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The

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1st QUARTER 1958

Vol. XXI

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MARCONI'S WIRELESS TELEGRAPH COMPANY LIMITED

Head Office, Marconi House, Chelmsford

Telephone, Chelmsford 3221

Telegraphic Address, Expanse, Chelmsford

Telegrams: Expanse, Chelmsford.

COMMUNICATION COMPANY, LIMITED

Telephone: Chelmsford 3221.

Telegrams: Thulium, Chelmsford.

DEVICE COMPANY, LIMITED

Telephone: Chelmsford 3221.

Telegrams: Thulium, Chelmsford.

ION COMPANY, LIMITED

Telephone: Chelmsford 3221.

Telegrams: Thulium, Chelmsford.

NAL CODE COMPANY, LIMITED

Telephone: Covent Garden 1234.

Telegrams: Docinocram.

UMENTS, LIMITED

Telephone: St. Albans 6161/5.

Telegrams: Measurtest, St. Albans.

S LIMITED

Telephone: Felling 82178.

Telegrams: Scanners, Newcastle-upon-Tyne.

THE MARCONI REVIEW

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RADIO OBSERVATIONS OF ARTIFICIAL SATELLITES

THE use of artificial satellites was originally suggested as part of the International Geophysical Year in order to investigate phenomena in the upper atmosphere more effectively than could be done from the ground or from a rocket. Some useful information has been obtained from the satellites launched so far, and in this the observation of radio signals from the satellites has played an important part.

The radio signals from a satellite can be used to determine its position and velocity and hence its orbit. If the gravitational field of the earth obeyed the inverse square law and if there were no atmospheric drag, the orbit would be a fixed ellipse. Deviations of the true orbit from an ellipse give information about the gravitational field and the atmospheric drag.

In addition, the radio signals travel through the ionosphere and consequently their characteristics, when they reach the ground, give information about the ionosphere.

The frequencies radiated from the first two Russian satellites were 20 Mc/s. and 40 Mc/s., sometimes on-off modulated and sometimes continuous wave. The characteristics measured on the ground were amplitude phase, frequency, and, for the modulated signal only, time of arrival. Many simultaneous measurements were made on different frequencies or on different aerials, either separated by a few wavelengths or of different polarizations. The nature of these measurements and some results for the first satellite were described in *Nature*, November 2nd and 16th.

Measurements of frequency and of phase difference between signals received on separated aerials were used with considerable success to determine the orbit of the satellite. It is noteworthy that a good estimate of the orbit and the rate of change of period was obtained in a few days from observation at one station only. Further

observations enabled the orbit to be determined more accurately, and the final figures obtained from radio measurements only have provided a good check on one of the expected effects of the oblateness of the earth. The amount of the atmospheric drag was also well determined from radio measurements.

In addition, radio measurements have provided information which facilitated optical and radar observation of the second satellite. No optical or radar observations of the first satellite from this country have yet been reported, although it was seen in U.S.A. in October; it seems reasonable to suppose that these sightings were made easier by the radio information available. There is no doubt that optical observation of a satellite provides the most accurate means of locating it, but this method of observation suffers from the disadvantage that it can only seldom be carried out. For example, the second satellite, which is quite large and bright, could be seen from Chelmsford on only about six occasions during December, although it was above the horizon and therefore radio transmissions from it would have been received on about two hundred occasions.

Optical observations are limited by the double requirements of twilight and clear skies. Neither of these limitations apply to radar, but rather special apparatus is required. Moon and meteor radars and ionospheric sounders have received echoes from satellites, but most other types of radar, as designed, are unsuitable for looking at them. The necessary modifications needed would, therefore, have made them unsuitable for other purposes.

Some long distance reception of signals from satellites has proved interesting. Signals which have gone right round the world have been detected on both frequencies, and it seems that satellites will afford a useful opportunity of investigating these "round-the-world echoes", the mechanism of which is still not understood.

So far it has proved difficult to deduce the detailed properties of the ionosphere from radio measurements. At the time of observation it was not fully realized what observations should be made, and such incomplete or inexact observation makes interpretation different. Also there is no optical information to compare with the radio data, and finally the theory is not fully worked out. However, it is to be expected that some information about the ionosphere will be obtained from the full analysis of observations made so far, and more exact information from observation on future satellites.

D. H. SHINN

A 3 cm. AIRPORT CONTROL RADAR SYSTEM

BY F. W. GARRETT

In a modern airport with many aircraft movements, the maintenance of a high traffic density flow consistent with safety tends to make the problem of Air Traffic Control fairly complex, particularly in adverse weather conditions.

In the Marconi Company, the design and application of an Airfield Control or Surveillance Radar System to assist in this problem has received considerable attention.

The following describes a high power 3 cm. system developed as one approach to the problem.

Introduction

THE general requirements of the system were as follows.

1. Operational cover up to 5,000 ft. at a range of 30 miles on a DC3-type aircraft with a minimum cone of silence.
2. The overall power consumption of the equipment with auxiliaries should not exceed 5 kW. if possible.
3. The equipment should be as compact as practicable and capable of fitting into existing control tower facilities.
4. The weight of the aerial system should be kept to a minimum and should not in any case exceed 2,000 lbs. maximum.
5. The system should be capable of resolving two aircraft targets at the same range, subtending an angle of three degrees and on the same bearing with a range of discrimination of the order of 100 yards.

The adoption of a system in the 3 cm. band in preference to one of a longer wavelength permitted the requirements to be fulfilled with lower power consumption and weight, coupled with a smaller physical size of aerial to obtain the desired resolution from the system.

The advantages and disadvantages of a 3 cm. system were appreciated and the susceptibility of the operational performance to the effects of adverse weather conditions were considered.

The measures adopted to counter these conditions and their effectiveness will be described.

General Technical Considerations and System Design

The operational cover was achieved by the use of a suitable twin aerial system; the long range cover by a cosec² beam, and the short range by a square fan beam.

The bottom cut off of both patterns were designed to give minimum ground reflections.

The R.F. power requirements for this cover were met by the use of the English Electric Valve Co. Type M502. (4J50) Magnetron.

Radio Observations of Artificial Satellites

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A 3 cm. Airport Control Radar System

Fig. 1 shows the vertical cover diagram derived from a series of test flights. The horizontal beam width is 1.6 degrees to half power points.

Other technical data of the system are listed below:—

R.F. Peak Power	...	...	...	...	200 kW.
P.R.F.	...	...	...	...	1,000 per sec.
Pulse length	...	...	...	...	0.5 μ sec.
I.F.	...	...	...	...	30 Mc/s.
I.F. Bandwidth	...	...	...	...	4 Mc/s.
N/F	...	...	...	...	12 dB
Amp. Gain	...	...	...	...	\leq 140 dB

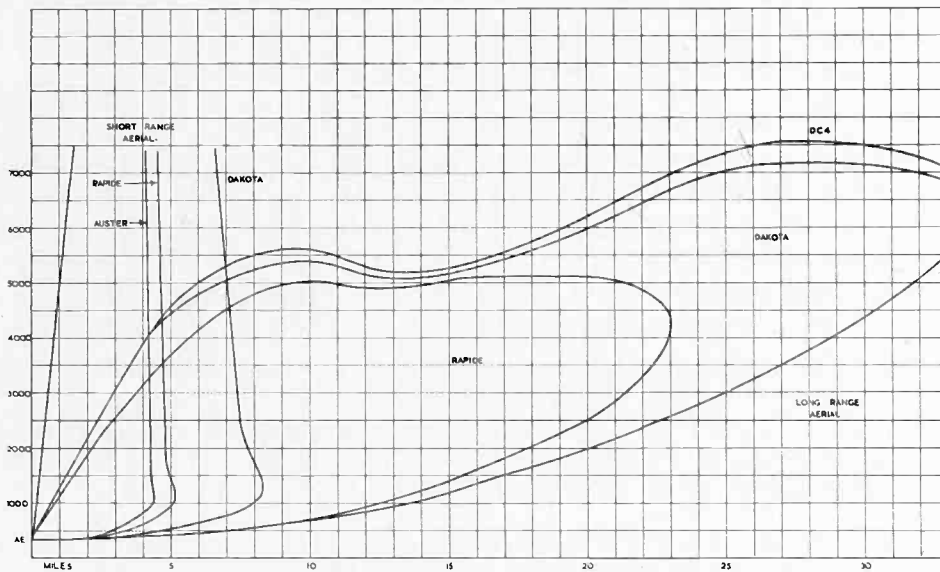


FIG. 1

Four range scales are provided of 2½, 5, 15 and 30 miles. Range marker rings at ½, 1, 3 and 5 miles respectively and a single adjustable ring can be displayed.

Provision is made for the display of a marker line from the Type AD200 VHF.D/F system and a north heading line.

A continuous scan through 360 degrees is maintained at 20 r.p.m. and the display is automatically aligned to the aerial. Changeover of aerial automatically switches the display trace to the correct orientation.

Selection of aerial is normally automatic with change of range, the 2½ and 5 mile ranges being covered by the short range aerial and the 15 and 30 mile by the long range cosec² aerial. An overriding switch is, however, provided for manual selection to meet possible operational requirements.

A block schematic diagram of the system is shown in Fig. 2.

A 3 cm. Airport Control Radar System

General Description of the Equipment

The equipment was divided into the following main units. Transmitter, Display Console, Aerial System, Motor Generator and Control Rack. Equipment control is automatic and electrically interlocked, manual controls being kept to a minimum.

Provision is made for local and remote operation.

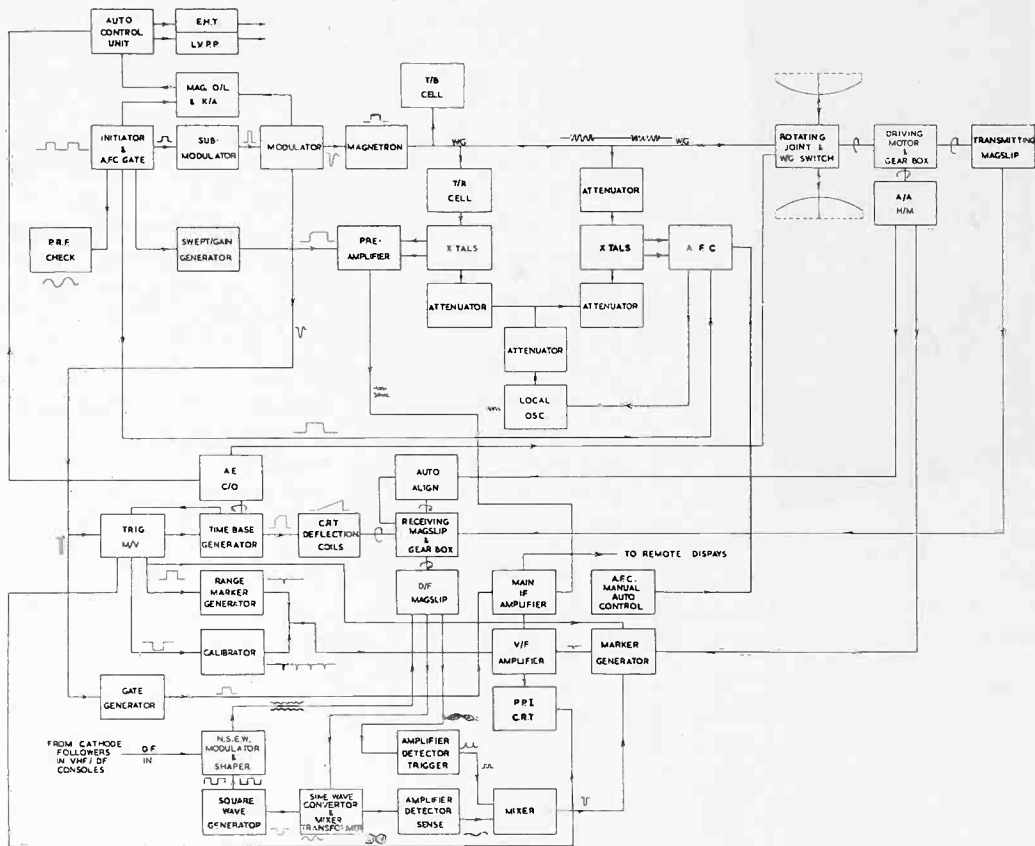


FIG. 2

In order to conserve valve life, particularly of the magnetron, and of the display Cathode Ray Tube, push button controls provide a two-stage sequence, Start/Stop and Run/Standby buttons being provided at the remote and local operating positions, the remote position being at the Display Console and the local position at the Transmitter and Power Rack.

The motor generator and aerial driving motor are supplied from a 400V 50 c/s. 3 Ph. supply (Star-Delta control in both cases), and the equipment supply is 180V 500 c/s. 1 Ph. from the motor generator with 50V D.C. for relay operation and signal lamps.

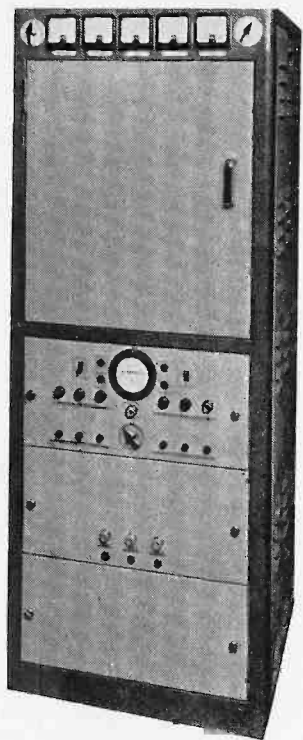


FIG. 3

Transmitter

The transmitter (Fig. 3) incorporates the following units. Initiator and Gate Generator, Modulator, R.F. system, I.F. Pre-amplifier and A.F.C., Control unit, L.T. and E.H.T. power supplies.

A number of ancillary items were included for test purposes. A Thermistor Bridge for R.F. power measurement, High Q Echo Box for performance checking, frequency measurement and spectrum analysis, and a P.R.F. check circuit.

A fan blown cooling system is incorporated, and where practicable the units were mounted on runners to facilitate servicing.

Initiator Unit. This unit provides the initial triggering pulse for the system and gating wave-forms for the A.F.C. and pre-amplifier units. Also included in this unit are protection circuits for magnetron overload, and the failure of "keep alive" voltage to the T/R cell.

Modulator. The modulator is of the Hydrogen Thyatron type and is triggered from a sub-modulator unit. Near resonance charging of the pulse forming network is employed. The output pulse is fed via a pulse transformer and magnetron heater unit to the magnetron. A shunt diode overswing circuit is incorporated.

Filter circuits are fitted for integrating the magnetron pulse current for E.H.T. auto-lock as a protection against undercurrent conditions, and for the diode

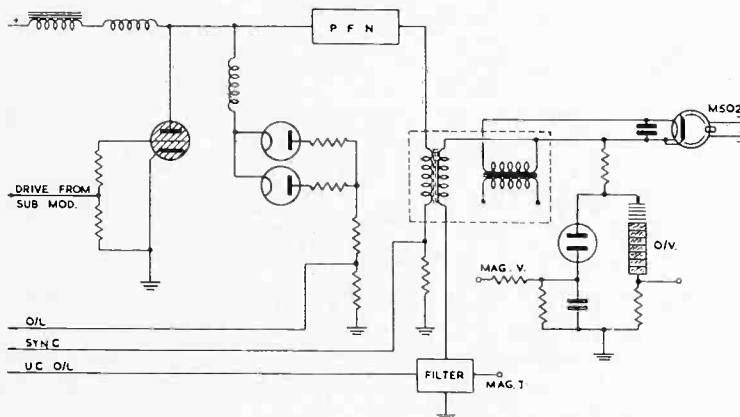


FIG. 4

overswing circuit against magnetron sparking. The short circuit condition resultant upon magnetron sparking is set at 15% of the P.R.F. rate to cause an overload trip.

A 3 cm. Airport Control Radar System

Short circuit conditions of this nature reflect onto the charging circuit and can rapidly lead to a dangerous build-up of potential, and the shunt diode network will protect against such a condition. A simplified schematic is shown in Fig. 4.

R.F. Section. This shelf houses the magnetron and a broad band balanced mixer system with a Type K302 local oscillator.

A double directional waveguide coupler and thermistor mount is provided for R.F. power and S.W.R. measurements. This feature allows for a check on the

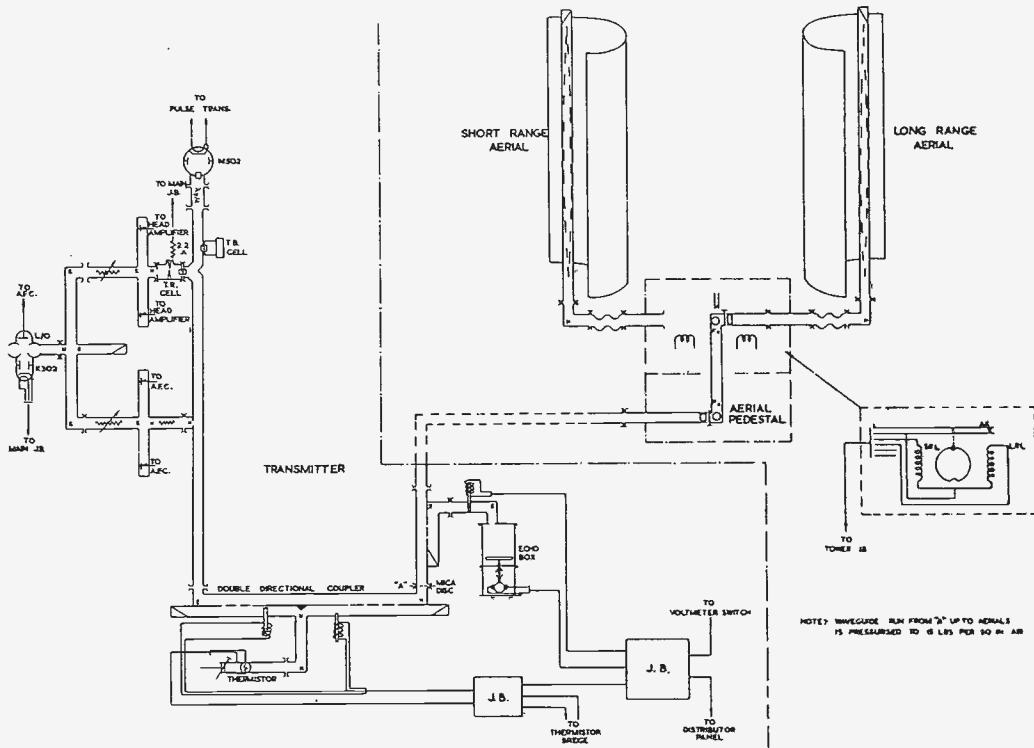


FIG. 5

condition of the transmission system. The high Q cavity echo box is fed from a single directional coupler. The coupling and slot directivity of these two items to the main waveguide run is controlled by solenoid operated probes. A schematic of the complete R.F. system is shown in Fig. 5.

The received signals are fed to a low noise cascode type pre-amplifier with a gain of the order of 25 dB. The input noise figure for this amplifier is of the order of 2 dB. In order to conserve valve life and power requirements the amplifier is gated "on" for the duration of the longest range time of the system. The leading edge of this switching waveform can be varied in rise time, thus permitting of "swept" gain. The slope to maximum gain is variable in one mile steps up to five miles and is set to suit local conditions and to prevent overloading of the amplifiers from strong nearby signals.

The A.F.C. comprises a three-stage amplifier feeding a discriminator via a delta type network, coupled to a sweep valve circuit which acts as a D.C. amplifier when locked, controlling the potential applied to the local oscillator klystron reflector.

Provision is made to ensure against klystron reflector "runaway."

The amplifier is gated "on" by a 15 μ sec pulse, derived from the Initiator Unit, which overlaps the transmitter pulse to which the unit is referenced via its crystal mixer.

Here again gating conserves power requirements and valve life, and an optimum gate time is provided for operating and load conditions.

Provision is made for manual control of the klystron reflector tuning in the event of a failure of the A.F.C. system.

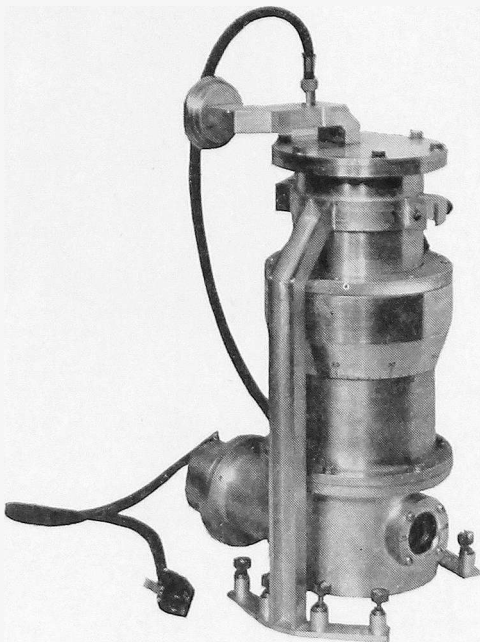


FIG. 6

Echo Box. As mentioned previously this unit, which is shown in Fig. 6, serves a number of functions. The ringing time of the cavity is in the order of 30 μ secs. and a motor driven piston can be made to oscillate in the cavity giving a bandwidth sweep of approximately 15 Mc/s. The cavity itself is tunable over a bandwidth from 9315 to 9485 Mc/s.

During a performance check the oscillating piston will produce a "sunflower" pattern on the Display Console C.R.T. as it sweeps through the bandwidth of the receiver system. A range check to the tips of the "petals" will provide a ready assessment on the performance of the system.

All supplies to this shelf are filtered and fed through screened leads.

Control Unit (Fig. 7). As mentioned earlier the system control is automatic and the sequencing and interlocking are provided by this unit. The interlocking also covers fault protection.

The initial control of the power supplies to the various units in the Transmitter is performed by a cam-timer. This form of control is particularly useful in allowing for the heating time of the Thyatron modulator valve. This timer will run the Transmitter up to the Standby condition.

Application of E.H.T. is controlled by a further small motor timer operated from the "Run" button, switching the E.H.T. step by step to the required value. The final value is pre-set by a "Variac" control to suit the particular magnetron operating condition. Operation of the "Run" button also starts the aerial driving motor.

Provision is made for the insertion of a negative temperature characteristic resistance into the magnetron heater supply to prevent surges during the initial switch-on. Effectively there are three interlocking lines for E.H.T. control:

- (1) Primary power supply sequencing, and low voltage fault protection, including air supply.
- (2) E.H.T. fault interlock, which protects against overloads, magnetron undercurrent and sparking conditions, modulator faults, etc.
- (3) Aerial changeover interlock to ensure that the main waveguide outlet in the Aerial Pedestal is aligned to the selected radiator. Removal and restoration of E.H.T. is automatic on aerial changeover during operations.

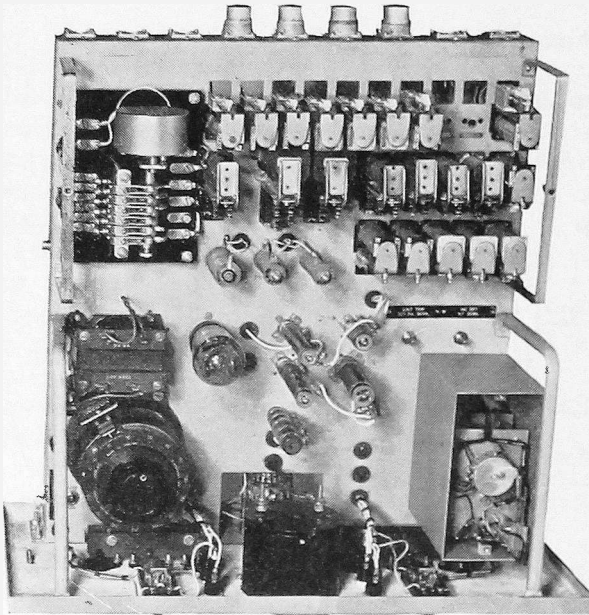


FIG. 7

bridge rectifier system and supplies up to +4 kV. to the modulator.

Display Console

This unit (Fig. 8) provides for the normal Plan Position Indicator (P.P.I.) type of presentation with a range scale coverage of $2\frac{1}{2}$, 5, 15 and 30 miles.

The Display unit, Control unit and Time Base Generator and associated powerpack is a modified version of the Radiolocator Display System⁽¹⁾ with a 12 inch diameter presentation.

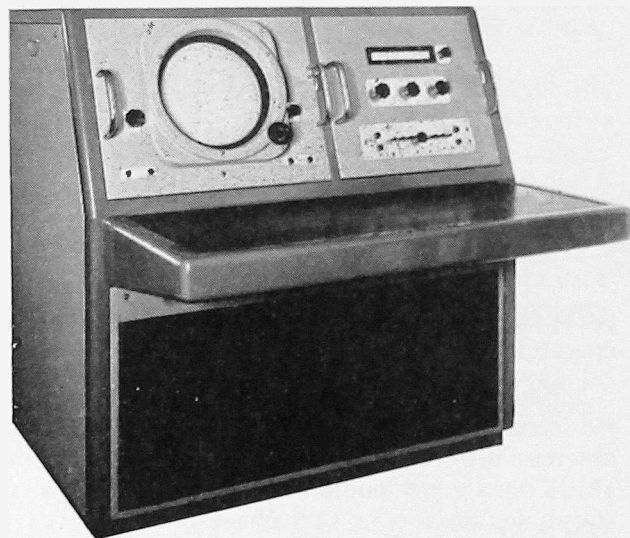


FIG. 8

This is a rotating coil system and bearing transmission between the aerial and the Display is provided by magflip transmission through a gearbox. Auto aligning is incorporated to ensure correct azimuth alignment. Coupled to the gearbox is a two phase magflip used in connection with the D/F superposition facility which will be referred to later.

Provision is made for the coupling of an additional display to the system.

Main I.F. Amplifier. Two types of amplifier are available; a Linear type and a Logarithmic or compression

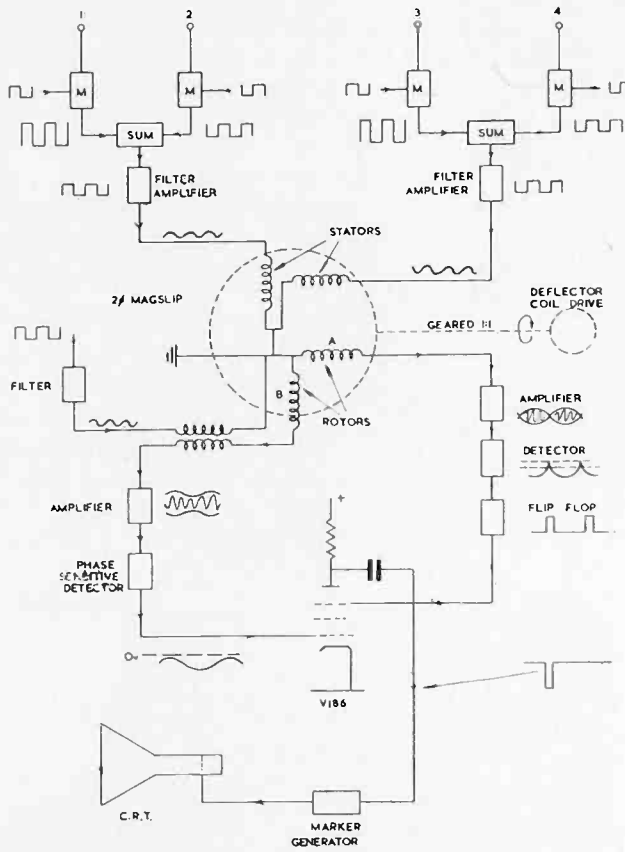


FIG. 9

particular aircraft echo signal⁽²⁾. The following is a brief description of the operation of this unit and a simplified block schematic is shown in Fig. 9.

Four D.C. levels relative to zero and corresponding to an indicated bearing are fed from the D/F system. These levels, the resultant of the NSEW vectors, vary differentially about a datum in proportion to the sine and cosine of the bearing. These signals are modulated, smoothed by filters and fed to orthogonally disposed stator windings of a two phase magflip. The rotor has two windings similarly disposed and is rotated in synchronism with the aerial. The rotor outputs are fed

and a Logarithmic or compression type. The logarithmic characteristic covers a range from -20 to $+60$ dB with respect to noise. Differentiation may be applied to either amplifier, the logarithmic amplifier having a particular application in mitigating the effects of rain, and on coastal sites of sea clutter. Also incorporated in the logarithmic amplifier is an inverse characteristic video stage to increase the contrast of signals in noise.

These amplifiers are gated and the output is fed to a video amplifier where the range and azimuth markers are added.

D/F Superposition Unit. This facility was developed to enable bearings from the Type AD200 VHF.D/F system to be superimposed on the P.P.I. display to facilitate identification of a

to a phase sensitive detector and a trigger circuit respectively, the former having a filtered modulating carrier added. This signal has one maximum per revolution whereas the output fed to the trigger circuit has two minima.

The respective signals are fed to the control and suppressor grids of a valve circuit to give sense and the resultant output is passed to a line marker generator.

General. Full metering and test facilities are available on the console and all units are mounted on runners to facilitate servicing. An engraved ground glass

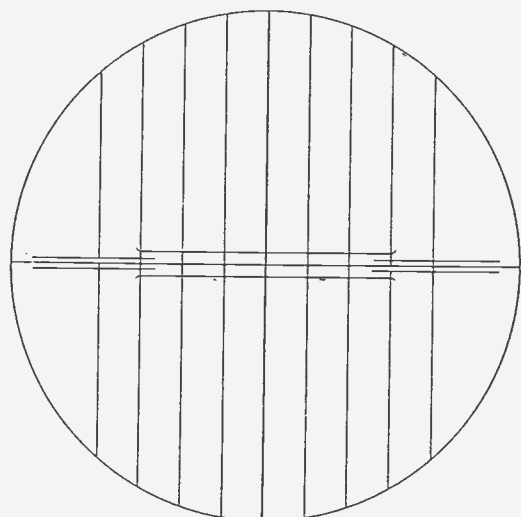


FIG. 10

screen was fitted to the desk for recording meteorological data and aircraft tracks. A special engraved cursor, shown in Fig. 10, devised by the author, was fitted to the display to facilitate off centre tracking and approach line-up.

Aerial Pedestal

The pedestal unit (Fig. 11) is supported on a tubular structure with twin back to back aerial radiator assemblies mounted on the rotating portion.

Housed in the unit is the driving motor, associated gearing and oil pump, bearing mag slip transmitter, waveguide rotating joint and switch for feeding to either

scanner, slip rings and auto-align contact assembly.

The rotating joint is a broadband iris matched E plane type and the waveguide switch position is controlled by two 50V solenoids, the rotation of the aerial being utilized to provide the necessary movement.

The aerial assemblies are parabolic reflectors with slotted waveguide feeds, the slot distribution being designed to give the desired vertical coverage. The respective assemblies can be tilted mechanically to give the desired elevation angle and to correct for frequency squint effect. The slotted radiators are encased in a Fibreglass-Dialux housing.

The waveguide feed from the Transmitter and the aerial radiators is supplied with "dry air," pressurized to approximately 15 lbs. per sq. inch. This is to minimize losses through possible condensation and to increase the power handling capacity of the system, giving an improved factor of safety against slot breakdown.

Circular polarizing "gates" are fitted to the reflector assembly and can be closed across the front of the reflector as and when required. They are of the delay lens quarter wave plate type, angled at 45 degrees.

Power Control and Distribution Rack

This unit, shown in Fig. 12, houses the starters for the motor generator and

aerial driving motor, the waveguide air compressor unit and desiccator and distribution boxes.

Interlocking contactors are provided on the motor generator starter to prevent running up on load and to disconnect the equipment when switching off. Local control is available for test purposes.

Operational Performance

A comprehensive programme of trials was conducted with the equipment with a view to assessing the performance and reliability under operational conditions. Particular attention was paid to the continuity of plot under adverse weather conditions.

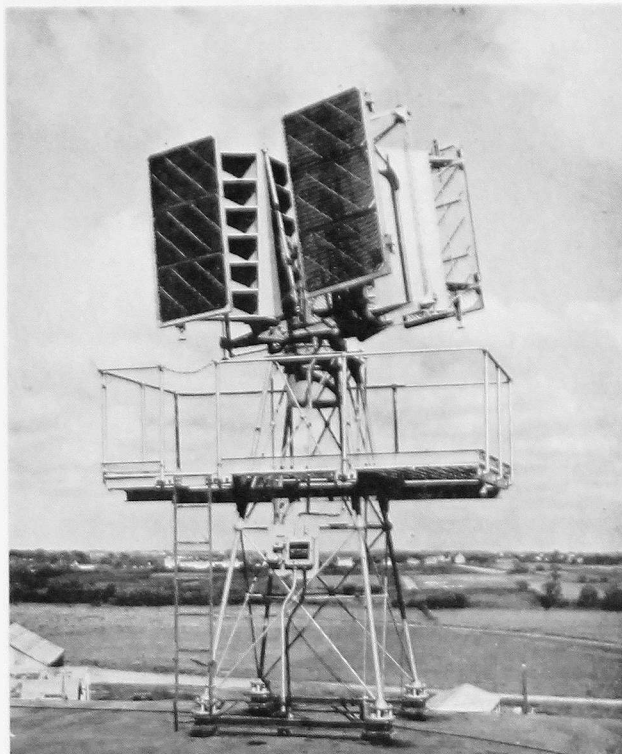


FIG. 11

The radiation coverage diagrams were checked by a series of "box pattern" flights. In addition, a considerable number of plots were taken on scheduled aircraft of many different types and the diagram shows the minimum coverage to be expected from the system.

In respect of continuity of plot, tracking results show an average signal strength of 85% strong, and 5% medium, weak and miss, respectively.

Tracking on the extremities of the radiated lobe, i.e. in the relatively low aerial gain region of the radiated beam, is to a certain extent dependent upon the aircraft aspect. In general, with propeller-

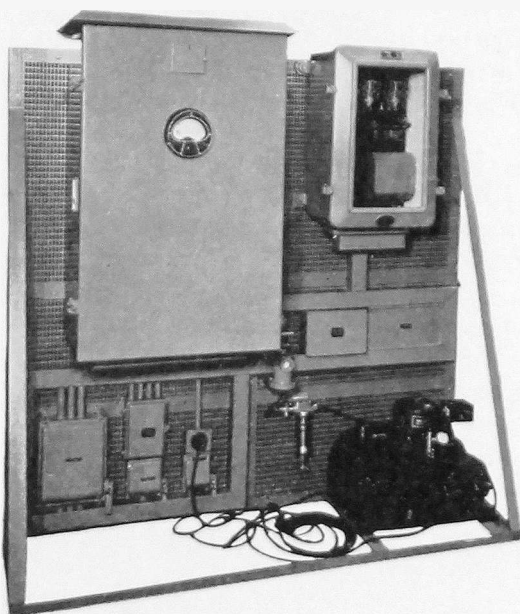


FIG. 12

type aircraft, the detection probability and continuity of plot is increased by some 20% with an aircraft presenting a head-on aspect as against a tail aspect.

Meteorological Effects

Examination was made, during the trials, of the effects of refractive changes of the atmosphere, e.g. temperature inversions resulting in ducting and the effect of high humidity and rainfall conditions on tracking; and a number of instances were recorded together with the appropriate meteorological data. Second trace signals and a small improvement in range tracking on light aircraft related to the particular sector and height have been noted under ducting conditions. A specimen

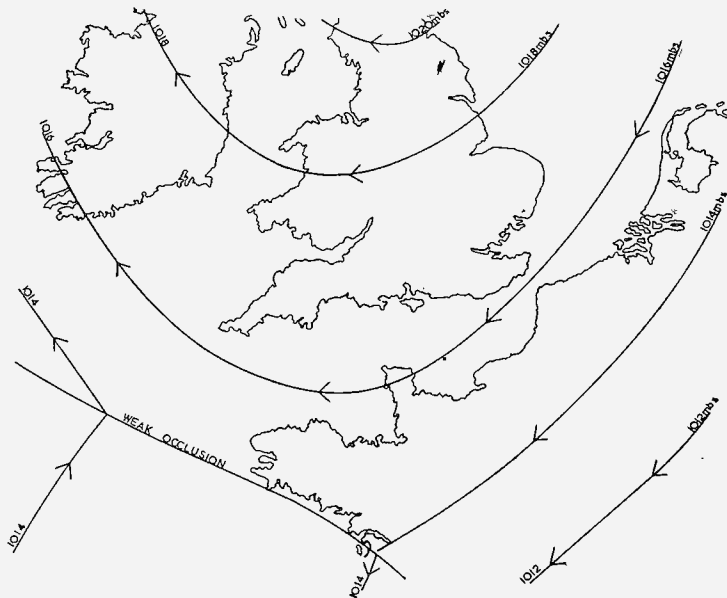


FIG. 13

synoptic chart is shown in Fig. 13. This condition resulted in second trace signals from a storm to the SW. It was not possible at the time to obtain a precise picture of the temperature gradient in this direction but the upper air temperature over Southern England indicated an inversion.

With high humidity and light rainfall a range reduction in the order of 10% to 15% may be expected due to scatter and attenuation. Masking may also be present with heavy rainfall. The effect of rainfall at these frequencies has been dealt with by many writers. Selected references from among the many available are given at the end of the text.

Effectiveness of Counter Measures to Combat Adverse Weather Conditions

It will be appreciated that three main types of unwanted signals can be present, namely, land P.E's, precipitation and, on a coastal or island site, sea clutter.

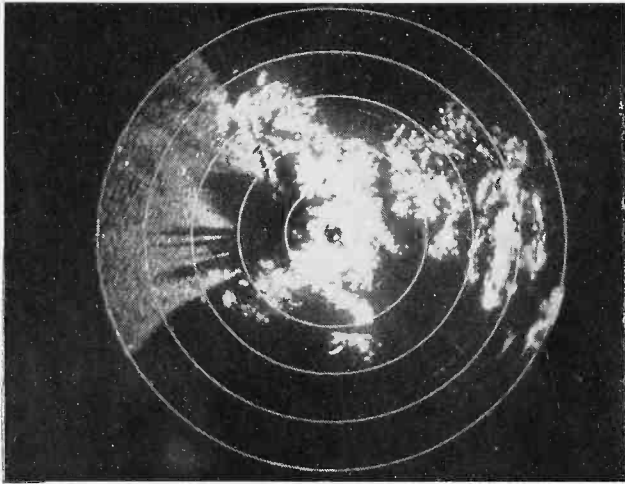


FIG. 14

Range five miles. Undifferentiated. Note sea clutter.

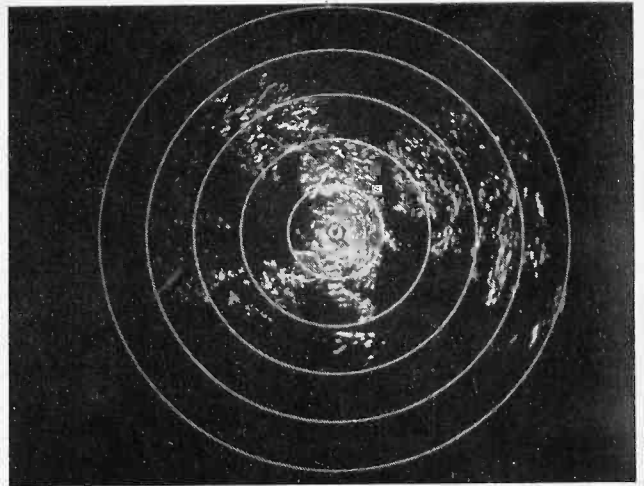


FIG. 15

As Fig. 14. Differentiated.

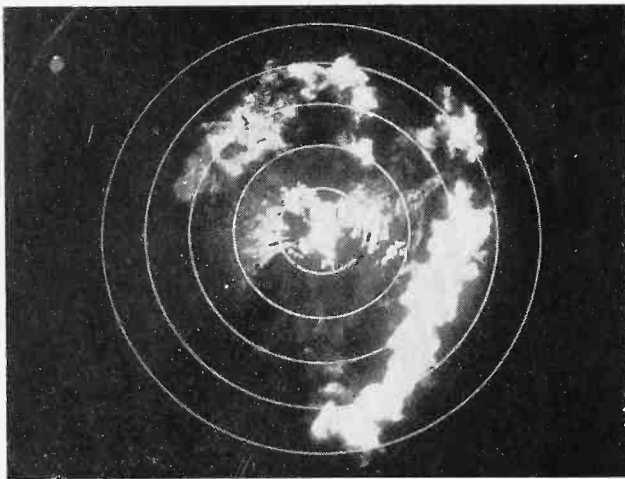


FIG. 16

Range 15 miles. Undifferentiated. General rainbelt.

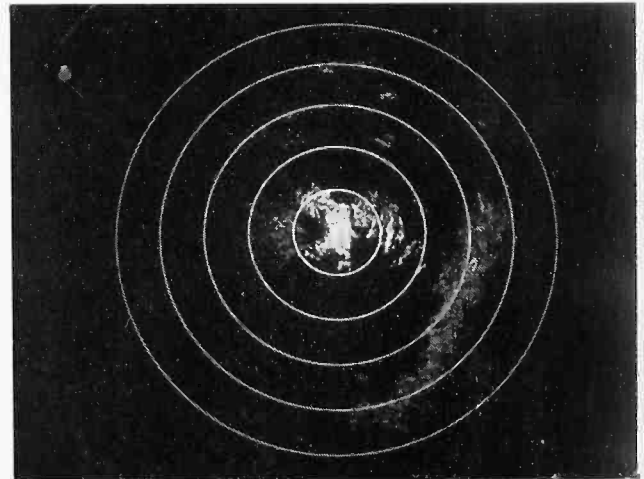


FIG. 17

As Fig. 16 but differentiated.

Analysis of the effectiveness of the various systems employed against unwanted signals shows a strong bias in favour of the logarithmic amplifier with aerial polarizers as required. The use of the logarithmic amplifier also provides an effective means of suppressing sea clutter where present.

In respect of aircraft tracking in adverse weather conditions when using the logarithmic amplifier, it must be remembered, however, that the wanted signal must have a greater effective strength than the unwanted to show, above the rain clutter, signals when differentiation is applied.

However, the use of the linear amplifier carries certain advantages in practice. It provides a smoother background of noise point on the display, thus giving better contrast to the picture, and no special "setting up" procedure for noise level is required to provide optimum operating conditions.

With a differentiation time constant of $2T$ ground returns could be broken up sufficiently to maintain a tracking sequence with a short range display.

Circular Polarization

The aerial polarizer provided a discrimination against rain of the order of 16 dB. The theoretical loss (in signal strength) consequent upon its use varies with the type of target due to asymmetric reradiation. In practice this loss with aircraft targets would appear to lie in the region of some 4 dB with a loss in range in the order of 20%.

Representative photographic records of operational performance are shown in Figs. 14-17.

Conclusion

In presenting the operational aspects of this Radar System emphasis has been given to considerations of its practical application. In evaluating its overall performance nature was not always conveniently obliging in providing a desired set of meteorological conditions. It was, however, possible to obtain sufficient recorded results and instances to show that the system adequately fulfilled the design requirements and within the limitations of the frequency band was capable of making a useful contribution to the air traffic control problem.

Acknowledgments

This equipment was developed for the Jersey C.I. authorities (Harbour and Airports Committee) and installed at St. Peter's Airport. The author wishes to express appreciation for the assistance and co-operation rendered during the installation and trials by the telecommunication and airport departments. He also wishes to thank Mr. R. P. Shipway for his suggestions and help in the preparation of this article, and to all his colleagues who contributed to the project.

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IMPROVEMENTS IN H.F. DIRECTION FINDING BY AUTOMATIC TIME AVERAGING

BY J. F. HATCH AND D. W. G. BYATT, B.SC., A.Inst.P.

The instrumental accuracy of H.F. Direction Finders can be made of a high order, but limits are imposed by the accuracy of arrival of the wave.

It has been found that considerable improvements can be made by averaging either in time or space. Space averaging involves the design of wide aperture aerial systems and introduces many complications and expensive equipment. Time averaging can be done by several fairly simple means with worthwhile results.

In the following article, the design of equipment for use both with C.W. and with interrupted signals is described. Simultaneous measurements with a Cathode Ray Direction Finder at the Radio Research Station at Slough were made and the results compared.

Introduction

THE effectiveness of H.F. Direction Finders in the frequency band 1.5-30 Mc/s for major navigational aids has always been open to doubt because of the apparent wide deviation of the wave from the direct path between the transmitter and receiver, caused largely by multi-path ionospheric propagation. However carefully the Direction Finder itself is constructed, the accuracy finally depends on propagation conditions which are entirely out of the control of the operator.

Direction Finders which have been in use for the past ten years have an overall instrumental accuracy including aerials, feeders and goniometer of the order of $\pm 2^\circ$ when carefully erected on a good site, and yet the accuracy of bearings measured on all types of signals may be considerably worse than this.

These propagation errors may be classed under several headings as follows:—

- (a) Polarization errors.
- (b) Wave interference errors.
- (c) Lateral deviation errors.

A carefully maintained Adcock aerial on a good site has been found to possess very low polarization errors, but there is room for improvement on poor conductivity sites. This can often be achieved by the use of spaced frames.

Wave interference errors combined with lateral deviation seem to be the major cause of variable and wandering bearings in this frequency band and the main object of work discussed below has been to devise methods of reducing these errors.

Experimental Method

The work carried out by Ross and Bramley⁽¹⁾ of the D.S.I.R. has shown that phase interference between rays arriving at the D/F aerials can cause rapid and violent changes in bearing of up to $\pm 90^\circ$ over periods of about 1 second.

Improvements in H.F. Direction Finding by Automatic Time Averaging

These fluctuations are superimposed on much slower variations with periods of the order of twenty minutes, reaching a magnitude of 2° - 3° . These slower variations are due to lateral deviation caused by tilting of the ionospheric layer.

It has been shown experimentally by Ross and Bramley that the accuracy of bearings of these fluctuating signals can be improved by taking the average of a number of bearings measured at frequent intervals.

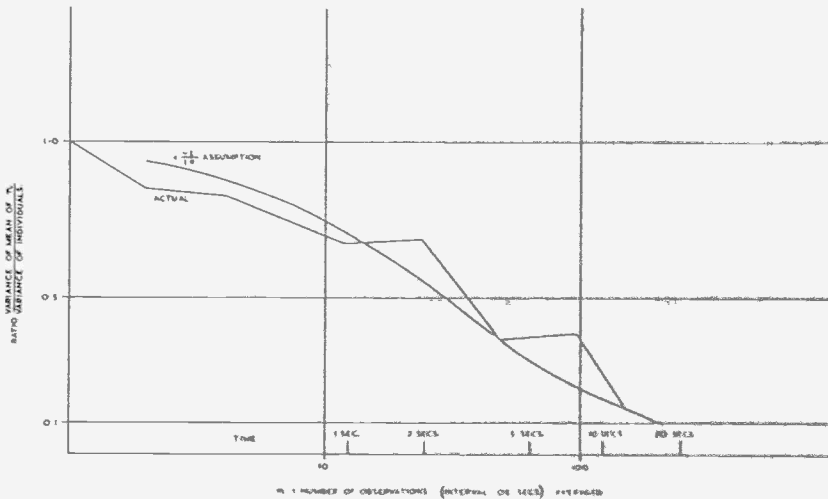


FIG. 1

Reduction in variance of D.F. bearings with time (sampling rate $12\frac{1}{2}$ times per sec.)

As a start to the investigation some H.F. bearings taken several years ago⁽²⁾ at the rate of one per 0.08 second were analysed in order to find the ratio of bearing improvement to length of time for averaging. From these observations the curve of Fig. 1 was obtained which shows the fairly rapid improvement obtained due to reductions of wave interference.

Results were extremely encouraging, as it was shown that in general the standard deviation of wave interference errors could be improved by about 2 : 1 by averaging over ten seconds. This result agreed very well with those obtained by Ross and Bramley. It was therefore decided to construct apparatus which would automatically record instantaneous bearings, and average them over any reasonable period of time.

A DFG26 Direction Finder with spinning goniometer was available, which produced a $12\frac{1}{2}$ c/s sinusoidal modulation on the signal carrier. This instrument was modified to include a $12\frac{1}{2}$ c/s A.C. generator for a reference voltage, and a 360-tooth tone-wheel generator driven by the goniometer shaft.

The phase difference between the signal modulation and the reference voltages gave the bearing of the incoming radio frequency signal.

These two A.C. voltages were fed into a phase detecting circuit⁽³⁾ which controlled the number of 1° pulses feeding two banks of Dekatron counters. One of these banks added up the numerical value in degrees of successive individual bearings and the other bank indicated the number of times the bearing was taken⁽⁴⁾.

By dividing one reading by the other the average bearing measured over a given period of time could be easily found. The results obtained with this equipment indicated that a worth-while improvement could be expected on the majority of signals in this frequency band by systematic time averaging. An indication of the improvements gained in this experiment is given in Fig. 10.

The limitations of this particular apparatus were that it could only be used on continuous carrier transmissions, as interrupted signals or morse operated the flip-flop phase meter in a random manner, and caused incorrect bearings.

In order to deal with the problems of interrupted signals it was decided to separate the counting part of the equipment from the wireless side.

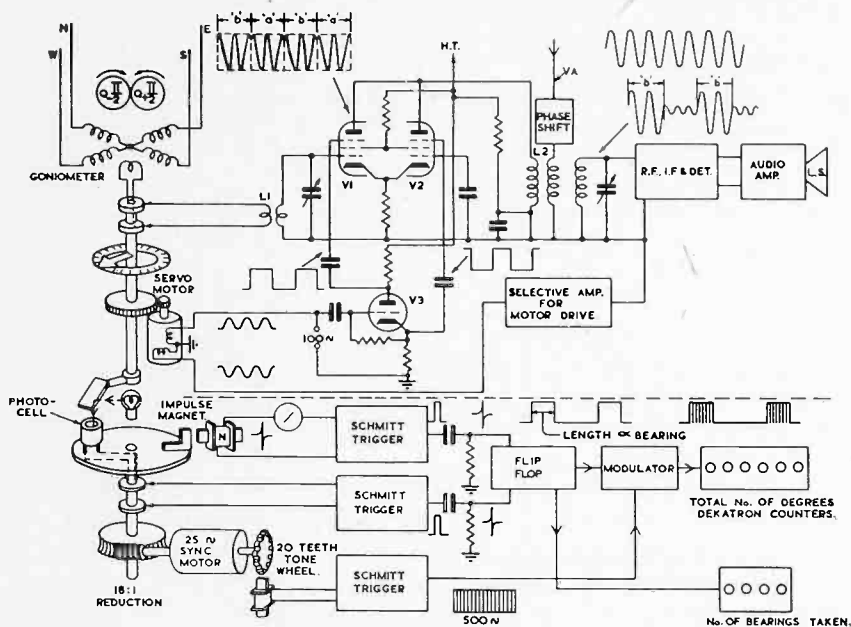


FIG. 2

Automatic D.F. with electronic bearing averaging.

The Automatic Direction Finder

It is possible to cause the goniometer of a Direction Finder to rotate to the figure of eight minimum automatically, in a manner similar to the Marconi Airborne A.D.F.⁽⁶⁾ Due to the field conditions within a goniometer, its output is essentially that of a frame aerial, which has a null or zero signal position when the plane of the loop (or goniometer) is perpendicular to the incoming wave. There is a phase difference of 180° between the voltages obtained on either side of this null.

In Fig. 2 the induced voltage from the goniometer is passed to an electronic switch comprising V_1 and V_2 . These are cathode coupled valves so that the voltage appearing at the anodes when V_2 is conducting is in anti-phase with that when V_1 is conducting. The phase splitting valve V_3 is driven by a 100 c/s source and alternately cuts off V_1 and V_2 . The output of the electronic switch passes to L_2 . Also coupled to this coil is the omni-directional sense aerial. If a suitable phase shifting network is inserted in the sense aerial lead, it can be arranged to oppose the voltage

due to V_1 and add to that due to V_2 . After passing through the signal frequency, intermediate frequency and detector stages of the receiver, and a motor amplifier, this A.C. power operates the small motor, which turns the goniometer round, through a reduction gear. As the goniometer passes through the null of the figure of eight polar diagram, the R.F. changes phase by 180° , and instead of the sense aerial R.F. cancelling "a" above, it cancels "b." The motor drive output is thus reversed in phase, causing the goniometer also to reverse its direction and finally to settle on the zero of the figure of eight polar diagram.

The system is virtually unambiguous as the unwanted zero of the polar diagram is unstable. It responds to both broadcast and telegraph signals, but on on/off telegraph signals the motor naturally drives only when there is a "mark" signal, remaining stationary on "space."

Incidentally, a valuable feature of this type of automatic system is its property of self-demodulation. When monitoring a signal on loudspeaker or headphones, there appears a strong 100 c/s modulation on the audio for a few seconds, while the system is finding the bearing, but this automatically disappears when the goniometer reaches the null of the polar diagram. Furthermore, unlike a manual Direction Finder, the receiver operates with automatic gain correction, and this fact, together with a limiting stage in the motor amplifier, produces an effective polar diagram with a very sharp minimum; in fact, full torque is developed by the motor about 3° from the null.

The automatic type has another advantage over the aural null D.F. in that the bearing can be observed while the signal intelligence is monitored. This is because the input from the vertical aerial is inserted after the electronic switch and is permanently connected to the input of the receiver. The omni-directional aerial can be made as efficient as possible so that there is always sufficient signal for monitoring.

Automatic Bearing Sampling

We have now available a pointer indicating the direction of arrival of the wave, and this pointer may be wandering considerably, due to the wave interference described above. The problem of finding the average position of the pointer over a given period was solved by a method similar to that used before, and is shown also in Fig. 2.

In order that the goniometer drive should not be loaded by friction it was decided to use a beam of light to indicate the position of the pointer. A $p-n$ junction photocell was rotated past the beam of light once every 0.72 seconds, which had been shown to be a suitable sampling time.

Attached to the rotating disc holding the $p-n$ junction was a small magnet, which produced a reference pulse when passing a coil (N on Fig. 2) and a phonic wheel which generated 360 impulses per revolution for producing 1° pulses for displaying the bearing on counters.

A brief description, only, of the circuit for displaying the bearing follows, a more detailed description being given later.

The pulse from coil N is sharpened by a Schmitt trigger circuit, then operates a flip-flop, which in turn causes a gating valve or modulator to conduct and pass the 500 c/s tone from the phonic wheel. Each pulse of this 500 c/s represents 1° of bearing. The pulse from the $p-n$ junction occurs at the angular position of the pointer corresponding to the bearing from true north, trips the flip-flop, and cuts off the modulator valve, thereby stopping the train of 500 cycles. Thus there are, on

the anode of the modulator, bursts of pulses representing the instantaneous position of the pointer in degrees from north, every 0.72 seconds. These pulses are additively displayed on a bank of six Dekatron counters. The number of bearings taken is obtained from the flip-flop and displayed on a second bank of counters. By dividing the first reading by the second the average bearing is obtained.

Results of Experimental Trials

In order to assess the relative performance of the equipment a series of trials was arranged in conjunction with the Radio Research Station, Slough.

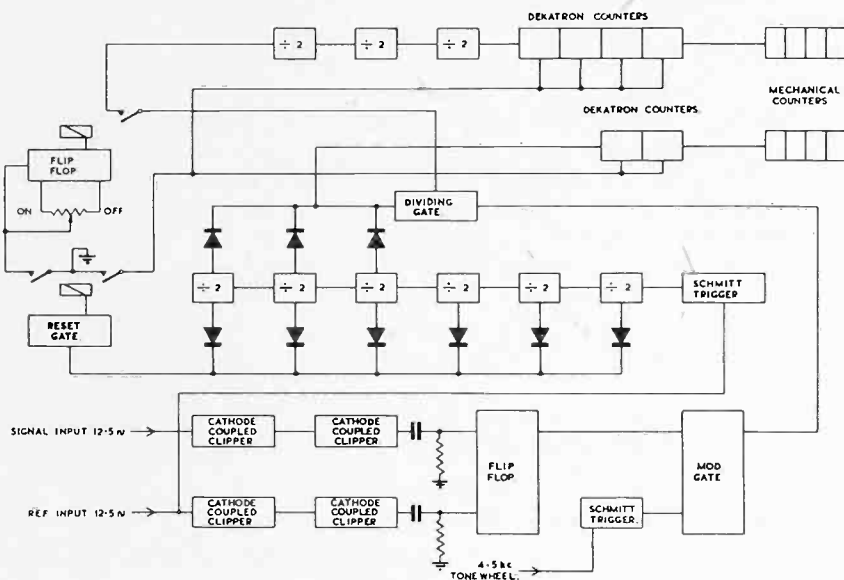


FIG. 3

Block schematic of spinning goniometer scheme.

A modification to the counting mechanism was made so that sufficient time was allowed to write down the bearings. This was done by triggering the counters on the fourth scan of the photocell only and automatically cancelling after a small time interval. This gave a bearing reading every 2.88 seconds.

The Slough equipment consisted of a two-path amplifier H.F. D.F. which was arranged to light up a long-persistence C.R. tube once every ten seconds⁽⁵⁾.

Observations were made during half-hour periods simultaneously on the following stations:—

Allouis	...	...	Broadcast
Schwarzenbroug	...	...	Broadcast
Aranjuez...	...	...	Morse
Warsaw	...	...	Morse
Prague	...	...	Morse
Scheveningen	...	...	Morse

A complete analysis of the results is given later under "D.F. Results," and on the whole very comparable results were obtained.

Improvements in H.F. Direction Finding by Automatic Time Averaging

The improvements due to time averaging were considerable on both cases and showed good agreement with results obtained previously on the spinning goniometer equipment.

The variances of individual bearings were higher on the automatic equipment than on the C.R. D.F. and this may be due to limitations of the servo-mechanism driving the goniometer. Further work will be required on this part of the equipment before the next model is designed, but the tests were useful in pointing out lines of future development and checking the degree of improvement already obtained.

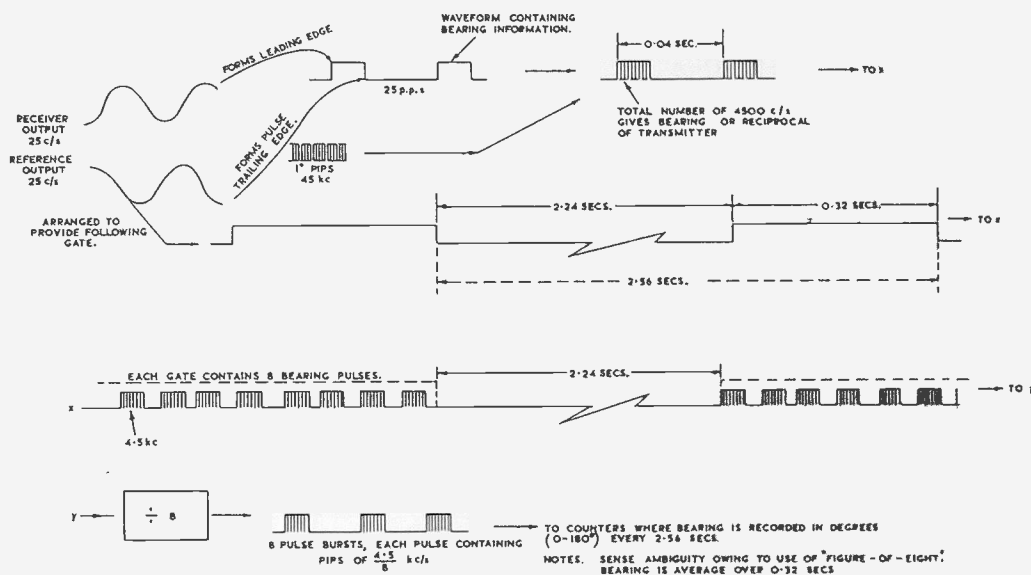


FIG. 4

Waveforms in Counter System of automatic direction finder.

Circuit Arrangement of Spinning Gonio System

The Direction Finder used was a DFG26 operating over the band 1.5-21 Mc/s. The goniometer was motor driven at 12.5 revs/sec. and the "figure of eight" polar diagram of the D.F. produced a 25 c/s sinusoidal component in the Receiver detector output, which was phase compared with a reference 25 c/s voltage from a generator on the goniometer spindle. Also attached to this spindle was a 360 tooth phonic wheel, producing a 4.5 kc/s tone. Referring to Fig. 3 clippers were used to square the signal and reference sinusoidal wave forms. After squaring, these signals were differentiated, and each fed to one side of the flip-flop. The output of this was, therefore, a rectangular pulse, of length equal to the time difference between the signal and reference differentiated pulses, and consequently representative of the phase difference between the goniometer output 25 c/s and the reference 25 c/s. This was adjusted to be proportional to the bearing of the incoming signal.

In order to measure the length of the bearing pulse, the 4.5 kc/s voltage from the tone wheel was fed into a modulating valve, which was gated by the bearing pulse. Thus, at the anode of the gate, there were bursts of 4.5 kc/s pulses, occurring twenty-five times per second, each burst containing the same number of pulses as the bearing of the distant transmitter, from North, in degrees.

Improvements in H.F. Direction Finding by Automatic Time Averaging

As it was considered that 4.5 kc/s was too high a frequency to be counted directly by the Dekatrons, the frequency was divided in the following manner.

Part of the reference signal was taken to a Schmitt trigger and then to six "scales of two," the anode of the last scale producing, therefore, square waves of equal mark-space ratio, with a frequency of one wave in 2.56 seconds (i.e. 25 c/s divided by 2^6). By tying the last three scales of two together through diodes as shown, and using the output to operate the dividing gate, it was possible to cause this valve to conduct for periods of 0.32 seconds followed by 2.24 seconds of cut off. In this 0.32 seconds, eight bursts of 4.5 kc/s bearing intelligence were allowed to pass. This is shown in Fig. 4. To obtain the bearing all that is required is that this signal be divided by eight, giving the correct bearing at the reduced frequency of about 560 c/s. The output of the last Dekatron was used to drive a four figure mechanical counter, giving, in all, a maximum count of 10^8 .

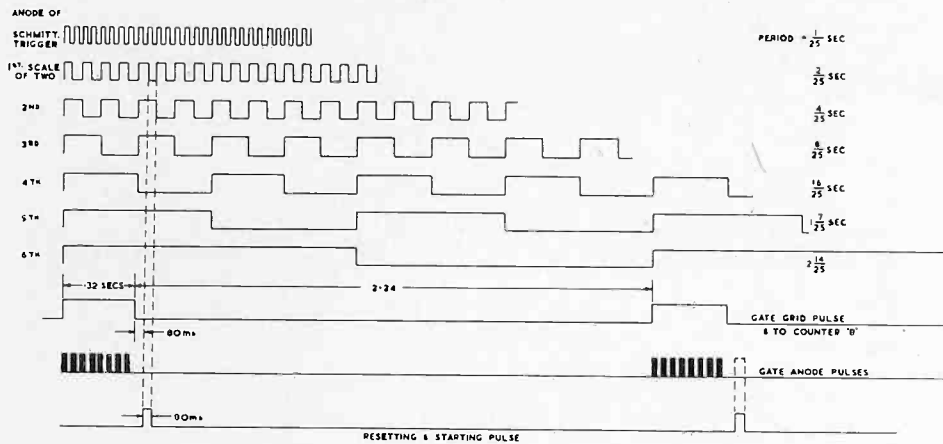


FIG. 5
Waveforms of "Scales of two" and gating circuits.

In order to find the average bearing, the number of bearings taken over a given period was required. This was obtained from the input of the dividing gate, and counted on a second bank of Dekatron counters and a mechanical counter.

However, to obtain analysis data, it was decided to reset the equipment after each bearing had been taken. That is, snap bearings had to be indicated every 2.56 seconds, recorded by the operator and cancelled automatically. To do this, the outputs of all the "Scales of two" were added through diodes and applied to a suitably biased reset gate to produce a short pulse every 2.56 seconds, just before the next burst of bearing pulses. Thus, the maximum time was allowed for reading the Dekatrons. This can be more clearly seen in Fig. 5. Only when all anodes are "positively going" is the potential high enough to cause the reset gate to conduct. In the anode circuit of this valve, a relay is used to cancel the reading of the Dekatrons, via the zero reset line. A second pair of contacts on the relay were used to trip a flip-flop either way depending on the setting of the on/off potentiometer.

This flip-flop controlled a relay which initially switched on, and finally switched off the counting equipment. This complexity was necessary when carrying out long additive runs, in order to avoid switching the equipment on and off in the middle of a burst of bearing pulses.

Circuit Arrangement of Automatic Goniometer D.F.

The electronic switching circuit of the goniometer servo drive was built between the first two stages of a C.R. 150 receiver, as shown in Fig. 2, and in more detail in Fig. 6. Valve V_1 isolates the goniometer from the balanced modulator V_2 and V_3 and provides some signal amplification. The high anode feed resistance and anode stray capacitances provide a 90° phase shift of the goniometer signal. This is necessary owing to the 90° phase difference between the output of the goniometer and sense aerial. From V_1 the R/F voltage passes to the grid of V_2 . V_3 is fed from the cathode

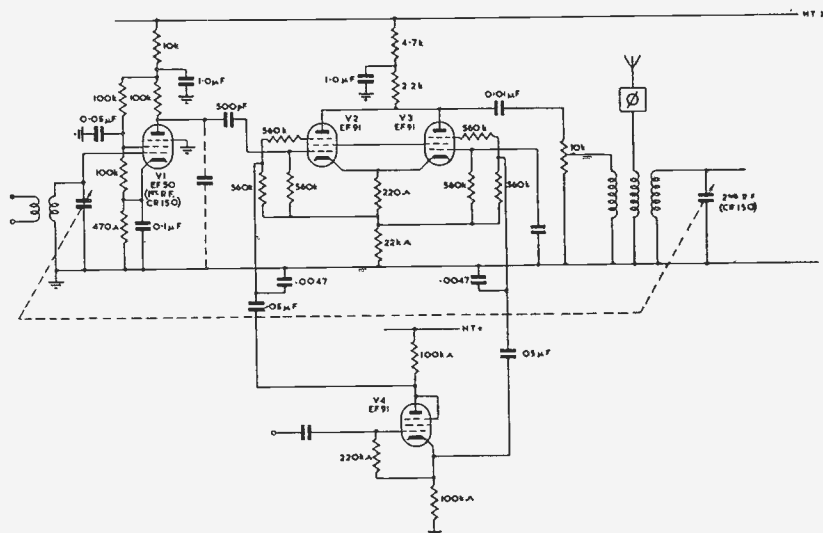


FIG. 6

Electronic switch.

of V_2 and therefore the signal on V_3 is 180° out of phase with the signal on V_2 . These valves are made to conduct alternately by the 100 c/s drive applied to their suppression grids by phase splitting valve V_4 , which in turn is operated by the 100 c/s obtained by doubling the mains frequency. Thus, the phase of the R.F. current in the common anode circuit is reversed each half cycle of the drive frequency.

This current is fed to the coupling winding of the second R.F. coil, where it adds to, or subtracts from, the vertical aerial signal each half cycle and this produces 100 c/s modulation. The C.R. 150/2 receiver is conventional except that A.G.C. is incorporated. A portion of the receiver output is separately rectified, and passed to the three valve amplifier shown in Fig. 7. Condensers C_1 C_2 C_3 serve for phase shift and also constitute a low pass filter with sharp cut off above about 150 c/s. This tends to prevent noise and modulation components of the received signal from blocking the grids, and so hindering the amplification of the 100 c/s voltage. From the selective amplifier, the 100 c/s A.C. output is passed to the two-phase goniometer drive motor. The other phase is obtained direct from the power pack ripple and is therefore in phase with the input to the phase splitter valve V_4 of Fig. 6. A phase angle of 90° is required between the two coils of this type of motor and this is provided by the phase shift network mentioned above, in connection with the amplifier.

Improvements in H.F. Direction Finding by Automatic Time Averaging

The overall gain of the selective amplifier circuits is such that the motor will exert its full torque when the goniometer is only 3° off the true null. When the goniometer is further from the null, the output to the motor is held constant by the limiting effect of the first valve saturation of the motor amplifier.

The scanning system was essentially as shown in Fig. 2. The impulse reference

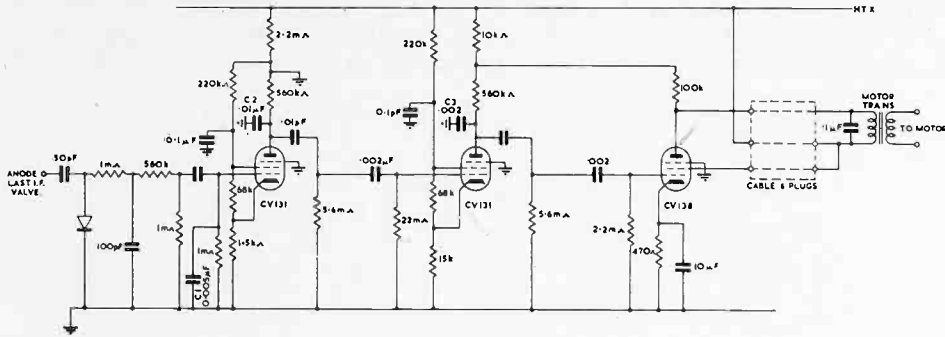


FIG. 7
Motor amplifier for servo drive.

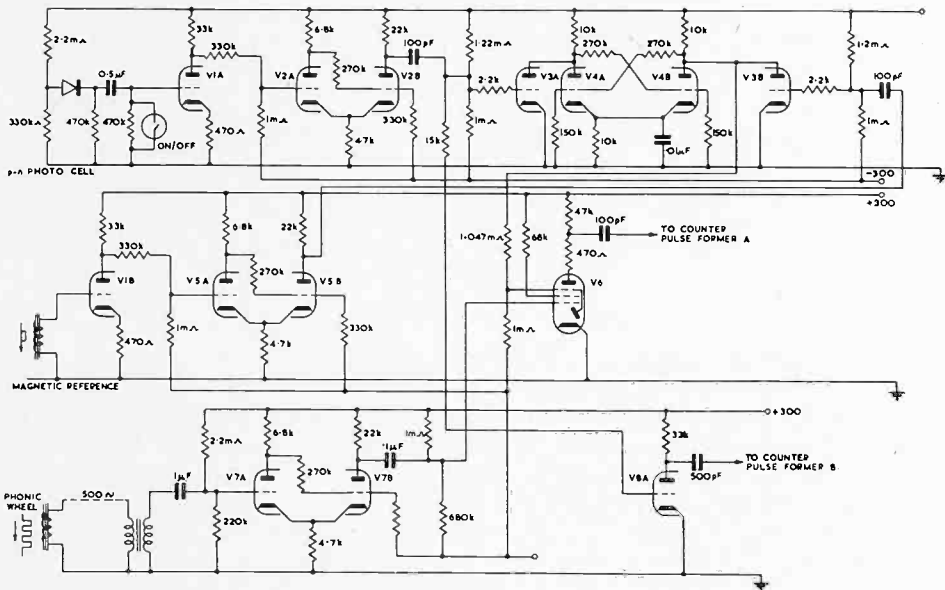


FIG. 8
Phase meter.

coil was as used on the DFG26 and the rotating pole-piece was made of Lowmoor iron. The arrangement of the phonic wheel was, in fact, rather different from that used with the spinning goniometer. This was made far more efficient and economical by making a twenty tooth wheel from Lowmoor iron, and attaching it directly to the motor. As the motor speed was eighteen times that of the scanning disc, the phonic head produced 360 pulses per revolution of the scanning disc. Fig. 8 shows the

circuit of the "phase-meter," for which a stabilized positive and negative supply was required. As the inputs from the *p-n* junction photo-cell, reference, and phonic head was constant it was found that the elaborate "squaring" circuits of Fig. 3 were not

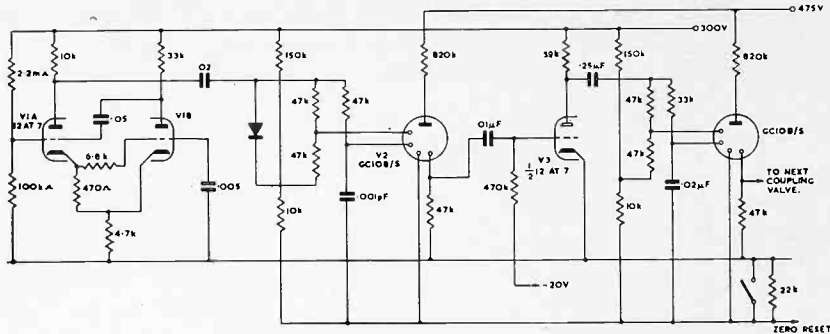


FIG. 9
Dekatron drive and coupling circuits.

required. The signals were squared by Schmitt triggers, differentiated, and made uni-directional pulses by V_{3a} and V_{3b} , by virtue of common anode loads, these valves operating flip-flop V_4 to produce the bearing pulse, the length of which was proportional to the bearing of the transmitter. The 500 c/s signal from the phonic output was sharpened by the Schmitt trigger V_7 , and was used to indicate the length of the bearing pulse, in degrees, by modulating the bearing pulse in V_6 . The number of bearings taken was obtained from V_2 and amplified by V_{8a} .

The outputs of V_6 and V_{8a} were taken to the two Dekatron chains, the first, fed by V_6 , containing six Dekatrons and counting the Total Number of Degrees, whilst the second bank, fed from V_{8a} , indicated the Number of Bearings taken. This bank contained four Dekatrons. The first stages of a bank are shown in Fig. 9. V_1 is a conventional pulse forming circuit driving an Ericsson G.C. 10B/S Counter Tube. Each counter tube is connected to the next via half a 12AT7. When the first Dekatron counter passed zero, a pulse at its output was fed to the next counter, and so on.

The total count possible depended on the bearing of the transmitter. For bearings 0° - 100° , the "Number of Bearings Taken" bank of four counters ran out after about two hours. Above 100° , the time decreased linearly until at 359° , the "Total Number of Degrees" bank ran out first after 35 minutes.

D.F. Results

Two series of observations were made, using the transmissions from various stations in different directions and at different ranges. The observations were effectively instantaneous indications of the direction finder taken mostly at intervals of $2\frac{1}{2}$ seconds.

First Series

Fig. 11 shows an example of bearings recorded at intervals of 2.56 seconds from transmissions from various broadcasting stations; each observation is actually the average of eight instantaneous bearings at 0.04 second intervals. The readings are taken to the nearest degree.

Improvements in H.F. Direction Finding by Automatic Time Averaging

The difference between the reading as plotted and the true direction of the station is defined as the bearing error; we may also consider the error from the mean of the observations.

According to Bain⁽⁷⁾ the short-term components have an auto-correlogram of the form e^{-t/t_0} , with t_0 about 0.75 second; with the present observations spaced at 2.56 seconds, such short-term components would not be reproduced.

RUN No.	STATION	VARIANCE (Individuals)	VARIANCE (Means of 16)	RATIO OF VARIANCES
11	Hilversum	80	7.7	10
13	Bayreuth	75.9	11.2	7
6	Horby	64.6	9.14	7
3	Luxemburg	37.9	2.77	14
15	Schwarzenbourg	31.8	1.55	21
2	Luxemburg	29	5.0	6
10	Allouis	27	2.3	12
1	Luxemburg	27	4.4	6
16	Schwarzenbourg	23	1.8	13
7	Colombo	15.3	.87	18
4	Horby	13.7	.63	22
12	Bayreuth	12.9	1.55	8
5	Horby	12.9	1.40	9
14	Schwarzenbourg	12.8	2.3	6
9	Sackville	4.5	.60	7.5
8	Schenectady	3.7	.44	8

Similarly the long-term components on the error curve are not revealed accurately because of the limited duration of the runs. The table above gives the

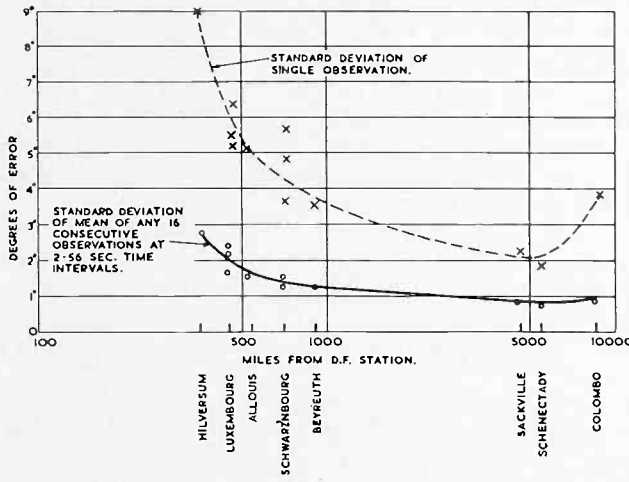


FIG. 10

Improvement to D.F. observations by averaging for different transmission distances.

variances (mean square error from the mean value as computed from the data) for the ten minute runs, in order of the variances of individual values. On the right are the variances of means of sixteen consecutive readings (making an average over forty-one seconds), and the ratio of the first variance to the second.

On the whole, errors are greater for the nearer stations as would be expected with the high angle of the reflected wave; the stations nearest the skip distance give the wildest figures and the two transatlantic stations are the best. The same station

Improvements in H.F. Direction Finding by Automatic Time Averaging

can give widely differing variances at different times, as is seen with Schwarzenbourg, Bayreuth and Horby.

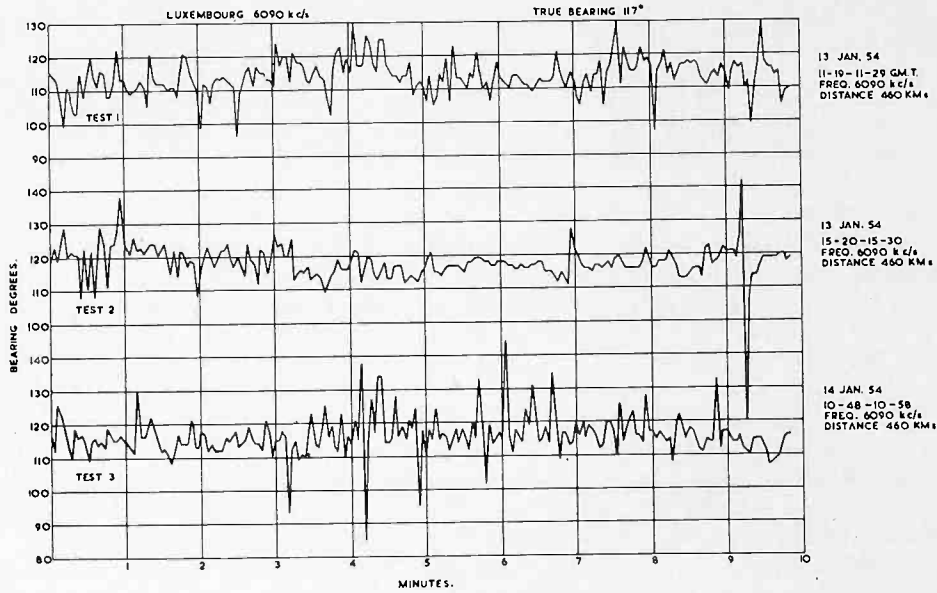


FIG. 11
D.F. bearings taken every 2.56 secs. Each bearing is average over 0.32 sec.

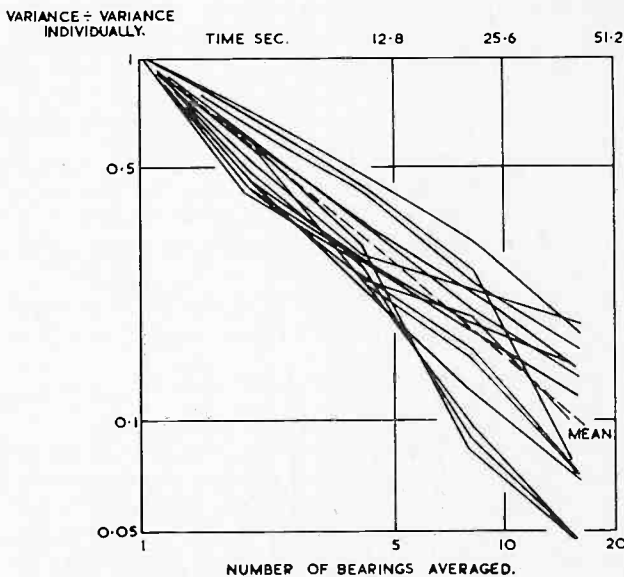


FIG. 12
Decrease of variance with number of bearings averaged. Variance is with respect to mean bearing. Chelmsford—First set.

The ratio of the variances would scatter round 16 if the values read were random; this would mean that the short-term errors had been averaged out and that no other systematic errors had appeared in the ten minutes. Our ratios average 11, and in some cases systematic medium-scale fluctuations are obvious—by this is meant roughly fluctuations of the type to show up in a ten minute run of record with 2.56 seconds between observations. In one test these fluctuations are exceptionally regular for the first five minutes, with a period of half a minute.

Long-term errors cannot be sorted out in ten-minute runs from the permanent bias,

if any; the mean values of the runs differ from the true bearings by amounts up to 3.3° and we cannot hope to eliminate this by averaging procedure over any reasonable length of time.

The pencil of lines of Fig. 12 gives for all the test runs the variances, of individual observations and of means, as 2, 4, 8 and 16, all with respect to the observed mean and all reduced to a common value of 1 for the variance of individuals. The scatter shows the variations in the effect of medium term errors on the randomness of the value, and the mean line gives the average effect. It is almost straight with a slope of -0.83 . Complete randomness would give a straight line of slope -1 .

Second Series

The main purpose of these test runs was to compare simultaneous direction determinations at Slough and Chelmsford on the same stations by different methods. The Chelmsford apparatus gave spot points every 2.88 seconds and the Slough

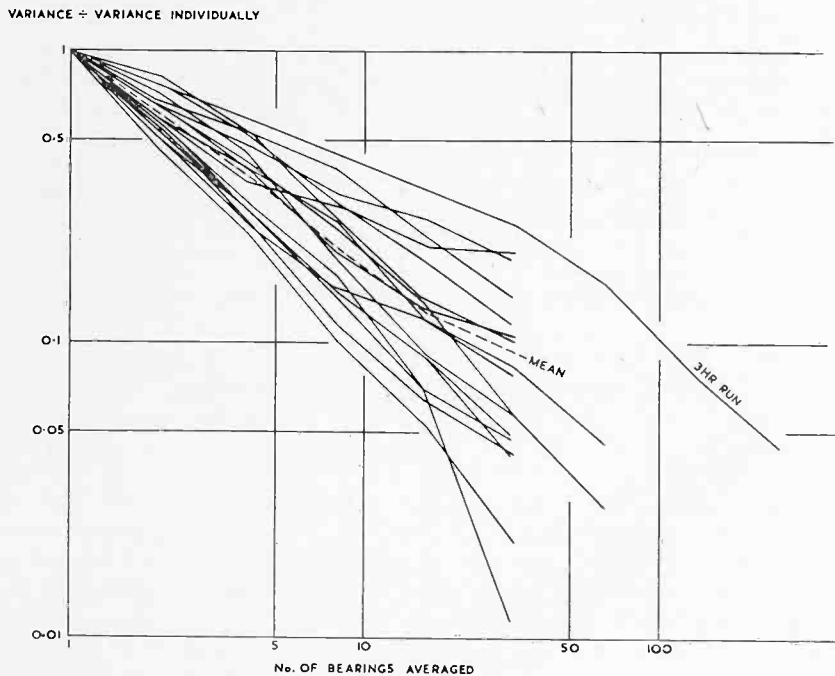


FIG. 13

Improvement to D.F. bearings by averaging. Chelmsford—Second Series.

apparatus spot points every ten seconds. In poor reception conditions Chelmsford would give wild results while Slough gave none at all. Adjustments could be made in the course of the run at Slough but were not attempted at Chelmsford. A good deal of "pruning" was possible in the results at both places, but it appeared more fair to treat the results as they stood. In a short signal from an unknown source, such as might be received in practice, such selection would be impossible. The only exception was the neglect of eight consecutive readings on Warsaw from Chelmsford, where the apparatus had obviously swung over to another transmitter.

Results for fourteen half-hour runs, two one-hour runs and one three-hour run are included in the results shown in Fig. 13.

The histograms of the data of the three-hour run, both from Chelmsford and from Slough, shows them to be more leptokurtic (i.e. sharper peaked, lower shouldered, and wider based) than Gaussian curves of the same standard deviation. This is characteristic of D.F. results and is presumably due to the mixture of at least two sources of error of different orders of magnitude.

Fig. 13 gives pencils corresponding to those of Fig. 12 for the second series of runs.

Conclusion

In considering the various methods of improving H.F. Direction Finding the methods described above show considerable promise as a practical way of obtaining a worthwhile increase in accuracy using a conventional Adcock Aerial system.

Phase tracking problems between omni and spaced aerials have not been found serious down to a bandwidth of 1 kc/s and any mis-phasing causes lack of torque rather than bearing errors.

In assessing improvements due to time averaging, it should be remembered that a skilled manual operator averages bearings by the swing bearing technique over a short period, so that the overall improvement is less than it would be if the operator recorded spot bearings.

On the other hand the automatic method described should give a more accurate answer over long or short periods than the manual operator, and is capable of providing useful results on signals that are fluctuating too rapidly and violently to be followed by the manual operator.

The system is flexible so that easy switching over to manual operation is possible for the reception of very weak or jammed signals where necessary, but with modern techniques of sharp cut-off filters a servo driven goniometer can be made to operate with extremely narrow band-width.

Acknowledgments

Dr. G. L. Grisdale directed the original work on the Spinning Goniometer method of time averaging, and acknowledgments are due to the members of his group who were associated with the detailed circuit work.

Mr. D. S. Palmer of the Mathematical Research Group carried out the analysis of the results, and acknowledgments also due to Dr. H. G. Hopkins and Dr. W. C. Bain of the Radio Research Station of D.S.I.R. who co-operated in the simultaneous measurements between Slough and Chelmsford.

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A 360° SCANNING MICROWAVE REFLECTOR

BY J. A. C. JACKSON AND E. G. A. GOODALL, B.Sc., M.Sc.

The design and constructional techniques for a 360° scanning toric reflector are presented. This parabolic torus reflector consists of a 45° wire grid mounted in a radome structure. Field trials showed that a $3\frac{1}{2}^\circ$ (-6dB) pencil beam with -25dB sidelobes in the principal planes could be obtained from this 6 feet diameter aerial fed with a primary horn. A full investigation of the scanning performance of this aerial was undertaken. No pattern change occurs for 360° azimuth scanning. The inherent phase errors of this type of aerial limit the elevation scanning.

Introduction

The need for a high gain aerial, capable of scanning rapidly through 360° , has long been recognized. In the usual form of P.P.I. radar system, for example, the rate at which data can be presented may well be limited by the power available to rotate a large reflector, and in high wind conditions a marked reduction in information rate is to be expected. If, however, the reflector can be held stationary and the relatively small primary feed rotated the power required to turn is much reduced and higher rotational speeds can be achieved. Systems of this type have been used in the past to give rapid scans over limited arcs but an aerial has now been developed by means of which the whole 360° of any preferred plane may be scanned⁽¹⁾. It has the additional advantage that the reflector forms its own radome and the system need not therefore be over-powered to enable it to rotate in gale conditions.

The aerial consists of a reflector which has symmetry in the plane of scan. The reflector surface is generated by rotating an arc of a parabola about a line parallel to its latus rectum. If this is done, the surface evolved is a closed surface, and hence radiation can neither leave nor enter the aerial. A surface transparent to microwave radiation yet which focuses this said radiation had to be devised.

A polarized grid if placed correctly to the oncoming radiation will transmit it, but can also reflect it if placed such that the grid is parallel to the radiation vector. If such a grid, at 45° to the horizontal, is placed around the surface of a cylinder it can readily be seen that at opposite ends of any diameter the grids are at 90° with respect to one another. Thus correctly polarized incoming radiation falling on such a cylinder will pass through one surface, but at the other end of the diameter will be reflected. It was upon this principle that the toric azimuth scanner was based and built. Polarized grids are not necessarily the only way to achieve such conditions, e.g. slots and dipoles may be used.

Since the surface has been formed by rotating an arc of a parabola about an axis (Fig. 1) one may expect the field pattern to be the same as the feed is rotated about the same axis. If the feed is placed at the focus of the parabola, then in the vertical plane at least, a plane wave front emerges. The outstanding problem is then to arrange that the foci of the vertical and horizontal sections coincide.

Design of Reflector

Kelleher and Hibbs⁽²⁾⁽³⁾ give, for a unit radius toric reflector, the deviation from a plane of the wavefront emerging along the X axis, for various azimuth angles and f/R ratios. (Fig. 1). A study of these curves suggests that for optimum performance the f/R ratio should lie between 0.43 and 0.45. In the present aerial a value of 0.44 was decided upon. The aerial was to be constructed for use at a wavelength of 3.2 cm. so that a usable beamwidth would be radiated from an aperture whose dimensions

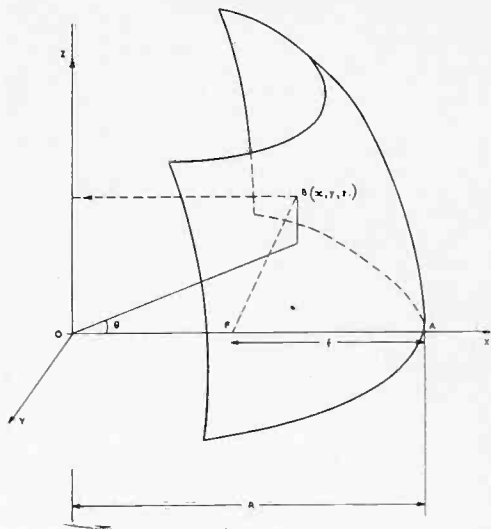


FIG. 1
Parameters of parabolic torus.

were within practical limits. A base diameter of 6 feet was chosen and this was expected to give a -6dB beamwidth of $3\frac{1}{2}^\circ$. With an f/R ratio of 0.44 and base diameter 6 feet the resulting focal length is 16 inches. A height of 32 inches was established, for increasing the height increased the phase errors⁽²⁾⁽³⁾.

Construction of the Aerial

The aerial constructed took the form of a radome with a wire grating inserted into the radome surface. Of the techniques readily available, the single sandwich radome was preferred. This consists of two skins of fibreglass cloth spaced apart by a core of low dielectric material, e.g. "Hycar" (expanded ebonite). As a fibreglass cloth with an interwoven unidirectional wire grid was available this was used in one of the skins to form

the grating. The grid wires were of 41 S.W.G. Nichrome and spaced $\frac{1}{16}$ inch apart by the weave of the cloth, the overall thickness of the wire woven cloth being 0.011 inch.

The exact dimensions of the composite wall had to be found by experiment. To this end flat sample panels were constructed and tested on a focused microwave spectrometer built for this purpose⁽⁴⁾. Measurements were taken of transmission loss and reflected power, with and without the wire grid present for various angles of polarization and over a range of incident angles from 20° to 80° . The results of this work led to the dimensions of radome panelling as used in the construction.

In order that the radome be supported during manufacture and that high dimensional accuracy be achieved (± 0.010 inch) a cast and machined metal former had to be made. The mould was then used as the basis for the normal wet lay-up technique of radome construction using Bakelite resin SR17749.

For the wire cloth to lie on the doubly curved surface of the mould the cloth was cut into strips between 8 inches and 4 inches wide and 48 inches long. To satisfy the electrical requirement of a 45° polarized grid, the wires were at 45° with respect to the sides of the strips. These strips of material were applied to the surface of the mould in horizontal zones, the weave of the cloth allowing it to be formed to the surface of the mould, without seriously displacing the wires from the required

position. The rule for the correct position of a particular wire was that it should lay at 45° to the horizontal in the tangent plane to the centre of each horizontal strip zone.

TABLE I

Outer Skin	Core	Inner Skin
0.025 inch (± 0.003 inch). Three layers of fibreglass cloth.	0.320 inch (± 0.015 inch) Hycar	0.025 inch (± 0.003 inch) Three layers of fibreglass cloth, one containing wires.

Having placed the wire grid correctly upon the machined former with the aid of the resin the construction of the aerial then became part of the usual radome technique, following the dimensions given in Table I. At the completion of the process the mould was withdrawn, leaving a toric aerial made of the usual radome materials but in whose inner surface lay a 45° wire grid (Fig. 2).

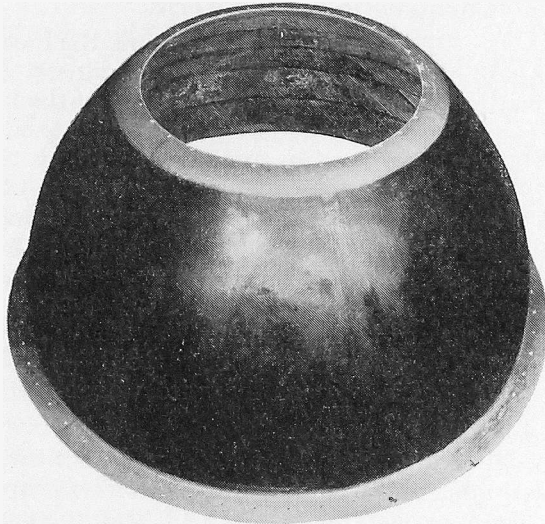


FIG. 2
External view of barrel aerial.

Field Trials

(a) *Primary Patterns.*—The E, H, 45° and 135° plane primary feed horn patterns were determined for various horns of different aperture and length. The pyramidal horn used in the tests on the complete aerial radiated a beam in which the power at $\pm 45^\circ$ was substantially 10dB down in all planes. The aperture of this horn was $1\frac{1}{4}$ inches \times $1\frac{3}{4}$ inches and had a tapered length of 3 inches.

(b) *Secondary Pattern Site Arrangements.*—For the focusing and pattern measurements on the complete aerial an open level site was chosen, 230 feet in length, so that the phase error across the effective aperture of 3 feet should not exceed $\lambda/20$. The 6 feet diameter barrel aerial was mounted on a table which could be rotated about a horizontal or a vertical axis. The primary horn was placed with its aperture at the focus and mounted on an adjustable slide. The arrangement was such that the feed could be moved in and out with respect to the reflector along a diameter of the aerial or up and down through the focus along the latus rectum. The feed horn had to be rotated about its own axis through 45° to the horizontal to accept the incoming 45° polarization from the polarized toric surface. The primary

horn also had to be tilted at 45° to the horizontal, so that it looked approximately at the centre of a vertical section and in order that the taper in



FIG. 3
Feed arrangements in barrel aerial.

the vertical plane should be approximately symmetrical (Fig. 3). A profile jig was made, to rest on the reflector surface and provide a reference focal point to facilitate the setting-up of the primary feed.

(c) *Measurements on Complete Aerial.*—In all measurements a crystal and amplifier which had previously been calibrated against a known standard were used. Although the feed had been set at the theoretical focus it was part of the experiment to find the position of the feed which gave the best performance. In the process of the experimental investigation on the aerial it was found that a movement of the feed horn in the $y = 0$ plane along a line 45° to the horizontal produced no scanning of the secondary beam. A measurement of power received for various feed positions along this line together with the azimuth and elevation beam widths and side lobe performance showed that the theoretical focal point of 16 inches was the best focal position for the feed aperture. Having established the focal position of the feed at 16 inches, a measurement of the solid polar diagram could be made. In order to do this the aerial was initially tilted through $+1^\circ$ and the horizontal polar diagram was taken. This tilting was continued in 1° steps to $+7^\circ$ and the respective horizontal polar diagrams were recorded. These measurements were then repeated for angles to -7° . From these horizontal sections the contour plot of the solid pattern was drawn (Fig. 4). The back lobe was measured and found not to exceed -32 dB. This is a measure of the cut-off of the aerial with respect to the oncoming radiation.

A 360° Scanning Microwave Reflector

It was necessary that some investigation was made of the scanning performance of the aerial. A simple displacement of the primary feed will produce scanning of the beam. No change was observed in the secondary pattern while the feed system was rotated through 360° in azimuth. Equal

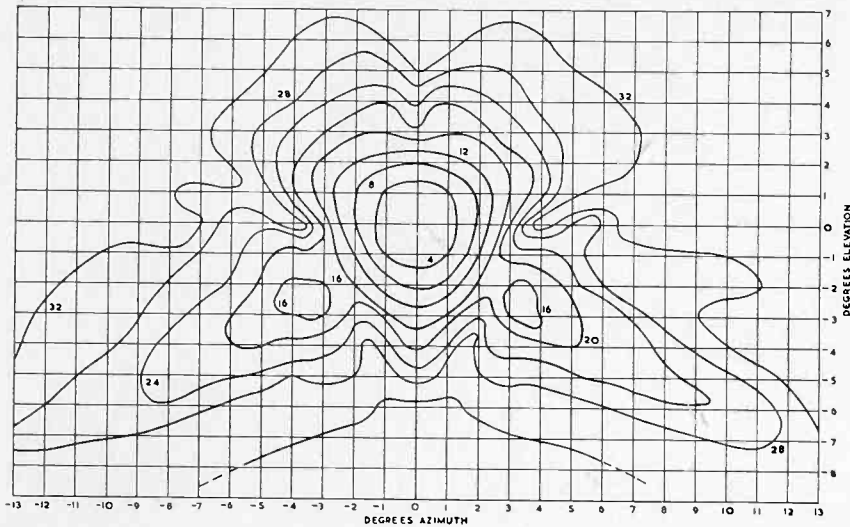


FIG. 4

Contours of secondary pattern (4dB Steps) $\lambda = 3.2$ cm. Feed aperture at theoretical focus.

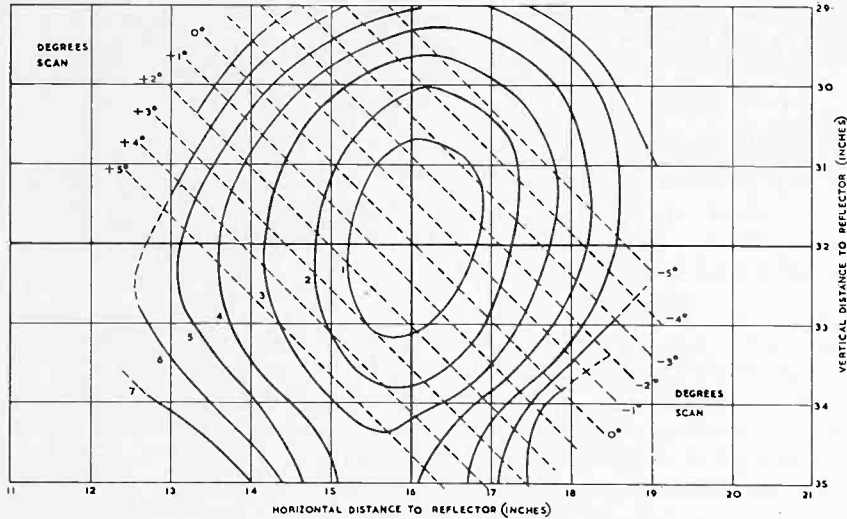


FIG. 5

Equal gain contours (dB) $\lambda = 3.2$ cms.

gain contours were plotted in the focal field, and in Fig. 5 the variation of power received for various positions of the horn is shown. Also upon these contours have been plotted lines of constant scan angle.

A 360° Scanning Microwave Reflector

Whilst investigating the power received at various positions in the focal field, a value of the elevation and azimuth beamwidth at each point was determined. A contour plot of these beamwidths for both planes is also

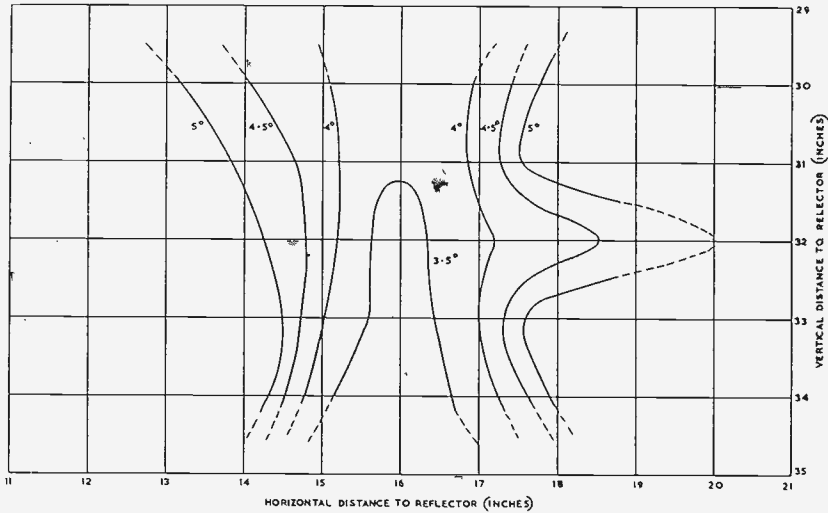


FIG. 6
Equal beamwidth contours (-6dB) Azimuth pattern. $\lambda = 3.2$ cms.

given in Figs. 6 and 7. A movement of the feed along a vertical line 16 inches from the reflector is the best compromise scanning locus to $\pm 5^\circ$ scan. Sidelobe performance along this line is shown in Fig. 8. The gain of the

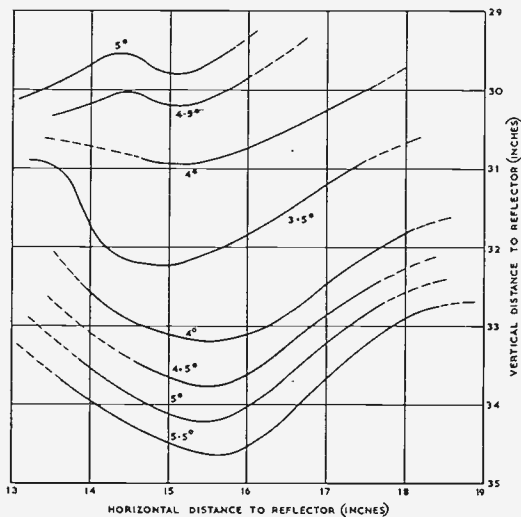


FIG. 7
*Equal beamwidth contours (-6dB) Elevation pattern.
 $\lambda = 3.2$ cms.*

reflector was determined by comparison with a pyramidal horn. This horn, of aperture 14.9 cms. \times 18.9 cms., had a measured gain of 22 dB above an isotropic source. The measured gain of the aerial compared with this standard horn was 36.8 dB (± 0.5 dB). The theoretical gain of a 36 inch diameter aperture is 39.1 dB, and compared with this the measured gain shows a loss of 2.3 dB (± 0.5 dB.)

The aerial, essentially a broadband reflector, was tested over a band of frequencies with the feed set at a focal distance of 16 inches. Azimuth and elevation patterns were measured at 3.04 cm. and 3.45 cm. A summary of these results is shown overleaf:—

TABLE II

λ cm.	- 6 dB Beamwidth		First Sidelobe (dB)	
	Azimuth	Elevation	Azimuth	Elevation
3.04	3.65°	3.75°	-25.5	-29.8
3.2	3.35°	3.5°	-25	-34
3.45	3.85°	4.1°	-24	-30

A measurement of the match of the complete aerial system was then made over the range 3.0 cms.-3.3 cms. Matching measurements showed that the individual components and not the reflector were responsible for a considerable part of the mismatch, but with the experimental arrangement of feed, twist, bend and reflector the match was still better than 0.85 V.S.W.R. over the band.

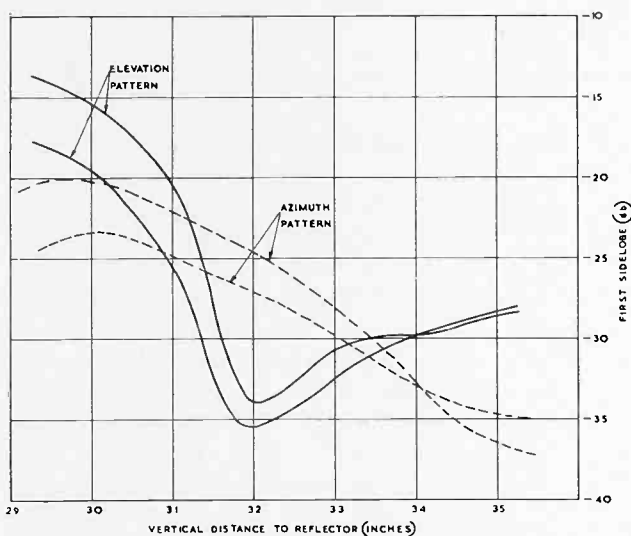


FIG. 8
Sidelobe variation due to vertical scanning.

A study of various sized feed horns and their effect on the secondary pattern was undertaken. As expected, a decrease of taper on the aperture produced an increase in sidelobe level and a decrease in beamwidth. In the horns tested the taper was changed from -8 dB to -14 dB and only a negligible change in the secondary beam was measured. However, the horn giving a -10 dB illumination taper and of aperture $1\frac{1}{4}$ inches \times $1\frac{3}{4}$ inches was decided upon as being the best compromise of the horns used.

With the feed horn tilted at 45° the reflector is fed asymmetrically due to the unequal distances to the upper and lower limits of the reflector. A tilt angle of 55° will give a more symmetrical amplitude taper and this arrangement was investigated. In the azimuth secondary pattern the beamwidth and sidelobes increase (-6 dB beamwidth 3.8°; sidelobes -21 dB). Elevation beamwidth remained constant with an increase in sidelobe level (-26 dB).

Theory

A calculation of the phase errors in the aperture produced by the toric surface has been made⁽⁵⁾.

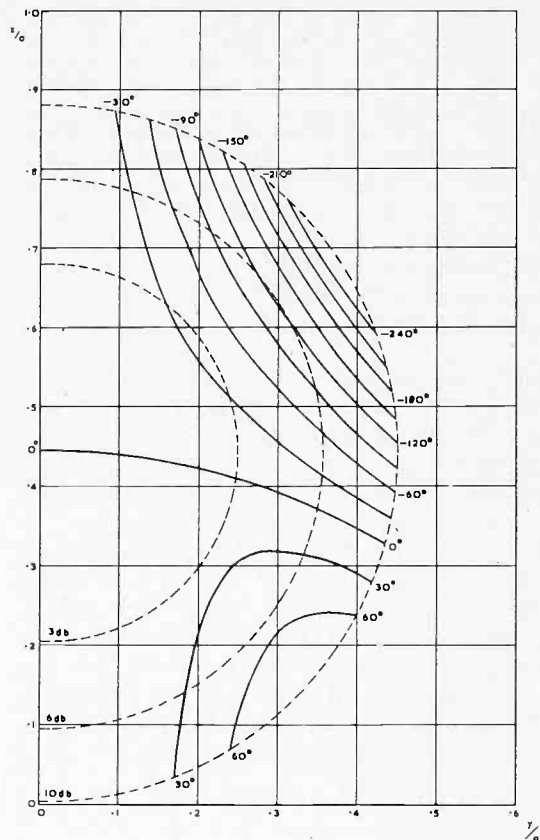


FIG. 9
Aperture phase error of the parabolic torus.

Thus curves of constant L in the y, z plane can be plotted.

Such curves are shown in Fig. 9, for

$R = 36$ inches $= 28.8 \lambda$ and $d = 20$ inches $= 0.56R$.

As a symmetrical reflector about the plane $x = 0$ has been considered and the phase contours shown only for the semi-aperture, the complete picture is in fact Fig. 9 plus its mirror image.

The broken semi-circles indicate approximately the taper in decibals of the primary pattern, disregarding, however, the effect of the inverse square law upon power distribution.

The conclusions which may be drawn from these phase contours are that the polar diagram of the toric aerial will deteriorate in the 35° planes, but in the vertical and horizontal planes it will be symmetrical and well focused. As every point of

In Fig. 1 F is the focus of the parabola, which is rotated about OZ to form the toric reflector. The equation of the parabola with respect to the shown axes is:—

$$Z^2 = 4kR(R - x) \quad (1)$$

where $OA = R$ and the focal length is kR , k being a dimensionless constant for any particular surface.

The equation of the toric surface is:—

$$Z^2 = 4kR(R - \rho) \quad (2)$$

where

$$\rho^2 = x^2 + y^2 \quad (3)$$

The optical path length from the focus F via a point $B(x, y, z)$ on the surface to the reference plane $x = 0$ has approximate length L such that:—

$$\begin{aligned} L &= x + \{(x - d)^2 + y^2 + z^2\}^{\frac{1}{2}} \\ &= x + \{\rho^2 + z^2 - 2xd + d^2\}^{\frac{1}{2}} \quad (4) \end{aligned}$$

where $OF = d = (1 - k)R$.

Solving (4) for x and obtaining

$$x = L - d \pm \{\rho^2 + z^2 + 2d(d - L)\}^{\frac{1}{2}} \quad (5)$$

and given L and z , ρ can be found from (2), x from (5) and y from (3).

the reflector contributes to some extent to all points on the secondary pattern, the position of the sidelobes may not easily be deduced.

It should be noted that the experimental measurement of the solid polar diagram of the aerial and the subsequent contour plot as shown in Fig. 4 shows that the conclusions drawn from the theoretical investigation of the phase errors across an aperture are well founded.

Conclusions

A reflector suitable for scanning over 360° in one plane, with a limited scan in the orthogonal plane, is a practical proposition at X-band. In the particular form investigated a pencil beam 3.5° wide (-6 dB) with sidelobes 25 dB down in the principal planes, was achieved but, as is seen in Fig. 4, a sidelobe 15 dB down is formed at an angle of 35° below the azimuth plane. This sidelobe performance is, however, relevant only to the particular vertical section selected, and a rather better performance (-18.5 dB) from a toric surface has been reported elsewhere⁽⁶⁾, although in this case the ratio of radius to height was greater than was chosen for our experiments.

The aerial does have considerable practical advantages. It forms its own radome and may be used in a system providing information at a much higher rate than is possible using rotating reflectors, especially in conditions of high wind. It is also suitable for use with multiple feeds, for example as the central element of a microwave link system radiating in a number of selected directions. Against its advantages must be weighed the comparatively high cost of manufacture of a former for this particular 6 feet diameter reflector. In the case treated above, the desire to maintain close tolerances on the contour necessitated the employment of a machined metal former. The cost would of course be reduced in proportion to the demand for reflectors and where the tolerances would permit the use, for example of wood or cement-plaster formers, a further substantial reduction should be possible.

The aperture efficiency of an aerial of this type is about 50%, that is the reflector has to be twice as large as its rotating counterpart to give the same beamwidth. On the other hand, where the system specification calls for a radome the overall dimensions of the two types of aerial will be approximately the same.

Acknowledgments

The authors wish to state that the original idea of the Toric Aerial was due to Mr. J. F. Ramsay.

Acknowledgments are made to the Board of Admiralty for permission to publish this work which was carried out under an Admiralty Contract.

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BOOK REVIEWS

"An Introduction to Junction Transistor Theory," by R. D. Middlebrook. Published by Chapman & Hall. Price 68/-.

This book is a useful contribution to the growing library of transistor literature, particularly for those concerned with the understanding of the physical processes in transistors and the effects of these processes on the behaviour of transistors as circuit elements.

The text is divided into three parts: Part I is a qualitative discussion of semi-conductor physics necessary for the basic theory of the p-n junction rectifier and junction transistor. Part II presents the fundamental treatment of transistor electronics leading to a small signal equivalent circuit, valid over the useful frequency range of the transistor as an amplifier. Part III is devoted to the transistor equivalent circuit from the point of view of the circuit engineer and includes hitherto unpublished work.

In the first three chapters there is a tendency for over-generalisations which, without qualification, lead to erroneous conclusions, particularly where reference is made to germanium and silicon power rectifiers on pages 9 and 28. The sections on metallurgy and transistor fabrication are understandably brief, but they are also sketchy and not authoritative.

The continuous development of the p-n junction and transistor theory which follows is clearly and logically presented and well illustrated. The physical significance of the parameters used in the equivalent circuit is extremely valuable and serves to emphasize the frequency limitations. The approximations made are clearly stated and a new high-frequency equivalent circuit is derived from the physics of the transistor.

It is unfortunate that the author has largely restricted his attentions to the germanium radio-frequency transistor when a direct comparison between the germanium and silicon device would have been of great value to the applications engineer. Similarly, enlarged sections on the variation of α_0 with emitter current (particularly at high injection levels) and the effects of surface recombination would have been welcomed now that the frequency and power ranges of current types of transistor have been extended.

In spite of these criticisms, however, this book accomplishes what the author set out to do and it can be recommended to all those in the electronic industry who wish to obtain a thorough grounding in basic transistor theory; a specialized knowledge of physics, mathematics and electronics not being a prerequisite for its understanding.

"F.M. Radio Servicing Handbook," by Gordon T. King, Odhams Press Ltd., 1957. 25s.

This book is less a handbook than a simplified introduction to the subject of V.H.F./F.M. receivers, with a heavy bias towards practical topics.

A clear and readable discussion of the nature of the F.M. signal, and of its advantages over the more conventional A.M. signal, provides a good beginning. The more difficult parts of a V.H.F./F.M. receiver, such as the discriminator stage and the V.H.F. circuits, are also adequately treated without recourse to mathematics.

Another attractive feature of the treatment is the description of present-day practice in the design of combined A.M./F.M. receivers, F.M. tuners and adaptors, and high fidelity amplifiers.

For the professional serviceman and amateur constructor, detailed testing and alignment procedures are also given.

The author is in difficulty, however, when he attempts to explain, in simple language, some of the more intricate aspects of the art, such as, for example, the residual phase modulation caused by amplitude limited noise.

Some of the terms used are incorrect and may, in a book of this kind, create a great deal of confusion. On page 36, interfering signals "heterodyne" with the wanted signal, when simple addition is meant, and we read in pages 179 and 180 of "harmoniously" instead of "harmonically" related signals.

On the whole, however, the book makes very absorbing reading and should prove a useful and interesting introduction to the subject for the beginner.

Book Reviews

The Services Textbook of Radio. The Services Textbook of Electrical Engineering, Volume I. Electrical Fundamentals, by G. R. Noakes, M.A. (Oxon), F.Inst.P. Published by H.M.S.O. 30/-.

The author is well known for his textbooks on all branches of physics and this latest volume is primarily written for the Services, but as it covers a wide field it is suitable for the beginner with certain marked sections for the advanced student.

One great asset of this book is the use of the rationalized m.k.s. system of units with its relationship to the c.g.s. system fully explained.

There are numerous numerical examples which help to elucidate the text, but a chapter on elementary mathematics with a table of the values of constants might have been an asset in order to assist the beginner and relieve the general text of such statements as "we can write the number 100 as 10×10 or 10^2 ; 1,000 as $10 \times 10 \times 10$ or 10^3 . . ."

The three pages devoted to electric shock and its treatment could have been given greater prominence, preferably at one end of the text.

Apart from the normal material found in an elementary textbook on electricity and magnetism there are chapters devoted to electrical machinery, to semi-conductors, to illumination, and to measuring instruments, with a very useful section by Messrs. G. W. A. Dummer and H. G. Manfield on materials used in radio equipment.

The chapter entitled "Semi-conductors" does not match up with the rest of the volume in the author's endeavour to explain everything fully and clearly. The first two pages of this chapter are very confusing and much of it is not required for the understanding of the rectifiers described in the rest of the chapter. The difference between an intrinsic and an extrinsic semi-conductor is not explained and some of the statements such as that the temperature co-efficient of resistance of a semi-conductor is always negative (pp. 85, 86, 569) and "the contact between a semi-conductor and a metal forms a layer which has a higher resistance in one direction than the other" (p. 569) are not true without qualification. On page 570 the author states that "any voltage applied across a semi-conductor requires two metallic contacts," but does not differentiate between the two metal/semi-conductor contacts which must have different electrical properties for a rectifier to be formed.

It would have been more explicit to have headed the chapter "Solid state rectifiers" as semi-conductors other than germanium silicon, copper oxide and selenium are not mentioned and most of the chapter is devoted to selenium and copper oxide rectifiers and their uses.

Whilst it may be strange to include a chapter on "Illumination" in this volume, it serves a useful purpose in linking light and radio waves, but a diagram showing the complete electromagnetic spectrum would have been desirable. The statement (p. 592) "the electric arc, which was generally used for street lighting until about 1914 . . ." is rather misleading.

The chapter on measuring instruments is really misnamed as it only covers those instruments generally known as "meters," but it deals with a wide range of meters and is probably of greater value to the electrical engineer than the preceding chapter on illumination.

As this volume is written for two series of textbooks, the author when referring to Volume 3 should state the series to which it belongs. There appear to be but few typographical errors but one appears in Fig. 3.1a (p. 67) where the hydrogen ion is shown with a negative charge.

This book can, however, be highly recommended and should be of great value to the elementary student of electrical fundamentals.

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GOA. E. Pinto Basto & Ca., Lda., 1, Avenida 24 de Julho, Lisbon. Sub-Agent: M. S. B. Caculo, Cidade de Goa (Portuguese India).

GREECE. P. C. Lycourezos, Ltd., Kanari Street 5, Athens.

GUATEMALA. Compania Distribuidora Kepaco, S.A. 9A, Avenida No. 20-06, Guatemala, C.A.

HONDURAS. (Republic.) Maquinaria y Accesorios S. de R.L., Tegucigalpa, D.C.

HONG KONG. Marconi (China), Ltd., Queen's Building, Chater Road.

ICELAND. Orka H/F, Reykjavik.

INDIA. Marconi's Wireless Telegraph Co., Ltd., Chawdhary Building, "K" Block, Connaught Circus, New Delhi.

INDONESIA. Yudo & Co., Djalan Pasar Minggu, 1A, Djakarta.

IRAN. Haig C. Galustian & Sons, Shahreza Avenue, Teheran.

IRAQ. Kumait Co., Ltd., Baghdad

ISRAEL. Middle East Mercantile Corpn., Ltd., 23, Yavneh Street, Tel-Aviv.

ITALY. Marconi Italiana S.p.A., Via Corsica No. 21, Genova.

JAMAICA. The Wills Battery Co., Ltd., 2, King Street, Kingston.

JAPAN. Cornes & Co., Ltd., Maruzen Building, Nihonbashi, Tokyo.

JORDAN. Hassan Hammad, Salt Road, Amman.

KOREA. The International Development Co. (N.Z.) Ltd., 602, Bando Bldg., 1st Street, Ul Chi Ro, Choong Ku, Seoul.

KUWAIT. Gulf Trading & Refrigerating Co., Ltd., Kuwait, Arabia.

LAOS. Henry Waugh & Co., Ltd., 204, Contonment Road, Singapore.

LIBYA. Mitchell Cotts & Co. (Libya), Ltd., 3, Maidan Asciuhada, Tripoli.

MALTA. Sphinx Trading Co., 57, Fleet Street, Gzira.

MOZAMBIQUE. E. Pinto Basto & Ca., Lda., 1 Avenida 24 de Julho, Lisbon. Sub-Agent: Entrepoto Commercial de Mocambique, African Life 3, Avenida Aguiar, Lourenco Marques.

NETHERLANDS. Algemeene Nederlandsche Radio Unie N. V., Wijnhaven 58, Rotterdam.

NEW ZEALAND. Amalgamated Wireless (Australasia), Ltd., Anvil House, 138 Wakefield Street, Wellington, C.I.

NORWAY. Norsk Marconikompani, 35 Munkedamsveien, Oslo.

PAKISTAN. International Industries, Ltd., 1, West Wharf Road, Karachi.

PANAMA. Cia. Henriquez S.A., Avenida Bolivar No. 7.100, Colon.

PARAGUAY. Acel S.A., Oliva No. 87, Asuncion.

PERU. Milne & Co. S.A., Lima.

PHILIPPINES. Radio Electronic Headquarters Inc., 173 Gomez Street, San Juan, Rizal, Manila.

PORTUGAL AND PORTUGUESE COLONIES. E. Pinto Basto & Ca., Lda., 1, Avenida 24 de Julho, Lisbon.

RHODESIA & NYASALAND. Marconi's Wireless Telegraph Co., Ltd., Central Africa Regional Office, Century House, Baker Avenue, Salisbury.

SALVADOR. As for Guatemala.

SAUDI ARABIA. Mitchell Cotts & Co. (Sharqieh), Ltd., Jeddah.

SINGAPORE. Marconi's Wireless Telegraph Co., Ltd., Far East Regional Office, 35, Robinson Road, Singapore.

SOMALILAND PROTECTORATE. Mitchell Cotts & Co. (Red Sea), Ltd., Street No. 8, Berbera.

SOUTH AFRICA. Marconi (South Africa), Ltd., 321-4, Union Corporation Building, Marshall Street, Johannesburg.

SPAIN AND SPANISH COLONIES. Marconi Española S.A., Alcalá 45, Madrid.

SUDAN. Mitchell Cotts & Co. (Middle East), Ltd., Victoria Avenue, Khartoum.

SWEDEN. Svenska Radioaktiebolaget, Alstromergatan 12, Stockholm.

SWITZERLAND. Hasler S.A., Belpstrasse, Berne.

SYRIA. Levant Trading Co., 15-17, Barada Avenue, Damascus.

THAILAND. Yip in Tsoi & Co., Ltd., Bangkok.

TRINIDAD. Masons & Co., Ltd., Port-of-Spain.

TURKEY. G. & A. Baker, Ltd., Prevuayans Han, Tahtakale, Istanbul, and S. Soyol Han, Kat 2 Yenisehir Ankara.

URUGUAY. Regusci & Voulminot, Avenida General Rondeau 2027, Montevideo.

U.S.A. Mr. J. S. V. Walton, 23-25 Beaver Street, New York City 4, N.Y.

VENEZUELA. English Electric de Venezuela C.A., Edificio Pan American, Avda. Urdaneta, Caracas.

VIETNAM. Henry Waugh & Co., Ltd., 204, Cantonment Road, Singapore.

YUGOSLAVIA. Standard, Terazije 39, Belgrade.