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# INFORMATION CONCERNING THE LONG DISTANCE RADIO NAVIGATION AID

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## CONSOL

Information submitted by Belgium, Canada, France, the Netherlands, Switzerland, the United Kingdom and the United States

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# INFORMATION CONCERNING THE LONG DISTANCE RADIO NAVIGATION AID - CONSOL

## FOREWORD

This circular contains certain operational and technical information on the long distance radio navigation aid - CONSOL. The information has been submitted by Contracting States, and is assembled herewith, in accordance with Recommendation No. 16 of the Communications Division, Fifth Session (Doc 7480-COM/548) as approved by Council at the Third Meeting of its Twenty-Second Session on 27 May 1954.

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## INFORMATION SUBMITTED BY BELGIUM

(Report of SABENA Airline)

Our operational experience with CONSOL as a long distance aid to navigation was derived from operations over the North Atlantic, and related particularly to the Bushmills and Ploneis stations, as the others (Lugo, Seville and Stavanger), either had irregular hours of transmission, or were located too far from the routes normally followed by our aircraft (Shannon, Gander).

Owing to the location (North Ireland and South-west Brittany) of the first two stations with reference to the routes normally followed over the Atlantic, positions can be determined with acceptable accuracy by means of a third, suitably selected position line (Astro and Loran), only roughly as far as the 25th meridian. Beyond this meridian the angle of resection becomes too narrow (less than 30 deg.).

We have noted that the maximum range of the CONSOL, under optimum propagation conditions, is about 800 NM. At that distance, and under the most favourable conditions, an error of 2 units in the signal count is normal. Such an error in the direction along which its effect is felt least (perpendicular to the antenna line), produces a displacement in the position line of 6 NM.

In practice, however, this range is reduced considerably by interference due to atmospherics and to transmissions (radio-beacons, radio-range, broadcasting, etc.) on neighbouring or harmonic frequencies.

Nevertheless, the results achieved could probably be improved upon by the use of a receiver specially designed for this purpose.

The receiver used on our aircraft for the reception of CONSOL signals is the Belmont B. C. 348 communications traffic receiver.

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## INFORMATION SUBMITTED BY CANADA

Canada submits four separate reports from operators in Canada, but no attempt has been made to give a co-ordinated analysis of the results. The comments and opinions in these reports are those of the personnel concerned in making the reports and do not represent the views or opinion of the Canadian Government.

### REPORT A

Our experience indicates that from standard type installations such as Bushmills and Ploneis and employing our standard medium frequency airborne receiving equipment (using beat frequency oscillator) we obtain useful ranges up to 1200 nautical miles reception at night north of 50° latitude. South of 50° N night time average range is about 1000 nautical miles. Useful range of CONSOL decreases somewhat during daylight hours. We find that the above two stations are generally quite reliable.

On the other hand we find the stations at Stavanger, Seville and Lugo, on higher frequencies, have considerably less range and have been operationally less reliable. This has been particularly true of Lugo and Seville.

From our experience we can say that reliability of CONSOL is comparable to LORAN, although on occasion adverse atmospheric conditions result in total CONSOL "blackout" for lengthy periods. Generally, we use CONSOL to supplement other navigational aids (including astro, LORAN, beacons, etc.) in the Eastern half of the North Atlantic.

### REPORT B

#### Range and Accuracy

An accurate aid from 35 degrees W to UK over the Trans-Atlantic route.

#### Reliability

Has been checked with astro observation and found to compare favourably with LORAN.

#### Availability

Usable under almost all conditions at heights of 10000 feet day or night from 35 degrees W to UK on the Goose Bay to Prestwick route.

REPORT C

First plottable readings obtained at 35 degrees W. An accurate fixing aid Prestwick to Keflavik and good for first 400 nautical miles on Keflavik to Goose Bay leg. Our navigators have consistently obtained good results from this aid.

REPORT D

(a) Range
Reliable overwater CONSOL bearings can usually be obtained at a distance of 500 - 600 NM. Reception has been experienced at over 1,200 NMs.

(b) Accuracy
When within 300 NMs of the transmitting station, position line error is usually less than 8 and 10 NMs. Errors gradually increase to 30 - 40 at 1,000 NMs.

(c) Reliability
Some difficulties have been experienced in using CONSOL, however, these are usually traced to inexperienced operators. The Spanish stations of Lugo and Seville were unreliable and seemed to close down at odd hours.

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## INFORMATION SUBMITTED BY FRANCE

### 1. Characteristics of Broadcasts - PLONEIS

- carrier frequency: 257 kc/s
- call sign: TRQ
- emission cycle: call sign repeated twice in 10 seconds, followed by 30 seconds' dot-dash keying
- geographic co-ordinates of base of central tower:

L = 48° 01' 05" 7

M = 4° 12' 55"

- azimuth of the line of towers: 16° 14' 51"

### 2. Equipment

The station includes:

- an operations building housing a group of two transmitters, each being used as an emergency replacement for the other;
- three radiating towers;
- three connecting lines between the transmitters and the radiating towers and three-antenna matching circuits;

The main features of this equipment are as follows:

i) Transmitters:

Each transmitter includes:

- one pilot crystal calibrated to 257 kc/s
- two power amplifiers, one feeding the central antenna, the other the outside antennas;
- coupling devices between the amplifier output circuits and the lines connected to the antennas;
- a device producing the phase shift in the currents of the outside antennas and the keying

The power supplied to the feed lines is 1,500 W for the central antenna and 750 W for each of the outside antennas.

ii) Radiating system:

The station has three radiating towers, spaced at 3,045.1 m from each other, i.e. 261 times the wavelength.

Each tower is of triangulate steel construction, having a height of 110 m, and weighing 30 t.

The area selected for the installation of the station offered no completely flat surface. Consequently, the towers had to be so sited as to ensure, as far as possible, conditions of general topographic symmetry around each of them and equality of levels between them.

The elevations of the feet of the towers are:

| | |
|---|---|
| north tower: | 131.5 m |
| central tower: | 143.5 m |
| south tower: | 133.0 m |

Siting of the towers was entrusted to the National Geographic Institute: it was carried out with an accuracy of one tenth of a second of arc for the geographic co-ordinates, and of 0.15 m for the levels.

The towers are grounded by copper conductors having a diameter of 35/10 of a mm. These conductors are placed along the radii of a circle centred on the foot of the antenna. The diameter of this circle is 150 m for the central antenna and 75 m for the outside antennas. The number of conductors is 120.

Ground resistance measurements at each tower, by means of direct current, gave the following results:

| | |
|---|---|
| central tower: | 1.45 ohms |
| north tower: | 2 ohms |
| south tower: | 0.35 ohms |

iii) <u>Connecting lines and antenna matching circuits</u>:

Connection between antennas and transmitters is effected as follows:

a) by a coaxial cable for the central antenna
b) by aerial two-wire feed lines for both outside antennas. These two-wire lines are 3,029.5 m long; they are joined to coaxial cables of 100 m in length which ensure connection between these lines and the antennas (in order to reduce horizontally polarized radiation).

### Antenna matching circuit

The impendance of the coaxial cables is matched to the impendance of the three antennas by means of three identical antenna matching circuits. The latter are encased in metal housings situated in huts near the towers. The housings also contain the HF filters for tower lighting.

The antenna matching circuits may be adjusted by remote control by means of three telephonic pairs.

The rough setting of the antenna phase is effected by a variable connection to an inductance. The fine setting is effected by remote control by means of two variometers.

These two variometers are driven by small electric motors controlled by contact stud switches and placed in the transmitter building.

Impendance matching indicators permit the control to be regulated from the transmitter building.

## 3. Operation

Pattern stability monitoring is effected by means of a nearby monitoring station and remote monitoring stations.

### a) Nearby monitoring station:

The nearby monitoring station is situated on a straight line at an angle of 1° 29' from the normal in the direction of rotation of the pattern, i.e. towards true North.

The distance from the monitoring station to the central antenna is 3,385 m. This station comprises a small building housing a single frequency receiver, connected to a panel situated in the transmitter building, by three telephonic pairs.

This panel is equipped with a telephone headset and an aperture lit by a neon tube.

When the transmitter is operating properly, the signal heard includes the call sign followed by five dots and the equisignal at the moment the neon tube lights up.

### b) Distant monitoring stations:

There are six distant monitoring stations:

LE HAVRE (lightship)

SAINT-MATHIEU (lighthouse)

LE VERDON (lighting park)

LA COURBE (lighthouse)

ILE DE SEIN (lighthouse)

PARIS (Service des Phares et Balises)

The stations at La Courbe, Ile de Sein (Sein Island) and Le Havre are equipped with ordinary receivers and stand on monitoring watch twice a day.

The stations at Saint-Mathieu, Le Verdon and Paris are equipped with receivers feeding a telegraphic ink tape of the type generally used for receiving high speed Morse signals. Monitoring is done twice a day.

The station staff sets the antenna matching circuits on the basis of data supplied by the nearby monitoring station.

When the distant monitoring stations find abnormal variations in the number of characters heard, they so advise the Ploneis staff by telephone.

A study of the results obtained has revealed variations of a few characters from hour to hour, in relation to the theoretical values, at all distant monitoring stations.

So far, no systematic errors such as the following have been uncovered:

- daily or seasonal variations;
- rotation of the entire beam with reference to the direction for which it is installed;
- compression or expansion of the pattern as a result of variations in transmission frequency or in the antenna matching devices;

Studies have been undertaken to find out up to what point spurious radiation from the aerial circuits might be responsible for the aberrations.

Up to the present, the results obtained have not led to any final conclusions.

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## INFORMATION SUBMITTED BY THE NETHERLANDS

K.L.M. Royal Dutch Airlines, makes a regular use of the CONSOL beacons at Bush Mills, Stavanger and Ploneis on its transatlantic flights for radiolocation purposes in the area east of 20° west. Maximum distance over which these facilities are utilized amounts to 800 miles.

Spanish CONSOL beacons Lugo and Sevilla are used on K.L.M. flights between Lisbon and the Azores. The irregular hours of emission of these beacons, however, often preclude the use thereof at the desired times.

As a rule reception takes place by means of an automatic direction-finder, type NA-1, but when receiving conditions are less favourable a communication receiver, type BC-348, is used. The latter has a more narrow bandwidth than the ADF receiver and is moreover adjusted with a beat frequency oscillator - instead of voice frequency injection as is the case with the NA-1 equipment - which results in a better readability of signals through interference.

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## INFORMATION SUBMITTED BY SWITZERLAND

1) Our national airline, Swissair, frequently uses CONSOL stations, on flights over the North Atlantic, to determine position lines. The results are, on the whole, satisfactory. However, it is unfortunate that the 5 Europear territorial stations do not all operate in the same manner. The accompanying table lists the advantages and drawbacks in each case as borne out by experience.

2) We believe that far better results could be obtained in the use of CONSOL stations if:

i) the navigational cycle of all stations were similar to that of station TRQ, and

ii) the portions which cannot be used at present were eliminated.

| STATION | ADVANTAGES | DISADVANTAGES |
|---|---|---|
| BUSHMILLS | Favourable location for flights to Prestwick and vice-versa. Relatively good navigational cycle; could be even faster (as Ploneis). | The non-navigational portion stretches too far westward for flights to Shannon. For direct flights to Europe, the service provided by this station is likewise not very effective. |
| PLONEIS | The navigational cycle may be considered as the best of all the stations. Favourable location for determining position lines above the Atlantic not too far from Europe; non-navigational portions well situated. | This station frequently stops transmitting without any warning. |
| STAVANGER | Location favourable only for flights over the North Sea area. | Navigational cycle far too slow. Can hardly be used for flights over the North Atlantic. |

| STATION | ADVANTAGES | DISADVANTAGES |
|---|---|---|
| LUGO | Very favourable location | Navigational cycle far too slow. Does not transmit any identification. Large non-navigational portions. Does not operate on a 24 hour basis. |
| SEVILLA | Location convenient for flights to Sta. Maria. Can also be used for flights to South America. | Navigational cycle far too slow. Does not transmit any identification. Large non-navigational sectors. Does not operate on a 24 hour basis. |

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## INFORMATION SUBMITTED BY THE UNITED KINGDOM

# THE BUSHMILLS CONSOL STATION

Royal Aircraft Establishment, Farnborough

(Tech. Note No. Rad.398 - March, 1947)

by

A.H. Brown, M.Sc., A.M.I.E.E.
and
R.A.G. Cooper

## SUMMARY

The report describes in detail the first Consol station built near Bushmills, Northern Ireland. The design of the equipment closely follows the German prototypes, but certain remote control facilities have been incorporated in order to reduce the normal operating staff from five to two. The station first went into operation on an experimental basis at the end of June 1946, and was handed over to the Ministry of Civil Aviation for commercial use on 1st January, 1947. The station is now operating continuously on a frequency of 263 kc/s. and with call-sign MWN.

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# THE BUSHMILL CONSOL STATION

## 1. - INTRODUCTION

The purpose of this Note is to describe in some detail the first Consol station to be installed under British auspices. It should be read in conjunction with an earlier paper which describes the system in general terms.

To provide a service as soon as possible, the station was designed on the lines of the German prototype in all essential features. Some changes and additional facilities have been incorporated, however, which enable the operating staff to be reduced from a minimum of five to two or even one per watch.

When first projected, the station was required for military operations which have now ceased. It is likely that any further stations will be provided under the auspices of P.I.C.A.O., following the plan proposed at the conference at Dublin in 1946. The installation of these stations will be a commercial undertaking so that the equipments used will differ from that at Bushmills, certainly in detail and possibly in technique.

## 2. - DESCRIPTION OF SITE

To satisfy operational requirements, Air Ministry requested the R.A.E. to select a site in Northern Ireland, the coverage to be centred about a line approximately 310 degrees E. of N., corresponding to a bearing of 40 degrees E. of N. for the line joining the outer masts. Having regard to the technical requirements laid down elsewhere, choice was limited to two reasonably satisfactory sites, one in the vicinity of Derrynacross, Co. Tyrone, and one near Bushmills, Co. Antrim. The depth of bog at the former site was too great for economic construction of the station so that Bushmills, although by no means ideal from the constructional point of view, was finally chosen.

The centre mast and associated transmitter building are sited about 600 yards from a main road and telephone route. The north-east and south-west sites are respectively 100 and 250 yards from roads leading to farms; comparatively little work has been necessary to provide suitable access.

From the point of view of suitability for radio frequency propagation, all three sites are very poor. For the most part the soil is only a few inches deep and overlies rock of varying hardness. Between the centre and north-east and, to a smaller extent, between the centre and south-west sites there are large areas of peat interspersed with outcrop of rock. Excavations to a depth of seven feet have been necessary in places in order to secure a solid bed for the open-wire feeder supports. In compensation, however, there is little habitation in the vicinity of and between the sites and only one small diversion of the feeder route round a hamlet near the south-west site has been necessary.

A location plan on a scale of 1/25,000 is provided at Fig. 1 and shows the contours in the immediate vicinity of the station. Fig. 2 shows the location of the station relative to neighbouring towns.

## 3. - GENERAL PLAN OF STATION

### 3.1. - Layout

The general layout of the station in schematic form is given in Fig. 3, which is not to scale. The frequency allocated to the station is 263 kc/s, so that the spacing of the outer masts is 5,040 metres, in accordance with the scheme of assigning three standard mast spacings for frequencies in the band 200-455 kc/s. An accurate survey following selection of the actual positions of the masts gave a true separation of 5,034.6 metres, a discrepancy of significance in the preparation of operational charts and tables. The survey also disclosed a small error in the position of the centre mast, as indicated in Fig. 4. A displacement of the centre aerial does not influence the location of the position lines radiating from the station, but broadens the equisignal between dots and dashes. In this case the displacement is too small to affect the beam width appreciably.

Two monitors are provided, one sited on the right bisector of the line joining the outer masts and one displaced by an angle of 1°18', corresponding to one tenth of the angular width of the sector adjacent to the normal to the line of masts. To achieve maximum discrimination, the monitors should be sited 2,220 metres from the centre of the line joining the outer masts. This distance is not critical and for convenience of access sites were chosen near a road at a distance of about 2,350 metres.

### 3.2. - Buildings

The transmitter building is 60 x 40 x 11 ft. high (to the eaves) and is constructed of 4-1/2 in. brickwork in accordance with wartime practice. A sketch of the building is given in Fig. 5 and shows the disposition of the two sets of transmitting equipment. Ample space is available for the installation of additional or higher power equipment. The building is sited 100 yards from the centre mast in order to minimise coupling between it and the open wire feeders leading to the outer aerials. Such coupling leads to re-radiation of unwanted horizontally polarised signals.

The buildings housing the aerial matching units are of Nissen hutting 16 x 12 ft. They are much larger than necessary but this type of hutting was readily available and was therefore used as a matter of expediency.

With regard to the monitor site, the receivers are unattended and are housed in a small wooden cubicle secured to the pole to which the associated aerial is attached. Two cubicles and aerials are provided, one for each monitor.

### 3.3. - Power Supplies

The normal power supply is derived from the 11 kv. public supply mains. The nearest supply was in the vicinity of the Giants Causeway and about two miles of overhead line had to be provided. To avoid re-radiation from these lines, the supply is brought in by buried cable for the last 500 yards. Although the maximum connected load is 35 KVA at the moment, a transformer capable of delivering 100 KVA at 415 volts three phase, 50 c/s, is provided and is located external to and at one end of the transmitter building.

Although it might have been more economical to provide power at the outer aerials and at the monitor site from the local public supply, it was decided in the interests of continuity of service to lay cables from the transmitter building to the three sites, so that a stand-by supply could be made available to the whole station. The use of the radio frequency overhead feeders was considered for carrying in addition power at 50 c/s to the outer sites. The staff engaged on the project was, however, fully occupied with the design and construction of equipment for the station and the idea was shelved for later investigation.

### 3.4. - Other Services

In the interests of economy of operating staff, arrangements have been made for remote control of the aerial matching units, details of which are given below. For this purpose a 7pr/10 cable has been laid from the transmitter building to each of the huts at the base of the masts. Instead of following the German practice of using the open wire feeders and an earth return as a speech circuit, one pair in each of these cables is used.

According to German literature, the mains cable has been used at Sonne stations for passing the output of the monitor receivers back to the transmitter building, suitable filters being provided for this purpose. According to R.A.F. sources, however, this device has not proved to be satisfactory, and a 7/10 cable has been laid at Bushmills between the monitor site and transmitter building.

## 4. - AERIAL SYSTEM AND ASSOCIATED EQUIPMENT

### 4.1. - Masts and Earth Systems

An efficient radiator cannot readily be realised at medium frequencies without considerable top loading or by erection of very tall mast radiators.

"T" or "L" aerials produce a certain amount of unwanted horizontally polarised radiation. Receiving aerials such as are normally installed on ships or aircraft are quite sensitive to horizontally polarised waves, so that errors may arise due to the mixture of the two components at the input of the receiver. The effect will be aggravated at night by the partial rotation of the plane of polarisation of the horizontal component due to reflection at the ionosphere.

A number of 325 ft. masts were due to be dismantled at certain R.A.F. stations and it was decided to convert three of them to self-radiators for use at Bushmills. A contract was placed with the Marconi Wireless Telegraph Co., who also undertook the laying of the extensive radial earth systems and transmission lines described below. Supervision of the actual constructional work was delegated to H.Q. 26 Group (now incorporated in 90 Group).

The conversion of the masts entailed the provision of adequate insulation of the base from the ground and the splitting up of the guys with insulators. Five pairs of porcelain insulators each 12 in. high and 8 in. diameter are provided at the base of each mast and are arranged at the corners and at the centre of a square, as may be seen by reference to Fig. 6. The breaking load of each insulator under compression is 100 tons so that an ample factor of safety was allowed on the maximum working load of 90 tons spread over the five pairs of insulators. "Kicking" insulators are also provided to cater for a maximum lateral thrust of one ton. All the guys are insulated from the mast at their points of attachment and the upper two sets are also broken at the middle. Egg type insulators 9 in. long and 6-1/2 in. diameter are used in pairs for insulation of the guys.

It was decided not to rely on the leg splices for electrical continuity, and a 19/064 copper conductor is cleated to the inside of each leg. The four wires are bonded together at the top and bottom of the mast. The four wires are also bonded diagonally by 1 in. 16 S.W.G. copper strips at a height of 12 feet from the ground and a similar strip is taken from their cross-over point to the lead-in insulator mounted on the wall of the hut housing the matching unit.

To minimise risk of damage to the equipment by lightning, a horn gap is mounted on the base of the mast as indicated in Fig. 6.

Obstruction lighting is provided by four 75-watt lamps, two at 220 feet and two at 325 feet from the ground. Power for this purpose is carried by two- and three-core Pyrotenax cables cleated to one leg of the mast. To prevent short circuiting of the mast to ground at radio frequency through the obstruction lighting cable, a simple filter is inserted in series with the cable. Fig. 7 shows the arrangement adopted in schematic form. The housing for the filter is of the type commonly used for a feeder pillar and may be seen at one side of the mast in Fig. 6.

Due to the poor ground conductivity in the vicinity of the station, it was decided to extend the earth wires to a radius of about half-a-wave-length in the case of the centre aerial. Since the outer aerials radiate a relatively small proportion of the available power, it was considered that radials about a quarter wavelength long would suffice and that the reduced radiation efficiency could be allowed for by modifying the power distribution. Finally, 120 radials of 14 S.W.G. hard drawn copper wire, of length 500 yards in the case of the centre aerial and 200 yards in the case of the outer aerials, were used.

The extension of the wires along precise radii from the masts would have entailed considerable expense in the matter of demolishing and making-good hedges and of crossing ditches. In the vicinity of the masts, therefore, the wires are bunched locally in groups of five and fan out again beyond the obstruction.

Where possible the wires were buried by means of a mole plough by which a furrow is cut and the wire laid simultaneously. The furrow is very narrow and consolidation of the soil is unnecessary. Usually a tractor was coupled direct to the plough. Over much of the centre site, however, the peat was too soft to bear the weight of the tractor. In such cases the tractor made a detour to firm ground and drew the plough over the soft ground by means of a long inter-connecting rope.

The earth wires were bolted and then sweated to a 3 in. 20 S.W.G. copper bus-bar surrounding the mast foundation block. The bus-bar in turn was sweated to 20 S.W.G. copper sheets covering the foundation block. 1 in. 16 S.W.G. strips were taken from the bus-bars into the neighbouring huts to provide an earth connection for the aerial matching units. In the case of the transmitter building, six wires were bonded together and a copper strip taken into the cable trench to provide a good earth connection for the transmitter. The lower section of each mast guy was earthed by means of a bonding wire clamped to it at one end and sweated at the other end to a buried wire sweated in turn to six of the radials.

## 4.2. - Transmission Lines

At the design stage, seasoned wooden poles of good quality were in very short supply, and it was decided to use steel supports for the open wire transmission lines. Since eighty supports spaced about 100 feet were required between the transmitter building and each of the outer aerials, insulators are used which introduce a minimum of shunt capacity across the line. An insulator having no metal top cap (designed by the Marconi Co.) was already available and is used for the majority of the supports. Insulators of a stouter pattern are used in groups of four at every ninth support for straining the 8 S.W.G. copper wires to a tension of 200 lbs. The wires are transposed at the same support to minimise electrical unbalance. Details of both types of feeder support are given in Fig. 8.

The feeder supports are normally 20 ft. high to provide adequate clearance between the transmission lines and local vehicles. Public roads had, however, to be crossed in four places and supports 30 ft. high are provided. Wire guards are fitted between these supports some six feet below the lines in order to avoid interference with passing traffic and G.P.O. telephone lines in the event of a breakage of the transmission lines. A photograph of part of the feeder route, showing one end of a road crossing, is given at Fig. 9.

The lines are terminated at "anchor" supports at each end of the run. Fig. 10 and 11 are photographs of the terminal arrangements at the transmitter building and the outer sites. Tubular brass bus-bars connected to the transmission lines are taken from one side of the transmitter building to the other, as shown in Fig. 12 and links are provided so that either control unit may be put into operation.

The open wire lines terminate at a distance of about 100 yards from each of the outer aerials and the feed is continued by means of Uniradio No. 36 cable. This cable has a surge impedance of 63 ohms and a loss of 0.07 db/100 ft. at the operating frequency of 263 kc/s. Moulded polythene terminations are used to prevent ingress of moisture. The same cable is used for feeding the centre aerial from the transmitter building.

## 4.3. - Matching Units

The aerial matching units are of conventional pattern and are shown diagrammatically in Fig. 7. The reactance of the aerial is tuned out by means of the loading coil which has an inductance continuously variable by taps and a variometer between 0 and 390 $\mu$H, and the resistance is matched to the line by means of a coupling coil. The coupling coil can be tuned approximately to resonance by a bank of fixed capacitors variable in steps of 0.001 $\mu$F up to 0.007 $\mu$F. Fig. 13 is a photograph of one of the matching units.

Since the unit may require adjustments at intervals of an hour or so, due to changes of the weather, remote control of fine tuning of the loading coil and of the coupling coil is available. For this purpose, the rotors of the tuning variometer and the coupling coil are driven through suitable gears by small A.C. motors. The direction of rotation of the motors is governed by relays which in turn are operated by keys fitted to the Consol control unit. The rotating coils are connected to the rest of the assembly by pig-tail connections so that over-running would result either in fracture of these connections or a stoppage of the driving motor with consequent overheating. Cams are therefore fitted to the driving shafts which cut off the motor supply at each end of the travel of the rotors and at the same time provide circuits for indicator lamps on the control unit. Fig. 14 is a schematic of the circuit associated with one rotor.

A simple unit (shown in Fig. 15), consisting of two coils and a capacitor, is used for connecting the balanced open wire transmission lines to the coaxial cable. To provide a balanced-to-unbalanced transformation it is necessary only to satisfy the condition that the reactances of the coils shall be equal, and double the reactance of capacitor. Since the components are preadjusted, modification of the coils would be necessary to cater for a change of frequency of operation. The work involved is, however, of small magnitude compared with the attendant labour of re-computing and printing new plotting charts. The centre-tapped coil is fitted in order to provide an alternative speech circuit over the open wire transmission lines with earth return in the event of development of a fault in the 7/10 control and telephone cable between the transmitter building and matching unit hut. In effect, speech is provided over a phantom circuit, so that transmission of radio frequency and speech currents may be fed simultaneously over the lines without mutual interaction. A 4/10 cable is laid between the centre-tapped coil and the matching unit hut and is terminated in a position convenient for the alternative connection of the local telephone set.

The balanced-to-unbalanced transformer does not at the same time provide a match between the 565-ohm open wire line and the 63-ohm coaxial line impedances. The aerial matching unit is therefore adjusted so that the cable presents a load to the transformer such that the open wire lines are correctly terminated. This means that a standing wave exists on the coaxial cable. By selection, however, of suitable reactance values for the components of the transformer, the mis-match does not exceed 3.5/1 so that neither the line current nor voltage rises to a dangerous value.

## 5. - TRANSMITTING EQUIPMENT

### 5.1. - General Plan

To ensure a service with a minimum of interruption due to breakdown or routine maintenance, two complete sets of transmitting equipment are installed. Full interconnection facilities are provided whereby either transmitter may be operated with either control unit. Interruption of service due to complete change-over of equipment lasts about ten minutes, most of the time being required for lining up the control unit. The two sets of equipment, shown in Fig. 12, are installed beneath the R.F. bus-bars. The unit mounted on the wall behind the transmitting equipment provides switching of the incoming control cables to either control unit and interconnection of the R.F. circuits, other than the outputs of the control units to the outer aerials. These latter connections are made by links from the R.F. bus-bars to bushing insulators mounted on the top of the control unit.

## 5.2. - Transmitter

The transmitter Type T1412 (Stores Ref. 10D/907) is used, having an output power of 2 KW. C.W. between 100 and 1,200 kc/s. Drive for the power amplifier stage is obtained from a stable tunable oscillator over the entire frequency range, or from a crystal-controlled oscillator between 150 and 1,200 kc/s. Crystal control is used at Bushmills.

The transmitter is designed to work directly into a conventional T-aerial, the reactance of which is tuned out by means of a large variable inductance mounted in a cubicle separate from the transmitter. Since the control unit presents a resistive impedance of 30 to 40 ohms to the transmitter, the tuning inductance is dispensed with and the variable inductance and capacitor fitted inside the power amplifier cubicle are used as an L-section to present the correct load to the output valves. Fig. 16 is a schematic of the output circuit.

## 5.3. - Control Unit

### a) General

The control unit has been described briefly elsewhere and it will be necessary only to elaborate the description where points of technical interest arise. Fig. 17 and 18 are a schematic diagram and photograph of the equipment. Variable components have sufficient range to enable the unit to be used between 260 and 300 kc/s.

### b) Keying Transformer and Keying Relay

The keying transformer, L3 of Fig. 17, is wound in two halves with adjustable coupling. The primary windings are selected in turn by the keying relay A operating a change-over contact A1. The relay is of the type common in telephone practice. The armature, however, operates the moving contacts of a pair of vacuum switches (CV298).

C2 and the coupling of the transformer windings are adjusted so that the input impedance of the primary of the keying transformer with C1 in series is 220 ohms. L1 and the combination of L2, C4 and C5 form an impedance transformer such that the control unit presents at TP1 an impedance to the transmitter of approximately 90 ohms. Neons V5 and V6 are operated by the radio frequency voltage appearing between earth and one end, in turn, of each of the transformer primary windings. One neon glows for the duration of a dot transmission and the other for the duration of a dash transmission, dots and dashes thus appearing visually as the keying relay operates.

V7, V8 and V9 are stabilivolts (CV1069) and are provided to ensure that the load presented to the transmitter does not change while the keying relay contact is momentarily disconnected from both primaries of the keying transformer. A change of load may result in slight changes of power output of the centre aerial in synchronism with the keying rhythm, thus giving rise to key clicks. The transmitter Type T.1412 has good regulation and the stabilivolts are not required in practice.

### c) Phase Shifter

The phase shifter, shown in diagrammatic form in Fig. 17 as four reactances, is detailed in Fig. 19. A lattice circuit is used, the reactances of the arms being varied by means of a seven position switch in order to provide phase shift in steps of 30 degrees between -90 degrees and +90 degrees.

For correct operation, the phase shifter must work into a resistive load of 330 ohms. Transformer L4 tuned by capacitors C9-C12 provides the impedance transformation required between the input of the goniometer rotor L5 and the output terminals of the phase shifter.

### d) Differential Phase Shifter

The phase shifter which advances and retards the phases of the currents in the outer aerials consists of the goniometer L5, the 90 degrees phase shifting transformer L6 and the capacitor bridge network C15-C22 (Fig. 17). The goniometer is driven by the motor, which is part of the keying unit. The stator windings are also capable of being rotated together to a limited extent by means of a knob on the front panel. The purpose of this adjustment will appear later.

In order that the transformer shall act as a 90 degrees phase shifter, its secondary must be tuned to resonance at the operating frequency. This is achieved by fixed inductances L7 and L8. The inductances are pre-adjusted to resonate the transformer secondary at mid-band frequency, 280 kc/s. The departure from resonance at 260 and 300 kc/s is not sufficient to introduce appreciable inaccuracy into the system.

### e) Matching Indicators

The output terminals of the capacitor bridge network are connected to the open wire transmission lines through matching indicators D2 and D3 (Fig. 17). These indicators have three windings, the first in series with the transmission line, the second connected across the transmission line, and the third coupled to the first two windings. The windings in series with the transmission line consist of a single turn only and do not introduce appreciable impedance discontinuity in the line. The winding across the line has a high resistance in series with it, so that the current in it is substantially in phase with the potential difference between the wires of the transmission line. The directions of the windings are such that the currents induced in the third winding from the first and second windings oppose each other, provided that the line volts and line current are in phase. The resistance in series with the second winding is adjusted so that the currents in the third winding are equal and opposite for a ratio of line volts to line current of 565. This means that there will be zero current in the third winding when the transmission line is properly matched and presents a resistance of 565 ohms to the matching indicator. A rectifier (CV101) and microammeter are connected in series with the third winding, the meter indicating zero current when the aerial matching unit is correctly adjusted.

The matching unit D1 is similar to matching indicators D2 and D3. Since coaxial cable is used for feeding the centre aerial from the control unit, the windings are connected as shown (Fig. 17). The current in the first winding is greater than in matching indicators D2 and D3, and a rectifier of lower sensitivity (Westector W6) is used.

### f) Keying Unit

The keying unit consists of a series of motor driven cams which control the keying cycle. Three cams fitted to the shaft of the goniometer rotor also form part of the control circuit. Apart from the addition of a cam for sending the station call sign, the keying unit is for practical purposes identical with that fitted at Sonne stations. The speed of operation is however doubled, a complete cycle lasting one minute. (The unit for reducing the keying cycle to 40 seconds, which is referred to in earlier papers, will replace this unit when available.) The operating cycle and the sequence of operation of the cams are shown in Fig. 20 and 21.

Referring to Fig. 20 it will be seen that the transmitter is on continuously, except for short breaks of 1-1/2 seconds and 1/2 second before and after the keying, and for the short period during which the station call sign is sent. The contacts of cams b, f and n are connected in parallel (see Fig. 17) and determine the 1-1/2 seconds and 1/2 second breaks of transmission. The contacts of cams c, l and o are also connected in parallel and ensure that the call sign is sent only once during the cycle. These contacts in effect replace the morse key normally used with the transmitter. Cam c, on the periphery of which the call sign is cut, is mounted below the keying unit and is easily replaced without removing the complete unit if a change of call sign is required.

Cam k releases relay B, thereby connecting the control unit to the transmitter via relay contact B1. At the same time, relay contact B2 extends the 24 volts supply to the keying relay A through the contact operated by cam i. The keying is subsequently controlled by this cam. It should be noted that sixty-one characters are actually transmitted. One character must, however, be lost at the equisignal where the dot and dash polar patterns intersect, so that an observer cannot count more than sixty characters.

For reasons which will appear later, the signals from the monitoring station are displayed at the control unit for a short time only. Cam m operates relay C which closes the secondary circuit of transformer T5. Cams d and h operate relay D which allows the neon V3 to flash at the appropriate time.

### g) Monitor Panel

The monitor panel consists of valve V1 and the associated components indicated in Fig. 17. The output of the remote monitor receiver is fed to V1 through the poteniometer R4. The output of V1 is rectified and is fed through the microammeter M8, which indicates the level of the received signal, and through the transformer T5.

Since the monitor receiver is offset one tenth of the dot sector adjacent to the normal to the line of aerials, it follows that characters received by it will be six dots and fifty four dashes. Since it is tedious to count the whole of the sixth characters to ensure that the correct pattern is being radiated, cam m referred to above ensures that only five characters each side of the equisignal effect the centre-zero meter in the secondary of the transformer T5. The amplitude of the signal in the vicinity of the equisignal is shown in Fig. 22. Transformer T5 differentiates the signal, so that the meter kicks clockwise on reception of dots and anti-clockwise on reception of dashes.

### h) Telephone Panel

The telephone panel provides ringing and speaking facilities to each of the three huts housing the aerial matching units and to the monitor site.

Referring to Fig. 23 the appropriate key KS1, KS2, KS3 or KS4 is thrown. Pressing the calling button of the operator's telephone operates relay C, which in turn extends an earth to relay D. Relay D, on operating, breaks its own battery circuit and also momentarily breaks the current in the primary of transformer T1, thereby inducing a pulse of current in the secondary. Relay D restores slowly due to the discharge of the 50 $\mu$F capacitor in series with its 100-ohm winding. In restoring, an earth is again extended to the relay and a second pulse of current is induced in the secondary of T1. Relay D again operates and the cycle is repeated. The pulses of current from the secondary of T1 are fed over the line chosen by operating KS1, 2, 3 or 4 and operate the bell set in the extension telephone. When the calling button is released, relay C restores and the extension is connected to the operator's telephone.

The extension telephones (Telephone Set Type L) are provided with hand driven generators for ringing purposes. Ringing tone from the centre aerial extension, for example, operates relay A which provides an earth for relay B.

Relay B locks up and at the same time operates the calling lamp LP1 and extends an earth to relay D. Relay D then produces ringing tone, as described above, which is applied to the bell set fitted behind the telephone panel. Operation of KS1 releases relay B and connects the extension to the operator's telephone.

KS1, 2, 3 and 4 are double-throw keys and provide the facility of connecting two or more extensions together while at the same time permitting the operator to speak to other extensions.

KS6 is used for connection of the operator's telephone or the loud speaker to the output of the monitor receiver via the amplifier in the monitor panel.

## 6. - MONITOR RECEIVERS

The receivers operate unattended and for this reason are designed to avoid drift of tuning and variation of the frequency and amplitude of the audio frequency output. Fig. 24 is a circuit diagram of the receiver. A superheterodyne circuit is used, the signal being fed through a band-pass filter, tunable between 250 and 450 kc/s, into a CV.1944 triode-hexode frequency changer. To avoid drift of tuning, the triode section of the frequency changer is a crystal oscillator operating at a frequency 125 kc/s higher than the frequency of the Consol transmitter. One stage of selective I.F. amplification (CV.1053) at 125 kc/s is used. The two I.F. transformers I.F.T.1 and I.F.T.2 have a bandwidth of ± 1 kc/s at 6 db. below maximum response. The first half, V3a, of the CV.181 double-triode is used as an infinite impedance detector, rectified signals positive with respect to earth appearing across the cathode resistor R13. The second half of the CV.181, V3b, is used as a Hartley oscillator for generating 1,000 c/s supply. The output of V3b appears across the secondary of transformer T1 and is applied to the suppressor grid of the output valve (CV.1091). The output valve is normally biased to cut-off by the application of positive bias to the cathode through the potential divider R20 and R21. No audio output therefore appears at the output transformer T3. Incoming radio frequency signals are converted to D.C., as explained above, which appears as a positive voltage between the control grid of V5 and earth. V5 then conducts and an audio signal of the same frequency as that applied to its suppressor grid appears at the output transformer. The rectified signal appearing at the cathode of V3a is also applied to the cathode of the diode V4 and the 0-500 microammeter. This meter provides an indication of the output of the receiver and is used for presetting the receiver gain.

## 7. - FACTORS GOVERNING THE ACCURACY OF THE RADIATED PATTERN

### 7.1. - Accuracy of Adjustment by the Operating Staff

In a previous report, consideration was given to errors arising from incorrect distribution of the currents in the aerial system both as regards amplitude and phase. The ideal distribution can never be realised in practice, partly on account of small asymmetries of the installation and partly on account of the unequal effect of the weather on the three radiators. Referring to para. 5.2. of the report in question, it may be seen that provided the error specified are small the equisignal bearings are given by

$$\frac{2\pi d}{\lambda} \cos\theta - \phi - \phi' = 0$$

where $\phi'$ is the lumped term appearing on the right hand side of equation (8).

Introducing a small initial phase shift (equal and opposite to $\phi'$) by means of the goniometer, eliminates the effect of the imperfection of the aerial system. Since the rotor of the goniometer is continuously moving when the station is operating, the correction is conveniently made by the rotational adjustment of the field coils. Provided that the aerials remain matched (adjustment normally being required at intervals of half an hour to an hour) the goniometer is usually re-set every other day. From the description given above of the monitoring facilities it will be evident that accuracy of adjustment is not better than one character.

### 7.2. - Instrumental Errors

Examining the control unit from the input to the output to the aerials, it is evident that the first possible source of error is inequality of the two halves of the keying transformer. No error can, however, arise from this cause since the dot and dash lobes will still intersect at the same angle, although their amplitudes will be different. For the same reason inequality of the contact resistances of the keying relay has no effect.

Imperfection of adjustment of the lattice phase shifter has already been considered and is allowed for in the manner described in para. 7.1.

The error introduced by the goniometer depends upon the nature of its own errors and may be stated in general terms as follows. If, for a setting G of the rotor with respect to one of the stators, the outputs in the stators are proportional to sin $G'$ and cos $G'$, then the error of count is $(G \sim G')/3$ characters. In practice, the errors of a well designed goniometer for medium frequency working do not exceed one or two degrees, so that the error of count will not be more than 1/3 or 2/3 of a character. The correct operation of the goniometer requires that the impedances presented to the stators shall be equal

If they are unequal and have a ratio 1 + a, where a is small, then the phase advance and retardation of the currents in the outer aerials, instead of being given by $\phi = G$, is given by $\tan\phi = (1 + a) \tan G$, thereby introducing a phase error of approximately 1/2 a sin 2G. The corresponding error of count for a count of N characters before the equisignal is $\frac{30}{\pi} a \sin \frac{(\pi N)}{30}$ characters. Since there is no difficulty in measuring impedances to an accuracy of 2 per cent. at medium frequencies, and equalising impedances to better than 1 per cent., the error of count due to this cause is unlikely to exceed 0.1 or 0.2 characters. During operation, inequality of the impedances of the two outer aerials has to be taken into consideration, and the extent to which the impedances presented to the goniometer remain equal depends upon the care taken by the operating staff to re-match the aerials.

The 90 degrees phase shifter transformer inserted between one stator of the goniometer and the bridge network depends for its operation on the resonance of its secondary. Since no provision is made for tuning the secondary over the frequency coverage of the control unit, it will be of interest to examine the errors introduced by small departures of the phase shift from 90 degrees. If the phase shift differs from 90 degrees by a small angle $\mathcal{E}$, then the phase advance and retardation of the currents in the outer aerials is given by

$$\tan \phi = \pm \tan G - \mathcal{E}$$

and the amplitudes of the currents in the outer aerials are different and are proportional to $1 \pm 1/2\, \mathcal{E} \sin 2G$. Taking both effects into account, the error for a count of N characters before the equisignal may be shown to be

$$\delta N = \frac{120}{\pi} \varepsilon^2 \sin \left(\frac{\pi N}{60}\right) \cos^3 \left(\frac{\pi N}{60}\right)$$

$\delta N$ is plotted against N in Fig. 25 for several values of $\mathcal{E}$.

The load presented to the goniometer stators is given by

$$Z_i = \frac{2j\, X_c\, (jX_c + Z)}{2j\, X_c + Z}$$

where $X_c$ is the reactance of the capacitors of the bridge network and Z is the series impedance equivalent to the surge impedance of the open wire lines and the reactance of L7 or L8 (see Fig. 17) in parallel. By proper choice of the components, $Z_i$ can have a negative reactive component which increases with frequency over a limited frequency range. Thus the tuning of the secondary of the phase shift transformer may be substantially maintained. In the case of the Bushmills equipment, the total secondary reactance does not exceed 15 ohms in the range 260-300 kc/s. The phase error $\varepsilon$ is given approximately by the ratio of the secondary reactance to the secondary resistance (250 ohms approximately) and is therefore not more than 0.06 radians, or 3.4 degrees. The resulting error of count is therefore negligible.

The analysis of the two remaining sources of error due to inequality of the capacitors of the bridge network and inequality of the impedances of the outer aerials is difficult and leads to cumbersome expressions. In practice the capacitors are within 1 per cent. of their nominal value, and the matching indicators permit adjustment of the aerial impedances to an accuracy of at least 5 per cent. Under operating conditions no appreciable error of count can be detected so that it is concluded that these tolerances are adequate.

## 8. - PERFORMANCE OF STATION

### 8.1. - General

In general the performance of the station has been satisfactory since the first transmissions at the end of June, 1946. The switches (CV298's) used for keying appear, however, to have too low a vacuum and severe arcing takes place unless the transmitter output is limited to 1 KW. This is necessary, in any case, since the output valves (CV1506) have a very short life if required to deliver 2 KW. continuously.

It is hoped in due course to improve the performance of both the CV298 and CV1506 so that the station can operate with 2 KW. input to the aerials.

### 8.2. - Radiation Efficiency

The input impedances of the three aerials were measured frequently between June and August, 1946. The reactive component was found to be constant and the same for all three aerials, while the resistive part varied considerably. The resistance was invariably found to be greatest in wet weather, indicating that losses were present due to leakage over the surface of the various insulators. The stay insulators, having a relatively small leakage path, appeared to be the major cause of increased loss, since drying the base insulators brought about no reduction of loss resistance.

The variations of input impedance of the three radiators are given in Fig. 26, 27 and 28. In general, the centre (No. 2) and the south-western (No. 3) radiators had the same resistance, while the resistance of the north-eastern (No. 1) radiator was considerably higher.

However, measurements of field strength made by the B.B.C. near Oxford during November, 1946, showed that the radiation efficiencies of the outer aerials were nearly equal and 60 per cent. of the radiation efficiency of the centre aerial. Taking these measurements into account, and including the measured loss resistance of one ohm in the aerial matching units, the radiation efficiency of the centre aerial is probably about 50 per cent. and that of the outer aerials 30 per cent.

### 8.3. - Range and Accuracy

It will be appreciated that the performance of a system such as Consol can be determined only by statistical means. Overland performance has already been studied in this way by the Germans but little data on performance over sea is available. To obtain reliable results it is evident that many hundreds of hours of observation are necessary. For this reason observations are best made on a ship. An extensive programme has been planned and, with the co-operation of Marconi International Marine and Messrs. Donaldson Bros. Ltd., observations have been made on a regular run between Glasgow, Montreal and Halifax. Glasgow is particularly convenient as a starting point since the ships course is substantially radial to Bushmills. It is hoped in due course to extend the observations so that the forward coverage is completely explored.

The results so far obtained have not yet been completely analysed and a separate report will be published as regards accuracy. With regard to range, however, the mean of the maximum ranges obtained on four trips between September and December, 1946, is 1,200 nautical miles by day and 1,500 nautical miles at night. A good communications receiver was used for the observations.

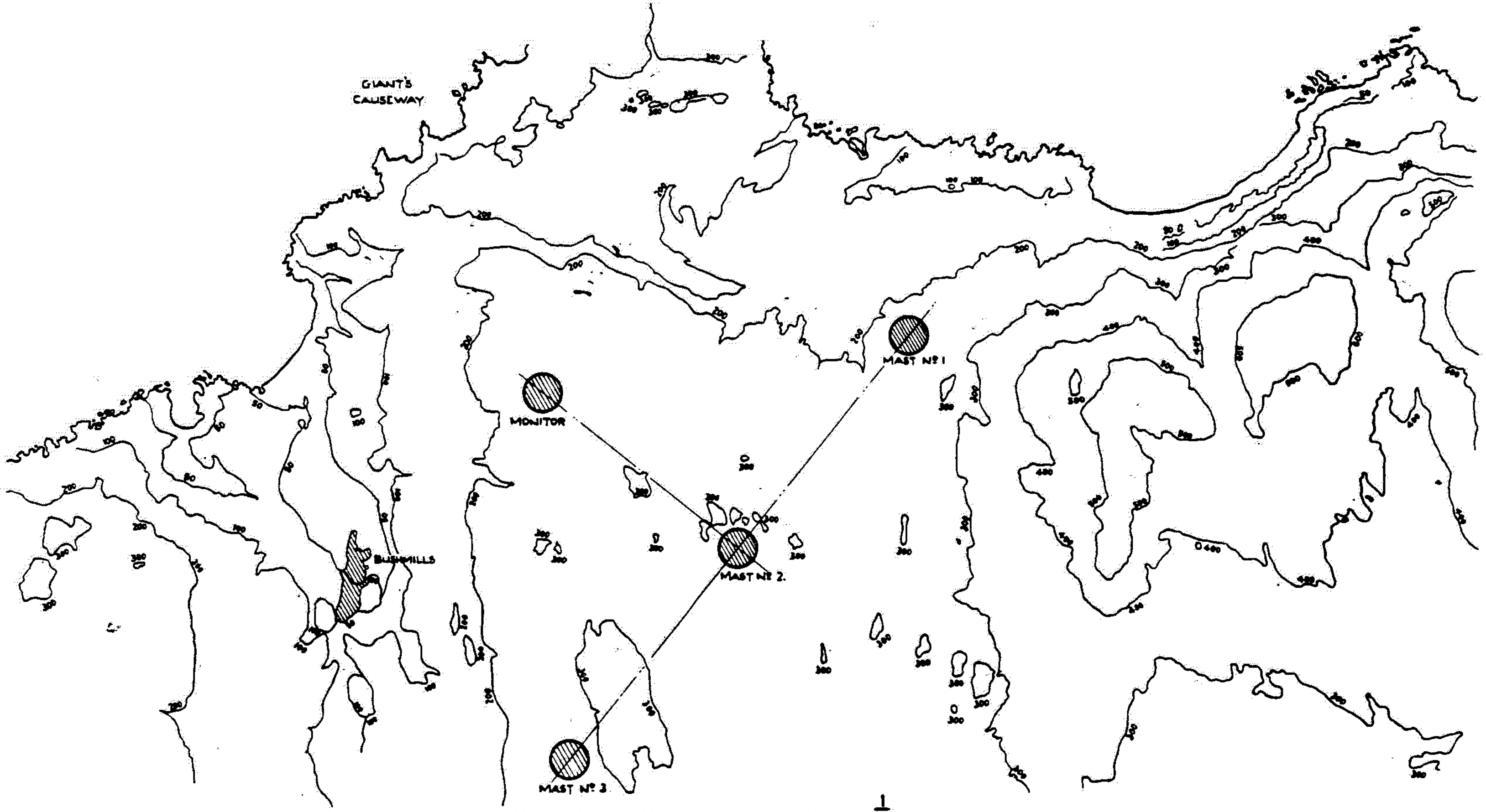


FIG. 1 BUSHMILLS LOCATION PLAN $\frac{1}{25,000}$

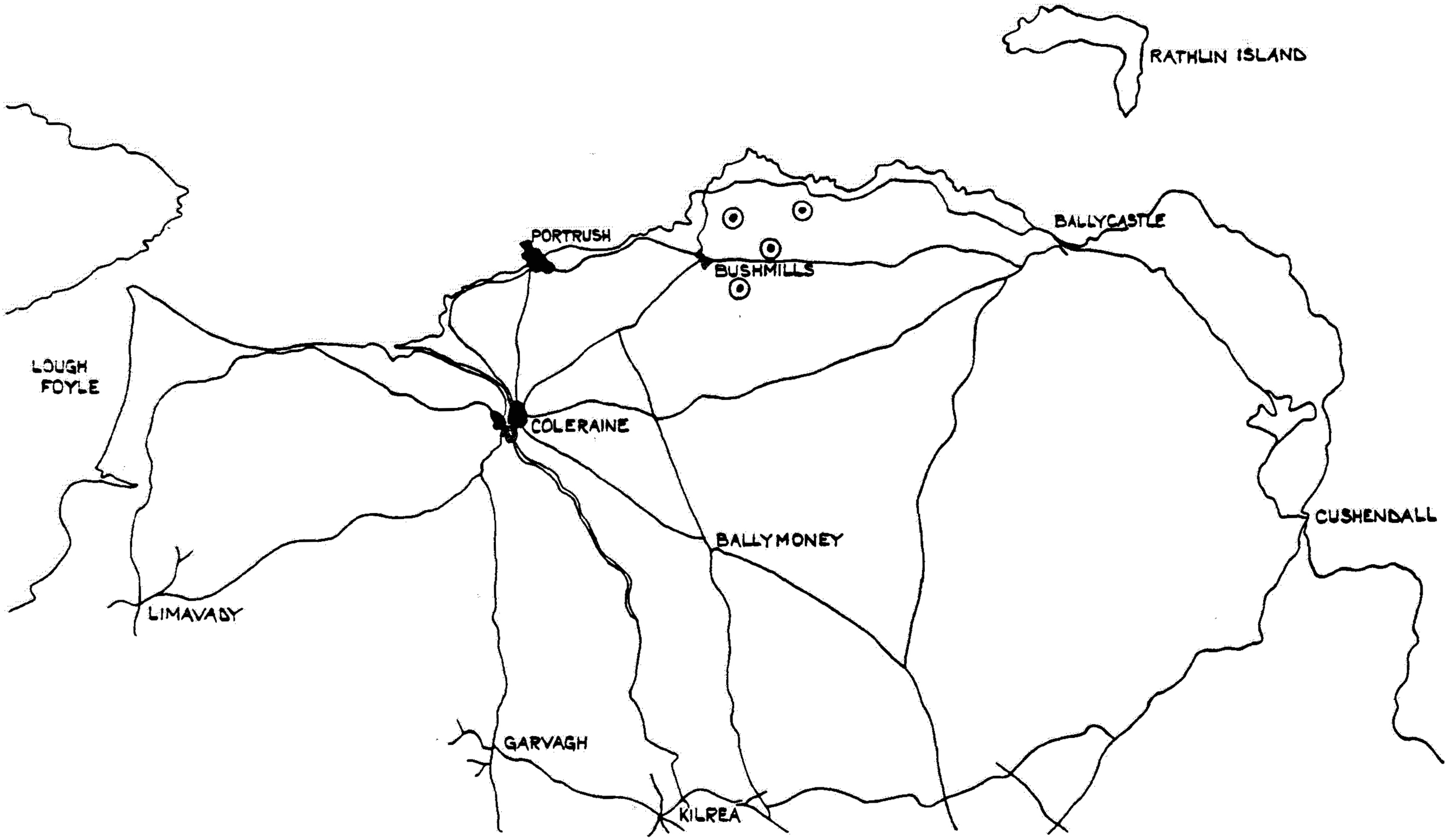


FIG. 2. BUSHMILLS - LOCATION PLAN 4 M = 1 INCH.

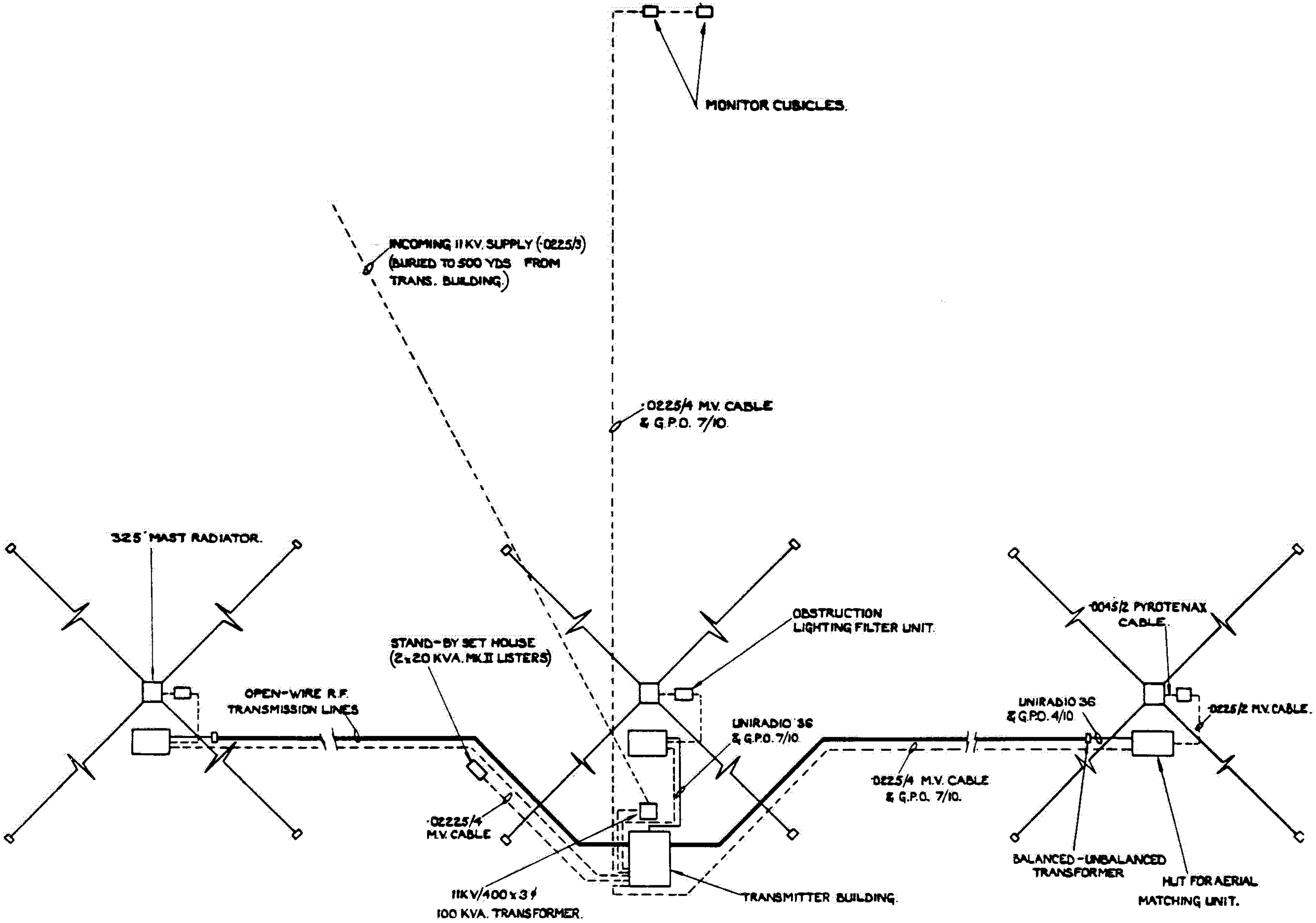
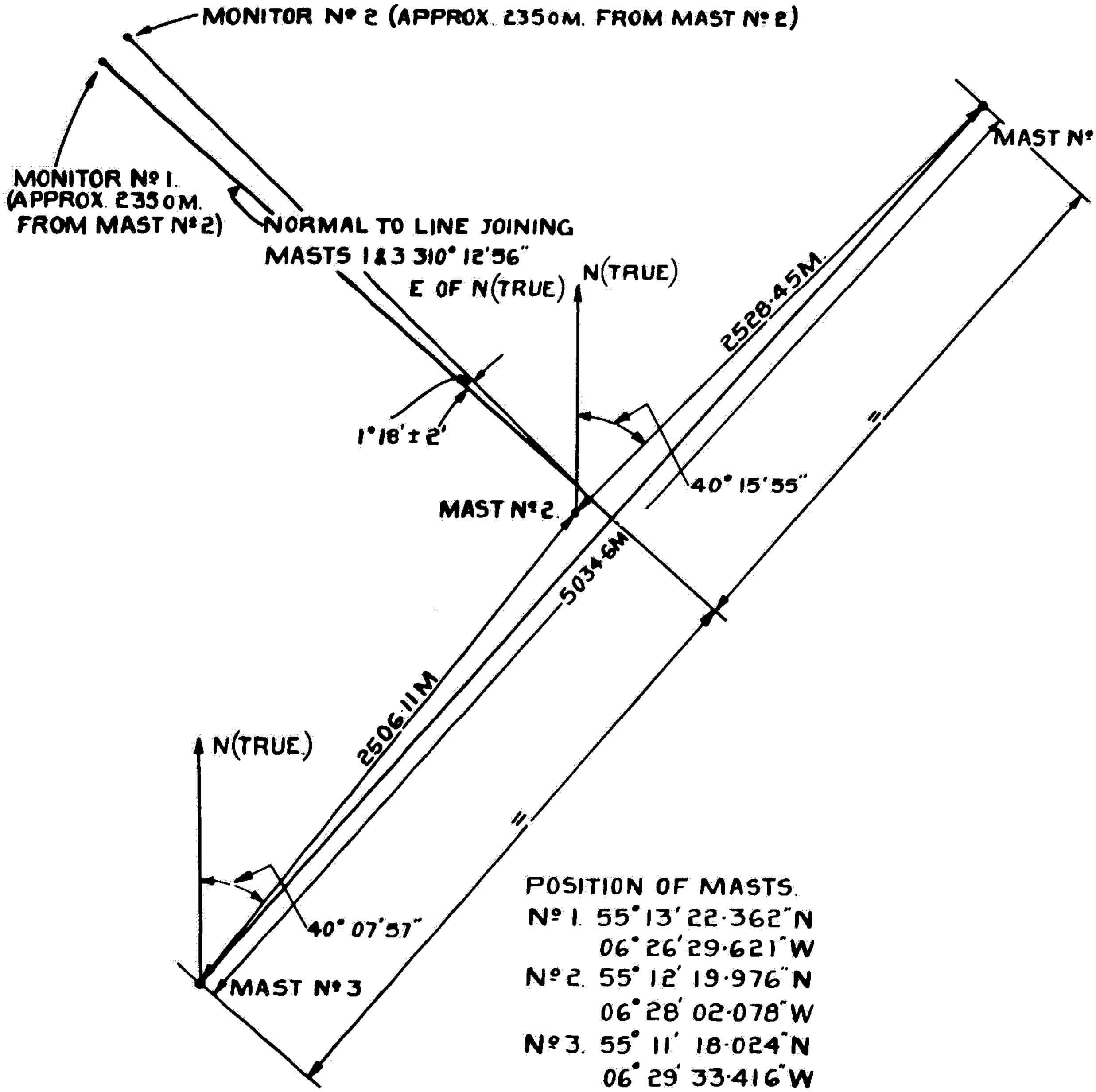


FIG.3 SCHEMATIC OF BUSHMILLS CONSOL STATION.



POSITION OF MASTS.

| | |
|---|---|
| Nº 1. | 55° 13' 22·362" N |
| | 06° 26' 29·621" W |
| Nº 2. | 55° 12' 19·976" N |
| | 06° 28' 02·078" W |
| Nº 3. | 55° 11' 18·024" N |
| | 06° 29' 33·416" W |

POSITION OF CENTRE OF LINE JOINING MASTS 1 & 3

55° 12' 20" N
06° 28' 02" W

HEIGHTS OF MASTS ABOVE SEA LEVEL

| | |
|---|---|
| Nº 1. | 233' |
| Nº 2. | 288' |
| Nº 3. | 256' |

NOT TO SCALE

FIG.4

BUSHMILLS - RECORD OF SURVEY

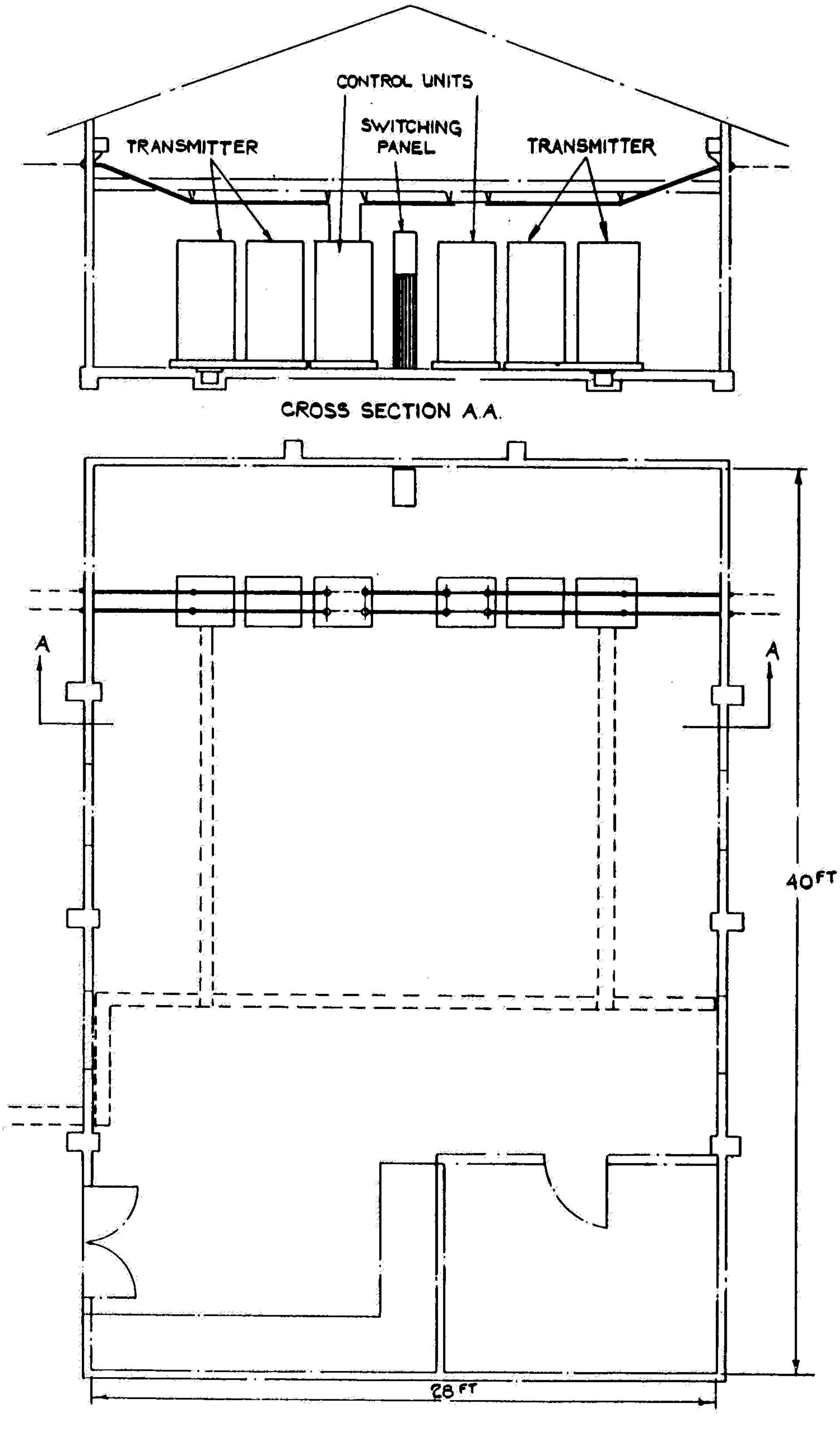


FIG.5. TRANSMITTER BUILDING

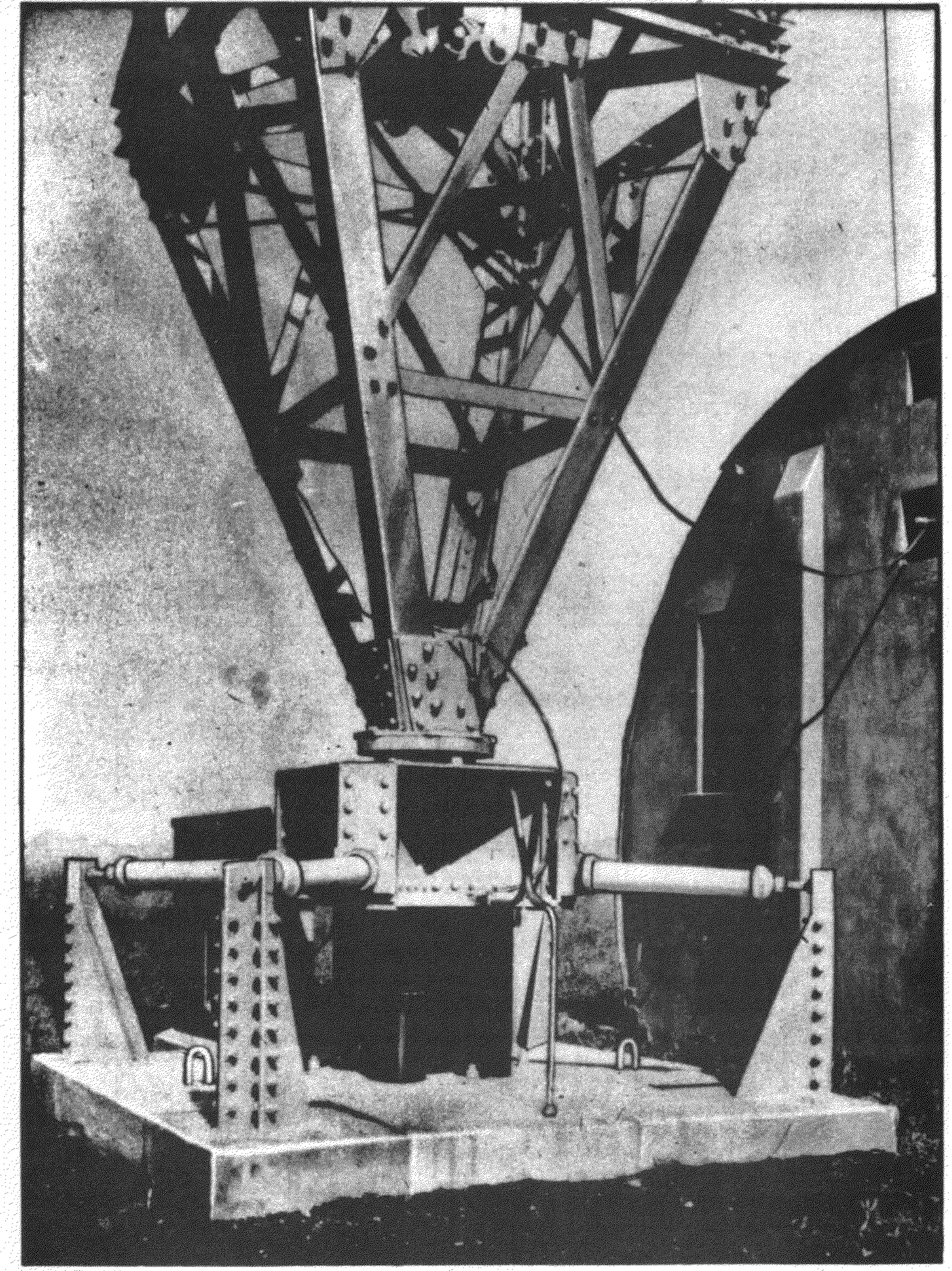
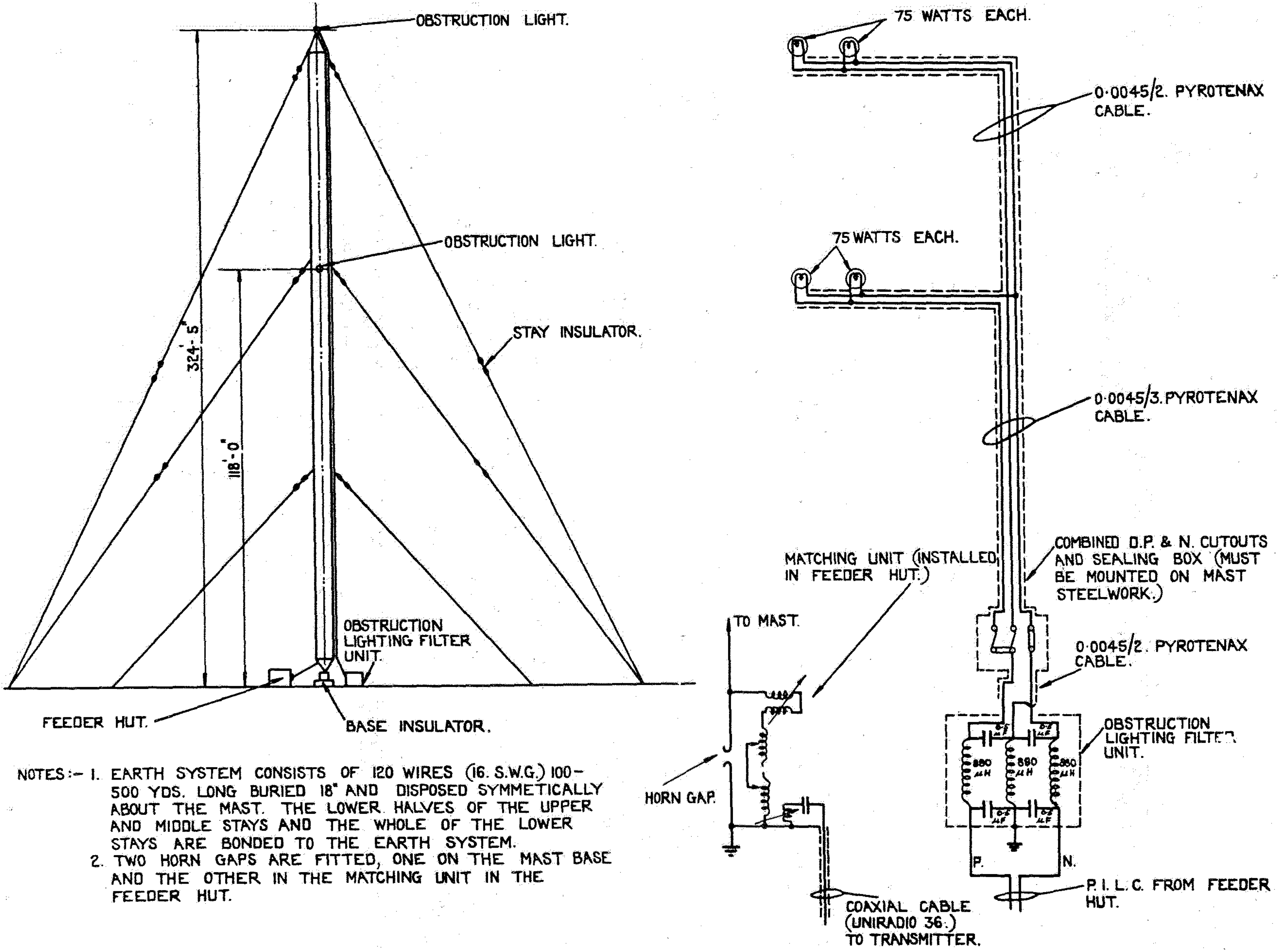


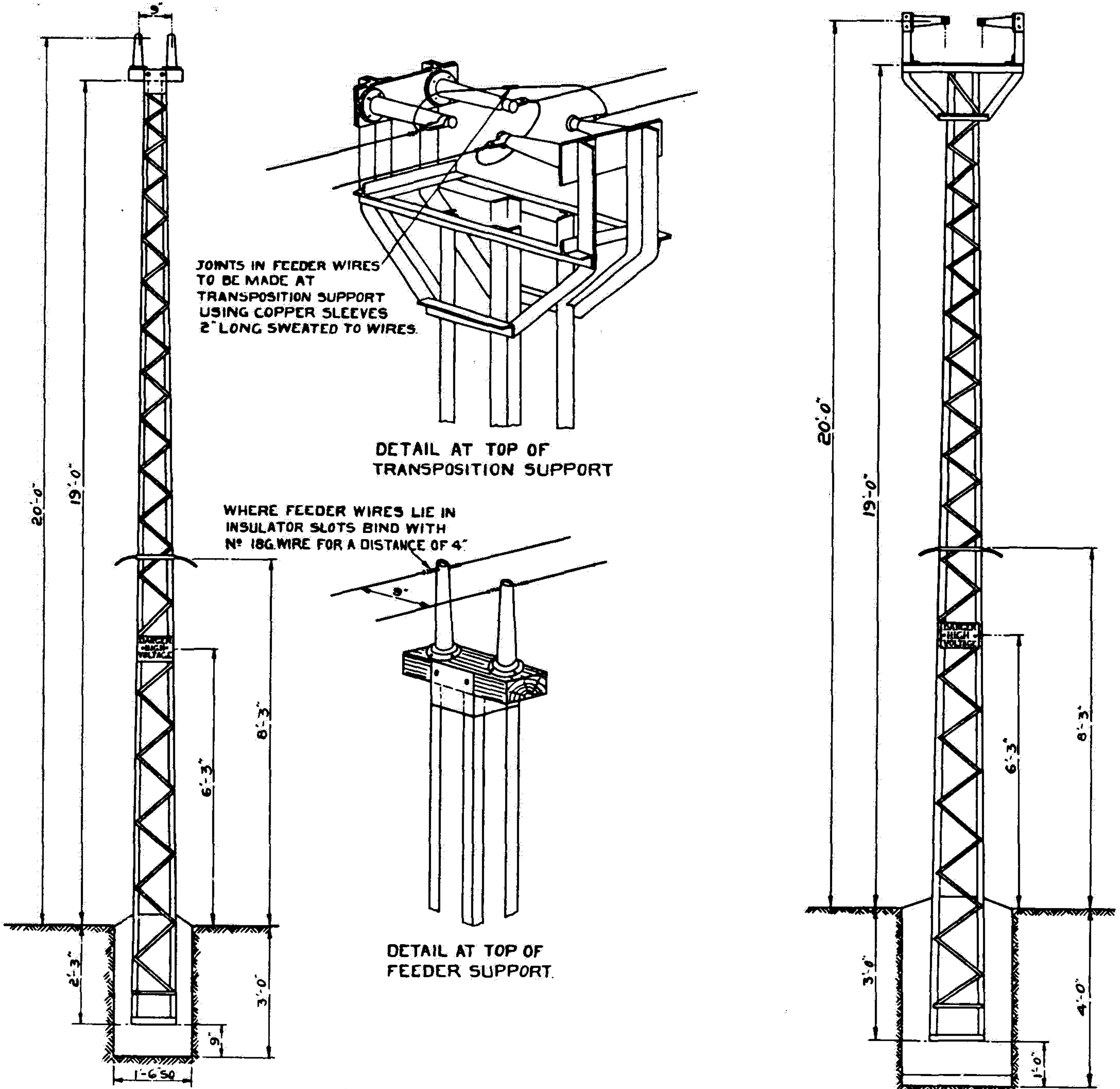
FIG.6. BASE OF MAST RADIATOR



NOTES:- 1. EARTH SYSTEM CONSISTS OF 120 WIRES (16. S.W.G.) 100-500 YDS. LONG BURIED 18" AND DISPOSED SYMMETICALLY ABOUT THE MAST. THE LOWER HALVES OF THE UPPER AND MIDDLE STAYS AND THE WHOLE OF THE LOWER STAYS ARE BONDED TO THE EARTH SYSTEM.

2. TWO HORN GAPS ARE FITTED, ONE ON THE MAST BASE AND THE OTHER IN THE MATCHING UNIT IN THE FEEDER HUT.

FIG.7 SCHEMATIC OF 325FT MAST RADIATOR.



JOINTS IN FEEDER WIRES TO BE MADE AT TRANSPOSITION SUPPORT USING COPPER SLEEVES 2" LONG SWEATED TO WIRES.

DETAIL AT TOP OF TRANSPOSITION SUPPORT

WHERE FEEDER WIRES LIE IN INSULATOR SLOTS BIND WITH Nº 18G WIRE FOR A DISTANCE OF 4"

DETAIL AT TOP OF FEEDER SUPPORT

FEEDER SUPPORT

FIG. 8. FEEDER SUPPORTS.

TRANSPOSITION OR

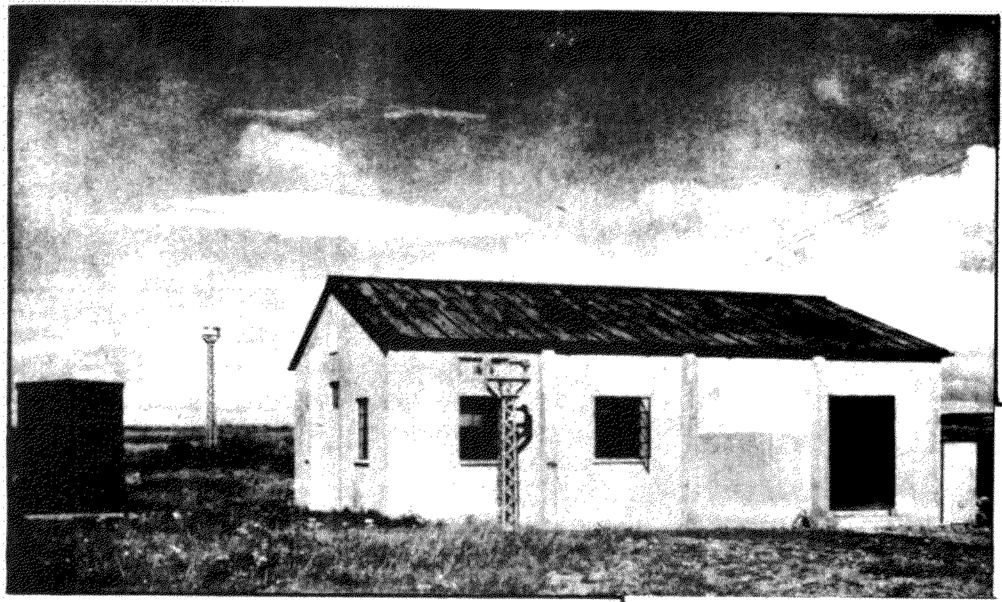


FIG.10. TERMINATION OF OPEN WIRE LINES AT TRANSMITTER BUILDING

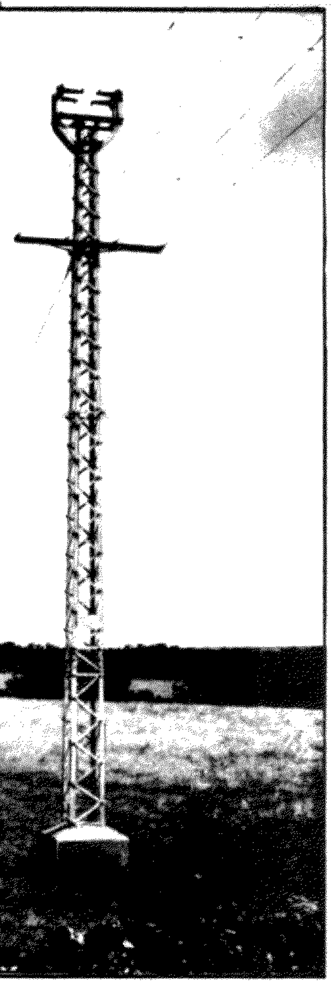


FIG.9. OPEN WIRE TRANSMISSION LINE

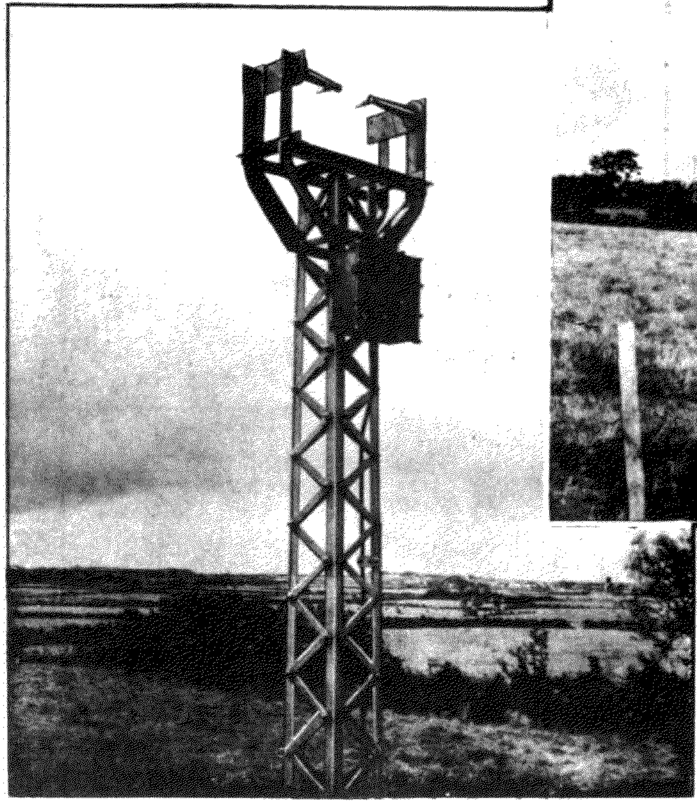


FIG.11. TERMINATION OF OPEN WIRE LINES AT OUTER SITES

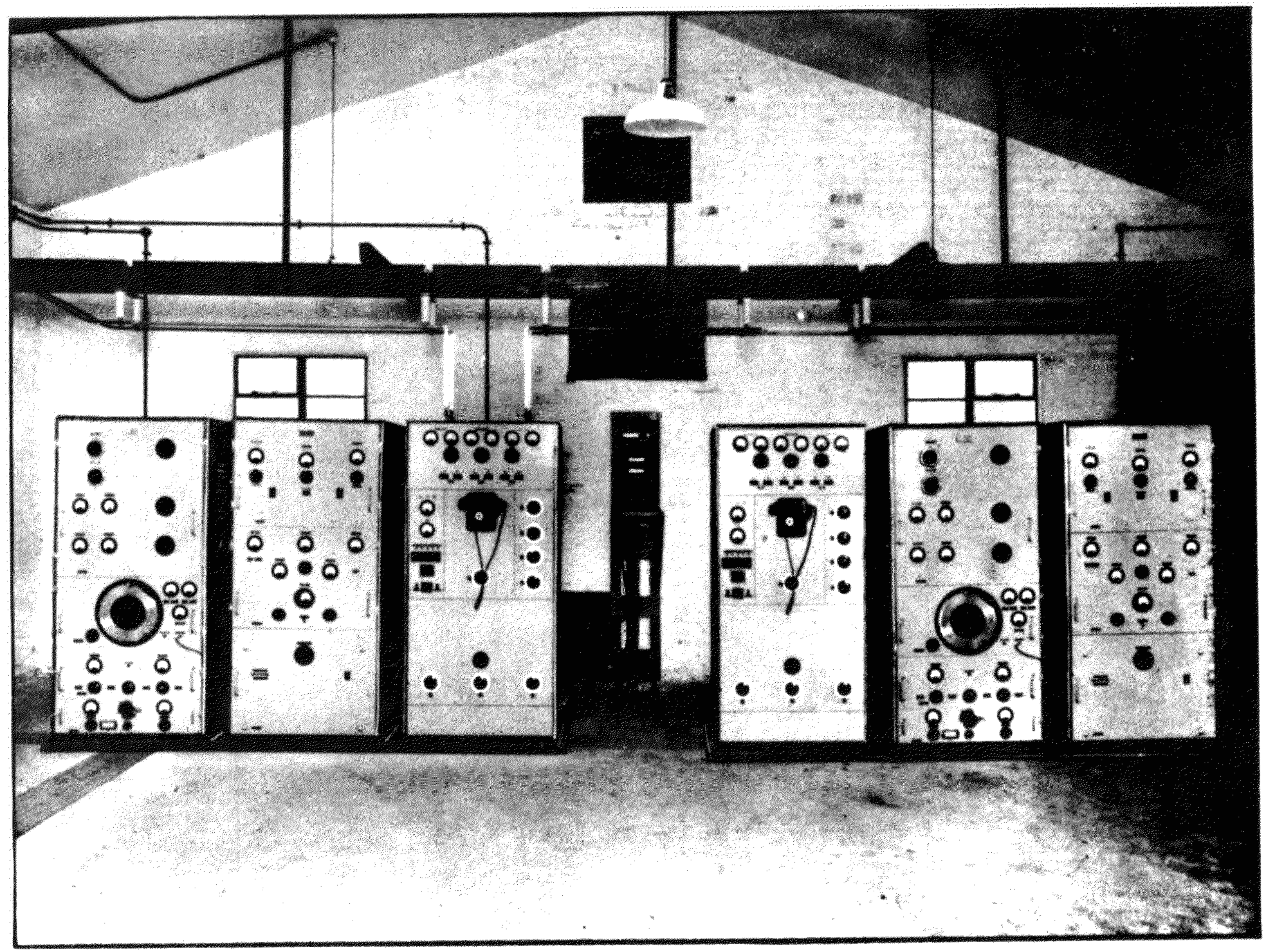


FIG.12. CONSOL TRANSMITTER EQUIPMENT

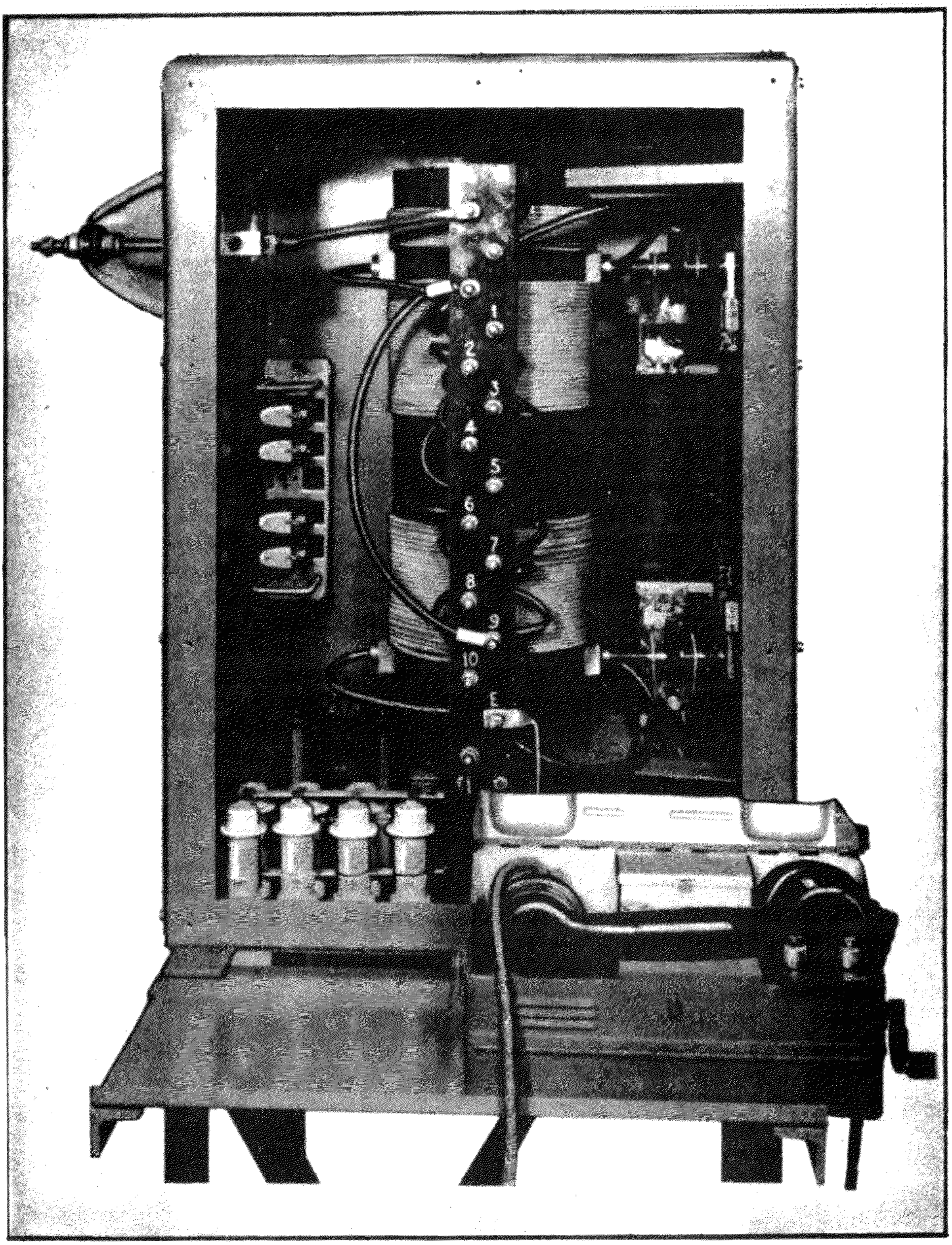
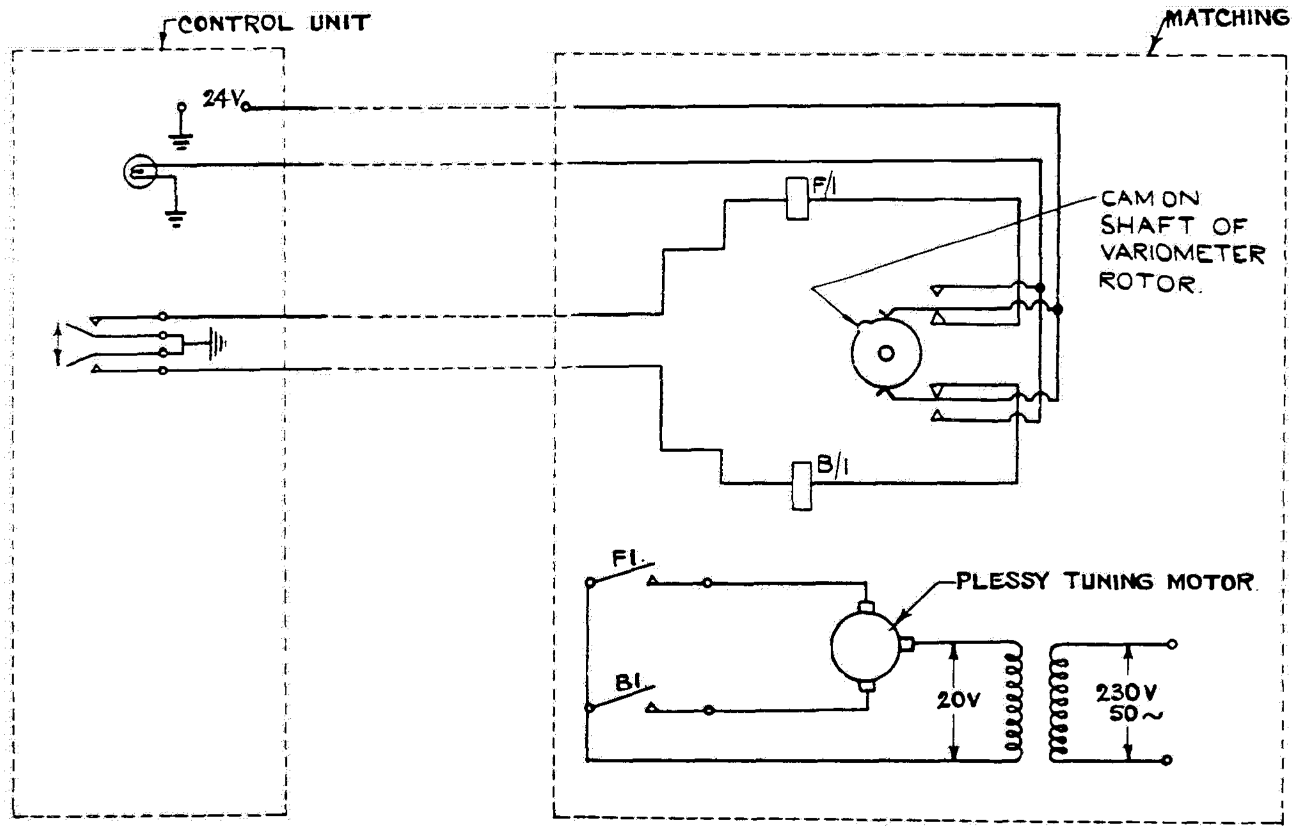


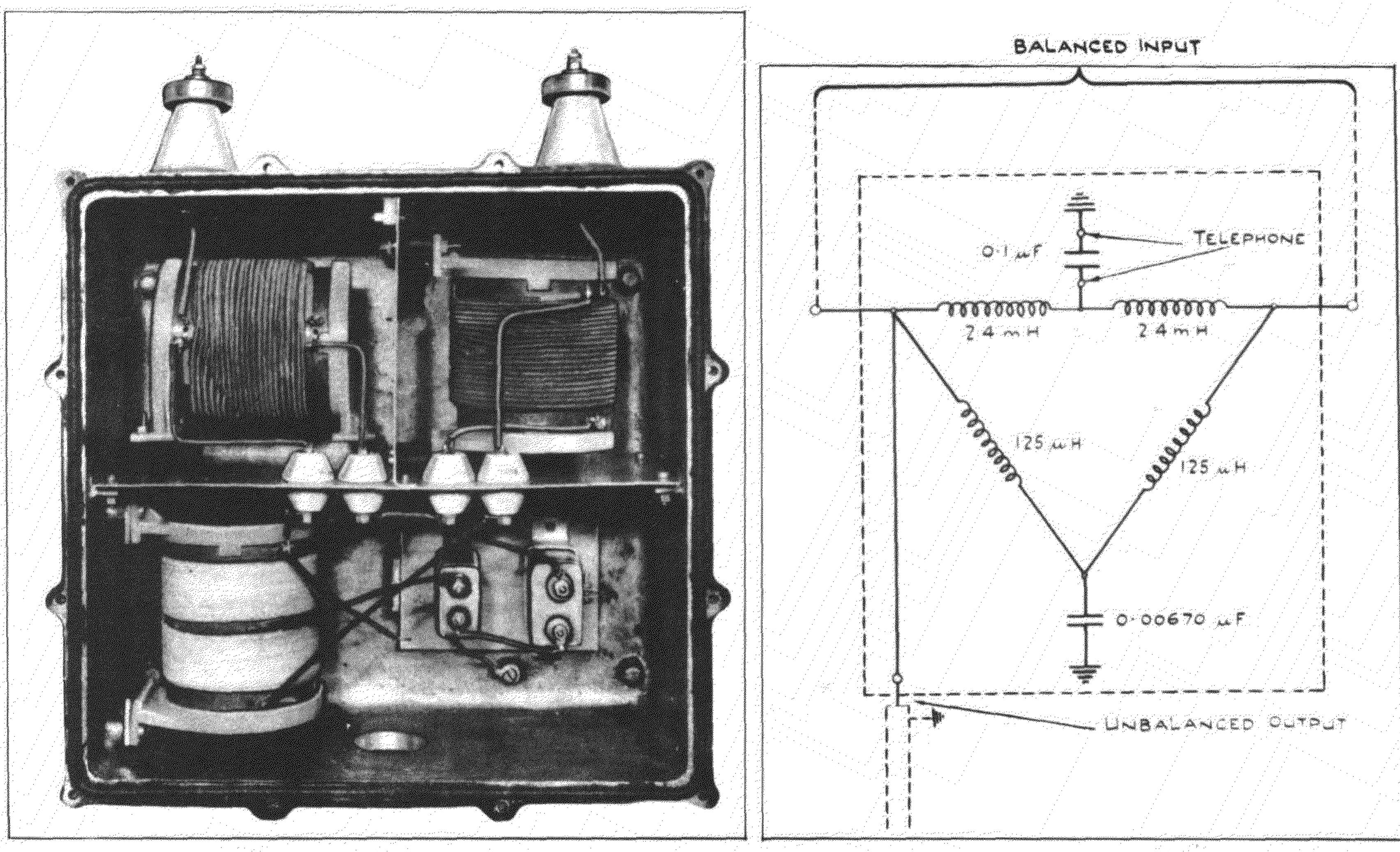
FIG. 13. AERIAL MATCHING UNIT



NOTE:- IDENTICAL CONTROLS PROVIDED FOR COUPLING COIL OF AERIAL MATCHING UNIT.

FIG.14

F.G.R.I. 5416.— SIMPLIFIED SCHEMATIC OF REMOTE CONTROL OF AERIAL MATCHING UNITS.



(a) (b)

FIG. 15. SCHEMATIC OF IMPEDANCE MATCHING UNIT TYPE 202

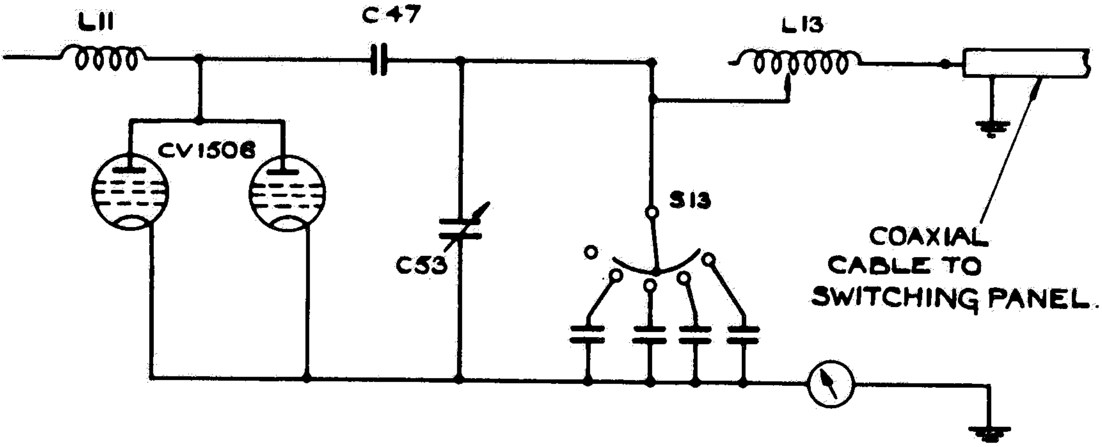
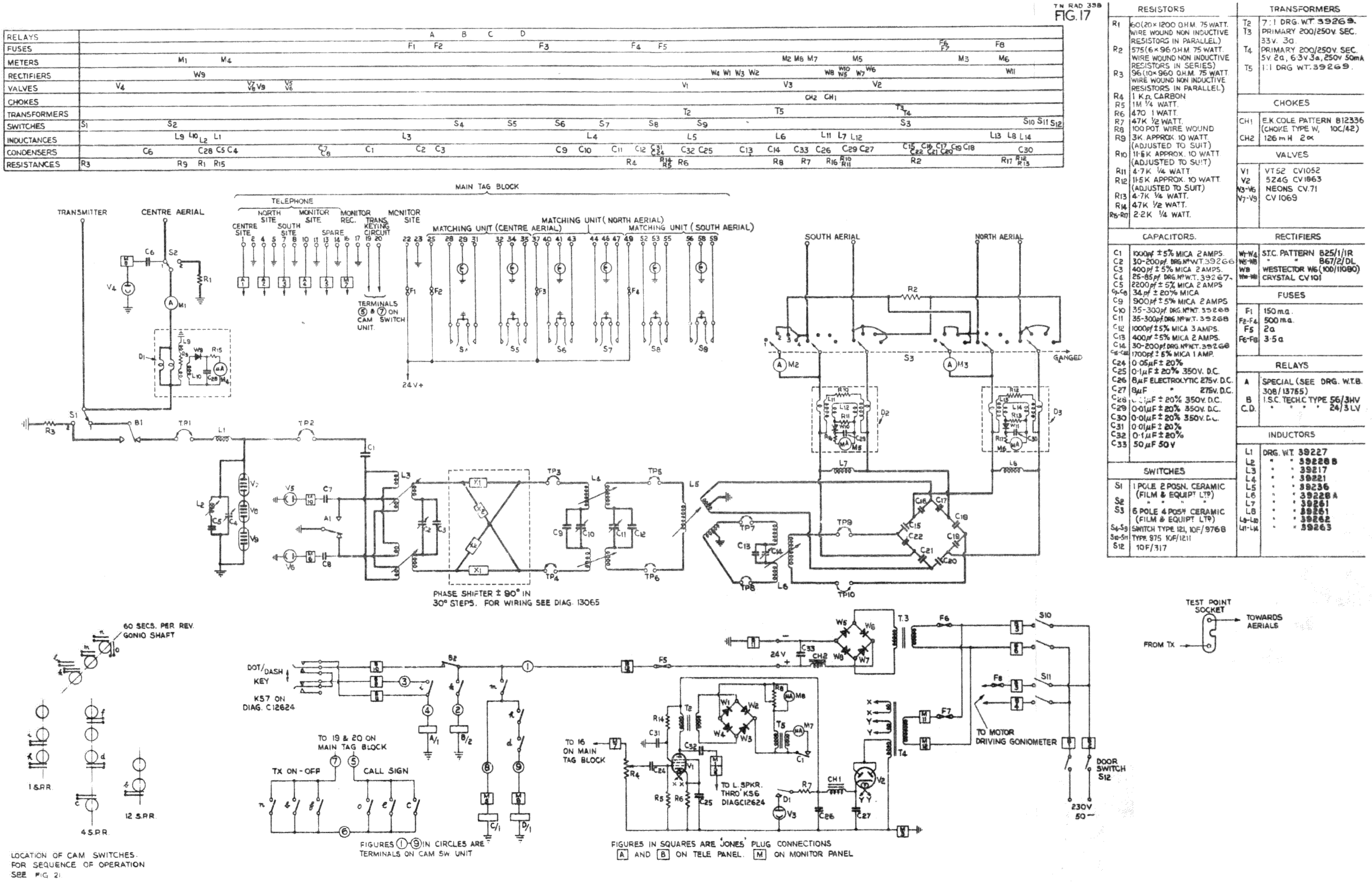


FIG.16

OUTPUT CIRCUIT OF T1412 TRANSMITTER.

T N RAD 398

FIG. 17



LOCATION OF CAM SWITCHES. FOR SEQUENCE OF OPERATION SEE FIG 21

FIGURES ①-⑨ IN CIRCLES ARE TERMINALS ON CAM SW. UNIT

FIGURES IN SQUARES ARE 'JONES' PLUG CONNECTIONS [A] AND [B] ON TELE PANEL. [M] ON MONITOR PANEL

RESISTORS

| | |
|---|---|
| R1 | 60 (20 × 1200 O.H.M. 75 WATT. WIRE WOUND NON INDUCTIVE RESISTORS IN PARALLEL) |
| R2 | 575 (6 × 96 O.H.M. 75 WATT. WIRE WOUND NON INDUCTIVE RESISTORS IN SERIES) |
| R3 | 96 (10 × 960 O.H.M. 75 WATT. WIRE WOUND NON INDUCTIVE RESISTORS IN PARALLEL) |
| R4 | 1 KΩ CARBON |
| R5 | 1M ¼ WATT. |
| R6 | 470 1 WATT. |
| R7 | 47K ½ WATT. |
| R8 | 100 POT. WIRE WOUND |
| R9 | 3K APPROX. 10 WATT. (ADJUSTED TO SUIT) |
| R10 | 11·5K APPROX. 10 WATT. (ADJUSTED TO SUIT) |
| R11 | 4·7K ¼ WATT. |
| R12 | 11·5K APPROX. 10 WATT. (ADJUSTED TO SUIT) |
| R13 | 4·7K ¼ WATT. |
| R14 | 47K ½ WATT. |
| R15-R17 | 2·2K ¼ WATT. |

CAPACITORS.

| | |
|---|---|
| C1 | 1000pf ± 5% MICA 2 AMPS. |
| C2 | 30-200pf. DRG. Nº W.T. 39266 |
| C3 | 400pf ± 5% MICA 2 AMPS. |
| C4 | 25-85pf. DRG. Nº W.T. 39267. |
| C5 | 2200pf ± 5% MICA 2 AMPS |
| C7-C8 | 34pf ± 20% MICA |
| C9 | 900pf ± 5% MICA 2 AMPS |
| C10 | 35-300pf. DRG. Nº W.T. 39268 |
| C11 | 35-300pf. DRG. Nº W.T. 39268 |
| C12 | 1000pf ± 5% MICA 3 AMPS. |
| C13 | 400pf ± 5% MICA 2 AMPS. |
| C14 | 30-200pf. DRG. Nº W.T. 39268 |
| C15-C22 | 1700pf ± 5% MICA 1 AMP. |
| C24 | 0·05μF ± 20% |
| C25 | 0·1μF ± 20% 350V. D.C. |
| C26 | 8μF ELECTROLYTIC 275V. D.C. |
| C27 | 8μF " 275V. D.C. |
| C28 | 0·1μF ± 20% 350V. D.C. |
| C29 | 0·01μF ± 20% 350V. D.C. |
| C30 | 0·01μF ± 20% 350V. D.C. |
| C31 | 0·01μF ± 20% |
| C32 | 0·1μF ± 20% |
| C33 | 50μF 50V |

SWITCHES

| | |
|---|---|
| S1 | 1 POLE 2 POSN. CERAMIC (FILM & EQUIPᵀ LTᴰ) |
| S2 | " " " " |
| S3 | 6 POLE 4 POSᴺ CERAMIC (FILM & EQUIPᵀ LTᴰ) |
| S4-S9 | SWITCH TYPE 121, 10F/9768 |
| S10-S11 | TYPE 975 10F/1211 |
| S12 | 10F/317 |

TRANSFORMERS

| | |
|---|---|
| T2 | 7 : 1 DRG. W.T. 39269. |
| T3 | PRIMARY 200/250V. SEC. 33V. 3a. |
| T4 | PRIMARY 200/250V. SEC. 5V. 2a, 6·3V 3a, 250V 50mA |
| T5 | 1 : 1 DRG. W.T. 39269. |

CHOKES

| | |
|---|---|
| CH1 | E.K. COLE PATTERN B12336 (CHOKE TYPE W, 10C/42) |
| CH2 | 126 m H 2 a |

VALVES

| | |
|---|---|
| V1 | VT52 CV1052 |
| V2 | 5Z4G CV1863 |
| V3-V6 | NEONS CV.71 |
| V7-V9 | CV 1069 |

RECTIFIERS

| | |
|---|---|
| W1-W4 | S.T.C. PATTERN B25/1/1R |
| W5-W8 | " " B67/2/DL |
| W9 | WESTECTOR W6 (100/11080) |
| W10-W11 | CRYSTAL CV101 |

FUSES

| | |
|---|---|
| F1 | 150 m.a. |
| F2-F4 | 500 m.a. |
| F5 | 2a |
| F6-F8 | 3·5a |

RELAYS

| | |
|---|---|
| A | SPECIAL (SEE DRG. W.T.B. 308/13765) |
| B | I.S.C. TECH.C TYPE 56/3HV |
| C.D. | " " " " 24/3LV |

INDUCTORS

| | |
|---|---|
| L1 | DRG. W.T. 39227 |
| L2 | " " 39228 B |
| L3 | " " 39217 |
| L4 | " " 39221 |
| L5 | " " 39236 |
| L6 | " " 39228 A |
| L7 | " " 39261 |
| L8 | " " 39261 |
| L9-L10 | " " 39262 |
| L11-L14 | " " 39263 |

FIG. 17. CONTROL UNIT TYPE 362 REF. Nº 10LB/398 CIRCUIT DIAGRAM

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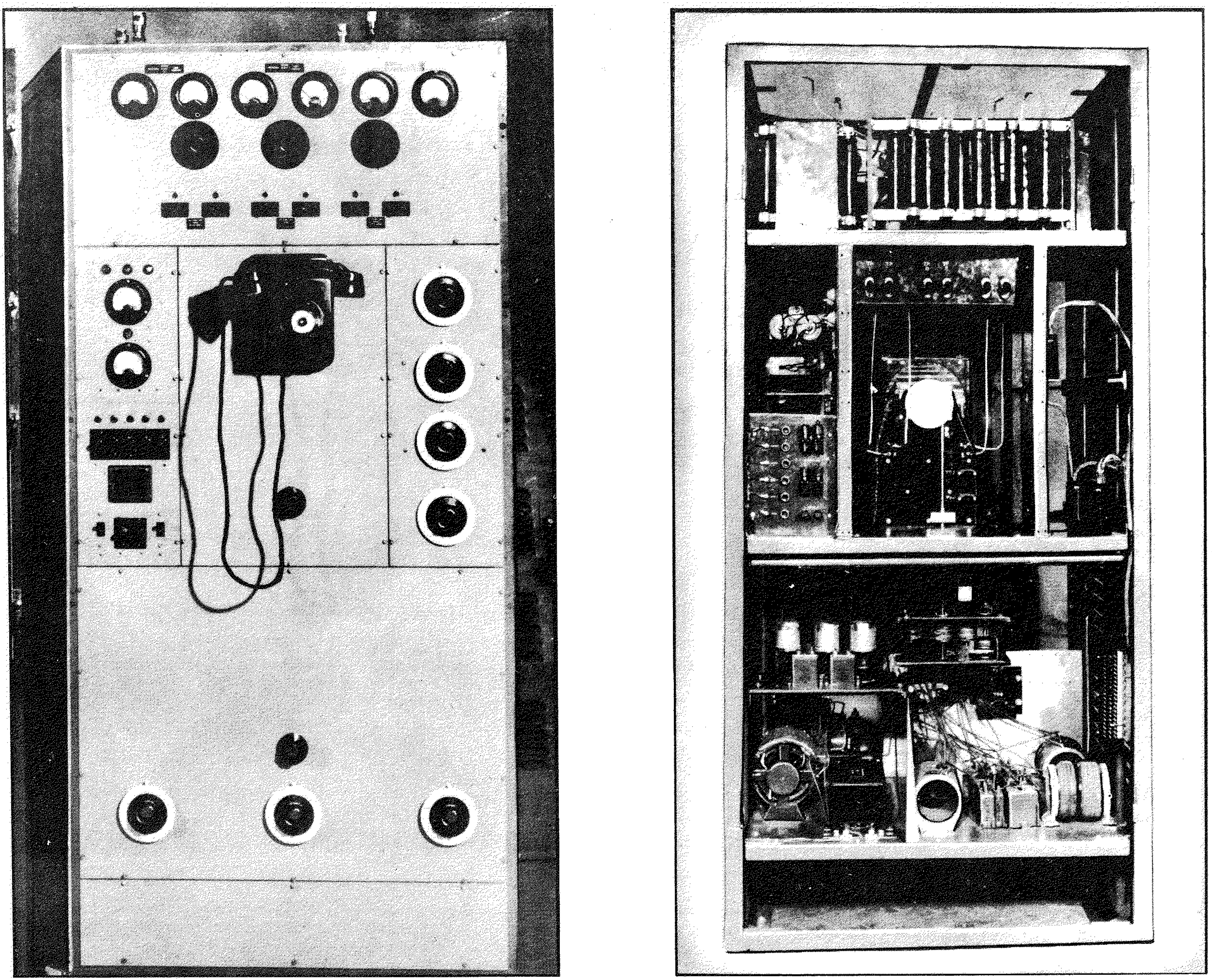
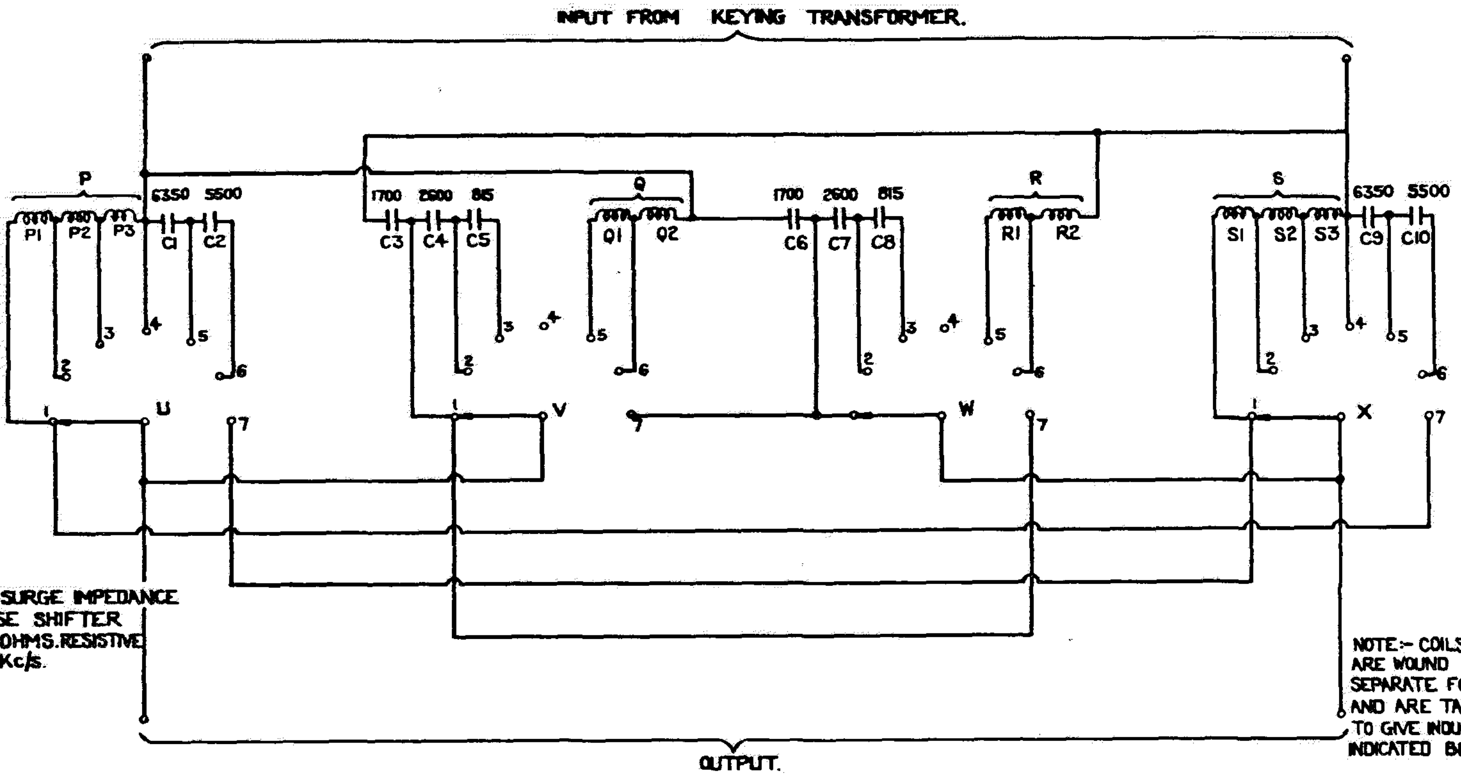


a

b

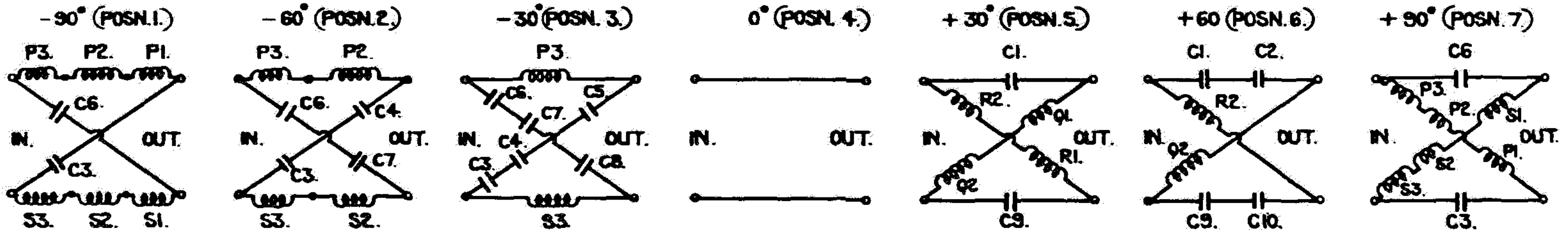
FIG. 18. CONTROL UNIT



NOTE:- SURGE IMPEDANCE OF PHASE SHIFTER IS 334 OHMS.RESISTIVE AT 280 Kc/s.

NOTE:- COILS P,Q,R,S ARE WOUND ON SEPARATE FORMERS AND ARE TAPPED TO GIVE INDUCTANCES INDICATED BELOW.

SIMPLIFIED SCHEMATICS OF PHASE SHIFTER FOR VARIOUS POSITIONS OF SWITCH.



P1.+ P2.+ P3. = 190μH.
S1.+ S2.+ S3. = 190μH.
C3. = C6. = 1700μμF.

P2.+P3. = 110μH.
S2.+S3. = 110μH.
C3.C4. (SERIES) 1030μμF.
C6.C7. (SERIES) 1030μμF.

P3. = 51μH.
S3. = 51μH.
C3.C4.C5. (SERIES) 455μμF.
C6.C7.C8. (SERIES) 455μμF.

Q1.+ Q2. = 708μH.
R1.+R2. = 708μH.
C1. = 6350μμF.
C9. = 6350μμF.

Q2. = 328μH.
R2. = 328μH.
C1.C2. (SERIES) 2950μμF.
C9.C10. (SERIES) 2950μμF.

P1.+P2.+P3. = 190μH.
S1.+ S2.+ S3. = 190μH.
C3. = 1700μμF.
C6. = 1700μμF.

FIG.19

CONTROL UNIT TYPE 362. WIRING OF PHASE SHIFTER.

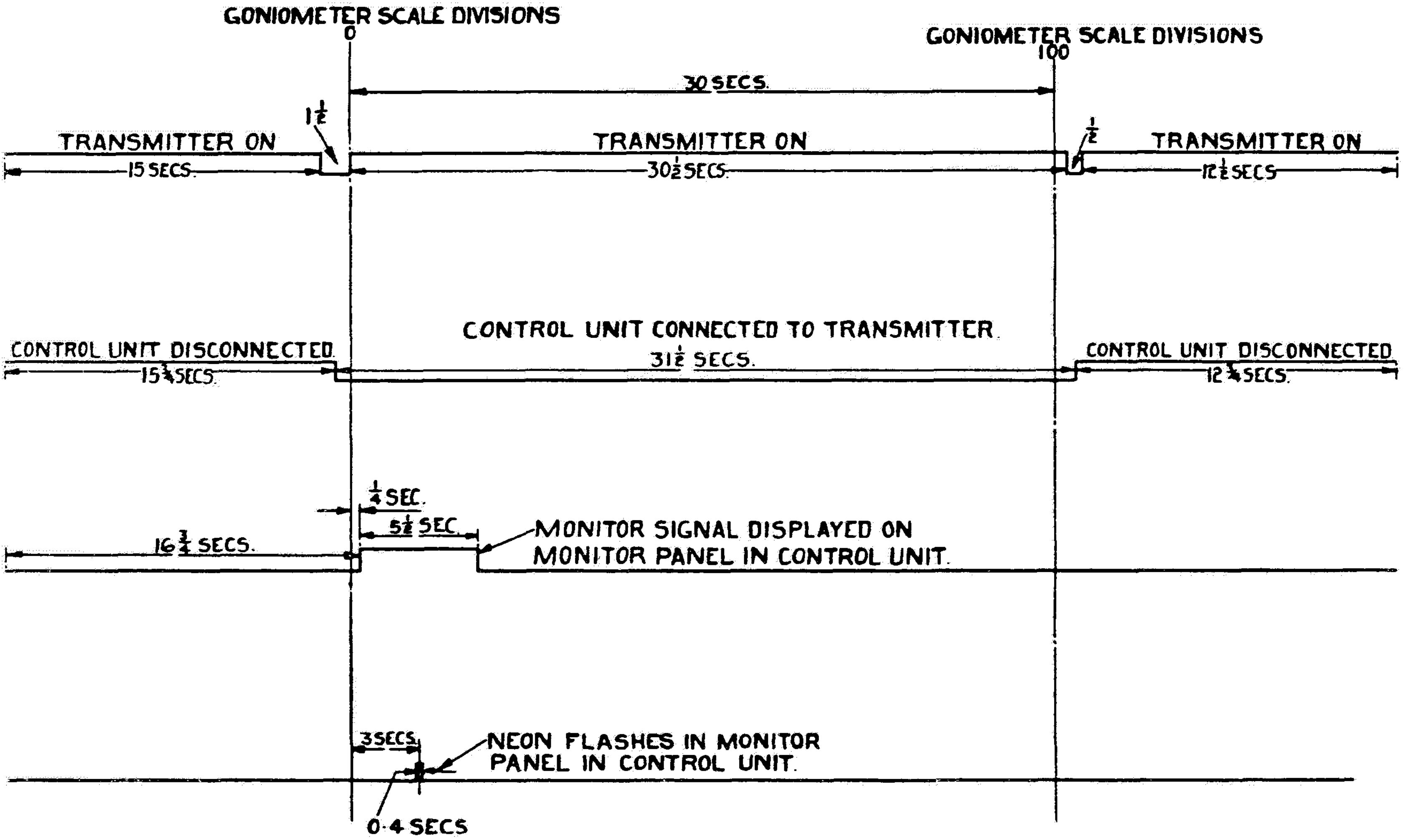
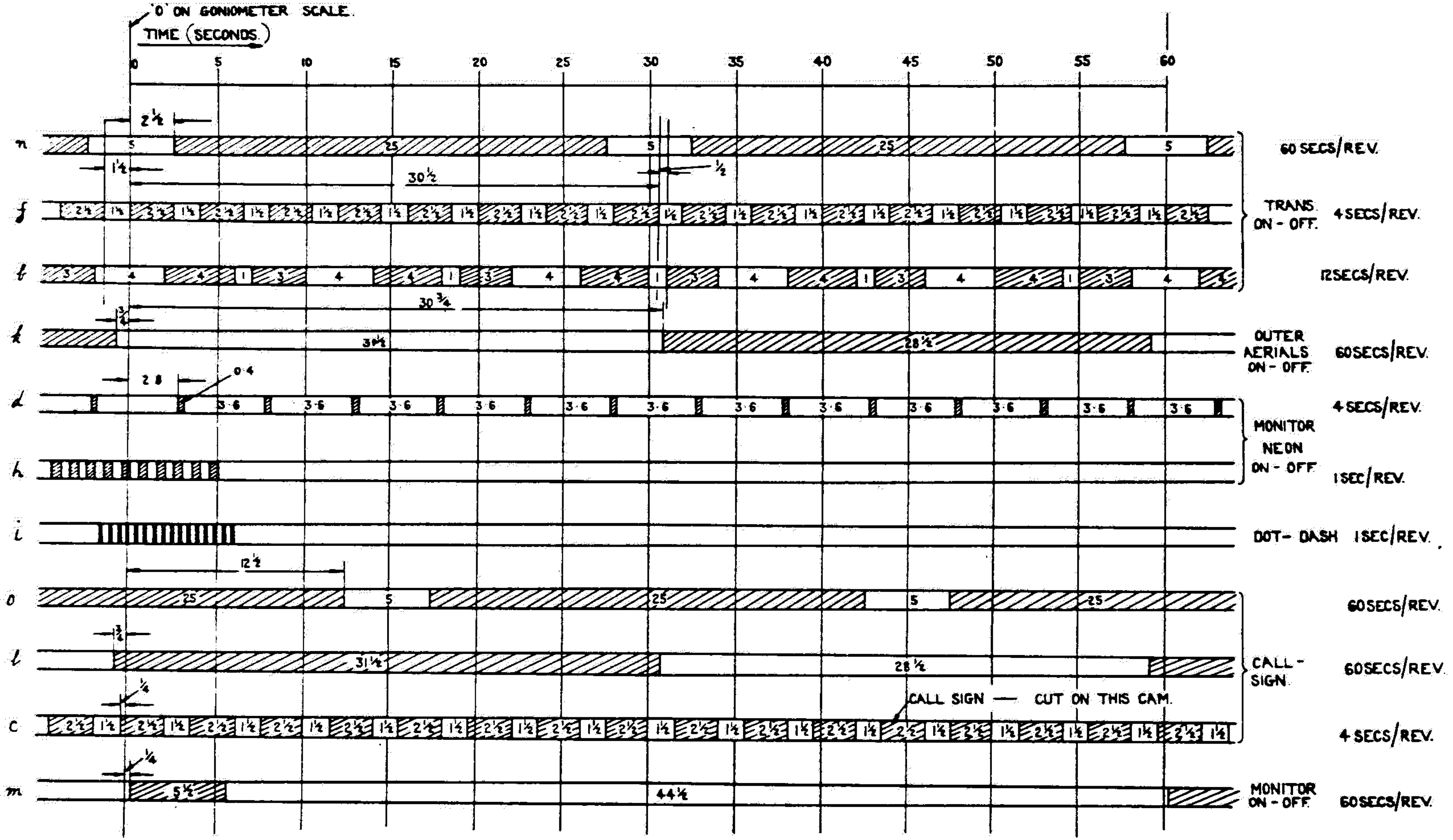


FIG. 20. KEYING CYCLE



NOTES:- 1. HATCHED RECTANGLES INDICATE SPRINGS CLOSED.
2. FOR WIRING OF SPRINGS SEE DIAG. 12785B.

FIG.21 CONTROL UNIT TYPE 362 — SEQUENCE OF OPERATION OF CAMS.

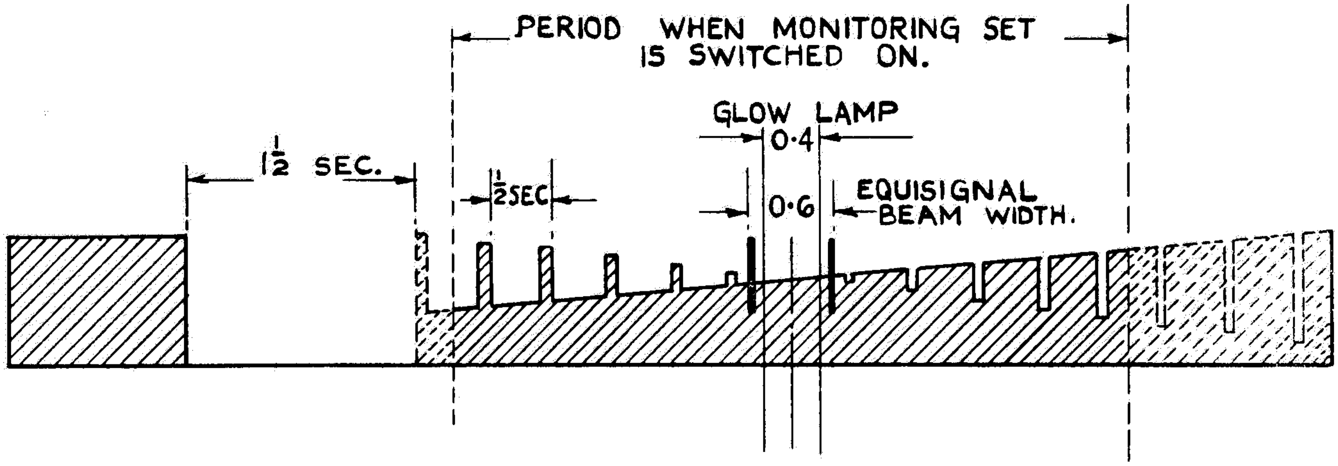


FIG. 22. MONITOR SIGNALS.

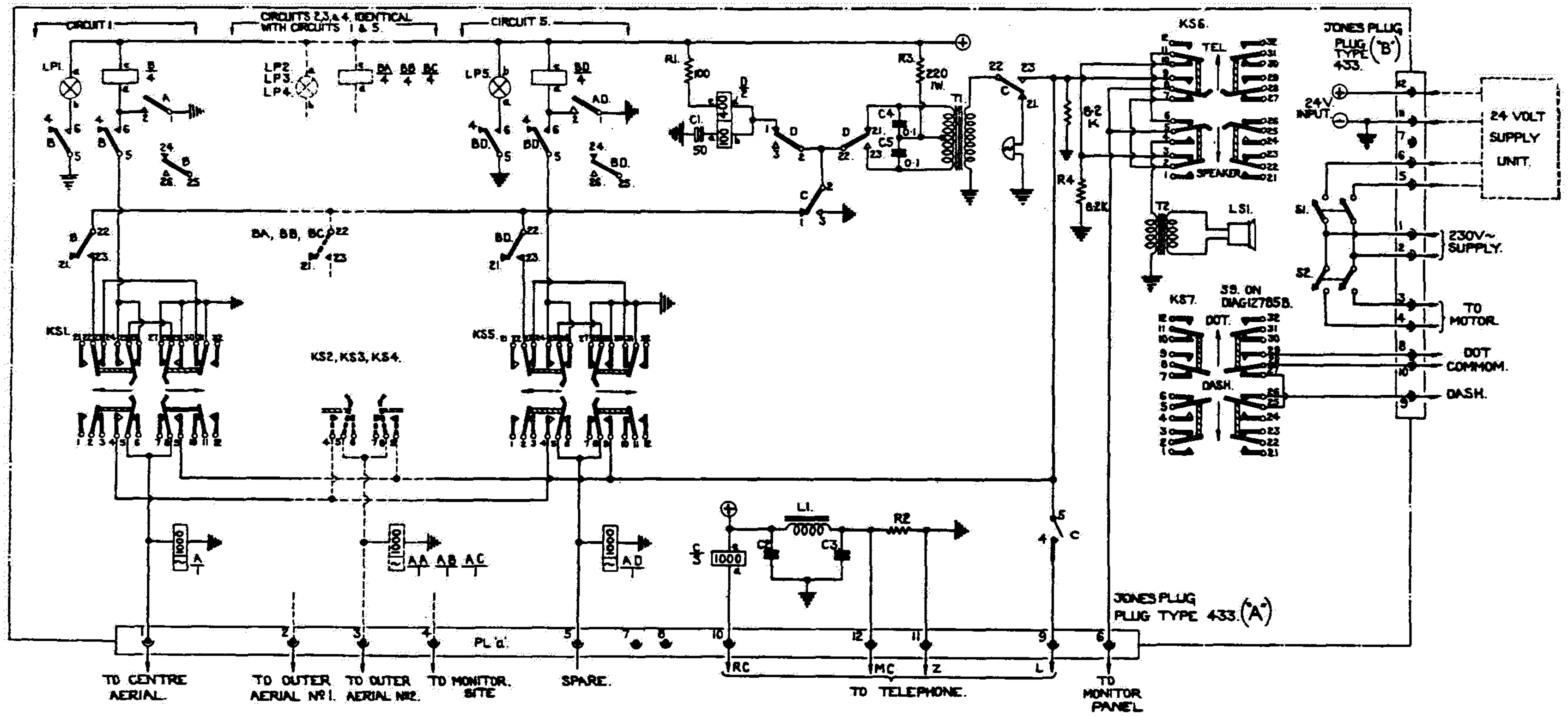
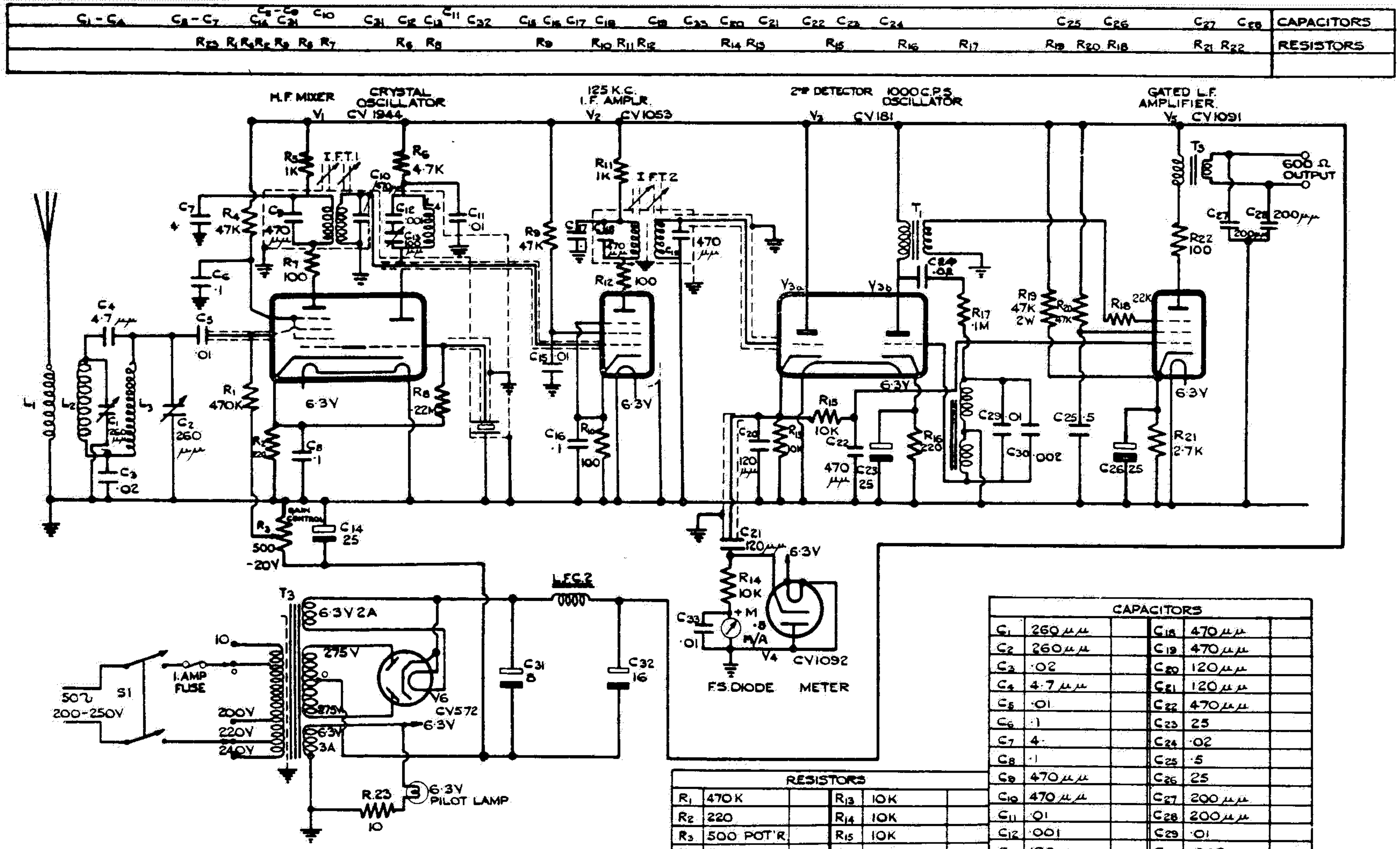
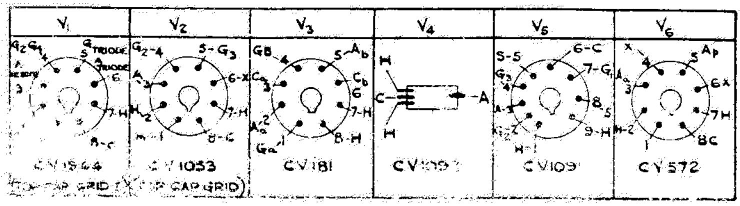


FIG.23 PANEL TYPE 564. (TELEPHONE) REF. Nº 10DB/2080. — CIRCUIT DIAGRAM.





RESISTORS

| | | | | | |
|---|---|---|---|---|---|
| R1 | 470K | | R13 | 10K | |
| R2 | 220 | | R14 | 10K | |
| R3 | 500 POT'R. | | R15 | 10K | |
| R4 | 47K | | R16 | 220 | |
| R5 | 1K | | R17 | ·1M | |
| R6 | 4·7K | | R18 | 22K | |
| R7 | 100 | | R19 | 47K 2W | |
| R8 | ·22M | | R20 | 47K | |
| R9 | 47K | | R21 | 2·7K | |
| R10 | 100 | | R22 | 100 | |
| R11 | 1K | | R23 | 10 | |
| R12 | 100 | | R24 | | |

ALL ½ W. UNLESS OTHERWISE STATED

CAPACITORS

| | | | | | |
|---|---|---|---|---|---|
| C1 | 260μμ | | C18 | 470μμ | |
| C2 | 260μμ | | C19 | 470μμ | |
| C3 | ·02 | | C20 | 120μμ | |
| C4 | 4·7μμ | | C21 | 120μμ | |
| C5 | ·01 | | C22 | 470μμ | |
| C6 | ·1 | | C23 | 25 | |
| C7 | 4· | | C24 | ·02 | |
| C8 | ·1 | | C25 | ·5 | |
| C9 | 470μμ | | C26 | 25 | |
| C10 | 470μμ | | C27 | 200μμ | |
| C11 | ·01 | | C28 | 200μμ | |
| C12 | ·001 | | C29 | ·01 | |
| C13 | 100μμ | | C30 | ·002 | |
| C14 | 25 | | C31 | 8 | |
| C15 | ·01 | | C32 | 16 | |
| C16 | ·1 | | C33 | ·01 | |
| C17 | ·1 | | C34 | | |

FIG. 24. RECEIVER, TYPE R.1903.

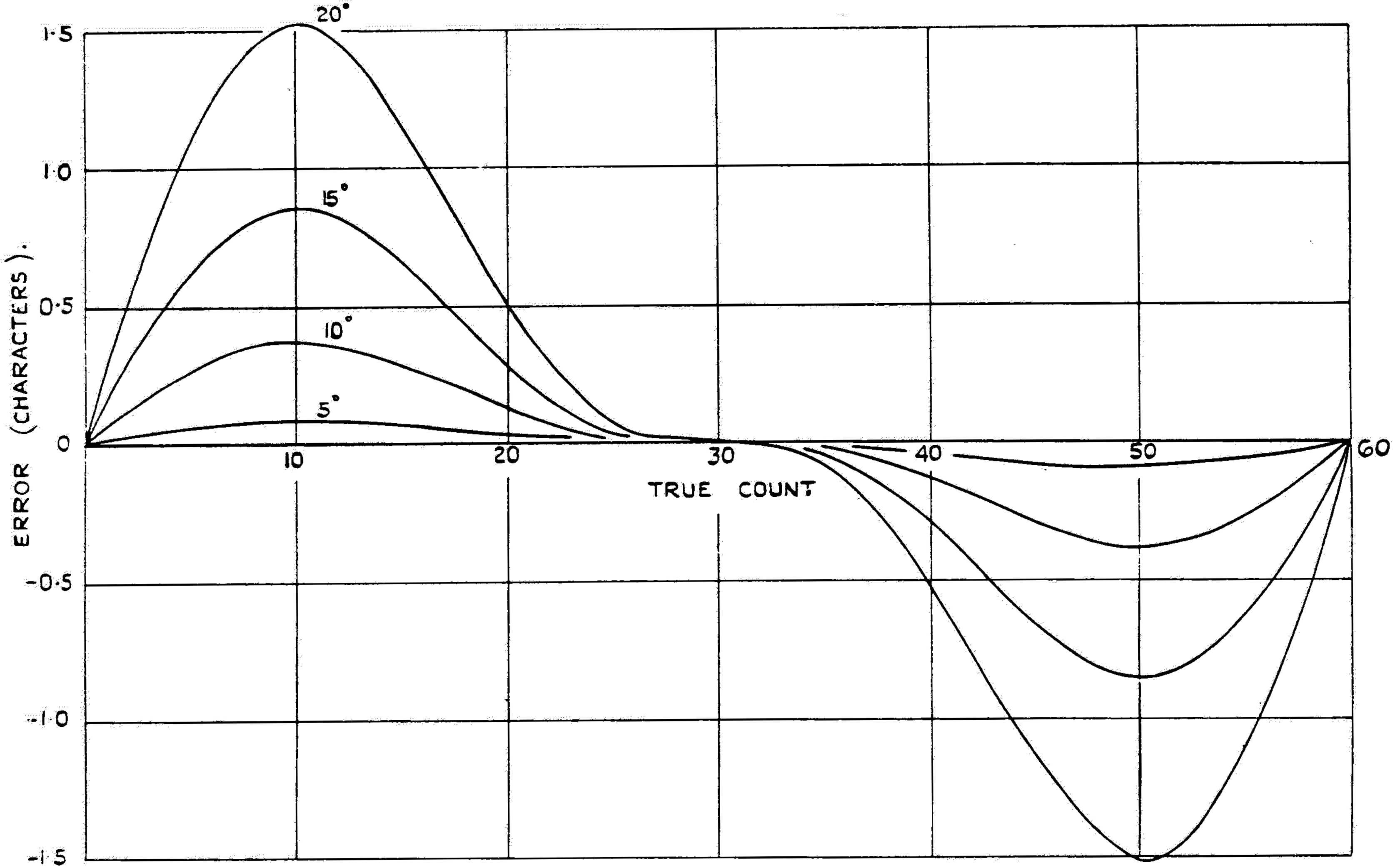


FIG. 25. ERROR OF COUNT DUE TO ERROR IN 90° PHASE SHIFTER.

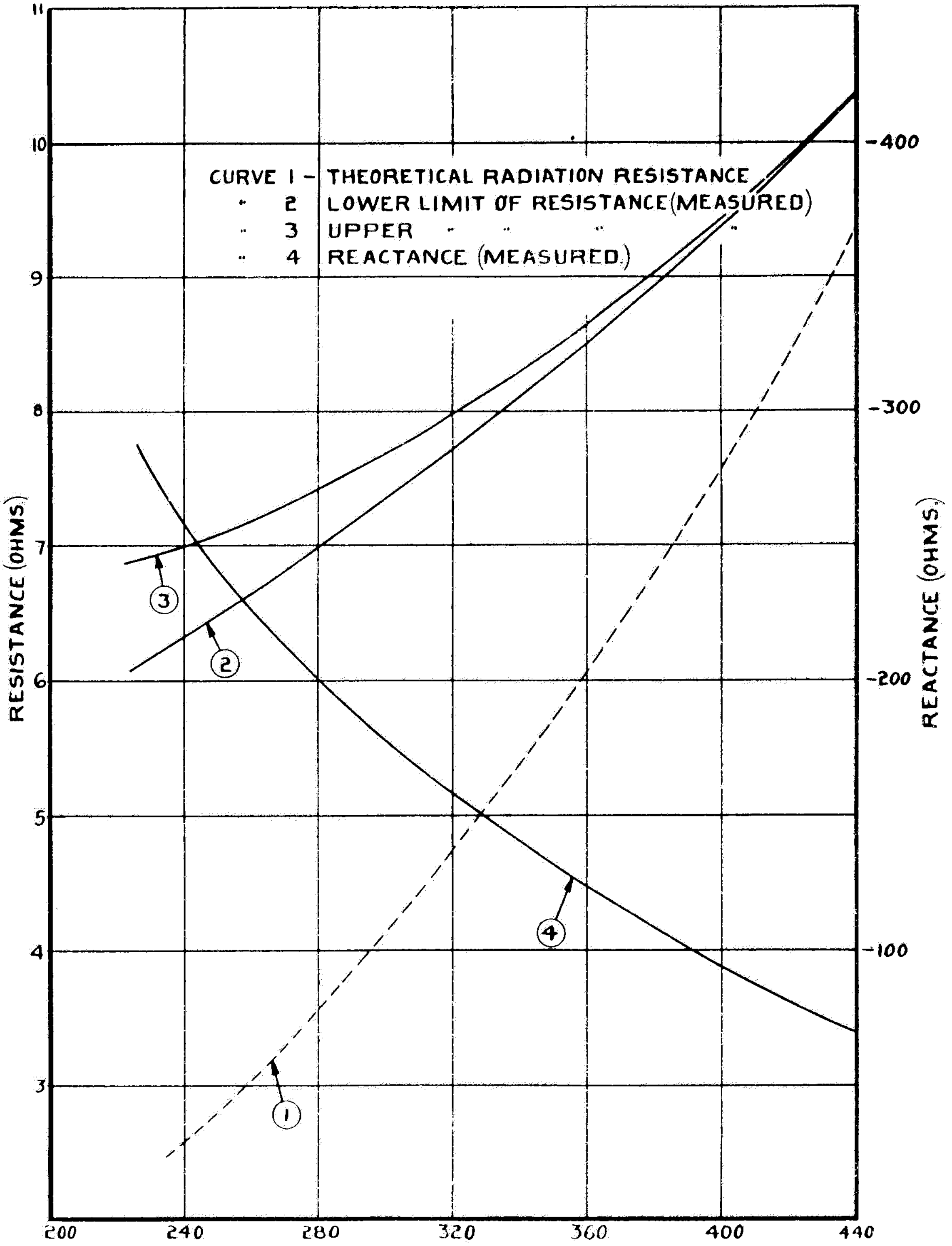


FIG.26

BUSHMILLS – IMPEDANCE OF 325FT. VERTICAL RADIATOR (No. 1 SITE.)

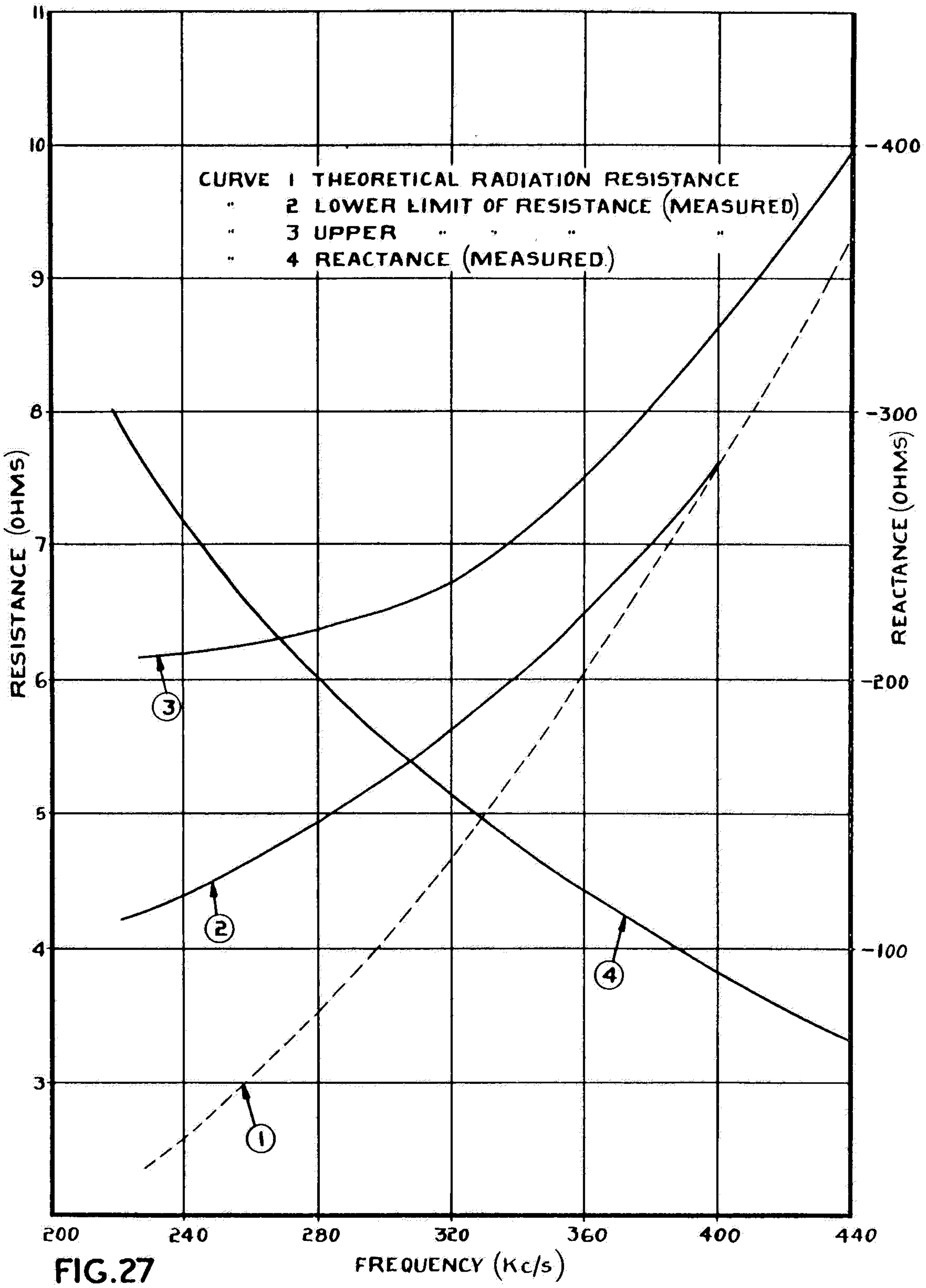


FIG.27
BUSHMILLS – IMPEDANCE OF 325FT. VERTICAL RADIATOR (Nº. 2 SITE)

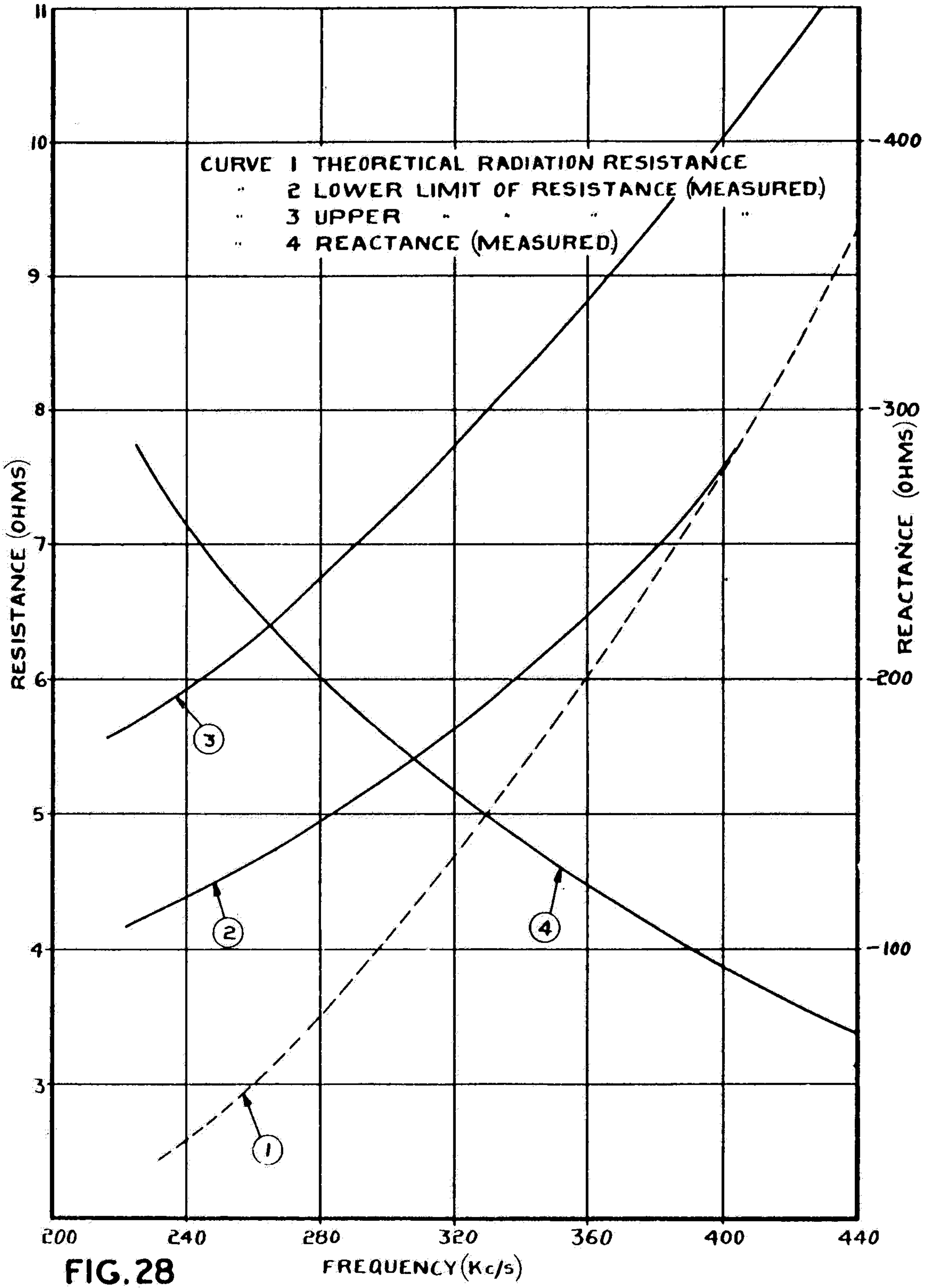


FIG. 28

BUSHMILLS – IMPEDANCE OF 325FT. VERTICAL RADIATOR (No. 3 SITE.)

# AN INVESTIGATION OF THE PERFORMANCE OF THE TWO AERIAL CONSOL SYSTEM

Royal Aircraft Establishment, Farnborough

(Technical Note No. Rad.472 - February, 1950)

by

A.H. Brown, M.Sc., A.M.I.E.E. and R.A.G. Cooper

## Summary

The report briefly describes the results of some tests carried out to determine the extent to which the two aerial Consol system is subject to key clicks in the vicinity of the equisignals.

Experiments have been carried out which show that it is practicable to replace the open wire feeders of a two or three aerial system by V.H.F. radio links, M.F. amplifiers being located adjacent to the mast radiators.

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## List of Illustrations

# AN INVESTIGATION OF THE PERFORMANCE OF THE TWO AERIAL CONSOL SYSTEM

## 1.- INTRODUCTION

Although it has been established that Consol can provide a useful long range fixing service, it appears that the capital cost of the ground installation has been one of the principal factors preventing extension of the existing coverage for civil use. Any means of reducing the cost to an appreciable extent are therefore worth investigation. A few experiments have been carried out by the R.A.E. during the last two years. It has not been possible to devote sufficient time to the matter to carry out the investigations as thoroughly as the authors would wish, but it is thought that the results are worth recording for the benefit of those considering the adoption of Consol.

## 2.- POSSIBILITIES OF THE TWO AERIAL SYSTEM

### 2.1.- General

A report was published in 1945 describing a two aerial Consol system which had subtantially the same characteristics as the three aerial form, but required only half the base line. It was pointed out, however, that the equisignals of the system would be likely to be masked by key-clicks, although, as will be shown later, not for the reason given in the report. The reduced cost and site area are attractive features of the system and it was decided to make use of a short period in January 1948 when the Bushmills station was out of service to carry out some practical tests.

### 2.2.- Practical Tests

With the co-operation of the Ministry of Civil Aviation, the Bushmills installation was converted temporarily to a two aerial system and arrangements were made for counts to be taken at twelve ground stations from Hull to Farnborough, one on the Isle of Man and one in Northern Ireland. It is difficult to devise a method of measurement of a key-click and reliance had to be placed on the judgement of the observers as to the quality of transmission. However from the practical point of view, the presence of key clicks is not important provided that they have no effect on the accuracy of count.

In so far as quality of transmission is concerned, the trial was inconclusive, four observers reporting good transmissions, three doubtful and five reported poor transmissions. It was not practicable to set up the two-aerial system correctly as regards orientation of pattern, so that the systematic errors at each monitoring station are not known. The complete tabulated counts for each station are not available at the R.A.E., so that it has not been possible to show how the spread of error of count compares with the standard deviation of 0.6 characters which is applicable to observations of the normal three aerial system at a fixed receiver. The mean counts for each station are however available and would ideally show a constant systematic error referred to the counts computed for a correctly aligned system. From other extensive observations it is known that terrain effects cause systematic errors varying rapidly from place to place. Taking observations over a very large area, the standard deviation has been shown to increase from 0.6 characters due to monitoring error alone to 1.5 characters due to the effect of these systematic errors. The standard deviation of the mean errors in the case of the observations of the two-aerial system was found to be 3 characters. Unfortunately the transmissions had to be made at dusk, so that the increased standard deviation may be at least partly due to sky wave rather than uncertain location of the equisignal as a result of key-clicks.

## 2.3.- Electronic Keyer

In the case of the three-aerial system, keying is achieved by reversing the phase of the currents fed to the outer aerials with respect to that in the centre aerial. The moving arm of the switch used for this purpose does not make contact with either fixed contact for a few milliseconds so that momentary changes of signal level may give rise to a key-click. The equisignal bearing however corresponds to a null in the polar pattern of the outer aerials, so that the signal at the receiver is produced by the centre aerial alone. Thus the equisignal is not masked by key-clicks.

In the case of the two-aerial system, one of the aerials radiates continuously. Keying is achieved by feeding the second aerial at either +90° or -90° of phase with respect to the first aerial. The method of operation of the system will be clear from Fig.1 which shows vector diagrams for the first sector on each side of the right bisector of the base line. Consider first the vector diagram on the right bisector of AB. Vector A represents the field due to aerial A, which radiates continuously. Vector B is the field due to aerial B and has the same magnitude as vector A. Its phase is advanced by 90° with respect to vector A for the duration of a dot and retarded by 90° for the duration of a dash. Thus, the magnitudes of the resultant received signal for the duration of a dot and a dash are the same, so that the right bisector of AB is an equi-signal.

Proceeding anti-clockwise from the right bisector of AB, and referring phases to the centre of AB, the phase of vector A is advanced while that of vector B is retarded. The resultant field for the duration of a dot is greater than that for the duration of a dash, so that dots will predominate in the received signal. Proceeding further anti-clockwise, vectors A & B are at right angles once more, corresponding to another equisignal. In a similar way, dashes predominate in the signal received on bearings clockwise with respect to the right bisector of AB. In addition to the dot-dash keying, the pattern as a whole is made to rotate, as in the case of the three-aerial system, by applying a phase shift proportional to time to the current feeding either one of the aerials.

It will be noted that two discontinuities occur at the equisignal which may give rise to key clicks (a) the break in transmission from aerial B while the keying operation takes place and (b) a shift of phase of the resultant received signal by 90°. In order to reduce the break of transmission, the electronic-keyer shown in schematic form in Fig.2 was made up. A keying trigger is produced by a motor operated cam which momentarily closes a pair of contacts. The trigger operates a transitron flip-flop generating a square pulse, the length of which can be varied by adjustment of the time constant of the flip-flop thereby altering the dot-dash ratio. The square wave from the flip-flop is fed into a phase splitter so that positive and negative square waves are fed into the suppressor grids of $V^1$ and $V^2$ respectively. The control grids of $V^1$ and $V^2$ are fed in parallel from an M.F. oscillator while their anodes are connected in push-pull. $V^1$ is normally biased to cut-off at the suppressor so that $V^2$ is in operation during the transmission of a dash. The keying trigger starts a pair of pulses as described above, so that $V^2$ is cut off and $V^1$ operates, thereby reversing the phase of the feed to aerial B for the duration of transmission of a dot.

A complete ground station was set up temporarily on the lines of Fig.2. The quality of transmission, as regards key click on the equisignal, was found to be no better than that observed during the trials with the Bushmills station. Since the break of transmission during the keying process was negligible it may be concluded that key clicks are due to phase discontinuity. Confirmation was obtained by reversing one half of the coil coupled to the anode circuit of $V^1$ $V^2$ so that the keying produced no phase reversal of the feed to aerial B. No trace of keying was then audible.

## 3.- REPLACEMENT OF OPEN-WIRE FEEDERS BY V.H.F. RADIO LINK

Existing designs of Consol stations require the installation of some 3.5 - 4 miles of open wire feeder line linking the centre site to each of the outer aerials. Should a requirement arise for a change of frequency to the new internationally agreed band of 90 - 110 kc/s, the length of feeder line would increase by a factor of three. Having regard to the heavy capital charge and high maintenance costs in some parts of the world their replacement by V.H.F. radio links is worth consideration.

An opportunity arose in the course of other work to check the phase stability of such an arrangement. Fig.3 is a schematic of the equipment used. The frequency difference of two crystal oscillators operating nominally at 275 kc/s (F) is maintained accurately at 83.1/3 c/s (f) by comparing in a discriminator the actual difference frequency with an 83.1/3 c/s supply derived by frequency division of the output of a 105 kc/s crystal oscillator. The output of the discriminator controls a reactance valve which in turn adjusts one of the crystal oscillators to the correct frequency. The output of one oscillator at frequency F drives a transmitter located at the same site (site A). The output of the other oscillator amplitude modulates a V.H.F. carrier which is transmitted to site B some six miles from site A. The V.H.F.

signal at the site B is demodulated and the M.F. modulation is used to drive a transmitter at frequency F + f. An M.F. receiver at site A receives a local signal at frequency F and a signal from site B at frequency F + f. The output of the receiver at frequency f is applied to the Y plates of a cathode ray tube, the X plates being connected to the local source of the same frequency. By observation of the change of shape of the ellipse on the C.R.T. the relative phase stability of the two M.F. transmitters can be measured. Limited short term observations so far made indicate that a phase drift of about 2° can occur in half an hour. No particular care has been taken to ensure that the transmitters were thoroughly warmed up and it is thought that improved stability is likely under continuous operation.

In order that the V.H.F. link may operate with the minimum radiated power and with maximum reliability, it is desirable that there should be a visual path between the two ends of the link. This means that the aerial at either end of the link should be well elevated above ground. The cost of providing a mast for this purpose may be avoided by installing the aerial on one of the M.F. mast radiators, either at the top, as shown in Fig.4 (a), or lower down if the local ground contours and obstructions permit. The coaxial cable to the V.H.F. aerial cannot be connected directly to the receiver at ground level since the M.F. aerial would be shorted to ground. The difficulty of providing a high impedance at M.F. in series with both the outer and inner of the coaxial without introducing unacceptable discontinuity at V.H.F. has been overcome by the device shown in Fig.4 (b). An inductance is formed by winding the coaxial at ground level onto a suitable former and tuned approximately to resonance by means of a fixed condenser as shown. Thus the high reactance of the tuned circuit is connected between the base of the M.F. aerial and ground and has negligible effect on the M.F. coupling transformer, while no discontinuity is introduced in the coaxial cable to the V.H.F. aerial.

In the case of short mast radiators, some attention must be given to the design of the tuned circuit in order to strike a balance between the M.F. power lost in it and the V.H.F. attenuation due to the length of cable used in making up the coil. For a coil of given Q, the loss in it is inversely proportional to its inductance. On the other hand the inductance cannot be increased indefinitely since the V.H.F. attenuation is directly proportional to the length of cable used. In the case of the experimental arrangement shown in Fig.4 approximately 25% of the M.F. power was lost in the coil and the V.H.F. loss in the 180 ft. of cable used was 4.3 dbs.

The quarter wave stub at V.H.F. shown in Fig.4 (b) is fitted in order to ensure that the core and sheath of the coaxial cable are at the same potential at the medium frequency, thereby preventing the feeding of M.F. power into the V.H.F. receiver. The receiver was installed about six feet from the 1 kw M.F. transmitter used, but no trouble was experienced due to feed-back.

## 4.- CONCLUSIONS

It has been established that the masking of the equisignals of the two-aerial system by key clicks is inherent in the system and is due to a phase discontinuity in the received signal. The limited field trials carried out suggest that the key clicks introduce an uncertainty of the location of the equisignals such that the standard deviation of error of count amounts to three characters; that is, double the error observed in the case of the three-aerial system. Further trials will be necessary to establish this point.

Experiments have been carried out which show that it is practicable to replace the open wire feeders to the outer aerials of a three-aerial system by V.H.F. radio links, M.F. amplifiers being installed adjacent to each of the outer aerials.

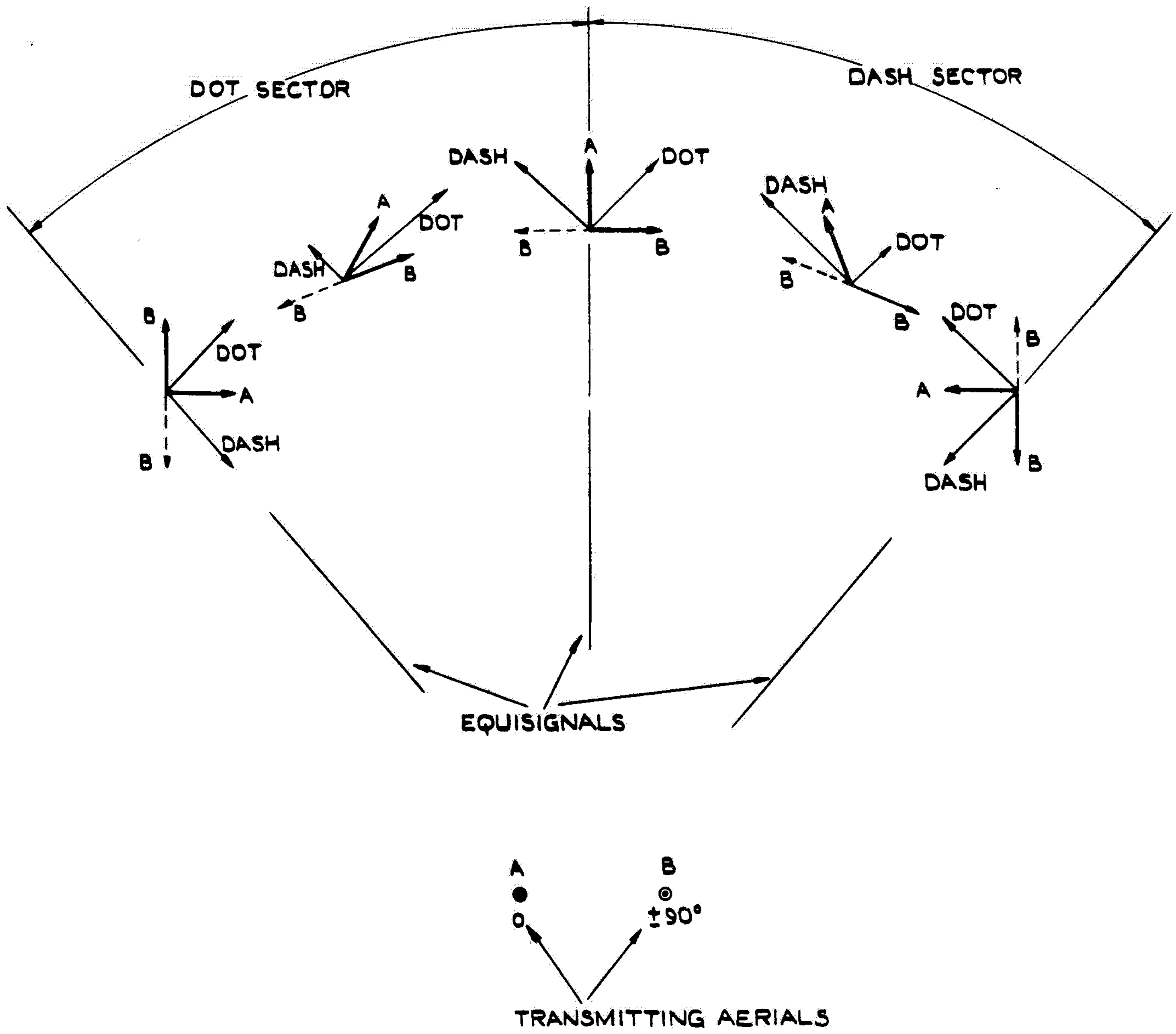

FIG.1. VECTOR DIAGRAM OF TWO AERIAL CONSOL SYSTEM.

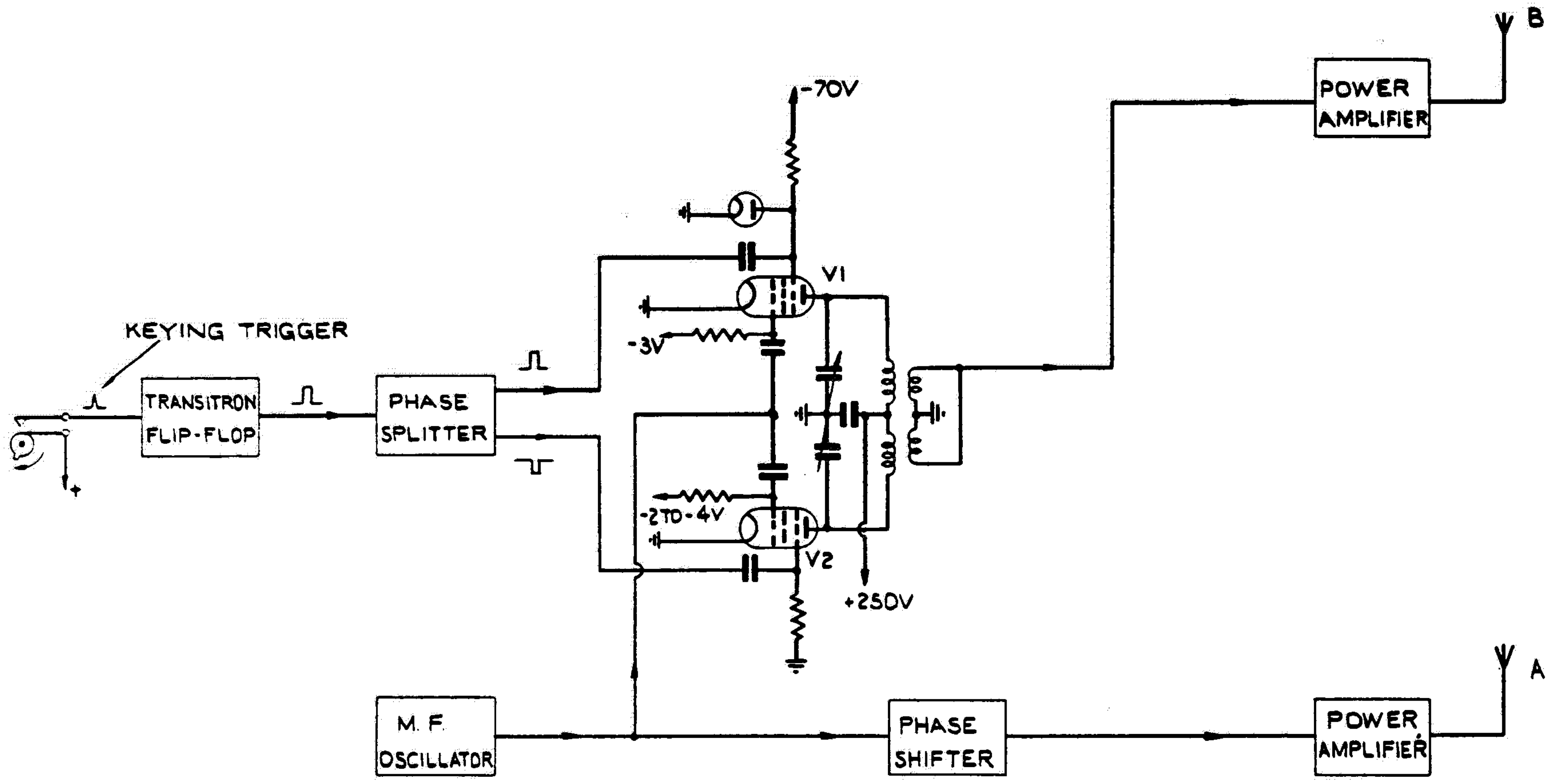

FIG. 2. TWO-AERIAL CONSOL SYSTEM WITH ELECTRONIC KEYING.

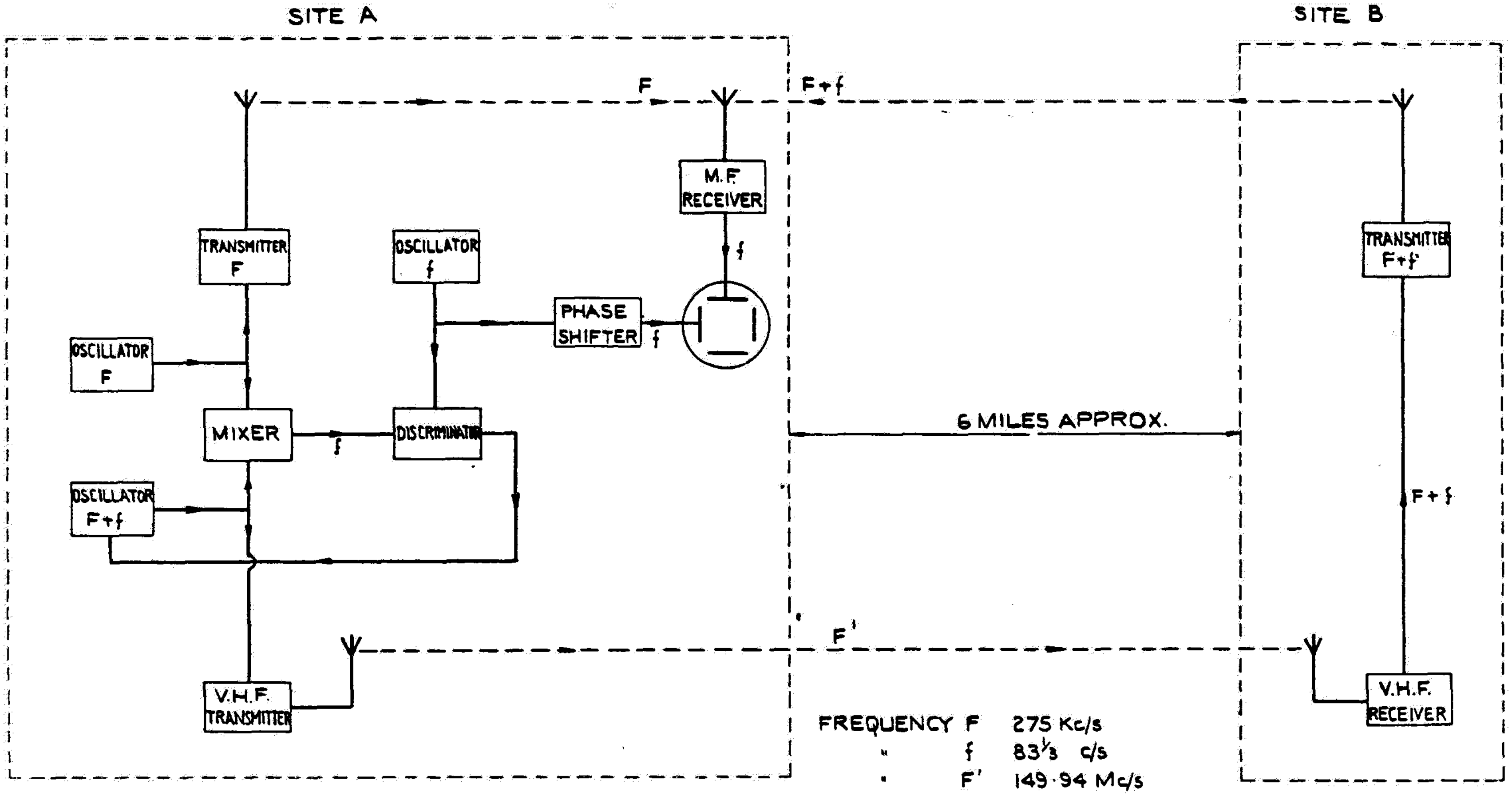

FIG.3. APPARATUS FOR MEASUREMENT OF PHASE STABILITY

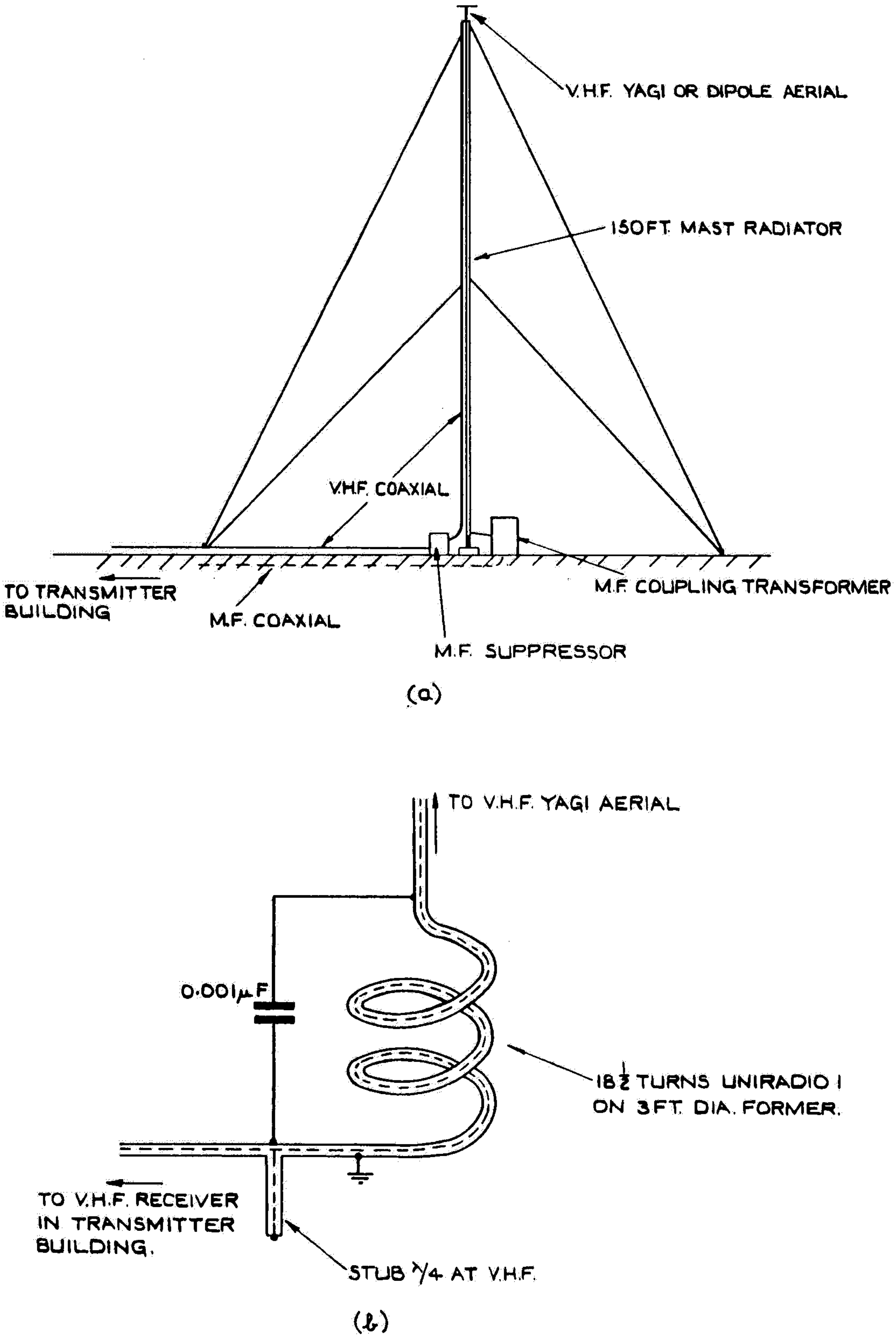

FIG.4. INSTALLATION OF V.H.F. AERIAL ON M.F. MAST RADIATOR.

# PRELIMINARY REPORT ON THE ACCURACY OF THE CONSOL NAVIGATION SYSTEM

Royal Aircraft Establishment, Farnborough

(Technical Note No. Rad.383 - September, 1946)

by

A.H. Brown

## Summary

A brief qualitative analysis of the night errors of the Consol system is given. Observed errors are shown to have the form predicted. Observations carried out by the Germans over land are the most comprehensive so far made and are summarised as Figs. 7, 8 and 9 of the report. These results are considered to be applicable for propagation over sea provided that the errors are scaled down by a factor of one and a half or two.

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# PRELIMINARY REPORT ON THE ACCURACY OF THE CONSOL NAVIGATION SYSTEM

## 1.- INTRODUCTION

The accuracy by day of the Consol navigation system is governed by instrumental errors of the transmitting equipment including errors in the setting up of the correct phases and amplitudes of the currents in the aerials, and by irregularities in the surrounding terrain. Propagation is almost entirely by ground wave and such errors as have been observed during the day may be attributed to the above causes, rather than to the presence of sky wave. At night, however, sky waves appear and have amplitudes which may be equal to, greater or less than the amplitude of the ground wave, depending upon the location of the observer with respect to the transmitting station. Combinations of ground and sky waves will give rise to bearing errors.

## 2.- THEORETICAL CONSIDERATIONS

The polar pattern of the Consol Aerial system due only to radiation reflected from the ionosphere is substantially the same at great range as that due to the ground wave. As the range is reduced, the patterns differ materially.

At night therefore, it is to be expected that three regions will exist:

a) a region at long range in which the sky wave will predominate

b) a region nearer to the transmitting station in which sky and ground waves have comparable magnitudes and

c) a region still closer to the transmitting station in which the ground wave predominates.

In region a) the bearings obtained will be somewhat different from those computed from the ground wave polar diagram. The error will however decrease as the range increases and can be computed with fair accuracy provided only one sky wave is present and provided that the sky wave does not deviate from the great circle path through the transmitting and receiving stations. In region b) ground and sky waves may combine in many ways and bearing errors may be large. In region c) the accuracy will be limited by instrumental errors and by irregularities in terrain.

Considering first region a), in which it will be assumed that a single sky wave only is present, the bearing error is small and is given approximately by

$$\Delta \theta = (1 - \cos \chi) \tan \theta \qquad (1)$$

where $\theta$ is the bearing referred to the normal to the line of aerials and $\chi$ is the angle of elevation of the sky wave at the earth's surface. This is a systematic error and is such as to give an apparent bearing too close to the normal to the line of aerials. Assuming normal E - layer reflection at a height of 90 kms., $\Delta\theta$ may be expressed in terms of range and azimuth, as indicated in Fig. 1. As the range is reduced, equ. (1) is no longer valid, and, in the limit, the systematic error may be negligible. Since ground and sky waves have comparable magnitudes at a range of about 370 miles for an oversea path, it is to be expected that the error curves will have maxima at this range for any azimuth. The maxima are likely to occur at a range between 250 and 300 miles for an overland path.

At extremely short and long ranges, the random errors are likely to be fairly small. At intermediate ranges, however, ground and sky waves combine with random phase, and probably with random relative amplitude. Random errors will therefore be superimposed upon the systematic error as shown in Fig. 2.

The effect of random combination of the ground and sky waves may be visualised as the opening and closing up of the polar pattern of the aerial system in a manner similar to the opening and closing of a fan. Provided that the change of phase and amplitude of the sky wave is slow, an incorrect count of characters will result. If the changes are rapid and sufficiently great, an equisignal may be heard twice or more during keying cycle. Such counts are of course meaningless, and must be discarded.

The above qualitative analysis has been confined to the case in which a single sky wave is present. If however multiple sky waves appear, as is quite likely at long ranges, subsidiary maxima will occur in the error curves.

A complete analysis has been published by the N.P.L.

## 3.- OBSERVATIONS OVER SEA

It will be evident that a complete picture of the errors of the Consol system can be obtained only by statistical means, that is, by analysis of large numbers of bearings taken throughout the whole twenty-four hours for many days at a fixed receiving station. By repeating the process simultaneously at many receiving stations suitably disposed in range and azimuth with respect to the transmitting station, complete curves of the form shown in Fig. 2 may be derived. Such a programme has so far been beyond the resources of the R.A.E. With the assistance of the R.A.F., however, observations have been made of bearings from the Stavanger Sonne station at receiving stations on the coasts of England and Scotland. Fig. 3 shows the disposition of the receiving stations. It will be seen that they are disposed over the coverage from the normal to the line of aerials to 40° to the normal, and at distances for which maximum night error is to be expected. Observations, spread uniformly over day and night between

October and December 1945 were made at four of these stations. Analysis of all observations at each station for hourly periods both during the day and night has been made. Error distributions are not Gaussian but show approximate symmetry about a mean. The general effects predicted in Section 2 above are confirmed; that is, systematic errors are present at night which are negligible along the normal to the line of aerials and increase with departure of azimuth from the normal. Further, the errors are such as to give apparent bearings too close to the normal. Fig. 4 shows the mean count of dots at four of the stations for all observations made from 0000-0100 hrs., 0100-0200 hrs., etc. Large numbers of observations were made at each station, with the exception of Anstruther for which relatively few counts were taken at night. The results are of the form anticipated, except that somewhat smoother curves might have been expected.

It is not possible to say with certainty whether small systematic error exists during the day. There are no accurate survey data relating to Stavanger and it is not possible to compute the count at a receiving station with an accuracy of better than one or two characters. An attempt has been made to work backwards from the observed counts at the four stations referred to above and counts taken by day only at D.F. stations operated by the Ministry of Civil Aviation at Inverness, Kirkwall and Sumburgh. Calculating from these data the best values of aerial separation and orientation of the line of aerials, inconsistencies of over two characters still remain. The matter will be left at this point and an analysis deferred until a careful survey of the Stavanger station has been made.

Standard deviation and 50% error have been computed as a function of time of day and are shown graphically at Figs. 5 and 6.

Investigations made by the Empire Air Navigation School show that observers differ in their ability and that the 50% error of one observer at a given receiving station may be as much as twice that of another observer at the same station. In view of the fact that different observers were necessarily used at the four stations and that two or three observers were on duty on a basis of one man per watch at each station, it follows that the scales of standard deviation and 50% error in Figs. 5 and 6 are subject to a possible expansion or contraction.

The E.A.N.S. trials show that the accuracy of count is independent of azimuth during the day. The 50% errors during the day plotted in Fig. 6 show the same effect, so that it is unlikely that there is much difference in the ability of the operators.

The analysis summarised in Figs. 4, 5 and 6 and the E.A.N.S. trials, provide the following data:

Day Errors

a) Systematic errors during the day are absent or very small.

b) Random errors in the count of characters are independent of azimuth and substantially independent of range. The 50% error is of the order of two characters, corresponding to about 0.25° error near the normal to 0.5° error near the edge of the coverage. The random error does not increase materially with range.

Night Errors

a) Systematic error increases steadily at sunset, is a maximum at about midnight and decreases steadily to zero or a small quantity at sunrise.

b) Systematic error increases with increase of azimuth referred to the normal.

c) Random errors vary in a manner similar to systematic errors. The 50% error varies from about 0.4° in the vicinity of the normal to about 1° at 40° to the normal. These errors are applicable to a range of about 400 miles and are not likely to be exceeded for smaller or greater ranges, unless multiple sky waves are received. (The 50% errors given by the E.A.N.S. are about one and a half times larger than those quoted here, and may be attributed to conditions of reception in an aircraft which are less favourable than those at a ground station).

d) Accuracy at ranges of the order of 400 miles from the station varies markedly from night to night. Poor accuracy is characterised by occasional reception of more than one equisignal and by fading during the keying cycle.

## 4.- OBSERVATIONS OVER LAND

Observations made entirely over land under favourable conditions and under British control have not been possible. The Germans however carried out large scale observations on Sonne 12 near Warsaw in which forty-five receiving stations spread uniformly over the coverage area took part. The results have been published in a comprehensive report and a summary only will be given here.

Accuracy by day appears to be much the same as that for oversea observations. Whereas however, the accuracy seems practically independent of range for an oversea path, errors are increased by a factor lying between two and four at 500 miles range for an overland path. Accuracy contours are given in greater detail in the German report.

Accuracy by night is summarised in Figs. 7, 8 and 9. Systematic and random errors have variations with range and azimuth of the form anticipated above. The errors are, however, considerably greater than those recorded over sea and have their maxima at a greater range than would be expected.

## 5.- CONCLUSIONS AND RECOMMENDATIONS

a) The presence of systematic and random errors of the form expected is confirmed both for oversea and overland paths.

b) German observations, although not carried out at ranges sufficiently great to give a complete picture, are the most comprehensive of those so far made.

c) Until more complete data are available for propagation over sea, it will probably be safe to use the German results, scaling down the systematic and random errors by a factor of one and a half or two.

d) A further programme of observation over sea should be initiated, covering the complete operational area of a station. For this purpose it is recommended that observations should be made on board ship so that many counts may be taken for a relatively small change of position of the receiver.

e) It is recommended that automatic recorders be used in order to remove the human element in the determination of random error. A separate investigation may be made separately in order to determine the multiplying factor to be applied for the average observer.

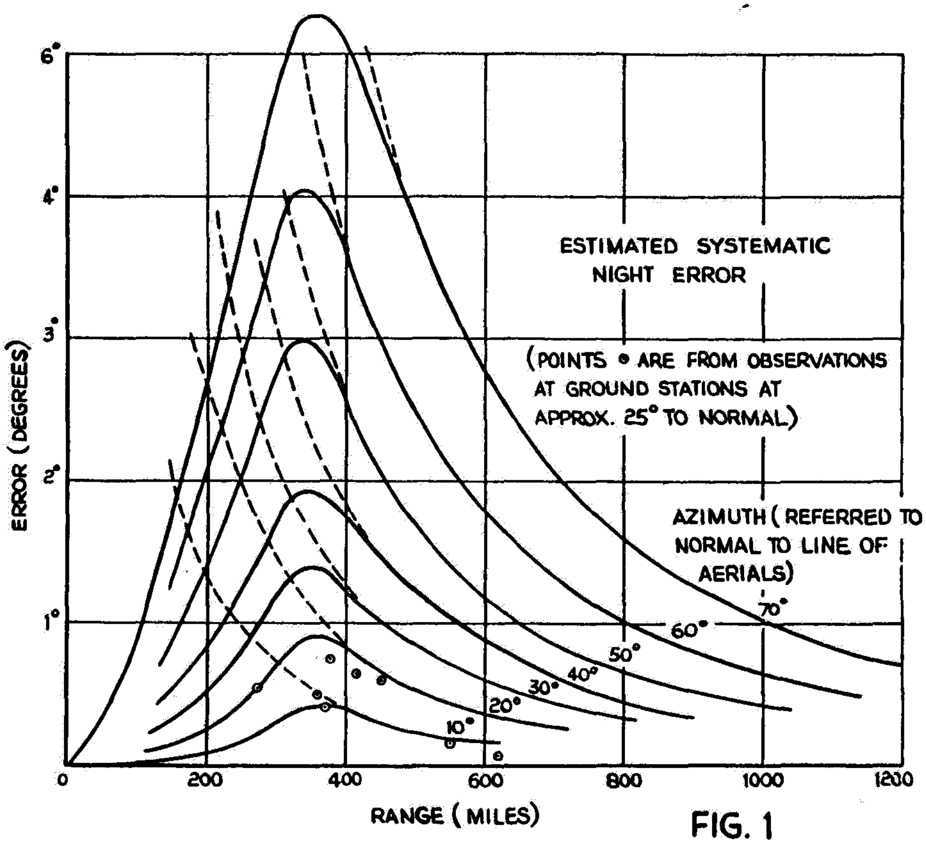


FIG. 1

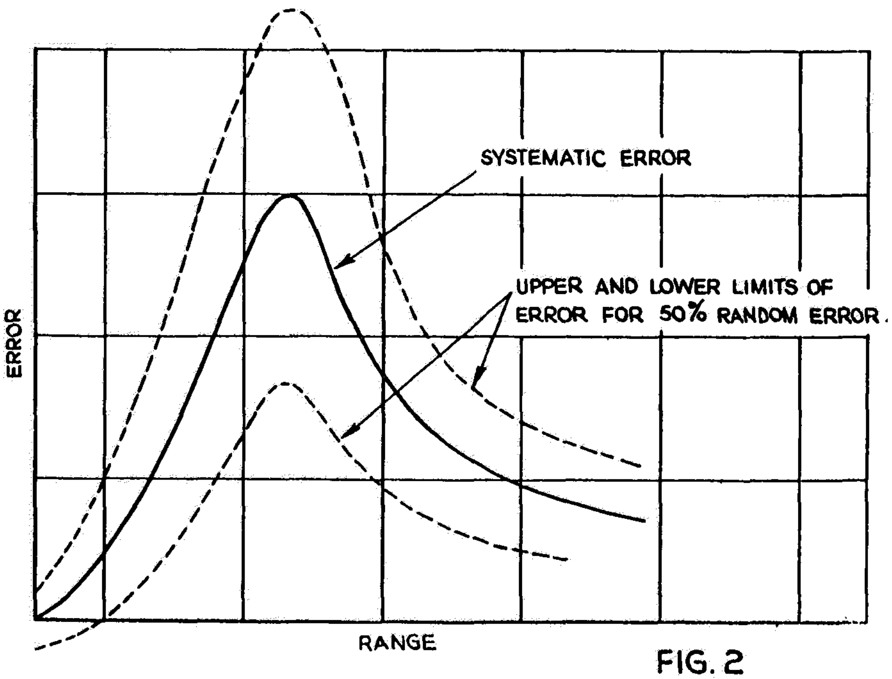
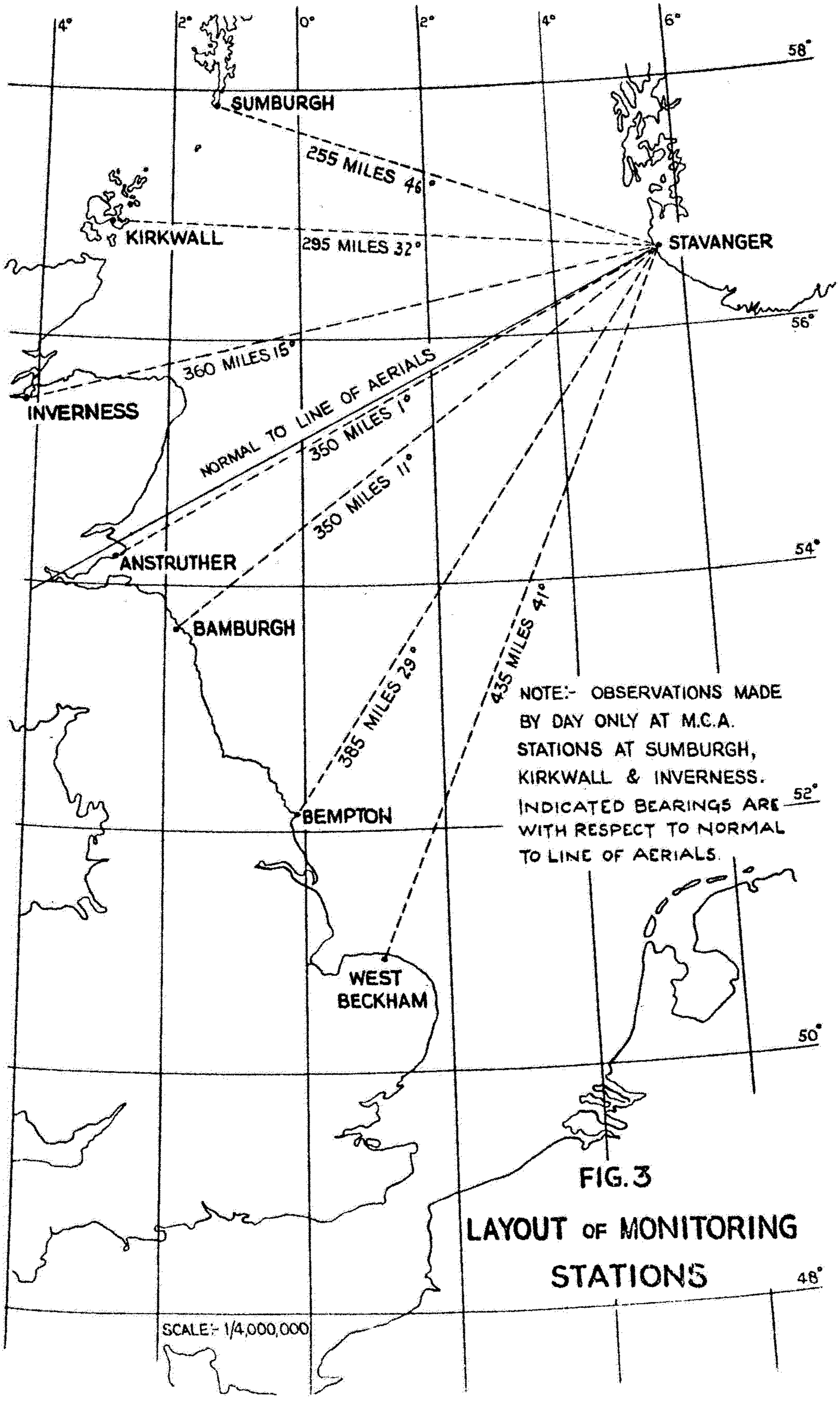


FIG. 2

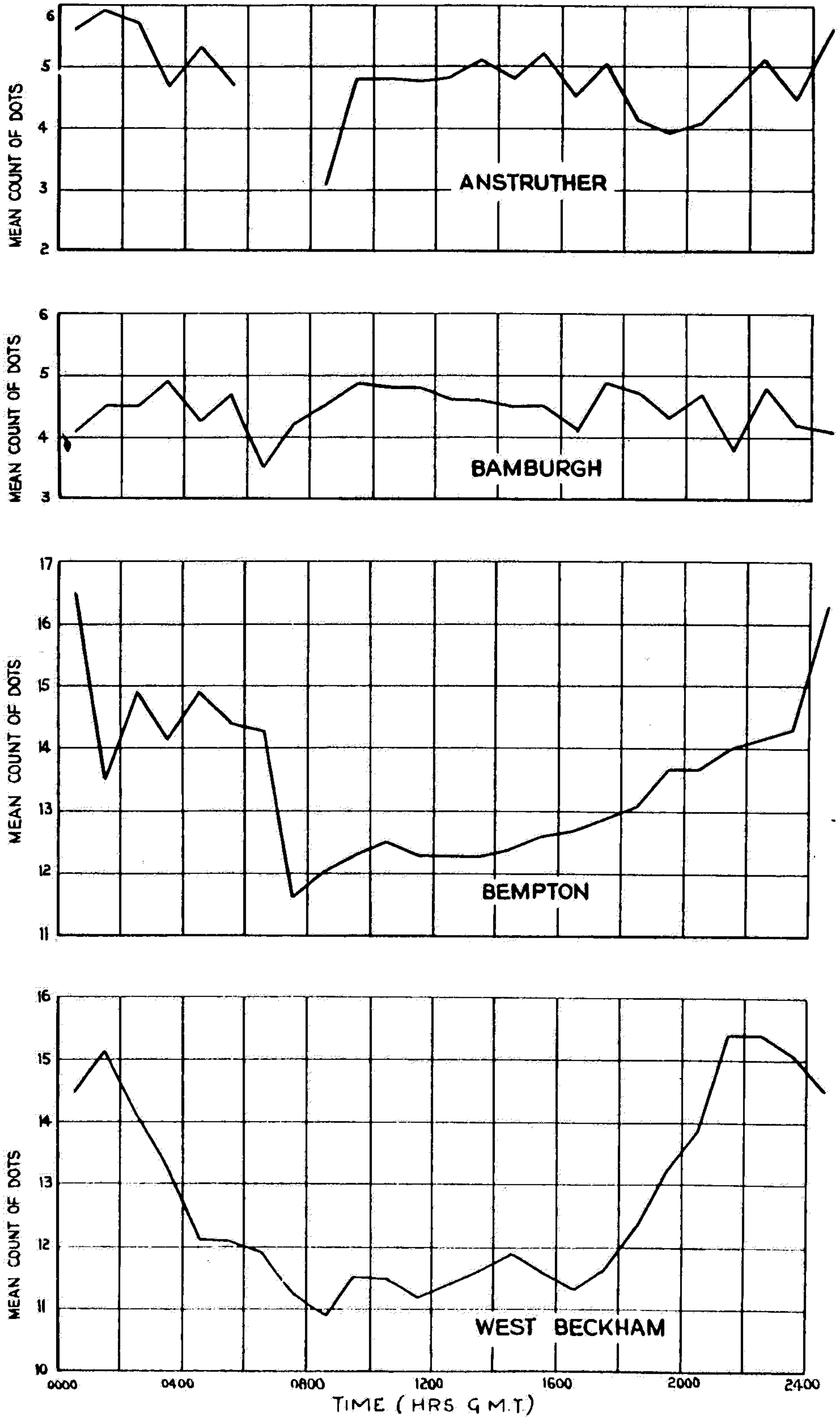
CONSOL - SYSTEMATIC NIGHT ERRORS



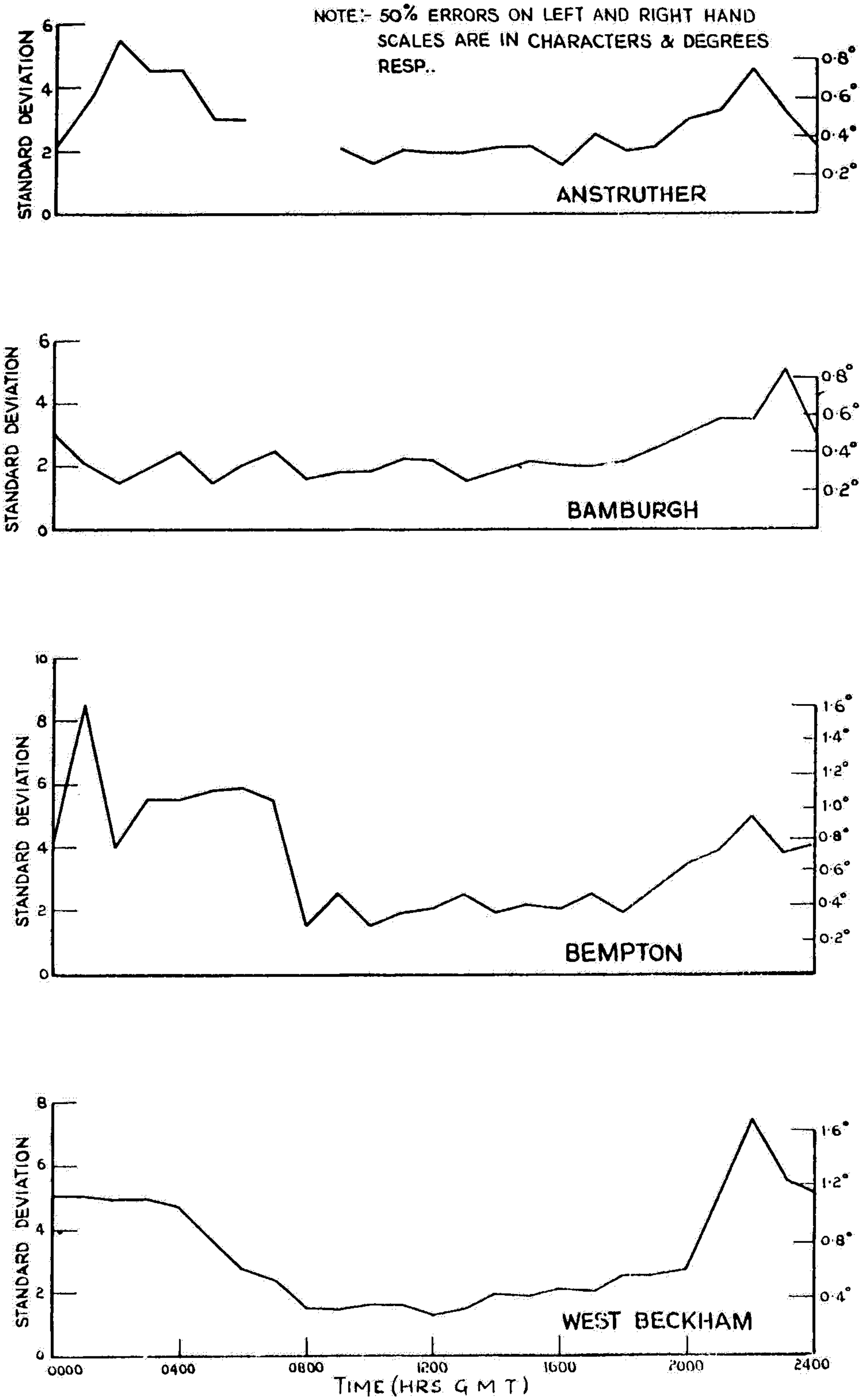
NOTE:- OBSERVATIONS MADE BY DAY ONLY AT M.C.A. STATIONS AT SUMBURGH, KIRKWALL & INVERNESS. INDICATED BEARINGS ARE WITH RESPECT TO NORMAL TO LINE OF AERIALS.

FIG. 3

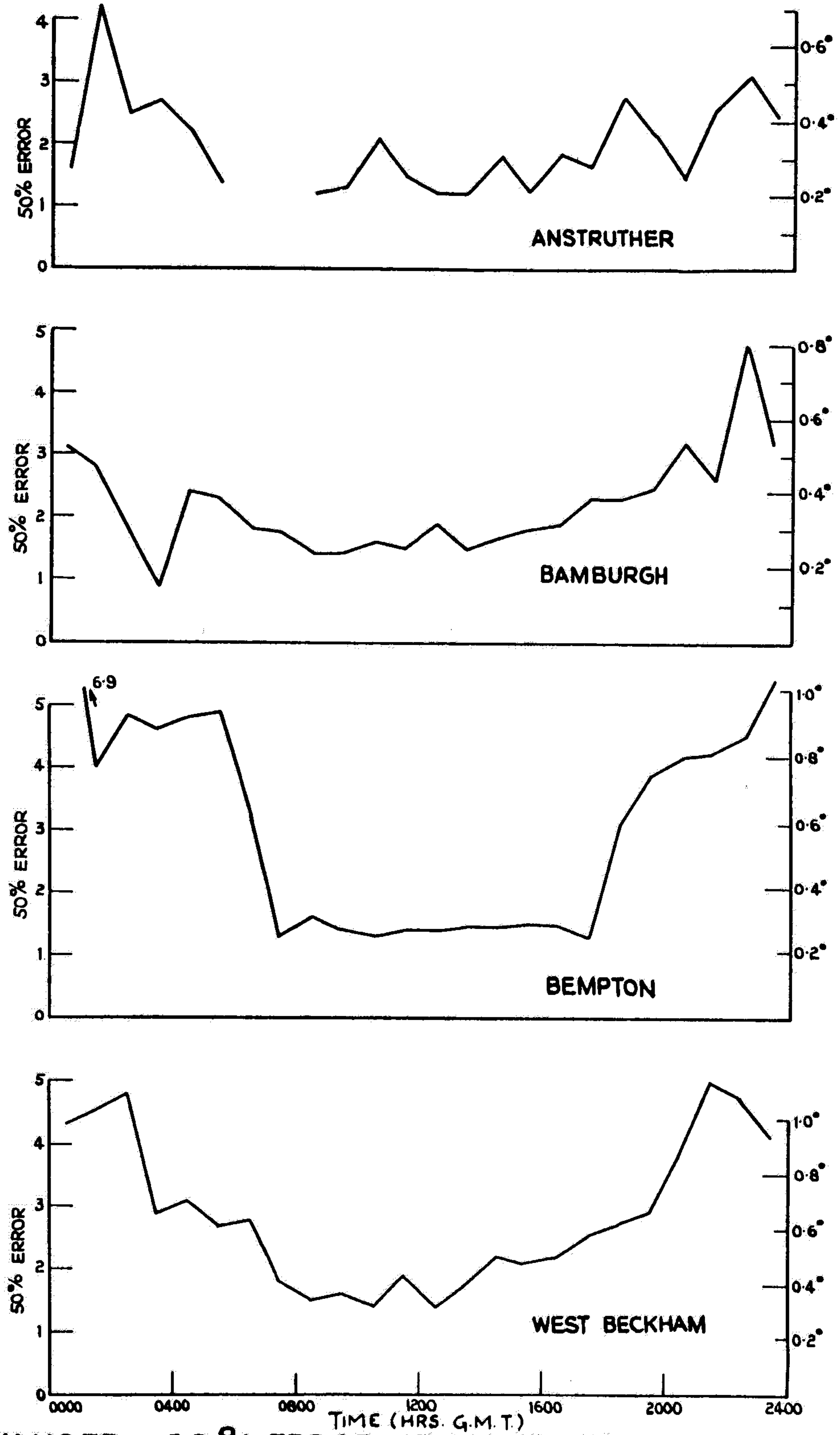
LAYOUT OF MONITORING STATIONS



STAVANGER-MEAN COUNTS OF CHARACTERS AT MONITORING STATIONS

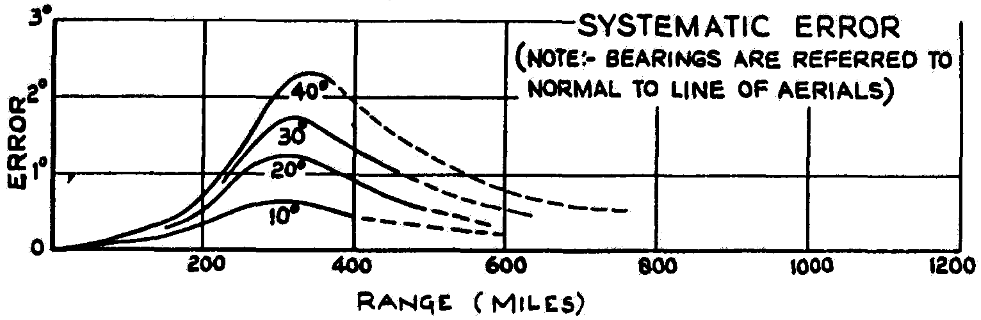


STAVANGER - STANDARD DEVIATION AT MONITORING STATIONS



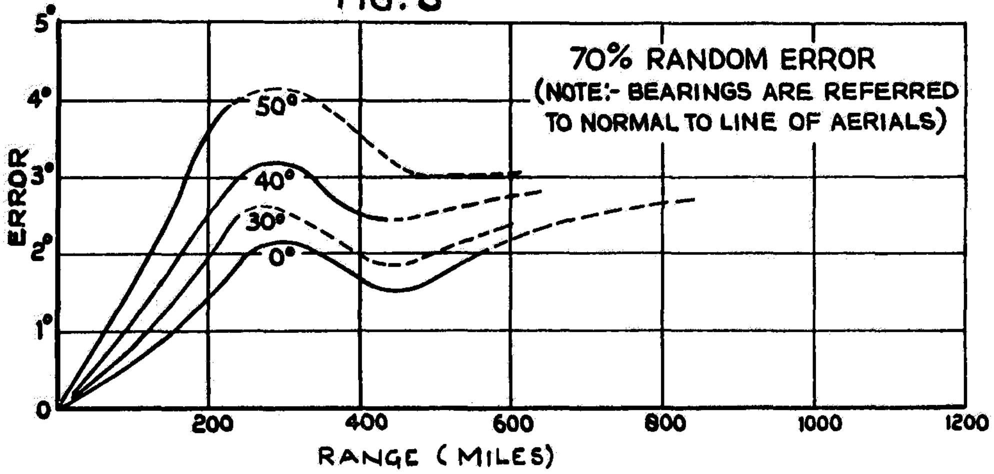
STAVANGER - 50% ERROR AT MONITORING STATIONS

FIG. 7



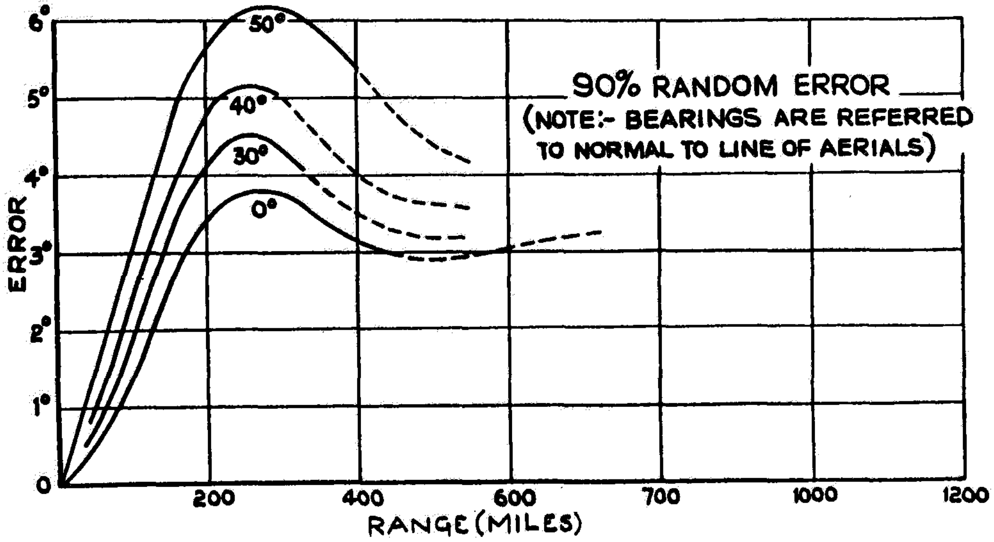
SYSTEMATIC ERROR
(NOTE:- BEARINGS ARE REFERRED TO NORMAL TO LINE OF AERIALS)

FIG. 8



70% RANDOM ERROR
(NOTE:- BEARINGS ARE REFERRED TO NORMAL TO LINE OF AERIALS)

FIG. 9



90% RANDOM ERROR
(NOTE:- BEARINGS ARE REFERRED TO NORMAL TO LINE OF AERIALS)

CONSOL-OBSERVED SYSTEMATIC & RANDOM ERRORS
(OBSERVATIONS AT NIGHT OVER LAND)

# THE ACCURACY OF THE CONSOL NAVIGATION SYSTEM - PART I

Royal Aircraft Establishment, Farnborough

(Technical Note No. Rad.404 - June, 1947)

by

A.H. Brown, M.Sc., A.M.I.E.E. and F/Lt. L. Hodgson

## Summary

The report describes the results of observations made, over sea, on the Bushmills Consol station by day and night. Observations were confined to a vector approximately 20 degrees to the normal to the line of aerials of the Consol station. The 50 per cent and 90 per cent random errors by day are about 0.3 characters and 1.2 characters respectively and are substantially independent of range. The corresponding bearing errors are 0.07 degree and 0.28 degree respectively.

The 50 per cent and 90 per cent random errors by night rise to a peak of about 1.0 and 3.5 characters at a range of about 250 nautical miles and fall off at the limit of range to about 0.6 and 2.0 characters respectively. The corresponding peak and limiting bearing errors are $0.23^\circ$, $0.81^\circ$ and $0.14^\circ$, $0.46^\circ$.

Systematic errors exist at all ranges both by day and night and are attributed to a combination of coastal refraction effects and distortion of the ground station polar pattern by mountainous country near the station. The effect is so great that the systematic error existing at night due to ionospheric wave interference is completely masked. Systematic errors appear to be extremely variable both in respect of range and small changes of azimuth; they may or may not exceed the random errors in magnitude.

Ultimate ranges by day and night were found to be about 1,200 and 1,500 nautical miles respectively.

A method of representing fix accuracy is described and accuracy contours for Bushmills - Stavanger are given.

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## List of Contents

## List of Illustrations

# THE ACCURACY OF THE CONSOL NAVIGATION SYSTEM - PART I

## 1.- INTRODUCTION

In a previous report, it was recommended that a programme of observations over sea should be carried out covering the complete operational area of a Consol station. For this purpose it was recommended that observations should be made on board ship so that many counts could be made for a relatively small change of position of the receiver. This programme was started during September, 1946, and observations were made on Bushmills during three voyages between Glasgow and Montreal. The choice of Glasgow as a port of departure was made because the route was practically on a constant bearing with respect to Bushmills; in this way, one of the variables influencing the accuracy of the system was held substantially constant for all the observations.

Part I of this Note provides an analysis of the observations made on one vector only, about 20 degrees with respect to the normal to the line of aerials of the Consol station. Due to the difficulty of finding ships which follow suitable routes, results for other vectors are not yet available. In view of the interest taken in Consol both for air and marine navigation, it is proposed to publish these results as they become available.

## 2.- SCOPE OF OBSERVATIONS

Experience has already shown that the errors of bearing derived from a Consol station have a regular variation with respect to time of day. The errors are greatest at about midnight and least at midday. It was therefore decided to confine the observations to periods of four hours about midnight and two hours about midday. Because of the large distances at which observations were possible, local midnight and midday half way between Bushmills and the ship were taken as the middle of the periods of observation. A high-grade communications receiver, connected to one of the ship's vertical aerials, was used for reception. Most of the observations were made by one of the authors, but some were made by Mr. C.G. Bruce, a supernumerary wireless operator. Comparison of counts made by the two observers indicated that no weighting was necessary to allow for difference of ability.

## 3.- ANALYSIS OF OBSERVATIONS

### 3.1.- Day Observations

The 50 per cent and 90 per cent random errors referred to the mean of each two-hour groups have been determined and are plotted in Fig. 1(a) and (b) as a function of range. The errors are small but by no means constant from day to day. The error distribution also varied from day to day as may be seen by comparing the ratio of 50 per cent to 90 per cent error for different groups of observations. There is an upward trend of error towards the limit of range. This is to be expected since there would naturally be a greater spread of error as the signal-to-noise ratio diminishes.

### 3.2.- Night Observations

The 50 per cent and 90 per cent random errors referred to the mean of each four hour group, are plotted in Figs. 1(c) and (d). The speed of the ship was only 10 knots so that sub-division of the four-hour group is hardly worth while.

The variation of error with respect to range is substantially in accordance with prediction except for the first trip, in which the large random errors to be expected between 300 and 400 miles did not appear. It is also apparent that were the observations "smoothed" the peak error would probably be at about 250 miles from the station instead of at the theoretical range of 350 miles. It is also interesting to note that there is no marked peak error at greater range, which would be expected if the "second hop" E layer reflection were of sufficient amplitude. At ranges greater than 600 miles the night errors exceed the corresponding day-time errors by a factor of about two, indicating fairly good ionospheric stability.

### 3.3.- Systematic Errors

In any series of experiments carried out to determine the accuracy of a navigational aid over sea, there is always the fundamental difficulty of determining the true position of the receiver. As far as random errors are concerned the difficulty is not great since variation both with range and azimuth is fairly slow. The systematic error may, however, be comparable to the error of estimation of the true position of the receiver and some consideration must be given to the treatment of the available data.

Observations in this country show that the day-time systematic error is small. No long term observations have been made, but counts made by various observers in different parts of the country agreed with the value given by the available charts to the accuracy to which they could be read, i.e. ± 0.5 character. It is therefore reasonable to assume that a day-time systematic error would not exceed 0.5 character and that the day-time observations over sea might themselves be used as a standard of reference with respect to which the night time systematic error could be determined. In Fig. 2 the mean counts for each two-hour day, and each four-hour night period have been plotted as a function of range. Smooth curves are drawn through the points representing the day and night observations and the difference of count at any range should give a fairly accurate measure of the systematic error at that range. It will be observed, however, that the count at night is always less than the count during the day at the same range. This corresponds to a systematic error giving an apparent bearing shifted away from the normal to the line of aerials. This is contrary to theoretical expectation and previous experience .

For purposes of comparison, the count as a function of range derived from the noon positions recorded in the ship's log is also plotted in Fig. 2. The agreement with the day Consol observations is poor and can hardly be attributed entirely to uncertainty of the ship's position. An error of one character corresponds to a position line error of approximately 0.4 mile at a range of 100 miles, so that errors of navigation up to ten miles would have been necessary to account for the discrepancies observed.

A possible explanation of the effect lies in the fact that, for the particular vector on which observations were made, Inishowen and Malin Heads lay between the station and the ship. These headlands are mountainous, having peaks over 1,000 ft. high, so that these together with coastal refraction may account for considerable distortion of the polar pattern of the aerial system. The distortion at night may not be so marked because of the reception of the sky wave, the difference between day and night readings being sufficient to account for the apparent systematic error in the opposite sense to that expected. On the other hand, it would be expected that the difference between night observations and counts computed from the estimated ship's position would be small beyond a range of 600 miles. From Fig. 2 it may be seen that this is not the case, the discrepancy being greatest at extreme range. The reasons for the observed effects are by no means clear and it is hoped to make further observations within sight of the Irish coast so that a careful check on the true position of the receiver can be made.

### 3.4.- Range and Reliability

The day and night ranges obtained were about 1,200 miles and 1,500 miles respectively, agreeing quite well with ranges obtained during aircraft trials. With regard to reliability, less than 1 per cent of the observations were lost. The loss is attributable to deterioration of signal-to-noise ratio at extreme range and not to the appearance of multiple equi-signals. The latter phenomenon has frequently been observed in the course of other trials but was absent throughout the trials described here. The reliability of the system is not as good in the air, some 36 per cent of the observations being lost. The high noise level experienced in an aircraft was probably the major cause of the poor performance and a considerable improvement would have resulted if a high-grade receiver, having a narrow band-width, had been used.

## 4.- REPRESENTATION OF FIX ACCURACY

In making use of any navigational aid providing a fix, a navigator requires to know the probable error of his position rather than the errors of the individual position lines from which the fix has been derived. Provided that the random position line errors have a Gaussian distribution, it is easily shown that a given proportion 1/N of a large number of fixes, determined at a fixed receiving point, will lie within an ellipse with centre at the point of reception. The dimensions of the ellipse are determined by N, the probable error of each position line and by the geometry of the system. This method of treatment has been widely used in assessing the accuracy of Gee, Loran and other aids, the area of the ellipse within which there is a 1:1 or 9:1 chance that a fix will fall having been commonly used as a measure of the probable position error. In the case of Consol, however, the random position line errors are not distributed normally. For this reason an alternative index of fix accuracy, the root mean square radial error, has been chosen and is defined as follows. If a large number of fixes, n, are determined at a given point of reception and the distances between the fixes and the point of reception are $d_1$, $d_2$ ... $d_n$ then the r.m.s. radial error is given by

$$d^2 = \frac{1}{n} \sum_{i=1}^{n} d_i^2$$

If the position lies from a pair of Consol stations $C_1$, $C_2$ intersect at an angle $\phi$ at a point P, then the r.m.s. radial error is given by

$$d^2 = \left( {}_1\sigma_\theta^{2} \sin^2 r_1 + {}_2\sigma_\theta^{2} \sin^2 r_2 \right) \operatorname{cosec}^2 \phi$$

where $r_1$, $r_2$ are the angles $PC_1$, $PC_2$ in accordance with the well known definitions of spherical trigonometry (d will also be in angular measure). ${}_1\sigma_\theta$ and ${}_2\sigma_\theta$ are the standard deviations of bearing error for the two position lines $PC_1$, $PC_2$. It is assumed that there is no correlation between the errors of the two position lines*.

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* It is worth pointing out that the same result is true for the various hyperbolic systems for the region in which the hyperbolae are substantially coincident with their asymptotes. Consol is itself a hyperbolic system for which the base line at each station is so short that the position lines are substantially straight at ranges greater than about 30 miles from the stations. The result is also true for D.F.

${}_1\sigma_\theta$ and ${}_2\sigma_\theta$ vary in a complex manner at night, both with range and azimuth, and insufficient data are available to form a picture of fix accuracy. During the day, however, it is established that the accuracy of count is reasonably independent of range and azimuth up to the limit of coverage and ${}_1\sigma_\theta$, ${}_2\sigma_\theta$ may be derived from the expression

$$\sigma_\theta = \frac{\sigma \lambda}{120 D} \cdot \frac{1}{\cos \theta}$$

where D is the aerial spacing, $\lambda$ the wavelength, $\theta$ the angle of position line makes with the normal to the line of aerials and $\sigma$ is the standard deviation of error of count.

The above expression for d, although simple, entails a good deal of computation if accuracy contours are required for the complete coverage of a pair of stations. As an example, the contours have been worked out (Fig.3) for the coverage of Bushmills and Stavanger over the British Isles and the North Sea. Earlier observations disclosed a standard deviation of count of about two characters for Stavanger. The standard deviation of count for Bushmills is about 0.9 character. It is known that there was difficulty in maintaining adequate monitoring at Stavanger at the time the observations were made, so that greater reliance may be placed on the figure obtained for Bushmills. The contours of Fig.3 have been determined for a standard deviation of one character and may therefore be considered as somewhat pessimistic for a normally monitored pair of stations.

On account of peculiarities of siting, Fig.3 is not to be taken as typical of the performance obtainable; siting may be so arranged as to vary the region of best fix over quite wide limits. For example, a pair of stations sited 1,400 miles apart, and arranged with the normals to the line of aerials intersecting at right angles, would have a fix accuracy of about three miles at 1,000 miles from each station.

It must be stressed that Fig.3 represents the basic accuracy of the Bushmills - Stavanger pair and does not take account of any systematic errors which might occur in unfavourable parts of the coverage.

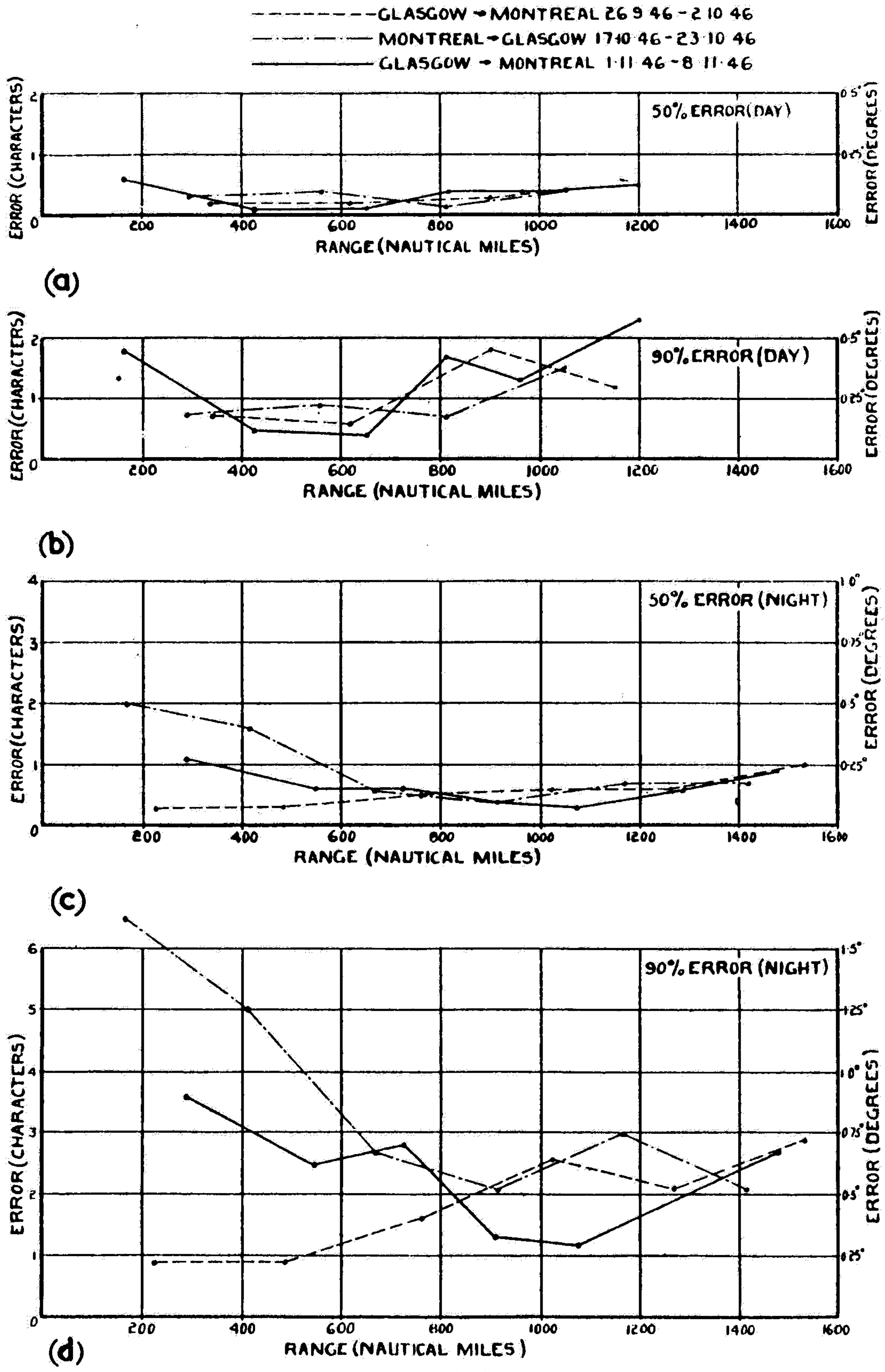

FIG. 1. CONSOL - DAY & NIGHT RANDOM ERROR.

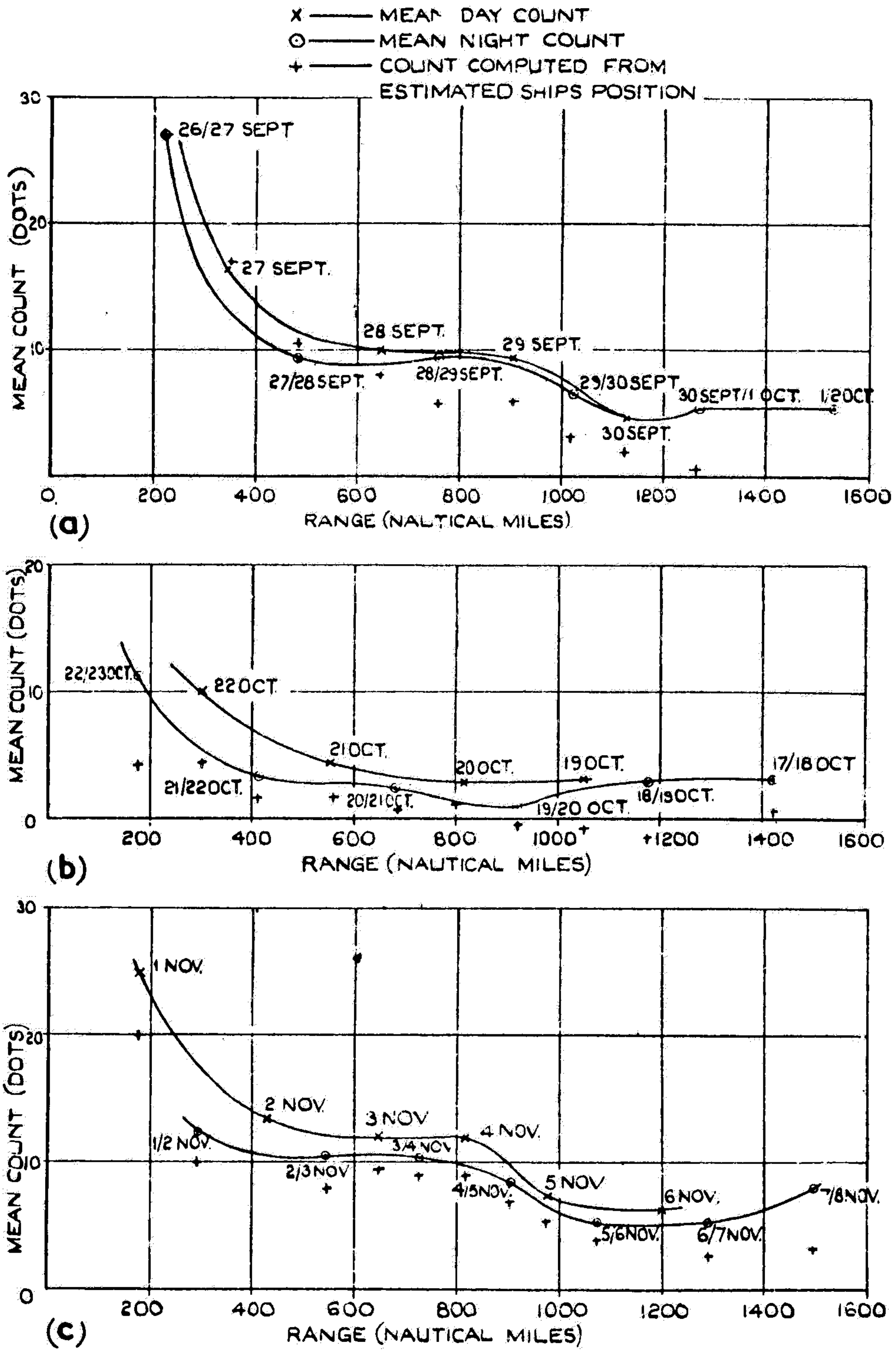

FIG.2 OBSERVED AND ESTIMATED COUNT AS A FUNCTION OF RANGE

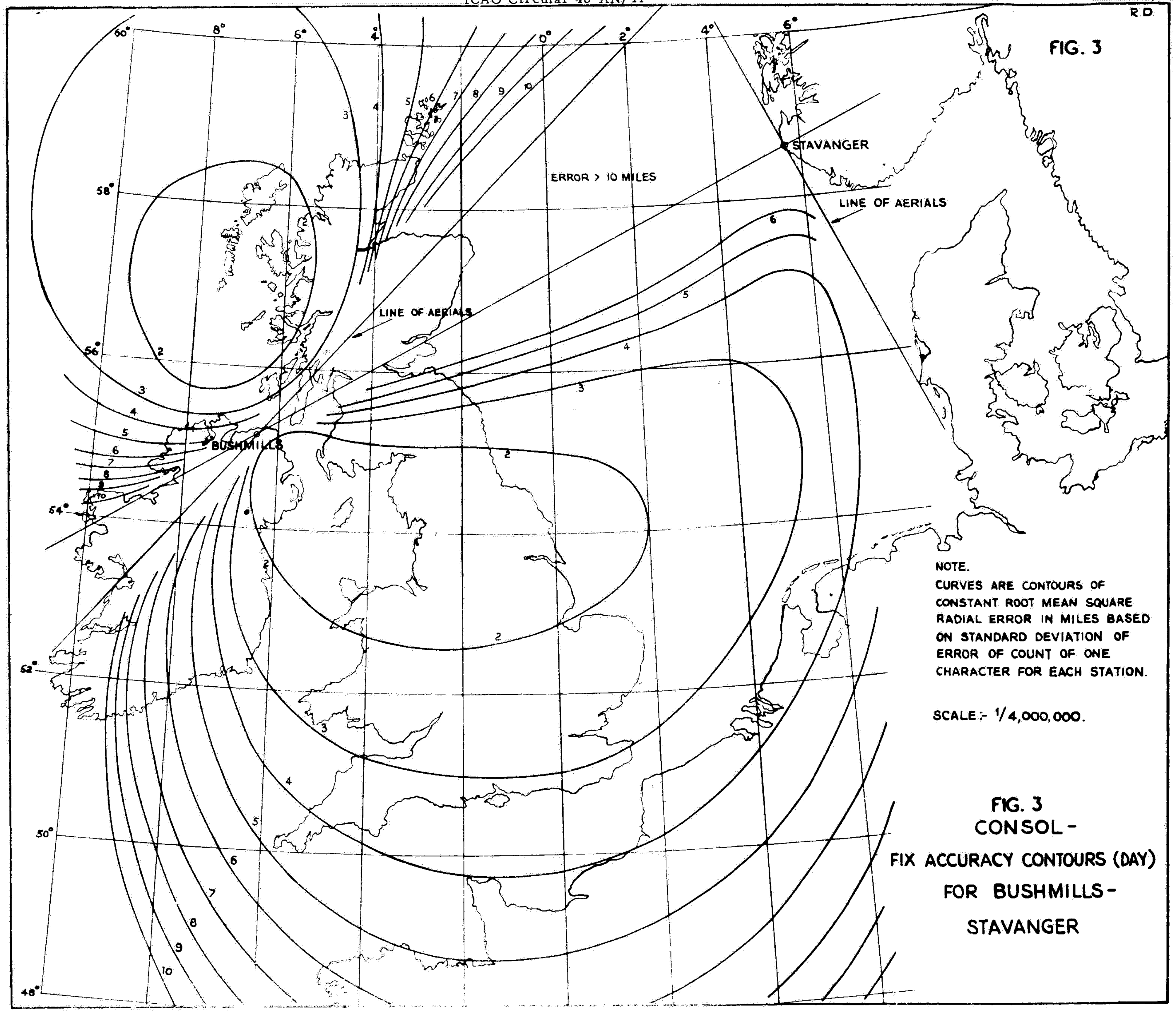

FIG. 3

NOTE.
CURVES ARE CONTOURS OF CONSTANT ROOT MEAN SQUARE RADIAL ERROR IN MILES BASED ON STANDARD DEVIATION OF ERROR OF COUNT OF ONE CHARACTER FOR EACH STATION.

SCALE :- 1/4,000,000.

FIG. 3
CONSOL -
FIX ACCURACY CONTOURS (DAY)
FOR BUSHMILLS -
STAVANGER

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# THE PERFORMANCE OF THE CONSOL SYSTEM OF NAVIGATION IN HIGH ATMOSPHERIC NOISE LEVELS

South African Council for Scientific and Industrial Research

Telecommunications Research Laboratory

by

D. Hogg

March, 1951

## Summary

A method is described by which the minimum field strength necessary for the operation of the Consol system of navigation under South African summer atmospheric noise conditions has been determined.

The use of a simulator enabled measurements to be made at a fixed site in atmospheric noise levels indicated by Telecommunications Research Laboratory Low Frequency Noise Recorder. Factors of signal to noise ratio for various degrees of accuracy were determined.

Certain noise level data for 1949 and 1950 are presented to show the duration of various noise levels.

The serviceability at various ranges of a Consol station radiating a total power of 1 kw has been estimated.

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## Contents

# THE PERFORMANCE OF THE CONSOL SYSTEM OF NAVIGATION IN HIGH ATMOSPHERIC NOISE LEVELS

## 1.- INTRODUCTION

During the Johannesburg summer season November to March 1951 Telecommunications Research Laboratory, C.S.I.R., undertook the testing of various navigational aids to aircraft in atmospheric noise. This work was done on behalf of the Council of Civil Aviation.

The objet of the tests was to find the useful working range of the navigational aids under the high levels of atmospheric noise prevailing in Southern Africa in the summer season.

Continuous records of atmospheric noise in Johannesburg as recorded on the T.R.L. 100 kc atmospheric noise recorder since January 1949 were available, together with recordings over a shorter period for Ladysmith, Natal, and Nairobi, Kenya.

By using this noise recorder as the criterion of noise and establishing the accuracy of the aids at various S/N ratios it was hoped to be able to predict serviceability over a long period.

This report refers to tests made on the "Consol" system of navigation.

## 2.- DESCRIPTION OF EQUIPMENT AND PROCEDURE

### 2.1.- Method of Measurement

The measurements were made on a fixed ground site with the aid of a signal generator and a "Consol simulator" to provide the signals normally obtained by movement through the transmitter pattern. Atmospheric noise was picked up by a vertical aerial of known characteristics.

By using the signal generator attenuator reading and the atmospheric noise level as indicated by the T.R.L. recorder, it was possible to obtain a signal to noise ratio.

It is apparent that the figure of S/N ratio obtained took no account of precipitation static likely to be encountered in a moving aircraft. Thus the noise quoted refers specifically to atmospheric noise only.

The frequency of the Consol signal used was in the neighbourhood of 300 kc/s and no factors were included for the different noise recorder frequency and bandwidth.

It is appreciated that noise data on 300 kc/s would have been preferable for this type of test, but no such information is at present available in this country.

The measurements, however, were all made during the afternoon and early evening, when the highest noise levels tend to occur, and at noise levels high enough to indicate that the major contribution came from nearby storms. It was therefore assumed that the noise measurements at 100 kc/s would be reasonably well correlated with the noise on 300 kc/s. At lower noise levels produced by more distant sources considerable discrepancy would be expected owing to different propagation conditions. These levels, however, are unimportant in so far as estimating the effect of noise on serviceability is concerned.

### 2.2.- Signal Source

The signal source in the test was a General Radio Signal Generator type 1001A. This is fitted with a decade attenuator and a slide wire for intermediate adjustment. Signals continuously variable from 1 µV to 100 MV were available. The output of this instrument when periodically checked against a General Radio Signal Generator type 805C showed close agreement.

### 2.3.- Consol Simulator

This unit was constructed in the T.R.L. and is shown schematically in Figure 1.

The signal generator was connected to a motor driven coder arranged so that the signal was passed to the stator of one variable condensor for $\frac{1}{12}$ sec.

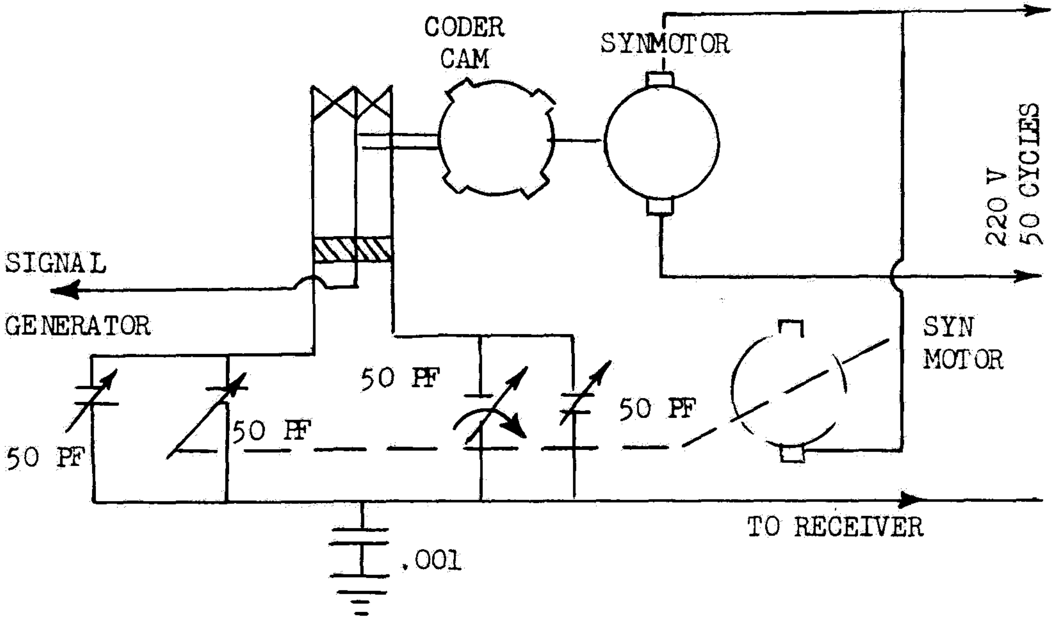


FIGURE 1

and to the stator of another for $\frac{5}{12}$ sec. The rotors of these condensers were connected together mechanically 180° out of phase and driven by a synchronous motor of 1 rev/minute. A 100 pF mica condenser connected to earth from the rotors completed a variable condenser potentiometer. Air trimmers connected across each variable condenser provided adjustment.

The resultant output of this device to the receiver was a number of dots (or dashes) gradually decreasing in amplitude until they merged into dashes (or dots) which first increased in amplitude and then decreased until another change-over occurred. The time taken to complete one cycle was 30 seconds and in this time 60 characters were produced.

The output to the receiver is shown in Figure 2.

The field strength ratio of maximum, cross-over and minimum of a consol lobe is 6:4:2, and in the simulator it was possible, by adjusting the parallel trimmers, to arrange for the maximum and cross-over points to bear the correct relationship to one another. The minimum of the lobe was below that of a normal consol station. This was not considered serious enough to warrant the cutting of specially shaped condenser plates.

The ratio of signal indicated on the Signal Generator to the output of the condenser potentiometer at the maximum of the lobe was found by measurement to be 11.1 to 1.

A switch across the coder contacts made it possible to change the simulator output from C.W. to Consol signal.

A dial attached to the condenser motor was graduated in dots and dashes and indicated the number of characters to the next cross-over point.

### 2.4.- Noise Aerial

The atmospheric noise was picked up on a whip aerial 18 feet 3 inches in height, mounted on an insulator which screws on to a metal stake driven into the ground. A low capacity co-axial cable 20 feet in length was used to feed the noise into the receiver.

The effective height of the whip aerial was measured to be 2.2 metres and its capacity as 47 pF.

### 2.5.- Receiver

The receiver used in the tests was a high quality communications receiver equipped with a bandpass selection switch giving bands of 10 kc, 5 kc, 1.5 kc., 500 cycles and 100 cycles. The latter was provided by an audio filter.

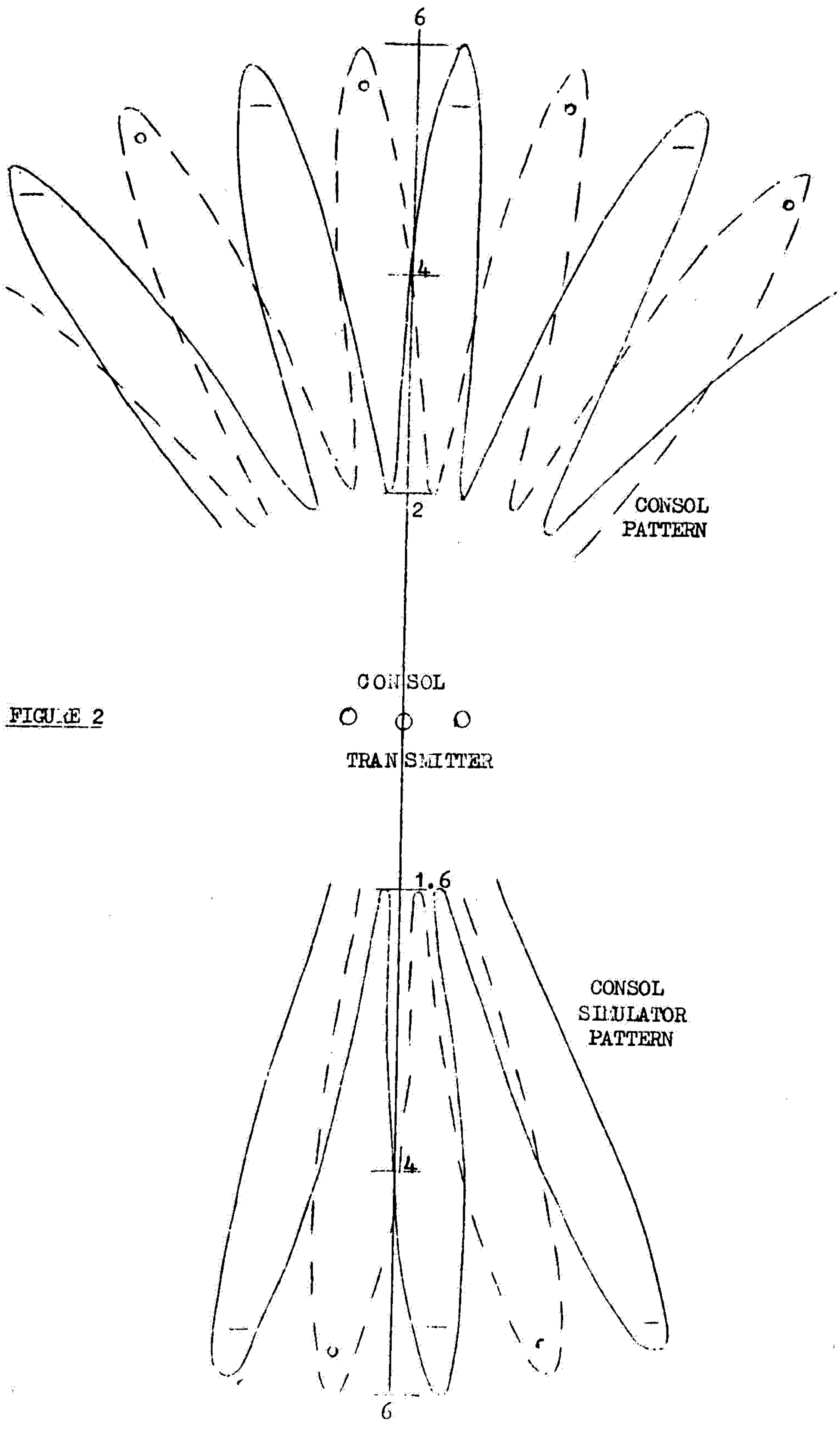

6
4
2
CONSOL PATTERN
CONSOL
TRANSMITTER
1.6
CONSOL SIMULATOR PATTERN
4
6

FIGURE 2

As the tests were performed on 300 kc/s and the lowest frequency obtainable on the receiver was 2 Mc/s, it was necessary to add a further mixer to the imput. The circuit diagram of this mixer is shown in Figure 3.

With the receiver dial set to 2.7 Mc/s a signal of 300 kc/s was received. The deterioration of noise factor caused by the addition of the mixer was not important as atmospheric noise was always the limiting factor.

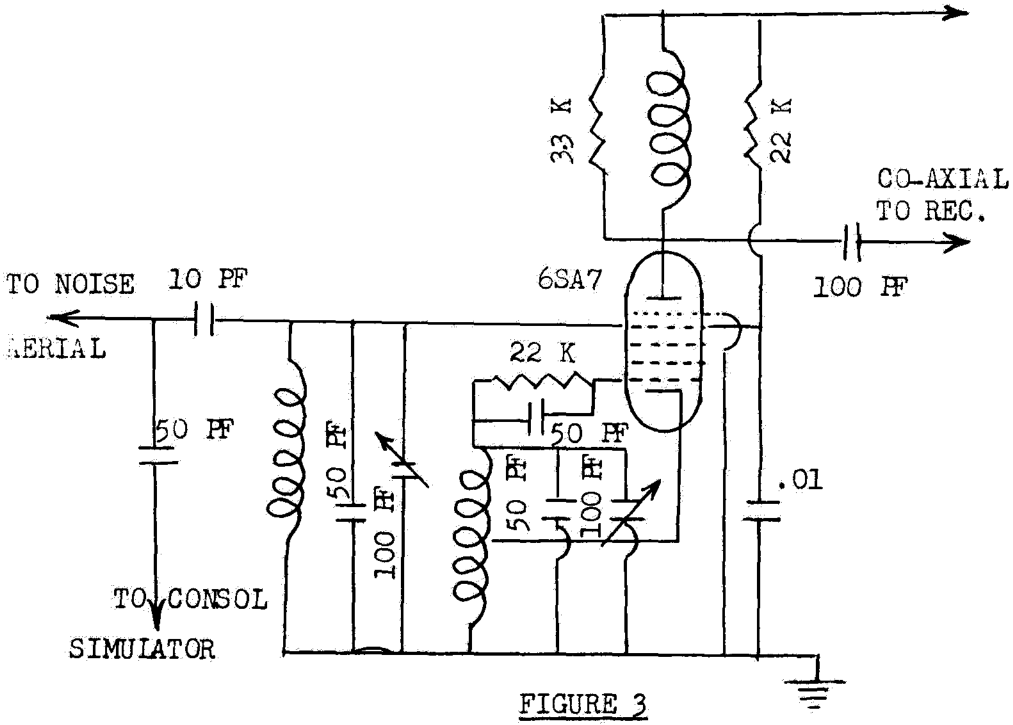


FIGURE 3

## 2.6.- T.R.L. 100 kc/s Noise Recorder

This unit is fully described in "The Measurement of Atmospheric Radio Noise in South Africa in the Low Frequency Band", Transactions of S.A.I.E.E., July 1950. For the purpose of the Consol tests the recorder was read visually at frequent intervals.

## 2.7.- Measurement Procedure

The various units were connected up as shown in Figure 4. The dummy aerial used to feed the Consol simulator signal was a 50 pF condenser.

Two operators were required to conduct the tests, one to interpret the signal heard in the phones, and the second to initiate the Consol sequence and to stop it at the correct moment by means of the C.W. - Consol Switch.

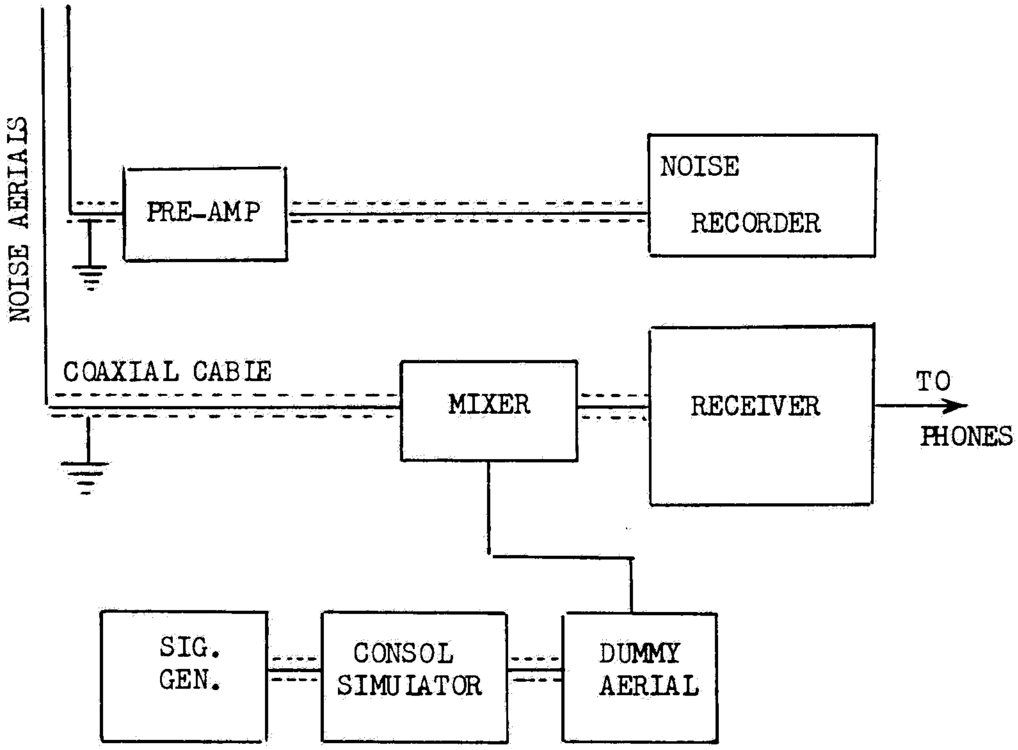


FIGURE 4

The noise level was read off the noise recorder by timing the movement of the cathode ray spot over a period of about two minutes, an appropriate signal level was set into the Consol simulator from the Signal Generator, and the Consol signal started at an arbitrary point on the simulator dial. After 30 seconds (i.e. 60 characters) the signal was switched back to C.W. and the apparent Consol position calculated from the count made in the headphones and compared with the dial indication. Four or five tests were taken at different cross-over points at each S/N ratio. Tests were also made at different receiver bandwidths.

A typical record sheet is shown in Figure 5.

The formula for deriving S/N ratios from the Signal Generator reading and the noise level was

$$S/N = \frac{\text{Signal Generator output}}{11.1 \times 2.2 \times \text{noise } \mu V/\text{metre}}$$

The Signal to noise ratio as calculated above refers to the signal at the maximum of the lobe and in this report all ratios will refer to lobe maximum.

FIGURE 5

| NOISE | SIG. | S/N | B.P. | READINGS | | TOTAL | MISSED | MEAN | ACTUAL | ERROR |
|---|---|---|---|---|---|---|---|---|---|---|
| 750 µv/metre | 1MV | .14 | 1500 | 8 | 35 | 43 | 17 | 16.5 | 15 | + 1-1/2 |
| | | .14 | 1500 | 35 | 15 | 50 | 10 | 40 | 41 | - 1 |
| | | .14 | 5000 | 32 | 18 | 50 | 10 | 37 | 35 | + 2 |
| | | .14 | 5000 | 39 | 12 | 51 | 9 | 43.5 | 44 | - 1/2 |
| | | .14 | 10kc | 12 | 12 | 24 | 26 | 25 | 21 | + 4 |
| | | .14 | 10kc | 37 | 4 | 41 | 19 | 46.5 | 50 | - 3-1/2 |

## 3.- ASSESSMENT OF PERFORMANCE IN ATMOSPHERIC NOISE

### 3.1.- Progress of Tests

The tests were carried out in December 1950 and January and February 1951 at Palmietfontein Airport, some 15 miles south-east of Johannesburg. The equipment was mounted in a panel van which was garaged in Johannesburg and driven out to Palmietfontein on suitable days. The testing site was situated on the south boundary of the Airport, about a mile from the nearest buildings from which man-made noise was likely to emanate. A 220 V 50∼ supply was available at this point.

No lack of atmospheric noise was experienced in the tests, which were carried out on a number of different days, with noise levels ranging from 100 µV/metre to 750 µV/metre. On a number of occasions violent local thunderstorms took place.

### 3.2.- Assessment of Performance

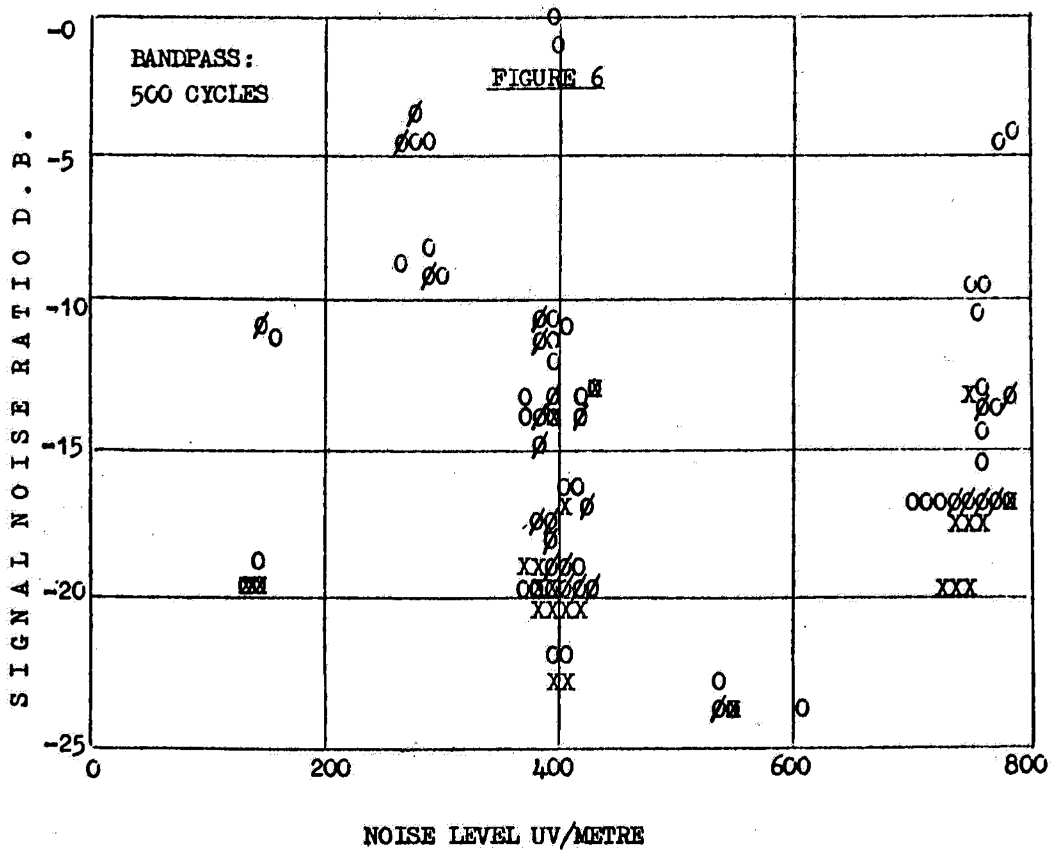
Figures 6 and 7 are graphs of signal to noise ratio in Db against noise level in µV/metre. The symbols indicate the accuracy in characters of each point. Each plot on the graph represents the error obtained by counting 60 characters in 30 seconds. The symbols are as follows:

0 to 1 character error ________ 0

1 to 3 " " ________ Ø

3 to 5 " " ________ ⊗

greater than 5 " " ________ X


BANDPASS:
500 CYCLES
FIGURE 6
SIGNAL NOISE RATIO D.B.
-0
-5
-10
-15
-20
-25
0
200
400
600
800
NOISE LEVEL UV/METRE

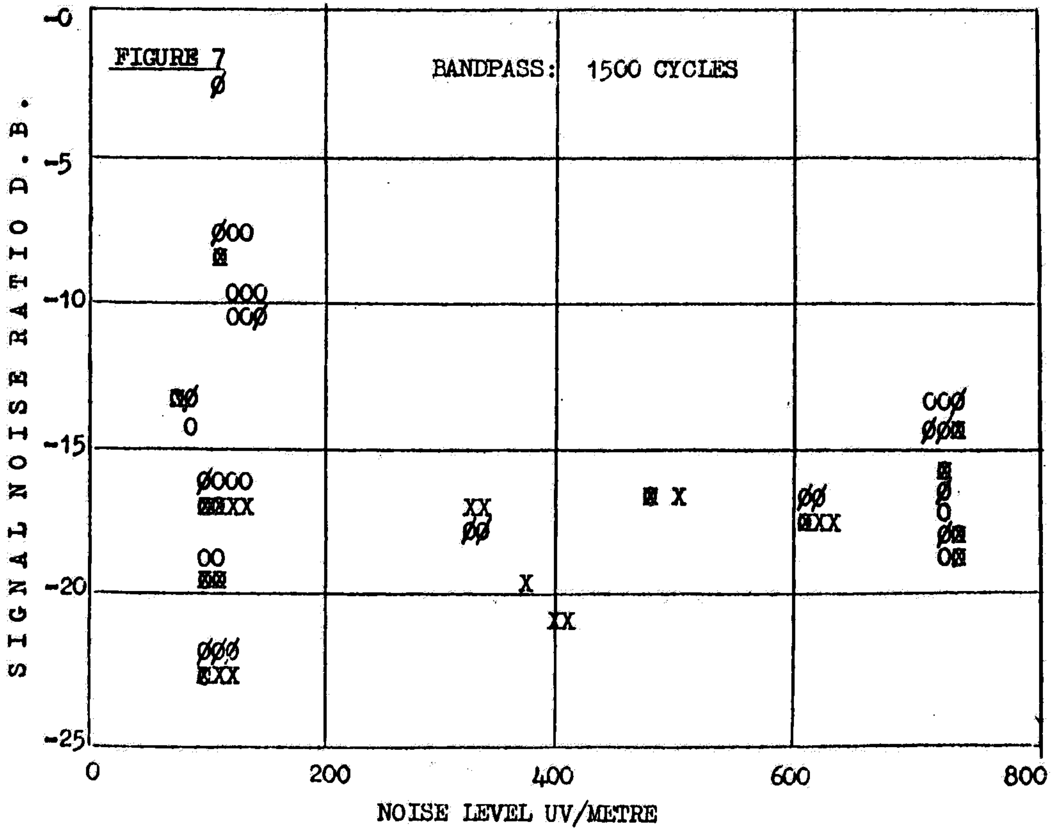


FIGURE 7
BANDPASS: 1500 CYCLES
SIGNAL NOISE RATIO D.B.
-0
-5
-10
-15
-20
-25
0
200
400
600
800
NOISE LEVEL UV/METRE

It is evident from these graphs that the noise level at which the measurement is made has little bearing on the accuracy of the answer. At any particular signal to noise ratio a considerable variation in the accuracy of the reading occurs. At - 16 db in Figure 6, for instance, a number of first class readings are interspersed with readings of 5 characters or more error. An error of characters in the final result is a serious one as it can mean that one count has been wrong by 10 characters or that each count has been out by 5 characters.

The deviation of accuracy at any particular S/N ratio can be accounted for by the nature of the noise. Typical noise consisted of a number of crashes followed by relatively quiet periods. These crashes at times completely obscured the signal heard in the headphones and on these occasions the operator counted through the crashes by knowing the rate of coding. If violent crashes occurred during the cross-over point or at the beginning or end of the cycle it was possible for the count to be badly out.

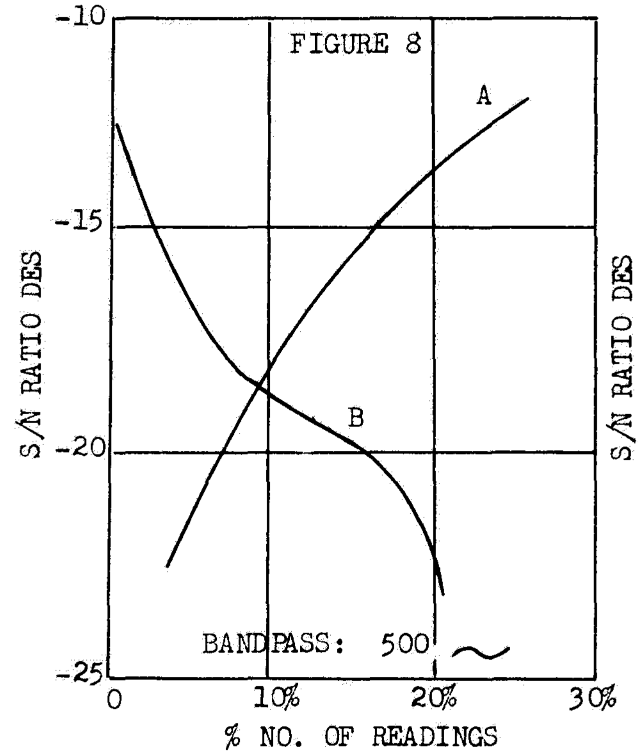
It is apparent from the above that the column marked "total" in Figure 5 is not the number of characters actually heard by the operator but includes some of those obscured by static crashes.

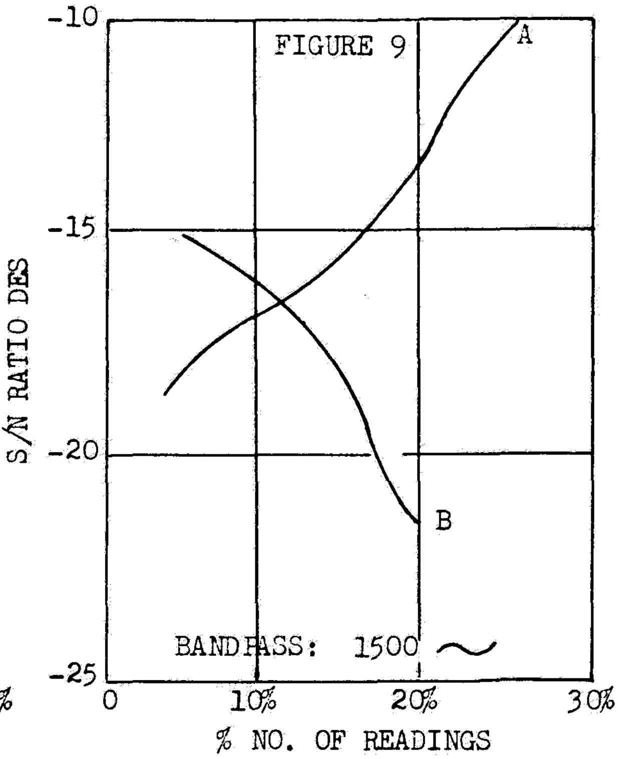
During the tests the operator's reaction to the changing signal to noise ratio was that at S/N ratios of - 16 db the Consol signals, although obscured by occasional crashes were readable without much effort. Below this ratio considerable doubt existed at the cross-over point but it was possible to obtain occasional good plots at ratios as low as - 22 db.

The points plotted in Figures 6 and 7 were taken at receiver bandwidths of 500 cycles and 1500 cycles. Figures 8 and 9 show cumulative frequency graphs drawn for the two bandwidths. Curve A in each case shows the number of observations indicated by Os expressed as a percentage of the total readings, at or below the S/N ratio in question. Curve B shows the number of observations indicated by Xs at or above the S/N ratio in question.

From the 500-graph it appears that at a S/N ratio of - 18 db 9% of the readings were bad and 9% good, with the rest intermediate. Taking 5 characters to one degree this means that a position line within ± $1^{o}$ is obtainable in 90% of readings at a S/N of - 18 db.

The cross-over point on the 1500 cycle bandwidth graph shows that for the same accuracy a signal to noise ratio of - 16 db is required. These figures agree well with the operator's impression when reading in noise.





It was found that the receiver bandpass had little effect on the S/N ratio required until the bandpass was of the order of 5 kc/s. Thus accurate plots were obtained during one test at a S/N ratio of - 16 db at all bandwidths except 10 kc, when the signal was practically obscured by noise. This effect has been observed in other work done by the Laboratory and it is assumed to be due to the ability of the operator to concentrate on one particular tone, in other words, the filtering action of the human ear.

## 4.- TELECOMMUNICATIONS RESEARCH LABORATORY 100 KC NOISE LEVEL DATA

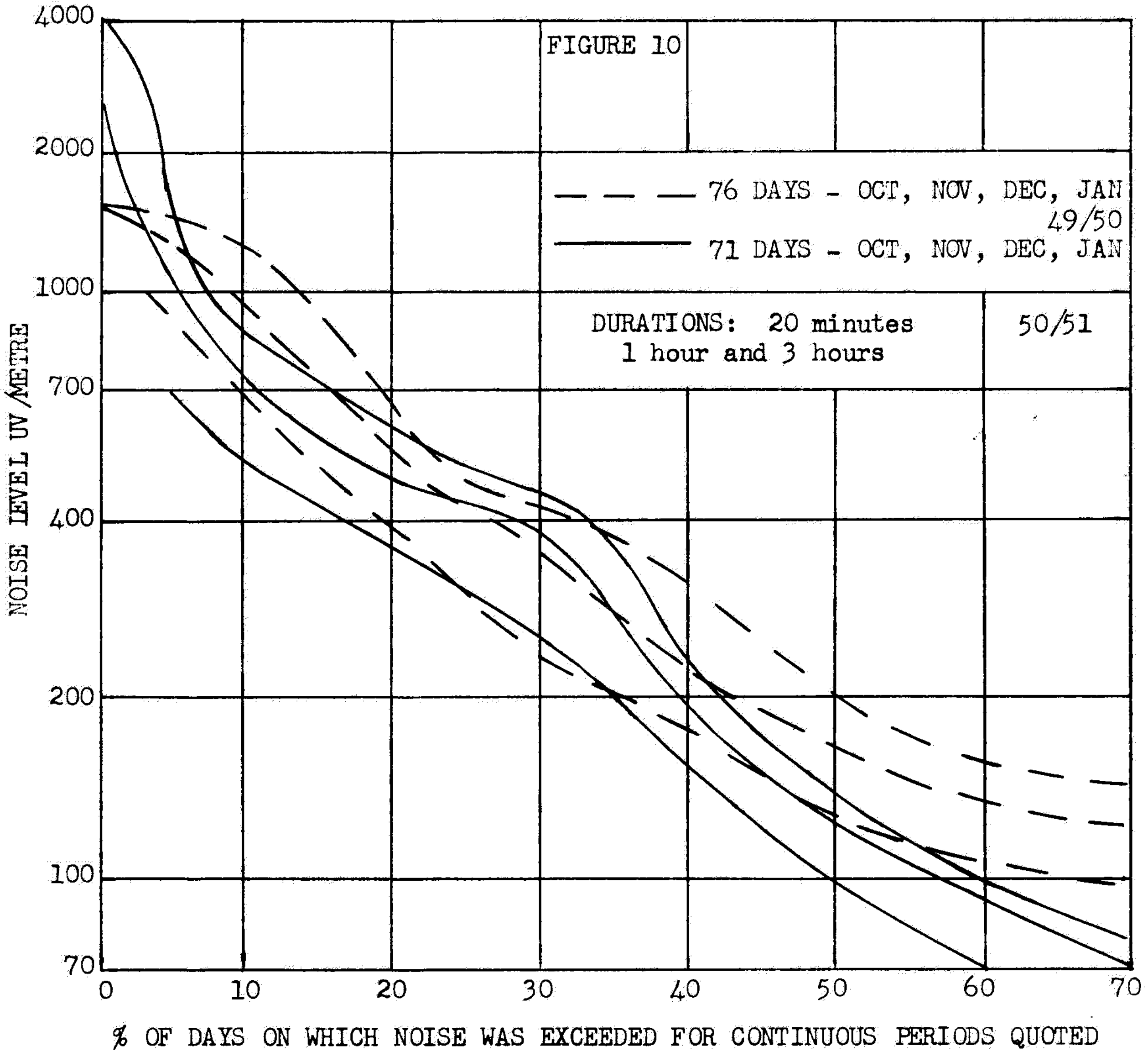
Information on 100 kc/s noise levels as recorded by T.R.L. in Johannesburg has been published in T.R.L. Report ETR-6, "The Performance of the Decca Receiver in High Atmospheric Noise Levels", and in the publication mentioned in 2.6 of this paper.

Since the publication of this data further information on 100 kc/s noise has been recorded. While a detailed analysis of these records has not been made, they appear to confirm the remarks made in the above-mentioned reports.

Figure 10 shows the percentage number of days on which the noise level exceeded a given level for various continuous periods of time. The results obtained in October, November, December 1949 and January 1950 are compared with those for the same period of 1950-51. It is apparent that the latter results are in general lower than those for the previous year.

## 5.- RANGE AND SERVICEABILITY

An estimate of the serviceability of a Consol station in atmospheric noise can be made with the aid of the graphs in Figure 10.



For this purpose the Consol frequency has been assumed to be 300 kc/s and the ground conductivity 6 x 10 - 14 e.m.u. The latter figure is a rough average conductivity for the Union of South Africa, based upon recent measurements. It is further assumed that the total radiated power from the three Consol aerials is 1 kW and the signal to noise ratio for reasonably good Consol operation is - 16 db or .15.

The field strength at the maximum of the Consol lobe at a given range will be $\sqrt{2}$ times the field strength set up by a single mast radiating 1 kW power and the following tables may be compiled.

TABLE I

| RANGE STATUTE MILES | 150 | 200 | 250 | 300 | 350 | 400 |
|---|---|---|---|---|---|---|
| SIGNAL STRENGTH μV/m | 480 | 255 | 156 | 92 | 57 | 35 |
| CRITICAL NOISE μV/m | 3200 | 1700 | 1000 | 610 | 380 | 230 |

TABLE II

| TIME U/S PER DAY | % NO. OF DAYS OF SUMMER MONTHS U/S* | | | | | |
|---|---|---|---|---|---|---|
| | 150 miles | 200 miles | 250 miles | 300 miles | 350 miles | 400 miles |
| 20 mins. | 3 | 6 | 14 | 21 | 36 | 47 |
| 1 hour | 0 | 3 | 9 | 17 | 33 | 44 |
| 3 hours | 0 | 0 | 3 | 12 | 22 | 34 |

* October, November, December, January.

The estimates in Table II were made by using the highest curve in Figure 10 at each period of time. The number of days unserviceable for the other months of the year at any of the ranges quoted will be small.

## 6.- CONCLUSIONS

The serviceability and accuracy which could be expected from a Consol station working in noise levels such as experienced on the Witwatersrand in summer has been estimated. It appears that with a total radiated power of 1 kW from a Consol station a range of 200 statute miles should be obtainable with a reasonable degree of serviceability. At this range during high noise levels the bearing accuracy will be ± 1° for more than 90% of the readings.

## INFORMATION SUBMITTED BY THE UNITED STATES

The following material contains some commercial airline operational experience with the five European CONSOL stations and with one experimental station which was operated within the United States in the years 1949-51.

The American CONSOL station installed at Allaire included Coarse and Fine systems, which practically eliminated the difficulties due to ambiguities. In the Fine system the ambiguities were approximately 30 degrees apart, and in the Coarse system were approximately 60 degrees apart. Automatic control circuits were provided for transmission of the Coarse system lines, every one to fifth transmission of the Fine system lines.

Three antennas were installed in a line, with the antenna at one end used in common with the other two to form two pairs of radiators. The common antenna and its nearest antenna were spaced one wavelength apart and were used to generate the Coarse system lines. The common antenna and the far end antenna were spaced three wavelengths apart and were used to generate the Fine system lines. Only one pair of antennas was energized at a time.

The Coarse pattern(average lobe width - 35 degrees) has since been discarded, since it is felt that the ambiguity factor of two lobe widths obtained with the Fine pattern, a minimum of 20 degrees in azimuth, can well be tolerated in a long range navigational system. At azimuths close to the antenna line, the observer may hear identical counts on both sides of the antenna line. However, movement of the observer one character laterally in either direction with respect to his initial line-of-position reading will enable the observer to determine the specific lobe covering his position. The reason for this is that the pattern's rotation on one side of the antenna baseline is counterclockwise, while the rotation on the other side of the baseline is clockwise.

One important improvement incorporated in the American CONSOL station was to minimize the horizontal radiation from the antenna feeders at the operating frequency, thus minimizing "night effect" and improving the system accuracy. This was accomplished by individually exciting each antenna at its base at the operating frequency. A low level signal which was a sub-harmonic of the operating frequency was transmitted over the transmission line feeders and multiplied and amplified at each tower site. Radiation from the transmission line would be at a sub-harmonic of the operating frequency and at low power level. This mode of excitation will be used in future American CONSOL stations.

Results of monitoring the CONSOL station indicated the 95 per cent system accuracy at fixed monitors to be between one-half and one and one-half degrees during the daytime and between approximately three-fourths and two degrees at night. It is, of course, not possible to state how much these errors would increase on the basis of one or two count readings in an airplane, but data from reports on evaluation of Sonne by the Germans showed that 25 percent of the readings of ground monitors were within one-third degree and all readings were within one degree, whereas in an airplane 25 percent of the readings were within one-third degree, but some readings were in error as much as three degrees. The results of some airline operational experience is attached hereto as Appendix 1.

## AIRLINE OPERATIONAL EXPERIENCE WITH CONSOL

Scheduled airline aircraft flying the North Atlantic Ocean are utilizing existing CONSOL stations on a routine operational basis.

Operators are using CONSOL because it utilizes equipments and practices which are a logical extension from current operating practice. Since CONSOL can be received on any one of a number of receivers already available in their aircraft, adequate standby is available with no additional increase in the weight or space requirement of the radio installation. The receivers are connected into the intercommunication system of the aircraft, thereby permitting full flexibility for use by all crew members on the flight deck as felt desirable. Special crew training and maintenance personnel training are minimized. CONSOL also provides a valuable high power NDB (non-directional beacon) service, and provides clean ADF overhead indications. The maximum range capabilities are good and the line-of-position accuracy for most of the coverage area is satisfactory.

An analysis by one carrier of flight logs and CONSOL route charts of sixty-six trans-North Atlantic flights indicated that the ranges obtained from three European CONSOL stations are as follows:

| CONSOL Station Used | No. of Flights which took Bearings (Line of Position) From Each Station | Averages of Usable Maximum Range | | |
|---|---|---|---|---|
| | | 10%* | 50% | 100% |
| Stavanger | 26 | 745 NM | 600 NM | 490 NM |
| Bushmills | 46 | 1160 NM | 890 NM | 240 NM |
| Ploneis | 28 | 1445 NM | 1260 NM | 600 NM |

---

* Percentages refer to the number of flights which used a particular CONSOL station. In other words, in the case of 10% factor for Stavanger, 745 nautical miles was the maximum range having satisfactory accuracy on 10% of the 26 flights which used the Stavanger station. These percentages were taken from a graph; therefore the fraction of a flight appears in the case of the 10% figures (10% x 26 = 2.6).

The above data was accumulated by the sixty-six flights over a <u>nine-month period in 1953</u>.

CONSOL counts were taken and lines of position plotted on specially prepared navigation route charts by pilots at their normal positions. Existing automatic direction finder and communications receiving equipments were utilized. There are certain refinements to existing airborne equipments which will significantly improve the maximum range of usefulness. The new automatic direction finder (ADF) equipment now under development for airline service will provide further improvements in signal-to-noise ratio and a general increase in range and accuracy.

The United States Air Force (1949-1951) operated an improved experimental model of CONSOL at Allaire, New Jersey on 193 kcs, and several airlines participated in the flight test program. One report consisting of 123 readings, taken in the North Atlantic on routine scheduled flights under winter conditions at ranges between 150 and 3005 miles, showed the following distribution of error:

39 bearings between 0 and 0.1 degrees
69 bearings between 0 and 0.5 degrees
101 bearings between 0 and 1.0 degrees
112 bearings between 0 and 1.5 degrees
120 bearings between 0 and 1.8 degrees
3 bearings at 1.8, 2.1 and 2.5 degrees

Although this is not a sufficient number of observations to rigorously apply probability theory, the figures show that 95 percent of the bearings were accurate to better than 1.6 degrees and 67 percent were within 0.6 degrees or better. Stated in another way, the system showed a standard deviation of 0.6 degrees.

The distribution in distance (i.e., range) of the above-reported values was:

| Number of Readings | Distance (Miles) |
|---|---|
| 14 | 100- 150 |
| 24 | 500-1000 |
| 34 | 1000-1500 |
| 32 | 1500-2000 |
| 11 | 2000-2500 |
| 8 | 2500-3005 |

Since the ground equipment was operated properly by competent engineers, and considering the pilot comments with each observation, it is believed realistic to say that this station, operating on a properly cleared frequency to avoid interference and utilizing standard airborne equipment modified slightly to obtain the signal-to-noise ratio improvement feasible in the CONSOL mode of reception, could have provided even better over-all range and accuracy.

An analysis of the over land readings taken by United Air Lines during the period from November 1949 to January 1950 gives some interesting results. Readings were taken at various altitudes up to 17,000 feet and up to distances of 1520 statute miles over known fixes, with one reading taken at 1650 miles on an airport with a measured error of 34 minutes. A plot of the data indicates the distribution of error independent of distance, to a marked degree. None of the flight crews were experienced in the use of CONSOL and some of the data reflects this fact. Using the total of 212 readings did not give a good Caussian distribution. Screening data and eliminating those that were noted on the data sheets by the crews as being doubtful, due to noise and other interference conditions, the resultant data improved but still did not approximate a normal random distribution by a factor of two to one between the 95 percent and 67 percent probabilities. Further screening of the data to eliminate the inexperience of pilots by discarding the readings of two flights brought the data in closer conformity to the Caussian distribution. The results of this screening reduced the useful readings to 194, with the following results as to probability;

95 percent readings - error less than 1° 25'

67 percent readings - error less than 0° 34'

50 percent readings - error less than 0° 24'

It will be noted that the standard deviation is approximately 0.6 degrees, which agrees reasonably well with the data taken over water. The 95 percent value is slightly better than the over water value, and is closer to the probability theory. The agreement between the measured mean and the computed mean from the standard deviation value is within one minute. The change in standard deviation by attempting to compensate for pilot inexperience changed only ten percent, while the mean changed four percent. The 95 percent value changed from 3.7 to one ratio with respect to the 67 percent value to a 2.5 ratio. For a true Caussian (normal random) distribution, the ratio is 2.0.

## Notes on Existing CONSOL Stations

There are five stations presently in operation along the east coast of U.K./Europe, as follows:

| | |
|---|---|
| Stavanger, Norway | 318 kcs. |
| Bushmills, Northern Ireland | 266 kcs. |
| Ploneis, France | 257 kcs. |
| Lugo, Spain | 303 kcs. |
| Seville, Spain | 311 kcs. |

The Stavanger, Lugo and Seville CONSOL stations have one common undesirable characteristic which, particularly at night, greatly impairs their usefulness, that is, they are "slow count" stations or operate on a sixty-second keying cycle with a sixty-second break period between keying cycles. It is necessary when using CONSOL at night to make three successive counts to check for the presence of sky-ground wave distortion and, in the case of a "slow count" station, the minimum period in which this can be achieved is five minutes, and if atmospherics and interference are present, it may take somewhat longer. A time requirement of five minutes, or possibly longer, to obtain a single line of position is longer than that required for other methods, including celestial.

These three stations also suffer from interference by marine radio beacons and other L.F. aeronautical aids, operating as they do in the 303, 318 kc. range. The other two CONSOL stations operating on 257 and 266 kcs. are not so affected.

The Stavanger, Norway CONSOL station has been very reliable with regard to maintaining continuous operation, and on the other hand, the two Spanish stations have been extremely unreliable, it being rare to find both stations operating simultaneously and occasionally both are off the air. The Spanish government is reported to be correcting the deficiencies of those two stations.

The CONSOL stations at Bushmills, Northern Ireland and Ploneis, France provide by far the most satisfactory service of the group. They are "fast count", or thirty-second keying cycle stations with Bushmills having a nearly perfect record from the standpoint of maintaining schedule. Ploneis has not been as good in this respect.

\- END -

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*The following summary gives the status, and also describes in general terms the contents of the various series of technical publications issued by the International Civil Aviation Organization. It does not include specialized publications that do not fall specifically within one of the series, such as the* ICAO Aeronautical Chart Catalogue *or the* Combined Meteorological Tables for International Air Navigation.

*INTERNATIONAL STANDARDS AND RECOMMENDED PRACTICES* are adopted by the Council in accordance with Articles 54, 37 and 90 of the Convention on International Civil Aviation and are designated, for convenience, as Annexes to the Convention. The uniform application by Contracting States of the specifications comprised in the International Standards is recognized as necessary for the safety or regularity of international air navigation while the uniform application of the specifications in the Recommended Practices is regarded as desirable in the interest of safety, regularity or efficiency of international air navigation. Knowledge of any differences between the national regulations or practices of a State and those established by an International Standard is essential to the safety or regularity of international air navigation. In the event of non-compliance with an International Standard, a State has, in fact, an obligation, under Article 38 of the Convention, to notify the Council of any differences. Knowledge of differences from Recommended Practices may also be important for the safety of air navigation and, although the Convention does not impose any obligation with regard thereto, the Council has invited Contracting States to notify such differences in addition to those relating to International Standards.

*PROCEDURES FOR AIR NAVIGATION SERVICES* (PANS) are approved by the Council for world-wide application. They comprise, for the most part, operating procedures regarded as not yet having attained a sufficient degree of maturity for adoption as International Standards and Recommended Practices, as well as material of a more permanent character which is considered too detailed for incorporation in an Annex, or is susceptible to frequent amendment, for which the processes of the Convention would be too cumbersome. As in the case of Recommended Practices, the Council has invited Contracting States to notify any differences between their national practices and the PANS when the knowledge of such differences is important for the safety of air navigation.

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| | |
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| **COM - Field Manual No. 1. — Communication procedures.**<br>(Doc 4478-COM/501/3). 2nd edition, April 1955.<br>34 pp. Letterpress | $0.50 |
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|---|---|
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