PART I

BASIC PRINCIPLES OF RADAR AND SUMMARY OF RADAR DEVICES

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CHAPTER 3

TYPES OF DISPLAY

Introduction

1. The echo from the distant object, having been picked up on the aerial and then amplified and rectified in the receiver, must be displayed to the operator in such a way that the co-ordinates (r, θ, α) of the echoing object may be deduced as desired. A visual display is almost invariably used, involving a cathode ray tube (c.r.t.). The c.r.t. employs a narrow pencil of cathode rays to produce a bright spot on a fluorescent screen formed on the end of the tube. By means of deflecting plates or by coils, this spot can be moved electrically as desired over the screen at a very fast rate. Owing to the persistence of vision, and afterglow in the fluorescent material, a steady display is formed on the screen. The various types of display are briefly described in the following paragraphs.

Range-amplitude or type A

2. This is historically the oldest type of display, and has already been mentioned briefly in Chapter 1. The tracing spot appears near one edge of the fluorescent screen at the same time as the transmitted pulse is emitted (or a little before) and moves across the screen with uniform speed, tracing out a line. It is then suppressed and appears again in its initial position when the next transmitter pulse is emitted and the process is repeated. This motion of the spot is produced by a sawtooth wave of voltage, synchronised with the pulse recurrence rate and applied to one pair of deflecting plates. The echo signal is applied to the other deflecting plates (at right angles to the first pair). Thus during the very short period when an echo is being received the trace on the screen is deflected by an amount proportional to the amplitude of the echo signal. Since noise is

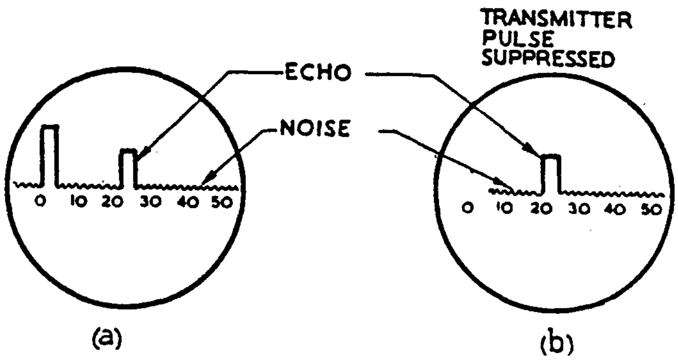


Fig. 1—Type A display

being generated in the receiver and aerial circuits, the trace also shows small irregular deflections of a random nature. The result is shown in fig. 1(a) and fig. 1 (b). In fig. 1(b) the receiver has been rendered insensitive during the time when the transmitter is sending out its pulse. This is a common procedure in radar equipment. It should be noted that the deflections of the trace may be arranged to be up or down according to the taste of the designer. The whole display may also be turned through a right angle from the position shown in fig. 1, so as to give a vertical trace with deflections to the right or left. The range, r, of the echoing object is determined by the distance on the trace from the leading edge of the transmitter pulse to the leading edge of the echo. A scale, or indicating marks, may be provided. If it is desired to display echoes up to a range of r miles, the corresponding echo delay will be 10·75r microseconds. Thus the tracing spot must move across the screen in 10·75r microseconds which figure determines the slope of the deflecting sawtooth voltage. It is often desirable to have a choice of traces which can be switched on as desired, including a very " fast " trace or time base, corresponding to a small range and giving an open and more accurate reading for nearby echoes. The maximum range that can be indicated (or the " slowest " trace that can be used) is decided by the time between successive pulses. Thus if the pulse recurrence frequency is p pulses/second, then the greatest range, r_{max} which can be indicated is given by

$$r_{max} = 93{,}000/p \text{ miles.}$$

This formula applies to all displays with a range co-ordinate. It is clear that, with type A display alone the co-ordinates θ and α must be found from dials or scales unconnected with the actual display tube, the operator studies the amplitude of the echo in relation either to physical movements of the aerial system or to electrical changes in the connections and couplings from the parts of the aerial system in the receiver.

Split display

3. The co-ordinates θ or α are sometimes determined by comparing echo signals received on two aerials with different polar diagrams or on the same aerial shooting in two different directions, as explained in Chapter 2. A switching motor may be employed, synchronised with the recurrence frequency so that the two different conditions of reception are obtained in turn. At the same time, alternate traces on the screen are displaced a little by having one start nearer to the edge of the screen than the other. The signals under the two different conditions are thus displayed side by side (fig. 2). The same effect can be obtained without displacing the traces but by arranging that the deflection is upwards (or to the right) under one condition and downwards (or to the left) under the other (fig. 3).

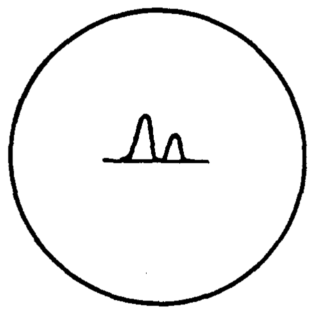


Fig. 2—Side-by-side split display

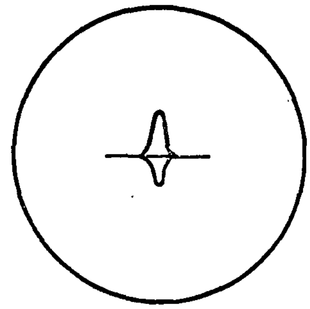


Fig. 3—Up-and-down split display

Strobe marker

4. The strobe is a " gate " circuit which is only open during each recurrence for a few microseconds. The signals occurring in that time are allowed through and may be displayed separately on another c.r.t. In order to strobe an echo a type A display may be used (or any display with a range co-ordinate). A small part of the trace is brightened up or otherwise made noticeable during the time that the " gate " is open. This is called the strobe marker (fig. 4). A control is provided to alter the position of the gate in the recurrence interval and this strobe control is moved until the bright mark coincides with the echo which it is desired to pass through the gate. The strobe control can also be used to provide a range indication, the operator merely keeping the echo covered by the strobe marker.

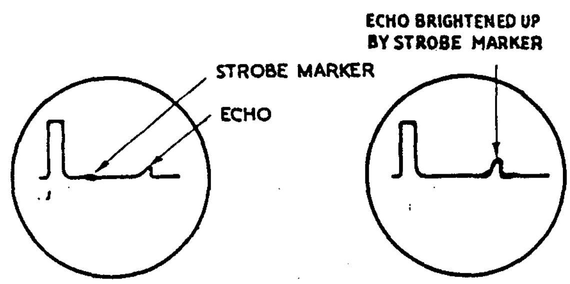


Fig. 4—Strobe marker

Plan position indicator (PPI)

5. The tracing spot of the c.r.t. starts, when the transmitter pulse is emitted, from the centre of the screen and moves out along a radius until the edge of the screen is reached. The spot is then suppressed but appears again at the centre with the beginning of the next transmitter pulse and the sequence is repeated. The particular radius along which the spot travels is controlled (either electrostatically or magnetically) so as to be related to the azimuthal direction in which the aerial system is shooting at that moment. If the aerial turns round at uniform angular speed, there is traced out in succession on the screen a series of spokes. Let the aerial scan 360° in azimuth at N revolutions /minute and let the pulse recurrence frequency be p pulses per second. Then the angle between the spokes or radial traces is 6N /p degrees. The traces not being superimposed as in type A display, one here relies entirely on the long afterglow of the specially designed fluorescent

screen in order to obtain a display which can be seen easily by the operator. The echo signal in the case of PPI display is applied to the grid of the c.r.t. so as to brighten up the tracing spot on the

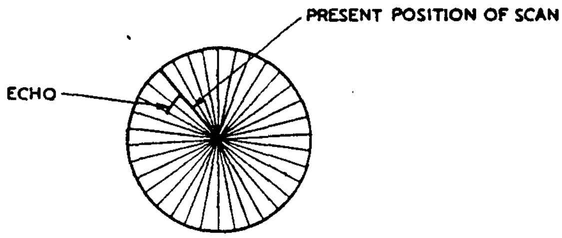


Fig. 5—PPI display

screen (intensity modulation). Depending on the size of the echoing object, the sharpness of the aerial beam and the length of the transmitter pulse, the echo appears on the long afterglow screen as a bright spot or smudge (see fig. 5). It is usual to adjust the controls so that the traces are only just visible unless there is an echo present. By correlating the positions of the radial traces relative to the directions of the aerial beam this display gives directly the coordinates r, θ of the echoing object, and, indeed, a transparent outline map can be superimposed in the case of a fixed ground station. The PPI, in its simple form, does not give the co-ordinate α

Skiatron

6. This is a special type of PPI in which the picture on the c.r.t. screen is transferred by strong reflected light to a large translucent glass plate. A larger display can thus be obtained than is pòssible with a c.r.t. alone. The tube employed has a screen which turns dark purple under the influence of a strong electron beam but soon returns to its original grey colour when subject to the heat produced by the associated high-density light scource.

Range-azimuth or type B

7. This display is used in aircraft sets with centimetre equipment. The tracing spot starts near the bottom edge of the screen when the transmitter pulse is emitted and traces out a vertical line. It reaches the top of the screen in a time determined by the maximum range which it is desired to indicate. The spot is then suppressed and appears at the bottom of the screen as the next transmitter pulse goes out, when the sequence is repeated. These successive vertical sweeps are spaced out across the screen so as to correspond with the azimuthal direction in which the aerial is shooting. When the aerial shoots straight forward along the axis of the aircraft the vertical sweep is along the centre line of the screen; when shooting at an angle to the left of the forward direction, the vertical sweep is a proportionate distance to the left of the centre line. As in PPI,

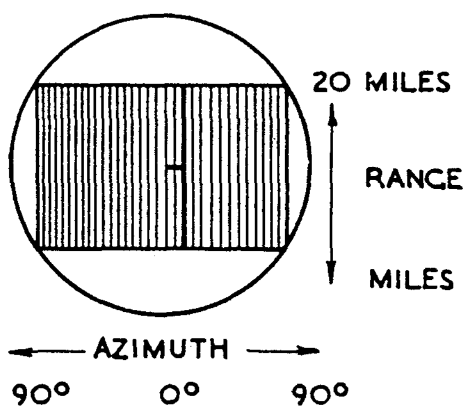


Fig. 6—Range-azimuth display

the echo signal is used to intensity-modulate the c.r.t. beam so that the tracing spot is brightened up when an echo is received. An afterglow screen is used and thus the echoes are displayed as spots or short lines or extended smudges (depending on the beam width and the size of the echoing object). The final result is a kind of distorted map of the region scanned by the aerial (fig. 6). Type B display does not show the co-ordinate α

8. If N is the number of aerial scans per minute and p the number of pulses per second then the number of vertical lines comprising the complete picture is 60p/N. Note that type B display is superior to the PPI in that it gives much greater angular resolution at short ranges; type B has the disadvantage that the picture is distorted, and does not correspond to a map, so that practice is required in interpreting the display. Type B is only suitable for scans up to the limits of + 90° and — 90°.

Range-elevation or type E

9. The tracing spot starts near the left-hand edge of the screen, at the moment when the transmitter pulse begins, and moves horizontally with uniform speed to the right-hand edge. As usual, this speed is determined by the maximum range it is desired to indicate. Successive horizontal sweeps are spaced up and down the screen so as to correspond with the zenithal or elevation angle at which the aerial is shooting at the moment in question. Intensity modulation is used to show the echo as in PPI and type B. The co-ordinates r, α can be read off. In the case of a ground station the alternative co-ordinates r, h may be obtained where h is the height of the echoing aircraft. For this purpose a series of lines may be drawn on the screen giving contours of equal heights and corresponding to solutions of the equation $h = r \times \sin \alpha$ with allowance for earth curvature (fig. 7 (a))

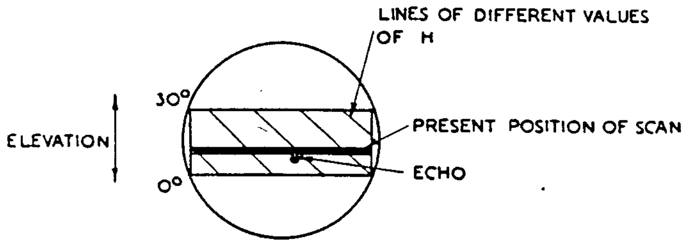
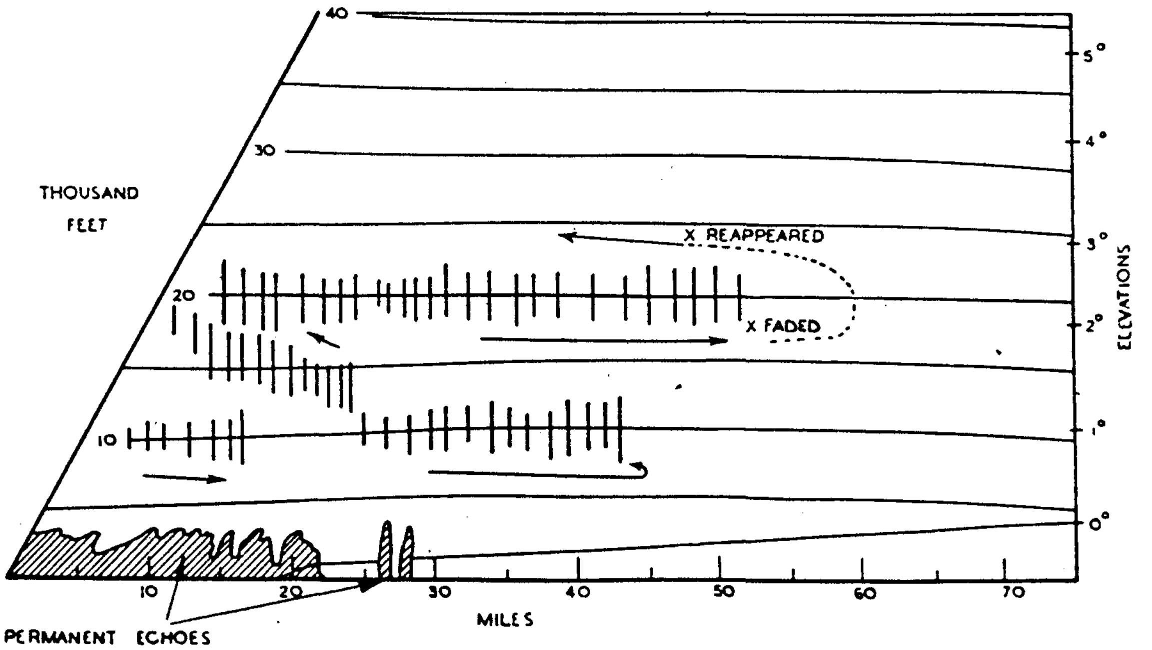


Fig. 7A—Range-elevation display

The curvature of the lines at constant h make this an unsatisfactory type of display and it is now obsolete. In the latest CMH (Centimetre Height) equipments the display assumes the following form. It is a Cartesian plot of kr sin α as ordinate, against r, where, k is a constant, r the range and α the elevation. This is achieved by imposing a portion of the sawtooth time base X-scan on the Y



HEIGHT CALIBRATION FLIGHT - 2 SPITFIRES - A.M.E.S TYPE 13.

Fig. 7B—Height calibration flight

plates, to an amount proportional to the elevation of the beam. The constant height lines are now almost straight and by tilting the line of zero elevation to correct for earth curvature they also can be set horizontal. A further advantage of this tilt is that the trace sweeps below the position of zero elevation of the aerial with the result that permanent echoes can be distinguished from low flying aircraft. Responses appear as vertical straight lines. A maximum range of 75 miles and height of 45,000 feet can be displayed in a space of 18 cm. × 10 cm. Fig. 7(b) shows the plots on a test flight with two Spitfires.

Elevation-azimuth or type C

10. The tracing spot moves up or down, left or right, in sympathy with the movements of the aerial system. Fig. 8 shows the traces for an aerial doing a helical scan. The receiver is made insensitive during the transmitting period and signals received at other times are used to intensity-modulate the brightness of the spot. The co-ordinates θ, α can be read off. It is clear, however, that the tracing spot is effectively stationary during a period between transmitter pulses. Consequently all extraneous signals including noise are accumulated together in the spot. The contrast between

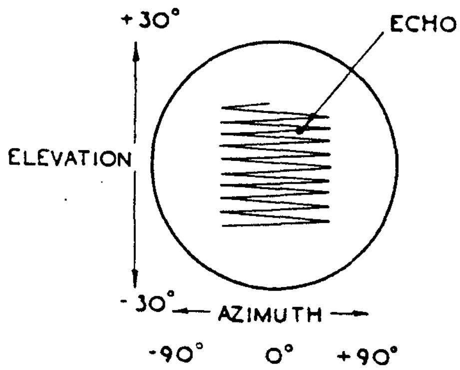


Fig. 8—Elevation-azimuth display

echo and noise is thus poor. This disadvantage can be eliminated by using in addition a display with a range co-ordinate (such as Type A or B), "strobing out" the desired echo in range and then displaying the selected echo alone on the type C indicator. The strobing may be done manually or automatically. Type C display does not give the coordinate r.

Spot indicator and pilot's indicator

11. These are type C indicators which must be preceded by a strobe or gate, as described in para. 10. The range of the echo (or strobe position) is shown in the pilot's indicator by adding horizontal "wings," of varying length, to the spot (fig. 9).

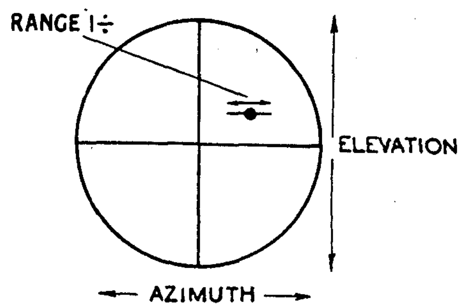


Fig. 9—Spot indicator display

Use of standard co-ordinate system

12. The co-ordinates (r, θ, α) of an echoing aircraft or ship, as determined by a radar equipment are measured with that radar station as origin. In airborne sets this is all that is desired in order to carry out attacks. But, in cases where there is a network or chain of ground radar stations, it is normal practice to report or " tell " to a central control operations-room ; the relative co-ordinates (r, θ, α) are then inconvenient. Before reporting the position of an echoing aircraft the " teller " might convert (r, θ, α) to latitude, longitude and height above sea level. This being an absolute co-ordinate system, the central operations-room plotter could easily show the result, with those of neighbouring radar stations, on a large scale map. Although latitude and longitude are used by the Navy, they have not found favour with the R.A.F. owing to the subdivisions of sixty which are required in latitude and longitude notation. Instead a decimal system has been introduced :—A straight line is drawn on the ordnance survey map through a point in the Isle of Wight and running

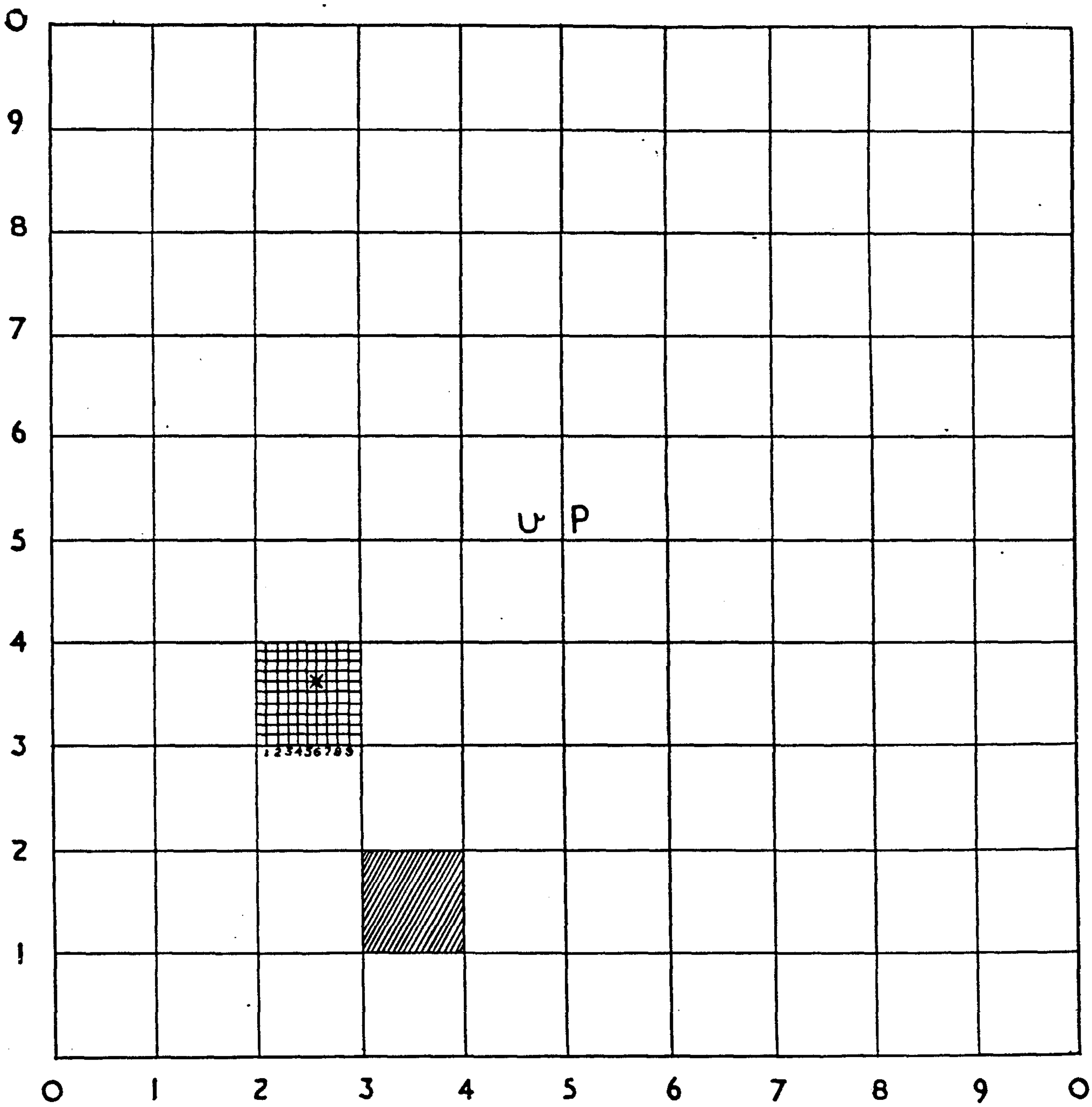


Fig. 10—Use of standard co-ordinate system

true North and South. A straight line is drawn East and West through the same point. A series of horizontal and vertical straight lines is then drawn parallel to the first pair and spaced out 100 kilometres apart. This divides the area of England, Scotland and Wales, with the surrounding coast, into 100 kilometre squares which are given letter references such as aA, aB and so on. Each square is further subdivided into squares of ten kilometre side by drawing parallel lines as shown in fig. 10. The lines are numbered from left to right and from bottom to top. Any square is referred to by the numbers of the vertical and horizontal lines crossing at its bottom left hand corner. Thus the shaded square in fig. 10 would be referred to as vP.31. A further subdivision of the kilometre squares into squares of 1 kilometre side yields a four figure reference; thus the point marked with a cross in fig. 10 lies in the square vP.2636. The first two figures refer to vertical lines (or x — co-ordinate) and the second two to horizontal lines (or y — co-ordinate). Six figure references are occasionally used. It should be noted that as one moves East or West of the vertical line through the Isle of Wight the sides of the squares no longer lie North and South. The whole network is referred to as the Air Force Grid and the co-ordinates are called "grid-references." The Ordnance Survey maps issued by the Air Ministry have this grid drawn on them. Each radar station of a network is required to convert the co-ordinates (r, θ) to a grid reference—either by ruler and protractor on a map or by a mechanical calculator—before reporting to the Central Operations room. The labour of converting is eliminated when a PPI display is available since the grid can be superimposed on the PPI screen and the reference read off. The calculation of height, h, above sea level from r and α must be done using charts or calculators, unless a type E display is provided.

CHAPTER 4

INSTALLATIONS IN USE

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CHAPTER 4

INSTALLATIONS IN USE

INTRODUCTION

1. The preceding chapters comprise a sketch of the basic principles of radar. The present chapter surveys the chief radar systems and devices. It is not intended to provide an exhaustive summary of all radar devices but rather to review the more important systems only. Further, R.A.F. equipments only are described.

NOMENCLATURE OF RADAR SYSTEMS

2. To each distinct radar system is allocated a code name or group of letters representing a name in abbreviation, such as Oboe (code name) or ASV (an abbreviation for Aircraft to Surface Vessel). The unit or units which comprise a specific radar system are given installation numbers and code letters according to the nomenclature that indicates crudely the nature and function of the unit. The unit has assigned to it an installation number which is associated with it alone but with no other unit. This number is prefixed by a group of letters that indicate the function of the unit. These letter groups are

A.R.I. = Airborne Radio Installation (unit installed in an aircraft).
A.T.R.I. = Air Transportable Radio Installation (transportable by aircraft).
F.G.R.I. = Fixed Ground Radio Installation.
M.C.R.I. = Marine Craft Radio Installation.
T.G.R.I. = Transportable Ground Radio Installation.
M.G.R.I. = Mobile Ground Radio Installation (housed in a prime mover).

American nomenclatures

3. *Army-Navy nomenclature—(examples)*

AN/APS.15 = Army-Navy/Airborne-Pulse (Radar)-Search-Type 15—(an ASV type equipment)
AN/CPS.1 = Army-Navy/Air Transportable-Pulse-Search-Type 1—(ground equipment)
AN/TPS = Army-Navy/Transportable-Pulse-Search.

Navy model nomenclature—(example)

ASG = Airborne-Search-Model G.

Army model nomenclature—(examples)

SCR.584 = Signal-Corps-Radio-Type 584—(GL type equipment).
SCR.720 = Signal-Corps-Radio-Type 720—(AI Mark X equipment).

CLASSIFICATION OF SYSTEMS

4. It is convenient, for the present review, to discuss the existing radar systems under the following broad headings :—

(*a*) Ground radar systems
(*b*) Airborne search and gun-laying devices
(*c*) Aids to identification
(*d*) Radar navigational aids and aids to blind bombing.

GROUND RADAR

General

5. The installations may be separated into

(*a*) Early warning stations
(*b*) Height finding equipments
(*c*) Stations for controlling aircraft from the ground.

Ground radar stations carry type numbers prefixed by the letters A.M.E.S. (Air Ministry Experimental Station). The main systems are also given code letters the commonest of which are :—

CH	=	Chain Home	Early warning equipments.
CHL	=	Chain Home Low	
CHEL	=	Chain Home Extra Low	
MRU	=	Mobile Radio Unit	
CHB	=	Chain Home Beamed	
COL	=	Chain Overseas Low	
L.W. Set	=	Light Warning Set	
VEB	=	Variable Elevation Beam	Height finding equipments
DMH	=	Decimetre Height Finding (λ = 50 cm.)	
CMH	=	Centimetre Height Finding (λ = 10 cm.)	
GCI	=	Ground Controlled Interception	Control of aircraft from the ground.

Early warning stations

6. We begin this section with a brief review of the reporting system associated with the chain of early warning stations. The earliest radar devices were designed to provide early warning of the approach of hostile aircraft, and to this end a chain of stations was built along the South-east, and East coasts of Britain. At the outbreak of war in 1939 there were already some eighteen of these stations in operation, and others quickly followed. Each station kept constant watch for aircraft flying out to sea and reported the position of any aircraft that it could see, to Fighter Command Headquarters. After the fall of France in June 1940 it became necessary to extend the chain of stations along the South-west and West coasts and to Northern Ireland, so that there is now available almost complete radar coverage round the whole country.

7. In order to appreciate the part played by radar as an early warning device it is necessary to understand the way in which Fighter Command is organised. The Headquarters of Fighter Command is at Stanmore in Middlesex. Directly controlled by this Headquarters are a number of Groups, each of which is responsible for the defence of a specified region. Each Group has in its area a number of sector stations on which the fighter aircraft are based. The movements of fighters at any sector station are under the direction of the Sector Controller, and he is responsible to the Group Controller, who, in turn, is responsible to the Chief Controller at Stanmore. It is necessary for the Controllers at Headquarters and at Groups and Sectors to have first hand information of the movements of all aircraft, and particularly of the whereabouts of hostile aircraft, and to this end an elaborate reporting system has been developed. It is not possible in this brief account to describe this reporting system in detail, and only a brief outline of its operation will be given.

8. Information concerning aircraft flying overland is supplied by the Royal Observer Corps and this part of the system does not concern us. Over the sea, however, aircraft are plotted by the radar stations round the coast and it is necessary to understand the way in which this information is used. Attached to each Group Station is a Filter Room where information is received from all the radar reporting stations in the Group area. In the Filter Room is a large scale map of the Group

area which extends for a considerable distance out to sea. This map is mounted on a table around which are seated W.A.A.F. plotters, each of whom is in constant telephonic communication with one of the radar stations in the area, and receives information concerning any aircraft that the station can see. The operator at the Station passes information to the Filter Room in the form of plots on the Fighter Command grid, and the plotter who receives these plots indicates their positions by placing coloured counters on the table. An aircraft will usually be plotted by more than one Station at one time, and it is the responsibility of an officer, known as a Filterer, to estimate the most probable position of the aircraft from the plots given by the various Stations, and to denote this position by placing the arrow on the table. As the radar stations are capable of measuring the range of a target with a greater degree of accuracy than the bearing, the Filterer, whenever two or more stations are plotting an aircraft, assesses its position by taking range cuts. In charge of the Filter Room is the Filter Officer, and assisting him are liaison officers who maintain contact with the various branches of the Services and supply information concerning the positions of our own aircraft and shipping. From the information supplied by the liaison officers, the Filter Officer is able to identify the tracks on the Filter Room table. The filtered plots are read off from the table by Tellers to the Control rooms of the Sector Stations in the area of the Group in question, to all Group Control rooms, and to the Central Control Room at Stanmore, where it is displayed, together with information from the Royal Observer Corps, on large scale maps. In this way it is possible to display reliable data before the Controllers with the minimum delay.

CH system of stations

CH (Chain Home) stations—A.M.E.S. Type 1

Frequencies :— 22·7 — 29·7 Mc/s (λ = 10·1 — 13·22 metres)
42·5 — 50·5 „ (λ = 5·94 — 7·06 „)

Pulse recurrence frequency :— 25 or 12½ per sec.

Transmitter power (peak pulse) :—200 — 800 kW.—Horizontal Polarisation.

9. CH equipment is historically the oldest radar equipment, and its function is purely that of early warning. The apparatus, which is housed in large ground stations, works on the usual echo principle, and is able to detect and plot aircraft at ranges up to some 200 miles. Each station has alternative wavelengths, one being between 10 and 13 metres and the other between 6 and 7 metres. The transmitting aerial arrays consist of stacks of horizontal half-wave aerials with reflectors and are slung between either 320 feet or 350 foot steel towers. These aerials floodlight a wide area in front of the station, transmitting short pulses of high peak power. The receiving aerials are mounted on 240 foot wooden towers, and are designed to measure the azimuth and elevation of the aircraft, the former being found by comparing the signals received in two crossed aerials by means of a goniometer, and the latter by comparing the signals received in two aerials at different heights with the same goniometer.

10 *Buried Reserve*. Many of the older CH stations have a type of standby equipment known as a Buried Reserve Station. A buried reserve station is built on the same site as its parent CH. It uses the same type of transmitter and receiver, but both transmitter and receiver are housed in underground rooms so that they will be less vulnerable to attack. These stations work only on the shorter 6 or 7 metre wave band, and both transmitting and receiving aerials are carried on 120 foot wooden towers.

MRU (Mobile Radio Unit)—A.M.E.S. Type 9

Frequency :—40 — 50 Mc/s.
Peak pulse power :—300 kW.

11. An MRU is a mobile station of the CH type. It employs the floodlight technique and the CH method for D/F and height finding. Its masts, 105 feet in height, are readily demountable. The station comprises a convoy of motor vehicles which carry all technical and barrack equipment and personnel. The maximum range on an aircraft at the optimum height is about 150 miles. It can be made operational in two days after the arrival of the convoy. These stations proved extremely useful in the North African campaigns.

General

12. Although stations of the CH type give maximum ranges which exceed those obtained by other radar equipments, yet the CH systems have inherent limitations. In particular, height finding even under the best conditions is limited to a range of aircraft elevations of $1\frac{1}{2}°$ to 16°. The stations must be repeatedly calibrated both for height finding and D/F, a troublesome and costly procedure, and the accuracy both of CH heights and D/F is inadequate for many operational requirements.

13. More serious however is the fact that CH stations give only short range warning of the approach of low flying aircraft (aircraft below 3000 feet). This is a physical limitation of the system arising from the relatively long operational wavelength (see para. 9) which, with mean aerial heights of about 220 feet, produces a radiation pattern in which the maximum intensity in the vertical plane first occurs at an elevation of about $2\frac{1}{2}°$. Consequently, aircraft at small elevations of 1° and less remain undetected.

CHL (*Chain Home Low*) *stations — A.M.E.S. Type* 2

Frequency :—200 Mc/s. ($\lambda = 1\cdot5$ metres).
Peak pulse power :—150 kW.
Pulse recurrence frequency—variable—of the order 400 p/s.

14. The CHL system was developed to supplement the coverage given by the CH chain, by providing detection of low flying aircraft. To achieve this result it was necessary for the stations to possess radiation patterns in the vertical plane with the lowest lobe at a small angle of elevation. The stations are therefore operated on the short wavelength of $1\frac{1}{2}$ metres and the stations themselves sited on cliffs overlooking the sea. Where the coast is flat the aerial arrays are mounted on towers 200 feet in height. With the aerial array at this height above sea level the range of first detection of an aircraft flying at 500 feet is at 110 miles. CHL stations do not read height.

15. The aerial system is a 5 bay—4 stack array of pairs of end-fed horizontal half-wave aerials placed at a distance of $\lambda/8$ in front of a reflecting screen of wire netting. Since the array is several wavelengths broad its horizontal polar diagram is markedly beamed falling to zero at about 10° from the axis of the main lobe.

16. To restore the horizontal coverage lost by beaming, the aerial array is rotatable about a vertical axis. The Caledon turning gear permits continuous rotation at speeds of 1·0, 1·5, 2·0 and 2·3 r.p.m. with facilities also for " inching " and reversing.

17. The region over the sea in front of the station can thus be swept. These stations employ a common T/R system of aerial working and the information is presented both on a linear time base and also on a P.P.I. tube from which the position of an aircraft or ship can be directly reported. The aerials are mounted on a wooden gantry 20 feet high.

CHB (*Chain Home Beamed*) *stations — A.M.E.S. Type* 8

Frequency :—209 Mc/s. ($\lambda = 1\cdot44$ metres).

18. CHB stations are stations of the GCI type sited close to the sea. The heights of their aerials are so arranged that the vertical polar diagram is similar to that of a CH station. Stations of this kind have been used instead of CH stations, on inaccessible sites where it would be difficult to instal a CH station. They measure the height of an aircraft by the ground reflection method.

L.W. Set (*Light Warning Set*) *— A.M.E.S. Type* 6 *— also known as " Transportable Radio Installation Type* 5124 "

Frequency :—176 Mc/s.
Peak pulse power :—85 kW.

American model:—AN/TPS 1 (25 cm.), AN/TPS 2 (75 cm.) and AN/TPS 3 (50 cm.— 70 miles range).

19. This is a highly mobile equipment which can be housed either in a van or in a tent. The aerial system which provides beaming in the horizontal plane and limited height finding facilities consists of two pairs of Yagi arrays one mounted above the other. The radiation is horizontally polarised and the aerial system is rotatable by power about a vertical axis. The display comprises a range-height tube and a P.P.I. presentation.

20. The maximum range is about 50 miles. The purpose of the equipment is to provide rapid coverage around a new site such as an aerodrome or camp, and also to provide radar coverage at sites which are inaccessible to the heavier radar equipments. The station can be made operational in two hours from the time of arrival. This type of equipment is growing in importance.

CHEL (Chain Home Extra Low) stations — A.M.E.S. Type 14

(λ = 10 cm.)

21. These are coastal stations whose purpose is to provide warning of the approach of aircraft flying so low (below 500 feet) as to be undetected by CHL stations. They also report the movements of shipping. The stations are sited on cliffs and work on an S-band (10 cm.) wavelength. Consequently the radiation pattern consists of very numerous and narrow lobes the lowest of which is at an extremely low angle of elevation (about 0·01° for a cliff height of 400 feet).

22. The transmitter employed is the 277 Navy transmitter. The aerial system in the latest marks consists of a pair of cheese aerials (parabolic cylinders) which may be fed at will in phase or antiphase (to direct the radiation up at greater elevation to improve high angle coverage). A common T/R wave guide system conveys power to the aerial, and the signal back to the receiver. A P.P.I. display is used with a range tube (type 3 display unit) or a P.P.I. tube and a display tube of the P.P.I. type in which range is displayed against elevation when a centimetre height finding equipment is associated with the type 14 equipment. This tube provides direct height reading.

23. The commonest equipment in use is A.M.E.S. Type 14—Mark III (MGRI.5554). The equipment is mobile. The narrow beam widths ($1\frac{3}{4}$° to the first zero in the horizontal plane and $6\frac{1}{2}$° in the vertical plane) give good angular resolution and accuracy on P.P.I. display.

24. Each cheese aerial has a rectangular aperture 20 feet × $18\frac{1}{2}$ inches with the long dimension horizontal, and is fed from a wave guide terminated in a flare.

A.M.E.S. Type 11 *Equipment*

Frequency :—500 — 600 Mc/s. (λ = 50 cm.)

25. This equipment was intended to be a standby equipment for CHL and GCI in the event of severe jamming which would render those equipments unusable.

26. The principal feature of the equipment is the wavelength of operation (50 cm.) which is small enough to permit the use of a parabolic reflector in a mobile equipment at the same time retaining a tunable transmitter and aerial system (unlike S-band transmitters and longer wavelength aerial arrays). Thus, a type 11 station can be operated on any frequency within the band 500 — 600 Mc/s and its frequency shifted at will in the event of jamming.

27. The aerials, mounted on the side of a mobile cabin, comprise a pair of netting paraboloids fed in phase and mounted side by side to produce a radiating rectangular aperture 25 feet (15λ) across and 6ft. 10in. (4λ) high. The horizontal beam width (maximum to first zero) is about 4° and vertical free space beam width 20°.

28. The small wavelength makes the equipment effective against low flying aircraft in CHL use. It cannot measure height. Each paraboloid is fed from a resonant slot radiator and the radiation is horizontally polarised. Type 11 equipments are losing in importance relative to S-band (10 cm.) equipments. The various Marks of Type 11 equipment are described in the following paragraphs.

29. *Mark II (T). MGRI.* 5193—comprises 2 vehicles, with the operations vehicle a prime mover and the aerial vehicle a trailer.

30. *Mark II (M)*, is similar, but both vehicles are prime movers.

31. *Mark III. MGRI.* 5299—Fully mobile and improved version of Mark II.

32. *Mark IV.* Includes universal operations vehicle (as does Mark III) and a high power transmitter T.3551.

Height finding equipments

General

33. The earliest method of height finding (elevation finding E/F) which is used in CH and GCI is unsatisfactory for several reasons. It uses the wave reflected from the ground or sea in front of the Station and is therefore dependent on the site, it is not highly accurate and (in CH) requires troublesome and costly calibrations. Further, the method is restricted in practice to elevation limits below or above which it yields ambiguous readings. Consequently there has existed, from the first, a requirement for a method of measuring height independent of ground reflections.

34. This in effect demands intense beaming in the vertical plane with the ability to move the beam through a range of elevations. Consequently the realisation of the method waited upon the development of radar practice on the shorter wavelengths of 50 centimetres and 10 centimetres, although an early equipment VEB (Variable Elevation Beam) used a wavelength of $1\frac{1}{2}$ metres.

35. These height finding equipments are designed for use as ancillary devices to other systems such as CHL, GCI and CHEL. They avoid the disadvantages of the original (ground reflection) method. The principal equipments are described in the following paragraphs.

VEB — Variable Elevation Beam

$\lambda = 1\frac{1}{2}$ metres.

36. Obsolete—Intended for use with CH stations on sites unsuitable for the reflection method of height finding. It employed a vertical stack of 56 pairs of end-fed half-wave aerials, supported on a CH receiving tower. A fan-like polar diagram, beamed vertically, was produced and this could be swung to different elevations by introducing predetermined phase shifts in the signals fed to the elements of the array.

DMH (Decimetre Height). A.M.E.S. Type 20.

$\lambda = 50$ cm.

37. This equipment is also obsolete. It worked on a frequency band 500-600 Mc/s and employed a large paraboloid 30 feet in height by 12 feet broad which could be rotated about a vertical axis and titled about a horizontal axis. The beam of radiation, 9° broad horizontally, and $4\frac{1}{2}°$ vertically, could thus be directed on to an aircraft whose height is obtained from the elevation of the beam at signal maximum, and from the radar range. As the aerial system is inconveniently large the equipment has been superseded by CMH equipment. The principal types of DMH equipment are described in the following paragraphs.

38. *A.M.E.S. Type* 20—*Mark I*—(*FGRI*.5537). Fixed equipment to provide accurate height finding at GCI stations.

39. *A.M.E.S. Type* 20—*Mark II*—Still-born—Mobile version.

CMH (Centimetre Height). A.M.E.S. Type 13 *and Type* 24.

Wavelength on S-band ($\lambda = 10$ cm.)

40. The aerial system is the same as that of the Type 14 equipment rotated through a right angle. Thus, the rectangular aperture of the paraboloid is set with its long dimension (20 feet) in the vertical plane. Since a pair of cheese aerials are used and are clamped together to form a single unit the horizontal dimension is 3 feet 1 inch. The beam widths, to first zero, are $1\frac{3}{4}°$ and $6\frac{1}{2}°$, vertically and horizontally respectively. The aerial may be turned in azimuth as required by the associated GCI or CHL, and sweeps in elevation between —1° and +20°.

41. Signals are displayed, by intensity modulation of a cathode ray tube (H/R tube) on a time base in which $k_r \sin \alpha$ is plotted against range r the elevation being α and k a constant. Constant height curves which are almost straight lines are drawn on the tube face so that the height of the aircraft may be read directly from the tube with an accuracy of ± 500 feet up to 60 miles range The maximum operational range on a Mosquito aircraft is 70 miles. Height finding is obtained from 0° (approx.) to 20° of elevation. The principal types of CMH equipment are described in the following paragraphs.

42. *A.M.E.S. Type* 13—*Mark II* (*CMH Mark II—MGRI*.5555). A mobile equipment used as an ancillary to any plan position equipment (CHL, GCI etc.). It comprises an aerial vehicle and an operations vehicle containing the display unit Type 58, (range-elevation scan (H/R tube) together with a PPI display on a second tube).

43. *Marks III and IV*. Similar to Mark II but with a display unit Type 5, which is a universal display unit for use with all beamed radar sets. It comprises two PPI tubes and an H/R tube.

44. *Mark V*. In this Mark the horn-fed cheese aerial of the earlier marks is replaced by a cylindrical parabola (20ft. × 5ft. 6in.) fed by a linear array of shunt coupled slots cut in the narrow face of the 3in. × 1in. wave guide. The spacing between the slots is $0 \cdot 55\lambda g$ (200°) at mid-band. The linear array has a tapered power distribution feeding to one quarter power at the ends. The beam width is $1\frac{1}{4}°$ vertically and 5° in azimuth.

45. *A.M.E.S. Type* 24. (*FGRI*.5595). A fixed long-range S-band height finding equipment which is ancillary to a Fighter Direction Station (A.M.E.S. Type 16).

46. *A.M.E.S. Type* 28—*Mark I*. (*ATRI*.5635). An air-transportable and tropicalised version of the CMH which can also be used as a GCI. It is suitable for use as a GCI in mountainous country and in the Pacific theatre.

47. *SCR*.615. An American S-band height finding equipment.

Radar control of aircraft from the ground

GCI (*Ground Controlled Interception*)

48. Night Fighting aircraft, unassisted by radar (Catseye Aircraft), achieve but little success against night raiders, except, perhaps over the target in bright moonlight. A successful technique of night interception (employing radar aids) has however been evolved. In the present system—the GCI—AI system—radar assistance to the night fighter is two-fold :—

(*a*) The night fighter carries a portable radar equipment which allows it to detect and " home " on to other aircraft from ranges of 4 to 5 miles and less. This airborne radar set is known as AI equipment.

(AI = Aircraft Interception.)

(*b*) Because the AI equipment has a small maximum range (4 to 5 miles) it is necessary first to vector the fighter into the vicinity of the raider and on to a favourable course so that it may detect the bomber on its AI equipment and complete the interception unassisted. The fighter is therefore controlled in the preliminary stages of an interception from a specialised radar ground station known as a GCI (Ground Controlled Interception) station. At this station the relative positions in plan and the courses of the fighter and bomber are judged from a PPI display tube ; the heights of the two aircraft are also measured. On the basis of this information the Controller issues appropriate vectors to the pilot until an AI contact is announced by the pilot or the interception is seen to have failed.

49. Our immediate concern is the nature of the GCI station. The earliest attempts at ground controlled interception were made from CH stations whose D/F and height readings proved too inexact. Later CHL stations with PPI display were employed but these, lacking in height finding facilities and possessing vertical polar diagrams with many gaps, proved equally inadequate. It was evident that specialised equipments were required. The normal GCI station is in fact similar

in many respects to a CHL station. It employs broadside aerial arrays (4 bay arrays) consisting of stacks of pairs of end-fed half-wave aerials mounted at $\lambda/8$ in front of a netting reflector. The operational frequency is 209 Mc/s ($\lambda = 1 \cdot 44$ metres). To obtain " gapless " vertical cover the station is sited on flat ground inland and transmission and reception made on one of several arrays (2 or 3) whose mean heights above the ground are such that the interference maxima (lobes) in the vertical polar diagrams of one or other of the arrays overlap the gaps in the others.

50. Thus, by feeding the arrays in turn, either at will or by rapid automatic switching, gapless cover is achieved over a wide range of elevations. The interception is therefore not vitiated by the disappearance of the fighter or raider from the PPI tube when either or both enter a gap in the polar diagram of one of the aerials.

51. The fighter is distinguished from the bomber on the display tube by its IFF (Mark IIIG) response.

52. Height finding is possible because the signals from a pair of aerials at different heights above the ground can be compared. CMH equipment is sometimes associated with the GCI to provide more reliable height data.

53. Preliminary warning of the approach of a hostile aircraft is given to the GCI station by the CH and CHL system. A GCI station is associated with each Sector of a Fighter Command Group. The chief types of GCI station are described in the following paragraphs.

54. *Fixed (or Final) GCI. A.M.E.S. Type* 7. (Frequency: 209 Mc/s.) This is the most elaborate and modern of the GCI stations. It works on a frequency of 209 Mc/s, and differs from earlier types in its ability to handle as many as 4 interceptions simultaneously, as well as in improved liaison with Sector and in the reception of information about the movement of aircraft outside the operational area of the station.

55. The aerial system is a single large broadside array mounted on a power turned frame 30ft. × 25ft. × 5ft. The broadside array is subdivided into 3 arrays which may be operated separately or in combination. Their mean heights above the ground are 7½ft., 12½ft., and 25ft. A common T/R feeder system is switched rapidly in turn, by means of a special " Capacity Switch " to the aerials in the sequence, top, middle, middle-bottom, bottom. In this way gapless vertical cover is achieved.

56. Height finding is also obtained over a range of elevations 2½° to 20°.

57. The aerial array is rotated as a whole about a vertical pillar at any desired speed between 0 and 8 r.p.m.

58. The PPI display covers a circular area with a radius of 90 miles centred on the station. Aircraft flying as low as 1000 feet are detected at a range of 30 miles.

59. The transmitter and receiver are located in an underground compartment below the aerial array, and information is distributed from the receiver to the display tubes in the main operations block.

60. A Chief Controller decides which aircraft are to be intercepted and two Interception Controllers conduct the interceptions (not more than two interceptions each at one time). In height finding the Interception Controllers are able to reject independently all signals from the aerials except those from the pair of aerials most suitable for giving the height of the aircraft. When permanent echoes are troublesome the echoes received in the lowest lobe can also be discarded.

61. There is an IFF Mark III Interrogator at each station. The transmitter is the standard CHL transmitter.

62. *GCI Intermediate Mobile. A.M.E.S. Type 8F.* This is an equipment that can be rapidly erected to provide temporary GCI cover during the erection of more permanent installation. The mobile equipment is driven to the selected site where it is housed in temporary huts except for the aerial array which is mounted on a trailer.

63. The array is known as the split 10 foot array. It is a broadside array of standard typo with its centre 10 feet above the ground. It can be operated as two equal but separate arrays, whose centres are at heights 7½ft. and 12½ft. The array can be power rotated at rates up to 6 r.p.m.

64. The display is a PPI whose radial time base is synchronised with the revolving aerial array. The operational frequency is 209 Mc/s.

65. The station reads heights between elevations of 4 to 20 degrees. Gap filling is imperfect. The maximum range on aircraft is 60 miles.

66. *GCI Intermediate Transportable. A.M.E.S. Type* 8C. (Frequency: 209 Mc/s.). The purpose of this station is the same as that of the Intermediate Mobile station. It differs from the Mobile station in its aerial system which comprises the " split 10ft." array with a second array at a mean height of 35 feet. The second array is the same as the 10 foot array but is not split. Its purpose is to increase the range of detection of low flying aircraft. The array is power driven at two revolutions per minute and can be " inched " and reversed. The transmitter is again the standard CHL transmitter T.3079.

67. *GCI Fixed Standby. A.M.E.S. Type* 19. This station is fully mobile and is intended either for use as a standby to a Fixed GCI station in the event of jamming or as a front line station. It can be operated on one of four spot frequencies, 265, 275, 285 and 295 Mc/s.

Fighter Direction Stations. A.M.E.S. Type 16.

Frequency: 580 — 600 Mc/s. (λ = 50 cm.)

68. This station was developed to assist air offensive operations over France preliminary to the Invasion. By employing a highly beamed radiation, high flying formations of friendly aircraft could be followed easily to great ranges of the order of 200 miles and their positions and heights reported to Group Headquarters and Filter Room.

69. Further, the appearance of intercepting enemy formations could be observed and the information transmitted to the friendly fighters who were enabled to gain tactical advantage.

70. The aerial is a large netting paraboloid 30 feet in diameter mounted on the aerial framework used in A.M.E.S. Type 7 (Fixed GCI). The beam scans in azimuth by rotation of the whole aerial frame and in elevation by oscillating the dipole that is used to feed the reflector up and down about the principal focus of the reflector ten times per second.

71. The transmitter, receiver and monitor cathode ray tube are housed in a cabin mounted on the back of the aerial frame. The transmitter used is the NT.99 transmitter. The reporting room is some 200 feet away from the aerial and houses the display tubes, plotting tables etc.

72. The width of the beam is about 5° from the maximum to the first zero on either side, both in azimuth and elevation.

73. Gap free coverage is obtained at elevations above 2° since the beam " clears " the ground. Below 2° an interference pattern with lobes and gaps results but the maximum range of detection is increased.

74. The axis of the paraboloid reflector is tilted at an elevation of 5° and the oscillation of the dipole in the focal plane swings the beam to ±3½ degrees of this elevation, thus giving a vertical cover of 0 to 10 degrees.

75. Height finding, from the elevation of the beam, is obtained over the range of elevations 2½—10 degrees with a probable accuracy of ±0·3 degrees.

76. The maximum range is 100 miles for gapless cover and 200 miles in the lobe and gap radiation pattern at low angles.

77. The array sweeps in azimuth at a maximum speed of 11 degrees per second over the operational arc and is speeded up over the non-operational portion of the sweep.

78. *MEW* (*AN/CPS.* 1). ($\lambda = 10 \cdot 7$ cm.) is an American S-band early warning general purpose equipment which can be used as a Fighter Direction Station. Height finding is then obtained from an associated A.M.E.S. Type 24 equipment. It uses an array of dipoles fed directly from a wave guide. Maximum range 100 miles.

Miscellaneous systems and equipments

79. *A.M.E.S. Type* 21

(*a*). *Mark I* (*FGRI.*5258) is an S-band equipment, giving plan position and height, which is used at a Fixed GCI station to combat certain forms of jamming (Window).

(*b*). *Mark II* is a mobile S-band GCI equipment used by the A.E.A.F. as an anti-Window equipment. It is a combination of A.M.E.S. Type 13 Mark II and the A.M.E.S. Type 14 Mark III aerial vehicle.

(*c*). *Mark III* is similar to Mark II but uses A.M.E.S. Type 13 Mark III.

80. *A.M.E.S. Type* 22

(*a*). *Mark I* (*MGRI.* 5579) is a combination of A.M.E.S. type 13 Mark II and the A.M.E.S. Type 11 aerial vehicle. It is a GCI equipment for general use anywhere, the Type 11 providing gap-filled plan position and the Type 13, accurate height finding.

(*b*). *Mark II* as Mark I, but with A.M.E.S. Type 13 Mark III.

(*c*). *Mark III* is a combination of A.M.E.S. Type 13 Mark IV and the A.M.E.S. Type 11 Mark III aerial vehicle.

(*d*). *Mark IV* is A.M.E.S. Type 13 Mark IV and the aerial vehicle of A.M.E.S. Type 11 Mark IV.

81. *A.M.E.S. Type* 23. See Loran.

82. *A.M.E.S. Type* 25, is a mobile convoy containing A.M.E.S. Type 11 Mark II(M), A.M.E.S. Type 15 Mark II (200 Mc/s GCI) and A.M.E.S. Type 21 Mark II.

83. *A.M.E.S. Type* 70 is a recent long range general purpose detection and control system. It is an S-band equipment employing modified Type 14 aerials to give greater vertical beaming and thus greater range.

Ground control of flying for approach to airfields

GCA (*Ground Control Approach*)

84. *Mark II* (*AN/MPN.*1). This is an American system for precision control of aircraft to permit blind approach to an airfield.

85. The control is of two types. Between 9 and 15 miles the aircraft are controlled from the PPI display of an S-band equipment, over the R/T using one of two frequency channels (channel A).

86. A selected aircraft is then brought in to land and at a range of 6 to 9 miles it is controlled over a second R/T channel (channel B) from a highly beamed X-band ($\lambda = 3$ cm.) equipment. This is a double equipment producing a pair of fan-like beams, the one beamed in the vertical plane and the other in the horizontal.

87. An accurate measurement of the aircraft's azimuth and elevation is obtained and also the deviation of the aircraft from the correct glide path. The necessary corrections are given to the pilot over channel B of the R/T by the controller.

88. *SCR.*584. (*MGRI.*5660). ($\lambda = 10 \cdot 7$ cm.). This is an American GL (Gun Laying) equipment which can be adapted to direct aircraft on blind bombing missions and reconnaissances for Close Range support of troops.

ACR. (*Air Control Radar*). *Formerly GCF.*

89. This is an equipment that provides a plan position display, to the controller of an aerodrome, of the traffic in the vicinity. The information supplied serves to speed up landing and to improve the efficiency of traffic control.

90. *Mark I* (*FGRI*.5656). Is a fixed installation used in Bomber Command. It uses the American S-band ASV equipment SCR.517B in a modified form.

91. *Mark II* (*MGRI*.5678). Is a mobile form of Mark I, which uses SCR.717B unmodified (an ASV equipment on S-band). The equipment is housed in a 3-ton Bedford Signals Vehicle.

AIRBORNE SEARCH AND GUN LAYING DEVICES

AI (Aircraft Interception)

General

92. As mentioned in the paragraphs on GCI, the most effective method of interception at night at present is to use AI equipped night fighters under GCI control.

93. AI equipments are airborne radar sets installed in night fighters (usually two-seater aircraft) to enable them to detect and intercept enemy aircraft under conditions of poor visibility. In practice the Radio Navigator operates the AI and interprets the display to the pilot. Since the maximum range of detection of existing forms of AI is small (4 to 6 miles) most interceptions involve GCI control in the early stages, but " free-lance " AI aircraft have achieved some measure of success and as the maximum ranges of equipments are improved, " free-lancing " will probably assume greater importance as a method of interception.

94. Owing to the unsatisfactory state of the art of radar identification, the fighter relies on visual identification of the target before attempting to shoot. However, AI equipments with blind firing facilities have been developed, but are not in use.

95. A review of the principal Marks of AI follows. All Marks greater than VI employ centimetre wavelengths. Fuller descriptions are given in Part II of this manual.

AI Mark IV (*ARI*.5003)

Frequencies: 188-198 Mc/s. ($\lambda = 1\frac{1}{2}$ metres approx.)

96. This was the first satisfactory Mark of AI and it achieved many successes against night raiders during the periods of heavy raids on Britain. Vertically polarised pulses are radiated from a transmitting aerial in the nose of the aircraft and the radiation is crudely beamed forwards although it spreads to a less degree downwards and backwards.

97. Reception is made on two pairs of aerials. The pair of azimuth aerials are mounted, one each, on the leading edge of each wing.

98. A switch motor selects in turn the signals received on these aerials and allows the echoes to be shown side by side on a split display (Chap. 3). A comparison of the relative sizes of these echoes indicates the azimuth of the raider.

99. The second pair of aerials, the elevation aerials, are mounted above and below one of the wings. A switch motor and a second " split display " tube allow elevation to be judged from the echoes received by this pair of aerials. Range is obtained from the display tube of either pair.

100. All $1\frac{1}{2}$ metre AI equipments suffer from serious operational defects, namely, the maximum range is small — (3 miles), and, ground returns.

101. The relatively long operational wavelength of $1\frac{1}{2}$ metres makes beaming of the transmission difficult. Consequently energy is radiated in unwanted directions, in particular downwards to the ground. The intense echoes received from the ground obliterate aircraft echoes on the time base at ranges that exceed the height of the fighter above the ground. Thus AI Mark IV was effective when raiders operated at 15,000 feet and above, but proved relatively ineffective against the low flying tactics subsequently adopted by the enemy.

102. For these reasons Mark IV has been largely replaced by AI equipments that use highly beamed transmissions. Mark IV has facilities for IFF interrogation, Homing Beacons and Blind Approach.

AI Mark V (*ARI*.5005)

103. This is a $1\frac{1}{2}$ metre equipment designed for single seater fighters. It contains a " pilot indicator " fed from a " split display " by means of an automatic strobe. It is obsolescent.

AI Mark VII (*ARI*.5049) — *Prototype AI on centimetre wavelengths*

($\lambda = 9 \cdot 1$ cm. — S-band)

104. Although AI Mark VII was developed as an interim equipment of which only a very small number of sets were constructed, yet it is of the greatest historical and operational interest in representing the first centimetre wave radar equipment (airborne) to become operational. It first went into service at the end of 1941 and immediately achieved significant success.

105. Centimetre wave AI equipments were developed in the first instance to provide an AI free from the limitations of AI on $1\frac{1}{2}$ metres. At the short wavelength of 9 centimetres and less it is possible to produce a highly beamed radiation and directional reception from aerials of dimensions small enough to be carried in an aircraft. In this way unwanted returns from the ground are rendered innocuous so that the equipment can be used with success against raiders operating at any height.

106. Further consequences of the intense beaming are, increased maximum range (4 — 6 miles), more accurate indications of azimuth and elevation, and improved display systems that can be easily interpreted.

107. The aerial system is a reflecting paraboloid fed from a half-wave aerial–coaxial line system. The beam width is about 6° and the scanning mechanism causes the beam to explore the interior of a conical region of space in front of the aircraft. The axis of the cone is the line of flight and the scan extends to 45° from it.

108. This type of scan is called a " spiral scan." The display employs a radial time base synchronised with the motion of the paraboloid. From it the range and direction of the target can be readily found.

109. The transmitter was an early type of magnetron CV.38 giving a peak pulse power of 5 kW.

AI Mark VIII (*ARI*.5093)

($\lambda = 9.1$ cm.)

110. This equipment, which is now in use, is a development of AI Mark VII that incorporates additional facilities and operates with more power. The scan and presentation are virtually the same as in Mark VII but the equipment has IFF and Beacon facilities.

111. Its magnetron CV.64 produces a 25 kW pulse. The maximum range is 5 to 6 miles, and the minimum range 400-500 feet.

AI Mark VIIIA (*ARI*.5093*A*)

112. This is a pre-production version of AI Mark VIII.

AI Mark VIIIB (*ARI*.5588)

113. This equipment incorporates Lucero for use with $1\frac{1}{2}$ metre Beacons, BABS and IFF.

AI Mark IX (*ARI*.5507)

114. This is not in service. It is under development and will incorporate automatic lock-follow facilities.

115. It uses a range-azimuth display (Chapter 3, para. 3). A development incorporates roll stabilisation of the scanner Later modifications also provide blind firing facilities.

AI Mark X (*SCR*.720, *ARI*.5570)
(S-band)

116. This is an American AI equipment which has come into general use in British night fighter aircraft in parallel with AI Mark VIII. The maximum range of the equipment is 6 miles, and minimum range 400-500 feet.

117. It uses a different scan and display from AI Mark VIII. The scan is a helical scan and two presentation tubes are employed, the one a range-azimuth tube and the other an azimuth-elevation tube.

AI Mark XI (*AIX*, *ARI*.5552)

118. This is an X-band (3 cm.) equipment developed for use in the Fleet Air Arm.

AI Mark XII (*ARI*.5646)

119. This is an improved version of AI Mark XI.

AI Mark XIII (*ARI*.5647)

120. This is a light weight version of AI Mark XI.

AI Mark XIV (*AN/APS*.6, *AIA*-1)

121. This is a pilot operated X-band equipment. It has X-band Beacon facilities.

ASV (Aircraft to Surface Vessel)

General

122. The purpose of ASV is to detect ships from aircraft at greater ranges than is possible by eye and under conditions of poor visibility. Such equipments are installed in aircraft of Coastal Command and the Fleet Air Arm to assist in the location of submarines, ships, and convoys. The earliest models employed a frequency of 176 Mc/s (1·7 metres) but their performances were inadequate. Recent Marks all work on the S or X wavelength bands (9·1 or 3 cm.) and are far more effective than the 1·7 metre ASV.

123. As the principle of the centimetre wave ASV is the same as that of H_2S it will not be described here. The principal types of ASV equipment are described in the following paragraph.

ASV Mark II (*ARI*.5002)
176 Mc/s (1·7 metres)

124. This was the earliest form of ASV to be put into operation. Its action is similar to AI Mark IV: a transmitter irradiates the surface of the sea in front of the aircraft from a transmitting aerial which produces a small degree of beaming. (Generally a Yagi aerial although not always). The echoes are received on a pair of aerials carried on the wings and by use of a rotating switch and a split display, the bearing and range of a surface target may be judged. The equipment resembles, in principle, AI Mark IV without its elevation aerials.

125. The equipments varied somewhat according to the type of aircraft, more especially in respect of aerial installations.

126. The equipment enjoyed beacon facilities and it formed a valuable homing device. Typical ranges are :—

Range on ship	up to 12 miles
„ „ coastline	50 — 70 miles
„ „ beacons	80 — 90 miles
„ „ BABS beacons	20 miles at 1000 feet.

Centimetre Wave ASV

127. In these equipments the surface of the sea is irradiated by a beam from a reflector scanning below the aircraft. The beam is narrow in azimuth but extends in the vertical plane from a direction almost vertically below the aircraft out to the horizon.

128. In X-band equipments the beam in the vertical plane is narrower and the surface of the sea out to the horizon is not covered in a single rotation of the reflector.

129. Objects on the surface of the sea are shown on a PPI display in the aircraft and coastlines are clearly depicted as a map so that the equipment can be a valuable navigational aid, and also a blind bombing device.

130. The heading of the aircraft is indicated on the PPI.

131. The best ranges obtained at present on fully surfaced submarines by a centimetre wave ASV (ASV Mark X — X-band) are of the order 20 to 35 miles according to aspect.

ASV Mark III (*ARI*.5119)

132. This was an S-band equipment similar to H_2S Mark I.

ASV Mark IIIA. (*ARI*.5153)

133. This is a 50 kW S-band equipment similar to H_2S Mark IIA. It carries Lucero TR 3190 or TR.3160, to provoke 1½ metre beacons, BABS and IFF.

ASV Mark V (*ASG*-1)

134. This is an American S-band equipment.

ASV Mark VA (*ASG*-3, *AN/APS*.2)

135. This is an improved version of ASV Mark V with increased power.

ASV Mark VI (*ARI*.5568)

136. This is a high power (200 kW) S-band equipment with an attenuator to control the radiated power. It carries Lucero TR.3566 for use with 1½ metre Beacons, BABS and IFF.

ASV Mark VIA

137. This is similar to ASV Mark VI but incorporates automatic lock follow.

ASV Mark VIII (*ASD*)

138. This is an American X-band equipment.

ASV Mark VIIIA (*ASD*-1, *AN/APS*.4, *ARI*.5607)

139. This is a lightweight American X-band forward locking equipment for use in the Fleet Air Arm. It is built in the form of a bomb and can be jettisoned if necessary.

ASV Mark X (*AN/APS*.15, *ARI*.5652)

140. This is an X-band all-round locking equipment of American design.

ASV Mark XI (*ASVX Mark I, ARI*.5553)

141. This is an X-band equipment for the Fleet Air Arm.

ASV Mark XII (*ARI*.5614)

142. This is the same as AI Mark VIIIB modified to possess automatic ranging facilities. It carries Lucero TR.3549.

ASV Mark XIII (*ARI*.5650)

143. This is ASV Mark XI improved by greater power output, better indicator, a ranging unit for attack and all-round locking scanner. The equipment is designed for aircraft of the Fleet Air Arm, and for Coastal Command Mosquitos.

ASV Mark IIIA (ARI.5603)
144. This is similar to ASV Mark XIII but carries a forward locking roll-stabilised scanner. For use in Coastal Command.

ASV Mark XIV (ARI.5637)

145. This equipment resembles Mark XIIIA but includes a completely stabilised (for roll and pitch) all-round locking scanner and incorporates the ASV Bombsight Mark V.

ASV Mark XV (ARI.5578)
146. This is lightweight X-band equipment for the Fleet Air Arm.

ASV Mark XVI (ARI.5663)
147. This is an S-band ranging device containing an American LHTR (light-weight Lighthouse valve transmitter-receiver) Unit and the British Strobe Unit Type 68.

AGLT (Airborne Gun Laying Turret) — (Formerly " Village Inn ")

148. AGLT is a centimetre wave (S-band) equipment installed in heavy bombers which also carry H_2S.

149. Its purpose is to provide the rear gunner with data about the position of enemy fighters attacking the bomber and to assist him to train his guns and to open fire on an unseen target with an accuracy of half a degree.

150. The AGLT also provides a warning to the whole crew, in the form of a " pipping " note injected into the intercommunication system. The frequency of the " pipping " gives a crude indication of the range of the attacking fighter.

151. The AGLT equipment can also feed information to the Gyro Gun Sight (Mark IIC) which then predicts the appropriate sighting allowance that must be made. This is usually performed by the crude method of firing tracer or by guess work. AGLT supplies among other data, the important quantity—the range of the fighter.

152. The gunner is given a " spot indicator " display (Chapter 3) which indicates the direction of the target and, by growing " wings," its range. An image of the display is thrown on to the plane of the gunsight graticule so that the gunner may sight on to the spot just as if he were sighting on to an actual aircraft in daylight. Early warning of the proximity of an attacking fighter is given to the rear gunner by the " Fish Pond " operator.

AGLT Mark I (ARI.5559)
153. The scanner is fixed to turret and linked mechanically to the guns. Equipment uses a Gyro Gun Sight.

AGLT Mark III (ARI.5562)
154. Provides continuous search and automatic change from search to lock-follow with the scanner attached to the airframe and not to the turret.

AGLT Mark IV (ARI.5632)
155. Is a miniature automatic equipment. It uses miniature components and is independent of the aircraft H_2S.

Harmonisation Equipment
156. Is an apparatus used to line up the AGLT equipment on the ground. It provides an artificial echo which allows the radar axis of the scanner to be made the same as that of the gun-sight.

Liquid Lunch. (ARI.5608)
157. Is a recognition system to be carried by bombers, which reveals them as friendly aircraft to the rear gunners of other bombers carrying AGLT. The recognition will probably be provided by a lamp which lights when the beam from the AGLT scanner strikes the friendly bomber.

IDENTIFICATION

IFF (Identification Friend or Foe)

General

157. It is important, in general, to know whether an echo on the display tube of a radar equipment comes from a friendly or from a hostile aircraft. To assist the identification of responses from friendly aircraft, a system of recognition known as IFF has been adopted. In essence this system permits the echo from a friendly aircraft to be given some distinguishing feature such as a periodic increase in size, or an associated mark or set of marks which appears on the display tube.

158. In the earliest operational IFF system, Mark II, friendly aircraft carried a special receiver-transmitter which received the pulses transmitted from the radar station and re-radiated them from the aircraft with inappreciable delay and with enhanced strength. Since the IFF set was periodically swept through the tuning band of the radar station the echo on the display was seen periodically to increase in size thus affording a means of identification.

159. This system which was suitable for the early needs of ground radar proved inadequate for later developments and was replaced by the IFF Mark III system.

160. In this system the aircraft still carries a receiver-transmitter which is however not stimulated by the actual normal pulses transmitted from the radar station. Instead, at the radar stations special interrogator transmitters and receivers working on a frequency different from the radar detection frequency can be operated at will to excite the airborne receiver-transmitter and to receive responses from it. Since the pulse recurrence frequency of the interrogator usually bears some simple relation to that of the radar station itself, the IFF responses can be displayed on the display tube along with the normal aircraft echoes that they serve to identify. Sometimes a separate IFF display is used. Some form of coding is generally adopted.

161. *Ground IFF installation.* This comprises, as mentioned, a transmitter called the Interrogator and a receiver.

162. *Transponder.* This is any device which receives a pulse from an external interrogator and transmits a coded reply. Thus the airborne IFF set is a transponder.

163. *Identification and Recognition.* Identification is the term applied to a universal IFF system (e.g. Mark III) but Recognition is the term applied to a local system associated with one equipment only (e.g. Liquid Lunch).

IFF Mark III (*ARI.*5025)
(157 — 187 Mc/s)

164. It gives a coded return to ground station interrogators and to airborne interrogators sweeping through the 157-187 Mc/s band. The American version is ABK (SCR.595).

IFF Mark III GR. (*ARI.*5131)

165. Is similar to Mark III but possesses a second frequency channel permitting it to give identification to GCI and CHL stations. The channel may be adapted to provide " Rooster " (Airborne beacon) facilities.

IFF Mark III Q. (*ARI.*5640)

166. Is a recent development purporting to give greater flexibility and security.

*SCR.*695 (*ABF*)

167. Is the American version of Mark IIIG. It possesses a second channel for GCI. It is modified in Europe to avoid interference with Lucero. The modified set is called Receiver R.3598 (ARI. 5628).

AN/APX-1

168. Is an American form of IFF Mark III G/R using miniature valves.

AN/APX-2 (ABJ, ARI.5669)

169. Is similar to AN/APX-1, but carries an interrogator-responder for interrogation of IFF in other aircraft and in ships, and long-range beacons.

AN/APX8 (ARI.5670)

170. Is AN/APX-2 with the addition of an AN/APA-1 indicator and an aerial system with "split."

IFF Mark IV

171. Is an American system on 400 Mc/s. It will probably not be used.

IFF Mark V

172. Is a system under development in America which it is hoped will be ready for use in 1947. It operates on 1000 Mc/s. It will possess greater security, greater traffic handling capacity and greater discrimination than IFF Mark III.

Lucero

173. This is not only a system of identification required between ground radar stations and aircraft, but also between one aircraft and another. For this reason a special airborne interrogator called Lucero has been developed to interrogate IFF equipments in aircraft. It also interrogates Homing Beacons and can be used with systems of Blind Approach.

174. Several versions exist to cover the range of aircraft voltages and the various intermediate frequencies found in airborne radar equipments.

Lucero Mark I

175. Interrogates IFF, Beacons and Beam Approach on a single frequency. The varieties are :—

- (i) TR.3190 for use with ASV Mark III.
- (ii) TR.3196 for use with ASVX in 12-volt aircraft of the Fleet Air Arm.
- (iii) TR.3197 for use with ASVX in 24-volt aircraft.
- (iv) TR.3526 for use with AIX pre-production equipment.

Lucero Mark II

176. Is a multi-frequency interrogator. The varieties are :—

- (i) TR.3160 and TR.3160A for use with H_2S Mark II and ASV Mark III.
- (ii) TR.3505 for use with AIX and ASVX in 24-volt aircraft of the Fleet Air Arm.
- (iii) TR.3507 for use with ASVX in 12-volt aircraft.
- (iv) TR.3532 for use with AI Mark IX.
- (v) TR.3566 and TR.3566A for use with ASV Marks V, VI, and VII and with H_2S Mark III.
- (vi) TR.3549 and TR.3549A for use with AI Mark VIIIB and ASV Mark XII.

AIRCRAFT NAVIGATIONAL AIDS AND BLIND BOMBING SYSTEMS

General

177. The radar equipments that we have discussed hitherto have been concerned with the detection and location of aircraft. Radar techniques have also been applied, with perhaps even more remarkable results, to assist the navigation of aircraft under any conditions of visibility. In the following paragraphs we shall summarise the principal systems in use and their characteristic features.

The Gee—7000 system

178. In this system, the code name Gee refers to the airborne units whereas the stations A.M.E.S. Type 7000 are ground stations.

179. The Gee-7000 system was introduced in 1941 to provide a more reliable and accurate system of navigation over enemy territory than the older methods of dead reckoning and astro-navigation Its outstanding operational advantage lies in its ability to handle any number of aircraft simultaneously. Over this country navigation by Gee is very accurate, and the system forms a valuable " homing " aid to bomber aircraft returning from operational flights.

180. At greater ranges from base the accuracy is less than that obtainable by other methods discussed below.

181. The Gee system provides a method of aircraft navigation in which the aircraft measures the difference between its ranges from two ground stations (A.M.E.S. Type 7000).

182. Imagine two ground stations A and B, each transmitting a regular set of radar pulses, one set locked to the other. An aircraft receiving these pulses can measure the time interval between their arrival. This will immediately give the range difference of the aircraft from A and B, and so will fix the latter along one set of confocal hyperbolic curves drawn with A and B as foci. A third ground station at C working in conjunction with A will give a further set of hyperbolae and the complete fix is given as the point of intersection of the appropriate curves of the AB set and the AC set. To overcome any ambiguity arising from a double cut of the curves, a further station, D, can be provided. The ground stations pulses are maintained in the same fixed phase relationship by a radio lock arrangement, pulses from the station A being picked up by the other ground stations as well as by the aircraft, and being used to synchronise the stations B, C and D. The station A is known as the Master Station while the stations B, C and D are called Slave Stations.

183. The wavelength on which Gee stations work is of the order of 6 or 7 metres.

184. It is clear that the Gee system virtually lays a radio mesh over a selected region of the earth's surface, so that the four ground stations can supply any aircraft with a fix provided that it carries a suitable receiver, and is within range of the ground transmitters. Its great merit is that any number of aircraft can use the system at the same time, or in other words the system does not saturate. The accuracy falls off as the distance from the ground stations increases, but the system has been used for navigation at ranges as great as 500 miles. Wind correction can be obtained by taking successive fixes.

185. The airborne equipment (Gee) comprises a special receiver and indicator. No transmissions from the aircraft are required.

186. A set of ground stations comprising a master, a monitor and three slave stations is called a Gee-7000 Chain. There are five chains, sited to cover different regions of Europe. The principal types of Gee-7000 equipments are as follows :—

Fixed Ground Stations

187. A.M.E.S. Type 7000 (Chain Stations).

A.M.E.S. Type 7000 — *Heavy Mobile*

138. A ground station composed of mobile units. It comprises a Master Convoy and a pair of Slave Convoys.

Gee Mark I (*ARI.*5033)

188. This equipment is obsolete.

Gee Mark II (*ARI.*5083)

189. This is the only Gee equipment in service.

Gee Mark IIT (*TGRI.*5337, *MCRI.*5358)

190. Modification of Gee Mark II to work from 50 cycle mains for ground training or for use in ships.

Gee-R (*ARI.*5342)

191. Is Gee Mark II with an additional unit that re-radiates the signals from the 7000 stations to a distant observer with a second Gee receiver tuned to the re-radiated frequency. This permits

the position of the aircraft to be determined from the ground. The additional unit was known as Speckled Band or Gee Send-Back.

Loran (Long Range Navigation)

192. Loran is an American system based on the same principles as Gee-7000 but providing longer ranges. The arrangement of the ground stations is different from that of a type 7000 chain. A number of ground stations operate together. Each station is the slave of one of its neighbours and the master of the other. Each master-slave pair operates on a specific pulse recurrence frequency and the time base of the aircraft equipment can be run to select any one of these recurrence frequencies. Two co-ordinate " fixes " are obtained from two " master-slave " pairs examined in turn. Thus " running " fixes only are obtained. There are two methods of operation—Loran and S.S. Loran. The frequency is 2 Mc/s.

(*a*) *Loran.* The ground stations (master-slave pairs) employ ground waves only but the aircraft or ship may obtain a fix from a ground wave (maximum range 600 miles) or from a sky-wave reflected from the E-layer (maximum range 1200 miles).

(*b*) *S.S. Loran.* Is an adaptation suitable for use by ships. The ground stations are more widely spaced than normal Loran stations and the master-slave pairs rely on sky-waves for synchronisation. The aircraft or ship obtains its fix from a sky-wave reflected once from the E-layer. The system is limited to use at night.

A.M.E.S. Type 700

193. These are Loran stations in the United Kingdom operated by the R.A.F.

A.M.E.S. Type 23

194. These are Loran stations controlled by the R.A.F. in North Africa, and form part of the European S.S. Loran system. These stations are identical with A.M.E.S. Type 700.

AN/CPN-11 *and AN/CPN*-12

195. These are light-weight ground stations.

Loran Mark I (*AN/APN*-4, *ARI.* 5267)

196. This is the airborne receiver and indicator in current use. Its shape, size and cable connections are such that it is interchangeable with Gee.

Loran Mark II (*AN/APN*-9)

197. This is the same as Mark I in function but will be built into a single unit the size of the present indicator.

The Gee-H system

(Gee airborne equipment with " H "-principle ground stations).

198. Whereas in the Gee-7000 system a fix is determined in essence from the differences in ranges between the aircraft and fixed ground stations, in the Gee-H system a fix is obtained directly from the ranges themselves in the form of a range-cut. The ground stations are in this case a pair of radar beacons which are interrogated by a transmitter carried in the aircraft. The beacons, which are located at the ends of a known baseline, retransmit the pulses received from the aircraft on a different frequency and these retransmitted pulses are received and displayed the normal Gee equipment of the aircraft.

199. The system may be regarded as an IFF system in reverse, with the aircraft interrogating and finding the ranges of the ground beacons from it. This is the H-principle.

200. Range cuts then tell the aircraft its position. This system is more accurate, at long ranges, than Gee-7000 but its maximum range is less. Moreover, the number of aircraft that can use a pair of beacons simultaneously is limited to about 30. Since the aircraft carries a Gee receiver it may also use the ordinary Gee-7000 system. The accuracy is such that the system can be used for blind bombing.

A.M.E.S. Type 100

201. This is a heavy ground equipment. Fixed and mobile forms exist which provide H-service.

A.M.E.S. Type 100 — *Light Transportable.* (*TGRI.*5615)

202. This is a ground equipment designed for transport in a van or by air. It is suitable for operation in the tropics. This equipment can be used either as a 7000 system or an H-system or both together.

Gee-H Mark I (*ARI.*5525)

203. This is an interim airborne equipment at present in use. It includes a Gee Mark II receiver, a modified Gee indicator, a modified AI Mark VI transmitter and modulator.

Gee-H Mark II (*ARI.*5597)

204. This is an improvement on Mark I. It has an extended frequency range, a high power transmitter (T.1629) and modulator, and a redesigned indicator system which can also serve as a Rebecca or BABS.

205. The combination of Gee-H Mark II and Rebecca Mark IIU is known as ARI.5611.

Shoran (Short Range Navigation)

206. This is an American blind bombing equipment employing the H-principle. AN/CPN-2 is the ground equipment. AN/APN-3 is the airborne equipment. Information obtained from the radar units is automatically fed into computors which control the flight of the aircraft and release the bombs.

Oboe-Type 9000

(Oboe refers to the Airborne Equipments and Type 9000 to Ground Stations).

207. The Oboe-9000 system is an accurate blind bombing and target marking system in which the aircraft is controlled from, and the bomb release signal is given by, two ground stations.

208. The ground stations perform different functions. The one, the Cat (or tracking station) controls the aircraft and causes it to fly on a path that will bring it over the target, and the other, the Mouse (or bomb release station), provides the signal for the bomb release.

209. The aircraft carries a transponder that returns the ground station responses, greatly enhanced, in order to increase the range of operation. The pilot is maintained on the correct bombing course by aural indications from the Cat station, and the bomb aimer is warned by the Mouse station.

210. The system employs, in essence, the range cut principle, but the control of the aircraft is entirely the responsibility of the ground stations. The early stations could only handle one aircraft at a time but Mark III stations permit several aircraft to be controlled simultaneously. The aircraft (usually Mosquitos) operate at great heights (20,000 to 30,000 feet). The maximum range of operation is about 250 miles but by the use of intermediate relay aircraft the range can be considerably extended. The various types of Oboe-9000 equipment are described in the following paragraphs:—

A.M.E.S. Type 9000 *Mark I* (*FGRI.*5534)

211. This is the original system working on 1½ metres The original stations have been modified to work on two frequencies at once to defeat jamming (Latched K working).

Oboe Mark I (*ARI.*5513)

212. This is the airborne equipment used with Type 9000 Mark I stations.

A.M.E.S. Type 9000 *Mark II* (*FGRI.*5606)

213. This is an S-band ground station using modified American ASG-3 transmitters and receivers. Space modulation is used to control the aircraft.

A.M.E.S. Type 9000 *Mark IIS* (*MGRI.*5653)

214. An interim S-band mobile equipment.

A.M.E.S. Type 9000 *Mark IIX* (*MGRI.*5655)

215. This is SCR.584 adapted to Oboe use. Two sets only in operation.

Oboe Mark II (*ARI.*5582)

216. This was formerly known as Album Leaf. It is an S-band airborne equipment comprising the British receiver (R.3540) and an ASG-3 transmitter and modulator. Works with either width or space modulated type 9000 stations.

Oboe-R (*ARI.*5605)

217. This was formerly known as Album Leaf II. It is installed in relay aircraft for increasing the operational range. It is essentially two sets of Oboe Mark II.

A.M.E.S. Type 9000 *Mark III* (*FGRI.*5565)

218. This is an S-band ground station with multiple display units associated with different pulse recurrence frequencies feeding into a common radio frequency equipment.

219. This station can control several aircraft each of which carries a p.r.f. selector. (Filter Unit Type 166).

Oboe Mark III

220. This is Oboe Mark II with a p.r.f. selector (Filter Unit Type 166) fitted. It works with width modulated ground stations.

H_2S (Centimetre wave navigational aid and blind bombing device)

General

221. The radar navigational systems that we have considered above, all comprise an airborne equipment and ground stations. In each case transmission of pulses from the ground is an essential feature of the methods.

222. In H_2S, the device which now concerns us, the equipment is entirely airborne and independent of transmissions from the ground.

223. As mentioned, the first operational centimetre wave equipment was AI Mark VIII whose purpose was to assist night fighters to intercept raiders.

224. It was observed that on the display tube of this equipment, there were echoes from the ground, or ground returns, which arose when the beam of radiation in the course of scanning was directed down on to the earth. This display of the ground returns proved to be an aid to navigation in providing a " horizon." More important, however, it was observed that the intensity and form of the ground returns depended on the character of the earth beneath, those from the sea being different, for instance, from the returns from land.

225. It was suggested that in a specially designed equipment the ground returns could be used primarily as an aid to navigation. Successful equipments using ground returns as aids to navigation are in common use and are called H_2S equipments. (In Coastal Command the same principle is used in ASV equipments whose Mark numbers exceed II).

226. An H_2S equipment radiates pulses from a scanner which produces a high degree of beaming in the horizontal plane but a relatively broad beam in the vertical plane. Consequently the beam extends in the vertical plane from a direction vertically downwards out to the horizon, but intersects the ground itself in a narrow band.

227. As the scanner rotates, this band rotates about a point directly below the aircraft and sweeps the whole surface of the ground out to the horizon during each complete rotation of the scanner. The returns scattered back from the ground are displayed on a PPI tube and provide a crude map of the territory below the aircraft.

228. It is found that towns, containing as they do a great many upright plane surfaces, give relatively intense returns which stand out on the display relatively brightly compared with the returns from the normal countryside. Again, the returns from the sea and from lakes are very feeble, so that the appearance of a coastline, an estuary or an island is easily recognisable on the display.

229. In a true map we are concerned with ground range, but the radar equipments provide slant ranges of which the ground range is the projection. Consequently the H_2S map on the PPI tube is distorted, especially near the origin. In particular, returns from the ground immediately below would normally be displayed at a range equal to the height of the aircraft above the ground and not at the centre of the tube which corresponds to zero map range. To bring zero map range to the centre of the tube the time base can be adjusted at will to start late by any time depending on the height. This to some extent overcomes the distortion. However, in recent Marks of H_2S the time base is made to sweep at a speed which is not constant and so adjusted that the distortions are compensated.

230. The H_2S is important in providing true ground speed and permitting wind drift to be estimated. The height of the aircraft is also given from the ground returns from immediately below. The equipment can thus be used as a blind bombing device. In recent developments the H_2S. and D.R. compass readings are fed automatically to the bombsight.

231. On the S-band of wavelengths ($\lambda = 9 \cdot 1$ cm.) the definition is poor since insufficient horizontal beaming is achieved. On the X and more recent bands a greatly superior " map " is obtained.

232. It is found that as the aircraft rolls and pitches the display tends to " smudge " and to lose definition. Consequently, in recent marks of H_2S, devices are incorporated for stabilising the display to avoid this effect.

Fish Pond

233. In H_2S equipment the first signal to return is that from the ground immediately below the aircraft, and nothing except the echo of an airborne object can appear on the display at a range less than the height of the aircraft. This causes a hole to appear in the centre of the map on the display tube. Bombers often carry an auxiliary equipment, known as Fish Pond, which makes use of this hole. A portion of the H_2S signal is fed into the Fish Pond unit and displayed on a PPI tube as a map of considerably larger scale than the H_2S map, so that the central hole almost fills the whole tube. Any other aircraft flying between the bomber and the ground can be seen easily, and the unit forms a valuable warning device. It was referred to in the paragraphs on AGLT. It is fitted into the wireless operator's compartment.

*H_2S Mark I (ARI.*5119)

234. This was the original S-band equipment and is now obsolete.

*H_2S Mark II and IIA (ARI.*5153)

235. These are the existing S-band equipments. Mark II has a dipole feed to the scanner and Mark IIA a waveguide feed. They can use Lucero TR.3160.

*H_2S Mark IIB (ARI.*5560)

236. This is Mark IIA with Fish Pond added.

*H_2S Mark IIC (ARI.*5590)

237. This is Mark IIB with, scan distortion correction (provided by Indicator Unit Type 184), roll stabilisation of the scanner and with the display of a drift marker.

*H_2S Mark IID (ARI.*5598)

238. This is Mark IIB with the addition of scan distortion correction (by using Indicator Unit Type 184).

*H_2S Mark III (ARI.*5564)

239. This is an X-band (3 cm.) equipment similar to Mark IIB. It incorporates Lucero TR.3566.

H_2S Mark IIIA (ARI.5583)

240. This is a modified form of Mark III. Indicator Unit Type 183 eliminates scan distortion. It has roll stabilisation of the scanner and the display of a drift marker.

H_2S Mark IIIB

241. This was an interim equipment between Mark III and Mark IIIA.

H_2S Mark IIIC

242. This equipment resembles Mark IIIA, but uses a 6-foot array to provide high definition.

H_2S Mark IV (ARI.5566)

243. This is a redesigned X-band equipment. It is linked to the Mark XIV bombsight.

H_2S Mark V (AN/APS.15, ARI.5652)

244. This is an American equipment (see ASV Mark X).

H_2S Mark VI (ARI.5619)

245. This is a high discrimination equipment.

H_2S Mark VIII (ARI.5599)

246. This is an equipment at present under development.

Swan Song (MCRI.5563)

247. This is an adaptation of H_2S Mark II for use in Naval Landing Craft.

Monica (Backward looking warning device for Bombers)

248. Although Monica is not a navigational aid it is convenient to interpolate it here as an airborne equipment carried by bombers.

249. It employs equipments similar to ASV Mark II and AI Mark IV, which radiate from the tail of the bomber and give warning of the approach of other aircraft. Originally a crude aural warning was given but in more recent equipments a cathode ray tube is used which gives the range and direction of the approaching aircraft.

Monica Mark I (ARI.5122)

250. This type is now obsolete ; frequency 225 Mc/s, gives aural warning.

Monica Mark IIIA (ARI.5281)

251. This is an interim equipment. It is Mark I modified to give a visual indication. It uses a modified ASV Mark II receiver. It gives azimuth.

Monica Mark IIIC (ARI.5617)

252. This is the production version of Mark I modified to give a visual indication. It uses Power Unit Type 626 and the Monica Mark I receiver unit. It provides azimuth.

Monica Mark IV (ARI.5641)

253. This is being designed to cover the frequency band 390–450 Mc/s with single knob tuning to avoid jamming. A visual display with D/F in azimuth and elevation.

Monica Mark V

254. This is an interim equipment based on AI Mark IV.

Monica Mark VI (ARI.5661)

255. This is an interim equipment. It uses a modified SCR.729F equipment with an AI Mark V Pilot's Indicator, Transmitter and modulator. It gives range, azimuth and elevation.

Monica Mark VII (AN/APS.13, ARI.5664)

256. This is an American light weight equipment. It gives warning by bell, klaxon or lamp.

Radar beacons and Beam Approach systems

Beacons

257. Radio beacons for guiding aircraft existed before the invention of radar, but the distinctive feature of a Radar Beacon is its ability to inform an aircraft of its range from the beacon, whereas earlier beacons individually gave bearing but not range. The aircraft usually carries an aerial system with directional properties which give the beacon's bearing. The American term for a radar beacon is a Racon.

258. The principle of a radar beacon system is essentially that of IFF in reverse.

259. The beacon itself is a transponder* which is usually located on the ground at the desired reference point (instead of in the aircraft as in IFF). This transponder (beacon) is interrogated by an interrogator carried in the aircraft and the returns are displayed on an associated receiver and cathode ray tube combination.

260. In practice, the interrogator transmits pulses on one frequency; these pulses are received by the beacon which retransmits them, with negligible delay, usually on a different frequency. In this way ground returns which reach the aircraft on the interrogator frequency are automatically " tuned out " when the receiver in the aircraft is tuned to receive the beacon returns.

261. The receiver display tube gives the range of the beacon from the position of the beacon " echo " on the time base. The maximum ranges are large and of the order of 80 miles, since ground returns have been removed from the trace.

262. Radar beacons find two principal uses :—

(i) As " homing " devices.
(ii) In association with Beam Approach systems which we consider separately.

Homing Beacons

263. If the aerial system in the aircraft which receives the beacon " returns " has directional properties, then not only is it possible to determine the range of the beacon but also its bearing. An aircraft so equipped is able to " home on to " the beacon from considerable ranges (up to 80 miles).

264. Beacons so employed are called " Homing Beacons." They may be located, for instance, at aerodromes, and when their responses are coded, the aircraft is enabled to home to specific aerodromes.

265. Beacons were first used by aircraft fitted with ASV Mark II and AI. Mark IV. The transmitters of these aircraft were used as interrogators and their receivers tuned to the beacon frequency as responsors. Bearing was obtained from the left-right display of the ASV Mark II or AI Mark IV indicator units. Unfortunately this practice led to the introduction of a variety of beacon types, even at a single aerodrome, and the present policy is to standardise on a few types of ground beacon and to install a special interrogator, and a special responsor in the aircraft.

266. The interrogator-receiver and its aerial system may be self-contained and independent of any other radar equipment carried by the aircraft. Such units are known as Rebecca. The equivalent American units carry the code designation SCR.729.

267. Frequently, the aircraft already carries radar equipment and it is convenient to modify the indicator unit of this radar equipment to display beacon returns. Lucero (see para. 173), is then used as the airborne interrogator and the aircraft responsor uses the indicator unit of the radar set (e.g. H_2S). The beacon frequencies may be quite different from the radio frequency of the radar set.

268. AI Mark VIII is an exception. Here the beacon receives and transmits on S-band and the AI Mark VIII set itself acts as interrogator and responsor. Azimuth is obtained from left-right display on the Mark VIII Indicator.

**For definitions of Transponder, Respondor, Interrogator, see the section on IFF.*

269. The beacon is classed as a Centimetre Beacon. There are American as well as British beacons of this type.

270. The earlier types of homing beacons were called ASV or AI beacons according to the airborne equipment that used them, but the more recent homing beacons that are interrogated by Rebecca or Lucero are called Eureka Beacons.

271. The beacon when located inland, as for instance at an aerodrome, transmits equally well on all azimuths so that there is no preferred direction of approach to it, but Coastal Command beacons situated on the coast usually radiate more powerfully out to sea than inland.

272. The principal uses of homing beacons are :—

(i) To permit aircraft to identify aerodromes and to home on to them from ranges as great as 80 miles.
(ii) To permit Fleet Air Arm aircraft to find their Carriers.
(iii) To assist cooperation of aircraft with ground troops.

273. The following summary surveys the principal beacon and associated airborne equipments.

Early beacon systems ($\lambda = 1\frac{1}{2}$ metres)

274. *ASV Mark II (Homing Beacons)*

(i) FGRI.5044 (Obsolete)—Receiver 173-179 Mc/s or 211-217 Mc/s. Transmitter 176 Mc/s or 214 Mc/s.
(ii) FGRI.5066 (Obsolescent)—Receiver 173-179 Mc/s. Transmitter 177 or 173 Mc/s.
(iii) TGRI.5108—A transportable form of FGRI.5066.

275. *AI Marks IV, V and VI (Homing Beacons)*

(i) FGRI.5043 (Obsolete)—Receiver 190-196 Mc/s. Transmitter 193 Mc/s or 197 Mc/s.
(ii) FGRI.5067—Receiver 188-196 Mc/s.

These early $1\frac{1}{2}$ metre beacons can be interrogated by Lucero.

276. *Lucero*—(See para. 173).

277. *Rebecca and SCR.729*

Rebecca—A self-contained airborne interrogator which works with beacons as an aid to navigation

(i) Rebecca Mark I (ARI.5120) is a single-channel equipment in use for training and in Bomber Command.
(ii) Rebecca Mark IC was a modification of Mark I for Coastal Command and was never produced.
(iii) Rebecca Mark II (ARI.5506) is a multi-frequency equipment, the frequency channels being selected by push-button. It includes Transmitter-Receiver type TR.3173 or TR.3173A.
(iv) Rebecca Mark IIA (AN/APN-2, ARI.5649) is an American version of Rebecca, using modified SCR.729A equipment and working on the same frequency band as Rebecca Mark II.
(v) Rebecca Mark IIB (ARI.5594) is a modification of Rebecca Mark II for use in Transport Command. The equipment includes Transmitter-Receiver type TR.3576 and it works with 214-234 Mc/s band beacons for Army Cooperation work, with 176 Mc/s Homing Beacons, and with 173 Mc/s BABS. It also interrogates IFF Mark III.

(vi) Rebecca Mark IIT (ARI.5652) is a modification of Rebecca Mark II with a communication unit to give two-way speech facilities to Eureka Mark IIIT.

(vii) Rebecca Mark IIU is a version of Rebecca Mark II for use with Indicating Unit type 166 and associated equipment. It consists of Transmitter-Receiver type TR.3590 and Control Unit type 222A. (ARI.5611 is the combination of Rebecca Mark IIU and Gee-H Mark II, the latter including Indicating Unit type 166 and associated equipment).

(viii) Rebecca Mark III (ARI.5161) is a light-weight multi-frequency battery equipment for use in gliders, transmitting and receiving on different frequencies. It includes Transmitter-Receiver type TR.3182 (screwdriver adjustment of frequency).

(ix) Rebecca Mark IIIA (ARI.5161) is identical with Mark III except that it includes Transmitter-Receiver type TR.3182A (five-position pre-selector frequency switch).

(x) Rebecca Mark IIIB (MCRI.5273) is a special installation, including Transmitter-Receiver type TR.3182, for use in landing craft.

(xi) Rebecca Mark IIIN (ARI.5592) is a modification of Rebecca Mark III with a daylight-viewing cathode ray tube. It includes Transmitter-Receiver type TR.3591. For use in Fleet Air Arm single-seater aircraft.

(xii) Rebecca Mark IV (ARI.5610) is a miniature equipment with a daylight-viewing cathode ray tube, for Fleet Air Arm use.

(xiii) Rebecca Mark V is a miniature interrogator for use, in the first instance, with ASV Mark XV (light-weight ASVX). It provides IFF, Beacon, and BABS facilities and, as it is completely self-contained, it can be used to give light-weight interrogator facilities in any two-seater or large aircraft.

(xiv) Rebecca Mark VI (ARI.5631) is a self-contained interrogator using Lucero Mark II, Indicator Unit type 233 (modified Indicator Unit type 96), and one other unit containing a universal 45 Mc/s IF strip, self-running master pulse circuits, and AVC. It provides IFF, Beacon, and BABS facilities. For use with H_2S Marks IV and VI, and in any aircraft without other forms of radar equipment and requiring interrogator facilities.

(xv) SCR.729A is the American production version of an interrogator on Coastal Command frequencies, giving IFF and Homing Beacon facilities only.

(xvi) SCR.729F is the SCR.729A equipment modified in the U.K. to give IFF, Beacon, and BA facilities for fighter aircraft.

(xvii) SCR.729C was originally envisaged as a modification of SCR.729A equipment in the U.K. to provide full IFF, Beacon, and BA facilities for Coastal Command. This has proved impossible without a major rebuild, and Coastal Command is fitting SCR.729A as a temporary measure until such time as a satisfactory interrogator becomes available.

278. *Eureka*—(Beacons for provision of homing facilities and also for use in identification of certain target points required in Army Cooperation and Airborne Supply Operations).

(i) Eureka Mark I (TGRI.5508) is a single-channel equipment in use for training.

(ii) Eureka Mark II (TGRI.5509) is a multi-frequency equipment on 214-234 Mc/s. It includes Transmitter-Receiver type TR.3174. A fixed version (FGRI.5666) will also be available if required, and will incorporate Aerial System type 350 (see iv) below).

(iii) Eureka Mark IIC (FGRI.5584) is a modification of Eureka Mark II for use by Coastal Command as a Homing Beacon. It includes Transmitter-Receiver type TR.3558 and operates on 177 Mc/s.

(iv) Eureka Mark IIF is a modification of Eureka Mark II for use by fighter aircraft as a Homing Beacon. It includes Transmitter-Receiver type TR.3559 and operates on 193-196 Mc/s. There are two versions, the first transportable

(TGRI.5585), and the second fixed (FGRI.5596). The only difference is that the fixed installation has a more elaborate aerial system (Aerial System type 350) and provides greater range.

(v) Eureka Mark III (TGRI.5510) is a miniature portable beacon. Mark III is the name given to the first hundred single-frequency models made by RRDE.

(vi) Eureka Mark IIIA (TGRI.5527) is the multi-frequency production version of Mark III. It includes Transmitter-Receiver type TR.3514 or TR.3514A (multi-frequency). This equipment is to be used in Fleet Air Arm aircraft, the installation being known as ARI.5648.

(vii) Eureka Mark IIIB (TGRI.5527) is the single-frequency production version of Mark III. It includes Transmitter-Receiver type TR.3563 (single-frequency) but is otherwise identical with Mark IIIA.

(viii) Eureka Mark IIIC (AN/PPN-1, 2) is an American version of miniature Eureka. AN/PPN-1 is similar to Mark IIIB but with frequency selection. AN/PPN-2 is similar to AN/PPN-1 but with small improvements.

(ix) Eureka Mark IIID is a single-frequency production version of Mark III, and is identical with Mark IIIB except that it includes the improved Transmitter-Receiver type TR.3593 with provision for the addition of "talking" facilities.

(x) Eureka Mark IIIT (TGRI.5643) is similar to Mark IIID but with a new communication unit to provide the facility of ground to air speech when used with Rebecca Mark IIT.

279. *Rebecca 'H.'* (An 'H' system of Navigation. The main use in the first instance is for night photography).

(i) Rebecca 'H' (ARI.5543) is an airborne equipment using modified Rebecca Mark II and a special strobe unit to measure range from two beacons. It includes Transmitter-Receiver type TR.3577 (a modification of TR.3173A).

(ii) Rebecca 'H' Mark II (ARI.5658) provides both Rebecca and Rebecca 'H' functions, being a homing device used with Eureka beacons and a navigational aid used with Eureka 'H' beacons. It is a combination of Rebecca Mark IIU and Indicating Unit type 166 and associated equipment, junction boxes and aerials.

(iii) Eureka 'H' (MGRI.5591) is a mobile ground beacon for use with Rebecca 'H.' The equipment is housed in a 15-cwt. van.

280. *Centimetre Beacons* (Ground beacons for use with airborne Centimetre equipments).

(i) MGRI.5511 is a pre-production mobile S-band equipment which includes Transmitter-Receiver type TR.3145 (Magnetron oscillator). Primarily for use with AI Mark VIII and VIIIA.

(ii) MGRI.5531 is a pre-production mobile S-band equipment which includes Transmitter-Receiver type TR.3145A (power klystron oscillator). Primarily for use with AI Marks VIII and VIIIA.

(iii) MGRI.5518 is the main production mobile S-band equipment which includes. Transmitter-Receiver type TR.3506 and a discriminator to eliminate unwanted triggering. Primarily for use with AI Mark VIII.

(iv) FGRI.5600 is similar to MGRI.5518 but is fixed in a hut instead of being housed in a trailer.

(v) BGS is an American beacon for use with S-band equipments.

(vi) AN/CPN-3 (YK) is the early production version of BGS.

(vii) AN/CPN-8 is an improved version of AN/CPN-3.

(viii) BGX is an American beacon for use with X-band equipments.

(ix) AN/CPN-6 is the production version of BGX.

281. *U.N.B. (United Nations Beacons).*—A system in development. It works on a separate band of frequencies (950-1150 Mc/s).

Beam Approach systems

282. *BABS (Beam Approach Beacon System).*—This is a radar system which enables an aircraft wishing to land at an aerodrome to make the correct approach to the runway under conditions of poor visibility.

283. It combines a radar homing beacon with a special radar beam approach system. The homing beacon, which is of the type described above, serves to bring the aircraft towards the aerodrome from ranges lying between 80 and 20 miles. At a range of 20 miles the beam approach system becomes effective and the pilot can use it in making the correct approach to the runway.

284. The beam approach equipment on the ground, like the homing beacon, is a transponder which receives pulses from the appropriate aircraft interrogator (Lucero, Rebecca, AI, ASV) and retransmits them to the aircraft.

285. Unlike the homing beacon, however, the beam approach equipment does not radiate indiscriminateiy in all directions but in a beam.

286. The axis of the beam does not lie along the direction of the runway but is directed first slightly to the right for a short interval and then to the left by the same amount for an even shorter interval. The two polar diagrams overlap along the line of the runway and give signals of equal strength, (but of different durations—dot and dash) to the aircraft only when it is flying along this line which bisects the angle between the two beam directions.

287. The signals from the beam approach aerials are displayed on a linear time base and appear as a broad echo (from the dash beam) inside which is a narrow echo (from the dot beam). The leading edges of the dot and dash echoes coincide on the time base and give the range of the end of the runway over which the aircraft is to approach. If the aircraft is approaching on the correct course, that is along the equisignal direction, the broad and narrow echoes are the same height. A deviation to one side or other alters their relative heights and the pilot is enabled to recover the correct course.

288. The frequency on which the beam approach aerial retransmits differs slightly from that of the interrogator and also that of the homing beacon, so that in order to receive the beam approach signal the responsor must be retuned. Thus, the echoes from the homing beacon vanish and are replaced by those of the beam approach equipment.

289. We note that in making the approach to the aerodrome from a distance by using the homing beacon it is the directional properties of the aircraft aerials that are employed to give bearing, but in the final approach to the runway those of the beam approach aerials on the ground.

290. Transponders can also be used to provide a glide path when their transmissions are made from two aerials at different heights above the ground the one vertically above the other. The lowest inteference lobe in the vertical polar diagram of the one can be made to overlap that of the other, so that the equisignal path is the correct glide path. To effect an actual blind landing some other system such as ACR must be used.

291. BABS radar beam approach beacon systems provide guidance in azimuth and range from remote end of runway in order to aid landing of aircraft in conditions of bad visibility. The principal Marks of BABS are as follows :—

(i) BABS Mark IC (formerly known as ASV/BA) is a version on 176 Mc/s for Coastal Command. There are two varieties, FGRI.5260 being a fixed mains-operated airfield installation and FGRI.5115 being a fixed installation for flying boat bases.

(ii) BABS Mark I CM (MGRI.5116) is a mobile version of Mark IC. Six models only were constructed

(iii) BABS Mark IF (FGRI.5259 formerly known as AI/BA), is a fixed mains-operated version on 193 Mc/s for work with fighter aircraft.

(iv) BABS Mark IA (TGRI.5609) formerly known as Air Transportable Radar BA) is a portable version made from Eureka Mark II equipment for A.E.A.F. use. Eighteen models only were constructed.

(v) BABS Mark II (FGRI.5644) is a fixed mains-operated wide band system working on 214-234 Mc/s for Bomber Command.

(vi) Lucero-BA. (BABS Mark IIM-MGRI.5577), is similar to Mark II but is a mobile equipment housed in a van. It employs horizontal slot aerials backed by a corner reflector. The beam is switched by exciting each aerial in turn.

(vii) BABS Mark IIFM (MGRI.5586) is a mobile equipment similar to Mark IIM but working with fighter aircraft on 193 Mc/s.

(viii) BABS Mark IICM (MGRI.5587) will be a mobile equipment similar to Mark IIM but working on 176 Mc/s for Coastal Command.

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