# BBC

## ENGINEERING DIVISION

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## A Quality-checking Receiver for V.H.F. F.M. Sound Broadcasting

by

C.G. MAYO, M.A. B.Sc., M.I.E.E.

and

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(Research Department, BBC Engineering Division)

BRITISH BROADCASTING CORPORATION

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# A QUALITY-CHECKING RECEIVER FOR V.H.F. F.M. SOUND BROADCASTING


## SUMMARY

The development of a quality-checking receiver for v.h.f. f.m. sound broadcasting is described. The results of tests on the original and final prototype models are given; both have a high standard of performance, the main advantage of the final model being its simpler design.


## 1. Introduction

A quality-checking v.h.f. f.m. receiver was made in the first instance to give a standard of performance which could be accurately predicted from the design. It was therefore designed with some disregard for complexity. In particular, it was thought preferable to use a discriminator based on current-sensitive rectifiers and physically separate 'staggered tuned' coils fed from a low impedance source. This receiver and its performance tests are described in Section 2.

When this receiver was nearing completion, it was realized that a Foster-Seeley discriminator could be designed to any required degree of linearity.[1] A second receiver was therefore constructed. In this a modification of the basic circuit enabled the discriminator to be combined with a diode limiter without deterioration of the performance of either; a further modification resulted in a considerable improvement of the limiting action of a simple diode limiter. These points are dealt with in more detail in Reference 2. Section 3 includes a description of this improved receiver and also the results of standard performance tests.

Both receivers were designed to incorporate their own mains-operated power packs, and were housed in a compact metal cabinet (a standard BBC Research Department portable-equipment case) of overall dimensions 17 in. by $5\frac{1}{2}$ in. by $9\frac{1}{2}$ in. (43 cm by 14 cm by 24 cm).

## 2. First Prototype Receiver (Receiver I)

### 2.1 *Description*

The receiver employs a total of ten valves and seven crystal diodes. The circuit is shown in Fig. 1 and the functions of the valves and crystal diodes are as follows:

| | | | |
|---|---|---|---|
| V1 | EF95 | pentode | r.f. amplifier |
| V2 | ECH81 | triode-heptode | oscillator-mixer |
| V3 | EF95 | pentode | i.f. amplifier |
| V4 | EF80 | pentode | i.f. amplifier |
| V5 | EF80 | pentode | i.f. amplifier |
| V6 | EF80 | pentode | i.f. amplifier |
| V7 | EF86 | pentode | a.f. amplifier |
| V8 | EF80 | pentode | a.f. output |
| V9 | EF80 | pentode | a.f. output |
| V10 | UU6 | rectifier | h.t. rectifier |
| MR1–3 | CV448 | crystal diode | limiters |
| MR4–7 | CV448 | crystal diode | discriminator rectifiers |

The receiver covers Band II (87·5–100 Mc/s) only. I.f. selectivity is provided by the confluent band-pass filter between V2 and V3 which has a total bandwidth of about 300 kc/s centred on 10·7 Mc/s. The i.f. stages are coupled by bifilar-wound coils which are damped to provide a flat response. Two static diode limiters are used, the bias being obtained by means of potential dividers across the h.t. supply. The discriminator is a version of the Round-Travis circuit, the resonant frequencies of the two tuned circuits being offset by approximately $\pm 400$ kc/s from 10·7 Mc/s. A centre-zero meter acts as a tuning indicator.

The a.f. amplifier is a standard BBC line amplifier adapted to use noval-based valves. It has a frequency response which is flat within $\pm 0 \cdot 5$ dB from 20 c/s to 20 kc/s and a voltage gain from the grid of V7 to a 600-ohm load of 42 dB; 23 dB of negative feedback is applied from a tertiary winding on the output transformer to the cathode of V7.

### 2.2 *Test Results*

The test procedure followed was that proposed by Maurice, Newell and Spencer[3] with the exceptions that the standard output was 1 mW in a 600-ohm load and that frequency modulation at 100 c/s, instead of 10 kc/s, was used in measuring the amplitude-modulation suppression ratio. Certain additional tests were performed, the results of which are given in Sections 2.2.6 and 2.2.10. The receiver was at all times tuned to give zero reading on the tuning meter.

The ratios of signal to noise, hum, or interference were measured with a mean square meter preceded by an aural sensitivity weighting network based on the C.C.I.F. (1934) curve for broadcast relay circuits.[4] Unless otherwise stated, all signal levels refer to the open-circuit voltage from a 75-ohm source.

#### 2.2.1 *Sensitivity*

The only figure applicable to this receiver is the sensitivity for the standard ratio of signal to noise. This is the minimum input carrier amplitude, deviated $\pm 35$ kc/s* at a frequency of 2 000 c/s, which will produce an output signal-to-noise ratio of 40 dB.

The measured value was 20 $\mu$V.

#### 2.2.2 *Signal-to-Hum Ratio*

An output signal-to-hum ratio of 40 dB was obtained when the input carrier was modulated $\pm 0 \cdot 4$ kc/s at 2 000 c/s; $\pm 35$ kc/s deviation would therefore result in a signal-to-hum ratio of 79 dB.

* This is equivalent to $\pm 30$ kc/s (or 40 per cent of $\pm 75$ kc/s) at a low audio frequency if allowance for standard pre-emphasis is made.

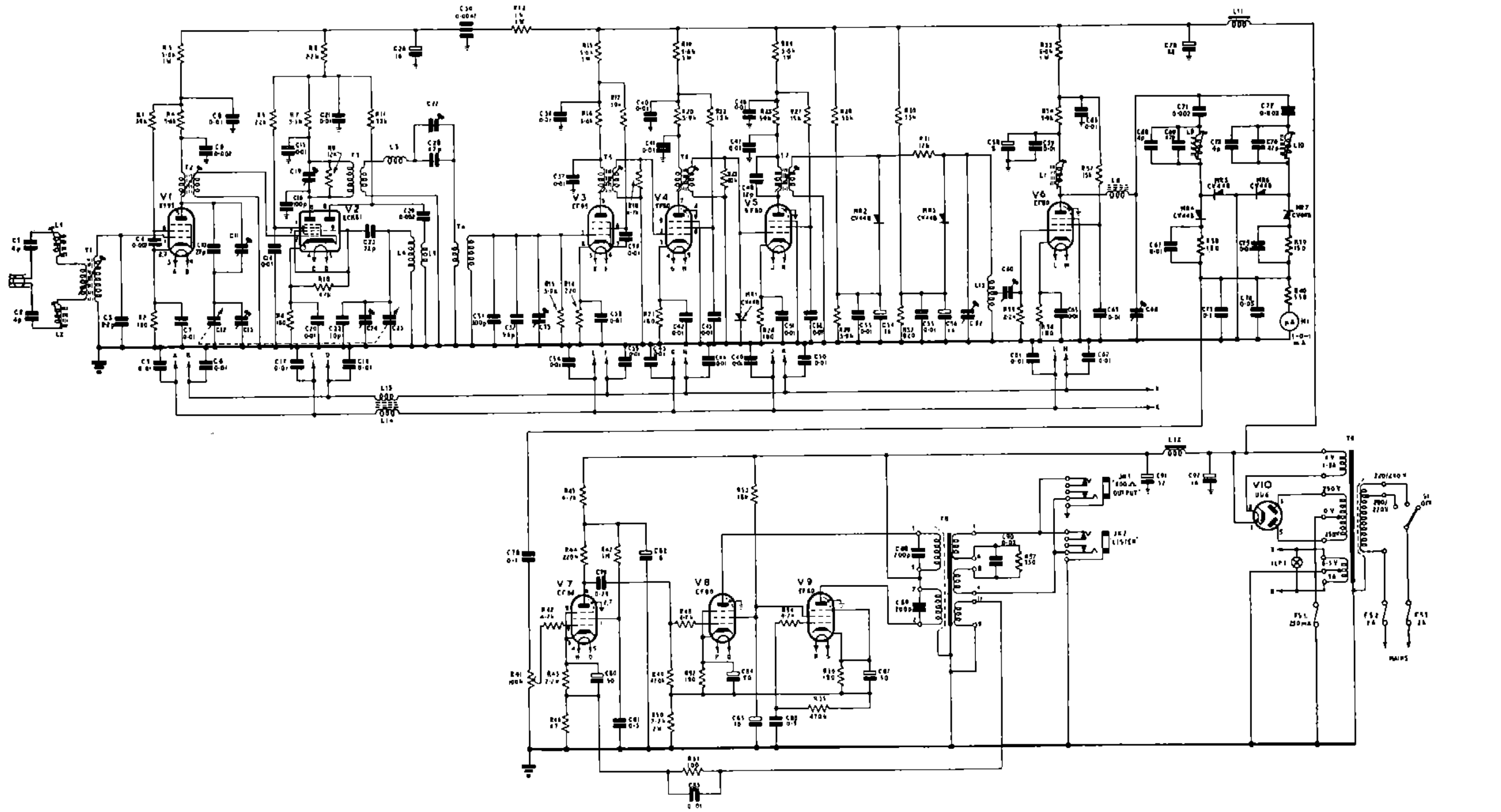


*Fig. 1 — F.M. Receiver I. Circuit diagram*

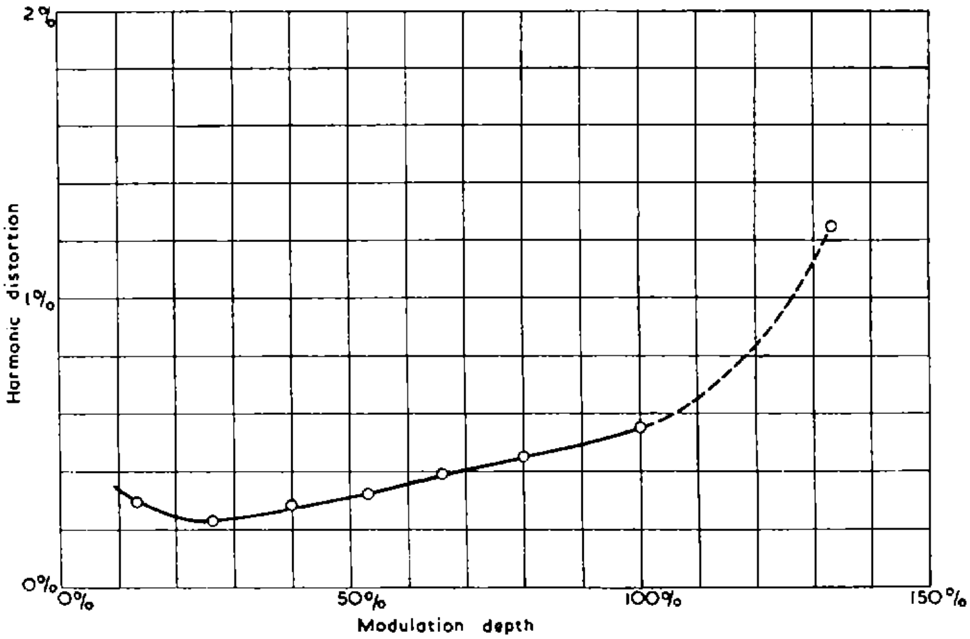


*Fig. 2 — F.M. Receiver I. Variation of harmonic distortion with modulation depth*

2.2.3 *Fidelity*

2.2.3.1 *Variation of Harmonic Distortion with Modulation Depth*

Fig. 2 shows the measured total harmonic distortion as a function of modulation depth with the gain control set to give 1 mW output with 40 per cent modulation at a frequency of 400 c/s. The residual distortion of the test signal was 0·1 per cent.

2.2.3.2 *Maximum Output Power*

The standard test was not carried out in this instance. As the a.f. amplifier employs a large amount of negative feedback, there is a sharply defined overload point. This occurs at an output level of +26 dB referred to 1 mW.

2.2.3.3 *Modulation/Frequency Characteristic*

This is shown in Fig. 3; the curve is corrected for a pre-emphasis time constant of 50$\mu$s.

2.2.4 *Selectivity*

The suppression ratio for an interfering signal is measured objectively as the ratio of unwanted-to-wanted carrier amplitudes giving a signal-to-interference ratio of 40 dB when the interfering carrier is frequency modulated at 2 000 c/s with a deviation of ±35 kc/s.

The results for adjacent, second, and third channel interference (i.e. with 200, 400, and 600 kc/s frequency separation respectively) are given in Table 1, together with the measured ratio for the image channel (−21·4 Mc/s).

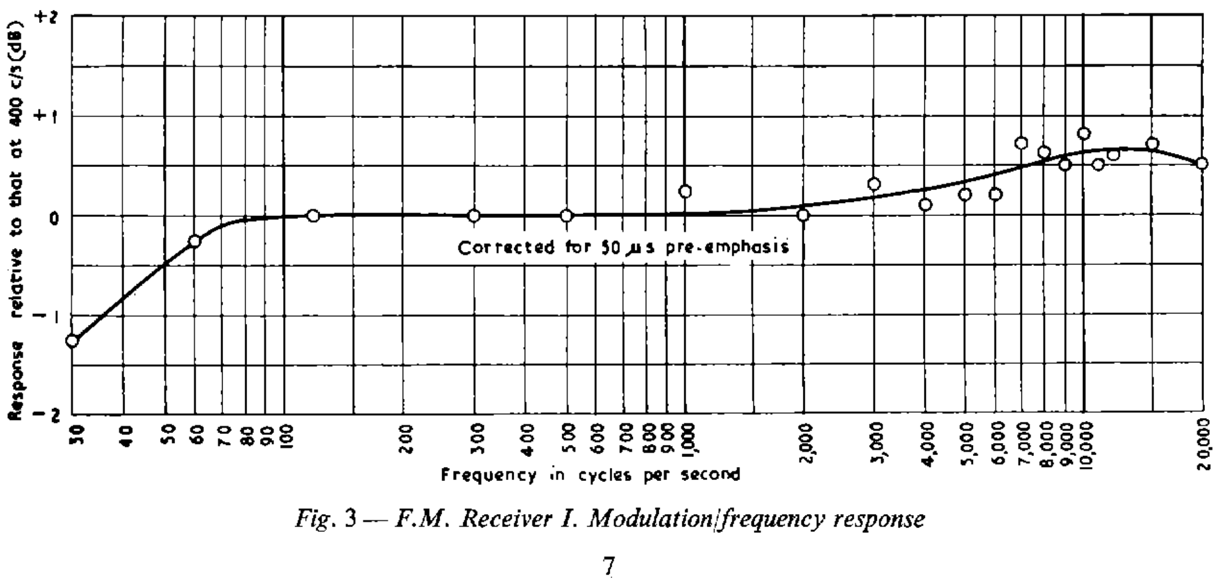


*Fig. 3 — F.M. Receiver I. Modulation/frequency response*

TABLE 1

| Relative frequency of unwanted carrier | −21·4 Mc/s | −600 kc/s | −400 kc/s | −200 kc/s | +200 kc/s | +400 kc/s | +600 kc/s |
|---|---|---|---|---|---|---|---|
| Suppression Ratio (dB) | >>+30 | +9 | −4 | −5 | −3 | 0 | +14 |

The suppression ratio at the intermediate frequency, and at all other frequencies spaced more than 1 Mc/s from the wanted carrier, was greater than +30 dB.

2.2.5 *Frequency Stability*

The drift in the frequency of the local oscillator on switching on the receiver from cold is shown in Fig. 4. The change in input carrier frequency necessary to maintain the tuning meter at zero is also plotted. This gives the overall stability of both local oscillator and discriminator.

2.2.9 *Impulsive Interference*

This test measures the performance of the receiver when receiving a frequency modulated signal and impulsive interference. In Fig. 6, the C.C.I.F. weighted output power in the a.f. band 250 c/s to 8 kc/s is plotted against the input impulse amplitude with and without frequency modulation of the wanted signal. The amplitude of the wanted signal was 0·5 mV and the modulation when present was at 12 kc/s with a deviation of ±30 kc/s. The impulsive interference repetition frequency was 2·5 kc/s.

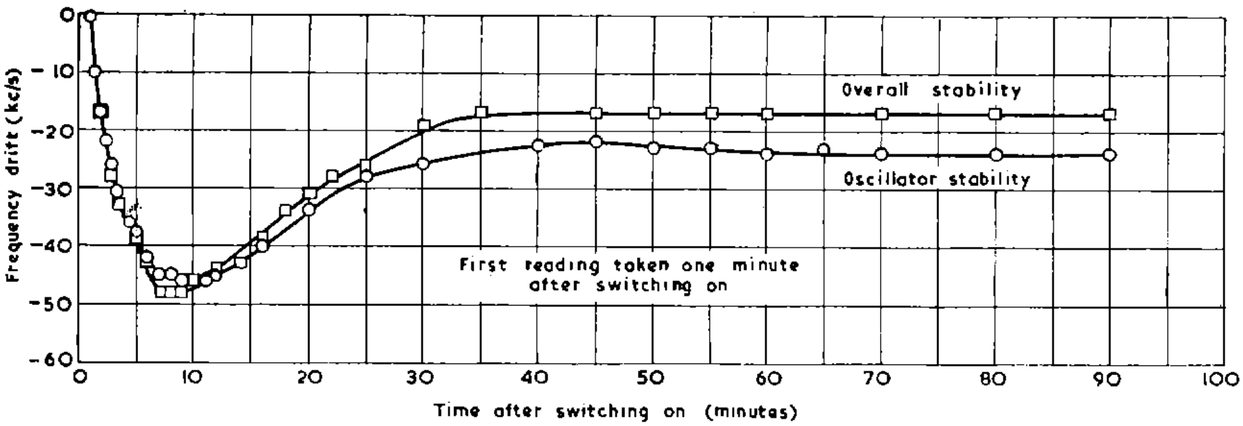


*Fig. 4 — F.M. Receiver I. Frequency stability*

The local oscillator frequency changed by less than 1 kc/s when the mains voltage was changed by ±10 volts.

2.2.6 *Oscillator Voltage at the Aerial Terminals*

The voltage at the local oscillator frequency developed across a 75-ohm resistive load connected to the aerial input terminal was 23 mV.

2.2.7 *Co-Channel Suppression Ratio*

As for test 2.2.4 but with the interfering signal differing in frequency from the wanted signal by less than ±1 kc/s.

The ratio measured was −7 dB.

2.2.8 *Suppression of Amplitude Modulation*

The a.m. suppression ratio is defined, given an audio response with the correct de-emphasis, as the ratio of the output due to f.m. to that due to a.m. when the input carrier is simultaneously frequency modulated to a peak deviation of ±30 kc/s at 100 c/s and amplitude modulated to a depth of 40 per cent at 2 kc/s. The ratio depended on the carrier amplitude as shown in Fig. 5.

The variation of audio output with a slow variation of the carrier input level was not tested in detail since, with the static type of limiter employed, suppression at very low frequencies is comparable with that at audio frequencies and is therefore considered to be more than adequate.

2.2.10 *Subjective Measurements of Selectivity and Co-Channel Suppression Ratio*

For these tests the receiver was fed with a wanted carrier of 1 mV and an interfering carrier of controllable amplitude at frequency spacings of ±1 kc/s, ±200 kc/s, and ±400 kc/s. Both carriers were frequency modulated with programme in accordance with standard BBC transmitter practice; the wanted programme was speech and the interfering programme was orchestral music giving a high level of modulation. The amplitude of the interfering signal was adjusted to give the following subjective grades of interference:

- JP The interference was just perceptible in the quiet passages of the wanted programme.
- P The interference was perceptible in the quiet passages of the wanted programme without careful listening.
- SD The interference was slightly disturbing when listening to the wanted programme.
- D The interference was disturbing.

The results given in Table 2 are the averages for three observers, the receiver having been tuned in each case in the absence of interference, using the tuning meter. The assessments were made using a wide-range high-quality loudspeaker.

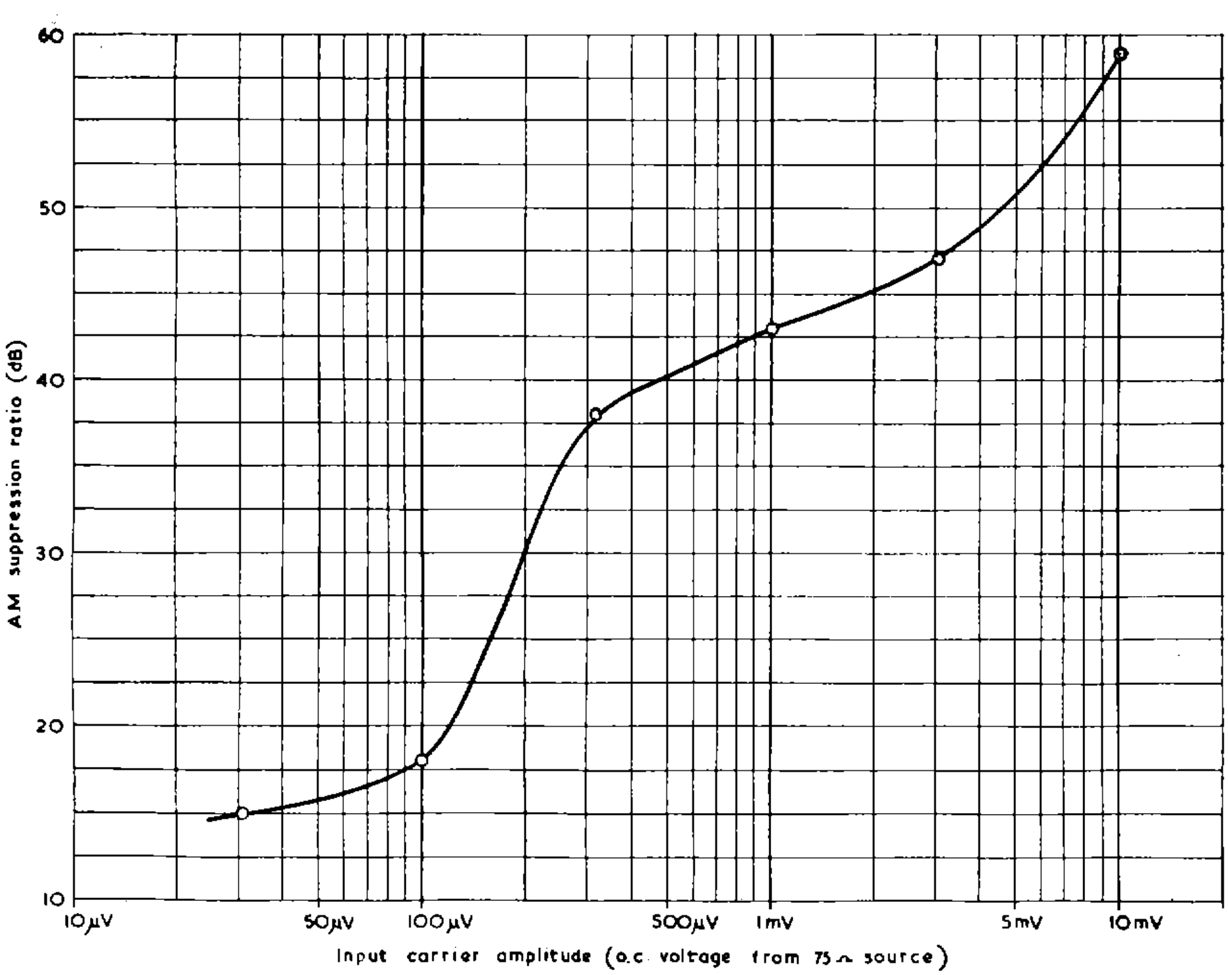


*Fig. 5 — F.M. Receiver I. Amplitude-modulation suppression ratio*

TABLE 2

| Frequency of interfering signal relative to wanted signal (kc/s) | | −400 | −200 | <+1 >−1 | +200 | +400 |
|---|---|---|---|---|---|---|
| Amplitude of interfering signal relative to wanted signal in dB to give the subjective grade of interference | JP | −5 | −7 | −29 | −3 | 0 |
| | P | −1 | −3 | −26 | −1·5 | +3 |
| | SD | +2 | −2·5 | −21 | −0·5 | +5 |
| | D | +5 | −1·5 | −16 | 0 | +8 |

## 3. Second Prototype Receiver (Receiver II)

3.1 *Description*

The circuit diagram of this receiver is shown in Fig. 7. There are eight valves and four crystal diodes; their functions are as follows:

| | | | |
|---|---|---|---|
| V1 | EF80 | pentode | r.f. amplifier |
| V2 | ECH81 | triode-heptode | oscillator-mixer |
| V3 | EF80 | pentode | i.f. amplifier |
| V4 | EF80 | pentode | i.f. amplifier |
| V5 | EF80 | pentode | a.f. amplifier |
| V6 | EF80 | pentode | a.f. output |
| V7 | EF80 | pentode | a.f. output |
| V8 | UU6 | rectifier | h.t. rectifier |
| MR1 | OA5 | crystal diode | limiter |
| MR2 | OA5 | crystal diode | limiter |
| MR3 | OA5 | crystal diode | discriminator rectifier |
| MR4 | OA5 | crystal diode | discriminator rectifier |

The receiver covers Band II (87·5—100 Mc/s) only. There are no unusual features in the r.f., frequency changing, or i.f. sections of the receiver. The two i.f. transformers are band-pass coupled circuits giving a total i.f. bandwidth of about 240 kc/s. The limiter-discriminator circuit following

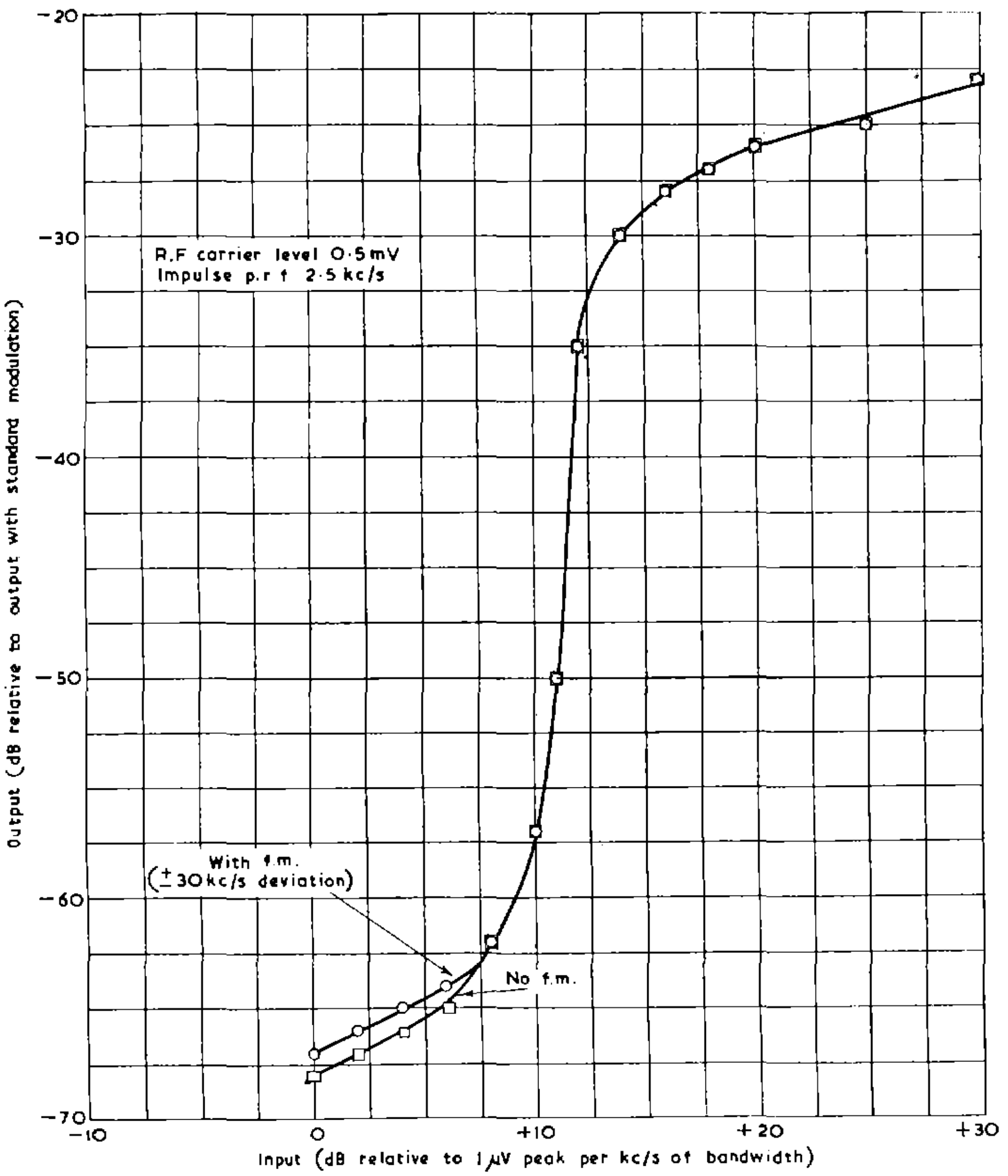


*Fig. 6 — F.M. Receiver I. Input/output characteristic for impulsive interference*

V4 is a novel version[2] of the Foster-Seeley discriminator. By the addition of a third winding, a simple diode rectifier can be used to provide amplitude limiting and conditions for the optimum design of the discriminator.[1] The limiting action of the diode is greatly improved by a rejector circuit (L9, C31) tuned to the frequency of the third harmonic of the intermediate frequency.* Amplitude-modulation suppression ratios of greater than 40 dB can be achieved with this arrangement. A centre-zero meter measures the d.c. output from the discriminator and acts as a tuning indicator.

The a.f. amplifier is similar to that used in Receiver I with the exceptions that the gain is reduced to 32 dB, and 26 dB of negative feedback is applied. The nominal output is 1 mW in a 600-ohm load.

* Provisional Patent Application No. 9568/57.

### 3.2 *Test Results*

Since the tests are identical with those given in the corresponding sub-divisions of Section 2, only the results are given. The standard output was 1 mW in a 600-ohm load and the receiver was tuned to give zero reading on the tuning meter.

#### 3.2.1 *Sensitivity*

The measured sensitivity for the standard ratio of signal-to-noise was 25 $\mu$V.

#### 3.2.2 *Signal-to-Hum Ratio*

An output signal-to-hum ratio of 40 dB was obtained when the input carrier was modulated $\pm 0{\cdot}25$ kc/s at 2 000 c/s; $\pm 35$ kc/s deviation would therefore result in a signal-to-hum ratio of 83 dB.

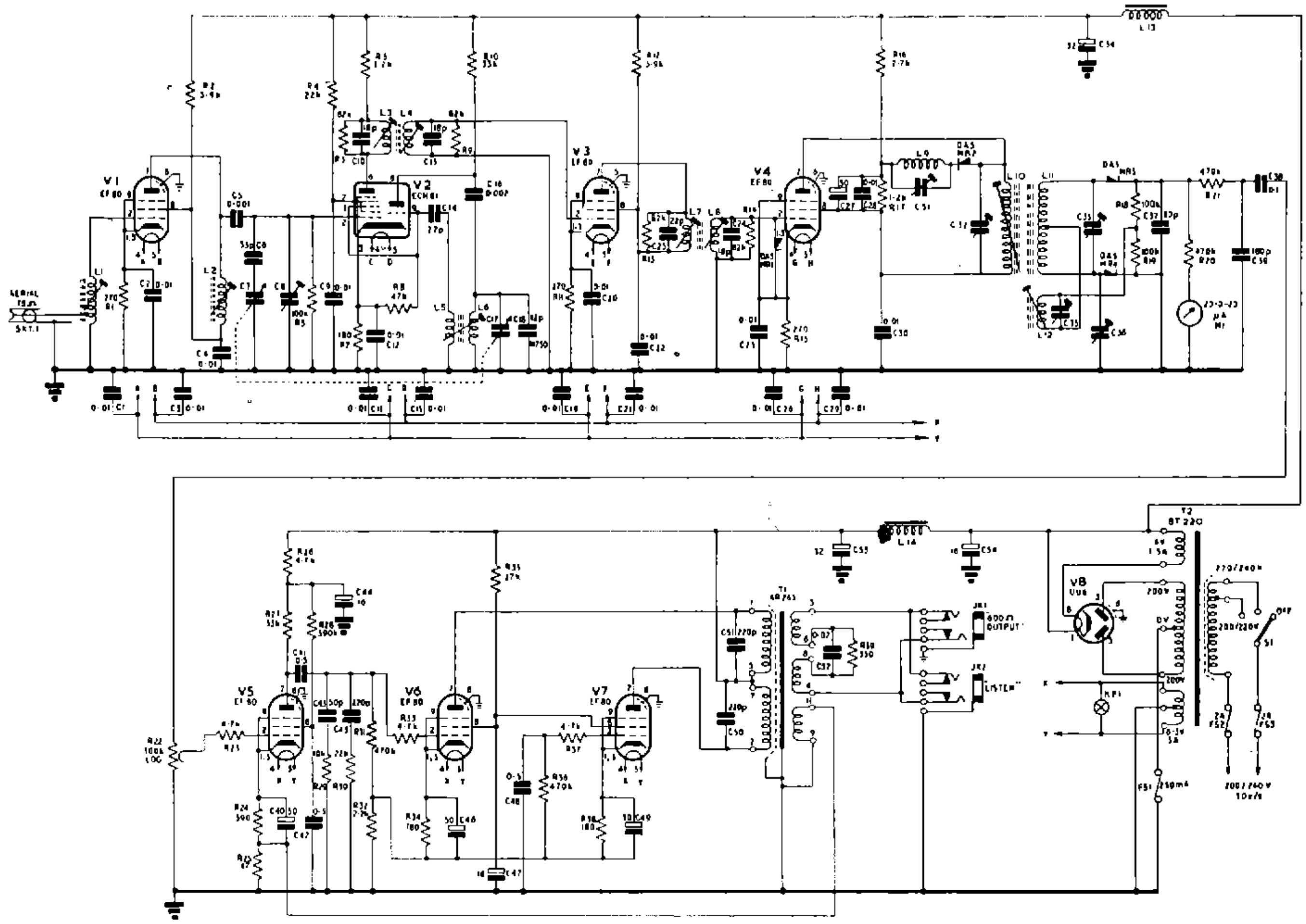

*Fig. 7 — F.M. Receiver II. Circuit diagram*

3.2.3 *Fidelity*

3.2.3.1 *Variation of Harmonic Distortion with Modulation Depth*

Fig. 8 shows the total harmonic distortion as a function of modulation depth with the gain control set to give 1 mW output with 40 per cent modulation at a frequency of 400 c/s. Although the weighted signal-to-hum ratio as measured by the previous test is very good indeed, when the total harmonic distortion is measured without the weighting network there is sufficient hum present at the output of the receiver to falsify readings at low modulation levels. A 250 c/s high-pass filter was therefore inserted between the output of the receiver and the distortion measuring apparatus. The residual distortion of the modulating oscillator was 0·1 per cent. At small deviations this equals the measured distortion; the distortion introduced by the receiver (and the modulator) is then presumably below 0·1 per cent.

3.2.3.2 *Maximum Output Power*

As in the case of the Receiver I, the amplifier employs a large amount of negative feedback, giving a well-defined overload point at an output level of +26 dB referred to 1 mW.

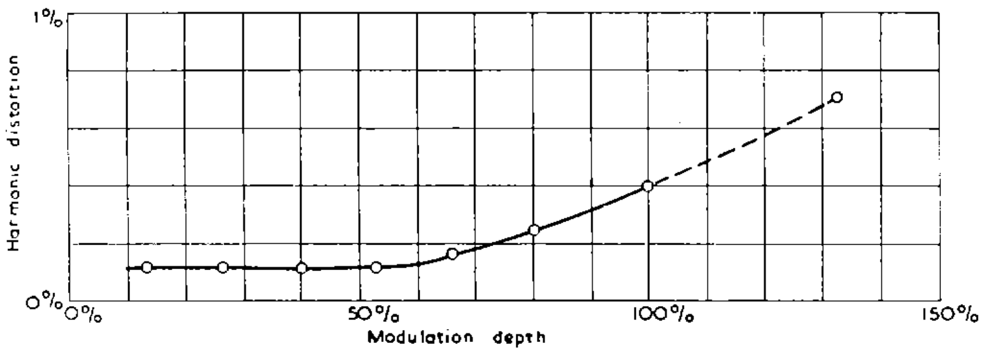


*Fig. 8 — F.M. Receiver II. Variation of harmonic distortion with modulation depth*

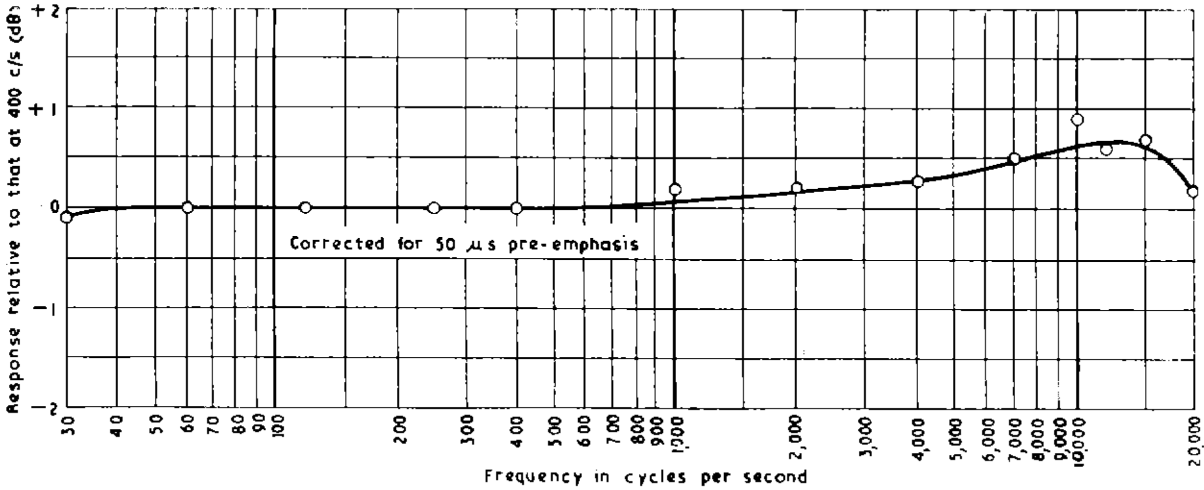


*Fig. 9 — F.M. Receiver II. Modulation/frequency response*

3.2.3.3 *Modulation/Frequency Characteristic*

This is shown in Fig. 9; the curve is corrected for a pre-emphasis time constant of 50$\mu$s.

3.2.4 *Selectivity*

The measured suppression ratios for adjacent, second, and third channel interference and for the image frequency are given in Table 3.

TABLE 3

| Relative frequency of unwanted carrier | −21·4 Mc/s | −600 kc/s | −400 kc/s | −200 kc/s | +200 kc/s | +400 kc/s | +600 kc/s |
|---|---|---|---|---|---|---|---|
| Suppression Ratio (dB) | +24 | >+30 | +9 | +4 | 0 | +14 | >+30 |

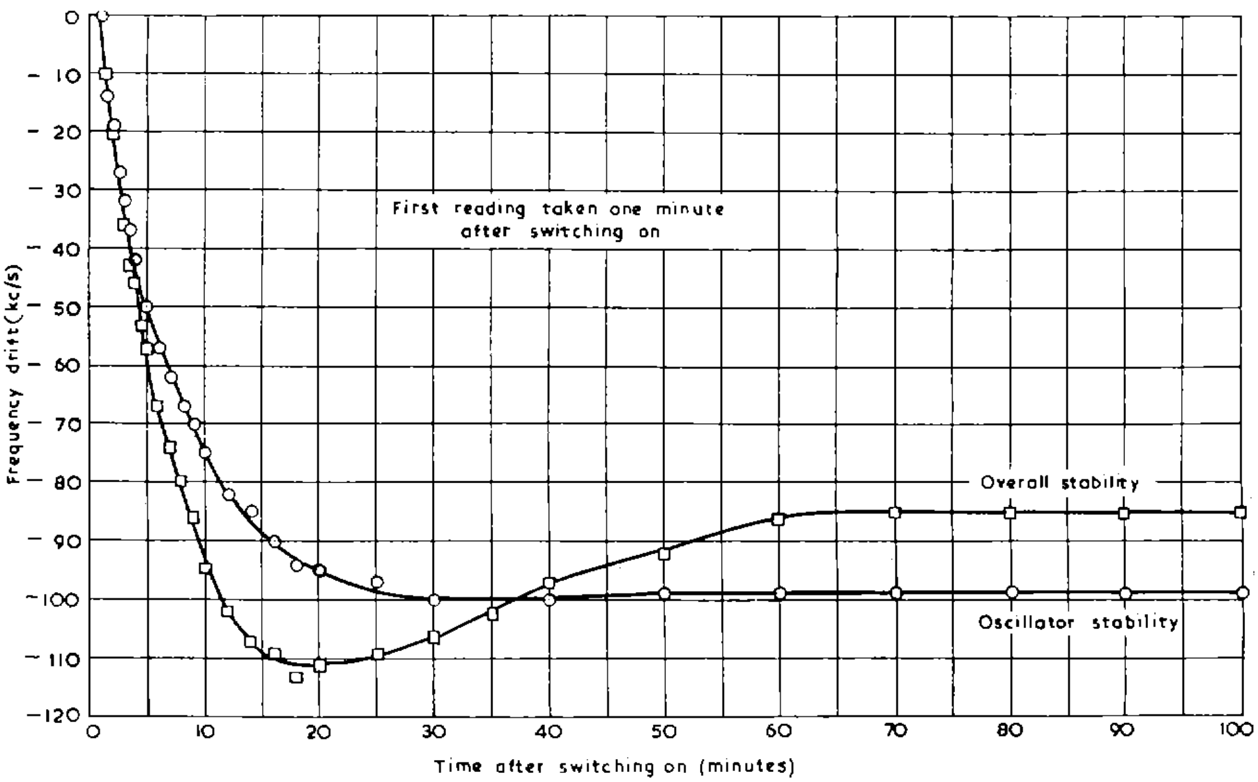


*Fig. 10 — F.M. Receiver II. Frequency stability*

The suppression ratio at the intermediate frequency and at all other frequencies not within 600 kc/s of the wanted carrier was greater than +30 dB with the exception of an interfering signal at a frequency close to the local oscillator frequency. With a wanted-carrier level of 1 mV the suppression ratio for this frequency was 29 dB; this suppression ratio will, however, vary with the wanted-carrier level. The reason is that the interference affects the local oscillator voltage in the mixer—either by pulling or by simple addition. The resultant is therefore frequency modulated at the difference frequency between the oscillator and interfering carrier. The audible interference is thus a function of the absolute level of the interfering carrier whatever the wanted-carrier level.

3.2.5 *Frequency Stability*

The drift in the frequency of the local oscillator on switching on the receiver from cold is shown in Fig. 10. The change in input carrier frequency necessary to maintain the tuning meter at zero is also plotted.

The variation of local oscillator frequency with mains voltage is plotted in Fig. 11.

3.2.6 *Oscillator Voltage at the Aerial Terminals*

The voltage at the local oscillator frequency developed across a 75-ohm resistive load connected to the aerial input terminal was 0·9 mV.

3.2.7 *Co-Channel Suppression Ratio*

The ratio measured was −7 dB.

3.2.8 *Suppression of Amplitude Modulation*

The a.m. suppression ratio depended on carrier amplitude as shown in Fig. 12. As in the case of the first model, the suppression of carrier fluctuations of very low frequency was considered adequate and was not tested in detail.

3.2.9 *Impulsive Interference*

The curve obtained under standard conditions is shown in Fig. 13.

3.2.10 *Subjective Measurements of Selectivity and Co-Channel Suppression Ratio*

The results given in Table 4 are the average for three observers. The receiver output was fed to a wide-range high-quality loudspeaker.

The oscillator stability of both receivers, on first switching on, is somewhat below the standard achieved in commercial practice. In view of the application, no steps were taken to improve this, since the stability is good if a warming-up period of ten minutes is allowed, and the presence of a centre-zero tuning meter gives an immediate indication of detuning. The stray voltage from the local oscillator appearing at the aerial terminal was rather high in the first model, but was reduced to a satisfactory level in the second model.

TABLE 4

| Frequency of interfering signal relative to wanted signal (kc/s) | | −400 | +200 | <+1 >−1 | +200 | +400 |
|---|---|---|---|---|---|---|
| Amplitude of interfering signal relative to wanted signal in dB to give the subjective grade of interference | JP | +13 | −4 | −34 | −5 | +10 |
| | P | +16 | −1 | −31 | −2 | +17 |
| | SD | +18 | +3 | −25 | +1 | +19 |
| | D | +19 | +7 | −20 | +3 | +21 |

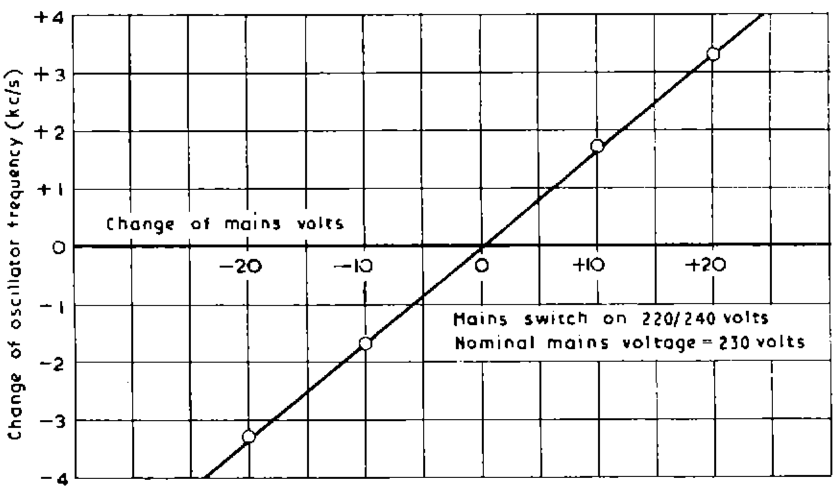


*Fig. 11 — F.M. Receiver II. Variation of oscillator frequency with mains voltage*

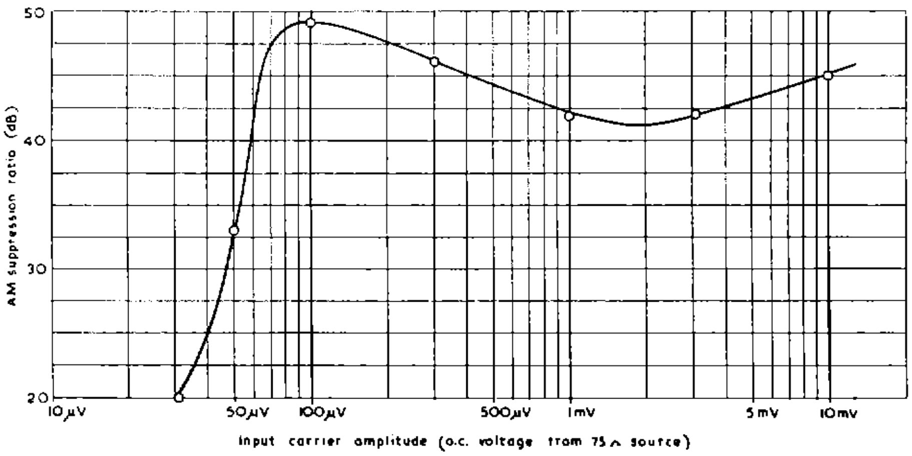


*Fig. 12—F.M. Receiver II. Amplitude-modulation suppression ratio*

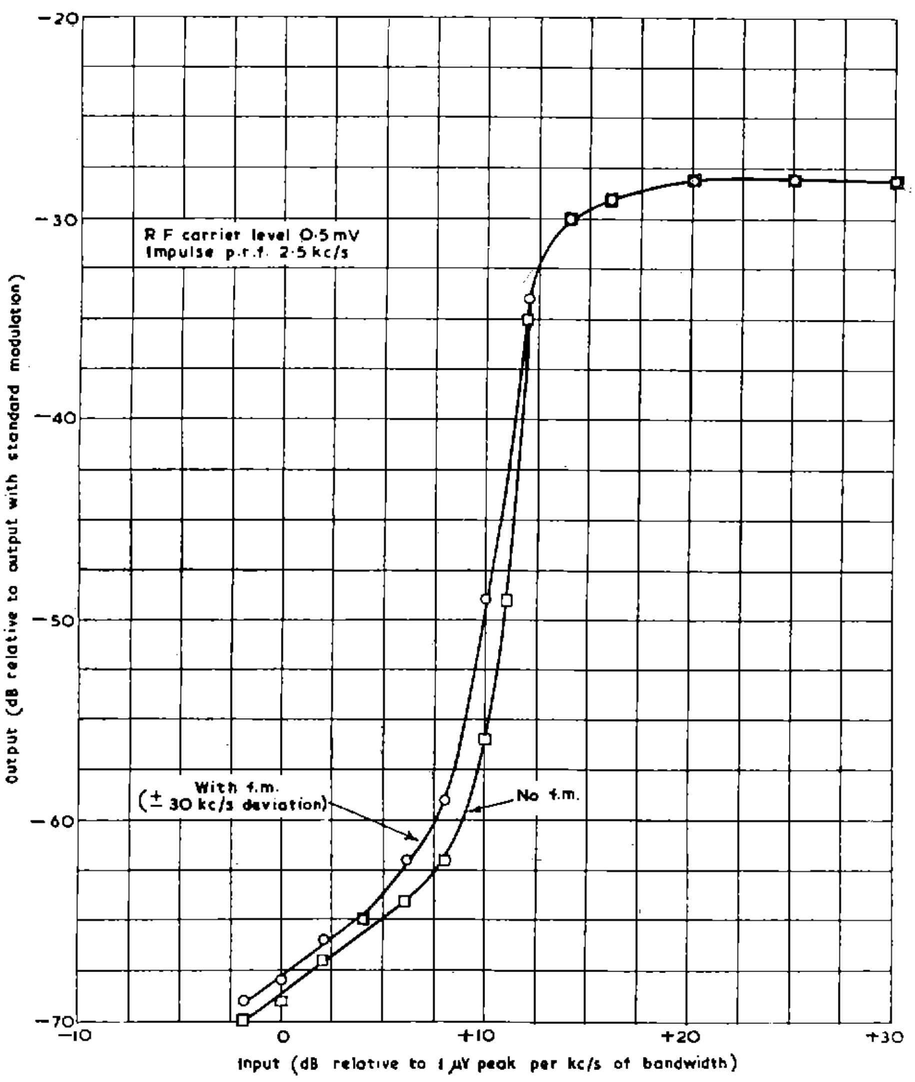


*Fig. 13 — F.M. Receiver II. Input/output characteristic for impulsive interference*

## 4. Conclusions

A brief comparison between the original model (Receiver I) and the final model (Receiver II) may be made as follows. Both models have a modulation frequency response which is flat to within $\pm 0\cdot 5$ dB throughout the audible range. The total harmonic distortion of Receiver II is very low particularly at modulation depths of less than 60 per cent, where the distortion is less than could be measured with the equipment available. Receiver I is slightly inferior in this respect although still of a high standard.

The a.m. suppression ratio is adequate (i.e. $>35$ dB) at inputs greater than 250$\mu$V for Receiver I and 52$\mu$V for Receiver II. On this criterion, Receiver II is the more sensitive receiver. The impulsive interference performance of the two models is very similar and both are superior to an experimental receiver used as a standard of comparison in the past.

The final model achieves a good performance with a reasonably simple circuit arrangement and may be regarded as the prototype of a useful quality-checking receiver. It could also serve as the basis for a f.m. re-broadcast receiver, but for this purpose further attention would have to be paid both to oscillator stability and to protection against large signals in nearby Band II channels.

## 5. References


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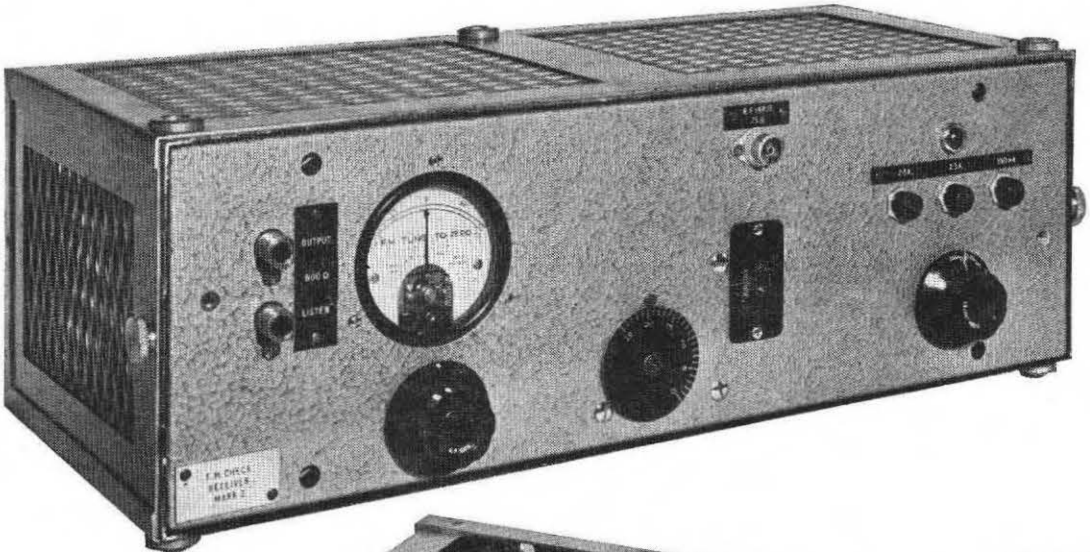


PLATE I.
*V.h.f. f.m. Quality-Checking Receiver Type II. Front view*

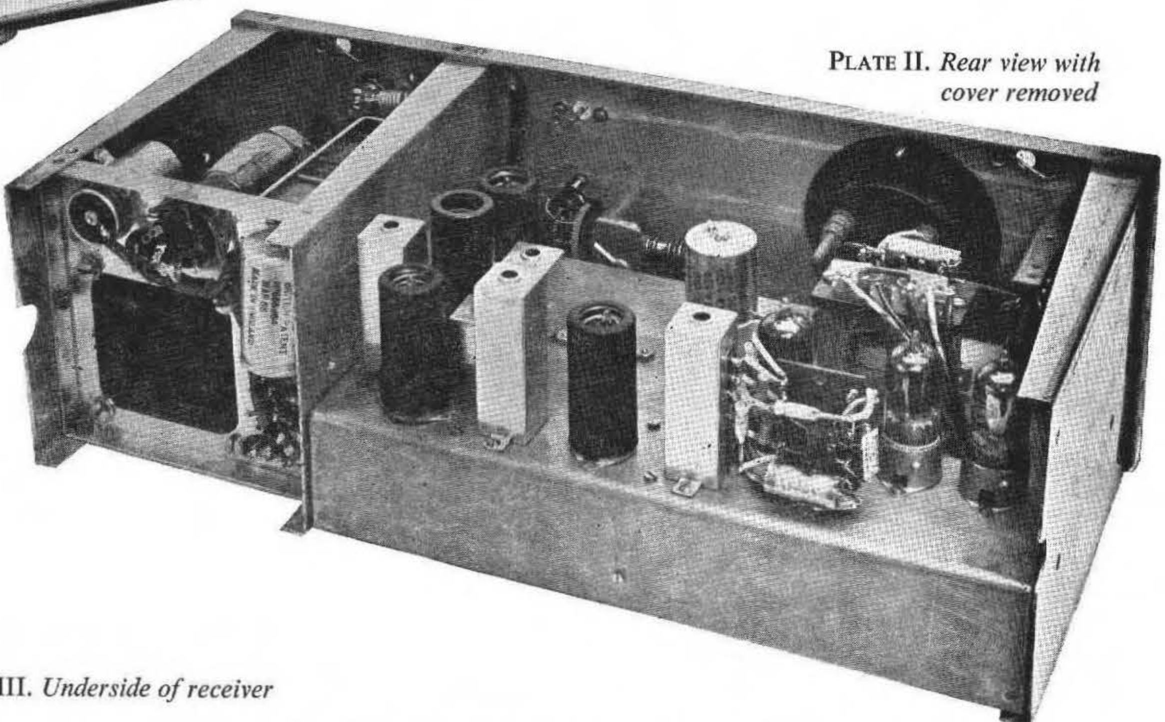
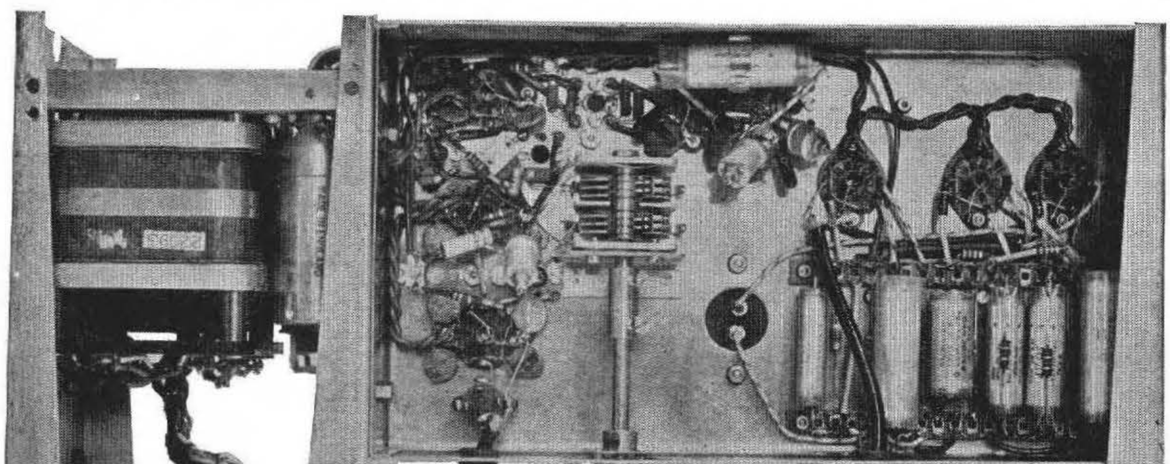


PLATE II. *Rear view with cover removed*

PLATE III. *Underside of receiver*



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