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MARCONI MULTI CHANNEL VISUAL H.F. DIRECTION FINDER TYPE DFG 28

By D. J. FEWINGS

The wartime development of the spinning goniometer with visual bearing presentation was carried to the point where four simultaneous bearings on differing frequencies were possible with sense on any one of the channels at a time. This was achieved by making modifications and additions to existing standard direction finders, as there was no time to design a special D.F. for the purpose. The problem of multi channel "sense" was not tackled until the development of the DFG 28.

Design of DFG 28.

The main criticism directed at previous spinning goniometer types of direction finder was that the noise produced by the driving mechanism was distracting. Accordingly, when the DFG 28 was projected, care was given to sound insulating the case housing the goniometer and driving motor. In addition, the commutator used previously in sense determination was dispensed with in favour of a device described below, which is silent in operation. The resulting noise level is exceedingly small.

When cabinet design was considered it was thought desirable to depart from the standard Marconi practice and to adopt a style more modern in appearance and to include in the cabinet all the apparatus which is normally added to D.F. equipment after installation, by the purchaser, generally to the detriment of the appearance of the apparatus.

General Description.

The DFG 28 H.F. D.F. operates on four channels in the frequency band 3–17·5 Mc/s. Each channel is independent both for bearings and for sense and all may work simultaneously.

The aerials are the standard type of Marconi Adcock spaced vertical masts (30 ft. high and 20 ft. spacing) with buried feeders.

No vertical aerial is used for sense.

A single spinning goniometer provides bearings to all channels without range switching.

Four Marconi type CR 150 receivers are employed, each in conjunction with a Marconi type OR 2/2 oscilloscope.

The overall sensitivity of the apparatus is such that 20 db S/N is obtained with signal strengths varying between ·5 and 6 uV per metre over the frequency range of 3–17·5 Mc/s.

Principle of Operation.

The principle of the spinning goniometer type of D.F. is briefly as follows. The search coil of the goniometer is spun electrically at about 700 r.p.m. The output of the search coil is fed to a receiver and the beat frequency output of the receiver to the Y plates of a cathode ray oscilloscope. The oscilloscope timebase is synchronised to the speed of rotation of the search coil by means of pulses generated electromagnetically every time the D.F. pointer passes 0° and 180° on the D.F. scale. A 0°–180° linear scale with reciprocals is engraved on the cathode ray tube face and shift and amplitude controls enable the undeflected line on the cathode ray tube screen to be superimposed on the engraved scale. Thus with an incoming signal deflecting the spot vertically and with the timebase moving the spot horizontally in a linear manner, the polar diagram of the goniometer is drawn on the cathode ray tube screen. As the timebase is tripped twice per revolution of the search coil, the two minima of the normal figure of eight are superimposed and indistinguishable from each other and the position of the bearing can be read off on the cathode ray tube scale.

Visual Sense.

As in the manual direction finder, a heart-shaped diagram is obtained by the addition of a circular diagram to the figure of eight. The heart has a single minimum and in order to ascertain sense visually, it is necessary to be able to see in which half revolution of the search coil the heart minimum appears. This is done by suppressing the signal appearing on the screen during either half revolution by means of some commutating device and a key. In order that no confusion be caused by the 90° difference between the heart and figure of eight minima, when sense is being determined the timebase is tripped 90° later so that the heart and figure of eight minima appear to coincide when viewed on the cathode ray tube.

Multi Channel Working.

In the DFG 28, the above principles have been adapted for multi channel working as follows:—

The search coil of the goniometer is fed to the grids of four pairs of valves in push-pull cathode follower circuits. The output of each pair is taken via DF/Sense selector keys to a receiver and the output of each receiver to an oscilloscope. In the interests of overall sensitivity, the search coil inductance together with the capacities of the screened leads and the eight grids to which it is joined is adjusted to resonate at approximately 11 Mc/s.

" Vertical " signals are derived from the centre points of the two field coil windings which are connected to the grids of two valves having a common anode circuit followed by a wide band amplifier. In this amplifier is also included a circuit tuned to 11 Mc/s arranged to follow the change of phase which accompanies the search coil resonance at this frequency.

The amplifier provides four separate outputs from four cathode follower valves with paralleled grids. Thus each channel has available an independent source of " vertical " signals. Each channel is provided with a tuned amplifier and mixing circuits for producing the heart-shaped diagram.

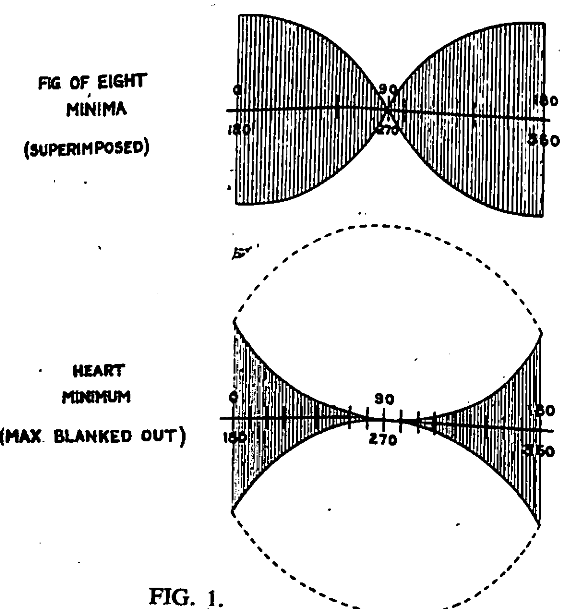

FIG. 1.

Synchronising.

Attached to the back of the goniometer dial which carries the engraved D.F. and sense pointers are two soft iron pole pieces set at 180° to each other about the axis of the goniometer spindle. As the search coil rotates these pole pieces pass in turn close to a magnet and coil assembly attached to the goniometer casing. This magnet and coil assembly is so placed that the pole pieces pass the magnet at the same instant that the D.F. pointer passes 0° and 180° on the D.F. scale. Thus each time that the D.F. pointer passes 0° and 180° a pulse of current is produced in the coil round the magnet. A second magnet and coil assembly spaced 90° further round the scale is provided to produce the pulses required when sense is to be determined. The two magnets are carried on an adjustable carrier which can be rotated about the axis of the search coil spindle through a few degrees by means of an adjusting screw which can be locked. This enables the phase of the pulse to be adjusted accurately. The coils are connected to the grids of two amplifying valves each providing four independent outputs. One output of each is taken to the DF/Sense selector key on each channel.

Sense Blanking.

The viewing of a visual heart necessitates the removal at will of the signal on the tube during either half revolution of the search coil.

Attached to the goniometer spindle is a disc in which is a slot cut around an arc extending to 180°. On one side of the disc is a lamp and on the other side a photocell. Thus the photocell is illuminated during one half revolution and darkened during the other half producing a square wave voltage across the photocell. This is amplified by a D.C. amplifier and taken to phase splitting circuits. These provide eight output signals, four in the original phase and four in the reverse phase. One output of each phase is taken to each channel where either can be selected at will by means of a key and applied to the modulating grid of the cathode ray tube thereby extinguishing the spot during

either half revolution of the search coil. On each channel, the blanking selector key is combined with the DF/Sense key which has three positions. In the centre position the figure of eight signals are taken direct to the receiver and the D.F. synchronising pulse is selected and applied to the oscilloscope. In the upper and lower positions the heart circuits are engaged, the sense synchronising signal is selected and the two blanking signals are selected, one with the switch in the upper position and the other in the lower position. The key is labelled " DF " in the centre position " Sense 0°–180° " in the upper position and " Sense 180°–360° " in the lower position.

The procedure for obtaining sense on any channel is very simple. Assuming a station has been tuned in on the receiver and a bearing obtained, the heart tuning control is set to the frequency of the received station. The DF/Sense key is then set to " Sense 0°–180° " and by adjusting the vertical amplitude control a minimum is sought in the same position on the tube as was the D.F. minimum. If no minimum is found the operation is repeated with the DF/Sense key in the " Sense 180°–360° " position. If the minimum is found with the key in the upper position the bearing is in the 0°–180° sector and the upper scale on the OR 2/2 should be read. If the minimum is found with the key in the lower position the bearing is in the 180°–360° sector and the lower scale of the oscilloscope should be read.

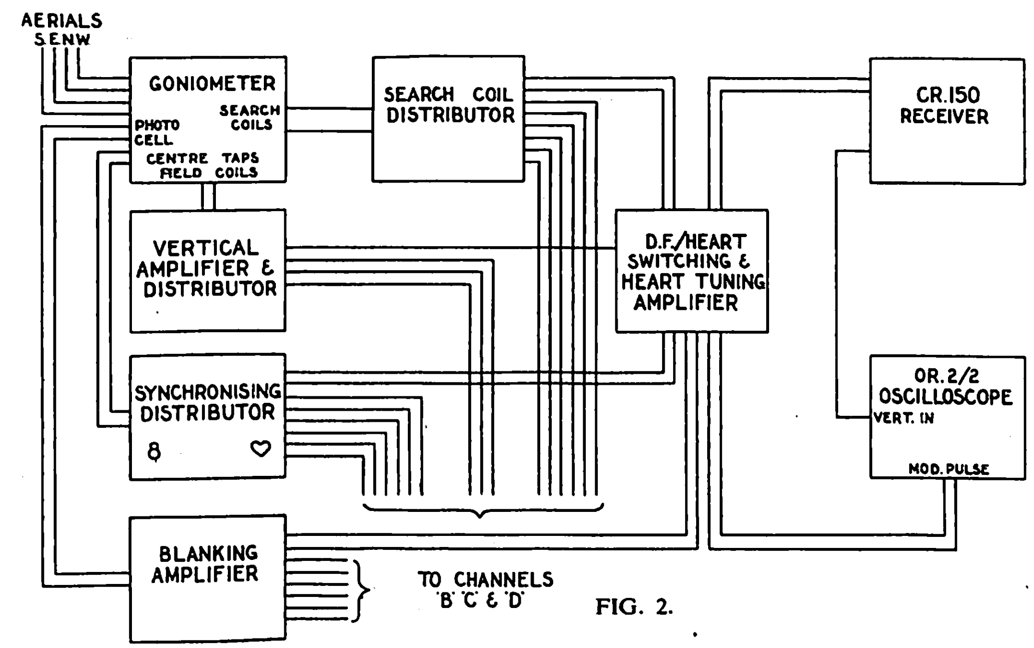

FIG. 2.

If a station lies due north or south or close to these positions the key should be set in the 0°–180° position and the heart minimum obtained in the usual way. If it occurs at the 0° end of the scale the bearing is near 0°, if at the 180° end the bearing is near 180°.

Each of the four channels have similar circuits and the procedure is identical on each. Typical bearing and heart patterns are shown in Fig. 1 and a block schematic diagram of the apparatus in Fig. 2.

Layout.

The apparatus is contained in four separate frameworks each containing a receiver, power pack, oscilloscope and heart circuits for direction finding and also a telephone, transmitting key, microphone, intercom. unit and transmitter control panel for communication purposes.

One of the frameworks is rather larger than the others and is so placed in the hut that the feeders from the aerials rise at the back and are screwed to a fitting about 12 in. above floor level. This framework carries in addition to the apparatus enumerated above, the goniometer with motor for spinning, the synchronising pulse amplifier, search coil distributing unit, " vertical " distributing amplifier, heart blanking amplifier and two further power packs. The three subsidiary units are distributed in the hut as shown in Fig. 3. They are mounted on castors and are movable with ease. Each is connected to the master unit by two flexible cableforms, one carrying RF signals, synchronising and blanking signals, mains and earth connection and the other, five pans of telephone lines.

The Master Unit.

The front view of this unit is shown in Fig. 4. This view shows the front panels of the receiver goniometer and oscilloscope while the drawer contains the intercom. unit and transmitter control panel. The various distributing units are fitted on shelves at the rear of the receiver and goniometer. All connections between units are made with plugs and sockets which are colour coded where necessary. The transmitting key is fitted beneath the writing desk with the operating knob projecting through it, while the microphone is fitted on a flexible support in the centre of the front panel.

In the top of the cabinet is a lamp which provides indirect lighting for the hut by illuminating the ceiling. Desk lighting on each unit is provided by a strip light under a cowl on each oscilloscope.

Fig. 5 shows the master unit together with one of the three subsidiary units. The layout of a subsidiary unit is similar to the master unit except that the intercom. unit and transmitter controls are carried on a hinged panel which occupies the space allotted to the goniometer on the master unit. The drawer which housed this apparatus on the master unit is replaced by the receiver power pack.

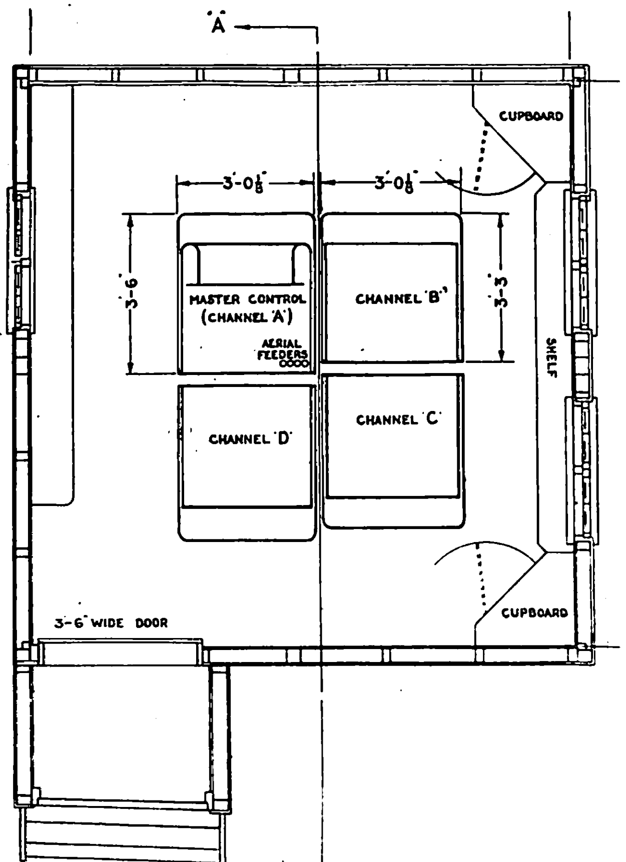

FIG. 3.

Notes on Component Sections.

Goniometer. The goniometer is driven through an approx. 2/1 step-down friction drive from a 1/100th H.P. synchronous motor running at 1,500 r.p.m. which is bolted to the goniometer casting. A clutch handle is brought out to the front panel for switching over to manual operation if required. The switch over is accomplished by pushing in and turning the knob. In the manual position this knob serves as a hand control.

On the right-hand side of the front panel are situated the heart controls which comprise heart tuning (with calibration carried on a drum illuminated from within), a three range switch with thumb control, a vertical amplitude control and a DF/Sense key which also serves as the 0°–180°/180°–360° Sense key.

An eight-day clock is fitted at the top of the panel.

The left-hand side panel of the goniometer case is removable and gives access to the aerial balancing condensers. These are differential air spaced condensers, the use of which in place of the single condensers used in earlier direction finders, renders aerial balancing a comparatively simple matter.

The photocell, shutter and lamp are mounted at the rear of the goniometer within the goniometer case.

The synchronising pulse producing magnets are situated just behind the goniometer scale and the phasing control comprises a knurled knob and wing lock-nut.

Oscilloscope OR 2/2.

This is a standard instrument whose main virtues comprise an exceedingly linear sweep, an exceedingly rapid flyback (less than 1/4° of the scale) and easy synchronisation. The scale which is applied to the face of the tube photographically, is corrected for bulb curvature.

Search Coil Distributing Unit.

This comprises four pairs of EF50 valves in push-pull cathode follower circuits. Search coil signals are fed in push-pull to each of these pairs of valves, the grids being connected in parallel.

Balancing condensers are provided for the grid and cathode circuits. In addition, each pair of cathode followers is fitted with balancing condensers (connected between each grid and the cathode of the other valve of the pair) to neutralise the grid cathode capacities.

The use of these balancing condensers effectively prevents interaction between the channels.

" Vertical " Distributing Amplifier.

The centre points of the field coil windings are taken through a high pass filter (cut off 2 Mc/s to avoid cross modulation from M.W. stations) to the grids of two EF50 valves having a common anode circuit. The anode circuit is tuned just below 3 Mc/s and is also partly resistive. A second stage of amplification is added, tuned to approx. 11 Mc/s at which frequency the search coil resonance occurs. This circuit also has a resistive element and the whole comprises a wide band amplifier over the band of frequencies 3–17·5 Mc/s. The output is taken to four cathode followers which distribute the " vertical " signals to the four channels.

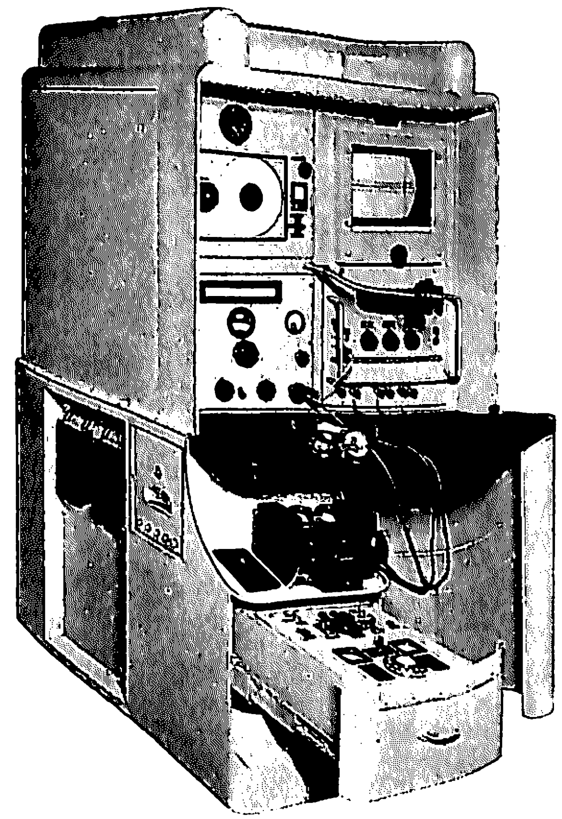

FIG. 4.

Synchronising Amplifier.

The two synchronising pulses from the goniometer are amplified by two KTW 61 valves. Each valve anode circuit consists of a step-down transformer which feeds a bridge network from which four independent signals are obtained through 1/1 transformers.

Heart Tuning Amplifiers.

Each output from the " vertical " distributing amplifier is taken to a tuned amplifier on each of the four channels. The valves employed are EF50's and the circuit in each case is that of a grounded grid amplifier, the input signal being applied to the cathode. The gain of the amplifier is controlled by a potentiometer through which positive volts are applied to the grid. This serves as the " vertical amplitude control."

The anode circuit comprises a transformer with the primary tuned. The band is covered in three ranges, 3–7, 7–13 and 13–17·5 Mc/s. The secondary is taken to the DF/Sense key and is switched into the DF circuit when the key is thrown to either of the sense positions. The key also switches on HT volts to the valve in the sense positions. Phase adjusting circuits are included on ranges 2 and 3 and a damping resistance across the primary serves the same purpose on range 1. The DF/Sense key also selects the appropriate synchronising signal for DF or sense and blanking signal for either 0°–180° or 180°–360°.

Blanking Amplifier.

This amplifies the signals from the photocell and comprises one L 63 valve with a resistive anode load directly coupled to four pairs of cathode coupled amplifiers (BL 63 valves). The latter are balanced and produce two square wave voltages, one in phase and one out of phase, with the original photocell output.

Receivers.

These are standard Marconi type CR 150 with a slight modification which desensitises the receiver when the transmitting key is depressed.

Performance.

Exceedingly good sensitivity has been achieved despite the use of an unswitched goniometer for the entire range, necessitated by multi channel requirements. From this point of view the DFG 28 compares very favourably with all previous direction finders.

It has the normal Adcock type H.F. D.F. accuracy and the visual indicators are of great value in assessing the value of a bearing obtained. A swinging bearing is very obvious on a visual indicator.

Each channel is exceedingly simple to operate since the receiver tuning is the only control knob which is required to be used for obtaining bearings once the gear has been set up.

Sense is simple and quick to obtain and there is no possibility of a reversed heart at any frequency in the band.

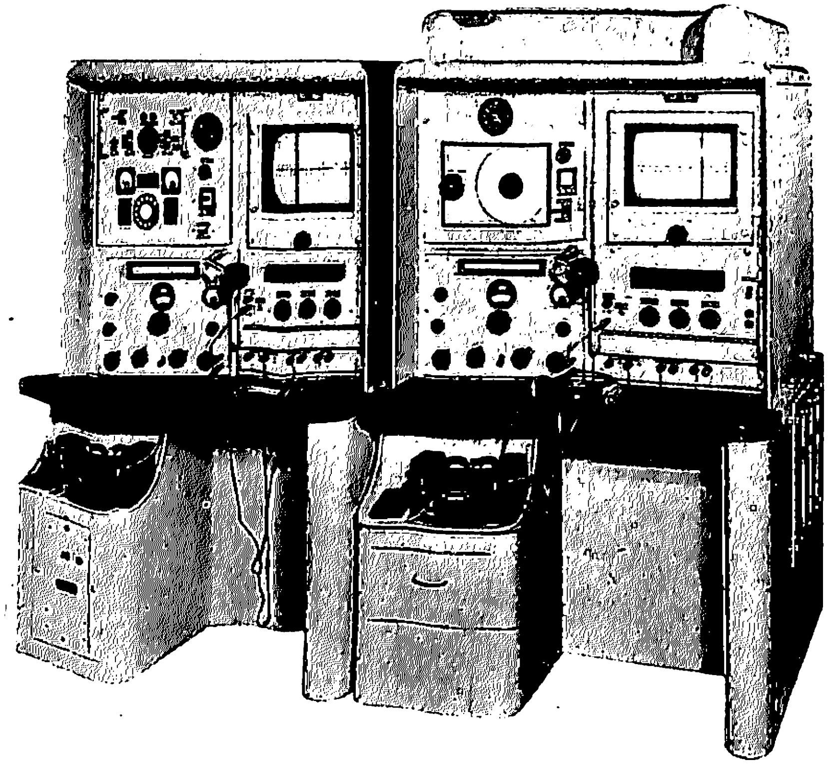

FIG. 5.

Transmission of D.F. Bearings by Lines.

One virtue possessed by the DFG 28 in common with all spinning goniometer type direction finders is the ease with which bearings can be transmitted over lines to remote indicators, a point which is becoming increasingly important.

If the distance over which it is desired to transmit the bearings is comparatively small and if two pairs of lines, independent of external telephone circuits are available (say from a local DF site to an aerodrome control tower), then all that is required is an additional oscilloscope.

The DF receiver output is sent down one pair of lines and the synchronising pulses down the other pair. At the receiving end of the line, the DF signals are applied to the Y plates of the tube and the synchronising signals to the oscilloscope timebase, and the bearings are reproduced without error. Over longer distances over private lines which do not pass P.O. repeaters, an amplifier at each end of the lines can be used and a phantom circuit for ordinary telephone use can be incorporated. The circuit of Fig. 6 was used in a successful demonstration during the war.

A more difficult requirement is to transmit bearings over a single pair of lines which may pass P.O. repeaters en route.

A normal requirement of such lines is that the frequencies employed shall be between 1000 and 2000 cps. This means that it is no longer possible to use the beat frequency output of the receiver which may vary beyond these limits, or to send the synchronising signal direct. A successful wartime demonstration was carried out as follows (Block schematic diagram Fig. 7).

The beat frequency output of the receiver was demodulated and the envelope employed to modulate a carrier at 1800 cps. Another carrier at 1500 cps. was modulated with the synchronising

pulse. The two signals were then mixed and transmitted down the line. At the receiving end of the line the signals were amplified and applied to two Wien bridge circuits. One of these was adjusted to reject 1800 cps and the other to reject 1500 cps. The bridges were followed respectively by amplifiers tuned to i 500 and 1800 cps.

The oscillator circuit shown in Fig. 8 was used to provide the carrier frequencies. It is a modification of the well-known two valve RC coupled L.F. oscillator circuit in which the frequency is controlled by the RC network in the feedback circuit $\left(f = \frac{1}{2\pi RC}\right)$ In the circuit shown, a single valve was

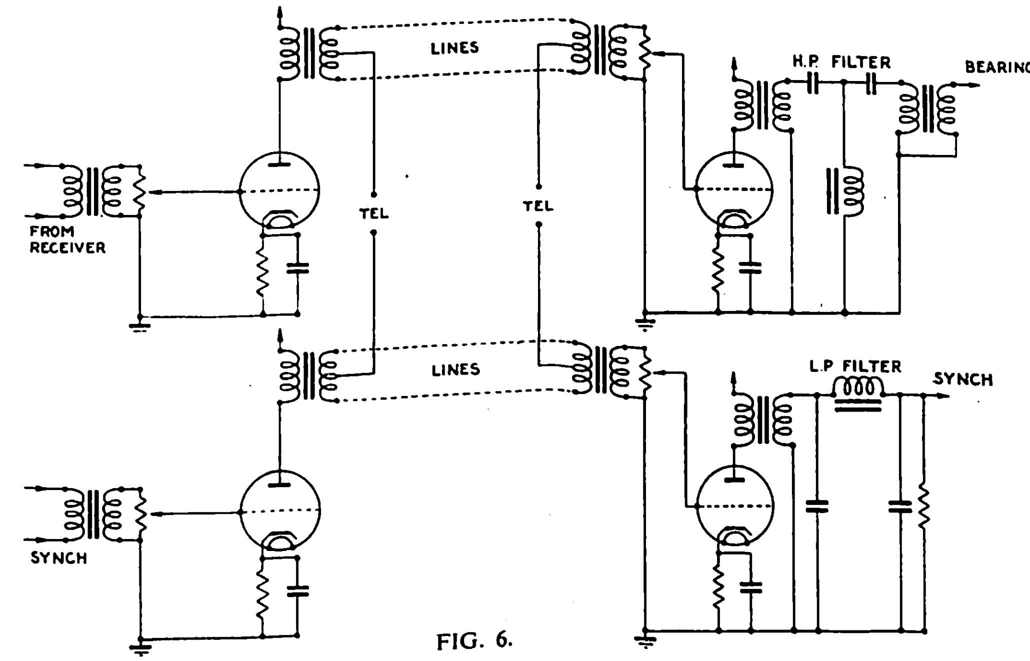

FIG. 6.

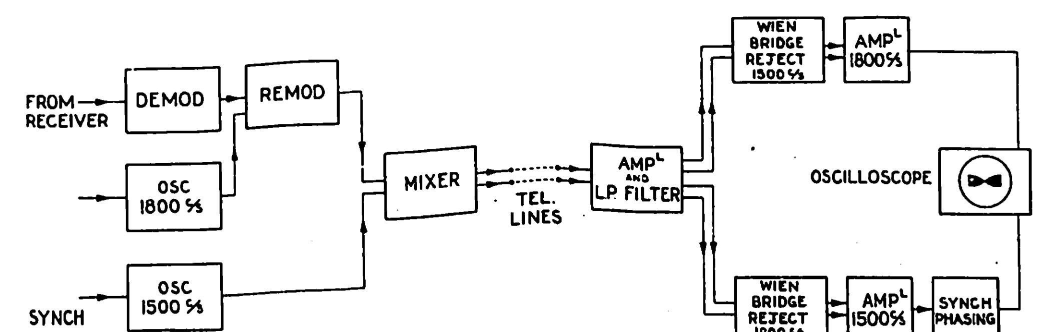

FIG. 7.

used with transformer feedback from anode to cathode via the RC network. An exceedingly good sinewave can be obtained from this circuit if the swing is not excessive, an important point, since the Wien bridges will not deal with harmonics. By increasing the resistor in series with the cathode the oscillations can be stopped and the valve then acts as an exceedingly efficient amplifier at the oscillation frequency. This was the circuit used to amplify the signals after their separation by the Wien bridges. This arrangement of the circuit is particularly useful since the valve grid is left free for the application of the signal. The output from the 1800 cps. amplifier was applied to the Y plates of the oscilloscope and that from the 1500 cps. amplifier through a demodulator, amplifier and pulse shaping circuit to the synchronising terminal of the oscilloscope.

The results obtained were excellent, bearings not being marred in any way. It was just possible to detect that the synchronising pulse carrier was not completely removed from the bearing carrier due to the fact that the Wien bridge circuit produces a perfect cut at one frequency only and the 25 cycle modulation produced sidebands which were incompletely removed. The resulting signal did not, however, interfere with bearings in any way.

When long lines are used it is possible for errors to occur due to different delays obtaining for the bearing and synchronising signals. It is thus desirable to have some control over the phase of the synchronising pulse. This was achieved in the first instance by producing the original pulse from an independent pulse coil which could be adjusted relative to the spinning search coil. To avoid modification to existing DF's, however, the phase control is better carried out at the receiving end of the line. The process is to pulse a circuit tuned at 25 cycles per second with the synchronising pulse, to control the phase of the resulting sinewave in the normal manner by means of a capacity resistance network, and to reform the pulse by triggering a pulse oscillator with the phase controlled sinewave. The pulse can also be reformed by applying the sine wave to a valve circuit employing a saturating transformer. This is probably the better method since it does not involve a second synchronisation.

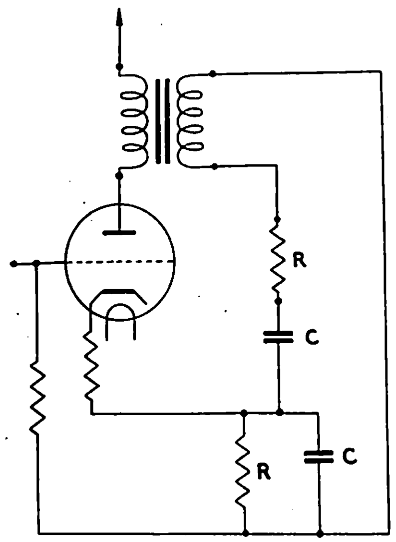

FIG. 8.

Sense. The sending of sensed bearings down lines does not present any difficulty if the co-operation of the DF operator is available. He takes his bearing in the normal manner and then sense, by operating the DF/Sense key, say, first up, then down. The blanking signals are employed to shutter the signals sent down the line and the normal heart diagrams are reproduced at the receiving end of the line. Modern requirements, however, tend towards unmanned direction finders with remote control. Providing spot frequencies are worked and the heart is set up manually to start with, a remotely controlled DF/Sense key will enable heart diagrams to be transmitted down the line at will. One additional pair of lines would suffice.

A completely remote controlled DF involving switching on and off, receiver tuning, heart tuning and "vertical amplitude" control is undoubtedly a possibility over short distances though the cost of the lines required would probably render the scheme uncommercial over long distances.

WAVECHANGING AND TUNING IN RECEIVERS BETWEEN 30 AND 180 MEGACYCLES/SEC.

By L. R. Head.

In a receiver designed to cover the above frequencies, the changing of the tuning coils, and hence the range of frequency available with a given tuning condenser, is a major problem. Various factors, some of which may be neglected at lower frequencies, become of great importance, and some such as stray inductance may become so vital as to determine the highest frequency to which the system can tune. A consideration of these various points will help in understanding the difficulties involved in designing a tuning and wavechange system for these frequencies.

(*a*) Stray inductance.

As is well known any lead connecting two points together possesses inductance according to the shape and size of the conductor. Wires from 16-22 S.W.G. possess some 5 to 10 centimetres of inductance per centimetre length of straight run (1 centimetre of inductance = 0·001 μH or 10^{-9} Henry). So that when it is considered that in a certain receiver in order to tune to 180 Mc/s at the minimum capacity of the variable condenser a total tuning inductance of about 0·035 μH = 35 cms. is required, a straight run of wire of 5 centimetres length is sufficient (taking an average for the quoted inductance figures), and the nature of the problem can clearly be seen.

Now this required inductance has to include the self-inductance in the variable condenser, together with that in the wavechange switch and in the coil itself. It can thus be seen that without some care the majority of the inductance required will disappear as "strays," leaving only a very small amount in the coil itself, and this in turn may give the circuit a poor Q value.

Another point to be borne in mind is that in general some adjustment of the tuning inductance must be provided for ganging purposes. If the majority of the inductance consists of strays then any adjustment of that in the tuning coil will have only a minor effect on the total inductance, and the range of the inductance adjustment will be very limited. In connection with this last point it is also seen that in designing an aerial coupling winding the maximum coupling factor (k) will be very restricted and a comparatively large coil winding might be required to effect the necessary impedance match. A coupling winding of greater inductance than the main tuned circuit is dangerous since it may result in absorption or mis-ganging due to resonance with its self-capacity.

(*b*) Minimum Capacity.

At frequencies lower then 30 Mc/s the minimum capacity of the tuned circuit is of less importance since the resulting impedance is much greater. A major part of the minimum capacity is due to the input and output capacities of valves, and it is unfortunate that the higher the mutual conductance of the valve the greater is the input capacity. The remainder is composed of the minimum capacity of the variable condenser, which by suitable choice of the type used can be quite low, the switch capacity, and odd strays, which can be made a minimum by careful layout.

The lower the minimum capacity that the circuit can be made the better since, for a given frequency, the greater is the inductance required and hence stray inductances become of less importance. Again the greater the minimum capacity the greater is the capacity sweep required for a given range factor. This gives a very low tuned circuit impedance at the low frequency end of the range which results in low stage gain and poor sensitivity. Also for a large value of sweep capacity the variable condenser must of necessity be made larger physically which increases the stray inductance.

(*c*) Mechanical Stability.

This of course is important at lower frequencies, but is doubly so in the frequency range under discussion, and all parts must be of sturdy construction. A base plate of $\frac{1}{8}$ inch thick metal is common in work of this nature. The wiring and assembly must be made as rigid as possible so that any vibration to which the receiver may be subjected causes negligible change in frequency.