

# A Five-Circuit F.M. VHF Junction Radio Equipment System SPO 5050

*The total cost of a system consisting of two complete terminals of this equipment, with associated aerials and feeders, is less than the cost of the copper required to derive a single open-wire pair for the provision of equal facilities over a 50-mile route. Designed for ease of installation, adjustment and maintenance, the equipment solves many of the problems of providing junction circuits where terrain is difficult for line construction and maintenance.*



Fig. 1.—Five-circuit terminal rack.

The complete equipment for a terminal, including radio, multiplex and power supply panels, is a rack 6' 0" high, 1' 8½" wide and 8½" deep (1.83m. × 0.52m. × 0.216m.) Its weight is 365 lbs. (166 kg.)

The transmitter output power is 15 watts, a complete terminal consumes 400 watts from an AC supply

A data summary relating to System SPO 5050 is to be found at the end of this article.

Designed for the tropics as well as for temperate zones, System SPO 5050 is in service in climates such as those of Zanzibar, Malaya, Sweden, Finland and Canada.

About 50 miles can be covered by a single link, the distance in an individual case being largely dependent upon the elevation of the aerials and the nature of the intervening terrain. By the use of repeater stations, which incorporate transmitters and receivers similar to those of terminal stations, considerably greater distances between one terminal and the other may be covered.

The equipment has been designed so as to be especially easy to transport, instal, adjust and maintain. All the panels may be removed from the lightweight rack, which can then readily be conveyed to difficult locations.

The equipment is mounted on panels, which slide into place on the rack. Electrical connexions are then made by plug-in links. Thus the removal of a panel from the rack, or its replacement, is effected in a very short time without the disconnexion of any wiring. For maintenance purposes, too, the equipment need not be disconnected for any time longer than that needed to replace the panel to be serviced by a spare one.

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## Frequencies

The equipment provides five audio circuits each with a bandwidth of 300 - 2800 c/s over a single duplex radio link by means of a frequency-division-multiplex system. Provision is made for the use of a tone of 2280 c/s either for generator signalling between telephone switchboards at the terminals or for dial impulses. If so desired, the upper limit of Channel 1 may be reduced to 2300 c/s, and the remaining space can then be used for a duplex telegraph channel, operating with carrier frequency of 2580 c/s. If specified, a programme channel is provided. The frequency range normally devoted to three speech channels is allotted to the programme channel, which has a bandwidth of 50 - 8000 c/s, or, if the frequency range of four speech channels is used, the programme channel bandwidth is 50 - 10 000 c/s.

The bandwidth of the radio equipment to accommodate the five speech channels is 300 - 20 000 c/s. The effectiveness of the transmitter output power of 15 watts can be considerably increased in the required direction by use of a highly directional aerial.

The transmitter and receiver are crystal controlled and work in the frequency band 156 to 184 Mc/s. Equipment can also be supplied to work in the following additional frequency bands:-

71.5 to 88.0 Mc/s	235.0 to 270.0 Mc/s
146.0 to 156.0 Mc/s	280.0 to 325.8 Mc/s

The changing of frequency within a band is performed quite simply by changing the crystals and then retuning the units. A meter and a multi-way switch are provided on both the transmitter and the receiver, and realignment on a new frequency is readily carried out with the aid of the meters in accordance with a simple procedure.

## Operation

The system operates on a duplex basis. Facilities are provided for the external connexions to the audio circuits to be either two-wire or four-wire, plugs being provided on each channel panel so that the change from the one to the other can readily be made.

The transmitter and receiver at a given terminal work on different frequencies. Transmission in one direction is on one frequency and in the other direction on another frequency

## (i) Multiplex Equipment

Fig. 2 shows a block schematic diagram of the multiplexing equipment. The five circuits of this system are arranged as follows :-

- Channel 1 One unmodulated speech band.
- Channel 2: One lower sideband of modulation with 6.667 kc/s.
- Channel 3. One upper sideband of modulation with 6.667 kc/s.
- Channel 4: One lower sideband of modulation with 13.333 kc/s.
- Channel 5: One upper sideband of modulation with 13.333 kc/s.

If four-wire extension circuits are used, the transmit and receive pairs are connected to input transformers on each channel panel. For two-wire circuits, the input and output channel transformers are combined by means of plugs to form a hybrid transformer, thus converting the two-wire extension circuit to four-wire working within the equipment.

## (a) Transmit Direction

The speech band of Channel 1 passes via a level adjustment pad, a fixed attenuator pad and a speech voltage limiter to a low-pass filter. For Channels 2 to 5, the four-wire audio input to each carrier channel passes by way of an adjustable attenuator to a ring modulator. The ring modulator is fed also with the appropriate carrier frequency, and the modulated carrier wave is produced at the output. The carrier frequency is considerably suppressed by the modulator, and the output signal, consisting mainly of upper and lower sidebands, passes via a fixed attenuator pad to the transmit band-pass filter, where the unwanted sideband and the residual of the carrier are virtually eliminated. The modulator also acts as a limiter

The outputs of the four carrier-channel band-pass filters and the unmodulated channel low-pass filter are connected in parallel with a filter compensating network and the combined signal in the frequency band 300 c/s to 16.33 c/s passes to the radio transmitter, via a matching transformer

### (b) Receive Direction

The output signal from the radio receiver is fed by way of a matching transformer directly to four receive band-pass filters and one receive low-pass filter, connected in parallel. A filter compensating network is also connected across these filters. The signal from Channel 1 passes through a low-pass filter and attenuator pads to the channel amplifier, which gives the required 4-wire output level. This level can be varied, by means of the pads, over a range of 7db in 1db steps, and over a further 7db by means of the continuously variable potentiometer.

In the case of Channels 2 to 5, the appropriate sideband is selected by a band-pass filter and fed via an attenuator pad to the demodulator. The low-pass filter following the demodulator rejects all but the audio frequency signal, which is passed through a fixed attenuator to the demodulator amplifier. The output level adjustment provided on Channels 2-5 is similar to that described for Channel 1

The demodulator employs the same type of ring circuit as the modulator and is fed with the same carrier frequency as the modulator for the particular circuit.

### (c) Frequency Generation

A highly stable 100 kc/s crystal oscillator is used as the master oscillator. Multi-vibrator circuits divide the output of the master oscillator by 15 to produce the first carrier frequency of 6.667 kc/s.

A frequency-doubler stage then produces the second carrier frequency of 13.333 kc/s. Thus any variation by the master oscillator from the normal frequency is divided by 15 and 7.5 respectively at the two carrier frequency outputs, the resulting stability gives a high standard of inter-terminal synchronism.

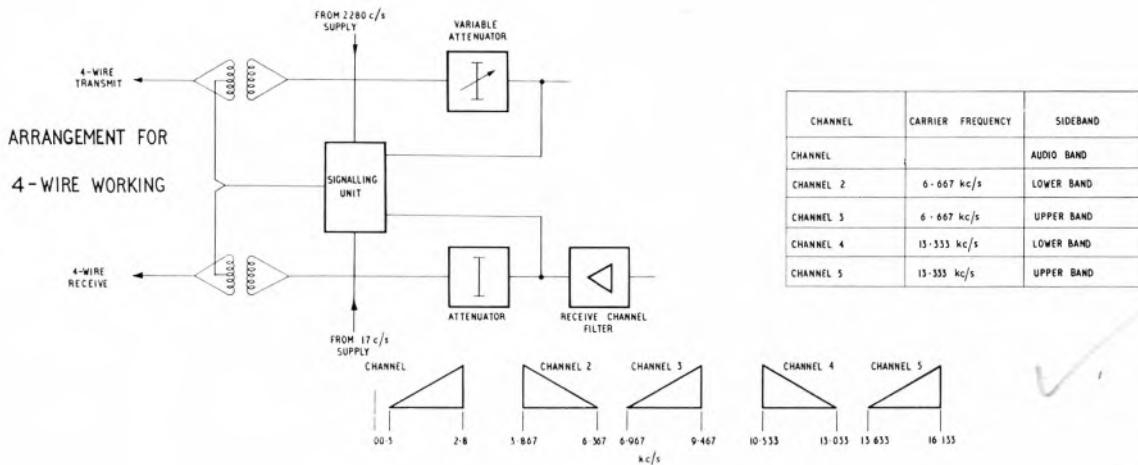
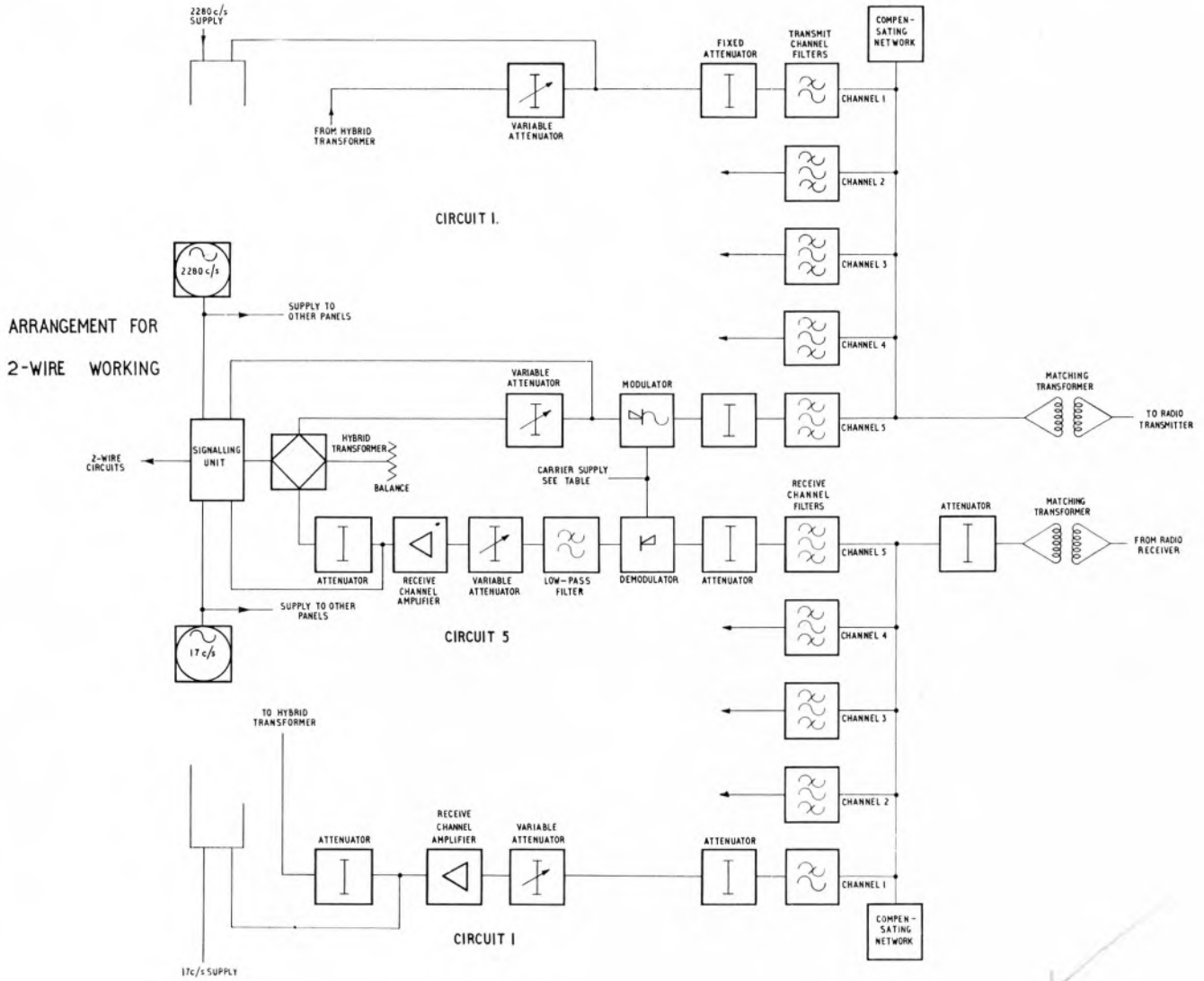
### (d) Signalling

Oscillators incorporated in the equipment generate the 2280 c/s and 17 c/s signalling frequencies. Provision is also made for the connexion of an external ringing generator supply, provided when particularly required.

At the transmit end, the apparatus receives 17 c/s or 20 c/s ringing current or a DC signal, and transmits the 2280 c/s tone. At the receive end, the 2280 c/s tone actuates a voice frequency receiver and causes the internally generated 17 c/s ringing current, or alternatively, externally generated 17 c/s, 20 c/s or DC ringing signals to be transmitted to the extension line.

These facilities are available over a two-wire extension, or over a four-wire extension using the phantom. As an alternative to simple ringing, facilities can be provided on a four-wire basis for transmitting and receiving dialling impulses. The three relays used for ringing purposes are replaced by an impulsing relay, and a number of minor circuit modifications are made. In addition, junction relay sets that may be suitable for one or both-way dialling are required, and are associated with the automatic switching equipment.

Fig. 2 (right) Simplified block schematic of the multiplexing equipment of System SPO 5050, illustrating the difference between the two-wire and four-wire arrangements.



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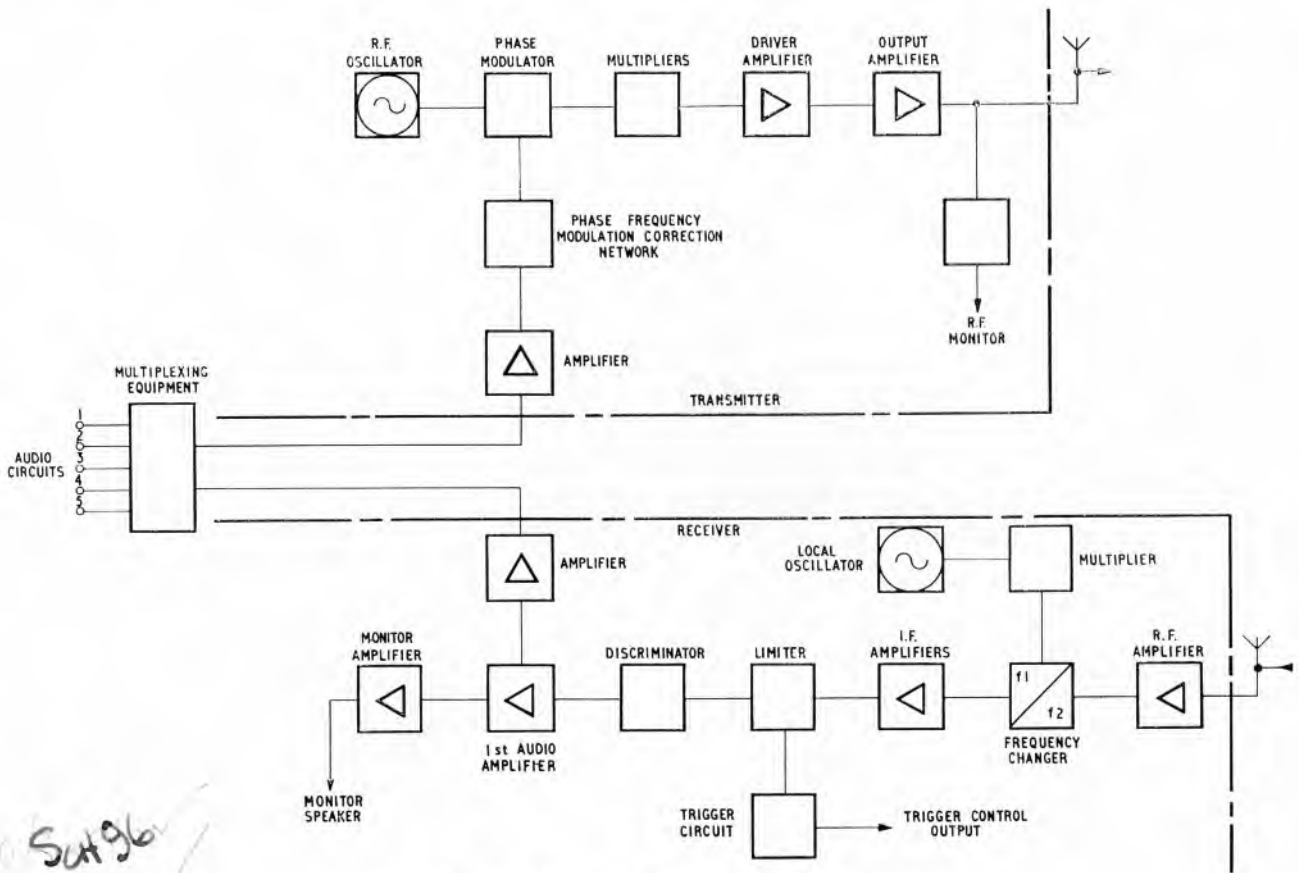


Fig. 3.—Schematic of the radio equipment.

**(ii) Radio Equipment**

Fig. 3 is a schematic diagram of the complete radio equipment.

**(a) Transmitter**

Operational frequencies within the frequency range of the equipment are selected by means of plug-in crystals. A low-power switch facilitates the tuning of the transmitter. The frequency-modulated output has a deviation of  $\pm 15$  kc/s.

The output from the multiplex equipment is fed to the input of a high gain pentode amplifier, by way of an isolating and matching transformer and an adjustable level control. The output of the amplifier is fed to the phase-to-frequency modulation correction network, and also to a level metering circuit.

The transmitter carrier frequency is generated by the crystal controlled master oscillator, which operates within the range 0.9 to 1.5 Mc/s. (Fig. 4.) In order to ensure a high degree of stability, the crystal is mounted inside a thermostatically controlled 'oven' which maintains the crystal at a constant temperature.

The output of the oscillatory circuit, which uses the cathode, control grid and screen grid of a pentode, is electron-coupled to the anode. The radio frequency is then taken from the anode, so that reactance changes in the following phase-modulator stage will have no effect upon the frequency generated by the oscillator. A common anode load is used for the oscillator and modulator valves, and a phase-shifting network is connected from

the anode to the grid of the modulator valve in order to feed the grid with crystal frequency shifted in phase by about 60°

The output of the input amplifier is also connected to the modulator valve grid by way of the phase-to-frequency modulation correction network. The modulator valve is biased to the non-linear portion of its characteristic, with the result that the audio signal amplitude modulates the radio frequency, which is also connected to the grid. The modulated wave then appears at the anode of the modulator, shifted in phase from the crystal frequency by approximately 120°. The direct crystal frequency and the modulated wave then combine to give a resultant that varies in phase and to a smaller degree in amplitude.

The phase-to-frequency modulation correction network (resistance-capacitance only) is arranged to give an attenuation of approximately 6db per octave above 500 c/s, with the result that the output of the modulator is frequency modulated rather than phase modulated.

The output from the modulator stage is then fed to a chain of five pentodes, arranged to multiply the frequency of the modulated signal to the required output frequency and deviation at a low level. Double-tuned circuits are used between all multiplier stages to select the required harmonics and to reduce radiation at undesired frequencies. As the multiplier stages are operated under Class C conditions, the amplitude modulation is lost during multiplication. The output from the last multiplier stage is then fed to a push-pull driver stage and finally to the output stage (Fig. 5). The output valve is fed with a fixed bias voltage in order to protect it from the effects of loss of drive.

The output of the transmitter is of some 15 watts and is fed to the aerial by means of coaxial cable of 75 ohms impedance. A pi network is used to couple the aerial to the output valve, and since the output is taken from the capacitive branch of a resonant circuit, undesirable harmonics are effectively rejected.

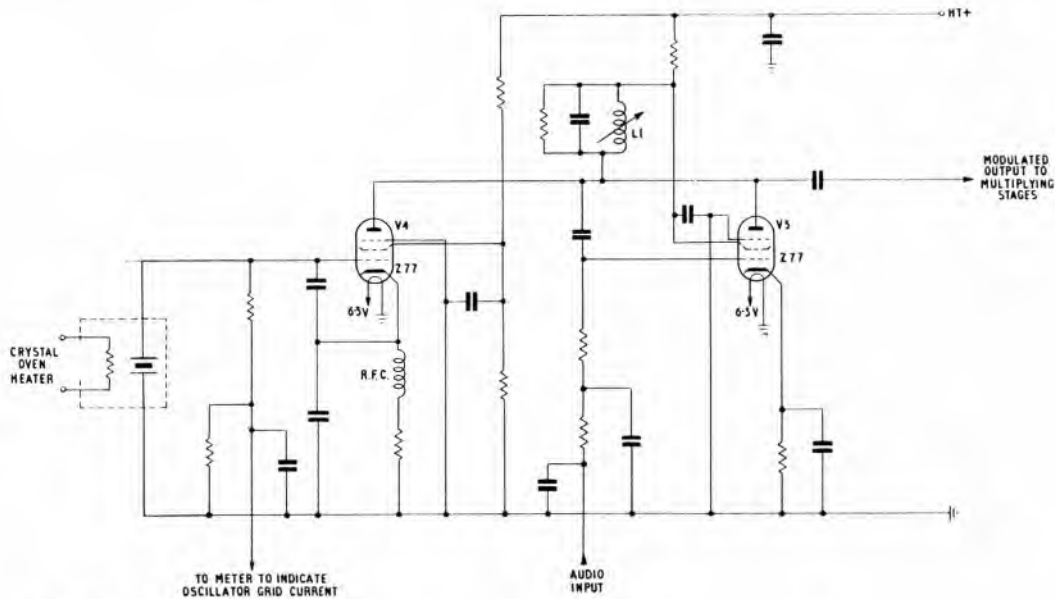


Fig. 4.—Transmitter master oscillator and modulator.

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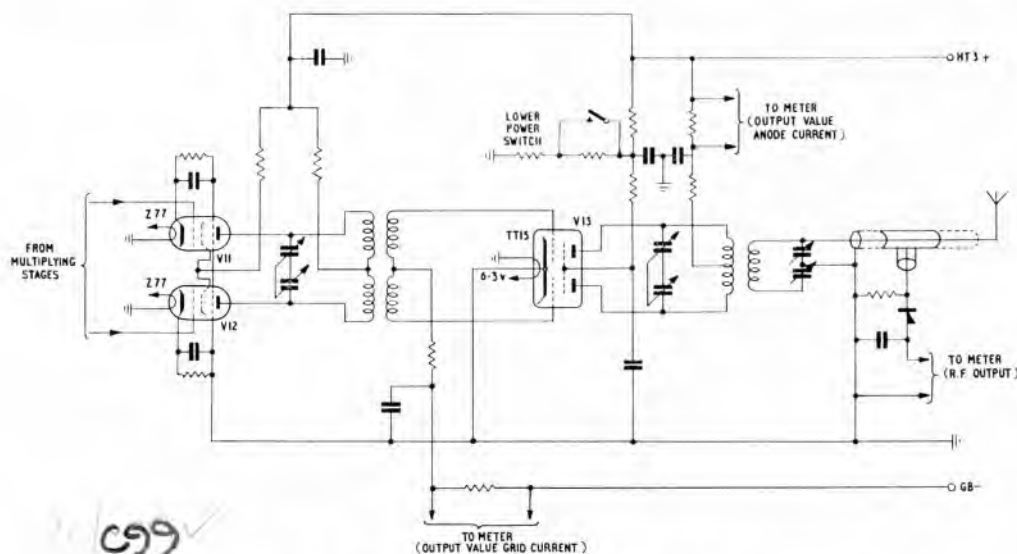


Fig. 5.—Transmitter driver and output stages.

A meter and a 11-position switch, fitted to the front of the transmitter panel, enable the currents in various circuits, the frequency deviation and the R.F. output to be measured at any time.

The R.F. output is measured by means of a germanium rectifier unit connected to a probe, which is inserted into a short length of rigid coaxial line fitted in the aerial feeder cable at the top of the rack.

### (b) Receiver

The receiver is of the single superheterodyne type, and the local oscillator is crystal-controlled. Amplitude limiters are fitted prior to the discriminating stage, so that variations in signal strength above the minimum figure of 3 microvolts can have no effect upon the demodulated output from the receiver.

The signal from the receiver aerial passes through a tuned rejector circuit before passing to the receiver proper. The rejector circuit is intended for use when the receiver is liable to suffer interference from a transmitter operating on a nearby frequency and has a tuning range which is somewhat greater than that of the receiver.

The first stage of the receiver (Fig. 6) consists of a twin triode valve connected as a push-pull amplifier. The two halves of the valve are cross-neutralised to prevent oscillation. This type of circuit generates only a very small amount of noise, enabling the receiver to be very sensitive. A signal of 3 microvolts is sufficient for full operation of the limiters. The input stage is followed by a second radio-frequency amplifier stage and then by a high-gain pentode, which operates as a mixer valve.

The local oscillator is controlled by an overtone crystal operating at a frequency within the range 24 to 30 Mc/s. The oscillatory circuit is of the Hartley type, and the anode load is tuned to twice the crystal frequency. The resultant second harmonic is then fed to a frequency tripler stage, the anode load of which is tuned to six times the crystal frequency. This frequency is then fed to the mixer valve.

From the mixer, the intermediate-frequency signal of 8 Mc/s is fed to four stages of amplification. A potentiometer, preset and mounted within the equipment,



Two outputs are taken from this stage. The first feeds the entire output signal of 300 to 20 000 c/s to a second amplifier and thence to the multiplexing equipment. The second output is taken via a low-pass filter, which passes only the frequency range of Channel 1, and feeds it to the monitor loudspeaker by way of another amplifier stage. This arrangement enables Channel 1 to be monitored and also facilitates its use as a speech circuit by engineers when setting up the equipment.

A trigger circuit is operated from the first limiter stage. This circuit is provided to operate a relay when the incoming signal drops below a certain preset value, and can be used to give an alarm. A delay of about one second occurs before the relay operates, and a pilot lamp on the receiver panel is illuminated upon operation.

A meter and a five-position switch, fitted to the front of the receiver panel, give a discriminator tuning indication, and enable the limiter current, the crystal oscillator grid current, the harmonic amplifier grid current and the receiver output level to be measured (Fig. 8).

The discriminator tuning switch mounted on the receiver panel is used in conjunction with the meter switch in a simple method of checking the discriminator balance. Operation of this switch short-circuits the coupling capacitor  $C_c$  (Fig. 7); the first A.F. valve (V 11) is then used as a DC amplifier and feeds the meter. The coil L is then tuned until operation of the switch causes no change of meter reading.



Fig. 8.—Radio receiver panel.



Fig. 9.—A section of the framework of an unequipped rack, showing the guides on which the panels slide into place.

### Construction of the Equipment

The framework of the rack is made of folded sheet steel with welded joints. A standard overall height of 6ft. (1.83 m.) has been adopted. The width of the rack is 1ft 8½ in. (0.52 m.) and the depth is 8 in. (0.216 m.). The rack is single-sided and two racks can thus be mounted back-to-back.

The equipment panels slide into guides fitted on the inside edges of the rack framework where they are locked in place by means of screws.

External connexions to the panels are made by multi-way plug-in links, for which sockets are provided on the ends of the panels and on the guides along which the panel slides into position on the rack. The rack wiring is run along both sides of the rack between the panel guides and the outer walls.

External connexions to the rack are made via terminal strips mounted at the top of the rack. Power wiring is taken direct to a distribution unit in the base of the rack.

Each rack contains its own power supply unit and is fed by AC current at 100 - 125 or 200 - 250 nominal voltages and 50 - 60 c/s nominal frequency. Where required, arrangements can be made for operation from supplies of a different voltage or frequency.

### Repeater Rack

A repeater rack uses the same radio equipment panel as does a terminal rack, but the multiplex equipment panels are not fitted.

A standard 6ft. rack mounts the radio equipment in a manner similar to a terminal rack. A monitor panel may also be added, it provides a handset which may be used for communication over Channel 1 by test engineers.

### Panel Design

The multiplex equipment and the radio equipment panels are, by virtue of their electrical design, assembled in slightly different ways, though when mounted in the rack they present a uniform appearance.

This method of construction enables panels to be removed and replaced rapidly should faults occur, and makes it unnecessary for spare equipment to be permanently incorporated in the rack. Efficient maintenance can then be carried out by the replacement of complete apparatus units by spare units during fault clearing.

Transport to difficult sites is also made easier since the racks can be moved and erected without the panels in position. Compactness is achieved without any loss of accessibility

#### (i) Multiplex Equipment Panels

These are assembled from a number of basic apparatus units, of which there are three types :-

- (a) Those carrying components that do not require replacement or adjustment.

- (b) Those carrying components which, for electrical reasons, are grouped together in a screened can, but to which limited access must be given for maintenance purposes.
- (c) Those carrying components that are adjustable.

Apparatus units in category (a), which carry groups of components forming for example, a filter, are hermetically sealed in metal cans. Category (b) units carry groups of components mounted in unsealed cans. The can covers are removable from the back of the panel without demounting the unit, or disconnecting any wiring.

Apparatus units in category (c) comprise small mounting boards carrying a number of components to form a complete electrical assembly such as a potentiometer or an attenuator

Apparatus units in categories (a) and (b) are clamped to a pair of rails, which extend along the top and bottom rear edges of the panel, whilst those in category (c) are fitted to small brackets screwed inside the front edge of the panel. Fig. 10 illustrates the mounting of apparatus units. Insulated strips carrying terminal tags, fitted along the top and bottom front edges of the panel, facilitate the mounting of self-supporting components such as resistors and tubular capacitors, and where necessary terminate the wiring from the apparatus units. In addition, the front edges of the panel are each provided with a row of earth tags. Each panel is fitted with a quickly removable dust cover

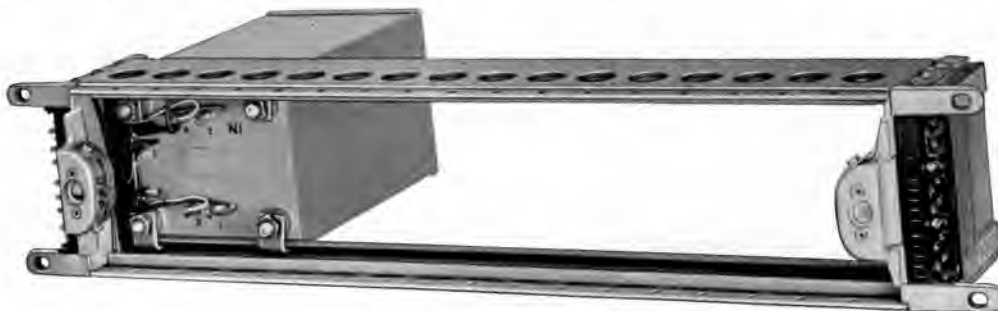


Fig. 10.—Mounting of an apparatus unit on a panel framework.

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There are altogether eight panels concerned with the multiplex equipment, as shown in the centre of the rack in Fig. 11

The five channel units mount all the equipment individual to each channel.

The power panel mounted immediately under the frequency generator panel supplies the multiplexing apparatus with H.T. (220V DC) and L.T. (6.3V AC) supplies.

A miscellaneous panel carries the transformers that match the multiplex equipment to the radio equipment.

### (ii) Radio Equipment Panels

These panels also follow the slide-in practice. The main chassis has been set well back from the front of the rack, and the valves are arranged to project into the vertical 'tunnel' formed by the panel covers and the chassis.

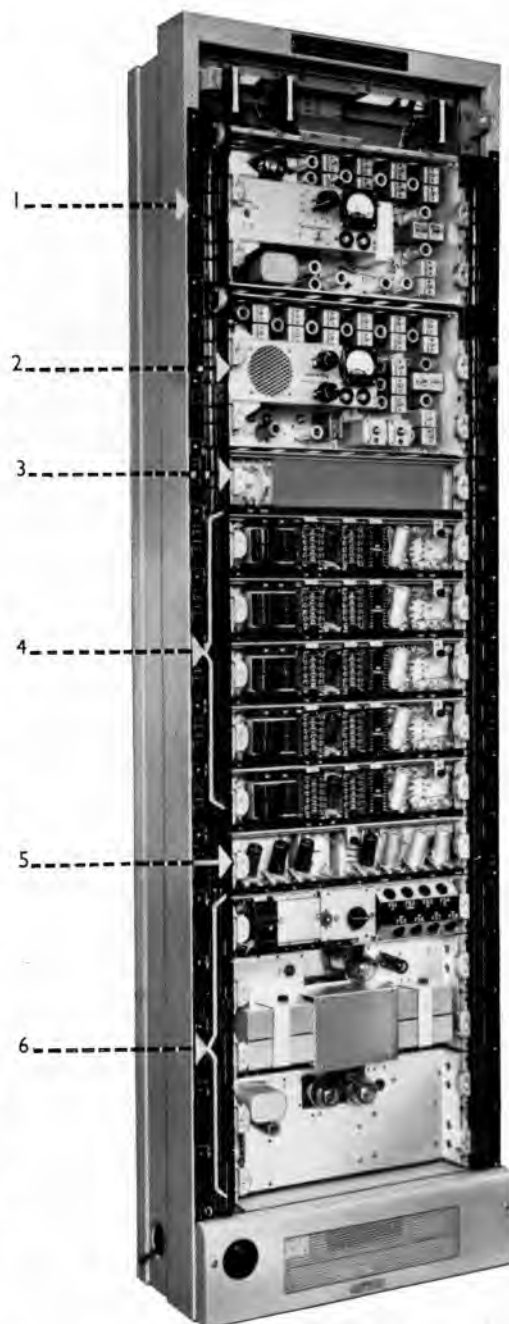
The valves are thus cooled by the natural flow of air caused by the convection current in the 'tunnel', forced cooling being unnecessary. All components that may require adjustment during the alignment of the equipment are easily accessible when the front dust-cover is removed.

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All components except those inside the sealed units are fully tropicalised, and impregnated to prevent the ingress of moisture.

P.V.C. insulated wires and cables are used throughout, the cable-forms being laced and stitched with plastic twine.

The R.F. feeder cable is of the coaxial type, using low-loss polythene dielectric. The connexions between the aerial feeders and the transmitter and receiver panels are made by way of coaxial U-links. The U-link socket fitted to the transmitter incorporates a safety device which causes the H.T. to be disconnected from the output valve when the U-link is removed, thus preventing the valve operating under no-load conditions.



- 1 VHF. TRANSMITTER
- 2 VHF. RECEIVER.
- 3 MATCHING TRANSFORMERS.
- 4 CHANNEL UNITS.
- 5 FREQUENCY GENERATOR.
- 6 MULTIPLEX, TRANSMITTER AND RECEIVER POWER UNITS.

Front view of one rackside with all covers removed.

Fig. 11.—Location of the various units in the assembled terminal rack.

**Yagi Aerials**

Separate six-element Yagi directional aerials as illustrated in Fig. 12 are employed for transmission and reception. Each aerial array consists of a radiating element, a reflecting screen and four directional elements. The radiating element consists of a half wave folded dipole fed via a co-axial balance-to-balance transformer (Calun). All metal components of the aerial are made of aluminium alloy chosen for its resistance to atmospheric corrosion. The forward gain of the array relative to a half wave dipole is 9db and the back-to-front ratio is greater than 15db.

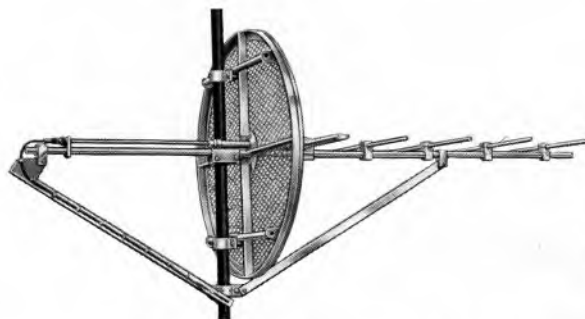


Fig. 12.—Typical six-element Yagi aerial.

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The aerials may be mounted with the elements vertical or horizontal.

**DATA SUMMARY**

Bandwidth of each speech channel	300c/s to 2800c/s
In-built VF signalling tone ..	2280c/s
4-wire input level range	14dbm to 0dbm
4-wire output level range	—4dbm to +10dbm
Multiplex baseband	300c/s to 16.133 kc/s.
V.H.F Band	156 Mc/s to 184 Mc/s.
Transmitter Output Power	15 watts.
Transmitter Peak Deviation	± 15 kc/s.
Transmitter Output Impedance	75 ohms.
Receiver Input Impedance	75 ohms.
Receiver Intermediate Frequency ..	8 Mc/s.
Receiver Gain Stability ..	± 2db with input signal variations 10 mV to 1 mV
Receiver Noise Factor	Less than 8db.
Power Supplies	Either 100 125 volt or 200 250 volt, 50 60c/s.
Power Consumption	Terminal 400 voltamperes. Repeater 600 voltamperes.
Size of Terminal Rack	6' 0" high, 1' 8½" wide, 8½" deep (1.83m. × 0.52m. × 0.216m.).
Weight of Equipment	Terminal Rack 365 lb. (166 kg.). Repeater Racks 425 lb. (193 kg.).