

CHAPTER 6

IFF AND RADAR BEACONS.

IDENTIFICATION FRIEND OR FOE

Introduction

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

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

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

tive pulses it was possible to obtain some measure of coding. In particular, a wide pulse of about 25 microseconds duration was used to denote distress. The widths of the transmitted pulses could be varied while in the air for coding purposes, by a remote-control switch available to the crew of the aircraft.

IFF Mk. I and II

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

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

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

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

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

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

A1 B A2 B A1 B A2 — and so on.

4 sec. 2 sec. 4 sec. 2 sec. 4 sec. 2 sec. 4 sec.

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

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

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

There were, in all, six available codes :—

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

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

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

The B-band—54·5—84 Mc/s and

The G-band—180—210 Mc/s—for use with GCI

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

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

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

The equipment had one pulse width on the G-band, and two on the B-band, viz. :—

G-band, Narrow only, 8 μ S ;

B-band, Narrow, 6 μ S ; wide, 18 μ S.

Various alternative codes were possible on the B-band.

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

The N-band : 195—227 Mc/s

The N2-band : 38—52 Mc/s

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

Limitations of IFF Mk. II

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

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

The function of radar beacons

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

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

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

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

16. BABS beacons are used for a purpose different from that of homing beacons. Their function is to enable an aircraft at night or in bad weather to approach an airfield from the correct direction for landing. Like homing beacons they are fixed-frequency transponders, but their aerial systems differ considerably from those of the previous type. The ground transponder is installed at the far end of the runway, and it usually has a receiving aerial whose line-of-shoot lies along the runway so that it will pick up signals from an aircraft approaching from approximately the correct direction. The beacon re-transmits these pulses

from two directional aerials whose lines-of-shoot make equal small angles with the direction of the runway, one looking slightly to the left of this direction and the other looking to the right. These two aerials are switched, so that the re-transmitted pulses are radiated first from one and then from the other. If the aircraft is making the correct approach it receives equal signals from the two aerials, but if it is not coming in from the correct direction it receives a greater signal from one than it does from the other. Provided that the pilot of the aircraft has some way of differentiating between the signals from the two aerials it is therefore possible for him to correct any errors in his course, and to make the proper approach without difficulty. Details of the precise method of arranging this are given in the section on beacons.

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

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

RADAR BEACONS

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

The history of homing beacons

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

21. The first beacons were used by Coastal Command. They were modified IFF sets tuned to a fixed frequency of 176 Mc/s to respond to the ASV Mark II sets in the Coastal aircraft. ASV Mk. II uses horizontal polarisation, so that these beacons had to be horizontally polarised also. With the introduction of BABS beacons, to be described later, which respond on a frequency of 173.5 Mc/s, it became necessary to raise the frequency of response of the ASV beacons to 177 Mc/s, so that the band would not overlap with that of the BABS. Thus the present ASV beacons receive on 176 Mc/s, and re-transmit on 177 Mc/s.

22. Fighter Command soon followed the example of Coastal Command, and introduced beacons on their aerodromes. These early Fighter beacons, like the Coastal ones, were modified IFF sets. This time, however, they used vertical polarisation, because the Marks of AI with which they were designed to work used vertical aeri-als. They could be interrogated by AI Mk. IV, V and VI, all of which work on a frequency of 193 Mc/s. They were interrogated on this frequency, and responded on a frequency of 196.5 Mc/s, so that the AI receiver had to be detuned in order to receive their signals.

23. Since these early days, there have been several new and improved types of Coastal and Fighter beacons. A number of these newer beacons use superheterodyne receivers, although some, especially the trans-portable types, are still super-regenerative transponders. The polar-isation and the frequencies remain the same, however. All Coastal beacons use horizontal polarisation, receive on a frequency of 176 Mc/s, and respond on 177 Mc/s. All Fighter beacons are vertically polarised, receive on 193 Mc/s, and respond on 196.5 Mc/s.

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

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

26. With the introduction of centimetre versions of ASV and AI, the problem of providing homing facilities became acute. The earliest equipments to work on wavelengths of about 10 cm. were AI Mk. VII and AI Mk. VIII. The first of these was a pre-production model, and only appeared in relatively small numbers. The second, however, was intended for general introduction into all fighter aircraft, and some

form of homing beacon was required to work with it. For this reason an AI Mk. VIII beacon was developed. This beacon was interrogated on the original AI Mk. VIII frequency (3285 Mc/s), and responded on a frequency of 3280 Mc/s. In order to see its response on the AI display it was necessary to detune the receiver. To do this the Mk. VIII equip-ment was supplied with two local oscillators. One of these local oscillators was used for normal operation, and, when its oscillations were mixed with the incoming 3285 Mc/s signal, they gave an intermediate frequency signal which was fed into the IF stage in the normal way. When the operator wished to home on to a beacon he switched over to the second oscillator, which was so tuned that when its oscillations were mixed with the incoming 3280 Mc/s beacon signal, the beat frequency was the same as before, and could be fed into the same IF stage.

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

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

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

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

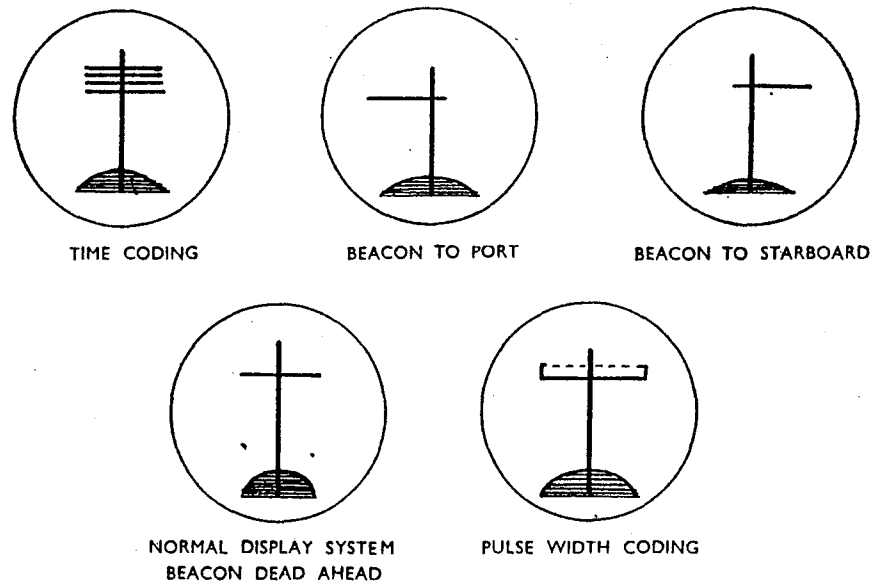


Fig. 1.—Beacon display

Coastal Command homing beacons (all horizontally polarised)

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

31. All the beacons mentioned below use *gap coding* to identify themselves. In this form of coding, the beacon response is switched on and off repeatedly, so that instead of seeing a continuous response on the interrogator display, the operator sees a response which appears for a space of time, disappears, appears again, and so on. By varying the

duration of consecutive periods of operation the beacon can be made to flash dots and dashes. It is usual to arrange for the response to give a two-letter code in this way. The two morse letters are repeated continually, and there are two such letters given to each beacon, so that the operator can distinguish between different beacons.

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

FGRI.5067—TR.3107B

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

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

FGRI.5066—TR.3213

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

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

TGRI.5302C—TR.3236

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

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

FGRI.5584—TR.3558 (Eureka Mk. II)

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

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

American YJ beacon

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

Fighter homing beacons (all vertically polarised)

39. The following 1.5 metre beacons are used by fighter aircraft. The S-band beacons used with AI Mk. VIII will be mentioned later. All the beacons listed below will operate with the older AI equipment or with AI Lucero. All but one use gap coding like the ASV beacons. The exception is the TR.3107 which was intended to be used with AI Mk. VI, which had a form of "range lock" system, and if the response was switched off, the lock was lost. To prevent this the TR.3107 uses wide and narrow pulses for coding.

FGRI.5067—TR.3107

40. This is the standard fixed fighter beacon in use at the present time. It is a mains-operated beacon, and uses a superheterodyne receiver. Production has ceased.

Receiver frequency, 193 Mc/s. Transmitter frequency, 196.5 Mc/s.

TGRI.5302F—TR.3236

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

FGRI.5585—TR.3559 (Eureka Mk. IIF.)

42. This is a fighter version of Eureka Mk. II, to replace the TGRI. 5302. Unlike the Coastal Eureka, it does not use a universal aerial system but has a lightweight aerial.

Receiver frequency, 193 Mc/s. Transmitter frequency, 196.5 Mc/s.

FGRI.5596—TR.3559 (Eureka Mk. IIF)

43. This is exactly the same as the FGRI.5585, except that it uses a universal aerial system.

Receiver frequency, 193 Mc/s. Transmitter frequency, 196.5 Mc/s.

Naval Air Arm homing beacons (all horizontally polarised)

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

Type 251

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

Types 251 M and 251 P

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

Type 953

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

The YJ beacon

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

Type 951

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

Modified American ABK

50. Modified ABK equipment is being installed in ships for the use of night fighters. It is used principally in Algerian waters. The programme corresponds to those of Coastal Command and Fighter Command, both of whom use this modified IFF as a beacon. Receiver frequency, 193 Mc/s. Transmitter frequency 196.5 Mc/s.

Eureka in ships

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

Eureka beacons (usually vertically polarised)

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

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

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

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

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

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

TGRI.5666—TR.3174 (Eureka II)

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

MGRI.5591—TR.3529 (Eureka-H)

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

TGRI.5509—TR.3174 (Eureka Mk. II)

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

TGRI.5527—TR.3514 (Eureka Mk. III A)

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

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

60. The TR.3563 is an ultra-lightweight Eureka designed for special purposes, including the landing of airborne troops. It is supplied with a lightweight aerial, and the whole equipment, including accumulators and power supplied, packs into a small bag. Receiver frequency, 213.5 Mc/s. Transmitter frequency, 216.5 Mc/s.

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

TGRI.5643—TR.3593 (Eureka Mk. III T)

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

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

Interrogation frequency, 213·5 Mc/s; Response frequency, 216·5 Mc/s.

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

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

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

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

| | |
|------------------|---------------|
| 5 seconds on and | 5 seconds off |
| 5 " " " | 10 " " |
| 5 " " " | 20 " " |
| Permanently on | |
| " off. | |

MGRI.5518—TR.3506

65. This is a superheterodyne mains-operated beacon, for use with AI Mk. VIII, and is used at the present time. Like all AI Mk. VIII beacons, it uses vertically-polarised waves, its aerial systems consisting

of two spun copper cones placed apex to apex, with a small gap between the two apexes in which the vertical aerial is mounted. The system radiates equally in all azimuthal directions, and most of the radiation is concentrated at angles of elevation less than $22\frac{1}{2}$ deg. The whole installation is mobile.

Receiver frequency, 3285 Mc/s. Transmitter frequency, 3280 Mc/s.

FGRI.5600—TR.3506

66. The FGRI.5600 uses the same transponder as the MGRI.5518, but it is a fixed installation.

Receiver frequency, 3285 to 3315 Mc/s. Transmitter frequency, 3280 Mc/s.

American S-band homing beacons (horizontally polarised)

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

Receiver frequency, 3270 to 3330 Mc/s. Transmitter frequency, 3256 Mc/s.

American X-band homing beacons

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

69. The AN/CPN-6 is a homing beacon for use with 3-cm. airborne equipments.

Receiver frequency, 9320 Mc/s. Transmitter frequency, 9310 Mc/s.

Special homing beacons

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

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

BABS Mk. I beacons

72. The general principle underlying the operation of BABS beacons has already been described. The beacon is situated at the farther end of the runway, so that the aircraft approaches it when landing. The receiving aerial array of the BABS is mounted so that its line-of-sight lies along the runway. There are two transmitting aerials, whose lines-of-sight are inclined at equal small angles on either side of the runway. The older BABS beacons, which are still in general use, respond for about $1\frac{1}{2}$ seconds on one of these aerials and for about one-sixth of a second on the other, changing over at the rate of approximately 30 or 40 cycles per minute. The beacon is interrogated by ASV Mk. II, AI Mk. IV, V or VI, or by Lucero. Its responses are in the form of fairly wide pulses. If an aircraft is approaching the airfield from the correct direction it receives equal responses from the two transmitting aerials, and the navigator sees a steady response on the display tube. If, however, the aircraft is approaching from a slightly wrong direction the signals received from the two aerials are unequal and the echo on the display tube changes in amplitude as the aerials are switched. The navigator can tell whether he is to the port or to the starboard of the BABS beam by noting whether the length of the echo increases for a short time and falls for a longer time or *vice versa*, and can therefore correct his course. From the ratio of the dot-and-dash signals the observer determines in what sector the aircraft is flying. The following table and fig. 2 shows how this may be done :—

| Ratio | Sector | Bearing of sector relative to runway |
|--------------------|--|--------------------------------------|
| Steady (1 : 1) | Along the runway (Equi-signal zone) | 0 deg. — $\frac{1}{2}$ deg. |
| 4 : 3 | Dots or Dashes 1 | $\frac{1}{2}$ deg. — 2 deg. |
| 4 : 2 | Dots or Dashes 2 | 2 deg. — 5 deg. |
| 4 : 1 | Dots or Dashes 3 | 5 deg. — $12\frac{1}{2}$ deg. |
| Greater than 4 : 1 | Dots or Dashes 4 | $12\frac{1}{2}$ deg. — 40 deg. |

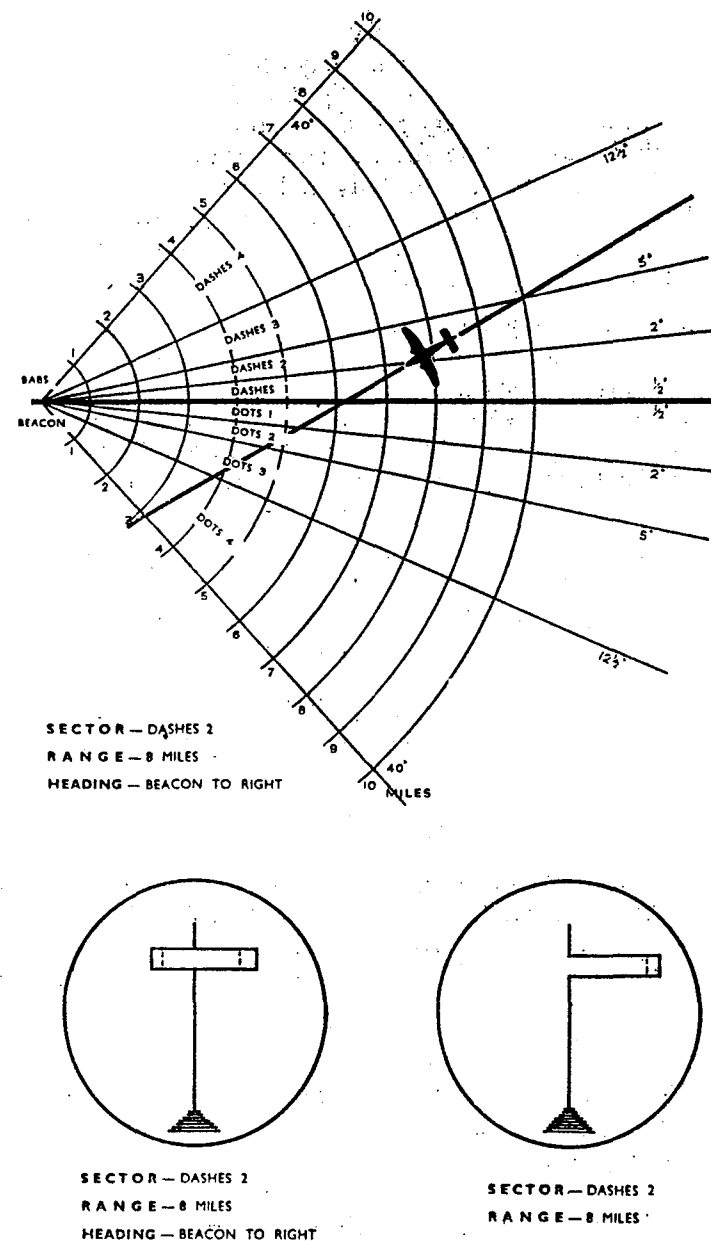


Fig. 2.—BABS Mk. I display

73. There are a number of BABS beacons of this type in use at the present time. The 1.5 metre ASV and AI sets are now becoming obsolete, so that these BABS are usually interrogated by Lucero. It is important to note, however, that fighter BABS is interrogated by fighter Lucero which is vertically polarised, so that the beacon must also use vertical polarisation, while for the same reason Coastal and Naval Air Arm BABS must be horizontally polarised. Bomber Command BABS is interrogated by a bomber version of Lucero which works on a frequency in the Rebecca band, and is used in conjunction with H2S equipment. It is vertically polarised.

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

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

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

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

Receiver frequency 176 Mc/s Transmitter frequency 173 Mc/s
FGRI-5115 — TR.3146 (BABS Mk. I C — ASV/BA)

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

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

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

Receiver frequency 193 Mc/s Transmitter frequency 190.5 Mc/s
Type 257 (BABS Mk. I for use on aircraft carriers)

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

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

BABS Mk. II beacons

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

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

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

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

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

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

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

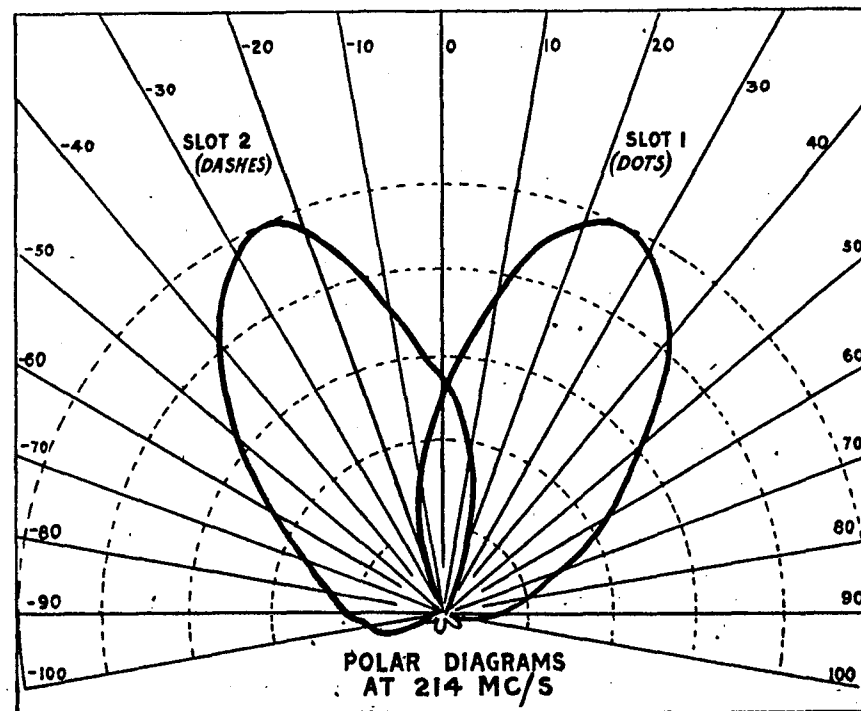


Fig. 3.—BABS polar diagram

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

87. In the BABS Mk. II the system of display is also changed. The slotted aeriels are switched more quickly than the aeriels of the old BABS, and they operate for equal intervals of time. There are ten switching cycles per second, so that each aerial transmits in turn for one-twentieth of a second. One aerial transmits narrow pulses and the other transmits wide pulses, and both pulses appear together on the interrogator display tube, see fig. 4. When the aircraft is making the correct approach, both these pulses have the same amplitude. If, however, the aircraft is to one side or the other of the BABS beacon, one of the pulses appears longer than the other. It is claimed that this display makes it easier for the navigator to judge whether he is making the correct approach. The accuracy is said to be between $\frac{1}{2}$ deg. and $\frac{3}{4}$ deg. in azimuth. The same system of sectors is used as with BABS Mk. I.

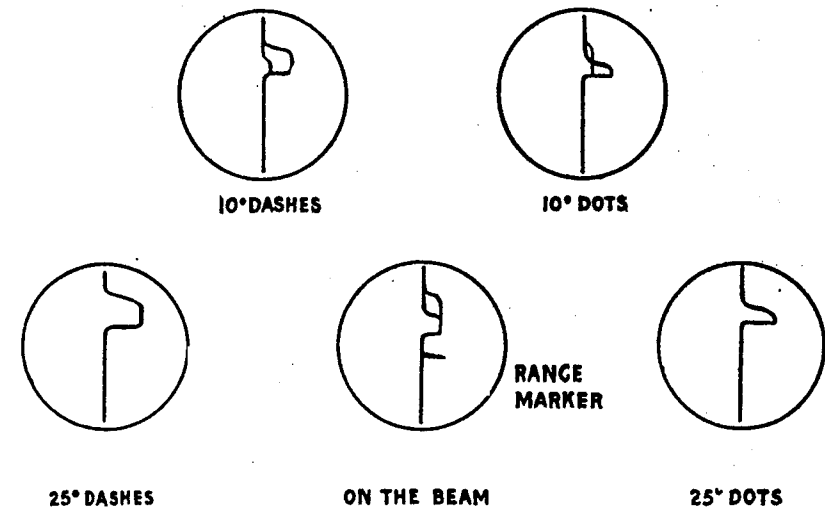


Fig. 4.—BABS Mk. II display

FGRI. 5644—TR.3567 (Lucero/BA)

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

MGRI.5577 — TR.3567 (BABS Mk. IIM)

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

MGRI.5586 (BABS Mk. II FM)

90. This is another version of BABS Mk. II, vertically polarised.
Receiver frequency 193 Mc/s Transmitter frequency 190.5 Mc/s

MGRI.5587 (BABS Mk. II CM)

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

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

Glide-path BABS

92. A new type of BABS beacon is in development; its function is to enable an aircraft to approach an aerodrome in conditions of poor visibility along the correct glide path—that is, to come down at an angle of inclination of about $2\frac{1}{2}$ deg. to the horizontal along a path which will enable the pilot to touch down close to the near end of the runway. This beacon receives interrogating pulses from a Lucero equipment working on a frequency of 214 Mc/s, and re-transmits on a frequency of 515 Mc/s. It requires a small extra receiving unit attached to the Lucero, to receive these higher frequency responses.

93. The glide-path beacon uses two transmitting aerial systems, situated at different heights above the ground. The transmitter is switched from one to the other, so that the aircraft responder receives pulses from each in turn, and there are 20 switching cycles per second as in the BABS Mk. II. Owing to ground reflection effects, the radiation patterns of these two transmitting aeriels consist of the usual lobes and gaps, and their heights are arranged so that equal signals are received from both at an angle of elevation of about $2\frac{1}{2}$ deg. It is necessary, of course, to use horizontally-polarised waves for this purpose, to ensure that the ground reflection conditions are independent of the type of surface from which the reflection takes place, and that the vertical polar diagrams of the two aeriels will be unaffected if the equipment is moved from one flat site to another. The radiating aerial system consists of two vertical slots in a wave guide. The transmitter output is switched continuously from one of these slots to the other.

94. The glide-path BABS will be used at the near end of the runway, that is the end from which the aircraft approaches, while the ordinary BABS will be at the far end. The higher and lower aeriels of the glide

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

Lucero interrogators

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

1. Different radar equipments require Lucero equipments of different frequencies. Thus Lucero used with ASV must interrogate on 176 Mc/s and receive on 177 Mc/s. Lucero used with AI must transmit on 193 Mc/s, and receive on 196.5 Mc/s, and so on.
2. Lucero uses the IF stages of the various equipments with which it is used, and different S- and X-band radar equipments have different IF frequencies.

Thus the IF frequency of H2S Mk. II is 13.5 Mc/s

Thus the IF frequency of H2S Mk. III is 45 Mc/s

Thus the IF frequency of ASV Mk. III is 13.5 Mc/s

Thus the IF frequency of later marks of ASV is 45 Mc/s

Thus the IF frequency of AI Mk. VIII is 30 Mc/s

Thus the IF frequency of AI Mk. IX is 45 Mc/s

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

Lucero Mark II and III equipments

| TR Number | Command | Equipment with which used | Frequencies Mc/s | | IF Freq. (Mc/s) | Remarks |
|------------------------|---|--------------------------------------|------------------------|-------------------------|-----------------|---|
| | | | Tx | Rx | | |
| TR.3160 (Lucero II) | Bomber Coastal | H2S Mk. II ASV Mk. III | 176 | 177 | 13.5 | |
| | | | | 173 | | |
| TR.3566 (Lucero II) | Bomber Coastal | H2S Mk. III ASV Mk. VI and VII | 176 | 177 | 45 | Particularly for use with Bomber aircraft to give beacon and BABS on Eureka frequencies |
| | | | Two between 214 & 234 | Three between 214 & 234 | | |
| | | | | | | |
| TR.3549 (Lucero II) | Fighter Command (can be used with Coastal aircraft) | AI Mk. VIII | 176 | 177 | 30 | For use in night fighter aircraft |
| | | | | 173 | | |
| | | | 183 193 | 190.5 196 | | |
| TR.3532 (Lucero II) | Fighter Command | AI Mk. IX | 176 | 177 | 45 | For use in night fighter aircraft |
| | | | | 173 | | |
| | | | 183 193 | 190.5 196 | | |
| | Bomber | H2S Mk. II | Four between 214 & 234 | Four between 214 & 234 | 13.5 | Under development for bomber aircraft |
| | | | | | | |
| | Bomber | H2S Mk. III | Four between 214 & 234 | Four between 214 & 234 | 45 | Under development for bomber aircraft |
| TR.3505 (Lucero II) | NAA | ASVX (Barracuda) | 176 | 177 173 | 45 | 24-volt model |
| TR.3507 (Lucero II) | NAA | ASVX (Swordfish) | 176 | 177 | 45 | 12-volt model |
| | | | Four between 214 & 234 | Four between 214 & 234 | | |

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

Rebecca interrogators

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

ARI.5506—TR.3173A (Rebecca Mk. II)

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

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

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

ARI.5649—AN/APN-2 (Rebecca Mk. II A)

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

ARI.5594—TR.3576 (Rebecca Mk. II B)

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

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

ARI.5642—(Rebecca Mk. II T)

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

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

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

ARI.5610 (Rebecca Mk. IV)

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

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

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

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

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

Vertical aerials for interrogating Eureka and IFF.

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

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

Rebecca Mk. V

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

Rebecca Mk. VI

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

American interrogators equivalent to Rebecca

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

SCR-729 A (Horizontally polarised)

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

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

SCR-729 F

112. This is a modification of the SCR-729 A, which has facilities for interrogating fighter beacons as well as IFF. It is used with AI Mk. X (SCR-720). It can transmit and receive on 183 Mc/s, or alternatively it can transmit on 193 Mc/s and receive on either 190.5 or 196 Mc/s. The aerial system is vertically polarised and is similar to that of the SCR-729 A.

AN/APX-2

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

AN/APX-8

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

THE IFF Mk. III SYSTEM

The operation of IFF Mk. III

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

116. IFF Mk. III sweeps a frequency band of 157 to 187 Mc/s. To do this a tuning control is rotated by an electric motor. The time sweep is 2.5 seconds and the period of flyback of the control, during which the set is suppressed, is 0.3 seconds. Interrogators working on any frequency in the IFF band will therefore receive a response once every 2.8 seconds. IFF Mk. III sets are carried by allied aircraft and also by certain allied warships and merchant vessels, and many types of ground and shipborne radar equipments have interrogators designed to operate with them. Certain aircraft radar sets, particularly AI, are also fitted with Mk. III interrogators. The IFF Band of 157 to 187 Mc/s is usually called the A-band (until recently it was called the I-band) and interrogators used with different equipments are allowed various spot frequencies in this band.

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

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

gators where reflection takes place from the sea, although the Brewster angle is very small at the frequency of Mk. III equipment, and the effect is not marked, it gives a greater amplitude than horizontal polarisation along the surface of the sea, and is therefore useful for ship-to-ship interrogation.

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

IFF Mk. III interrogators

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

Navy, equipments (shipborne)

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

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

Army equipments (ground)

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

| Name of radar | Freq. of radar | Purpose of radar | Type of Intergr. | Freq. of Intergr. | Remarks |
|---|------------------------------------|---|----------------------------------|--|---|
| GL Mk. II (AA No. 1 Mk. II) | 54.5 to 89 Mc/s | Anti-aircraft gun laying | Ident. RDF No. 1 | 165 Mc/s and 171 Mc/s | |
| SLC (AA No. 2) | 204 Mc/s | Searchlight control | Ident. RDF No. 3 | 159 Mc/s and 168 Mc/s | |
| GL Mk. III (AA No. 3 Mk. II) | 3,000 Mc/s | Anti-aircraft gun laying | Ident. RDF No. 1 | 165 Mc/s and 171 Mc/s | In this interrogator the usual Yagi aeriels are replaced by vert. half wave aeriels |
| GL Mk. III C (AA No. 4 Mk. I) | 130 to 170 Mc/s | Anti-aircraft gun laying | American Intergr. BL3 | Any fixed frequency in 157-187 Mc/s band | |
| Light warning (2 versions AA No. 4 Mk. II and AA No. 4 Mk. III) | 176 Mc/s and 212 Mc/s | Early warning of aircraft | None 242 | 184 Mc/s | The Mk. II works on A band frequency so no intergr. is required |
| GCI (AA No. 5 Mk. I) | 209 Mc/s | Control of fighters in conjunction with searchlights | T.3117 R.3118 | 174 Mc/s | Similar intergrt. to that of GCI |
| CD/CHL (CD No. 1 Mk. I) | 200-203 Mc/s | Early working of aircraft and shipping | T.3117 R.3118 | 162 Mc/s and 174 Mc/s | Similar intergrt. to that of CHL |
| CD No. 1 Mk. II | 3,000 Mc/s | Coastal defence-early warning of surface vessels | 242 | 184 Mc/s | |
| CA No. 2 Mk. I | 3,000 Mc/s | Coastal gunnery on surface craft | 242 | 184 Mc/s | |
| CD No. 1 Mk. III and IV | 3,000 Mc/s | Coastal defence early warning of surface craft | 242 | 184 Mc/s | |
| AN/TPS-1 AN/TPS-2 AN/TPS-3 | 1,071 Mc/s 400 Mc/s 600 Mc/s | Light warning sets similar to British LW in function, but US equipments | AN/TPX-1 AN/TPX-2 AN/TPX-3 | Spot frequencies in A-band not yet known | |

RAF equipment (ground)

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

| Name of radar | Freq. of radar | Purpose of radar | Type of Intergr. | Freq. of Intergr. | Remarks |
|-------------------------|-----------------------------------|--|-------------------|------------------------------------|---|
| CH | 22.7-29.7 Mc/s and 42.5-50.5 Mc/s | Early warning of aircraft approaching coast | T.3117 and R.3118 | 162 Mc/s and 172 Mc/s | Interrogator aeriels not beamed |
| MRU | 42.5-50.5 Mc/s | Early warning of aircraft | T.3117 and R.3118 | 174 Mc/s | Interrogator aeriels not beamed |
| CHL | 200-203 Mc/s | Early warning of aircraft and ships | T.3117 and R.3118 | 159 Mc/s and 165 Mc/s and 174 Mc/s | Beamed arrays for interrogators |
| CO (overseas stations) | 22.7/29.7 Mc/s and 42.5-50.5 Mc/s | Early warning of aircraft | T.3117 and R.3118 | 178 Mc/s | Interrogator aeriels not beamed |
| COL (overseas stations) | 200-203 | Early warning of aircraft and ships | T.3117 and R.3118 | 178 Mc/s | Beamed arrays for interrogators |
| Light warning type | 176 Mc/s and 212 Mc/s | Early warning of aircraft | None 242 | 184 Mc/s | No interrogator required with 176 Mc/s. Changing over interrogator aeriels to Yagis in 212 Mc/s version which uses type 242 |
| GCI fixed type | 209 Mc/s | Fighter control especially of night fighters | T.3117 and R.3118 | 162 Mc/s and 174 Mc/s | Beamed interrogator arrays |
| Mobile type | 209 Mc/s | | | 174 Mc/s only | |
| AMES type 11 | 500-600 Mc/s | Standby GCI and CHL | T.3117 and R.3118 | 174 Mc/s | Beamed interrogator arrays |
| AMES type 16 | 500-600 Mc/s | Fighter control during offensive sweeps | T.3117 and R.3118 | 174 Mc/s | Beamed interrogator arrays |

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

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

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

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

127. The G facility requires the inclusion of a second tuned circuit in the transponder. This circuit, the G circuit, is permanently tuned to the frequency of the GCI station with which it is to operate and it

will give responses only to interrogation on this preset frequency. During G operation the tuning of the A-band circuit continues its normal frequency sweep and the chopped responses are obtained by switching from the G to the A circuit.

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

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

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

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

- (1) A-band sweeping from 157 to 187 Mc/s once every 2·8 seconds, when it responds to any Mk. III interrogator.
- (2) G working when it gives a chopped response, replying alternately for 1/10 second on the A-band and for one twenty-fifth second on a preset frequency on the G-band. It can be switched on to this state either by depressing the G button, in which case it automatically returns to normal A-band working after 20 seconds, or by depressing the R switch, when it remains in this state indefinitely.
- (3) R working, when it responds continuously to a preset frequency on the R-band. It can be switched on to this condition by depressing the R switch and will continue to work on the R-band until switched back to the A-band condition. The responses can be keyed.

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

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

IFF Mk. III can work in condition (1) only.

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

132. Certain Rebecca interrogators used in H.M. ships work on a frequency of 214 Mc/s and require Roosters to respond on this frequency. This has led to the installation of two modified Mk. II N sets in some

aircraft ; one to respond on 176 Mc/s and the other on 214 Mc/s. A British Mk. III G(R) equipment is modified to perform both these functions. The normal A-band sweep can be stopped as before at 176 Mc/s, while the G circuit is tuned to respond on 214 Mc/s. The set modified in this way therefore becomes a Mk. III (R) with double R facilities.

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

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

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

137. Normal Mark III operation.

| | |
|-------------------|---|
| Function | Identification to interrogators working on the A-band |
| Frequency | Continuous sweeping of the A-band, 157 to 187 Mc/s. |
| Time of sweep | 2·5 seconds with 0·3 second flyback period, giving overall repetition rate of 2·8 seconds. |
| Peak power output | 6 to 8 watts. |
| Sensitivity | 100 microvolts. |
| Pulse widths | Narrow (N) 6 to 8 microseconds. Wide (W) 17 to 25 microseconds. Very wide (VW) 60 to 100 microseconds. (The latter is used only for distress). |
| Coding | There are six possible codes :— |
| | 1. N N N N |
| | 2. N N N — |
| | 3. N — N — |
| | 4. N N W W |
| | 5. N N W — |
| | 6. N — W — |

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

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

138. G operation.

Function To respond to GCI stations, working on the fixed GCI frequency on the G-band while normal A-band sweeping continues.
The set gives chopped responses, 1/10 second A-band and 1/25 second G-band.

Frequency On A-band sweeps from 157 to 187 Mc/s every 2.8 seconds. On G-band has fixed frequency between 200 to 210 Mc/s.

Peak power output 6 to 8 watts on both A and G bands.

Sensitivity 100 microvolts.

Pulse widths A-band—6 to 8 microseconds, 20 to 35 microseconds.
60 to 100 microseconds.
G-band—10 to 20 microseconds.

Coding A-band—as for normal Mk. III operation.
G-band—no coding.

Aerials As for normal Mk. III operation.

139. R operation.

Function To respond as a Rooster beacon to frequencies in the R-band. The set gives a continuous response to interrogation on a preset frequency in this band, and enables other aircraft carrying ASV Mk. II or suitable Lucero and Rebecca to home on to it.

Frequency Preset frequency in R-band between 172 and 182 Mc/s, usually 176 Mc/s. (For certain Naval uses it may be outside this band, usually on 214 Mc/s.)

Peak power output 6 to 8 watts.

Sensitivity 100 microvolts.

Pulse widths 10 to 20 microseconds.

Coding None.

Aerials As for normal Mk. III operation.

Remarks While on Rooster operation the set gives no normal Mk. III responses. The Rooster response can be keyed to pass messages to the homing aircraft.

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

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

IFF Mk. III transponders

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

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

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

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

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

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

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

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

Interchangeability of airborne IFF sets:

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

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

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

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

- (1) A pulse of large amplitude and of a few microseconds duration to suppress the IFF during the time of operation of the Lucero transmitter.
- (2) A longer pulse, usually of 1.2 to 1.6 milliseconds duration, to give suppression during the time of transit of the timebase on the Lucero display tube. This pulse need not be of so great an amplitude as the former. The two pulses are fed from the Lucero to the IFF transponder along the same cable.

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

period of Lucero transmission. In this way suppression begins before the Lucero transmission, but extends until the transmission is over.

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

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

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

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

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

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

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

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

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

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

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

| <i>Set</i> | <i>Facilities available</i> | <i>Suppression to Lucero, etc.</i> |
|--------------------|-----------------------------|--|
| R.3067/ R.3090 | Normal Mk. III | Suppression of noise may be incomplete |
| ABK and SCR-595 | Normal Mk. III | Suppression of radiated noise not complete. This will be cured by a modification which is being carried out by Squadrons |

| <i>Set</i> | <i>Facilities available</i> | <i>Suppression to Lucero, etc.</i> |
|-------------------|--|---|
| R.3120/ R.3121 | Normal Mk. III, but G(R) not available owing to differences in control circuits (British thermal delay and American fed back time constant for 20 sec. G switch) | |
| SCR-695 | Mk. III and G—No Rooster | Set triggered by Lucero and no noise suppression |
| R.3598 | Mk. III and G—No Rooster | Modified SCR-695 to give complete Lucero suppression |
| AN/APX-1 | Full Mk. III and G(R) | Triggered by AI Mk. VIII Lucero, and no noise suppression to Lucero of any type |

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

| <i>Set</i> | <i>Facilities available</i> | <i>Suppression to Lucero, etc.</i> |
|--------------------|--|--|
| R.3067/ R.3090 | Normal Mk. III (adaptor required) | |
| ABK and SCR-595 | Normal Mk. III (adaptor required) | The AN/APX2 includes an interrogator as well as a transponder. The substitution of other transponders renders the interrogator ineffective, and if another interrogator is substituted the same suppression problems arise as those already enumerated above |
| R.3120/ R.3121 | Normal Mk. III, but G(R) not available owing to difference in control circuits (British thermal delay and American fed back time constant for 20 sec. G switch (adaptor required) sec. G switch (adaptor required) | |
| SCR-695 | Mk. III and G—No Rooster (adaptor required) | |
| R.3598 | Mk. III and G—No Rooster (adaptor required) | |
| AN/APX-1 and 2 | Full Mk. III G(R) | |

Naval Mk. III transponders

159. Special models of Naval IFF Mk. III have been produced, primarily for installation in H.M. ships, although they are similar to the airborne types and can be used in aircraft. Generally speaking these Naval transponders are primarily used as beacons, but they have identification as a second function. Some of these sets have already been mentioned in the part of this report which deals with Beacons.

160. *Type 251.* This set was designed for use in certain of H.M. ships. Its function is partly that of identification and partly that of a homing beacon. It sweeps a frequency band of 173 to 179 Mc/s continuously, and will respond to ASV Mk. II and ASV Mk. II N. It has now been replaced by later equipments. It had no coding.

161. *Type 251 M.* This is a modified type 251. It receives on a fixed frequency of 176 Mc/s and re-transmits on 177 Mc/s. It is gap-coded, that is it responds with pulses which are all of the same width, but the transmission is switched on and off so that the pulses are radiated in a succession of trains with blank spaces between. A train lasting for a longer time forms a dash, while one of shorter duration is taken as a dot.

162. *Type 251 P.* This set is a modification of the type 251 M. Its operation is identical with that of former equipment.

163. *Type 252.* Type 252 is the Naval nomenclature for IFF Mk. II N, details of which have already been given. It responded directly to Naval radar equipment, type 79, 279, 286, 290, 291 and 241. It is now obsolete. It was used in Naval aircraft and in ships. It was horizontally polarised.

164. *Type 253.* This is normal IFF Mk. III and sweeps a frequency band of 157 to 187 Mc/s in the usual way. It is identical with British Mk. III transponder, and is used both in aircraft and ships of the Royal Navy.

165. *Type 253 M.* This was a forerunner of the type 253 P which will be described later. It differed principally from this later set in that its responses had to be keyed whereas the 253 P is automatically coded. It is sometimes called the IFF Mk. III M. Attempts were made to use it in aircraft, particularly for Rooster working, but it interfered considerably with other aircraft sets, so the project was abandoned. The type 253 P has now rendered it obsolete.

166. *Type 253 P.* This is a new shipborne IFF set which is described later.

LIMITATIONS OF IFF Mk. III AND PROPOSED FUTURE SYSTEMS

167. IFF Mks. III, III G and III G(R) suffer from serious operational limitations. The failings of the Mk. III system as it exists at the present time, and a number of suggested improvements and alternative systems are described in the following paragraphs.

Clutter

168. Such a large number of aircraft and ships now carry some form of IFF Mk. III that the traffic-handling capabilities of the system are no longer adequate, and ground and ship-borne interrogators, during periods of great activity, receive so many responses that the trace of the IFF display tube shows one solid mass of echoes through which it is impossible to recognize any one individually. This appearance of crowded responses on the IFF display is called *clutter*, and it arises from four main causes.

Over-interrogation

169. The chief factor in producing clutter is simple over-interrogation. If a large number of aircraft are operating in one area, and all their transponders are switched on, clutter is the inevitable result; it occurs also on the main radar display tube when the concentration of aircraft in any one area is too high. In certain cases, in fact, IFF clutter is not an important operational limitation. If the normal radar echoes cannot be identified individually, there is little point in worrying about clutter on the IFF tube; a single hostile aircraft which happened to be present among the others could not be seen in any case. This is true when CH and CHL stations are plotting bomber raids leaving and returning to the coast. The IFF clutter can still be troublesome, however, when the concentration of aircraft is not sufficiently great to cause clutter on the main radar. This suggests that there are also other factors which add to the trouble, and although no controlled experiments have been performed to prove this conclusively, it is almost certain that the following factors are contributory.

Mutual triggering

170. It is possible for the response from one IFF set to trigger a second set in its neighbourhood. Because IFF transponders have a bandwidth of some 6 Mc/s this can happen if the two sets are tuned to slightly different frequencies, and it can be shown that if a large number of IFF Mk. III sets are working in one neighbourhood complex mutual triggering effects may occur and a single interrogator can cause multiple response on all frequencies in the A-band.

Triggering by engine noise

171. A transponder can be triggered at random by the engine of the aircraft.

Triggering by CHL

172. There has been evidence recently that IFF sets are being triggered by CHL stations working on a 193 Mc/s. Although this is 6 Mc/s outside the A-band it appears that the bandwidths of the CHL transmitter and the IFF transponder are sufficient to permit overlap.

173. All these factors are probably instrumental in producing clutter. The Operational Research Section of Fighter Command are investigating the whole question, and are hoping to obtain more conclusive experimental evidence. Whatever the causes, however, the problem is so serious that it often renders IFF Mk. III virtually useless, so that the number of aircraft and ships allowed to show IFF had to be seriously reduced.

Methods of overcoming clutter

174. There have been many suggestions of possible methods of overcoming clutter. The following appear to be the most promising:—

Switching of interrogators

175. Interrogators should be switched on only when required, and all interrogators should be fitted with spring-loaded switches which automatically return to the OFF position when released. In this way, each interrogator will work only during occasional periods of a few seconds, and the interrogation will be materially reduced.

176. One attempt has been made to cut down interrogation by automatically switching interrogators. In this method interrogators working on the same frequency are switched on in rotation, so that each one works only for a short period and no two are ever operating together. This certainly reduces clutter, but it involves locking all neighbouring interrogators by land-line to some form of electrical timing equipment, so that its application is limited.

Reduction of repetition rate

177. The interrogator repetition rates should be as low as possible in order to reduce the rate of interrogation of transponders. This is limited by the fact that if the repetition is too low it leads to flicker and insufficient brightness on the display tube.

Reduction of power output of interrogators

178. The power output of interrogators should be as low as possible. This will decrease their ranges, and will therefore reduce the number

of interrogators working with any IFF set at any given time. The necessity for adequate IFF ranges clearly limits the extent to which this method can be applied. The Admiralty has already reduced the power output of a number of interrogators, and almost all Naval interrogators now in use have peak powers of less than 100 watts. The power rating of Lucero has been fixed by beacon rather than by IFF requirements. An Optec paper of July, 1944 suggests that some experimental investigation is required to decide whether reduction of Lucero power is possible or desirable.

Reduction of sensitivity and power output of transponders

179. The sensitivity and the power output of transponders should be as low as possible. This will serve the same purpose as reducing the power output of the interrogator. The decreased sensitivity should also lessen the probability of triggering by engine noise.

Beaming of interrogator and transmitter aerials

180. Highly-beamed and continuously-rotating transponder aerial systems should be used. However, it is important to note that the possible extent of beaming is severely restricted; a transponder which continuously sweeps a frequency band must remain in the interrogator beam for a length of time at least equal to the time of frequency sweep if it is to be sure of giving one response. This same restriction is imposed in transponders which give coded responses. The time taken for the beacon to sweep past such a transponder must be at least equal to the time taken for one complete coding cycle. In the case of ground and shipborne interrogators it is clearly possible to tolerate narrower beams if the speed of rotation of the interrogator aerial system is reduced. Other operational requirements, however, make it impracticable to reduce this speed indefinitely. The following table shows what the beam-width of an interrogator aerial system must be in order to obtain one response and four successive responses from a Mk. III IFF set at different speeds of rotation of the aerials.

| <i>Speed of rotation of aerials (r.p.m.)</i> | <i>Beam-width in deg. required to obtain one response</i> | <i>Beam-width in deg. required to obtain four consecutive responses</i> |
|--|---|---|
| 1 | 17 | 68 |
| 2 | 34 | 136 |
| 3 | 51 | 204 |
| 4 | 68 | 272 |

181. It would be possible to work with narrower beams if the interrogator aeriels were not continuously rotated, but were turned by the operator when he wished to look at a particular echo whose identity was required. The beam could then be held on this echo indefinitely. Many interrogators now in use, however, have their systems mounted on the same framework as those of the main radar, so that stopping the rotation of the interrogator aerial means also stopping that of the main equipment.

182. 8-bay and 12-bay aerial systems have been used with RAF interrogators, and the beaming has probably been carried to its practical limit. CHL and GCI equipments fitted with these highly beamed aeriels usually carry them above the normal radar aerial, and have to stop their continuous rotation during interrogation. Army equipments usually have a much wider interrogator beam, whose width is of the order of 50 deg. This is not a great disadvantage, however, because the interrogators have low power output (about 30 watts) and being used with precision radars such as GL, the timebase is necessarily fast and gives good range resolution. The problem is most acute in the case of the LW set which had a slow timebase, and this is now being fitted with a more highly-directional interrogator aerial.

183. Naval interrogators have simple interrogator aeriels which give wide beams. The problem of clutter has not been serious with the concentrations of aircraft so far used in Naval operations, but it is most necessary to bear it in mind if greater densities are expected in the future. With the advent of greater concentrations of aircraft it will certainly be necessary to use beamed arrays.

Sippi

184. A technique known as *Sippi* has been developed for artificially narrowing the beam-width of the responder. This does not reduce the total amount of clutter, because the interrogator can still transmit over a wide azimuthal range, but it does reduce the amount of clutter scan by the particular interrogator. It is very effective, but again necessitates stopping to "look" at the target which is to be identified.

Double interrogation

185. It is possible to introduce a system of double interrogation which would completely cure clutter arising from mutual triggering and from triggering by engine noise and by CHL stations. There are two alternative methods of accomplishing this. The first of these methods involves the use of a double pulse. The interrogator must be modified to transmit two pulses spaced a few microseconds apart. The transponder must be so designed that it will not respond unless interrogated by two such pulses.

186. The second method uses the ordinary single-pulsed interrogation system, but arranges that the transponder will not reply to the interrogation pulse unless it is receiving simultaneously a priming signal on a second chosen frequency. The priming signal may be radiated continuously from the interrogating station, or may consist of a second series of pulses radiated on the priming frequency. This latter alternative is operationally better and more convenient, as it is possible to use the pulses from the parent radar for priming purposes; the interrogator is usually locked to the parent radar in any case, so that the pulses are always coincident. This system of using a transmission on a second frequency to put the transponder into an operational state is called the system of *prime-and-poop*.

187. Both these systems are discussed in paras. 194 to 197, dealing with security problems. Either one could eliminate mutual triggering and triggering by engine noise and by other radar equipments.

Reducing bandwidths

188. It may be desirable to narrow the transponder bandwidths. This should reduce the effect of cross-interrogation and of interrogation by radar equipments, such as CHL, which are just outside the IFF band.

189. The duration of each response clearly depends on the bandwidths of the transponder and the responder, and it will be reduced if these bandwidths are reduced. It is also true that if the response curves of the transponder and responder are not steep sided, the duration of each response will depend very much on the range, being much greater at short ranges. It has been suggested that it would be advantageous to make the response curves as steep-sided as possible in order to make the response duration as nearly as possible independent of the range. The RAF organization known as 60 Group (now 90 Group) have attempted to improve the operational performance of IFF by reducing the responder bandwidth and by steepening the response curve, and have had some success.

Slow build-up display

190. It is easier to deal with clutter operationally if a slow build-up display tube is used.

Signal gating by radar

191. ASE have developed a method of signal-gating, whereby a strobe can be set to the range of any echo on the radar display tube whose identity is required. The interrogator then displays only those IFF returns coincident in range with this echo. The system as it exists displays IFF responses on any azimuth if they are at the correct range, but ASE are investigating the possibility of further confining responses to a small azimuthal sector.

Split interrogation

192. It has been suggested that a new system might be developed whereby the interrogator transmits pairs of pulses, one of each pair being radiated from one of the two halves of a split array. The lines-of-shoot of the two halves of this array would be inclined at a small angle, and the transponder would be so designed that it would respond only if the amplitude of the two pulses which it received were almost equal. The effective beamwidth could then be made as small as required. To put this method into operation would require an entirely new IFF system.

Raster presentation

193. In the case of interrogating equipments where it is possible to display IFF echoes as brightness modulation on an afterglow tube, it may be helpful to give the timebase of the tube a slow vertical sweep, synchronised as nearly as possible with the time of frequency sweep of the IFF transponder. The echoes will then appear on a raster and signals from aircraft at the same range will not usually be superimposed.

Integration

194. It is possible to obtain better range resolution with equipments where the timebase of the display tube is slow, by introducing a range strobe with an interrogator. A portion of the timebase can then be strobed and magnified.

Security aspects

195. There were two serious problems of security that arose in the operational use of IFF during the last war.

- (1) The enemy could interrogate IFF Mk. III, and use the responses to detect and identify allied aircraft.
- (2) Many of our IFF equipments inevitably fell into enemy hands, and he was able to fit them into his own aircraft and ships to confuse our identification system. With sufficient time and labour he even manufactured copies of our sets himself and used them for this purpose.

196. The second of these problems was considered to be the more important, and it might be expected that the enemy would attempt to compromise our system by carrying British and American IFF sets. IFF Mk. III as it exists at the present time can be both easily interrogated by enemy equipment and also, if captured, used by him to cause confusion. It is, therefore, essential either to develop some new system or to increase the security of the present IFF.

197. Any of the following schemes could be adopted to alleviate the problem of security.

Double-pulse interrogation

198. This method has already been mentioned in dealing with clutter. Its advantage, from a security point of view, is that the enemy would have some difficulty in interrogating our transponders. He would first have to discover that we were using this method of interrogation and then he would have to build suitable double-pulsed interrogators. The system offers no cure for the second security problem.

199. Exponents of this method say that the necessary facilities could be provided by the addition of a small box to the airborne transponder. It would also require modification to all existing interrogators including Lucero, and it would be impossible to interrogate IFF with ASV Mk. II. Another difficulty would also arise from the fact that the interrogator response would be delayed, and to obtain correlation between the radar responses and those from the IFF it would be necessary to modify the existing forms of display.

200. The U.S. Army and Navy have considered the possibility of adopting the system and have modified the ABK and the SCR-695 sets to take double pulses. They are also contemplating modifications to the AN/APX-1 and AN/APX-2 for the same purpose.

The prime-and-poop system

201. A brief statement of the principle underlying the operation of this system has been given. It offers the same security facilities as the double-pulse method, but it is, perhaps, more acceptable. It would not require any modification to the interrogator, as it could use exactly the same interrogating pulses as the Mk. III IFF, while the priming pulses could be supplied by the parent radar. It also has the advantage of causing no range error, so that it would require no modification to the IFF display. This system is used by the type 950 IFF system, which is being developed for Naval use.

Coded responses

202. Neither of the systems so far described offers any security against the possibility of the enemy capturing and using Allied IFF sets. The most satisfactory way of overcoming this system is to give a coded response. The response of the present Mk. III set can be coded, but something far more elaborate than this is required so that the code can be changed from day to day, or even from hour to hour.

203. Transponders can be coded in several ways, but the method which is usually considered the most satisfactory from both a technical and an operational point of view is to use a transponder which gives a sequence of wide and narrow responses in the same way as the Mk. III set, but with a greater number of possible permutations.

The present problem

204. The facts outlined in the foregoing paragraphs show that the two major limitations of IFF technique as it exists at the present time are its low traffic-handling capacity and its lack of security. There are two alternative remedies; one can either patch up the existing Mk. III system, or devise an entirely new method of interrogation. Both these courses have, in fact, been adopted. With existing Mk. III equipment all feasible steps are being taken to reduce the clutter, and Britain is developing new types of IFF Mk. III which will be less easily compromised than the present sets; in America work is being carried out on IFF Mk. V.

205. Any type of IFF can, of course, be compromised, to some extent, and the best that one can expect is that the system shall be as fool-proof as possible, and that if the enemy attempts to use it to his own advantage he will experience the maximum amount of trouble in doing so. Similarly, no system can have infinite traffic handling capacity, and it is only possible to reduce the clutter problem to a minimum. The more secure the system, and the higher its traffic capacity, the greater will be its technical complexity, and the greater, therefore, its weight, the length of time required for its development, and the difficulties involved in its production. In developing any new form of IFF, therefore, it is necessary to strike a balance between these conflicting factors, and to consider the price that must be paid for greater operational efficiency.

206. The various IFF systems being developed are described briefly here. They all incorporate some of the methods which have already been outlined for reducing clutter and for increasing security. Some of these are merely improvements on the present Mk. III system, while one is an elaborate new scheme, considerably more efficient, but requiring long and tedious development.

NEW SYSTEMS

Type 253P

207. The question of security is particularly important to the Navy, and the type 253 P has been developed in Great Britain for use in H.M. ships. It follows the type 253 M which has already been mentioned, and fulfils the functions of that equipment and has in addition some extra facilities. Type 253 M is now obsolescent, and requires no further mention.

208. Type 253 P differs from the Mk. III IFF (that is, the Naval type 253) in having facilities for giving a coded response on a fixed frequency. It is supplied with a special control unit which has three

buttons, the I, A, and B buttons, and each of these selects a particular state of working as follows:—

Button I When this is depressed the equipment gives ordinary Mk. III operation, and sweeps the A-band from 157 to 187 Mc/s. (Note: The name I Button was given before the change of nomenclature, when what is now called the A-band was named the I-band).

Button A Depressing the A button gives 6 seconds of normal A-band operation followed by 6 seconds of automatically coded response on a fixed frequency. The coded response consists of 9 characters, each lasting for approximately half of a second, with a short blank space between each one during which the transponder is suppressed. Each one of these nine characters consists of a series of either wide or narrow pulses, or is blank, so that the number of possible permutations and combinations is very large. They are usually arranged in the form of two morse letters, which can be changed as often as required.

Button B This gives chopped responses on the fixed frequency with no A-band operation. The signal received by the responder is, therefore, rather similar to that received by a GCI station when it interrogates the Mk. III G on the G-band. There is no coding.

209. The fixed frequency which the set is to use when on buttons A and B will probably be 184 Mc/s, the frequency of the type 242 interrogator which is used on all H.M. ships and shore stations. The operation of the 253 P on each of the three buttons is shown graphically in fig. 5.

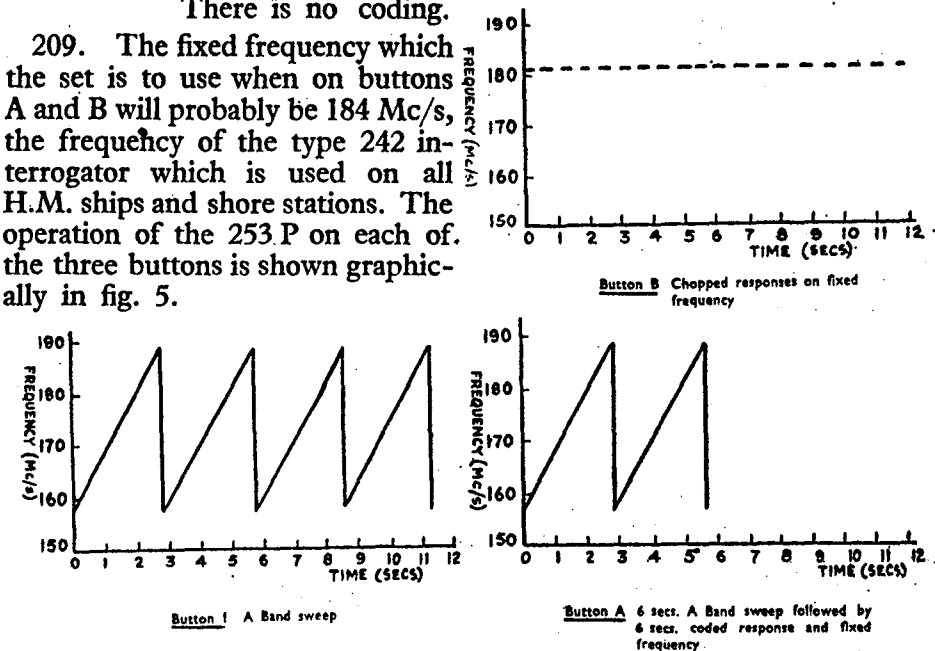


Fig. 5.—Operation of 253-P equipment

210. Type 253 P is essentially a shipborne set, and it is proposed to install it in all H.M. ships, and in corvettes, submarines, and certain smaller craft of all those nationalities which may contact the enemy. Neither the 253 P nor any other type of IFF will be fitted into craft employed on local duties in areas where no enemy action is expected.

211. The uses of the various buttons will be as follows:—

Button I will only be used by ships co-operating with foreign warships on occasions when the use of Button A might cause confusion, or in co-operating with aircraft when it may be desirable to use one of the Mk. III functional codes.

Button A will be the normal method of operation used by all ships fitted with type 253 P.

Button B will be used only by ships wishing particularly to distinguish themselves from others, such as a flagship in a night action, or a ship acting as a datum point.

212. An important point in the operation of the type 253 P equipment is that it is possible, when operating on button A, to reduce the power output of the transponder to one-sixteenth of its normal value during the period of A-band sweep. This means that the range of the set on the A-band is reduced theoretically to one-quarter of its normal value, and that aircraft must approach more closely before they can identify the ship with their Lucero or ASV Mk. II equipment. The purpose of this is to reduce the possibility of enemy aircraft detecting ships at great distances by interrogating this IFF equipment.

213. The coding system operates only on button B. The Admiralty have prepared a key memorandum allocating a two-letter morse group to each ship fitted with type 253 P. These groups will be changed each day at 0001 GMT. In this way any other ship or shore station receiving a response from a ship fitted with 253 P transponder will be able to identify it immediately. Some extra security will be gained by knowledge of the ship's movements.

214. If the enemy shows signs of breaking our morse groups, the use of this code will be discontinued, and a new code will be substituted. The first five responses on the fixed frequency will then be used as a security code which will be changed every day, and which will be the same for all ships on any one day. The last three characters will be used as a functional code to describe the type of operation in which the ship is engaged. The sixth character will always be blank, to separate the security and functional codes. IFF Mk. III Q will use this second coding system, and IFF, type 253 P will begin to use it in any case when coding system, and type 253 P will begin to use it in any case when IFF Mk. III Q comes into service.

Type 950

215. Type 950 is under development, and although it will probably not be used, it is to be held in readiness as a standby.

216. Type 950 is designed for fixed-frequency operation only, and it does not sweep the A-band. Its most interesting characteristic is that it uses the prime-and-poop system of interrogation. It is designed to operate with the type 271, 272 or 273 radar together with the type 242 interrogator. It will respond to a pulse on the interrogator frequency only if it receives simultaneously a priming pulse from the parent radar. The interrogator frequency is 184 Mc/s, and the frequency of the types 271, 272 and 273 is 3000 Mc/s, so that the transponder is effectively interrogated simultaneously on both these frequencies. It responds on a frequency of 181 Mc/s

217. The adoption of the prime-and-poop system, together with the principle of responding on yet a third frequency materially increases the security. It is necessary, of course, for the responders of the type 242 interrogators to be detuned to 181 Mc/s in order to receive the responses.

218. Type 950 gives a 9-character code lasting for about 6 seconds in the same way as the type 253 P, but the code is followed by a continuous response lasting for the same length of time. The whole cycle is then repeated. If the set is used operationally the coding will be similar to that of the type 253 P, and will contain either two morse groups or a security code followed by blank and a functional code. The set has no other mode of operation than this, and the only variables are the nine coding characters. It is extremely doubtful whether sets of this type will ever come into operation.

Type 953

219. Type 953 is a modification of the type 950. It is, in fact, the former set working without the prime-and-poop system. It receives interrogator pulses and it re-transmits its responses on two preset frequencies. Its responses and coding will be exactly similar to that of the type 950. It will replace the type 251 M and will be fitted in convoy escort groups, independently routed merchant ships, and H.M. Ships-carrying aircraft.

IFF MK. III Q

220. While the Navy are asking for a more secure form of IFF, certain branches of the RAF also require types of IFF set to perform G, Rooster and other special functions, and this led to the suggestion that, as the Mk. III G(R) set has all the necessary circuits to provide many of the

facilities required, it might, with some modification, be suitable for use as a multi-purpose set. Discussions with representatives of the Navy and the RAF resulted in more concrete proposals and in the conception of a new IFF which would have advantages over the type 253 P, which could also be used as Mk. III G(R) set, and which would have other facilities besides. This new transponder became known as IFF Mk. III Q, and the first development model is being produced by Messrs. Ferranti Ltd. It now appears unlikely that Mk. III Q IFF will ever go into service, but it is useful to investigate its possibilities, as some simplified form of this system may be held for particular Naval requirements in the future.

221. Before describing the Mk. III Q transponder it is necessary to consider the requirements of the RAF and the Navy, and to state what facilities this new set must have.

Normal Mk. III

222. All aircraft of the RAF and the NAA require the normal Mk. III facility and must carry an IFF set which sweeps the A-band in the usual way, to identify themselves to Naval, Army and RAF ground stations, to ships and to aircraft.

The G facility

223. Fighter aircraft, particularly night fighters, of the RAF and the NAA require the G facility. In the past the NAA has used ship radars of the GCI type working on a frequency of 179 Mc/s. They recently decided to come into line with the RAF, however, so that for all night fighters the G frequency will be 209 Mc/s.

The R facility

224. Reconnaissance aircraft of Coastal Command and of the NAA require the R facility. Aircraft using Rooster will never require G.

Fighter plotting

225. Fighter Command recently considered a scheme of fighter plotting, whereby fighter aircraft should carry IFF sets tuned to a fixed frequency, and fighter control centres should use some form of IFF interrogators working on this frequency to give the positions of all fighters in their area on a PPI display. Only fighters carrying IFF sets tuned to the fighter plotting frequency would appear on the display, and the system would show less clutter than if the fighters were plotted by a radar equipment such as a GCI which shows ordinary echoes. The scheme was tested by installing specially modified IFF sets in a number of fighter aircraft, and Fighter Command seriously considered adapting it generally. It appears to be falling into disuse at the moment.

Searchlight douse

226. SLC interrogators have not been so efficient as those of many other equipments, and the identification of night fighters by searchlights has been a difficult problem operationally. Many night fighters have been carrying a special modified version of the IFF Mk. II G, usually called the Mk. II D, which could be switched on when the fighters were illuminated by searchlights, and which "squattered" or gave a squegging signal on the SLC interrogator frequency. When the SLC operator receives this type of response he knows that the aircraft which is being illuminated is friendly, and that he must douse the searchlights. Some better method of dousing searchlights is required, and it would be more satisfactory if the normal IFF set carried by the aircraft was capable of performing this function.

Mayday distress

227. When a fighter is being controlled by a GCI station, the GCI controller knows its movements and its position at any time very accurately, and it is an advantage if, in the event of an emergency, he receives the distress signal. In the normal way, of course, the distress is shown on the A-band and not on the GCI frequency. Fighter Command therefore stated a requirement for a new form of distress code, where the broad IFF should be shown on the G frequency. This new type of distress signal is called *Mayday distress*. If a fighter plotting system is used it is also an advantage if Mayday distress is shown on the fighter plotting frequency rather than A-band distress.

IFF for H.M. ships

228. Some type of IFF such as the 253 P is required for H.M. ships. It must have facilities for identification to aircraft and to other ships and shore stations, and must have adequate security.

229. It is possible to give the necessary facilities for all these purposes by modification of the Mk. III G(R) set. The changes and additions required do not involve alterations to the circuit, but only to the control and switching units, and the Mk. III Q, like the Mk. III G(R), has only two tuned circuits, the A-band and G-band circuits. The set, thus modified, is capable of performing any of the following normal functions:—

230. *Normal Mk. III working*, when the set sweeps the A-band in the usual way.

231. *Normal G-band working*, when the transponder chops between the G- and A-bands as in Mk. III G. The two bands are equally time-shared, and the set works for one twenty-fifth of a second in each state.

It is possible to go into G working by pressing either the G button on the R switch; if the first-named is used the set works for 20 seconds or the G-band, and if the latter is used the set functions indefinitely until the R switch is returned.

232. *Normal R-band working*, when the set responds on the fixed frequency in the R-band. This can be keyed in the usual way.

233. *Fighter plotting*, which consists of a continuous response on a fixed frequency, probably 190 Mc/s, time-shared with the A-band as for G working, the set working for 1/25 of a second in each state in turn. The fighter-plotting response is given by the G circuit, and the operation is exactly similar to G operation; the only change being in the G frequency. A transponder can be set up to operate as a Mk. III, III G, or III—fighter-plotting set. On switching from the G to the fighter-plotting state, the tuning of the G circuit is changed from 209 to 190 Mc/s by switching over condensers.

234. *Mayday distress*, which may replace ordinary A-band distress and may appear on the G or on the fighter-plotting frequency. It is only used in fighter aircraft, and will usually be given on the G frequency. If the interrogator is set up for Mayday distress, depressing the distress switch gives a broad response which overrides any other operation that the IFF may have been performing.

235. *Searchlight douse*. This is a continuous response on the frequency of the SLC interrogator which can be made to override any other operation that the set is performing. It will be operated by a push-button, and will probably be produced by the A-band circuit, the A-band sweep being stopped at the correct frequency.

Alternate A-band and fixed-frequency working

236. This is similar to the method of operation of the type 253 P, and is used by the Navy. The set gives two sweeps of the A-band in which there is no coding, and this is followed by a coding cycle lasting for about 6 seconds on a fixed frequency. There are nine coding characters as in the type 253 P, and the first five of these will be used as a security code, the sixth will be blank, and the last three will be used as a functional code. Further details of the coding are given below. The set in this state is capable of performing another function in addition to those of the 253 P. It can, if required, transmit and receive on different frequencies during its period of fixed frequency working. The state involves the sacrifice of G and Rooster facilities. For interrogation and response on two frequencies it must receive on the A-tuned circuit and retransmit on the G, or *vice versa*. The tuning sweep of the A-circuit must be stopped at a pre-determined frequency for this purpose.

Fixed frequency working only

237. This gives a type of operation similar to that of the type 953. The set is interrogated and responds on preset fixed frequencies in the A-band. The two frequencies involved may be the same or different. They can be chosen either for this state or for the previous one anywhere in the following bands:—

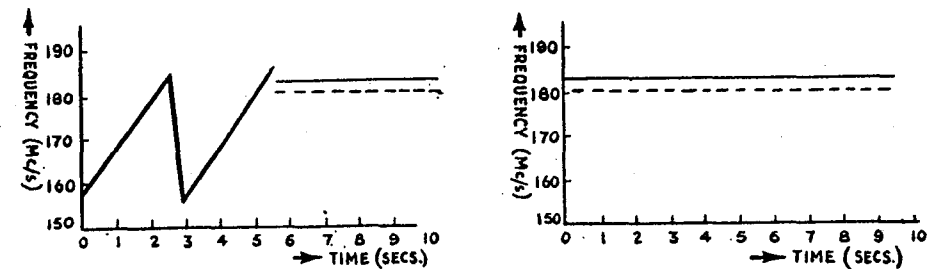
Interrogation frequency:— between 157 and 187 Mc/s.

Response frequency:— between 172 and 187 Mc/s.

For dual frequency working the A and G fixed circuits must be used again as in para. 236. The response is coded in the usual way. The coding cycle of G characters lasts for about 5 seconds, and is followed by a 5-second period of continuous response.

Coding

238. The operation described in paras. 236 and 237 is required by H.M. ships and aircraft of the NAA, although it may be used also by Coastal Command aircraft operating with ships. The two operations are shown graphically in fig. 6.



5 secs. A-band sweep followed by 5 secs. coded response on two frequencies

5 secs. continuous working on two frequencies followed by 5 secs. coded response on same frequencies

Fig. 6—"A" band and fixed frequency working

239. The coding in these two operations may be described in rather greater detail. In the operation described in para. 236, there is no coding during the A-band sweep. The coding is given entirely in the fixed frequency when working as described in para. 236 and 237.

240. The first five coding characters give the security code. They will be changed each day, but will be the same for all ships and aircraft

on any one day. Each character can be either a narrow pulse, a wide pulse, or a blank, with the following provisos :—

- (1) The first and last of the characters shall not be blank.
- (2) There shall be only one blank in each set of five.

This gives 80 possible codes. The codes are selected by a key switch. 80 different keys will be produced, and any one, when inserted in a special control unit, will give one of the possible permutations. The pilot of an aircraft, or the responsible officer on board ship will be given the appropriate key each day.

241. The last three characters which give the functional code can be arranged in any of the following ways.

| <i>Aircraft</i> | <i>Ships</i> |
|-----------------|--------------|
| NNN | WNN |
| NNW | WNN |
| NWN | WWN |
| NWW | WWW |
| N-N | W-N |
| N-W | W-N |

242. It will be noticed that aircraft will always have a functional code which commences with a narrow character while the functional code of ships always commences with a wide. This gives an easy method of distinguishing between the two.

243. On depressing the distress switch very wide pulses are transmitted during the whole cycle of operation except the five intervals occupied by the functional code. Thus in the state described in para. 236 the set will give very wide response during the A-band sweep and on the fixed frequency during the period occupied by the functional code. In the state described in para. 237, it gives distress on the fixed frequency during the whole operation again excepting the time occupied by the five security letters. The security letters occur always, and nothing is allowed to interfere with their transmission.

244. The width of the pulses used are approximately :—
Narrow—6 microseconds ; wide—15 microseconds ;

Very wide—60 to 100 microseconds.

When the set sweeps the A-band in normal Mk. III, III G or III R operation, it can use the normal Mk. III coding.

Controls

245. The necessary remote controls for the set are as follows :—

- | | |
|--|---|
| (1) On-off switch. | } These controls are on control units, type I as in Mk. III G(R). |
| (2) Emergency switch (giving distress) | |
| (3) Selector switch for 6 A-band functional codes. | |
| (4) G button and R switch and morse key. As in Mk. III G(R). | } These will have to be contained in a small additional control unit. |
| (5) Selector buttons A, B and C | |
| (6) Security code selector key. | |

All these controls are available to the crew of the aircraft in which the set is installed. For use in ships certain controls will not be required (e.g., the G button and R switch and key).

246. In night fighter aircraft there may be additional controls, and the pilot will probably be provided with a row of six switches or buttons. These will be :—

- (1) A remote on/off switch (in addition to that on the control unit).
- (2) A remote emergency switch (in addition to the normal distress switch on the control unit. It will usually give Mayday distress in this case).
- (3) The G button. (This is the G button mounted here for convenience).
- (4) The G switch (this is the usual G or R switch mounted here for convenience).
- (5) The Douse button (giving a response to searchlights on a preset frequency. It will probably be arranged to operate only while held down).
- (6) Personal identity button for fighter plotting (probably this will not now be used. It gives continuous unchopped response on the fighter plotting frequency).

247. The state in which the set works will be chosen primarily by a *circuit selector plug*. This is a multi-contact plug which can be wired in different ways. The particular way in which it is wired will automatically choose three possible states in which the set can operate. The set can then be put into any one of these three states by depressing one of the state-selector buttons A, B or C. A set will be fitted with a particular circuit-selector plug according to the operation required of it. There

will probably be five types of plug, each having different wiring, one being fitted into sets used in fighter aircraft, another into sets used in NAA aircraft, and so on. The following table shows the probable states that will be possible with each type of plug.

| Circuit selector plug | Button A | Button B | Button C | Remarks |
|-----------------------|---|---|--|---|
| I | Normal Mk. III(G) facilities, including normal distress | 5 seconds continuous fixed frequency response followed by 5 seconds coded response on same frequency. T and R both on same frequency. Distress during continuous response, during functional code | 5 seconds A-band sweeping followed by 5 seconds coded response on a fixed frequency. T and R both on the same frequency. Distress during A-band sweep and during functional code | Initially for NAA and coastal aircraft to follow |
| II | As I above but with reduced power on the A-band | As I above but with reduced power on A-band | As I | For H.M. ships |
| III | As I | As I but with T and R on different frequencies | As I but with T and R on different frequencies | Alternative to I for CC. and NAA aircraft |
| IV | As I but with reduced power on A-band | As I but with reduced power on A-band | As I | Alternative to I for H.M. ships |
| V | As I but with May-day distress | Fighter Plotting consisting of I A-band sweep time shared with response on Fighter plotting channel II Operational G which overrides fighter plotting III Searchlight douse | Not used | For Fighter aircraft, including those co-operating with ships |

IFF MK. V.

248. IFF Mk. IV is an entirely American system, and is not designed for use with British radar equipments. It will probably not be used operationally, and will certainly never be used by British forces. No account of its operation is given. It has the disadvantage of operating on a frequency largely employed by the enemy.

General

249. IFF Mk. V, or the United Nations beaconry, is being developed in America at the present time. It differs considerably from previous systems, and incorporates the functions of both IFF and homing beacons. It was to be used by British and American forces, and to replace the present IFF and homing beacon systems.

250. Mk. V IFF/UNB will operate on a frequency band of 950 to 1150 Mc/s, and will employ pulsed interrogation and response on any two of twelve spot frequencies in this band. It will provide the following facilities:—

- (1) IFF identification of aircraft and ships from aircraft, ships and ground radar stations.
- (2) Identification, together with azimuth and range, of ground, shipborne, and airborne beacons, from aircraft and ships.
- (3) Other miscellaneous functions which can be added by later adaptation of the existing IFF/UNB units, and which include blind approach (BABS), bombing aids (Oboe), navigation, and certain forms of communication.

251. The system envisaged at the present time differs considerably in detail from the scheme as it was planned in the early days of development. To bring forward the date of introduction into the service, it has been necessary to reduce the technical complexity of the various units, and this could only be achieved by sacrificing certain security measures which were originally to be incorporated. The following account gives a brief outline of the system as it is envisaged at the present time.

List of units

252. The Mk. V scheme employs a number of radar interrogators and transponders, of which the following list includes the most important. All use vertical polarisation. In addition to those mentioned here there will be various display units, connectors, and special units which have not been fully developed as yet, but which may be required for particular applications.

| Equipment | Purpose | Transmitter peak power | Receiver sensitivity | Weight | Remarks |
|-----------|---|------------------------|----------------------|----------------------|---|
| AN/APX-6 | Airborne transponder for IFF and Rooster | 500 W. | 100 μ V. | 30 lb. | Fits into Mk. III transponder shock-mount Omni directional aerial |
| AN/CPX-3 | High power surface interrogator-responder | 8 kW. | 10 μ V. | 400 lb. | Will use one of several forms of directional antenna |
| AN/APX-7 | Airborne interrogator-responder for all IFF and beacons | 2 kW | ? | TR unit alone 45 lb. | Carries semi-directional antenna, acting as a common T and R aerial, and also separate T and R aeriels, the latter of which can be lobe-switched to give the usual directional facilities. This directional R aerial fits into an 8-in. "egg," which permits it to be rotated to take bearings off the line of flight |

| Equipment | Purpose | Transmitter peak power | Receiver sensitivity | Weight | Remarks |
|-----------|---|------------------------|----------------------|---|--|
| AN/SPX-1 | High powered shipboard IFF transponder | 8 kW. | 10 μ V. | 400 lb. | This will be the AN/CPX3 converted into a transponder |
| AN/CPX-4 | Medium power surface interrogator responder | 2 kW. | ? | TR unit alone about 45 lb. | Modified form of the AN/APX-7 for surface use |
| AN/SPX-2 | Medium power shipboard IFF transponder | 2 kW. | ? | TR unit alone about 45 lb. | This will be the AN/CPX-4 modified for use as a transponder |
| AN/CPN-8 | Paratroop beacon | ? | ? | 25 lb. including aerials and power supplies | This is a light-weight beacon. Its reply can be coded or hand keyed |
| AN/UPN-5 | High power surface beacon | 8 kW. | 10 μ V. | 400 lb. | This is a converted AN/CPX-3. It differs from the AN/SPX-1 in its coding and de-coding mechanism |
| AN/TPN-4 | Medium power surface beacon | 2 kW. | ? | IR unit alone about 45 lb. | This will be the AN/CPN-4 converted for use as a transponder. It differs from the AN/SPX-2 in its coding and de-coding mechanism |

Test sets

253. The following paragraphs list the principal items of test equipment envisaged for the IFF Mk. V/UNB scheme.

AN/UPM-4

254. This is a transportable equipment which will be capable of making all the measurements required for servicing and testing any of the Mk. V IFF/UNB units.

AN/UPM-5

255. The AN/UPM-5 is a depot equipment, which includes the transportable set and also certain standards required for checking its calibration.

AN/UPN-6

256. This is a light portable equipment which can be carried by one person. It is limited in its scope, and will check only the following operations :—

- (1) Frequency of the transmitter and the receiver.
- (2) Coding of the interrogator-responder and of the transponder-transmitter.
- (3) Decoding in the transponder receiver.
- (4) Receiver sensitivity.
- (5) Transmitter power output.

Maximum range

257. The range of the system will depend upon the particular equipments involved. The following table gives an approximate estimate of the ranges to be expected :—

| | <i>Estimated range (statute miles)</i> |
|--|--|
| <i>Interrogator and transponder</i> | |
| AN/CPX-3 to AN/APX-6 | |
| (1) With overall antenna gain of 15 dB | |
| Aircraft at 1,000 ft. | 40 |
| Aircraft at 10,000 ft. | 120 |
| Aircraft at 20,000 ft. | 170 |
| (2) With overall antenna gain of 5 dB | |
| Aircraft at 1,000 ft. | 30 |
| Aircraft at 20,000 ft. | 100 |
| AN/CPX-3 to AN/SPX-1 | |
| With antenna heights 100 ft. and overall antenna gain of 11 dB. | 35 |
| AN/APX-7 to AN/SPX-1 | |
| (Calculated free space range). | 100 |
| AN/APX-7 to AN/UPN-5 | |
| (Calculated free space range). | 140 |
| AN/APX-7 to AN/APX-6 | 40 to 80 |
| AN/APX-7 to AN/QPN-8 | 30 to 40 |
| AN/CPX-3 to AN/SPX-2 | |
| With overall antenna gain of 11 dB, and I-R antenna at 100 ft. and transponder antenna at 50 ft. | 25 |
| AN/CPX-4 to AN/APX-6 | |
| With overall antenna gain of 5 dB, and aircraft at 10,000 ft. | 90 |
| AN/APX-7 to AN/TPN-4 | |
| (Provided that aircraft is above horizon) | 90 |

Coding

258. The Mk. V IFF/UNB provides the following coding facilities :—

- (1) Variation of interrogation frequency.
- (2) Interrogation signal modulation (i.e., double-pulsed interrogation).
- (3) Variation of response frequency.
- (4) Response signal modulation (i.e., coding of response in a way similar to that used in the Mk. III Q).

259. These variables are used to provide functional and security coding. The following account gives a brief description of the use of each of the four characteristics in the system as it is visualised at the present time.

260. Interrogation can occur at any one of twelve channels which are spaced about 17 Mc/s apart. These channels can be divided between IFF and UNB as required. It is expected that beacon interrogation may require the use of several channels at any one time, but that IFF may require either only one channel, or, at the most two, one for interrogation of aircraft and the other for interrogation of surface vessels. There will be no provision for remote control of the frequency in the early interrogators and responders, but all are being designed for the optional addition at a later date of a remote control mechanism which will permit click settings to any of the twelve interrogation frequencies.

261. The system employs double-pulse interrogation. The pulses will each be one microsecond wide, and their leading edges will be separated by a time interval of either 3, 5 or 8 microseconds. The transponders are provided with decoding units which can be set up to give response on any one of these codes. The three codes will normally be used for the following purposes :—

- (1) *IFF*. The 3-microsecond interval can be used for normal IFF working.
- (2) *PI*. Personal identity is often required by a fighter-direction station. This can be obtained by requesting the pilot to turn on his PI, in which case he switches his transponder over to the 5-microsecond code. If the interrogator is also switched over to this interval, it will receive replies only from this particular aircraft, as all other airborne transponders will normally be using the 3-microsecond code.
- (3) *FLI*. In a large formation of aircraft the IFF clutter renders the reading of the reply code impossible. In this case it is possible to ask the formation leader to switch over to Flight Leader Identity, which uses the 8-microsecond interval. When the interrogator is also switched to this code it will receive only replies from the one aircraft.

262. These codes are available as follows :—

- (1) *High power surface interrogators* can use IFF and either PI or FLI simultaneously.
- (2) *Medium power surface interrogators* can use any one of the three codes at a given time.

- (3) *Airborne interrogator responders* can use any one of the three codes at a time. The pilot can select the one required.
- (4) *Airborne and surface IFF transponders* can be set up to respond to the IFF code alone, IFF and either PI or FLI simultaneously, or all three simultaneously.
- (5) *Beacons* will be able to decode any of the interrogation codes, one at a time.

263. The response frequency can be varied in the same way as the interrogation frequencies, the transponders being capable of replying on any one of the same twelve channels. The response channel will usually be different from the interrogation channel. Although there will be no provision for remote selection of the response frequency in the first place, interrogators and transponders are being designed with a view to their use with remote selectors at a later date, as in the case of the interrogation frequency.

264. The reply signal can be modulated to give a considerable measure of coding. The IFF response will consist of a single pulse, one microsecond wide, transmitted for each double-pulse interrogation signal. The width of this pulse can be increased to $2\frac{1}{2}$ microseconds when desired, and coding is achieved by a similar method to that employed in the Mk. III Q system. For a short period of time the transponder gives a succession of either wide or narrow responses ; it is then switched off for a brief interval, after which it comes into operation again for the same length of time as before. Its response then appears as a succession of short flashes, each lasting for the same length of time. Each flash may consist of a succession of narrow pulses or a succession of wide pulses. The response code consists of two or three morse letters transmitted in this way, and is repeated indefinitely as long as interrogation continues.

265. For aircraft, the normal reply will consist of a two-letter code, providing 80 possible combinations, followed by two blank periods each of which lasts for about the same time as a letter. A third letter can be introduced in place of one of these blanks if desired. These two possible conditions are therefore :—

First condition—1st Letter, 2nd Letter, Blank, Blank, 1st Letter,— and so on.

Second condition—1st Letter, 2nd Letter, 3rd Letter, Blank, 1st Letter,— and so on.

266. This code is known as the *slow reply code* in contrast to another type of code, the fast code, which the original Mk. V system incorporated in addition, but which has been abandoned in the present set.

267. The distress signal for aircraft will be brought into operation by a pilot control. On depressing this emergency control the response to any of the three interrogation codes will consist of a characteristic signal, composed of four one-microsecond pulses spaced eight microseconds apart. These are followed by a fifth pulse which can be keyed for communication purposes.

268. Ship IFF transponders will radiate a multi-letter code group by variation of pulse width in the same way as that described for aircraft. The coding of these equipments will be more flexible than that of the airborne sets, however, and will only be limited by the possible arrangements of 150 elements.

269. Surface beacon transponders also use pulse-width coding, and give a two-letter group on reply to interrogation. This time, however, the pulse width is two microseconds or nine microseconds.

270. The aerial systems of ground interrogators will usually be

highly directional, and will sweep continuously to cover all azimuthal bearings. They may be mounted either on the same turntable as the aeriels of their parent radars or separately on their own turntable.

271. Airborne interrogators will be fitted with two aerial systems. One will be a simple omnidirectional antenna, while the other will be a lobe-switched type which will be housed in an eight inch "egg" which permits the mechanism to be rotated to take bearings off the line-of-flight. The former aerial will normally be used for transmission, while the latter will, of course, feed into the receiver to give indication on an L-type display in the usual way. If no directional facilities are required, however, it will be possible to use the single aerial for common T and R working.

272. All IFF and beacon transponders will normally have simple omnidirectional aeriels, so that they are able to respond to interrogation from any direction.

APPENDIX I

CONCLUSIONS

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Present system and possibility of improvement

1. H.M. ships and NAA aircraft carry, or will shortly carry, the following types of interrogators and IFF and beacon transponders:—

| <i>Equipment</i> | <i>Purpose</i> | <i>Fre- quency (Mc/s)</i> | <i>Polarisation</i> | <i>Remarks</i> |
|---------------------------|------------------|-----------------------------------|---------------------|----------------|
| Ship Interrogators | | | | |
| Type 242 | IFF interrogator | 184 | Vertical | |
| Type 243 | IFF interrogator | 173 | Vertical | |

Airborne Interrogators

| | | | | |
|----------------|-------------------------|--------------------------------------|------------|---|
| ASV. Mk. II N | Interrogator beacons | 176 | Horizontal | |
| ASB | Interrogator beacons | 515 | Horizontal | |
| Lucero | IFF beacon interrogator | 176 | Horizontal | |
| Rebecca III N | Beacon interrogator | 214-234 | Vertical | |
| Rebecca Mk. IV | Beacon interrogator | 214-234 Tx, 176 Rx, 177 173 | Doubtful | Rebecca Mk. IV in NAA aircraft may use either horizontal or vertical polarisation or both |

| <i>Equipment</i> | <i>Purpose</i> | <i>Fre- quency</i> | <i>Polarisation</i> | <i>Remarks</i> |
|-------------------------------|--------------------|------------------------|---------------------|---|
| Shipborne Transponders | | | | |
| Types 251M and 253P | Beacon transponder | 176 | Horizontal | |
| Types 253M and 253P | IFF transponder | 157-187 | Vertical | |
| Type 953 | Beacon transponder | | Horizontal | |
| Y J beacon | Beacon transponder | 176 and 515 | Vertical | American beacon for use with ASB and also with 176 Mc/s interrogators |
| Eureka | Beacon transponder | 214-234 | Vertical | Will be used in H.M. ships in the future. Probably vertically polarised |

Airborne Transponders

| | | | | |
|-------------------|--------------------|-------------------------------|------------|--|
| R.3067 and R.3090 | IFF Mk. III | 157-187 | Vertical | |
| ABK | IFF Mk. III | 157-187 | Vertical | |
| SCR-695 | IFF Mk. III G | 157-187 | Vertical | |
| AN/APX-1 | IFF Mk. III G(R) | 157-187 200-210 172-182 | } Vertical | |
| Eureka | Beacon transponder | 214-234 | Vertical | |

Airborne IFF Interrogator-transponder

| | | | | |
|----------|--------------|-------------------------------|------------|---|
| AN/APX-2 | Interrogator | 160-184 | Vertical | |
| | Transponder | 157-187 172-182 200-210 | } Vertical | Has no directional aerials to home auto-beacons |
| AN/APX-8 | Interrogator | 160-184 | Doubtful | |
| | Transponder | 157-187 172-182 200-210 | Vertical | The AN/APX-2 fitted with directional aerials for homing |

2. The present beacon and IFF equipment may eventually be replaced by the Mk. V IFF/UNB interrogators and transponders. The operation of the present system is complicated by the fact that certain interrogators and transponders use horizontal polarisation while others use vertical polarisation, and it is worth considering the possibility of introducing some uniform scheme.

Relative merits of horizontal and vertical polarisation

3. The advantages of a change over to a uniform system of polarisation must be considered in conjunction with the difficulties and time involved in making the necessary modifications to the surface and airborne equipments. It will be useful, however, to give a brief summary of the purely technical advantages and disadvantages of horizontal and vertical polarisation.

4. Horizontal polarisation

The following points are important :—

- (1) Horizontally polarised aerial systems will not give such good all-round-looking facilities as vertically-polarised aeriels.
- (2) Horizontal polarisation, in most cases, gives poorer vertical coverage, particularly at low angles of elevation.
- (3) The sea returns are much smaller if horizontally-polarised waves are used. This is not important when different frequencies are used for interrogation and response, but it will be a distinct advantage in the case of the Rebecca Mk. IV which will probably be used not only as an interrogator but also as a low power ASV set.
- (4) With the glide path BABS it is essential to use horizontal polarisation but on a different frequency for response.

5. Vertical polarisation

Vertical polarisation has the following advantages and disadvantages :—

- (1) With vertically-polarised aeriels it is a simple matter to obtain all-round azimuth cover. This is important in IFF and homing beacon transponders.
- (2) Vertical polarisation gives better vertical coverage than does horizontal.
- (3) With the new BABS Mk. II beacons it is a simpler matter to design vertically-polarised aerial systems than horizontally-polarised ones. It is also important to note that vertically-polarised aeriels for BABS Mk. II have already been designed, while horizontal systems are still in the early stages of development.

- (4) Although the glide-path BABS must use horizontal polarisation for response, it responds on a frequency of about 500 Mc/s, so that separate receiving aeriels must be installed in the aircraft in any case if it is to work with this type of transponder. It is doubtful, moreover, whether the NAA will ever use such a beacon.
- (5) The present ASV Mk. II uses horizontal polarisation for interrogation. The conversion of NAA beacons to vertical polarisation would involve the use of cross-polarisation when they are interrogated by Mk. II and Mk. IIN equipments. The high power of the ASV transmitter, and the high sensitivity of its receiver would compensate for the small reduction in range entailed, so that this objection is not serious.
- (6) Vertical aeriels must protrude from the fuselage of the aircraft where they cause increased drag. This is not serious in the case of the aerial on IFF transponder, which consists of a single vertical quarter-wave rod, which, if properly streamlined, detracts but little from the performance of the aircraft. The directional aerial systems of interrogators such as Lucero and Rebecca present a more difficult problem. It may be possible to overcome the difficulties in this case by using resonant slot aeriels situated in the wing tips. No such aeriels have yet been developed, and their design may be difficult.
- (7) Perhaps the most important disadvantage of vertical polarisation lies in the fact that the sea returns are very marked. This would only be troublesome in the case of Rebecca Mk. IV when and if it is used as an ASV equipment.

6. Taking all the facts mentioned above into account, it appears that vertical polarisation has distinct advantages over horizontal. Its only serious disadvantage lies in the excessive sea returns which may lead to difficulties in its use with Rebecca Mk. IV as an ASV. This can be overcome by fitting extra horizontal aeriels. If there is to be any standardisation at all, it seems clear that vertical polarisation should be adopted.

Work involved in standardising polarisation

7. The aircraft of the NAA work in close co-operation with Coastal Command of the RAF and in order to achieve best results from any standardisation of polarisation it would be necessary to apply any change to the NAA and to Coastal Command simultaneously. Insofar as the NAA alone is concerned, the adoption of universal vertical polarisation would involve the following changes to existing equipments.

- (1) *Shipborne interrogators.* These are already vertically polarised and would require no alteration.

- (2) *Airborne interrogators.* Existing Lucero interrogators would require vertical aerials which would have to be substituted for the present horizontal aerials. Rebecca Mk. III N is already vertically polarised. Future Rebecca and Lucero equipments could be provided with either type of aerial, and they present no serious problem. If resonant slot aerials can be developed to decrease drag there will be some delay before they can be used. The existing vertical aerials of the interrogator portion of AN/APX-8 would have to be used.
- (3) *Shipborne transponders.* The aerials of all shipborne homing beacons must be changed. This also applies to the aerials of the BABS beacons. The latter could be replaced by the existing Bomber Command BABS Mk. II equipments which would have to be slightly modified in order to allow for the difference of frequency.
- (4) *Airborne transponders.* These are already vertically polarised and would require no change.
- (5) *ASV equipments.* ASV Mk. II N is necessarily horizontally polarised and would have to use cross polarisation for interrogation. Its high power and sensitivity would render this immaterial, Rebecca Mk. IV when used as a low power ASV would require extra horizontal aerials which could be housed in the wing tips.

Suggestion of standardising frequencies

8. A report, issued by the Sub-Panel on Beacon Policy of the Optec

Committee, and dated October 3rd, 1944, suggests that it would be advantageous to standardise not only the polarisation but also the frequency of existing beacons. If all beacons used the same polarisation and also operated on the same frequency band, it would clearly enable any aircraft to avail itself of the facilities offered by all commands.

9. The most desirable frequency range appears to be the present Rebecca-Eureka band (214-234 Mc/s), and the suggestion is to modify all existing beacon equipments to work within this band, and to use vertical polarisation. This would also have the additional advantage of reducing the traffic on the IFF Mk. III band (157-187 Mc/s). It would render ASV Mk. II useless as a beacon interrogator, but it is estimated that the change would take about a year to effect and by this time there will be few ASV Mk. II equipments left in Service.

10. The proposed scheme is discussed fully in the report, and no further details need be given here. Its most serious practical handicap lies in the work involved in the conversion. In this connection it is necessary to take into account the fact that the USA have supplied the British Navy with beacon transponders which work on a frequency of 176 Mc/s, and these would also have to be modified.

11. If this more comprehensive scheme is not adopted, it would still be an advantage to rationalise the polarisation only, and to continue to work with the existing frequencies. The suggested standardisation of frequency merely offers an additional improvement.

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