CHAPTER 1

AIRCRAFT INTERCEPTION

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CHAPTER 1

AIRCRAFT INTERCEPTION

INTRODUCTION

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

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

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

The different marks of AI

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

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

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

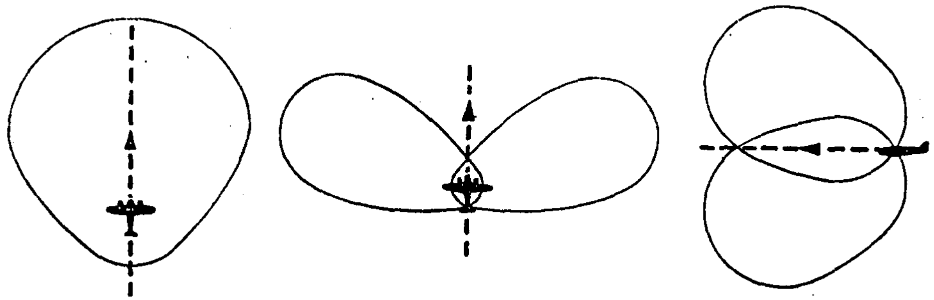
7. *Mk. IV, V and VI* transmitted on 1½ metres, but all later designs used centimetre wavelengths. The improved performance obtained by this reduction in wavelength was so great that earlier 1½ metre systems are obsolescent. The advantages of centimetre transmitters will be discussed later. Mk. VII which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

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

AI MK. IV

General principles of operation

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



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

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

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

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

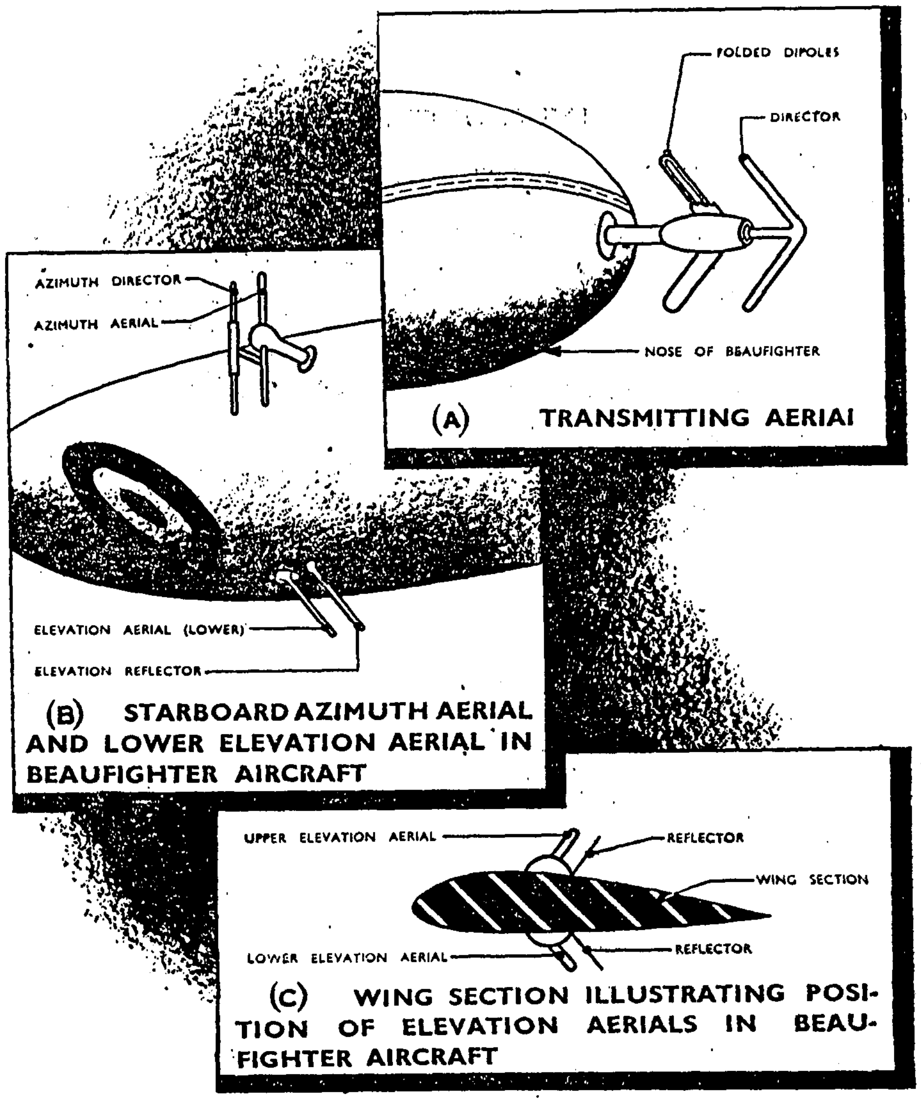


Fig. 2.—AI Mk. IV., aerials

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

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

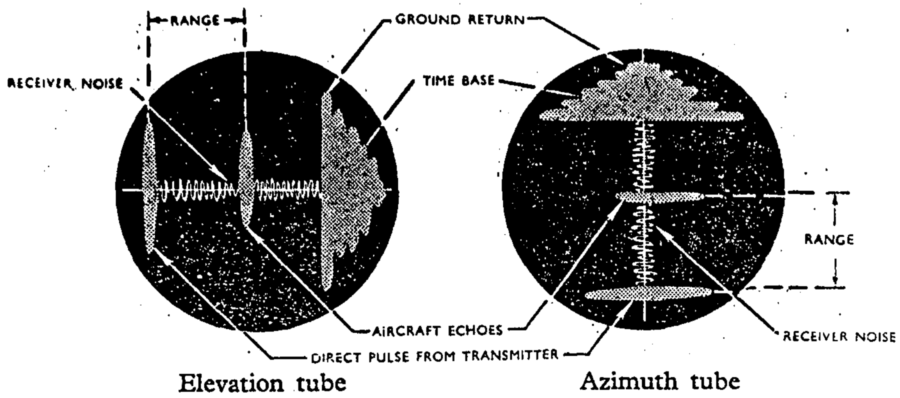


Fig. 3.—AI Mk. IV., typical indications

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

Minimum range

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

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

Maximum range

16. In additon to echoes from aircraft a large echo is produced by ground reflection. This is called *ground return*, and it appears on the tube as an extensive echo rather like a Christmas tree in shape. The leading edge of the ground return is at a range corresponding to the height of the aircraft above the land over which it is flying. Unfortunately the ground return is very strong indeed compared with aircraft returns, and consequently there is no chance of detecting aircraft at ranges greater than the height of the fighter aircraft. This is the most serious limitation on the performance of AI Mk. IV. Note, therefore, that above 18,000 feet the maximum range of the equipment is of the order of $3\frac{1}{2}$ miles, but below this height the maximum range is limited to the height of the fighter. This is illustrated in fig. 9.

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

Sensitivity of direction finding

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

Facilities for identification of friend or foe

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

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

Elevation tube

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

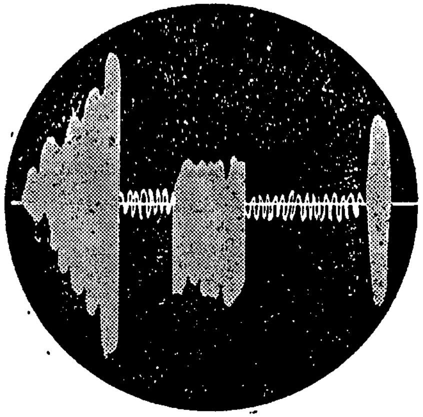


Fig. 4.—AI Mk. IV., IFF response

Homing beacons

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

AI beam approach (AIBA)

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

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

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

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

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

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

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

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

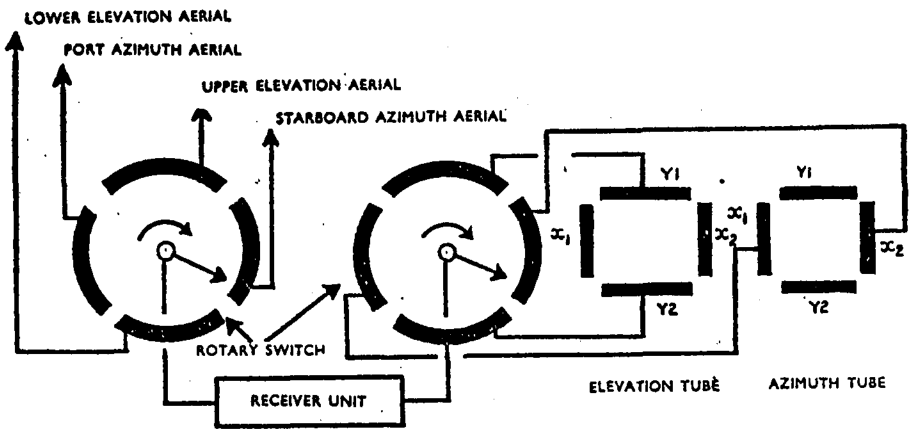


Fig. 6.—AI Mk. IV., schematic diagram of the aerial switching

Leading particulars

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

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

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

AI MK. V

General principles of operation

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

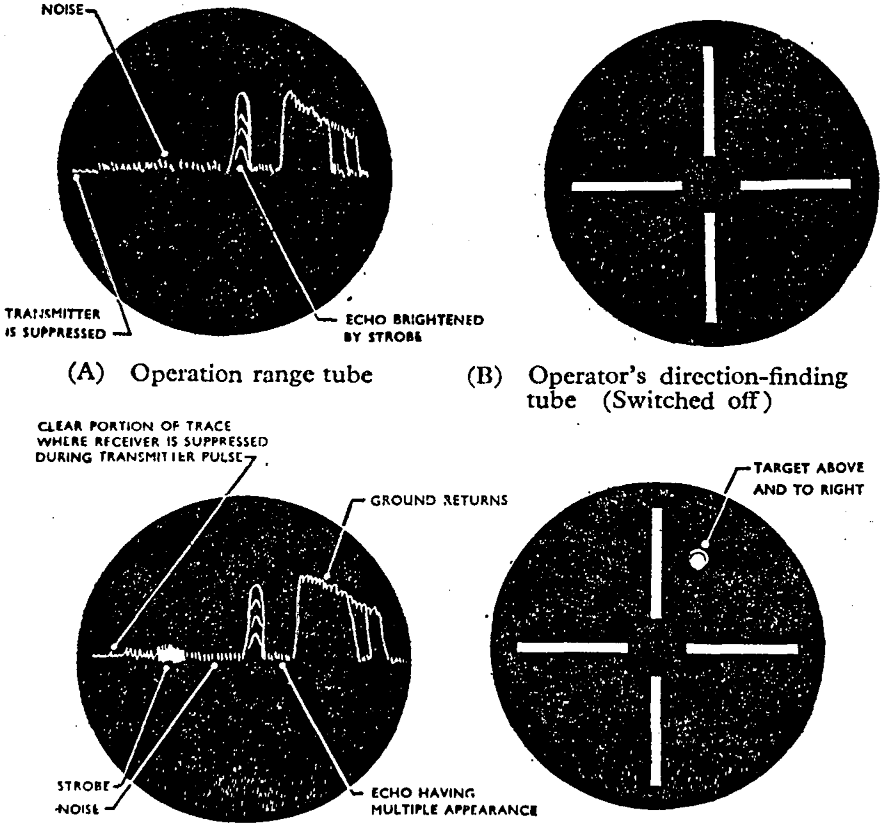
27. In operating AI Mk. IV the observer must interpret his picture and tell the pilot what to do. This introduces a time delay which must be cut to a minimum if a dodging target is to be successfully followed. There are several sources of error; the operator may mis-interpret the picture; he may give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

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

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

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

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



(A) Operation range tube

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

(C) Operator's range tube target strobed

(D) Operator's direction finding tube (Switched on after contact)

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

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

The pilot's indicator

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

Homing facilities

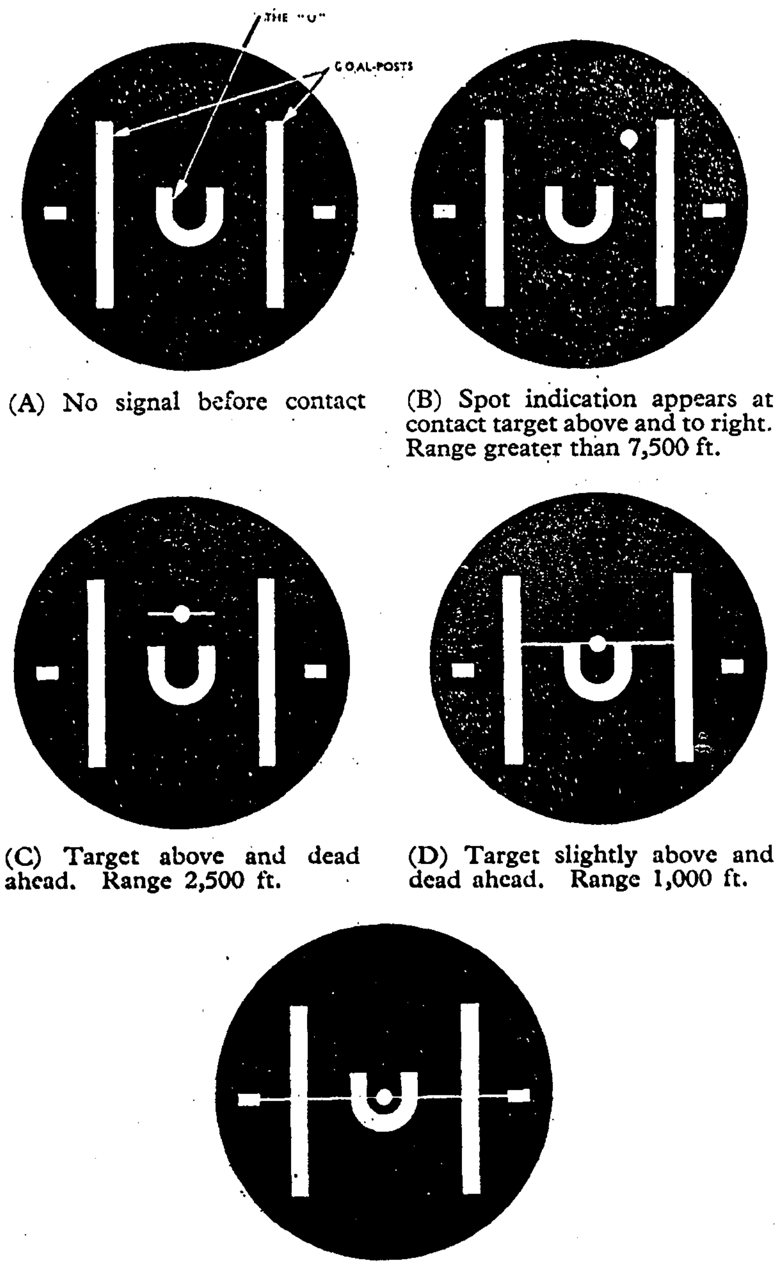
33. For homing on a ground beacon, a switch for increasing the range scale on the operator's tube is fitted. The beacon signal, which appears beyond the ground returns, is selected by the strobe and the directional information concerning it appears on the pilot's indicator, as in the case of an aircraft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

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

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

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

(3) No spot indicates no contact.



(A) No signal before contact

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

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

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

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

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

Other facilities

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

Performance

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

Leading particulars

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

Wavelength, 1·5 metres approximately. 193 Mc/s. approximately.

Pulse recurrence frequency, 670 p.p.s.

Pulse width, 2·8 microseconds.

Peak pulse power, 10 kW.

Aerial systems, half wave dipoles as in Mk. IV

Maximum range over 18,000 feet, 3½ miles.

Minimum range, 400 to 500 feet.

Sharpness of DF at dead ahead, 5 degrees.

Facilities for IFF, homing beacon, beam approach.

Pilot's indicator

Units :

Modulator, type 29 produces 5 kV pulse.

Output stage consists of four V.T. 75A valves in parallel.

Transmitter, type T.3100. Two VT90 valves in push-pull.

Receiver, type R.3085 : 2 RF stages, 4 IF stages, IF frequency 27 Mc/s. Automatic gain control. Strobe circuit.

Indicator, type 41. Exponential range scan. Spot indicator tube.

Pilot's indicator, type 42. Spot indicator with range wings.

Control unit, type 87, Pilot's control unit.

Power supply. 80-volt, 500 watt, 1,600 c/s, engine-driven alternator with control panel, type 3.

Weight 135 lb.

AI MK. VI

General principles of operation

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

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

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

Method of operation

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

(1) An echo is detected and strobed.

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

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

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

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

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

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

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

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

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

Performance

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

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

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

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

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

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

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

Leading particulars

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

Wavelength 1·5 metres approximately.

Frequency band 193 Mc/s.

Pulse recurrence frequency, 670 p.p.s.

Pulse width, 2 microseconds.

Peak pulse power, 10 kW.

Aerial systems, half wave dipoles as in Mk. IV.

Maximum range 2½ to 3 miles.

Minimum range 500 feet.

Sharpness of DF at dead ahead, 5 degrees.

No facilities for beacons or IFF on pilot's indicator.

No operator required.

Units

Modulator type 16, produces a 2-microsecond pulse, output stage consists of 4 VT75A valves; delay network used for shaping modulator pulse.

Transmitter, type T.3074. Two type VT90 valves in push-pull.

Receiver, type R.3075

(a) Receiver unit, type 36: 2 RF stages, 4 IF stages, IF frequency 20 Mc/s, automatic gain control.

(b) Automatic strobe unit, type 2.

Indicating unit, type 30, pilot's indicator.

Indicating unit, type 32, observer's indicating unit (if fitted).

Control unit, type 67, main switch, panacea button.

Control unit, type 96, tube controls.

Power supply 500 watts, 80 volts, 1,600 c/s engine-driven alternator and control panel, type 4.

Weight 134 lb.

AI MKS. VII AND VIII

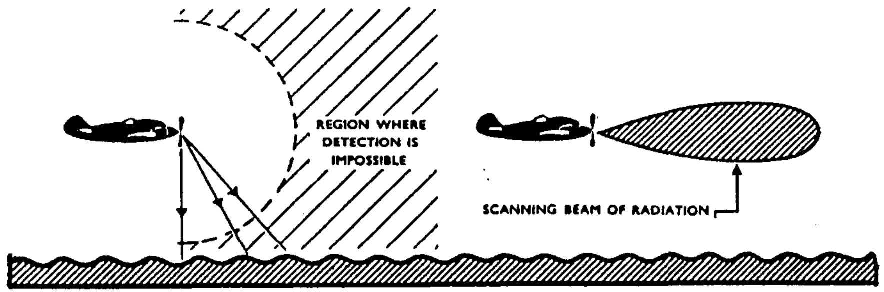
General principles of operation

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

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

AI Mk. VII

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



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

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

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

Leading particulars

54. AI Mk. VII (ARI5049).

Wavelength 9·1 cm., 3,300 Mc/s.

Frequency band S.

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

Pulse width, 1 microsecond.

Peak pulse power, 5 kW.

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

Common transmitting and receiving aerial.

Spiral scan.

Maximum range, 3 miles.

Minimum range, 400-500 feet.

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

No beacon or IFF facilities.

No pilot's indicator.

Units:

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

Transmitter, CV38, magnetron feeding into a coaxial line.

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

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

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

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

AI Mk. VIII

Aerial system

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

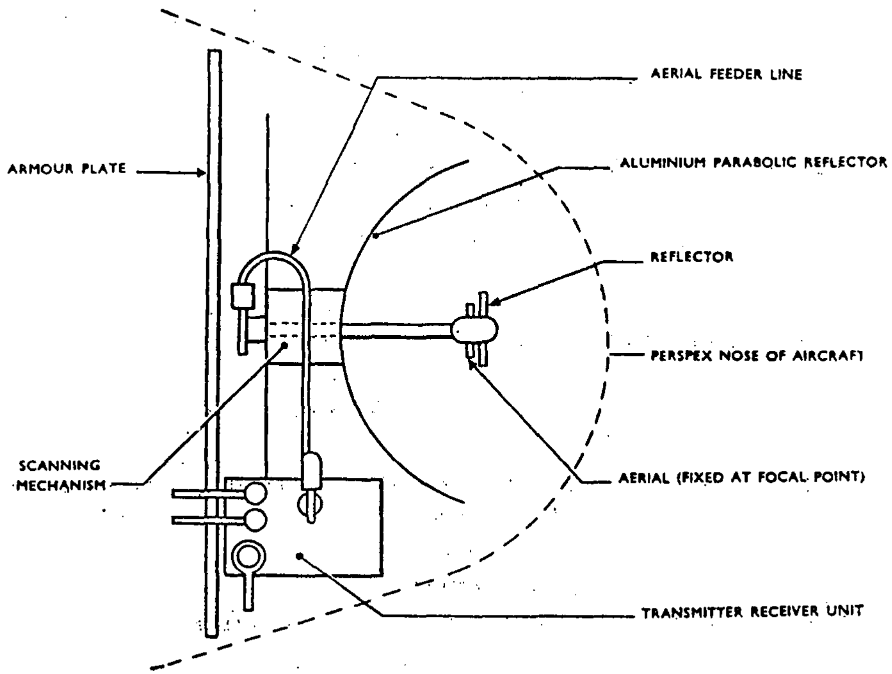


Fig. 10.—Scanning mechanism and aerial system mounted on nose of Beaufighter or Mosquito

Spiral scan

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

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

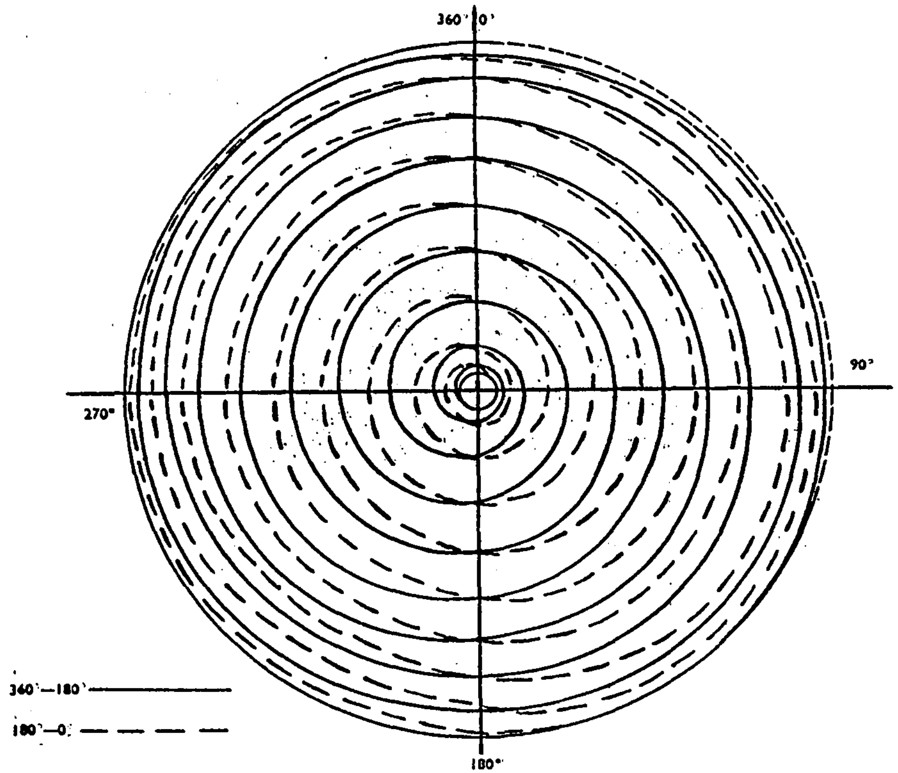


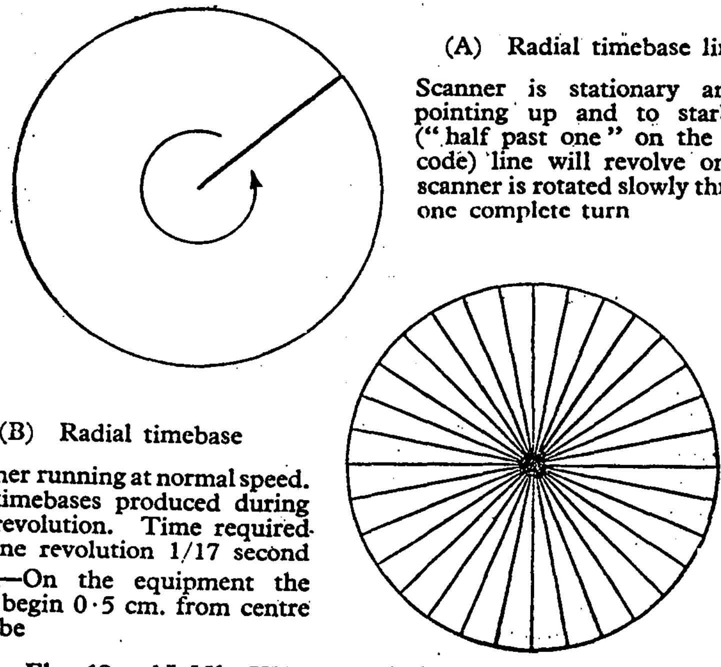
Fig. 11.—Scanning diagram

Radial timebase

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

Range and direction finding properties

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



(A) Radial timebase line

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

(B) Radial timebase

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

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

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

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

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

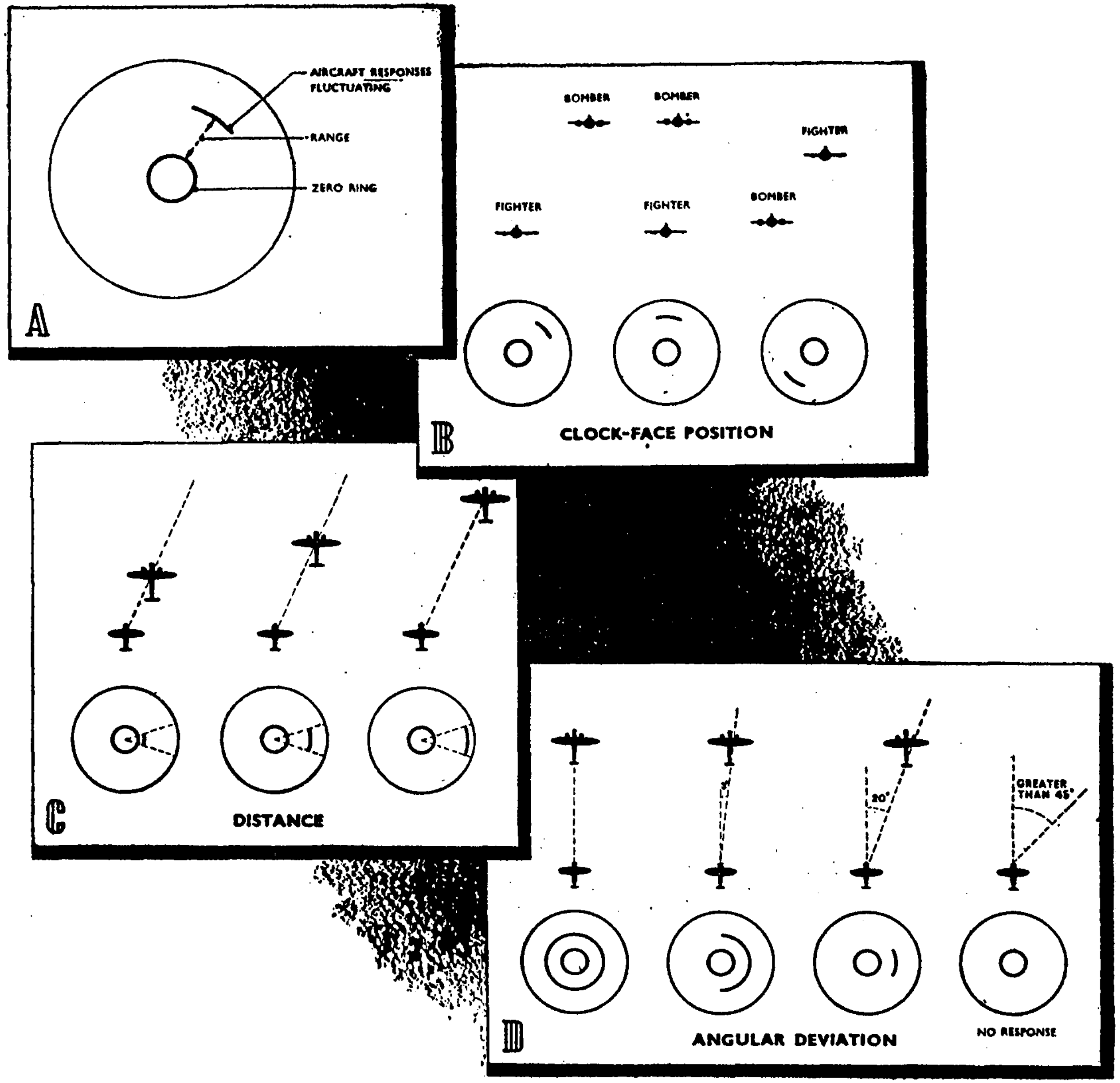


Fig. 13.—ARI. 5093 display system on AI

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

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

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

Zero-circle and range marker rings

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

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

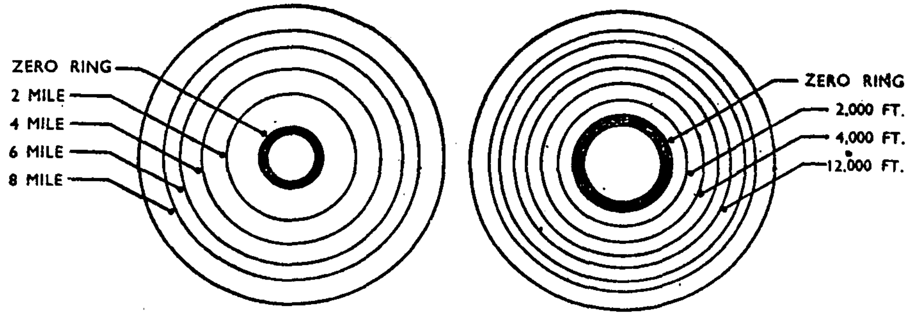
(a) (1) From zero to two miles, the latter being at the edge of the tube.

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

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

Ground returns

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



Range marker rings on the 0 to 8 mile range

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

Fig. 14—AI Mk. VIII, marker rings

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

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

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

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

Performance

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

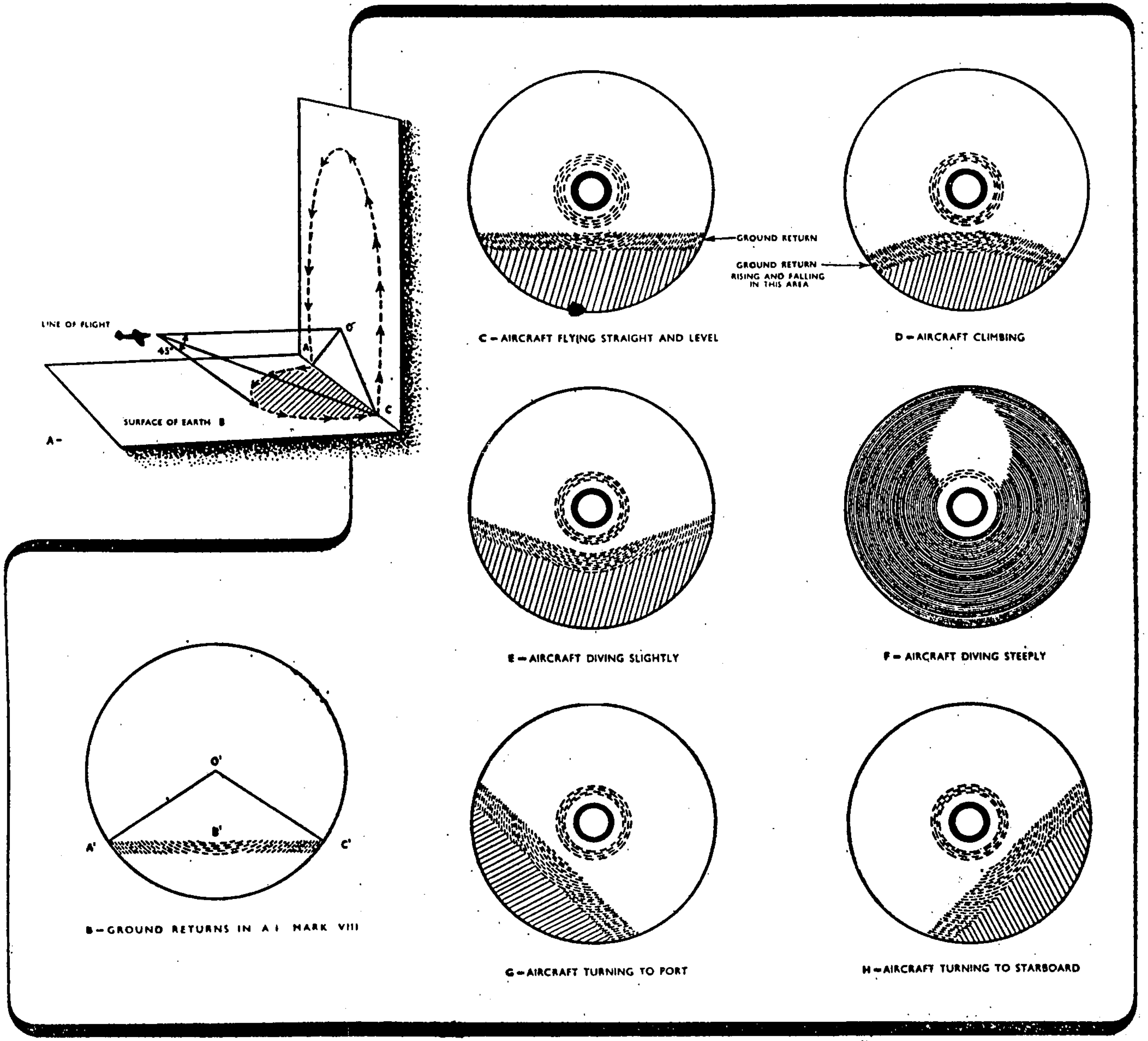


Fig. 15.—AI Mk. VIII, indications

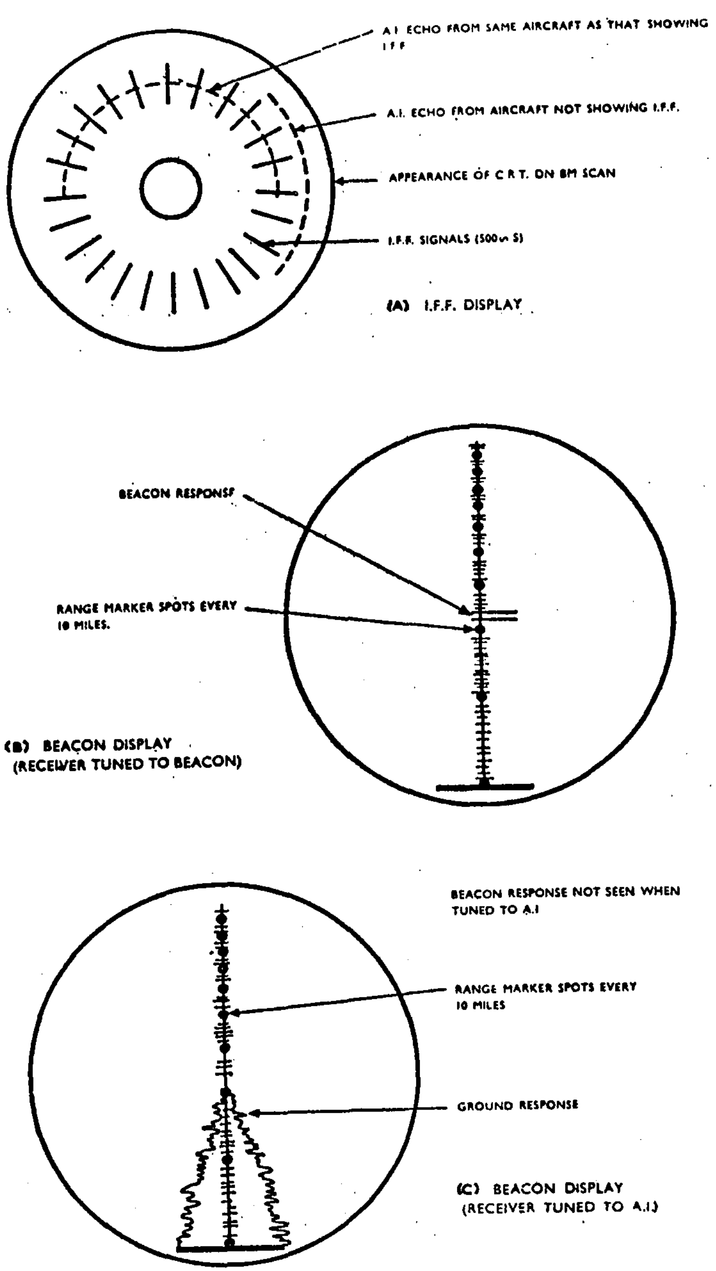


Fig. 16.—AI Mk. VIII, IFF and beacon display

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

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

IFF facilities

70. When an operator wishes to identify an aircraft as friendly or otherwise he presses an interrogator switch on the indicating unit. If the target aircraft is friendly, and carries a Mk. III or IIIG IFF set, there immediately appears on the timebase, in addition to the normal signal, a very distinctive signal as shown in fig. 16 (A). The friendly signal consists of a series of radial lines corresponding to $\frac{3}{4}$ mile in length and appearing in every fifth timebase. The distance represented by these responses may be increased to $1\frac{1}{2}$ miles for coding purposes or to six miles to indicate distress. In the case of the short IFF signal ($\frac{3}{4}$ miles) the target response should be half way along the radial lines, and in the other cases at a distance from the inside edge equivalent to $\frac{3}{8}$ mile. Even when the target is off centre and is indicated by an arc the friendly signal is a complete circle of IFF responses. Should there be two targets showing on the tube at different ranges, and only one friendly signal, the operator can tell which aircraft is showing the signal by noting the range of the two targets and the range corresponding to the beginning of the IFF signals. The friendly signals should begin at a range $\frac{3}{8}$ mile less than that of the sending aircraft. Should there be two arcs at the same range, and one IFF signal, the observer cannot tell which is friendly,

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

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

Beacon operation and display

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

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

AI beam approach

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

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

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

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

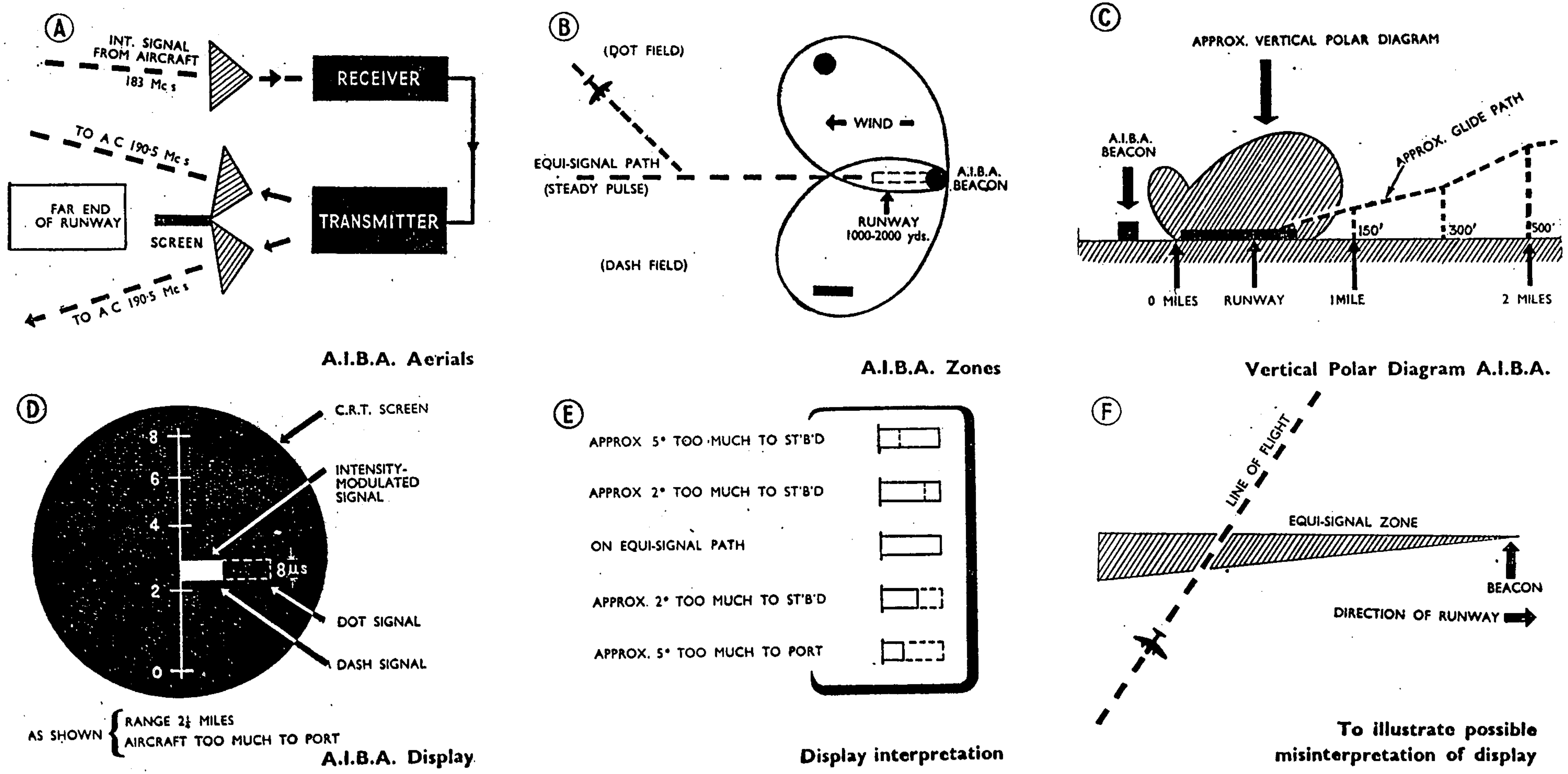


Fig. 17.—AIBA display

78. *Leading particulars*

AI Mk. VIII, ARI. 5093

Wavelength: 9·1 cm., 3,300 Mc/s.

Frequency band: S.

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

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

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

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

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

Minimum range: 400-500 feet.

Sharpness of D.F.:	1·3 deg. at dead ahead but less accurate as the angle of centre increases.
Facilities:	Centimetre beacon facilities for homing up to 90 miles from base. IFF and AI/BA facilities. No pilot's indicator.
Units	
Modulator:	Type 53, hard valve modulator using three CV57 tetrodes in parallel in output stage, produces 35 amp. pulse at about 10 kV.
Transmitter:	Type TR.3151, CV64 magnetron modulated at 13 kV.. Soft rhumbatron switching valve, CV43; crystal mixer.
Receiver:	Type 50, reflector kylstron local oscillator, CV67. 4 IF stages. IF frequency, 13·5 Mc/s.
Indicating:	Type 73, one tube, radial timebase. 2-mile and 8-mile ranges. 90-mile exponential beacon timebase. 8-mile AI/BA timebase.
Interrogator:	Type TR.3152. Transmits on 183 Mc/s for Mk. III. IFF and AI/BA.
Power:	Type 225.
Power supply:	1,200-watts, 80 volts, 1,600 c/s engine-driven alternator. 500 watts DC generator with control panel, type 5.
Weight:	212 lb. (This is the weight of the six main units only).

AI Mk. X (Modified American SCR-720)

General principles of operation

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

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

Aerial system

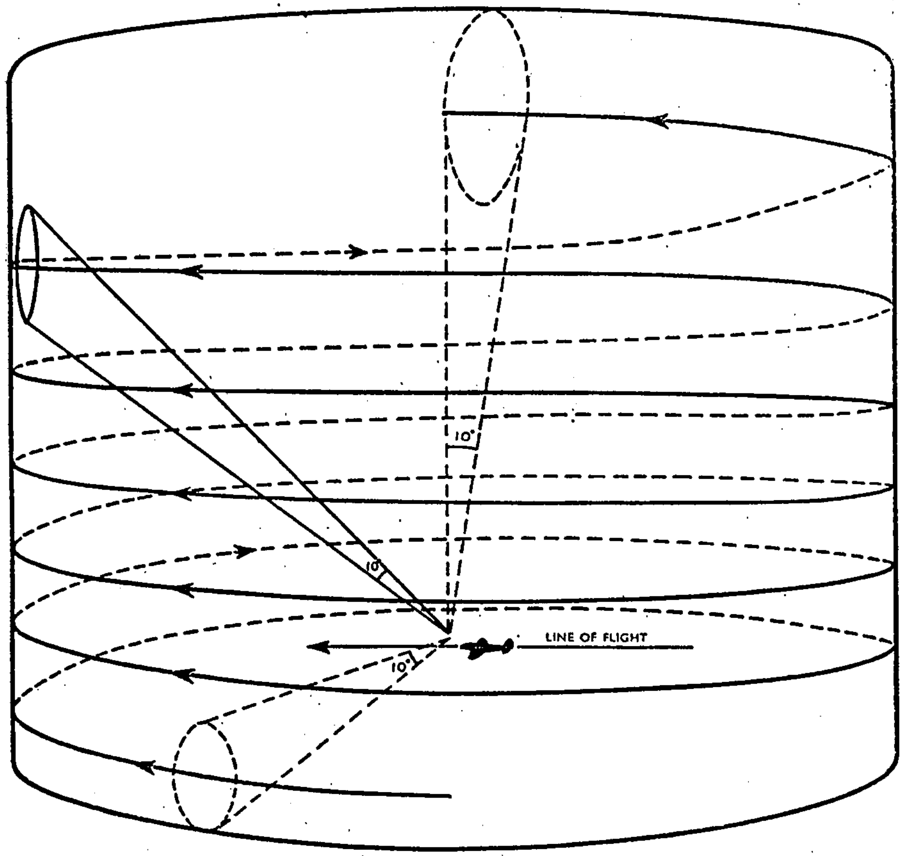
81. AI Mk. X is in many ways similar in design to Mk. VIII. The transmitting valve is a magnetron which radiates power on a wavelength of 9 cm. The output is fed to a small vertical dipole aerial fixed at the focal point of a parabolic mirror 29 inches in diameter. This system produces a narrow beam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

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

Helical scan

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

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



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

Fig. 18—Helical scan

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

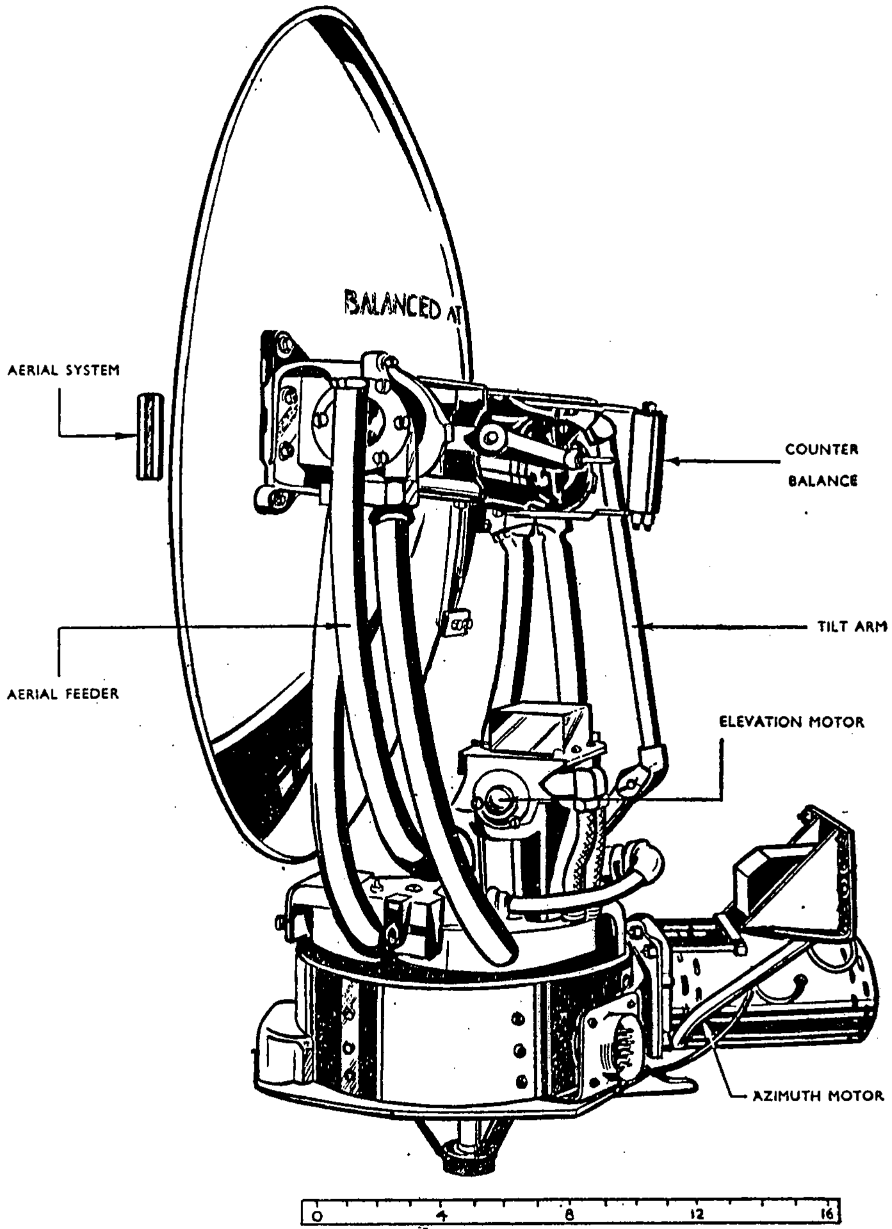
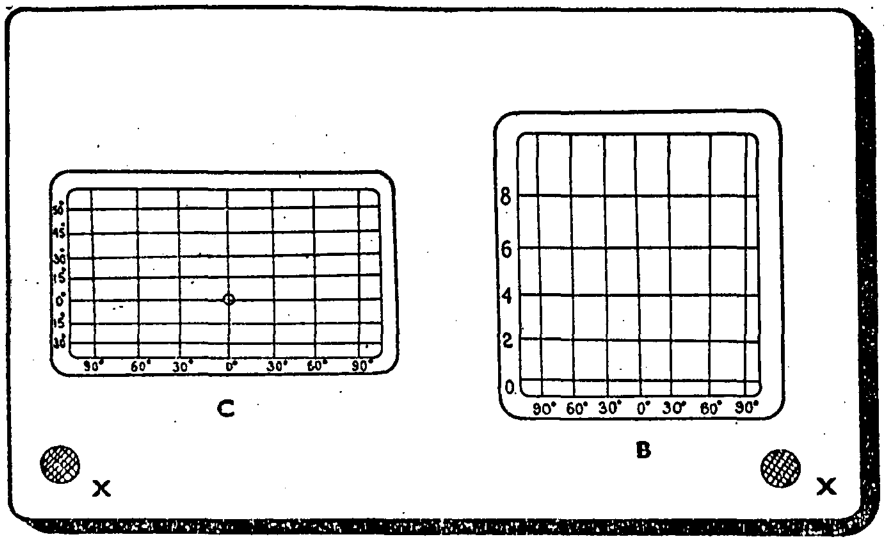
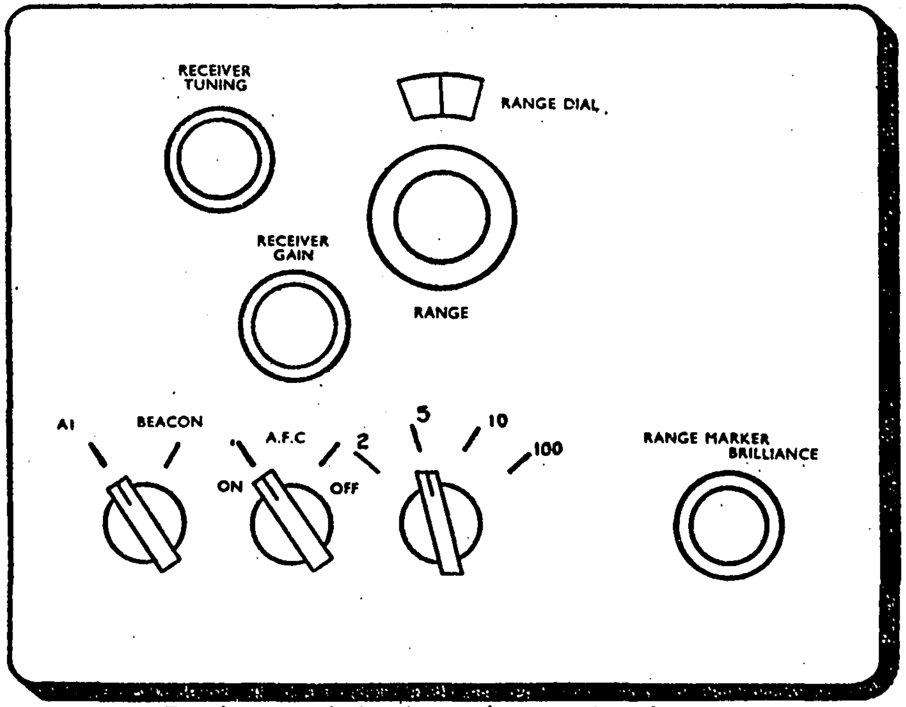


Fig. 19.—SCR-720, scanner



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



Receiver panel showing main controls only

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

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

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

The scanner is illustrated in fig. 19.

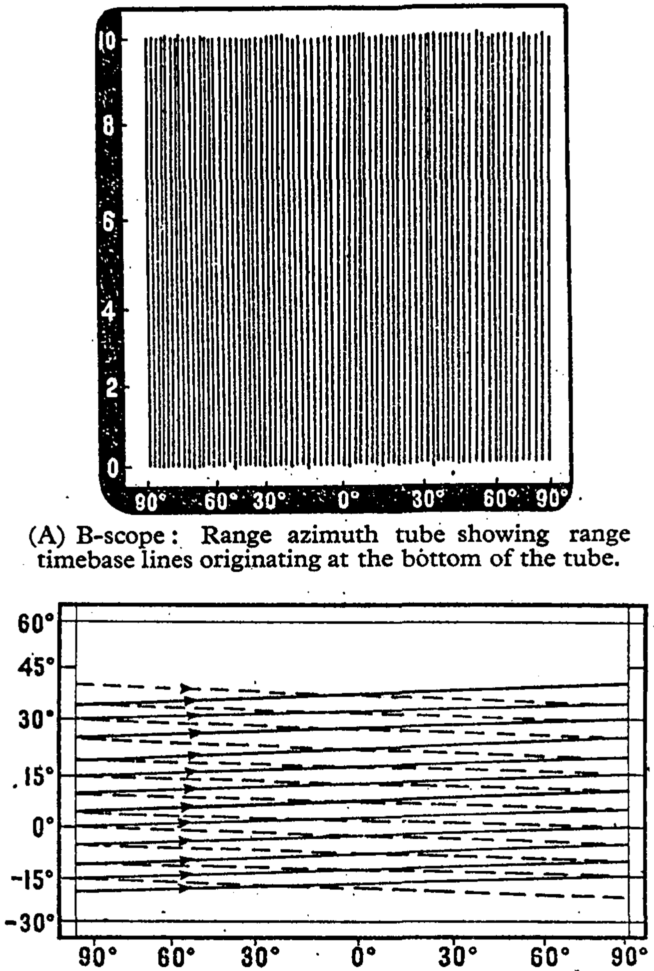
86. Suppose that the —20 deg. to +40 deg. tilt limits have been selected. All the space in front of the aircraft from 20 deg. below the line of flight to 40 deg. above it will be scanned. Hence the region of search in a sideways direction is greater for SCR-720 than in the case of AI Mk. VIII, where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

Display system

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

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

tube, which corresponds to zero range, and finishes at the top, which in this case corresponds to a range of 10 miles. Although the tube appears to be filled with these lines they are, of course, being traced in succession from left to right as the scanner moves from port through line-ahead to starboard. During the next half revolution of the scanner, when



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

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

Fig. 21—SCR-720, timebase displays

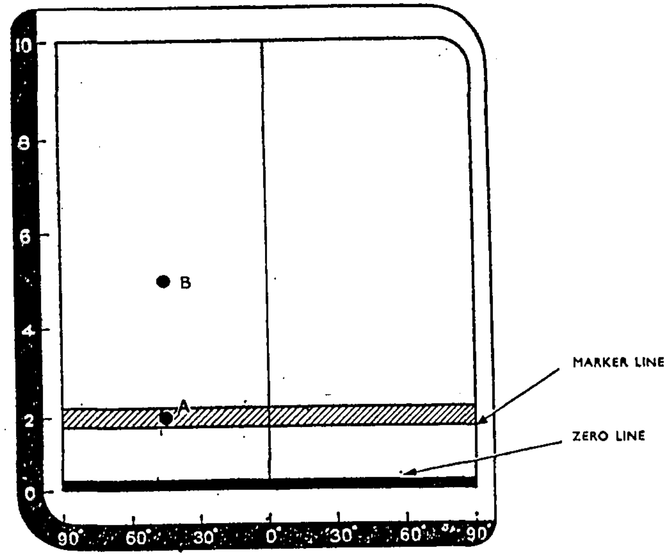
the mirror is towards the rear, no lines are traced; and then once again the picture is traced out from left to right as before. Because each line takes a few seconds to disappear the whole tube appears to be filled with timebase lines. The scanner runs at 6 revolutions per second, so it takes one-twelfth of a second to trace out one complete set of scan lines on the range/azimuth tube. Also, each scan line originates at the same time as a pulse is radiated from the aerial, and on the AI range 1,500 pulses are sent out in a second. Hence there are about 125 timebase lines on the range/azimuth tube (fig. 21(A)).

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

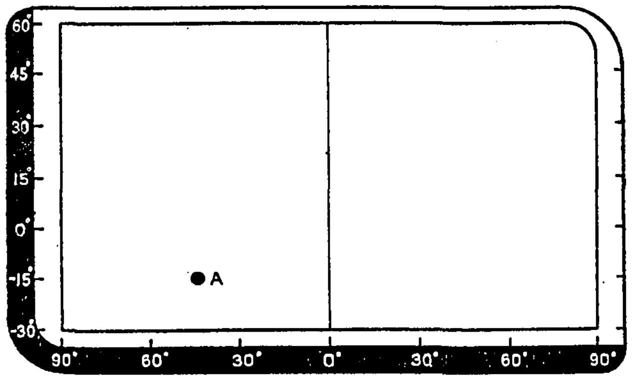
90. If narrower tilt limits were chosen, such as the —5 deg. to + 10 deg., then fewer horizontal scan lines would be seen. In this case, there will be 3 lines when the mirror is moving upwards, and 3 lines when it is moving down. The mirror will complete this cycle in one-quarter of the time required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

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

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



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



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

Fig. 22—SCR-720, development of display

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

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

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

96. The following ranges are available on the equipment.

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

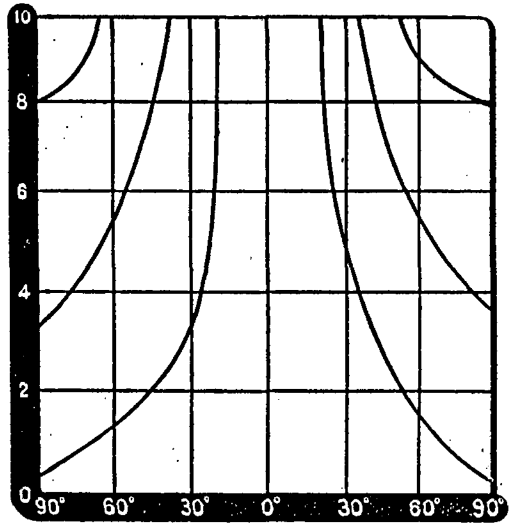
97. The range marker is used, as explained previously, on the three short ranges only; on the 100-mile range the elevation tube is not used, and no marker line is seen on the range tube.

Ground returns

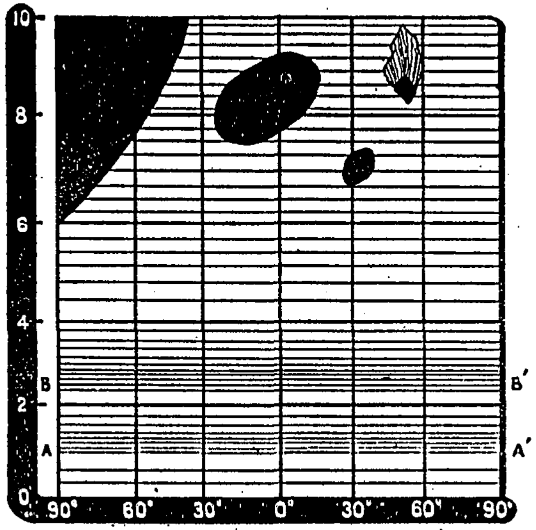
98. As in the case of AI Mk. VIII, responses are obtained on the range tube due to reflection from the ground, and there are two kinds of ground returns, namely,

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

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



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



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

Fig. 23.—SCR-720, typical display

Performance

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

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

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

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

Comparison between AI Mk. X and AI Mk. VIII

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

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

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

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

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

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

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

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

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

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

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

Beacon facilities

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

Beam approach and IFF

110. No provision is at present made on SCR-720 equipment for receiving identification signals from friendly aircraft, or for making a beam approach to the runway. Instead, an auxiliary equipment called SCR-729 may be installed, which has a transmitter of its own radiating on the $1\frac{1}{2}$ metre band. This triggers IFF Mks. III and IIIG sets, and also triggers beam approach beacons.

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

Leading particulars

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

Wavelength: 9·1 cm., 3,300 Mc/s.

Frequency band: S.

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

Pulse width:	$\frac{3}{4}$ microseconds on AI range. $2\frac{1}{4}$ microseconds on beacon range.
Peak pulse power:	70 kW. (approx.).
Aerial system:	Half-wave dipole, vertically polarised, at focal point of 29-inch parabolic reflector. Common transmitting and receiving aerial. Helical scan. Coverage, 75 deg. to each side of line-ahead, and from —30 deg. to +50 deg. in elevation.
Maximum range:	About 6 miles at all azimuths between 75 deg. port to 75 deg. starboard. (This is limited in cases where the target is below the fighter to about four times the height of the fighter).
Minimum range:	300 feet.
Sharpness of D/F	5 deg. at all azimuths.
Centimetre beacon facilities:	No IFF or AI/BA. SCR-729 used for IFF and AI/BA. Pilot's indicator not used by R.A.F.
Units:	
Modulator.	Rotary spark gap producing 4 kV pulse. Pressurised modulator.
Transmitter.	Magnetron. Pressurised container for RF unit.
Mixer.	Soft rhumbatron switch valve. Crystal mixer.
Receiver.	Reflector klystron local oscillator. 6 IF stages. IF frequency, 60 Mc/s. Automatic frequency control.
Indicating.	Two tubes, range azimuth, and azimuth elevation. Ranges: 2, 5, 10, 100 miles.
Power supply.	1,200 watt, 80-volt, 1,600-cycle, engine-driven alternator. Output transformed to 115 volts for American equipment. 1,500 watt, 24 volt DC generator with control panel, type 5.
Weight.	500 lb. including scanner, cables and mounting racks.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