Single-Sideband Multi-Channel Operation of Short-Wave Point-to-Point Radio Links

W. R. H. LOWRY, B.Sc., and W. N. GENNA†

Part 3.—An Independent-Sideband Short-Wave Radio Receiver

U.D.C. 621.396.41: 621.396.619.24: 621.396.62.029.58

The design, construction and performance of an "independent-sideband" receiver, suitable for use on long-distance point-to-point radio links in the range 4 to 30 Mc/s, are described. The independent-sideband signal comprises a reduced-level pilot carrier and two 6-kc/s wide sidebands, one being above and the other below the pilot carrier frequency. The present article is Part 3 of a series; earlier articles in the series have given a general survey of the principles of single-sideband multi-channel operation and described the generation of single-sideband signals. Part 4, concluding the series, will deal with an independent-sideband high-power short-wave transmitter.

Introduction.

THE receiver described in this article has been designed for operation on long-distance point-to-point short-wave radio links forming part of the international trunk network. This application demands a high standard of performance from the receiver, particularly in respect of its ability to function satisfactorily under conditions of severe fading, high levels of noise due to adverse propagation conditions, and in the presence of strong unwanted transmissions on frequencies adjacent to the wanted transmission.

The advantages of single-sideband compared with double-sideband operation of short-wave radio links have been described elsewhere[1]; from the point of view of reception the most significant advantages are perhaps the reduction of the non-linear distortion which is due to multiple-path propagation and the improvement in the signal-to-noise ratio.

The present receiver has been designed to receive an independent-sideband signal comprising two single-sideband signals, each 6 kc/s wide, one being above and the other below the frequency of a reduced-level pilot carrier.[2] Each sideband can accommodate two 3 kc/s wide telephony channels or several voice-frequency telegraphy channels. The carrier level is reduced some 26 db. below the peak sideband level in order that nearly all the power output of the transmitter shall be available for the sidebands, thus improving the signal-to-noise ratio.

The receiver can also be used to receive double-sideband transmissions; there are certain advantages in so doing, e.g. the reduction of non-linear distortion due to multiple-path propagation and the possibility of selecting one sideband to avoid interference appearing in the other sideband.

Spaced-aerial diversity operation can be provided by the addition of certain units to the receiver, other units, e.g. oscillators, being used in common.

† The authors are, respectively, Senior Executive Engineer and Assistant Engineer, Radio Experimental and Development Branch, E.-in-C.'s Office.

[1] For References see end of Article.

Schematic Arrangement of Receiver.

The schematic arrangement of the receiver, in its non-diversity form, is shown in Fig. 1. The double-superheterodyne principle has been employed, since it enables an adequate image ratio to be achieved by the use of a high first intermediate frequency (i.f.), whilst effective filtering of the carrier and sideband signals can be best achieved at a low second intermediate frequency. The first i.f. of such a receiver is usually in the range 1-4 Mc/s; a frequency of 3·1 Mc/s has been adopted in this receiver and is identical with the second i.f. in the transmitter drive equipment.[2] For the most effective and economical designs of sideband and carrier filters using quartz-crystal resonators, the range 50 kc/s-200 kc/s is preferred; a second i.f. of 100 kc/s is suitable and is identical with the first i.f. in the transmitter drive equipment. The sideband filters used in the transmitter drive and receiver are of identical design, performance and construction; this arrangement reduces the number of types of filter required, thus reducing costs and simplifying maintenance.

It is necessary to select the pilot carrier in a filter of relatively narrow bandwidth, so that the carrier may be amplified and used for the automatic gain- and frequency-controls and, if required, for demodulation of the sideband signals to audio frequency. The necessity for deriving the automatic gain-control (a.g.c.) voltage from the filtered and amplified pilot carrier arises from the fact that the sideband energy is intermittent and frequently exceeds the carrier level. The filtered and amplified carrier is applied to a limiter to remove fading and unwanted amplitude modulation before being used for automatic frequency-control (a.f.c.) or demodulation; the carrier so obtained is called the reconditioned carrier.

The necessity for a.f.c. arises mainly from the need to prevent the carrier from being removed from the narrow pass-band of the carrier filter by drifts in frequency of the oscillators in either the transmitter or the receiver. The a.f.c. may be applied to either the first or second oscillator in a double-superheterodyne receiver, the correction being such as to compensate for the drifts in frequency of all the oscillators in the transmitter and in the receiver. If the control is applied to the second oscillator, as shown in Fig. 1, it is possible to replace the variable (inductor-capacitor) type of first oscillator that is normally provided, by a quartz crystal-controlled oscillator. This is a convenient arrangement for a point-to-point service in which the number of operating frequencies is limited, since it reduces the drift of the first oscillator, avoids sudden frequency changes due to vibration and other causes that may cause loss of frequency control, and

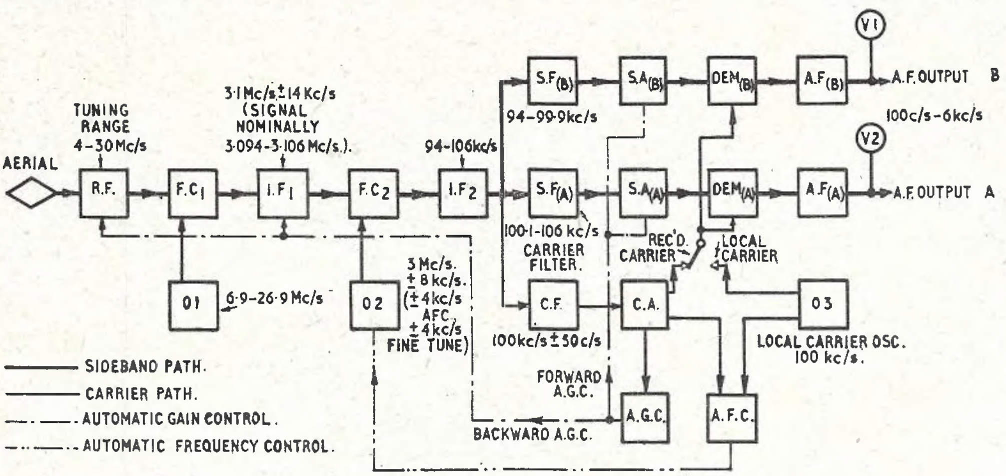

FIG. 1.—SCHEMATIC DIAGRAM OF INDEPENDENT-SIDEBAND RECEIVER.

simplifies the tuning of the receiver by reducing the range of search required.

For the reception of a single-sideband transmission a sideband filter is not essential, but it is usual to provide such a filter to attenuate noise and interfering signals which may occur in the range of frequencies on the side of the carrier opposite to the wanted sideband. By the use of two sideband filters, each accepting one sideband and rejecting the other, outputs corresponding to the upper and lower sidebands of an independent-sideband transmission are obtained.

The standard independent-sideband transmission has sideband A above the carrier frequency when the latter exceeds 10 Mc/s, and below the carrier frequency when it is below 10 Mc/s. It is desirable that the first oscillator in the receiver should be below the carrier frequency when the latter exceeds 10 Mc/s, and above the carrier frequency when it is above 10 Mc/s, in order that a given sideband may always be identified with a given a.f. output from the receiver.

Construction and Layout.

Fig. 2 shows the receiver mounted on one side of each of

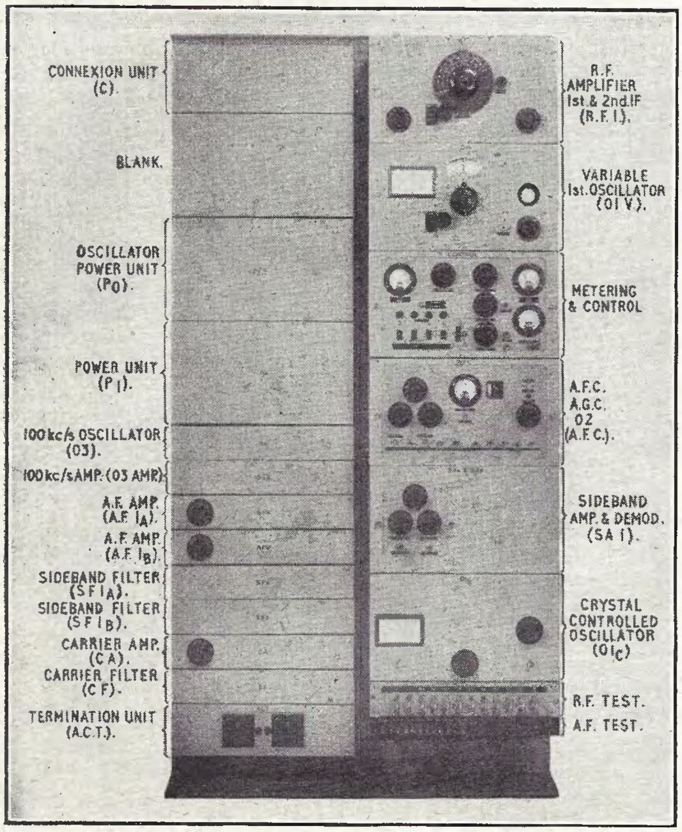

Fig. 2.—The Receiver Layout; Showing Front to the Right and Rear to the Left.

two adjacent 6 ft. 5 in. standard racks; normally it is constructed on front and back of one rack. The controls most frequently requiring adjustment are placed at a convenient height on the front of the rack. The apparatus is assembled in units, interconnection of r.f. and i.f. circuits being made by coaxial cable. The units on the front of the rack, other than the metering and control unit, are built on withdrawable chassis, connections being detachable through the use of plugs and sockets. The construction of a typical unit can be seen in Fig. 3, which shows the unit containing the r.f. amplifier.

The anode currents of individual valves can be selected for metering by the operation of switches on the main units, together with a switch on the control unit which selects the unit required.

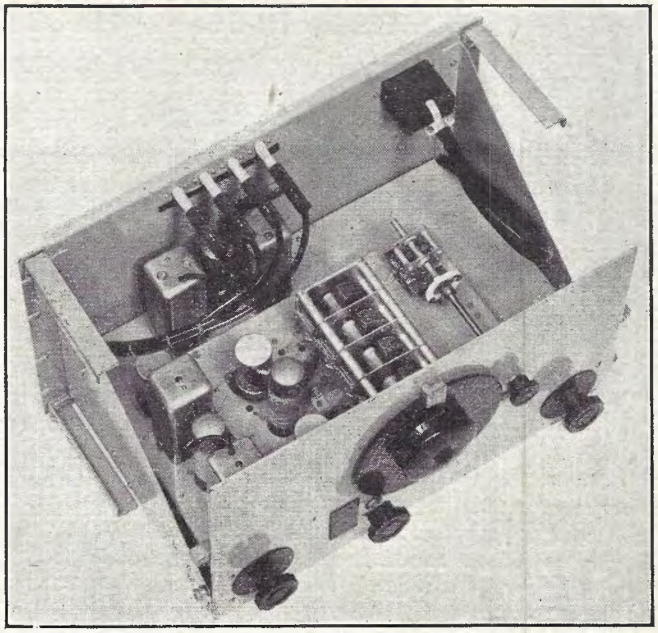

Fig. 3.—Construction of a Typical Unit, the R.F. Amplifier.

Description of Receiver

Radio-Frequency Amplifier.

The radio-frequency amplifier comprises two stages; the first stage uses a short-grid-base low-noise pentode valve, and the second stage a normal variable-mutual-conductance pentode valve.

The gain of the r.f. amplifier is not more than is necessary to ensure that the noise produced by the first frequency-changer is adequately exceeded by that arising in the input circuit and the first valve. To employ more gain than is necessary for this purpose would render the receiver unnecessarily liable to cross-modulation and blocking by strong unwanted signals, or to interference from intermodulation products such as may arise, for instance, from pairs of strong signals spaced by the first intermediate frequency. Blocking refers to changes in level of the wanted signal, produced by strong unwanted signals as a result of overloading in the amplifier or frequency-changer stages. The selectivity provided enables an image ratio of at least 80 db. to be obtained at all signal frequencies.

On the lower frequency ranges the grids of the r.f. amplifier valves are connected to tappings on the tuning inductors, thus keeping the gain of the amplifier nearly the same on all ranges. The r.f. amplifier is preceded by a rejector circuit for the first intermediate frequency, and an i.f. response ratio of at least 110 db. is obtained.

Frequency-Changers.

The familiar hexode valve has not been used as the first or second frequency-changer because the high level of noise produced by it would have necessitated greater r.f. amplification than is desirable; furthermore, the signal-to-noise ratio would have been degraded when the gain of the r.f. amplifier was reduced by the action of the a.g.c. Instead, a low-noise r.f. pentode has been used in both positions as an anode-bend mixer, with cathode injection from the oscillator.

First Intermediate-Frequency Amplifier.

The first i.f. amplifier should have an image ratio (referred to the second frequency-changer) of at least 80 db., but should have little variation of gain over the band of frequencies occupied by the two sidebands of the transmission. The carrier frequency at the first intermediate frequency may vary over the range to be corrected by the a.f.c. and over a further range of frequency if a fine tuning control is provided on the second oscillator. In this receiver, the band of frequency over which the amplifier gain should be uniform is 28 kc/s, allowing $\pm$ 6 kc/s for sidebands, $\pm$ 4 kc/s for a.f.c. and $\pm$ 4 kc/s for fine tuning.

The gain in the amplifier is not more than is necessary to prevent the noise arising in the second frequency-changer from setting too low a limit to the signal-to-noise ratio obtained with strong signals. If the amplifier gain is excessive there will be a risk of cross-modulation and blocking from strong transmissions on adjacent frequencies, because the selectivity against such transmissions is necessarily limited. A single stage is used, employing a variable-mutual-conductance pentode with i.f. transformers at grid and anode.

Second Intermediate-Frequency Amplifier.

The signal at the output of the second frequency-changer consists of a 100 kc/s carrier and 6 kc/s wide sidebands; this signal is amplified by a single stage, the anode transformer of which provides an output of 75 ohms impedance. The output of the amplifier is distributed to the carrier and sideband filters by hybrid transformers to prevent interaction between the filters. This stage employs a valve of relatively large signal-handling capacity, as it might otherwise be overloaded by interfering signals which are later attenuated by the filters.

Sideband Filters.

It is necessary for a sideband filter to have a very steep attenuation/frequency characteristic in the neighbourhood of the carrier frequency, in order to discriminate against the other sideband in an independent-sideband transmission, or against adjacent channel noise and interference in a single-sideband transmission. The attenuation in the wanted sideband should be nearly constant from 6 kc/s to within 100 c/s of the carrier, but rise to 45 db. or more (relative to that in the pass-band) for a frequency 200 c/s from the carrier, in the unwanted sideband. The attenuation should be at least 60 db. for frequencies 350 c/s or more away from the carrier frequency in the unwanted sideband.

For frequencies more than 6 kc/s from the carrier and on the same side as the wanted sideband, the overall attenuation should increase by at least 10 db. per kc/s in order to adequately attenuate transmissions on adjacent frequency allocations. This attenuation need not be provided solely in the sideband filter, as the circuit of the sideband amplifier preceding the demodulator is designed to provide part of the required selectivity. The design, construction and performance of the sideband filters is described elsewhere.[3]

Sideband Amplifier.

The sideband amplifier incorporates two stages of amplification with an adjustable attenuator for correcting sideband/carrier amplitude ratios when necessary. Forward-acting a.g.c. is provided in the sideband amplifier to correct small changes in signal level remaining after the main backward-acting a.g.c. has corrected the larger level changes. Two such amplifiers with demodulators and single-stage a.f. amplifiers are accommodated in the same unit.

Demodulator.

The signal applied to the demodulator from the sideband amplifier consists of one sideband with a low-level pilot carrier, which is attenuated below its normal level by the sideband filter. The main carrier feed (100 kc/s) to the demodulator is supplied either as a reconditioned carrier or from a quartz-crystal-controlled local oscillator. The demodulator is of a linear and balanced type, using diode valves, and is operated with a carrier level approximately 10 times the peak sideband level. The high ratio of carrier to sideband level enables distortion of the a.f. signal to be reduced to a low level, whilst the balance of the demodulator prevents unwanted amplitude modulation on the carrier (due to noise or interfering signals) from producing an audio output. Furthermore, the wanted signal a.f. output is independent of carrier level over a considerable range; thus, if the pilot carrier applied to the limiter falls below the threshold of limiting during fading, there is little effect on the a.f. output other than a slight increase in distortion. Since the a.f.c. system synchronises the pilot carrier with the 100 kc/s local oscillator, the latter can be used to demodulate the sideband signal without frequency error; the carrier from the local oscillator has the additional advantage of being free from noise. However, provision has been made for the use of the reconditioned carrier if need arises, since it is sometimes of value in preventing a.f. errors, due to small fluctuations of the received signal frequency, which are too rapid for correction by the a.f.c.

The sideband level at the demodulator is determined by the gain of the carrier amplifier as well as that of the sideband amplifier; this arises because an increase in gain of the carrier amplifier results in an increased a.g.c. voltage and a reduced signal level at the input to the sideband amplifier. Provision is therefore made for the adjustment of the gain of the carrier amplifier to a suitable value.

A.F. Amplifier.

Each demodulator is followed by a single-stage amplifier providing a normal output on speech or line-up tone of about 1 mW in 600 ohms. If a higher level is to be sent to line, a two-stage amplifier with adjustable attenuator is provided.

Carrier Filter.

The bandwidth of the carrier filter is a compromise between the small bandwidth desirable to exclude noise and other signals (including the sidebands of the wanted signal) from the carrier amplifier, and the larger bandwidth required to make tuning easy and to prevent the loss of a.f.c. should there be sudden changes in the frequency of any oscillator.

Tests have shown that with an electro-mechanical a.f.c. system capable of dealing with a carrier displacement of $\pm$ 50 c/s the bandwidth of the carrier filter 20 db. below the maximum response should be between 100 and 150 c/s. The attenuation of the filter at sideband frequencies should be such that, even with selective fading of, say, 20 db., (*a*) the carrier level should exceed the sideband level at the limiter used for the reconditioned carrier supply, and (*b*) the ratio of carrier to sideband level after filtering should be sufficient to prevent the crosstalk attenuation between sidebands from falling below 30 db. when using the reconditioned carrier supply. Ideally the attenuation should rise to a large value for frequencies more than 100 c/s from the mid-band frequency, but the limitations of carrier filter design set a limit to the attenuation which can be economically provided. An attenuation of more than 60 db. relative to that at the carrier frequency, for frequencies more than 250 c/s from the carrier enables both requirements to be met, but sets a limit to the highest levels of sideband components which can be permitted at frequencies less than 250 c/s from the carrier. The equivalent bandwidth for transmission of noise is about 70 c/s, and is 0·01 of that of the sideband channel of 6 kc/s, i.e. the noise power in the carrier path is lower by 20 db. than that in the sideband path. The carrier-to-noise power ratio is thus only 6 db. worse than the peak sideband-to-noise power ratio in the sideband path when the peak sideband-to-carrier ratio is 26 db.

The design, construction and performance of the carrier filter are described elsewhere.[3]

Carrier Amplifier.

The carrier amplifier is preceded by an attenuator by which the sensitivity can be varied to suit independent or single-sideband transmissions with 26 or 16 db. peak sideband-to-carrier ratios, or double-sideband transmissions. The carrier amplifier is a two-stage linear amplifier which raises the carrier level to a value sufficient for operating the automatic gain-control.

Automatic Gain-Control.

Fig. **1** shows backward-acting a.g.c. applied to all the amplifier stages preceding the second i.f. amplifier. An increase in signal level of 80 db. above the threshold at which the gain-control commences to operate produces a gain-control bias of about 10V, necessary to reduce the sensitivity by about 80 db. However, although the a.g.c. rectifier is provided with a fixed bias of 10V in order to improve the a.g.c. characteristics, an increase of signal level of 80 db. must result in a 6 db. increase of carrier level after the gain-controlled stages. The corresponding increase in the level of the sidebands at the demodulators is minimised by the use of a small amount of forward-acting a.g.c. on the sideband amplifier, as already mentioned.

The most effective time-constants for the charge and discharge of the automatic gain-control system are determined by the nature of the fading. If the fading were normally general-level fading which affected the carrier and sidebands simultaneously to the same extent, small charge and discharge time-constants (e.g. less than 1 sec.) would be preferable, to enable the change of receiver gain to follow the change of signal level quickly. However, the fading of the short-wave signals is selective most of the time, i.e. the fading affects different parts of the transmitted spectrum at different times. Hence, if the a.g.c. is operated from the pilot carrier alone as is usual in s.s.b. operation, it is necessary to use a relatively large discharge time-constant to prevent an increase of a.f. output from occurring as a result of a carrier fade. A discharge time-constant of approximately 50 sec. enables sustained changes of signal level to be corrected, but prevents the gain from changing appreciably during the period of typical selective fades. The optimum value of the discharge time-constant depends on the strength of the signal being received as well as on the period of the fading. This is because the rate at which the gain of the receiver will rise, when the level of the carrier falls below that for which the a.g.c. rectifier is conducting, is proportional to the voltage to which the smoothing capacitor is charged. A smaller value of charge time-constant is preferred to prevent overloading of the receiver when the signal level is rising rapidly; a value of 2 sec. is used in this receiver.

Although the a.g.c. system can be made very effective in correcting relatively slow changes in the average received signal level over a range of some 80 db. or more, it may be desirable to use additional means for correcting the more rapid changes of level due to propagation conditions, but which do not normally exceed some 15 db. For this purpose a constant-volume a.f. amplifier[4] is frequently employed.

Automatic Frequency Control.

The primary function of the a.f.c. is to maintain the pilot carrier in the narrow-band carrier filter, irrespective of drifts of the incoming carrier frequency or of the frequency of the receiver oscillators. As a secondary function it may be required to synchronise the i.f. carrier with that of the 100 kc/s local oscillator.

The a.f.c. is of the electro-mechanical type employing a motor-driven capacitor to adjust the frequency of the

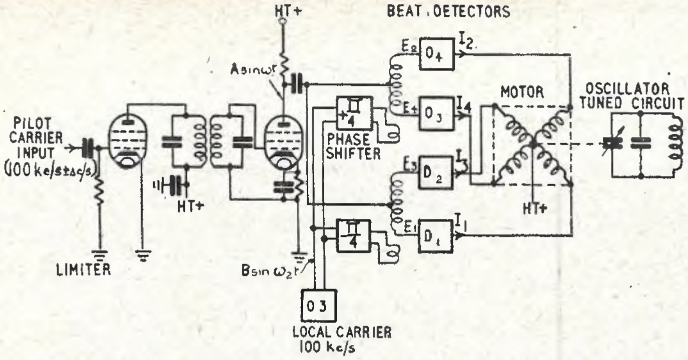

FIG. **4**.—ELECTRO-MECHANICAL AUTOMATIC FREQUENCY CONTROL SYSTEM.

second frequency-changer oscillator. Fig. **4** shows that by the use of four anode-bend detector valves supplied from a local oscillator at relative phase shifts of 0°, 90°, 180° and 270°, a four-phase supply at the difference or beat frequency △ c/s is obtained. As the frequency of the pilot carrier is varied through that of the local oscillator, the beat frequency at the output of the detectors passes through zero and the order of the phases is reversed.

The four-phase current from the detectors is applied to the four stator windings of a variable-reluctance motor, shown in Fig. **5**. The speed of this motor is proportional to

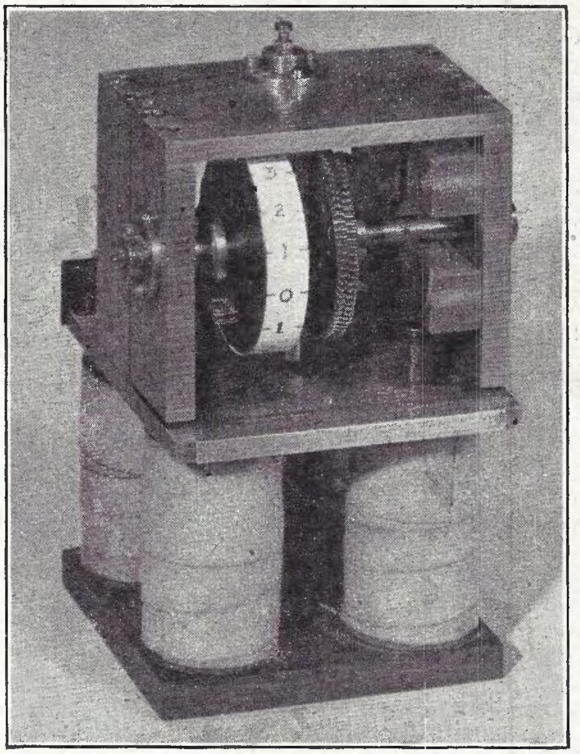

FIG. 5.—VARIABLE-RELUCTANCE MOTOR USED IN AUTOMATIC FREQUENCY CONTROL.

the frequency, △ c/s, of the applied current. If the pilot carrier frequency is varied through that of the local oscillator, the motor speed falls to zero and the direction of rotation then reverses. The motor is geared to a small variable capacitor connected across the tuned circuit of the second frequency-changer oscillator, and made to drive it in such a sense that the difference in frequency between the pilot carrier and the local oscillator is reduced, the motor continuing to run until the frequency difference, △ c/s, is zero.

The electromechanical form of a.f.c. differs from the electronic (reactor valve) system in that there is no residual error-frequency and no tendency of the a.f.c. to drift, should the pilot carrier be interrupted; local carrier can, therefore, be used for demodulation normally without any frequency error.

The relative phase of the pilot and local carriers is shown by a small oscilloscope mounted on the variable first oscillator unit; the spot traverses a circle rapidly when the motor is first synchronising the oscillators, but then moves slowly as the a.f.c. corrects any drift.

Crystal-controlled First Oscillator.

The crystal-controlled first oscillator provides a choice of nine pre-set frequencies in the ranges 7·1 to 13·1 Mc/s and 6·9 to 26·9 Mc/s; these frequencies are required for frequency-changing signals in the ranges 4 to 10 Mc/s and 10 to 30 Mc/s. A nine-position switch mounted on the oscillator unit selects the crystal, the pre-set amplifier or doubler circuits and the level control appropriate to the desired frequency. Each set of pre-set circuits is adjustable over a frequency range of about 1 : 1·5, the ranges covering 6 to 15 Mc/s being duplicated because they correspond to two ranges of signal frequency.

Variable-Frequency First Oscillator.

Good short-term stability of oscillator frequency is essential in s.s.b. or i.s.b. receivers because, although a slow drift of several kilocycles per sec. can be corrected, a sudden jump of 50 c/s or more can render the a.f.c. ineffective by removing the pilot carrier from the narrow bandwidth carrier filter. Mechanical stability is required both in the sense of freedom from vibration and as regards uniformity of expansion and contraction of the oscillator circuit elements with changes of temperature.

In this receiver the oscillator sub-chassis is isolated from the main chassis by shock-absorbing mountings, and the inductor is of simple, robust construction. The inductor is self-supporting and is mechanically damped with strips of polythene; the connection to the variable capacitor is made by a glass-to-metal seal. The valve electrodes are tapped across part of the inductor in order to minimise changes of frequency due to changes of valve capacitances. Frequency-range changing is achieved by frequency doubling in a later stage, thereby avoiding instability due to switching in the oscillator circuit. The use of a specially designed tuning drive with spring-loaded split gears avoids backlash and enables the tuning to be accurately reset.

The effect of the valve on the frequency of oscillation is so small that stabilisation of the mains supply voltage to the H.T. supply unit feeding the oscillator is usually unnecessary. The heater supply is rectified and smoothed to avoid frequency modulation at the mains frequency.

Performance Characteristics

Sensitivity and Signal-to-Noise Ratio.

In the absence of radio noise the peak sideband voltage, which is necessary to produce a 25 db. signal-to-noise ratio with a 6 kc/s band, is approximately + 7 db. relative to 1 μV in series with a 75-ohm source to which the receiver is matched. With suitable design it is possible to approach this theoretical limit within a few decibels, as is shown by the measured characteristic in Fig. 6.

The a.f.c. system operates effectively even though the signal-to-noise ratio in the sideband path is barely sufficient for an order-wire circuit.

When the signal-to-noise ratio in the sideband path is 15 db., the pilot carrier in an independent sideband system

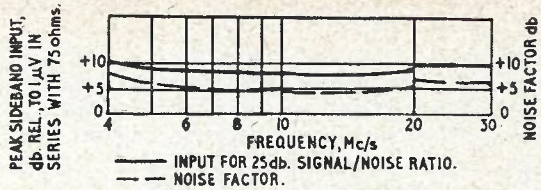

Fig. 6.—Input for 25 db. Signal/Noise Ratio and Noise Factor.

would have a level of approximately − 26 db. relative to 1 μV, which may be regarded as a suitable threshold level for the carrier. If the carrier fades below this level the a.f.c. remains at the last corrected value until the carrier level rises again to the threshold value.

Selectivity.

The overall selectivity is determined mainly by the sideband filters and the sideband amplifiers; Fig. 7 shows the

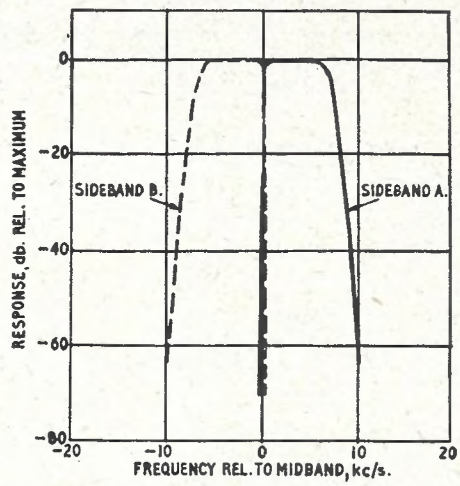

Fig. 7.—Overall Selectivity Characteristic (up to Demodulator Input).

measured overall selectivity characteristic of the receiving equipment from the aerial input to the demodulator input. The contribution of the sideband filters to the selectivity is shown by Fig. 8, which also includes the response of the

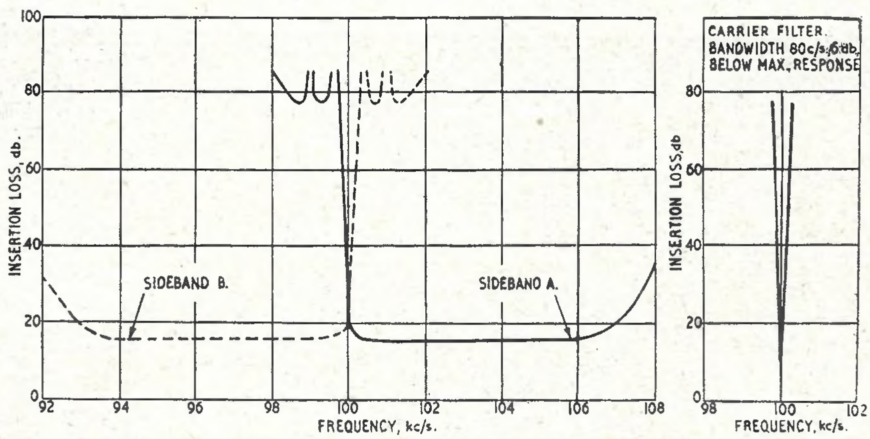

Fig. 8.—Characteristics of Sideband and Carrier Filters.

narrow-band carrier filter.

Interference from other speech-modulated transmissions takes the form of unintelligible sideband splash owing to the sharp selectivity provided and the use of a high-level carrier in the demodulator, and is due to those components of the unwanted signal that fall within the pass-band of the receiver, all other components being effectively excluded.

Automatic Gain-Control.

By the use of a forward-acting a.g.c. on the sideband amplifier in addition to the normal backward-acting control on the r.f. and first i.f. stages of the receiver, the a.f. output for a given sideband-to-carrier ratio varies by less than 3 db. when the peak sideband input is increased from + 10 to + 100 db. relative to 1 μV, as shown in Fig. **9**.

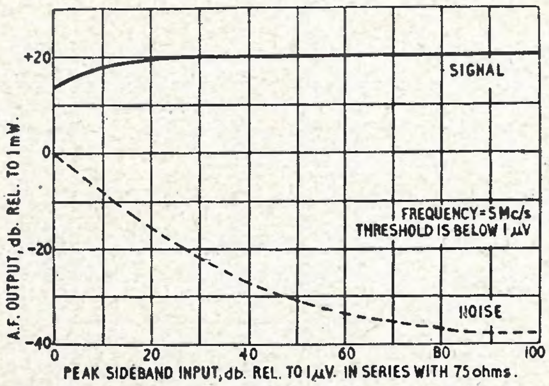

FIG. **9**.—AUTOMATIC GAIN CONTROL CHARACTERISTIC.

As the input signal level is increased the gain of the receiver is reduced and the noise output decreases nearly proportionately, up to a limit set by the noise from the non-gain-controlled stages, as shown by the dotted curve.

Overall Frequency/Response Characteristic.

The overall audio-frequency/response characteristic between 200 c/s and 6 kc/s is determined mainly by the attenuation characteristic of the sideband filter, since the r.f. and first i.f. circuits are designed to have a negligible variation of response over the range of frequencies which may be occupied by the transmission. An overall response uniform to within about 2 db. from 100 c/s to 6 kc/s is obtainable, as shown in Fig. **10**.

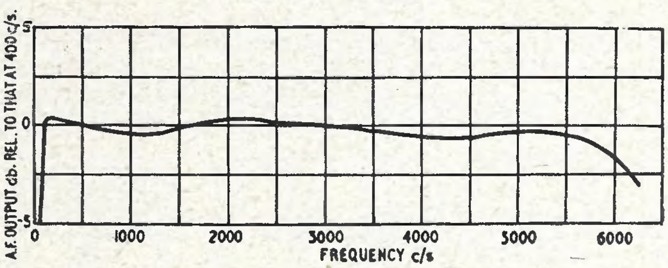

FIG. **10**.—SIDEBAND FREQUENCY/A.F. RESPONSE.

Cross-Modulation and Blocking Characteristics.

The cross-modulation and blocking characteristics are shown in Fig. **11**.

In the cross-modulation test, the unwanted carrier is $\pm$ 10 kc/s from the pilot carrier of the wanted signal, and is modulated 30 per cent. at 400 c/s. The cross-modulation produces unwanted components 400 c/s above and below the frequency of the wanted tone. The level of the unwanted carrier required to produce 400 c/s cross-modulation 20 db. below the level of a single-frequency wanted sideband signal is determined for various levels of the latter. The good performance shown in Fig. **11** is the result of careful distribution of the gain and selectivity in the receiver. The gain distribution of the stages preceding the filters is shown in Fig. **12**.

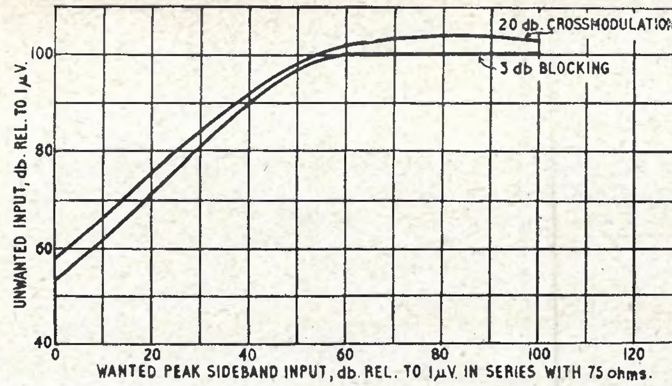

FIG. **11**.—BLOCKING AND CROSS-MODULATION CHARACTERISTICS AT 4 Mc/s.

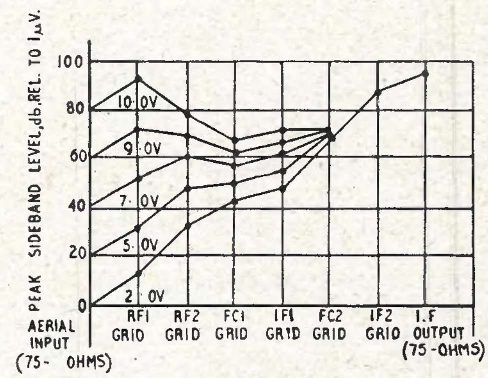

FIG. **12**.—LEVEL DIAGRAM (VOLTAGES SHOWN AGAINST CURVES ARE A.G.C. VOLTAGES).

Non-Linear Distortion.

Third-order intermodulation products of the type $2f_1 - f_2$, that might cause cross-talk from one sideband into the other, do not exceed a level of $-$ 50 db. relative to either of the two sideband signals of frequencies f_1 and f_2 for all levels of the peak sideband, up to + 80 db. relative to 1 μV.

CONCLUSIONS

The receiver described closely approaches the limits of performance theoretically obtainable in respect of sensitivity, faithful reproduction of the intelligence conveyed by the signal and freedom from avoidable interference. The satisfactory nature of the design has been confirmed by extensive tests at one of the Department's short-wave radio receiving stations. A considerable number of receivers of this type are now in production.

ACKNOWLEDGMENT

The authors wish to acknowledge the part played by Mr. W. J. Bray in the initial planning of the receiver and the assistance of the Radio Maintenance Branch in the tests at a radio station.

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