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RADIO LANDING BEACONS FOR AERODROMES

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Summary. Following a short introduction dealing with the principles of radio landing beacons and a consideration of the advantages and disadvantages of long and short waves for this purpose, the radiation diagrams of modern landing beacons working on ultra short waves are discussed in detail. Finally a description is given of the Philips ultra short wave beacon transmitter B.R.A. 075/4.

Introduction

In an article on position finding and course plotting on board an aeroplane, in the June number of this periodical [1]), the functioning of the Philips long wave landing beacon B.R.A. 101 was explained. Different signals, are heard on either side of the course line which crosses the aerodrome. for example dots on the one side and dashes on the other. These signals complement each other in such a way that when both signals are equally strong an uninterrupted constant signal is observed. This is made possible by transmitting from a vertical aerial and a loop aerial, the ratio of whose currents can be regulated. By a combination of the circular radiation diagram of the vertical aerial with the figure of eight diagram of the loop aerial a heart shaped radiation diagram is obtained when the maximum field strengths are the same, as shown in *fig. 1*. The phase of the loop current is reversed

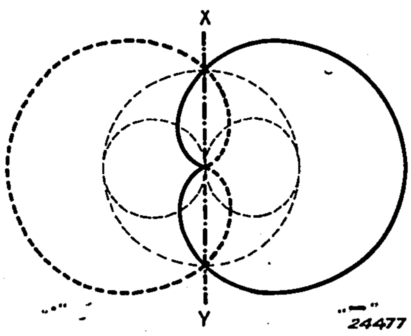

Fig. 1. Heart-shaped radiation diagram of a long wave beacon consisting of the circular diagram of a vertical aerial and the figure-of-eight diagram of a loop aerial. *XY* in this and the following figures is always the course line. To the right of the course line dashes are audible, to the left dots.

in a dot-dash rhythm, so that the heart-shaped diagram is mirrored along the course line *XY*, and therefore the full line and the broken line diagram are sent out alternately in the dot-dash rhythm and together form the total radiation.

The nature of the signal heard when flying „off course" (either dots or dashes) determines the direction which must be steered to reach the course line. By means of the continuous signal on the course line it is possible to fly directly toward the aerodrome, and to estimate roughly the distance to the landing beacon from the field strength read from the corresponding meter. In addition two warning beacons are set up several kilometres apart along the course line, and close to the boundary of the aerodrome. These are weak transmitters which radiate a signal of their own audible only from directly above. The first indicates to the pilot that he may begin to descend and the second that he may land. Such a landing installation on long waves has already proved its usefulness many times.

It is desirable that one should hear an obvious difference in the intensity of the dots and dashes upon a slight deviation from the course line (cf. fig. 10). The smaller the angle at which the full line diagram and the broken line diagram cut each other on the course line, the sharper the landing beacon indicates the course line, since a correspondingly smaller deviation is observable.

By making the signal received from the vertical aerial weaker than that from the loop, the course line of the long wave beacon can be made sharper than is shown in fig. 1.

Choice of wave length.

One advantage of the use of long waves for landing beacons is that the beacon signal may be heard with the ordinary communication receiver of the aeroplane, and no special apparatus for blind landing by means of radio signals need be installed on board. One important disadvantage, however, is that in the long wave range only a very limited frequency band is available for beacon transmitters. With a multiplicity of beacon transmitters there is therefore the danger that they may interfere with each other. Atmospheric disturbances may also prove troublesome in the reception of long waves.

Landing beacons of the types B.R.A. 075/4 and B.R.A. 200/8 work on a wave length of 9 m which is internationally reserved for landing beacons, and

1) Philips techn. Rev. *2*, 184, (1937).

the corresponding warning beacons on 7.9 m. The combination of vertical and loop aerial usual for long wave landing beacons cannot be adopted without modification for short waves. The dimensions of the loop would be of the same order of magnitude as the wave length, and consequently the currents in the loop would no longer have the amplitudes and phases necessary for the formation of the figure-of-eight diagram. We must therefore choose a different aerial system for the beacon transmitter on short waves. It will be shown that this may be done in such a way that, in addition, the course line is more sharply demarcated than in the case of the long wave beacon whose radiation diagram was given in fig. 1.

For the sake of simplicity in the receiving apparatus on board the aeroplane, the beacon transmitter for ultra short waves is modulated with an audible frequency of 1150 cycles per second.

The symmetry of the radiation diagram

With short waves various different aerial systems may be employed for the beacon transmitter. For example the aerial may consist of two directional antennae at an acute angle to one another and which are energized in turn in a dot-dash rhythm so that together they form the radiation diagram which is given in an idealized form in *fig. 2*. Another

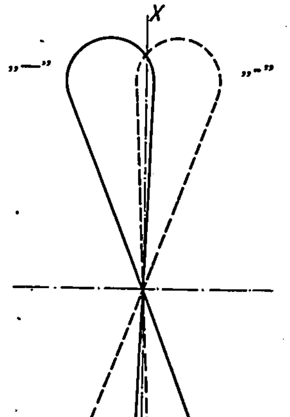

Fig. 2. Radiation of two directional aerials which make an acute angle with each other. In the first and third quadrants dots are heard, in the second and fourth dashes.

suitable aerial system consists of a vertical aerial A of a half wave length, flanked on either side by reflectors R. These reflectors are alternately rendered ineffective in a dot-dash rhythm by means of a relay so that the radiation diagram given in *fig. 3* is produced.

From these two simple examples we may now easily distinguish between the two possible methods of indicating the course line. The regions where dots of or dashes respectively may be heard alternate quadrant by quadrant in fig. 2, but in fig. 3 they

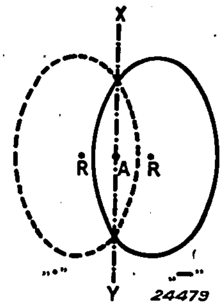

Fig. 3. Radiation diagram of a vertical aerial A with two reflectors R. To the right of the course line XY dashes are heard, to the left dots.

alternate only on either side of the course line, as was the case with the long wave beacon of fig. 1.

In the case of a beacon with quadrant zones as in fig. 2, one always hears dashes to the right of the beacon line and dots to the left, independently of the direction in which one approaches the aerodrome along this line. When dashes are heard, therefore, one must always turn to the left, and when dots are heard, to the right. In flying over the aerodrome another quadrant is entered and the nature of the signal changes. If the aerodrome has already been passed, dots are heard to the right and dashes to the left, as may be seen from fig. 2.

With a beacon having only two zones the same signal is always heard on one side of the beacon line, and this signal is not reversed when the aerodrome has been passed. In such a case the course must be followed by compass in order to know in which direction to turn to reach the beacon line when either dots or dashes are heard. Further, in the case of the two-zone beacon, there is the advantage that there can be no false course line perpendicular to the correct one, as may be the case with a beacon having quadrant zones when the field strength at the transition line from dots to dashes is not zero because of field distortions by large metal objects, such as for example hangars.

For economical operation of the landing beacon the radiated energy must be confined as much as possible to the landing line. In this repect the beacon with quadrant zones (*fig. 2*), which theoretically has no radiation perpendicular to the course line, is more satisfactory than the beacon with two zones (fig. 3) which sends out considerable radiation in that direction.

Aerial systems employed

As we have seen, a loop aerial cannot be used for the short wave beacon; in place of this two „half wave" vertical aerials were placed at a distance of one wave length from each other. Since the circuit is so arranged that the currents and the voltages in the two vertical aerials are always in opposite phases, we shall continue to call this combination the loop system (A and B in *fig. 4*). Let us now consider the field

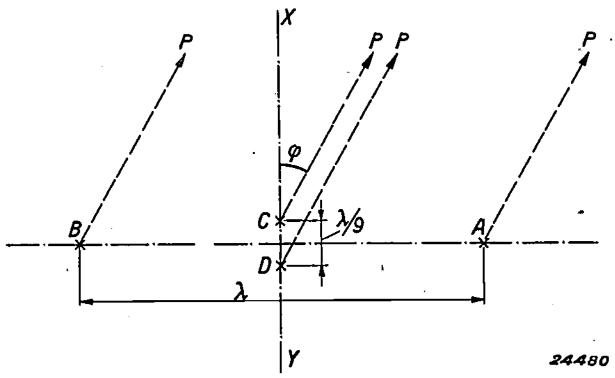

Fig. 4. Aerial system for an ultra short wave beacon. The two vertical aerials A and B are placed at a distance of one wave length λ from each other. A U-aerial, whose two arms C and D are separated by a distance of $\lambda/9$, is placed midway between A and B and with its plane perpendicular to AB. P is any given point in the horizontal plane which is so far away from the aerial that the various lines joining it to P may be considered parallel.

produced by A and B at point P at a great distance R from the middle of the line joining A and B ($R \gg \lambda$) and lying in the horizontal plane which makes an angle φ with the beacon line. At an angular frequency ω the two vertical aerials of opposite phase and the same amplitude F_m produce the following fields:

$$F_A = F_m \sin \omega \left(t - \frac{R - \frac{\lambda}{2} \sin \varphi}{c} \right) \text{ and}$$

$$F_B = F_m \sin \left\{ \omega \left(t - \frac{R + \frac{\lambda}{2} \sin \varphi}{c} \right) + \pi \right\}, \quad \cdot \ (1)$$

since $\lambda/2 \sin \varphi$ is the difference in path for the waves from A or B reaching point P.

The mean value of the resulting field at point P is then:

$$F_P =$$
$$2 F_m \sin \left\{ \omega \left(t - \frac{R}{c} \right) + \frac{\pi}{2} \right\} \cos \left\{ \omega \left(\frac{\lambda/2}{c} \sin \varphi \right) - \frac{\pi}{2} \right\}$$
$$= 2 F_m \sin (\pi \sin \varphi) \cos \omega \left(t - \frac{R}{c} \right) \quad \cdot \ \cdot \ (2)$$

This field is therefore zero at the beacon line and perpendicular to it, while it is at a maximum at angles of 30° with the beacon line, and shifted in phase 90° with respect to the fields which each arm produces separately. For the mean value of the field strength we thus obtain the radiation diagram given in *fig. 5* consisting of four loops.

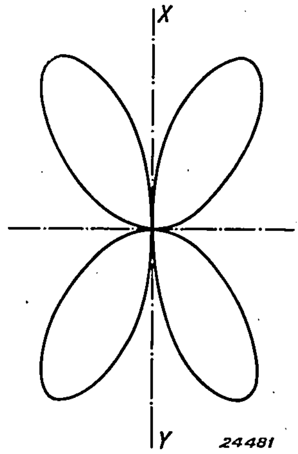

Fig. 5. Four-loop radiation diagram of the two vertical aerials A and B of fig. 4.

This four-loop diagram is still completely symmetrical with respect to the landing line, and we must add still another radiation in order to indicate the beacon line. A radiation diagram with quadrant zones may be obtained by introducing a U-aerial with its plane along the beacon line (C and D in fig. 4) between the aerials of the loop system. The U-aerial may be obtained by bending a tube of a half wave length $\lambda/2$, in a U-shape with a base of $\lambda/9$, so that the arms are somewhat less than $\lambda/4$ in length. The U-aerial is fed through its base, which is placed at the height of the middle of vertical aerials A and B, in such a way that the two arms C and D are in opposite phase, and each one is in phase with one of the aerials A and B. At point P the two arms of the U-aerial then produce the following fields:

$$F_C = F_u \sin \left\{ \omega \left(t - \frac{R - \frac{\lambda}{2} \frac{\cos \varphi}{9}}{c} \right) \right\} \text{ and}$$

$$F_D = F_u \sin \left\{ \omega \left(t - \frac{R + \frac{\lambda}{2} \frac{\cos \varphi}{9}}{c} \right) + \pi \right\} \quad \cdot \ \cdot \ (3)$$

The field produced by the U-aerial at P is thus:

$$F_P = 2 F_u \sin \left(\frac{\pi}{9} \cos \varphi \right) \cos \omega \left(t - \frac{R}{c} \right). \quad \cdot \ \cdot \ \cdot \ (4)$$

This field is zero perpendicular to the beacon line and maximum on the beacon line, so that we obtain the radiation diagram for the U-aerial given in *fig. 6* and consisting of only two loops.

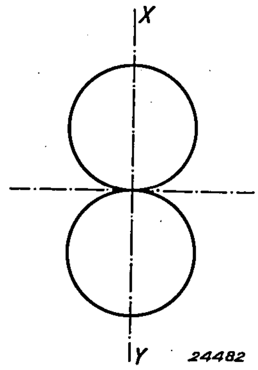

Fig. 6. Two-loop radiation diagram of the U-aerial (*CD* of fig. 4).

The total field produced at P by the whole aerial system is the sum of the two expressions (*2*) and (*4*):

$$F_P = 2\left\{F_u \sin\left(\frac{\pi}{9}\cos\varphi\right) + F_u \sin(\pi\sin\varphi)\right\}\cos\omega\left(t-\frac{R}{c}\right) \quad (5)$$

Since the phases of the fields produced by the loop and U-aerials (eq. (2) and (4)) are the same, we can obtain the total radiation diagram of *fig. 7*

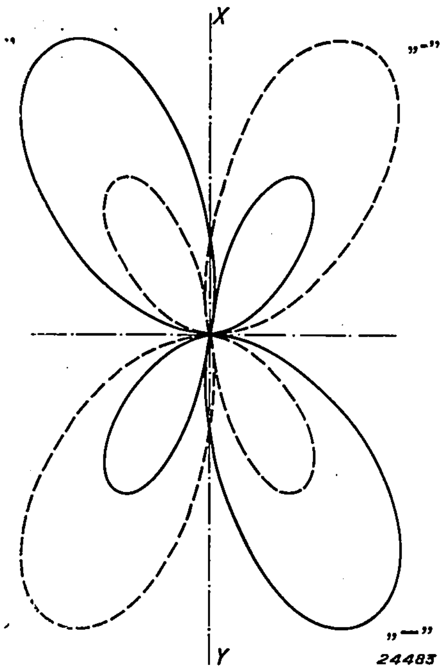

Fig. 7. Resultant radiation diagram for the aerial system shown in fig. 4.

by adding the two polar diagrams of figs. 5 and 6 with the correct sign. If the phase of the loop system is reversed, the total field at P is given by:

$$F_P = 2\left\{F_u \sin\left(\frac{\pi}{9}\cos\varphi\right) - F_m \sin(\pi\sin\varphi)\right\}\cos\omega\left(t-\frac{R}{c}\right) \quad (6)$$

In this way the full line and the broken line radiation diagrams of *fig. 7* are produced. If the loop current is reversed in a dot-dash rhythm the zones in which dashes are louder than dots and vice versa alternate in the successive quadrants.

If a beacon transmitter with half zones is desired, we may add an ordinary vertical aerial of a half wave length to the loop system having the radiation diagram given in fig. 5. This aerial is placed midway between the two wires A and B of the loop system, while the current is shifted 90° in phase with respect

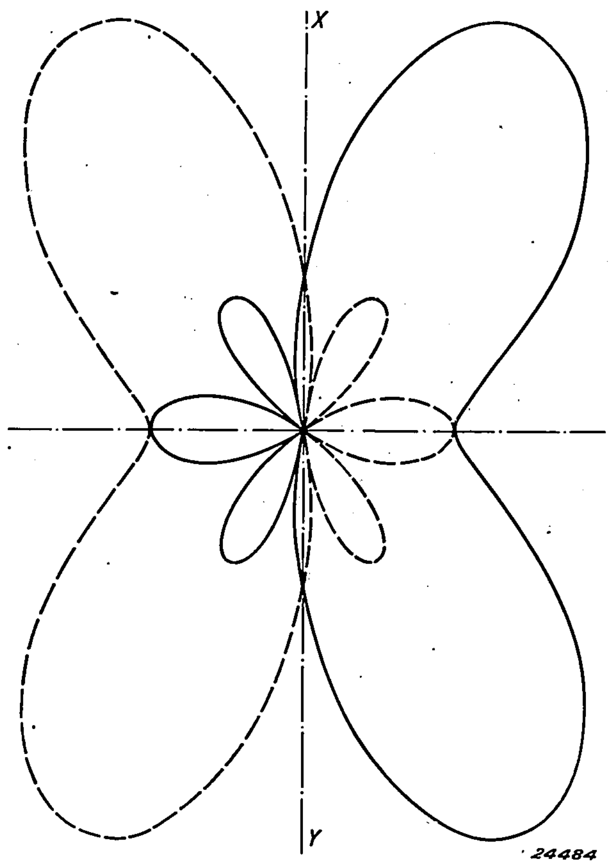

Fig. 8. Total radiation diagram for an aerial system consisting of two vertical aerials one wave length apart and working in opposite phase, with another vertical aerial half way between them whose current differs in phase by 90° from that in the first two.

to that of the loop system. The vertical aerial then radiates a field which is in phase with the field of the loop system, so that the polar diagram of the resultant average field is simply the sum of the circular radiation diagram of the vertical aerial and the four-loop diagram given in fig. 5 of the loop system, taken with the correct sign. The field at point P is:

$$F_P = \left\{F_a \pm 2\,F_m \sin(\pi\sin\varphi)\right\}\cos\omega\left(t-\frac{R}{c}\right), \quad (7).$$

when F_a represents the average value of the field of the added vertical aerial. In *fig. 8* is given the total radiation diagram for the case when F_m is taken equal to F_a; the full and the broken line figure refer again to the two directions of the loop current.

In the above-described manner we have obtained a beacon transmitter with half zones in which dots and dashes are heard respectively, while the energy radiated is fairly well confined to the direction of the landing line along which it is desirable to be able to hear the beacon signals clearly. One disadvantage however is that perpendicular to the beacon line dots and dashes are also heard equally clearly, so that a false landing course might be given in that direction. This can be prevented by a slight modification; we have to arrange the loop system whose phase is reversed in a dot-dash rhythm so that it fails to radiate exclusively on the beacon line. This may be done by placing the two vertical aerials at a distance of not exactly one wave length from each other. If we take a separation of $^5/_6\ \lambda$, for example, the resultant field of the beacon transmitter becomes:

$$F_P = \left\{ F_a \pm 2\, F_m \sin\left(\frac{5}{6}\pi \sin\varphi\right)\right\} \cos\omega\left(t - \frac{R}{c}\right), \quad (8)$$

the radiation diagram of which is given in *fig. 9*

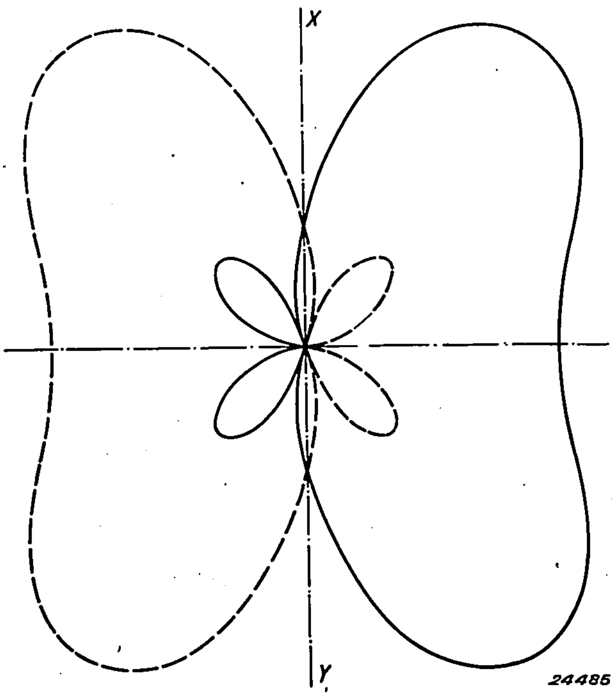

Fig. 9. Radiation diagram for the same system as in fig. 8, but in this case with the two vertical dipoles which form the loop aerial situated only $^5/_6\ \lambda$ apart.

for $F_m = F_a$. The avoidance of a false course has been made possible somewhat at the expense of the confinement of the radiation to the direction of the beacon line.

Sharpness and regulation of the course line

With a small deviation $d\varphi$ from the course the difference in the field strengths for dots and dashes is dF as shown in *fig. 10*. For a sharp course the

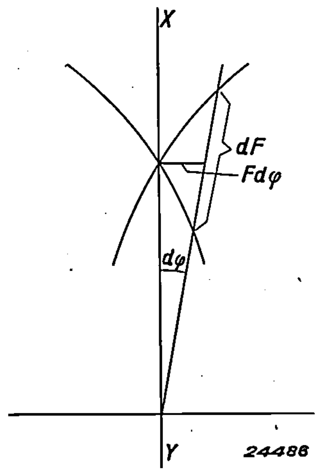

Fig. 10. Difference in intensity dF between dots and dashes with a slight deviation $d\varphi$ from the course line.

difference dF in the field F must be audible at a small deviation $d\varphi$. A good standard for the sharpness of the course line is therefore:

$$S = \lim_{\varphi \to 0} \frac{dF}{F\, d\varphi} \quad \cdots \quad (9)$$

For the combination of two rods with a U-aerial the sharpness of the course line thus becomes:

$$S = \frac{F_m\, \pi}{F_u \sin\frac{\pi}{9}} = 9.2\, \frac{F_m}{F_u} \quad \cdots \quad (10)$$

For the last aerial system discussed in which the rods were placed $^5/_6\ \lambda$ apart, we obtain:

$$S = \frac{2\, F_m \cdot \frac{5}{6}\pi}{F_a} = 5.2\, \frac{F_m}{F_a} \quad \cdots \quad (11)$$

If we now keep in mind that the field F_m from one of the arms of the loop aerial is always several times as large as that of one of the arms of the U-aerial or of the vertical aerial F_a, we see that these aerial systems are always much sharper than for example the aerial system shown in fig. 3, whose sharpness S is only of the order of magnitude one.

For satisfactory observation by the pilot of the aeroplane it is desirable that the difference in intensity between dots and dashes be at least four decibels. This means that the ratio of the squares of the amplitudes F_1 and F_2 of dots and dashes respectively must be at least $10^{0.4}$:

$$\left(\frac{F_1}{F_2}\right)^2 = 10^{0.4} \text{ or } \frac{F_1}{F_2} = 1.7 \quad \cdots \quad (12)$$

In the combination of two rods with a U-aerial for which F_u is taken equal to F_a, the above relation is already reached at an angle of 1° 30′ with the course line; if F_m is made greater than F_u it is true for still smaller angles. This shows how sharply the course line is indicated by these beacons. Such a sharp beacon is also less sensitive to disturbances, because, due to the great difference in field strength between dots and dashes, the influence of a given interfering field is of course relatively less.

The beacons here described are not only inherently very sharp, they have in addition the advantage of allowing regulation. As may be seen from formulae (10) and (11), the sharpness of the course line may be regulated by changing the ratio between the fields from the different components of the aerial system. It is also possible to change the direction of the course line. This is done by allowing the two arms of the loop aerial to radiate in not quite exactly opposite phases. If the difference in phase is $\pi - \lambda$, then, with the combination of two rods and a U-aerial, the deviation from the course line becomes:

$$\varphi = \arcsin \frac{\gamma}{2\omega} .$$

Thus for example if $\lambda = 15°$, $\varphi = 2° 23'$. Small deviations from the course line due to field distortion by metal hangars and the like may in this simple way be compensated.

Because of the symmetrical arrangement no total EMF is induced in the U-aerial by the current change in one arm of the loop aerial; there is said to be no radiation coupling. Upon changing the phase of the loop current we are therefore not concerned with a compensation for the changes thereby caused in the currents of the U-aerial, and this holds good for the aerial systems which produce the radiation diagrams of figs. 8 and 9.

Arrangement of the Philips ultra short wave beacon transmitter type B.R.A. 075/4.

Since the beacon transmitter must interfere as little as possible with other transmitters, its working radius must not be greater than 30 km. Because of the great sharpness of the ultra short wave beacon a high absolute field strength is not necessary. The final stage for the loop aerial may, for instance, consist of two T.B. 1/60 valves with a power of 60 watts, connected in push-pull. The final stage for the U-aerial may have even less power. The coupling of this final stage with the oscillator is variable, because with strong coupling the oscillator might easily be affected. For that reason the final stage for the U-aerial has been made similar to that for the loop aerial, and the coupling may then be looser.

The circuit of the beacon transmitter is shown in the block diagram of *fig. 11*. The frequency of the self-generating oscillator *1* is kept constant by placing the whole oscillator circuit in a thermostat and stabilizing the anode voltage. The heating voltage is supplied by a separate rectifier. The anode self-inductance is divided into two parallel portions which are coupled respectively with the final stage *2* for the U-aerial, and the phase-reversing stage *3*. The latter consists of two valves whose grids are in phase, and whose anode alternating voltages are in opposite phase. In a dot-dash rhythm the grids of these two valves are in turn made so negative that the valve concerned passes no anode current. The anodes of these two valves thus in turn supply the excitation voltage for the final stage of the loop aerial, whose phase is therefore reversed in a dot-dash-rhythm. The two valves are rendered inactive in turn in such a way that no intermediate state exists at which neither has a closed grid circuit. The occurrence of "click" phenomena in the receiver telephone is prevented in this way.

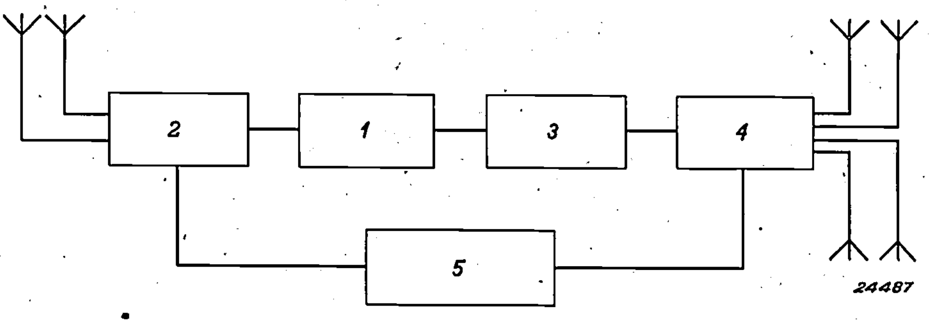

Fig. 11. Block diagrams of the ultra short wave beacon transmitter type B.R.A. 075/4. *1* oscillator stage; *2* final stage for U-aerial; *3* phase-reversing stage; *4* final stage for the loop aerial and *5* modulator.

The final stage *4* for the loop aerial also has an anode self-inductance divided into two parallel portions, each of which is coupled with the feeder of one of the two vertical rod aerials. The strength and the phase of these couplings can be altered for the purpose of regulating the sharpness and direction of the course.

The modulator *5* is a self-generating valve which feeds two parallel modulator stages each of which is coupled to one of the two final stages by means of a transformer. The various heating currents are alternating currents, except for that of the oscillator, and they are kept constant by regulator valves. The various negative grid voltages and the anode voltage for the modulator are supplied by separate rectifiers. The complete beacon transmitter is housed in a cabinet illustrated in *fig. 12.*

At present a new type of landing beacon type B.R.A. 200/8 is being built, and it will be installed at Schiphol. In addition to changes in the transmitter, the aerial system also differs somewhat from that described in this article. The radiation diagram corresponds in principle with that given in fig. 9.

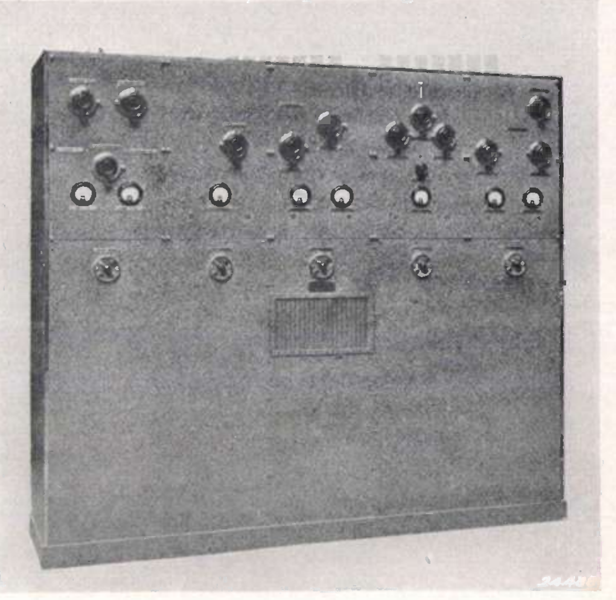

Fig. 12. Philips ultra short wave beacon transmitter type B.R.A. 075/4.