165

HARTLEY ON HI-FI
BOOK ONE

30p

# RADIO TUNERS

by
H. A. HARTLEY

F.M., A.M. AND STEREO TUNERS

BERNARDS HI-FI MANUALS

# RADIO TUNERS

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*by H. A. HARTLEY*

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# CONTENTS

# RADIO TUNERS

## CHAPTER 1

## RELATIVE MERITS OF AMPLITUDE AND FREQUENCY MODULATION

### General Considerations

The basic purpose of this book is to explain the fundamental processes involved in reproducing musical programmes with as little distortion as is humanly possible. " Perfect reproduction " as so often claimed in the advertisements is not possible in the imperfect world we live in, simply because it is quite impossible to produce a practical piece of equipment that will conform to a theoretically perfect design.

The loudspeaker is often quoted as being the weakest link in the chain, simply because we know of no way whereby we can design a speaker which will radiate sound waves of all frequencies with exactly the same amplitude either on the axis or in all directions, and the sound pressure at all frequencies must also be equal in all directions if *reproduction* of the original programme is desired. Yet although there are very great difficulties in the way of designing good speakers, it does not follow that the speaker is the weakest link, for even a perfect speaker's performance is controlled by the way it is mounted in an enclosure and by the acoustics of the room in which it is heard. The room itself might indeed be the " weakest link ".

However, the best speaker can only reproduce what is fed into it, and the best speaker will also reproduce quite faithfully the distortion that is created before the speaker accepts it. Distortion arises in the equipment existing between the original performance and the signal fed into the speaker. Some of this is under the control of the high fidelity user, some of it beyond his control; the latter includes shortcomings of broadcast transmitters, telephone lines, record manufacturers and the people who design, make and sell pickups.

It is not my purpose to say that Mr. A's amplifier is a better amplifier than Mr. B's, nor Mr. C's pickup better than Mr. D's. It is very difficult to define what we mean by " better " for we have to ask the question " better for what?". Mr. C's pickup may have a wider, flatter response than Mr. D's, but if it has more cross-talk between stereo channels we could justly say it is a worse pickup, for the frequency shortcomings of the D pickup could be rectified by tone correction, but we can't eliminate the cross-talk of the C design.

The most successful high fidelity installation must be considered as a whole, yet the ultimate user of it does not buy it as a whole, for no manufacturer has yet succeeded in designing, manufacturing and selling at a reasonable price a completely integrated system, and it is doubtful if such a manufacturer will ever exist. The various problems involved are so many and complex that we find manufacturers who are conscientious and responsible confining themselves to creating those pieces of equipment which they are best fitted to produce, and that leaves the final responsibility of selection in the hands of the buyer.

The ultimate selection will, of course, be made on the basis of what he likes the sound of best; but supposing he says that he is in no position whereby he can compare one against another, what is he going to do? Being myself a high fidelity designer of some 35 years' experience I confess I still don't know all the answers. At one period I was so much preoccupied with a particular piece of original research I felt I had become somewhat isolated from the work of others, and when stereo reproduction was launched on an unsuspecting world I felt that I ought to know what it was all about.

I knew what was involved, but what I didn't know was what had been achieved, so, seeing an advertisement of a dealer who offered spot A-B tests of all current equipment by a well-thought-out switching control panel, I went to the shop and asked to hear stereo. What I heard was neither stereo nor high fidelity and the salesman seemed annoyed when I didn't get enthusiastic. My only comment was that I was ready to buy something which would increase my pleasure in music at home, but what he had demonstrated didn't strike me as any advance on what I already had, so I couldn't summon up any enthusiasm.

Now, I knew why his demonstration failed, and that knowledge I had acquired as a result of my professional work over several decades; it is even possible that I might have been able to get hi-fi stereo out of the equipment he had in his shop, but if I had made such a suggestion I feel sure I would have been branded as an interfering busybody. Well, I may be a busybody, but I am not an interferer, and so I can state that this book is intended to guide you in making suitable choices in your equipment.

The rules of the game are not very difficult to learn, provided you keep an absolutely open mind. Nor is it necessary to have a profound mathematical ability to evaluate what others have done. Mathematics is required to design a piece of equipment in the first place, but mathematics is just one of the tools of the designer's trade, and the wrong use of mathematics can be fatal to success. As manufacturers don't give you the mathematical design when they invite you to buy their product, you cannot say if their theoretical design was originally right or wrong. But you can criticise the outcome if you know what the rules of the game are, and those rules are, simply, scientific " laws ".

Unfortunately, since scientific laws are man-made rules, a certain proportion of these laws are not valid. They are valid within certain limitations, or perhaps they are only statements of opinion masquerading under the name of laws or principles, and I can state from positive knowledge that quite a few of the opinions held in the field of high fidelity reproduction, and accepted as " laws ", have no real validity at all. So, in giving you the rules of the game, it is also my duty to tell you what opinions are not rules; for, in examining the multitude of different makes and designs presented to you by the " industry ", there are some designs which are not so much the result of serious scientific effort as of a particular bee in the bonnet of someone who wants to get on to the high fidelity band-wagon. At all times you should keep in mind that sound legal maxim—" Let the buyer beware!".

## Defects in Radio Reception Beyond Your Control

These have to be mentioned because, although there is little or nothing you can do about it, they affect the final result in terms of satisfying reproduction. It is all too easy to think about the nature of a proposed installation and forget that the world of reality may make the desired results impossible to attain. I have made that mistake myself. At one time I was dissatisfied with the programmes I received from the B.B.C. and felt it would be a good thing to be able to turn to the broadcasting stations of the world. As I had neither the time nor the inclination to design and make a tuner myself I investigated the market and decided, at great cost, to buy a certain multi-waveband tuner fitted with variable selectivity, AVC, tuning indicator, and having high sensitivity; in fact the best that money could buy.

After a fortnight's use I found that the degree of interference between stations and from man-made static added to " night distortion " and other distortions was so intolerable that the signal injected into my audio amplifier had no entertainment value at all. I should have known better, if I had only stopped to think; but I just didn't think that conditions were so bad. I am told that today they are even worse, but as I have no sensitive tuner unit I don't know. I have just accepted as something not to be disputed that you cannot hope to achieve high-grade reproduction from distant stations.

The interference that one suffers on " ordinary " transmission and reception can take several forms. You get interference from stations on adjacent channels as a beat note set up by the two carriers, in theory at 9000 c.p.s., and as sideband splash through overlap of the modulated carriers. Electrical machinery which has not been suppressed behaves as a transmitter, generally of untuned characteristics, which further modulates the desired carrier. Fading, resulting from varying reflection from the Heaviside layer, can only partly be neutralised by automatic volume control because the reflected wave is not reflected consistently in all its frequency and amplitude components. And, finally, even on local station reception, the quality of the received signal is limited by the quality emanating from the transmitter and passing through the land-lines.

Taking these various factors in reverse order, it is certainly true that the increasing demands of broadcasting have acted as a spur for telephone engineers to develop better land-line characteristics (although they are still not good enough for the best results); broadcasting authorities do within reasonable limits take care that their transmitters do not distort; electrical interference will always be with us so long as people who use such machinery do not care or are not compelled by law to care about the amenities of others; and adjacent channel interference can be substantially avoided if you are content to listen only to your local transmitter with a tuner insensitive enough to pick up an interfering station. If you are within the service area of your transmitter you can also forget about fading and night distortion.

That, substantially, was the position of listeners before the advent of FM broadcasting, and it should be borne in mind before considering now the possibilities of high quality radio reproduction and in the future the ways to be adopted for stereo broadcasting.

## Amplitude Modulation

All transmitters of the CW (continuous wave) type send out a carrier which is fixed in frequency. On this carrier is superimposed the programme material. Whatever method may be used to do the superimposing, the process is called modulating the carrier; the function of the receiver detector circuit is to remove the carrier component and pass on the programme signal in intelligible form. My reason for making this statement of the (to many readers) obvious is to call attention to some incorrect and misleading terms now in common use.

Presumably because it sounds more highbrow, the process of detection is now usually called " demodulation ", and the detector the demodulator. It is nothing of the sort. What the detector does is to suppress the carrier and pass on the modulation. Hence the process that takes place in this section of the receiver is " decarrierisation " and the detector is a " decarrierifier ". As there is no point in calling a spade anything other than a spade, I shall use the terms detection and detector, for we all know what they mean.

In an equally misguided and incorrect manner the term VHF in Britain (but not in the U.S.A.) is applied to the system of frequency modulated broadcasting provided by the B.B.C. Such a term implies that the only difference between this service and the ordinary one is that the carrier frequency of the former is higher than that of the latter. This difference certainly exists, but the much more profound difference is that they are two entirely different systems of modulation. I believe it correct to state that this misuse of the term VHF originated in the B.B.C. and although I tried to have this corrected before it became common usage, I made no impression on the philological bureaucrats. Manufacturers these days label certain tuner units AM/FM to show what is included in the designs, but many writers still talk of our FM service as being VHF.

Amplitude modulation is used in medium and long wave broadcasting and in both television video and sound, and these latter are certainly VHF. Why a totally different type of transmission in Band 2 should not receive its distinctive nomenclature is one of those things that will not be adopted in this book. When I say AM I mean amplitude modulation whatever the carrier frequency, and when I say FM I mean frequency modulation whatever the carrier frequency.

Let us now consider what happens with amplitude modulation. Fig. 1.1.1. shows the effect of superimposing both a sine wave and a non-sinusoidal wave on the sinusoidal carrier wave of the transmitter. The carrier wave is, of course, at some radio frequency and the modulating wave is within the audio spectrum. For high fidelity reproduction the audio spectrum is generally considered to extend from 40 to 15,000 c.p.s.

The shaded area is called the envelope and it is shaded because the oscillations of the carrier are at such high frequency as compared with the modulating audio wave that they could not be

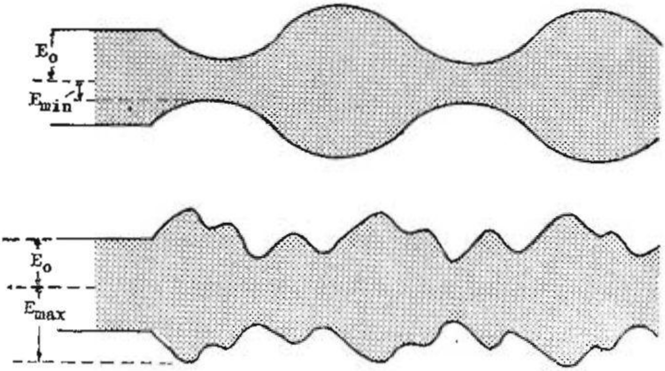


Fig. 1.1.1. *Modulated envelopes of RF signal, sinusoidal, and irregular.*

shown on the drawing true to scale. The drawing does, in effect, show what would be displayed on the tube of a cathode ray oscilloscope. The amplitude of the carrier, $E_o$, is determined by the power of the transmitter, and is substantially the average envelope amplitude. When the audio wave is added there is a variation in the modulated carrier amplitude between $E_{max}$ and $E_{min}$. For sinusoidal modulation the *degree of modulation* is given by the simple equation

$$\text{Degree of modulation} = (E_o - E_{min})/E_o$$

If it is desired to express this value, which can vary between 0 and 1, as a percentage, you simply multiply by 100. When the audio wave is not sinusoidal, as always happens when a programme is being transmitted the degree of modulation must necessarily vary and is expressed in this manner

$$\text{Positive peak modulation} = \frac{E_{max} - E_o}{E_o} \times 100$$

$$\text{Negative peak (trough) modulation} = \frac{E_o - E_{min}}{E_o} \times 100$$

In both cases if the amplitude of modulation were such that at trough modulation the envelope were reduced to a point on the axis of the envelope, the trough modulation would be zero and the positive peak modulation 100%. This represents the *limit* of undistorted amplitude modulation, and a moment's thought will indicate that the actual power sent out by the transmitter only occurs on peak modulation. As programmes do not consist exclusively of very loud signals it is obvious that AM is not a very efficient system since it only uses a fraction of the available power in the transmitter.

In a subsequent part of this book I shall explain how it comes about that the *shape* of the modulating audio wave has a direct bearing on the actual frequencies contained in it. All musical sounds contain harmonics as well as the fundamental frequency. and the number of harmonics is closely allied to the steepness of the wavefront. For the moment, we need only remember that the postulate—that frequencies up to 15,000 c.p.s, are needed for high quality reproduction—derives from the need to reproduce the harmonics as well as the fundamental, and when ordinary commercial receivers are designed to give a treble cut-off of about 4000 or 5000 c.p.s. it is not because the designers are unable to appreciate the advantages of wider range reproduction but because their prime duty is to produce a sensitive receiver which will not introduce interference from adjacent channels.

This suppression of higher harmonics is a form of distortion and has to be considered alongside the distortion that may already exist in the modulated envelope. Between the original performance in the studio and the transmitted signal there is a chain of equipment which introduces certain defects which can be classified. The introduction of frequencies not in the original programme is amplitude or non-linear distortion; disturbance of the relative amplitudes of the frequencies in the original is frequency distortion, and incorrect phase relationships is phase distortion. These terms crop up in discussing amplifiers, and so should be borne in mind, and distortions of these types obviously exist in the transmission whether it is amplitude or frequency modulated.

There is, however, a further source of distortion and this is under the control of the operator of the receiver. Any tuned circuit has a response shown by a resonance curve, and a typical resonance curve is shown in Fig. 1.1.2. Such a curve shows impedance plotted against frequency and is almost symmetrical about a vertical axis located at the tuned frequency. At this point the gain of the circuit is maximum. If the tuned circuit has a high Q (efficiency) it will be sharp-pointed, as at (a); if of low Q, or shunted by a resistance, which can actually be the resistance of the coil winding itself, the curve will be more rounded, as at (b), but the gain will be less because the efficiency is lower. If there

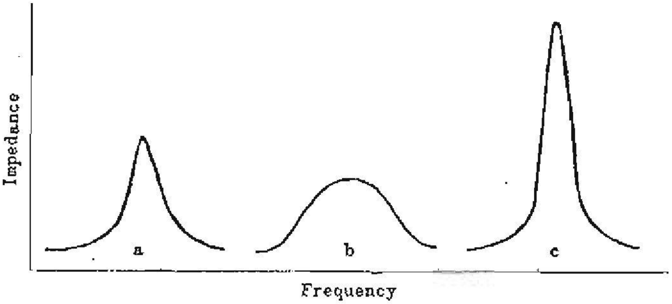


Fig. 1.1.2. *Resonance curves of tuned LC circuits: (a) high Q; (b) low Q; (c) two high Q circuits in series.*

are two tuned circuits accurately ganged the curve will be higher and steeper as at (c); in other words the two circuits will be more selective than one circuit. Since the response falls the further you go away from the tuned frequency it will be obvious that the higher frequencies will be amplified less than those near the carrier frequency, hence the expected treble loss with selective receivers. This is ordinary frequency distortion.

Now suppose the tuned circuit is tuned to some other frequency than that of the carrier; not a lot, just " off tune ". The modulation envelope is symmetrical about its axis of zero amplitude, but after passing through (or more correctly, being rejected by) the tuned circuit then the upper and lower halves of the envelope are not handled equally and the envelope becomes unsymmetrical about its axis, since the symmetry of the resonance curve only exists about its own tuned frequency. This results in amplitude distortion. There is also some phase distortion both on and off tune, but I do not want to complicate the issue too much.

If the frequency distortion is something we more or less have to put up with, we certainly need not add amplitude distortion to it, and this virtually demands a tuning indicator to give a positive indication when the receiver is exactly tuned to the desired carrier. Mistuning on a TV set is instantly noticeable because of the nature of the picture, but even a highly trained ear cannot determine with precision when a continuous-tuned receiver is right on the carrier, judged aurally. It is somewhat easier with AM than with FM, but an electron-ray tuning indicator should be considered an essential part of any high fidelity tuner unit.

Assuming the receiver is correctly tuned to the desired carrier frequency, the distortion caused by loss of sidebands through too selective tuning over the whole signal frequency circuits can be avoided to a considerable extent by using band-pass tuning. In Fig. 1.1.2., curve (a) shows the response of one tuned circuit and curve (c) of two circuits tuned to the same frequency. If, now, the first tuned circuit is adjusted to resonate at, say, 5 kc.p.s. below carrier frequency and the second adjusted to 5 kc.p.s. above carrier frequency, you will get a resonance curve similar to that shown in Fig. 1.1.3. (a), and the width across the two peaks will be 10,000 c.p.s. If the two circuits were adjusted to carrier frequencies of ± 10 kc.p.s. the width between the peaks would be 20,000 c.ps. and this would be nearly enough to give a good audio response after the detector.

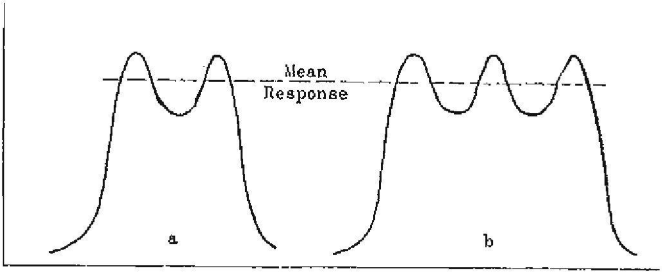


Fig. 1.1.3. *Band pass response of (a) two and (b) three staggered circuits.*

But in such a case, and although it is not drawn in the figure, it will be obvious that the dip between the two peaks would be rather severe; this valley can most easily be filled up by a third tuned circuit tuned exactly to carrier frequency, as shown in Fig. 1.1.3. (b). The most convenient circuit arrangement to include three tuned circuits is to use a TRF receiver with one stage of RF amplification; the first two tuned circuits are included in the grid circuit of the RF amplifier and the third in the anode circuit of the same valve.

In theory adjustment of these three tuned circuits could be carried out by adjusting each separately with a signal generator; in practice, it can't be done with any precision so simply. The only satisfactory way is to use a signal generator set to the desired signal frequency, have this signal swept over a frequency band of the desired width by a wobbulator, and examine the detector output with a CRO. Visual indication of what is happening is essential, for the aim must always be to get an entirely symmetrical response centred on the carrier frequency.

Consider Fig. 1.1.4. In (a) we have the response of a band-pass filter in which both tuned circuits have the same Q; but one circuit is tuned further away from the carrier frequency than the other with the consequence that the impedance at carrier frequency has been reduced. As a consequence the modulation envelope has been passed on with frequency distortion, as described above with mistuning, but in addition the flat top of the band-pass has been severely tilted, resulting in one set of sidebands being amplified more than the other, with consequent complex distortion made up of a mixture of amplitude, frequency and phase distortion.

With three tuned circuits, of a type already mentioned, again let us assume that the three circuits still have the same Q. This is illustrated in (b), and because the third tuned circuit is tuned on the carrier frequency the effective Q is higher that that of the band-pass filter. So we have lost the desired flat top and introduced frequency distortion once more. The remedy is to lower the Q of the third tuned circuit, and although, admittedly, this is shunted by the grid impedance of the detector, it is unlikely to be low enough to reduce the Q of the tuned anode circuit sufficiently. So the shunt resistance across the tuned circuit must be lowered still more to, literally, spoil its efficiency. However, the impedance of a tuned circuit varies with frequency, and what shunt resistance may be desired at, say 450 metres, will not be the same as that required at 200 metres.

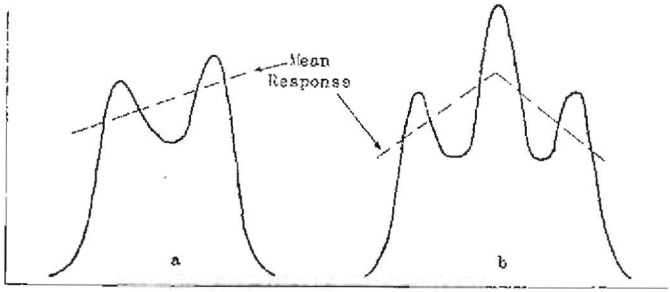
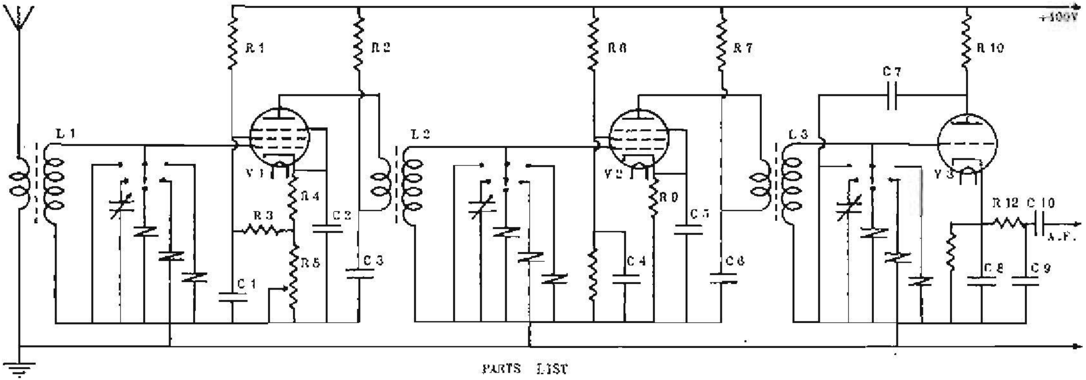


Fig. 1.1.4. *Misaligned band pass responses.*

This is one example of the not so obvious snags that plague the life of a designer of high fidelity equipment, and it will now be seen that such an apparently simple task as designing an ordinary TRF receiver for one broadcast band is not so easy as it would seem. I had to face this problem many years ago when designing my own tuner unit for the market, and after considering all the factors involved, came to the conclusion that the only solution was to have a switch-tuned receiver in which the Home, Light and Third programmes were handled by pretuned and preadjusted circuits. From the commercial point of view, each tuner had to be preset in the test room for the three wavelengths operating in the district to which it was ultimately despatched, by the wobbulator-oscilloscope method; a great nuisance as it turned out, but at least it did ensure that the customer would be getting a non-distorting tuner.

The complete circuit of this tuner unit is given in Fig. 1.1.5. and includes some features not previously mentioned. The first position of the switch short-circuits each tuned circuit to remove any possibility of radio break-through when reproducing gramophone records. The second position connects a three-gang variable tuning capacitor, and in this position the receiver is peak-tuned in perfect alignment. The circuit shows that a band-pass grid circuit to the first RF amplifying valve is not used, but in point of fact two RF amplifiers are included. The reason for so doing is that a detector stage which does not distort under normal conditions requires a fairly considerable input as " normal conditions ". My choice fell on the so-called infinite impedance or cathode-follower detector, and this, like the diode, requires several volts input for distortionless operation. Particularly if an antistatic aerial is used in any other than an area of " saturation service ", a fair amount of RF gain is required and with the loss of amplification consequent on staggering the tuned circuits, one RF stage may not be enough for a non-distorting detector. By using two stages the three tuned circuits could be perfectly aligned and considerable RF amplification results; this makes the tuner suitable for reception of distant stations, admittedly with loss of treble, but wide-band reception of distant stations is impracticable in any case; this sensitivity approached that of a conventional superhet but withal a much quieter receiver. The same three circuits could also be stagger tuned to give the requisite band-pass effect by switching in pre-set air dielectric capacitors; this is done by positions 3, 4 and 5 of the switches.

Note that the RF transformers are permeability tuned in addition. These, obviously, cannot be adjusted by any switching process, but it was found that exact band-pass alignment for any given three wave-lengths required a certain value of inductance;



PARTS LIST

R1 56K 1W 20%
R2 6.8K ½W 20%
R3 56K ¼W 10%
R4 160 ¼W 10%
R5 10K Pot.[Radio gain]
R6 56K 1W 20%
R7 6.8K ½W 20%

R8 56K ¼W 10%
R9 160 ¼W 10%
R10 10K ¼W 20%
R11 47K ¼W 20%
R12 22K ¼W 20%
C1 0.1 paper tubular
C2 0.1 do do

C3 0.1 paper tubular
C4 0.1 do do
C5 0.1 do do
C6 0.1 do do
C7 8/500V electrolytic
C8 .0003 mica
C9 .0003 do

C10 0.5 paper tubular

| | Octal | Miniature |
|---|---|---|
| V1 | 6SG7 | 6BA6 EF93 |
| V2 | 6AC7 | 6AH6 6BA6 |
| V3 | 6J5 | 6C4 EC90 |

L1,L2,L3 medium wave RF transformers with dust cores

Main tuning condenser (switch position 2.): 3-gang .0005 mfd.swing. Preset trimmers (switch positions 3,4,5): .0001 mfd. air dielectric, shunted when required with SM condensers of appropriate capacity. Condensers C1,2,4,5,10 must have metal tubes with tubes grounded. Ground connections must be grouped as shown.

Fig.1.1.5. The author's high fidelity TRF receiver with switched tuning for three MW channels with bandpass response and continuous tuning with peaked response for distant reception, Radio gain is manually controlled.

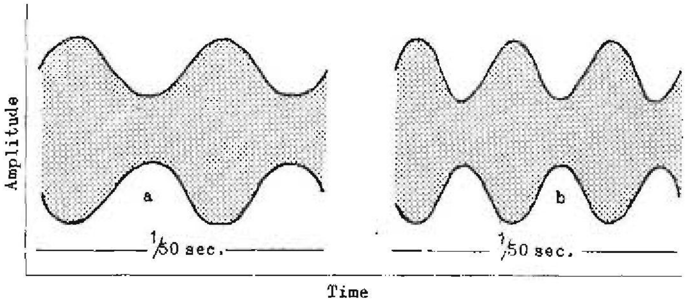


Fig. 1.1.6. *Sine wave modulated RF envelopes at (a) 100 and (b) 150 cps.*

the optimum L value for, say, the London area, was not necessarily the optimum value for another. The best value of L being determined, the band-pass alignment was then completed by adjusting the C's. If this did not produce the desired flat topped response the cores of the transformers were reset and the operation repeated. This will, perhaps, indicate how necessary it is that a visual indicator like an oscilloscope be used to align even a simple receiver like a TRF unit.

**Electrical Interference**

This, as I mentioned earlier, is a form of distortion beyond the control of the listener in terms of high fidelity reproduction, but it can be modified by using the " tone control ", in other words, by cutting the treble. But it cannot be eliminated except by special circuits which in themselves produce results which are not free from distortion. It is important to understand why this should be so.

The modulation envelope of Fig. 1.1.1. illustrates the shape of the transmission involving factors of amplitude and frequency, but you should not get confused as to which is which. Fig. 1.1.6. represents two modulation envelopes and the axes of the diagram have been called " amplitude " and " time ". Envelopes (a) and (b) represent two frequencies but with the same degree of modulation, hence the mean width about the axis in each case is the same. On the time axis, let us assume that each envelope extends over 1/50th. of a second. (a) would therefore represent a carrier modulated at 100 c.p.s. and (b) modulation of 150 c.p.s. Since the carrier frequency is so high in comparison with the modulating frequencies it appears, as before, as a shaded area.

Now assume the presence of a nearby " transmitter " in the

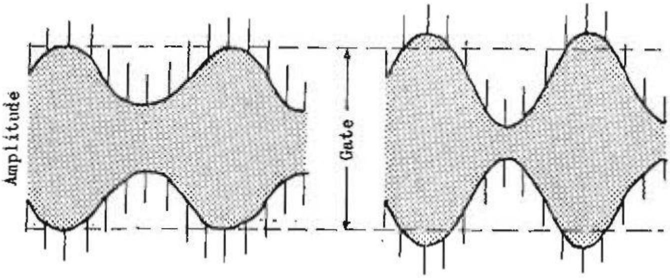


Fig. 1.1.7. *Noise impulses on modulated envelopes.*

shape of an electric motor, hair-dryer, or the like. This will send out signals of a sharp impulse type of fixed amplitude but at a frequency depending on the rate of the sparking between commutator and brushes of the motor. Since this has its own amplitude, this will be added to the envelope amplitudes as depicted in Fig. 1.1.7. (a). If the degree of modulation is increased, as for example with a loud passage of music, the envelope would appear as at (b), but since the amplitude of the interference has not increased, the proportion of signal to interference is better. This proportion is, of course, the signal-to-noise ratio.

In the case of interference from another radio transmitter it is generally reckoned that the ratio between wanted and unwanted signal should be about 25 to 1, and the " service " area of a broadcasting station is that in which such conditions are presumed to exist. Obviously the service area must be a function of the degree of modulation, and necessarily varies continuously with any programme having loud and soft passages, but the mean modulation defines the area. Electrical interference could reduce the service area of a station to nothing at all, and this actually does happen if the interference is close to the receiver, especially if the receiver is not close to the transmitting station.

Since the interference produces an increase of amplitude of modulation it should be possible to restrict the amplitude, and to illustrate the effect of putting up such a " gate " I have drawn two parallel lines on Fig. 1.1.7. to indicate a gate wide enough to pass the modulation envelope (a). This will cut out the interference on the peaks but do nothing in the valleys. Moreover, when the modulation amplitude is increased, as in (b), the gate will chop off part of the signal. Note that this is not cutting out the high frequencies; it is cutting out the signal entirely. An amplitude limiter on AM is therefore out of the question.

But one can have a frequency limiter—the tone control. The interference spikes on the envelope are duly passed on by the detector, and appear as such in the audio amplifier. If the radio circuits were so sharply tuned that frequency limitation operated before detection, the upper frequencies of the spikes, as with those of the wanted signal, would be removed, and use of a post-detector tone control will remove still more. But by virtue of the shape of the interfering spikes a very wide band of frequencies is involved, and all tone control can do is to remove the sharp edge of the sound of the interference; it cannot remove it. There is, of course, a marked difference between the sound of interference with a top cut at 2000 c.p.s. as compared with one at 10,000. The latter reproduces sufficient harmonics to make the sound very incisive, and some people prefer " mellowness " to the edginess of distortion, but that isn't high fidelity.

So long as AM was the only available system of broadcast transmission and reception a good deal of attention was paid to electronic noise-suppressors and interference eliminators, and some circuits are highly effective in doing what they are intended to do. There is, however, an appreciable risk of introducing distortion of the modulation by " doing things " to the response which includes the interference; the tendency today is not to use these circuits. Undoubtedly the best way of reducing interference to a high fidelity installation is to use one of the special antistatic aerials designed by a company which specialises in such problems.

## The Best Type of AM Receiver for High Fidelity

Before discussing this question I should point out one last source of distortion of the desired signal—valve noise. Except in the case of specially designed and made valves where considerable attention has been given to eliminating this fault, valves are, to greater or lesser degree, " noisy " in that they add a hiss to the detected signal. This, called shot noise, is generally originated in the anode circuit of a valve and due to the random variation of the anode current resulting in random variation in the rate of electron arrival on the anode itself. There is also noise generated by thermal agitation in the associate circuits, but this is of lesser magnitude and only becomes prominent with a high degree of amplification.

If a noisy valve is at the front end of a receiver then the noise will be amplified by successive stages. In a superheterodyne receiver there may be two or three stages of amplification in the

IF amplifier and the noise as well as the signal will be suitably amplified; it is also unfortunate that frequency-changer (mixer) valves are noisier than triode or pentode amplifiers. A superhet is therefore basically noisier than a TRF receiver for this reason, and the mere fact that there are more valves in the whole arrangement, each of which is capable of adding its mite of noise, emphasizes the fault. Moreover the superhet has other disadvantages not present in the TRF receiver—oscillator hiss and microphony, image production, oscillator drift and consequent tracking difficulty.

In a well-designed and properly adjusted superhet, the latter troubles are not present, but no design will overcome valve noise, unless specially selected valves are used and almost certainly a separate oscillator triode. And, of course, the supreme merit of the superhet is its constant selectivity. I pointed out above that the tuned L/C circuit impedance varies with frequency, and in an ordinary TRF receiver the selectivity will be greater at 200 metres than at 500. Any medium and long wave band TRF receiver is very noticeably more selective on medium than on long waves, and the same applies to the medium wave band itself. This was one of the reasons why I decided on a switch-over TRF receiver, as illustrated in Fig. 1.1.5, for not only could I ensure that the band-pass on each received wavelength was level, but of the same width.

Where the required signal has that 25:1 preponderance over an interfering signal the extra sensitivity of a superhet is entirely unnecessary. Moreover, it is only in such a receiving location that high fidelity reception can be ensured. If we add to this the inherently quieter characteristics of the TRF receiver, the choice seems inescapable. But if the receiver is of the continuous tuning type, then it seems highly desirable that the proper steps be taken to provide reasonably equal selectivity over the whole medium wave band, and that the band-pass has a flat top at all wavelengths. As this is not very easy to attain, the switch-tuned arrangement has a great deal in its favour—if it is properly set up in the first place. Remember, however, that an unswitched receiver should most certainly have a tuning indicator.

### Frequency Modulation

The basic difference between AM and FM is that in the former the frequency of the carrier is constant and its amplitude varies with the modulation, whereas in the latter the amplitude of the carrier is constant and its frequency varies with the modulation.

An illustration of what happens is shown in Fig. 1.1.8 where an unmodulated carrier is followed by modulation by a sine wave. The drawing is far from being to scale, since, to show the variation in carrier frequency with FM, shading cannot be used. Moreover the frequency of an unmodulated carrier is very much higher than that of the usual amplitude-modulated carrier, for reasons we shall see in a moment.

It is not the purpose of this book to give a complete description of the process of transmitting and receiving FM signals. There are plenty of books dealing with the subject in both an elementary and complete manner, to which the reader is referred if he feels inclined. Among the former it is commonly stated, as a matter of fact, that there are many more side band frequencies in FM than in AM, and if this is so, then it is obvious that a wider frequency separation in adjacent channels is necessary. The statement is perfectly correct, but many writers do not make it clear to the reader why it should be so; perhaps in some cases the writer has just copied what has been said by an authority. Yet since the aim in this book is to cultivate a critical attitude in your mind, it seems to me necessary that the thing should be explained.

Frequency modulation is not new; it was suggested nearly 40 years ago. Once it had been thought possible at all to convey intelligence by varying the frequency of the carrier instead of its amplitude the difficulty of an " overcrowded ether " seemed to vanish. But the early workers did not spot a trap which was artfully concealed by the very nature of the beast.

Fig. 1.1.1 shows an AM envelope; the vertical axis is in units of voltage or amplitude; the horizontal in units of time or duration. There is no frequency axis, so the only way to determine the frequency of any part of the envelope is to count the number of oscillations in a known lapse of time, as is done in Fig. 1.1.6. This, of course, is simple sinusoidal modulation, and only one modulating frequency has to be counted. In the case of a complex wave—and the waveform of music is always complex—there are not only the fundamental frequencies of the modulation but the harmonics as well. The amplitude of these harmonics is nearly always less, individually, than the fundamental, and so the power at which they are radiated is also less; but radiated they are and they constitute the frequency width of the AM transmission. If the carrier frequency is, say, 1000 kc.p.s. (1 megacycle) and the highest modulation frequency (fundamental or harmonic) is

10 kc.p.s. the side band spread will extend from 1000 — 10 kc. to 1000 + 10 kc.; that is, a total width of 20 kc.

Without stopping to think, one could assume that since the basis of conveying the signal is " doing something " to the carrier so many times a second, exactly the same would apply to FM. But supposing you do stop and think; you would have some justification for supposing that you could do with a very much narrower frequency band. First let us get some definitions set down.

In AM the audio modulation produces an instantaneous change in carrier amplitude and the whole envelope is a summation of the whole series of instantaneous changes. In FM the amplitude is kept constant and the modulation produces an instantaneous change in frequency. In case the word ' instantaneous ' worries you, just remember that in dealing with complex entities, analysis (mathematical or physical) precedes synthesis; you have to break the thing down into little bits, see how the bits are related to each other, and then reassemble the bits. If you want to kid the ignorant layman that you are a swell mathematician you call it the differential and integral calculus. It sounds more impressive but that is all it is. In the present case our little bits are instantaneous amplitudes and instantaneous frequencies, and as they change from instant to instant with respect to each other, we have to get hold of an instantaneous bit and see what happens to it.

The *rate* at which the instantaneous frequency varies is called the *modulating frequency*, and obviously is related to the *frequency* of the modulating audio wave. The *amount* of frequency variation from the unmodulated carrier frequency is called the *deviation frequency* and is determined by the *amplitude* of the modulating wave.

Suppose, now, that the FM carrier is modulated with a sine wave of such amplitude that the deviation frequency is ± 10 c.p.s.; that is to say the instantaneous frequency of the carrier is varied between 1000.01 and 999.99 kc.p.s., if the unmodulated carrier frequency is 1000 kc.p.s. If the modulating sine wave has a frequency of 500 c.p.s. then all we have to do is to change the instantaneous frequency at the rate of 500 times per second. If the modulating sine wave had twice the amplitude and twice the frequency, the deviation frequency band width would be ± 20 c.p.s. and the instantaneous frequency varied 1000 times per second. And this can be proved mathematically! It follows,

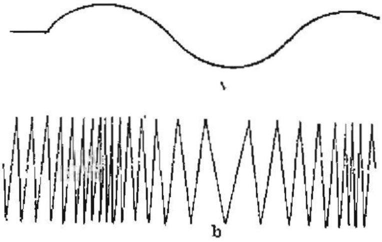


Fig. 1.1.8. *Frequency modulated carrier.*

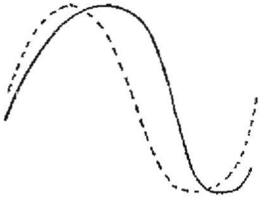


Fig. 1.1.9. *Enlarged portion of FM signal showing divergence from sine wave when frequency changes.*

therefore, that it should be possible to transmit a 500 c.p.s. frequency on a carrier with a band width of only 20 c.p.s. And therein lies the trap.

The snag is that when the frequency of the carrier is changed by modulation it ceases to be sinusoidal, as can easily be seen from Fig. 1.1.8, and when it is not sinusoidal it must consist of a fundamental sine wave of carrier frequency plus a series of harmonic sine waves. A small portion of Fig. 1.1.8 is shown enlarged in Fig. 1.1.9. The dotted wave represents the unmodulated carrier; when modulation is applied the frequency changes and is shown as a solid line. If the unmodulated carrier is sinusoidal then the modulated carrier is not, and what it consists of can be found by Fourier analysis, which will show that the modulated carrier consists of a fundamental sine wave of carrier frequency plus a family of other sine waves having 2, 3, 4, 5 . . . times the carrier frequency. The amplitudes of fundamental and harmonic frequencies will produce various deviation frequencies, and so will produce a lusty crop of side band frequencies. The result is that, for a given modulation frequency, you will get *more* side frequencies with FM than with AM, for in AM only the frequencies of the modulation vary the frequency of the carrier, whereas in FM you also get the frequencies developed as a result of the change of frequency of the carrier.

The equivalent in FM of AM depth of modulation is called the modulation index and is specified by dividing the deviation frequency by the modulating frequency. As we have seen, in AM maximum undistorted modulation is 100% when the amplitude of the envelope has been reduced to zero. As the FM amplitude remains constant, it can be seen that the modulation is always 100% (to use that term somewhat loosely), and the power radiated

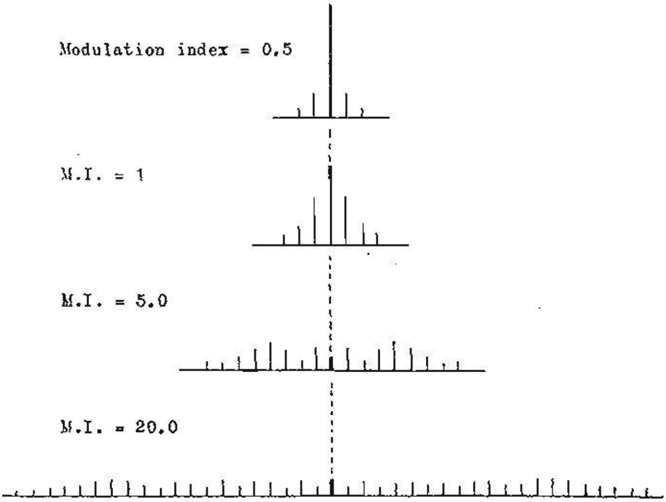


Fig. 1.1.10. *FM carrier and sidebands for various values of modulation index.*

by the transmitter is always a maximum. Since, however, side frequencies are produced, the power for these must be taken from somewhere, and it is in fact taken from the carrier power. A condition can arise when, for a certain value of modulation index, all the power is taken from the carrier and appears only as side frequencies. Fig. 1.1.10 shows the proportion and number of side frequencies for various values of modulation index, and where power is drawn from the carrier the solid line representing the carrier in the top diagram is replaced by a dotted line for purposes of comparison. These diagrams are graphical representations of mathematical analysis of simple cases involving sine waves. In real life the waveforms of musical modulation are very complex, and each sine wave component of the complex waveform produces its own band of side frequencies. These various frequencies further produce combination frequencies, so that it may well be said that the side bands of an FM transmission are infinite. Many of these have so little power that they can be neglected.

As a standard for FM transmission has had to be laid down, it has been adopted that the highest modulating frequency is 15,000 c.p.s. of such amplitude that the deviation frequency is

± 75 kc.p.s. To provide enough elbow room for side frequencies of importance, those which have a magnitude of 1½% of the carrier, a further 35 kc. is provided on either side of the carrier frequency. This makes the total width of the FM channel 220 kc., and is considered adequate for high fidelity broadcasting.

Obviously, such a wide frequency spectrum is impossible in the medium wave band, where even 12 kc. is enough to set up interstation interference. When the needs of FM were properly realised, further consideration was postponed until VHF technique was sufficiently advanced to make it readily available. The even wider frequency spectrum demanded by TV was a spur in the required direction. Advances in TV and FM have been made almost hand in hand.

**Interference on FM**

In a general way those forms of interference which make AM unsuitable for high fidelity reproduction also apply to FM. There is nothing in the nature of FM to make it free-er from interference than AM just because it is FM; it is the conditions under which FM is used that determine relative freedom from interference and distortion.

Because FM transmissions occur in the VHF band certain forms of distortion and interference are eliminated or reduced. For example, selective fading as experienced on medium wave AM does not occur as there is virtually no indirect signal reflected from the Heaviside layer; reception only of the direct signal occurs at the receiver and so out-of-range direct signals from other transmitters do not interfere. Ordinary electrical interference is much less troublesome in the VHF band, yet it can occur as can be seen on any TV set. These same advantages would, of course, be obtained with AM operating in the VHF band.

Use of the VHF band does, however, necessitate the use of the di-pole aerial, and this can be made very selective, unlike the ordinary medium or long wave band aerial which is almost entirely non-directional. With the adoption of the di-pole aerial we can at once establish a better signal-to-noise ratio, and in the case of TV it is common knowledge that, except in swamp areas, the aerial must be designed for the locality of the receiver. Even so, " snow " on the TV screen and accompanying noise in the speaker can be seen and heard, yet an FM receiver working in the same situation and at the same time would not reveal such interference. This contrast is due to the nature of FM, and if we could have FM-TV the same benefit would be gained.

The reason for this is quite simple to explain. In Fig. 1.1.7. I show that electrical interference is represented on the modulation envelope as added spikes, since the interference is added amplitude modulation. In a British TV set both video and audio signals are AM, hence the interference is both seen and heard. Now the interference will inevitably add spikes to a modulated FM carrier, but since the amplitude of the carrier is constant, the gate of Fig. 1.1.7 can be so adjusted that it passes the envelope but rejects the spikes. In addition, the detector of an FM receiver must obviously be designed to respond to changes of frequency, not amplitude, and if it can be designed so that it refuses to handle amplitude variations, then the interference, in theory at any rate, will be rejected. In practice perfect rejection is not possible, so the detector must be aided by a " gate ", which is the *limiter* in an FM receiver.

General noise existing in either system, noise in the transmitter, created between transmitter and receiver, shot effect and thermal agitation in the receiver, does not operate quite the same in FM as in AM. So far as the first and the last two are concerned, the position is the same in both cases, but the sensitivity to outside noise is about half with FM as with AM. It seems hardly necessary to give the reason for this as it has no bearing on the design of FM tuners, but it is important to point out that general noise can be given a treatment to reduce it which is not possible with AM.

You will be conversant with the surface noise of the old-fashioned short-playing record which, in its plastic make-up, had an abrasive ingredient which, so legend holds, was intended to wear the steel needle so as to make replacement essential. Be that as it may, surface noise was aperiodic in the sense that it had no natural resonant frequency; but if there was any resonance in the reproducing system (and there usually was a very bad one at about 3000 c.p.s. in speakers) this aperiodic noise tended to gather round the resonance—to modulate it, as it were—and produce a prominent hiss. If one then applied a " mellow " tone control, by cutting the audio response to something of the order of 2000 c.p.s., or even less in the cheapest equipment, the surface noise was eliminated, and most of the musical value of the reproduction, too. Nowadays, of course, our L.P. records are much quieter, inherently, but, as in the old days, they have a recording characteristic which is not level. The bass is attenuated to provide more room on the record surface, and the treble is boosted to make the signal-to-noise ratio better at the high frequencies. In the reproducing amplifier, to compensate for this, the bass is boosted and the treble given a predetermined roll-off.

If this idea were applied to AM broadcasting it would be found that it doesn't work. First, the modulating signal is controlled so that on peaks the modulation is 100%, and that means 100% at any frequency. It usually happens, too, that in a musical programme a peak signal also contains a lot of high frequencies, for the harder you hit a percussion instrument, the more vigorously you blow a trumpet, so will you generate higher harmonics. Now if you think of injecting a treble boost you will overmodulate in the very region where distortion is most noticeable, and if you decide to reduce the basic modulation so that you do not overmodulate on loud passages, you will so reduce the mean power radiated by the transmitter that the signal-to-noise ratio at the receiving end may be worse than it was in the first place; and that is where you came in.

In the second place, pre-emphasis, as it is called, of the treble will pre-emphasize the side bands, and if all AM transmitters did the same the inter-station interference through side band splash would be made worse than ever, demanding still greater receiver selectivity, so cutting the treble you are trying to emphasize.

With FM the treble can be pre-emphasized without these dire results. Admittedly, pre-emphasis will increase the deviation frequency, but a system of pre-emphasis can be used without exceeding the allotted frequency spectrum. So, in practice, pre-emphasis of the treble is an accepted routine in FM broadcasting, and it follows that de-emphasis is an integral process in the receiver. This combination results in a better signal-to-noise ratio, just as in the reproduction of records.

Shot effect and thermal agitation noise are inherent in the receiver, whether it is handling AM, FM or any other system of modulation. So far from FM being better than AM in this respect, it is actually worse, since noise in the receiver requires much more careful treatment at VHF than at the frequencies of the medium wave band or the IF frequencies of a medium/long wave superhet. Moreover, in the VHF band a superhet is virtually obligatory, since RF amplification at very high frequencies is extremely difficult, and not practicable on a commercial scale; and I have already pointed out that a superhet is fundamentally a noisier type of receiver than a TRF unit.

This does not mean to say, in spite of the dismal outlook, that FM is worse than AM in this direction; but it does mean that an

FM receiver must be very much more carefully designed and constructed than its AM counterpart. Almost anyone can fling together an AM—TRF unit, even if correct alignment is not so easy, and make it work. It does not require much skill to put an AM superhet together, provided the difficulties of tracking and alignment are faced and overcome. But any VHF receiver is much more critical than its medium wave companion because the placement and interconnections of every single component must be most carefully thought out.

The next chapter will deal with the design features of the FM tuner and consider the implications of adopting the AM/FM technique. It is my personal conviction, which I am always ready to modify, that combining two types of receiver in one unit is a mistake in terms of high fidelity, because it is a compromise determined by capital outlay. I believe that if one wishes to receive FM programmes as a source of high fidelity entertainment, then it is best to use a device which has been specially and carefully designed for the job. I think, when the arguments in this chapter have been absorbed, you will agree that FM is a must if high fidelity is desired, and the consequences of adopting FM technique must be faced. Then, if contact with the radio world outside the local FM station is desired, select a suitable and separate AM tuner.

But I must stress once again that selecting a high-grade FM tuner requires quite a lot of thought. Merely because some manufacturer gaily offers an FM tuner is no guarantee that the advantages of FM are assured. It is a matter of statistical record that both in Britain and the U.S. the arrival of FM broadcasting produced a crop of extremely unsatisfactory FM receivers. This was not because manufacturers were more unscrupulous when FM arrived, but just because they had more opportunities for making mistakes. This, in the result, created a situation where the FM customer found himself much more badly served than the AM customer.

Responsible manufacturers, with adequate research and design facilities, are perfectly capable of solving the problems involved; and intelligent home-constructors, with good guidance, can make their own units and expect good results. But both selection and construction demand care and discrimination.

## CHAPTER 2

# DESIGN FEATURES OF FM RECEIVERS

The logical design of an FM receiver involves consideration of all its parts in their relations with each other. This is in some contrast to the equivalent design of AM units. For example, in any superhet it is important to have a signal frequency amplifier before the frequency changer for several reasons: such an amplifier provides a better signal-to-noise ratio and makes for more efficient frequency changing; the existence of the RF stage prevents, to a considerable extent, interference from the oscillator being injected into the receiving aerial and causing interference to other receivers in the district. The local oscillator is a transmitter, and its output must be restricted to the sole purpose of providing an RF frequency to be combined with the incoming signal to provide a new signal of a frequency for the amplification of which the IF amplifier was designed.

In an AM superhet what is desired is efficient amplification, and the noise generated by the RF stage is just one of those things that have to be accepted as inherent in the principle. Admittedly, it is just as important to reduce noise in an AM receiver as in an FM, but because there is a limit to what can be got out of an AM in terms of " noiseless " high fidelity, the noise of the RF stage does not become quite so important. If the full virtues of FM are to be preserved, which includes reproduction of audio frequencies up to 15,000 c.p.s., then noise must be kept down to the minimum. It is certainly true that the FM principle does make for noise elimination, in view of the fact that noise is AM modulation of the FM signal and the limiter tends to get rid of the AM component, but the position is more complicated than would appear, for noise generated in the receiver is a constant and the incoming signal's magnitude is not constant as between stations. Sometimes the receiver noise will be too great for a given desired signal and so increased AM limitation is required. Thus the selection of the RF stage can only be made bearing in mind the degree of limiter action it is proposed to incorporate in the design, and the degree of limiter action is in great measure involved in the design of the IF amplifier.

The best way of disposing of these problems is to deal with each section of the FM circuit separately, showing the various techniques used, how the sections are linked together and their interrelations. A block diagram of an FM receiver is shown in Fig. 1.2.1 terminating in the audio frequency output. The block

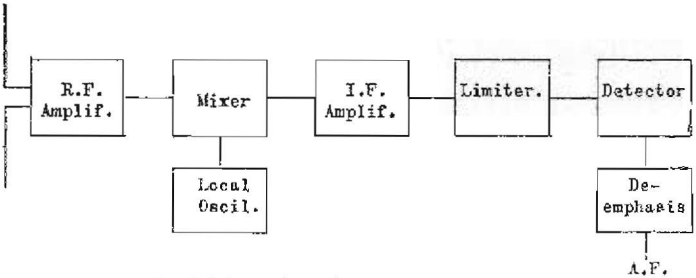


Fig. 1.2.1. *Block diagram of FM receiver.*

diagram of an AM superhet would, of course, look exactly the same except for the omission of the limiter and de-emphasis sections.

**The Radio Frequency Amplifier**

As compared with ordinary AM receivers the frequencies to be treated in an FM receiver are very high indeed; they are, in fact " very high frequencies ". Quite apart from the mere fact that the connecting wires themselves have sufficient inductance to play havoc with the actual inductor design and the physical presence of the various components with their inevitable inter-component capacity can equal or surpass the inter-electrode capacity in the valves, tending towards instability, shot effect and thermal agitation noise increases with frequency. In the world of VHF, it can be stated as a general principle that a pentode is noisier than a triode, due to the electron stream between screen grid and anode taking on random characteristics. This is called partition noise, and for a given amount of amplification gives the pentode some 3 to 5 times the noise from a triode.

It would seem, therefore, that the answer is to use a triode; but to use a triode in the conventional manner will introduce self-oscillation at VHF frequencies owing to the inter-electrode capacities in the valve itself. In the old days of broadcasting, before the invention of the screen grid valve, RF instability occurred at medium wave band frequencies with triode amplifiers, especially when two RF stages were attempted. This was overcome by the process called neutralising and consisted simply of feeding back a small voltage 180° out of phase with the voltage fed back by the capacity between the grid and anode of the valve. A precisely similar technique can be used today in a VHF triode amplifier and is illustrated in Fig. 1.2.2 (a) where NC is the neutralising or feedback capacitor.

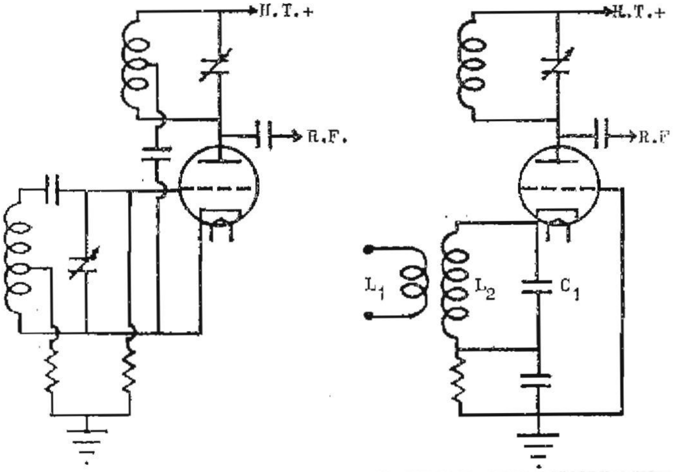


Fig. 1.2.2. *RF amplifiers: (a) neutralised triode; (b) grounded grid.*

An alternative method is to use a grounded grid amplifier; this is depicted in Fig. 1.2.2 (b), and is a radical modification of the ordinary amplifying circuit wherein the signal voltage is applied to the grid of the valve and the cathode is earthed, usually through the bias resistor and its capacitative bypass. In the grounded grid circuit the grid is earthed and the signal voltage applied to the cathode. Since the grid is earthed it acts as an electrostatic screen between cathode and anode, and virtually eliminates the inter-electrode capacity, so producing stability.

Unfortunately something is lost in the process. The circuit has inherent negative feedback and so the voltage gain of the stage is reduced, but if a suitable valve is selected so that there can be a stage gain of about 10, this would be sufficient to achieve the requirements of having an RF stage at all. A stage gain of 10 would be quite impossible with an un-neutralised triode.

The grounded grid amplifier has a low impedance cathode circuit, and the LC circuit in Fig. 1.2.2 ($L_2C_1$) is rather heavily damped. If this circuit is made to resonate at the mid-frequency of Band II, by suitable choice of value $C_1$, it need not be tuned over the band, for the impedance curve of the circuit is fairly flat topped. However, there will be little gain from the stage if it is not tuned to the desired signal frequency, so tuning is effected in the anode circuit, either by a variable capacitor or by varying the inductor slug, or both. This is indicated in Fig. 1.2.2 (b). The

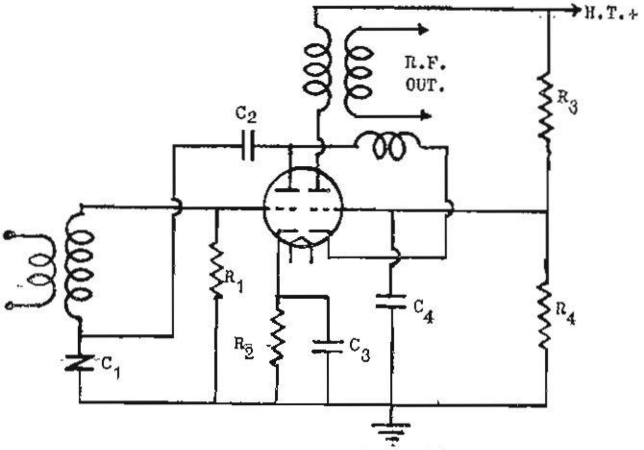


Fig. 1.2.3. *Cascode amplifier.*

damping of the cathode tuned circuit can be reduced by returning the cathode to a low tapping on $L_2$, but this may so sharpen the selectivity as to make cathode tuning necessary; this modification is rarely used.

The advantages of both a neutralised triode (with fairly high gain) and the low noise characteristics of the grounded grid can be combined in a technique widely used in multichannel TV receivers —the cascode amplifier. A typical circuit is given in Fig. 1.2.3 and requires the use of a valve specially designed for the job (ECC84), consisting of two high gain triodes well screened from each other. The first triode is neutralised by the feedback capacitor $C_2$ in series with $C_1$; the second is the grounded grid valve.

It may be thought a very odd state of affairs that there seems to be no HT on the first triode, but it should be realised that the basic idea of the cascode amplifier is two valves connected in series, and the operating conditions for the first triode are obtained through the second. This means that the cathode of the second triode is positive with respect to earth and the voltage on the grid must be adjusted to suit so that the valve may function normally. This is achieved by the potentiometer $R_3R_4$ connected between HT+ and HT−. Thus, the grid of the second triode is not grounded for D.C. but it is for RF (which is all that matters) by the capacitor $C_4$. In the figure, $R_1$ is the conventional grid return resistor, $R_2$ the bias resistor, bypassed for RF by capacitor $C_3$. It is customary to include a small inductor in the lead from the

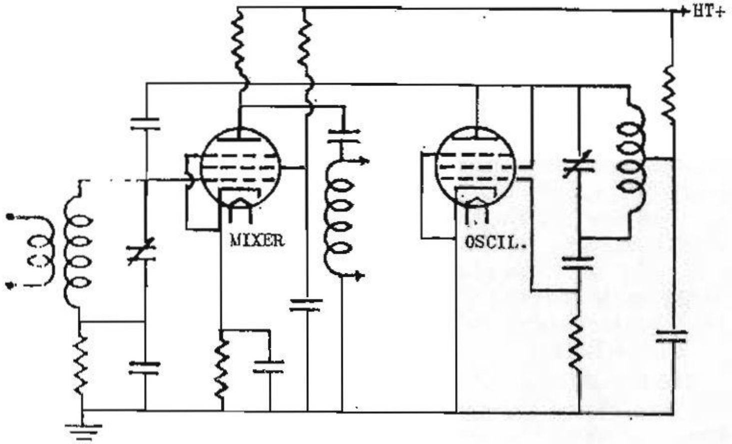


Fig. 1.2.4. *Two pentode oscillator-mixer* (*Courtesy Mullard Limited*).

first anode to the second cathode to give reasonably constant gain over the frequency range the stage has to amplify.

In spite of the obvious advantages of a triode as an RF amplifier at high frequencies the extra gain to be obtained from a pentode is of considerable importance. Provided a suitable valve is selected and used correctly, noise can be kept down to a reasonably small level. This requires co-operation between valve and set designers, and particularly with the advent of Band III television new pentodes have been developed, of which the EF91 is a typical example. A tuner should not, therefore, be condemned just because its circuit shows a pentode in the signal frequency amplifying stage. If it is the right valve it will be a quiet amplifier. The EF91 is a quiet valve, so much so that it may usefully be employed as a local oscillator (where an ordinary triode could serve) in an arrangement such as that shown in Fig. 1.2.4. This application is found in certain TV receivers and can also be used as an FM frequency changer.

### The frequency changer

There is no basic difference between the frequency changer of an AM or FM receiver. The principle is quite simple—a locally generated sine wave is created in the oscillator and this is made to beat with the incoming signal in the mixer, the outcome of which process is a new signal having a frequency equal to the difference between the carrier frequency and the oscillator frequency. This is the intermediate frequency, and it is of no mathematical importance whether the oscillator frequency is above or below that of the carrier. Thus, in an AM superhet, the unmodulated carrier may have a frequency of 1000 kc.p.s., and if an intermediate frequency of 470 kc. is selected the oscillator frequency can be either 530 or 1470 kc. When the carrier is modulated the intermediate frequency sine wave will be AM modulated in exact sympathy with the modulation on the carrier. In FM reception, the frequency of the intermediate frequency will be modified in exact sympathy with the modulation on the carrier. Speaking generally, the choice as to whether the oscillator frequency is above or below the carrier frequency will be determined by the purity of the oscillator output and the degree of interfering signals passed on by the RF amplifier.

The oscillator output should be free from harmonics, for if it is not the harmonics will beat with the signal frequencies and create unwanted intermediate frequencies which will be duly amplified and detected. In mass-produced receivers it is sometimes found easier to use a harmonic of the oscillator frequency to avoid these spurious signals, but this is a design practice not to be recommended for high fidelity. An overdriven oscillator will produce harmonics just as happens with an overloaded amplifying valve, so the oscillator must be designed to ensure sinusoidal output.

The oscillator frequency must be held constant, either in AM or FM, but it is particularly important in FM because the frequency spread passing through the amplifier must be presented perfectly symmetrically to the FM detector. The two halves of the FM detector deal with signals which are symmetrically equal but opposite in phase, and if they are not, detector distortion will be serious. This is related to my earlier statement that an accurate tuning indicator is virtually essential in a high fidelity FM receiver, for the oscillator tuning must be so controlled that it gives exactly the right intermediate frequency; and it must stay right.

In the medium wave band oscillator drift is of no great consequence, but in the VHF band it becomes a serious problem since even the leads inside the valves themselves have appreciable inductance and any change in length due to temperature will change the characteristics of the circuits. This applies, of course, to every part of the signal frequency section of the receiver, and the utmost care has to be taken to make the dimensions as small as possible with the shortest possible leads, with uniform temperature and humidity, and well screened. In practice the temperature cannot be kept within very narrow limits, so suitably chosen fixed capacitors having the proper temperature coefficients must be added to the basic circuit.

Oscillator drift is an infuriating defect, and many readers will have suffered from it when ITV programmes were started on Band III. A " Band III converter " is simply a frequency changer added to the single channel TV set, making the whole set-up a double superhet, the signal frequency amplifier of the TV set being used as the first IF amplifier. Many of these converters were rushed on to the market without much attention being paid to drift, with the consequence that there was a pictorial demonstration of what happens when the oscillator goes off tune. No FM tuner is worth considering unless the greatest care has been taken to prevent oscillator drift. The difficulty is that this cannot be checked by mere inspection, but if the specification categorically states that automatic frequency control has been incorporated then you can be reasonably sure that stability will be achieved in practice.

Noise in the frequency changer increases with the number of electrodes in the valve selected; thus, a triode is quieter than a pentode, and a pentode quieter than a hexode or heptode. This statement assumes that the mixer valve is included, for the frequency changer in an AM receiver is commonly a triode hexode. Conversion efficiency in a triode hexode is not good at VHF and the valve is noisy, although some FM receivers do include it, the valve being specially developed for the job (e.g. ECH81). The mixer valve is, of course, the beginning of the IF amplifier, and can be entirely separate from the oscillator. At the other extreme it can be the same valve, when it is called a self-oscillating frequency changer. It is widely used in inexpensive FM receivers, where economy of components is of importance, and comprises a double triode of the ECC84 or B719 type; the first half is used as the RF amplifier, the second as a combined oscillator-mixer in a manner shown in Fig. 1.2.5.

Here the coupled inductors $L_1L_2$ are in the grid and anode circuits of the valve, the latter through the medium of the feedback capacitor $C_5$. The oscillator frequency is governed by the variably tuned circuit $C_3L_1$. The oscillator output voltage is developed across $L_1$ and could be fed back to the aerial and cause interference to other nearby receivers. To avoid this the output from the RF amplifier is fed into a capacitative centre-tap of the grid inductor

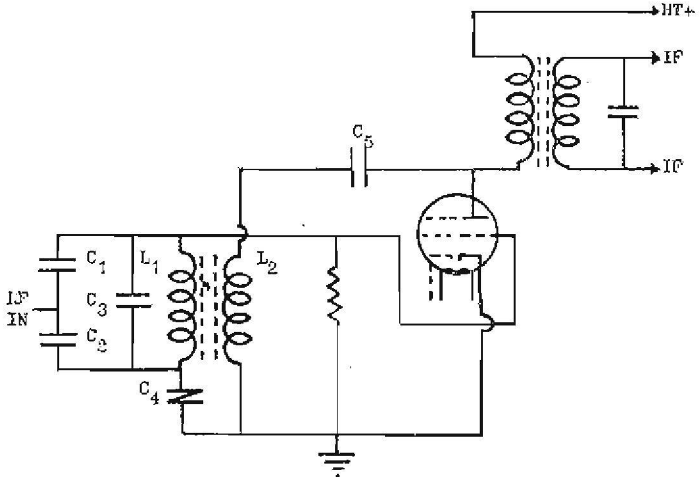


Fig. 1.2.5. *Self-oscillating frequency changer.*

and $C_4$ is added, thus making the whole circuit $C_1$, $C_2$, $C_3$, $C_4$, $L_1$, $L_2$ and the interelectrode capacity of the valve a bridge which can be balanced by adjusting the semi-fixed capacitor $C_4$. When balanced the oscillator voltage at the point of RF entry is practically zero.

This arrangement, therefore, disposes of RF amplifier, oscillator and mixer in one valve envelope; but there are drawbacks. It is necessary to neutralise the triode by feeding back some of the IF to the grid (not shown in Fig. 1.2.5); as an oscillator, spurious oscillation can cause trouble, and there is certainly some pulling of frequency between it and the RF amplifier, making the oscillator frequency unstable. It must therefore be ruled out for a high grade tuner.

There are many other possible arrangements for frequency changing, each having merits that appeal to designers, but it can be taken as a safe working rule that, for a high fidelity FM tuner, the RF amplifier valve should be in its own envelope; the oscillator should be a triode, for quiet operation, and the mixer valve again in a separate envelope, either triode or pentode of the EF91 type. The oscillator triode could be half of a double triode, the other half of which is used for AFC of the oscillator.

Admittedly, this separation of valves does not lead to so compact an RF tuner/frequency changer unit as one incorporating valves with combined functions, and more care is required in layout and connection; but the refined performance makes the extra trouble and expense well worth while if high fidelity results are desired.

### The Intermediate Frequency Amplifier

The problems associated with designing an IF amplifier for FM are much more difficult than in the case of AM. Since the noise reducing characteristics of the FM system can only operate if the AM component representing the noise is rejected by the limiter, it follows that a sufficiently large signal must be presented to the limiter to enable it to slice off the AM noise spikes. This means there must be a greater degree of amplification in an FM amplifier than in an AM, yet the conditions under which the FM has to operate militate against high efficiency.

First, the frequency band width to be amplified is very much wider, a matter of 150 to 200 kc., and this demands either staggered tuning of the IF transformers or they must be of the band pass type; as was pointed out when I discussed TRF receivers for AM reception, this results in loss of gain per stage. Next, the frequency at which an FM amplifier has to work, something of the order of 10 mc., does not permit the amplifying valve to give the gain that would be normal with an IF of 470 kc. If attempts are made to boost the gain by using transformers having very high Q, the interelectrode capacity of even a pentode is sufficiently high to give positive feedback resulting in instability. As in the old days triodes were neutralised to give stability on medium wave frequencies, so today pentodes are sometimes neutralised to give stability in the VHF band.

There is, of course, the saving grace that FM receivers are not normally expected to receive distant stations, since only the direct ray from the transmitter is supposed to be available, yet both TV and FM DX (long distance reception) has become a regular activity of a certain dedicated type of enthusiast. Even for ordinary high grade reception the receiver may be on the fringe of the service area of the transmitter, with a consequent weak signal; if there is insufficient IF amplification with accompanying adequate limiting action, the signal-to-noise ratio will be poor.

As a general rule, therefore, it may be reckoned that a really well designed high fidelity FM receiver will have three IF stages as compared with the home-constructor and commercial types with only two, and I have come across a gadget which purported to be an FM receiver having only one, the excuse being that as a ratio detector was used no limiter was needed at all.

Now, as I have already pointed out, it is correct to suppose that a ratio detector has inbuilt limiting characteristics, but these are not sufficient for full noise suppression, and will only operate properly if the detector is absolutely balanced about its datum operating point. As there are certain economic advantages in using an unbalanced detector (as will be described later), it can be taken that a properly designed limiter stage is necessary for good results, and for first-class results two limiter stages, irrespective of the type of detector used.

The block diagram, Fig. 1.2.1 suggested that the limiter was a separate piece of equipment tacked on to the end of the IF amplifier, but in reality it is part of the amplifier, to such an extent that under certain conditions one and the same valve may act either as an amplifier or as a limiter. The first IF amplifier would not normally be designed for such operation but be treated as a straight voltage amplifier, as efficient as possible. It would be recognised as such in the circuit diagram of an IF amplifier by having the earthy end of the IF transformer secondary returned direct to earth, the " hot " end of the secondary being, of course, taken to the grid of the valve. Bias is applied in the normal manner.

Whether one or two IF stages follow this first straight voltage amplifier the situation is that we have an FM signal on which is imposed AM modulation produced by noise, and it will be obvious that further straightforward amplification will only increase the amplitude of both FM signal and noise. As the amplitude of the FM signal may already be adequate, further ordinary amplification is not only unnecessary but undesirable. So we put up our " gate " and open it only sufficiently to admit the FM and keep out the AM.

This is most usually achieved by using a sharp cut-off pentode of the 6AU6 type in a circuit substantially similar to a leaky-grid detector, and with reduced screen and anode voltages. This causes the valve to operate on a short grid base, and the inclusion of the R/C network in the grid circuit, as shown in Fig. 1.2.6, produces negative bias proportional to the amplitude of the incoming signal. If the amplitude is greater than the grid base laid down for the operating conditions of the valve the increased negative bias will produce cut off of the anode current, and so the signal will not be amplified. Apart from the value of screen and anode voltages,

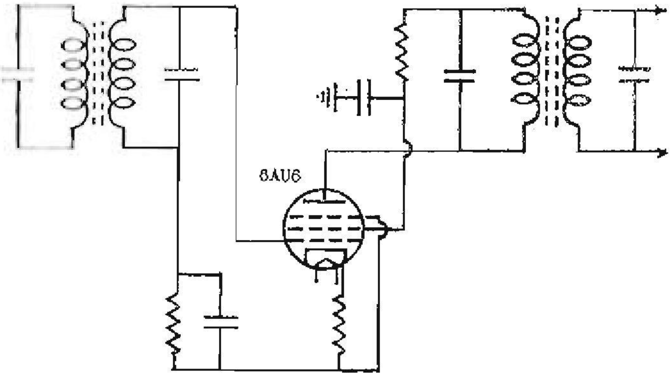


Fig. 1.2.6. *Amplitude limiter using short grid base pentode.*

operation is controlled by the time constant of the RC circuit, and the value of this must be decided with some care. It must be short enough to ensure that the bias changes proportionally with signal amplitude, but if too short the change of bias will not be great enough to produce the limiter action. The usually selected value is between 2 and 3 microseconds, when only one limiter stage is used.

A moment's thought will indicate that if the incoming signal is of smaller amplitude than the short grid base of the limiter stage and is AM noise modulated, it will still get through the gate with at least some noise superimposed on it. Clearly, therefore, a second limiter is required to amplify the FM signal so that its noise is cut off by the limiter action. This would be obligatory with a sensitive high fidelity tuner and is actually much to be recommended even for reception of strong signals, for the action of the two limiters can be designed to deal with most forms of interfering noise. For example the shorter the time constant the more likely can car ignition noise be suppressed, so in a two stage limiter the time constant could be reduced to about 1½ microseconds in the first stage and increased to from 10 to 20 microseconds in the second to deal with most other types of noise impulses.

Even so, some car ignition interference can get through, for this " burst " type of noise is extremely difficult to suppress entirely; the best results will always be obtained when the centre frequency of the already carefully aligned IF amplifier is made to coincide exactly with the centre frequency of the discriminator or detector. There is a perfectly routine method of making sure that this double alignment has been carried out properly in the first place, but as the technique involves a degree of know-how and instrumentation the average reader can hardly be expected to possess, it can be taken as a reasonable working rule that any tuner offered to you which incorporates three IF stages and two limiter stages and still does not have adequate noise suppression is not properly aligned and should be rejected.

## The Phase Discriminator or Detector

There are various methods such as the Travis, super-regenerative and locked oscillator, whereby the IF varying frequency can be converted into the desired audio signal using more or less standard valves and components, and two involving special valves. The former have gradually fallen out of use because of difficulties in maintenance, adjustment and instability, and the latter are not generally available in Britain but certainly deserve mention. The more popular is the gated beam discriminator, quite widely used in the U.S., the specially designed valve carrying the type number 6BN6, and it has good properties of limiting and detection and saves an appreciable amount of circuitry, not even requiring an input IF transformer. As, however, it is unlikely to be met with in British tuners I shall not describe it in detail but refer the interested reader to these papers: A.P.Hasse " New one-tube limiter-discriminator for FM ", (Tele-Tech. Jan. 1950. p. 21); R. Adler " A gated beam discriminator ", (Electronics, Feb. 1950. p. 82); Heller & Shulman " The gated beam discriminator ", (Radio-Electronics, Nov. 1955. p. 50). The other is the Philips EQ80 nonode, called the " ø detector ", described by Jonker & van Overbeek in Philips Technical Review, July 1949, p. 1.

In one or two cases the counter-diode detector will be met, and this should be given some brief description since it will crop up in the discussion in the next chapter. The principle of operation is entirely different from those of the commonly met FM detectors. If you consider the action of the rectifying diode detector in an AM receiver the voltages so produced represent the amplitude of the modulation. In FM the amplitude is constant, so diode detection of an FM signal will produce no output voltage change and there will be no audio output, whatever the carrier frequency. Now if a diode detector is presented with a burst signal instead of a sine wave the voltages across the load resistance will behave somewhat differently.

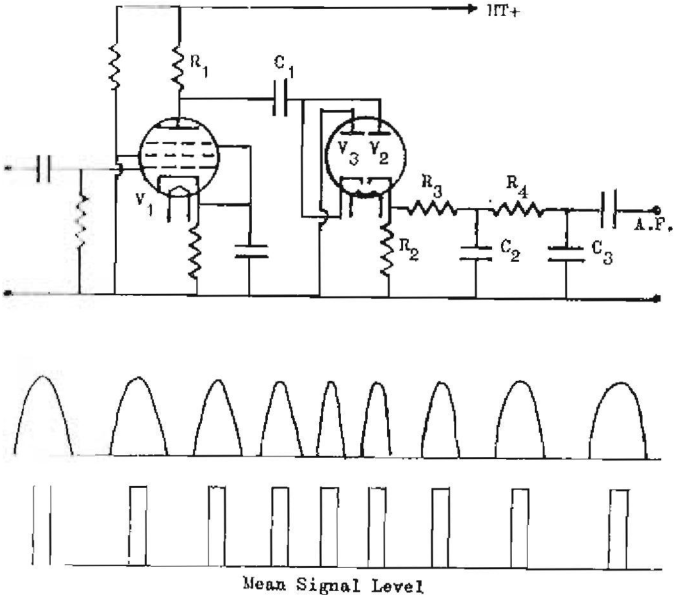


Fig. 1.2.7. *Counter-diode detector.*

In Fig. 1.2.7 the IF signal is fed to the grid of a pentode, $V_1$, whose circuit constants have been selected so that the valve operates between saturation and cut-off. Under these conditions alternate positive and negative pulses would be developed across $R_2$ if $V_2$ were short-circuited and $V_3$ omitted. The circuit time constant, $(R_1 + R_2)$ $C_1$ and the amplitude limiting action of $V_1$ ensure that the pulses have constant voltage even if there is AM on the FM wave. The function of $V_2$ is to provide a path for positive-going pulses to $R_2$ and reject negative-going, while $V_3$ serves to discharge $C_1$ on the negative cycle. Thus a series of positive pulses is developed across $R_2$ and the process is illustrated in the diagram in the lower part of Fig. 1.2.7. It will be observed that the mean value of the signal is a function of the separation of the pulses. The two-stage filter, $R_3C_2$, and $R_4C_3$ not only provide the necessary de-emphasis but remove the RF component of the FM signal.

Selection of the correct values for the circuit time constant is very critical, and to ensure correct operation it is found that the intermediate frequency must be unusually low. For ordinary FM

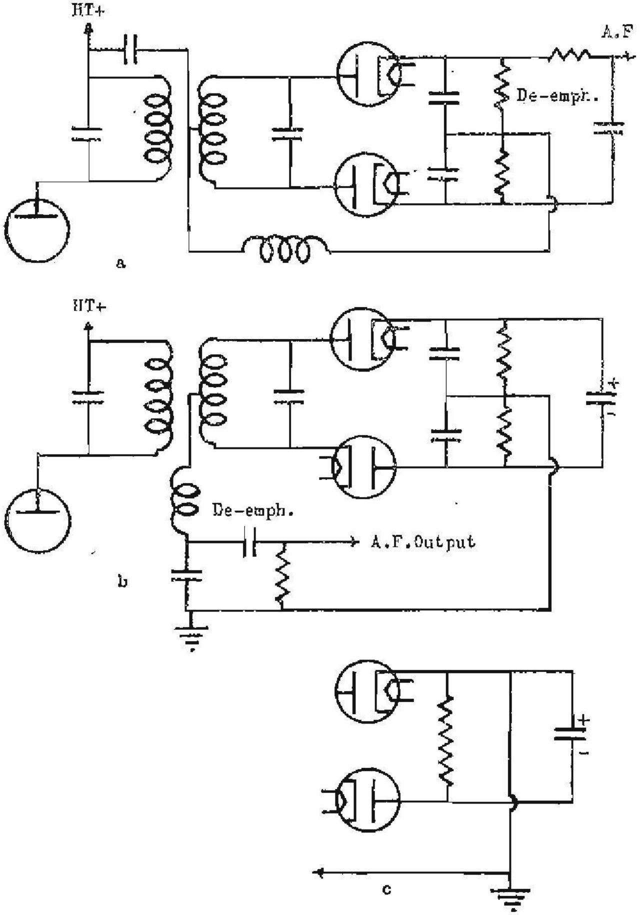


Fig. 1.2.8. *FM detectors: (a) Foster-Seeley discriminator; (b) balanced ratio detector; (c) unbalanced ratio detector.*

broadcasting it would be of the order of 175 kc.p.s., and although this seems to be an odd state of affairs it becomes of some importance in multiplexing systems, which will be discussed in Chapter 3.

So far as more conventional FM receivers are concerned the most frequently used detectors are the Foster-Seeley discriminator and the ratio detector, shown in Fig. 1.2.8. Every book describing the FM principle gives an explanation of how they work, and it would be pointless to repeat it here. But in terms of high fidelity reproduction their respective merits and shortcomings must be discussed, not only in relation to each other, but in respect of their influence on other sections of the complete receiver. One or the other type would be selected for a specific object, but as some FM receivers have to be designed down to a price and others up to a standard of performance, the mere mention in a specification that a discriminator or a ratio detector is used means nothing without also considering what other features are in the complete tuner.

Inspection of Fig. 1.2.8 suggests there is little difference between the discriminator and the balanced ratio detector apart from the fact that in the former the diodes appear to be in parallel and in the latter in series. In practice it is found that provided both are properly balanced and have the correct circuit parameters they will have the same low distortion. The action of the ratio detector is, however, quite different, and the significant addition is the large capacitor, usually an electrolytic, at the right hand end of the circuit diagram. The function of this capacitor is to stabilise the voltages across the diode loads, represented by the centre-tapped potential divider connected across the two diodes. The size of this capacitor is of some importance and will be discussed shortly; its presence indicates the noise limiting characteristics of the ratio detector. I suggested earlier that even a ratio detector should have a limiter preceding it, and we have reached the point when this can be made clearer.

The F-S discriminator imposes comparatively small damping on the preceding IF stage; the ratio detector damps it heavily. The discriminator is more sensitive than the ratio detector and easier to align. In both systems it is of the highest importance that the input to the diodes be symmetrical, and that the diodes are matched. The centre tap of the IF transformer secondary must be in the exact electrical centre of the winding, inductively and capacitatively, and the coupling of the two halves to the primary identical. The ratio detector damping can be reduced by the addition of a tertiary winding, shown in the figure, tightly coupled to the " cold " end of the primary; together with the secondary it forms an impedance transformer, for to get any gain from the amplifier the anode circuit should have high impedance. This also increases the sensitivity.

The presence of this winding makes the primary of the transformer asymmetrical, and to restore the necessary balance steps have to be taken to neutralise its presence. With the discriminator all that need be done is to adjust primary and secondary to the centre resonant point of the IF amplifier.

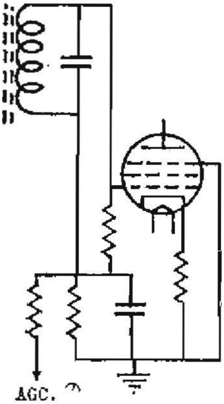


Fig. 1.2.9.
*AGC for RF amplifier taken from IF amplifier and limiter.*

For the moment, then, let us suppose the first choice is the F-S discriminator and consider what is involved. A diode detector will distort with too small a signal input, and this applies to any type of receiver, AM or FM. Furthermore, the discriminator has no limiting properties, so effective limiting must be carried out before detection, and effective limiting can only be performed when the limiter stages produce very little real amplification. In other words, and in spite of the greater sensitivity of the discriminator, a considerable amount of RF amplification must be built into the tuner, either at signal or intermediate frequency to make sure there is adequate limiting on weak signals. It has been suggested that a receiver of this type should produce full limiting for a maximum input of 12 to 15 microvolts.

On the other hand it may be argued that in most cases reception will take place where the signal is not only adequate but possibly more than adequate. Within reason the diode will rectify quite a large input without distortion, so there will be no trouble through overloading in the detector circuit, but if the limiters have been adjusted for a medium strength signal and they get a very large input a " squelch " phenomenon occurs, which chops off part of the wanted signal. This can be avoided by adequate AGC before limiting, but this involves taking the AGC voltage from an IF amplifier, since it is not available from the F-S discriminator; a way of doing this is shown in Fig. 1.2.9, where the IF pentode operates as a limiter and as a source of AGC voltage, which is taken back to the signal frequency amplifier. Another way of reducing input is to use a poor aerial, but this, unfortunately, at once reduces the signal-to-noise ratio, for noise seems to be able to come in at full strength with practically no aerial at all.

For real high fidelity results a properly designed dipole is essential, so any tuner offered as having a Foster-Selley discriminator should also have enough amplification to secure adequate limiting under all conditions and enough AGC to avoid squelch.

Now let us consider the ratio detector, which is rapidly gaining in popularity. The superficial reasons are attractive and logical enough—limiting is incorporated, so there is no need to increase IF amplification to secure adequate pre-detector limiting and AGC is there for the asking. For the designer who wishes to create an FM receiver at minimum cost and complication the ratio detector is the answer. But in the realm of high fidelity it isn't as easy as that.

This detector, as in the discriminator, will produce non-linear distortion on small inputs, simply because of the characteristics of the diodes, but the distortion is much greater owing to the characteristics of the circuit. When receiving a weak signal, therefore, the ratio detector must be preceded by more " straight " amplification than in the case of the discriminator to maintain the same freedom from distortion, quite apart from the loss of amplification due to the heavy damping on the IF transformer. Unlike the discriminator, the ratio detector distorts with very large inputs, so it might be said that the range of input with the ratio detector is less than in the other case. This calls for adequate AGC in a tuner which might be used anywhere. An AGC voltage can be obtained from either a balanced or unbalanced ratio detector, as shown in Fig. 1.2.8 (b) and (c), but in the balanced detector it will be noticed that the centre of the post-diode network is earthed, so only half the voltage across the load resistance is available for AGC. In the unbalanced detector, since one end of the load resistance is earthed the whole rectified voltage is available; hence the reason why many designers prefer the unbalanced type.

So far as noise rejection is concerned the situation is more critical in terms of signal input. It is certainly true that the ratio detector rejects noise, and, as I have already mentioned, the effectiveness is determined by the value of the stabilising capacitor;

but the inherent limiting action is only effective at one specific level of input, decreases very rapidly at lower inputs, and slowly at higher inputs. The tolerance in noise suppression is much narrower than in distortion.

The obvious way to surmount this difficulty would be to arrange that the AGC works so precisely that the input to the detector is always held at the optimum point whatever the reception conditions, but in practice this is almost impossible to attain other than as a very rough approximation. Moreover, as the optimum point is determined by such factors as almost every parameter of the IF transformer, the characteristics of the diodes and the values of the load resistors, the designer is faced with an extremely complicated situation, and the owner of the tuner is entirely dependent on the designer's original calculations being held through the whole process of factory production, final alignment, and static conditions in the home. As all radio components age and alter their characteristics, precise performance of this sort simply cannot be attained and maintained.

Various devices are, therefore, adopted to simplify the position. If the stabilising capacitance is increased, limiting characteristics are improved, but if increased too much, tuning is made difficult; the capacitor has to be charged by the AM and a large capacitor would require several seconds to charge up, during which time tuning cannot be carried out. The more usual device is to include resistors in the post-diode network at the points $R_x$ in Fig. 1.2.8. These resistors are unequal and one is adjusted to balance the unbalance residual in the entire circuit from the IF transformer onwards. The inclusion of these resistors decreases the sensitivity of the detector.

The unbalanced circuit, (c) in Fig. 1.2.8, is used not only to get twice as much AGC voltage but to simplify the receiver, so reducing the cost. It will not perform with the precision of the balanced detector, but much of the unbalance can be corrected by resistors $R_x$, otherwise there is no basic difference in performance, except that a higher value of stabilising capacitor would be required than with the balanced circuit, since limiting does depend on precise balance.

From all this it will be seen that the limiting characteristics of the ratio detector depend on a certain precision of design and execution (not to mention subsequent changes due to ageing in use), and the elimination of limiting in the IF amplifier can therefore only be tolerated in receivers built down to a price, which would include commercial mass-produced AM/FM receivers, combined TV and FM sets, and the cheaper separate tuners.

The very best ratio detector operation is obtained from a perfectly balanced network and it would be advisable, in this connection, not to take the AGC voltage from the detector but from an IF stage. Careful AGC design is obligatory to avoid distortion resulting from wrong inputs, and since the limiting factor operates well only within narrow limits, pre-detector limiting is essential. It is impossible to state categorically that because the ratio detector has limiting potential only one IF limiter stage in the IF amplifier is necessary. I have given in the discussion on the IF amplifier my reasons for preferring two stages, and this really does apply to both types of detector. Given this, there seems to be very little reason for preferring a ratio detector to a discriminator in a high fidelity tuner. Both will work well if the whole receiver has been well designed.

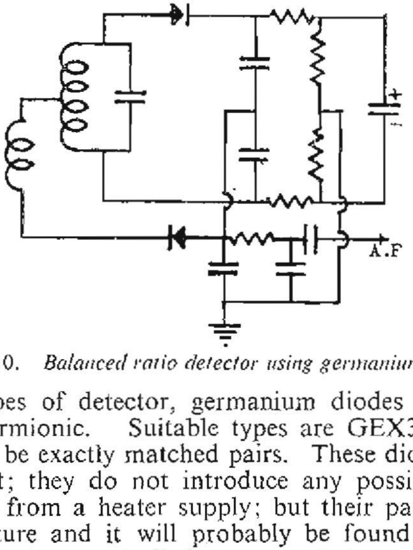


Fig. 1.2.10. *Balanced ratio detector using germanium diodes.*

In both types of detector, germanium diodes may be used instead of thermionic. Suitable types are GEX34 and OA79, but they must be exactly matched pairs. These diodes are much more compact; they do not introduce any possibility of hum being injected from a heater supply; but their parameters alter with temperature and it will probably be found necessary to provide temperature controlled components to maintain balance under all conditions. A typical circuit using such diodes is given in Fig. 1.2.10.

It will be noticed that the de-emphasis network has been included in the detector circuit diagrams. It is a simple top-cutting circuit, and is logically associated with the detector.

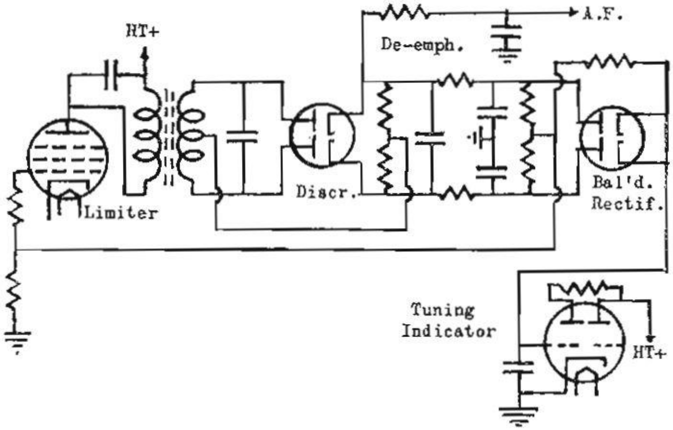


Fig. 1.2.11. *Tuning indicator connected direct to detector.*

## Tuning Indicators

It will be obvious from the foregoing that accurate tuning is essential to avoid distortion, and as accurate tuning in FM is extremely difficult to judge by even an expert ear, some form of tuning indicator is essential. Tuning indicators are commonly fitted to FM tuners, but it does not follow that the existence of the indicator will ensure accuracy. The "magic eye" type (EM34) is becoming obsolescent, being succeeded by the EM80 and later the EM81. These indicators are generally operated by connecting the control grid to the AGC line, and if the receiver is an AM/FM combination the indication is excellent on AM and virtually useless on FM, for the simple reason that the properly aligned FM receiver has a band pass of 100 kc. on either side of the central frequency and the indicator will show a constant pattern over this band. If the response has a small peak in the centre frequency (which it shouldn't have, but often has) then the tuning could be done aurally or by the simple magic eye circuit by watching for the small indication on the indicator screen.

The only satisfactory way to drive the indicator is to connect direct to the detector, and this necessarily complicates matters. A suitable circuit for doing this is shown in Fig. 1.2.11 and involves either a double diode or a pair of germanium diodes.

It is unfortunate that there is no British equivalent of the very fine AL7GT cathode ray indicator. This has the great merit that it not only indicates exact tuning but has patterns which show whether the receiver is off tune positively or negatively. If connected only to the discriminator, the off channel display is almost the same as that for exact tune, so in tuning one watches carefully. Between stations the display remains constant; as one encroaches on the carrier of the desired station the display changes until the point is reached when the two sections are again of equal height; further movement beyond the carrier frequency is appropriately shown, so it is a simple matter to return exact tune. If a muting stage is included in the receiver and the indicator is connected to detector and muting voltage, the display is removed entirely.

Space forbids any description of muting circuits for the suppression of inter-station noise; in general, so far as Britain is concerned, it is hardly worth the trouble involved. What is worth the trouble involved is the erection of a properly designed Band II aerial. Every good tuner deserves a good aerial.

## CHAPTER 3

## STEREO BROADCASTING AND MULTIPLEXING

At the time of writing, this chapter is entirely theoretical. By this I do not mean that I am discussing only theoretical ideas that have no practical significance, but simply that there is no official system of stereo broadcasting in existence. Certainly experiments have been carried out in this country and other countries in Europe, for there is no technical difficulty in transmitting the two channels of a stereo programme, and in the U.S. stereo broadcasting has been in actual existence for some few years. The last meeting of the European Broadcasting Union was held in Cannes in the last week of January 1960 and at that meeting various techniques of stereo broadcasting were discussed and considered. But at this moment, neither the communications authorities of the U.S., Britain, nor Europe have yet decided which method will be selected as standard technical procedure for the future.

In any scientific development which will become the subject of the vested interests of commerce, the purely scientific aspect will be subordinated, not to what commerce may have to cope with in the future, but what its interests are right now. So long as the aim of commerce is to provide stereo broadcasting as easily and cheaply as possible, from the point of view of the manufacturers of equipment, then corners will be cut to achieve that object. This is nothing new; it has always been with us, and I am not suggesting that it is other than completely ethical. In the early days of broadcasting, quality of reproduction was not considered very important; the mere novelty of the thing had great sales appeal. Similarly with early TV; and, I was very sorry to notice, precisely the same thing happened when stereo records were launched on an unsuspecting world. A great deal of junk was unloaded on an uninformed public.

Sooner or later a more informed public demanded better standards of performance, and so came a popular demand for " high fidelity ", improved TV and stereo records and equipment. But in respect of stereo we are not on such sure ground as with hi-fi and TV. A decent pair of ears can soon hear if what is presented is hi-fi or lo-fi and a pair of eyes can soon see whether the TV picture is good or bad; but how do you assess stereo ? I confess to being unable to answer that question, but I do know that a lot of stereo I have heard may be " sound in depth " but it isn't a reproduction of what goes on in real life.

This book is about high fidelity and I maintain that high fidelity stereo postulates that the three dimensional sound picture shall be true to life. All kinds of electrical and acoustical stunts are being devised and pressed on the world, but whether they have merits or not need not be discussed here and now. It is quite simple to lay down the basic requirements of two channel high fidelity stereo broadcasting in terms of what we know today. It is of no consequence, here and now, to argue that three channels are really required for the best results. We are considering only the straightforward proposition that if one high fidelity channel can be produced by broadcasting for monophonic audio, and it is considered that two channels are needed for stereophonic audio, then we have to provide two high fidelity broadcast transmissions. The discussion will, therefore, be restricted to considering how this can be done, with particular stress on the fact that the two channels have to be hi-fi.

## What Multiplexing is

Before we go any further it should be made clear that multiplexing is a certain technical process for conveying several programmes on a single carrier, whereas stereo broadcasting is simply the transmission of a left and right hand aspect of a single programme through the medium of a combining receiver and speaker system. Stereo broadcasting can and does exist without multiplexing being involved, but the advent of multiplexing indicates the possibility of broadcasting stereo programmes from a single transmitter. There is no quarrel as to the desirability of stereo broadcasting; but there are widely differing opinions as to how it should be done.

The simplest illustration of multiplexing is to be found in carrier telephony. With the development of the low-loss coaxial cable it became possible to send a high frequency carrier along an underground conductor, chop up the frequency band of the carrier into sections, and transmit speech along each section. Provided there is a frequency space between each section there will be no crosstalk, and sending and receiving the separate conversations is simply a matter of selection by frequency selecting filters. This, of course, is a very crude description, but it illustrates the basic idea.

Turning, now, for a moment to stereo broadcasting, the standard practice in the U.S., where it is a regular feature of the broadcasting scene, is to transmit one stereo channel on AM and the other on FM, but if the AM transmitter is only sending out the left hand channel and the FM the right hand, a monophonic receiver tuned to either will not reproduce the entire programme, for the AM receiver will only be able to reproduce the left and the FM receiver only the right. As it is a cardinal principle of broadcasting that the main transmission should not be made of such a nature that it can only be received by a minority of special receivers, the transmitted signal must be made *compatible*. This compatibility became a burning question when colour television was launched on the U.S. public; the federal authorities would not approve any system which did not make a " monocolour " picture available to the ordinary TV set owner. The man with a colour TV set would get the picture in colour, but the same picture must be available to the rest in black and white. So with stereo; if a stereo programme is sent out and can be received as stereo by the man with stereo equipment, it must also be receivable as monophonic by the man with an ordinary set.

In previous chapters I have explained how, except under very favourable conditions, AM is not suitable for high fidelity reception; yet it is quite suitable for mass-produced receivers and the listener who isn't particularly interested in hi-fi. It seems obvious that hi-fi stereo should have hi-fi on both channels, and so we have to rule out any permanent system that depends on an AM/FM arrangement. In actual fact transmissions so far carried out have only been experimental here and in the U.S., and not too much attention has had to be given to the high fidelity aspect, for the first thing to do was to " stereoise " the transmissions; refinements could come later.

At this point it should be realised that the broadcasting background in Britain is very different from that in the U.S. Here we have a B.B.C. service paid for by the " subscriptions " of the listeners; in the U.S. broadcasting is free and the cost of providing the stations and programmes has to be borne by the advertisers who buy time on the air. It is no part of the purpose of this book to say which system is the better, but the net result is that in Britain we have an integrated AM and FM service which has been paid for by the people who use it, and we have some say, and ought to have more, on the way the service is run. In the U.S., as in Britain, the number of people who have no FM receiver is considerably greater than those who have, and the AM service is virtually self-supporting and profitable. The erection of stations for FM was an aspect of private enterprise, and so far, because of the limited listener market, has not proved profitable. There was a crying need for something that would increase station income.

A solution was found in the notion that if private subscriptions to a private service could be found as a sideline, this would pay off, and suitable subscribers could be found in such enterprises as hotels and restaurants desiring background music free from the commercials of ordinary radio. If a new transmitter were built for such a service, no solution of the non-profitable public broadcasting problem would emerge, so the private programme had to go out through the same transmitter and the same carrier, but entirely separated from the public programme. The ever-competent technicians and engineers produced the technical solution, and so radio multiplexing was born.

The most widely used is the Crosby system, and for the purpose for which it was designed compatibility was the very last thing that was desired; the background music programme was provided only for subscribers and could only be received by using a device called a multiplex adaptor. The system works in this manner: the basic programme is broadcast as a regular FM transmission on a carrier frequency, say, of 100 mc., with the usual deviation frequency of ± 75 kc. This permits an audio frequency spectrum of 15 kc. The private service programme goes out on a sub-carrier, which is superimposed on the main carrier; the sub-carrier frequency has been chosen as 50 kc. with a maximum deviation frequency of 25 kc., thus giving a frequency spread from 25 to 75 kc.

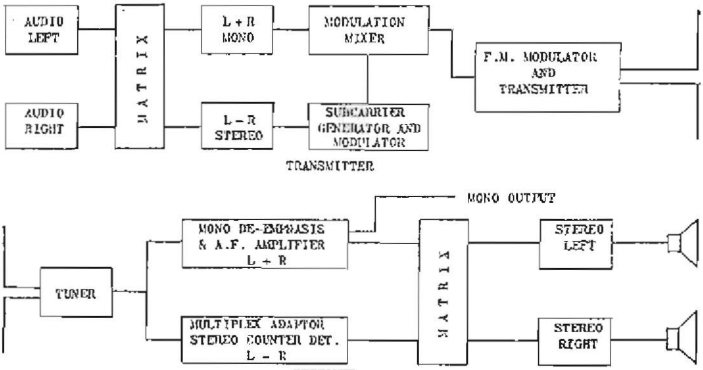


Fig. 1.3.1. Block Diagram of Crosby Compatible System.

A monophonic receiver tuned to the FM broadcast frequency of 100 mc. will consider this subcarrier as some sort of deviation frequency, but as it is the equivalent of an audio modulation of 50 kc. ± 25 kc., it will be treated as audio even if it is supersonic audio., but it will be filtered out in the audio part of the receiver, particularly by the de-emphasis section of the receiver. On the other hand, if the private programme is to be received, then the regular broadcast programme must be suppressed or filtered out and the subcarrier treated as the main carrier and duly handled in the usual FM manner. This is done by the multiplex adaptor, which consists primarily of a separating frequency discriminating network to supress the 100 mc. carrier and pass on the 50 kc. subcarrier; thereafter follow the usual processes of amplification (no superhet being needed for such a low frequency), limiting, detection and audio amplification.

Obviously, the subcarrier could be used to transmit a second channel for stereo, but if the two channels transmitted are left and right, then whatever is on the main channel of 100 mc. is only half the programme, and the system is not compatible. To render the main transmission compatible, which means both left and right channels superimposed, calls for certain tricks. Fig. 1.3.1 is a block diagram of the Crosby compatible system and can be explained in this way: the main L + R programme is sent out as one channel and the special stereo information goes out on the subcarrier, having L-R characteristics. These two modulations are derived from the originating left and right microphone outputs being fed into a matrixer, as shown in the figure, subsequently merged in the special mixer, used to modulate the transmitter, and so broadcast.

At the receiving end the composite carrier is handled by the tuner in the usual manner, and the emerging rectified signal fed into the usual de-emphasizer-amplifier (from which it emerges as the L + R mono. signal) and to the multiplex adaptor, from which it emerges as the special L-R stereo information. The outputs from both units are then fed to the " dematrixer " and finally appear as the left and right stereo signals.

Among the more ingenious of the multiplex adaptors is the Madison-Fielding, and it is not a simple piece of apparatus. It embraces a cathode follower input, a frequency network to reject the L + R carrier, an amplifier for the subcarrier, a limiter stage and a detector. So far as the detector is concerned only the counter type can be used, for the percentage frequency change is far too great to be handled by a discriminator or ratio detector. With a 100 mc. carrier the frequency change is only small (referred to the carrier frequency) being from 100.075 mc. to 99.925 mc., but in the case of the 50 kc. subcarrier the frequency change is from 25 to 75 kc. and the ratio detector simply will not handle it. The Madison-Fielding uses a two valve multivibrator to produce the square pulses and a triode counter followed by a phase-splitter to get rid of the negative-going pulses; the whole unit calls for four double triodes and their associated circuitry.

It has always seemed to me that if real high fidelity involves precise design and constancy of operation, and as the productions of mortal man cannot be perfect, the most reliable course to pursue is one of simplicity, for there are fewer things to go wrong. The compatible system I have just described adds very considerably to the complexities of both transmitting and receiving, particularly at the receiving end, and this strikes me as an unsatisfactory state of affairs. Broadcasting stations have their skilled maintenance engineers, but such don't exist in ordinary households, and it is expecting an awful lot for this complex receiving equipment to go on working in a perfectly normal manner. Aurally horrible faults exist in stereo gramophone reproduction; they could be twice as bad with this sort of stereo broadcasting. Diagnosis of faults will be extremely difficult, even as it is in stereo gramophones, because it is more than mere circuit checking; the performance of one channel must be identified with the performance of the other, and there is as yet no proof that the L + R and L – R combination will give real stereo. They just say it will.

There are some other things they are saying, too, which haven't been proved. The band width of 150 kc. for FM transmission has been laid down as minimum for audio reproduction up to 15 kc. and even that is cutting corners, hence the allocation of 220 kc. for FM channels. The band width on the subcarrier is only 50 kc. and in FM it isn't the carrier frequency that matters but the side bands on that carrier. With a band width of only 50 kc. it doesn't seem that the subcarrier can transport a very high fidelity programme. Now this is no criticism specifically directed against the Crosby system. Reports are that it gives very good results, and it has spurred others into emulating those results, among which can be mentioned Burden, Halstead, Bell and Calbest. These all involve frequency restriction of the subcarrier audio response and learned arguments have been produced to prove that frequencies over 8000 c.p.s. have no stereo effect; others have proved that nothing over 3500 contributes to stereo, provided the main transmission is good; some demand a reduction in the 150 kc. band for FM since " it isn't necessary ". The clamour has become so great that one respected American high fidelity critic has complained that new theories seem to be produced simply to buttress the competing systems, without any regard for the poor guys who have to buy the equipment. And, as a gesture of indifference to this battle, R.C.A. have devised a complete AM system, but it doesn't seem to have aroused much enthusiasm.

In Britain the E.M.I. Percival system appears, from what information has already been divulged, to have a family resemblance to the Crosby, but differing in certain aspects: but it also takes in certain assumptions as to the behaviour of the ear which have not as yet been proved beyond dispute, and which I for one would be prepared to dispute. The whole field has been so slightly investigated that it is safe to say we cannot be sure, and until we are sure, it seems to me that it is better to forget all about L + R and L − R, and transmit both left and right channels just as they would come from a stereo pickup, give them the " full treatment " as to audio response, make the system compatible, make it simple to instal and maintain, and make it cheap. We already have enough capital outlay in doubling up audio amplifiers and speakers, and don't want to have to double up on anything else. The recently announced (February 1960) Mullard Multiplex System seems to meet these requirements.

## Mullard Stereo Broadcasting System

I should say I have no connection with the Mullard Company; I am an independent consultant and when I write I cannot be influenced by commercial interests. This being so I state that in my opinion this system is the best that has so far appeared from the point of view of meeting the needs of a high fidelity enthusiast who doesn't want his home to resemble an electronics laboratory.

The system has outstanding features. It is simple; it can be applied to any existing FM transmitter with only minor modifications; any existing FM receiver can be modified for stereo reception by adding one valve and making a few circuit changes. If the listener already has a stereo audio system and a mono FM receiver all he needs is the one valve adaptor; if he has no stereo at all, he needs the adaptor and an additional audio amplifier and speaker. If he doesn't want stereo in any shape or form, his FM tuner will accept the stereo transmission as a monophonic one; and if the transmitter decides to send out a mono programme the stereo owner will get the programme on both channels and his two speakers will reproduce everything. In other words, the system is completely compatible both ways. There is no matrixing, so worries about the receiver matrix matching the transmitter matrix don't arise. Each channel transmits the full frequency range, so there are no arguments as to whether stereo can stop at 8000 c.p.s.

The fundamental difference between this system and the others already described is that it is a system in time rather than in space. If you interrupt a steady tone sufficiently rapidly, at any supersonic frequency, the ear cannot hear the interruption. In the Mullard system the transmission is interrupted at 32.5 kc.p.s. and the left and right hand channels are sent out alternately. They arrive at the receiving end in the same order and if the receiver is monophonic it just takes them all in and adds them together. If the receiver is stereo, it picks them out alternately and feeds them into their respective amplifiers. And that is all there is to it!

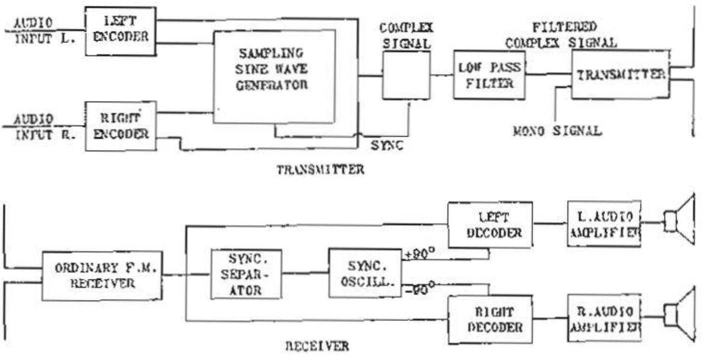


Fig.1.3.2. Block Diagram of Mullard Compatible System.

Fig. 1.3.2 gives a block diagram of transmitter and receiver. The multiplexer is a sampling audio generator operating at 32.5 kc. and right and left encoders. The generator has two outputs 180° out of phase with each other, so the left hand channel can be leading 90° and the right lagging 90°. A sync. signal is also produced, whose function will be described later. The circuit of the generator and two encoders is given in Fig. 1.3.3 (the sync. source being omitted for clarity). The out-of-phase outputs are fed into encoders, half wave rectified, and produce pulse trains in each encoding valve. These pulse trains are modulated by audio signals fed into the encoders and combined to form a complex signal consisting of left and right hand pulse trains occurring alternately, passed through a low-pass filter to get rid of spurious harmonics, and applied to the modulator of the transmitter. (Fig. 1. 3. 4.)

At the receiving end precisely the reverse takes place. A normal FM tuner accepts, amplifies and detects the complex signal in the ordinary way and the rectified output is fed into a left and right

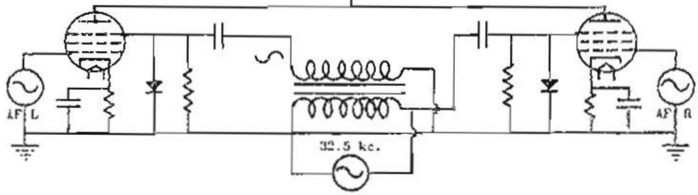
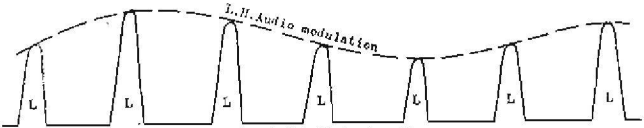


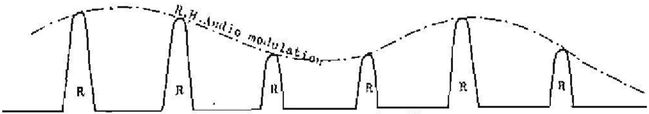
Fig.1.3.3. Circuit of Mullard Transmitter Encoder-oscillator.

decoder operating at the same frequency as the transmitter sampling generator. Naturally, the whole scheme depends on the these sampling frequencies at transmitter and receiver operating at precisely the same frequency, and synchronism is achieved in a manner similar to that used in TV.

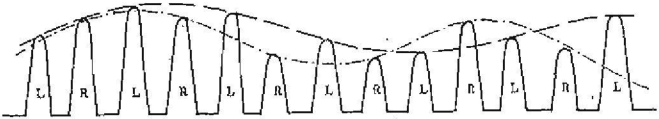
Fig. 1.3.4 also shows the operations in the receiver. Diagram A shows the train of pulses in the left hand decoder, B that in the right hand. The signal before being split into two appears at C. and there is an interval between each pulse. This interval is used to transmit a sync. signal, as shown in D, a negative-going pulse which can be separated by the sync. separator shown in the receiver block diagram in Fig. 1.3.2. Here the sync. oscillator is simply an electronic switch directing the alternate pulses into their proper decoders which it can do by the phase difference; the left decoder rejects the right-hand signal and *vice-versa*. If the receiver oscillator stops, the complete signal appears in each amplifier; if the receiver is monophonic the complete signal still goes into the single audio amplifier, for no electronic switching is involved.



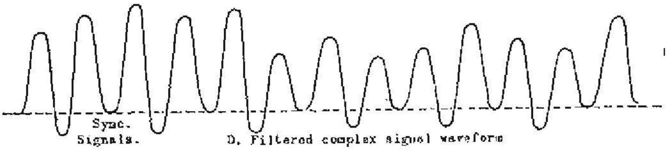
A. Sampled left-hand audio wave



B. Sampled right-hand audio wave



C. Complex signal waveform.



D. Filtered complex signal waveform

Fig.1.3.4. Synthesis of complex waveform in Mullard system.

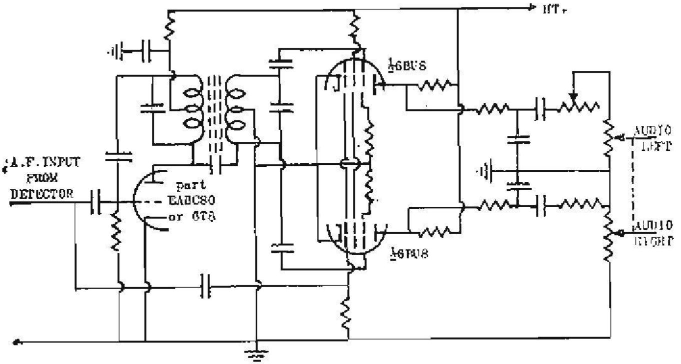


Fig. 1.3.5. Circuit of Mullard sync. separator and decoder for any conventional F.M. receiver. If the triode oscillator (part EABC80) is stopped, left and right signals appear at both audio outputs.

The added circuitry for the receiver is shown in Fig. 1.3.5. On the left is seen the conventional ratio detector of the FM receiver, and it is usually the case that the two diodes are part of a double-diode-triode, the triode being the first AF amplifier. If so this triode can be used as the sync. oscillator; if not the case, a new triode must be provided. The oscillator is tuned by the sampling frequency transformer which passes them to the double pentode 6BU8, whence the separate signals are fed to their respective audio amplifiers.

It should be noted that the dotted lines representing the two audio waves in Fig. 1.3.4 have no real existence, for they merely represent the profiles of the successive pulses. Since, however, the interruption is inaudible, the profiles do represent what the ear will actually hear.

The foregoing is, of course, a very simplified account of all that is involved, but it does describe the properties and simplicity of the system. I have heard it in operation and there can be no doubt that the two channels are reproduced with the full 30 to 15,000 c.p.s. response. What system is ultimately inflicted on us is something we cannot as yet forecast, but at least you will now know some of the things that could be in store for you when stereo broadcasting becomes a regular service. Perhaps before that happens even better systems will be devised, but I have tried to show that it is possible to transmit two channels from one

FM transmitter without any lower standard of performance than would be got from two of the present standard of excellence, and without our being involved in costly equipment at the listener's end of the proceedings. I want high fidelity reception, mono and stereo, but I am not prepared to pay throught the nose for it, nor am I content to be fobbed off with inferior performance when I could get what I want at a reasonable price. No doubt you feel the same way too!

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