# FREQUENCY MODULATION RECEIVERS MANUAL

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# FREQUENCY MODULATION MANUAL

by

"RADIOTRICIAN".

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# CONTENTS

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## CHAPTER I

## THE THEORY OF F.M.

Frequency modulation as a method of transmitting intelligence by radio was first proposed and described in its present form by Major E. H. Armstrong in 1935, although the underlying principles and several diverse methods of frequency modulation had been worked out and tested before that time. The Armstrong method, however, is the basis of operation for frequency modulation transmitters at the present time and, in America at least, there are several broadcast and experimental stations giving a constant F.M. service.

The non-technical press, including the daily papers, have given prominence at intervals to the much-boosted superiority of frequency modulation. It has been reported that by the use of this system broadcasts of greater tone fidelity and quality than ever before will be achieved, with absolutely no interference from external sources of static, either natural or man-made, whilst since frequency modulated transmissions will be carried out at very high or ultra high frequencies, there is virtually no limit to the number of stations which may be accommodated within the tuning range of a suitable receiver, all without interference one with another.

These reports are, of course, over optimistic, although there is more than a grain of truth in such statements. Let us first examine the method of frequency modulation, and then discuss its advantages, real or apparent, over the broadcasting system in present use.

At the moment every broadcasting station and the vast majority of amateur stations which are to be heard, in Great Britain at least, use amplitude modulation to impress sound signals on the transmitted carrier. Amplitude modulation, or A.M., consists of varying the carrier wave's amplitude, or strength, in time with the sound vibrations which are impinging on the microphone. The whole signal as transmitted has a central frequency to which a receiver is tuned and the high frequency circuits of the receiver are stimulated by the signal and pass to the receiver's detector or demodulator a high frequency amplitude modulated carrier which may, in a really good receiver, be a true picture of the transmitted wave. The detector then " separates " the audio component from the high frequency component of the signal, the audio signal being amplified and passed to the loudspeaker.

An amplitude modulated wave is shown in Fig. 1 as a graph of the

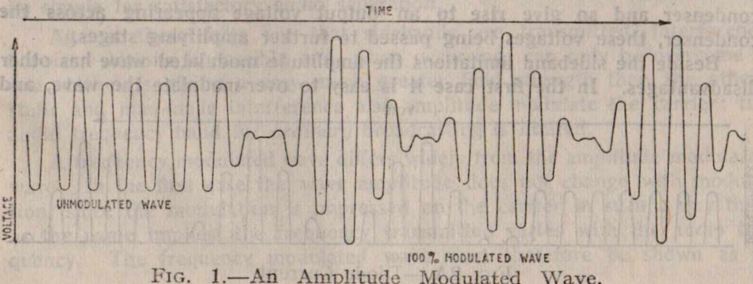


FIG. 1.—An Amplitude Modulated Wave.

high frequency voltages appearing at the input terminals of a detector, the graph being drawn to the two axes of voltage and time. The diagram cannot, however, give a full picture of the true state of affairs. The impressing of an audio frequency upon the carrier frequency gives rise to sidebands —that is, to frequencies on either side of the central transmitted frequency. Since the audio frequency heterodynes the carrier frequency these sidebands will be separated from the carrier by the audio frequency at any given moment, and one sideband will appear above, and another below, the central frequency. The whole transmission, therefore, takes up a band of frequencies rather than a single central frequency, and the bandwidth is obviously twice the highest modulation frequency.

By international agreement the bandwidth of broadcasting stations in the medium and low frequency tuning ranges at least is limited to 9 or 10 kcs. (1 kc. = 1,000 cycles). This means that the highest audio frequency which may be transmitted is of the order of 4,500 or 5,000 cycles, and whilst this is perfectly adequate for speech, which may be transmitted intelligently with an upper limit of less than 3,000 cycles, there must necessarily be some loss in the transmission of music.

When the modulated high frequency wave of Fig. 1 is applied to a simple detector such as a diode, the wave as a whole is rectified. In Fig. 2 is shown such a circuit, together with further graphs of the modulated wave's output. The diode will conduct only when the anode is positive with respect to the cathode, so that only one half of the modulated wave passes through the diode as a series of spurts of current, the amplitude of the current obviously depending on the original wave amplitude and thus on the audio modulation. The currents passed by the diode charge the condenser and so give rise to an output voltage appearing across the condenser, these voltages being passed to further amplifying stages.

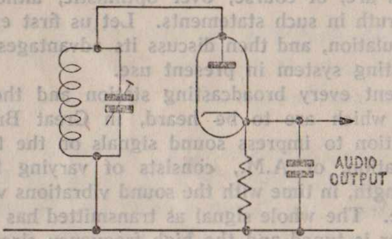


FIG. 2.—Simple Diode Detector with first cycle of A.M. wave of Fig. 1

Beside the sideband limitations the amplitude modulated wave has other disadvantages. In the first case it is easy to over-modulate the wave, and

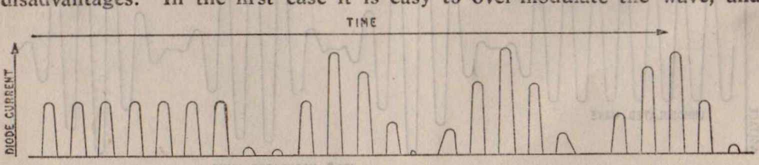


FIG. 2A.—Diode Current.

whilst precautions against such an occurrence are taken as a matter of course in a broadcasting station, the amateur transmitter is often not so well guarded against overmodulation. When the effect takes place the sidebands deviate further from the central frequency and at the same time harmonics of the audio frequency are generated in the receiver, giving serious distortion.

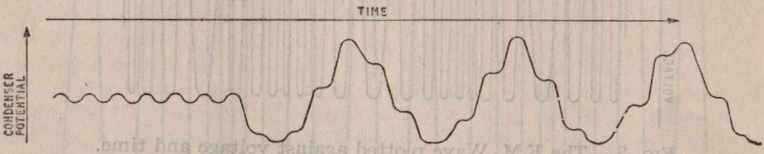


FIG. 2B.—Condenser Potential.

Should a sideband of one station take up the same frequencies as a sideband of an adjacent station, the result will be "sideband splash," and neither station will be received clearly unless one signal is very much stronger than the other, the actual extra signal strength necessary for the elimination of an interfering signal (unless the interfering station is radiating the same programme) being of the order of 45 decibels (dbs.) which is a very considerable increase indeed when it is remembered that a rise in signal strength of 6 dbs. is equivalent to doubling the field strength.

Again, atmospheric noises or static, together with interference from electrical machines and apparatus, ignition interference and the like, are all passed through a receiver, together with the modulated wave, as amplitude modulations, and thus can completely swamp the transmitted intelligence whilst the noise modulations last. In communications receivers there is usually provision made for suppressing interference by noise, the method usually being to pass the audio output from the detector through a second diode so biased that an audio signal of greater amplitude than the amplitude of the required signal is literally "cut off." The noise level is thus kept at the same level as the speech or music, the noise being much less troublesome under such conditions.

To summarise, then. The amplitude modulated wave is produced at the transmitter without difficulty; is useful for communication at practically any frequency; may be modulated up to 100 per cent but over-modulation is possible and undesirable; and the receiver detector circuit need only be simple for satisfactory audio separation.

Against these facts are that sidebands are transmitted, interference between stations is possible and, when occurring, can only be overcome if one station is giving a very much greater field strength than the other; static and man-made interference also amplitude modulate the carrier; the audio frequency band *for ordinary* broadcasting is limited.

A frequency modulated wave differs widely from the amplitude modulated wave. In the first case the wave amplitude does not change with modulation, since the modulation is impressed on the carrier in such a way that, as the name implies, the frequency transmitted varies with the audio frequency. The frequency modulated wave must therefore be shown as in

Fig. 3 if voltage is plotted against time, or as in Fig 4 if frequency is plotted against time.

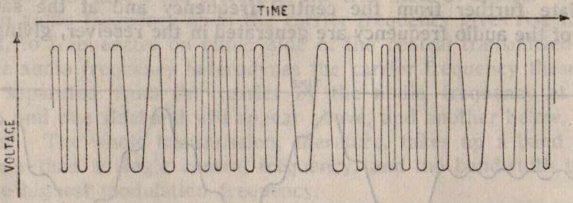


FIG. 3.—The F.M. Wave plotted against voltage and time.

Substitute the frequency modulated wave, as shown in Fig. 3, for its amplitude modulated counterpart, as shown in Fig 1, and imagine such a wave fed to an ordinary detector of the diode type. The spurts of current passed by the valve will now be all of the same amplitude, and the fact that there is some variation in the time between one spurt and another will have no effect on the voltage across the diode condenser. Each spurt of current will only serve to keep the condenser charged to the same potential,

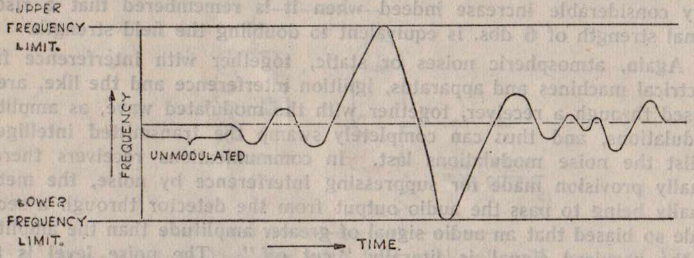


FIG. 4.—The F.M. Wave plotted against frequency and time.

so that a frequency modulated wave applied to an ordinary detector will give no audio output *so long as the tuned circuits of the receiver do not discriminate between the excursions of frequency which make up the modulation.*

The amplitude of the wave no longer matters. Consider an enlarged section of the F.M. wave as shown in Fig. 5a and then, by cutting off the wave tips, reduce this amplitude to the extent shown in Fig. 5b. The intelligence carried in the original wave is still present and the clipping of the wave peaks does not affect the sound quality in any particular, although such a process would cause very serious distortion in an amplitude modulated wave. Any interference or static which has affected the amplitude of the wave may therefore be removed almost completely simply by amplifying the F.M. carrier to an extent greater than is necessary, and then, by a clipping or limiting circuit, reducing the wave amplitude by discarding the wave peaks, amplitude changes being also discarded in the same operation. The detector must now respond not to amplitude changes, but to frequency changes, but discussion of the detector is left to another chapter.

Although the wave peaks may be cut away completely, a trace of interference may still be passed through the receiver to appear in the loudspeaker in the manner shown in Fig. 6. Here the wave is shown with interference appearing not only at the wave peaks but also as a noise modulation all

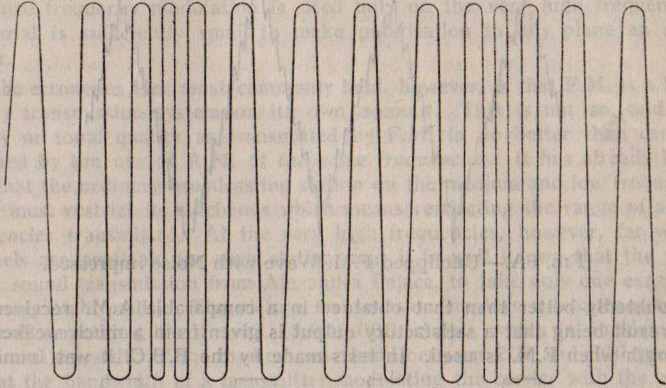


FIG. 5A.—Unclipped F.M. Wave.

along the wave. Clipping of the peaks does not affect the noise modulations along the wave, and over one magnified half-cycle these noise fluctuations will have the effect shown in Fig. 6c. The detector of the F.M. receiver must respond to the frequency—that is, to the time interval—between each wave. It can be seen from the figure that, with the noise modulations on the wave, there are two possible time intervals at any instantaneous frequency, the detector having to respond twice instead of once between an up and a down swing, the net result being a certain degree of noise passed on for amplification.

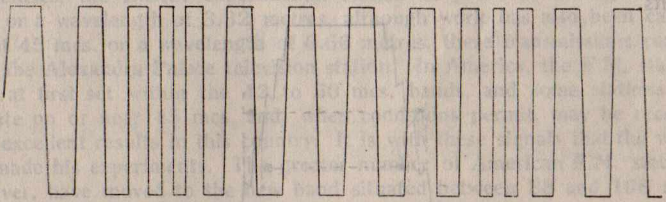


FIG. 5B.—Clipped F.M. Wave.

The majority of readers will know, however, that the most important fact relating to noise so far as the receiver is concerned is the signal-to-noise ratio—the comparison of signal voltage and noise voltage throughout the receiver and especially in the first stage—where the noise is actually caused by the working of the receiver components and consists of valve and circuit hiss. The signal-to-noise ratio is of importance in all types of receiver, whether broadcast, communications, A.M., F.M., television or any other kind of circuit is under observation, and in this direction clipping the peaks of the F.M. carrier in the receiver is of little avail in reducing circuit noise. The fact remains, however, that the signal-to-noise ratio in an F.M. receiver is undoubtedly better than that obtained in a comparable A.M. receiver, the net result being that a satisfactory output is given from a much weaker field strength when F.M. is used. In tests made by the B.B.C. it was found that a satisfactory field strength was 50 microvolts per metre with a frequency modulated carrier, an amplitude modulated carrier under similar conditions requiring to give a field strength of 900 microvolts per metre for similar results.

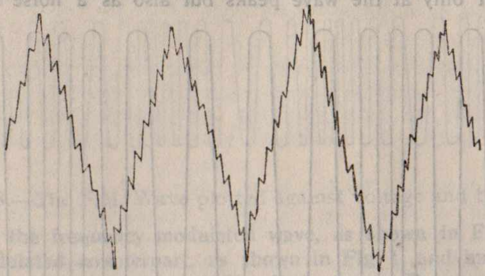


FIG. 6A.—Unclipped F.M. Wave with Noise impressed.

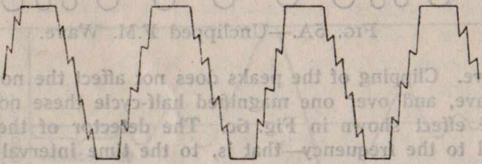


FIG. 6B.—Clipped F.M. Wave.

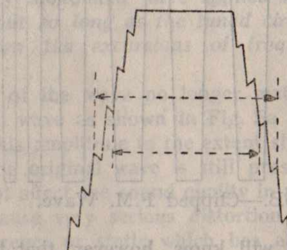


FIG. 6C.—Possible time Intervals caused by noise.

On the whole, therefore, it is perfectly true to say that frequency modulation gives a very considerable reduction in noise and external interference. The one type of noise which persists in breaking through is ignition interference, which also has very bad effects on ordinary amplitude modulated signals. Here again there is a reduction of the trouble by the use of frequency modulation, and experiment shows that for best results, particularly in overcoming interference, the transmitting and receiving aerials should be horizontally polarised—that is, the aerial wire itself should be in the horizontal plane. A vertical aerial gives better all-round coverage with a simpler array, but since frequency modulation is used only on the very high frequencies the aerial is sufficiently small to make polarisation in any plane an easy matter.

The erroneous idea most commonly held, however, is that F.M. is a high fidelity transmission system on its own account. This is not so, and the fidelity or tonal quality as transmitted by F.M. is no better than can be obtained by the use of A.M. *at the same frequencies.* It has already been seen that the ordinary broadcasting station on the medium and low frequency bands must restrict its sidebands which means restricting the range of audio frequencies transmitted. At the very high frequencies, however, far wider channels are available for each station, and it is well known that the television sound transmission from Alexandra Palace, to take only one example, is of very high quality. The picture transmission employs a frequency bandwidth of something like 5 mcs. (5,000,000 cycles), which is, incidentally, five times the width of the medium waveband between 200 and 600 metres, so that the bandwidth of a transmitter modulating the carrier with the audio frequencies up to, say, 15,000 cycles is still very narrow by comparison. On the very high frequencies, therefore, F.M. is at no greater advantage than is A.M., and the mistaken idea has arisen through comparison of the F.M. channelwidth at the very high frequencies with the A.M. channelwidth at medium frequencies. Indeed, it may be said that A.M. is the more versatile of the two systems, for an F.M. station on the medium frequencies would be quite impracticable. Not only would the channelwidth stretch across one-seventh of the medium wave band, but the tuned circuits could not be made sufficiently broad for reception.

F.M. stations, therefore, are limited to operation on the very high frequencies, the B.B.C. experimental station at present working at 90.3 mcs. or a wavelength of 3.32 metres, although work has also been carried out at 45 mcs. or a wavelength of 6.66 metres, these transmissions coming from the Alexandra Palace television station. In America, the F.M. stations were at first set within the 42 to 50 mcs. bands, and some stations still operate on or near 45 mcs. and, when conditions permit, may be received with excellent results in this country. It is with these signals that the writer has made his experiments. The greater number of American F.M. stations, however, have moved to the new band situated between 88 and 108 mcs., so that reception is virtually impossible.

Since modulation in F.M. working is impressed on the carrier wave as variations in frequency, there must obviously be limits set between which the frequency excursions take place. The present standard both in America and Great Britain is plus or minus 75 kcs., and it would appear that this standard will be retained. At the same time it is not possible to overmodulate the F.M. wave, and frequency deviations of either more or less than the maximum have no effect other than to cause some reduction in the signal-to-noise ratio of the received signal. These effects correspond to under and over-modulation of an A.M. carrier, where under-modulation gives a weak signal and over-modulation a distorted signal.

Some remarkable claims have also been published at various times relating to the effect of two F.M. stations operating with different programmes on the same frequency. Where A.M. stations are working under these conditions it has already been seen that the field strength of one must be 45 dbs., or more, greater than the field strength of the other if the stronger station is to overcome the interference and a garbled reception of both stations is to be avoided. With F.M., however, an effect known as the " capture effect " occurs, and the stations, it is said, do not interfere one with the other unless the field strengths due to each are very nearly equal. One early report claimed that a difference of only 6 dbs. in the two field strengths allowed the stronger station completely to swamp the weaker, with no interference.

This capture effect does exist, but the recent B.B.C. trials show that a field strength superiority of well over 6 dbs. is necessary to avoid interference. To completely swamp out an unwanted signal, the stronger station must give a field strength of 30 dbs. greater than the weaker station. Even so, the performance is better than that obtained from A.M. stations, and it may be that climatic and geographical considerations combined to paint a less glowing picture than that presented by certain American reporters concerning early American tests with Major Armstrong's own station, W2XMN, working on 40 mcs. in 1938 and 1939.

Frequency modulation still presents several advantages, however, which may thus be summarised: the frequency modulated wave is produced at the transmitter without difficulty; it is useful for communications at very high frequencies; it is virtually impossible to over-modulate; the signal-to-noise ratio is improved and external noise is greatly reduced, chiefly through receiver design coupled with the nature of the wave. Against this may be set the facts that fidelity as obtained with F.M. is no greater than that obtainable with A.M. under similar conditions; the service area is restricted for the reason that the very high frequencies must be used; special receivers are necessary, which require very careful tuning or crystal control (of which more later); the standard station channelwidth is 150 kcs.; and sidebands are set up which can be even more troublesome than the sidebands due to an A.M. carrier.

Consideration of deviation ratios, sidebands and similar matters of frequency require a separate chapter.

## CHAPTER 2

# FREQUENCY CONSIDERATIONS FOR F.M.

We have so far seen that a frequency modulated wave does not have changes in its amplitude, but changes in its frequency, these frequency changes being applied to a special detector circuit in order that the audio content may be passed on to amplifying stages and thus to a loudspeaker in the usual manner. For the benefit of those to whom the idea of frequency modulation is novel, and therefore difficult to understand, it may be as well to show one of the simplest systems by which sound may be allowed to change the frequency of a high frequency carrier.

In Fig. 7 is shown a simple oscillator circuit of the self-excited type, that is, the circuit is not crystal controlled, but has a conventional grid inductance and capacitance. The grid and anode circuits are tuned to the same fundamental frequency, and the anode inductance may be coupled to further amplifying stages to give a high output suitable for transmission in the usual way.

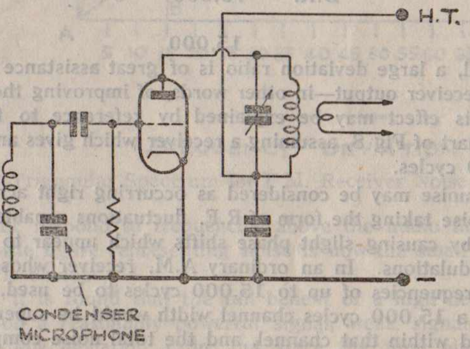


FIG. 7.—Oscillator frequency modulated in grid circuit.

The grid capacitance, however, is not the usual variable condenser, but is a condenser microphone. When sound waves impinge upon the microphone diaphragm, which is an extremely thin sheet of aluminium or similar metal spaced by a small amount from a massive backplate, the diaphragm vibrates in sympathy with the sound waves and the air spacing between the diaphragm and backplate thus varies in accordance with the sound waves. The capacitance between the diaphragm and backplate is thus also varied, and if this capacitance is used, as in the diagram, to tune the inductance, the tuning obviously must vary over a range of frequencies exactly in step with the sound waves causing the effect.

If the tuned circuit in the anode lead is made to have a broad tuning characteristic, this band of frequencies will be passed on to the next stage and thus to the aerial, and so the carrier wave will not change in its amplitude, but will change in frequency from one instant to another. When no sound affects the microphone the carrier will be transmitted on its central frequency and so will, in effect, be unmodulated.

In actual practice this system is no longer used, but it serves as an illustration. The amount of frequency deviation obtained by direct modulation of the wave in this way would actually be too small to give the desired results, and a chain of frequency multiplier stages would be necessary, the oscillator running at a low frequency, to give a final carrier frequency with correct deviation.

### DEVIATION RATIO

The ratio of the maximum frequency deviation of the carrier from its central, unmodulated, frequency to the highest audio frequency to be transmitted is known as the Deviation Ratio, and also as the modulation index. For example, if it is required to transmit audio frequencies up to 15,000 cycles with a maximum deviation of the standard 75 kcs. the deviation ratio is obviously 5, since

$$\text{D.R.} = \frac{75{,}000}{15{,}000} = 5$$

In general, a large deviation ratio is of great assistance in reducing the noise in the receiver output—in other words, of improving the signal to noise ratio—and this effect may be explained by reference to the " triangular spectrum " chart of Fig 8, assuming a receiver which gives an audio response up to 15,000 cycles.

Receiver noise may be considered as occurring right across the channel in use, the noise taking the form of R.F. fluctuations capable of affecting an F.M. carrier by causing slight phase shifts which appear to the detector as frequency modulations. In an ordinary A.M. receiver whose circuits would allow audio frequencies of up to 15,000 cycles to be used, the noise components over a 15,000 cycles channel width would be superimposed on the carrier centred within that channel, and the total noise component could be represented by the line FE in Fig. 8. In this diagram, receiver audio response is shown along the Y axis, AF, with carrier deviation along the X axis, AC.

The rectangle ABEF can also relate to an F.M. carrier with a deviation ratio of 1, however, and in this case the noise must be considered as a frequency beating with the carrier frequency, giving a frequency deviation proportional to the difference between the carrier and noise frequency with an audio frequency heterodyne of the same frequency. The response characteristic then takes the form of the line AE with the noise amplitude proportional to the audio heterodyne frequency, and since the average noise output amplitude is proportional to the square root of the sum of all the squares of all the noise amplitudes, the final effect is that the noise over the F.M. channel with a deviation ratio of only 1 is still only one-third of the noise which would be obtained with a comparable A.M. receiver.

(Remember that the amplitude or volume of the audio output is caused by the *extent* of the frequency deviation, the audio frequencies depending on the *speed* of frequency change.)

Increasing the deviation ratio to 5 gives the rectangle ACDF in the diagram, with a noise response represented by the line AD. In this case, however, the noise will only have effect along the line AG, since the

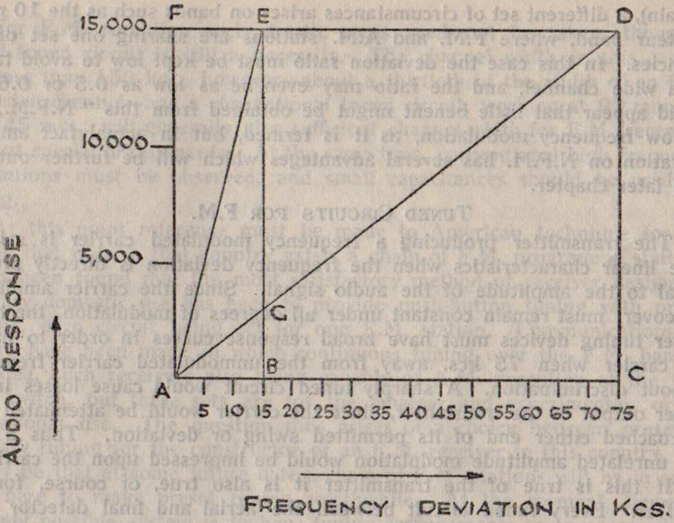


FIG. 8.—Triangular Spectrum for F.M. Receiver Noise Response.

receiver will not respond to frequencies above the audio limit of 15,000 cycles, and so the figure representing noise is now the small triangle ABG. The reduction is obvious.

In practice it is found that the full benefit of a high deviation ratio is obtained only on a reasonably powerful signal, weak signals giving better results with a low deviation ratio, but since the final aim of the F.M. service must be to cover a number of service areas with strong signals from a station central within each area, the high deviation ratio will almost certainly be retained.

### SIDEBANDS

An unfortunate aspect of frequency modulation transmission are the sidebands, which are inevitably set up by the fluctuating carrier, a series of sidebands existing on either side of the main carrier for each audio frequency component in the modulating signal. The ordinary A.M. wave has sidebands which correspond to the sum and difference frequencies of the audio modulating wave with the carrier, but, besides these two sidebands, there are, with an F.M. carrier, a series of sidebands caused by sum and difference effects between the carrier and harmonics of the audio frequencies.

The number of sidebands for any audio modulating frequency increases with the frequency deviation of the carrier, but as the deviation ratio rises the sidebands become less important for the reason that they are contained, for the most part, within the channel-width of the station, and the channel-width may be taken as twice the frequency deviation.

For amateur working, however (F.M. is permitted for amateur operation in America, and it is to be hoped that it will soon be allowed in Great

Britain), a different set of circumstances arises on bands such as the 10 metre amateur band, where F.M. and A.M. stations are sharing one set of frequencies. In this case the deviation ratio must be kept low to avoid taking up a wide channel, and the ratio may even be as low as 0.5 or 0.6. It would appear that little benefit might be obtained from this "N.F.M.," or narrow frequency modulation, as it is termed, but in actual fact amateur operation on N.F.M. has several advantages which will be further outlined in a later chapter.

## TUNED CIRCUITS FOR F.M.

The transmitter producing a frequency modulated carrier is said to have linear characteristics when the frequency deviation is directly proportional to the amplitude of the audio signal. Since the carrier amplitude, moreover, must remain constant under all degrees of modulation, the transmitter tuning devices must have broad response curves in order to handle the carrier when 75 kcs. away from the unmodulated carrier frequency without discrimination. A sharply tuned circuit would cause losses in the power output of the transmitter, since the carrier would be attenuated as it approached either end of its permitted swing or deviation. Thus a false and unrelated amplitude modulation would be impressed upon the carrier.

If this is true of the transmitter it is also true, of course, for the receiver. Every tuned circuit between the aerial and final detector must be capable of passing the full frequency range of an F.M. carrier without excessive attenuation of any one part of the channel-width, and this fact again shows the need for high frequency F.M. operation.

The tuning arrangements for an F.M. receiver may be said to have characteristics which fall between those desirable for A.M. broadcasting on the one hand and television picture reception on the other. In A.M. broadcast work selectivity is not only desirable, but necessary, the tuned circuit response curve being narrow and fairly sharply peaked, with a high value of "Q" or tuned circuit efficiency, whilst for television reception selectivity is the last desirable quality. Here the tuned circuit must pass without discrimination a whole band of frequencies up to 5 mcs. in width, so that the response curve in this case must be very broad with as flat a top as can be achieved. These requirements, together with the valve characteristics at the very high frequencies used, force the tuned circuit "Q" down to an undesirably low figure, so that several amplifying stages are necessary to give as much gain as a single stage will give at lower frequencies. This state of affairs must be accepted, however, if the picture frequencies are to be passed.

To make a tuned circuit sufficiently broad for television work one or two methods may be used. A conventional circuit of coil and capacitance may be shunted with a resistance of 10,000 or 20,000 ohms., the result being a loss of efficiency and a broadening of the response curve, or the circuits may be coupled, with their associated valves, in such a way that the tuning capacitances are supplied by the valve input capacitances, tuning condensers as such, disappearing from the circuit. The valve anode load resistances are then chosen in such a manner that they effectively shunt the following coil and broaden its response curve whilst giving as high a gain as possible in their own stage. Such a circuit for television reception will be found in Bernard's Television Constructor's Manual.

For F.M. reception such drastic steps need not be taken, though a broad tuned circuit is still a necessity. The channel width in this case is no more than 150 kcs., however—about a thirtieth of the width of an ideal television channel—and a conventional tuned circuit, working at 90 mcs., or even 45 mcs., will generally give sufficient channel-width for F.M. reception without special arangements. At the same time, conventional high frequency precautions must be observed, and small capacitances should be used for tuning.

At this point reference must be made to American technique for the reason that only in that country exists a chain of F.M. programme stations. It has been found that the most satisfactory method of receiver design for ordinary domestic use has been to provide push-button tuning with preset circuits, each circuit being set for one F.M. station. Communications receivers have been made in which continuous tuning over the F.M. band is provided, such receivers also being capable of A.M. reception at the turn of a switch, but these sets are for the amateur and experimenter, or for professional use. The question thus arises of a choice between preset or ordinary tuning for the constructor of an F.M. receiver in this country, and it may be that at some future date a chain of F.M. stations will be in existence here to make preset tuning worthwhile. At the moment, however, the only possible system is to have tuning arrangements to cover as wide a band as possible, since the British experimenter must rely on the Alexandra Palace 90 mcs. transmissions until further stations are erected, a few Armed Forces F.M. transmitters in occasional use, some F.M. telephone bands at various parts of the very high frequency spectrum and such fortuitous fragments of F.M. as may come his way from America when conditions permit. Frequency modulated signals from America will increase in the 10 metre amateur band, however, and whilst the N.F.M. used can be tuned fairly successfully on an ordinary high and very high frequency superhet or communications receiver, the F.M. receiver proper can be used with advantage.

For the first tuned circuits of the F.M. receiver, then, the ordinary coil and condenser can be used, but the F.M. receiver must be of the superhet type so that there are further types of tuned circuit to be considered apart from the circuit or circuits tuned to the fundamental carrier channel.

The intermediate frequency chosen for the set will naturally set the oscillator frequency. Presume, for the moment, that it is desired to receive the B.B.C. test transmissions on 90 mcs. and that the receiver I.F. is to be 10 mcs. The receiver's local oscillator must therefore work at either 80 mcs. or 100 mcs.

The F.M. superhet should, however, be very stable in operation, with frequency drifting cut down to an absolute minimum. An oscillator working at a frequency as high as 80 or 100 mcs. cannot possess good inherent stability unless a special oscillator such as a long lines or crystal stabilised oscillator is used, and if it is desirable to use an ordinary inductance-capacitance circuit, as is usually the case, the simplest way out of the difficulty is to allow the oscillator to work on a low fundamental frequency, using one of its harmonics for frequency changing. Thus, in the example above, the oscillator circuit could be designed and constructed to operate on a fundamental frequency of 20 mcs. when its fourth harmonic would be at 80 mcs. to beat with the 90 mcs. signal and produce a 10 mcs. intermediate frequency.

The difficulties of ganging the first tuned circuits with the oscillator tuning is at once apparent—another pointer to the desirability of push-button tuning for F.M.—and the problem is best solved, for the experimenter, by supplying separate tuning controls for the signal and oscillator frequencies.

The high intermediate frequency necessary for F.M. reception is related to the very high frequency used for transmission of the carrier. In the ordinary broadcast receiver used for programme reception at medium and low frequencies the I.F. is now standardised at a value round about 465-470 kcs., and there is no difficulty in designing and building a superhet using such an I.F. to tune right up to the very high frequencies. The chief disadvantage of using such a (relatively) low intermediate frequency is that image interference increases rapidly with signal frequency, so that at 14 or 15 mcs.—approximately the 20 metre band—it is almost impossible to build a superhet which will not give image interference without an R.F. stage.

Image interference may be briefly explained by saying that any signal will heterodyne with the receiver's local oscillator to give two I.F. signals, one above and one below the oscillator frequency. The conventional receiver is so arranged that it accepts the heterodyne below the oscillator frequency as the I.F. signal, and the selectivity of the first tuned circuits is quite sufficient to reject the signal completely at the point where it would cause image interference. As the signal frequency rises, however, the selectivity of the first tuned circuits falls until image reception becomes a real trouble in the ordinary "all wave" commercial set, whilst at frequencies of 45 and 90 mcs. an I.F. of 465 kcs. is much too low for trouble-free operation.

At the same time, the I.F. transformers are required to pass a wide band of frequencies rather than a single frequency with sidebands, and the use of high frequency I.F. transformers simplifies the solution of this problem also.

The amateur or experimenter engaged on building a receiver for frequency modulated signals is advised to wind his own transformers, not only for the greater practice and insight into the receiver's operation thus obtained, or for the very real saving of expense, but also for the reason that the receiver I.F. might require changing if and when a chain of British F.M. stations is erected and working. At the present time, with only one or two F.M. stations in operation, the actual I.F. chosen is not of prime importance, but if, as in America, a band of frequencies is given over to F.M. broadcasting it will be necessary to incorporate in the receiver an I.F. system whose image frequency or second harmonic falls outside of the band width.

To take an example, the two American bands at present in use lie between 42 and 50 mcs. and 88 and 108 mcs. Taking the first band, 42 to 50 mcs., the band width is 8 mcs. and common practice was to use 4.3 mcs. I.F. transformers, the image frequency then being 8.6 mcs. With the introduction of the new 88 to 108 mcs. band, however, the band width increased to 20 mcs. and 10 mcs. I.F. transformers were hardly sufficiently high in frequency.

For operation in Great Britain, however, a 9 or 10 mcs. I.F. system will be perfectly satisfactory at the present time and probably for some time to come, and a lower I.F. might also be used without trouble.

In some surplus war apparatus there are included 9 mcs. I.F. transformers, which would probably give excellent results, or television I.F. transformers might be used, if to hand, since these are generally wound to work at about 13 mcs. Television I.F. transformers are designed to operate with a very wide band of frequencies, though, and will not give as much gain as a more sharply tuned component. Details for winding suitable transformers and coils are given in Chapter 4.

## CHAPTER 3

## THE F.M. RECEIVER

With a clear picture of the F.M. wave and the knowledge that a suitable receiver will take the form of a superhet designed and adjusted for wide-band operation on the very high frequencies, we can now inspect the receiver in greater detail and discover the methods which may be employed to obtain an audio response of high quality from a carrier wave varying in frequency.

The receiver may be built for F.M. reception only or may combine the two functions of an F.M. and A.M. very high frequency receiver. In the former case the number of controls will be rather less, but in neither case need the receiver be unduly complicated. The number of stages naturally depends on conditions, but as F.M. broadcasting comes into greater use the F.M. receiver, at least for domestic purposes, will probably shrink, rather than grow, and become a simple frequency changer, I.F. amplifier, detector and output stage circuit, much as is the usual domestic receiver of the present.

To receive F.M. under the present conditions, however, an R.F. stage is desirable, although not absolutely necessary, especially for workers living within the main service area of the present Alexandra Palace experimental transmitter. This service area may be taken as a 35 or 40 mile radius circle around the transmitter, although, just as is found in television, local geographical features will have considerable effects on the signal at the receiving point. A dipole aerial should be used for preference, cut to resonate at 90.3 mcs., and should be tested for both horizontal and vertical polarisation. Experimenters who are outside this service area should explore the very high frequency bands for F.M. signals, and have a selection of plug-in coils, by means of which the F.M. receiver can be tuned over a fairly wide range of frequencies.

An R.F. stage, if used, will feed into the frequency changing stage where the signal is hetrodyned by the local oscillator to provide the intermediate frequency. So far the set follows normal practice, except that a lower frequency oscillator might be used, a harmonic of the oscillator fundamental frequency beating with the signal frequency, or a crystal oscillator frequency changer might be employed. For the sake of efficiency, it is usual to provide a separate oscillator, but the experimenter might well test a conventional triode-hexode type of frequency changer for performance.

The I.F. amplifier may consist of only one stage, but it is necessary to supply a strong signal to the limiter which follows the I.F. amplifier, so that two stages at least are generally employed. These will be operated at a high intermediate frequency of 10 mcs., or thereabouts, and there need be no I.F. gain control such as is usually fitted to a two-stage I.F. amplifier of a communications or similar receiver. The I.F. amplifier should always run at full gain for F.M. reception.

With the limiter stage the receiver leaves conventional design.

It has already been shown that clipping the peaks of a frequency modulated wave has no effect upon the audio content of the carrier—no distortion is caused and the only effect is to remove any amplitude modulation which may have been added to the wave by interference—or by poor design in any part of the apparatus. The limiter stage in an F.M. receiver is designed to carry out this clipping operation. The carrier, now at the intermediate frequency, is passed through the limiter stage, so that it appears at the output side of the limiter as a wave of rather less amplitude than the wave at the limiter input terminals. The amplitude, however, is now absolutely constant, providing that the I.F. amplifier has sufficient gain to supply a wave of sufficiently large amplitude for the limiter to cut, and no amplitude modulation can exist on the carrier which is passed to the detector.

The detector in the F.M. receiver is renamed the discriminator, for no longer does it detect changes in wave amplitude—rather it discriminates between frequency changes. The wave is fed to a tuned circuit, so arranged that it is resonant at the centre of the I.F. channel-width, the tuned circuit being centre tapped and, with diode detectors, connected to either end of the inductance. As the frequency of the carrier shifts, or deviates, an induced current in the tuned circuit is fed to the diodes together with a current tapped capacitively from the I.F. amplifier, and these currents assist or oppose each other by phase changes according to the deviation of the carrier from its central frequency. The result is that the two diodes receive voltages varying with deviation, one diode receiving the higher voltage when the deviation is below resonance, and the other receiving the higher voltage when the deviation is above resonance. The two voltages are fed into a common network, and the difference voltage is passed to the amplifying and output stages.

A slightly simpler type of detector utilises two tuned circuits, one being tuned above and the other below resonance. As the carrier deviates the tuned circuit most nearly in tune at any instant will supply a greater signal voltage to its associated diode, the voltages again being supplied to a common network so that the output is the difference voltage between the two diode voltages.

The various circuits may now be studied in greater detail.

There are two forms of limiter chiefly used, the preferred type being the anode-saturation limiter shown in Fig. 9. The working of the circuit is

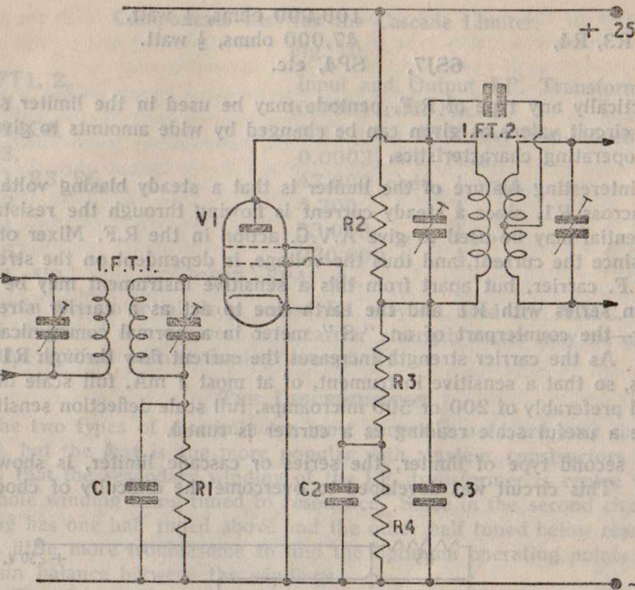


FIG. 9.—The Anode-Saturation Limiter Stage.

simple, and depends on the fact that an R.F. pentode, working at the intermediate frequency of the receiver, is supplied with low voltages on its anode and screen. The effect is, of course, to limit the anode current in such a way that the output of the stage, with a large input voltage, is restricted. All carrier amplitudes above a critical amplitude are thus clipped or limited to the same output amplitude, which, theoretically, remains constant. A compromise must be effected, however, in the self biasing grid leak circuit of R1, C1. A small time constant in this combination gives good suppression of impulse noise-ignition interference, for example, but this also limits the range of carrier amplitudes at the input terminals over which a constant output amplitude can be maintained. Making the time constant of the R1, C1, combination large widens the range of input amplitudes over which a constant output amplitude can be maintained, but gives less noise suppression. The values of the capacitance and resistance must therefore be chosen to suit both requirements to the best degree possible, and typical circuit values are given below.

Components List for the Anode-Saturation Limiter,

Fig. 9.

| | |
|---|---|
| IFT1, 2, | Input and Output I.F. Transformers. |
| C1, | 0.0001 mfd. Mica. |
| C2, C3, | 0.01 mfd. 350 v.w. Non-inductive. |

| | | |
|---|---|---|
| R1, | | 100,000 ohms, ½ watt. |
| R2, R3, R4, | | 47,000 ohms, ½ watt. |
| V1, | 6SJ7, | SP4, etc. |

Practically any type of R.F. pentode may be used in the limiter stage, and the circuit values as given can be changed by wide amounts to give the desired operating characteristics.

An interesting feature of the limiter is that a steady biasing voltage is set up across R1, since a steady current is flowing through the resistance. The potential may be used to give A.V.C. action in the R.F. Mixer or I.F. stages, since the current, and thus the voltage, is dependent on the strength of the I.F. carrier, but apart from this a sensitive instrument may be connected in series with R1 and the earth line to act as a carrier strength indicator—the counterpart of an " S " meter in a normal communications receiver. As the carrier strength increases the current flow through R1 also increases, so that a sensitive instrument, of at most 1 mA. full scale deflection, and preferably of 200 or 500 microamps. full scale deflection sensitivity will give a useful scale reading as a carrier is tuned.

The second type of limiter, the series or cascade limiter, is shown in Fig. 10. This circuit was developed to overcome the difficulty of choosing values for R1 and C1 in Fig. 9, which could deal both with noise and carrier amplitudes over wide ranges. In the cascade limiter the time constant of the resistance-capacitance combination in the grid circuit of the first valve is adjusted to deal effectively with noise fluctuations, whilst the grid circuit of the second valve can cope with a wide range of carrier amplitudes. The operation of this limiter again relies upon low screen and anode voltages, and a typical set of circuit values is given.

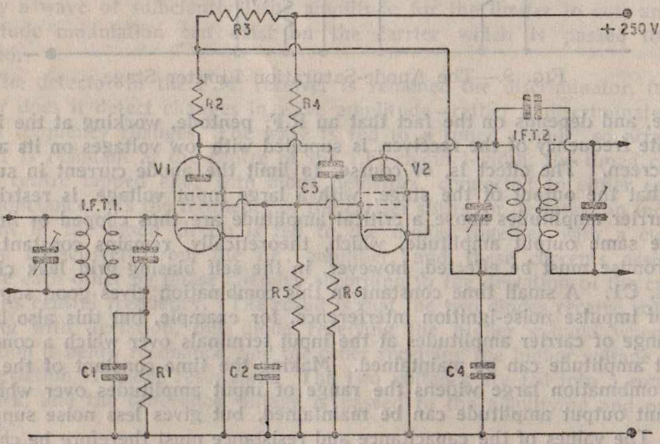


Fig. 10.—The Cascade Limiter Stage.

Components List for the Cascade Limiter,
Fig. 10.

| | |
|---|---|
| IFT1, 2, | Input and Output I.F. Transformers. |
| C1, | 0.0001 mfd. Mica. |
| C2, C4, | 0.01 mfd. 350 v.w. Non-inductive. |
| C3, | 0.0003 mfd. Mica. |
| R1, R3, R5, | 47,000 ohms, ½ watt. |
| R2, | 4,700 ,, ½ ,, |
| R4, | 33,000 ,, ½ ,, |
| R6, | 220,000 ,, ½ ,, |
| V1, V2, | 6SJ7, SP4, etc. |

Again the potential drop across R1 may be used for A.V.C. on the earlier stages of the receiver, or a carrier strength meter may be operated from the rectified current flowing through R1.

### THE DISCRIMINATOR

The two types of discriminator most generally used are very similar in circuit, but the first is the more popular with amateur constructors for the reason that the secondary winding of the I.F. transformer is centre tapped, the whole winding being tuned to resonance. Since in the second circuit the winding has one half tuned above and the other half tuned below resonance, it is a little more troublesome to find the optimum operating points and to maintain balance between the windings.

In Fig. 11 is shown the first discriminator circuit. The small capacitance, C1, is connected between the centre tap of the input transformer secondary and the anode of the limiter valve and supplies the signal against which the induced signals in the secondary winding are " compared " with respect to phase. According to whether the carrier frequency deviation is to the low or high side of the central frequency, the induced secondary current leads or lags on the current introduced through C1, with the result that the diodes are supplied with differing voltages. With no carrier deviation, of course, the diode voltages remain constant and equal.

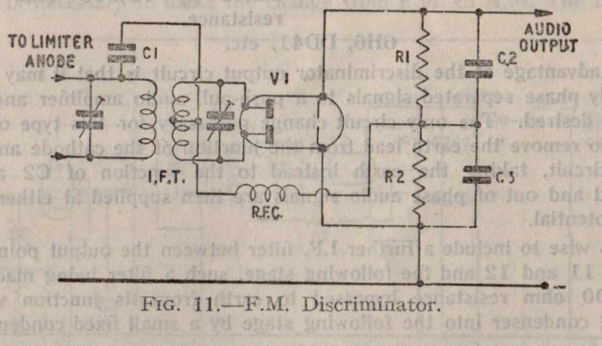


FIG. 11.—F.M. Discriminator.

The diode output voltages appear across R1 and R2, the smaller voltage being subtracted from the larger, with the result that the difference voltage is available as the audio output voltage which is taken off with respect to earth, so that an ordinary type of feed to the amplifying and output stages can be utilised, with normal volume control arrangements.

The R.F. choke shown in the first discriminator circuit should naturally be effective at the I.F. used, but a resistance of up to 100,000 ohms may be substituted for this choke if desired, the substitution being advisable if several different intermediate frequencies are to be tested experimentally.

The second discriminator circuit is shown in Fig. 12. Here the small condenser, sometimes known as the phasing condenser, is omitted, and it is easily seen that deviations in carrier frequency will induce varying currents in the two halves of the I.F. secondary winding when they are tuned to either side of resonance. Here, again, the diode output voltages subtract one from the other, leaving a final audio signal voltage to be tapped off from the cathode load resistances with respect to earth.

In both circuits the discriminator arrangement will be seen to be remarkably simple, and no more expensive, so far as valves and components are concerned, than is the ordinary A.M. detector.

### Components List for the Discriminator Circuits, Figs. 11 and 12.

| | |
|---|---|
| IFT1, | Discriminator input I.F. Transformer. |
| C1, | 50 mmfd. Silver Mica. |
| C2, C3, | 0.0001 mfd. Mica. |
| R1, R2, | 100,000 ohms, ½ watt. |
| R.F.C. | R.F. Choke effective at I.F. used, or replaced by 75,000 ohm ½ watt resistance. |
| V1, | 6H6, DD41, etc. |

An advantage of the discriminator output circuit is that it may be used to supply phase separated signals to a push-pull audio amplifier and output stage if desired. The only circuit change necessary for this type of operation is to remove the earth lead from the junction of the cathode and C3 in either circuit, taking the earth instead to the junction of C2 and C3. Balanced and out of phase audio signals are then supplied at either side of earth potential.

It is wise to include a further I.F. filter between the output point shown in Figs. 11 and 12 and the following stage, such a filter being made up of a 50,000 ohm resistance bypassed to earth from its junction with the coupling condenser into the following stage by a small fixed condenser.

## F.M. AND A.M. RECEIVERS.

For both amateur operation on narrow band F.M. and straight A.M. and experimental operation on F.M. in this country it is a wise economy to make the F.M. receiver capable of receiving A.M. also. The F.M. receiver will obviously perform well on A.M. so far as the frequency changer and I.F. stages are concerned, but the limiter will have to be cut out of circuit for A.M. reception, whilst the discriminator will be useless for A.M. detection.

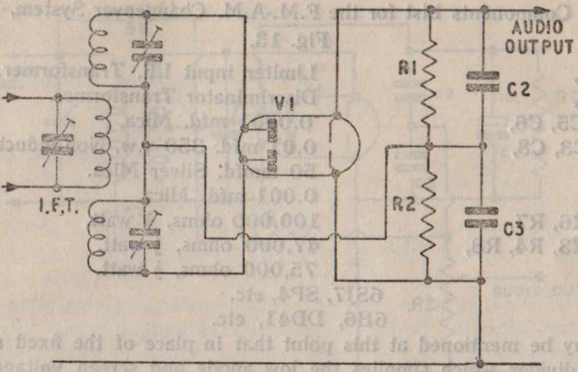


FIG. 12.—F.M. Discriminator.

The simplest approach to the problem is to allow the limiter to act as the A.M. detector, since its grid circuit is already acting as a detector and passing a rectified current through the grid leak. The grid and cathode of the limiter valve may therefore be used as a straightforward diode A.M. detector, the A.M. audio output being fed directly from the limiter grid leak to the audio amplifier.

The simple circuit is shown in Fig. 13, a small two-way switch being all that is necessary to make the change from F.M. to A.M. The I.F. filter is shown as R8 and C7, with C8 as the condenser, giving coupling into the audio amplifier. As in the previous circuits, the I.F. transformer condenser values are not shown, and these, with the transformer windings, are discussed in the next chapter.

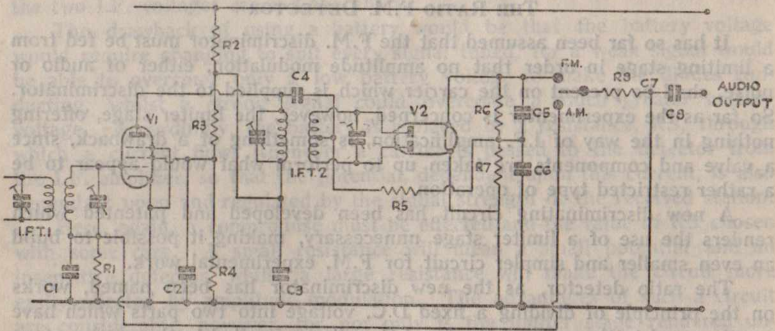


FIG. 13.—F.M.—A.M. Operation.

### Components List for the F.M.-A.M. Changeover System, Fig. 13.

| | |
|---|---|
| IFT1, | Limiter input I.F. Transformer. |
| IFT2, | Discriminator Transformer. |
| C1, C5, C6, | 0.0001 mfd. Mica. |
| C2, C3, C8, | 0.01 mfd. 350 v.w. Non-inductive. |
| C4, | 50 mmfd. Silver Mica. |
| C7, | 0.001 mfd. Mica. |
| R1, R6, R7, | 100,000 ohms, ½ watt. |
| R2, R3, R4, R8, | 47,000 ohms, ½ watt. |
| R5, | 75,000 ohms, ½ watt. |
| V1, | 6SJ7, SP4, etc. |
| V2, | 6H6, DD41, etc. |

It may be mentioned at this point that in place of the fixed resistance potential divider which supplies the low anode and screen voltages to the limiter valve a variable potential divider may be used instead, the arrangement being in the form of a fixed resistance in series with a potentiometer, preferably of the wirewound type, straight across the H.T. supply and earth. The supply end of the limiter output transformer may then be strapped to the screen of the limiter valve and the common connection taken to the slider of the potentiometer, the limiter anode and screen voltage thus being under control and adjustable to suit conditions and to give the best limiting action on an individual signal. This method of limiter supply is recommended especially for the present experimental conditions under which F.M. reception must be carried out, and is shown fully in the complete receiver circuit diagrams of Chapter 5.

## The Ratio F.M. Detector

It has so far been assumed that the F.M. discriminator must be fed from a limiting stage in order that no amplitude modulation, either of audio or noise, shall be present on the carrier which is supplied to the discriminator. So far as the experimenter is concerned, however, the limiter stage, offering nothing in the way of I.F. amplification, is something of a drawback, since a valve and components are taken up to perform what would appear to be a rather restricted type of operation.

A new discriminating circuit has been developed and patented which renders the use of a limiter stage unnecessary, making it possible to build an even smaller and simpler circuit for F.M. experimental work.

The ratio detector, as the new discriminator has been named, works on the principle of dividing a fixed D.C. voltage into two parts which have a ratio equal to the ratio of the two I.F. voltages applied to the anodes of an ordinary double diode discriminator. The circuit is so arranged that the detector responds only to changes in this ratio—a stronger or weaker carrier will still give the same ratio, although a greater voltage output will be supplied from the ordinary discriminator—so that the ratio detector is inherently insensitive to amplitude changes and works only with frequency changes. The ratio detector is shown in Fig. 14, and to understand the action the resistance, R3, may be supposed as replaced by a small battery,

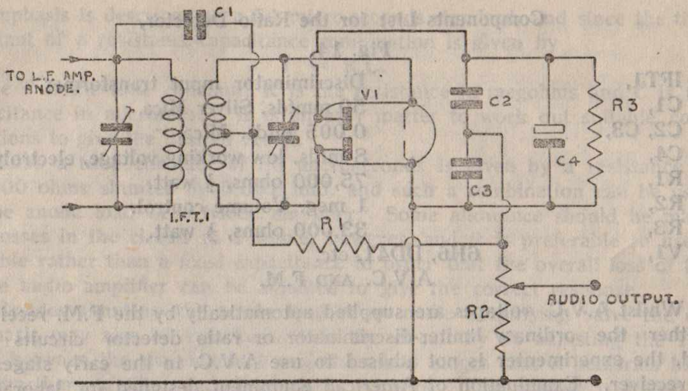


FIG. 14.—The Ratio F.M. Detector.

so connected that the anode of the upper diode is negative and the cathode of the lower diode is positive.

Under these conditions the diodes are non-conducting and the condensers C2 and C3 will be equally charged.

If equal I.F. signals are applied to the two diodes so that the circuit becomes conducting current will flow, but there will still be no change in the balance of potentials across the condensers. When, however, the potential applied from the I.F. amplifier to one diode becomes greater than that applied to the other diode, the potentials across the cathode condensers will change until the ratios of the potentials are the same as the ratios between the two I.F. voltages causing the effect.

The drawback of using a battery would be that the battery voltage would require changing to suit every signal tuned, for a weak signal would be able to overcome only a low battery voltage to make the diodes conducting, whilst a strong signal could overcome a much greater battery voltage. Accordingly, the battery is replaced by a resistance, R3, through which a current flows whenever a carrier is passed to the detector from the I.F. amplifier, so that the potential, dependent upon this current, is also dependent upon and regulated by the signal strength of the received station.

Here, again, a compromise must be effected and the value of R3 chosen with some care. A small resistance will mean a small potential and an insensitive detector, whilst a large resistance will make the circuit more easily affected by amplitude modulation. The advantages of such a circuit are considerable, however, for not only is the limiter stage rendered unnecessary, but so, in many cases, is one stage of I.F. amplification. In the ordinary F.M. receiver a high I.F. gain is needed to load correctly the limiter stage. The need for such high gain is obviated by the use of the ratio detector.

Since the voltage across R3 of Fig. 14 depends on signal strength, the potential set up across this resistance may be used for supplying A.V.C. to previous stages just as is the limiter grid current in an ordinary F.M. circuit.

### Components List for the Ratio Detector,
### Fig. 14.

| | |
|---|---|
| IFT1, | Discriminator input transformer. |
| C1, | 50 mmfds. Silver Mica. |
| C2, C3, | 0.005 mfds. Mica. |
| C4, | 8 mfds. low working voltage, electrolytic. |
| R1, | 75,000 ohms, ½ watt. |
| R2, | 1 meg. Volume control. |
| R3, | 33,000 ohms, ½ watt. |
| V1, | 6H6, DD41, etc. |

## A.V.C. AND F.M.

Whilst A.V.C. voltages are supplied automatically by the F.M. receiver, whether the ordinary limiter-discriminator or ratio detector circuits are used, the experimenter is not advised to use A.V.C. in the early stages of his receiver. Examination of American equipment designed for laboratory use in a well served F.M. area shows that the circuit as a whole is run at maximum gain, and for some time to come the British experimenter on F.M. will certainly need as much gain as his receiver will give. There seems little point in adding A.V.C. to the R.F., Mixer or I.F. stages, therefore, unless the receiver is to be used for both F.M. and A.M., but even in this case the A.M. stations received will still be on the very high frequency bands, where a high gain receiver is most desirable.

In the receiver circuits of Chapter 5, therefore, no A.V.C. arrangements will be shown. The experimenter will have no difficulty in following purely normal practice if he desires to include A.V.C. in his own receiver, but it is suggested that control, if used at all, is confined to the Mixer stage or to the Mixer and R.F. stages. The I.F. amplifier should always be run at full gain, at least when a limiter stage is following the I.F. stages.

## PRE- AND DE-EMPHASIS

It was shown by the triangular spectrum that the noise introduced into an F.M. receiver has a rising characteristic—the noise causes phase modulation of the carrier which, when detected as F.M. gives the effect of an increase of noise with an increase of audio frequency, so that the F.M. receiver will give a greater hiss output on treble notes than on bass. By cutting the treble the hiss will also be reduced, but the tonal fidelity of the audio signal is spoilt at the same time. This is overcome by applying pre-emphasis at the F.M. transmitter so that the treble frequencies are transmitted a little more strongly than are the middle and bass frequencies, de-emphasis then being applied to the audio signal at the receiver. De-emphasis is no more than treble attenuation or cutting with a purely conventional attenuation circuit, but has the effect of correcting the overall frequency response and reducing the noise output of the receiver.

The degree of attenuation is described, rather unusually so far as the experimenter is concerned, by the time constant of the resistance-capacitance combination which gives the correct degree of cutting. The proposed British de-emphasis is described as a 50 micro-seconds standard, and since the time constant of a resistance-capacitance combination is given by

$$T = R.C.$$

where T is the time constant, R is the resistance in megohms and C is the capacitance in microfarads, it is an easy matter to work out suitable combinations to give the desired result.

Thus a time constant of 50 microseconds is given by a resistance of 50,000 ohms shunted by 0.001 mfd. and such a combination can be used as the anode load of a triode amplifier. Some allowance should be made for losses in the circuit as a whole, however, and it is preferable to use a variable rather than a fixed capacitance in order that the overall loss of the whole audio amplifier can be adjusted to give the correct response.

Besides shunting the anode load of an audio amplifying valve the de-emphasis may also be introduced into the circuit by so adjusting the I.F. filter between the discriminator and the audio stages that it performs both the functions of filter and de-emphasis network. The method is shown in Fig. 13 where the filter has component values fitted to both tasks, and the complete circuit diagrams of Chapter 5 also obtain the de-emphasis from the I.F. filter.

In all cases a fixed 0.001 mfd. capacitance is shown, but a preset condenser may be used in order that a slightly smaller capacitance may be used, thus compensating for any losses introduced by the amplifier or output stages.

The American standard of de-emphasis is rather higher than the British, being set at 75 microseconds. The substitution of a 75,000 ohms resistance for the 47,000 ohms resistance shown in the circuits would thus be necessary to give correct de-emphasis on American stations.

## CHAPTER 4

## COILS AND TUNED CIRCUITS FOR THE F.M. RECEIVER.

Mention has already been made of the types of tuned circuit involved in the various stages of the F.M. receiver, together with the intermediate frequencies necessary, and the actual coil sizes, capacitance values and transformer windings may now be discussed in detail.

Whether or not the receiver has an R.F. stage, the first tuned circuit will be working at the signal frequency, and unless operation is to be confined to the B.B.C. test band at present on 90.3 mcs., the receiver must tune over as wide a band as possible. The most likely bands for F.M. reception would appear to be situated—

1—From 29.0 to 29.7 mcs. in the amateur 10 metre band, where N.F.M. is used by some American amateurs;

2—From 42 to 50 mcs. where some American commercial F.M. broadcasting stations still operate;

3—From 52.5 to 54.0 mcs. in the amateur 6 metre band where F.M. is used by some American amateurs;

4—From 88 to 110 mcs. where American commercial broadcasting and the British F.M. test stations are located.

Note that whilst the band under heading (2) can often give good results in this country from American stations, there is no chance of receiving signals from America at higher frequencies. The first amateur trans-Atlantic contact on 6 metres is still recent history.

Between these bands at various points may sometimes be heard civil and Armed Forces F.M. transmissions. Any experimenter receiving such a transmission must abide by the regulations printed on the back of his receiving licence.

The F.M. receiver, then, should tune over the high and very high frequency bands from about 28 to 100 mcs., which is a tuning range sufficiently broad to require a number of plug-in coils. The coils will be very small, however, and easily fitted into sockets mounted directly on the tuning condensers, so that band changing is not a major operation. Switched band changing is, of course, possible, but unless very elaborate coil mountings and low loss switches are used the system will merely result in loss of efficiency, and is not worth the extra expense and chassis space required.

The tuned circuits operating at signal frequency may be made up of the following components for coverage of the band:—

Coil 1. 28-50 mcs. 17 turns 18 S.W.G. enam. closewound.
Coil 2. 50-75 mcs. 6 turns 18 S.W.G. enam. spaced to 1″ long.
Coil 3. 75-100 mcs. 2½ turns 18 S.W.G. enam. spaced to ½″ long.

All coils to be self-supporting and wound to a diameter of ½″ with the ends left (as short as possible) to plug into sockets mounted directly on the terminals of the associated tuning condenser. The tuning condenser should have a maximum capacitance of 40 mmfd. and the Raymart VC40X is strongly recommended.

The sockets into which the coil legs plug may be made from cylindrically shanked soldering tags, the cylinder being squeezed slightly to give good contact, the coil legs being thinly tinned.

The coil sizes given will only fall on the frequencies specified if the stray capacitances of the circuit are kept to the barest minimum. Every wire must be short and direct, grid leads in particular must be kept short, and neither coils nor condensers must be in close proximity to sheet metal panels or the like. The condenser drive must be through a short extension spindle, and, highly important, as many by-pass condensers as possible must be of mica rather than paper separation, whilst by-pass and earthing wires must run to one point only for each stage. This means that no currents are running from point to point through the metal chassis, and components are all grouped neatly around their associated valve.

Aluminium should be used in preference to iron or steel for the chassis of V.H.F. equipment. If obtainable, a copper chassis may give still better results.

Whether a separate oscillator valve is used in the frequency-changer stage or whether a combined mixer-oscillator is relied upon, the oscillator tuning should vary with the frequency band as has already been suggested. For operation on the 29 mcs. band, the oscillator may work at its fundamental frequency, the actual frequency being determined by the I.F., of course, whilst for operation on the 40 to 50 mcs. band the oscillator may operate on either the fundamental or second harmonic. For the 80 or 90 mcs. band, however, the second harmonic or even the third harmonic of the oscillator's fundamental frequency should be used in order that the fundamental frequency may be kept as low as possible.

The heterodyning frequency, whether fundamental or harmonic, should be lower than the signal frequency, not higher as is the usual case where a medium and low frequency receiver is concerned.

Presuming that an intermediate frequency of 10 mcs. is used, this means that the oscillator frequency or its harmonic used must be 10 mcs. lower than the signal frequency. For operation on the 29 mcs. amateur band this will mean an oscillator frequency of 19 mcs. at which frequency there should be little trouble in stabilising the oscillator. The Ultraudion oscillating circuit is recommended, whether separate or combined mixer-oscillators are used, since once again a single coil only is required which can be mounted directly across the oscillator tuning condenser and be self-supporting, and whilst this circuit has the slight disadvantage of having both sides of the tuning condenser above earth potential this is of little moment since the condenser must be extension spindle-driven in order that no hand capacity effects are obtained at the higher working frequencies.

By using fundamental and harmonic operation the whole band can be covered with one oscillator coil, the fundamental tuning range of the oscillator being from 16-40 mcs. The coil is again mounted directly across the capacitance which, to assist stability, is made higher than that of the first tuning circuit, a 100 mmfds. tuning condenser being used. The Raymart VC100X is recommended.

Coil 4. 16-40 mcs. 14 turns 18 S.W.G. enam. spaced to 1″ long and ½″ diameter.

This coil and condenser combination will thus give a 10 mcs. heterodyne over range 1, since it will be required to tune from 18-40 mcs., whilst range 2, using Coil 2 in the first tuned circuit, will be completely covered by the second harmonic. With the main tuning range from 50 to 75 mcs. the oscillator range will be 40 to 65 mcs., and since the full second harmonic range of the oscillator is 32 to 80 mcs. it can be seen that the coverage is complete. See Appendix A.

For the third tuning range, where Coil No. 3 is tuning from 75-100 mcs., the oscillator frequency will be over the range 65-90 mcs. If these frequencies are counted as third harmonics, however, the fundamental frequency range will be 21.6-30 mcs., and here again the oscillator will work with Coil 4, its third harmonic beating with the signal frequency to produce a 10 mcs. I.F.

The experimenter who has not worked with harmonic oscillators before may find that in their handling they appear to be rather " lively " and there may be some little trouble in bringing the signal frequency and oscillator frequency tuned circuits into line until a little practice has made the handling of the receiver less novel. The use of a signal generator which can give signals on these high frequencies, or even an oscillating v.h.f. receiver, will help, however, for the carrier can then be found at roughly known frequencies either by the use of a carrier indicator meter in the limiter grid circuit or by using the limiter as an A.M. detector, and the set thus calibrated with at least some degree of accuracy. Since a small oscillating or super-regenerative receiver is advised as a " search " receiver, by means of which the bands can be monitored for F.M. signals, and is described in Chapter 5, this receiver could be used as a signal source for the preliminary lining up of the F.M. tuning arrangements.

It has already been said that there can be no attempt at ganging the signal frequency and oscillator circuits whilst it is necessary to search over such wide bands of frequencies. The amateur who works within the service area of the B.B.C. test F.M. station can attack the tuning problem from another angle, however.

### CRYSTAL OSCILLATORS FOR F.M. RECEPTION

Within the service area of the B.B.C. experimental station an F.M. signal is reasonably assured at least while the tests proceed, and here the amateur can concentrate on the limiter and discriminator sections of the receiver—after all, the most interesting sections—and use simple tuning arrangements in the R.F. and oscillator sections. Since the receiver can have fixed tuning, variable condensers can be dispensed with, the original tuning being performed by adjustable trimmers and then left set, and the oscillator stability can be increased to an extremely high degree by the use of a crystal such as is used by the transmitting amateur for the stabilising of his transmitter. The crystal frequency will depend, once again, on the signal frequency and the I.F. used in the receiver, and some compromise may be necessary if an easily available crystal is to be used.

The signal frequency is 90.3 mcs. Assuming an I.F. of 10 mcs., the oscillator frequency applied to the mixer valve must be 80.3 mcs. This can be the second, third or even the fourth harmonic of an oscillator working on a much lower frequency, and if 80.3 mcs. be taken as the fourth harmonic this will mean that the oscillator is actually working at 20.07 mcs.

It would be difficult to obtain a crystal working at 20.07 mcs., however, since the most easily obtained crystals are cut for resonance in the amateur bands. An overtone crystal might be obtainable with a frequency at about 28 to 30 mcs., but a more likely crystal would have a fundamental frequency of about 7 or 7.15 mcs.

The twelfth harmonic of 7.15 mcs. is 85.8 mcs., however, and this frequency will heterodyne with the signal frequency to give an intermediate frequency of 4.5 mcs. If the I.F. transformers are wound to this frequency instead of to 10 mcs. the receiver could then operate as a fixed tune set, and, whilst the twelfth crystal harmonic is undoubtedly high, there should be no trouble, given a good crystal, in obtaining sufficient oscillator voltage to ensure good mixing. There are no awkward image frequencies and the only necessary precaution would be to give really good shielding to the oscillator circuit to prevent the radiation of a 7 or 14 mcs. signal.

The I.F. transformers, working at 4.5 mcs. will be situated at about 66 metres, where there is little chance of break-through from a strong signal. The transformers therefore need not be screened—at least in the first experimental stages—and at the same time there is little likelihood of trouble from other signals at frequencies which would beat with different order harmonics of the crystal to produce other 4.5 mcs. I.F. signals.

Any conventional crystal oscillator circuit may be used, but since the twelfth harmonic is rather high a circuit which gives good output on even harmonics should be tried, such as the Tritet. Admittedly, this oscillator requires two tuned circuits, but fortunately L1 and C1, the cathode tuned circuit in Fig. 15, is tuned to a higher frequency than the crystal fundamental, so that a small coil and condenser are all that is required.

C1, in this figure, is a fixed condenser. For transmitter work, C1 would be kept variable in most cases, but for this oscillator this is unnecessary.

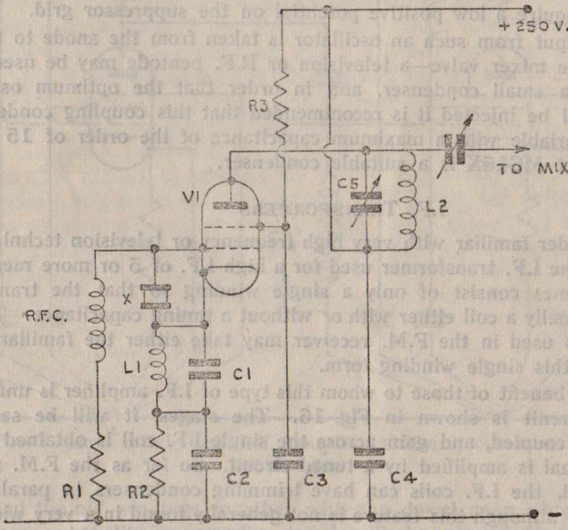


Fig. 15.—The Crystal Oscillator.

The anode coil and condenser, Fig. 15, are tuned to the harmonic required, and since at this high frequency the tuning will cover more than the one harmonic required, some care must be exercised in tuning the output tank. The operation should be performed against the station or, preferably, a high frequency signal generator.

### Components List for the Crystal Oscillator, Fig. 15.

| | |
|---|---|
| L1, | For 7 mcs. crystals, 10 turns 24 S.W.G. enam. 1in. diam. spaced over 1in. Wind on tube or rod. |
| L2, | For 85-86 mcs. harmonic, 5 turns 18 S.W.G. ½in. diam. spaced over 1in. |
| C1, | 0.0001 mfd. Mica. |

| | |
|---|---|
| C2, C3, C4, | 0.01 mfd. 350 v.w. Non-inductive. |
| C5, | 40 mmfds. tuner, Raymart VC40X. |
| R1, | 47,000 ohms, ½ watt. |
| R2, | 220 ,, ½ ,, |
| R3, | 33,000 ,, 1 ,, |
| X, | 7.15 or near frequency crystal. |
| R.F.C., | R.F. Choke, effective at crystal frequency. |
| V1, | almost any pentode or beam power tetrode may be used. The circuit is shown using a beam tetrode such as the 6V6, however, and it is advised that such a valve be used since some pentodes require a low positive potential on the suppressor grid. |

The output from such an oscillator is taken from the anode to the grid of a separate mixer valve—a television or R.F. pentode may be used as the mixer—via a small condenser, and in order that the optimum oscillating voltage shall be injected it is recommended that this coupling condenser be a midget variable with a maximum capacitance of the order of 15 mmfds. The Raymart MC15X is a suitable condenser.

### I.F. TRANSFORMERS

The reader familiar with very high frequency or television technique will know that the I.F. transformer used for a high I.F. of 5 or more megacycles may sometimes consist of only a single winding so that the transformer becomes actually a coil either with or without a tuning capacitance. The I.F. transformers used in the F.M. receiver may take either the familiar double winding or this single winding form.

For the benefit of those to whom this type of I.F. amplifier is unfamiliar, a typical circuit is shown in Fig. 16. The stages, it will be seen, are capacitively coupled, and gain across the single I.F. coil is obtained just as an R.F. signal is amplified by a tuned circuit. So far as the F.M. receiver is concerned, the I.F. coils can have trimming condensers in parallel with the winding, although this feature is not generally found in a very wide band amplifier such as is used in a television superhet.

In general, however, it is advised that this type of I.F. " transformer " should be reserved for an intermediate frequency of 10 mcs. or so, the more conventional double winding transformer being used for the I.F. required by the fixed tune, crystal oscillator circuit recently discussed. Winding data is given for both types of I.F. transformer.

### THE DOUBLE WINDING I.F. TRANSFORMER FOR 4.5 MCS.

One advantage of the lower frequency I.F. transformer is that ordinary trimming condensers can be used with a capacitance range of from 100 to 250 mmfds., so that the actual I.F. can be changed over a relatively wide frequency band to suit the receiver characteristics. An ideal start for the construction of such transformers is to obtain a set of old I.F. transformers with 465 or 110 kcs. windings, of the type where the windings are positioned on a single central dowel. The can and the top plate bearing the two trimmer condensers will then form the basis of the new 4.5 mcs. transformers.

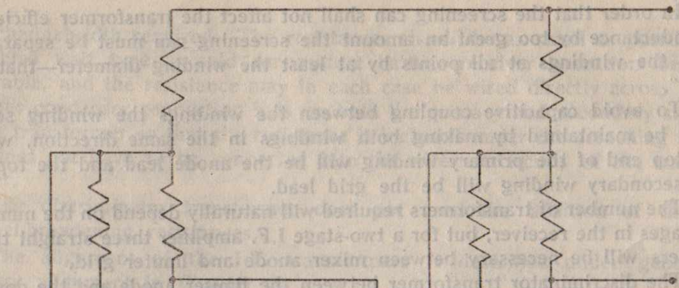


FIG. 16.—Typical Single-Coil I.F. coupling showing common earthing connections.

Discard the old windings together with the dowel upon which they are fixed, since a bakelite or paxolin dowel will be needed for the higher frequency. If polystyrene rod is obtainable, this will give better results than paxolin.

The dowel upon which the new windings are to be made should be ½" in diameter, and the can should be of such a size that the dowel or rod length is at least 3".

The windings may be made upon the rod before it is finally fastened to the top plate bearing the trimmers, but it should, of course, be drilled and tapped and fitted to the top plate before winding to ensure that the transformer is ready for mechanical assembly when the windings are made. The rod is then removed from the top plate and wound.

The windings for the ordinary I.F. transformers and limiter input transformer all consist of 36 turns of 22 S.W.G. enamelled copper wire, the winding length for each coil being very slightly over 1" since the coils are wound with turns touching. Primary and secondary windings are equal in size and the separation between them should be three-sixteenths of an inch.

In order that the screening can shall not affect the transformer efficiency or inductance by too great an amount the screening can must be separated from the windings at all points by at least the winding diameter—that is, by $\frac{1}{2}''$.

To avoid capacitive coupling between the windings the winding sense must be maintained by making both windings in the same direction, when the top end of the primary winding will be the anode lead and the top of the secondary winding will be the grid lead.

The number of transformers required will naturally depend on the number of stages in the receiver, but for a two-stage I.F. amplifier three straight transformers will be necessary between mixer anode and limiter grid.

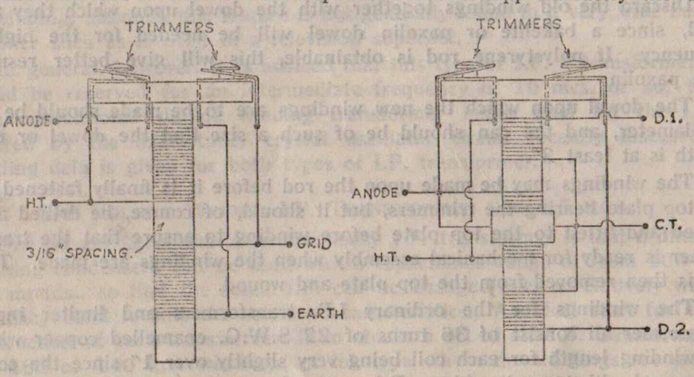
The discriminator transformer between the limiter anode and the double diode discriminator is wound in much the same way as the straightforward transformers except for the fact that the secondary winding is split centrally with the primary winding wound at the centre of the secondary. The same trimmer values will be needed, the maximum trimmer capacitance being 250 mmfds., and again the windings must be made in the same sense.

The phasing condenser whose capacitance is usually 50 mmfds. is mounted within the transformer can between the secondary winding centre tap and the anode side of the primary trimmer. In this case the top of the primary winding is taken to the anode of the limiter and the two extreme ends of the secondary winding to the two diode anodes, and the secondary winding is given an extra turn on both halves to allow for a slight inductance loss.

The winding sizes in the discriminator transformer thus become 36 turns for the primary with a 38-turn secondary divided into two half-windings of 19 turns each.

The transformers and windings are show diagrammatically in Fig. 17.

Across each winding in the straightforward transformers must be connected a resistance of 10,000 ohms. This adds damping to the tuned circuit and thus broadens the response curve to approximately the 150



STRAIGHT TRANSFORMER.

DISCRIMINATOR TRANSFORMER.

FIG. 17.—4.5 mcs. T.F. Transformers.

kcs. channelwidth required. The resistances should be as small as possible, the third watt type as sold for midget battery receiver operation being admirable, and the resistance may in each case be wired directly across the trimmer condenser connecting lugs on both the primary and secondary sides of the transformer so that the resistance is included under the screening can and does not have to be connected into the external circuits of the transformer.

The discriminator transformer does not need the addition of these channel-broadening resistances.

The alignment of the I.F. transformers is described under general receiver alignment in Chapter 6.

### SINGLE WINDING I.F. COILS FOR 10 MCS.

When single winding coils are used in place of transformers for the I.F. stage couplings, a double winding coil must still be used for the limiter-discriminator coupling. The frequency range of the transformer tuning will also be restricted by reason of the fact that a small capacitance is used, the capacitance of the whole circuit, together with the loading in the anodes of the I.F. valves being balanced to give the correct damping and channel-width to the I.F. coil so that no resistances need be used as are connected across the double winding transformers.

The high frequency transformers are simpler to adjust if they can be wound on a former with an iron-dust core so fitted that it can be screwed in and out along the central axis of the coil to give an inductance variation and thus variable tuning, but such formers are not easily come by, and the simplest form of construction which can be employed is to wind the coil on a rod or tube of paxolin to the top end of which the trimmer condenser is fixed or cemented. The actual capacitance of the trimmer, together with the actual coil winding size, is somewhat dependent on the type of valves used, for different valves will give widely different input and output capacitances across the coil, but in general a good trimmer with a 100 mmfds. maximum capacitance and a reasonably low minimum capacitance will serve admirably.

The coil, with this trimmer set nearer minimum than maximum capacitance, should consist of 25 turns of 20 S.W.G. enamelled copper wire close-wound, the winding then taking up almost exactly an inch in winding length, whilst the coil former, whether rod or tube is used, should be ½″ diameter stock.

If these transformers are screened, the screen should again be separated from the winding at all points by at least the winding diameter—i.e., ½″—but it is wise to make the first tests with unscreened transformers so that if for any reason a change in winding is desirable there is easy access to the component.

The discriminator transformer should be made in the same way as the transformer already described for this purpose, the windings being for 10 rather than for 4.5 mcs.

The primary winding, tuned by a 100 mmfds. trimmer, is set between the two halves of the split secondary coil, each half of which contains 13 turns, the whole winding again being tuned by a 100 mmfds. maximum trimmer, the spacing between the secondary half windings and the primary being three-sixteenths of an inch.

The phasing condenser of 50 mmfds. capacitance is connected directly across the transformer by short leads, and the trimmers should be mounted on a ceramic or paxolin top plate unless an old I.F. transformer top plate with suitable trimmers ready mounted is to hand. A top plate with larger trimmers could, of course, have the trimmers replaced by new components of correct size.

In circuits where a ratio detector is under trial, the limiter being cut out, the same discriminator transformers may, of course, be used.

## CHAPTER 5

## PRACTICAL F.M. RECEIVERS

The F.M. receivers to be described in this chapter must all be considered as experimental, as must any British F.M. receiver at the present time until the conditions of F.M. broadcasting in this country are stated and known facts. For this reason, therefore, the diagrams show circuits as dissimilar one from the other as possible, so that the F.M. experimenter may choose the type most suited to his own situation both now and later.

A fixed tune set as well as a crystal oscillator fixed tune receiver is shown, together with variable tuned circuits, and it is regretted that at the present time no circuit details for a restricted tuning band, ganged circuits tuning system can be given. The variable tuning systems are based on the coil and tuning condenser values as stated in Chapter 4, unless otherwise stated.

The first consideration in the design of an F.M. receiver is that of most very high frequency work—the choice and specification of valves for the first tuned circuits. The majority of valves will work well in the I.F. stages, especially when the I.F. is of the order of 5 mcs., but the circuits tuned to frequencies as high as 90 mcs must have the correct valve if any gain at all is to be obtained. Fortunately, selectivity is not a prime consideration, as it generally is in the communications or normal short-wave receiver, and the signal-to-noise ratio, affected to a great degree by the design and valve type of the first stage, is assisted by the very nature of the receiver operation, so that valve choice automatically falls on television pentodes or acorn type valves. These types are, unfortunately, more expensive than the standard R.F. pentodes, but the experimenter with a good stock will almost certainly have one or two such valves spare. The EF50 British valve or the American 6AC7-1852 are the first choice both for R.F. amplification, if used, and separate oscillating and mixing stages, but the American type is in very short supply, whilst the British valve is very expensive. The EF50 can, however, sometimes be bought as Government surplus at a reasonable price, whilst the experimenter who wishes to use 4-volt valves is in a fortunate position at present for the reason that the SP41 television pentode is also widely obtainable as surplus.

For combined oscillator-mixing, the British ACTH1 is capable of surprisingly good results at very high frequencies, although the gain is naturally low, partnered by the 6K8 for the 6-volt valve-users.

Receiver layout is, in general, conventional except where the unusual circuits, such as a crystal oscillator, are to be tested. In this case, the oscillator assembly should be totally enclosed in a metal screening box at the R.F. end of the chassis—there will be no tuning controls on the front panel—but so far as the more ordinary circuits are concerned, the conventional " Left to Right " layout will be found satisfactory. The aerial input is at the left-hand end of the chasis feeding directly into the R.F. or mixer stage, with the oscillator, if separate, mounted near the mixer. Remember that the drives to the variable tuning condensers are via extension spindles and that slow-motion driving is a necessity so that the condensers and coils can be mounted beside their respective valves with the leads cut down to the minimum length.

The method of making common earthing connections for each stage is shown in Fig. 16 and should be adopted for both R.F. and I.F. stages for the extra stability introduced by such simple means can be of surprising proportions.

The H.T. voltage should not be allowed to rise above 250 volts—extra gain in the high frequency stages is accompanied by an undue possibility of feedback—so that only the simplest type of power pack is required for these receivers. The power packs, accordingly, are not shown in these diagrams since the conventional circuit is used.

Instability in the I.F. amplifier, if encountered, will probably be due to the use of unscreened I.F. coils. Careful layout is required if these coils are to work without screening, and the I.F. amplifier which gives parasitic oscillation will need screening cans of suitable size over the I.F. coils or transformers and possibly over the valves also. The " In Line " method of construction is suitable for all high frequency intermediate frequency amplifiers, and is much used in television receivers. In this type of layout, the I.F. valves and I.F. coils or transformers are set in line, the transformers between the valves so that the amplifier proceeds in logical steps and the screening of one component assists the screening of another.

The gain over the F.M. receiver is dependent on signal strength just as in any other receiver, so that in some localities an R.F. stage and a stage of I.F. amplifiation might be cut out of the receiver which would still give results as good as those in other places where the extra stages were needed. What can be said, however, is that the final output of the I.F. amplifier to the limiter stage is set approximately at 10 volts or so, and it is necessary for proper limiting that the receiver should have sufficient gain to produce this carrier amplitude.

Using the ratio detector signals considerably weaker than this are usable, and naturally weaker signals will still be heard on the ordinary F.M. receiver. Amplitude modulation will not be so completely clipped, however.

At the same time, the I.F. stage gain can be made quite reasonably high and a receiver using high frequency pentodes in all stages can give over a mixer and two I.F. stages a gain of between 10 and 20,000 times, a figure which stresses both the need for careful construction and elimination of feedback and the relative unimportance of an R.F. stage preceding the mixer from the point of view of extra amplification. The R.F. stage, even using the most suitable valve, will give a further gain factor of considerably less than 10, a factor of 6 being as high as may be expected, but if further amplification is required it should be obtained through the use of one or even more R.F. stages since extra I.F. gain will be difficult to control.

The experimenter will not desire to build an F.M. receiver, however, until he is certain that there are F.M. signals available with which he can proceed to development work. A very simple monitoring set is therefore indicated, and it is the writer's contention that a single valve super regenerative receiver is as good a circuit for this purpose as any other.

Using the super regenerator an F.M. transmission can be recognised and yet heard quite well even though the receiver is built for A.M. signal reception. This is by reason of the fact that the super regenerator has a wide channel-width, together with other operating factors, and whilst several authorities state that super regenerative F.M. reception is not easily obtained the writer has heard, using the circuit shown in Fig. 18, the B.B.C. experimental station, F.M. stations attached to the Services, WGTR, Boston, on 44.3 mcs. and other unidentified signals all with clearly understandable speech. The distinguishing characteristic of an F.M. station when tuned on such a receiver is, as would be expected, the broad channel occupied by the carrier. A super regenerator has a loud hiss when working properly, the hiss diminishing or fading right out as a carrier is tuned. The broad carrier is thus easily identified, and added to this the audio content, especially on speech, is tuned not at the central frequency, where generally no audio signal is heard at all, but to either side of the central frequency. Speech can be very distinct, but a carrier frequency modulated with music gives, on the super regenerator, very deep distortion.

With the original model of the receiver whose circuit is shown in Fig. 18 N.F.M. signals from American amateurs have also undoubtedly been received, although the relatively narrow band and the fact that modulation is always speech has masked the F.M. effect.

The best valve to use in the super regenerative receiver is the Acorn triode 955, since with this type the stray capacitances across the tuning coil can be kept very low and the receiver can be made very small in size. Most workshops have a standby power pack into which such a receiver can be plugged, and there is no point in building a power pack just to operate such a low drain circuit.

The coils and condenser specified cover from 28 mcs. up to a frequency limit which is set by the valve, but which, with the Acorn, is well above 100 mcs.

If an Acorn valve is not procurable or if it is desired to use a 4-volt heater valve, the AC2HL triode gives very good results with perhaps a lower frequency limit. Provided that the receiver, using a full-size triode, is carefully constructed, however, with every lead cut down to the bare minimum in length and with the valve mounted horizontally so that the tuning condenser carrying the coil can be mounted close to and opposite the valve socket pins, the loss of the large over the small valve will be very small.

A suitable full-size 6-volt triode is the 6J5, which super regenerates well up to a high frequency. If any trouble is experienced, either with Acorn or full-size triodes in obtaining super regeneration, the 220,000 ohms grid leak shown should be cut right out of circuit and the valve given positive quench drive by connecting a 2 or 4 megohms leak directly across the grid condenser, the grid then being connected through this high resistance and the coil to the positive line. The high resistance should not be allowed to fall below 1 megohm.

Any ordinary aerial may be connected in to the monitor through the semi variable aerial condenser, but the best type of aerial, once the favoured band is discovered, is a vertical or horizontal half-wave wire with one end connected to the receiver to give voltage rather than current feed.

With this receiver monitoring the very high frequency bands is a simple task, and will show not only the advisability of building an F.M. receiver, but also the approximate gain the receiver will have to give, as well as the favoured tuning band.

Components List for the Super Regenerative Monitor Receiver,
Fig. 18.

| | |
|---|---|
| L1, | 17 turns. 18 S.W.G. enam. closewound ½in. diam.<br>6 turns. 18 S.W.G. enam. spaced to 1in. long, ½in. diam.<br>2½ turns. 18 S.W.G. enam. spaced to ½in. long, ½in. diam. |
| to cover 28 to 100 mcs. approx. | in three bands. |
| C1, | 40 mmfds. tuner. Raymart VC40X. |
| C2, | 0.0001 mfd. Mica. |
| C3, | 3 to 30 mmfds. trimmer. |
| C4, | 0.005 mfd. Mica. |
| C5, | 0.05 mfd. 350 v.w. Non-inductive. |
| R1, | 220,000 ohms, ½ watt. |
| R2, | 0.5 megohm. variable, quench control. |
| R.F.C., | 60 turns 30 S.W.G. spaced to 1in. long on ¼in. diameter former. |
| V1, | 955, 6J5, AC2HL. |

Run R2 with as great a resistance in circuit as will give good operation.

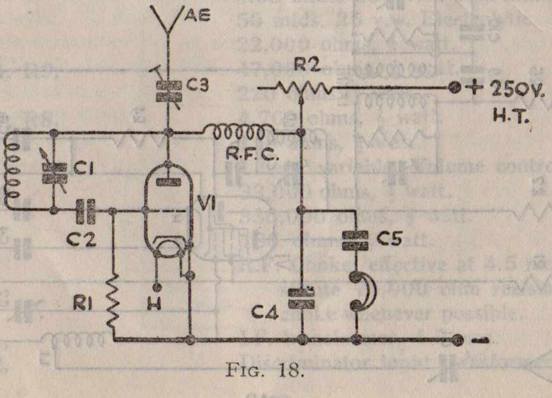


FIG. 18.

In Fig. 19 is shown a circuit of probably as simple a frequency modulation receiver as can be built. The gain is not great and the receiver will be of interest only to those living close to the B.B.C. test station or in the proximity of some other F.M. station, but it may well be that in the course of time a net of F.M. broadcasting stations over the country will make the use of such a receiver possible, and for this reason it is shown here. The circuit does away with the limiter stage by using a ratio detector which is coupled directly via a filter for I.F. plus de-emphasis to a sensitive output valve.

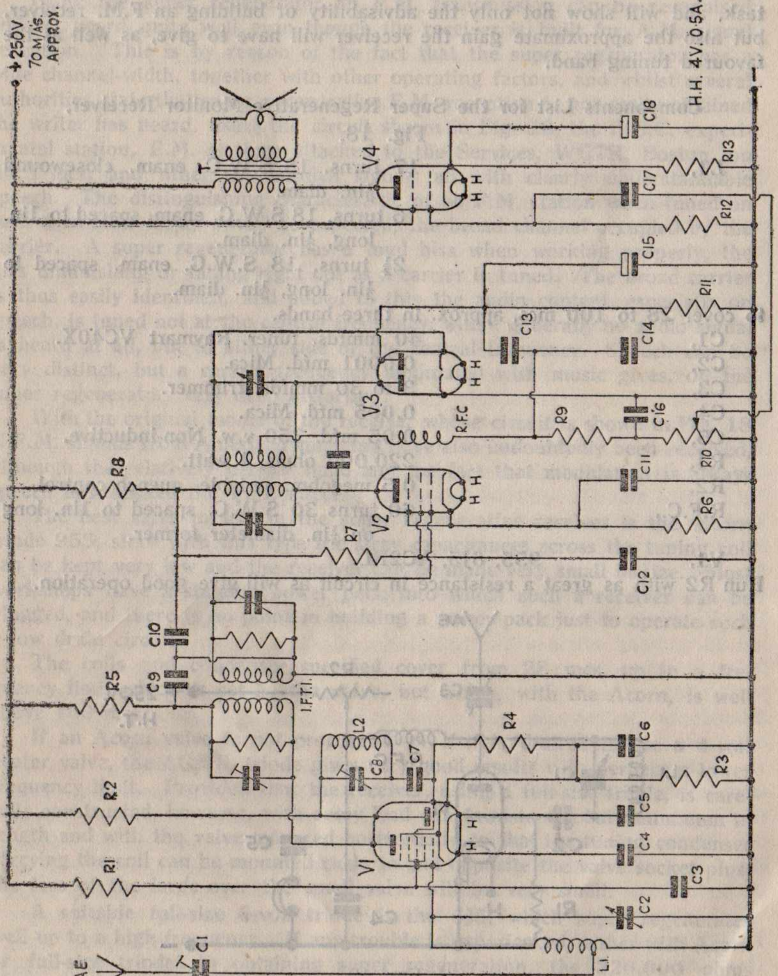


FIG. 19.—Simple Local Station F.M. Receiver.

The frequency changer utilises a combined valve feeding into a single I.F. stage, this latter supplying practically the whole amplification of the receiver. Sensitivity obviously is low, and it is stressed once again that this receiver is no more than a local set, " local " indicating a distance of no more than a few miles from a reasonably strong transmitter.

The tuning coils must be made to suit the station whose carrier is to be tuned, but presuming this is situated at 90 mcs. or so the highest frequency coils given in Chapter 4 may be used. Although these coils are specified for 10 mcs. I.F. operation the use of 4.5 mcs. transformers as in this circuit will not affect the tuning of the oscillator circuit by a great amount, and since the circuits are not ganged the difference in frequency will be taken up automatically in the tuning.

### Components List for the Local Station F.M. Receiver,
### Fig. 19.

For 90 mcs.

| | |
|---|---|
| L1, | 2½ turns 18 S.W.G. enam. spaced to ½in. long, ½in. diam. |
| L2, | 14 turns 18 S.W.G. enam. spaced to 1in. long, ½in. diam. |

Tune L2 to 42.7 mcs. for second harmonic working to produce a 4.5 mcs. I.F.

Tap aerial on to bottom turn of L1, or test tap on each turn for best results.

| | |
|---|---|
| C1, | 4 to 50 mmfds. trimmer. |
| C2, | 40 mmfds. variable. Raymart VC40X. |
| C3, C4, C5, C6,<br>C9, C10, C11, C12, | 0.01 mfd. 350 v.w. Non-inductive, or, if possible, Mica. |
| C7, | 50 mmfds. Silver Mica. |
| C8, | 100 mmfds. Variable. Raymart VC100X. |
| C13, C14, | 0.005 mfd. Mica. |
| C15, | 8 mfds. low voltage, Electrolytic. |
| C16, | 0.001 mfd. Mica. |
| C17, | 0.05 mfds. 350 v.w. Non-inductive. |
| C18, | 50 mfds. 25 v.w. Electrolytic. |
| R1, | 22,000 ohms, ½ watt. |
| R2, R4, R9, | 47,000 ohms, ½ watt. |
| R3, | 220 ohms, ½ watt. |
| R5, R7, R8, | 4,700 ohms, ½ watt. |
| R6, | 150 ohms, ½ watt. |
| R10, | 1 meg. variable, Volume control. |
| R11, | 33,000 ohms, ½ watt. |
| R12, | 330,000 ohms, ½ watt. |
| R13, | 180 ohms, ½ watt. |
| R.F.C., | R.F. Choke, effective at 4.5 mcs., or substitute 75,000 ohm resistance. Use choke whenever possible. |
| I.F.T.1, | I.F. transformer, 4.5 mcs. |
| I.F.T.2, | Discriminator input transformer. |

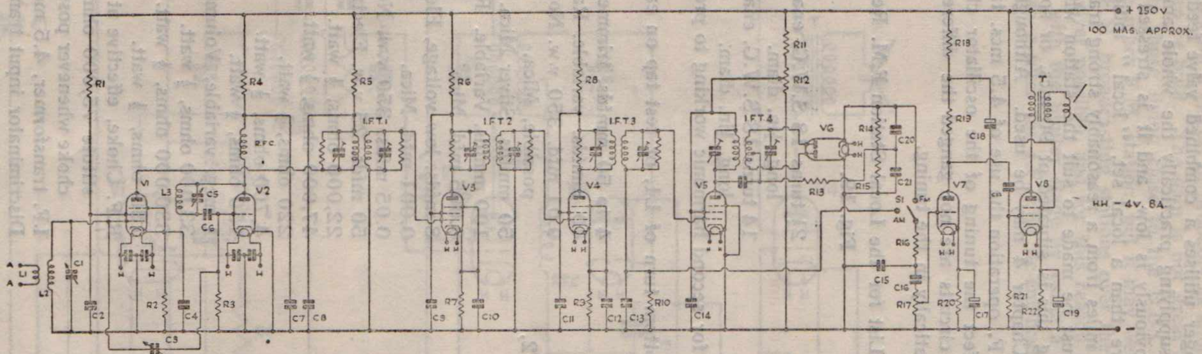


FIG. 20.—F.M.-A.M. V.H.F. Receiver.

Both transformers as described in Chapter 4. Resistance values and trimmer condenser and phasing condenser values not shown in diagram.

| | |
|---|---|
| T, | Output transformer, to match speaker to 5,200 anode load. |
| V1, | ACTH1. |
| V2, | SP41. |
| V3, | DD41. |
| V4, | Pen 45. |

1 British 7-pin chassis mounting valveholder.

3 Mazda octal chassis mounting valveholders.

Extension spindles and slow motion drives with supporting brackets for C2 and C8 or replace the variable tuning condensers with trimmers, 4-50 mmfd. type, and set for fixed tune to local signal.

In Fig. 20 is shown a typical circuit for an A.M.-F.M. receiver tunable over the V.H.F. ranges. A separate oscillator-mixer system is used with a triode oscillator injecting into the mixer grid, and the amplitude of oscillation should be watched. Any tendency of the triode to squegging must be prevented, the simplest method being to reduce the grid condenser, C6, to a lower capacitance. No trouble should be encountered in this respect, however. See Appendix B.

An R.F. amplifying stage is not included in this circuit, but if required it may be added by using the circuit of V1 in Fig 21, although, of course, without the switching, and with a variable condenser and coil to match the tuning arrangements of V1 in Fig. 20. If considerable trouble over alignment is taken it is possible to gang the R.F. and Mixer stage tuning, but at 90 mcs. or so, this is not easy, although the tuning of the R.F. stage is very broad, and slight discrepancies in the matching of the two circuits will cause but small losses.

The real value of the R.F. stage at these high frequencies is to give an improvement of the image response ratio.

It will be noticed that in this figure, as well as in Figs. 21 and 22, the aerial input is shown as coming from a dipole. The actual aerial feed arrangements must be made to suit the worker's conditions, of course, and either the dipole inductive coupling or the tapped coupling shown in Fig. 19 may be employed. A dipole may also be tapped into the first tuned circuit by the simple method of taking one feeder to earth and the other feeder to the coil tap, the feeders thus being connected across the last turn of the coil to give an impedance matching effect. Signal energy transference by this system can be excellent.

The actual sizes of L1 if the inductive coupling is used will vary with the feeder impedance, but in general the following sizes will serve:—

| | |
|---|---|
| L1, | For Coil 1, Chapter 4, 4 turns 18 S.W.G. enam. Closewound. ½in. diameter. Mounted ¼in. from grid end of Coil 1. |
| L1, | For Coil 2, Chapter 4, 2 turns 18 S.W.G. enam. Closewound. ½in. diameter. Mounted ¼in. from grid end of Coil 2. |
| L1, | For Coil 3, Chapter 4, 1 turn 18 S.W.G. enam. ½in. diam. Mounted ¼in. from grid end of Coil 3. |

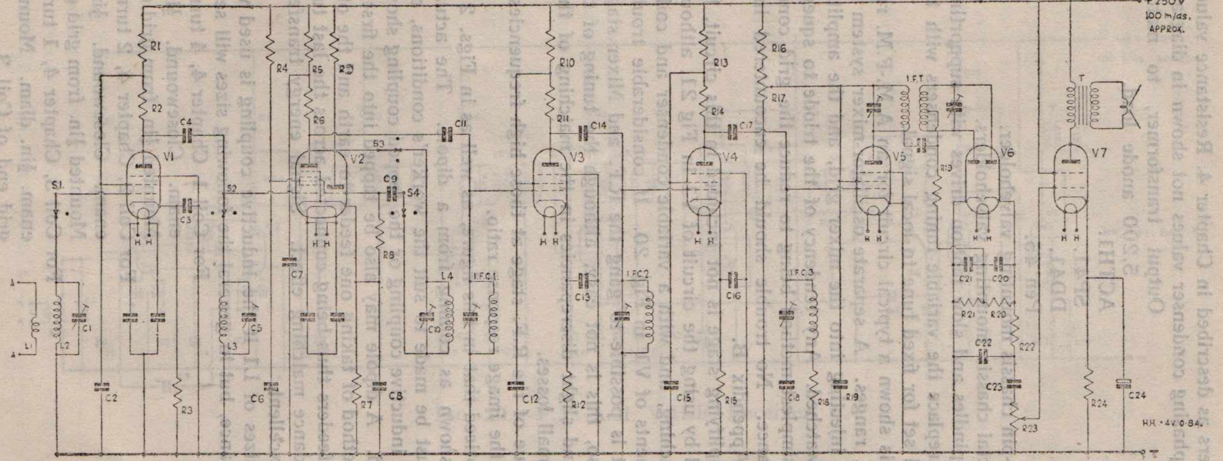


Fig. 21.—Specimen Fixed-Tune F.M. Receiver.

Nevertheless, tests to obtain the best coupling of aerial to the receiver should always be made.

### Components List for A.M.-F.M. V.H.F. Receiver, Fig. 20.

| | |
|---|---|
| L1, L2, L3, | As in Chapter 4, for band coverage. |
| C1, | 40 mmfds. tuner. Raymart VC40X. |
| C2, C4, C7, C8,<br>C9, C10, C11,<br>C12, C14, | 0.01 mfd. 350 v.w. Non-inductive |
| C3, | 15 mmfds. Injection control. Raymart MC15X. |
| C5, | 100 mmfds. tuner. Raymart VC100X. |
| C6, | 50 mmfds. Silver Mica. |
| C13, C20, C21, | 100 mmfds. Mica. |
| C15, | 0.001 mfd. Mica. |
| C16, C22, | 0.05 mfd. 350 v.w. Non-inductive. |
| C17, C19, | 50 mfd. 25 v.w. Electrolytic. |
| C18, | 8 mfd. 350 v.w. Electrolytic. |
| Heater bypass condensers, unnumbered, | 0.01 mfd. Non-inductive. |
| R1, R18, | 33,000 ohms, ½ watt. |
| R2, | 470 ,, ½ ,, |
| R3, R4, R16, R19, | 47,000 ohms, ½ watt. |
| R5, R6, R8, | 4,700 ,, ½ ,, |
| R7, R9, | 150 ,, ½ ,, |
| R10, | 100,000 ,, ½ ,, |
| R11, | 22,000 ,, 2 ,, |
| R12, | 10,000 ohms wirewound variable, limiter setting control. |
| R13, | 75,000 ohms, ½ watt. |
| R14, R15, | 150,000 ,, ½ ,, |
| R17, | 1 megohm. Volume control. |
| R20, | 1,500 ohms, ½ watt. |
| R21, | 330,000 ,, ½ ,, |
| R22, | 180 ,, ½ ,, |
| S1, | S.P.D.T. A.M.-F.M. Switch. |
| I.F.T. 1, 2, 3, 4, | 4.5 mcs.. Straight and Discriminator I.F. Transformers as described in Chapter 4. Components values not shown in Fig. 20. |
| T, | Output transformer, to match speaker to 5,200 ohms, anode load. |
| V1, V3, V4, | SP41. |
| V2, | AC2HL. |
| V5, | SP4. |
| V6, | DD41. |
| V7, | ACHL. |
| V8, | Pen 45. |

5 Mazda octal chassis mounting valveholders.

2 British 5-pin chassis mounting valveholders.
1 British 7-pin chassis mounting valveholder.
Slow motion drives, extension spindles, etc., for C1, C5.
Grid clips, control knobs, etc.

In Fig. 21 is shown a circuit, adapted for use with British valves, of a type which can be used to receive a number of local F.M. stations, the receiver following the design of a set used in New York. By substituting variable tuned circuits for the pre-tuned circuits, however, together with elimination of the switching, the circuit may be used as a tuned F.M. receiver for the V.H.F. bands. An R.F. stage precedes the mixer, which in this case is a combined valve. This stage thus gives little or no gain, but simplifies the oscillator-mixer arrangement and feeds easily into the I.F. amplifier. Here the I.F. coils are used in place of transformers and the receiver, although employing a number of valves, contains the minimum of circuit components.

The switching of the pre-tuned circuits must be carried out through a good switch of the Yaxley type, with the wiring and circuit layout kept as clean as possible to avoid the introduction of stray capacitances, and also to prevent feedback. As many coils and trimmers as there are stations in the area will naturally be provided.

The aerial may be tapped on to each coil through another switch section, or an inductive coupling to each tuned circuit in the first stage may be made through another switch section, this extra switching not being shown.

The component values for the tuned circuits are given to suit a 90 mcs. signal, the oscillator working at the second harmonic.

Components List for the Fixed Tune F.M. Receiver,
Fig. 21.

| | |
|---|---|
| L1, | 1 turn 18 S.W.G. enam. ½in. diam., ¾in. from L2. |
| L2, | 2½ turns 18 S.W.G. enam ½in. diam, spaced to ½in. |
| L3, | As L2. |
| L4, | 14 turns 12 S.W.G. enam. ½in. diam., to 1in. long. |
| C1, C5, | 3 to 30 mmfds. trimmers. |
| C2, C3, C6, C7, C8, C12, C13, C15, C16, C19, | 0.01 mfd. 350 v.w. Non-inductive. |
| C4, C11, C14, C17, C22, | 0.001 mfd. Mica. |
| C9, | 50 mmfd. Silver Mica. |
| C10, | 100 mmfds. max. trimmer. |
| C18, C20, C21, | 100 mmfds. Mica. |
| C23, | 0.05 mfd. 350 v.w. Non-inductive. |
| C24, | 50 mfd. 25 v.w. Electrolytic. |
| Heater bypass condensers, unnumbered, | 0.01 mfd. Non-inductive. |
| R1, R5, R10, R13, | 4,700 ohms, ½ watt. |
| R2, R6, R11, R14, | 10,000 ,, 1 ,, |
| R3, R7, | 220 ,, ½ ,, |

| | |
|---|---|
| R4, | 22,000 ,, ½ ,, |
| R8, R9, R22, | 47,000 ,, ½ ,, |
| R12, R15, | 150 ,, ½ ,, |
| R16, | 22,000 ,, 2 ,, |
| R17, | 10,000 ohms wirewound variable. Limiter setting control. |
| R18, | 100,000 ohms, ½ watt. |
| R19, | 75,000 ,, ½ ,, |
| R20, R21, | 150,000 ,, ½ ,, |
| R23, | 0.5 megohm, Volume control. |
| R24, | 180 ohms, ½ watt. |
| S1, 2, 3, 4, | Ganged station selector switches. |
| I.F.C., 1, 2, 3, | 10 mcs. I.F. coils, as in Chapter 4. |
| I.F.T., | 10 mcs. Discriminator transformer, as in Chapter 4. Components values of I.F.C.s and I.F.T. not shown in Fig. 21. |
| T, | Output transformer, to match speaker to 5,200 ohms anode load. |
| V1, V3, V4, | SP41. |
| V2, | ACTH1, |
| V5, | SP4. |
| V6, | DD41. |
| V7, | Pen 45. |

5 Mazda octal chassis mounting valveholders.

2 British 7-pin chassis mounting valveholders.

Grid clips, control knobs, etc.

This circuit may also be used with British or American 6-volt valves with very few changes in components values. The EF50 or the 6AC7-1852 may be used in place of the SP41's, when it would be wise to include a 4,700 ohm ½ watt resistance in the screen leads to these valves. The limiter valve would then become a 6SJ7 with the same circuit as that shown, whilst the discriminator might be either a 6H6 or an EB4. The EF50's in the I.F. amplifier would require biasing resistances of 220 ohms rather than the 150 ohm resistances specified and R24 would require changing to suit the output valve used, an EL3 or EL6 or 6V6 being indicated.

A suitable frequency changer would be the 6K8, which works reasonably well at high frequencies. The screen resistance should have a 1 watt rating, but all components may be as specified for use with the 4-volt valve.

In Fig. 22 is shown an experimental crystal oscillator-pentode mixer stage using television pentodes. The circuit of V1, the crystal oscillator, is rich in harmonics and is a stable oscillator by reason of the feedback employed in both screen circuits. The stage obviously must work with a fixed-tune receiver, so that the oscillator tank coil is tuned with a trimmer condenser, and the efficiency of this circuit must be high to accentuate the required harmonic of the crystal against the unrequired harmonics. Since, for 90 mcs. operation, the twelfth harmonic is used it is not an easy matter to obtain a high output from the oscillator anode at this frequency, and added

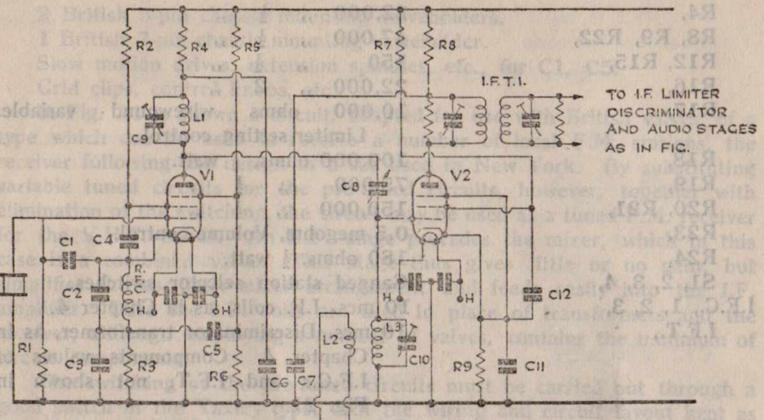


FIG. 22.—Fixed-Tune Crystal Oscillator Mixer Stage.

to this fact, different crystals give widely differing performances. The circuit, therefore, is definitely experimental.

The mixer characteristics can be changed to some degree to suit the oscillator characteristics by varying the resistance of R9, the mixer bias resistance, and various values might be tried here between 150 and 1,000 ohms, or even higher.

The stage as a whole is intended to feed into a normal 4.5 mcs. I.F. amplifier, limiter, discriminator and output system, the circuit being as shown in Fig. 20. Four or six volt valves may be used in the circuit of Fig. 22, of the types SP41, EF50 or 6AC7-1852.

Components List for the Crystal Oscillator-Mixer Stage,
Fig. 22.

| | |
|---|---|
| L1, | 5 turns 18 S.W.G. enam. ½in. diam. spaced to ½in. long. |
| L2, | 1 turn 18 S.W.G. enam. ½in. diam, ¼in. from L3, or use tapping on L3. |
| L3, | 2½ turns 18 S.W.G. enam. ½in. diam., spaced ½in. long. |
| C1, | 10 mmfds. Silver Mica. |
| C2, | 0.1 mfd. 350 v.w. Non-inductive. |
| C3, C4, C5, C6, | 0.01 mfd. 350 v.w. Non-inductive. |
| C7, C11, C12, | |
| C8, | 15 mmfds. variable. Injection control. Raymart MC15X. |
| C9, C10, | 3 to 30 mmfds. Trimmers. |

Heater bypass condensers, unnumbered, 0.01 mfd.

| | |
|---|---|
| R1, R5, | 100,000 ohms, ½ watt. |
| R2, R7, | 33,000 ,, ½ ,, |
| R3, | 150 ,, ½ ,, |
| R4, R8, | 4,700 ,, ½ ,, |
| R6, | 22,000 ,, ½ ,, |
| R9, | See text. |
| V1, V2, | Television type pentodes. |
| Crystal, | 7.15 mcs. |

## CHAPTER 6

## ALIGNING THE F.M. RECEIVER.

To align the F.M. receiver it is necessary to use a signal generator capable of giving an unmodulated carrier at the intermediate frequency to be used, together with an output meter which, with this type of receiver, is an ordinary 0-1 or 0-0.5 milliameter.

Switch on the receiver and generator and allow them to reach operating temperature. The milliameter must first be connected into the limiter grid circuit, at the point A in Fig. 23. Temporarily break the connection of R1 with the earth line and connect the meter in circuit (unless a meter is permanently in circuit as an " S " meter). Short the oscillator grid to earth for R.F. by connecting an 0.1 mfd. condenser directly from the grid of the oscillator, and connect the output line from the signal generator to the grid of the last I.F. amplifier—the valve before the limiter. The generator earth line is connected, in the usual way, to the receiver earth.

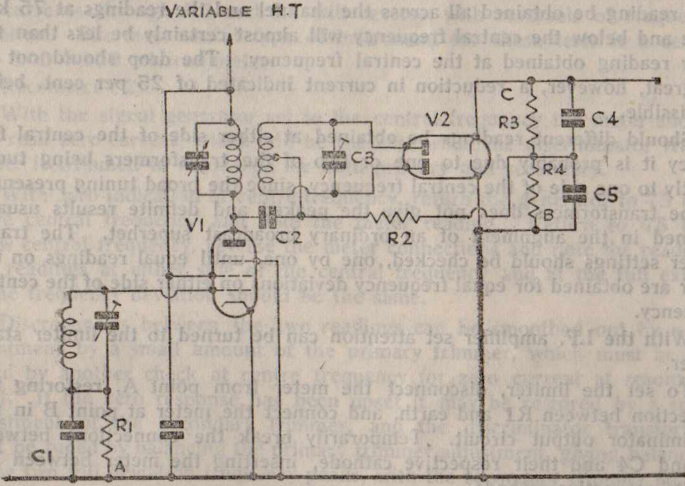


FIG. 23.—Limiter-Discriminator Test Points.

Swinging the generator through the I.F. will give an indication on the output meter connected in the limiter grid circuit, since rectified grid current will flow. Adjust the last I.F. transformer feeding from the last I.F. valve to the limiter for maximum response as shown on the milliameter, and then connect the generator to the next I.F. valve, working back towards the mixer stage. The meter reading should increase as the next transformer is brought into resonance. To align the I.F. transformer coupling the mixer to the first I.F. stage the generator is connected into the signal grid of the mixer valve, whether this is combined with or separate from the oscillator, and the transformer again brought into resonance by watching the increased reading on the limiter stage meter.

With the transformers aligned to their frequency, the response curve of the whole I.F.-Limiter combination must now be checked. Note the reading on the output meter with the generator set at the central I.F. (4.5 mcs. or 10 mcs. using the transformers described), and then set the signal generator to frequencies deviating from the central frequency by equal amounts. For the normal channelwidth suitable test points would be 15 kcs., 30 kcs., 45 kcs., 60 kcs. and 75 kcs., both above and below the central frequency. The meter reading at 15 kcs. above the central frequency should equal the reading obtained at 15 kcs. below, that at 30 kcs. above should equal that at 30 kcs. below, and so on. It is not necessary that the same reading be obtained all across the channel and the readings at 75 kcs. above and below the central frequency will almost certainly be less than the meter reading obtained at the central frequency. The drop should not be too great, however, a reduction in current indicated of 25 per cent. being permissible.

Should different readings be obtained at either side of the central frequency it is probably due to one or two of the transformers being tuned slightly to one side of the central frequency, since the broad tuning presented by the transformers does not give the peaked and definite results usually obtained in the alignment of an ordinary broadcast superhet. The transformer settings should be checked, one by one, until equal readings on the meter are obtained for equal frequency deviations on either side of the central frequency.

With the I.F. amplifier set attention can be turned to the limiter stage proper.

To set the limiter, disconnect the meter from point A, restoring the connection between R1 and earth, and connect the meter at point B in the discriminator output circuit. Temporarily break the connections between R3 and C4 and their respective cathode, inserting the meter between R4 and its respective cathode.

Temporarily disconnect C2, the phasing condenser, thus setting the discriminator to work as a simple diode detector inductively coupled to the limiter. With a signal from the generator still feeding into the mixer stage on the central frequency, adjust the trimmers on the limiter-discriminator transformer to bring this into resonance, the resonant condition being shown by an indication on the meter in the diode cathode circuit.

Swing the signal generator through the whole channelwidth from 75 kcs. below to 75 kcs. above the central frequency to ensure that the band is covered by the discriminator transformer, and then proceed to set the H.T.

supplied to the limiter's anode and screen to give limiting action with as great an output as can be obtained. To set the H.T., note the meter reading at 75 kcs. below the central frequency and then, sweeping the generator slowly through the channel to 75 kcs. above central frequency, watch for increase or decrease in the meter reading. Since the limiter has the task of giving a constant output to the discriminator there should be no change in the current through the diode, and the limiter H.T. may be increased little by little until a change in the diode current is observed as the generator is swept through the channel. The limiter is then failing and the H.T. must be backed off until the diode current is constant over the whole channel.

The limiter stage in correct operation, it remains to check the discriminator working, and this is best performed on an actual F.M. signal. The signal generator may be used, however, and the meter should first be removed from point B to point C, remaking the connection of R4 to its cathode and connecting R3 to its cathode through the meter, C4 also being reconnected into circuit.

All the meter connections in the discriminator output circuit must be made in such a way that the meter connections can be easily reversed, since the currents through R3 and R4 will reverse with reversals of frequency deviation. The most useful type of instrument for these tests is a centre zero 100-0-100 microammeter.

Reconnect C2.

With the signal generator set to the central frequency the meter should now read zero current, which will be the case when the discriminator transformer is trimmed to resonance for both primary and secondary.

With zero indication at centre frequency, return the generator to 75 kcs. above central frequency and note the meter reading. Return to 75 kcs. below central frequency, reverse the meter connections and note the reading. The readings at either side of the central frequency and at the full extent of the frequency deviation should be the same.

Discrepancies between the two readings can be smoothed out by a readjustment by a small amount of the primary trimmer, which must be followed by another check at centre frequency for zero current at resonance point. If the zero response has been upset it may be restored by a small adjustment of the secondary trimmer, and the discriminator transformer must be tuned by balancing the primary trimmer adjustment, giving balancing of the two full deviation frequency peaks, with the secondary trimmer adjustment which chiefly affects the central frequency zero response.

The broad tuning characteristic of the I.F. transformers (the I.F. coils are adjusted in the same way) has already been mentioned and should be tested during alignment by trimming each coil or transformer winding right through resonance as shown by the indication of the output meter. Failure to tune completely through resonance indicates a faulty winding or trimmer condenser or an incorrect valve, and the trouble must be located.

With the I.F., limiter and discriminator stages adjusted and working properly the receiver can be tested as a whole. There are no trimming or padding adjustments to be made to the first tuned circuits, and the oscillator since no ganging is used and the circuits are separately tuned, but the receiver should be tested against a very high frequency generator, or against harmonics from a standard generator or against the radiation signals from the super-regenerative receiver to test both the frequency bands given by the coils and also to calibrate the two tuning dials for frequency. If a fixed tune receiver is in use the tuning trimmers must be adjusted to bring the set into tune.

Remove the generator connections to the mixer stage and disconnect the R.F. short circuit across the oscillator grid, feeding in a modulated signal to the aerial connections. Check for response over the whole tuning band of the receiver, using headphones across the limiter grid resistor, connected to earth and, via an 0.1 mfd. condenser, to the top of the resistor or else inserting the test milliameter in circuit with the limiter grid resistor, thus obtaining an audible or visual A.M. output without having to use an F.M. input.

The oscillator tuning control is the main tuner, and this control should be given the main attention when tuning over the bands, the mixer tuner being kept roughly in step and brought up to final adjustment when a station is heard. The two tuning dials can be calibrated so that the condensers can be rotated more easily in step.

The only likely trouble that might be experienced is failure to cover the bands as specified, especially to the high frequency limits. This will be caused by stray capacitances, and it will be necessary to trim the coils slightly, possibly removing a turn of wire or slightly opening the turns out to give correct frequency coverage. A.M. signals may be tuned on an F.M. receiver as tests. The audio output should be low or inaudible at centre frequency, rising as the set is tuned off the carrier.

## CHAPTER 7

## F.M. AND THE AMATEUR

The use of frequency modulation, especially in the higher frequency bands, can be of considerable advantage to the amateur transmitter. In the first place, the need for a high power modulator such as is used for anode modulation, where the modulator output is required to be half as great as the P.A. stage power input, is completely obviated and a single receiving type triode can modulate a 20-watt transmitter.

Admittedly, a transmitter can be amplitude modulated by a low-power modulator if screen or grid modulation is used, but F.M. working is simpler to adjust and operate, and the modulator power is still smaller.

The greatest advantage of F.M. for the amateur, however, is in the possible reduction of Q.R.M. The British amateur is not yet licensed for F.M.—although it is used to some extent, perhaps, unwittingly, in modulated oscillators on 5 metres!—and so attention must be paid to reports from American amateur operators. They have found that F.M. in the crowded 28-30 mcs. band not only assists contacts, but that a great reduction in B.C.I. is also obtained.

B.C.I., or Broadcast Interference, is a trouble experienced by many amateurs situated in populous areas, the amateur signal breaking through on either C.W. or telephony into the ordinary broadcast receivers around the transmitter, and it is the amateur's duty to prevent such interference to domestic radio listening. The trouble can be attacked in two ways—the domestic sets affected can be fitted with aerial chokes, or mains filters or similar appliances, according to the means whereby the interference is breaking through, or the amateur station may be operated at agreed times or at times outside the hours of broadcasting. When the transmitter is operated on the very high frequency bands it is found in many cases that the second cure is the only cure, for the reason that the interference is caused by break through into the audio section of the broadcast receiver, so that no amount of aerial or mains filtering can give relief from the trouble. It is in this type of trouble that F.M. operation can effect a cure, for the reason that even if the F.M. signal is rectified by an ordinary diode or similar detector, the constant carrier amplitude can pass on no audio content to the amplifying stage and loud speaker.

F.M. as used by the American amateur becomes of necessity N.F.M., or narrow band F.M. A deviation ratio of 5 would cause a much wider channel to be required by the transmitter, whereas the real need is either for a narrow A.M. channel or a reasonably wide F.M. channel which will not interfere with nor suffer interference from an adjacent amateur frequency, either amplitude or frequency modulated. A deviation ratio of 0.5 or 0.6 has been found to give promising results and, moreover, such a channel can still retain crystal control at the transmitter.

The low deviation ratio used does not accommodate a high fidelity range of frequencies, but the carrier can still be modulated with a full range of speech frequencies which, for amateur communication, is all that is required.

To frequency modulate a crystal oscillator, it is only necessary to shunt a reactance modulator stage across the crystal oscillator. A reactance modulator consists of an ordinary valve driven from the audio amplifying stage in such a way that it appears to act as a varying capacitance or inductance, the reactance variations being in step with the speech frequency fluctuations. Such a circuit will thus vary the output frequency of an oscillator by means of phase differences, the final result being deviations from the crystal frequency to either side of the fundamental. The deviations are only small, but if a low frequency crystal is used and the frequency multiplied through a series of frequency doublers, a final 28 mcs. or higher frequency carrier can have correct deviations of frequency to either side of the central frequency.

It is still under discussion, however, as to whether this type of working leads to true frequency modulation or to phase modulation, in which latter type of operation the modulation changes the phase of the carrier rather than the frequency. Phase modulation gives a wave which is less subject to selective fading over long transmission paths than is a frequency modulated wave, and phase modulation is as simple to effect as is the frequency modulation of a carrier. Whichever type of modulation the amateur employs, however, the signal can be received on an ordinary communications receiver, rendering a special F.M. receiver unnecessary.

The communications receiver employs a crystal gate (in the majority of commercial instruments) which is used to give very high selectivity in the I.F. amplifier. At resonance the crystal filter acts as a resistance, whilst at points off resonance there is a reactance effect, giving a change of phase. A phase modulated carried with the central frequency tuned the filter peak and with the crystal phasing condenser tuned to give a rejection notch will be converted to give amplitude modulated R.F. to the detector input with a correct audio characteristic, and F.M. will also be converted to A.M., although in this case there is some fall-off at the low or bass frequencies.

F.M. may also be received on an ordinary communications receiver, however, by tuning the carrier to one side of the selectivity curve of the receiver, that is by tuning the receiver not to the central frequency, but to one side. The frequency deviations thus sweep across a selectivity curve which causes a varying input to the detector, the amplitude of the variations depending both on the frequency deviations of the carrier and the shape of the selectivity curve of the receiver. This method would be useless for F.M. with a deviation ratio of 5 or so, but for N.F.M. the whole carrier deviation can usually be accommodated on the linear selectivity curve edge. A consequent drop in audio output can be compensated by an increase in audio gain.

The modulated oscillator, still used for 56 mcs. operation, especially as a portable transmitter, generally has the modulation applied to the oscillating-transmitting valve as fluctuations of anode voltage. This causes the frequency of the self-excited oscillator to vary between limits set by the inherent stability of the circuit with the final result that the carrier has a mixture of amplitude frequency and, in many cases, phase modulation impressed upon it, the received signal thus appearing both broad and poor in quality. It would appear possible to use either phase modulation or F.M. with such a transmitter to provide a channel which might be less broad than that occupied by the conventional self-excited oscillator, given a low deviation ratio, and it is to be hoped that F.M. operation is soon permitted in this country to the amateur.

# APPENDIX A.

Whilst harmonic operation of the oscillator in a frequency-changing system is quite capable of producing good results, the efficiency of the whole system unfortunately falls, particularly when the oscillator is combined with the mixer in a single valve such as an ACTH1 or 6K8.

It must always be remembered that the F.M. receiver is a local set, and, under present British conditions, harmonic frequency conversion may give poor results on the signals available.

If this is found to be the case, the best cure is to make the oscillator work on the correct fundamental frequency; e.g. for receiving a 90.3 mcs. signal, using an I.F. of 4.5 mcs., the oscillator must work at 85.8 mcs., and any oscillator drift must be accepted although a neon stabiliser tube controlling the oscillator H.T. supply is of assistance. For such a frequency the oscillator tuning circuit may be identical with the signal tuning circuit, a 6-turn coil being tuned by a 40 mmfds. capacitor. The triode section of an ACTH1 will work quite well at this high frequency and may, indeed, even " squeg " so that the value of the grid capacitance may need a little reduction below the usual 50 mmfds.

# APPENDIX B.

An alternative mixer circuit for an SP41 valve may be substituted for that shown in Fig. 20 with, possibly slightly improved results

In the alternative circuit the SP41 is biased by a condenser-resistor combination in the grid circuit, the valve cathode being taken directly to earth, the circuit changes being as follows:—

Remove R2 and C4 from the circuit, connecting the cathode and suppressor grid of V1 directly to earth.

Break the earth connections of L2 and C1, joining the " bottom " or " earthy ends " of these components together, as in any ordinary tuned circuit.

Connect this junction to earth (i.e. the chassis) through a 1 megohm ½ watt resistor, by-passing the resistor by a 0.001 mfd. mica condenser. If there is any tendency for hum break-through, add further by-passing in the shape of a 0.02 mfd. tubular condenser, but the 0.001 mfd. condenser must be retained as the R.F. by-pass.

Increase R1 to 200,000 ohms, ½ watt.

The rest of the circuit of Fig. 20 is as shown when this type of frequency mixed is used.

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