CHAPTER 35

DESIGN OF SUPERHETERODYNE A-M RECEIVERS

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SECTION 1 : INTRODUCTION

The design of A-M receivers as discussed in this chapter is taken as design for quantity production, since it is normally only under these conditions that a signal generator, a wave analyzer, a low-distortion beat frequency oscillator and suitable valve voltmeter and other meters are available.

The design of the individual stages in a receiver has been covered in the earlier chapters of this Handbook. It is assumed here that the receiver designer has already studied these earlier chapters or has equivalent knowledge. The present chapter covers the design procedure and certain general features which affect more than a single stage.

The first stage in a design is the drawing of the circuit of the receiver. This statement contrasts with the views of those who believe the circuit to be the last stage, but whereas most engineers can readily draw a usable circuit for any normal type of receiver, there are few conscientious engineers who could build such a receiver and not find that after alignment and adjustment they did not wish to make some modifications to remove faults or to improve the performance in some way. Accordingly the circuit is the first stage, modifications to layout and perhaps to the circuit as a result of measurements and operating tests are the second stage, the measurement of all performance figures and checking of all ratings and tolerances the third stage and the making of a final sample the last stage.

The fact that after the final sample is finished it frequently becomes necessary to revert to stage two again, should not be taken as a reflection on the design engineer but rather as an illustration that there is far more to a receiver than the circuit (Ref. 29). What are (apparently) minor changes in layout may introduce unforeseen difficulties with, say, the symmetry of the i-f amplifier, a tendency to instability due to feedback from the i-f amplifier to the aerial terminal or any one of a dozen other possible sources of trouble.

In a good design preliminary calculation will have been carried far enough to ensure that the circuit as first drawn will be such as to allow the specifications to be met with a minimum of components and the model will have been built with an adequate knowedge of the practical troubles likely to be encountered so that they may be a minimum.

SECTION 2 : SPECIFICATIONS AND REQUIREMENTS

The designer of a commercial radio receiver has in general three sets of specifications to meet. Firstly there are the specifications of the relevant authorities in the countries concerned.

Secondly a brief technical specification is usually supplied to the designer. This will include the more obvious electrical features of a receiver such as

1. Power supply details ; a.c., a.c./d.c., accumulator or dry battery, with the required range of operating voltages in the first two cases.
2. Frequency coverage of various wave ranges, including any bandspread ranges.
3. Sensitivity at three points on each wave range covered.
4. Noise ratio, usually at one input only, say 5 μV.
5. I-F selectivity for an attenuation of 2 times, 10 times, and 1000 times, and perhaps figures for similar conditions on the broadcast band.
6. Image ratio at three points on each wave range covered.
7. Battery consumption for battery receivers and perhaps power consumption for a.c. receivers.

Thirdly, there is usually a large number of requirements which are unwritten and taken for granted as being part of a good design, but which are all-important from the point of view of the ultimate buyer and user of the receiver. These requirements include such details as

8. Suitable a.v.c. and noise performance of the receiver, as discussed later in this chapter.
9. A-F fidelity, including the response of the loudspeaker as mounted in the cabinet.
10. A satisfactory tuning response, i.e., a minimum of unpleasant effects as the receiver is tuned to a strong or weak station or even when tuned between stations.
11. An absence of objectionable hum under all conditions, such as, for instance, with a strong unmodulated carrier tuned in and the volume control well advanced.
12. A low volume level when the volume control has been turned to its minimum position.
13. An absence of microphonic effects under normal conditions of use.
14. An absence of unnecessarily objectionable effects when the volume control is turned up to or past the a-f overload point.
15. A satisfactorily low heat rise in the power transformer and other components after long periods of continuous operation, and operation of all components within their maximum ratings under all conditions.
16. Satisfactory performance from battery operated receivers even when the battery voltage under load has fallen by at least one-third of the original voltage.

SECTION 3 : GENERAL DESIGN

(i) A.V.C. and noise (ii) Audio-frequency response (iii) Hum (iv) Microphony (v) Instability (vi) The local oscillator (vii) Cabinet design (viii) Ratings (ix) Field testing.

(i) A.V.C. and noise

(A) Noise measurements as such can conveniently be made by the e.n.s.i. method as described in Chapter 37 ; however a.v.c. and noise are grouped together in this section as they are plotted on the same a.v.c. curve, around which a large part of the design of a receiver may take place. Such curves are preferably taken by Scroggie's method (Ref. 50) as described in Chapter 27 Sect. 3(xiv) ; Fig. 35.1 shows typical curves which might have been taken during the development of a receiver.

Before the curves are studied in detail it is proposed to discuss briefly the way in which overall receiver noise may vary with the application of a.v.c. bias to different valves in a receiver. Shot noise is generated essentially in the plate circuit of a valve. The expression connecting noise current in the anode circuit, and direct anode current is

$$I_n = A\sqrt{I_d \Delta F} \tag{1}$$

where I_n = noise component of anode current,
I_d = direct anode current
ΔF = bandwidth
and A = a factor which varies with different valve types, triodes having the lowest values, and converters or mixers the highest.

Since the multiplication by g_m of the signal at the grid of a valve gives the plate current due to the signal, so the division of a plate current component by g_m gives the magnitude of an equivalent signal at the grid. Thus the equivalent shot noise at the grid is

$$E_{shot} = \frac{A\sqrt{I_d \Delta F}}{g_m} \tag{2}$$

from which it can be seen that for an equivalent valve type the lower the ratio of $\sqrt{I_d}$ to g_m the lower will be the shot noise of the valve.

It will be found with remote cut-off valves that as the grid bias is increased above the value used to obtain maximum gain the shot noise is also progressively increased. A convenient demonstration of this can be found in Fig. 27.39 which gives characteristics of the 6SK7, a type frequently used as a r-f amplifier. With 5 volts bias the numerical value of the factor $\sqrt{I_d}/g_m$ is 1.6 whilst with 10 volts bias the value is 3.5. Thus the shot noise of the valve has more than doubled when the bias is increased from 5 to 10 volts.

In addition, the gain of the stage is of course also decreased, and if the following stage is contributing to the total noise of the receiver it will add a larger amount to the total equivalent noise as increased negative bias is applied. This is because the noise voltage of the second stage is divided by the gain of the first stage to refer it to the grid of the first valve.

It is worth noting that, if noise calculations are carried out in terms of noise resistance, then the noise resistance of the second stage will be divided by the square of the voltage gain when being referred to the first stage. This follows from eqn. (2) in Chapter 23 Sect. 6 which expresses thermal agitation as a voltage e_n in series with a resistor R where

$$e_n^2 = 4KT\Delta FR.$$

Thus as noise voltages are directly multiplied, or divided, by stage gains, noise resistances must be multiplied, or divided, by the square of the stage gain to give the same result.

With an ideal receiver a ten times increase of signal input would give a ten times increase of signal-to-noise ratio. In addition the output of the receiver would be unchanged (because of the ideal a.v.c. curve) so that the gain of the receiver must decrease ten times and the noise must also decrease ten times. This could be accomplished by decreasing the a-f gain ten times, or by decreasing the gain of any stage which made no contribution to the equivalent noise at the first grid. Such a stage would be one with a large amount of gain between its own grid and the grid of the first stage. If however the gain of the input stage were decreased by a.v.c. bias, even in conjunction with a reduction in gain of other stages, then the noise of the input stage could increase and the improvement in signal to noise ratio be less than the maximum possible.

This applies particularly when the input valve is a converter. From Fig. 23.20 it will be seen that the noise resistance of a 6SA7 is 240 000 ohms whereas the impedance of an aerial coil secondary of 200 microhenries and with an effective Q of 50 is approximately 60 000 ohms when resonated at 1000 Kc/s. With such an input valve and coil, receiver noise would be determined by the input valve noise alone—

see Chapter 23 Sect. 6(iv) for method of adding noise voltages—so that any increase in valve noise would decrease the signal-to-noise ratio.

However if the input valve were a 6SK7 r-f amplifier its noise resistance of 11 000 ohms would be appreciably less than the tuned circuit impedance (at 1000 Kc/s) and an increase in valve noise resistance of 14 db due to a.v.c. application would make less than 3 db difference to the receiver's signal-to-noise ratio. At the low frequency end of the band the tuned circuit impedance would be only about 30 000 ohms and a correspondingly smaller increase in valve noise resistance would be permissible.

On the short wave band, where tuned circuit impedances are of the order of 5000 ohms in the middle of the tuning range, noise from valves must always be considered.

Thus from the point of view of signal-to-noise ratio, the best point of a.v.c. application is the last i-f valve. However with a.v.c. applied to the last i-f valve alone, severe overloading of this valve would occur with quite small inputs. The result therefore must be a compromise and a solution is to delay the application of a.v.c. to the first stage of a receiver until the desired signal-to-noise ratio has been achieved for the smallest possible input, and to apply as much a.v.c. as possible to the stage as the input increases above this point.

The importance of this is not always realized, but money and time spent on improving aerial coils to obtain chiefly a good signal-to-noise ratio at, say, 5 μV input, can be largely wasted by poor a.v.c. circuit design which at larger inputs wastes the advantage gained. Consider two receivers, A and B. A has a good aerial coil giving a 1000 Kc/s signal-to-noise ratio of 15 db at 5 μV input and its a.v.c. characteristic is such that a 20 db increase in input gives a 14 db increase in signal-to-noise ratio. B has a poorer input circuit giving a 9 db signal-to-noise ratio at 5 μV and an a.v.c. characteristic giving 19 db increase in signal-to-noise ratio for each 20 db increase in input. The signal-to-noise ratios of the two receivers for various inputs are tabulated below.

SIGNAL TO NOISE RATIO (db)

Input (μV)	Receiver A	Receiver B
5	15	9
50	29	28
500	43	47
1000	47	53

It will be seen that although the noise ratio of A is twice as good (6 db difference) as that of B at 5 μV, yet for an input of 1000 μV B is twice as good as A. Far more use is made of a receiver with inputs above 80 μV—where B is superior—than with inputs below 80 μV where A is superior. In receivers with average a-f characteristics the signal-to-noise ratio cannot be ignored until it is in excess of 40, and preferably 45 db.

A typical a.v.c. design problem is illustrated in Fig. 35.1 where curves A1 and B1 represent the output of a receiver with an input modulated 30% at 400 c/s, and curves A2 and B2 represent the noise output with unmodulated input.

Curves A1 and A2 could be taken on a receiver with high i-f gain, low a-f gain and with a.v.c. obtained from the primary of the 2nd i-f transformer and applied to the converter and i-f amplifier without any delay. The curves show the following faults in the receiver.

(a) The sensitivity of the receiver (for 50 mW output) could readily be improved. As the output is 6 db below 50 mW for 1 μV input, it could be increased to 50 mW by doubling the input, if the effects of noise were neglected. As some of the output from the 1 μV input is noise, somewhat more than 2 μV input would be needed, but the existing sensitivity of the receiver (6.5 μV) could at least be doubled.

(b) An output of even two watts cannot be obtained from the receiver for a 30% modulated signal less than 1000 μV. Although all normal signals have a maximum

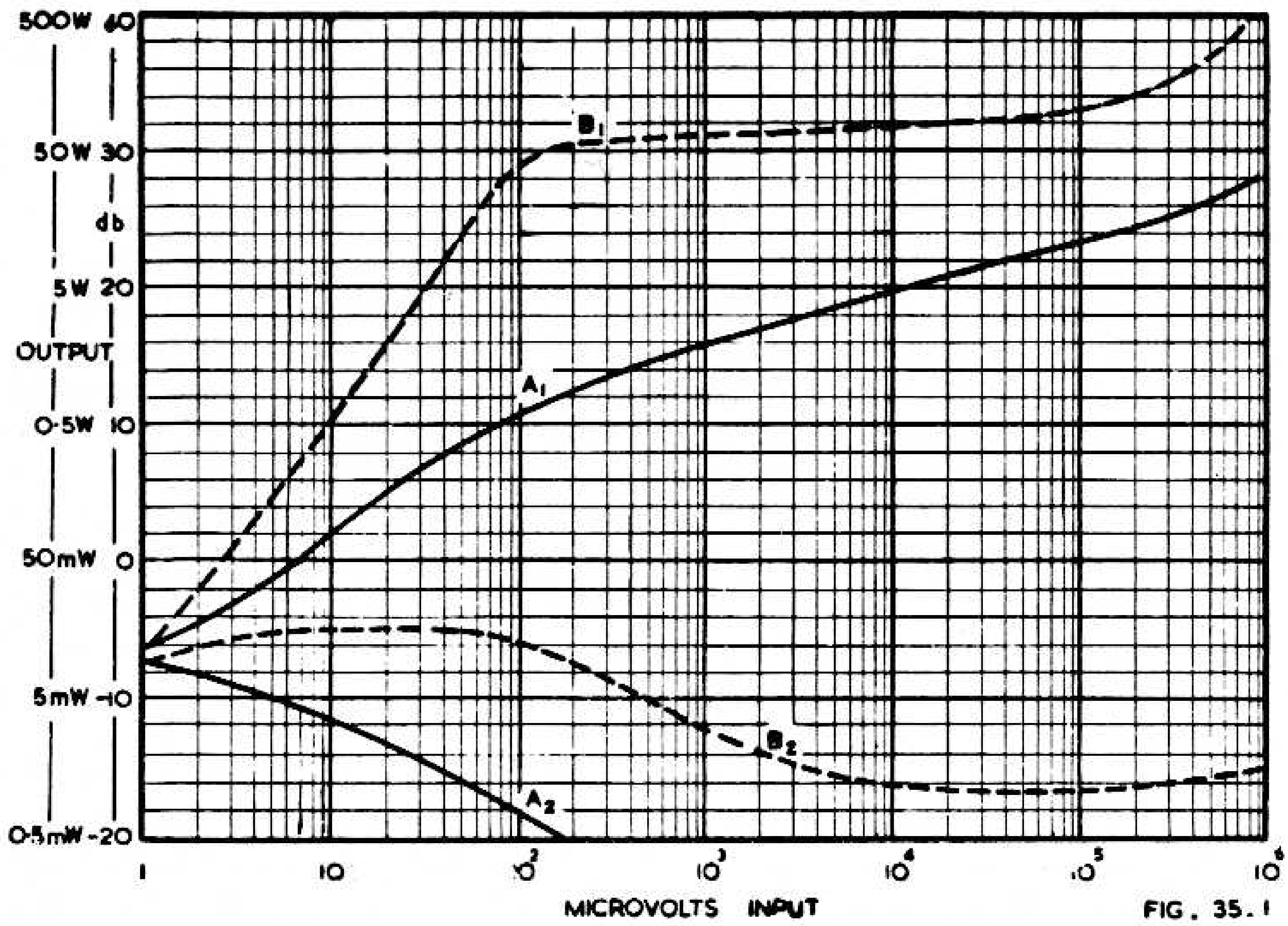

FIG. 35.1

Fig. 35.1. *A.V.C. and noise characteristics.*

modulation depth greater than this, experience shows that if the impression of insufficient output on a weak signal is to be avoided, a receiver should deliver its full a-f output from a 30% modulated signal.

(c) The signal-to-noise ratio of the receiver could be improved at any input between 5 μV and 1000 μV with the greatest improvement at the higher inputs.

Faults (a) and (b) could be removed by increased a-f gain, perhaps by reduction of negative feedback, or by substituting a pentode a-f amplifier for a triode. For instance the curve A1 shows that with another 6 db of a-f gain the receiver would have a sensitivity of 1 μV and would give a power output of 2 watts with 80 μV input. A-F gain is specified since additional i-f gain would alter the a.v.c. characteristic.

However a different modification to the receiver would simultaneously correct faults (a) (b) and (c). Fault (c) is due to the fact that at all inputs above 1 μV, a.v.c. is applied to input valve of the receiver. This is known because the rate of increase of signal-to-noise ratio is appreciably worse than the ideal. Accordingly an obvious remedy is to use delayed a.v.c., and with the object of obtaining the maximum possible signal-to-noise ratio up to 100 μV, the delay might be removed at this figure, with results as shown in B1 and B2. From these curves the following information is obtained.

(a) The sensitivity of the receiver (for 50 mW output) is now slightly better than 3 μV.

(b) An input of 20 μV will give an output of 2 watts.

(c) The noise ratios of the receiver before and after modification are as tabulated below.

SIGNAL-TO-NOISE RATIO (db)

Input μV	Original receiver	Modified receiver
5	9	10
10	14	15½
10^2	29	34½
10^3	—	43

Correction of the three previous faults has however introduced other troubles.

(d) Although the a.v.c. characteristic of the receiver is now flat within ± 2db for inputs varying between 100 and 100 000 μV, severe modulation rise occurs with inputs of the order of 1 volt. This is because the much larger signal at the plate of the last i-f valve (3 times larger with 0.1 volt input) is causing overloading.

(e) With any input from 100 μV upwards, the a-f system will be severely overloaded if the volume control is turned to maximum. In other words the useful range of the control is decreased and the receiver will behave unpleasantly if carelessly handled.

Depending on the amount of design time and component expenditure which can be afforded, a compromise between the various faults might take the form of

(a) No delay to the a.v.c. and only a fraction (say one half) of the developed a.v.c. voltage applied to the controlled grids. This would allow curve A1 to rise more rapidly, and would minimize the increase in noise in the first valve with a.v.c. application.

(b) A smaller amount of delay than that used for curve B1. An appropriate amount would allow the receiver output to reach its maximum just as the delay disappeared. This would give maximum possible signal-to-noise ratio up to about 30 μV only.

(c) A better solution might be to use a fraction of simple a.v.c. on the i-f valve and full delayed a.v.c. on the first valve. By this means the signal-to-noise ratio could increase at the maximum rate until say 500 μV input, without the maximum output rising excessively, and for larger inputs the first valve could be heavily controlled.

For further information which can be obtained from curves such as those shown in Fig. 35.1 see Chapter 27 Sect. 3.

(B) Miscellaneous matters

1. Consideration of a typical a.v.c. curve will show that it is quite possible to have too much a-f gain (Refs. 26, 31) or too much i-f gain in a normal receiver. Too much a-f gain will merely move the whole a.v.c. curve upwards, and after full output from a receiver can be obtained for some reasonably small input, any further increase in a-f gain will allow severe overloading to occur with the volume control at maximum, and increase any hum troubles.

On the other hand as i-f gain is increased, so developed a.v.c. voltages are increased and an extremely sensitive i-f channel could develop sufficient a.v.c to bias the valves back appreciably for 1 μV input. As a result the signal handling capabilities of the valves would be seriously reduced at large inputs due to their having unnecessarily high bias.

It is even possible to have too much r-f gain, at least on a particular band. If the gain of a r-f stage is 50 on the broadcast band, and 10 at the low frequency end of the short wave band, then the a.v.c. curves for the two bands can only be a compromise, and if there is sufficient sensitivity on the short wave band, excessive a.v.c. voltages will be developed with large inputs on the broadcast band, leading to i-f overloading.

A convenient method of reducing broadcast band r-f gain is to tune the high impedance r-f transformer primary to a very low frequency by using an additional capacitance, say 80 $\mu\mu$F, across a 4 mH primary. This method has the advantage of reducing the pulling of the primary on the tuned secondary circuit which may minimize tracking problems. Also it needs no additional switching as the wave ranges are changed.

2. Mention has previously been made of the necessity for having a suitable time constant for the a.v.c. system [Chapter 27 Sect. 3(xii)]. One type of distortion which can be very distressing is caused by a time constant which is too small. Under these conditions the potential on the a.v.c. line follows the a-f modulation on the diode load, although because the filter used is a resistance capacitance type, only low frequencies are present and the lower the frequency the less the attenuation by the a.v.c. filter. As a result the i-f gain of the receiver is varied at an a-f rate and while the effect on a single low frequency is to reduce its amplitude, the effect on a musical programme is to modulate the whole a-f output with its lower frequency components. The resulting reproduction sounds very rough, broken up and unpleasant. A time constant of 0.1 second must be regarded as a minimum if this effect is to be avoided and larger values are preferable.

3. Unpleasant tuning effects are usually due to the a-f frequency characteristics of a receiver, the a.v.c. system or a combination of the two (assuming that the receiver is stable under all conditions). So far as the a.v.c. is concerned it can be appreciated that with the a.v.c. voltage derived from the signal diode it is quite possible to overload the first valve in a receiver while a strong station is being tuned in. Signals of 0.5 volt are quite frequently met, and as a receiver having a resonant aerial coil gain of 10 is tuned towards such a station the signal voltage on the grid of the first valve where the selectivity is very poor compared with the selectivity of the i-f channel might reach 4 volts before any appreciable a.v.c. voltage is developed. Since the first valve might be operating with only 3, or even 2, volts of standing bias severe overloading and distortion would occur, although with the receiver tuned in correctly the valve would probably receive enough bias to allow it to handle the signal without distortion. To minimize this trouble a.v.c. is best developed from a less selective source, the primary of the last i-f transformer, even at the expense of another few components. Some advantage in smoothness of tuning is obtained on all stations, apart from extreme cases such as mentioned above, since whenever the receiver is detuned from a station, a larger a.v.c. voltage is obtainable from the less selective source, so that the volume of sound distorted by the mistuning of the receiver is reduced.

4. Although the ideal often aimed at is a flat a.v.c. curve, it must be realised that too close an approach to such an ideal has disadvantages, and is in fact undesirable for a normal A-M commercial receiver. Many receivers are used in situations with high noise levels, although in most cases the noise is of lower amplitude than the local stations. Under these conditions an a.v.c. curve flat from say 10 μV to 1 volt input will be responsible for the receiver making far more noise than is necessary when being tuned between stations.

For the purpose of providing minimum noise between stations, an a.v.c. curve would be designed to be reasonably flat over the range of inputs covering most of the local stations, and at lower inputs would decrease as rapidly as possible. Of course the minimum tuning noise requirement for an a.v.c. curve is not the only one, or even the main one, but it should not be overlooked.

It will be found that the flattest a.v.c. curve that is desirable is one which rises perhaps 20 db between 1 μV and say 250 μV input and increases between 250 μV and the maximum input at the rate of 2 or 3 db for each 10 times increase in input. The noise and static heard on stations below 250 μV give the illusion of a curve much flatter than is actually the case.

(ii) Audio-frequency response

(A) The design of the a-f end of a radio receiver is of particular importance, as its ‘ tone ’ is the one feature of a receiver's performance which is continually evident to the user. In spite of flat-frequency-response ideals, the object to be aimed at is always to provide pleasing performance, and consideration of the intended use of a receiver is necessary before it can be known what constitutes pleasing performance.

For the majority of its working life an A-M broadcast receiver provides background music for people whose main attention is concentrated on something else, and the chief purpose of a receiver is consequently to sound pleasant under all conditions.

As a secondary requirement, the frequency range of the receiver should be as great as possible, so long as this does not introduce any undesirable effects. For instance a restricted frequency range is preferable to an extended one with added distortion.

If a receiver were designed with a very flat frequency response the listener's reaction would probably be that it was lacking in bass. This is readily explainable from the effects of scale distortion as discussed in Chapter 14 Sect. 8, and the designer's first modification to the response of the a-f end of a receiver is to increase the bass. This can be done in three ways ; an increase which is not affected by any of the receiver's controls ; an increase which can be altered by means of a tone control ; and an increase which is dependent on the setting of the volume control so that at maximum volume there is little or no bass boost. A circuit of the last type is shown in Fig. 35.2, or negative feedback can be used as in Fig. 35.3. In each case the values of components shown are typical, but final sizes are governed by the acoustical qualities of the cabinet and loudspeaker, and the response of the remainder of the receiver. See also Chapter 15 Sects. 3 and 10.

There is a limit both in frequency and amplitude to the amount of bass boosting that can be used. Considering frequency first, if the response is too high in the region of 150 c/s, reproduction becomes boomy and is very annoying to listen to for a period of time. Even worse is excessive gain at frequencies lower than the bass resonant frequency of the loudspeaker. These frequencies cannot be reproduced as fundamentals and any output is due to frequency doubling.

In addition the primary impedance of the output transformer falls to such a low value, due to insufficient primary inductance in a normal cheap transformer, that the output valve can only provide a small fraction of its mid-frequency undistorted output before distortion becomes serious at frequencies appreciably below 100 c/s.

Even if these objections are overcome it is found that a good response below 50 c/s in the great majority of radio receivers is a liability rather than an asset, as hum, turntable rumble, wow and extraneous noises from broadcasting stations become objectionable. Within the receiver itself microphonic and hum troubles are increased.

FIG. 35.2

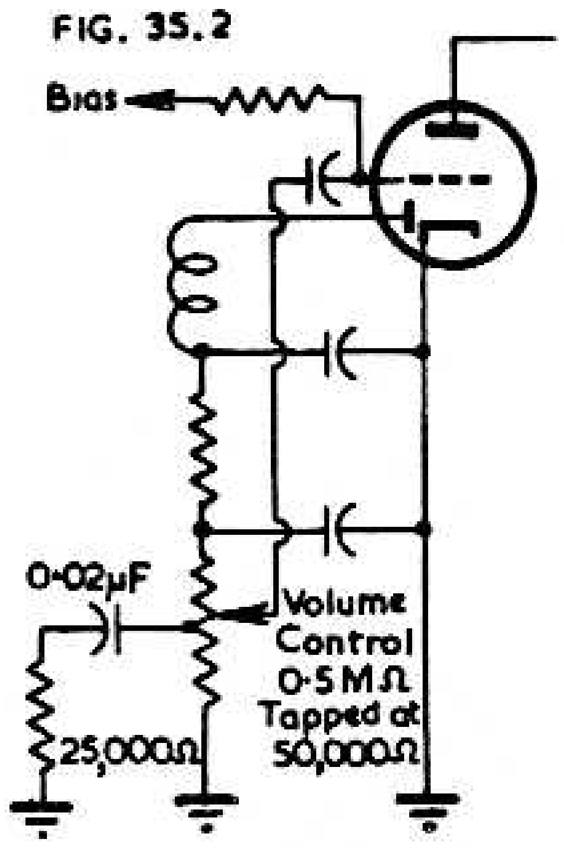

Fig. 35.2. *Bass boost varied with volume control setting.*

From the aspect of the amplitude of the bass boost it must be remembered that a receiver, with say 4 watts maximum undistorted output and a 12 db bass boost at some frequency below 100 c/s will overload very readily at the bass boost frequency. Assuming power output at low frequencies equal to that at mid-frequencies [which is certainly not the case in an average radio receiver owing to the reduced load impedance and the elliptical load line of the output valve (see Chapter 2 Sect. 4)] then an input which will give 300 milliwatts of output at the mid-frequency will overload the amplifier at the bass boost frequency. Although the overloading is due to low frequency excitation, intermodulation products will occur throughout the a-f spectrum when music is being reproduced.

On the other hand excessive high frequency response can also have undesirable effects. The frequency range from 2500 c/s to 3500 c/s is very unpleasant if over-

FIG. 35.3

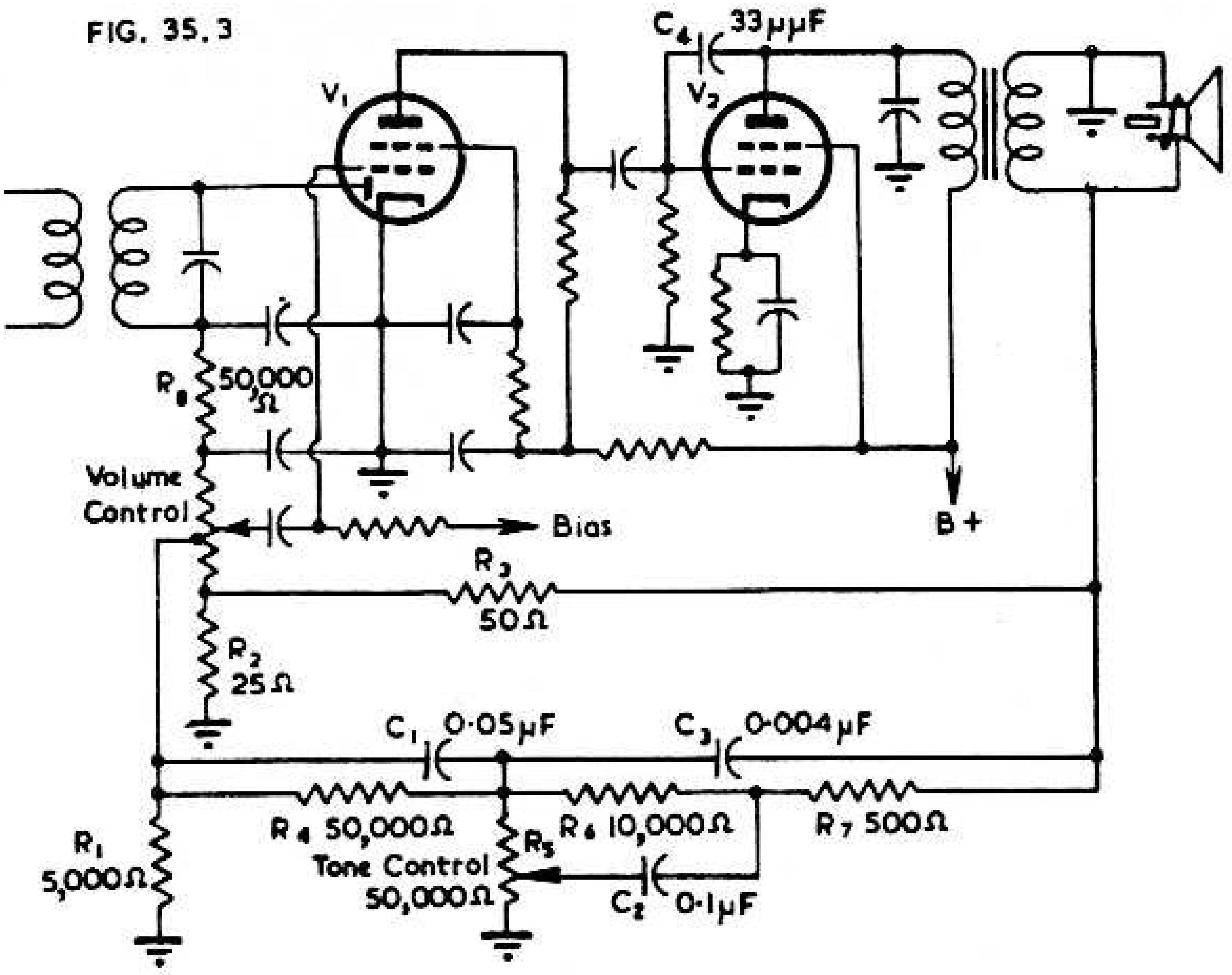

Fig. 35.3. *A-F end of receiver with compensated negative feedback and feedback tone control.*

accentuated, and where higher frequencies are to be emphasized it is essential that distortion throughout the system be kept to a minimum (Ref. 32).

Particular care must be paid to the tuning characteristics of the receiver if the a-f response is to be extended above 5000 c/s. When listening to a correctly tuned station the selectivity of the receiver normally limits the high frequency input to the a-f end, but during tuning both distortion and emphasis of high frequencies occur, and these effects are exaggerated with an extended high frequency response.

Since in a normal superheterodyne receiver the selectivity is such as to give an attenuation of 6 db at about 3500 c/s and 20 db at about 7500 c/s, it is obvious that the upper end of an a-f response which is flat to 7500 c/s is useless. If any serious attempt is to be made to reproduce frequencies above 5000 c/s the first step to be taken is to broaden the i-f amplifier—Chapter 11 Sect. 3(iii).

It was mentioned above that under conditions of reasonably extended a-f response the distortion throughout the system must be kept to a minimum. The system, of course, can include a recording, a pick-up, and a transmitter, in addition to the receiver, and as only one link in the chain needs to cut the high frequencies from the reproduction—or add distortion—to make extended high frequency response in the receiver either useless or a liability, it is seldom that it is desirable to extend the response of the a-f end of a typical radio receiver beyond about 5000 c/s.

(**B**) It sometimes becomes necessary to design the frequency response of a receiver to do more than provide the most pleasing tone. For instance, in small battery receivers the a-f output is always restricted because of the small output valve used and the need to economize on battery current, and it is usually desirable to modify the frequency response to make the most of the output that is available. This can be done by providing a comparatively high level between 1000 c/s and 2500 c/s compared with the 400 c/s output. This emphasis should not of course be carried to the stage of making the receiver sound unpleasant either when playing normally, or when overloaded, as receivers with small output are often operated in this latter condition.

(**C**) In addition, the frequency and damping of the loudspeaker low frequency resonance and the frequency and prominence of the high frequency resonance can have a considerable effect on the apparent maximum output when no electrical frequency compensation is used. If the low frequency resonance is too heavily damped, there will be loss of bass response. In mantel battery-operated receivers the damping is often reduced to the minimum by the use of a power pentode either without feedback or with negative current feedback (e.g. Fig. 35.4). In the latter case there will also be reduction of distortion. Care should be taken when using this circuit that the high frequency response does not extend to frequencies where it is undesirable. A suitable value of resistance for *R* would be 0.1 or 0.2 ohm (depending on the gain of the a-f amplifier) so that the loss in output power is more than offset by the advantages.

FIG. 35.4

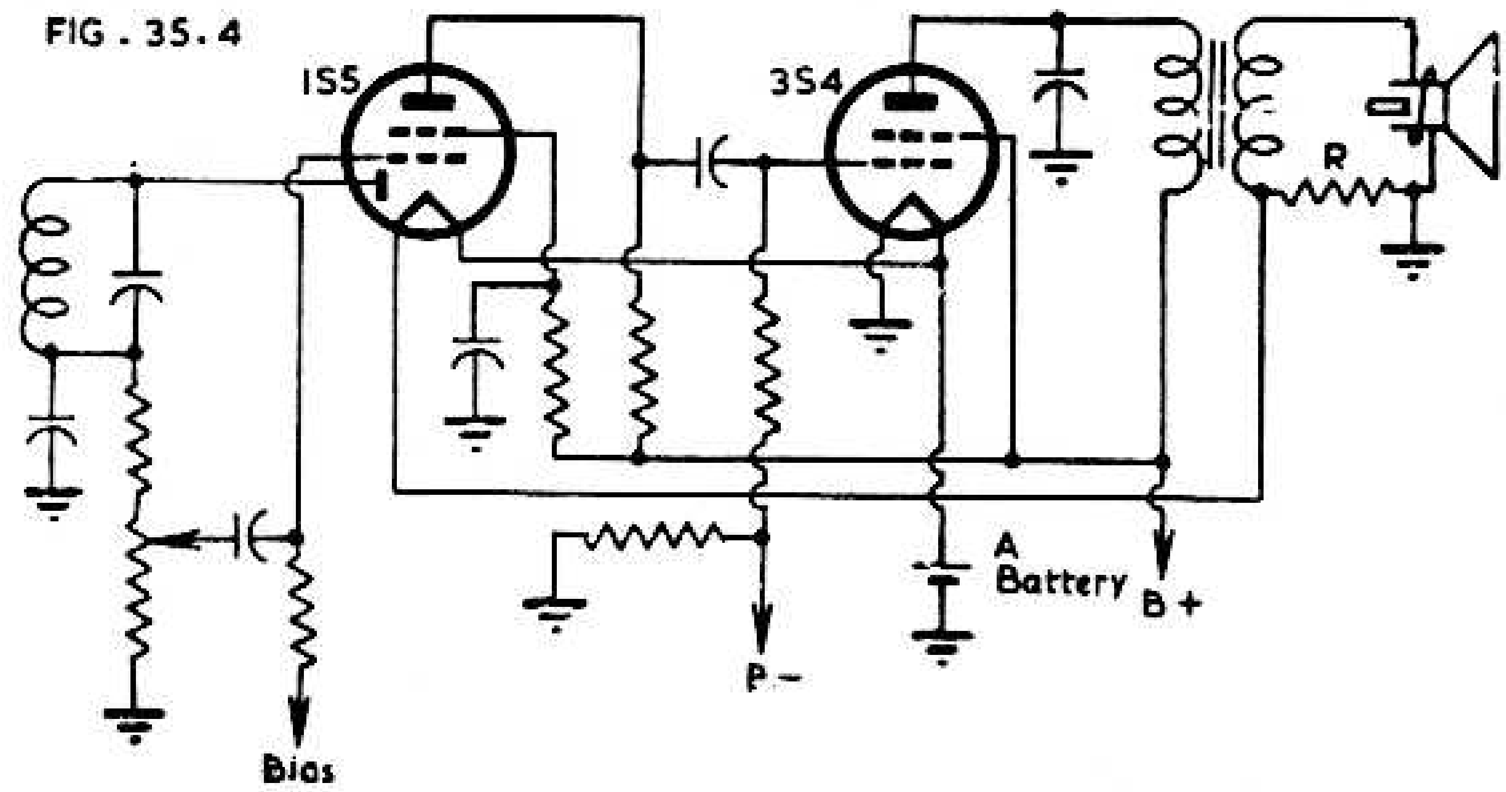

Fig. 35.4 *Simple current feedback.*

Where frequency compensation is used in a receiver, the speaker resonances are chosen with a different object in view. The electrical response can, owing to the compensation, be raised to any desired level at any frequency within reason, but the loudspeaker will not reproduce satisfactorily frequencies below its main resonance.

Accordingly the frequency of the main resonance is chosen to be as low as possible consistent with the type of receiver—and speaker—being used. For instance the resonance for a 12 inch speaker to operate in a large console model might possibly be as low as 55 to 60 c/s, for an 8 inch speaker in a table model receiver 65 to 70 c/s, and a 6 inch speaker in a small mantel model perhaps 110 c/s.

The high frequency resonance is made as high as possible although for different reasons. When a receiver's high frequency response is increased, a distressing screech occurs if the response between 2500 and 3500 c/s is too high. Many loudspeakers have a peak of sound output in this range of frequencies and when this is the case only a very small amount of high frequency boosting can be used. However if the frequency of the peak can be increased to say 4500 c/s, preferably with a dip between 2500 and 3500 c/s, more high frequency boosting up to say 5000 c/s can be used, and improved results obtained.

(D) The correct application of negative feedback to a radio receiver can reduce the distortion, permit the boosting of appropriate frequencies and provide damping of the loudspeaker bass resonance, but it must be realised that the greater the number of features expected from the feedback, the more critical will be the design. For example bass boosting is usually required at about the same frequency as the loudspeaker main resonance, and unless care is exercised it will be found that when the required bass boosting has been obtained, the feedback may be positive, in the vicinity of the resonant frequency of the loudspeaker, so that the damping required for high quality reproduction will be reduced rather than increased.

Negative feedback is used in the circuit of Fig. 35.3 to give distortion reduction, increased speaker damping, bass boosting, treble boosting with sharp cut-off, hum and minimum volume reduction, a decrease in the low and high frequency boosting as the volume control is advanced, and a tone control. The tone control gives treble boosting at one end, a comparatively flat response in the middle and a treble cut at the other end.

It will be seen that feedback is taken from the voice coil of the loudspeaker to the volume control by two separate paths. The simpler path through the 50 ohm resistor R_3provides a large amount of feedback, independent of frequency within reasonable limits, to the bottom of the volume control. This serves to reduce hum and play-through with the volume control in its minimum position as explained in Sect. 3(iii) of this chapter. Resistors R_3 and R_2 are designed to provide the desired amount of feedback, which must be limited to avoid instability.

The second feedback path is more complicated but can readily be explained in steps. With the variable tone control R_5 set to the position of maximum treble boost (slider connected to ground), R_7 and C_2 form a voltage divider, and the higher the frequency the smaller the voltage that appears across C_2. It is this voltage which is the main feedback voltage applied to the amplifier, and the decreasing negative feedback as the frequency increases gives increasing output from the amplifier, thus providing treble boost.

The next component in the main feedback path is the resistor R_6 which isolates the treble and bass boosting sections of the network. In the absence of R_6, C_1 and C_2 would give 0.033 μF to earth from the tap on the volume control. R_6 also serves a purpose in the operation of the tone control to be described below.

The next part of the feedback network is another frequency discriminating voltage divider composed of C_1 and R_1. The effect of this divider is the reverse of the previous one in that the lower the frequency the smaller the voltage appearing across R_1, owing to the increasing reactance of C_1, and as feedback is reduced at low frequencies so the overall gain of the amplifier is increased. In this way the bass boost is obtained. However as mentioned earlier there is a limit to the amount of bass boosting which can be used and to prevent the feedback from increasing indefinitely as the frequency is reduced the resistor R_4 is used.

Excessive high frequency response is also undesirable and capacitor C_3 provides a sharp cut-off above the desired range. The reactance of C_3 is so high at mid-frequencies that it has no effect on the response, but as the frequency becomes higher it provides a progressively lower impedance path between the source of the feedback voltage and the tap on the volume control. Above the useful range of frequencies it becomes the main feedback path.

To prevent instability at very high frequencies where the fraction of the output voltage fed back to the input is very high owing to the small reactance of C_3, the gain of the amplifier itself is made to decrease rapidly at frequencies above the desired a-f range. This is the purpose of the 33 $\mu\mu$F capacitor C_4, and it has the added advantage of giving a sharper overall cut-off than could be provided by C_3 alone.

The resistor R_1 has been mentioned as one element of the bass boosting voltage divider, but its size is governed by another consideration, the adjusting of the volume at which maximum bass and treble boost are provided. The feedback current flowing into the tap on the volume control returns to ground by two main paths, the volume control and the resistors R_2 and R_3 in parallel providing one, and the volume control, the decoupling resistor R_8 and the diode-cathode path of V_1 being the other. Thus as the slider of the control is turned up from its minimum setting the amount of frequency-compensated feedback applied to the amplifier is increased until the slider reaches the tap and thereafter decreases. With the slider at the tap, the volume should therefore be the lowest normal listening level so that as the volume is increased, the amount of compensation is reduced. The normal type of tapped volume control has its tap at about 50 000 ohms for a 0.5 megohm control and this gives too much volume for maximum compensation, so the value of R_1 is chosen to reduce it to the required level.

The operation of the tone control is comparatively straightforward. With the slider at the earthed end of the resistance element, R_7 and C_2 remove most of the high frequencies from the feedback path to provide a treble boost. However as the slider is turned away from the earthed end the resistance in the capacitive arm of the voltage divider is increased and its frequency discriminating properties are reduced. For example when the resistance between slider and ground is 5000 ohms the amount of feedback used varies only between 10/11 and 11/11 of the total amount as the frequency is increased from zero to infinity. Thus the treble boost is removed over the first part of the rotation.

When the control is set to the other extreme, C_2 is in parallel with R_6 and the sizes of these components are adjusted so that their impedances are the same in the lower mid-frequency range. Under these conditions C_2 offers an increasingly lower impedance path for feedback currents as the frequency increases above say 400 c/s, and the larger amount of feedback results in a falling high frequency response for the amplifier as a whole.

It must be realised that while the foregoing explanation of the feedback circuit is correct as far as it goes, a complete picture of its operation cannot be obtained without a knowledge of the phase shifts introduced by the various coupling elements both in the feedback circuit and in the main amplifier circuit. Feedback which is 180° out of phase with the input at the mid-frequency is no longer negative when a phase shift of 90° has taken place. In Fig. 35.3 at low frequencies the coupling condensers to the grids of V_1 and V_2, and the primary of the output transformer will each give a maximum phase shift of 90° while capacitors C_2, C_1, the screen by-pass of V_1, the cathode by-pass of V_2 and the decoupling by-pass in the B supply of V_1 will each give a phase shift with a maximum varying between perhaps 20° and 50°, so it is obvious that the phases of the feedback voltages become far more important than their magnitudes. By far the most difficult part of the design of such a circuit is to maintain the feedback negative over the usable a-f range, rather than to obtain the desired frequency response.

Because of the variation in frequency response with the phase of the feedback voltage it is possible to obtain bass and treble boosting without frequency discriminating elements in the feedback path. Such a circuit would be the same as Fig. 35.3 with all feedback components removed except R_2 and R_3. In such a case circuit elements such as the grid coupling condensers, which would normally be as large as possible to avoid phase shifts in the working range, would be decreased in size to cause phase shifts and thus develop a bass boost. This is the reverse of what would be expected from such a change in an amplifier without feedback. Similarly a high frequency boost could be obtained by adding a by-pass in the plate circuit of V_1 or elsewhere.

As the amount of negative feedback applied to an amplifier is increased, the peaks of response at low and high frequencies are removed further from the mid-frequency and become greater in amplitude, and with the fewer components available in the simplified circuit it usually becomes necessary to vary the amount of feedback to assist in obtaining the desired response.

(iii) Hum

The a-f gain in a radio receiver is seldom high enough to make hum elimination difficult except in so far as space or economy considerations make it so. Nevertheless economy is such an ever-present need in commercial design that the majority of receivers have hum reduced to a barely acceptable minimum.

The amount of hum permissible at any stage in a receiver can be expressed as the maximum tolerable hum at the output of the receiver divided by the gain at the appropriate frequency between the output and the stage in question. Thus the filtering required by the plate of the output valve is less than that for any other part of the a-f system. Advantage can be taken of this effect in small receivers, in which the plate of the output valve can be fed directly from the capacitor across the rectifier output. Since the output valve plate draws a large proportion of the total B current in a small receiver, the filter used for the supply for the rest of the receiver can be decreased considerably in size, and it may be possible to use a resistive filter instead of a choke without an excessive voltage drop. It should be noted however that since there is gain between the screen of a normal tetrode or pentode and its plate the screen of the output valve in such a case will probably need to be supplied from the filtered source.

Filtering becomes more important when the grid circuit of the output valve and the plate circuit of the a-f amplifier valve are considered. Designs using back-biasing for the output valve normally have the grid of the output valve decoupled for hum reduction, and similarly the plate supply to the first a-f amplifier is often decoupled. It is worth noting that the hum introduced from these two sources is out of phase, and whilst if one decoupling is used as a matter of course, or if the output valve is cathode biased, the other may become essential, yet the results obtained with both omitted are often satisfactory.

Hum introduced between grid and cathode of the a-f amplifier is usually the most difficult to eliminate since the following amplification is high, and the circuit is usually a high impedance one which makes the effects of small capacitive couplings appreciable. The impedance of course is variable, depending upon the volume control setting, and when tracing hum introduced into this stage it is best to turn the volume control to maximum. If noise from the r-f end of the receiver then drowns the hum, the last i-f valve can be removed.

Hum can be introduced into a receiver before the second detector, although under these circumstances (assuming transformer coupling to the detection diode) it can only be troublesome if it modulates the signal. **Modulation hum** can usually be traced to two general sources, firstly amplitude or frequency modulation of the local oscillator in a superheterodyne receiver by hum from the power supply, and secondly amplitude modulation of the signal in a valve working on a non-linear part of its characteristic and with a hum voltage impressed on one electrode.

Modulation hum due to the local oscillator is as a rule only met when the oscillator plate has a separate filter from the rectifier output to eliminate flutter—see Sect. 3(vi) of this chapter. The filter is usually resistive and arranged to give the proper voltages so that an increase in the size of the filter capacitor is the cure.

Modulation hum occurring because of a non-linear characteristic in a r-f or i-f valve is greatest at the point of maximum non-linearity and this as a rule is at some intermediate value of bias, so that the hum may increase up to some particular input and decrease thereafter. This can readily be checked on the a.v.c. characteristic, plotted as described earlier in this section. A common reason for this type of hum is insufficient filtering for the screen of a r-f amplifier. If the a.v.c. line carries bias generated across a back bias resistor it is also possible for hum from this source to modulate incoming signals in any of the remote cut-off valves to which a.v.c. is applied.

A third source of modulation hum is sometimes met in a.c./d.c. receivers. Owing to insufficient filtering in the mains leads or perhaps to insufficient shielding, the rectifier becomes a part of the circuit in which signal currents circulate. The signal in this path is modulated by the mains frequency since the rectifier is conductive for only half of each mains frequency cycle. A cure for this type of hum is to use a r-f by-pass across the rectifier, a typical capacitor being a 0.001 μF mica type.

A receiver with high a-f gain can give trouble with hum due to potentials developed between different soldering lugs on the chassis, and because of this it is usually best to return directly to the cathode of the a-f valve any leads coming from the ' earthy ' side of components in the grid circuit of the valve. In addition, the lead between cathode and ground must be separate from the lead earthing one side of the valve's heater. When building the pilot model of a receiver which is likely to give hum trouble it is best to take all possible precautions initially, trying any economy measures one by one after the model is in operation. The alternative of building first for maximum economy may lead to delay, since when several sources of hum are present cancellation usually occurs, and the removal of one source may lead to an increase in total hum.

One aspect of hum which can be put to good use during design is that a hum level which is objectionable at very low listening levels may be satisfactory at higher levels when it is masked by the programme. A circuit which at very small cost reduces hum at the minimum volume setting of the volume control is shown in Fig. 35.5. The connection from the voice coil is in the direction to give negative feedback, and this feedback is a maximum with the volume control turned to zero, decreasing as the volume control is turned up, until at maximum volume the gain of the receiver is reduced only by one or two db. The feedback is also valuable in reducing play-through, and this aspect has a particular application in reflex receivers.

There is a maximum value of feedback which can be used without instability, and in a high gain amplifier use of the full amount of feedback available from the voice coil may give trouble (see Chapter 7 Sect. 3). In addition, the feedback into the bottom of the diode load results in an apparent reduction of the a.c./d.c. impedance ratio.

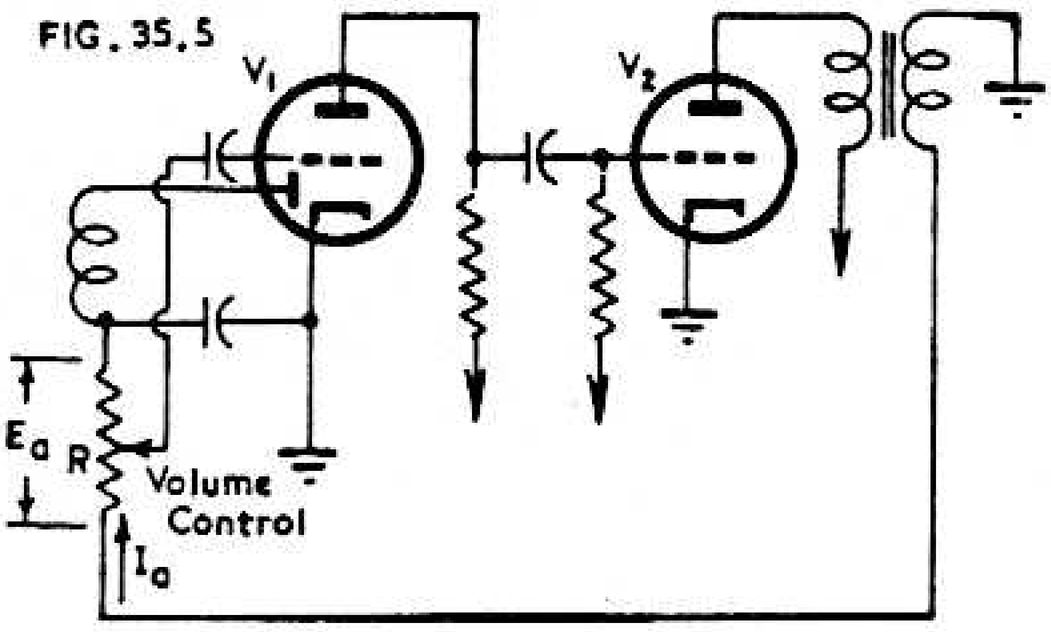

Fig. 35.5. *Negative voltage feedback varied by volume control setting.*

The reason for this latter effect can readily be visualized from Fig. 35.5 as follows. Neglecting for the moment the negative feedback, the diode load is the 0.5 megohm resistor R, and an a-f voltage E_a due to the modulation of an incoming carrier produces in the diode load an a-f current I_a of a magnitude given by $I_a = E_a/R$.

Now when feedback is applied, an a-f voltage of magnitude—in a typical case—equal and opposite to E_a with the audio volume control at maximum, is applied to the bottom of the diode load. The a-f voltage across the resistor R is now $2E_a$ and

$$I_a' = 2E_a/R$$

where I_a' = a-f current in diode load with feedback applied.

Thus the a-f current flowing in the diode load has been doubled by the application of feedback for the same demodulated a-f signal E_a. An alternative way of considering this effect is that the a-f voltage E_a is generated across an impedance equal to $R/2$. This is the usual conception of the effect, and the explanation for the statement that the a.c./d.c. ratio is reduced by such a feedback application.

Of course as the volume control is turned down from its maximum setting the feedback voltage applied to the bottom of the volume control is reduced and the a.c./d.c. ratio is improved, even although the amount of a-f gain reduction is increased.

To overcome the trouble of possible instability and increased a.c. loading on the diode load when the full voice coil voltage is used for feedback, the circuit of Fig. 35.6A can be used. Resistors R_1 and R_2 may be of equal size, say 25 ohms each, and the phase of the feedback is such that the feedback at the bottom of the diode load is still negative, so that the feedback into the top of the diode load is positive. The values of the resistors can readily be arranged so that the gain reduction with the volume control at maximum is zero, when the a.c./d.c. ratio is no worse than in the no-feedback condition.

It is quite possible of course to have positive feedback predominating, giving an a.c./d.c. ratio greater than unity, but the reduced detection distortion in this case may be more than offset by increased a-f distortion.

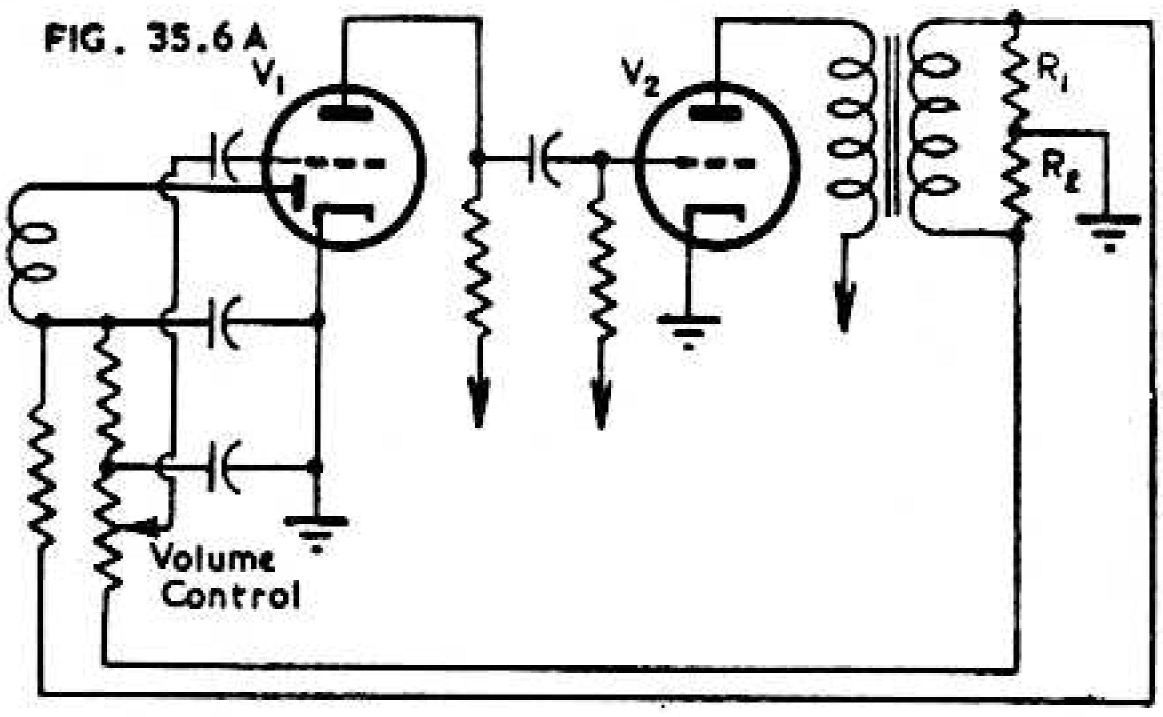

Fig. 35.6A. *Combination of positive and negative voltage feedback.*

When tracing hum it is essential to be in a location quiet enough for the character of the hum to be recognisable, and a meter reading hum amplitude and an oscilloscope showing hum waveform can each be useful on occasions.

The amount of hum which can be tolerated is very dependent on the frequency of the hum, and pure 50 c/s hum could be of much greater amplitude than say a 150 c/s hum for two reasons. Firstly, the sensitivity of the ear is greatly reduced at 50 c/s, and secondly the sensitivity of the reproducing equipment also decreases rapidly below the resonance of the loudspeaker. Nevertheless a receiver with a small speaker which cannot reproduce 100 c/s satisfactorily can suffer badly from 100 c/s modulation hum, which, although not audible in itself, modulates any other audio frequencies which are present and thus gives a very harsh, broken-up type of reproduction.

Since the effects of hum are to such a large extent subjective it is natural that final approval in a doubtful case must come from a listening test. It is essential that such a test be carried out in a home under the quietest conditions possible, as the masking effects of noise in a normal factory, or even laboratory, make an evaluation of the hum level very difficult.

See also Chapter 31 for a general treatment of hum, Chapter 7 Sect. 2(ix) for hum with feedback, Chapter 12 Sect. 10(vi) for hum in voltage amplifiers, and Chapter 18 Sect. 2(iii) for hum in pre-amplifiers

(iv) Microphony

Microphonic effects in electronic equipment are those in which mechanical movement produces undesired electrical output from the equipment. Many such effects are self-sustaining in that the microphonic noise produced reinforces the original mechanical movement and a continuous output builds up at the frequency of the mechanical vibration.

There are two main sources of microphony in an A-M receiver, the local oscillator and its circuit, and valves. Since all tuned circuits and all valves are microphonic to some extent, the object of a designer when laying out a receiver must be to isolate from the output of the loudspeaker those components which are most likely to give trouble.

Tuning condensers probably give more microphonic trouble than any other component, although frequently this is due to the mounting method used or to the dial drum. Some receivers have the complete tuning unit (condenser, coils, wave-change switch and valves) mounted on a subchassis which is floated on rubber. This precaution, although comparatively expensive, is usually sufficient to remove any microphony, and even the cheaper solution of floating the gang condenser alone will usually give a substantial improvement. A drawback to the use of floating tuning units is that as a rule the dial and tuning knob must float too, or flexible couplings must be provided to them, in which case backlash between the tuning knob and the gang condenser or the dial usually becomes a problem.

The type of gang condenser microphony which can be cured by floating the condenser is usually due to movement of masses of metal such as the complete gang body, or the whole rotor shaft, and an alternative to floating the gang is to make it more rigid. The first step is to stiffen the body by soldering with large fillets of solder the junctions between the cross bracing strips and bars, and the end and dividing plates in the gang. For extreme cases it may be necessary to solder a plate to the back of the body of the oscillator section. An alternative is to mount the gang normally on its feet and then add an additional bracing from the top of the gang to some nearby solid mounting. Such a bracing may be better either rigid or rubber mounted, in the latter case acting more as a vibration damper. A gang condenser with its framework stressed by the mounting is more likely to be microphonic than one which is not stressed. Thus a suitably designed three point mounting may be an improvement on the conventional four point suspension, although in each case care must be taken to see that it is not possible for the condenser to rock.

It does sometimes happen that a complete stator packet vibrates and causes microphony. In such cases it may be possible to reinforce the brackets supporting the stators sufficiently at least to remove the resonance to a frequency at which it will not be troublesome.

Some microphonic effects are due to a large dial drum mounted on the gang spindle. Such a drum may be self resonant if made of metal or it may because of its weight induce flexing effects in the condenser shaft. In other cases its position may give trouble ; for instance the drum may be spaced only slightly from the front panel of a mantel model receiver, with the loudspeaker mounted on the same panel. Very considerable acoustical coupling will then exist between the loudspeaker and the gang rotors. Should the drum itself be resonant it may be possible to alter the frequency sufficiently to avoid microphony by punching suitably placed holes in it. Spraying with flock or attaching a piece of felt may damp the resonance adequately.

Another type of gang microphony is due to the vibration of the plates of the condenser. This is more often due to sound waves impinging directly on the plates themselves and acoustical shielding between speaker and gang condenser should be tried as a cure.

Should a valve be causing microphony it can be mounted on a floating socket and shielded as far as possible from the noise from the loudspeaker. Sometimes a rubber sleeve around the glass envelope may effect a cure.

With battery valves, microphony can be affected by circuit design. If the plate current of a remote cut-off valve has been reduced almost to cut-off by a.v.c. action, movement of the filament under the influence of noise from the loudspeaker may cause some sections of the valve which have been completely cut off to conduct again. The resulting change in plate current creates noise in the loudspeaker which maintains the vibration of the filament and the microphony is sustained. An alteration to the circuit which will result in smaller a.v.c. potentials being applied to the valve in question should be tried.

Microphony is also encountered between pickups and loudspeakers, although more recent types of combined gramophone motors, turntables and pickups use very flexible mountings which almost completely remove such troubles.

If the remedies suggested above fail to cure a particular case of microphony there are other methods of attack. The simplest is to mount the loudspeaker on rubber or felt with no solid connection between loudspeaker and cabinet. Even if this should result in a gap of up to one quarter of an inch between the edge of the loudspeaker frame and the baffle, little change of a-f response need be expected. Such a mounting is, of course, mainly effective in keeping low frequency vibration from the cabinet, and is most likely to cure low frequency microphony.

An alternative method of achieving the same result is to mount the loudspeaker solidly to its baffle, and float loudspeaker and baffle from the cabinet on suitable rubber grommets.

Similar results can be obtained electrically by reducing the bass response of a receiver. If the response is already satisfactory this is undesirable, but it may be found possible to attenuate severely frequencies below say 70 c/s without appreciably affecting the tone, and this could produce the required effect. Alternatively, since microphony is usually much worse on short waves, a bass cut can be switched in with the wave change switch as the receiver is turned to short waves. This possible cure can actually improve short wave reception since fading and noise can be less objectionable with a restricted bass response.

Since some types of microphony are due to a change in receiver output as the oscillator frequency is varied, it follows that the greater the selectivity of a receiver, the more prone it will be to this type of microphony. Receivers with a sharp peak to the selectivity curve are particularly susceptible and this is frequently caused by regeneration in the i-f channel which may be reduced by improved layout or by neutralization—see Chapter 26 Sect. 8(ii).

(v) Instability

This sub-section is confined to instability problems commonly met in A-M receivers. For general information on the subject see Ref. 22.

Probably the most common trouble with new models when wired up for the first time is instability, although the reason can usually be found with little trouble by bypassing possible " hot " points with a large capacitor, say 0.5 μF, or by placing an earthed piece of metal between stages across which feedback is likely to occur.

More annoying instability problems are those which do not show up in pilot models but which affect production receivers, a typical instance being instability which occcurs only at the low frequency end of the broadcast band. The regeneration is due to some of the i-f output being returned to the aerial coil and thus back to the i-f input again. The effect usually becomes evident only towards the low frequency end of the broadcast band where the aerial coil secondary tuning is approaching the intermediate frequency, and in addition the high impedance aerial primary must be resonating at or near the intermediate frequency.

The i-f output is often radiated directly from the second detector valve or from the last i-f transformer, in which case shielding may be needed, or at other times from the loudspeaker leads or frame. Earthing the frame will cure the latter trouble and a r-f bypass in the audio circuit the former.

Since the instability is due to intermediate frequency fed back to the aerial primary, a reduction in impedance of the primary reduces the feedback. A resistor, say 10 000 ohms, across the primary may be sufficient damping, but usually gives a greater loss in gain, selectivity and signal-to-noise ratio than a condenser tuning the primary to a lower frequency than the intermediate frequency. When the latter method is used, additional capacitance due to the aerial can only tune the primary further from the intermediate frequency, but otherwise some critical aerial length may resonate the primary at the intermediate frequency and lead to instability.

Battery receivers are particularly prone to trouble in this respect when operated without an earth, as the aerial capacitance is in series with the capacitance between receiver and ground, so that even a large aerial does not tune the primary much lower in frequency.

A very similar trouble is instability when the receiver is tuned to the second harmonic of the intermediate frequency. In this case the second harmonic is radiated from the second detector circuit—where it has a high amplitude—picked up by the input circuit and returned to its source. Care in confining the i-f harmonics to appropriate sections of the chassis is sufficient to cure this fault. Sometimes actual instability will not be encountered, but the a-f output of the receiver will decrease as the volume control is turned up over the last few degrees. This is due to rectification by an a-f valve of i-f voltages on its grid, thus increasing the bias on the valve and decreasing its gain. By-passing, or if possible improved layout, will cure this trouble, and it is worth checking with a good oscillograph each new model developed, to see that a-f valves are not handling i-f voltages of the same order of magnitude as the a-f voltages.

A more difficult problem is presented by multistage battery receivers in which coupling occurs in the filament leads. Since some couplings may be regenerative and some degenerative it becomes difficult to determine the true gain. However by filament by-passing and by wiring the valves in a suitable order regeneration can be removed, and if the gain can be spared it is well worth while to introduce degeneration. Under these conditions variations in sensitivity with decreasing battery voltage are minimized.

Battery sets in particular are prone to a type of instability which shows up as a squeal when a strong signal is tuned in rapidly. This is due to interaction between i-f and a-f circuits, and in battery receivers adequate a-f by-passing of the B supply will prevent the trouble from developing when the internal impedance of the battery rises with use. If back biasing is used the resistor may need by-passing for audio frequencies. Filtering of i-f voltages from the a-f end of the receiver is in some cases the only cure necessary for other troubles of this type.

Electrolytic condensers are not always satisfactory r-f by-passes and where more than one i-f stage is returned directly to the B supply an additional paper by-pass is advisable. When two or more circuits have a common by-pass they should be returned to it individually to avoid common impedances.

A tendency to instability at the high frequency end of the short wave band of a receiver is often due to excessive coupling between the signal grid and the oscillator circuit of a receiver and can be cured by coupling from the opposite phase of the oscillator. If a r-f stage is used the trouble may be due to resonance or near resonance in the r-f coil primary and a suitable cure is a small carbon resistor, say 25 ohms, between r-f plate and r-f coil primary.

An indication of the stability of an i-f channel can be obtained from its selectivity curve. While complete symmetry is rarely obtained with the mixture of capacitive and inductive coupling encountered in most receivers, a marked degree of asymmetry at small attenuations can usually be traced to regeneration and it may be difficult to remove the last traces. Apart from coupling due to leads or capacitances inside or outside the amplifying valves—not forgetting capacitances above the chassis where they are apt to be overlooked—magnetic coupling can occur between two transformers either in air, or in the metal of the chassis, the latter trouble being more prevalent with the small spacing occurring with miniature valves.

The two leads from the signal generator should be twisted together when i-f selectivity measurements are made, to keep the loop formed by them as small as possible and so avoid coupling between the first and later stages of the i-f amplifier.

See also Chapter 23 Sect. 7 for instability in r-f amplifiers and Chapter 26 Sect. 8 for instability in i-f amplifiers.

(vi) The local oscillator

(A) Recommended values of **oscillator grid current** are specified for all converter types, and it might be thought that if these values were obtained and the oscillator tuned over the required range, no further design work would be required for the oscillator. However the local oscillator circuit can be responsible in a receiver for flutter, squegging, poor sensitivity with high noise level, unstable short wave tuning, apparently short battery life in battery receivers and other more obscure faults.

(B) The term " **flutter** " covers two different effects, the sound emitted from the loudspeaker being the same in each case. As a strong signal is being tuned in, the voltages in a receiver are varied by the application of a.v.c. to the controlled stages and by the changing plate current of the output valve. If the changes in voltage reach the oscillator valve the oscillator frequency is altered, and a case could be visualized in which the tuning-in of a station generated voltages sufficient to detune the receiver. The additional voltages would then disappear and the receiver would retune the signal, only to be detuned again. This is actually what happens when a receiver flutters, although the station may not be completely tuned and detuned on each cycle. The time taken for a cycle is dependent on the time constants of the circuits involved, but it is usually low enough for each cycle to be heard separately.

The voltage applied to the oscillator may come from the B supply or from the a.v.c In each case a receiver is more prone to the trouble when operating on short waves, since a given percentage of detuning is a larger number of cycles per second than on the medium waveband. If the fault originates in the B supply the effect is that as a carrier is being tuned-in the a-f signal causes a large variation in the current drawn from the B supply by the output valve. This variation in current sets up a voltage across the series impedance of the power supply and this voltage is applied to the oscillator plate and detunes the oscillator from the signal.

The time constants concerned are those of the a-f amplifier and of the power supply, and since the a-f amplifier must amplify the flutter frequency, which is very low, a cure is to decrease the bass response of the a-f amplifier. If this leads to excessive bass cutting—although as in the case of microphony it may be necessary only on the short wave band—the alternative of increasing the time constant of the power supply can be tried. This is not so desirable since a larger electrolytic condenser is required at additional expense.

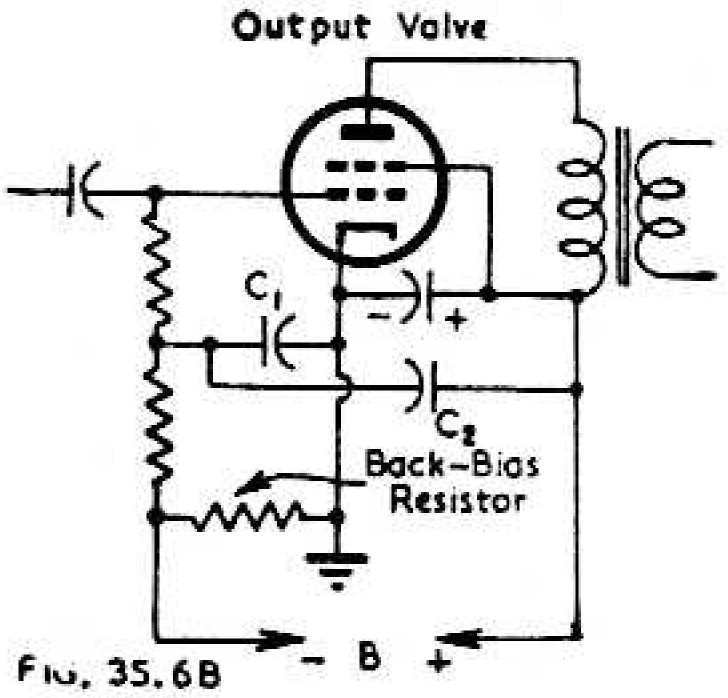

FIG. 35.6B

Fig. 35.6B. *Reduction of "flutter" by negative feedback.*

A cure which has been used successfully is shown in Fig. 35.6B. The condenser C_2 is connected between B+ and the power valve grid circuit and applies negative feedback to any a.c. potentials (due to flutter or hum) appearing across the B+ filter condenser. The usual decoupling condenser C_1 is also necessary unless the hum level on the B supply is very low (complete cancellation of hum across the B supply is not the same as cancellation of hum across the output transformer primary) and values of 0.1 μF for C_1 and 0.05 μF for C_2 have been used to give appreciable reduction in flutter while leaving the hum level almost unchanged.

To remove the cause of the flutter, rather than curing the symptoms of the trouble, it is necessary to reduce the impedance common to the oscillator and the output valve. A large part of this impedance is the filter in the B supply, and by supplying the oscillator plate directly from the output of the rectifier a big improvement can be effected. A separate filter to remove the hum from the oscillator plate supply will be needed and typical values are a 20 000-ohm resistor from the rectifier cathode and an 8 μF electrolytic condenser. The normal oscillator plate resistor, perhaps 30 000 ohms, is connected from the junction of these components to the oscillator plate. A careful check for modulation hum—see Chapter 37 Sect. 1(vi)H—should be made if this circuit is used.

Flutter due to a.v.c. application to converters is confined to short wave bands, and is due to coupling within the valve between the control grid and the oscillator section. Reference should be made to Chapter 25 Sect. 2 for an explanation of this effect. The simplest cure is to use fixed bias on the converter on the short wave band, and this is not unduly detrimental to receiver performance since the maximum signal input to be expected on short waves is less than on the broadcast band. The a.v.c. curve will not be so flat with one less stage controlled, but this may be an advantage because it is not desirable to hold receiver output too flat when selective fading is experienced as this unduly emphasizes the accompanying distortion. Even when the a.v.c. applied to the converter does not cause flutter, it may make the tuning of strong signals at the high frequency end of the short wave band very difficult, the effect being that no matter how carefully the tuning knob is handled, the receiver tunes just past the station. In addition, the fading of a signal may cause it to be detuned.

(C) **Squegging** of the local oscillator in a receiver is usually confined to the short wave range, but cases have been encountered on the broadcast band when unusual coupling circuits have been used. Squegging is due to high oscillator amplitude in conjunction with a large time constant in the oscillator grid circuit. Oscillation at the desired frequency becomes interrupted at another frequency which is dependent on the time constants in the oscillator circuit. The interruption frequency may be audible or supersonic and depends upon the rate at which the oscillation amplitude at the desired frequency builds up sufficiently to bias the valve to cut-off, and the time required for the charge on the grid condenser to leak away sufficiently for oscillation to start again.

The possible results of a squegging local oscillator are a very high noise level (with or without multiple tuning points and with or without a heterodyne at each point) when the squegging frequency is supersonic, or a continual squeal when the squegging frequency is in the audible range. Such a squeal should not be confused with another which sounds almost identical and which is due to signal grid and oscillator grid circuits being tuned to approximately the same frequency on the short wave band. This second type can be stopped by detuning the signal frequency circuit, but a squeal due to squegging can not.

A third squeal which sometimes occurs at the high frequency end of the broadcast or short-wave band sounds similar but needs a small resistor (say 25 ohms carbon) in series with the control grid of a converter, as close to the grid as possible, for a cure.

The simplest remedy for squegging is to reduce the oscillator grid capacitor and resistor to the lowest values that can be used without reducing unduly the oscillator grid current at the lowest tuning frequency. This may not be sufficient if the same components are used on both the broadcast band and the short wave band (100 $\mu\mu$F and 25 000 ohms are about the smallest combination possible if these components are not to affect the oscillator amplitude excessively at frequencies below 600 Kc/s) and a simple alternative is to switch the grid coupling condenser together with the coil as the wave range is changed.

A third possibility is to connect a small carbon resistor in series with the oscillator grid capacitor or oscillator plate lead. This resistor reduces the amplitude of oscillation at and near the high frequency end of the band, where it is a maximum, without noticeably affecting the low frequency end, and thus removes the tendency to squeg.

The varying effect of the resistor can readily be visualized when it is realised that at the high frequency end of the band the total tuning capacitance may be 30 $\mu\mu$F and the resistor is in series with the oscillator input which amounts to about 10 $\mu\mu$F, or one third of the total. At the low frequency end of the range the 10 $\mu\mu$F with the resistor in series amounts to only about one fiftieth of the total capacitance.

(D) To produce the required **oscillator grid current** at a specified frequency is usually simple, but to obtain the same grid current over a range of frequencies which is usually greater than three to one can be quite difficult. Fortunately considerable variation in grid current is possible with little change in conversion characteristics and full use is made of this in design.

Battery receivers usually present the most difficult local oscillator problems because of the lower initial slope in the oscillator section of the converter and because of the necessity for the oscillator to operate with A and B batteries reduced to (preferably) 2/3 of their initial voltage. For this reason **battery converter problems** are considered here.

The first trouble to be experienced is usually insufficient grid current at the low frequency end of the short wave band—assuming that preliminary design is such as to allow the required band to be covered. Figure 35.7 shows a simple circuit (" padder feedback ") for increasing this grid current without loss of frequency coverage, the only variation from a conventional circuit being that the cold end of the primary coil is connected to the cold end of the secondary. If this circuit is already in use, attention must be given to coil design as discussed in Chapter 11 Sect. 5.

FIG. 35.7

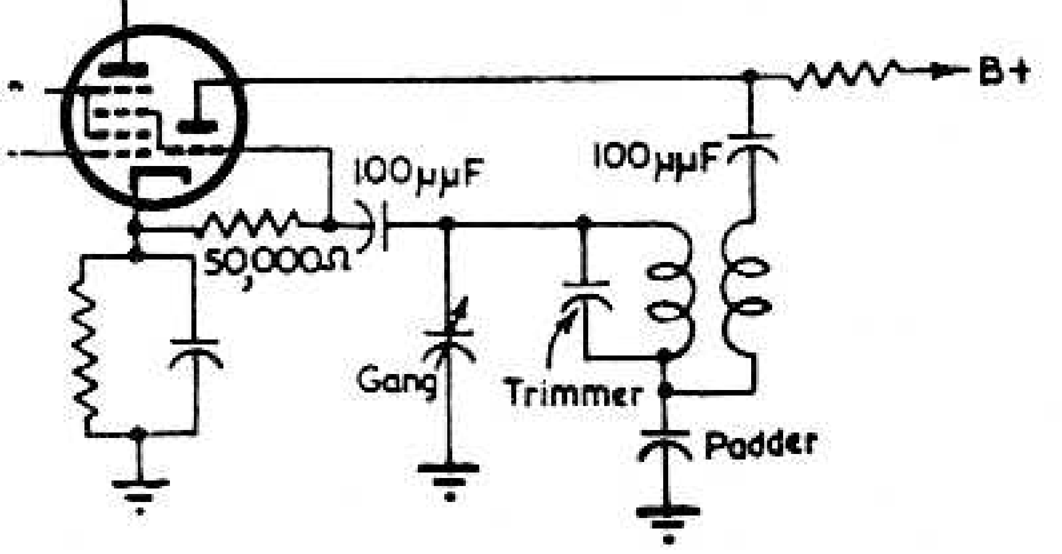

Fig. 35.7. *Oscillator circuit with padder feedback.*

With valves which do not oscillate readily at high frequencies, it sometimes happens that a frequency range which is impossible when mixing with the oscillator fundamental can be covered with the second harmonic of the oscillator used for mixing. This method of operation also has the advantage of practically eliminating pulling and, in spite of decreased gain at the low frequency end of the short wave band and additional spurious responses arising from unwanted signals beating with the oscillator fundamental, it is often worth trying.

It is important to remember that it is the voltage across a grid resistor which is the essential requirement. The oscillator grid current published by valve manufacturers is used because it is easier to measure, but it only applies to the published value of grid resistance. If a different value of grid resistance is used, the grid current should be inversely proportional to the ratio of the resistances. For example, if the published grid current is 0.4 mA in 50 000 ohms, then the equivalent value would be 0.8 mA in a 25 000 ohm resistor.

A choice of series feeding or shunt feeding the oscillator plate is often available (see Figs. 24.2B and C for series and shunt feeding of a tuned plate oscillator). An increase in grid current, dependent in size on the value of the resistor used, can be obtained by using series feed as this removes the damping of the resistor from the plate coil.

With series fed oscillator circuits, an increase in coverage can be obtained by connecting the by-pass capacitor in the oscillator plate supply directly to the cold end of the oscillator primary coil, rather than to some other place in the circuit. All oscillator wiring must be kept as short as possible and removed as far as possible from other components and from the chassis if maximum frequency coverage is to be obtained. As the oscillator grid capacitor is in series with the capacitance of the oscillator valve it should be kept as small as possible, and if the capacitor is switched with the oscillator coil, a substantial improvement in frequency coverage can be obtained by the use of the smallest possible value. At the same time the effect of the change in oscillator input capacitance as the valve warms up is reduced, thereby increasing the frequency stability.

It is unfortunate that in battery receivers, in which frequency coverage with sufficient grid current is difficult to obtain, it is also necessary for the oscillator to provide sufficient output for reasonable conversion conductance when the battery voltage is considerably reduced. As a routine test during oscillator coil design for battery receivers, the sensitivity should be checked from time to time with A and B battery voltages simultaneously reduced to two thirds of their initial values, with a converter valve having an oscillator slope as low as is likely to be encountered in production, and under these conditions the oscillator should not only start readily each time the receiver is switched on, but it should also provide enough grid current to give reasonable conversion conductance.

It should be remembered when laying out any receiver that the characteristics of the valves can be seriously affected by the presence of a **magnetic field**. All valves are likely to fall off in performance if placed too close to a loudspeaker, and oscillator grid current can be seriously reduced in this way.

(E) In a.c. receivers it is a simple matter to obtain sufficient oscillator grid current but excessive values should be avoided. On the broadcast band, where so many signals can be tuned, self generated spurious responses must be reduced to a minimum and it is helpful **to reduce the oscillator amplitude** as far as possible. This should be done experimentally as it is found that the reduction can be carried, without undue loss of sensitivity, further than would be expected from a study of published curves of conversion conductance versus oscillator voltage. Signal-to-noise ratio should also be measured when the grid current is reduced as it may even improve with moderately low values of oscillator voltage.

An additional advantage of using the lowest possible oscillator grid current is that radiation from the local oscillator is reduced.

(F) With most converters it is found that the shortwave sensitivity is affected when the oscillator frequency is changed from one side of the signal frequency to the other. The reasons for this are set out in Chapter 25 Sect. 2(ii), but it is not always realised that a useful gain in short-wave sensitivity can be obtained with certain types of converters by determining the better method of operation and using it, even if this necessitates an oscillator frequency lower than the signal frequency. Under these conditions the signal frequency circuit (or circuits) is padded and the oscillator circuit is not, but no other changes are necessary, and an increase in sensitivity of two or three times at the high frequency end of the short wave band is sometimes obtainable. In addition image responses are reduced proportionately.

A disadvantage of operating the oscillator on the low frequency side of the signal is that a given ratio of signal frequencies becomes more difficult to cover.

Under all conditions it is advisable to make sure that the converter is not in need of neutralizing on short waves. Neutralization of oscillator voltages in the signal frequency circuit need not require additional components, as an undesired voltage from the oscillator grid circuit can often be offset by a wiring change which increases the capacitance between the oscillator plate and the control grid and vice versa, the wiring to and the capacitances of the wave change switch being very useful for this purpose. **Plate tuned oscillators** develop high oscillator voltages in the plate circuit and need particular care in layout even on the broadcast band.

(vii) Cabinet design

(A) The subject of cabinet design for direct radiator loudspeakers is covered in Chapter 20 Sect. 3. Open-back cabinets have many shortcomings—see Chapter 20 Sect. 3(ii). Completely enclosed cabinets, even with an enclosed volume as small as 2 cubic feet, are capable of giving very much improved low frequency response—see Chapter 20 Sect. 3(iii). Vented baffles give about 3 db additional response over a limited frequency range equivalent to bass boosting—see Chapter 20 Sect. 3(iv)

The cloth used for loudspeaker grilles should be very light and of suitable texture—see Chapter 20 Sect. 1(viii).

Some form of diffuser is highly desirable to increase the angle of radiation at the higher frequencies—see Chapter 20 Sect. 2(vii). One simple form of diffuser is cone shaped and mounted directly in front of the loudspeaker.

Sharp angles (e.g. 90°) on the exterior front of the cabinet should be avoided because of deleterious diffraction effects—see Chapter 20 Sect. 3(vii).

In console and radiogram cabinets improved reproduction can be obtained if the speaker can be directed upwards, particularly if the controls are on the top of the receiver. The high frequencies produced by a loudspeaker are propagated in a beam, and where the speaker is mounted close to the floor the high frequencies do not reach ear level unless the loudspeaker is directed upwards.

When two loudspeakers are used, both reproducing high frequencies, a desirable effect can be obtained by directing the speakers outwards at an angle of about 30°

with respect to each other and upwards if necessary. In this way the high frequency response is spread over a much greater angle.

(B) A small amount of time spent on the **ventilation** of a receiver in a cabinet to which a back is fitted can often materially reduce the operating temperature of the components. Provision must be made for cold air to enter near the bottom of the cabinet and to leave it at the top. The components which affect the frequency of the local oscillator should have a supply of air from outside the receiver passing over them before it passes over any other heat sources. Ventilation should also be provided to permit a copious flow of air to pass over the output and rectifier valves and power transformer.

An efficient ventilation system is essential in the case of small a.c./d.c. receivers. For the power—of the order of 60 watts in a typical case—to be dissipated by radiation alone, the cabinet and the components inside it would rise to excessive temperatures, so that the greatest possible amount of heat should be carried away by convection.

This involves a maximum volume of air passing through the receiver at as high a speed as possible, so that restrictions on the flow must be minimized and the air paths provided should be as direct as possible. At the same time all heat sources within the receiver must be included in the ventilation system.

In the case of wooden cabinets it is essential that some means be employed for preventing hot spots from forming on the timber. Ventilation is the best method where it is possible, but in extreme cases it may be necessary to use asbestos sheeting to protect the wood. Failure to avoid hot spots will sooner or later result in the finish of the cabinet being marred where the heat is excessive, although the seriousness of the blemish will depend on the quality of the veneering and on the type of finish.

When investigating ventilation, it is helpful to allow cigarette smoke to be drawn into the back of the receiver, and to watch its course through, and exit from, the receiver, which should be at operating temperature.

See also Chapter 3 page 81.

(viii) Ratings

Standard laboratory tests in most cases cover the requirement that all components be operated within their ratings. There are some cases however where circumstances arise under which components may be over-run, although the operating conditions under test may be quite satisfactory. A typical case is that of an i-f valve screen by-pass condenser on which the no-signal operating voltage may be 80 volts, rising to perhaps 180 volts when a strong signal is tuned in, and to 380 volts for some 15 or 20 seconds every time the receiver is switched on. The last effect would be due to the use of a directly heated rectifier with a complement of indirectly heated valves and of course a condenser with a working voltage of at least 400 must be used.

Whilst such a case would rarely be overlooked, it should be remembered that even with an indirectly heated rectifier, the same high voltages may be experienced for a shorter time, and electrolytic and other condenser **working** voltages should be specified accordingly.

Other points which have given trouble are

(A) The screen dissipation of an output valve should always be checked with a large signal input to, and a large a-f output from, the receiver. A large signal input biases the controlled valves, thus causing the B supply voltage to rise and the bias to decrease if back bias is used, whilst the large a-f output increases the screen dissipation.

The output valve **plate dissipation maximum** will occur with a large r-f signal and no output, since any output is subtracted from the plate dissipation.

(B) If a transformer is to be operated on **frequencies** of 60 c/s and 50 c/s, or 50 c/s and 40 c/s as is the case with transformers in some Australian receivers, the heat run should always be carried out at the lowest rated frequency. The flux density on 40 c/s is 25% higher than on 50 c/s, which will seriously affect the temperature rise.

(C) The dissipation of the resistors forming screen circuit voltage dividers changes with applied signal, and the resistor from B supply to screen should be checked under no signal conditions, and the resistor from screen to ground at maximum signal input. These dissipations should also be checked when the value of each resistor is on the upper or lower tolerance limit, whichever will give the greater dissipation.

(D) When 1.4 volt valves are operated in series across a 6 volt wet battery, a large capacitance (500 μF) electrolytic capacitor is often used to by-pass some of the valves. It frequently happens that every time the receiver is turned on, this capacitor is charged through one or more of the filaments in the string. The resulting flash can readily be seen and can seriously reduce the life of the valve, although the filament voltage may be correct when tested.

Special cases of one sort or another occur in most receivers and emphasize the need to investigate the worst conditions in every case.

(ix) Field testing

Receiver design is, more than anything else, a matter of compromise between various sets of conflicting requirements. The success with which these compromises have been made can only be judged by operation of the receiver over a period of time under normal operating conditions in the field.

Perhaps the most contentious part of a design centres around the frequency response, and final approval can only be given after prolonged listening, so that the widest possible variety of programme material and listening conditions is included. In a receiver in which distortion is kept to a minimum an extension of the a-f response progressively improves such items as a live-artist programme, but also makes progressively more annoying any poor quality recordings. Whether the best fidelity position of the tone control is one which can be consistently used or not is a question which must be decided over a period of time in a home. It may happen too that an extended a-f response sounds pleasant for one item but, probably because of distortion, becomes irritating if left playing for some hours, even on items of good fidelity. A careful check for listener irritation or fatigue after long periods of listening should be made.

Hum may change its apparent volume or character under quiet conditions, and a different level of background noise can also affect the volume control setting at which maximum frequency compensation is needed.

Controls should of course all operate smoothly and it frequently happens that noisy dial drives are heard for the first time in a home, or it may be that non-technical users find a receiver difficult to tune on short waves owing to insufficient drive reduction ratio between tuning and gang spindles.

The number of small points which may be discovered under field testing conditions could be extended indefinitely, but the main point is that no design is complete until it has been used critically and for a period of time in a home and has been found satisfactory.

SECTION 4 : FREQUENCY RANGES

(i) Medium frequency receivers (ii) Dual wave receivers (iii) Multiband receivers (iv) Bandspread receivers.

(i) Medium frequency receivers

A large percentage of commercial A-M receivers have two wave ranges, medium frequency (say 540 to 1600 Kc/s) and short wave (say 5.9 to 18.4 Mc/s). The short wave band is largely ignored in actual use and in most cases a more useful receiver could be made to sell more cheaply if the short wave range were omitted.

The obvious advantage would be that the cost of the extra components (wave change switch, two coils, s.w. padder and knob, as a minimum) could be used to provide, for instance, improved fidelity which would be available to the user at all times.

Another factor is that, particularly in cheaper receivers, the inclusion of a short-wave band restricts the design, to the detriment of the broadcast band performance. For example, microphonic trouble is far more prevalent on the short wave band and the bass response of a dual wave receiver is frequently reduced for the sole purpose of avoiding short wave microphony ; a.v.c. application to the various stages may be a compromise between the broadcast band and short-wave band requirements, and in order to save money on switching, the final circuit may lead to increased overloading or reduced signal-to-noise ratio on the broadcast band ; to reduce costs it is also customary to operate the s.w. and broadcast aerial primary coils in series, thus avoiding switching, but somewhat reducing the broadcast aerial coil performance ; if switching is used, the capacitance between the leads to the switch may on the other hand reduce the broadcast band image ratio.

When a receiver is designed only for the broadcast band it is possible to use less i-f amplification owing to the increased aerial coil gain on medium frequencies (average perhaps 8 times) as against that on the short wave band (average not greater than 2 times). This may result in a more pleasant tuning characteristic as a single i-f stage giving maximum gain usually verges on regeneration.

In an extreme case, say in a 3 valve plus rectifier receiver, the inclusion of a short wave band may even make the difference between a reflex and a straight receiver to obtain the required i-f sensitivity for the short wave band. This introduces the problems of a remote cut-off valve used as an a-f amplifier, rectification in the i-f amplifier, and high play-through as discussed in Chapter 28 Sect. 2(i), for the sake of increased amplification which is cancelled by turning down the volume control.

(ii) Dual wave receivers

In Australia many country areas are outside the daylight service range of medium frequency broadcasting stations and dual wave receivers are used in such districts to receive daylight programmes from short wave stations provided especially for this purpose.

The international allocations for the world wide broadcasting bands are given in Chapter 38 Sect. 4(ii), and it will be noticed that a tuning range of 4.2 : 1 would be needed to provide coverage for all short-wave bands on one wave range. Such a tuning range is impossible with standard components and the usual compromise is to omit the two highest frequency bands and to design receivers which tune from about 5.9 to 18.4 Mc/s. The 13 and 11 metre bands give very variable performance, depending upon ionospheric conditions, and although they can provide some of the best short wave entertainment—owing to the absence of static—when conditions are good they are so often unusable that their omission from a dual-wave receiver is not counted a serious disadvantage.

The signal strengths obtainable from international short wave broadcasting stations are of course less than those from a local medium wave station, and more sensitivity is consequently required from the receiver. A minimum sensitivity for 50 mW output for international short-wave listening might be taken as 25 μV from 18 to 10 Mc/s, falling off to 50 μV at 6 Mc/s where static drowns the weaker stations. Local conditions and the aerial used will of course considerably affect the required sensitivity.

Selective fading, i.e. fading accompanied by distortion of the signal, is far more prevalent on short waves than on medium frequencies, and has an effect on the preferred type of a.v.c. curve. A curve which is too flat results in the signal being held at the same output level throughout each individual fading cycle, so that the unpleasant effect of the distortion is greatly emphasized. Even in the absence of distortion a flat curve in a sensitive receiver results in the " troughs " of each fading cycle being filled in with noise (receiver or external) which is much less desirable than the silent space in the programme resulting from an a.v.c. curve sloping steeply at low inputs.

To provide the required difference between the broadcast and short wave a.v.c. curves it is often desirable to use a.v.c. on the converter on the broadcast band and not on the higher frequencies. This has the added advantage of improving the oscillator stability on the short wave band.

The frequency of each fading cycle varies from some seconds for each cycle to many cycles a second on the high frequency bands, and in a good receiver a special tone control position is sometimes fitted to improve short wave intelligibility. Such a control limits the treble response of the a-f section and also reduces considerably the bass response, which removes the " fluttering " effect of rapid fading cycles and some of the more objectionable features of bursts of static and ignition interference from passing cars.

Microphony is an ever-present problem in the design of dual wave receivers, and Sect. 3(iv) of this chapter is devoted to the subject.

A problem peculiar to receivers with more than one wave band is the resonance of unused coils within an operating wave range. It is usually a low frequency coil which, resonated by its own distributed capacitance, interferes with a higher frequency band, and when broadcast and short wave coils are wound on the same former the effect is aggravated. Even in the absence of inductive coupling however, wave change switch wiring often provides enough coupling to give trouble.

A resonance affecting the oscillator coil is easily detected by measuring oscillator grid current. A sharp dip in the grid current (whether to zero or not) is an indication of an unwanted resonance. With an aerial or r-f coil more care is necessary as the resonance will be indicated only by a reduction in sensitivity over a very narrow band. To check for such an effect the receiver must be tuned in step with the signal generator over the whole tuning range using very small increments of frequency.

Whether the resonance is affecting the oscillator, r-f or aerial coil it can be traced by leaving the receiver tuned to the dip (in grid current or sensitivity) and touching with a conductor the " hot " terminals of the disconnected coils. When the resonating coil is touched the grid current (or sensitivity) will return to normal.

The normal cure for such resonances is to use a wave change switch which earths, when necessary, any low frequency coils as the receiver is switched to a higher frequency band.

One type of resonance which is not cured by earthing occurs when a broadcast band coil is wound with two or more pies. Each pie can be self resonant in some other frequency range and as one end, at most, of each pie is available, short circuiting is not possible. It may be possible with a certain value of capacitance to tune such a resonance to some harmless frequency, or it may be necessary to redistribute the turns on the pies, or to remove the coupling between the self resonant coil and the coil in use.

Since the broadcast range of a typical receiver covers 1100 Kc/s and the short wave range 12.5 Mc/s, a movement of the tuning knob sufficient to tune the receiver through 10 Kc/s on the broadcast band will tune more than 100 Kc/s on the short wave band. The difference between the two tuning rates is so great that it is difficult to provide a tuning ratio sufficiently large for the short wave band which does not make the tuning of broadcast stations undesirably slow. One solution is the use of a large ratio and a weighted " flywheel " tuning spindle which will spin when flicked, allowing rapid broadcast tuning.

The requirement for satisfactory tuning seems to be a certain linear movement of the outside of the tuning control for a given frequency change rather than a particular ratio of rotation between tuning spindle and gang spindle. Thus a possible broadcast drive is a very large knob (at least three inches in diameter) mounted directly on to the gang spindle, although this gives quite critical tuning.

For normal knobs of perhaps one inch diameter a twelve to one ratio between tuning and gang spindles is sufficient for the broadcast band but the short wave ratio should be at least eighteen to one for non-technical users of the receiver.

Probably the best mechanical solution is to use a dual ratio tuning control either with concentric knobs or with one knob and the slow speed tuning available for only one revolution of the tuning knob.

(iii) Multi-band receivers

Little expenditure is involved in the provision of additional short-wave bands in a normal dual-wave receiver, and considerable advantages are possible.

Receivers manufactured for export to some tropical countries need to receive frequencies as low as 2.3 Mc/s as well as the normal broadcasting bands and with two short wave ranges and one broadcast range it is possible to provide continuous coverage from 22 Mc/s to 540 Kc/s with standard components.

However the more usual type of multi-range receiver is one in which the coverage of individual ranges is restricted by reducing the effective change in tuning capacitance. From the view point of ease of tuning it is best in such receivers to give each range an equal coverage in megacycles rather than an equal tuning ratio, as the highest frequency band may otherwise still be quite difficult to tune.

Improved oscillator performance is possible because higher (if necessary) and more constant values of oscillator grid current can be obtained, while r-f and aerial coil performance can be improved because higher values of inductance can be used.

Microphony is reduced because part of the oscillator tuned circuit capacitance is a fixed capacitor. Further advantages of using a number of short wave tuning ranges are brought out in the next subsection.

(iv) Band-spread receivers

Although the short wave tuning range of a dual-wave receiver is usually greater than 12 Mc/s, with consequent difficulties in tuning, the majority of short-wave programmes are to be found within the 16, 19, 25, 31 and 49 metre international broadcasting bands, which have a combined coverage of only 1.65 Mc/s. If the bands could be arranged consecutively on one tuning scale the tuning speed would be quite acceptable. However their separation in the spectrum makes this impossible, and many ingenious methods have been used to spread the short-wave broadcasting bands without spreading equally the whole short-wave spectrum.

When the actual tuning-in of a short wave station has been made easy by mechanical or electrical means, other possible refinements to short wave tuning become obvious. As adjacent short-wave stations are, with band-spreading, separated by a greater mechanical movement of the tuning control it may be possible to give short wave calibrations sufficiently accurate for the identification and relocation of short-wave stations. This is most desirable.

On the other hand any frequency drift which occurs during warming up is made very obvious by the much greater tuning control travel required to correct it, and unless the drift is only of the order of 10 Kc/s, useful calibrations are not possible.

The various general types of bandspreading are shown clearly in Fig. 35.8 (Ref. 14). The mechanical types mentioned are not commonly used in mass production because the accuracy needed to provide the necessary mechanical amplification without undue blacklash is not readily achieved. Nevertheless the National H.R.O. dial is one well known example of the precision drive and scale.

A broad distinction is made on the electrical side of the " family tree " shown in Fig. 35.8 between switched inductance and switched capacitance types of band spreading. However it is quite possible for the two types to be used in one receiver, a capacitor being switched in parallel with a coil to tune it to a lower frequency and an inductor to tune it to a higher frequency band. When fixed capacitors are switched for band selection the frequency stability can be at least as good as when inductors are switched, although for draughting convenience this is not indicated in the figure.

Some of the more unusual band-spreading methods include the use of tuning condensers with specially shaped plates to give very rapid tuning between bands, and adequate spreading on the short wave broadcasting bands. Another ingenious system has a normal tuning condenser coupled to an iron core moving continually into and out of the inductor. This increases and decreases the inductance, and the mechanical coupling is arranged so that on the international bands the inductance variation opposes the capacitance variation, giving very slow tuning, while between the bands the two variations are additive, giving very rapid tuning.

The double frequency changing method mentioned on the chart has the advantages of giving the same tuning range on each spread band and of separating the bandspreading and local oscillator circuits. However it is a comparatively expensive system and its use is limited because of this.

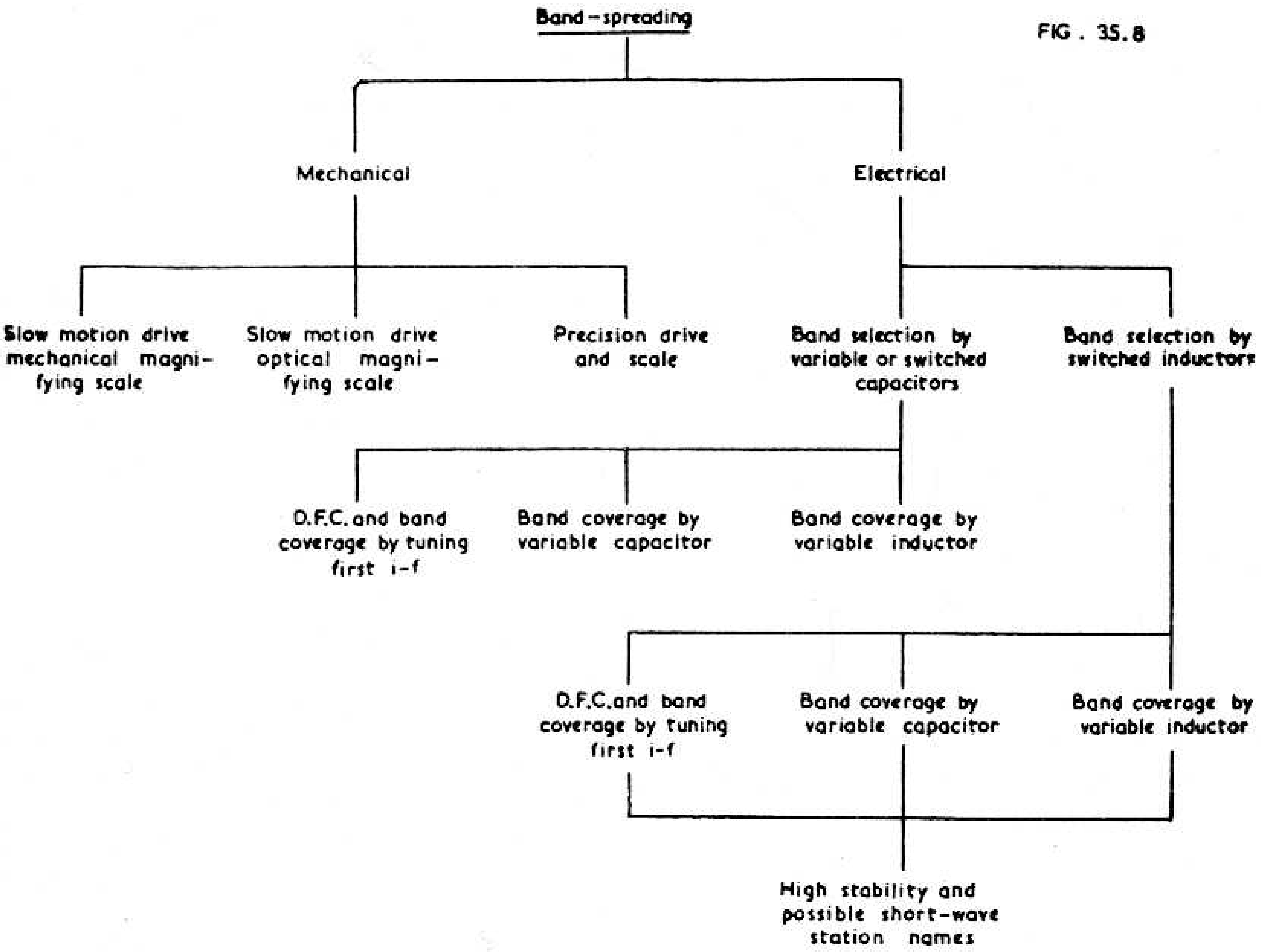

Fig. 35.8. *Possible types of bandspreading (from Ref.* 14).

Bandspreading by means of moving iron cores has been used in many models, but although this is an electrical type it introduces mechanical problems of core location if the band-spread ranges are calibrated.

The small parallel variable capacitor used for spreading is well known to amateurs but gives a very variable amount of band-spreading, depending upon the capacitance of the main tuning condenser, with which it is in parallel, at different parts of the tuning range. Moreover unless the band-spreading condenser has as many sections as the main tuning condenser the signal frequency circuits become detuned when band-spreading is used. This restricts the proper use of the spreading condenser to the passband of the signal frequency circuits between values of about 6 db loss, and when a r-f stage is used this contains very few broadcasting channels.

A simple method of spreading which avoids the use of an additional tuning condenser is the tapped coil system. When the tuning condenser is tapped down the coil, its effective capacitance is reduced approximately by the square of the tapping ratio. If distributed capacitance across the whole coil is neglected, the coverage at each tapping point will be a constant proportion of the frequency. Distributed capacitance reduces the coverage at the higher frequencies, giving a more nearly equal coverage measured in Kc/s. To restrict the coverage at each tapping point, a capacitor can be connected in parallel (Ref. 20) or in series with the main tuning condenser. Such capacitors can conveniently be brought into circuit by the band-spread switch.

The series capacitor method of bandspreading (Refs. 15, 16) has been widely used. It has the advantage of providing, if desired, continuous coverage of the normal short-wave band (6 to 18 Mc/s) together with tuning on the international broadcasting bands which is comparable with that of the medium wave band. In addition it requires few additional components, all of which are standard types.

Fig. 35.9 shows the essentials of such a band-spreading circuit as applied to an aerial stage. Only two wavebands are shown, but as many as can conveniently be switched can be used. A typical value for the capacitor in series with the gang is 50 $\mu\mu$F and at the high frequencv end of the band, with gang capacitances of the order of 15 $\mu\mu$F it has only a small effect on the resonant frequency of the tuned circuit. With the gang approaching its maximum setting of 400 $\mu\mu$F or more, however, C

is the main frequency determining component, as the total capacitance approaches 50 $\mu\mu$F asymptotically.

The value of C can be chosen to give continuous short-wave coverage with one international band at the low frequency end of each range, where the maximum bandspreading is obtained. In this case C will have a capacitance of about 57 $\mu\mu$F for a typical tuning condenser. Alternatively the requirement might be a tuning rate at least as slow as that at the low frequency end of the broadcast band, in which case C will be 30 $\mu\mu$F. Padding for the oscillator circuit is obtained by using a smaller series condenser for the oscillator section of the gang, assuming that the oscillator operates at a higher frequency than the signal circuits.

FIG. 35.9

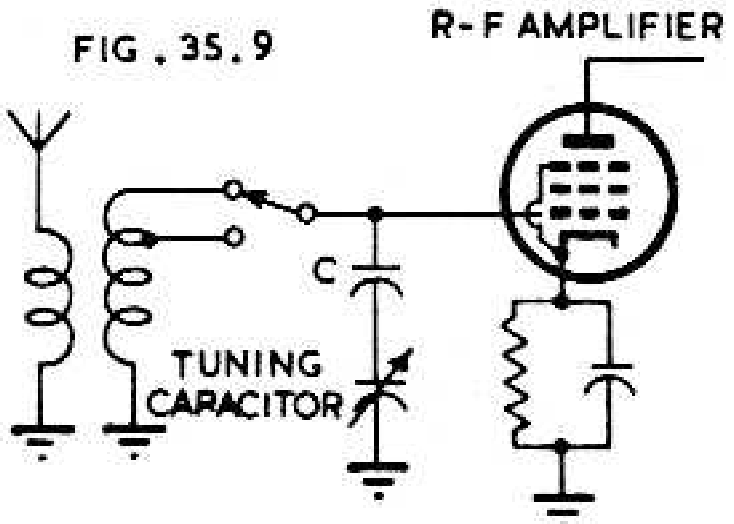

Fig. 35.9. *Series-capacitor method of bandspreading.*

FIG. 35.10

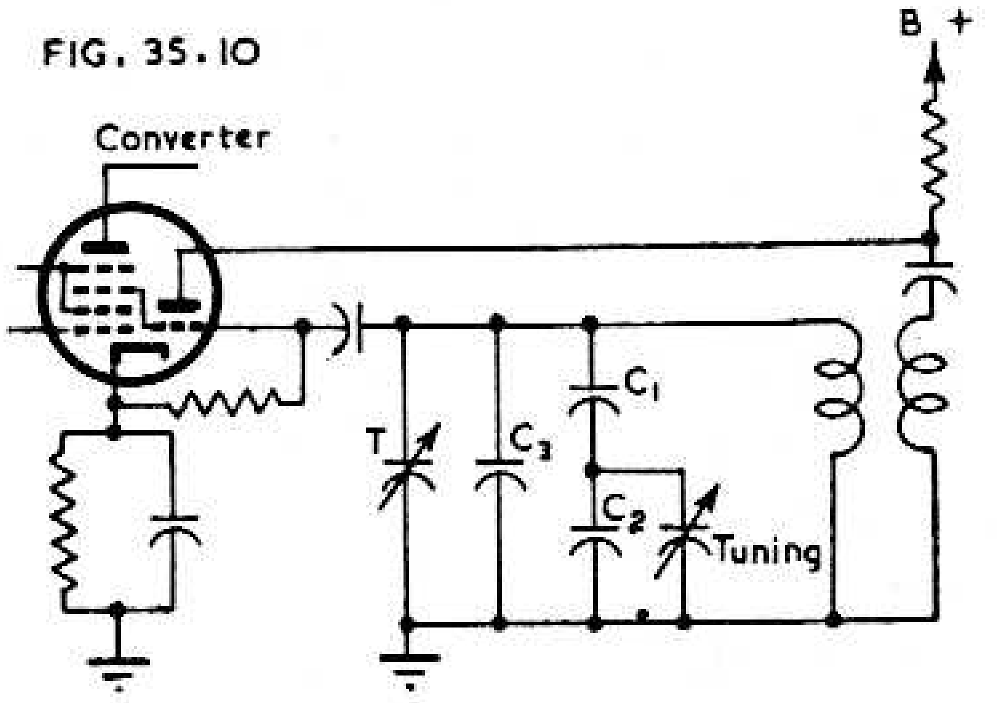

Fig. 35.10. *Bandspread circuit to give linear scale.*

The system has the advantage of providing a high L/C ratio, owing to the small maximum tuning capacity, thus giving high gain, and microphony due to the tuning condenser is reduced or eliminated on the spread ranges because capacitance variations in the gang itself are minimized by the series condenser. The main disadvantages are the large number of inductors required—even when full advantage is made of tapped coils—if all short wave bands are to be covered, the unequal spreading within the bands if a large amount of spreading is used, and the small parallel capacitances in the oscillator circuit even on the low frequency ranges, which makes difficult the stabilizing of the oscillator frequency as the valve warms up.

The system just described gives its maximum spreading at the low frequency end of the band. An alternative circuit could be imagined in which no series capacitor was used, but a capacitor in parallel with the gang (say 100 $\mu\mu$F) gave spreading at the high frequency end of the band. A combination of the two circuits (Fig. 35.10) gives an almost linear spread over the whole tuning range when suitable components are used.

For a case in which one short wave band is to be spread over the whole tuning range, typical values for the components in Fig. 35.10 are

Tuning condenser	12 to 420 $\mu\mu$F
C_1	60 $\mu\mu$F
C_2	100 $\mu\mu$F
C_3	80 $\mu\mu$F
T	2 to 25 $\mu\mu$F trimmer.

These values give a tuning range slightly greater than 400 Kc/s on the 31 metre band. Although different values of C_3 will obviously affect the tuning range, different bands can be tuned by altering its capacitance and if the oscillator is operated for example on the low frequency side of the 17 Mc/s band, and on the high frequency side of the adjacent 15 Mc/s band, the difference in coverage is not serious. Higher frequency bands can be tuned by substituting a smaller inductor, or by connecting another inductor in parallel with the tuned circuit.

The unlimited spreading capabilities of the circuit of Fig. 35.10 allow a short-wave band of 200 Kc/s to be tuned over the whole dial scale. This is not advisable however, as the tuning becomes too slow, and a suitable minimum tuning range is about 500 Kc/s. A good reason for restricting the tuning range is that a fixed tuned aerial circuit can be used without any serious loss in gain. The gain of an aerial circuit with an effective Q of 50, tuned to the middle of a band 500 Kc/s wide and including the 15 Mc/s band, falls about 6 db between the centre point and the extremes of the band.

With such a system spreading only the international bands, it may be advisable to provide one short wave band giving continuous coverage from 6 to 18 Mc/s, as many stations of interest are heard outside the bands. This is not a great disadvantage as the components used for continuous coverage can also be used for at least some of the spread ranges.

Apart from the possibility of providing linear spreading up to any reasonable limit (and the consequent need for bandspreading for the oscillator circuit alone in a receiver without a r-f amplifier) the circuit has the advantage of preserving suitable L/C ratios while maintaining at all times a capacitance in parallel with the oscillator input large enough to minimize frequency drift as the valve warms up. Capacitor C_3 can be a temperature compensating condenser to improve the frequency stability.

Microphony from the gang is completely eliminated because, with normal component values, the tuning capacitance is only altered 10% as the gang is turned from maximum to minimum.

An interesting image rejection circuit is given in Ref. 14 (1) Its use is confined to bandspread receivers with a r-f stage and covering one short-wave band only on each band spread range, but image ratios from 35 to 50 db are claimed. Few additional components are required.

SECTION 5 : A.C. OPERATED RECEIVERS

(i) Four valve receivers (ii) Five valve receivers (iii) Larger receivers (iv) Communication receivers.

(i) Four valve receivers*

(A) T-R-F receivers

Because it has no local oscillator coil or i-f transformer, the t-r-f receiver is the cheapest to build, but has a performance equivalent to its cost. Using modern valves a sensitivity of a few hundred microvolts can be obtained, or even better if some form of fixed regeneration is used and can be made effective over the whole tuning range, but the selectivity is in general insufficient to separate local stations if they are of high power or situated close to the receiver.

The main application of t-r-f sets is in absolute minimum cost receivers which operate with 3 stages and a rectifier, although using only three or even two actual valve types. In such a case there is a resulting loss in sensitivity, which might then be no better than one millivolt.

Volume controlling is most conveniently carried out by varying the bias of the r-f amplifier, and to ensure low minimum volume on strong local stations the aerial is sometimes wired to the control as in Fig. 35.11 so that it is earthed in the minimum volume position.

(B) Superheterodyne with a-f amplifier

An improvement in selectivity can be obtained by using the superheterodyne principle even when no i-f amplifier is used. Such a receiver would have a converter followed by an i-f transformer, a second detector, an a-f amplifier and an output valve. Detection can be by diode (included in an a-f valve), anode bend, or leaky grid detector with possible regeneration in the last case. Since the input to the detector is fixed tuned, pre-set regeneration can provide a constant and appreciable improvement to both sensitivity and selectivity over the whole tuning range without the care which is needed in a t-r-f receiver.

Selectivity is improved since there are three tuned circuits, two of which are fixed tuned and give constant selectivity over the band.

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*i.e. three amplifying stages and rectifier.

(C) Superheterodyne with i-f amplifier

The majority of three valve and rectifier receivers are superheterodynes with an i-f amplifier, in which selectivity can be made as good as required. Sensitivity too, while presenting some problems, can usually be made adequate, i.e. less than one hundred microvolts and, in extreme cases, less than fifteen microvolts on the medium wave band.

Three types of second detectors have been used, power grid, anode bend (each carried out by the output valve) and diode, although diodes are now used universally. The power grid detector had the disadvantage of high plate dissipation when no signal was being received, and the anode bend had somewhat higher distortion and needed a very high impedance plate load. The maximum power output when the output valve is detecting is of course seriously reduced. The diodes can be combined with the i-f amplifier or with the output valve, and one receiver has been marketed in which the suppressor grid of the i-f amplifier was used as a diode.

FIG. 35.11

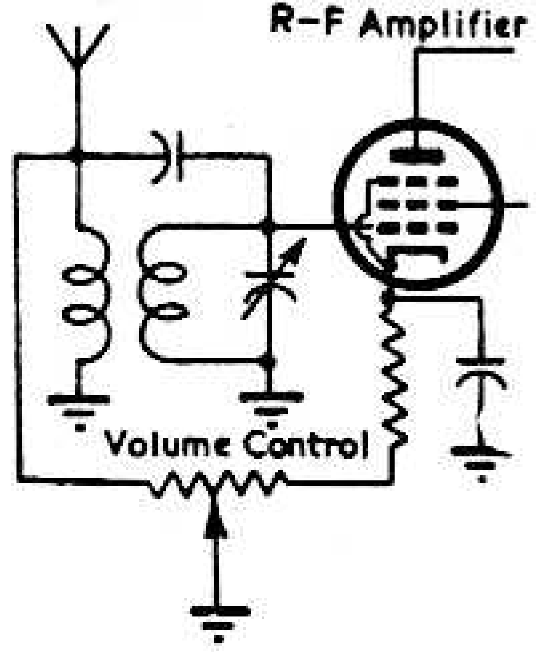

Fig. 35.11. *Volume-control circuit used with t-r-f receivers.*

FIG. 35.12

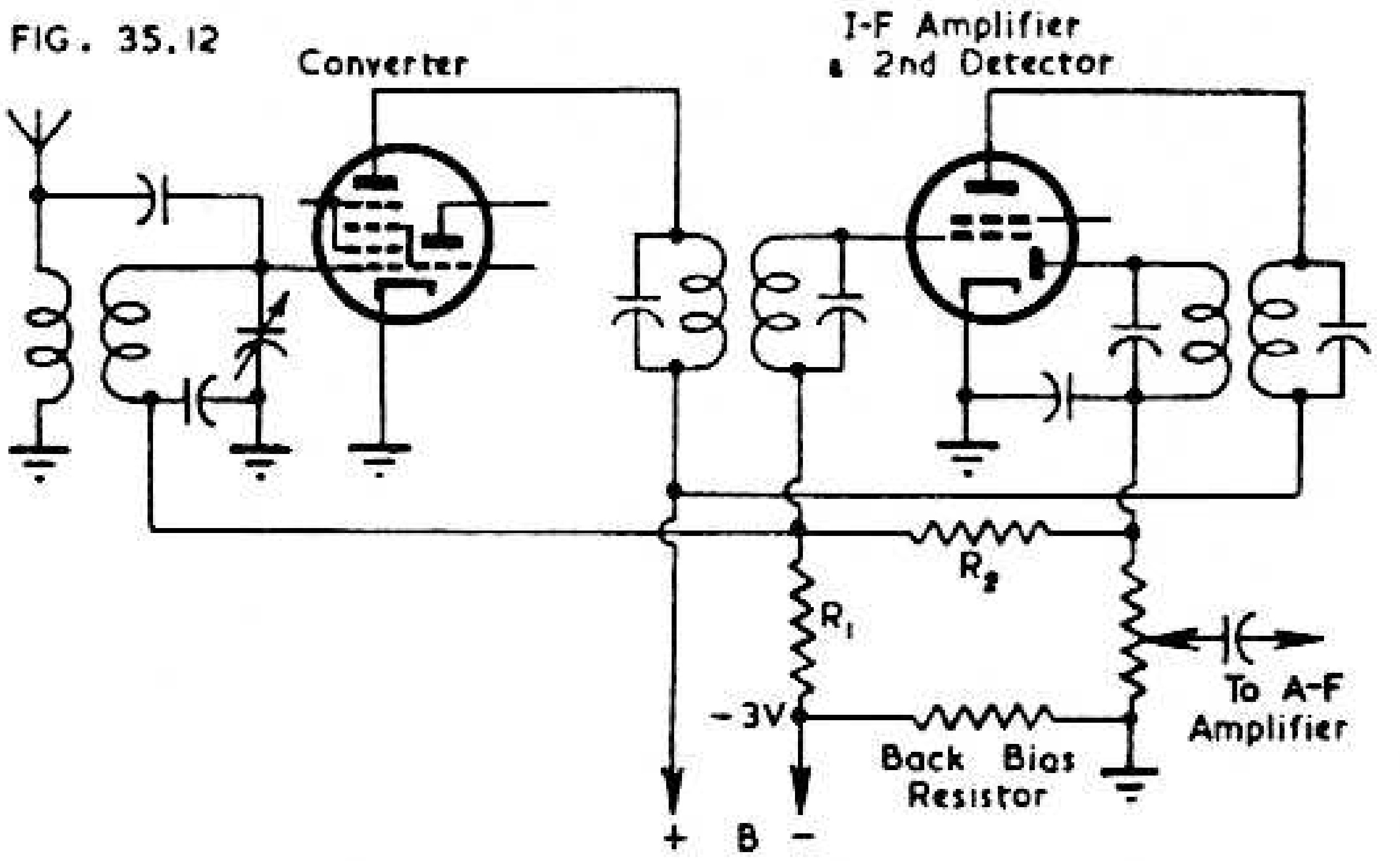

Fig. 35.12. *A.V.C. circuit suitable for 3/4 valve receiver.*

Volume controlling is carried out by manual control of converter and i-f bias or by a.v.c. and an a-f volume control. The design of a.v.c. circuits for low gain receivers without an a-f amplifier presents some problems since they must be cheap, and must give full a-f output with the smallest possible input, which prohibits the use of full, simple a.v.c. as commonly used in cheap receivers with an a-f amplifier. On the other hand the low sensitivity means that the required range of a.v.c. control is less than normal and advantage is taken of this in the usual a.v.c. circuit which is shown in Fig. 35.12.

This circuit needs only one more resistor (R_1) than the simplest possible circuit, and R_1 and R_2 form a voltage divider so that only a fraction of the voltage developed across the diode load is applied to the grids of the controlled stages. The most suitable fraction depends on the initial sensitivity and the valves used, but values of one third to one fifth are common. Two details need care, the negative voltage applied to the diode must be kept to a minimum, to reduce distortion and to prevent the diode from being muted in the absence of a signal and the a.c. shunting on the diode load must be as small as possible. Large values for R_1 and R_2 fulfil both requirements and minimum values can be taken as 1 megohm and 2 megohms respectively. With the normal value of 0.5 megohm diode load the bias on the diode is less than ½ volt, and the shunting reduces the a.c./d.c. ratio to 0.8. Better values to give almost the same ratio would be 2 megohms and 5 megohms (0.2 volt bias on diode ; a.c./d.c. ratio = 0.9).

The use of only part of the developed voltage allows the output to rise rapidly with increasing input, which is an advantage for small signals, but there is little flattening of the characteristic with larger inputs.

For a slight increase in cost, delayed a.v.c. can be used and this will give the most rapid rise in output with increasing input, followed by a flat output-input characteristic. A suitable circuit is the " sinking diode " type shown in Fig. 27.38B, and provided that an additional diode is available the increase in cost is slight.

With manual volume control the circuit of Fig. 35.11 is usually employed. However if the B supply voltage is low, the signal handling capabilities of the i-f valve are reduced (owing to the reduced plate-cathode voltage) when a strong signal is tuned in, the volume control is turned back and the cathode voltage of the controlled valves thus increased. This objection can be overcome by using a negative voltage applied to the grids of the controlled stages. One method of obtaining the negative voltage is to connect the power supply filter in the negative lead and use the d.c. voltage generated across it. Some decoupling is necessary, but one stage is sufficient as high value resistors can be used.

A second method of obtaining a suitable negative voltage is to use the volume control resistor as, or in parallel with, the oscillator grid leak (with suitable decoupling). Oscillator grid current must be kept as constant as possible throughout the tuning range when this is done.

Three valve and rectifier receivers with an i-f stage and using i-f transformers with a Q of about 115 and good aerial coils are capable of producing sensitivity figures of the order of 15 μV on the medium wave band when the most suitable commercial valve types are used. This sensitivity is ample for almost any listening conditions providing full volume is not required from very weak signals. In fact, successful dual-wave receivers giving short wave sensitivities not worse than 50 μV have been made with such a circuit.

(D) Superheterodyne with reflexing

Reflexing in a three valve and rectifier superheterodyne receiver provides enough a-f gain to allow full simple a.v.c. to be used, and to allow good short wave performance to be obtained. The additional problems involved are discussed in Chapter 28.

A convenient a.v.c. circuit consists of full a.v.c. voltage applied to both converter and reflexed i-f amplifier, which can give a very flat a.v.c. characteristic. An a.v.c. circuit in which control is applied only to stages before the a.v.c. detector, can never give a completely flat output curve, because some rise is necessary to provide the additional bias needed to reduce the output as the input signal is increased. Such a circuit is a "backward acting" a.v.c. circuit.

A " forward acting " a.v.c. circuit is one in which the developed a.v.c. voltage is applied to a stage after the detector, and with such a circuit the output voltage may even fall with increasing input. The reason is that although the detector output must rise as in the previous case, the gain after the detector will fall, and the net result may be an increase or a decrease or a flat characteristic depending on the constants used.

In a reflex receiver the application of a.v.c. to the reflexed stage controls the mutual conductance of the valve and thus its gain at intermediate and at audio frequencies. As the a-f gain follows the detector the a.v.c. system is a forward acting one.

Alternative a.v.c. designs in a reflex receiver may use full a.v.c. on the converter and a fraction or none on the reflexed stage.

The increased a-f gain makes it possible to use inverse feedback, frequency compensated or otherwise, in the a-f amplifier, and resistive feedback into the bottom of the volume control (see Sect. 3(iii) of this chapter) is useful in reducing minimum volume.

The combination of audio a.v.c. and negative feedback (particularly when frequency compensated) is not always advisable, either in reflex receivers or in larger types in which a.v.c. may be applied to a valve acting only as an a-f amplifier. Since the purpose of the a.v.c. is to vary the gain of the stage, and one of the functions of negative feedback is to minimize any changes within the loop, the two effects oppose each other. This is not undesirable in itself, but the result is that on strong signals, such as local stations, the a-f gain is reduced and the feedback is consequently reduced so that the full effects of distortion reduction are not obtained. When the feedback incorporates frequency compensation the result is that weak stations receive maximum compensation and local stations a reduced amount, which is the reverse of the normal requirement.

Advantage has been taken of this effect in a receiver having one a-f stage with deliberately attenuated high and low frequency response. Audio a.v.c. was applied to this stage so that on strong stations no attenuation resulted—slight high and low frequency boosts were incorporated elsewhere in the a-f circuit—whereas on weak stations considerable treble and bass cutting was automatically introduced, giving a very effective automatic tone control. Suitable treble cutting for such a circuit could be by means of a small capacitor between plate and grid of the controlled stage, and bass cutting could be brought about by a small value of screen by-pass in a pentode.

In conjunction with a pick-up of good sensitivity a reflexed three valve receiver can reproduce gramophone records without added circuit complications.

The most common type of reflexing has the a-f and i-f signals applied to the control grid, with the load for each in the plate circuit. Another type which has been used has the two signals applied to the control grid with the i-f load in the plate circuit and using the screen dropping resistor as the a-f load, with an i-f by-pass from screen to ground. The a-f path to the grid of the output valve is provided by means of a normal grid coupling capacitor.

Since the a-f gain available from a reflex stage is comparatively small if the i-f operation is to be satisfactory, the reduced amplification between control grid and screen grid may be more than offset by the increased a-f load resistor which can be used and by the fact that proper i-f by-passing can be used on the cold side of the i-f transformer in the plate circuit.

(ii) Five valve receivers*

General comparison of types

The three valve receiver using a converter, an i-f amplifier and an output valve can be considered to be the smallest conventional superheterodyne receiver, and a valve can be added to it in three ways, as an a-f amplifier, an i-f amplifier or a r-f amplifier. Three very different types of receivers result, and the comparison serves to show the main ways in which the conventional 4 valve receiver with a-f amplifier can be improved.

The table below lists the order of preference for each type of receiver against a variety of headings.

Additional stage	A-F	I-F	R-F
Cost	1	2	3
Sensitivity	2	1	3
Selectivity	3	1	2
A-F Response	1	2	2
A.V.C.	3	1	2
Stability	2	1	2
Noise	3	2	1
Spurious Responses	2	3	1

The names " a-f receiver," " i-f receiver " or " r-f receiver " are used to identify a receiver with such an additional stage.

Although the performance of the a-f receiver can be improved upon in many ways, its characteristics can be satisfactory, as evidenced by the fact that the great majority of five valve receivers are built in this form. Since most receivers are tuned only to local stations, the advantages of the i-f and r-f types would rarely be displayed, and their additional cost might be more profitably used on a refinement on an a-f receiver such as a tuning indicator, bandspread ranges, or a better loudspeaker, cabinet or a-f system.

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*i.e. four amplifying stages and rectifier.

(iii) Larger receivers

The conventional six valve receiver* has r-f, converter, i-f, detector, a-f and output stages, but although the stage usually added to the conventional four valve and rectifier receiver is a r-f one with advantages outlined in the previous section, the customer usually expects improvements in all features of the receiver's performance. To the average listener an improvement in fidelity is more noticeable than, for example, a reduction in image response, and it seems probable that the public would in most cases be better served with a six valve receiver with push-pull output rather than by a single ended receiver with a r-f stage.

Whether or not push-pull is used, some improvement in a-f response is required, for instance an increase in acoustical output, in conjunction with a suitable negative feedback circuit to give a reduction in distortion and a compensated frequency response.

A valve delivering more than four watts into an efficient output transformer and a sensitive loudspeaker can produce a considerable volume of noise but, even without push-pull, impressive reproduction can be obtained from the larger tetrodes and pentodes which draw between 70 and 80 mA of plate current.

The additional selectivity provided by a r-f amplifier with a high *Q* coil is appreciable and gives even more sideband cutting than is experienced with the usual 4 valve and rectifier receiver, particularly at the low frequency end of the broadcast band. As a result the high frequency response of the larger receiver may be inferior and, in fact, inadequate. The remedy of expanding the selectivity can be quite inexpensive, particularly if a " local broadcast " position is used on the wave change switch, or if one position on a tone control switch is used. Push-button receivers can have one button set aside for expanding the selectivity, which has the additional advantage of minimizing the result of frequency drift of the settings of the other push buttons.

Expanding of the i-f selectivity can be carried out simply and cheaply as described in Chapter 11 Sect. 3(iii), and the wiring is not critical because all leads have a low impedance to ground. It is only necessary to expand the first i-f transformer in a conventional single i-f stage receiver with an untapped second i-f transformer because the heavy damping on the second i-f reduces its selectivity appreciably from that of the less heavily damped first i-f transformer.

After the i-f amplifier has been expanded to give say 6 db attenuation at 8 Kc/s detuning, it may be found that the overall selectivity for small attenuations is still excessive, and the remedy is to expand the r-f stage. The damping of the aerial on the aerial secondary makes it unnecessary to expand the aerial coil: A convenient method of decreasing the r-f coil selectivity is to switch a small resistor (25 ohm carbon) in series with the cold end of the secondary. Gain is not seriously reduced, and the leads involved are low impedance so that they can be taken to the appropriate switch section without giving trouble.

After the high frequency response has been brought up to the required level, the small expense involved in fitting a high frequency diffuser is well repaid. With such a diffuser, the quality of reproduction becomes reasonably independent of the listener's position in front of the receiver, and the usual beam of accentuated high frequency response directly in front of the loudspeaker disappears.

(iv) Communication receivers

(A) Definition

A communication receiver has been defined (Ref. 33) as one which is not designed for limited or specific purposes. In some respects a communication type may be inferior to another receiver (perhaps an interception receiver to operate on a fixed frequency) in a particular application, but in general it has high performance and flexibility. Control of many of the circuits is available to the operator, of whom some technical knowledge is required.

(B) Frequency coverage and calibration

Communication receivers have been designed to provide coverage between 15 Kc/s and 25 Mc/s and between 30 and 300 Mc/s, but many do not tune above

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*i.e. five amplifying stages and rectifier.

30 Mc/s or below 540 Kc/s. Provision for reception of F-M broadcasting on 88-108 Mc/s is included in some models.

Owing to the wide range of frequencies covered, the calibration of a communication receiver is important, and increasing emphasis is being placed on the inclusion of facilities for calibration checking and even on the possibility of the receiver being tuned to any given channel in its range without external aids.

An inbuilt crystal oscillator is the usual method of checking calibrations, and when the oscillator operates at 0.5 or 1.0 Mc/s, convenient checking points occur throughout the tuning range. Movable cursors have been used with receivers of this kind to allow corrections to be made to the calibration when found necessary. Figure 35.13 (British patent No. 8706/44) shows a simple circuit to increase the amplitude of the higher harmonics of the oscillator output up to the self-resonant frequency of the choke *L*. The choke is designed to keep the harmonic output as constant as possible throughout the tuning range of the receiver. Such an inbuilt calibrator can be very useful in the alignment of the receiver. A possible refinement is the modulation of the oscillator output by pulsing with a neon tube, or even by the mains frequency, for ease of identification.

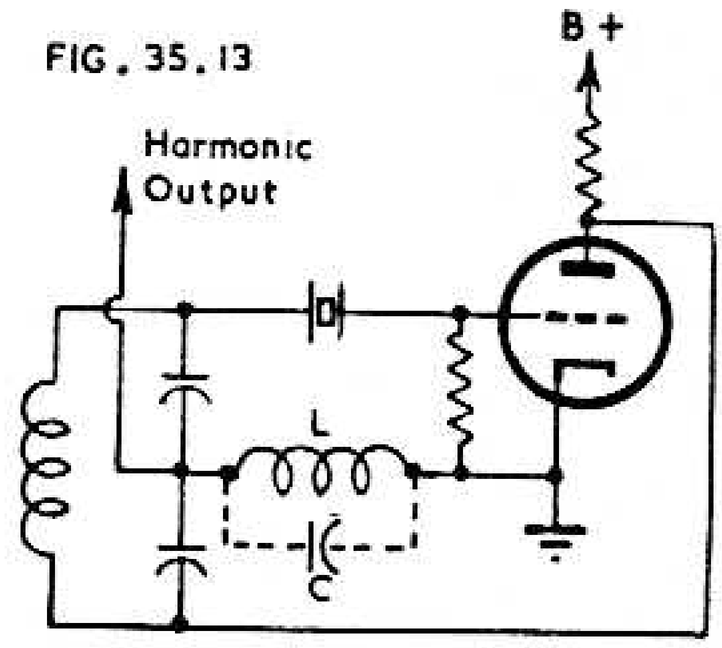

Fig. 35.13. *Circuit for increasing amplitude of high-order oscillator harmonics (from Ref.* 33).

For the second requirement of setting the receiver accurately to any desired frequency, a crystal oscillator and its harmonics are used as a part of the mixer input, and tuning is provided by a comparatively low frequency oscillator which bridges the spaces between the harmonics of the crystal. The variable oscillator can be designed to operate at a low frequency and to have high stability, any residual fluctuations being a much smaller proportion of the total mixing frequency than of the variable oscillator frequency.

To minimize the possibility of incorrect frequency settings, some receivers have sliding dial scales which expose only the calibration actually in use. Where high setting accuracy is required the frequency may be displayed as the sum of two readings, one in Mc/s and the other in Kc/s.

(C) Bandchanging

Methods of bandchanging can be divided into three main categories, mechanically operated moving coils with stationary contacts, plug-in coils and switched coils. The most common form of moving coil arrangement uses a rotating turret with the coils inside it, but moving platforms which travel along the chassis have also been used. Particularly when high frequencies are tuned, the contacts for the moving coils present a problem as the inductance of the contacts can form a large part of the required inductance—with consequent loss of gain—and the inductance may vary each time a particular band is brought into circuit or when the receiver is subjected to mechanical movement.

Plug-in coils can be efficient as they do away with the need for a wavechange switch—each plug-in unit can even carry its own calibration—but the necessity for grouping the coils adjacent to an opening in the case restricts the layout somewhat. Storage must be provided for the unused coil units close to the receiver.

Switched coils are most commonly used and the main associated problem is the disposing of a number of coils adjacent to each switch. The switches need to be reliable, but modern types using rhodium plating properly applied are satisfactory.

(D) Stability

Many stability problems are automatically eliminated by the use of suitable circuits, e.g. crystal controlled oscillators. Methods of improving electrical stability are outlined in Chapter 24 Sect. 5. However mechanical stability is a first requirement and the tuning units at least should be made as rigid as possible, some receivers even using a cast chassis with this end in view.

(E) Sensitivity and noise

Owing to the number of stages used, the sensitivity is always limited by the noise in the first stages of a receiver. This is taken into account in one method of measurement by defining sensitivity as the lowest intensity of an input r-f carrier modulated at 400 cycles to a depth of 30% such that the total r.m.s. output power (signal and noise) is halved when the modulation is removed from the input carrier. Such a definition of sensitivity gives a good indication of the minimum signal which can be used and figures of the order of one micro-volt and better can be obtained.

Another method of defining the noise ratio is by comparing it with the signal-to-noise ratio of an ideal receiver under the same conditions. The factor by which the noise ratio of an actual receiver is worse than that of an ideal receiver is known as its noise factor. Further details of this method of noise measurement are given in Chapter 37 Sect. 1(vi)G.

(F) Selectivity

The selectivity requirements of a communication receiver are severe and depend on the type of service for which the receiver is being used. For telephony the bandwidth cannot be less than about 5 Kc/s at 10 db attenuation, whereas for telegraphy a bandwidth of a few hundred cycles per second is sufficient while greater bandwidths give increased noise interference.

These requirements can only be met by variable selectivity under the control of the operator, and a good receiver will usually have at least six i-f tuned circuits to provide adequate " skirt " selectivity, with a crystal filter providing varying degrees of " nose " selectivity perhaps together with a variable rejection control for dealing with an interfering station on a nearby frequency. A representative crystal circuit will give an attenuation of 20 db when detuned 200 c/s in its sharpest position and 2000 c/s in its broadest position. With a rejection or " phasing " control in use, an attenuation in excess of 40 db can be obtained within 250 c/s of resonance. The associated i-f amplifier will give an attenuation of 60 db when detuned less than 15 Kc/s. Crystal bandpass filters are becoming increasingly popular and they provide a pass band of say 300 or 3000 c/s with severe symmetrical attenuation on each side. Details on the design of variable selectivity crystal filters are given in Chapter 26 Sect. 6.

An additional means of discriminating between a desired telegraphy signal and an undesired one separated by perhaps only a few hundred cycles per second, is the use of a-f selectivity. A typical selective circuit centred on 1000 c/s gives an attenuation of 15 to 20 db only 100 c/s from resonance and of course much greater reductions with greater separation. Apart from discrimination against undesired signals, such a circuit reduces random noise in the same ratio as it reduces the bandwidth, and the ringing which is experienced with crystals at maximum selectivity when subjected to bursts of noise is eliminated.

Such selective a-f circuits are normally designed with iron-cored inductors because maximum Q is required, but it may be possible to produce equivalent or improved performance with a bridged T negative feedback circuit.

(G) Volume control and a.v.c.

Volume control presents some problems because the range of signal levels which the receiver is expected to use exceeds one million to one, and because different types of control are required for different functions of the receiver. For reception of telegraphy many operators prefer a manual control and some receivers provide separate controls for a-f gain and i-f gain ; even separate r-f gain is sometimes provided. A convenient compromise which obtains good results from the receiver and requires no care on the part of the operator is to gang the a-f and r-f controls and delay the application of bias to the first stage by means of a diode as discussed in Chapter 27 Sect. 3(iii). The r-f control is rendered ineffective when a.v.c. is switched on, and the a.v.c. voltages can be applied to the r-f control circuit.

A.V.C. is frequently used for c.w. reception when a suitable time constant is provided. For telephony a normal time constant is 0.2 second but this needs to be increased to at least 1 second for c.w.

Amplified a.v.c. is used in most large communication receivers to provide maximum control, and results such as a 2½ db increase in output for a 100 db increase in input can be obtained (Ref. 34). Control should begin at the minimum signal level which can be used by the operator.

(H) Beat frequency oscillator

To produce an a-f output from a c.w. signal it is necessary to beat another signal with it. The beat frequency oscillator operates at, or close to, the intermediate frequency and beats with any signal in the i-f channel. The oscillator frequency can usually be varied a small amount (± 2½ Kc/s is typical) by a control on the front panel to allow adjustment of the beat frequency (perhaps to the peak of the a-f response) without detuning the signal from the peak of the i-f circuits.

The required amount and method of B.F.O. injection need some consideration. Sensitivity is lost if the B.F.O. amplitude at the second detector is too small, but when the coupling is increased a large input signal pulls the B.F.O. into zero beat from increasing frequency separations. Pulling into zero beat from a difference frequency of the order of 1000 c/s is not uncommon in bad cases. Another effect of too much B.F.O. injection is that the B.F.O. provides a signal at the second detector large enough to generate appreciable a.v.c. voltages and so reduce the sensitivity of the receiver even without an external signal.

Pulling can be minimized by electron coupling of the B.F.O. into the i-f channel, and with careful control of the amount of beat frequency voltage it is possible to obtain adequate injection without appreciable a.v.c. sensitivity reduction.

(I) Signal strength meter (S meter)

Many receivers use a calibrated meter to indicate the strength of signals tuned. The calibration is usually arbitrary (S1 to S9 for example) because the variation of receiver sensitivity across the various bands, and on different bands, makes an absolute calibration impossible. If this effect, and the varying efficiency of different aerials on different frequencies are borne in mind, the S meter can be a useful reference.

Circuits have been devised (Ref. 34) in which the S meter operates in conjunction with the manual volume control to provide signal strength indications on all types of reception, with or without the beat oscillator

The usefulness of the meter can be greatly increased by providing a switch which allows appropriate currents and voltages throughout the receiver to be measured.

(J) Aerial input

To allow maximum efficiency to be obtained from different aerial systems, provision is often made for different types of aerial inputs, such as a single wire with separate earth connection, a balanced two wire feeder or a low impedance concentric cable.

An aerial trimmer on the front panel is very desirable when a variety of aerial inputs is provided. Even with a single wire aerial the changes of impedance throughout the short wave ranges allow considerable improvements in sensitivity and signal-to-noise ratio to be obtained by the use of an aerial trimmer, and aerial coil design is not restricted so greatly by the possibilities of mistracking.

An analysis of the effects on signal-to-noise ratio of the ratio of feeder impedance to receiver input impedance with various detuning ratios is given in Ref. 33.

(K) Noise (crash) limiters

These are commonly fitted to communication receivers. Details of the many varieties will be found in Chapter 16 Sect. 7 and Chapter 27 Sect. 5.

(L) Diversity reception

Provision for diversity reception is sometimes incorporated in communication receivers by providing facilities for combining the a.v.c. voltages and outputs of the individual receivers.

Another requirement for diversity receivers is that oscillator reradiation should be kept to a minimum. This can be done by using the lowest possible oscillator grid current, by earthing the whole oscillator circuit at one point and treating other amplifier circuits between oscillator and aerial in the same way, by reducing to a minimum capacitance couplings between primaries and secondaries of signal frequency coils (this includes using high impedance externally wound primaries wherever possible) and by minimizing all couplings other than the coils between the signal frequency and oscillator stages. The tuning condenser rotor shaft is the worst of such couplings and a rotor shaft insulated between sections is very desirable. If this is not possible, low impedance earthing should be provided for the rotor shaft and gang framework between each section.

(M) Cross-modulation

Communication receivers are frequently used close to a transmitter and may be required to receive another station while the transmitter is in operation. Under such conditions the cross-modulation characteristics of a receiver may be of more importance than its signal-to-noise ratio or sensitivity (Ref. 33).

A system known as counter-modulation has been used to allow receivers to operate more satisfactorily in the presence of very strong signals. The cathode resistor of the first valve in the receiver is by-passed to radio, but not to audio, frequencies, so that a-f components due to cross-modulation appear across it. The value of the resistor is adjusted so that the a-f voltages developed are sufficient to remodulate the wanted carrier with signals approximately equal and opposite in phase to the original cross-modulation. Correct bias for the valve is obtained by applying a suitable voltage to its grid.

Further improvement can be obtained by operating the first valve solely to give minimum cross-modulation and substantial improvements can be obtained for slight reductions in signal-to-noise ratio.

The possibility of cross-modulation occurring in non-linear conductors close to the receiver should not be overlooked (Ref. 3).

SECTION 6 : A.C./D.C. RECEIVERS

(i) Series-resistor operation (ii) Barretter operation (iii) Dial lamps (iv) Miscellaneous features.

(i) Series-resistor operation

A receiver for use with d.c. supply cannot use a power transformer with low and high voltage windings, and some of the main problems in designing such a receiver are concerned with providing power for the comparatively low voltage valve heaters.

The problems are partly due to the non-linear relationship between voltage and current in a valve heater (owing to the increased resistance of the wire as the heater warms up) and Fig. 35.14 shows this relationship for a normal 6.3 V 0.3 A heater and for a 21 ohm resistor which draws the same current with 6.3 volts applied to it. It will be seen that with the normal heater a 10% variation in applied voltage gives approximately 6% increase in current.

In a.c./d.c. receivers, power is supplied to the heaters by connecting them in series across the mains, with or without an additional series impedance. When the sum of the required heater voltages is equal to the mains voltage the method is as satisfactory as when a power transformer is used, but when a series resistor is used, a variation of the mains voltage results in a larger percentage variation of the voltage across the heaters.

This effect is illustrated in Fig. 35.15. Curve ABC represents the current voltage characteristic of a string of heaters used in a radio receiver. The rated operating voltage is 108 for a nominal current of 150 mA, and a series resistor of 880 ohms is used to give the required voltage drop with a 240 volt mains supply. The intersection of the line with a slope of 880 ohms, and the current-voltage characteristic of

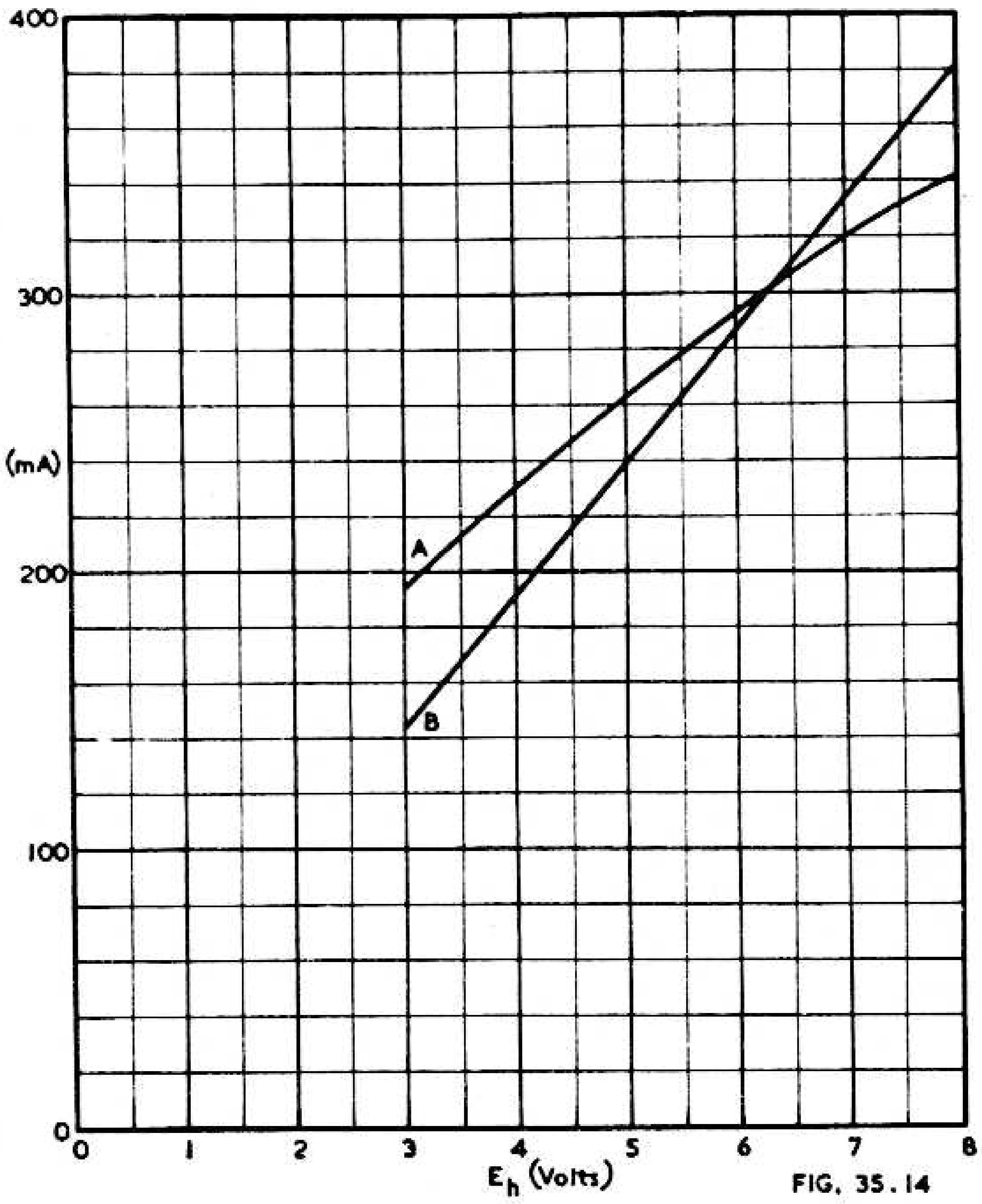

FIG. 35.14

Fig. 35.14 (A). *Voltage-current characteristic of* 6.3 *volt* 0.3 *amp. heater* ; (B) *Voltage-current characteristic of* 21 *ohm resistor.*

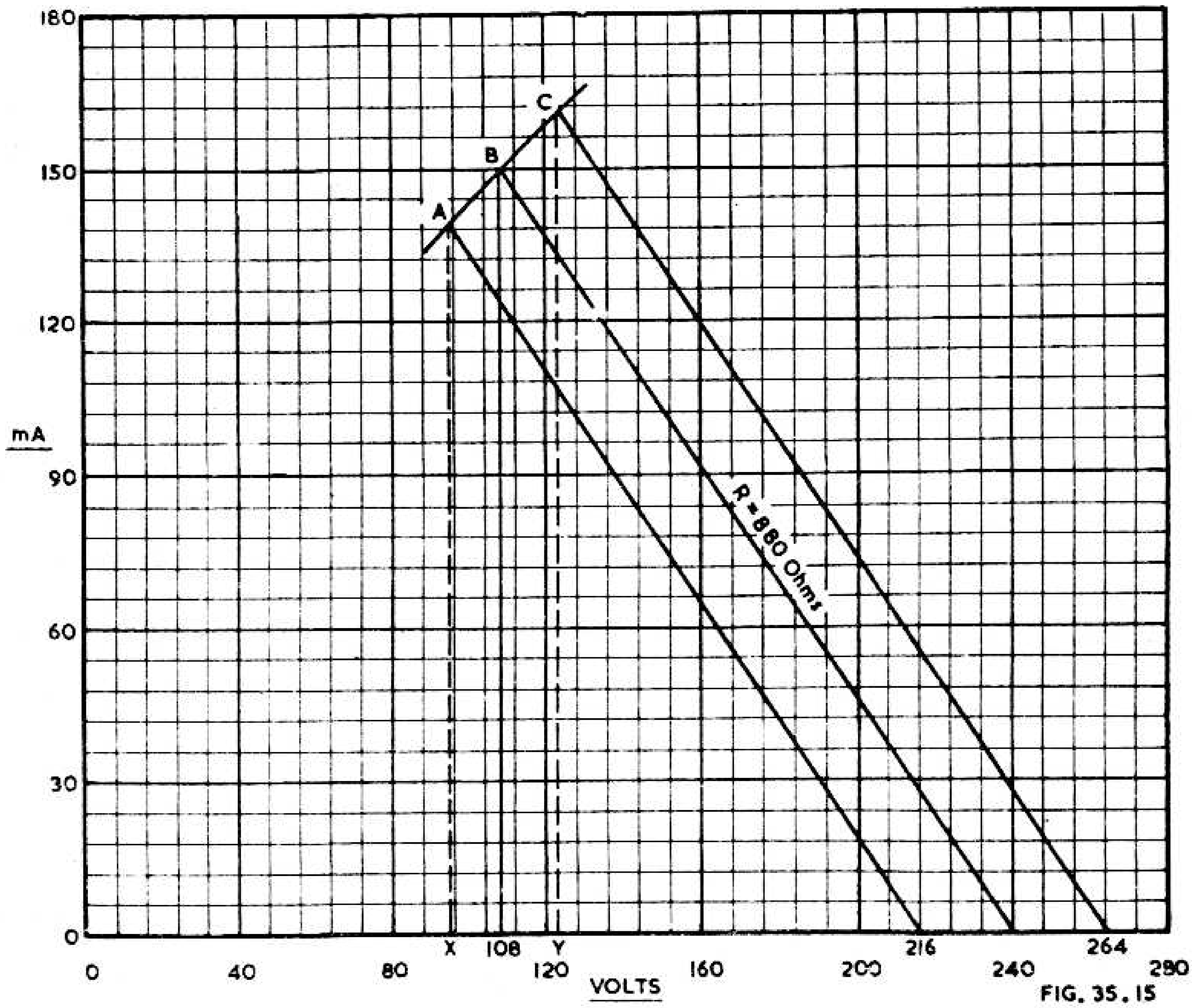

FIG. 35.15

Fig. 35.15. *Illustration of the effect of mains voltage variation on heater voltage (Method from Ref.* 41).

the heaters, is point B, the operating point under normal conditions. Now if the mains voltage is increased 10% to 264 volts the slope of the resistive line is unchanged and it intercepts the curve at point C. A vertical from C cuts the base line at Y, representing a voltage of 123, and an increase of 15 volts, i.e. 14% in the voltage applied to the heaters. Similarly a decrease of 10% in the mains voltage gives more than 10% decrease in the voltage applied to the heaters.

Because of this fact, it is necessary to provide more tappings on a series dropping resistor for various primary voltages than would otherwise be the case. Variations in supply voltages around the nominal value must be taken into account, in conjunction with the manufacturer's tolerance on the valve heaters. For American types this tolerance is usually taken as ± 10% of the rated voltage, but other tolerances are also used, and some types have a tolerance on the permissible current variation.

When the dropping resistor is designed for one primary voltage only, it often takes the form of resistance in the power lead. This has the advantage of dissipating the heat outside of the cabinet. However if a receiver was originally designed for 115 volt operation and is converted for 230 volt operation by means of a series resistor, the B+ voltage is liable to be reduced by this method (Ref. 36). The reason is that the value of the series resistor must be adjusted to give the correct average heater voltage (or current) but the rectifier draws its current in pulses and these pulses flowing through the series resistance decrease the applied voltage during the time the rectifier is drawing current. This gives a decrease in the d.c. output of the rectifier, which in a severe case might amount to 30 volts in 110. Methods of providing separate voltage dropping impedances for the heaters and rectifier which are suitable for use on both a.c. and d.c. are given in Ref. 36. Where voltage dropping of this type is required on a.c. only, a series condenser of the correct impedance can be used in series with the power lead (Ref. 42) provided that an adequate voltage rating is specified.

(ii) Barretter operation

A barretter is a device which passes a substantially constant current as the applied voltage varies within the operating range—see Chapter 33 Sect. 1(i) and Fig. 33.1.

The heat dissipation of a barretter is appreciable, and as most of the heat should be carried away by convection, ample ventilation is needed. This is necessary both for the barretter and for the whole receiver, if it is a small one, to prevent the cabinet from becoming unduly hot. The same problem exists, of course, if a series resistor is used.

Apart from eliminating the effects of mains voltage fluctuations on filament current, a barretter does away with the need for changing tappings with different supply voltages over a range covered by the operating characteristics of the barretter. When a receiver is switched on, the initial current surge is limited by the barretter, which has the effect of noticeably increasing the time taken for the receiver to begin playing. The limitation of the surge is of no particular value to the valves themselves but may reduce dial light overloading in some circuits.

Since the barretter contains an iron wire carrying an alternating current it is susceptible to magnetic fields, which cause the filament to vibrate. The vibration leads to mechanical fatigue and breakage and if the barretter cannot be located at some distance from the loudspeaker, a magnetic shield must be used— preferably one which interferes with ventilation as little as possible.

(iii) Dial lamps

The protection of dial lamps from surges when the receiver is first switched on is one of the problems of a.c./d.c. receivers. If a 0.15 A dial lamp were connected in series with an appropriate number of 0.15 A valve heaters across the mains, the high current (several times greater than 0.15 A) drawn by the heaters for some seconds each time the receiver was switched on would drastically reduce the life of the dial lamp. If a series resistor were used the surge would be reduced, but not sufficiently, and even if a barretter replaced the resistor the dial lamp would be overloaded before the barretter filament reached its operating temperature. The use of a dial lamp of higher current rating than the valve heaters is a possible method of operation. Some manufacturers have produced special lamps for series running. Nevertheless in each of these cases the failure of the dial lamp would remove the voltage from the valve heaters and stop the receiver.

One method of avoiding this trouble is to use a negative coefficient resistor (Thermistor) in series with the valve heaters—see page 190 (n).

A system in which both heater current and high tension supply current are used is given in Fig. 35.17. Special rectifier valves (e.g. 35Z5-GT) have been produced for use in such circuits, and the initial surge is offset by the fact that until the rectifier heater reaches its operating temperature the high tension component of the dial lamp current does not flow. No. 40 or No. 47 dial lamps (0.15 amp) should be used, and when the rectified current exceeds 60 mA a shunting resistor (R_s in Fig. 35.17) is required, its value being 300, 150 and 100 ohms for rectified currents of 70, 80 and 90 mA respectively.

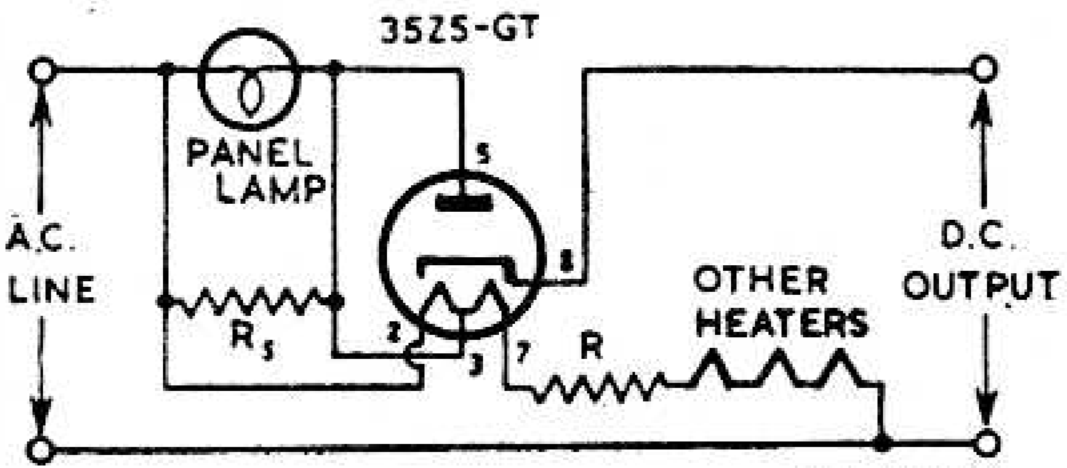

FIG. 35.17

Fig. 35.17. Circuit using 35Z5-GT and dial lamp. The drop across R and all heaters (with panel lamp) should equal 117 volts at 0.15 ampere. R_S *= shunting resistor required when d.c. output current exceeds 60 mA.*

Other rectifiers making similar provision for a pilot lamp are the miniature 35W4 and the 45Z5-GT.

The trend in small a.c./d.c. receivers is to use a simple dial without a lamp, and thus entirely avoid the use of the troublesome light source.

(iv) Miscellaneous features

(A) Rectifier

Since there is no centre-tapped source of high voltage a.c. in an a.c./d.c. receiver it is not possible to use a normal full wave rectifier. Bridge rectifiers or voltage doublers are possible but half wave rectifiers are most commonly used. They introduce some filtering problems since the frequency of the ripple in the output is one half of that from a full wave rectifier. To give the same electrical attenuation, filter capacitors and inductors would need to be increased in size, but speaker inefficiency and the poorer response of the ear at the lower frequency help in minimizing the effects of higher hum level.

When the receiver is operating on d.c., the rectifier acts only as a series impedance but serves a useful purpose in protecting the electrolytic filter condensers from damage if the mains connection is reversed in polarity, although the receiver will not operate under these conditions.

The high tension voltage is likely to be different with a.c. or d.c. mains of the same rated voltage. The reason is that on a.c. the peak voltage applied to the rectifier is $\sqrt{2}$ times the rated r.m.s. voltage and with small to medium loads and a large input condenser for the rectifier the d.c. output voltage will exceed the r.m.s. value of the a.c. input.

Modulation hum is frequently experienced in a.c./d.c. receivers operating on a.c. due to the presence of r-f signals in the mains, and to the direct connection of the rectifier to the mains. A suitable filter in the mains lead will stop the modulation hum, and any interference coming from the mains, but a satisfactory cure for the hum alone is a small (1000 $\mu\mu$F) mica condenser connected between plate and cathode of the rectifier.

(B) Valve order

When the valve heaters are wired in series and connected across the mains the potential between heater and cathode of any valve will be dependent on its position in the string. Each valve must be placed so that the maximum heater-cathode potential specified by the valve manufacturers is not exceeded, and also so that the potential is not great enough to introduce hum into the receiver output.

The position of a valve in the circuit determines its susceptibility to hum pick-up, and an a-f amplifier is generally the most critical. The usual wiring order, starting from the grounded end is second detector and first a-f amplifier, converter, r-f amplifier, i-f amplifier, output valve, rectifier. The converter is kept as close to ground as possible to avoid modulation hum. It will be found that allowable maximum heater-cathode potentials (90 V max. design centre for American amplifying valves) always allow this order, which is the best for modulation hum, to be used.

(C) Earth connection

Two main types of a.c./d.c. receivers are produced, one with one side of the mains directly connected to the chassis, and the other with mains wiring connected to an earth bus which is by-passed to the chassis proper with a suitable capacitor, perhaps shunted by a high value resistor.

The first type of receiver has fewer design difficulties but does not comply with the safety requirements in some countries, e.g. the Radio Code of the Standards Association of Australia (A.S.S. No. C.69—1937) states: V.7 (f) (ii) "Power units and sets of the transformerless type shall have the live parts of the inner structure isolated from the case or frame by an isolating condenser or other approved means, which shall not be capable of passing a current exceeding 5 milliamperes to case or frame when the full rated voltage is applied in the normal manner of operation."

The main trouble encountered with the other type of a.c./d.c. receiver is instability due to impedance between the earthed bus and the chassis proper, the impedance being made up of the reactance of the by-pass capacitor and the inductance of its leads. This impedance can be reduced to a low value by making up a unit consisting of an inductor wound on the body of the capacitor, the two being connected in series and resonated at the intermediate frequency, at which most amplification occurs.

Many cases of instability need individual treatment and it often becomes necessary to return particular circuits (e.g. the cathode by-pass of the i-f amplifier) to the chassis through a series tuned circuit instead of to the negative bus.

To avoid modulation and other types of hum it may be helpful to use back-bias for amplifying valves so that the cathodes can be directly grounded. This avoids the possibility of hum voltages appearing between cathode and ground.

Where there is any possibility of interconnection of two or more a.c./d.c. units, such as for instance a radio tuner and a separate public address amplifier, it is essential that the mains be isolated from the chassis.

SECTION 7 : BATTERY OPERATED RECEIVERS

(i) General features (ii) Vibrator-operated receivers (iii) Characteristics of dry batteries.

(i) General features

Most battery operated receivers are used in locations where signal strengths are low, and the main requirements are therefore high sensitivity and low noise. The cost of power obtained from batteries is high and every effort is made in the design of battery receivers to keep the current drain to a minimum. This is done by reducing the a-f power output considerably from that available in an a.c. receiver and by using high Q aerial and i-f coils so that high gain can be obtained without operating the valves at their maximum ratings. Many receivers have an economy switch which reduces battery drain by decreasing the screen voltage on the i-f and output valves or by other means. The reduced power output and sensitivity are still adequate for most uses.

The mutual conductance of battery valves is lower than that of corresponding a.c. types to such an extent that although the smallest a.c. receivers in general use have three valves and a rectifier, the smallest battery sets need four amplifying valves to obtain similar sensitivities. The four types are a converter, an i-f amplifier, an a-f amplifier and an output valve. The i-f output is severely limited by the low plate voltage on the last i-f valve—about 84 volts with fresh batteries in a typical modern receiver—and an a-f amplifier is needed to obtain sufficient a-f voltage to drive the output valve.

The more general type of battery receiver has five valves and uses the additional valve as a r-f or second i-f amplifier. On the broadcast band sensitivities of the order of 1 μV are readily available in each case, and if a high gain aerial coil is used there is not a great deal of difference in signal-to-noise ratio. On the short-wave band the r-f stage receiver is noticeably quieter but the average sensitivity at 6 Mc/s may be of the order of 25 μV, against perhaps 10 μV for the receiver with an additional i-f stage.

Because of the low i-f plate voltage the signal handling capacity of battery operated receivers is limited, and taken in conjunction with the requirement for high initial sensitivity, this means that a normal battery receiver overloads with a comparatively small r-f signal applied. Nevertheless the conditions of use are such that large inputs are not usual, and a receiver which will not distort seriously with an input of 0.1 volt will give satisfactory service in almost all locations.

There is usually only one diode available in a battery receiver, and this severely restricts the a.v.c. design as it makes delayed a.v.c. impossible. The most satisfactory compromise is probably to apply a fraction (say one third) of the developed a.v.c. voltage to the first and last controlled stages (unless the first valve is a r-f amplifier which may take full a.v.c. without increased signal-to-noise ratio) and full a.v.c. to the intermediate one. The small amount of a.v.c. on the input stage minimizes the increased noise from the first valve as a.v.c. is applied and on the last i-f stage it allows larger signals to be handled without overload. The middle stage has no effect on the noise, handles only small signals, and consequently can do most of the gain controlling.

A.V.C. design affects high tension current consumption and if too small a fraction of the developed a.v.c. voltage is used, current will be wasted when a local station is tuned.

Bias for the output valve is usually obtained from a back-bias resistor in dry battery operated receivers. Receivers have been made in which the voltage developed across the oscillator grid leak has been used for this purpose (with suitable decoupling) but if the A battery voltage falls more quickly than that of the B battery, the output valve is operated in an underbiased condition and draws excessive B current.

Separate C batteries have also been used, but the difficulty of discharging the C battery at the proper rate has led to the popularity of back biasing, in which the voltage remains approximately optimum throughout the B battery life.

When a back-bias resistor is used it should be effectively by-passed to audio frequencies, otherwise a-f voltages developed across the resistor are applied to the plate circuits of the i-f and perhaps oscillator valves. This may cause instability as a receiver is being tuned to a station.

Another advantage of back biasing is that if B+ is short circuited to the valve filaments, the bias resistor restricts the current to an amount which will not damage the valves. With a 500 ohm resistor and a 90 volt supply the current is 180 mA, whereas even a four valve receiver normally draws 250 mA from its filament battery.

When a battery receiver is turned off, the B supply voltage does not disappear as in the case of an a.c. operated receiver. The filament voltage being turned off stops the valves from passing current but small leakage currents (for instance, through condensers) have merely to flow through another series leakage—that of the B supply switch. Particularly in humid conditions, the resistance between switch contacts may be only of the order of tens of megohms and the uninterrupted current which flows can lead to electrolysis of fine wires and consequent open circuits.

Unless precautions are taken, the fine wire of the output transformer primary is particularly susceptible to this trouble, leakage occurring between the primary (connected to B+) and the core (connected to chassis), and interwound coils with one wire earthed and the other connected to the B supply also give trouble.

Output transformer electrolysis can be prevented by connecting the primary winding to the core and isolating the assembly from the chassis, for instance in a pitch filled container.

Interwound coils have a satisfactory life if they are baked to remove moisture and then impregnated and flash-dipped in a moisture resisting wax or varnish.

In designing battery receivers it is important to check power output, sensitivity and oscillator grid current with reduced voltages and with many valves. A large number of valves is required because no tests are made by valve manufacturers at voltages as low as those commonly employed by receiver designers as the " end of life " point.

For battery converter problems see Sect. 3(vi).

(ii) Vibrator-operated receivers

Chapter 32 deals with the design of vibrator operated power supplies. Receivers to operate with such supplies have some associated problems, mostly concerned with the elimination of r-f and a-f interference from the vibrator unit.

Separation of all vibrator circuits from the receiver is essential if hash is to be satisfactorily eliminated. If for instance various parts of the vibrator circuit are earthed at different places in a receiver chassis, interference can occur which no amount of filtering will remove. The correct method is to earth all vibrator by-passes and earth returns at one point and connect the lead from the battery to the same point.

The same principles apply to a-f interference. It is assumed that adequate filtering is used in the B supply so that interference from that source is negligible. Even under these conditions, vibrator noise can be troublesome and the first source is the battery itself. Although the internal impedance of a battery is very low it is not negligible, and the pulses of current drawn by the vibrator set up voltages across it which are applied to the filament of the a-f amplifier and result in noise from the loudspeaker.

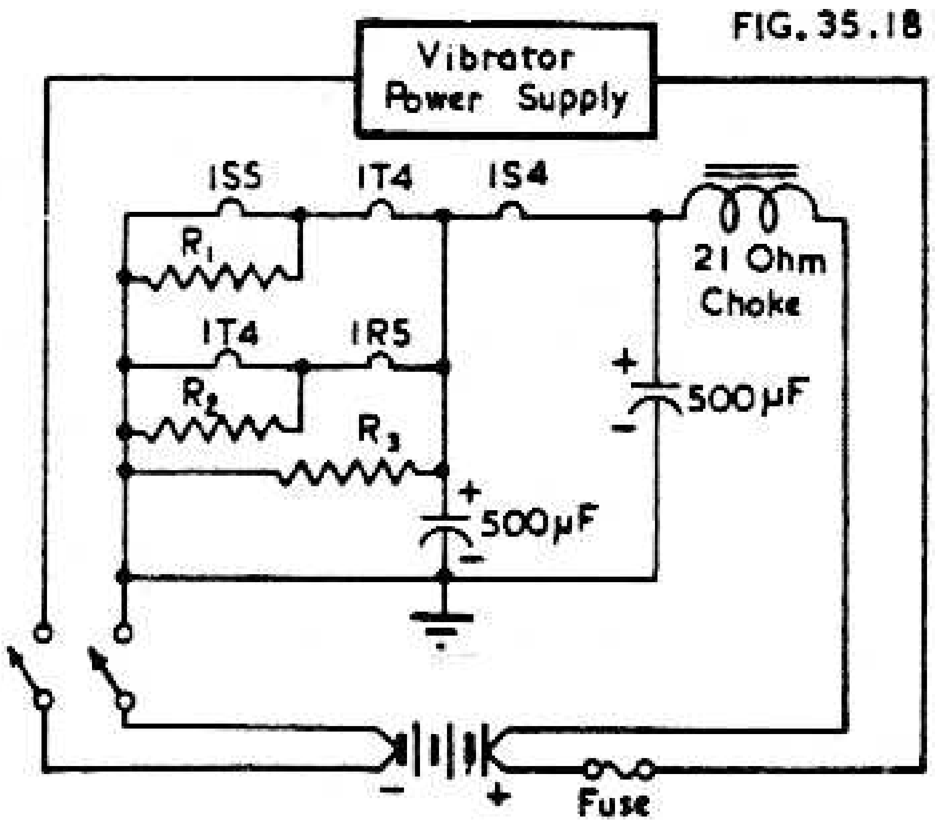

FIG. 35.18

Fig. 35.18. *Filament circuit of vibrator-operated receiver. Any output valve with* 100 *mA filament current could be used in place of the* 1*S*4 *(e.g.* 3*Q*4, 3*S*4 *or* 3*V*4 *with parallel filament connections).*

A cure is an iron-cored choke between the positive battery terminal and the filaments of the valves, which are normally connected in series-parallel. A large (500 μF) condenser is usually required in addition to the choke, and receivers with high a-f gain may need two condensers. A typical circuit is shown in Fig. 35.18. With the reduced filament drain of 1.4 volt valves it is possible in some cases to do away with the iron-cored choke and use a resistor. When used with a 6.0 volt battery the filament voltage for each valve should be 1.3 volts so that a dropping resistor of 21 ohms would be required in place of the iron cored choke shown in Fig. 35.18. Where two large condensers must be used in any case the resistor usually has sufficient impedance.

Even when the filtering (due to the electrolytic condensers and choke or resistor) is adequate, serious buzz can still occur. In Fig. 35.18 two leads are taken from each battery terminal, and the vibrator and filament circuits are entirely separate. However it sometimes happens that two switches cannot be used and a common switch section and negative battery lead must be used. This will introduce some buzz although the degree will depend on the a-f sensitivity and the value of the mutual impedance. An undesirable feature is that the interference may vary each time the switch is operated and may become progressively worse with age as the contact resistance of the switch increases.

If the a-f gain is high, even the common impedance of a fuse may cause trouble and in some cases only the vibrator circuit is fused for this reason.

The electrolytic condensers are also useful in preventing coupling between the filament circuits of the various valves. However high gain receivers usually need additional r-f by-passes on the filament string to prevent regeneration at the intermediate frequency or to keep i-f voltages from the a-f end of the receiver.

One undesirable feature of the circuit of Fig. 35.18 is that if any one of the 1R5, 1S5 or 1T4 valves is removed from its socket, or if one filament becomes open circuited, two other valves will have excessive filament voltage applied. The additional voltage is normally not enough to open circuit the other filaments but if the receiver is left unattended in this condition the valves will deteriorate rapidly.

The resistors R_1, R_2 and R_3 equalize the filament voltages on the different valves. Since the filament string requires 100 mA and the cathode current of the 3S4 alone is 8.8 mA under typical operating conditions, some adjustment to the voltage across the filaments (in which the cathode currents flow) is necessary. However calculation of the values required for the various valves is not straightforward since the cathode current of each valve has alternative paths of different impedance. For instance in Fig. 35.18 the 1R5 cathode current will flow partly in the negative filament lead and partly in the positive, this latter current splitting into one component which flows through the 1S5 and another which flows through the 3S4. As a result the resistor values are most readily determined experimentally, and with average valves in a receiver and decade boxes connected where shunting resistors are needed, a few minutes' manipulation of the decade boxes will determine the correct values. A.V.C. application will affect plate currents and hence filament voltages, and the resistor values should be decided with an average input signal. By making slight compromises it is often possible to do without one or more resistors, but if this is done conditions should be checked with freshly charged and discharged batteries as well as at the rated battery voltage.

A.V.C. design is complicated in vibrator receivers with series-parallel filament circuits, but satisfactory solutions can usually be obtained by means of a.v.c. voltage dividers returned to different potentials. For instance in Fig. 35.18, which might be the filament circuit of a receiver with two i-f amplifiers, the diode load would be returned to the 1S5 negative filament, i.e. to ground, and a.v.c. would be taken directly to the grid of the 1T4 acting as the first i-f amplifier. This is possible because the filaments are at the same potential. However the 1R5 and second i-f 1T4 have their filaments more positive and would be biased 1.3 volts negative if connected directly to the diode load. A solution would be to connect a two megohm resistor from the top of the diode load to the 1R5 and 1T4 grids, and another two megohm resistor from the grids to the positive side of the 1R5 filament. This would remove the bias from the 1R5 and 1T4 and reduce the amount of a.v.c. to these valves which would be desirable—see subsection (i) of this section.

The elimination of hash from a vibrator operated receiver usually involves work on the power unit (Chapter 32) but some precautions in the receiver may be necessary. A frequent source of interference which is difficult to trace is hash picked up by the converter valve. A very small amount of interference in the B supply may modulate the oscillator and be fed into the i-f amplifier with the local oscillator injection, or interference on the converter filament may be troublesome. In each case the interference receives the total receiver amplification. A separate r-f choke is often used for the converter filament to eliminate this trouble.

When tracing hash, a convenient method is to connect a shielded wire, with one end bared, to the receiver's aerial terminal through a capacitor. The bared end of the wire is used as a probe and when in contact with various points in the receiver circuit indicates whether interference is present. The first points to check, of course, are the incoming leads from the vibrator unit to the receiver and in general these should be filtered until they are quite " cold ".

To be sure of trouble-free production runs it is advisable to work on hash elimination until, with an aerial wrapped around the battery leads and battery, no interference can be heard at any frequency with the receiver operated at maximum gain in a screened room.

Mechanical noise and vibration from the vibrator also present a problem. The high frequency noise components can readily be minimized by felt or other sound-absorbing material, and even the metal shielding box in which vibrators are often used may be sufficient. However noise at the fundamental frequency of the vibrator is more difficult to cure and much trouble can be avoided by using a very flexibly mounted vibrator socket. Each new receiver usually presents different problems in this respect.

(iii) Characteristics of dry batteries*

A knowledge of dry battery characteristics is essential in designing receivers which are to use the batteries to the best advantage. It is also helpful in obtaining maximum battery life with a particular receiver.

The decrease in battery life caused by a receiver design which gives unsatisfactory performance—or none—when the battery voltage falls below certain levels is best illustrated in Fig. 35.19. If the average B current of a receiver is taken as 15 mA it will be seen that the useful life of the battery is increased from 1.16 to 1.49 ampere hours, an increase of 28%, by designing the receiver so that it will operate satisfactorily when the output of the 90 volt B battery has fallen to 60 volts, instead of becoming unusable when the output is 68 volts.

It will be noticed that as the current drain in Fig. 35.19 is reduced, the output rises to a maximum and then falls. This is due to the fact that the batteries were discharged for 2 hours each day so that with a 10 mA drain for instance the test lasted for 175 days. Tests with smaller drains take longer and the effects of shelf life become more important than the decreased drain.

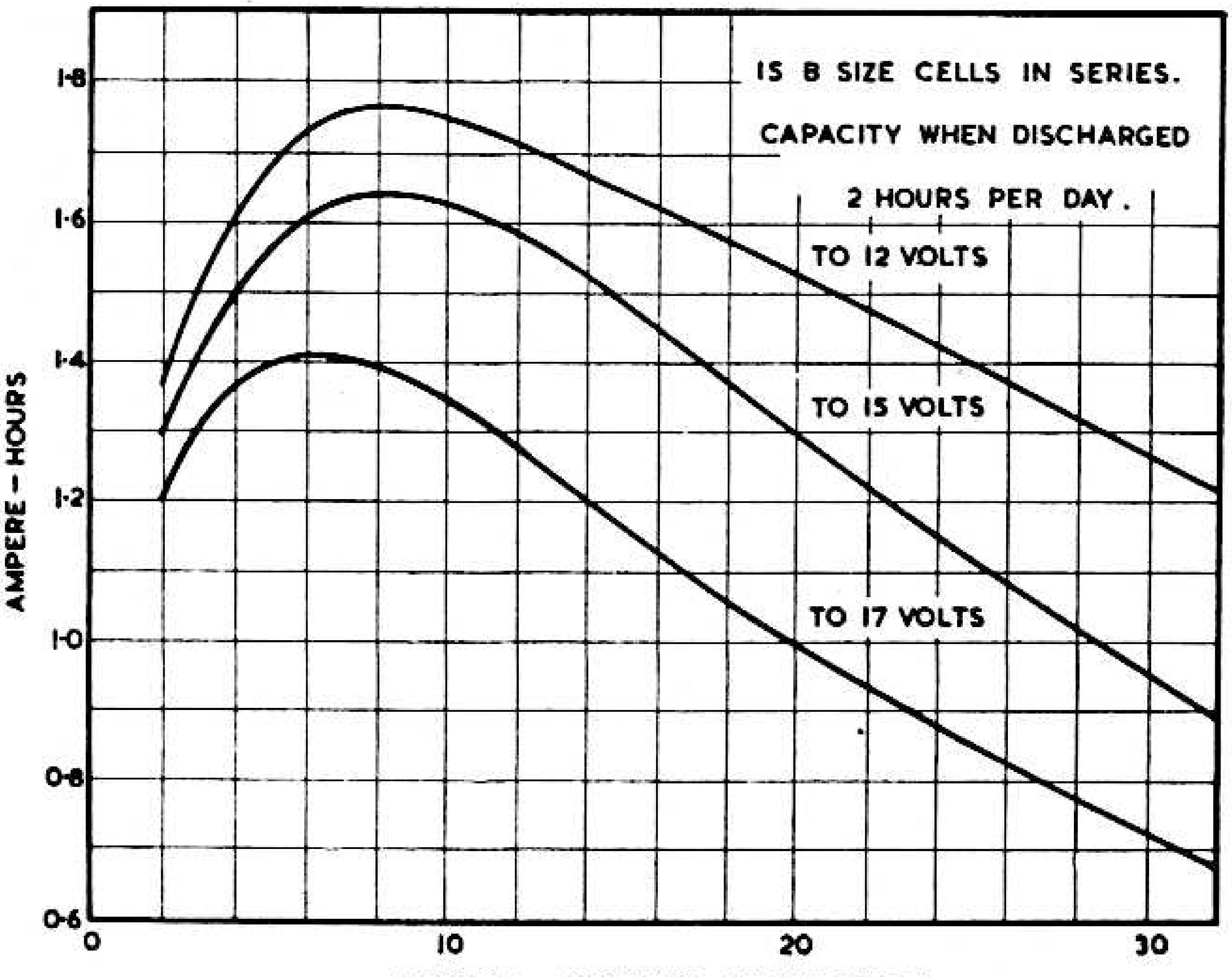

FIG. 35.19

Fig. 35.19. *Ampere-hour output versus discharge current for various end-point voltages (Ref.* 25).

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*Information taken from Ref. 25.

Fig. 35.20 shows the importance of reducing battery drain to a minimum or alternatively of specifying batteries of as great a capacity as possible. As the drain is reduced a progressively greater amount of the battery output is made available at a high voltage, and as an extreme example, a 2.9 mA drain on the cell will give 83% of the battery's output (assuming that the cell can be used until discharged to 0.8 volt) at a voltage greater than 1.3, whereas a 187 mA drain gives only 16% of the battery's output at 1.3 volts or more. The curves of Fig. 35.20 were taken on continuous discharge, and with operation of say 4 hours a day the effects of shelf life would modify the figures obtained.

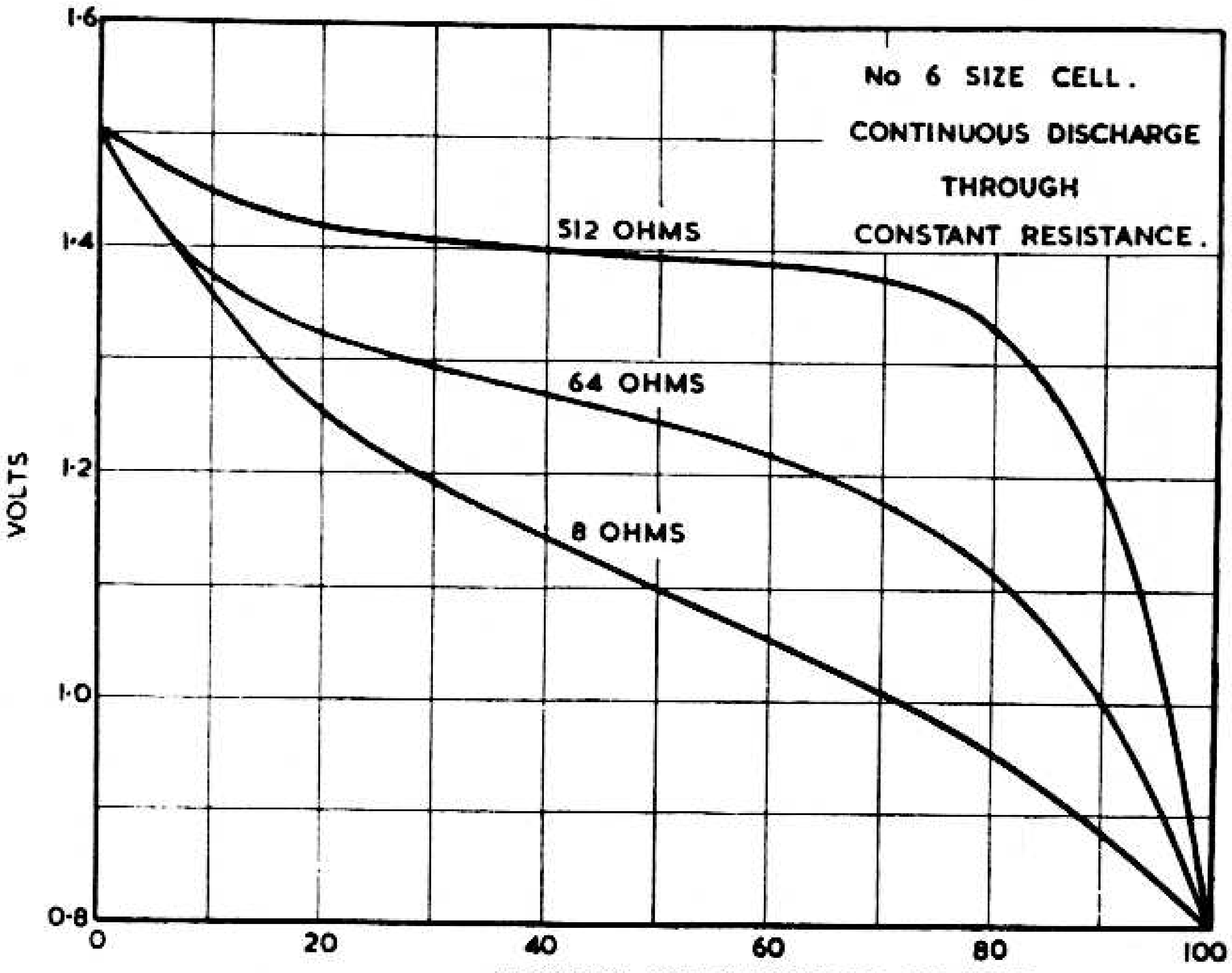

FIG. 35.20

Fig. 35.20. *Working voltage of No.* 6 *size cells during discharge through various resistances* (*Ref.* 25).

The main interest of Fig. 35.21 is to the user of the receiver, as it shows the effects of heavy battery usage in decreasing battery output. For a B drain of 15 mA and 8 hours of use each day, each cell will give 1.13 ampere-hours output, but with 2 hours daily usage the output rises to 1.48 ampere-hours. Thus the batteries will last for about 50 days with 2 hours of use, but less than 10 days with 8 hours of use. The effects of shelf life in Fig. 35.21 are clearly indicated at low current drain and with decreasing hours of discharge per day.

An aspect of dry battery performance which is of particular importance to receiver designers is the increase of internal resistance of each cell as it becomes discharged. The resistance of a new cell can be ignored for radio purposes, as it varies from about one third of an ohm for small B battery cells, to one fiftieth of an ohm for large A battery cells. However as the battery ages, an impedance of the order of 20 ohms per cell may develop and for a 90 volt battery this represents a series impedance of 1200 ohms.

Such impedances cause coupling between circuits, and in the case of an A battery may cause instability due to coupling between different i-f stages or between i-f and a-f stages. The remedy is an adequate by-pass (0.5 μF may be necessary) across the filament circuit, and the necessity for this should be tested with a discharged battery during design. Impedance in the B supply circuit can cause trouble between almost any pair of stages (including the oscillator) in the receiver. An electrolytic condenser in parallel with a r-f by-pass (0.1 μF) is commonly used to avoid this trouble.

The only completely satisfactory method of testing a receiver for performance with discharged batteries is to use a set of batteries which has been used normally until the voltage has fallen to the required level. Accelerated rates of discharge do not

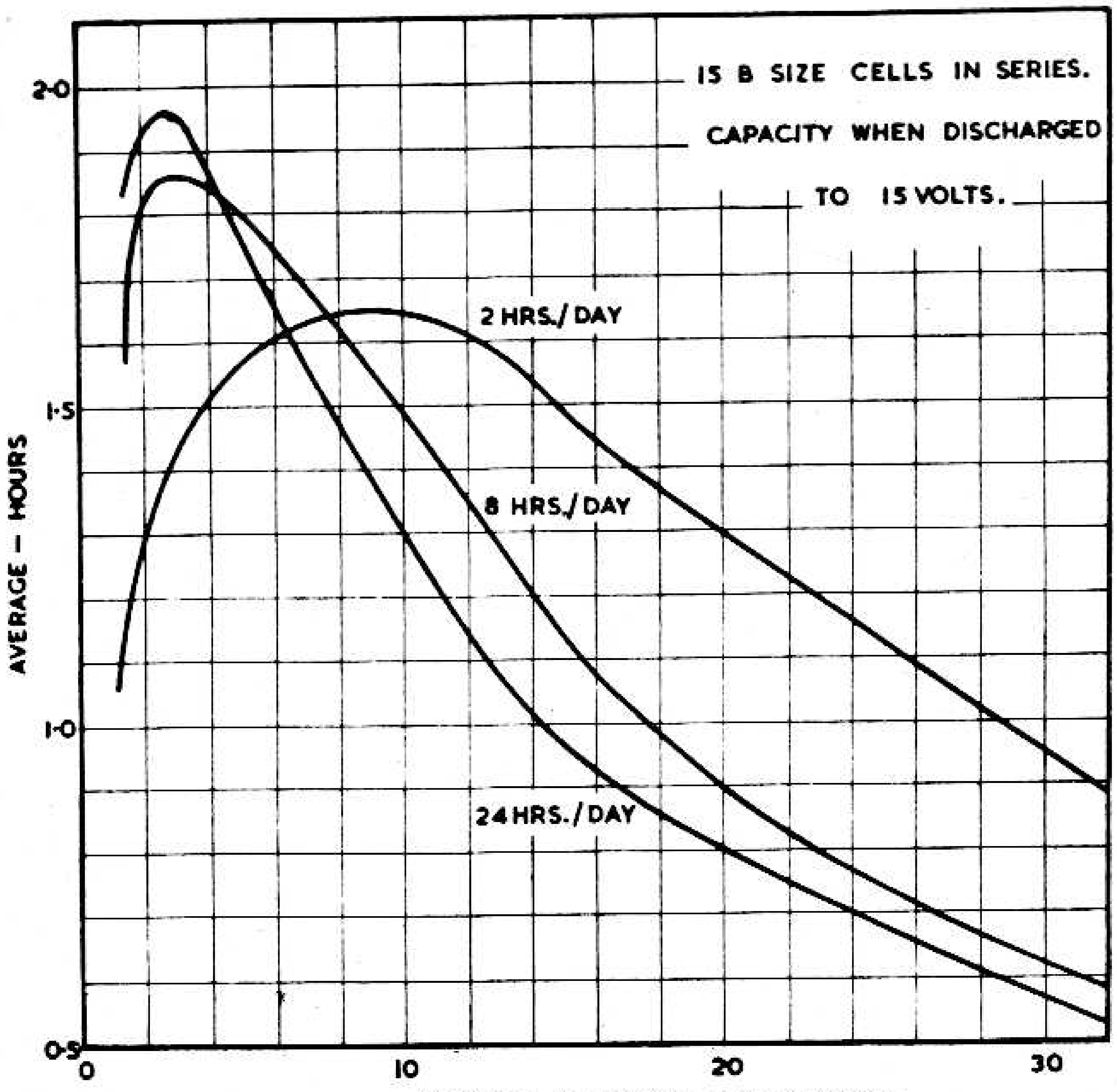

FIG. 35.21

Fig. 35.21. *Ampere-hours output versus discharge current for various operating cycles* (*Ref.* 25).

produce such a high internal resistance. Noise will sometimes be encountered with a discharged battery unless a large by-pass is connected in parallel with it.

The effect of temperature on dry cells is very marked. At high temperatures the deterioration of unused cells is rapid and tests have shown that batteries stored for one year at 104°F. have deteriorated more than similar batteries stored for five years at 48°F. Small cells have a shorter shelf life than large ones stored under the same conditions.

The reasons for the increased rate of deterioration at high temperatures are increased moisture loss from the electrolyte, and increased chemical activity in the battery. This latter effect is beneficial when the battery is actually in use and a battery discharged in a comparatively short time at 100°F. has been found to give 140% of the output of a similar battery at 70°F. At 40°F. the output fell to 48% of the output at 70°F.

When testing batteries it is important to realise that there is no relationship between the current delivered by a dry cell on a short circuit amperage test and the service capacity of the cell. On the other hand the working voltage of a dry cell does decline progressively as the cell becomes exhausted, so that a voltage test under normal load is a good indication of a battery's condition. The voltmeter used should have a resistance of not less than 100 ohms per volt for single cells or 1000 ohms per volt for B batteries. The current drawn by lower sensitivity meters may lead to a lower voltage indication than actually occurs in use.

In some types of portable receivers which can be used with dry batteries or an a.c. power supply the dry batteries can be charged during a.c. operation or while the receiver is not in use. This is claimed to increase the service obtainable from the dry batteries although the degree of improvement depends on the conditions of use. It is important that the charging current should not be excessive. Further information is available in Refs. 56, 57, 69, 70, 71.

SECTION 8 : CAR RADIO

(*i*) *Interference suppression* (*ii*) *Circuit considerations* (*iii*) *Valve operating conditions.*

(i) Interference suppression

The main problem in car-radio design is the suppression of interference from the car and from the power supply of the receiver. Ignition interference is the more troublesome, and while there are methods of suppression which apply in all cases any particular installation is liable to present problems of its own.

One theory as to the mechanism by which interference is produced is that each spark causes oscillatory currents in the ignition leads covering a wide band of frequencies. The spectrum is propagated from the ignition lead which acts as an aerial, and the receiver amplifies those frequencies to which it is tuned. See Ref. 10 for a comprehensive survey of reports on the nature, measurements and suppression of ignition interference.

Another possible mechanism has been described in Ref. 1, although objections to it are brought forward in Ref. 10C. This conception of interference generation is that the radiated field is an impulse which is short compared with the period of the carrier frequency up to frequencies of hundreds of megacycles. Each burst of interference heard is thus the impulse response of the receiver and its aerial, so that the interference is more dependent on the bandwidth of a receiver than on the frequency to which it is tuned, although of course the signal received will vary in amplitude with large variations in frequency.

In addition to ignition noise, interference is caused by the brushes on the generator but this is readily removed by by-passing. Special suppression capacitors are available of 0.5 μF capacitance, 200 volt working, encased in a metal can to which one side of the capacitor is connected.

Methods of dealing with the majority of straightforward interference suppression problems are given below (Ref. 60).

(a) Cut the high tension lead connecting the ignition coil to the centre of the distributor head as close as possible to the distributor head and screw the two ends of the leads into a resistor suppressor. Suitable suppressors consisting of a carbon resistor of 15 000 ohms with facilities for attaching the two leads are available commercially.

(b) Connect a suppression capacitor to the point where the receiver low tension cable is connected to the car's low tension system, with the metal case clamped to the chassis.

(c) Clamp the metal case of another suppression capacitor to the generator housing and connect the lead to the generator armature-terminal. The capacitor must not be connected to the generator field-terminal. In American cars the correct terminal is usually the larger one.

In most English cars the armature terminal is not accessible on the generator and the suppression capacitor should be connected in such cases to the "D" terminal on the voltage distribution channel.

If trouble is still experienced the following points should be investigated.

(d) See that the distributor contacts and spark plug points are clean, in good condition and correctly adjusted. Replacements may be needed.

(e) If the engine is rubber mounted a bond may be necessary between the engine block and the chassis. This bond should be a piece of flexible copper braid not less than ⅜ in. wide and as short as possible, although allowing for engine movement.

(f) See that the low tension leads do not come close to any of the high tension wiring. In some cars it may be necessary to remove the low tension wires from channels provided for the spark plug leads.

(g) Make sure that there is a good connection between the ignition coil can and the engine block.

(h) Bond all oil pipes, bowden cables, etc., to the bulkhead as they pass through to the driving compartment.

(i) Try the effect of bonding various parts of the bodywork to the bulkhead or engine block with $\frac{3}{8}$ in. copper braid. It sometimes happens that a large section of metal, for example a mudguard, is insulated by rubber or fabric beading, or even by paint, from the rest of the body. Bonding of such sections may eliminate interference.

(j) By-pass separately the various electrical components of the car, such as the horn, ignition switch, windscreen wiper motor, petrol pump, head lights, dome light, parking lights, petrol gauge, electric clock, etc.

In fitting the various units of the radio itself it is necessary to remove some paint from the metal to make sure that the unit is electrically earthed.

Occasionally trouble is experienced from wheel and tyre static. Graphite grease in the wheel bearings, may be sufficient to effect a cure, but in some cases spring contacts bearing on the wheel hub have been used.

(ii) Circuit considerations

The main requirements for a car radio are high sensitivity, high signal-to-noise ratio, good a.v.c., high a-f output, compactness, the ability to withstand vibration, and mechanical flexibility for installation purposes.

The first four items have almost standardized the design into the form of a receiver with r-f, converter, i-f, a-f and output stages. Such a combination allows the receiver sensitivity to be limited only by the noise in the first stage—which is desirable.

The high over-all sensitivity (1 μV input for 0.5 watt output is not uncommon) causes high a.v.c. voltages to be developed with comparatively small inputs so that strong a.v.c. action is available even when signals fade to very low levels. The a.v.c. diode load is often returned to a source of bias for the r-f and i-f amplifiers so that a delay of two or three volts is obtained and this flattens the a.v.c. characteristic even more, after the delay has been overcome. The a-f sensitivity is adequate to allow full output.

When full a.v.c. is applied to the r-f stage a check should be made from Scroggie's curves—Sect. 3(i) of this chapter—to see that the noise from the first valve does not become comparable in size with that from the input circuit and so affect the signal-to-noise ratio.

FIG. 35.22

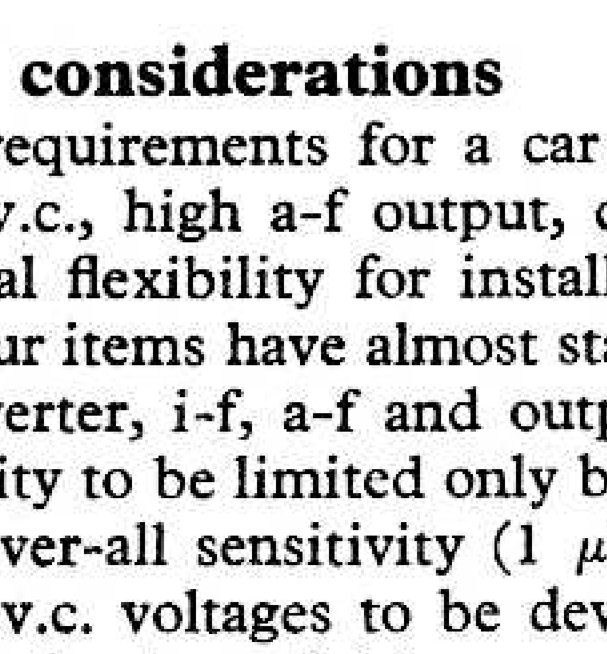

Fig. 35.22. Car-radio aerial input circuit.

The design of the aerial input circuit is very important in a car radio, because of the small effective height and physical size of the aerial itself. Different aerials may be used with the receiver, but telescopic types with a capacitance of about 50 $\mu\mu$F are commonly assumed. One of the most popular circuits is shown in Fig. 35.22. L_1 is a choke consisting of a few spaced turns of thick wire, resonant at about 40 Mc/s. It is used to minimize incoming ignition interference without seriously affecting the desired signals. L_2 is the aerial coil primary, which is arranged to resonate with the aerial and the rest of the circuit outside the low frequency end of the required band. However the resonance is kept as close to the band as possible without introducing too much mistracking between the aerial and r-f circuits, in order to obtain the maximum possible gain at the low frequency end of the band.

The capacitor C_1 is from 50 to 100 $\mu\mu$F in a typical case, and provides capacitance coupling to improve the gain at the high frequency end of the band. L_3 is tapped at from one quarter to one third of the total number of turns from the cold end. Coupling between L_2 and L_3 usually approaches 20%. The Q of L_3 must be as high as possible and iron cores are commonly used. Q values in air as high as 250 at the maximum point in the band have been used, and a gain of from 8 to 10 is obtainable over the band with such a coil mounted in the chassis. Gain is measured with the output of the signal generator connected through a 50 $\mu\mu$F capacitor to the aerial end of the shielded input cable. Noise figures obtainable are of the order of equal noise and power output when the input signal is from 0.3 to 1.0 μV, 30% modulated.

A series trimming condenser (say 50-350 $\mu\mu$F) is sometimes used between the spark coil and the aerial primary so that the aerial coil can still be tracked with the r-f coil even when a high capacitance aerial is connected to the receiver.

Power supplies for car radios are vibrator operated, using either synchronous or non-synchronous types. The non-synchronous system has the advantage of keeping a constant output polarity when the input polarity is reversed, so that the lack of uniformity between car manufacturers as to positive or negative grounding of the battery becomes unimportant. Non-synchronous systems also have fewer troubles from vibrator hash in the receiver and are generally assumed to be more reliable in operation but of course they are more expensive, since a rectifier must be provided, and consume more current if a hot cathode type of rectifier is used.

In the elimination of interference either from the vibrator or from ignition noise in a car radio, " spark plates " are often used. These are by-pass capacitors using the chassis as one plate, a thin sheet of insulating material, preferably mica, as the dielectric and tin-plate or brass as the other plate, the assembly being eyeletted together with suitable insulating washers. Because components are soldered directly to the top plate and the bottom plate is the chassis, the series inductance of such a capacitor is very small. It has been recommended that incoming leads should be soldered to one end of a spark plate and outgoing leads to the other end. Capacitances between 10 and 200 $\mu\mu$F are commonly made up in this way.

Because of the intense ignition interference field it is often necessary to filter all leads coming into the receiver. Tone control leads and even loud speaker leads may need by-passes or series chokes to eliminate interference.

The effects of vibration must be considered in car radio design. Reliable air dielectric trimmers are more stable than compression mica types, but need to be sealed after alignment. Large paper capacitors need to be held by means other than their own leads, and smaller components must be mounted so that they cannot vibrate on their leads. Older types of valves, such as G types and others of similar size can give trouble through falling out of their sockets under the influence of vibration, particularly when mounted horizontally. For this reason and for the extreme compactness which they allow, miniature valves are well suited for car radio designs.

(iii) Valve operating conditions

Valves in car radios are subjected to heater voltages outside both the top and bottom limits specified by valve manufacturers. Extremes of perhaps 8.0 and 4.5 volts may be encountered with the battery on charge and fully charged, and off charge and discharged.

Excessively high heater voltages reduce valve life by evaporating the coating from the cathode, and care should be taken to see that plate or screen dissipations do not exceed valve manufacturers' ratings under any anticipated working condition, particularly as the ambient temperature inside the car radio is likely to be very high at times.

When heaters are operated at excessively high voltages it is possible for control grids to rise to a temperature at which grid emission takes place. To reduce the effects of this grid emission current, it is advisable to use the lowest convenient values for output valve grid leaks and a.v.c. series resistors in car radios.

When the supply voltage is very low, the receiver loses sensitivity and power output but remains usable so long as the oscillator operates. To guard against oscillator stoppage a new design of receiver should be checked with a large number of valves including some with low oscillator grid current under normal operating conditions.

Since valves are only tested by manufacturers to the recommended voltage limits, there is no guarantee of uniformity of operation between valves at voltages outside those limits

SECTION 9 : MISCELLANEOUS FEATURES

(i) Spurious responses (ii) Reduction of interference (iii) Contact potential biasing (iv) Fuses (v) Tropic proofing (vi) Parasitic oscillations (vii) Printed circuits (viii) Other miscellaneous features.

(i) Spurious responses

With a superheterodyne receiver, several types of signal can be received which do not originate in stations broadcasting on the frequency to which the receiver is tuned. The signals are not necessarily objectionable of themselves, but owing to the congested condition of the broadcasting band, almost any spurious signal will interfere with a true signal. These spurious responses are due to several causes which are listed below.

(a) Harmonics of a station operating at a lower frequency.
(b) Two stations broadcasting on frequencies separated by the intermediate frequency of the receiver.
(c) A station broadcasting on the image frequency of a desired station.
(d) A combination of local oscillator harmonics with other signals or harmonics.
(e) Feedback of intermediate frequency harmonics.
(f) A station broadcasting on the intermediate frequency of the receiver.

Interference of type (a) will be received by any receiver of sufficient sensitivity and cannot be minimized in the design of a receiver.

When type (b) interference is experienced, the two stations will be heard together over two bands of frequencies centred on the frequencies of each of the stations. The interference continues even when the local oscillator is stopped. Since it is necessary for the two signals to be present at the grid of the frequency changer for the interference to be troublesome, selectivity before this point is required to eliminate it. Alternatively the intermediate frequency of the receiver can be altered to a frequency at least 10 Kc/s removed from the difference frequency.

Type (c) interference can be cured by adequate signal frequency selectivity, and is the main reason for this selectivity. Particularly in the short-wave range of dual wave receivers is trouble experienced (although not always recognised) from this source, and it is so prevalent that the signal frequency selectivity of a receiver is always expressed as its image ratio.

Methods of calculating image ratio are given in Chapter 23 Sect. 4(ii) for coils without capacitance coupling. To obtain the full calculated rejection, particularly at the high frequency end of a band, it is necessary to reduce to a minimum all couplings other than that by mutual inductance. Separation of circuits and earthing at one point for each circuit will be found beneficial when high gain is used. Capacitance coupling must be particularly avoided. Ref. 21 (pp. 225-237) gives circuits which increase image rejection.

There are many possibilities of type (d) interference but it is not a major problem in most receiver installations. Nevertheless it is advisable to restrict oscillator grid current to a minimum, consistent with other requirements, to minimize this source of interference.

Feedback of intermediate frequency harmonics can occur through B supply, a.v.c. or other wiring, or by means of voltages induced into the converter input circuit from the second detector, or any part of the a-f amplifier. The feedback may be sufficient to cause actual instability or merely an annoying heterodyne on stations adjacent in frequency to the harmonics of the i-f. Shielding and perhaps decoupling or an r-f by-pass in the a-f circuit readily remove the trouble.

Interference from a signal on or near the intermediate frequency continues when the local oscillator is stopped and becomes progressively worse as the receiver tuning approaches the intermediate frequency. It is seldom encountered in superheterodynes with a tuned r-f amplifier, but receivers with an untuned r-f amplifier or with none usually have very poor i-f rejection at frequencies lower than 600 Kc/s.

A method of plotting interference signals is given in Ref. 21, Part 1, page 201. An example of the estimation of the interference to be expected in a given set of conditions will be found in Ref. 53.

(ii) Reduction of interference

There are two main methods of minimizing the effects of external noise on radio reception. The first is by the use of noise limiters in the receiver (Chapter 16 Sect. 7 and Chapter 27 Sect. 5) and this method is equally applicable whether the noise is of man-made or natural origin. The second method consists of using filters and noise-reducing aerials and is only applicable to noise from man-made sources.

Most mains operated receivers receive appreciable r-f inputs from the supply lines, and when noise is troublesome the ratio of signal to noise is often much lower in the mains than in an aerial. This occurs when the source of interference is connected to the power supply and induces interference into the mains wiring. In such a case filtering of the mains leads can give a substantial improvement in signal-to-noise ratio.

An electrostatic shield between primary and secondary windings of the power transformer is the most common method of treatment. Methods of incorporating such a shield in the power transformer are described in Chapter 5 page 233. The alternative method (b) of winding the earthed low voltage filament between primary and secondary, due to its inductance, is probably less effective than the normal shield (a).

Fig. 35.23. *Interference from power-supply induces noise into input circuit of receiver.*

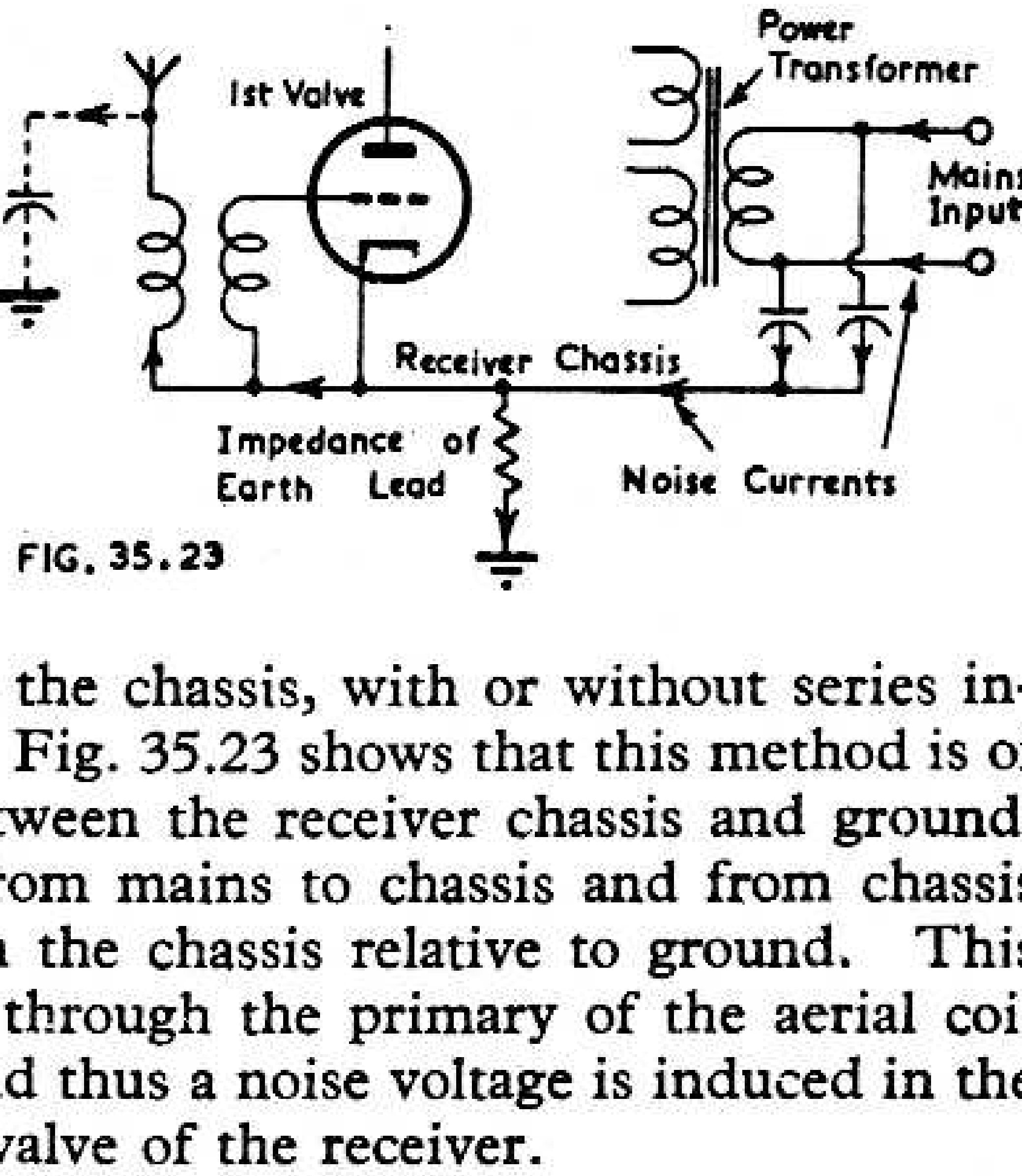

FIG. 35.23

By-passing of the incoming mains leads to the chassis, with or without series inductors, is often used to reduce interference. Fig. 35.23 shows that this method is of limited use, depending on the impedance between the receiver chassis and ground. Noise currents represented by arrows flow from mains to chassis and from chassis to ground, thus setting up a noise voltage on the chassis relative to ground. This voltage causes another noise current to flow through the primary of the aerial coil and the capacitance of the aerial to ground, and thus a noise voltage is induced in the aerial coil secondary and applied to the first valve of the receiver.

The fact that interference stops when the aerial is removed from the receiver is not proof that the noise is picked up by the aerial. If the aerial were removed in Fig. 35.23 the interference would stop because the path to ground through the aerial primary would be removed, but the noise source is the supply mains.

Figure 35.23 indicates how improvements in noise reduction can be made. Firstly, if the earth lead for the mains by-passes is separated from the receiver earth, the noise potential between chassis and ground is eliminated. The separation needs to be more than electrical, as if two wires were close to each other the noise currents in the filter earth would induce noise currents in the receiver earth.

Secondly the incoming noise currents can be considerably reduced by using a r-f choke in series with the mains leads before the first by-pass to increase the impedance of the path. This will reduce the noise voltage between chassis and ground, but increase the noise voltage between mains leads and ground, and the capacitance between mains and aerial leads may lead to increased noise from this source.

A third possibility is the use of a balanced aerial coil primary connected to the ends of a symmetrical lead-in from the aerial. When the two ends of the primary are balanced with respect to capacitance to chassis (a small trimmer can be used on either side of the primary if found necessary to give the greatest noise reduction) then noise currents flowing from receiver chassis to ground through the aerial capacitance do not give rise to noise voltages in the aerial coil secondary or the remainder of the receiver. An electrostatic shield can be used between primary and secondary as an added precaution against electrostatic asymmetry between primary and secondary windings.

The symmetrical lead-in can be terminated at the aerial end in another transformer coupling it to the aerial, in a dipole, or aerial and counterpoise or the lead-in may be merely a two wire feeder with one end extended to form the aerial. In any of these cases additional noise reduction can be expected from the fact that the aerial proper can be placed at some distance from the power supply mains or any other known source of interference, e.g., it can be removed as far as possible from, and placed at right angles to, tram lines.

Before proceeding with elaborate noise reduction methods it is advisable of course to make sure that the receiver itself is not picking up noise directly. In strong fields large voltages are induced into grid leads and under-chassis wiring, and complete shielding of the receiver proper may reduce interference without other assistance, or it may be essential if the full benefit of more elaborate methods is to be obtained.

In-built aerials on mains operated receivers usually work on the principle of providing an earth return for signals coming from the mains, in some cases as shown in Fig. 35.23, and in other cases with a capacitance between mains and aerial terminal, and the receiver chassis providing, through capacitance or direct connection, the return to ground. In the first case the requirement for the " aerial " is merely the largest possible capacitance to ground, and a ground connection to the chassis should reduce the signal input. In the second case an earth connection should improve signal strength as the current through the coil will be increased.

Even when a mains-operated receiver is equipped with an in-built loop aerial, some of the signal input is due to the capacitance effect of the loop as a whole. A mains filter may improve the signal-to-noise ratio in such a case, but with the other two types of in-built aerial a mains filter will reduce the signal and noise by the same amount leaving the ratio unchanged.

(iii) Contact potential biasing

Electrochemical activity between the electrodes of a valve produces potential differences without the application of external e.m.f's. The effect is most noticeable on grids and diode plates since their " contact potential " may be of the same order as potentials applied from other sources. The effective bias depends on the surfaces of the two electrodes and the impedance connected between the respective valve pins. The control grid contact potential will vary with different types of valves, with different valves of the same type and with age in a particular valve.

In practice, control grid and diode contact potentials are found in indirectly-heated valves to vary between -0.1 and -1.1 volts with different types of valves, and the contact potential of a particular valve may vary as much as 0.4 volt during life. Because of this, the contact potential of valves has a restricted application as a source of bias, but it can be satisfactory if its limitations are borne in mind.

The two types of contact potential bias are " grid leak bias " of a-f amplifiers and " diode bias " of i-f and other amplifiers. Some valve types which are likely to be used with grid leak bias e.g. Radiotron types, 6B6-G, 6SQ7-GT, and 6AV6, are given a 100% production test for grid leak bias by Amalgamated Wireless Valve Co., under conditions sufficiently severe to ensure that any change of characteristics during valve life will not affect their performance. These types can be recommended for this type of service provided that the plate current is restricted to a maximum of 1 mA, the grid leak is 5 megohms or larger (2 megohms can be used with a small signal input but distortion should be checked) and the output required is not greater than 25 V r.m.s. Under these conditions less distortion can be expected from grid leak bias than from cathode bias (Ref. 43).

Pentode valves have more critical bias requirements when used as low distortion resistance coupled a-f amplifiers and because of this are not so suitable for grid leak biasing. However when used with a series screen resistor of high value and comparatively small a-f inputs they can be satisfactory, and remove some of the hum problems from fairly low-level a-f amplifiers since there is no bias supply to be filtered, and the cathode is at ground potential so that heater-cathode conductance is not troublesome.

Diode biasing finds its main application in minimum cost 5 valve (4 valve plus rectifier) receivers. A.V.C. is applied to the i-f and converter valves directly from the diode plate of the second detector, the diode load and the cathode of the i-f amplifier being returned to ground. Under these conditions the contact potential of the diode is the only bias applied to the i-f amplifier, and its screen voltage is adjusted to keep plate and screen dissipations within tolerances. The converter may need additional bias, obtained from a cathode resistor and by-pass, depending on the type used.

A trouble which occasionally occurs with this circuit is that the diode bias is too small, the i-f valve draws grid current, and its reduced input impedance damps the i-f transformer sufficiently to cause a serious drop in sensitivity with small inputs. As the input is increased, the additional i-f bias from the a.v.c. line restores the sensitivity to normal so that over a small range of input signals the receiver output increases much more rapidly than the input. A receiver with this defect may show poor sensitivity for 50 mW output, but normal sensitivity for the larger signal required to give 0.5 watt output as recommended by the I.R.E. " Standards on Radio Receivers, 1948."

Additional methods of using contact potential for bias are given in Ref. 44.

(iv) Fuses

Commercial A-M receivers rarely incorporate a fuse owing to the difficulties involved in providing a satisfactory one. The peak current in the primary of the power transformer when a receiver is switched on may be twenty times the average current for a time not exceeding 0.01 sec. This occurs during normal operation, but on the other hand a fault resulting in twice the normal primary current over a period of time may lead to transformer breakdown.

Since a normal cartridge fuse will blow within 0.01 sec. with five to ten times its rated current applied, a fuse of four times the rated current of a receiver would be the smallest value which could be used. Such a fuse would probably not fail immediately, even with a complete short circuit on the whole high tension winding of a receiver, and would be almost useless.

Two types of fuse which can be used satisfactorily under such conditions have been described (Ref. 30). The first consists of the normal glass cartridge and ends, containing in series a small spring soldered under tension to a fine manganin resistance wire by means of a blob of low temperature solder (e.g. Wood's metal). A prolonged overload produces enough heat in the resistance wire to melt the solder and allow the fuse to clear, but the thermal inertia of the mass of solder protects the fuse against short duration surges. With a severe overload the resistance wire clears almost instantaneously. An advantage of this type of fuse is the low temperature required for operation—of the order of 100°C compared with perhaps 900°C for a normal type of fuse.

Another fuse has been made consisting of a high melting point nickel wire with blobs of magnesium powder in a binding varnish supported on it. Once again the thermal inertia of the blob allows short duration surges to occur without damage, but a prolonged overload raises the magnesium powder to ignition point (about 500°C) and the fuse clears.

A different type of protection has been used in other types of receivers. This consists of an insulated strip of metal with high heat conductivity which is included in the power transformer during winding. One end of the strip projects outside the winding and to this a small stirrup is soldered with very low melting point solder. A spring engages in the stirrup under tension and the primary current to the whole receiver passes through the assembly. Any overheating of the power transformer melts the solder and the spring disconnects one side of the mains from the receiver. Such a device might not protect a low impedance rectifier from damage if the input condenser were to break down, but it could save the power transformer and would certainly prevent a fire.

A heat-operated overload cut-out is described in Ref. 65.

See also Chapter 38 Sect. 12 for general information on fuses, and Table 55.

(v) Tropic proofing

Tropic proofing has been the subject of a large amount of investigation (Ref. 40). However many treatments described are not applicable to commercial A-M receivers —even if only because of expense—and in any case are not required for equipment which, although in the tropics, is to operate inside a home.

For " commercial tropic proofing " the following points might be taken as a minimum requirement :—

(a) Good quality resistors, derated to dissipate no more than two thirds of the manufacturer's rating.

(b) Good quality paper capacitors, preferably sealed in glass, but at least moulded in some non-hygroscopic composition, with particular care (non-cracking wax or varnish sealing for instance) against ingress of moisture along leads. Voltage rating to be at least twice that experienced under working conditions. Mica capacitors to be used in positions critical to leakage e.g. a-f coupling capacitors, or a.v.c. by-pass capacitors.

(c) Mica capacitors in tuned circuits to be of silvered mica type, flash-dipped in non-hygroscopic wax or varnish.

(d) Trimmers to have air dielectric.

(e) Power transformer to be moisture proofed, preferably by baking and vacuum impregnation with bitumen, or with a varnish which can be made to set satisfactorily right through the winding (this must be checked). Failing vacuum impregnation, pitch sealing can be used providing good penetration is obtained. Penetration is assisted by baking the transformers, standing them on edge with the top of the winding just above the surface of the pitch immediately after baking for perhaps half an hour, and then lowering the whole transformer below the surface in the same position and leaving for another quarter hour. The transformers can then be drained.

(f) A-F transformers and chokes to be vacuum impregnated and to have the core connected to the winding, the whole assembly being isolated from the chassis.

(g) Coils to be wound on moulded or ceramic formers and baked, impregnated (preferably under vacuum) and flash dipped in non-hygroscopic wax.

(h) Very fine wire to be avoided ; 36 A.W.G. is a suitable minimum size.

(i) Hook-up wire to be covered only with good quality rubber of low sulphur content, or P.V.C.

(j) All corrodible metals to be suitably treated, e.g. steel to be well and heavily plated (and lacquered where possible), aluminium to be anodised if possible or chromate dipped in such places as gang plates, brass to be plated. Die castings and readily corrodible metals, such as zinc, to be avoided.

(k) Plywood to be urea-bonded.

(l) Good quality micarta to be used for lug strips, wavechange switch wafers, etc. Micarta to be baked and vacuum impregnated in non-hygroscopic compound where possible.

(m) All fungus-supporting media such as cloth and other organic materials to be avoided as far as possible and fungus and moisture proofed if used.

(n) Wiring to be arranged as far as possible to minimize the effects of leakage e.g. B+ and a.v.c. not to be wired to adjacent lugs on a lug strip, etc.

(o) All-glass valve types to be used to avoid losses in moulded insulating material, together with high quality valve sockets.

(p) Ceramic insulation to be used in the tuning gang if possible. Micarta—if used—must be baked, vacuum impregnated in varnish and rebaked.

Additional improvements which can be incorporated include the use of ceramic instead of micarta for such items as lug strips, wavechange switch, and valve sockets, hermetic sealing for individual components (particularly transformers), hermetic sealing for the complete equipment with silica gel used for dehydration, and the avoiding of contact potentials in excess of a small fraction of a volt between contacting metals. Platings of appropriate metals can be used to minimize potential differences between adjacent metal surfaces.

See also Chapter 11 Sect. 7 for tropic proofing of coils.

(vi) Parasitic oscillations

The high slope of modern valves makes them particularly liable to generate parasitic oscillations unless suitable precautions are taken. In a radio receiver, a power output stage employing a high slope valve is the most probable cause of trouble, which may show up as a continuous " frying " noise, as an irritating " buzz " perhaps only on loud passages, or merely as reduced output with distortion.

Parasitic oscillations often occur at frequencies of the order of 100 Mc/s with leads from valve sockets forming resonant circuits and with a feedback path provided by a few micromicrofarads of capacitance between plate and grid circuits. In such a case a suitable remedy is a non-inductive resistor (say 50 000 ohms, ½ watt, carbon) wired directly to the grid pin. This increases the losses in the high frequency circuit to such an extent that oscillation is not possible.

Because the placing of wires is liable to vary between receivers, oscillation may occur only in some receivers of a production run, but it is normal practice to provide a grid stopper in each set to avoid rejects. In extreme cases it may also be necessary to use stoppers in screen grid or plate circuits, but the values must be much smaller to avoid excessive d.c. voltage drop.

Valves other than high slope output valves can be troublesome, and in one instance some of a production run of receivers having i-f amplifiers with bare tinned-copper leads a few inches in length connecting the grid and plate pins to the i-f transformers were found to be oscillating at a frequency in excess of 200 Mc/s. The trouble showed up as poor i-f sensitivity with high noise level, and was cured by wiring the hot side of the i-f trimmer directly to the valve socket, thereby including the inductance of the lead to the transformer in the i-f tuned circuit.

The best test for parasitic oscillation in an a-f amplifier is to examine with an oscilloscope the output waveform with the amplifier driven from zero input to overload at various frequencies. Oscillation may be shown as a thickening of the trace over part or all of the cycle or by a higher frequency superimposed on the correct trace. In the absence of an oscilloscope, unusual or varying plate current in an output valve may be taken as an indication of oscillation particularly if the plate current can be varied by moving the hand near the valve.

Additional details on parasitic oscillations are given in Ref. 52.

(vii) Printed circuits*

Printed electronic circuits are no longer in the experimental stage. Introduced into mass production early in 1945 in the tiny radio proximity fuze for mortar shells developed by the National Bureau of Standards, printed circuits are now the subject of intense interest on the part of manufacturers and research laboratories in this country and abroad.

Circuits are defined as being " printed " when they are produced on an insulated surface by any process. The methods of printing circuits fall into six main classifications. (1) Painting. Conductor and resistor paints are applied separately by means of a brush or a stencil bearing the electronic pattern. After drying, tiny capacitors

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*Reprinted by permission of The Institute of Radio Engineers from Ref. 38.

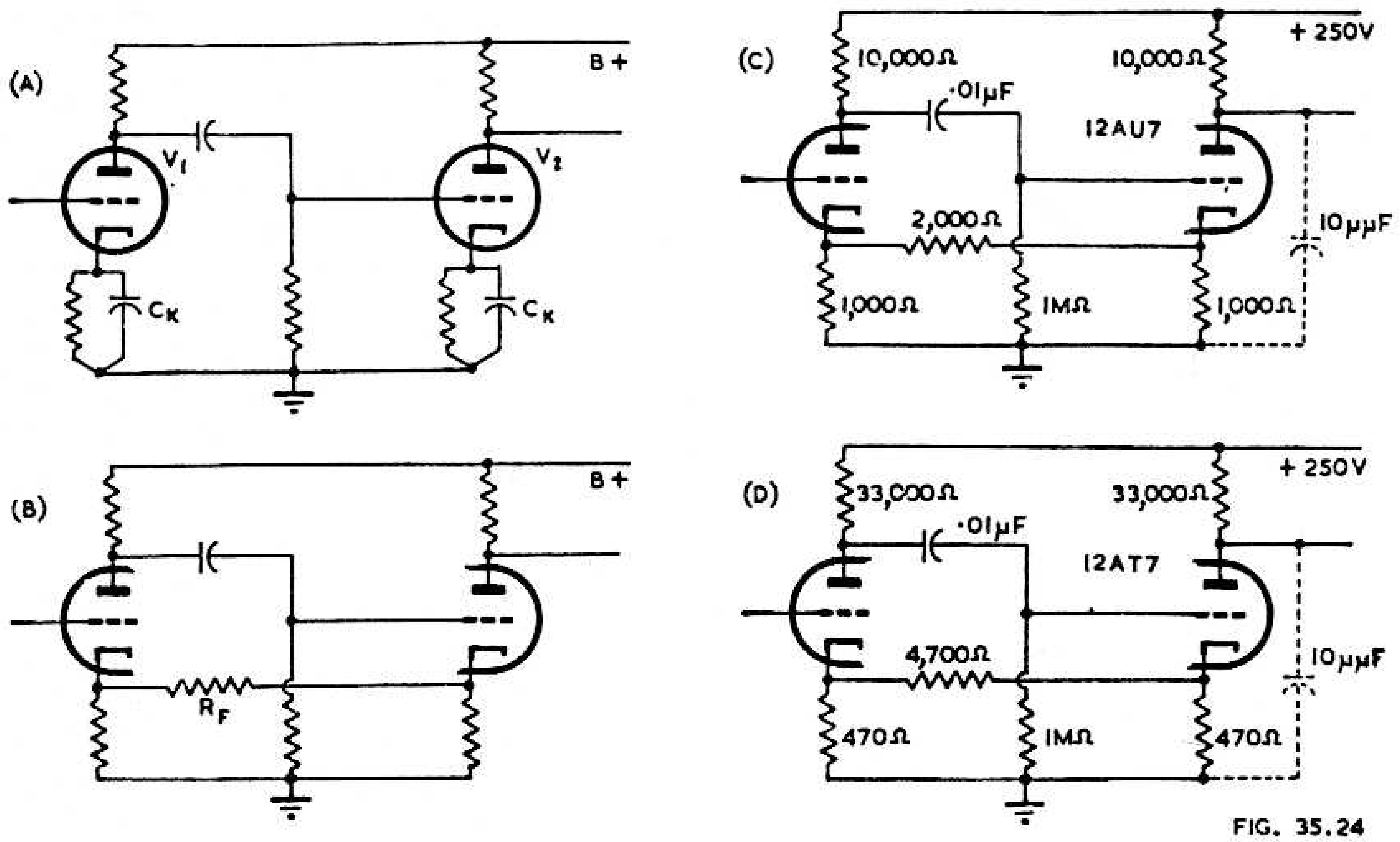

FIG. 35.24

Fig. 35.24. *Positive feedback circuits for eliminating cathode bypass capacitors* (*Ref.* 51).

and subminiature tubes are added to complete the unit. (2) Spraying. Molten metal or paint is sprayed on to form the circuit conductors. Resistance paints may also be sprayed. Included in this classification are an abrasive spraying process and a die-casting method. (3) Chemical deposition. Chemical solutions are poured onto a surface originally covered with a stencil A thin metallic film is precipitated on the surface on the form of the desired electronic circuit. For conductors the film is electroplated to increase its conductance. (4) Vacuum processes. Metallic conductors and resistors are distilled onto the surface through a suitable stencil. (5) Die-stamping. Conductors are punched out of metal foil by either hot or cold dies and attached to an insulated panel. Resistors may also be stamped out of a specially coated plastic film. (6) Dusting. Conducting powders are dusted onto a surface through a stencil and fired. Powders are held on either with a binder or by an electrostatic method.

Methods employed have been painting, spraying, and die-stamping. Principal advantages of printed circuits are uniformity of production, and the reduction of size, assembly and inspection time and cost, line rejects, and purchasing and stocking problems.

See Ref. 37 for a description of the production of complete radio receivers by printing techniques. See also Refs. 38, 39, 46, 47, 61, 62, 63, 64.

There are components which it is not practicable to produce by printing, e.g., electrolytic and other high value capacitors. In Ref. 51 details are given of circuit techniques to eliminate such components without seriously affecting performance.

Fig. 35.24A shows a conventional two-stage triode. amplifier and Fig. 35.24B a circuit with similar gain which does not use electrolytic capacitors. In Fig. 35.24B the removal of the cathode by-passes decreases gain and results in an a-f voltage appearing across each of the two cathode resistors. These voltages are in opposite phase and by adjusting the positive feedback through R_F from the cathode circuit of the second valve to the cathode circuit of the first valve the gain of the amplifier can be restored to the original level.

Fig. 35.24C shows a practical amplifier with a voltage gain of 80 and a bandwidth (3 db down) of 250 Kc/s. Fig. 35.24D gives a single valve amplifier with a gain of 1000 and a bandwidth of 100 Kc/s. Two such valves can be used in a four stage amplifier with a gain of one million and a volume of six cubic inches.

Fig. 35.25A shows a method of eliminating screen by-passes by using positive feedback from the plate of a following valve, while Fig. 35.25B demonstrates a screen regeneration circuit similar to the cathode regeneration circuit of Fig. 35.24B.

Circuits for high frequency compensation by means of positive feedback used in place of compensating inductors are also given in Ref. 51.

An analysis of a-f circuits with " cathode neutralization " will be found in Ref. 54

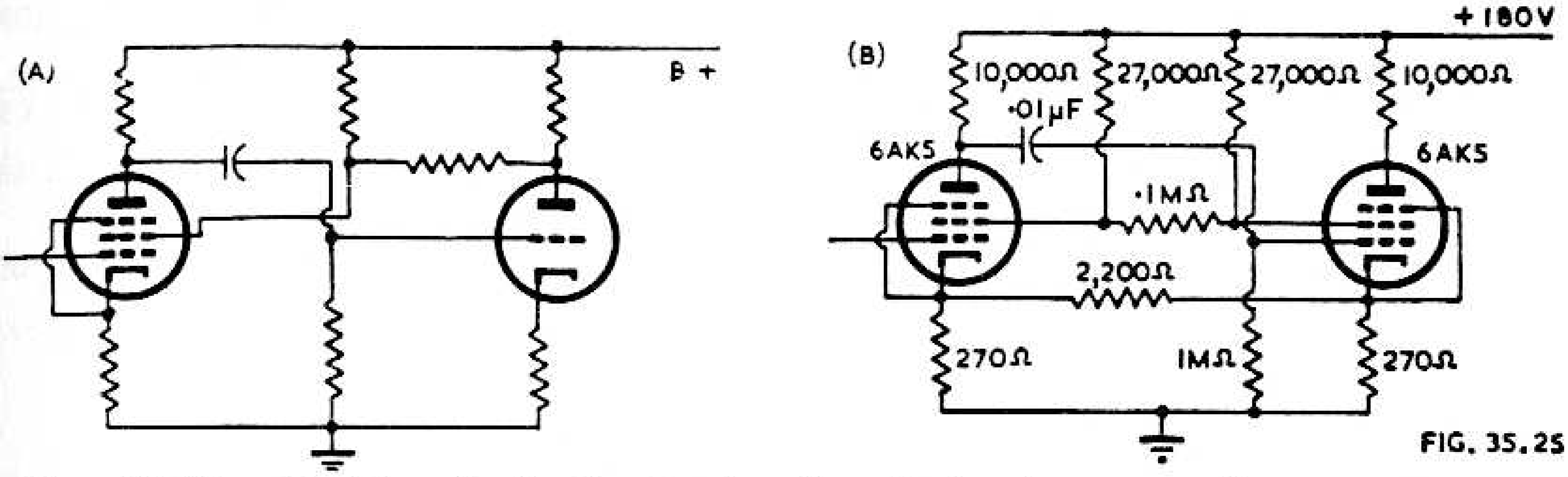

FIG. 35.25

Fig. 35.25. *Positive feedback circuits for eliminating screen bypass capacitors* (*Ref.* 51).

(viii) Other miscellaneous features

Synthetic bass is described in Chapter 14 Sect. 3(viii) and its application in receivers in Chapter 15 Sect. 12(ii).

Tone control is covered in Chapter 16.

Whistle filters are covered in Chapter 16 Sect. 11.

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