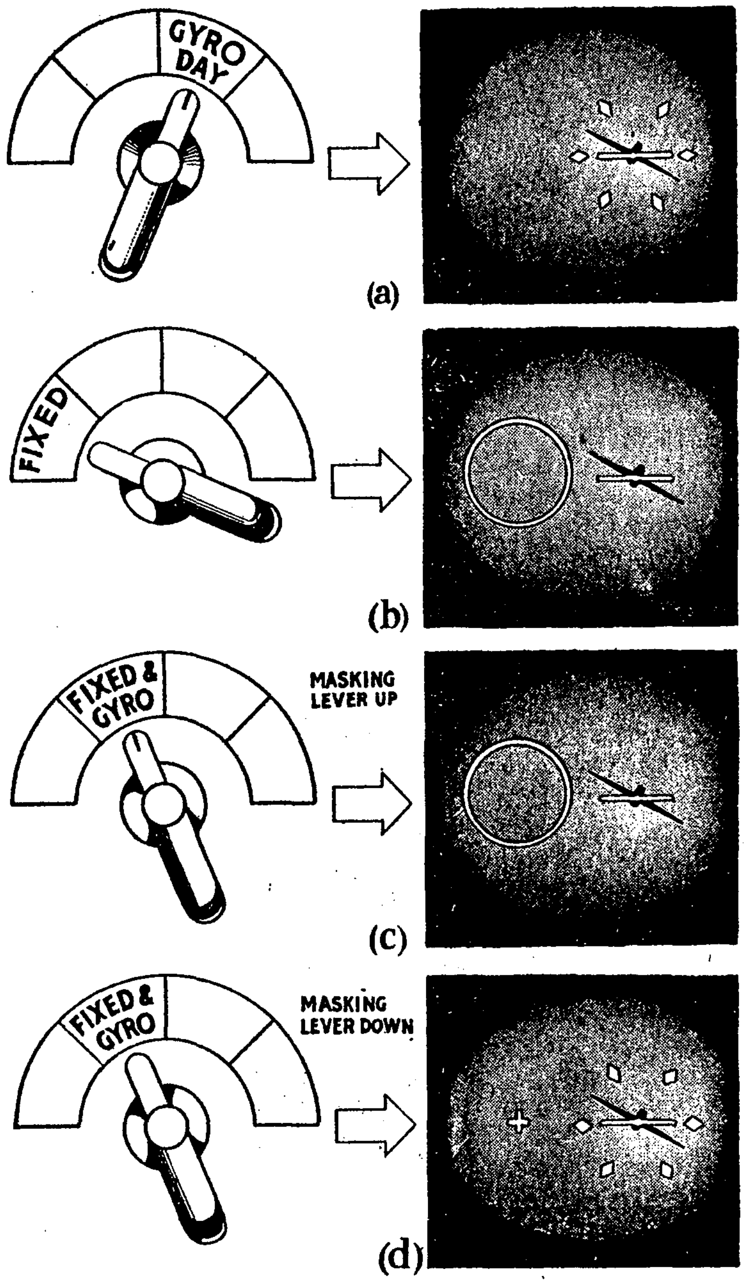


Fig. 4.—Gunsight display with visual contact

For blind firing, the difficulty is overcome by making the spot grow wings to give the gunner an approximate idea of range. The length of the wings is about equal to the projection in the gunsight of an aircraft with a wing-span of 120 ft. The wings, however, do not grow at a steady rate as an aircraft approaches. They lengthen gradually at first and then rapidly at about 500 yards, which is a suitable range for opening fire.

11. This arrangement has a number of advantages. In the first place it allows the rear gunner to change instantly from radar to visual aiming. This is important because there will probably be many occasions on which the rear gunner can aim visually when he has been directed to the right position by radar. Another reason for needing a quick transition is that the gunner will want to know whether the enemy aircraft is returning his fire. He will also want to see if his own ammunition is hitting the target and causing " strikes " which are often visible at night. Finally, he will want to see if the enemy is on fire. All these operations would be difficult if the gunner had to focus his gaze continuously from the distant target to the near image on a cathode ray tube. Another advantage of the projection system employed in the display is that it simplifies checking the radar equipment. When AGLT is flown in the daytime with a target aircraft, both spot and aircraft can be seen in the sight at the same time. If the system is operating satisfactorily the cathode ray tube spot can be seen within about half a degree of the target aircraft. Hence the harmonisation and sensitivity of the radar equipment can be checked with great ease.

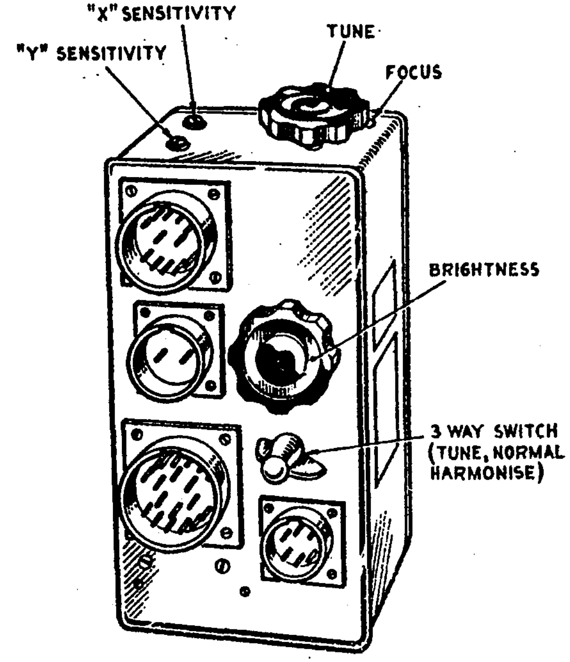
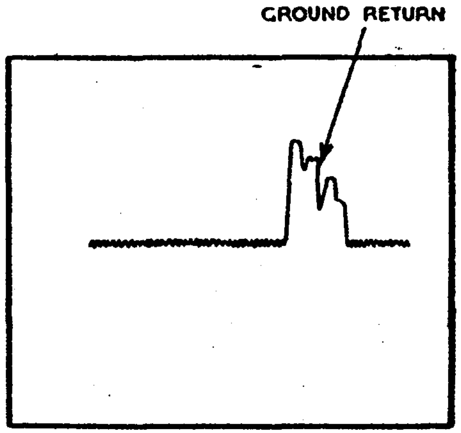


Fig. 5.—Gunner's control unit

Operation

12. The navigator is responsible for switching on the H2S and AGLT equipments. The PEDAL/RADAR switch in the turret is placed in the RADAR position to ensure that automatic range information is fed to the gunsight computer. The AGLT controls which are available to the operator are three in number, and are situated on the gunner's control unit, fig. 5. The intensity of the cathode ray tube spot may be varied by means of a brightness control. A similar control is provided on the gunsight for adjusting the intensity of the graticule. The gunsight selector switch is turned to the GYRO-DAY position. Height and airspeed are set in, and these require resetting should an appreciable change take place. Should the gunner wish to check the tuning of the AGLT receiver a switch on the control unit is rotated to the TUNE position. The cathode ray tube spot is then replaced by a horizontal range timebase which is reflected into the sight, *see* fig. 6. The guns are depressed, and a tuning knob adjusted until the ground returns appear at maximum amplitude.



Range timebase reflected into gunsight for tuning on ground return

Fig. 6.—Gunsight view of range timebase

13. When the receiver is tuned as described, the switch is returned to NORMAL and the spot reappears. It should be coincident with the centre of the graticule when the turret is stationary and there is no target within range. If attack is probable the gunner searches by moving the guns in azimuth and elevation in a regular manner. Usually he may confine his attention to the region behind and above the aircraft because the Fishpond equipment gives warning of attack from below. Should the Fishpond operator observe an aircraft, he informs the gunner of the approximate direction of attack. If the range of the target is greater than 4,000 ft. the gunner will see no change in his gunsight, except that during movement of the turret and guns and for about a second afterwards, the graticule will appear to move in a direction opposite to the direction of motion of the guns and turret.

14. When the target comes within range of the AGLT equipment three things happen. The cathode ray tube spot starts to grow wings, and a choppped-up 1,500 cycle per second note is heard by all the crew on the intercommunication system. This note consists of pips at about two second intervals. In addition, the spot moves to a position where it is collinear with the target and the gunner's eye. The gunner must now move the turret and guns so that the centre spot of the graticule follows as closely as possible the projection of the spot. By doing this he is feeding information into the gyro gunsight. As the fighter aircraft approaches, the wings continue to grow larger, and the pips heard in the intercommunication system grow more frequent, until at 500-ft. range the total wing-span extends over about 11 degrees, and the pips are occurring at a rate of about six a second.

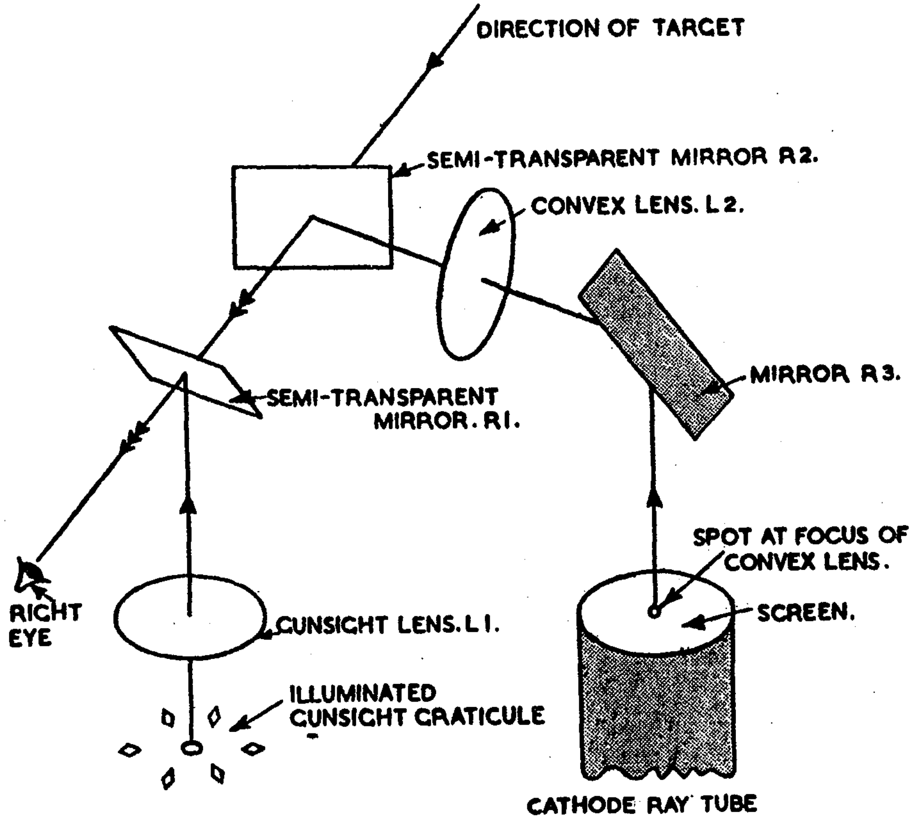
15. If the gunner can see the enemy aircraft he changes over to visual firing. In order to remove the green spot from the cathode ray tube during visual firing, a SPOT CUT OFF switch is fitted between the turret-rate handles.

16. Range is also fed from the radar equipment to a range metre above the wireless operator's position. As an additional aid to the gunner the wireless operator calls the ranges during the interception, and the pilot can judge when to start evasive action.

17. It is apparent that some rapid and sure means must be provided to enable the rear gunner to identify a friendly aircraft picked up on his beam. An IFF equipment called *Liquid Lunch* was being designed to fulfil this function. Another scheme which has been used operationally employs infra-red radiation. Friendly aircraft are fitted with an infra-red lamp in the nose. This is on continuously, but is invisible to the naked eye. A Type Z infra-red receiver, which incorporates an infra-red filter and a fluorescent screen, is mounted on the sight arch to the left of the gunsight. When the gunner wishes to determine the nature of the target picked up on his beam, he looks through the eyepiece of the Type Z telescope, and if he sees a green spot he knows that his target is friendly, but if he sees no such light he knows that he has picked up an enemy target.

The optical system of the gunsight and collimator

18. Fig. 7 is a sketch of the optical system of the gunsight when used with AGLT. The target is observed through a transparent plate R1, which is inclined so that the reflection of the illuminated graticule can be seen. As already mentioned, the central point of the graticule is the gun aiming point, and the turret is operated to make the image of this spot coincide with the target. The illuminated graticule is itself



Optical system of Mark IIC Gyro gunsight and AGLT collimator. (The gunsight fixed graticule which is seen by the left eye is omitted.)

Fig. 7—Optical system

situated at the focus of a convex lens L1, and, therefore, its image appears to be at a very distant point. There is then no error in sighting due to movement of the gunner's eye. The collimator is fitted with two reflectors. The outer one, R2, is a transparent plate mounted obliquely in the line of sight, so that the image of the cathode ray tube spot may be observed. This image also appears at a distant point because the spot itself is at the focus of the collimator lens L2.

19. A selector switch is fitted in the turret and the graticule described above may be seen when the switch is rotated to the GYRO DAY position, (fig. 4(a)). When it is turned to the position marked FIXED, the graticule is no longer visible, but a bright ring with a cross at the centre takes its place, (fig. 4(b)). This is a second aiming point which will be called the fixed graticule to distinguish it from the moving or predictor graticule already described. The ring and cross is illuminated and projected into the sight through another lens placed on the left of L1. Both graticule images are visible if the switch is rotated to the FIXED AND GYRO position (fig. 4(c)). The fixed graticule is in fact seen by the left eye only, and the moving graticule by the right eye, but this is not confusing if the target is some distance away as in actual combat. The fixed graticule indicates the direction in which the guns are pointing, and if it is used in airfiring the gunner must estimate an allowance and place the graticule ahead of the target as shown in fig. 4(d). But when the computer is working and the guns are being laid, the moving graticule is displaced from the fixed one, and automatically gives the correct allowance, so that the gunner simply keeps the six diamonds encircling the target as in fig. 4(a).

20. The computer can deal with allowances up to about 5 degrees, but for greater values errors in prediction are considerably increased, and firing is unlikely to be successful. It is sometimes useful for the gunner to see both graticules as he is then aware of the magnitude of the allowance and can judge when fire is likely to be effective.

THE PROBLEM OF PREDICTION

21. The nature of the allowance which must be made for air firing, and which is worked out automatically by the predictor gunsight, must be considered more fully. Three main factors need to be taken into account.

Relative speed allowance

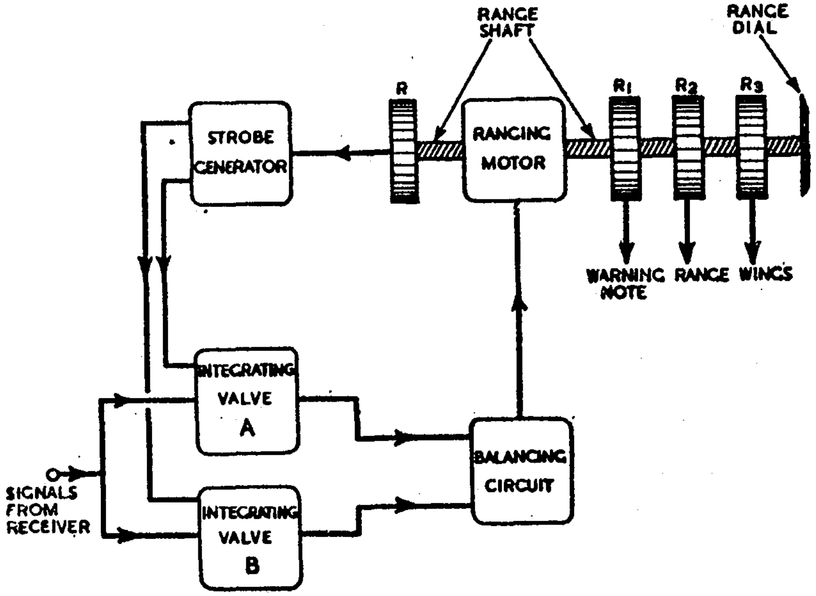
22. Suppose that the gunner's aircraft is flying straight and that the line of sight to the target is rotating at 10 deg. per second. If the image is such that the bullet takes one-half second to reach the target, then the allowance to be made is 5 deg.

23. In the example given, it was assumed that the aircraft was flying straight; it is often necessary, however, for the defended aircraft to take evasive action, and the turning movement of the aircraft must then be taken into account. This is achieved as follows.

24. The sight measures this rotation with respect to a line fixed in space, and not relative to the aircraft axis, by means of a gyroscope. This makes it possible for the sight to calculate the correct allowance even when the gunner's aircraft is taking evasive action. The gunner tracks the target smoothly, keeping the guns correctly aligned, and from the mechanical movement in azimuth and elevation, the relative speed allowance is computed. Target range is supplied continuously by the radar equipment, and time-of-flight is computed therefrom. If AGLT is not fitted, an optical method of rangefinding must be used.

Bullet trail allowance

25. When a bullet leaves the gun, it is deflected backwards by the slipstream, which may be regarded as having the same effect as a wind blowing at aircraft speed past a stationary gun. This dragging effect is zero when firing straight backwards from the tail of an aircraft, and



R Variable resistor controlling strobe generator

R1 Variable resistor controlling warning note frequency

R2 Variable resistor giving range output to gunsight

R3 Stud switch controlling growth of wings on C.R.T.

Fig. 8—Automatic ranging, schematic

is a maximum when firing at right angles to the line-of-flight. The magnitude of the allowance depends on the direction in which the guns are pointing, relative to the line-of-flight, and also to some extent on the range of the target.

26. The direction in which the guns are pointing, relative to the line-of-flight is electrically transmitted to the computer, and the range is fed in continuously from the radar equipment.

27. The drag is also dependent on the aircraft speed and on the density of the air, which is a function of altitude. The computer is therefore provided with height and airspeed controls which are preset by the gunner. The settings are only altered when an appreciable change has taken place.

Gravity drop allowance

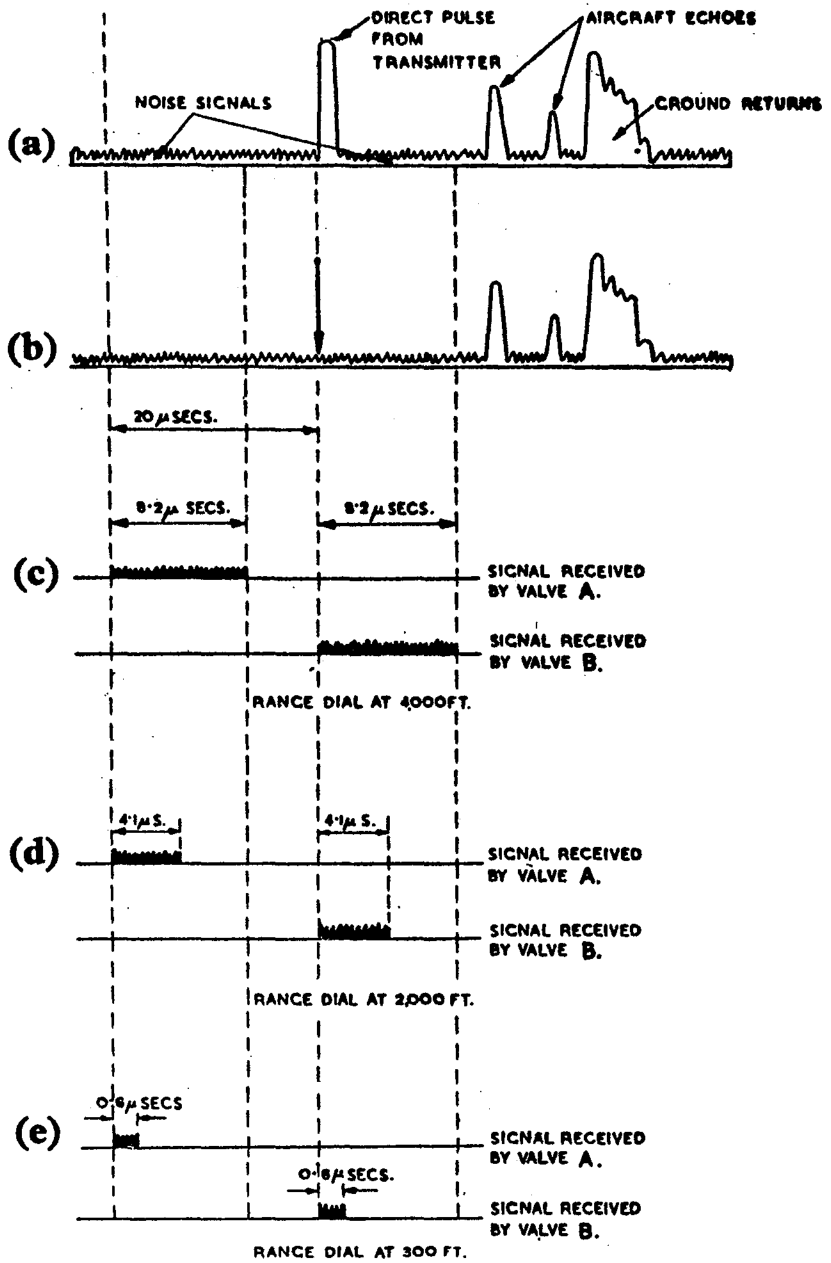
28. The third allowance to be made is for downward deflection of the bullet due to gravity. Here again target range information is required.

29. The three allowances previously mentioned are compounded, and the moving graticule is automatically offset from the fixed aiming point by an amount corresponding to the total. Angles up tc 5 deg. are quite common in the daytime, but at night they are not likely to exceed 3 deg., owing to the limitation imposed by darkness on fighter tactics.

Optical rangefinding

30. As previously mentioned, the calculation of relative speed and gravity allowances by the predictor demands the feeding-in of target range information. When the sight is used without radar, an optical system of rangefinding is employed as follows. Suppose that the target is flying directly towards the gunner. The diameter of the moving graticule can be varied by means of pedals. If attacking aircraft all had the same wing-span, the gunner could move the graticule until it just encircled the aircraft, and the movement could be calibrated to give range.

31. It is necessary, however, to take into account the diffierent wing-spans of attacking aircraft. This is done by means of a " span setting " knob situated on the front of the gunsight which varies the diameter of the graticule independent of the pedals (fig. 3). The gunner sets this control to the wing-span of the attacking aircraft. The pedals are then moved until the graticule is encircling the aircraft. Range is then automatically fed into the computer. The wing-span scale is marked in feet and the names of the commoner types of enemy aircraft are engraved on it at points corresponding to their wing-spans.



(Diagram not actual waveforms, strobe times slightly altered for simplicity)

Fig. 9—Automatic ranging (1)

32. The optical method of rangefinding has many disadvantages. The gunner may be unable to recognise the enemy aircraft so he must guess the wing-span by noting the number of engines. The span is usually set at 35 ft. for a single engined aircraft and at 60 ft. for a twin-engined one. Again, the aircraft may present a side view of the gunner, or even some intermediate aspect, so that an estimate must be made of the correct graticule diameter. Radar range, on the other hand, is transmitted automatically to the computer leaving the gunner free to concentrate on smooth laying on the target.

33. A further disadvantage of the optical method is that at long ranges the enemy aircraft appears small, and ranging tends to be inaccurate, but it is more important that long ranges should be accurate than short ones. At short ranges allowance is small—perhaps one or two degrees—and range errors may well be negligible, but at long ranges, when allowances may be of the order of 5 degrees or more, range accuracy is important if firing is to be effective. The radar method of rangefinding has the advantage that it is equally accurate at all ranges. With AGLT Mk. I, ranges are measured to within 30 yds., an accuracy which is more than adequate for present predictor design. Ranges up to 4,000 ft. can be read off from the dial on the equipment but ranges greater than 2,400 ft. are not electrically transmitted since this is the maximum range at which the computer can operate.

Automatic ranging

34. A detailed description of the AGLT ranging system is given in A.P.2917A or B, and the following account merely deals with the main principles involved in the design.

35 The signal output from a radar receiver installed in an aircraft usually consists of noise, a direct pulse from the transmitter, and echoes from other aircraft and from the ground (fig. 9). In the AGLT receiver the direct transmitter pulse is eliminated and the output might be displayed on an oscilloscope as in fig. 9(b). The arrow marks the time at which the transmitter triggers off. It is important to notice that no echoes are received in the short time before the transmitter fires, and only random noise would be visible on the 'scope during that time. The waveforms of figs. 9 and 10 are not seen by an AGLT operator as no oscilloscope with range timebase is provided in the equipment.

36. Fig. 8 is a diagram of the ranging system. The receiver output is passed into two integrating valves A and B. Valve A switches on 20 microseconds before the transmitter fires, and accepts the receiver output for a short interval of time as shown diagramatically in fig. 9 (c) Valve B switches on just at the instant when the transmitter fires and accepts the receiver output for an equal interval of time (fig. 9(c)). No echoes are received during the first period because it precedes the transmitter pulse. The time intervals during which A and B are active are always equal, but they vary from a maximum of 8·2 microseconds to zero. (The timing figures have been slightly altered for ease of explanation; the "strobes" do not in fact run to zero). The duration of the intervals is determined by a strobe generator valve which is itself controlled by a variable resistance R mounted on the same shaft as the range dial. The latter is graduated in 20 yard intervals from 0 to 1,400 yards, and the shaft is driven through gearing by an electric motor (fig. 8). Suppose that the motor is switched on so that the variable resistance is driven fully clockwise. At this point the dial will indicate maximum range,—4,000 ft. (fig. 9(c)). If the motor is run so that the range shaft rotates counterclockwise both intervals shorten. For example when the dial reads 2,000 ft. they are both 4·1 microseconds (fig. 9(d)), and when the dial is at minimum range of 300 ft. both are reduced to 0·6 microseconds (fig. 9(e)). Finally when the variable resistance is fully counterclockwise the intervals are zero.

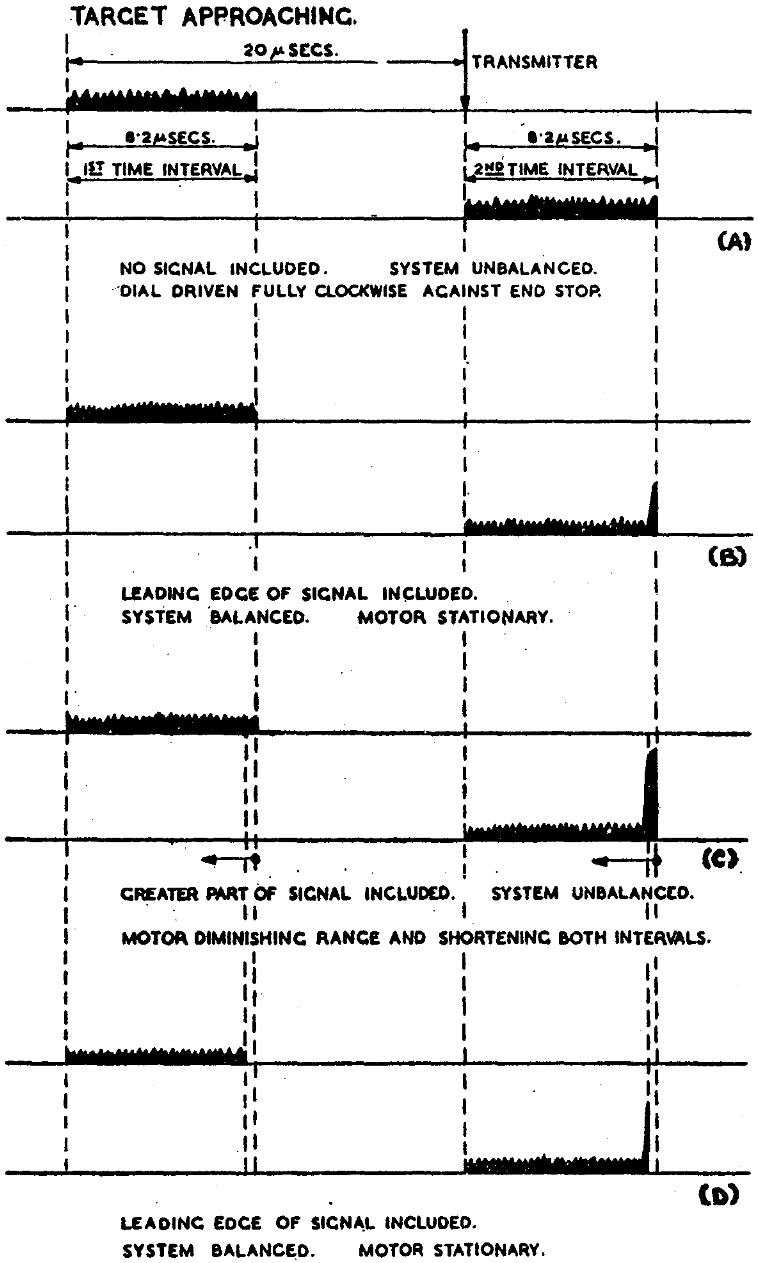
37. Valve A adds up all noise signals received in the interval before the transmitter fires. No echoes are present before the transmitter fires so the output consists of the total noise signal received during the first interval. Similarly valve B integrates the receiver output for the equal interval of time after the transmitter fires, and the output of B consists of the total noise plus any echo signal received during the second interval. The total or integrated outputs of the A and B valves are represented by the shaded areas in figs. 9 and 10. The outputs of A and B are fed into a balancing circuit which really subtracts them. The balancing circuit is set up as follows :—

(1) If output B *is equal to* output A the motor is switched on so that the shaft is driven clockwise and the range readings increase.

(2) If output B *is slightly greater than* output A the motor is switched off, and the range dial remains stationary.

(3) If output B *is much greater than* output A the motor is reversed so that the range readings diminish.

38. Consider what happens when the equipment is switched on in flight. Suppose no aircraft is within 4,000 ft. Only noise and, perhaps, interference will be present and these random signals will be received during each time interval. Output B, on the average, will equal A and the motor is switched on so that the shaft is driven clockwise and the



(Diagram not actual waveforms, strobe time slightly altered for simplicity)

Fig. 10—Automatic ranging (2).

range readings increase. Finally when the dial has reached maximum range it strikes an end stop and the motor is cut off. Nothing further happens as long as there is no aircraft within the beam at range less than 4,000 ft., *see* fig. 10(A). When an aircraft comes within 4,000 ft., the echo appears within the second time interval. At first only the leading edge of the signal is included and nothing happens (fig. 10(B)), but soon a larger part of the return signal is included and the output of B becomes much greater than that of A. According to condition 2 the motor then operates in the reverse direction and the range reading is diminished (fig. 10(C)). As the motor drives the range shaft, both time interval. are reduced and part of the echo is excluded from the second one. Output B is then only slightly greater than A and so the motor stops (fig. 10(D)). The process is repeated as the range diminishes, the motor driving the range shaft in steps of about 15 yds. The aircraft range may therefore be read from the dial. If at any time the target range increases the echo disappears, and output B becomes equal to A, so that the range dial is driven clockwise again until equilibrium is restored. The ranging system therefore follows a receding target as well as an approaching one.

39. There is only one condition of balance—when the output of B is slightly greater than that of A. In absence of echo the dial is driven to maximum range and comes to rest on the end stop. When a signal is present the time intervals are automatically set so that the leading edge of the signal just comes within the second one, and the dial indicates the range of the aircraft.

40. The system measures the range of the nearest aircraft within the beam because only the leading edge of the nearest echo is included in the second interval, and all other echoes are excluded. This limits the number of casual contacts and eliminates the ground returns. The accuracy of the ranging system depends largely on the care with which the balancing circuits are set up, but the time should be measured to within 0·12 microseconds which gives a range accuracy of about 20 yds., and therefore, allowing for slight errors in setting up, an accuracy of 30 yds. should be obtained. The minimum range which can be measured is about 150 yds.

41. Referring again to fig. 8 it will be seen that the range shaft drives three variable resistors in addition to the one already mentioned for controlling the strobe generator. The first of these additional resistors, R1, controls the frequency of the warning note pips. The second resistor, R2, feeds out range to the gunsight computer, and the third, R3, determines the rate of growth of wings on the cathode ray tube.

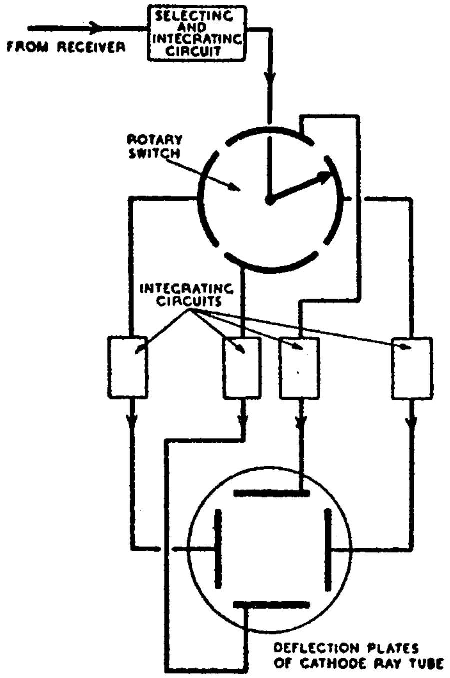


Fig. 11.—Direction finding schematic

Direction finding

42. The AGLT aerial is mounted eccentrically so that the beam is deflected 5½ deg. from the main axis of the mirror, and the aerial is spun at 33 revolutions per second. The beam therefore scans out a cone of vertical angle 11 deg. This conical movement is not required for ranging but is necessary for direction finding.

43. To explain how the direction of an enemy is found, suppose that a bomber aircraft is in flight with the guns pointing straight backwards from the rear turret. Consider a fighter is approaching from directly behind the bomber, but slightly above, so that it subtends an angle of 5 deg. in the gunsight. For convenience this target position from the gunner's point of view is designated as 12 o'clock at an angle of 5 deg. off centre. The beam then sweeps across the fighter 33 times per second, and each time it passes through the 12 o'clock position maximum signals are received. On the other hand when the beam is at 6 o'clock, signals of minimum amplitude are received (fig. 12). Of course, echoes are returned from the ground and from other aircraft, but the receiver output is passed into a selecting circuit which passes out only the signal from the nearest aircraft as in the case of the ranging system. A waveform represented in fig. 12 is thus obtained.

44. It should be noted that the receiver output is being considered over a much longer period of time than when describing the ranging system. The waveforms drawn for the ranging system had a time-scale of about 40 microseconds and included one transmitter pulse only. For direction finding one must deal with one complete scanning cycle which takes place in one-thirtythird part of a second (approximately 30,000 microseconds). During this comparatively long time about 45 pulses are transmitted.

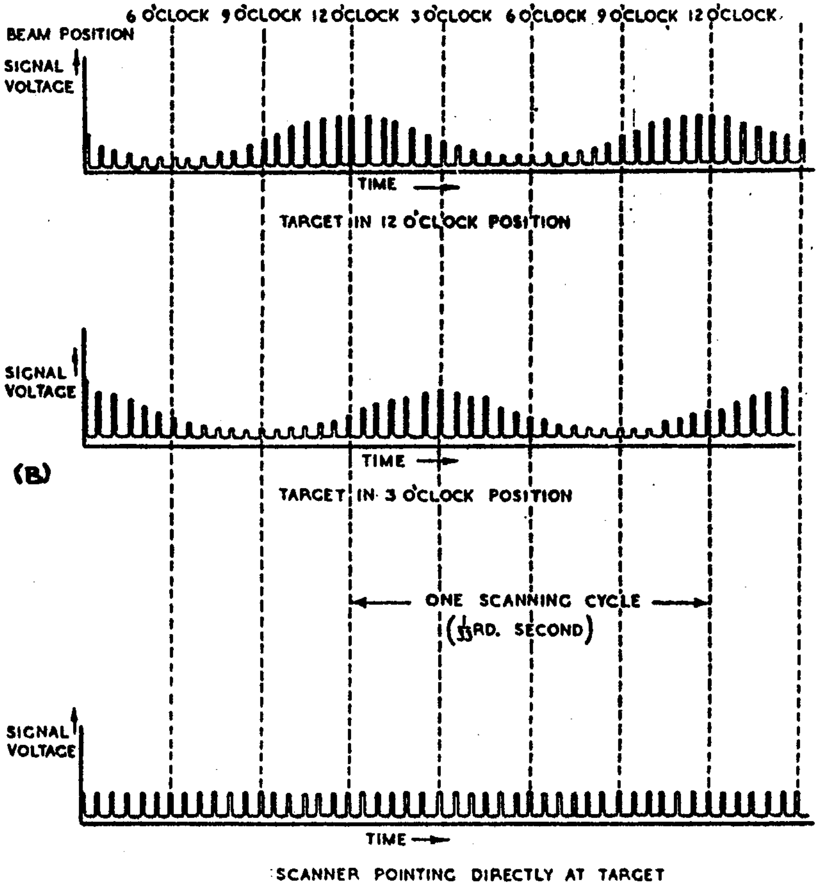


Fig. 12.—Direction finding (not to scale)

45. Returning to the waveform obtained by selecting signals from the nearest aircraft for a complete scanning cycle, it is noted that the signals vary in amplitude as the beam rotates, and are at maximum when the beam is at 12 o'clock and crossing the target. This amplitude variation can be used to control the deflection of the cathode ray tube spot in the following manner. The output waveform is first integrated in order to smooth out the rapid variations of each individual echo signal. The output of the integrating circuit is distributed to the four deflection plates of the cathode ray tube by means of a four-position switch rotating in synchronism with the aerial (fig. 11). Each quadrant of the switch is connected to the appropriate deflection plate of the cathode ray tube. When the beam is pointing upwards (12 o'clock position) the upper quadrant of the switch is being traversed, and the signals are then being applied to the upper deflection plate of the tube. When the beam is to starboard they are applied to the right-hand plate of the tube and so on for the other quadrants. The spot moves towards the deflection plate receiving the maximum signal strength. In the example given it will move towards the upper plate, but, should the fighter be below the bomber, the lower plate will receive maximum signal strength and the spot will be deflected downwards. Provided that the switch is correctly synchronised with the scanner the spot moves from the centre of the tube giving the correct clock reference of the target aircraft. It is arranged also that the magnitude of the deflection is proportional to the target angle "off-centre," so that if the equipment is used in daylight the spot and the target are coincident. The latter relationship, however, only holds for angles "off-centre" less than 4 degrees.

46. As shown in fig. 11 there are integrating circuits between the switch quadrants and the cathode ray tube deflecting plates. These are included to average the signals applied to the deflection plates over a period of about one-quarter of a second, so that the spot does not flicker as the switch rotates, and a steady deflection is obtained corresponding to the target bearing and elevation. When the system is in use the directional accuracy obtainable is of the order of half a degree.

LIMITATIONS OF THE DISPLAY

47. AGLT Mk. I display suffers from four defects, three of which limit the blind firing accuracy attainable. The first of these may be called *spot wander* or *jitter*. This is caused by the rapid fading of an echo due to propeller modulation. As a result of this, the cathode ray tube image does not coincide exactly with the target, but wanders over a small circle which has a maximum radius of about half a degree.

48. The second defect is that correspondence between the cathode ray tube and target position does not hold for angles greater than 4 deg. off-centre. Suppose that a target aircraft is at the same height as the bomber, but 6 deg. to the gunner's right, and that the guns are pointing straight backwards. The spot moves to indicate the correct clock reference (3 o'clock), but the deflection from the centre of the tube does not correspond exactly to 6 deg. Hence, when flying during the day, target and spot are not quite coincident for angles greater than 4 deg. This happens because the spot deflection from the centre of the tube depends on the beam width and the 11-deg. scanning cone, as well as on the angle subtended by the fighter.

49. The third defect of the display is that there is a time lag in the movement of the spot which does not take up its final position instantaneously. The lag for the AGLT equipment is about one-quarter of a second and is due to the integrating circuits between the rotary switch and the tube deflection plates. The gyro gunsight computer also introduces a lag of about 1½ seconds. The total effect is not very serious, but can be seen if the equipment is flown in the daytime. If the guns are jerked or moved rapidly the spot leaves the target and does not return for an appreciable fraction of a second.

50. A fourth limitation of the display is that it cannot present more than one aircraft at a time on the cathode ray tube. Confused results will be obtained if there are two aircraft within 100 yds. of one another in range and within about 30 deg. of one another in direction. Under these conditions the spot will tend to wander in an indeterminate way between the two aircraft.

AGLT Mk. III

51. When using AGLT Mk. I the gunner must keep moving the turret to be sure of obtaining early warning of attack. The process of manual searching is tedious and an equipment known as Mark III is now (December, 1944) under development to overcome the difficulty. A project known as AGLT Mk. II has been discontinued. The scanner is mounted on the airframe below the rear turret and does not move with the turret. For searching, a wide coverage is got by an automatic scanning movement of the mirror. When a target is detected the scanning ceases and the mirror "locks" on to the target. The axis of the mirror then indicates the azimuth and elevation of the fighter aircraft, and the information is displayed on a collimator. The gunner operates the turret until the green cathode ray tube spot is coincident with the predictor graticule as in the case of AGLT Mk. I.

CHAPTER 4

AIRCRAFT NAVIGATIONAL AIDS

LIST OF CONTENTS

LIST OF ILLUSTRATIONS

THE GEE - 7,000 SYSTEM

Introduction

1. In the early part of the war, apart from the ordinary DF facilities, there were very few radio aids to navigation. Navigators had, in the main, to make use of dead-reckoning and astro-navigational methods. Both these methods are open to serious inaccuracies, and the main disadvantage of the DF system was that it could easily become saturated, i.e. there was a definite upper limit to the traffic which could be handled by a set of DF stations.

2. To overcome these difficulties, radar technique was summoned to the aid of navigation, and the Gee system was devised. Though Gee is classed as a radar equipment, since it uses pulse technique, it is in many ways completely different from all earlier equipments. The main difference lies in the fact that there is involved only transmission from ground stations to the aircraft. There is no transmission whatsoever back from the aircraft to the ground, either in the form of a repeated signal or as a re-radiated signal. Since the aircraft, therefore, is merely a receiver of radiation from the ground and does not retransmit, it follows that there is no limit to the number of aircraft that can use the system at any one time, just as there is no limit to the number of receivers which can tune in to an ordinary broadcast programme. Gee-7000 was first introduced into the service in the early part of 1941, and it was the aim to fit the equipment to as many aircraft as possible.

General principles of operation

3. The Gee-7000 system involves locked transmission from three or more ground stations ; and, in the air, the measurement of path differences from these stations. It is proposed, in the first place, to discuss the principle of path differences.

4. Suppose a ground station is set up at A (fig. 1), which is allowed to transmit a regular set of pulses, in the normal radar manner. An aircraft situated at P will receive these pulses a certain time after transmission.

5. In fact, if v be the velocity of electromagnetic waves, the time t_1 taken for a pulse to travel from A to P is

$$t_1 = \frac{AP}{v}$$

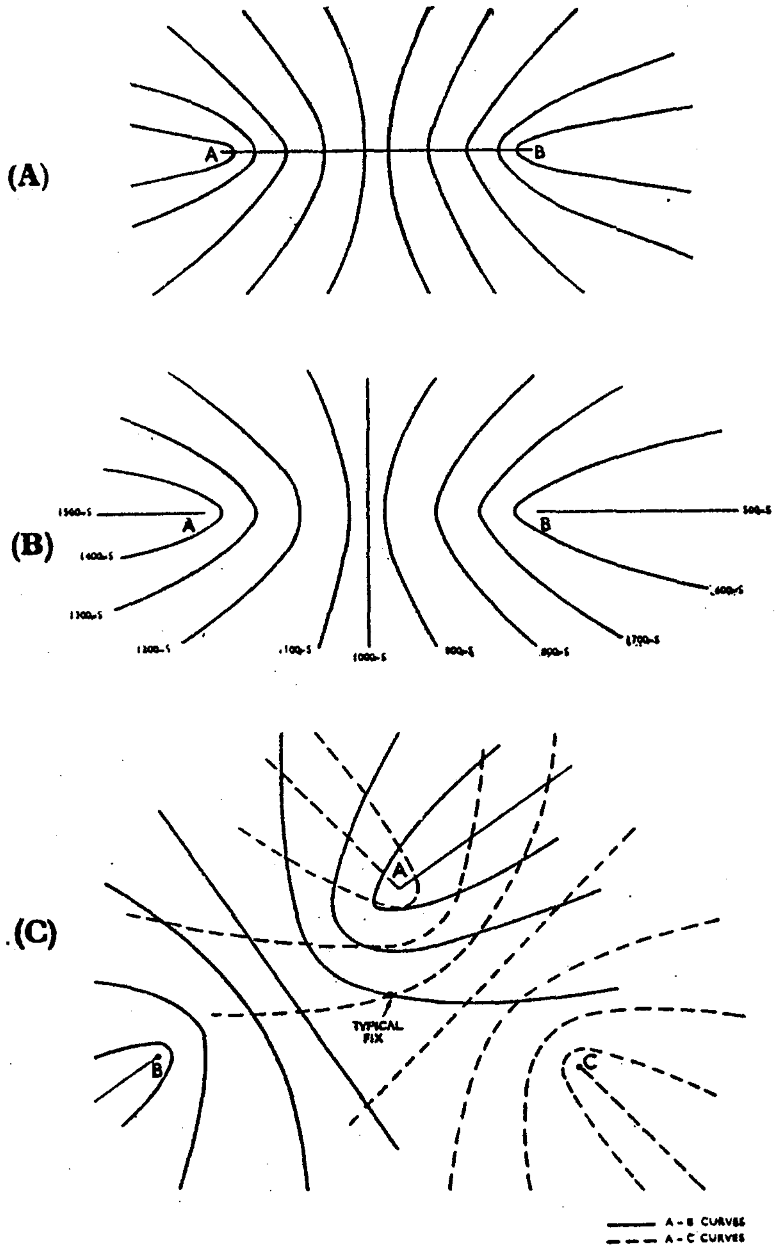


Fig. 1.—Gee hyperbolae

6. Suppose now that at the same time, the pulse from A is picked up at a second ground station situated at B, and that this second station itself transmits a pulse at definite time T after receiving the A pulse. Then, counting as an origin for time reference, the time at which A transmits, it follows that the aircraft will receive the pulse from B after a time

$$t_2 = \frac{AB}{v} + T + \frac{BP}{v}$$

(where T is the inevitable delay between reception of an A pulse at B and transmission from B).

7. It will be noticed that t_2 is made up of three parts :—

(1) Time of travel from A to B.

(2) Delay introduced at B.

(3) Time of travel from B to P.

It will be seen that $t_2 > t_1$.

8. The equipment carried in the aircraft enables the navigator to measure rapidly the time difference between the arrival of the A and B pulses, that is, the quantity $t_2 - t_1$.

Now,

$$t_2 - t_1 = \frac{AB}{v} + T + \frac{PB}{v} - \frac{AP}{v}$$

The quantities AB, and v are known constants, and the equipment at a ground station enables T also to be kept constant. It follows, therefore, that if $t_1 - t_2$ is known, (PB — AP) will also be known.

9. The best way to use this information is clearly to draw on a map containing A and B, a set of curves of constant path difference from those points. Along such a curve BP — AP will remain constant, and so therefore will $t_2 - t_1$ remain constant. Each of the curves is labelled with the appropriate value of $t_2 - t_1$ which applies to it. All that has then to be done by the navigator is to measure $t_2 - t_1$ and this will immediately enable him to fix himself along one or other of the curves in the system.

10. It may be shown that these curves of constant path difference are hyperbolae about A and B as foci.

Example

11. Assuming the separation of the A and B stations to be 100 miles, a normal figure. Assume also that the delay introduced at the B station is 500 microseconds. As a further approximation, say the velocity of electromagnetic waves is such that it takes 5 microseconds for them to cover one mile. Then it can easily be seen that everywhere along AB produced (fig. 1(B)) a constant time difference of 500 μs will be observed between reception of the A and B pulses,

$$(t_1 = \frac{AP}{v} = \frac{AB + BP}{v}$$

in this instance.)

12. Similarly, along BA produced, a constant time difference of 1500μs will be observed. Finally, the perpendicular bisector of AB will be the line of 1000μs time difference.

13. These three instances are those in which the hyperbolae mentioned previously degenerate into straight lines. All the other cases are, however, true hyperbolae as shown in fig. 1(B), and all have time-difference values lying between 500 and 1500 μs. Hence one can deduce an important fact, namely, that there is a definite *upper limit* (1500 μs) to the time-difference observed anywhere.

14. This fact is of importance in determining the length of timebase to be used in the display scheme, and means that (as compared with all other radar equipments) maximum range is not limited in any way by the length of timebase. For clearly, provided our timebases are of greater length than 1500 μs, an A pulse displayed to the extreme left of a timebase will give rise to a B pulse always on that same timebase wherever the aircraft may be. In fact, a timebase length of 2 milliseconds (including blackout period) is used.

The hyperbolic mesh

15. To obtain a " fix," it is necessary to introduce a third ground station C (fig. 1(C)) which functions in the same manner as the B station, and a further set of hyperbolae can be drawn, this time with A and C as foci. By measuring the time difference between arrival of the A and C pulses the navigator can fix the aircraft along one of this family of curves.

16. It follows that the position of the aircraft can be fixed by measuring the (A-B) and the (A-C) time difference, and by finding where the corresponding curves in the two families of hyperbolae intersect.

17. The hyperbolic curves are very often called *lattice lines* and the whole system is said to provide a *hyperbolic mesh* over the map.

Ambiguity

18. It will be apparent that ambiguity may possibly arise because any two branch hyperbolae from the two systems have two points of intersection, (Fig. 2(a)). Difficulty may therefore be experienced in this respect, particularly in the vicinity of the A station. This may be overcome by introducing a fourth station D similar to the B and C stations. For though the A-B and A-C curves may intersect at two points P and Q, the navigator by measuring the A-D time difference can tell which is the correct point to take. A more important function of the D station is discussed later.

Accuracy

19. In the main the accuracy of the system is determined by two factors :—

(1) Maintenance of constant value of T at a B, C or D station (this can be done to limits of less than 0·1 microsecond); and accuracy of reading of time difference in the aircraft (this can be done to limits of about 0·5 microsecond).

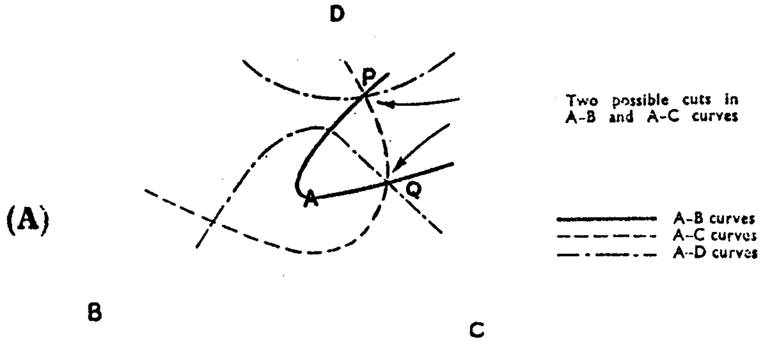
(2) The number of lattice lines that can be drawn on a map without undue confusion, and the accuracy with which the navigator can determine their points of intersection (particularly when interpolating).

20. Provided pulses remain of sufficient strength, the errors introduced in (1) are appreciably independent of range. The errors introduced in (2), however, increase with range, for as the range from the ground stations increases the acute angle of cut of the hyperbolic curves will decrease. It is seen by reference to fig. 2(B) and 2(C) that as the angle of cut diminishes so does the decisive nature of that cut. The optimum case will be that of a right-angled cut.

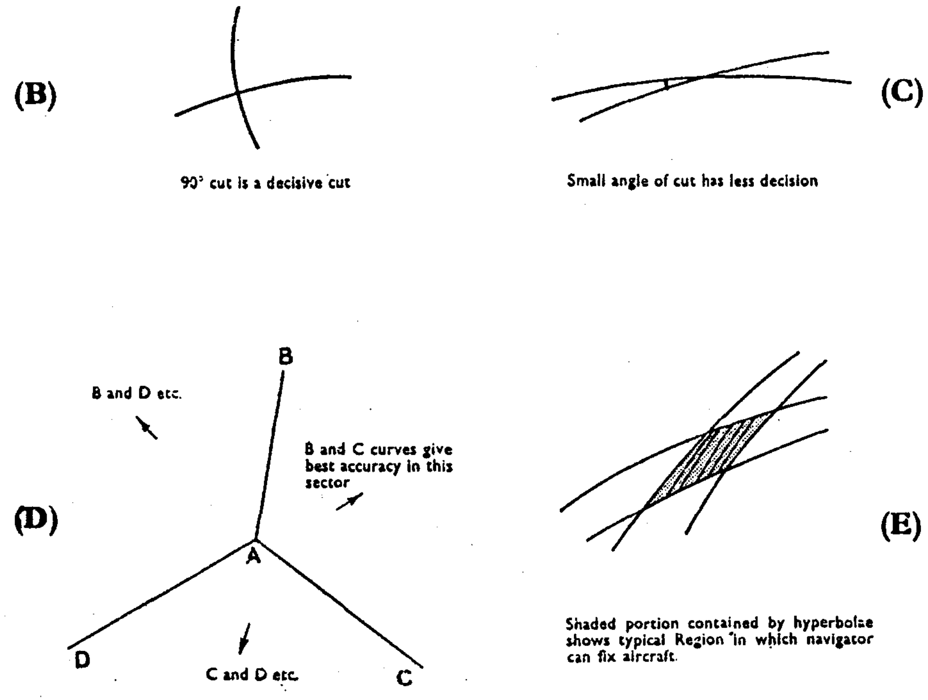
21. If care is taken in the siteing of the D station it can be arranged that in places where the angle of cut of the A-B and A-C curves begins to fall off then a better cut is obtained with either the A-B and A-D curves or the A-C and A-D curves, (fig. 2(D)).

22. In the vicinity of the stations, fixes can be obtained to an accuracy of a few hundred yards. Then, as range increases, the accuracy gradually falls until at extreme range of 500 miles the navigator could, in theory, place himself somewhere within a diamond figure (fig. 2(C)), with diagonals 5 and 3 miles long.

In practice the accuracy attained is somewhat inferior to this.



RESOLUTION OF AMBIGUITY BY D STATION



STATION CONFIGURATION

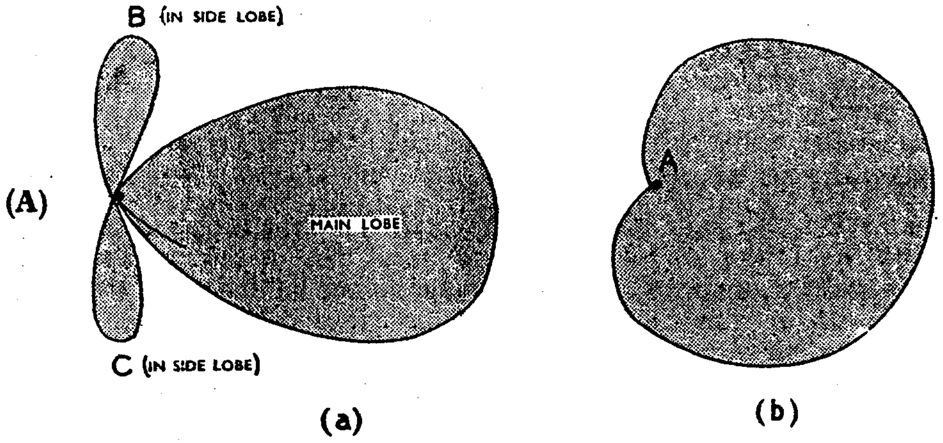
Fig. 2.—Ambiguity and accuracy

Range and coverage

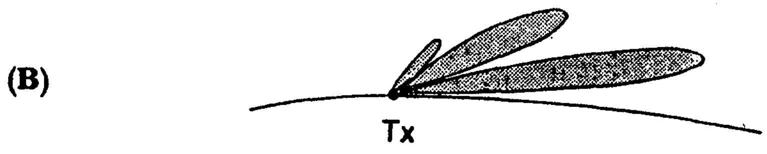
23. The range of Gee is limited by the power of the ground transmitters and by the height at which the aircraft can fly in order to remain within the radiation lobe in spite of earth curvature. At 15,000 feet a range of 450 miles is attainable with the present equipment, provided no jamming is present. At greater heights and under favourable atmospheric conditions greater ranges may be observed.

24. No special steps are taken to give intense beaming of the radiation from the ground, for a wide service area is desirable, compare the floodlight technique at CH stations. In general a simple reflector system on the ground station antennae serves to throw the bulk of the radiation forward, and to cut down back-radiation see fig. 3(A).

25. A stack of vertical dipoles is employed to provide vertically polarised radiation (≈ 6 metres).



(A) Typical horizontal polar diagrams



(B) Typical vertical polar diagram

(radiation may be beamed in a vertical plane as much as is convenient)

Fig. 3—Polar Diagrams

Monitoring of ground stations

26. It can be seen that though the precise value of T (the time delay introduced at B, C or D) is not particularly important; it is, however, of the utmost importance to keep it constant. It may be mentioned that its value need not be the same for all three stations.

27. In general an alteration in the value of T demands a corresponding change in the numbers affixed to the hyperbolic grids.

28. The B, C and D stations each have monitoring facilities in order to measure their individual T values, but in addition a cross-check is kept by introducing a final ground station into the scheme. This is the *monitor station*, and its function is to pick up pulses from the other ground stations, and to inform them if they are in error.

Ground station organisation

29. By examining the method by which the scheme has been developed it will be seen that the A station originates transmission, but that the other stations in the scheme follow it. For this reason the A station is commonly referred to as the MASTER station. At the same time, B. C and D are referred to as the SLAVE stations, the D in particular as the STAR SLAVE.

30. A complete Gee system, as described, comprises a master, monitor and three slave stations. It is known as a *Gee-7000 chain.*

31. Though the rôle of a monitor station is essentially passive, yet it serves as headquarters for its chain. It maintains constant telephonic communication with the other stations of the chain and through it are passed all operational messages from the Command using the system.

32. In general all chains transmit continuously, each chain having its own radio-frequency. At present there are five chains situated in Great Britain. They are, in order of erection :—

(1) Eastern Chain, with stations in central England, directed towards Holland, Belgium and N.W. Germany.

(2) Southern Chain, with stations in Southern England, directed towards France.

(3) Northern Chain, with stations in the Northern part of Scotland, directed towards the North Sea and Norway.

(4) South-Western chain, with stations in South Wales and Western England, directed towards the Bay of Biscay.

(5) North-Eastern chain, with stations in North East England, directed towards Denmark.

Station identification and presentation in the aircraft

33. To enable the navigator to identify the ground stations of any one chain, a complex system of pulse recurrence frequencies is used, and, in consequence, a rather complex timebase system.

34. In the first place consider the master station transmission. The master sends out a steady set of pulses at a p.r.f. of 500 c/s. These pulses will occur at 2 millisecond intervals, and when they are put on a time scale, divided into two-millisecond sections, they appear as in fig. 4.

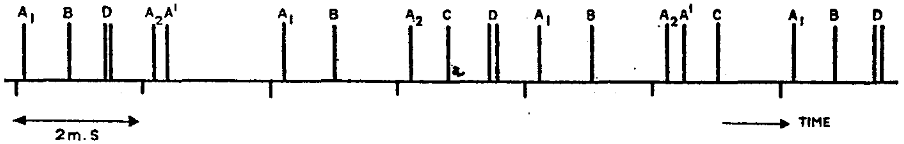


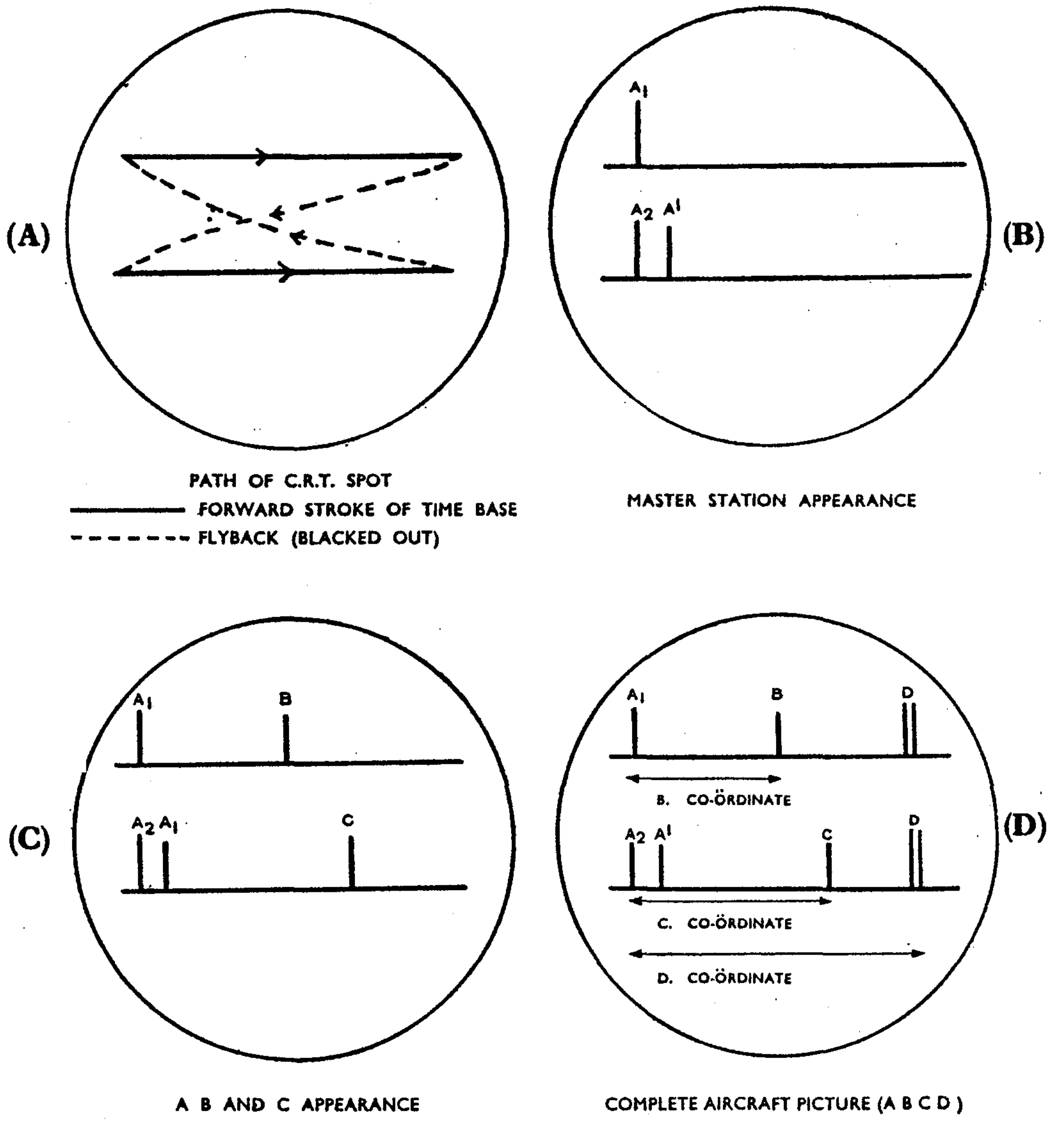
Fig. 4.—Pulse recurrence frequencies

35. The A pulses are now divided into two different sets ; one set will be referred to as A_1 set and the other A_2. The division into sets is done in such a manner that A_1 and A_2 are interleaved (again as seen in fig. 4.

36. The aircraft timebase is made to run also at 500 c/s, but alternate timebase traces are deflected downwards as in fig. 5(A). If follows that a complete timebase picture takes 4 milliseconds to complete (including flyback time). Moreover it will be seen that one A pulse will appear on each of these timebase traces, (an A_1 on one trace and an A_2 on the other).

37. Since the aircraft timebase is allowed to run freely, there is no means of estimating when the equipment is first switched on, where exactly the A pulses will be, relative to the timebase. However, the navigator can control the timebase phase, which controls the starting time of the timebase. By adjustment of this control, therefore, the navigator can set the equipment so that the A station pulses appear at the extreme left of the timebases.

38. It is impossible for the navigator so far to distinguish between A_1 and A_2 ; to help him do this, however, an auxiliary transmission A^1 is sent out from the master station. This is transmitted on a p.r.f. of 125 c/s, and will therefore occur once for every fourth main A pulse. It is phased so that it occurs at about 100 μs after every second A_2 pulse. The general appearance of the master transmission on the aircraft timebase is as in fig. 5(B).



PATH OF C.R.T. SPOT
——— FORWARD STROKE OF TIME BASE
- - - - FLYBACK (BLACKED OUT)

MASTER STATION APPEARANCE

A B AND C APPEARANCE

COMPLETE AIRCRAFT PICTURE (A B C D)

Fig. 5.—Development of display

39\. Notice that even though an A^1 pulse appears after only every other A_2, an impression of continuity will be obtained in the picture as in fig. 5(C). A^1 will, however, appear somewhat less brilliant than the other pulses, because the CRT spot only paints a pulse picture on every other trace, and for this reason A^1 is sometimes referred to as the *A ghost* or *A shadow* pulse rather than A identification pulse.

40\. It is again stressed that the A pulses can occupy any position on the timebase initially, but that the timebase phasing control should always be adjusted so that the single A pulse (i.e. A_1) stands at the extreme left of the top trace. The sole purpose of the pulse A_1 is to enable the navigator to differentiate between A_1 and A_2, for a reason which follows.

41\. By employing a suitable filter, a B station is able to retransmit only the A_1 set of pulses, consequently the p.r.f. of the B station is 250 c/s; moreover, on reference to para. 11 it will be seen that the delay introduced at B is less than 500 μs, so that wherever an aircraft may be it will always receive a B pulse not more than 1,500 μs after the A_1 pulse.

42\. In a similar manner the C-slave retransmits only the A_2 pulses. Its p.r.f. is therefore 250 c/s also and again an aircraft will receive a C pulse always not more than about 1,500μ seconds after an A_2 pulse. The sequence of transmission can be seen on reference to fig. 4, and the appearance on the aircraft timebase as in fig. 5(C).

43\. Thus, provided A_1 has been moved to its conventional position at the left of the top trace, then the B pulse will always appear some way out along the top trace and the C pulse out along the bottom trace. It follows that the existence of A^1 is necessary for distinguishing between the B and C pulses. The point to remember is that C is always associated with A^1.

44\. Finally the D station is made to retransmit every third A station pulse, i.e. first an A_1 and then an A^1. Its p.r.f. is therefore $166\frac{2}{3}$ c/s and it will appear on every third timebase trace, (fig. 4 and fig. 5(D)). Moreover the D transmits a double pulse.

45\. By virtue of its p.r.f. the D pulses will only occur on every other top trace and on every *other* bottom trace, but as far as the eye can perceive it will appear on each trace like A^1. It should be noted, however, that if D and A^1 could be examined closely they would be found not to break the base-line of the trace.

46\. Moreover fig. 5(D) indicates the time to be measured to give the B, C and D co-ordinates of the fix. For this measurement it is necessary to have some form of time calibration on the timebase traces, as explained later.

Strobing

47\. On examination of the aircraft timebase it will be noticed that there are two small troughs, one on the top trace and one on the bottom (fig. 6(D)), and that signals occurring in these troughs are inverted. The timebase presentation that we have described so far is known as the Main Timebase or MTB.

48. In order to achieve greater accuracy in the measurement of time intervals shown in fig. 5(D), a system of strobing is used. Strobing enables a small section of the trace to be selected and to be speeded up in the X direction. In the Gee indicator it is possible to select four small parts of the MTB for such magnification :—

(1) The first 80μ seconds of the top main timebase (the A_1 strobe).

(2) The first 80μ seconds of the bottom main timebase (the A_2 strobe).

(3) Any 80μ seconds of the top main timebase (the B strobe).

(4) Any 80μ seconds of the bottom main timebase (the C strobe).

49. The first two of these strobes are fixed in position. The B and C strobes can, however, be positioned at will along their respective traces (two position controls, coarse and fine, being provided for each strobe). It is therefore necessary to have the positions of the B and C strobes marked out on the MTB. For this reason the two troughs are provided. These troughs can therefore be moved in position along their traces by means of the B and C strobe position controls respectively.

50. The four 80μ second intervals mentioned above can be shown in an enlarged form by using the timebase change-over switch. Normally this switch enables the MTB to be displayed on the CRT, but another position is provided to give us the strobe timebase or STB picture. (figs. 6(B) and 6(C)). The timebase now has four traces, each lasting about 80μ seconds). Reading downwards these give a magnified version of the A_1, B, A_2 and C strobe regions of the MTB.

51. It follows that any pulse occurring in any one strobe region of the MTB will appear in a magnified form on the corresponding STB trace. Signals during the B and C strobe intervals remain inverted, as on the MTB.

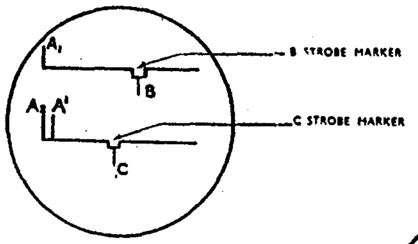
Calibration

52. Both types of timebase can be calibrated for time by X-deflection pips. A calibration switch enables signals to be removed from the trace and calibration applied instead.

53. On the MTB there is a set of pips with every fifth one of greater amplitude for ease in counting (fig. 6(D)). The pips on the top trace are numbered from 0 to 25 and those on the bottom from 30 to 55 (5 pips are lost in each flyback period, which of course is blacked out).

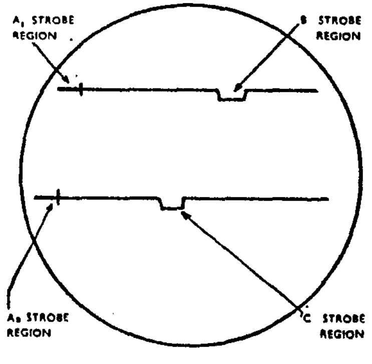
54. These pips are $66\frac{2}{3}\mu$ seconds apart, but for convenience $66\frac{2}{3}\mu s$ seconds is called *Gee unit* of time. It should be noted here that all maps are drawn and all operational instructions given in reference to Gee units of time. Pips on the MTB are therefore spaced at unit intervals.

(A)



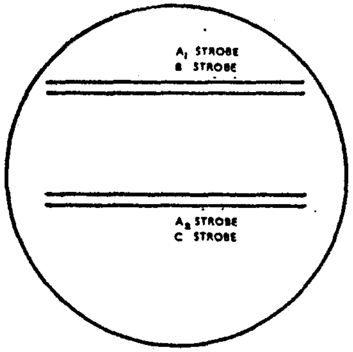
STROBE MARKERS SHOWING B AND C PULSES INVERTED

(B)



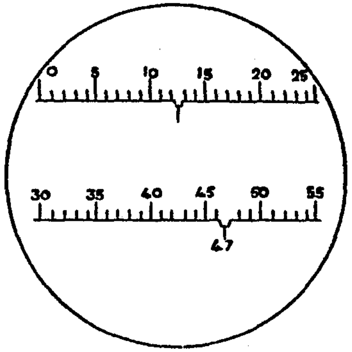
MAIN TIME BASE (M.T.B.)

(C)



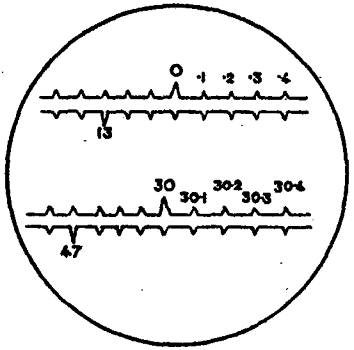
STROBE TIME BASE (S.T.B.)

(D)



MAIN TIME BASE CALIBRATION

(E)



STROBE TIME BASE CALIBRATION

Fig. 6.—Range and strobe display

55. The STB is calibrated with pips occurring at 1/10 Gee unit intervals, with every tenth pip of greater amplitude (unit pips). The large pips on the A_1 and A_2 strobes are respectively the same as pips 0 and 30 in the A_1 and A_2 strobe regions of the MTB. As an example, if fig. 6(E) is the strobe picture of fig. 6(D), the unit pips on the B and C strobes there are 13 and 47 respectively. Note that calibration pips, as well as signals are inverted during the B and C strobe periods.

Taking a fix

56. Since there is a slight instability inherent in the frequency of the aircraft timebase, it is found impossible to keep received pulse exactly stationary on the trace for any length of time. It is thus impossible to set A_1 exactly at the zero pip and read off the calibration number under the B pulse. A differential method is needed (subtraction by sliding graduated scales against one another).

57. The procedure adopted for taking a fix is as follows (for B and C stations).

(1) Pick out single A pulse on MTB (*see* fig. 7(A)).

(2) Use TIMEBASE PHASE CONTROL to get A_1 to left of top trace into the A_1 strobe region. A_2 will then be in A_2 strobe region on the bottom trace (*see* fig. 7(B)).

(3) Put B strobe marker over B pulse, and C strobe marker over C pulse, *see* fig. 7(C). B and C pulses will not be inverted.

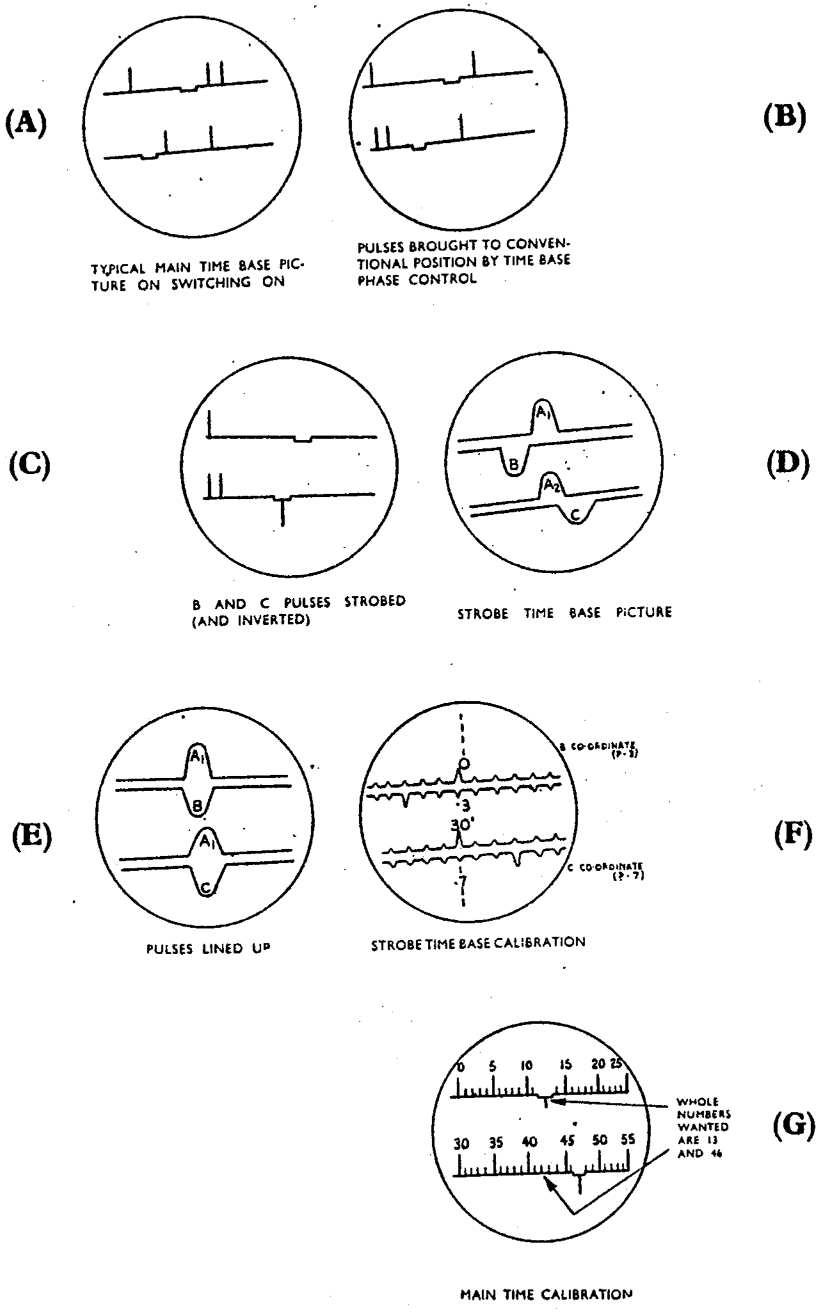
(4) Switch to STB when A_1, A_2 B and C should appear within their strobes, *see* fig. 7(D).

(5) By fine adjustment of strobe position controls, place B with its leading edge under A_1 leading edge; and C under A_2 in the same way, *see* fig. 7(E).
Note the time of the operation.

(6) Switch to calibration, *see* fig. 7(F).

(7) The number of the calibration pip on the B strobe vertically beneath A_1 zero pip gives the B co-ordinate, and similarly that on the C strobe vertically beneath A_2 zero pip gives the C co-ordinate. The decimal part of the fix is read on the STB.

The whole number must be obtained by reference back to MTB, *see* fig. 7(G).



TYPICAL MAIN TIME BASE PICTURE ON SWITCHING ON

PULSES BROUGHT TO CONVENTIONAL POSITION BY TIME BASE PHASE CONTROL

B AND C PULSES STROBED (AND INVERTED)

STROBE TIME BASE PICTURE

PULSES LINED UP

STROBE TIME BASE CALIBRATION

MAIN TIME CALIBRATION

Fig. 7.—Taking a fix

58. Care must be exercised in determining the whole numbers in the fix. Sometimes the whole number wanted is the one within the strobe marker; sometimes the one to the left. The example shown gives both cases. The fix gives the position of the aircraft at the time of operation (5). It will be observed that the B co-ordinates always turn out to lie between 0 and 25, while the C co-ordinate lies between 30 and 55.

59. The maps are labelled accordingly. There is therefore no possibility of confusion of the numbers as they are transferred from tube face to the map.

60. If a fix is required from the D station, the latter can be strobed by either of the strobes. However, the numbering of the D lines on the map runs between 30 and 55. If D is strobed on the C trace, therefore, all is well. If it is strobed on the B trace, however, 30 must be added to the number obtained.

Unit details

61. Gee Mk. I (ARI 5033), comprises a receiver, type R.1324 and indicator unit, type 60. The equipment is now obsolete, being replaced by Mk. II. The general principles of the Mk. I and Mk. II aircraft equipment are the same, but Mk. II has an improved display.

62. Gee Mk. II (ARI 5083), comprises a receiver, type R.1355 and indicator unit, type 62.

Frequency. There are four frequency bands in use:—

20 — 30 Mc/s.
40 — 50 Mc/s.
50 — 65 Mc/s.
65 — 80 Mc/s.

Receivers are fitted with interchangeable RF units, one for each band; and the navigator can select one of five spot frequencies in each band.

These spot frequencies are preset on the ground.

RF units. RF stage.
Local oscillator.
Mixer.

Main receiver. 5 IF stages at 7·5 Mc/s.
Diode second detector.
VF amplifier.
Cathode follower output.
The gain control is on the indicator unit.

Supply. 80 volt, 1,600 c/s engine-driven generator.

Voltage control panel. Type 3.

Aerial. $\lambda/4$ whip aerial and matching unit into receiver.

Ground equipment

63. The master station possesses a transmitter and the associated drive equipment.

64. At a slave station it is necessary to have both a receiver, to receive locking pulses from the master, and also a transmitter to send on pulses to the aircraft. The receiver contains a monitoring section for measuring the time delay introduced at that station.

65. The display is as shown in fig. 8(A) and fig. 8(B). A main timebase with a step is used and this is calibrated with unit markers in the form of brilliance modulation. There are three strobes, their positions being indicated by brilliance markers. One of them can be positioned over the step, one along the rest of the top trace and one along the bottom trace.

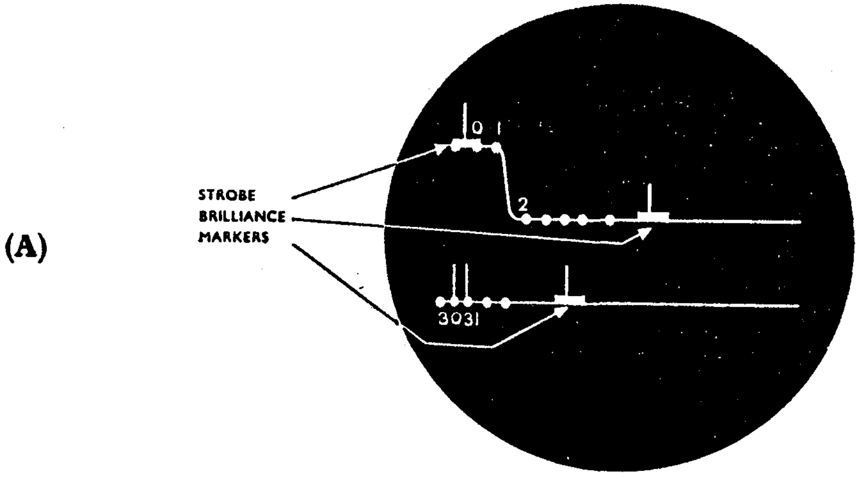
66. The strobe timebase is calibrated by unit and 1/10 unit brilliance markers; there now being three strobe timebases, corresponding to the three strobe markers (this type of display was used in the airborne Mk. I equipment).

67. The slave station transmitter pulse is displayed on the tube as well as those coming from the other stations, and the equipment enables the local pulse to be sent out a fixed time after reception of the A pulses.

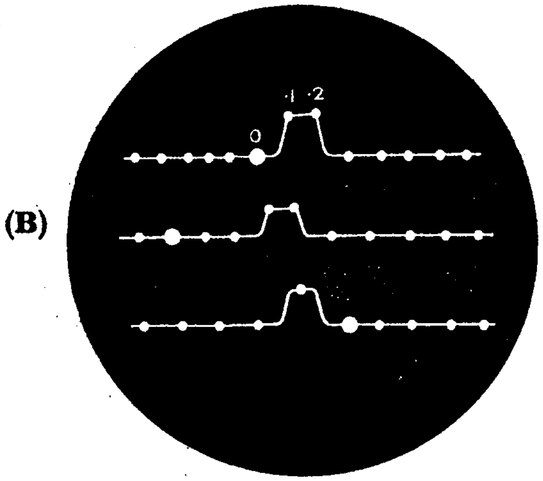
68 A monitor station does essentially the same thing as an aircraft observer, but since its position is known, errors at a slave station can be corrected.

Units

69. *Transmitters.*	T.1348 (M.B.3 modified), or T.1356 or G.L. type transmitter.
Output.	300 kW.
Oscillators.	VT 58's in push-pull followed by push-pull power amplification in two VT114 A's.
Frequency.	As for aircraft equipment.
Aerials (in general).	Floodlight technique. Vertically stacked dipoles with reflectors to throw main lobe forward. Wide-band aerials now used frequently to avoid matching difficulties as frequencies are changed.



MAIN TIME BASE (SHOWING FIRST FEW CALIBRATION PIPS)



STROBE TIME BASE (WITH CALIBRATION)

Fig. 8.—Display

Receivers.	R.1363 (Slave). R.1364 (Monitor).
Aerials.	1. Vertically stacked dipoles, beamed towards master station. (Slave normally in a side-lobe of the master) alternatively. 2. Inverted V aerials, the plane of which contains the master station.

LORAN (LONG RANGE NAVIGATION) EQUIPMENT

General principle

70. This is the American counterpart of Gee and is based on the British equipment. The same principle of hyperbolae is used, but the ground station arrangement is somewhat different.

71. A number of ground stations are erected and they work in interlaced pairs. Any one station acts as a slave for one of its neighbours and as a master for its other neighbour. Different master-slave pairs work on different pulse recurrence frequencies and the aircraft timebase can be run at any one of these p.r.f.'s. Thus, any one station-pair can be picked up at any one time. This will give one co-ordinate of the fix and the other must be obtained by switching to a different timebase speed. This means, of course, that only a running fix can be taken, one co-ordinate after another.

Other details

72. *Frequency.*	Around 2 Mc/s.
P.R.F.	Different for each pair but around 25 c/s.
Range.	600 miles using direct radiation: 1,200 miles under favourable atmospheric conditions by using waves reflected from the E-layer.
Accuracy.	On the direct ray, comparable with Gee: on the reflected ray, errors approximately doubled.

The Loran aircraft equipment is made to conform in shape, size and cable connections with the Gee equipment to enable rapid interchanges to be made.

S.S. Loran

73. SS Loran is an adaptation of Loran, which is suitable for use by surface craft. For a summary of recent Marks of Gee-7000, Gee-H and Loran equipments refer to A.P.1093C, Chapter 4.

THE GEE-H SYSTEM

74. The Gee-H system implies (Gee airborne equipment with type 100 ground stations, employing the H-principle).

General principles

75. The Gee-H system applies the principle of the radar beacon to accurate blind bombing and precision navigation. Two ground beacons or transponders at the ends of a base line respond to interrogating pulses emitted by the aircraft desiring to fix its position. The beacons re-transmit pulses on another frequency, with negligible delay, to the aircraft, and these pulses are received by the Gee receiver of the aircraft and displayed on a linear timebase. The aircraft is thus able to find its range from the beacons whose positions are known and to find its own position from a range cut.

76. This system is more accurate than the Gee-7000 system and should not give an error greater than 300-400 yards at a range of 250 miles, but its aircraft handling capacity is lower, the maximum number that can be handled at one time being 50.

77. The beacons—or H-beacons (AMES, type 100) comprise a receiver R.1441 and a transmitter T.1488.

78. The aircraft equipment comprises a Gee set (slightly modified), a transmitter and modulator, and auxiliary devices. An aircraft carrying this equipment is able both to navigate by using the type 7000 ground stations (Gee-navigation) or by interrogating the AMES, type 100 ground beacons (Gee-H navigation).

79. The procedure for obtaining a Gee-H fix is very similar to that for finding a Gee fix, and again involves the lining up of pulses on the timebase of the display tube. The appearance of the Gee timebase is approximately preserved in Gee-H but the airborne transmitter is synchronised to pulse at the start of each timebase. The responses returned by the beacons appear on the timebase and the navigator notes their ranges from their positions relative to the aircraft transmitter pulse which appears at the beginning of the timebase. The technique of " lining up " and strobing is the same as that used in Gee.

80. To avoid saturating the ground beacons which would occur if the aircraft transmitted at 500 c/s, the normal recurrence rate of a Gee timebase, eight out of every 10 timebases and transmitter pulses are suppressed. The interrogating pulses are therefore emitted in pairs at the recurrence rate of 50 pairs per second.

81. To avoid mutual interference between aircraft using the same beacons, the recurrence rate is actually varied about 50 pairs per second as a mean value. Only the beacon response excited by its own transmitter then appears stationary on the timebase.

82. As it is necessary to associate the two beacon responses with their correct ground stations, one of the latter codes its responses by delaying its return periodically. The result is that the response from this ground station moves periodically a small distance to the right of its main position on the timebase of the aircraft receiver.

83. The normal Gee timebase runs for 1660 microseconds and is followed by a blackout interval of 340 microseconds before the next timebase.

84. Since a radar mile of range is equivalent to 10 microseconds of the timebase, the maximum range, if a normal Gee timebase were employed, would be 166 miles. Responses from beacons at ranges lying between 166 miles and 200 miles would fall in the blackout interval; and those from beacons at ranges greater than 200 miles, on the second timebase.

85. To permit the aircraft to receive all beacon responses up to the maximum operational range of about 360 miles, the normal Gee timebase is modified by introduction of an intricate system of switching; details will be found in the appropriate technical manuals.

86. Marks of Gee-H

Mk. I. (ARI.5525) is an interim airborne equipment.

Mk. II. (ARI.5597). Includes a high-power transmitter (type T1629). and a redesigned indicator unit (type 166) which affords Rebecca and BABS facilities.

ARI.5611 is a combination of Gee-H Mk. II and Rebecca Mk. II U.

87. Gee-H ground installations

AMES, *type* 100 is a heavy ground beacon equipment but mobile forms exist.

AMES, *type* 100—*Light transportable*, is a combination of types 100 and 7000 equipment which can provide both a Gee and a Gee-H service to aircraft. It is designed to be transportable by van or by air and is tropicalised.

Three ground stations form a normal Gee chain and any two of the three can function as a pair of Gee-H beacons.

A common transmitter is shared between the type 700 and type 100 equipment at a ground station.

The equipment provides close range support in army co-operation with Gee for navigation and Gee-H for blind bombing.

For special tasks the equipment may be resolved into separate type 7000 and type 100 stations.

SHORAN

88. *Shoran*—(Short Range Navigation), is an American blind-bombing equipment using the H principle.

AN/CPN-2 is the ground equipment.

AN/APN-3 is the airborne equipment. Radar information is automatically fed to computors which control the aircraft and release the bombs.

CHAPTER 5

OBOE-9000 SYSTEM

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General details

Ground station equipment

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GENERAL DETAILS

Introduction

1. Oboe is a system of blind-bombing wherein an aircraft is controlled by two ground stations. Each of these stations uses the normal radar technique to measure the range of the aircraft from it; thus it can be seen that at any time the position of the aircraft can be found by the range-cut principle. The code name Oboe covers airborne equipments whereas the ground stations are called AMES type 9000.

2. In order to increase the range of the device above that which would be obtained were the reflected waves alone used, a pulse repeater is carried in the aircraft. Thus there is a two-way transmission (compare the IFF principle); and it can be seen that without multiple equipment, any two stations will only be able to control one aircraft at a time.

3. Oboe was first used operationally in the early part of 1943. The Mk. I equipment was used at that time, but since then other Marks have been developed. These will all be described later. There are, however, certain fundamental facts common to all of them, and these will be dealt with first.

Ground stations (AMES, type 9000)

4. The two ground stations previously mentioned have different functions in an Oboe operation. One station keeps the aircraft flying along a track which will take it over the target (fig. 1). In general the track along which the aircraft is made to fly is a circle drawn about the ground station as centre with a radius equal to the target range from that station, but it is possible to arrange to have arcs of approach to the target other than circular ones. In all cases, this station is known as the *cat* or the *tracker* station, the latter being the more modern name. The tracker station measures the range of the aircraft, and so can determine whether or not the latter is on its correct track. Indications of error in track are sent out from the tracker to the aircraft in such a manner that the pilot hears a series of dashes in a pair of headphones if he is too far from ground station, or a series of dots if he is too close. If he is on the correct track the pilot hears a continuous note in his headphones. All such indications to the pilot are sent out automatically from the tracker station by a modulation of the same pulse transmission that is used for range measurement. The form assumed by this modulation will be discussed in each particular case.

5. The function of the second ground station is to send out to the aircraft (this time to the navigator or bomb-aimer) the bomb-release signals and such warning signals as are deemed necessary. This station is known as the *Mouse*. It measures the range of the aircraft and so also can obtain the velocity of the aircraft along a radius drawn towards it. Having this information, and also the height of the aircraft and bomb ballistic data, the *Mouse* can send the release warning so that the bombs fall on the target. Usually the release signal is sent by breaking completely transmission from the *Mouse*.

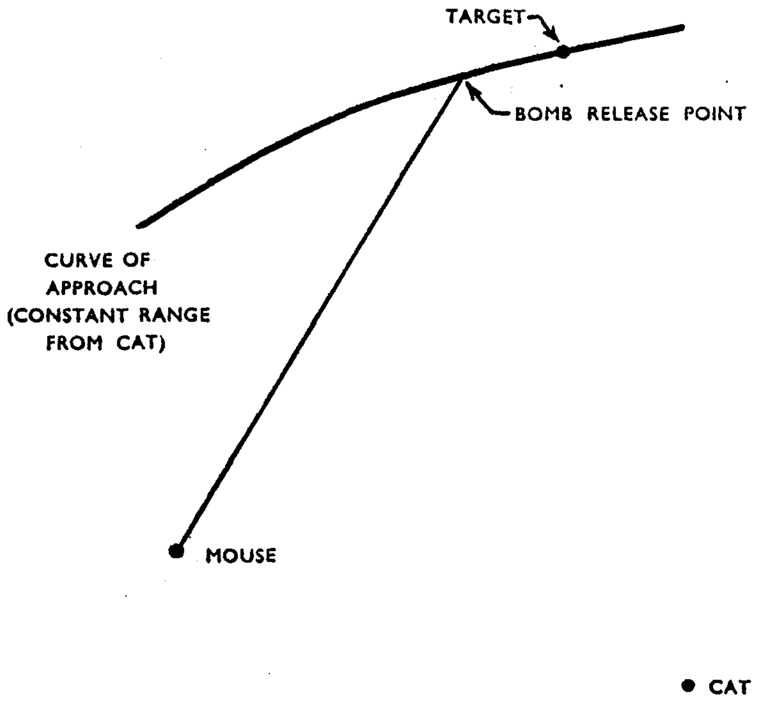


Fig. 1.—Oboe, showing general principles

Aircraft equipment

6. There is no need for any form of display in the air, all signals received by the pilot and navigator being aural. The equipment carried in the air, therefore, consists in the first place of a receiver which is used to trigger the pulse repeater transmitter. A double filter is also required to separate signals from the two ground staions and to convert the pulse intelligence received into audible indications for the aircrew, who wear headphones.

Operational technique

7. On large scale raids the Oboe equipped aircraft act as pathfinders for the main force, dropping marker flares on the target. On small scale raids on specialised targets the Oboe aircraft carry a bomb-load. Both Cat and Mouse stations can communicate with the aircraft in morse over the radar pulsed beam. This is used for the preliminary positioning of the aircraft before it starts its run-in. The range achieved is of the order of 250 miles.

Accuracy

8. Though the accuracy with different Marks of equipment may, to a certain extent, vary, it is remarkably good for all. The errors involved are usually of the order of 100 yards. The accuracy is better with a greater base line between the stations, because then the angle of cut of the Cat and Mouse circles at the target is greater.

GROUND STATION EQUIPMENTS

Mk. I (FGRI.5534)

9. In this equipment a CHL transmitter and converted CHL receiver racks are used. The frequency is about 220 Mc/s (just under 1½ metres).

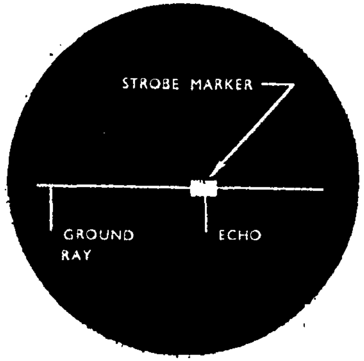


Fig. 2.—Long timebase and strobe marker

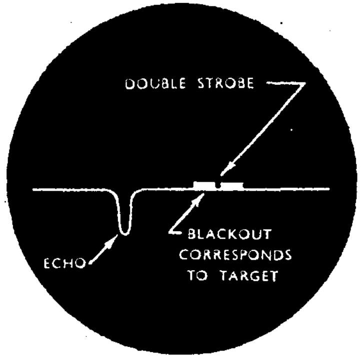


Fig. 3.—Magnified timebase (Cat) and double strobe marker

10. The display consists of two CRT presentations. On one of the tubes is a timebase of some 400 miles length which is known as the *long timebase* (fig. 2). On this timebase appears the ground ray (at the beginning) and the return pulse from the aircraft (at a point depending on the aircraft range). In addition a small part of the trace has extra brightness (*strobe marker*). This strobe marker can be moved at will

along the trace and it is the function of the other tube to give a magnified picture of the section of the long timebase so brightened. This second presentation, a timebase of something like 3 miles length, is known as the *magnified timebase* (fig. 3).

11. At a Cat station the recurrence frequency of the long timebases is 133 c/s and so also is that of the ground rays which appear at the beginning of each long timebase.

12. On the magnified timebase trace appear two brilliance markers separated by a small interval. These are known as the *double strobe* markers (fig. 3).

13. The gap between the twin strobes may be positioned accurately to correspond to target range, and it is the function of the equipment to compare the position of the aircraft return signal with the positions of the twin strobes. The two strobes define two zones, one to the inside of the target circle and one on the outside. The comparing circuits on the ground are very sensitive and can detect even the slightest difference in time overlap of the aircraft signal with the two strobe zones. Thus the circuits see automatically whether the aircraft is too close to, or too far from, the Cat station.

14. A further set of pulses is now sent out from the Cat station. These are sent out during the blackout period, so that they cause no interference to the operator. The actual position occupied by the pulses in the blackout period is controlled by the circuit which compares the position of the return pulse with the double strobes.

15. If the aircraft is at correct range from the Cat station then these second pulses remain steady at a position one-quarter the way into the blackout period. This is their mean position. As the aircraft deviates from the correct track these pulses are space modulated in a dot-dash manner about their mean position. Extreme modulation takes them from the beginning of the blackout period to halfway through the blackout (fig. 4).

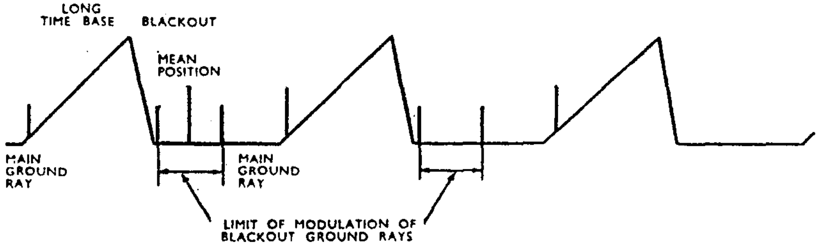
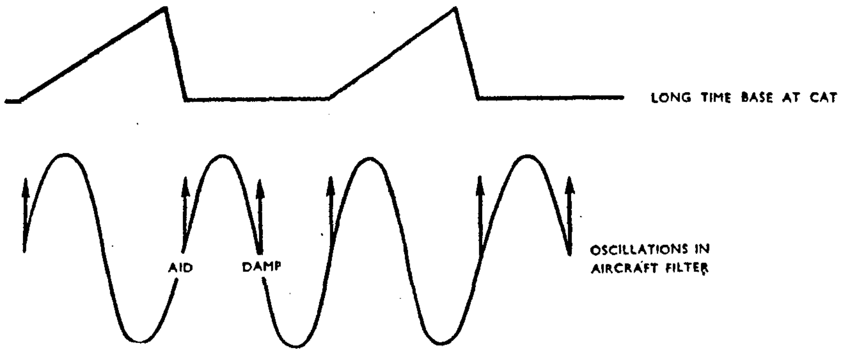


Fig. 4.—Ground rays and modulation

16. The aircraft filter consists of a ringing circuit tuned to 266 c/s This will be maintained in oscillation by the normal pulses sent from the ground. At the same time the second type of pulses from the ground will, according to their position, reinforce or damp down these oscillations. Thus it can be seen that the filter will convert dot-dash space modulation of the pulses into dot-dash amplitude modulator for the pilot. *See* fig. 5.

17. To give an example: if the aircraft is too close to the Cat station, then the blackout ground rays spend about 1/12 second at the beginning of the blackout and then about 5/12 second half-way through the blackout and so on (taking the case of extreme modulation). In this case the filter oscillations are reinforced for 1/12 second and damped for 5/12 second. This results in a series of dots heard in the aircraft (fig. 6(A)). Similarly, dashes can be obtained by reversing the timing of the dot-dash space modulation (fig. 6(B)).



Normal ground rays maintain oscillations
Blackout ground ray at beginning of blackout aids oscillations
Blackout ground ray halfway through blackout damps oscillations

Fig. 5—Aircraft ringing circuit

18. The extent of swing of the pulses is governed by the error in range of the aircraft and so the amplitude of dots or dashes will tell the pilot the extent of his error. When he is on the correct track there is no space modulation and so a constant amplitude in the aircraft filter.

19. A Mouse station has both long and magnified timebases as before. However, on the latter, a series of equidistant blackout pips appear, replacing the double strobe pulses of the Cat (fig. 7(a)). These pips can be positioned on the trace so that one of their number corresponds to target range and the others then mark out constant intervals from the target range such as PQ and QT (fig. 7(b)). The general principle adopted

is that the aircraft is timed as it covers the distance PQ, and information derived from this timing (velocity of aircraft) is then used to enable the bombs to be released at a point R in the interval QT so that they actually fall on the target (fig. 7(b)). Again, most of this work is done automatically.

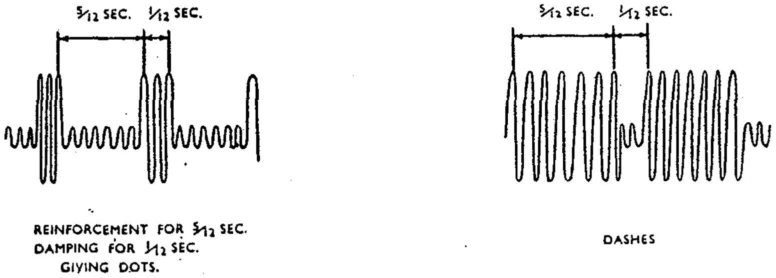


Fig. 6—Operation of ringing circuit

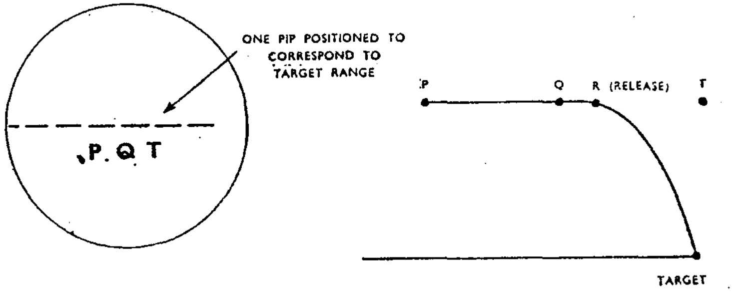


Fig. 7.—Magnified timebase (Mouse) showing blackout pips

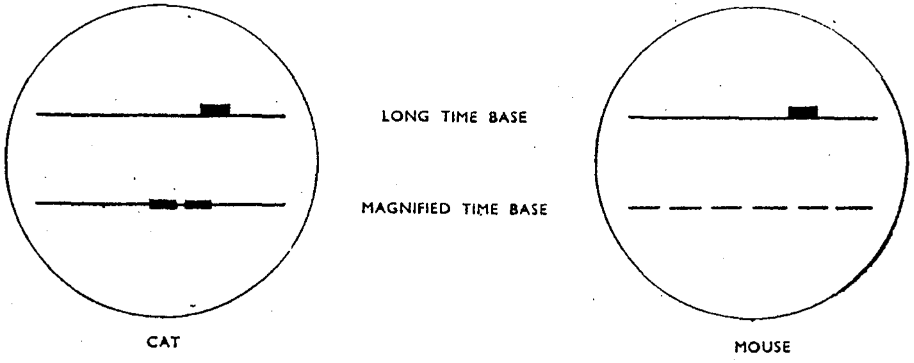


Fig. 8.—Mk. II MS display

20. The recurrence frequency of the Mouse long timebase is 97 c/s and pulses are sent out at the beginning of this timebase and at the beginning of the blackout period.

21. The aircraft filter has a ringing circuit at 194 c/s feeding the bomb-aimer's headphones, and this will clearly be kept ringing at maximum amplitude by the Mouse pulses received. The release signal is given by a complete break in transmission. Cat and Mouse arrays are directed towards the target area

Mk. II F (FGRI.5606)

22. This uses the same display scheme as for Mk. I and, in fact, differs from the latter only in radio-frequency. It uses centimetre waves (about 9·3 cm.). The transmitter used normally is an American ASG type converted for ground use.

Mk. II MS

23. This, again, uses the same principles as the Mk. I equipment. It has been possible, however, to put the equipment into a smaller space, and an interesting feature is that both long and magnified timebases are displayed on one tube (fig. 8). The equipment is designed to work with a transmitter on 1½ metres or on a centimetre wavelength, and the whole is mobile (being housed in a trailer).

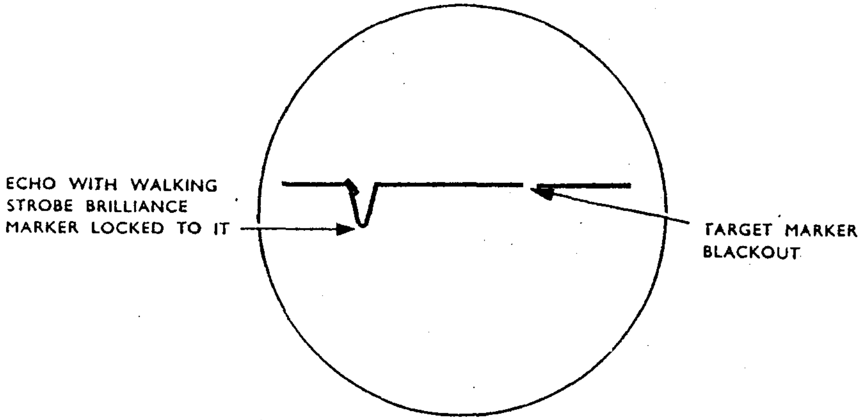


Fig. 9.—Mk. II M and Mk. III magnified timebase

Mk. II M (MGRI.5539)

24. This equipment has timing circuits which are completely different from those in the earlier type. A console display is used mounting two tubes.

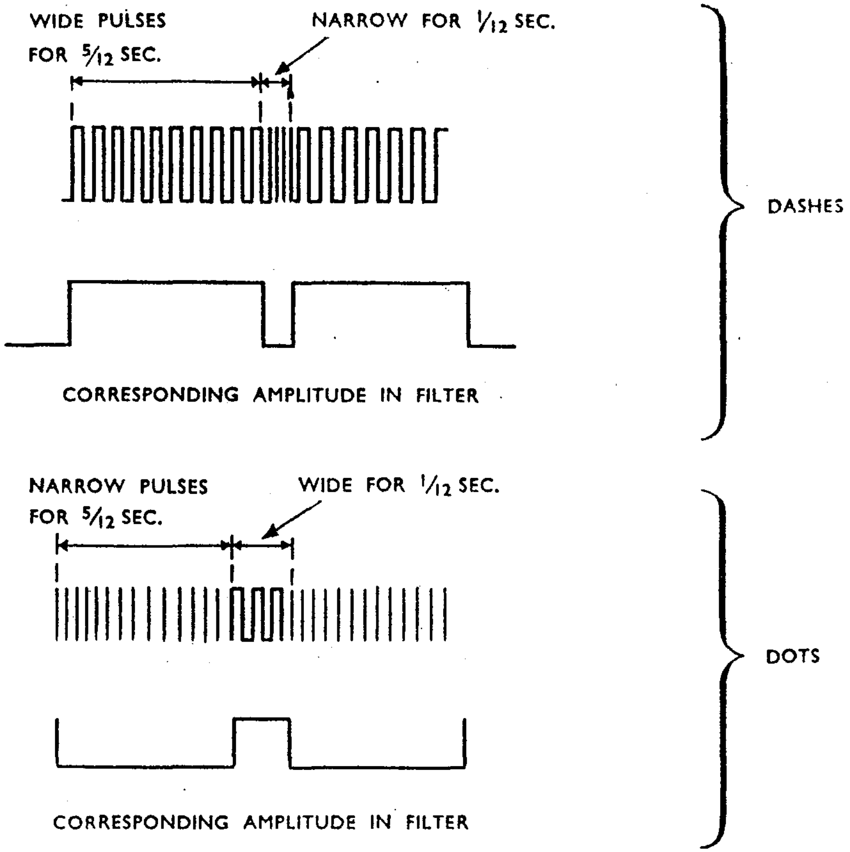


Fig. 10.—Scheme for dot-dash width modulation

25. These show respectively a long timebase with strobe marker and a magnified timebase. The magnified timebase display is now the same for both Cat and Mouse stations. A short blackout pip is used to mark out the target range and in addition there is a short brilliance marker known as the *walking strobe* pulse (fig. 9). This walking strobe has the property that it can lock to and follow any selected aircraft echo as it moves across the trace (compare the walking strobe in AI Mk. VI). Circuits then translate both range and velocity of the aircraft echo into DC voltages which are used to control those circuits which send signals to the aircraft (for either Cat or Mouse operation).

26. Space modulation of alternate ground rays is not now employed. Instead the pulse transmission is width modulated in accordance with signals to be sent. The modulation of pulse width is done in a dot-dash manner, width now being modulated exactly as position of the blackout ground rays was modulated previously (*see* fig. 10). Consequently, at a Cat station, for example, pulses of constant width are sent out if the aircraft is on track.

27. The aircraft filters are now adjusted so that they convert dot-dash width modulation into dot-dash amplitude modulation for the pilot and bomb-aimer to hear.

28. The p.r.f.'s can now be varied to a certain extent for different station pairs, but they are always of the order mentioned before (97 c/s for Mouse and 133 c/s for Cat. The transmitter is on a centimetre wavelength (about 9·3 cm.). The equipment is mobile, being housed within a trailer.

Mk. III (FGRI.5565)

29. Oboe Mk. III is really the fixed version of Oboe Mk. II M, a feature being the provision for multichannel working. The method adopted for multichannel working is to have a number of display consoles similar to those of Mk. II M, and a calibrator rack supplying a number of p.r.f.'s. A common transmitter is used for all the p.r.f. channels, each pulse train being width-modulated by the relevant console and control gear. Apart from the fact that a common transmitter is used, a Mk. III station can be said to be a Mk. II M station reproduced *n* times, where *n* is the number of p.r.f.'s used. Mk. III employs a wavelength of about 9·3 cm.

30. It will be seen that both in Mk. II M and Mk. III operation, where a number of p.r.f. pairs may be used, it is necessary to be able to discriminate between these p.r.f. pairs in the aircraft. It is necessary, therefore, for the aircraft to carry what is known as a p.r.f. selector.

SUMMARY OF AIRCRAFT EQUIPMENT

31. To summarize what has already been said, the aircraft equipment must contain a receiver which triggers the pulse repeating transmitter and which feeds also to a double filter for station selection. For multichannel operation a p.r.f. selector is needed.

32. The early gear was known as the *Pea-cock* equipment (ARI.5513) and worked on the 1½ metre band.

33. For centimetre working *Album Leaf* equipment is used (ARI.5582). This uses an American ASG type transmitter. Album Leaf is now termed Oboe Mk. II.

34. Oboe Mk. III is similar to Oboe Mk. II fitted with a p.r.f. selector, and works with width-modulated ground stations. For a summary of recent Marks of Oboe and 9000 equipments see A.P.1093C, Chapter 4.

CHAPTER 6

IFF AND RADAR BEACONS.

IDENTIFICATION FRIEND OR FOE

Introduction

1. The primary function of IFF equipment is to enable radar operators to recognise friendly aircraft and ships, and it was first introduced for this purpose into British aircraft in the early days of the war. Changing operational needs, and the increasing number and complexity of radar equipments, have since led to the introduction of new types of IFF, and the original version has long been obsolete. The fundamental principle underlying the method of operation, has, however, remained the same.

2. The IFF set which is carried in aircraft and ships, consists essentially of a receiver-transmitter. The receiver receives and amplifies the pulse from a radar equipment and uses it to trigger the transmitter with inappreciable delay, so that if both the receiver and transmitter are tuned to the frequency of a particular radar equipment, a large echo will appear on the radar display tube. When reception and re-transmission occur on the same frequency the receiver-transmitter is called a *responder*, and when on different frequencies, a *transponder*. Thus IFF sets are usually responders, but beacons are transponders.

3. The older types of IFF used a system of direct interrogation. In this system the transmitter and the receiver of the IFF set both worked on the same frequency, and this frequency was varied continuously by rotating the tuning control by means of a small electric motor, so that it swept periodically through a fairly wide band. The time taken for each sweep was of the order of a few seconds. A radar equipment working at some frequency within this band received a response from the IFF responder only for a fraction of a second each time the responder tuning swept through the radar frequency. Thus, for the greater part of the time the radar display tube showed only a normal echo, but every few seconds this echo increased in amplitude for an instant. Echoes showing this periodic increase were identified as friendly. The duration of the return pulse or *response* from the IFF was of the order of a few microseconds. By a slight adjustment of the responder circuit it was possible to vary this pulse width, so that the IFF set could show narrow, wide or very wide pulses. By varying the widths of consecutive pulses it was possible to obtain some measure of coding. In particular, a wide pulse of about 25 microseconds duration was used to denote distress. The widths of the transmitted pulses could be varied while in the air for coding purposes, by a remote-control switch available to the crew of the aircraft.

IFF Mk. I and II

4. The earliest type of IFF was the Mk. I. It was purely experimental and only about 50 models were produced; it is now obsolete.

5. IFF Mk. II was a production model developed after operational experience had been obtained with Mk. I. Like the Mk. I equipment it responded to direct interrogation, sweeping a frequency band as described in para. 3. To be more precise, it covered three frequency bands, including the frequency ranges of CH and GL Mk. II stations and Naval type 79 equipments. These bands were as follows :—

The A1-band—22·2-30 Mc/s—covering CH main frequencies.

The A2-band—39-51·25 Mc/s—covering the CH standby and type 79 frequencies.

The B-band—54·55-84 Mc/s—covering the GL Mk. II frequencies.

6. It required 4 seconds to sweep the A1 band, 2 seconds to sweep the B band, and 4 seconds to sweep the A2 band. The sweeping was in the following order :—

A1	B	A2	B	A1	B	A2	— and so on.
4 sec.	2 sec.	4 sec.	2 sec.	4 sec.	2 sec.	4 sec.	

so that a station on the A1-band or the A2-band received a response once every 12 seconds and a station on the B-band received one every 6 seconds. The Mk. II transponder could retransmit pulses of three widths, viz :—

Narrow (N) 10 μS; Wide (W) 25 μS; Very Wide (VW) 60 μS.

7. By using these different pulse widths it was possible to code the response. During any one complete sweeping cycle, which included the A1-band, the B-band, and the A2-band sweep, the response pulses were all of the same width; either narrow, wide, or very wide. During the next cycle the pulses could either be of the same width as before, or they could all have a different width. The third and fourth cycles could also be characterised by further possible changes in the pulse width. Thus each group of four cycles could include four narrow responses, two wides and two narrows, or other similar combinations. The fifth, sixth, seventh and eighth repeated the first, second, third and fourth respectively, so that the code was repeated every four cycles.

There were, in all, six available codes :—

(1)	N	N	N	N
(2)	W	W	W	W
(3)	VW	VW	VW	VW
(4)	N	W	N	W
(5)	W	VW	W	VW
(6)	N	VW	N	VW

Only code (1) was ever used in service, however. Code (2) was reserved to denote distress.

8. When GCI stations came into use, late in 1940, it became necessary to identify night fighters to the controllers of GCI. The GCI equipments worked on frequencies between 180 Mc/s and it was necessary to design an IFF set to work in this band. This led to the development of IFF Mk. II G, which swept two bands, viz :—

The B-band—54·5—84 Mc/s and
The G-band—180—210 Mc/s—for use with GCI

The time of sweep of these bands was as follows :—

G	B	G	B	————and so on.
4 secs.	2 secs.	4 secs.	2 secs.	

9. The G-band was swept alternatively up and down, while the B-band was always swept up—from the lowest frequency (54·5 Mc/s) to the highest (84 Mc/s). Thus responses on the B-band occurred every 6 seconds, while a station on the G-band received two responses every 12 seconds, although these two responses were not generally spaced exactly six seconds apart.
The equipment had one pulse width on the G-band, and two on the B-band, viz. :—

G-band, Narrow only, 8 μS ;
B-band, Narrow, 6 μS ; wide, 18 μS.

Various alternative codes were possible on the B-band.

10. IFF Mk. II N was installed in Coastal Command and Naval Air Arm aircraft to give IFF indications to certain ship-borne radar sets. It swept two bands:—

The N-band : 195—227 Mc/s
The N2-band : 38—52 Mc/s

It swept each of these bands in turn, taking 6 seconds for each sweep so that responses to radar equipment working on either band occured every 12 seconds.

Limitations of IFF Mk. II

11. In the early days of radar when equipments were few in number and when the frequencies were relatively low, Mk. II IFF worked satisfactorily. As the number of ground and ship-borne radar equipments increased, however, the situation became more complicated. The general trend in the newer equipments was towards higher frequencies, and it became increasingly difficult to design IFF sets to cover the ever extending radar frequency band. Soon after the development of IFF Mk. II for instance, it became necessary to introduce the Mk. II G to cover the GCI band and the Mk. II N to cover some of the higher frequencies of the newer Naval equipments. This introduction of new types of Mk. II showed every sign of continuing indefinitely and was leading to an impossible situation, and in 1941 it became evident that a new system must eventually be introduced, using the principle of indirect interrogation.

12. In the *indirect interrogation* system, the IFF is not interrogated by the main radar equipment. Every radar equipment which needs to interrogate IFF is provided with a second subsidiary equipment. This subsidiary equipment is itself a small radar set, and it uses a different frequency from the parent equipment. It is called an *interrogator*, and consists of a transmitter which radiates radar pulses in the normal way, and a receiver or *responser* which receives the response from the IFF. All IFF sets work on the same frequency band, and all interrogators have a frequency somewhere in this band, so that any radar set, no matter what its frequency, can, if provided with an interrogator working in the IFF band, interrogate the IFF in any aircraft. The interrogator is normally of very low power, so that normal echoes from aircraft are too weak to appear on the responser display tube, and it can only " see " the relatively strong IFF responses. It is generally locked to the main radar equipment so that its pulses are radiated at the same instant as the radar pulses, and it often has a counting-down circuit incorporated, which causes it to transmit only on every fourth, fifth, or sixth transmission of the main radar. The later Marks of IFF employ the system of indirect interrogation for most purposes, although there are special cases in which direct interrogation is still used. These systems are discussed later.

The function of radar beacons

13. Transponders of the IFF type can be used not only for identification but also as navigational aids to aircraft. When used for this purpose they are termed radar beacons. Radar beacons were first introduced into service in 1940 and since that time there have been many types produced for different purposes. They fall into two main cate-

gories; *homing beacons* and *beam approach beacons* or BABS, and the function of each of these will be described separately.

14. Homing beacons are transponders, working on the IFF principle, but installed at some reference point, such as an airfield or a ship. Aircraft wishing to use these beacons carry interrogators working on the beacon frequency, and can receive responses back from the beacons in the usual way. Instead of continuously sweeping a frequency band, the beacon transponders work on a fixed frequency, so that the aircraft interrogator receives a continuous response. Most beacons do not re-transmit continuously but are switched on and off for short periods so that they return "flashes" to the aircraft in the same way as visual beacons, and these flashes can be coded to give mores letters. Coding can also be arranged by the transmission of wide and narrow pulses as in IFF.

15. Aircraft using these beacons for homing have interrogators with specially designed aerial systems. The usual scheme is to have a forward-looking aerial for transmission and two separate receiving aerials, one mounted on each wing. The starboard receiving aerial has its line-of-shoot not along the line of flight of the aircraft, but a few degrees to starboard, while the port receiving aerial has its line-of-shoot offset by the same angle to port. The horizontal polar diagrams of the two aerials overlap. If the aircraft is flying directly towards the radar beacon the signals received by the two aerials will be equal; but if its course does not coincide exactly with the direction of the beacon, one aerial will receive a signal of slightly greater amplitude than that received by the other. These receiving aerials are switched continuously, so that they receive pulses alternately. The display is of the range-amplitude type, the timebase being vertical, and the received signal from the starboard aerial appears as a deflection to the right, while the signal from the port aerial appears as a deflection to the left. By noting the relative lengths of the deflections on either side of the trace, some indication of the bearing of the beacon can be estimated, and it is possible for the crew of the aircraft to home on to the beacon.

16. BABS beacons are used for a purpose different from that of homing beacons. Their function is to enable an aircraft at night or in bad weather to approach an airfield from the correct direction for landing. Like homing beacons they are fixed-frequency transponders, but their aerial systems differ considerably from those of the previous type. The ground transponder is installed at the far end of the runway, and it usually has a receiving aerial whose line-of-shoot lies along the runway so that it will pick up signals from an aircraft approaching from approximately the correct direction. The beacon re-transmits these pulses from two directional aerials whose lines-of-shoot make equal small angles with the direction of the runway, one looking slightly to the left of this direction and the other looking to the right. These two aerials are switched, so that the re-transmitted pulses are radiated first from one and then from the other. If the aircraft is making the correct approach it receives equal signals from the two aerials, but if it is not coming in from the correct direction it receives a greater signal from one than it does from the other. Provided that the pilot of the aircraft has some way of differentiating between the signals from the two aerials it is therefore possible for him to correct any errors in his course, and to make the proper approach without difficulty. Details of the precise method of arranging this are given in the section on beacons.

17. Both homing and BABS beacons often use two frequencies; one for transmission and one for reception. The transmitter of the aircraft interrogator and the receiver of the ground transponder must, of course, use the same frequency; but the beacon transmitter re-transmits and the responder in the aircraft receives on a second frequency. The use of two frequencies in this way reduces clutter due to normal echoes from the ground.

18. In certain instances, particularly in the case of ship-borne transponders, a single set can fulfil the functions of both an IFF and a beacon, being used both to identify the ship to aircraft, and also to enable the aircraft to home.

RADAR BEACONS

19. In the following paragraphs appears a brief survey of the history of radar beacon systems up to the present time, and of the various types of beacon now in use. The two main categories of beacons are treated separately. Homing beacons are described first and radar BABS systems afterwards. Then follows a short account of the principal airborne equipments used to interrogate these beacons. The majority of the beacon systems used at the present time are British. Both the RAF and NAA have some American beacons, however, and these are also mentioned.

The history of homing beacons

20. The general principle underlying the operation of homing beacons has already been described. The beacon is a transponder, situated on an airfield, on board ship, or at some point on the ground. It responds to pulses transmitted by an aircraft interrogating equipment, and if the interrogator is supplied with suitable directional aerials it is possible for the aircraft to home on to the beacon. Ships can also carry similar interrogators and can use them to find their range and bearing from other ships or from shore stations.

21. The first beacons were used by Coastal Command. They were modified IFF sets tuned to a fixed frequency of 176 Mc/s to respond to the ASV Mark II sets in the Coastal aircraft. ASV Mk. II uses horizontal polarisation, so that these beacons had to be horizontally polarised also. With the introduction of BABS beacons, to be described later, which respond on a frequency of 173·5 Mc/s, it became necessary to raise the frequency of response of the ASV beacons to 177 Mc/s, so that the band would not overlap with that of the BABS. Thus the present ASV beacons receive on 176 Mc/s, and re-transmit on 177 Mc/s.

22. Fighter Command soon followed the example of Coastal Command, and introduced beacons on their aerodromes. These early Fighter beacons, like the Coastal ones, were modified IFF sets. This time, however, they used vertical polarisation, because the Marks of AI with which they were designed to work used vertical aerials. They could be interrogated by AI Mks. IV, V and VI, all of which work on a frequency of 193 Mc/s. They were interrogated on this frequency, and responded on a frequency of 196·5 Mc/s, so that the AI receiver had to be detuned in order to receive their signals.

23. Since these early days, there have been several new and improved types of Coastal and Fighter beacons. A number of these newer beacons use superheterodyne receivers, although some, especially the transportable types, are still super-regenerative transponders. The polarisation and the frequencies remain the same, however. All Coastal beacons use horizontal polarisation, receive on a frequency of 176 Mc/s, and respond on 177 Mc/s. All Fighter beacons are vertically polarised, receive on 193 Mc/s, and respond on 196·5 Mc/s.

24. The Naval Air Arm next developed beacons for use on ships and shore stations. These beacons were interrogated by ASV Mk. II, which many NAA aircraft carried, and, like the Coastal beacons, they were horizontally polarised. The earlier NAA beacons swept a frequency band, as did the IFF sets, but later models are tuned to fixed frequencies, and are interrogated on 176 Mc/s and respond on 177 Mc/s.

25. Transport Command also use ASV Mk. II beacons. Bomber Command does not use homing beacons at the present time, but uses Gee for homing purposes.

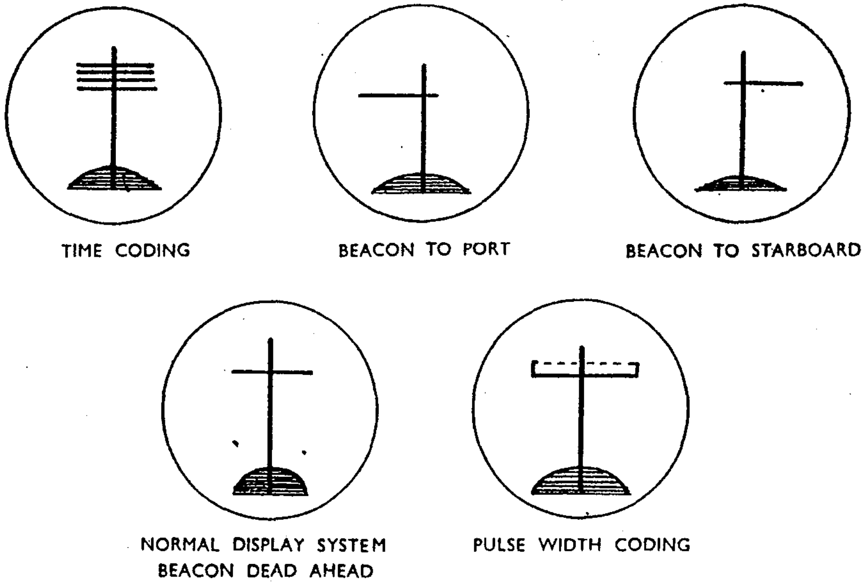
26. With the introduction of centimetre versions of ASV and AI, the problem of providing homing facilities became acute. The earliest equipments to work on wavelengths of about 10 cm. were AI Mk. VII and AI Mk. VIII. The first of these was a pre-production model, and only appeared in relatively small numbers. The second, however, was intended for general introduction into all fighter aircraft, and some form of homing beacon was required to work with it. For this reason an AI Mk. VIII beacon was developed. This beacon was interrogated on the original AI Mk. VIII frequency (3285 Mc/s), and responded on a frequency of 3280 Mc/s. In order to see its response on the AI display it was necessary to detune the receiver. To do this the Mk. VIII equipment was supplied with two local oscillators. One of these local oscillators was used for normal operation, and, when its oscillations were mixed with the incoming 3285 Mc/s signal, they gave an intermediate frequency signal which was fed into the IF stage in the normal way. When the operator wished to home on to a beacon he switched over to the second oscillator, which was so tuned that when its oscillations were mixed with the incoming 3280 Mc/s beacon signal, the beat frequency was the same as before, and could be fed into the same IF stage.

27. Several AI beacons of this type have been produced for use with AI Mk. VIII. No other British equipment uses centimetre beacons, although there are American beacons which work on both the S and the X bands. Certain new British airborne equipments working on 10 cm. and on 3 cm. are also being provided with a second local oscillator, so that they can be used with beacons if required.

28. The H2S and short wave ASV sets, which appeared somewhat later than AI Mk. VIII, do not use centimetre beacons. Instead they are provided with a separate interrogator called *Lucero*, which works on the old ASV Mk. II beacon frequencies. The Lucero equipment is now a separate radar set; it uses the same IF stages and the same display as its parent H2S or ASV. It is an interrogator for beacons and comprises a transmitter and parts of a receiver. The adoption of the principle of indirect interrogation by Lucero had some advantages. It enables the old beacons to be used with the new ASV, and thus saves the expense of installing new centimetre beacons in all Coastal Command aerodromes. It can also be used to interrogate IFF Mk. III which is carried by ships and by other aircraft, and to home on to *Rooster beacons*. *See* para. 70. The newer AI sets also came to be fitted with Lucero; and AI Mk. VIII, besides having its own centimetre beacons, can now home on to the old AI beacons with the help of its Lucero interrogator. Whereas ASV Lucero must use horizontal polarisation, AI Lucero must be vertically polarised. The Americans have also designed interrogators of the Lucero type for use with some of their S band and X band equipments.

29. While these AI and ASV homing beacons were being designed to enable aircraft to home on to their aerodromes in darkness and bad weather, another system was being developed to enable aircraft co-operating with the Army to home on to points where troops and supplies had to be dropped. This system uses a ground beacon called *Eureka*,

and an airborne interrogator, *Rebecca*. One type of Eureka beacon is a light, portable, super-regenerative transponder, which can be dropped by parachute, together with the necessary collapsible aerial system and accumulators. Rebecca is rather similat to a Lucero interrogator, but differs from the normal Lucero in having its own IF strip and its own display tube, so that it is independent of any other equipment. The bearing of the beacon is indicated by a left-right display as shown in fig. 1.


TIME CODING

BEACON TO PORT

BEACON TO STARBOARD

NORMAL DISPLAY SYSTEM BEACON DEAD AHEAD

PULSE WIDTH CODING

Fig. 1.—Beacon display

Coastal Command homing beacons (all horizontally polarised)

30. The first ASV Mk. II beacon used by Coastal Command was the TR.3111. It was a modified IFF set, and has been obsolescent for a considerable time. It was replaced by the TR.3112 which was a super-regenerative beacon. This did not come up to expectations and it is no longer used. A fighter beacon, the TR.3107, which is super-heterodyne, was modified for Coastal working, to replace the TR.3112. Since then other beacons have also been designed.

31. All the beacons mentioned below use *gap coding* to identify themselves. In this form of coding, the beacon response is switched on and off repeatedly, so that instead of seeing a continuous response on the interrogator display, the operator sees a response which appears for a space of time, disappears, appears again, and so on. By varying the duration of consecutive periods of operation the beacon can be made to flash dots and dashes. It is usual to arrange for the response to give a two-letter code in this way. The two morse letters are repeated continually, and there are two such letters given to each beacon, so that the operator can distinguish between different beacons.

32. It is important to note the difference between this form of coding and the pulse-width coding which is used by IFF and which has already been described. In gap coding the response pulses are all of the same width, and the dots and dashes are achieved by varying the length of time that the response persists on the responser display tube. In using pulse-width coding, the transponder is switched on and off in the same way, but this time every " on " period lasts for the same length of time. The coding consists of verying the widths of the pulses. During each period of operation all the pulses radiated are of the same width, but the width in successive operations may differ. The resultant appearance on the responser display tube is a response which appears, disappears, appears again for the same length of time; and so on, but whose width can differ at each successive appearance.

FGRI.5067—*TR*.3107*B*

33. This is the fighter beacon TR.3107 modified for use with Coastal interrogators. It is now the standard type of fixed beacon installed in Coastal Command aerodromes.

Receiver frequency, 176 Mc/s. Transmitter frequency, 177 Mc/s.

FGRI.5066—*TR*.3213

34. This is a modification of the TR.3112 mentioned above. The superregenerative TR.3112 being replaced by a superheterodyne transponder.

Receiver frequency, 176 Mc/s. Transmitter frequency, 177 Mc/s.

TGRI.5302*C*—*TR*.3236

35. This beacon is a converted 24-volt American ABX IFF set. It is battery operated, with a petrol-electric charging set. It is used because Coastal Command require easily transportable beacons for use with mobile aerodromes. It will be replaced by the TR.3558 mentioned in para. 37 when this becomes available.

36. Because it is an IFF Mk. III responder the TR.3236 has only one tuned circuit, and it cannot transmit and receive on different frequencies. Both interrogation and response occur on a frequency of 167 Mc/s.

*FGRI.*5584—*TR.*3558 (Eureka Mk. II)

37. The prefix "FGRI" is a misnomer here. The equipment is easily transportable, and will replace the TGRI.5302C for use with mobile aerodromes. It is a Eureka transponder, specially modified for use by Coastal Command. It will work with a universal aerial system (aerial system, type 350). This aerial array consists of a stack of two half-wave aerials fixed one above the other, and a half-wavelength apart. The aerials can be mounted either horizontally or vertically, with or without reflectors. Aerials of slightly different lengths are supplied with the set, one being for use with Coastal interrogators (176-177 Mc/s), one for Fighter use (193-197 Mc/s), and one for the Rebecca band (214-234 Mc/s).
Receiver frequency, 176 Mc/s. Transmitter frequency, 177 Mc/s.

American YJ beacon

38. A few American YJ beacons are being used on those Coastal Command aerodromes where squadrons are fitted with American ASB equipment and American interrogators. These beacons can operate on two frequency bands, one near to 176 Mc/s and the other near to 515 Mc/s. They use horizontal polarisation.

Fighter homing beacons (all vertically polarised)

39. The following 1·5 metre beacons are used by fighter aircraft. The S-band beacons used with AI Mk. VIII will be mentioned later. All the beacons listed below will operate with the older AI equipment or with AI Lucero. All but one use gap coding like the ASV beacons. The exception is the TR.3107 which was intended to be used with AI Mk. VI, which had a form of "range lock" system, and if the response was switched off, the lock was lost. To prevent this the TR.3107 uses wide and narrow pulses for coding.

*FGRI.*5067—*TR.*3107

40. This is the standard fixed fighter beacon in use at the present time. It is a mains-operated beacon, and uses a superheterodyne receiver. Production has ceased.
Receiver frequency, 193 Mc/s. Transmitter frequency, 196·5 Mc/s.

*TGRI.*5302*F*—*TR.*3236

41. Like the Coastal TGRI.5302 C, this is a converted American ABX set, which is used temporarily on mobile aerodromes until a transportable Eureka beacon becomes available. It both receives and responds on a frequency of 193 Mc/s.

*FGRI.*5585—*TR.*3559 (Eureka Mk. IIF.)

42. This is a fighter version of Eureka Mk. II, to replace the TGRI. 5302. Unlike the Coastal Eureka, it does not use a universal aerial system but has a lightweight aerial.
Receiver frequency, 193 Mc/s. Transmitter frequency, 196·5 Mc/s.

*FGRI.*5596—*TR.*3559 (*Eureka Mk. II* F)

43. This is exactly the same as the FGRI.5585, except that it uses a universal aerial system.
Receiver frequency, 193 Mc/s. Transmitter frequency, 196·5 Mc/s.

Naval Air Arm homing beacons (all horizontally polarised)

44. The homing beacons used by the NAA are also intended to fulfil the function of IFF. They are installed in ships, and are interrogated by aircraft in the usual way, but they are used both for identification and as navigational aids. H.M. ships do carry IFF sets in addition to these beacons, however, to provide identification to other ships and shore stations. The following list includes the principal types of homing beacon used in H.M. ships.

Type 251

45. This was the original beacon transponder used in convoy escort groups and certain other H.M. ships. It is now obsolete. It swept a frequency band of 173 to 179 Mc/s. and responded to ASV Mk. II and to ASV Mk. II N.

Types 251 *M* and 251 *P*

46. The type 251 M has been the standard shipborne beacon up to the present time. It responds to ASV Mks. II and II N and to NAA Lucero. It uses gap-coding, and gives any combination of two morse letters followed by a 10 seconds period of continuous operation. The type 251 P is a modification of the 251 M, and it functions in the same way.

Type 953

47. The type 953 beacon is a new model adapted from type 950 IFF transponder, and is described later.

The YJ beacon

48. The YJ beacon mentioned in describing Coastal Command beacons, is also used on H.M. ships.

Type 951

49. This is a portable transponder which is fitted in certain ships. It is similar to the Type 953 in operation.

Modified American ABK

50. Modified ABK equipment is being installed in ships for the use of night fighters. It is used principally in Algerian waters. The programme corresponds to those of Coastal Command and Fighter Command, both of whom use this modified IFF as a beacon.
Receiver frequency, 193 Mc/s. Transmitter frequency 196·5 Mc/s.

Eureka in ships

51. It has been suggested that Eureka beacons should be installed in ships for use with Rebecca III N and IV. They offer a number of advantages, amongst which is the important fact that they will work on the Rebecca-Eureka band and will not, therefore, trigger IFF sets. If ordinary NAA beacons are used, their frequency is in the centre of the IFF band, and the aircraft Rebecca equipment must be tuned to this frequency, so that IFF sets are triggered both by the Rebecca interrogating pulses and by the beacon responses.

Eureka beacons (usually vertically polarised)

52. The following list includes most of the Eureka beacons used for normal Rebecca-Eureka operation. It does not contain any account of Eureka sets which have been modified for special purposes, such as those mentioned above which are used by fighters and coastal aircraft for homing.

53. The first type of Eureka, Eureka Mk. I, was used with Rebecca Mk. I. Both these equipments are now obsolete. Eureka Mk. II is the standard version which is used at the present time. It works on the Rebecca-Eureka band, which extends from 214 Mc/s to 234 Mc/s. Its receiver and its transmitter can be set independently to any two of the following frequencies :—

A	B	C	D	E
214 Mc/s	219 Mc/s	224 Mc/s	229 Mc/s	234 Mc/s

The Rebecca interrogator with which it operates can also be set to two of these frequencies in the same way.

54. Eureka Mk. III is a lightweight equipment which uses miniature components throughout its construction. It usually operates in the same way and on the same frequency as Eureka Mk. II.

55. Special types of Eureka Mks. II and III have been developed for special purposes, some of these versions operate outside the normal Eureka frequency band, and have special aerial systems fitted. Normally, however, Eureka sets operate on any two of the five frequencies given above, and they use vertical polarisation. They are always super-regenerative in their action. Eureka beacons are usually width-coded. The response can often be keyed.

TGRI.5666—TR.3174 (Eureka II)

56. This Eureka Mk. II beacon can be either mains or battery operated. It is fitted with the universal aerial system, type 350. Its transmitter and its receiver can each be set independently to one of the five frequencies of the Rebecca-Eureka band.

MGRI.5591—TR.3529 (Eureka-H)

57. This is a mobile ground beacon for use with Rebecca-H. It is installed in a 15 cwt. vehicle on which the aerial array is mounted. It works on the standard frequencies, as the TR.3174.

TGRI.5509—TR.3174 (Eureka Mk. II)

58. This beacon is similar to the TGRI.5509, but is fitted with a lighter aerial system to facilitate transportation. It is used by airborne troops, being more robust than the ultra lightweight Mk. III B which is specially designed for paratroops, and it can be employed for purposes which may involve rough handling. It works on the standard frequencies.

TGRI.5527—TR.3514 (Eureka Mk. III A)

59. This is an ultra-lightweight beacon working on the standard frequencies.

TGRI.5527—TR.3563 or TR.3593 (Eureka Mk. III B)

60. The TR.3563 is an ultra-lightweight Eureka designed for special purposes, including the landing of airborne troops. It is supplied with a lightweight aerial, and the whole equipment, including accumulators and power supplied, packs into a small bag.
Receiver frequency, 213·5 Mc/s. Transmitter frequency, 216·5 Mc/s.

61. The TR.3593 is mentioned again below. It can be fitted with a talking attachment, although when used as a Eureka III B this attachment is not provided and the set works in exactly the same way as the TR.3563. The frequencies are also the same.

TGRI.5643—TR.3593 (Eureka Mk. III T)

62. The TR.3593 is a newly-designed ultra-lightweight Eureka, which, when it is used as a Mk. III T set, is fitted with a talking attachment. The Eureka fitted with this attachment, with the help of a corresponding talking attachment which is fitted into the Rebecca in the aircraft, can be used by the Eureka operator to communicate orally with the pilot of the aircraft. To do this the pulse recurrence frequency of the Rebecca equipment is increased to 5 kc/s. The Rebecca talking attachment then modulates the pulse recurrence frequency by ± 1 kc/s as the pilot speaks, so that the rate of change of p.r.f. corresponds to the voice frequency. The Eureka talking attachment feeds the receiver signal into an integrating circuit, filters out the 5 kc/s carrier frequency, and supplies to the tele-

phone headphones a current whose fluctuations correspond to those of the pilot's voice. When the Eureka operator speaks into his microphone, the talking attachment modulates the pulse length of the Eureka response, so that the rate of change of pulse length corresponds to the speech frequency. The Rebecca talking attachment translates this back into speech at the other end. The Rebecca used with talking Eureka is Rebecca III T. The talking Rebecca-Eureka system works on two spot frequencies :—
Interrogation frequency, 213·5 Mc/s ; Response frequency, 216·5 Mc/s.

American Eureka Mk. III C—AN/PPN 1 *and* 2

63. There are two American Eureka equipments. Both are miniature, and both work on the standard Rebecca-Eureka frequencies. The AN/PPN-1 is now in service. The AN/PPN-2 embodies some small improvements.

S-Band beacons for use with AI Mk. VIII (vertically polarised)

64. The following beacons have been designed for direct interrogation by AI Mk. VIII. The way in which they operate has already been described briefly. A particular point of interest is the coding system of this type of beacon. On receiving a single interrogating pulse, the beacon can respond not once but five times. The first response pulse occurs immediately on receipt of the interrogation ; the second follows automatically after a time delay of about 21·8 microseconds, the third follows after twice this time delay, the fourth after three times the delay, and the fifth after four times the delay. 21·8 microseconds is the time required for electro-magnetic waves to travel a double journey of about 2 miles, so that the response appears on the AI display tube as a series of 5 echoes, spaced about 2 miles apart. The position of the first of these echoes gives the range of the beacon. The first response always appears, but the other four can each be switched on or off independently, and it is possible to make the beacon transmit any combination of them. They are switched automatically, and any one of them can appear in the following way :—

5 seconds on and 5 seconds off
5 „ „ „ 10 „ „
5 „ „ „ 20 „ „
Permanently on
„ off.

*MGRI.*5518—*TR.*3506

65. This is a superheterodyne mains-operated beacon, for use with AI Mk. VIII, and is used at the present time. Like all AI Mk. VIII beacons, it uses vertically-polarised waves, its aerial systems consisting of two spun copper cones placed apex to apex, with a small gap between the two apexes in which the vertical aerial is mounted. The system radiates equally in all azimuthal directions, and most of the radiation is concentrated at angles of elevation less than 22½ deg. The whole installation is mobile.
Receiver frequency, 3285 Mc/s. Transmitter frequency, 3280 Mc/s.

*FGRI.*5600—*TR.*3506

66. The FGRI.5600 uses the same transponder as the MGRI.5518, but it is a fixed installation.
Receiver frequency, 3285 to 3315 Mc/s. Transmitter frequency, 3280 Mc/s.

American S-band homing beacons (horizontally polarised)

67. Beacons have been developed in America for use with American S-band equipments. They are known as BGS beacons. The *BGS beacons—AN/CPN* 3 *and* 8 are horizontally-polarised homing beacons designed to work with American 10-cm. equipments of the AI, ASV and H2S types. The AN/CPN3 is an early version, and the AN/CPN 8 is the main production model which embodies some small improvements.
Receiver frequency, 3270 to 3330 Mc/s. Transmitter frequency, 3256 Mc/s.

American X-band homing beacons

68. There are also American beacons, BGX beacons, working on the X-band. They are horizontally polarised, and are used with American 3-cm. equipments.

69. The AN/CPN-6 is a homing beacon for use with 3-cm. airborne equipments.
Receiver frequency, 9320 Mc/s. Transmitter frequency, 9310 Mc/s.

Special homing beacons

70. Special beacons are used by the R.A.F. and the NAA to fulfil specific operational requirements. Perhaps the most important of these is the Rooster beacon. Certain aircraft of Coastal Command and the Naval Air Arm, which are engaged in searching for enemy submarines and surface craft, may wish to call in other aircraft when they sight an enemy vessel. For this purpose they carry a *Rooster beacon*, which is a modified IFF set, tuned to respond on a fixed frequency of 176 Mc/s, so that it will respond to ASV Mk. II and to Coastal Command and NAA Lucero. IFF Mk. III G(R) sets are designed to operate either as ordinary airborne IFF transponders or as Rooster beacons, and are now used for this purpose so that the aircraft will not have to carry separate IFF and beacon equipments.

71. Some Naval Air Arm Avengers and Barracudas are fitted with Eureka, so that fighters and fighter bombers can home on to them with Rebecca. The reason for this is that fighters have not sufficient range to carry out standing patrols to locate enemy surface craft and submarines, so that the longer range Avengers and Barracudas carry out the reconnaissance work, and the fighters are able to home on to them when required. By keying the Eureka, the crew of the reconnaissance craft can speak to the pilots of the fighters. This use of Eureka corresponds closely to that of a Rooster beacon.

BABS Mk. I beacons

72. The general principle underlying the operation of BABS beacons has already been described. The beacon is situated at the farther end of the runway, so that the aircraft approaches it when landing. The receiving aerial array of the BABS is mounted so that its line-of-shoot lies along the runway. There are two transmitting aerials, whose lines-of-shoot are inclined at equal small angles on either side of the runway. The older BABS beacons, which are still in general use, respond for about 1⅓ seconds on one of these aerials and for about one-sixth of a second on the other, changing over at the rate of approximately 30 or 40 cycles per minute. The beacon is interrogated by ASV Mk. II, AI Mk. IV, V or VI, or by Lucero. Its responses are in the form of fairly wide pulses. If an aircraft is approaching the airfield from the correct direction it receives equal responses from the two transmitting aerials, and the navigator sees a steady response on the display tube. If, however, the aircraft is approaching from a slightly wrong direction the signals received from the two aerials are unequal and the echo on the display tube changes in amplitude as the aerials are switched. The navigator can tell whether he is to the port or to the starboard of the BABS beam by noting whether the length of the echo increases for a short time and falls for a longer time or *vice versa*, and can therefore correct his course. From the ratio of the dot-and-dash signals the observer determines in what sector the aircraft is flying. The following table and fig. 2 shows how this may be done :—

Ratio	*Sector*	*Bearing of sector relative to runway*
Steady (1 : 1)	Along the runway (Equi-signal zone)	0 deg. — ½ deg.
4 : 3	Dots or Dashes 1	½ deg. — 2 deg.
4 : 2	Dots or Dashes 2	2 deg. — 5 deg.
4 : 1	Dots or Dashes 3	5 deg. — 12½ deg.
Greater than 4 : 1	Dots or Dashes 4	12½ deg. — 40 deg.

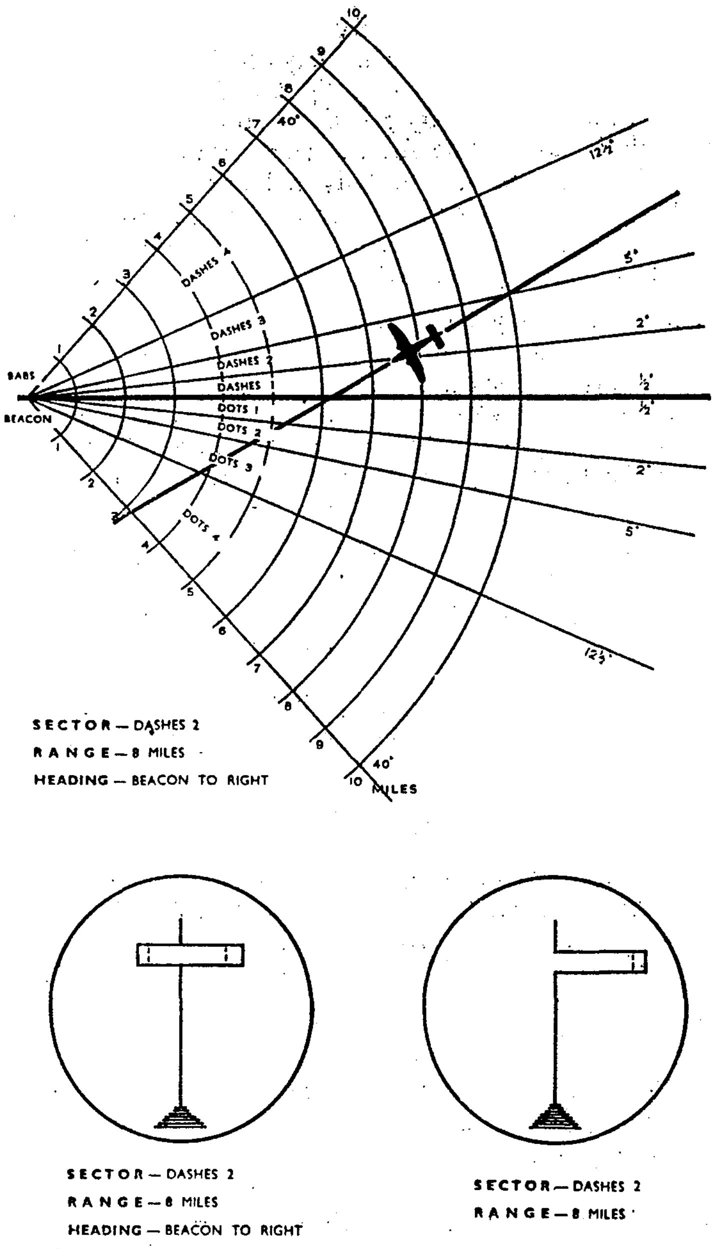


Fig. 2.—BABS Mk. I display

73. There are a number of BABS beacons of this type in use at the present time. The 1·5 metre ASV and AI sets are now becoming obsolete, so that these BABS are usually interrogated by Lucero. It is important to note, however, that fighter BABS is interrogated by fighter Lucero which is vertically polarised, so that the beacon must also use vertical polarisation, while for the same reason Coastal and Naval Air Arm BABS must be horizontally polarised. Bomber Command BABS is interrogated by a bomber version of Lucero which works on a frequency in the Rebecca band, and is used in conjunction with H2S equipment. It is vertically polarised.

74. Generally speaking BABS transponders receive and respond on different frequencies just as do homing beacons. Coastal, Fighter and NAA BABS usually receive on the same frequency as the homing beacons used by their respective Commands, because they are interrogated by the same airborne equipment. They re-transmit on a different frequency from the corresponding homing beacon, however, in order to prevent confusion.

75. The range of BABS is limited to be approximately 20 miles to avoid interference between neighbouring aerodromes, much less than the range of homing beacons. When an aircraft has approached to within a few miles of an aerodrome by using the aerodrome homing beacon, the navigator switches his interrogator over to BABS. In doing this he must detune his receiver to the BABS response frequency.

FGRI-5260 — TR-3146 (BABS Mk. I C — ASV/BA)

76. This is a Coastal Command version of BABS, and is a mains-operated airfield installation. It is horizontally polarised for use with ASV Mk. II and ASV Lucero.

Receiver frequency 176 Mc/s   Transmitter frequency 173 Mc/s

FGRI-5115 — TR.3146 (BABS Mk. I C — ASV/BA)

77. This is the same transponder as before fitted into a different installation for use in flying-boat bases. The working frequencies are the same as before.

FGRI.5259 — TR.3137 (BABS Mk. IF *— AI/BA)*

78. The TR.3137 is the fighter version of the BABS transponder. It is a fixed installation, mains-operated, and is in use on all fighter aerodromes. It is vertically polarised.

Receiver frequency 193 Mc/s   Transmitter frequency 190·5 Mc/s

Type 257 *(BABS Mk. I for use on aircraft carriers)*

79. The type 257 Naval equipment is used on aircraft carriers and on Naval aerodromes. It is similar to ASV/BA, and is used with ASV Mk. IIN or with ASV Lucero. It is horizontally polarised.

Receiver frequency 176 Mc/s   Transmitter frequency 173 Mc/s

BABS Mk. II beacons

80. There are certain inaccuracies inherent in the design of the present BABS system. They arise primarily from faults in the aerial system, and a new type of aerial is designed to eliminate them.

81. One of the principal errors occurring in the BABS Mk. I system is that the side lobes of the aerial radiation patterns give rise to false equi-signal lines. It can only be effectively cured by using radiators which give polar diagrams free or almost free of side lobes, and with the Yagi and corner types of aerial used in BABS Mk. I it is difficult to accomplish this.

82. Another source of error in the present aerial systems is the mismatching of arrays. If the two transmitting aerials are not equally matched into their respective transmission lines they will not radiate equal power. This will cause the beacon to squint; the locus of points of equal signal strength will no longer be the line bisecting the angle between the lines of shoot of the two aerials. Mismatches inevitably occur in any aerial system in practice, and it is almost impossible to ensure that both transmitting arrays radiate equally. Attenuation in one of the feeders would also lead to the same result.

83. Other inaccuracies arise owing to cross-polarisation effects. Suppose, for example, that the beacon is vertically polarised. Metal frameworks and wires in the vicinity of its transmitting aerial will inevitably give rise to horizontally-polarised radiation, and just as the two transmitting aerials have overlapping polar diagrams so far as their normal vertically-polarised radiation is concerned, each will also have associated with it a polar diagram due to horizontally-polarised waves. These horizontally-polarised radiation patterns are due to random scattering of the electromagnetic waves, and will not in general be similar for the two aerials, nor will their equi-signal direction correspond to that for the true vertically-polarised patterns. An aircraft attempting to land with the aid of the BABS will use a vertically-polarised interrogator. Whenever the pilot banks, however, the interrogator receiving aerials will pick-up some of the horizontally-polarised radiation from the beacon. Metal struts and wires in the aircraft will also enable the interrogator to pick up horizontally-polarised waves, even flying on an even keel. This, of course, may lead to serious error.

84. In the new BABS Mk. II, the mismatch problem is overcome by using a special resonant-cavity radiator. The beacon transmitter feeds into a resonant cavity consisting of a large rectangular box. Two exactly similar half-wave slots are cut opposite to one another in the sides of the box. At the centre point of each of the slots there is a relay which, when closed, can short out the slot and prevent it from passing

radiation. If both relays were left open, both slots would radiate equal signals. In practice, however, the relays are closed alternately so that each slot transmits in turn. Behind the box is a corner reflector, which is arranged to give a suitable radiation pattern from each slot.

85. The advantage of this arrangement is that any mismatches or attenuation occurring in the feeder system between the transmitter and the aerial are exactly similar for both transmitting aerials. The only factor which could cause a difference between the powers radiated from the two slots would be lack of symmetry in the system. Provided that the two slots are identical, and are in identical positions relative to the corner reflector and to other conductors, the radiation pattern must be the same for each. Cross-polarisation effects are cut down to a minimum by using a cavity of such dimensions that it will not support vertical modes of vibration, by reducing the number of metal supports and cross members as far as possible, by designing the corner reflector to give as much electrical shielding as possible, and by making the whole arrangement perfectly symmetrical so that what cross polarisation there is will have the same effect for both aerials.

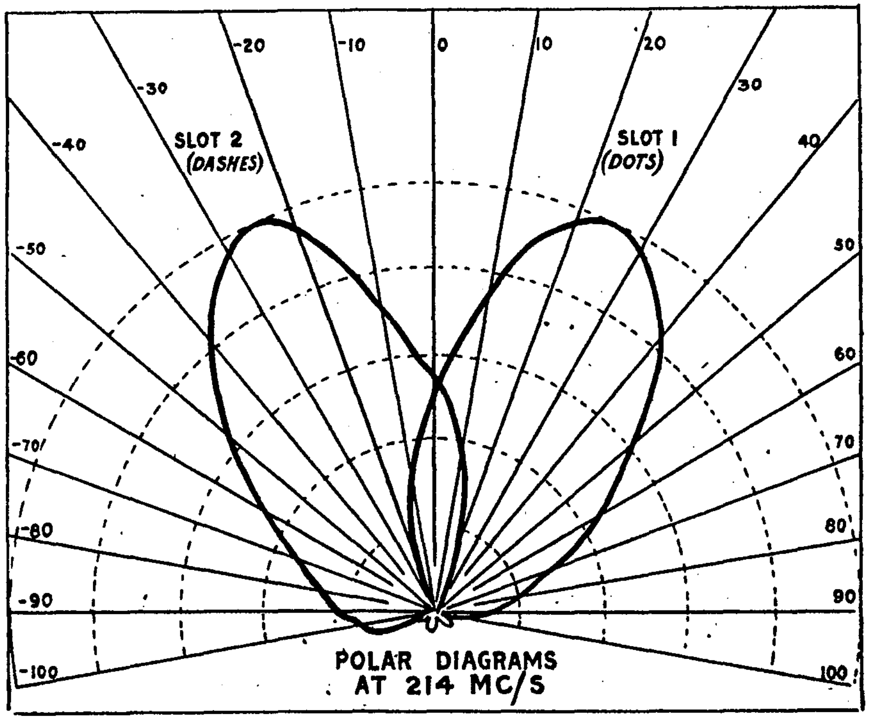


Fig. 3.—BABS polar diagram

86. The same slots are used both for transmission and for reception and the system is almost entirely free from side lobes, so that there are no false equi-signal lines within 150 deg. of the correct direction. (Fig. 3).

87. In the BABS Mk. II the system of display is also changed. The slotted aerials are switched more quickly than the aerials of the old BABS, and they operate for equal intervals of time. There are ten switching cycles per second, so that each aerial transmits in turn for one-twentieth of a second. One aerial transmits narrow pulses and the other transmits wide pulses, and both pulses appear together on the interrogator display tube, *see* fig. 4. When the aircraft is making the correct approach, both these pulses have the same amplitude. If, however, the aircraft is to one side or the other of the BABS beacon, one of the pulses appears longer than the other. It is claimed that this display makes it easier for the navigator to judge whether he is making the correct approach. The accuracy is said to be between ½ deg. and ¾ deg. in azimuth. The same system of sectors is used as with BABS Mk. I.

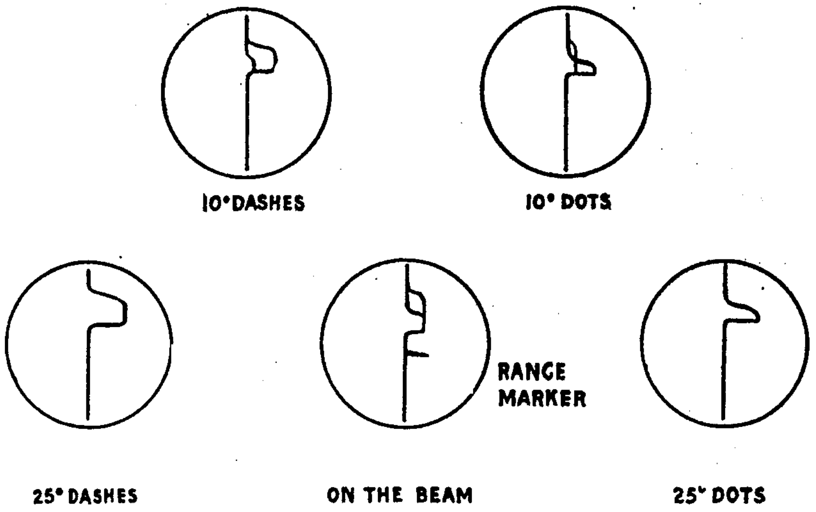


Fig. 4.—BABS Mk. II display

FGRI. 5644—*TR.*3567 (*Lucero*/BA)

88. This is the Bomber Command version of BABS which is about to go into production. It uses vertical polarisation (which involves horizontal slots) and will operate with Bomber Command Lucero. It works on the Rebecca band, and is suitable for all aircraft which carry interrogators on the Rebecca/Eureka frequency. It is a fixed installation, and can be either mains- or battery-operated. Its transmitter and its receiver can each be independently tuned to any one of the five Rebecca standard frequencies.

MGRI.5577 — TR.3567 (BABS Mk. IIM)

89. This is a mobile type of Lucero/BA. It will be fitted into a DRLS type van. It is similar in operation to the FGRI.5644.

MGRI.5586 (BABS Mk. II FM)

90. This is another version of BABS Mk. II, vertically polarised.

Receiver frequency 193 Mc/s   Transmitter frequency 190·5 Mc/s

MGRI.5587 (BABS Mk. II CM)

91. The MGRI.5587 is a Coastal version of BABS Mk. II. It is horizontally polarised, so that there is some modification of the aerial systems. The slots in the resonant cavity must be cut vertically.

Receiver frequency 176 Mc/s   Transmitter frequency 173 Mc/s

Glide-path BABS

92. A new type of BABS beacon is in development; its function is to enable an aircraft to approach an aerodrome in conditions of poor visibility along the correct glide path—that is, to come down at an angle of inclination of about 2½ deg. to the horizontal along a path which will enable the pilot to touch down close to the near end of the runway. This beacon receives interrogating pulses from a Lucero equipment working on a frequency of 214 Mc/s, and re-transmits on a frequency of 515 Mc/s. It requires a small extra receiving unit attached to the Lucero, to receive these higher frequency responses.

93. The glide-path beacon uses two transmitting aerial systems, situated at different heights above the ground. The transmitter is switched from one to the other, so that the aircraft responser receives pulses from each in turn, and there are 20 switching cycles per second as in the BABS Mk. II. Owing to ground reflection effects, the radiation patterns of these two transmitting aerials consist of the usual lobes and gaps, and their heights are arranged so that equal signals are received from both at an angle of elevation of about 2½ deg. It is necessary, of course, to use horizontally-polarised waves for this purpose, to ensure that the ground reflection conditions are independent of the type of surface from which the reflection takes place, and that the vertical polar diagrams of the two aerials will be unaffected if the equipment is moved from one flat site to another. The radiating aerial system consists of two vertical slots in a wave guide. The transmitter output is switched continuously from one of these slots to the other.

94. The glide-path BABS will be used at the near end of the runway, that is the end from which the aircraft approaches, while the ordinary BABS will be at the far end. The higher and lower aerials of the glide path equipment will transmit wide and narrow pulses respectively, so that the display will be similar to that for the new BABS. The two equipments will be used together, and their two responses shown on the same display tube. Because of the smaller range of the glide-path transponder, its response will appear on the display before the response of the ordinary BABS. The navigator can thus control both the azimuthal direction and the glide angle of approach by watching the one display and passing the necessary directions to the pilot.

Lucero interrogators

95. Lucero interrogators are used with most British S-band and X-band radar equipments. There have been three marks of Lucero, and there is in addition a new miniature type which is under development. The situation is complicated, however, by the fact that each radar device requires a Lucero of its own which differs from that of any other radar device, so that there are a number of models of each mark. The reasons for this are:—

1. Different radar equipments require Lucero equipments of different frequencies. Thus Lucero used with ASV must interrogate on 176 Mc/s and receive on 177 Mc/s. Lucero used with AI must transmit on 193 Mc/s, and receive on 196·5 Mc/s, and so on.
2. Lucero uses the IF stages of the various equipments with which it is used, and different S- and X-band radar equipments have different IF frequencies.

Thus the IF frequency of H2S Mk. II is	13·5 Mc/s
Thus the IF frequency of H2S Mk. III is	45 Mc/s
Thus the IF frequency of ASV Mk III is	13·5 Mc/s
Thus the IF frequency of later marks of ASV is	45 Mc/s
Thus the IF frequency of AI Mk. VIII is	30 Mc/s
Thus the IF frequency of AI Mk. IX is	45 Mc/s

96. The Lucero Mk. I is now obsolete and the equipments at present in service are all variations of Lucero Mk. II. Lucero Mk. III is now in service with the NAA. The various models of Lucero Mk. II are included in the following list. Generally speaking, except in the case of Bomber Command aircraft which do not use homing beacons, these Lucero sets are capable of interrogating either homing or BABS beacons.

Lucero Mark II and III equipments

TR Number	*Command*	*Equipment with which used*	*Frequencies Mc/s Tx*	*Rx*	*IF Freq. (Mc/s)*	*Remarks*
TR.3160 (Lucero II)	Bomber Coastal	H2S Mk. II ASV Mk. III	176	177 173	13·5	
TR.3566 (Lucero II)	Bomber Coastal	H2S Mk. III ASV Mk. VI and VII	176 Two between 214 & 234	177 173 Three between 214 & 234	45	Particularly for use with Bomber aircraft to give beacon and BABS on Eureka frequencies
TR.3549 (Lucero II)	Fighter Command (can be used with Coastal aircraft)	AI Mk. VIII	176 183 193	177 173 190·5 196	30	For use in night fighter aircraft
TR.3532 (Lucero II)	Fighter Command	AI Mk. IX	176 183 193	177 173 190·5 190·5 196	45	For use in night fighter aircraft
	Bomber	H2S Mk. II	Four between 214 & 234	Four between 214 & 234	13·5	Under development for bomber aircraft
	Bomber	H2S Mk. III	Four between 214 & 234	Four between 214 & 234	45	Under development for bomber aircraft
TR.3505 (Lucero II)	NAA	ASVX (Barracuda)	176	177 173	45	24-volt model
TR.3507 (Lucero II)	NAA	ASVX (Swordfish)	176 Four between 214 & 234	177 173 Four between 214 & 234	45	12-volt model

97. A miniature Lucero is being developed. It will have its own power pack, IF stages, and display, and so will effectively be similar to a Rebecca equipment. It is, in fact, called Rebecca Mk. V.

Rebecca interrogators

98. The following Rebecca interrogators are used or will be installed in aircraft of the RAF and the NAA.

ARI.5506—TR.3173A (Rebecca Mk. II)

99. This is a standard Rebecca installation, which is usually used in conjunction with Eureka Mk. III. The transmitter and the receiver can be independently tuned to any four of the standard Rebecca frequencies, namely :—

A	B	C	D	E
214 Mc/s	219 Mc/s	234 Mc/s	229 Mc/s	234 Mc/s

The frequency is selected by a remote push-button control.

ARI.5649—AN/APN-2 (Rebecca Mk. II A)

100. ARI.5649 is an American Rebecca. It is a modified SCR-729 A, whose transmitter can operate on any one of the five standard Rebecca frequencies, while the receiver can operate only on two of these frequencies.

ARI.5594—TR.3576 (Rebecca Mk. II B)

101. Rebecca Mk. II B is a modified form of the Mk. II, specially adapted to give homing beacon and BABS facilities on coastal frequencies. It will be used in Transport Command and Coastal Command aircraft, and also for aircraft of the NAA.

Transmitter frequency 176 Mc/s *or* three of the Eureka frequencies.	Receiver frequency 173 or 177 Mc/s or two of the Eureka frequencies.

ARI.5642—(Rebecca Mk. II T)

102. Rebecca Mk. II T is a Mk. II installation with a " talking attachment " to give two-way speech facilities with Eureka Mk. II T. The system has been mentioned in dealing with Eureka. The transmitter and the receiver can each be independently set up to any one of four pre-selected frequencies in the Rebecca-Eureka band.

ARI.5151—TR 3182 or TR.3182 A (Rebecca Mk. III)

103. This Rebecca is a battery-operated type for use in gliders.

ARI.5610 (Rebecca Mk. IV)

104. Rebecca Mk. IV is a miniature version under development for Naval Air Arm aircraft. It is used to interrogate all forms of Eureka IFF Mk. III, Mk. III G(R) and the American equivalents including AN/APX-I and AN/APX-2, the shipborne beacons such as the types 251 M and 251 P and possibly Radar beam approach beacons of the BABS type. The equivalent may also be used as a low power ASV set for detecting surface targets.

105. The question of polarisation is important with this equipment, because it will interrogate both vertically and horizontally polarised transponders. It may be necessary to carry both horizontal and vertical aerials, although this will add slightly to the weight. The following facts must be taken into account in deciding what type of aerials the set must use:—

(1) It interrogates shipborne horizontally polarised homing beacons on a frequency of about 176 Mc/s.
(2) It interrogates vertically polarised IFF sets, probably on the same frequency, 176 Mc/s.
(3) It interrogates vertically polarised Eureka beacons, on a frequency of 214 to 234 Mc/s.
(4) It may interrogate horizontally polarised BABS beacons on a frequency of about 176 Mc/s.
(5) It will probably be used as a low power ASV, in which case it will be better to use horizontal polarisation, as this gives smaller sea returns.

106. If both horizontal and vertical aerials are fitted, the set will use the one or the other according to the transponder with which it is working, viz:

Horizontal aerials for interrogating shipborne homing beacons such as types 251 M and 251 P, BABS beacons, and for normal ASV use.

Vertical aerials for interrogating Eureka and IFF.

The horizontal aerials will be tuned to the ASV Lucero band (172-182 Mc/s) and the vertical aerials to the Eureka band (214-234 Mc/s). The mismatch when the vertical aerials are used to interrogate IFF will have to be tolerated; the only alternative is to use horizontal aerials which will be tuned to the correct frequency and to tolerate the consequent reduction in range due to cross-polarisation.

107. It may be possible to fit horizontal aerials only, and to use cross polarisation for both IFF and Eureka working. One difficulty of this scheme is that it may be difficult to design an aerial system with a sufficiently wide frequency band to work efficiently on both the ASV Lucero frequency and on the Eureka frequencies.

Rebecca Mk. V

108. It has now been decided to dispense with this equipment, and to use Rebecca Mk. IV for the purposes for which it was intended.

Rebecca Mk. VI

109. This equipment is an independent interrogator comprising a Lucero II *plus* an IF amplifier and an improved indicator, so that it is independent of any other radar.

American interrogators equivalent to Rebecca

110. The following American interrogators are used by the RAF and the NAA to fulfil the functions of British Rebecca and Lucero equipments.

SCR-729 A (*Horizontally polarised*)

111. SCR-729 A is an airborne interrogator which can be used either in conjunction with a centimetre radar equipment or independently. The equipments with which it is used are the ASD, ASG, AN/APS-3, AN/APS-4, and the AN/APS-15. Its transmitter frequency is preset to 176 Mc/s, and it can work on either one of two receiving frequencies, 177 Mc/s or 173 Mc/s. These receiving frequencies are selected by a switch; one is for use with homing beacons and the other with BABS. The equipment uses vertically-polarised directional aerials with which it can home on to beacons.

With NAA and Coastal beacons this involves working with cross-polarisation.

SCR-729 *F*

112. This is a modification of the SCR-729 A, which has facilities for interrogating fighter beacons as well as IFF. It is used with AI Mk. X (SCR-720). It can transmit and receive on 183 Mc/s, or alternatively it can transmit on 193 Mc/s and receive on either 190·5 or 196 Mc/s. The aerial system is vertically polarised and is similar to that of the SCR-729 A.

AN/*APX*-2

113. The AN/APX-2 is an equipment which combines the functions of an interrogator and an IFF transponder. It is considered somewhat more fully later, and its IFF operation is described. The interrogator of AN/APX-2 transmits and receives on a frequency band of 160 to 184 Mc/s. Its transmitter and its receiver can be tuned independently to any two frequencies of this band. The set is intended primarily to interrogate IFF Mk. III, and it is supplied with a single vertical aerial for this purpose. The aerial system is not directional, and it cannot be used for homing on to beacons. The equipment can operate independently with its own display tube, but it is usually used with a centimetre radar. It will be used primarily as an IFF interrogator with aircraft carrying American radar equipment.

AN/*APX*-8

114. The AN/APX-8 is an AN/APX-2 transponder fitted with vertical Yagi aerials to enable it to home on to beacons. It also includes, in addition to the AN/APX-2 set, a separate AN/APA-1 radar repeater indicator and an antenna switch unit to switch the two aerials. Like SCR-729 it must use cross-polarisation when interrogating beacons. The AN/APX-8 interrogator works on the same frequency band as the AN/APX-2.

THE IFF Mk. III SYSTEM

The operation of IFF Mk. III

115. The method of direct interrogation employed by the earlier Marks of IFF worked satisfactorily only when the frequencies of the interrogating equipments were confined to fairly narrow limits, and in 1941 it became evident that the increasing range of radar frequencies merited a completely new IFF system, using direct interrogation. The IFF Mk. III equipment was therefore developed.

116. IFF Mk. III sweeps a frequency band of 157 to 187 Mc/s. To do this a tuning control is rotated by an electric motor. The time sweep is 2·5 seconds and the period of flyback of the control, during which the set is suppressed, is 0·3 seconds. Interrogators working on any frequency in the IFF band will therefore receive a response once every 2·8 seconds. IFF Mk. III sets are carried by allied aircraft and also by certain allied warships and merchant vessels, and many types of ground and shipborne radar equipments have interrogators designed to operate with them. Certain aircraft radar sets, particularly AI, are also fitted with Mk. III interrogators. The IFF Band of 157 to 187 Mc/s is usually called the A-band (until recently it was called the I-band) and interrogators used with different equipments are allowed various spot frequencies in this band.

117. IFF Mk. III set is a superregenerative transponder. It has suppression circuits which stop its operation during the operation of Lucero and of other equipments which may be carried in the same aircraft. It also has an AGS circuit which automatically stabilises the gain over the whole frequency band.

118. The older types of IFF necessarily had horizontal aerials because the radar stations with which they operated used horizontal polarisation. Further, the sets had to work over such a wide band that it was not possible to match the aerial systems into the IFF equipment, and this naturally led to considerable inefficiency in operation. This was not very important, however, because the power of the transmitters and the sensitivity of the receivers in the interrogating stations were so high that inferior working of the IFF was unimportant. With the new Mk. III equipment, however, which is designed to operate with interrogators of low power, it is necessary to reduce losses to a minimum and the aerial must be matched carefully into the set. The relatively small frequency band over which the Mk. III sets operate makes this possible. Vertical polarisation was chosen for the new system, principally because it enables the airborne transponder to respond to interrogation from any direction. It also gives rather better coverage. With ground interrogators where reflection takes place from the land, the Brewster angle effect gives partial gap-filling in the polar diagram, while with interrogators where reflection takes place from the sea, although the Brewster angle is very small at the frequency of Mk. III equipment, and the effect is not marked, it gives a greater amplitude than horizontal polarisation along the surface of the sea, and is therefore useful for ship-to-ship interrogation.

119. The airborne IFF Mk. III sets are provided with vertical quarter-wave aerials which protrude from the fuselage of the aircraft, and which are tuned to the mid-frequency of the A-band. It is used for both reception and transmission. Ground interrogators often have beamed arrays which are mounted on the same turntable as the aerials of the parent radar, so that they always look in the same direction as the main equipment. These beamed aerial systems may be broadside arrays, or Yagi aerials, or they may consist of an aerial mounted in a corner reflector. Some stations, such as CH, use an aerial system with such a broad horizontal polar diagram that no rotation is necessary.

IFF Mk. III interrogators

120. The following list includes the various interrogators used in conjunction with British radar equipments to interrogate IFF, Mk. III, and shows with which radar each interrogator is used. The interrogators are usually locked to their parent radar, and their echoes appear either on a special IFF display tube or a second trace on the main radar display.

Navy, equipments (shipborne)

121. The navy use two interrogators, the type 242 working on 184 Mc/s and the type 243 working on 179 Mc/s.

Name of radar	*Freq. of radar*	*Purpose of radar*	*Type of Intergr.*	*Freq. of Intergr.*	*Remarks*
79,279 and 279 M	39-42 Mc/s	Long range early warning of A/c and ships. Anti-aircraft gunnery ranging	243	179 Mc/s	279 is an improved version of the 79 and has practically replaced it. The 279M is the set modified for single mast operation
281	86-94 Mc/s	Long range warning and short range ranging against aircraft. Range and bearing of surface targets	243	179 Mc/s	The 281 is a later set than the 279 and replaces it in function. The 281M is the set modified for single mast operation
286	214 Mc/s	Warning set for aircraft and surface targets generally used on destroyers	242	184 Mc/s	
290 and 291	214-240 Mc/s	Warning of aircraft and surface targets with L.A. gunnery ranging. General purposes set	242	184 Mc/s	
271, 272 and 273	3,000 Mc/s	Detection of small surface vessels from ships, particularly for anti-submarine warfare	242	184 Mc/s	

Army equipments (ground)

122. The Army use two interrogators : Identification RDF Number 1 and Number 3. These equipments have Yagi aerials, and are used with GL and SLC. They also employ Naval, type 242 interrogators for certain purposes, and with one equipment they use an American type.

Name of radar	*Freq. of radar*	*Purpose of radar*	*Type of Intergr.*	*Freq. of Intergr.*	*Remarks*
GL Mk. II (AA No. 1 Mk. II).	54·5 to 89 Mc/s	Anti-aircraft gun laying	Ident. RDF No. 1	165 Mc/s and 171 Mc/s	
SLC (AA No. 2)	204 Mc/s	Searchlight control	Ident. RDF No. 3	159 Mc/s and 168 Mc/s	
GL Mk. III (AA No. 3 Mk. II)	3,000 Mc/s	Anti-aircraft gun laying	Ident. RDF No. 1	165 Mc/s and 171 Mc/s	In this interrogator the usual Yagi aerials are replaced by vert. half wave aerials
GL Mk. III C (AA No. 4 Mk. I)	130 to 170 Mc/s	Anti-aircraft gun laying	American Intergr. BL3	Any fixed frequency in 157-187 Mc/s band	
Light warning (2 versions AA No. 4 Mk. II and AA No. 4 Mk. III)	176 Mc/s 212 Mc/s	Early warning of aircraft	None 242	184 Mc/s	The Mk. II works on A band frequency so no intergt. is required
GCI (AA No. 5 Mk. I)	209 Mc/s	Control of fighters in conjunction with searchlights	T.3117 R.3118	174 Mc/s	Similar intergt. to that of GCI
CD/CHL (CD No. 1 Mk. I)	200-203 Mc/s	Early working of aircraft and shipping	T.3117 R.3118	162 Mc/s and 174 Mc/s	Similar intergt. to that of CHL
CD No. 1 Mk. II	3,000 Mc/s	Coastal defence-early warning of surface vessels	242	184 Mc/s	
CA No. 2 Mk. I	3,000 Mc/s	Coastal gunnery on surface craft	242	184 Mc/s	
CD No. 1 Mk. III and and IV	3,000 Mc/s	Coastal defence early warning of surface craft	242	184 Mc/s	
AN/TPS-1 AN/TPS-2 AN/TPS-3	1,071 Mc/s 400 Mc/s 600 Mc/s	Light warning sets similar to British LW in function, but US equipments	AN/TPX-1 AN/TPX-2 AN/TPX-3	Spot frequencies in A-band not yet known	

RAF equipment (ground)

123. The RAF usual ground interrogator is the T.3117 transmitter used with the R.3118 receiver. The frequency can be varied over the whole A-band and with different radars it uses different spot frequencies. The type 242 is used with one ground equipment and various airborne radar sets also have their own irregularities.

Name of radar	*Freq. of radar*	*Purpose of radar*	*Type of Intergr.*	*Freq. of Intergr.*	*Remarks*
CH	22·7-29·7 Mc/s 42·5-50·5 Mc/s	Early warning of aircraft approaching coast	T.3117 and R.3118	162 Mc/s and 172 Mc/s	Interrogator aerials not beamed
MRU	42·5-50·5 Mc/s	Early warning of aircraft	T.3117 and R.3118	174 Mc/s	Interrogator aerials not beamed
CHL	200-203 Mc/s	Early warning of aircraft and ships	T.3117 and R.3118	159 Mc/s 165 Mc/s and 174 Mc/s	Beamed arrays for interrogators
CO (overseas stations)	22·7/29·7 Mc/s 42·5-50·5 Mc/s	Early warning of aircraft	T.3117 and R.3118	178 Mc/s	Interrogator aerials not beamed
COL (overseas stations)	200-203	Early warning of aircraft and ships	T.3117 and R.3118	178 Mc/s	Beamed arrays for interrogators
Light warning	176 Mc/s and 212 Mc/s	Early warning of aircraft	None 242	184 Mc/s	No interrogator required with 176 Mc/s. Changing over interrogator aerials to Yagis in 212 Mc/s version which uses type 242
GCI fixed type Mobile type	209 Mc/s 209 Mc/s	Fighter control especially of night fighters	T.3117 and R.3118	162 Mc/s and 174 Mc/s 174 Mc/s only	Beamed interrogator arrays
AMES type 11	500-600 Mc/s	Standby GCI and CHL	T.3117 and R.3118	174 Mc/s	Beamed interrogator arrays
AMES type 16	500-600 Mc/s	Fighter control during offensive sweeps	T.3117 and R.3118	174 Mc/s	Beamed interrogator arrays

IFF Mk. III G AND Mk. III G(R)

124. For certain operations aircraft require other identification facilities in addition to those provided by IFF Mk. III. This is particularly true in the case of fighters operating with GCI stations. IFF Mk. III responds to the GCI interrogator, but this is not sufficient since the response appears only on the IFF display and not with the normal echoes on the PPI tube. It is necessary for the controller to be able to identify echoes appearing on the PPI tube quickly and conclusively, and he must therefore be able to see IFF responses in this tube. The old Mk. II G fulfilled this requirement because it was directly interrogated by the GCI, and if the Mk. III equipment is to work satisfactorily with GCI stations it also must have similar facilities for direct interrogation, in addition to its normal A-band working. For this reason the Mk. III G was developed. This transponder is capable either of sweeping the A-band in the normal way or of responding directly on the frequency of the main GCI equipment.

125. The frequency band allotted to GCI stations is called the G-band, and it extends from 200 to 210 Mc/s. At the present time all GCI stations use a spot frequency of 209 Mc/s although future equipments may use other frequencies within the band. The Mk. III G transponder will respond either to normal interrogators or directly to a GCI station working on any frequency in the G-band. It normally sweeps the A-band in the usual way, but the pilot can, when requested by the GCI Controller, press a button which will temporarily put the set into a state known as *G working*. The set remains in this state for about twenty seconds, during which time it gives direct responses on the GCI frequency and after which it automatically reverts to the normal A-band sweep.

126. While in the condition of G-working, the IFF does not entirely abandon its A-band operation. It continues to sweep the A-band in the usual way, but gives chopped A and G responses, replying alternately on the A-band and on the fixed frequency, usually 209 Mc/s, in the G-band, in such a way that the A-band operation continues for one-tenth of a second and is followed by G-band operation for one-twenty-fifth of a second. Thus, for a period of twenty seconds after the pilot has depressed the G button, the set gives a rapid succession of short responses on the GCI frequency, which appear on the PPI tube of the GCI, and meanwhile it responds in the normal way to A-band interrogation.

127. The G facility requires the inclusion of a second tuned circuit in the transponder. This circuit, the G circuit, is permanently tuned to the frequency of the GCI station with which it is to operate and it will give responses only to interrogation on this preset frequency. During G operation the tuning of the A-band circuit continues its normal frequency sweep and the chopped responses are obtained by switching from the G to the A circuit.

128. The inclusion of this second G circuit in the IFF set enables it, with only slight modification, to be used for another special purpose. The use of Rooster beacons in aircraft has already been mentioned in dealing with homing beacons. It is obviously an economy to use the IFF transponder, which the aircraft carries in any case, as a Rooster beacon, and IFF Mk. III G(R) has been developed for this purpose. The Mk. III G(R) transponder can operate either as an ordinary Mk. III set, as a Mk. III G or as a Rooster beacon. In the latter case the G circuit is used to give continuous responses on a preset frequency in the Rooster band (172 to 182 Mc/s). When operating in the latter way it will usually be interrogated by ASV Mk. II equipment or by Lucero working with Coastal Command or NAA aircraft, so that its preset frequency will be 176 Mc/s. For Rooster operation, the transponder uses the G circuit as it does for normal G operation, but this time the responses are not time shared between the A-band and the fixed frequency operation. The responses on the R-band are continuous. The G-band (200 to 210 Mc/s) and the R-band (172 to 182 Mc/s) are fairly widely separated, and to change the G circuit from G to R operation it is necessary to open the set, and to change a tuning element. Thus it is not possible to change from G to R. operation by using external controls, and the equipment must be set up either for the one or for the other on the ground before a flight. This is no disadvantage, since G operation is required only by fighters, while R working is required only for reconnaissance work and the same aircraft will never require both facilities. When it is set up for G working, the Mk. III G(R) set operates in exactly the same way as the Mk. III described above. When set up for R working it will give either normal A-band sweeping or continuous response on the preset R frequency. Changeover from the A to the R state is effected by a remote switch, the *R switch*. When this switch is depressed the set ceases to give any responses at all to A-band interrogation and goes over entirely to Rooster working until the switch is thrown back into the A position. When operating as a Rooster beacon it is possible to switch the set on and off by means of a morse key and hence to communicate with the homing aircraft.

129. When the Mk. III G(R) transponder is set up for G working, it is possible to switch over from A-band sweep to G response in two ways. The G button can be depressed as in the Mk. III G set, in which case the transponder will automatically revert to A-band working after about 20 seconds, or alternatively the set can be switched into the G state by depressing the R button. In the latter case there will be no automatic

return to normal A-band working, and the set will continue to give chopped responses, shared between the A and G frequencies, until the R switch is thrown back.

130. To sum up, the Mk. III G(R) transponder will perform any of the following functions :—

(1) A-band sweeping from 157 to 187 Mc/s once every 2·8 seconds, when it responds to any Mk. III interrogator.

(2) G working when it gives a chopped response, replying alternately for 1/10 second on the A-band and for one twenty-fifth second on a preset frequency on the G-band. It can be switched on to this state either by depressing the G button, in which case it automatically returns to normal A-band working after 20 seconds, or by depressing the R switch, when it remains in this state indefinitely.

(3) R working, when it responds continuously to a preset frequency on the R-band. It can be switched on to this condition by depressing the R switch and will continue to work on the R-band until switched back to the A-band condition. The responses can be keyed.

The equipment can be set up to work in conditions (1) and (2) or in conditions (1) and (3).

IFF Mk. III G can work in conditions (1) and (2) only.
IFF Mk. III can work in condition (1) only.

131. In the past it has been customary for certain aircraft of Coastal Command and of the Naval Air Arm to carry IFF Mk. II N for use as Rooster. The continuous frequency sweep was stopped and the equipment was set up on a fixed frequency so that it operated as a Rooster beacon only. Certain Mk. III sets have now been modified for this purpose and converted into Mk. III R equipments. They will replace the old Mk. II N and will operate either as ordinary Mk. III IFF or as Rooster beacons. The Mk. III transponder has, of course, only the normal A-band tuned circuit and is not provided with a circuit for G working and in order to change from the A-band to the R-band state it is necessary to stop the sweeping of the A-band at fixed Rooster frequency. The usual Rooster frequency is 176 Mc/s. This is in the A-band so that it is not difficult to make the necessary modification on switching from the A to the R condition, the variable tuning mechanism is brought to rest by a stop whose position can be adjusted to give fixed frequency working on any required spot frequency in the band.

132. Certain Rebecca interrogators used in H.M. ships work on a frequency of 214 Mc/s and require Roosters to respond on this frequency. This has led to the installation of two modified Mk. II N sets in some aircraft; one to respond on 176 Mc/s and the other on 214 Mc/s. A British Mk. III G(R) equipment is modified to perform both these functions. The normal A-band sweep can be stopped as before at 176 Mc/s, while the G circuit is tuned to respond on 214 Mc/s. The set modified in this way therefore becomes a Mk. III (R) with double R facilities.

133. The two types of specially modified sets mentioned are, of course, very specialised, and rather different from the principal types of Mk. III set which are being produced. They are mentioned because they apply particularly to the Naval Air Arm and because they illustrate the way in which modifications, which have been demanded from time to time by special requirements of the different services, have complicated the whole history of the IFF and beacon situation, and have led to so many different types of equipment.

134. Because GCI stations and ASV Mk. II and certain Lucero equipments use horizontal polarisation, horizontal aerials were designed for Mk. III for use when working on the G- or the R-band. These have been abandoned, however, and the equipment now works with cross polarisation. This does not decrease its efficiency very materially; and in any case the extra power of GCI and ASV Mk. II over that of ordinary interrogators more than compensates for the loss entailed.

136. The general details of IFF Mk. III G(R), are summarised in the following list. Marks III and III G only perform part of these functions.

137. *Normal Mark III operation.*

Function	Identification to interrogators working on the A-band
Frequency	Continuous sweeping of the A-band, 157 to 187 Mc/s.
Time of sweep	2·5 seconds with 0·3 second flyback period, giving overall repetition rate of 2·8 seconds.
Peak power output	6 to 8 watts.
Sensitivity	100 microvolts.
Pulse widths	Narrow (N) 6 to 8 microseconds. Wide (W) 17 to 25 microseconds. Very wide (VW) 60 to 100 microseconds. (The latter is used only for distress).
Coding	There are six possible codes :—

1.	N	N	N	N
2.	N	N	N	—
3.	N	—	N	—
4.	N	N	W	W
5.	N	N	W	—
6.	N	—	W	—

Distress is shown by transmitting a succession of very wide pulses.

Aerials	Vertical quarter-wave aerials tuned to 176 Mc/s. It will stand up to 550 MPH.

138. *G operation.*

Function	To respond to GCI stations, working on the fixed GCI frequency on the G-band while normal A-band sweeping continues. The set gives chopped responses, 1/10 second A-band and 1/25 second G-band.
Frequency	On A-band sweeps from 157 to 187 Mc/s every 2·8 seconds. On G-band has fixed frequency between 200 to 210 Mc/s.
Peak power output	6 to 8 watts on both A and G bands.
Sensitivity	100 microvolts.
Pulse widths	A-band—6 to 8 microseconds, 20 to 35 microseconds. 60 to 100 microseconds. G-band—10 to 20 microseconds.
Coding	A-band—as for normal Mk. III operation. G-band—no coding.
Aerials	As for normal Mk. III operation.

139. *R operation.*

Function	To respond as a Rooster beacon to frequencies in the R-band. The set gives a continuous response to interrogation on a preset frequency in this band, and enables other aircraft carrying ASV Mk. II or suitable Lucero and Rebecca to home on to it.
Frequency	Preset frequency in R-band between 172 and 182 Mc/s, usually 176 Mc/s. (For certain Naval uses it may be outside this band, usually on 214 Mc/s.)
Peak power output	6 to 8 watts.
Sensitivity	100 microvolts.
Pulse widths	10 to 20 microseconds.
Coding	None.
Aerials	As for normal Mk. III operation.
Remarks	While on Rooster operation the set gives no normal Mk. III responses. The Rooster response can be keyed to pass messages to the homing aircraft.

British and American version of IFF Mks. III, III G and III G(R) for airborne use

140. Britain and America have collaborated in the development of IFF Mks. III, III G and III G(R) and each country has produced versions of all three. The aim has been to obtain a universal system such that aircraft and ships of either country could identify themselves to the other country's ground stations and ships, and so that airborne IFF sets produced in either country would be interchangeable. The various equipments listed below are not all in Service at the present time, but all are in production. Some equipments work on 24-volt power supplies and some on 12 volts so that two versions of each set are required. In the case of the British sets these versions are given different R numbers.

IFF Mk. III transponders

141. The following list enables the available types to be compared.

British or U.S.	*Mark*	*Type No.*	*Description*
British	III	ARI.5025, comprising R.3067 (12 volt) or R.3090 (24 volt)	IFF Mk. III used by British aircraft
	III	ABK	12-or 24 volts used by U.S. Navy; Mk. III facilities only;
American	III	SCR-595	12-or 24-volt equipments used by U.S. Army. Similar to ABK in all respects
American	III G	SCR-695	12- or 24-volt equipments used by U.S. Army. Mks. III and III G facilities but no Rooster
American-British	III G	R.3598	American SCR-695 modified for reasons to be described later, to fit into British aircraft
British	III G(R)	ARI.5731, comprising R.3120 (12 volt) or R.3121 (24 volt)	Standard British equipment, giving full Mk. III G(R) facilities
American	III G(R)	AN/APX-1	Standard U.S. Army and Navy Mk. III G(R) equipment. 12- and 24-volt versions available
American	III G(R)	AN/APX-2	AN/APX-1 together with interrogator which will interrogate beacons and other IFF; 12-and 24-volt versions available
American	III G(R)	AN/APX-8	AN/APX-2 with directional aerials for interrogator to give homing facilities

The only equipments in this list which deserve special mention are the AN/APX-2 and the AN/APX-8. The former is an ordinary Mk. III G (R) set, giving full G and R facilities, but with an interrogator incorporated

142. The interrogator of AN/APX-2 will work on any frequency between 160 and 184 Mc/s and is used for identifying other aircraft. It usually transmits and receives on the same frequency: for interrogation of IFF Mk. III this is of course necessary. The response can either be displayed on the display tube of the main radar carried in the aircraft, or on a special display tube. The equipment has two similar vertical quarter-wave aerials, one for its normal Mk. III G(R) working, and the other for interrogation. It is possible to dispense with one of these, however, and to use the same aerial for all purposes. Because the aerial system is non-directional it is impossible to use the equipment for homing on to beacons, and a special conversion kit has been produced in America to give homing facilities. This kit includes directional antenna systems and when fitted to the AN/APX-2 it enables the operator to determine the azimuthal bearing of the replying transponder, and so to home on to it. The AN/APX-2 with the conversion kit is called the AN/APX-8. It operates in the same way as a Lucero or Rebecca interrogator.

143. The AN/APX-2 can be used either on its own or in conjunction with another radar equipment of the AI or ASV type. In the former case its interrogator pulses are timed to have a repetition rate of about 100 per second on long range work and about 500 per second on short range work. In the latter case it is locked to the transmitter of the other radar so that they transmit simultaneously, and it employs a counting-down circuit so that its pulses will not have a repetition rate substantially greater than if it worked alone.

144. All types of Mk. III G(R) IFF equipment comprise the following units:—

(1) Main transponder unit: transmitter-receiver complete with power supplies.
(2) Control unit assembly, type 1, comprising two small control units side by side:—
    Control unit, type 89—with six-way selector switch for selecting any one of the six possible codes.
    Control unit, type 90—with on/off switch, and distress switch which gives normal distress signal.
(3) G button.
(4) R switch and morse key for keying Rooster reply.
(5) Plugs, sockets, connectors and switch units for detonating an explosive charge to destroy set in emergency.

145. In the Mk. III G installation there is no morse key, and in the Mk. III installation there is no G button, R switch, or morse key. The original intention was to make British and American installations as nearly as possible identical, so that in any aircraft fitted with any type of IFF Mk. III, III G or III G(R), if the main transponder unit were removed and any other type of transponder substituted in its place, the new set would work satisfactorily in the old installation, using the old original switches, control units and connections. For this reason, the various types of transponder and their associated units were made as nearly as possible identical in size and it was arranged that all use the same plugs, sockets and connectors and all have the same control knobs and switches. The following paragraphs deal with the interchangeability of transponders, and show to what extent this object has been achieved in practice.

Interchangeability of airborne IFF sets

146. Although the various types of British and American IFF transponder are to some extent interchangeable there are several factors which cause difficulty when a transponder is fitted into an installation other than its own. For example, if any type of Mk. III G(R) set is fitted into a Mk. III installation it will not operate as a Mk. III G(R), because the necessary controls for switching on to G and R working will not be present. Conversely, if a Mk. III transponder is fitted into a Mk. III G(R) installation it can operate only as a Mk. III set, as it has no G circuit, and pressing the G switch or the R button will have no effect on its mode of operation.

147. These limitations would be expected, but there are others, which, while not immediately obvious, are equally important. Difficulties arise where a British Mk. III G or Mk. III G(R) transponder is fitted into an American AN/APX-1 installation. This is due to the difference between the control circuits. The American transponders use miniature valves, and can therefore empoly much more elaborate circuits than the British sets which use standard components throughout. Thus, whereas the British Mk. III G(R) transponder has only 14 valves, the AN/APX-1 has 28. When the G button is depressed in the AN/APX-1 equipment, the set is automatically brought back to A-band working after 20 seconds by a fed-back time-constant valve circuit. In the British equipment space limitations prohibit the use of an extra valve for this purpose, and the automatic time delay is supplied by a thermal delay switch. This difference between the two sets leads to complications when one is used in the other's installation. When the AN/APX-1 is used in the British Mk. III G(R) installation it works satisfactorily. When the British Mk. III G(R) set is used in the AN/APX-1 installation, however, when once

switched to G or R working it continues indefinitely in that state and will not return to A-band working until the LT has been switched off. This fault is common to the AN/APX-2, the AN/APX-8 and the SCR-695 installations. It can be cured by replacing the G switch of the American installations by one of the DPDT variety, and by using two more wires which are available in the existing control cables. Another difficulty arises when certain American IFF sets are used in aircraft which carry Lucero.

148. To prevent triggering of the IFF set by the Lucero transmitter it is necessary to suppress it during each operation of the Lucero transmitter. Because the IFF set is a superregenerative transponder, and therefore radiates noise, it is also necessary to suppress it during the time that the Lucero is receiving signals, otherwise the operation of the Lucero would be seriously affected. This second type of suppression must continue over the whole period of Lucero reception, which extends for one or two microseconds after each operation of the transmitter. Thus, it is necessary to feed two suppression pulses from the Lucero to the IFF set :—

(1) A pulse of large amplitude and of a few microseconds duration to suppress the IFF during the time of operation of the Lucero transmitter.

(2) A longer pulse, usually of 1·2 to 1·6 milliseconds duration, to give suppression during the time of transit of the timebase on the Lucero display tube. This pulse need not be of so great an amplitude as the former. The two pulses are fed from the Lucero to the IFF transponder along the same cable.

149. It would appear at first sight that the obvious method of providing the first suppression would be to feed a small portion of the Lucero transmitter pulse to the IFF. Unfortunately, however, the long cable lead between the two sets would cause distortion of this short, steep-sided pulse, and the suppression would be incomplete. The remedy would be to use elaborate input and output circuits in the two equipments, but considerations of size and weight render this impossible. It is, therefore, usual to use a prepulse from the Lucero. Most of the equipments which have a Lucero interrogator, namely, various marks of H2S, ASV and AI, are therefore triggered by a prepulse. It is a square pulse, usually of about 20 microseconds duration, and the pulse which impresses the transmitter is initiated by its trailing edge. Part of the prepulse is also fed to the Lucero, which uses the trailing edge in the same way to trigger its interrogator. Thus, the main Lucero transmitter pulse immediately follows the prepulse. When the latter is fed into the IFF set, its trailing edge is deformed and delayed, so that it extends over the period of Lucero transmission. In this way suppression begins before the Lucero transmission, but extends until the transmission is over.

150. The second longer pulse for noise suppression does not present such difficulty.

151. When certain American equipments are used with Lucero they refuse to accept the two suppression pulses. The AN/APX-1, for example, differentiates the suppression pulses, and whatever width the pulse may have, suppression cannot occur for more than about 70 microseconds. This will be satisfactory with a 20 microsecond prepulse, but the longer noise suppression pulse will not pass, and noise suppression will be incomplete. Furthermore, with AI Mk. VIII which does not use a prepulse, there is a second difficulty. The Lucero used with this AI must manufacture its own prepulse, and it uses a special phantastron circuit for this purpose. The pulse which it produces is of about 300 microseconds duration, and when this is passed to the AN/APX-1 it is quite inadequate, and gives no form of suppression whatever. The AN/APX-1 equipment is being modified for use with Lucero and it is hoped that the defect will be cured.

152. SCR-695 also has the same fault, but a British modification has already cured this. The modified SCR-695 is called R.3598.

153. The difficulty of suppression to Lucero of the AN/APX-1 and SCR-695 also occurs when other interrogators similar to Lucero are used. It happens in particular with the American SCR-729 interrogator.

154. The following tables summarise the facts stated above, and show the limitations imposed on the operation of various types of IFF when used in different installations.

155. The following table shows the degree of interchangeability in installations designed for R.3067 or R.3090.

Set	*Facilities available*	*Supresesion to Lucero, etc.*
R.3067/ R.3090	Normal Mk. III (157-187 Mc/s)	Suppression of noise to Lucero may be complete, i.e. may not last for full duration of Lucero trace
ABK and SCR-595	Normal Mk. III (157-187 Mc/s)	Suppression of radiated noise not complete. This is cured by a modification which is carried out by Squadrons
R.3120/ R.3121	Normal Mk. III—No G facilities (dummy 7-pin plug required with 4 pins short circuited to short out certain connections)	Suppression to noise with Lucero may be incomplete

Set	*Facilities available*	*Suppression to Lucero, etc.*
SCR-695	Normal Mk. III—No G facilities (no dummy plug required)	Set triggered by Lucero and no noise suppression for Lucero
R.3598	Normal Mk. III—as for SCR-695	British modification made to SCR-695 to render noise suppression complete
AN/APX-1	Normal Mk. III as for SCR-695	Triggered by AI Mk. VIII Lucero, i.e. Lucero TR.3549 and TR.3549A. No noise suppression with any type of Lucero

156. The following table shows the interchangeability in British Mk. III GR installation for R.3120, R.3121.

Set	*Facilities available*	*Suppression to Lucero, etc.*
R.3067/ R.3090	Normal Mk. III (157-187 Mc/s)	Suppression of noise to Lucero may be incomplete
ABK and SCR-595	Normal Mk. III (157-187 Mc/s)	Incomplete noise suppression to Lucero cured by modification which is being carried out by Squadrons
R.3120/ R.3121	Full Mk. III and G(R) facilities	Suppression of noise to Lucero may be incomplete
SCR-695	Full Mk. III and G—No Rooster	Set triggered by Lucero and no noise suppression to Lucero
R.3598	Mk. III and G—No Rooster	Modification to SCR-695 to give complete Lucero suppression
AN/APX-1	Full Mk. III and G(R)	Triggered by Lucero TR.3549 and TR.3549A. No noise suppression with any type of Lucero

157. Interchangeability in American installations for SCR-695 is as follows :—

Set	*Facilities available*	*Suppression to Lucero, etc.*
R.3067/ R.3090	Normal Mk. III	Suppression of noise may be incomplete
ABK and SCR-595	Normal Mk. III	Suppression of radiated noise not complete. This will be cured by a modification which is being carried out by Squadrons
R.3120/ R.3121	Normal Mk. III, but G(R) not available owing to differences in control circuits (British thermal delay and American fed back time constant for 20 sec. G switch)	
SCR-695	Mk. III and G—No Rooster	Set triggered by Lucero and no noise suppression
R.3598	Mk. III and G—No Rooster	Modified SCR-695 to give complete Lucero suppression
AN/APX-1	Full Mk. III and G(R)	Triggered by AI Mk. VIII Lucero, and no noise suppression to Lucero of any type

158. Interchangeability in American installations for AN/APX-2 is as follows :—

Set	*Facilities available*	*Suppression to Lucero, etc.*
R.3067/ R.3090	Normal Mk. III (adaptor required)	The AN/APX2 includes an interrogator as well as a transponder. The substitution of other transponders renders the interrogator ineffective, and if another interrogator is substituted the same suppression problems arise as those already enumerated above
ABK and SCR-595	Normal Mk. III (adaptor required)	
R.3120/ R.3121	Normal Mk. III, but G(R) not available owing to difference in control circuits (British thermal delay and American fed back time constant for 20 sec. G switch (adaptor required) sec. G switch (adaptor required)	
SCR-695	Mk. III and G—No Rooster (adaptor required)	
R.3598	Mk. III and G—No Rooster (adaptor required)	
AN/APX-1 and 2	Full Mk. III G(R)	

Naval Mk. III transponders

159. Special models of Naval IFF Mk. III have been produced, primarily for installation in H.M. ships, although they are similar to the airborne types and can be used in aircraft. Generally speaking these Naval transponders are primarily used as beacons, but they have identification as a second function. Some of these sets have already been mentioned in the part of this report which deals with Beacons.

160. *Type* 251. This set was designed for use in certain of H.M. ships. Its function is partly that of identification and partly that of a homing beacon. It sweeps a frequency band of 173 to 179 Mc/s continuously, and will respond to ASV Mk. II and ASV Mk. II N. It has now been replaced by later equipments. It had no coding.

161. *Type* 251 *M*. This is a modified type 251. It receives on a fixed frequency of 176 Mc/s and re-transmits on 177 Mc/s. It is gap-coded, that is it responds with pulses which are all of the same width, but the transmission is switched on and off so that the pulses are radiated in a succession of trains with blank spaces between. A train lasting for a longer time forms a dash, while one of shorter duration is taken as a dot.

162. *Type* 251 *P*. This set is a modification of the type 251 M. Its operation is identical with that of former equipment.

163. *Type* 252. Type 252 is the Naval nomenclature for IFF Mk. II N, details of which have already been given. It responded directly to Naval radar equipment, type 79, 279, 286, 290, 291 and 241. It is now obsolete. It was used in Naval aircraft and in ships. It was horizontally polarised.

164. *Type* 253. This is normal IFF Mk. III and sweeps a frequency band of 157 to 187 Mc/s in the usual way. It is identical with British Mk. III transponder, and is used both in aircraft and ships of the Royal Navy.

165. *Type* 253 *M*. This was a forerunner of the type 253 P which will be described later. It differed principally from this later set in that its responses had to be keyed whereas the 253 P is automatically coded. It is sometimes called the IFF Mk. III M. Attempts were made to use it in aircraft, particularly for Rooster working, but it interfered considerably with other aircraft sets, so the project was abandoned. The type 253 P has now rendered it obsolete.

166. *Type* 253 *P*. This is a new shipborne IFF set which is described later.

LIMITATIONS OF IFF Mk. III AND PROPOSED FUTURE SYSTEMS

167. IFF Mks. III, III G and III G(R) suffer from serious operational limitations. The failings of the Mk. III system as it exists at the present time, and a number of suggested improvements and alternative systems are described in the following paragraphs.

Clutter

168. Such a large number of aircraft and ships now carry some form of IFF Mk. III that the traffic-handling capabilities of the system are no longer adequate, and ground and ship-borne interrogators, during periods of great activity, receive so many responses that the trace of the IFF display tube shows one solid mass of echoes through which it is impossible to recognize any one individually. This appearance of crowded responses on the IFF display is called *clutter*, and it arises from four main causes.

Over-interrogation

169. The chief factor in producing clutter is simple over-interrogation. If a large number of aircraft are operating in one area, and all their transponders are switched on, clutter is the inevitable result; it occurs also on the main radar display tube when the concentration of aircraft in any one area is too high. In certain cases, in fact, IFF clutter is not an important operational limitation. If the normal radar echoes cannot be identified individually, there is little point in worrying about clutter on the IFF tube; a single hostile aircraft which happened to be present among the others could not be seen in any case. This is true when CH and CHL stations are plotting bomber raids leaving and returning to the coast. The IFF clutter can still be troublesome, however, when the concentration of aircraft is not sufficiently great to cause clutter on the main radar. This suggests that there are also other factors which add to the trouble, and although no controlled experiments have been performed to prove this conclusively, it is almost certain that the following factors are contributary.

Mutual triggering

170. It is possible for the response from one IFF set to trigger a second set in its neighbourhood. Because IFF transponders have a bandwidth of some 6 Mc/s this can happen if the two sets are tuned to slightly different frequencies, and it can be shown that if a large number of IFF Mk. III sets are working in one neighbourhood complex mutual triggering effects may occur and a single interrogator can cause multiple response on all frequencies in the A-band.

Triggering by engine noise

171. A transponder can be triggered at random by the engine of the aircraft.

Triggering by CHL

172. There has been evidence recently that IFF sets are being triggered by CHL stations working on a 193 Mc/s. Although this is 6 Mc/s outside the A-band it appears that the bandwidths of the CHL transmitter and the IFF transponder are sufficient to permit overlap.

173. All these factors are probably instrumental in producing clutter. The Operational Research Section of Fighter Command are investigating the whole question, and are hoping to obtain more conclusive experimental evidence. Whatever the causes, however, the problem is so serious that it often renders IFF Mk. III virtually useless, so that the number of aircraft and ships allowed to show IFF had to be seriously reduced.

Methods of overcoming clutter

174. There have been many suggestions of possible methods of overcoming clutter. The following appear to be the most promising :—

Switching of interrogators

175. Interrogators should be switched on only when required, and all interrogators should be fitted with spring-loaded switches which automatically return to the OFF position when released. In this way, each interrogator will work only during occasional periods of a few seconds, and the interrogation will be materially reduced.

176. One attempt has been made to cut down interrogation by automatically switching interrogators. In this method interrogators working on the same frequency are switched on in rotation, so that each one works only for a short period and no two are ever operating together. This certainly reduces clutter, but it involves locking all neighbouring interrogators by land-line to some form of electrical timing equipment, so that its application is limited.

Reduction of repetition rate

177. The interrogator repetition rates should be as low as possible in order to reduce the rate of interrogation of transponders. This is limited by the fact that if the repetition is too low it leads to flicker and insufficient brightness on the display tube.

Reduction of power output of interrogators

178. The power output of interrogators should be as low as possible. This will decrease their ranges, and will therefore reduce the number of interrogators working with any IFF set at any given time. The necessity for adequate IFF ranges clearly limits the extent to which this method can be applied. The Admiralty has already reduced the power output of a number of interrogators, and almost all Naval interrogators now in use have peak powers of less than 100 watts. The power rating of Lucero has been fixed by beacon rather than by IFF requirements. An Optec paper of July, 1944 suggests that some experimental investigation is required to decide whether reduction of Lucero power is possible or desirable.

Reduction of sensitivity and power output of transponders

179. The sensitivity and the power output of transponders should be as low as possible. This will serve the same purpose as reducing the power output of the interrogator. The decreased sensitivity should also lessen the probability of triggering by engine noise.

Beaming of interrogator and transmitter aerials

180. Highly-beamed and continuously-rotating transponder aerial systems should be used. However, it is important to note that the possible extent of beaming is severely restricted; a transponder which continuously sweeps a frequency band must remain in the interrogator beam for a length of time at least equal to the time of frequency sweep if it is to be sure of giving one response. This same restriction is imposed in transponders which give coded responses. The time taken for the beacon to sweep past such a transponder must be at least equal to the time taken for one complete coding cycle. In the case of ground and shipborne interrogators it is clearly possible to tolerate narrower beams if the speed of rotation of the interrogator aerial system is reduced. Other operational requirements, however, make it impracticable to reduce this speed indefinitely. The following table shows what the beam-width of an interrogator aerial system must be in order to obtain one response and four successive responses from a Mk. III IFF set at different speeds of rotation of the aerials.

Speed of rotation of aerials (r.p.m.)	*Beam-width in deg. required to obtain one response*	*Beam-width in deg. required to obtain four consecutive responses*
1	17	68
2	34	136
3	51	204
4	68	272

181. It would be possible to work with narrower beams if the interrogator aerials were not continuously rotated, but were turned by the operator when he wished to look at a particular echo whose indentity was required. The beam could then be held on this echo indefinitely. Many interrogators now in use, however, have their systems mounted on the same framework as those of the main radar, so that stopping the rotation of the interrogator aerial means also stopping that of the main equipment.

182. 8-bay and 12-bay aerial systems have been used with RAF interrogators, and the beaming has probably been carried to its practical limit. CHL and GCI equipments fitted with these highly beamed aerials usually carry them above the normal radar aerial, and have to stop their continuous rotation during interrogation. Army equipments usually have a much wider interrogator beam, whose width is of the order of 50 deg. This is not a great disadvantage, however, because the interrogators have low power output (about 30 watts) and being used with precision radars such as GL, the timebase is necessarily fast and gives good range resolution. The problem is most acute in the case of the LW set which had a slow timebase, and this is now being fitted with a more highly-directional interrogator aerial.

183. Naval interrogators have simple interrogator aerials which give wide beams. The problem of clutter has not been serious with the concentrations of aircraft so far used in Naval operations, but it is most necessary to bear it in mind if greater densities are expected in the future. With the advent of greater concentrations of aircraft it will certainly be necessary to use beamed arrays.

Sippi

184. A technique known as *Sippi* has been developed for artificially narrowing the beam-width of the responsor. This does not reduce the total amount of clutter, because the interrogator can still transmit over a wide azimuthal range, but it does reduce the amount of clutter scan by the particular interrogator. It is very effective, but again necessitates stopping to " look " at the target which is to be identified.

Double interrogation

185. It is possible to introduce a system of double interrogation which would completely cure clutter arising from mutual triggering and from triggering by engine noise and by CHL stations. There are two alternative methods of accomplishing this. The first of these methods involves the use of a double pulse. The interrogator must be modified to transmit two pulses spaced a few microseconds apart. The transponder must be so designed that it will not respond unless interrogated by two such pulses.

186. The second method uses the ordinary single-pulsed interrogation system, but arranges that the transponder will not reply to the interrogation pulse unless it is receiving simultaneously a priming signal on a second chosen frequency. The priming signal may be radiated continuously from the interrogating station, or may consist of a second series of pulses radiated on the priming frequency. This latter alternative is operationally better and more convenient, as it is possible to use the pulses from the parent radar for priming purposes; the interrogator is usually locked to the parent radar in any case, so that the pulses are always coincident. This system of using a transmission on a second frequency to put the transponder into an operational state is called the system of *prime-and-poop.*

187. Both these systems are discussed in paras. 194 to 197, dealing with security problems. Either one could eliminate mutual triggering and triggering by engine noise and by other radar equipments.

Reducing bandwidths

188. It may be desirable to narrow the transponder bandwidths. This should reduce the effect of cross-interrogation and of interrogation by radar equipments, such as CHL, which are just outside the IFF band.

189. The duration of each response clearly depends on the bandwidths of the transponder and the responder, and it will be reduced if these bandwidths are reduced. It is also true that if the response curves of the transponder and responser are not steep sided, the duration of each response will depend very much on the range, being much greater at short ranges. It has been suggested that it would be advantageous to make the response curves as steep-sided as possible in order to make the response duration as nearly as possible independent of the range. The RAF organization known as 60 Group (now 90 Group) have attempted to improve the operational performance of IFF by reducing the responder bandwidth and by steepening the response curve, and have had some success.

Slow build-up display

190. It is easier to deal with clutter operationally if a slow build-up display tube is used.

Signal gating by radar

191. ASE have developed a method of signal-gating, whereby a strobe can be set to the range of any echo on the radar display tube whose identity is required. The interrogator then displays only those IFF returns coincident in range with this echo. The system as it exists displays IFF responses on any azimuth if they are at the correct range, but ASE are investigating the possibility of further confining responses to a small azimuthal sector.

Split interrogation

192. It has been suggested that a new system might be developed whereby the interrogator transmits pairs of pulses, one of each pair being radiated from one of the two halves of a split array. The lines-of-shoot of the two halves of this array would be inclined at a small angle, and the transponder would be so designed that it would respond only if the amplitude of the two pulses which it received were almost equal. The effective beamwidth could then be made as small as required. To put this method into operation would require an entirely new IFF system.

Raster presentation

193. In the case of interrogating equipments where it is possible to display IFF echoes as brightness modulation on an afterglow tube, it may be helpful to give the timebase of the tube a slow vertical sweep, synchronised as nearly as possible with the time of frequency sweep of the IFF transponder. The echoes will then appear on a raster and signals from aircraft at the same range will not usually be superimposed.

Integration

194. It is possible to obtain better range resolution with equipments where the timebase of the display tube is slow, by introducing a range strobe with an interrogator. A portion of the timebase can then be strobed and magnified.

Security aspects

195. There were two serious problems of security that arose in the operational use of IFF during the last war.

(1) The enemy could interrogate IFF Mk. III, and use the responses to detect and identify allied aircraft.

(2) Many of our IFF equipments inevitably fell into enemy hands, and he was able to fit them into his own aircraft and ships to confuse our identification system. With sufficient time and labour he even manufactured copies of our sets himself and used them for this purpose.

196. The second of these problems was considered to be the more important, and it might be expected that the enemy would attempt to compromise our system by carrying British and American IFF sets. IFF Mk. III as it exists at the present time can be both easily interrogated by enemy equipment and also, if captured, used by him to cause confusion. It is, therefore, essential either to develop some new system or to increase the security of the present IFF.

197. Any of the following schemes could be adopted to alleviate the problem of security.

Double-pulse interrogation

198. This method has already been mentioned in dealing with clutter. Its advantage, from a security point of view, is that the enemy would have some difficulty in interrogating our transponders. He would first have to discover that we were using this method of interrogation and then he would have to build suitable double-pulsed interrogators. The system offers no cure for the second security problem.

199. Exponents of this method say that the necessary facilities could be provided by the addition of a small box to the airborne transponder. It would also require modification to all existing interrogators including Lucero, and it would be impossible to interrogate IFF with ASV Mk. II. Another difficulty would also arise from the fact that the interrogator response would be delayed, and to obtain correlation between the radar responses and those from the IFF it would be necessary to modify the existing forms of display.

200. The U.S. Army and Navy have considered the possibility of adopting the system and have modified the ABK and the SCR-695 sets to take double pulses. They are also contemplating modifications to the AN/APX-1 and AN/APX-2 for the same purpose.

The prime-and-poop system

201. A brief statement of the principle underlying the operation of this system has been given. It offers the same security facilities as the double-pulse method, but it is, perhaps, more acceptable. It would not require any modification to the interrogator, as it could use exactly the same interrogating pulses as the Mk. III IFF, while the priming pulses could be supplied by the parent radar. It also has the advantage of causing no range error, so that it would require no modification to the IFF display. This system is used by the type 950 IFF system, which is being developed for Naval use.

Coded responses

202. Neither of the systems so far described offers any security against the possibility of the enemy capturing and using Allied IFF sets. The most satisfactory way of overcoming this system is to give a coded response. The response of the present Mk. III set can be coded, but something far more elaborate than this is required so that the code can be changed from day to day, or even from hour to hour.

203. Transponders can be coded in several ways, but the method which is usually considered the most satisfactory from both a technical and an operational point of view is to use a transponder which gives a sequence of wide and narrow responses in the same way as the Mk. III set, but with a greater number of possible permutations.

The present problem

204. The facts outlined in the foregoing paragraphs show that the two major limitations of IFF technique as it exists at the present time are its low traffic-handling capacity and its lack of security. There are two alternative remedies; one can either patch up the existing Mk. III system, or devise an entirely new method of interrogation. Both these courses have, in fact, been adopted. With existing Mk. III equipment all feasible steps are being taken to reduce the clutter, and Britain is developing new types of IFF Mk. III which will be less easily compromised than the present sets; in America work is being carried out on IFF Mk. V.

205. Any type of IFF can, of course, be compromised, to some extent, and the best that one can expect is that the system shall be as fool-proof as possible, and that if the enemy attempts to use it to his own advantage he will experience the maximum amount of trouble in doing so. Similarly, no system can have infinite traffic handling capacity, and it is only possible to reduce the clutter problem to a minimum. The more secure the system, and the higher its traffic capacity, the greater will be its technical complexity, and the greater, therefore, its weight, the length of time required for its development, and the difficulties involved in its production. In developing any new form of IFF, therefore, it is necessary to strike a balance between these conflicting factors, and to consider the price that must be paid for greater operational efficiency.

206. The various IFF systems being developed are described briefly here. They all incorporate some of the methods which have already been outlined for reducing clutter and for increasing security. Some of these are merely improvements on the present Mk. III system, while one is an elaborate new scheme, considerably more efficient, but requiring long and tedious development.

NEW SYSTEMS

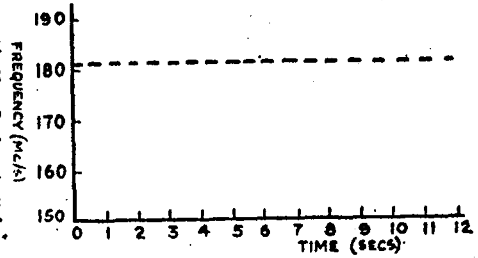
Type 253P

207. The question of security is particularly important to the Navy, and the type 253 P has been developed in Great Britain for use in H.M. ships. It follows the type 253 M which has already been mentioned, and fulfils the functions of that equipment and has in addition some extra facilities. Type 253 M is now obsolescent, and requires no further mention.

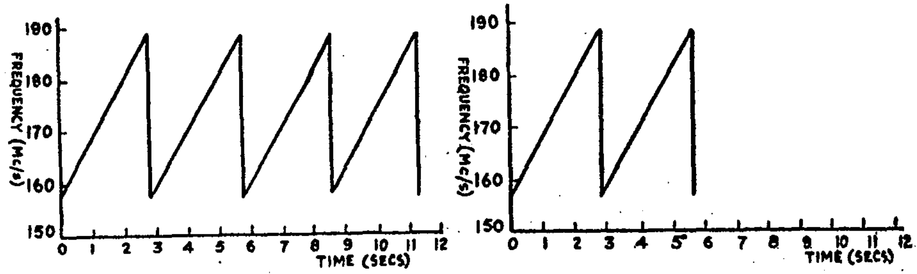
208. Type 253 P differs from the Mk. III IFF (that is, the Naval type 253) in having facilities for giving a coded response on a fixed frequency. It is supplied with a special control unit which has three buttons, the I, A, and B buttons, and each of these selects a particular state of working as follows:—

Button I	When this is depressed the equipment gives ordinary Mk. III operation, and sweeps the A-band from 157 to 187 Mc/s. (*Note*: The name I Button was given before the change of nomenclature, when what is now called the A-band was named the I-band).
Button A	Depressing the A button gives 6 seconds of normal A-band operation followed by 6 seconds of automatically coded response on a fixed frequency. The coded response consists of 9 characters, each lasting for approximately half of a second, with a short blank space between each one during which the transponder is suppressed. Each one of these nine characters consists of a series of either wide or narrow pulses, or is blank, so that the number of possible permutations and combinations is very large. They are usually arranged in the form of two morse letters, which can be changed as often as required.
Button B	This gives chopped responses on the fixed frequency with no A-band operation. The signal received by the responser is, therefore, rather similar to that received by a GCI station when it interrogates the Mk. III G on the G-band. There is no coding.

209. The fixed frequency which the set is to use when on buttons A and B will probably be 184 Mc/s, the frequency of the type 242 interrogator which is used on all H.M. ships and shore stations. The operation of the 253 P on each of the three buttons is shown graphically in fig. 5.



Button B Chopped responses on fixed frequency



Button I A Band sweep

Button A 6 secs. A Band sweep followed by 6 secs. coded response and fixed frequency

Fig. 5.—Operation of 253-P equipment

210. Type 253 P is essentially a shipborne set, and it is proposed to install it in all H.M. ships, and in corvettes, submarines, and certain smaller craft of all those nationalities which may contact the enemy. Neither the 253 P nor any other type of IFF will be fitted into craft employed on local duties in areas where no enemy action is expected.

211. The uses of the various buttons will be as follows :—

Button I	will only be used by ships co-operating with foreign warships on occasions when the use of Button A might cause confusion, or in co-operating with aircraft when it may be desirable to use one of the Mk. III functional codes.
Button A	will be the normal method of operation used by all ships fitted with type 253 P.
Button B	will be used only by ships wishing particularly to distinguish themselves from others, such as a flagship in a night action, or a ship acting as a datum point.

212. An important point in the operation of the type 253 P equipment is that it is possible, when operating on button A, to reduce the power output of the transponder to one-sixteenth of its normal value during the period of A-band sweep. This means that the range of the set on the A-band is reduced theoretically to one-quarter of its normal value, and that aircraft must approach more closely before they can identify the ship with their Lucero or ASV Mk. II equipment. The purpose of this is to reduce the possibility of enemy aircraft detecting ships at great distances by interrogating this IFF equipment.

213. The coding system operates only on button B. The Admiralty have prepared a key memorandum allocating a two-letter morse group to each ship fitted with type 253 P. These groups will be changed each day at 0001 GMT. In this way any other ship or shore station receiving a response from a ship fitted with 253 P transponder will be able to identify it immediately. Some extra security will be gained by knowledge of the ship's movements.

214. If the enemy shows signs of breaking our morse groups, the use of this code will be discontinued, and a new code will be substituted. The first five responses on the fixed frequency will then be used as a security code which will be changed every day, and which will be the same for all ships on any one day. The last three characters will be used as a functional code to describe the type of operation in which the ship is engaged. The sixth character will always be blank, to separate the security and functional codes. IFF Mk. III Q will use this second coding system, and IFF, type 253 P will begin to use it in any case when coding system, and type 253 P will begin to use it in any case when IFF Mk. III Q comes into service.

Type 950

215. Type 950 is under development, and although it will probably not be used, it is to be held in readiness as a standby.

216. Type 950 is designed for fixed-frequency operation only, and it does not sweep the A-band. Its most interesting characteristic is that it uses the prime-and-poop system of interrogation. It is designed to operate with the type 271, 272 or 273 radar together with the type 242 interrogator. It will respond to a pulse on the interrogator frequency only if it receives simultaneously a priming pulse from the parent radar. The interrogator frequency is 184 Mc/s, and the frequency of the types 271, 272 and 273 is 3000 Mc/s, so that the transponder is effectively interrogated simultaneously on both these frequencies. It responds on a frequency of 181 Mc/s

217. The adoption of the prime-and-poop system, together with the principle of responding on yet a third frequency materially increases the security. It is necessary, of course, for the responders of the type 242 interrogators to be detuned to 181 Mc/s in order to receive the responses.

218. Type 950 gives a 9-character code lasting for about 6 seconds in the same way as the type 253 P, but the code is followed by a continuous response lasting for the same length of time. The whole cycle is then repeated. If the set is used operationally the coding will be similar to that of the type 253 P, and will contain either two morse groups or a security code followed by blank and a functional code. The set has no other mode of operation than this, and the only variables are the nine coding characters. It is extremely doubtful whether sets of this type will ever come into operation.

Type 953

219. Type 953 is a modification of the type 950. It is, in fact, the former set working without the prime-and-poop system. It receives interrogator pulses and it re-transmits its responses on two preset frequencies. Its responses and coding will be exactly similar to that of the type 950. It will replace the type 251 M and will be fitted in convoy escort groups, independently routed merchant ships, and H.M. Ships carrying aircraft.

IFF MK. III Q

220. While the Navy are asking for a more secure form of IFF, certain branches of the RAF also require types of IFF set to perform G, Rooster and other special functions, and this led to the suggestion that, as the Mk. III G(R) set has all the necessary circuits to provide many of the

facilities required, it might, with some modification, be suitable for use as a multi-purpose set. Discussions with representatives of the Navy and the RAF resulted in more concrete proposals and in the conception of a new IFF which would have advantages over the type 253 P, which could also be used as Mk. III G(R) set, and which would have other facilities besides. This new transponder became known as IFF Mk. III Q, and the first development model is being produced by Messrs. Ferranti Ltd. It now appears unlikely that Mk. III Q IFF will ever go into service, but it is useful to investigate its possibilities, as some simplified form of this system may be held for particular Naval requirements in the future.

221. Before describing the Mk. III Q transponder it is necessary to consider the requirements of the RAF and the Navy, and to state what facilities this new set must have.

Normal Mk. III

222. All aircraft of the RAF and the NAA require the normal Mk. III facility and must carry an IFF set which sweeps the A-band in the usual way, to identify themselves to Naval, Army and RAF ground stations, to ships and to aircraft.

The G facility

223. Fighter aircraft, particularly night fighters, of the RAF and the NAA require the G facility. In the past the NAA has used ship radars of the GCI type working on a frequency of 179 Mc/s. They recently decided to come into line with the RAF, however, so that for all night fighters the G frequency will be 209 Mc/s.

The R facility

224. Reconnaissance aircraft of Coastal Command and of the NAA require the R facility. Aircraft using Rooster will never require G.

Fighter plotting

225. Fighter Command recently considered a scheme of fighter plotting, whereby fighter aircraft should carry IFF sets tuned to a fixed frequency, and fighter control centres should use some form of IFF interrogators working on this frequency to give the positions of all fighters in their area on a PPI display. Only fighters carrying IFF sets tuned to the fighter plotting frequency would appear on the display, and the system would show less clutter than if the fighters were plotted by a radar equipment such as a GCI which shows ordinary echoes. The scheme was tested by installing specially modified IFF sets in a number of fighter aircraft, and Fighter Command seriously considered adapting it generally. It appears to be falling into disuse at the moment.

Searchlight douse

226. SLC interrogators have not been so efficient as those of many other equipments, and the identification of night fighters by searchlights has been a difficult problem operationally. Many night fighters have been carrying a special modified version of the IFF Mk. II G, usually called the Mk. II D, which could be switched on when the fighters were illuminated by searchlights, and which " squettered " or gave a squegging signal on the SLC interrogator frequency. When the SLC operator receives this type of response he knows that the aircraft which is being illuminated is friendly, and that he must douse the searchlights. Some better method of dousing searchlights is required, and it would be more satisfactory if the normal IFF set carried by the aircraft was capable of performing this function.

Mayday distress

227. When a fighter is being controlled by a GCI station, the GCI controller knows its movements and its position at any time very accurately, and it is an advantage if, in the event of an emergency, he receives the distress signal. In the normal way, of course, the distress is shown on the A-band and not on the GCI frequency. Fighter Command therefore stated a requirement for a new form of distress code, where the broad IFF should be shown on the G frequency. This new type of distress signal is called *Mayday distress.* If a fighter plotting system is used it is also an advantage if Mayday distress is shown on the fighter plotting frequency rather than A-band distress.

IFF for H.M. ships

228. Some type of IFF such as the 253 P is required for H.M. ships. It must have facilities for identification to aircraft and to other ships and shore stations, and must have adequate security.

229. It is possible to give the necessary facilities for all these purposes by modification of the Mk. III G(R) set. The changes and additions required do not involve alterations to the circuit, but only to the control and switching units, and the Mk. III Q, like the Mk. III G(R), has only two tuned circuits, the A-band and G-band circuits. The set, thus modified, is capable of performing any of the following normal functions :—

230. *Normal Mk. III working*, when the set sweeps the A-band in the usual way.

231. *Normal G-band working*, when the transponder chops between the G- and A-bands as in Mk. III G. The two bands are equally time-shared, and the set works for one twenty-fifth of a second in each state.

It is possible to go into G working by pressing either the G button on the R switch; if the first-named is used the set works for 20 seconds or the G-band, and if the latter is used the set functions indefinitely until the R switch is returned.

232. *Normal R-band working*, when the set responds on the fixed frequency in the R-band. This can be keyed in the usual way.

233. *Fighter plotting*, which consists of a continuous response on a fixed frequency, probably 190 Mc/s, time-shared with the A-band as for G working, the set working for 1/25 of a second in each state in turn. The fighter-plotting response is given by the G circuit, and the operation is exactly similar to G operation, the only change being in the G frequency. A transponder can be set up to operate as a Mk. III, III G, or III—fighter-plotting set. On switching from the G to the fighter-plotting state, the tuning of the G circuit is changed from 209 to 190 Mc/s by switching over condensers.

234. *Mayday distress*, which may replace ordinary A-band distress and may appear on the G or on the fighter-plotting frequency. It is only used in fighter aircraft, and will usually be given on the G frequency. If the interrogator is set up for Mayday distress, depressing the distress switch gives a broad response which overrides any other operation that the IFF may have been performing.

235. *Searchlight douse.* This is a continuous response on the frequency of the SLC interrogator which can be made to override any other operation that the set is performing. It will be operated by a push-button, and will probably be produced by the A-band circuit, the A-band sweep being stopped at the correct frequency.

Alternate A-band and fixed-frequency working

236. This is similar to the method of operation of the type 253 P, and is used by the Navy. The set gives two sweeps of the A-band in which there is no coding, and this is followed by a coding cycle lasting for about 6 seconds on a fixed frequency. There are nine coding characters as in the type 253 P, and the first five of these will be used as a security code, the sixth will be blank, and the last three will be used as a functional code. Further details of the coding are given below. The set in this state is capable of performing another function in addition to those of the 253 P. It can, if required, transmit and receive on different frequencies during its period of fixed frequency working. The state involves the sacrifice of G and Rooster facilities. For interrogation and response on two frequencies it must receive on the A-tuned circuit and retransmit on the G, or *vice versa.* The tuning sweep of the A-circuit must be stopped at a pre-determined frequency for this purpose.

Fixed frequency working only

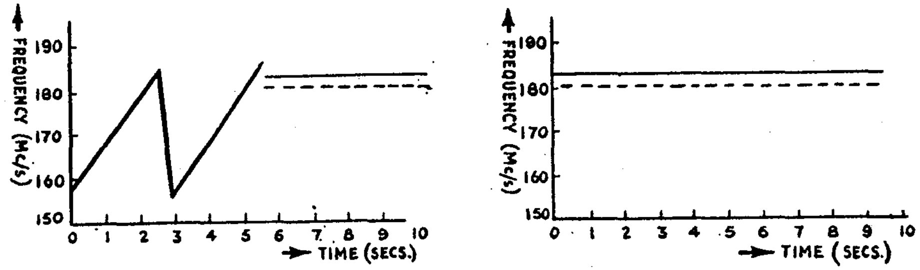
237. This gives a type of operation similar to that of the type 953. The set is interrogated and responds on preset fixed frequencies in the A-band. The two frequencies involved may be the same or different. They can be chosen either for this state or for the previous one anywhere in the following bands:—

Interrogation frequency:—	between 157 and 187 Mc/s.
Response frequency:—	between 172 and 187 Mc/s.

For dual frequency working the A and G fixed circuits must be used again as in para. 236. The response is coded in the usual way. The coding cycle of G characters lasts for about 5 seconds, and is followed by a 5-second period of continuous response.

Coding

238. The operation described in paras. 236 and 237 is required by H.M. ships and aircraft of the NAA, although it may be used also by Coastal Command aircraft operating with ships. The two operations are shown graphically in fig. 6.



5 secs. A-band sweep followed by 5 secs. coded response on two frequencies

5 secs. continuous working on two frequencies followed by 5 secs. coded response on same frequencies.

Fig. 6—"A" band and fixed frequency working

239. The coding in these two operations may be described in rather greater detail. In the operation described in para. 236, there is no coding during the A-band sweep. The coding is given entirely in the fixed frequency when working as described in para. 236 and 237.

240. The first five coding characters give the security code. They will be changed each day, but will be the same for all ships and aircraft

on any one day. Each character can be either a narrow pulse, a wide pulse, or a blank, with the following provisos :—

(1) The first and last of the characters shall not be blank.

(2) There shall be only one blank in each set of five.

This gives 80 possible codes. The codes are selected by a key switch. 80 different keys will be produced, and any one, when inserted in a special control unit, will give one of the possible permutations. The pilot of an aircraft, or the responsible officer on board ship will be given the appropriate key each day.

241. The last three characters which give the functional code can be arranged in any of the following ways.

Aircraft	*Ships*
NNN	WNN
NNW	WNN
NWN	WWN
NWW	WWW
N-N	W-N
N-W	W-N

242. It will be noticed that aircraft will always have a functional code which commences with a narrow character while the functional code of ships always commences with a wide. This gives an easy method of distinguishing between the two.

243. On depressing the distress switch very wide pulses are transmitted during the whole cycle of operation except the five intervals occupied by the functional code. Thus in the state described in para. 236 the set will give very wide response during the A-band sweep and on the fixed frequency during the period occupied by the functional code. In the state described in para. 237, it gives distress on the fixed frequency during the whole operation again excepting the time occupied by the five security letters. The security letters occur always, and nothing is allowed to interfere with their transmission.

244. The width of the pulses used are approximately :—
Narrow—6 microseconds ; wide—15 microseconds ;

Very wide—60 to 100 microseconds.

When the set sweeps the A-band in normal Mk. III, III G or III R operation, it can use the normal Mk. III coding.

Controls

245. The necessary remote controls for the set are as follows :—

(1) On-off switch. (2) Emergency switch (giving distress) (3) Selector switch for 6 A-band functional codes.	These controls are on control units, type 1 as in Mk. III G(R).
(4) G button and R switch and morse key.	As in Mk. III G(R).
(5) Selector buttons A, B and C (6) Security code selector key.	These will have to be contained in a small additional control unit.

All these controls are available to the crew of the aircraft in which the set is installed. For use in ships certain controls will not be required (e.g., the G button and R switch and key).

246. In night fighter aircraft there may be additional controls, and the pilot will probably be provided with a row of six switches or buttons. These will be :—

(1) A remote on/off switch (in addition to that on the control unit).

(2) A remote emergency switch (in additon to the normal distress switch on the control unit. It will usually give Mayday distress in this case).

(3) The G button. (This is the G button mounted here for convenience).

(4) The G switch (this is the usual G or R switch mounted here for convenience).

(5) The Douse button (giving a response to searchlights on a preset frequency. It will probably be arranged to operate only while held down).

(6) Personal identity button for fighter plotting (probably this will not now be used. It gives continuous unchopped response on the fighter plotting frequency).

247. The state in which the set works will be chosen primarily by a *circuit selector plug*. This is a multi-contact plug which can be wired in different ways. The particular way in which it is wired will automatically choose three possible states in which the set can operate. The set can then be put into any one of these three states by depressing one of the state-selector buttons A, B or C. A set will be fitted with a particular circuit-selector plug according to the operation required of it. There

will probably be five types of plug, each having different wiring, one being fitted into sets used in fighter aircraft, another into sets used in NAA aircraft, and so on. The following table shows the probable states that will be possible with each type of plug.

Circuit selector plug	*Button A*	*Button B*	*Button C*	*Remarks*
I	Normal Mk. IIIG(R) facilities, including normal distress	5 seconds continuous fixed frequency response followed by 5 seconds coded response on same frequency. T and R both on same frequency. Distress during continuous response, during functional code	5 seconds A-band sweeping followed by 5 seconds coded response on a fixed frequency. T and R both on the same frequency. Distress during A-band sweep and during functional code	Initially for NAA and coastal aircraft to follow
II	As I above but with reduced power on the A-band	As I above but with reduced power on A-band	As I	For H.M. ships
III	As I	As I but with T and R on different frequencies	As I but with T and R on different frequencies	Alternative to I for CC and NAA aircraft
IV	As I but with reduced power on A-band	As I but with reduced power on A-band	As I	Alternative to I for H.M. ships
V	As I but with Mayday distress	Fighter Plotting consisting of I A-band sweep time shared with response on Fighter plotting channel II Operational G which overrides fighter plotting III Searchlight douse	Not used	For Fighter aircraft, including those co-operating with ships

IFF MK. V.

248. IFF Mk. IV is an entirely American system, and is not designed for use with British radar equipments. It will probably not be used operationally, and will certainly never be used by British forces. No account of its operation is given. It has the disadvantage of operating on a frequency largely employed by the enemy.

General

249. IFF Mk. V, or the United Nations beaconry, is being developed in America at the present time. It differs considerably from previous systems, and incorporates the functions of both IFF and homing beacons. It was to be used by British and American forces, and to replace the present IFF and homing beacon systems.

250. Mk. V IFF/UNB will operate on a frequency band of 950 to 1150 Mc/s, and will employ pulsed interrogation and response on any two of twelve spot frequencies in this band. It will provide the following facilities :—

(1) IFF identification of aircraft and ships from aircraft, ships and ground radar stations.

(2) Identification, together with azimuth and range, of ground, shipborne, and airborne beacons, from aircraft and ships.

(3) Other miscellaneous functions which can be added by later adaptation of the existing IFF/UNB units, and which include blind approach (BABS), bombing aids (Oboe), navigation, and certain forms of communication.

251. The system envisaged at the present time differs considerably in detail from the scheme as it was planned in the early days of development. To bring forward the date of introduction into the service, it has been necessary to reduce the technical complexity of the various units, and this could only be achieved by sacrificing certain security measures which were originally to be incorporated. The following account gives a brief outline of the system as it is envisaged at the present time.

List of units

252. The Mk. V scheme employs a number of radar interrogators and transponders, of which the following list includes the most important. All use vertical polarisation. In addition to those mentioned here there will be various display units, connectors, and special units which have not been fully developed as yet, but which may be required for particular applications.

Equipment	*Purpose*	*Transmitter peak power*	*Receiver sensitivity*	*Weight*	*Remarks*
AN/APX-6	Airborne transponder for IFF and Rooster	500 W.	100μV.	30 lb.	Fits into Mk. III transponder shock-mount Omni directional aerial
AN/CPX-3	High power surface interrogator-responser	8 kW.	10μV.	400 lb.	Will use one of several forms of directional antenna
AN/APX-7	Airborne interrogator-responser for all IFF and beacons	2 kW	?	TR unit alone 45 lb.	Carries semi - directional antenna, acting as a common T and R aerial, and also separate T and R aerials, the latter of which can be lobe-switched to give the usual directional facilities. This directional R aerial fits into an 8-in. " egg," which permits it to be rotated to take bearings off the line of flight

Equipment	Purpose	Transmitter peak power	Receiver sensitivity	Weight	Remarks
AN/SPX-1	High powered shipboard IFF transponder	8 kW.	10μV.	400 lb.	This will be the AN/CPX3 converted into a transponder
AN/CPX-4	Medium power surface interrogator responser	2 kW.	?	TR. unit alone about 45 lb.	Modified form of the AN/APX-7 for surface use
AN/SPX-2	Medium power shipboard IFF transponder	2 kW.	?	TR unit alone about 45 lb.	This will be the AN/CPX-4 modified for use as a transponder
AN/CPN-8	Paratroop beacon	?	?	25 lb. including aerials and power supplies	This is a light-weight beacon. Its reply can be coded or hand keyed
AN/UPN-5	High power surface beacon	8 kW.	10μV.	400 lb.	This is a converted AN/CPX-3. It differs from the AN/SPX-1 in its coding and de-coding mechanism
AN/TPN-4	Medium power surface beacon	2 kW.	?	IR unit alone about 45 lb.	This will be the AN/CPN-4 converted for use as a transponder. It differs from the AN/SPX-2 in its coding and de-coding mechanism

Test sets

253. The following paragraphs list the principal items of test equipment envisaged for the IFF Mk. V/UNB scheme.

AN/UPM-4

254. This is a transportable equipment which will be capable of making all the measurements required for servicing and testing any of the Mk. V IFF/UNB units.

AN/UPM-5

255. The AN/UPM-5 is a depot equipment, which includes the transportable set and also certain standards required for checking its calibration.

AN/UPN-6

256. This is a light portable equipment which can be carried by one person. It is limited in its scope, and will check only the following operations :—

(1) Frequency of the transmitter and the receiver.
(2) Coding of the interrogator-responsor and of the transponder-transmitter.
(3) Decoding in the transponder receiver.
(4) Receiver sensitivity.
(5) Transmitter power output.

Maximum range

257. The range of the system will depend upon the particular equipments involved. The following table gives an approximate estimate of the ranges to be expected :—

Interrogator and transponder	*Estimated range (statute miles)*
AN/CPX-3 to AN/APX-6	
(1) With overall antenna gain of 15 dB	
Aircraft at 1,000 ft.	40
Aircraft at 10,000 ft.	120
Aircraft at 20,000 ft.	170
(2) With overall antenna gain of 5 dB	
Aircraft at 1,000 ft.	30
Aircraft at 20,000 ft.	100
AN/CPX-3 to AN/SPX-1	
With antenna heights 100 ft. and overall antenna gain of 11 dB.	35
AN/APX-7 to AN/SPX-1	
(Calculated free space range).	100
AN/APX-7 to AN/UPN-5	
(Calculated free space range).	140
AN/APX-7 to AN/APX-6	40 to 80
AN/APX-7 to AN/QPN-8	30 to 40
AN/CPX-3 to AN/SPX-2	
With overall antenna gain of 11 dB, and I-R antenna at 100 ft. and transponder antenna at 50 ft.	25
AN/CPX-4 to AN/APX-6	
With overall antenna gain of 5 dB, and aircraft at 10,000 ft.	90
AN/APX-7 to AN/TPN-4	
(Provided that aircraft is above horizon)	90

Coding

258. The Mk. V IFF/UNB provides the following coding facilities :—

(1) Variation of interrogation frequency.
(2) Interrogation signal modulation (i.e., double-pulsed interrogation).
(3) Variation of response frequency.
(4) Response signal modulation (i.e., coding of response in a way similar to that used in the Mk. III Q).

259. These variables are used to provide functional and security coding. The following account gives a brief description of the use of each of the four characteristics in the system as it is visualised at the present time.

260. Interrogation can occur at any one of twelve channels which are spaced about 17 Mc/s apart. These channels can be divided between IFF and UNB as required. It is expected that beacon interrogation may require the use of several channels at any one time, but that IFF may require either only one channel, or, at the most two, one for interrogation of aircraft and the other for interrogation of surface vessels. There will be no provision for remote control of the frequency in the early interrogators and responsors, but all are being designed for the optional addition at a later date of a remote control mechanism which will permit click settings to any of the twelve interrogation frequencies.

261. The system employs double-pulse interrogation. The pulses will each be one microsecond wide, and their leading edges will be separated by a time interval of either 3, 5 or 8 microseconds. The transponders are provided with decoding units which can be set up to give response on any one of these codes. The three codes will normally be used for the following purposes :—

(1) *IFF.* The 3-microsecond interval can be used for normal IFF working.

(2) *PI.* Personal identity is often required by a fighter-direction station. This can be obtained be requesting the pilot to turn on his PI, in which case he switches his transponder over to the 5-microsecond code. If the interrogator is also switched over to this interval, it will receive replies only from this particular aircraft, as all other airborne transponders will normally be using the 3-microsecond code.

(3) *FLI.* In a large formation of aircraft the IFF clutter renders the reading of the reply code impossible. In this case it is possible to ask the formation leader to switch over to Flight Leader Identity, which uses the 8-microsecond interval. When the interrogator is also switched to this code it will receive only replies from the one aircraft.

262. These codes are available as follows :—

(1) *High power surface interrogators* can use IFF and either PI or FLI simultaneously.

(2) *Medium power surface interrogators* can use any one of the three codes at a given time.

(3) *Airborne interrogator responsers* can use any one of the three codes at a time. The pilot can select the one required.

(4) *Airborne and surface IFF transponders* can be set up to respond to the IFF code alone, IFF and either PI or FLI simultaneously, or all three simultaneously.

(5) *Beacons* will be able to decode any of the interrogation codes, one at a time.

263. The response frequency can be varied in the same way as the interrogation frequencies, the transponders being capable of replying on any one of the same twelve channels. The response channel will usually be different from the interrogation channel. Although there will be no provision for remote selection of the response frequency in the first place, interrogators and transponders are being designed with a view to their use with remote selectors at a later date, as in the case of the interrogation frequency.

264. The reply signal can be modulated to give a considerable measure of coding. The IFF response will consist of a single pulse, one microsecond wide, transmitted for each double-pulse interrogation signal. The width of this pulse can be increased to 2½ microseconds when desired, and coding is achieved by a similar method to that employed in the Mk. III Q system. For a short period of time the transponder gives a succession of either wide or narrow responses ; it is then switched off for a brief interval, after which it comes into operation again for the same length of time as before. Its response then appears as a succession of short flashes, each lasting for the same length of time. Each flash man consist of a succession of narrow pulses or a succession of wide pulses. The response code consists of two or three morse letters transmitted in this way, and is repeated indefinitely as long as interrogation continues.

265. For aircraft, the normal reply will consist of a two-letter code, providing 80 possible combinations, followed by two blank periods each of which lasts for about the same time as a letter. A third letter can be introduced in place of one of these blanks if desired. These two possible conditions are therefore :—

First condition—1st Letter, 2nd Letter, Blank, Blank, 1st Letter,— and so on.

Second condition—1st Letter, 2nd Letter, 3rd Letter, Blank, 1st Letter,— and so on.

266. This code is known as the *slow reply code* in contrast to another type of code, the fast code, which the original Mk. V system incorporated in addition, but which has been abandoned in the present set.

267. The distress signal for aircraft will be brought into operation by a pilot control. On depressing this emergency control the response to any of the three interrogation codes will consist of a characteristic signal, composed of four one-microsecond pulses spaced eight microseconds apart. These are followed by a fifth pulse which can be keyed for communication purposes.

268. Ship IFF transponders will radiate a multi-letter code group by variation of pulse width in the same way as that described for aircraft. The coding of these equipments will be more flexible than that of the airborne sets, however, and will only be limited by the possible arrangements of 150 elements.

269. Surface beacon transponders also use pulse-width coding, and give a two-letter group on reply to interrogation. This time, however, the pulse width is two microseconds or nine microseconds.

270. The aerial systems of ground interrogators will usually be highly directional, and will sweep continuously to cover all azimuthal bearings. They may be mounted either on the same turntable as the aerials of their parent radars or separately on their own turntable.

271. Airborne interrogators will be fitted with two aerial systems. One will be a simple omnidirectional antenna, while the other will be a lobe-switched type which will be housed in an eight inch " egg " which permits the mechanism to be rotated to take bearings off the line-of-flight. The former aerial will normally be used for transmission, while the latter will, of course, feed into the receiver to give indication on an L-type display in the usual way. If no directional facilities are required, however, it will be possible to use the single aerial for common T and R working.

272. All IFF and beacon transponders will normally have simple omnidirectional aerials, so that they are able to respond to interrogation from any direction.

APPENDIX I

CONCLUSIONS

LIST OF CONTENTS

Present system and possibility of improvement

1. H.M. ships and NAA aircraft carry, or will shortly carry, the following types of interrogators and IFF and beacon transponders :—

Equipment	*Purpose*	*Frequency (Mc/s)*	*Polarisation*	*Remarks*
Ship Interrogators				
Type 242	IFF interrogator	184	Vertical	
Type 243	IFF interrogator	173	Vertical	
Airborne Interrogators				
ASV. Mk. II N	Interrogator beacons	176	Horizontal	
ASB	Interrogator beacons	515	Horizontal	
Lucero	IFF beacon interrogator	176	Horizontal	
Rebecca III N	Beacon interrogator	214-234	Vertical	
Rebecca Mk. IV	Beacon interrogator	214-234 Tx, 176 Rx, 177 173	Doubtful	Rebecca Mk. IV in NAA aircraft may use either horizontal or vertical polarisation or both

Equipment	*Purpose*	*Frequency*	*Polarisation*	*Remarks*
Shipborne Transponders				
Types 251M and 253P	Beacon transponder	176	Horizontal	
Types 253M and 253P	IFF transponder	157-187	Vertical	
Type 953	Beacon transponder		Horizontal	
Y J beacon	Beacon transponder	176 and 515	Vertical	American beacon for use with ASB and also with 176 Mc/s interrogators
Eureka	Beacon transponder	214-234	Vertical	Will be used in H.M. ships in the future. Probably vertically polarised
Airborne Transponders				
R.3067 and R.3090	IFF Mk. III	157-187	Vertical	
ABK	IFF Mk. III	157-187	Vertical	
SCR-695	IFF Mk. III G	157-187	Vertical	
AN/APX-1	IFF Mk. III G(R)	157-187 200-210 172-182	Vertical	
Eureka	Beacon transponder	214-234	Vertical	
Airborne IFF Interrogator-transponder				
AN/APX-2				
Interrogator	IFF interrogation	160-184	Vertical	
Transponder	IFF Mk. III G(R)	157-187 172-182 200-210	Vertical	Has no directional aerials to home auto-beacons
AN/APX-8				
Interrogator	IFF and beacon interrogation	160-184	Doubtful	The AN/APX-2 fitted with directional aerials for homing
Transponder	IFF Mk. III G(R)	157-187 172-182 200-210	Vertical	

2. The present beacon and IFF equipment may eventually be replaced by the Mk. V IFF/UNB interrogators and transponders. The operation of the present system is complicated by the fact that certain interrogators and transponders use horizontal polarisation while others use vertical polarisation, and it is worth considering the possibility of introducing some uniform scheme.

Relative mertits of horizontal and vertical polarisation

3. The advantages of a change over to a uniform system of polarisation must be considered in conjunction with the difficulties and time involved in making the necessary modifications to the surface and airborne equipments. It will be useful, however, to give a brief summary of the purely technical advantages and disadvantages of horizontal and vertical polarisation.

4. *Horizontal polarisation*

The following points are important :—

(1) Horizontally polarised aerial systems will not give such good all-round-looking facilities as vertically-polarised aerials.

(2) Horizontal polarisation, in most cases, gives poorer vertical coverage, particularly at low angles of elevation.

(3) The sea returns are much smaller if horizontally-polarised waves are used. This is not important when different frequencies are used for interrogation and response, but it will be a distinct advantage in the case of the Rebecca Mk. IV which will probably be used not only as an interrogator but also as a low power ASV set.

(4) With the glide path BABS it is essential to use horizontal polarisation but on a different frequency for response.

5. *Vertical polarisation*

Vertical polarisation has the following advantages and disadvantages :—

(1) With vertically-polarised aerials it is a simple matter to obtain all-round azimuth cover. This is important in IFF and homing beacon transponders.

(2) Vertical polarisation gives better vertical coverage than does horizontal.

(3) With the new BABS Mk. II beacons it is a simpler matter to design vertically-polarised aerial systems than horizontally-polarised ones. It is also important to note that vertically-polarised aerials for BABS Mk. II have already been designed, while horizontal systems are still in the early stages of development.

(4) Although the glide-path BABS must use horizontal polarisation for response, it responds on a frequency of about 500 Mc/s, so that separate receiving aerials must be installed in the aircraft in any case if it is to work with this type of transponder. It is doubtful, moreover, whether the NAA will ever use such a beacon.

(5) The present ASV Mk. II uses horizontal polarisation for interrogation. The conversion of NAA beacons to vertical polarisation would involve the use of cross-polarisation when they are interrogated by Mk. II and Mk. II N equipments. The high power of the ASV transmitter, and the high sensitivity of its receiver would compensate for the small reduction in range entailed, so that this objection is not serious.

(6) Vertical aerials must protrude from the fuselage of the aircraft where they cause increased drag. This is not serious in the case of the aerial on IFF transponder, which consists of a single vertical quarter-wave rod, which, if properly streamlined, detracts but little from the performance of the aircraft. The directional aerial systems of interrogators such as Lucero and Rebecca present a more difficult problem. It may be possible to overcome the difficulties in this case by using resonant slot aerials situated in the wing tips. No such aerials have yet been developed, and their design may be difficult.

(7) Perhaps the most important disadvantage of vertical polarisation lies in the fact that the sea returns are very marked. This would only be troublesome in the case of Rebecca Mk. IV when and if it is used as an ASV equipment.

6. Taking all the facts mentioned above into account, it appears that vertical polarisation has distinct advantages over horizontal. Its only serious disadvantage lies in the excessive sea returns which may lead to difficulties in its use with Rebecca Mk. IV as an ASV. This can be overcome by fitting extra horizontal aerials. If there is to be any standardisation at all, it seems clear that vertical polarisation should be adopted.

Work involved in standardising polarisation

7. The aircraft of the NAA work in close co-operation with Coastal Command of the RAF and in order to achieve best results from any standardisation of polarisation it would be necessary to apply any change to the NAA and to Coastal Command simultaneously. Insofar as the NAA alone is concerned, the adoption of iniversal vertical polarisation would involve the following changes to existing equipments.

(1) *Shipborne interrogators.* These are already vertically polarised and would require no alteration.

(2) *Airborne interrogators.* Existing Lucero interrogators would require vertical aerials which would have to be substituted for the present horizontal aerials. Rebecca Mk. III N is already vertically polarised. Future Rebecca and Lucero equipments could be provided with either type of aerial, and they present no serious problem. If resonant slot aerials can be developed to decrease drag there will be some delay before they can be used. The existing vertical aerials of the interrogator portion of AN/APX-8 would have to be used.

(3) *Shipborne transponders.* The aerials of all shipborne homing beacons must be changed. This also applies to the aerials of the BABS beacons. The latter could be replaced by the existing Bomber Command BABS Mk. II equipments which would have to be slightly modified in order to allow for the difference of frequency.

(4) *Airborne transponders.* These are already vertically polarised and would require no change.

(5) *ASV equipments.* ASV Mk. II N is necessarily horizontally polarised and would have to use cross polarisation for interrogation. Its high power and sensitivity would render this immaterial, Rebecca Mk. IV when used as a low power ASV would require extra horizontal aerials which could be housed in the wing tips.

Suggestion of standardising frequencies

8. A report, issued by the Sub-Panel on Beacon Policy of the Optec Committee, and dated October 3rd, 1944, suggests that it would be advantageous to standardise not only the polarisation but also the frequency of existing beacons. If all beacons used the same polarisation and also operated on the same frequency band, it would clearly enable any aircraft to avail itself of the facilities offered by all commands.

9. The most desirable frequency range appears to be the present Rebecca-Eureka band (214-234 Mc/s), and the suggestion is to modify all existing beacon equipments to work within this band, and to use vertical polarisation. This would also have the additional advantage of reducing the traffic on the IFF Mk. III band (157-187 Mc/s). It would render ASV Mk. II useless as a beacon interrogator, but it is estimated that the change would take about a year to effect and by this time there will be few ASV Mk. II equipments left in Service.

10. The proposed scheme is discussed fully in the report, and no further details need be given here. Its most serious practical handicap lies in the work involved in the conversion. In this connection it is necessary to take into account the fact that the USA have supplied the British Navy with beacon transponders which work on a frequency of 176 Mc/s, and these would also have to be modified.

11. If this more comprehensive scheme is not adopted, it would still be an advantage to rationalise the polarisation only, and to continue to work with the existing frequencies. The suggested standardisation of frequency merely offers an additional improvement.

67M/C M40482 11/47 500 C.B.&S.Ltd. Gp.30