



Fig. 1.—Front view of typical VHF link transmitter, BRT 143.



Fig. 2.—Front view of typical VHF link receiver, BRT 186.

Design Considerations for VHF Link Radio Equipment

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The author sets out in detail the various considerations which influenced the design of the present range of VHF Radio Link equipment for operation in the band 54-330 Mc/s. Photographs illustrate the mechanical construction of the equipment and various aspects of performance are shown in graphical form.

A future article will give further details of the transmitters and receivers in this range, and will describe a number of variants which have been introduced to cater for special applications.

In a previous issue of this journal (Vol. 3, No. 1, 1948) an article was published describing a range of VHF¹ equipment designed primarily for mobile use. The main features of this mobile equipment were small size, light weight, and low power consumption. Suitable power units were available for use either as mobile installations operating from a car battery or for fixed installations where AC mains were available. After a time, however, it became apparent that the compact lay-out devised for mobile equipment was perhaps a disadvantage

for fixed installations since it inevitably resulted in some loss of accessibility and also made some form of forced air cooling necessary to dissipate the heat from the closely-packed components. Thus it was felt that if the equipment designer could be relieved of the necessity for keeping size, weight and power consumption to an absolute minimum improved electrical performance could be achieved. As VHF radio is the most suitable medium for point-to-point links in areas where the laying of cables or the erection of lines is

uneconomic or where cable and line communication is liable to interruption by unfriendly elements either natural or human, a range of VHF equipment was developed for use in fixed installations where mains power is available. The most important requirements of the new equipment were as follows :—

- (a) The highest standard of performance possible without recourse to uneconomic valves and circuitry i.e. avoiding the use of disc-seal valves and temperature-compensated coaxial tuning systems.
- (b) The maximum reliability economically possible.
- (c) The best possible accessibility for maintenance and repair
- (d) A simple set-up procedure for both operation and maintenance.
- (e) Low temperature rise without recourse to forced air cooling of the individual units.

The problems set by the above requirements and the approach taken to overcome each of them will now be discussed in greater detail.

(a) Performance

The electrical performance of a VHF radio telephone system has many aspects. Some, such as sensitivity and quality of reproduction, which control the range and intelligibility of the system, are quickly appreciated, whilst others, such as freedom from spurious responses of the receiver and spurious radiations from the transmitter may remain unnoticed for a considerable period. A close study has therefore been made of the factors which would ensure lasting satisfaction on the part of the users of this range of equipment. These may be summarised as follows :—

Sensitivity Sensitivity is the ability of the receiver to pick up weak signals and present them in an intelligible form, it is limited by the noise generated in the early circuits of the receiver. A

perfect receiver, generating no noise of its own, would produce only the noise level present at the source of the signal i.e. the antenna. At the terminals of the antenna there would appear a voltage equivalent to the Johnson noise generated in a resistance equal to the radiation resistance of the antenna, together with various e.m.f.s. due to atmospheric and man-made noise or cosmic radiations. At very-high-frequencies the contributions due to atmospheric noise and cosmic radiation are usually small and man-made noise can sometimes be avoided or suppressed, thus the ideal receiver would add nothing to the Johnson noise mentioned above. A measure of the performance of a receiver in this respect is the noise-factor or noise-figure which defines the ratio of the noise power generated by the receiver to the noise power which would be developed by an ideal receiver of the same gain and bandwidth, the output of which would be solely due to the Johnson noise at the antenna terminal. The noise-factor is expressed as a ratio, thus an ideal receiver would have a noise factor of unity or in decibel notation 0db.

Receiver noise at VHF is predominantly that due to shot noise, induced grid noise and partition noise in the first amplifying stage. Since partition noise occurs only in multi-electrode valves in which the cathode current is divided between plate and screen or screens it is logical that the simple triode valve would produce less noise. The difficulty in using such a valve is that the capacitance between the plate and the control grid has a very low reactance at VHF and must therefore be neutralised if stable amplification is to be obtained. An alternative method is to use a triode valve as a grounded-grid amplifier but such an arrangement limits the power gain available and the input circuit is heavily damped by the very-high input conductance of a valve operated in this manner. Neutralised grounded cathode connexion is therefore to be preferred and it was decided that a double-triode operated as a push-pull cross-neutralised amplifier was the arrangement most suited to the needs of the receivers in this range of equipment. By the use of this arrangement it has been found possible to achieve a noise factor of 4db for frequencies up to 100Mc/s and 7 or 8db at frequencies up to 200Mc/s.

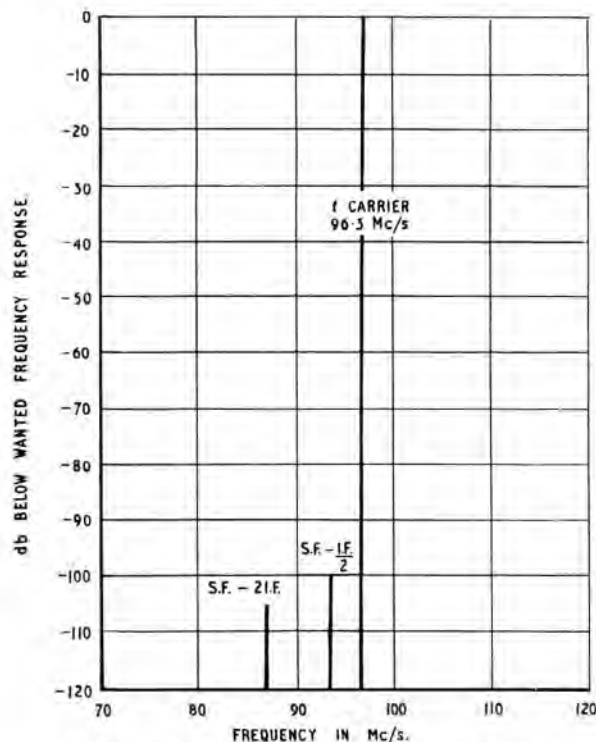


Fig. 3.—Spurious responses in AM and FM VHF Link receiver.

Selectivity Selectivity can be defined as the ability of a receiver to discriminate between the wanted signal and other signals of different frequency. In its widest sense the term includes in addition to the basic adjacent-channel selectivity, the rejection of image and other spurious responses and freedom from cross-modulation and blocking. The degree of adjacent-channel selectivity required is determined by the channel spacing laid down by the authorities responsible for frequency allocation. In Great Britain the General Post Office have allocated a channel spacing of 50kc/s for frequencies below 100Mc/s and 100kc/s for frequencies above 100Mc/s. The G.P.O. also specify that the adjacent-channel rejection shall be not less than 50db. In view of these specifications the receivers operating below 100Mc/s in this range of equipment were designed to provide an adjacent-channel rejection of greater than 50db at a point 50kc/s from the wanted carrier and not more than 6db rejection for frequencies within 15kc/s of the

assigned centre frequency. The receivers operating above 100Mc/s were designed to have a rejection of not less than 50db at a point 80kc/s from the wanted carrier and not more than 6db rejection for frequencies within 25kc/s of the assigned centre frequency. The bandwidth at the nose of the IF response curve was made as wide as possible to keep to a minimum the effects of frequency drift of either the transmitter or the receiver local oscillator. On VHF it is impracticable to provide the degree of selectivity mentioned above on signal frequency, thus a superheterodyne circuit must be used. Such a design gives rise to troubles due to unwanted beats between signal and local-oscillator frequencies and other harmonics. An additional source of spurious response arises with receivers of this type since quartz-crystal control of the local-oscillator circuits is necessary to ensure that the receiver stays permanently *on tune*. Quartz crystals for fundamental-mode operation at frequencies above 12Mc/s are very fragile and if lower frequencies were used, a chain of frequency-multiplying stages would be needed to produce the required beat frequency. The output of the last frequency multiplier would inevitably contain traces of all harmonics of the crystal frequency. To reduce spurious responses due to these unwanted components to a suitably low value, it would be necessary to provide a high degree of selectivity in the multiplying stages and in the RF circuits of the receiver. This can be done more easily if the crystal frequency is higher, thereby reducing the number of unwanted frequencies present and simplifying the problem of isolating the required harmonic as the spacing of the unwanted components will be increased. Such a means is provided by the operation of a crystal on a mechanical overtone of its fundamental resonant frequency and it is possible to obtain frequencies approaching 200Mc/s from crystals operating at overtones as high as the 23rd. Two differences should be stressed between the overtone mode of operation and the more usual harmonic generation. The first is that the crystal is actually oscillating at the overtone frequency and no components of the fundamental frequency exist. The second is that since the overtone is a mechanical function of the crystal, the overtone frequency is not an exact multiple of the fundamental. Overtone crystals

must therefore be ground to the correct operating frequency when required for overtone operation.

From the above remarks it might well be assumed that harmonic generation would be unnecessary but operation at high-overtone modes presents considerable difficulty in circuit design and crystal processing, so that the use of overtones is generally restricted to the third mode. This affords a considerable advantage since the local oscillator can be operated at frequencies in the order of 30Mc/s, thus simplifying the problems set out above.

The remaining aspects of receiver selectivity are those concerned with the reduction of interference due to cross-modulation and blocking, caused by strong signals whose frequency is close to that of the wanted signal. In the past it was suggested that these troubles were primarily due to overloading of the first RF stage, which then produced harmonics and, if more than one signal were present at the antenna terminal, inter-modulation products. Later stages of the receiver are even more prone to overloading than the first if the attenuation of an off-frequency signal is less than the gain available at that frequency in the stages preceding the one in question. If the networks governing the adjacent-channel selectivity of the receiver could be placed between the aerial and the input to the first amplifier, cross-modulation and blocking troubles would cease to exist because only the desired signal would reach the valve. Since this is not possible a compromise must be found which can be loosely defined by saying that in any stage the gain should not exceed the attenuation afforded to the nearest off-frequency signal which it will be desired to reject. When this definition is met all amplifier stages receive the same input from the unwanted signal at their grids and cross-modulation then occurs in the stage which produces the greatest non-linearity for a given input.

As this problem involves gain, selectivity and handling capacity in all stages up to the second detector, the use of valves with large power-handling capacity would undoubtedly improve the cross-modulation characteristic of the receiver but at the

expense of a higher noise-factor and a consequent degradation of sensitivity. In the present range of VHF receivers of which Fig. 2 is a typical example, the following means have been adopted to minimise the effects of cross-modulation and blocking:—

- (1) Adjustment of valve operating conditions for best linearity
- (2) Use of the minimum gain consistent with maintenance of a given noise-factor in RF stages, where an adequate degree of selectivity is difficult to provide.
- (3) Design of the IF amplifier such that the attenuation of an adjacent-channel signal is always greater than the gain of any given stage.

Selectivity Requirements in Transmitters.

The requirements of transmitters in regard to selectivity are similar to those of the receiver local oscillator. If the oscillator generated the frequency which was to be radiated, only harmonics of this frequency would need to be discriminated against. However, since crystal control is essential at VHF, the carrier must be generated at some frequency for which crystal control can be arranged and harmonic generators employed to multiply it to the desired output frequency. Some degree of selectivity is therefore necessary so that the output at unwanted frequencies may be kept to a low level. At the time of writing, overtone crystals are not being used because present circuits do not provide sufficient output for the efficient operation of a subsequent harmonic generator. The amplitude modulation transmitters of this range make use of crystals in the 7 to 10Mc/s band, sufficient tuned circuits being included between the multipliers to reduce the output at unwanted crystal harmonics to over 60db below the output at the wanted frequency. In FM transmitters the problem is more acute, since in order to generate frequency-modulated signals whose centre frequency can be accurately crystal controlled, phase modulation must be used, which is discussed in a later section. Crystals in the range of 0.9 to 1.5Mc/s are used to generate the fundamental frequency and the

maximum frequency multiplication in a given stage is limited to three. Double tuned circuits are employed between stages in order to provide the requisite low output at unwanted frequencies.

Quality of Reproduction.

Whereas in the case of mobile equipment up to 10% distortion may be quite tolerable, radio links forming sections of a network must have lower distortion levels. Care has therefore been taken in the design of the AM transmitter modulator and in the receiver demodulator and audio circuits, to keep the distortion level well below 5%. Even 5% would be too high for radio equipment used for frequency-division-multiplex working, and as it was apparent that a considerable field of usefulness existed for a comparatively simple radio equipment capable of handling up to four channels, a considerable amount of work has been carried out on the frequency-modulated equipment to enable a very low overall distortion to be achieved.

Distortion due to the audio circuits was not difficult to overcome. Careful design and application of negative feedback enabled distortion to be kept below 0.1% at the working levels required. This meant that significant distortion was confined to the purely radio frequency parts of the equipment. In an FM system amplitude non-linearity between the modulator of the transmitter and the demodulator of the receiver has virtually no effect on distortion but unless the phase characteristic of the coupling networks is linear over the required bandwidth, distortion will be introduced. With the comparatively narrow bandwidths used in this equipment the phase characteristics of the radio frequency tuned circuits of the receiver and the later stages of the transmitter are unimportant.

The section contributing the largest amount of phase distortion is the intermediate frequency amplifier. There are three main causes:—

- (i) The phase characteristics of the tuned coupling networks between stages which become appreciably non-linear as the signal deviates from the *on tune* frequency

Two methods are used in the present receiver to minimise this. Firstly, the coupling between pairs of circuits has been chosen to give minimum distortion over a band of frequencies and secondly the bandwidth of the circuits has been made sufficient to accommodate the significant sideband components of the highest modulating frequency. This form of distortion consists of only odd harmonics at the receiver output when the circuits are properly tuned, but mistuning will introduce even harmonics, the amplitude of which will depend on the amount of mistuning. Careful tuning of the IF amplifier of an FM receiver is therefore essential if a low distortion level is to be realised.

- (ii) The second source of phase distortion is allied to the first in that it is caused by mistuning. It is well known that the input capacitance of a thermionic valve changes when the negative grid-bias voltage is altered. Such a change may well be produced in an FM receiver by changes in the level of the incoming signal either due to variation of grid current in grid-limiter stages or to AGC action. Two methods are adopted to minimise the effect of this change of capacitance in the present receiver, one being to use comparatively large capacitances in the tuned circuits so that the variation of the input capacity of the valve is *swamped*, and the other is to include in the cathode circuit of the valve an un-bypassed resistor. If the value of this resistor is carefully chosen, the capacitance change due to bias variations can be reduced to about one tenth of its original value.
- (iii) A third form of distortion can be caused if the time constant of the grid condenser and grid leak of valves which are being driven into grid current is made too long. It should be made short enough to allow the bias produced by grid current to follow closely any amplitude variation caused by the amplitude characteristics of the tuned

stages, up to the highest modulation frequency to be used.

The remaining portion of the receiver which may contribute a significant amount of distortion, is the frequency-to-amplitude converter (usually referred to as the discriminator). Most types of discriminator suffer from some form of non-linearity but fortunately in the simpler types, where the deviation is small compared with the centre frequency, sufficiently good linearity can be provided if the discriminator bandwidth is made two or three times that required to accept maximum frequency excursion of the signal. The disadvantage of this system is that the sensitivity of the discriminator is thereby reduced and noise due to imperfect limiting is increased. It is therefore necessary to effect a compromise between the linearity and sensitivity of the discriminator. In practice it has been found possible with a simple

discriminator circuit to obtain distortion levels of the order of 0.5% with little or no additional noise from imperfect limiting and the loss in sensitivity is unimportant as ample gain can be provided in the audio-frequency amplifier.

Turning to the transmitter, the modulator circuit is one in which non-linearity may easily occur. In the transmitters for this range of equipment direct crystal control is used in conjunction with a phase modulator. This method was chosen because it is the most simple method of ensuring a highly-stable carrier frequency. The disadvantage of a phase modulator is that the maximum phase shift which can be produced by means of simple circuits is limited to ± 0.5 radian and as the frequency deviation is equal to the phase shift in radians multiplied by the modulating frequency, a large amount of frequency multiplication is necessary in order to produce a

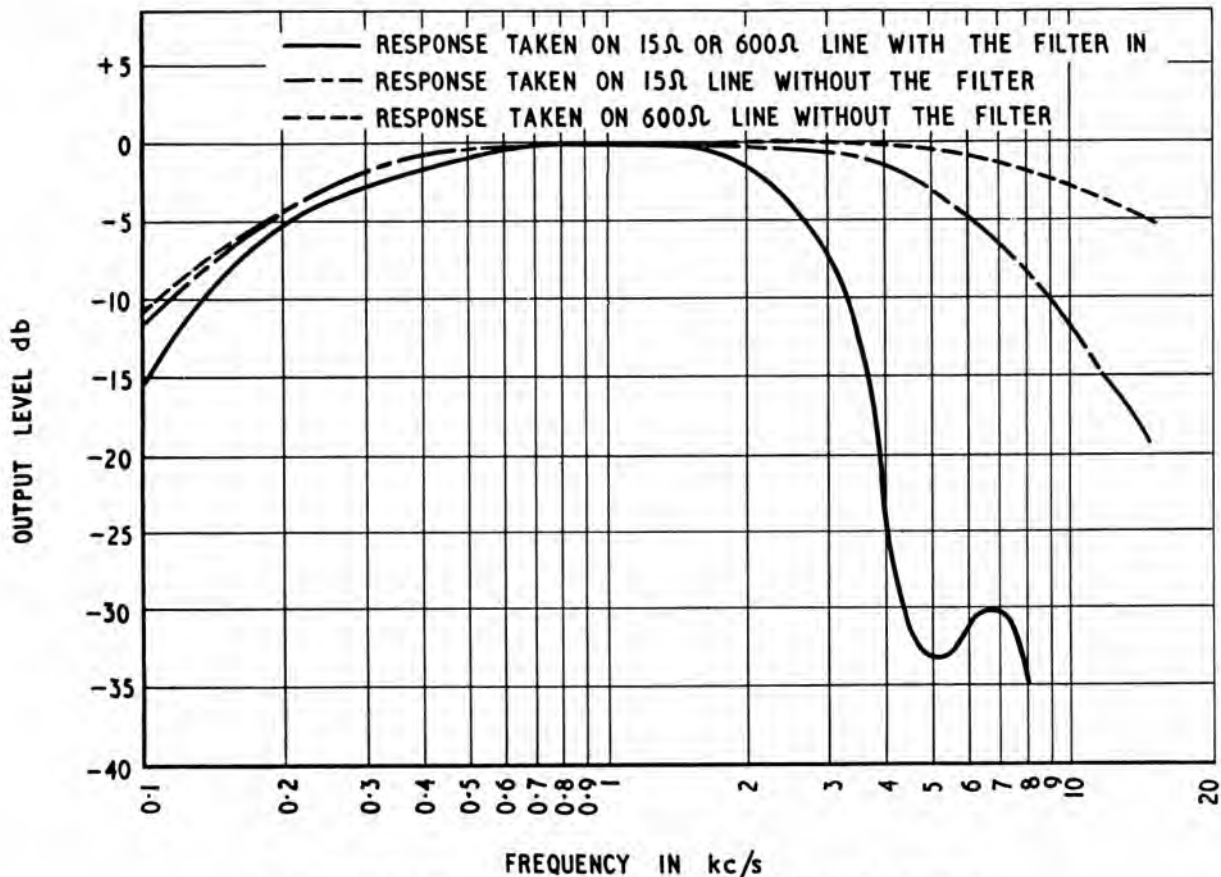


Fig. 4—Typical audio response curves for AM and FM VHF link receivers.

deviation of 15kc/s with the lowest modulating frequency that it is necessary to reproduce. From this, however, it is apparent that as the modulating frequency is increased, the phase swing required at the modulator to produce a given deviation is reduced, so that if the deviation is to be constant for a given amplitude of modulating signal irrespective of the frequency of that signal, a network must be provided which causes the amplitude of the signal applied to the modulator to vary inversely with frequency. The result of this is that distortion caused by the modulator is greatest at low frequencies and falls off very rapidly with increasing frequency. If therefore the modulator is designed to give a tolerably low distortion at the lowest modulating frequency required (in this case 300c/s) very little distortion will arise at higher modulating frequencies. This is a suitable characteristic for transmitters intended for multiplex operation, as most of the distortion is due to 2nd and 3rd harmonics and for the audio frequency at which these are of significant amplitude, the 2nd and 3rd harmonic fall within the physical channel and do not interfere with the carrier channels.

The remaining form of distortion introduced by the transmitter is of a different nature. In an earlier paragraph it was stated that the tuned circuits in the later stages of the transmitter did not introduce any appreciable phase non-linearity because the frequency deviation is a very small fraction of the frequency to which the circuits are tuned. This also applies to the tuned circuits of

the earlier frequency-multiplying stages of the transmitter, where although the frequency is much lower, the deviation is the same fraction of the centre frequency. Another factor becomes important here however, namely that the sidebands produced by high modulating frequencies become appreciable in relation to the carrier frequency and if they are attenuated by sharply-tuned circuits the higher frequencies (at the output of the receiver) will be attenuated by a similar amount. In addition to this, if one or more of the circuits is mistuned, the phase of the sidebands in relation to the carrier will be changed and non-linear distortion will result. The cure for such troubles is to make the tuned circuits broad enough to accept the sidebands produced by the highest modulating frequency with negligible attenuation.

Receiver Automatic Gain Control or Limiter Characteristic

The attenuation of radio waves over even short distances at VHF is subject to wide variation and in the case of the reception of signals from a mobile vehicle the level may vary from 1microvolt to upwards of 100millivolts. In order to maintain a comfortable listening level from the output of the receiver such wide variations must be reduced. In an AM receiver a voltage derived from the demodulator stage and proportional to the average carrier level is used to bias the early stages of the receiver in such a manner that as the carrier level is increased the amplification of these stages will be reduced. A delay voltage is usually introduced in

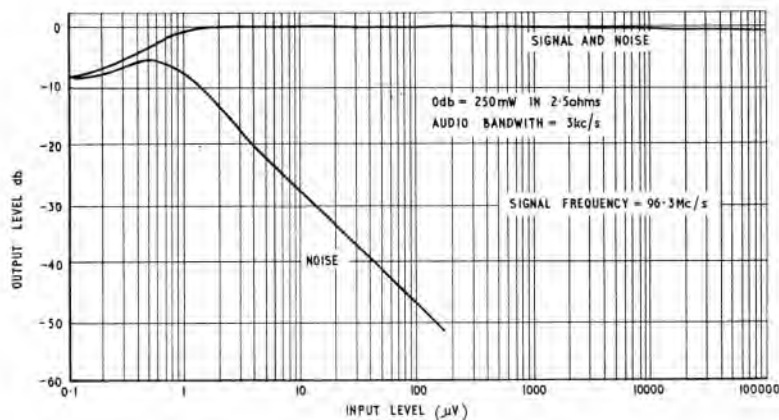


Fig. 5.—AGC response curve for AM VHF link receiver.

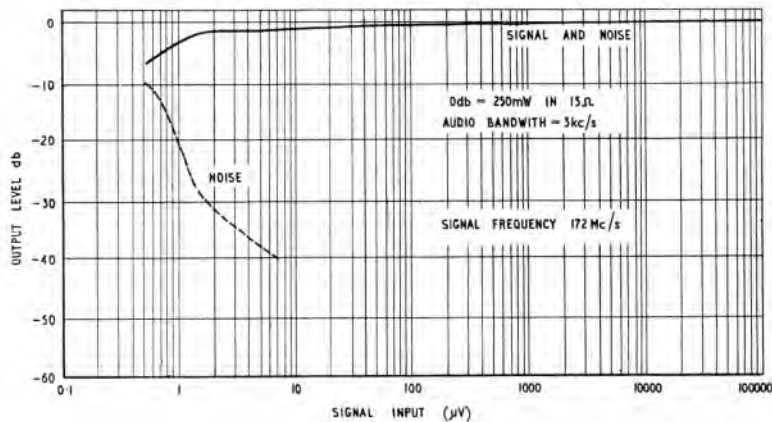


Fig. 6.—AGC response curve for FM VHF link receiver

the circuit so that no reduction in gain occurs until the signal has reached a usable level. It is obvious that this method will not eliminate the effect of input variations, but only reduce it. In the present receivers this AGC voltage has also been applied to the first audio amplifying stage, enabling the output to be held almost constant over a very wide range of input signals. The efficiency of an automatic gain control system is largely a function of the amount of gain between the controlled stages and the source of control voltage, and in consequence it is often found better not to apply AGC to the later IF stages of the receiver. In fact it would seem that the ideal arrangement would be to control only the 1st RF amplifier of the receiver, but the range of control would be strictly limited and it must be remembered that the signal-to-noise ratio of the receiver is very dependent on the gain of this stage. The present receiver has AGC applied to both RF stages and to the first two IF stages, the AGC to the first RF stage being delayed, so that its gain is not reduced until a signal strong enough to provide a good signal-to-noise ratio is received. The performance of the system is such that variations of signal between 2microvolts and 100millivolts affect the output level by only 3 to 4db.

A similar system is used on the FM receiver with similar results. It would have been possible to use a limiter system which would give the same result with fewer components but the AGC system by reducing the gain, renders the receiver less susceptible to cross-modulation. It has been found however, that slightly more distortion is

introduced and in receivers for multiplex working simple limiter circuits are used.

(b) Reliability

In the preceding section stress was laid upon the necessity of giving a performance which would ensure satisfaction on the part of the user. If this satisfaction is to be lasting it is obvious that the performance of the equipment must remain at a high standard without recourse to elaborate maintenance or expensive repairs. The designer is to some extent in the hands of the component manufacturer in that the reliability of the equipment as a whole may be prejudiced by the failure of any one of a large number of component parts. It is however for the designer to decide from specifications, past experience, and laboratory



Fig. 7.—Typical rear view of transmitter or receiver showing rear connexions.

tests, the components which he considers will give adequate performance and reliability of service. He is also responsible for establishing operating conditions such that no component is overrun and if possible arranging circuitry so that adequate allowance is made for normal changes during life and deterioration in service. An example of the way in which the designer can help is in the stabilisation of gain by means of inverse feedback. This provides some compensation for the inevitable fall in amplification of a valve with age and enables the equipment to function for a longer time before valve changes become necessary. The importance of this is particularly noticeable in a high-gain amplifier such as the intermediate-frequency amplifier of the receiver, in which five stages of amplification are used to provide an overall gain of approximately one million. If no inverse feedback were used and the gain of each valve fell to 70% of its initial value, the overall gain would fall to 17% of its initial value. In the receiver in question however, inverse feedback is employed to reduce the gain per stage by a factor of approximately three, which means that the same loss of gain in the valves causes a drop to only 60% of the initial gain. From this it will be seen that although more valves have been used to obtain the amplification, fewer replacement valves are likely to be used in the life of the receiver than would have been needed in a receiver in which the maximum amplification from each stage was obtained and which initially used a small number of valves.



Fig. 8.—FM transmitter BRT 143 with RF chassis swung open for inspection.

(c) Accessibility

Even the best of radio and electronic apparatus is subject to faults of one kind or another after a period of service. It is important that when they occur the job of tracing and rectifying them should be as simple as possible and with this object in view a novel form of mechanical construction has been adopted for this equipment.

The transmitters and receivers each comprise two units which are mounted vertically, with the valves facing outwards, in a framework which fastens to the rack or cabinet. At the front is the transmitter or receiver proper, which is hinged along one vertical edge so that it can be swung outwards through 90° to give access to the underside and to the underside of the power unit which is rigidly fixed to the framework with the valves facing rearwards. Examination of Figures 8 and 9 will show the excellent accessibility thus afforded. A simple catch holds the unit in the closed



Fig. 9.—FM receiver BRT 163 with RF chassis swung open for inspection.

position. Front and rear covers with quick-release fastenings and top and bottom covers of perforated sheet metal, which slide into place on guide flanges, protect the unit from accidental damage while allowing access to essential controls. Mains input connexions, signal input and output are brought to plugs and sockets at the rear of the unit. Connexions between the units are made through a flat multi-way cable, which is built up of separate leads to ensure maximum flexibility.

In the construction of the transmitter and receiver units extended use has been made of series decoupling networks, which when used in conjunction with feed-through capacitors of the high-dielectric-constant ceramic type, provide

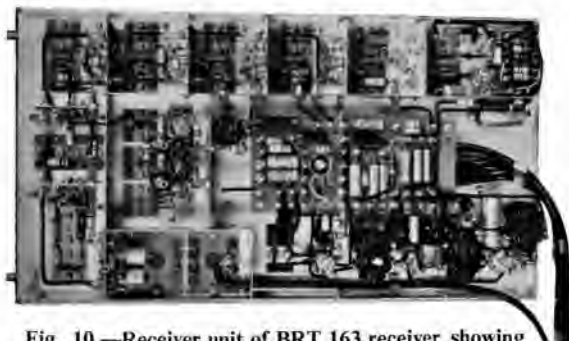


Fig. 10.—Receiver unit of BRT 163 receiver showing clean layout of components and ease of accessibility.

very effective de-coupling and by-passing, whilst at the same time permitting a very clean layout to be achieved. It will be seen from Fig. 10 that most of the stages are separately screened and that these screens are used as supports for the de-coupling capacitors and other components, thus eliminating the need for component panels and enabling connexion leads to be kept very short. Very little wire is used in the connexions and the only cable forms used in the units are those for connexions to the meter panel. Thin bakelite plates with close-fitting holes over the lead-out stems of the coil units are fitted to prevent small pieces of wire and solder from falling into the space between the bottom plate of the coil unit and the chassis and causing short circuits. A further protection against short circuits is afforded by a single turn of high-grade insulation around the complete coil unit before the cover is fitted. Most of the coils are single-layer solenoids wound on grooved formers of a special high grade low-loss laminated-plastic material which has been chosen to give good stability. Tuning in most cases is by means of dust-iron cores or silver-plated brass slugs, or in cases where a very wide tuning range is required, a dust-iron core combined with a brass slug, so arranged that either of them may be brought to the centre of the coil. Exceptions to the above are the *drive* and output tuned circuits of the transmitters in which small split-stator air-dielectric capacitors are used for tuning. These are used because these circuits are of the push-pull type and it is important that a good balance be maintained.

The degree of reliability which has been achieved in the range of equipment described is best illus-

trated by the fact that certain items have been operating continuously on unattended sites, visited about once a month, for over three years and have given every satisfaction.

(d) Alignment

As so often happens in other spheres, the reliability of a radio system is also a function of simplicity of operation and maintenance. If an equipment is difficult to handle or to repair it will always be regarded with suspicion and it is unlikely that the best use will be made of it.

All units in this range are crystal controlled so that once the initial alignment has been carried out after the installation of the scheme only minor adjustments should be needed and these only after valve changes or changes to other components which might affect tuning. Other controls have been reduced to a minimum and even these should not require attention in normal circumstances. The only controls that have been made accessible with the front cover in position are the meter switch and level control for the monitor loudspeaker on the receiver and the meter switch and a microphone jack on the transmitter. The mains switch, fuses and input and output sockets are accessible from the rear with the rear cover in position on both the transmitter and receiver units. Removal of the front cover provides immediate access to all tuning controls and metering has been provided to facilitate the alignment of all circuits. In the receivers, meter positions have been provided to indicate the grid current of the local oscillator and harmonic amplifier and



Fig. 11.—Rear view of receiver power unit with cover removed, BRT 186



Fig. 12.—Front view of FM VHF link transmitter BRT 143 with cover removed.

on the A.M. receiver an indication of the cathode current of one of the stages with automatic gain control enables all RF and IF circuits to be accurately aligned when a suitable signal is fed into the receiver. In the FM receiver a limiter current indication is provided for RF and IF alignment and a special circuit is included for quick and accurate alignment of the discriminator on an incoming signal. This circuit uses the 1st audio amplifier as a valve voltmeter and consists of a position on the main meter switch which connects the meter in the cathode circuit of the 1st audio amplifying stage to indicate the standing anode current of this valve and a spring-loaded toggle switch which when operated short circuits the coupling capacitor between the discriminator and the grid of the audio amplifying stage so that any steady potential at the output of the discriminator would cause the cathode current of this valve to vary and consequently change the reading shown on the meter. When correctly tuned the discriminator load resistances have equal and opposite currents flowing, thus no steady potential should exist. The tuning procedure is therefore to note the meter reading, depress the toggle switch and adjust the discriminator tuning until the meter reads the same whether the switch is depressed or released.

The intermediate-frequency stages of all receivers have been designed with less than critical coupling between primary and secondary circuits so that alignment can be carried out by adjusting each circuit to a peak reading on the meter.

(e) Cooling

The type of construction adopted, with chassis in the vertical plane and valves projecting horizontally allows a free air-flow through the unit, because spaces are left between bulky components. Examination of the various illustrations will give a good idea of the way in which the effect of such obstructions has been minimised. The temperature rise of these units is very low and in temperate climates several equipments may be mounted on a six-foot rack or in a six-foot cabinet without resorting to forced air cooling. If however cabinet mounting is used, ample openings must be provided for air ingress in the lower part of the cabinet and for air egress at the top. In hot climates it is recommended that spaces should be left between equipments and baffle plates fitted so that heated air from the lower units does not flow through the upper units and cause a progressive increase of temperature. Cabinet installations can of course be provided with a forced-air cooling unit in the base which will enable six units to be operated in a six-foot cabinet even in the hottest of climates.

Conclusion

It is hoped that the preceding paragraphs will have given the reader some insight into the considerations which have influenced the design of this range of VHF equipment. A subsequent issue of this Journal will contain an article describing the transmitters and receivers in greater detail and describing variants of the basic range which have been developed for special purposes.



Fig. 13.—Front view of FM VHF link receiver BRT 163 with cover removed.