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Frequency Modulation

By the Engineering Department, Aerovox Corporation

A CARRIER wave can be modulated in three ways: by variation of its amplitude, its frequency or its phase. These three methods are known respectively as amplitude modulation, frequency modulation and phase modulation.

So far, the only system in extensive use is amplitude modulation. One of the old c.w. systems would change the frequency of the emitted wave when the key was depressed, but otherwise frequency modulation never before found acceptance.

The subject has been analyzed by different investigators in the past. It is true, they were not then looking for a system of noise-free transmission but rather for a system which would require a narrower band of frequencies for the transmission of a given band of audio frequencies. In this respect frequency modulation was found wanting because it produces side bands as well as amplitude modulation and more of them. This fact, plus the greater difficulty in producing frequency modulation and detecting it, probably accounts for the long delay in its application.

SIDE BANDS

It can be shown mathematically that a carrier wave which is being amplitude-modulated by an audio signal of sinusoidal wave-form can be considered as a carrier plus two other radio-frequency waves, at frequencies equal to the sum and the difference of the radio-frequency carrier and the modulating frequency. Thus, a 1000 kc. carrier modulated by a 1 kc. audio signal consists of the carrier at 1000 kc. plus the two side bands at 1001 and 999 kc. More complicated modulating signals consist of many sine wave components each of them causing two side bands as described above. Therefore, to transmit an audio range up to 5000 cycles, the side bands will extend 5 kc. either side of the carrier and a band width of 10 kc. is required. Similarly, a band width of 20 kc. is needed to transmit all frequencies up to 10,000 cycles, etc.

These side bands and the carrier have a definite phase relation. At the moment when the upper and lower side bands are in phase they are either in phase or exactly 180 degrees out of phase with the carrier wave.

Now suppose we have a carrier which is frequency-modulated. It is possible to swing the frequency by different amounts. The amount of frequency shift will determine the amplitude of the audio signal at the detector while its "rate of change" or speed determines the audio frequency. Such a signal can be shown to consist of a carrier plus an infinite number of side bands. The side bands are in pairs, symmetrically placed with respect to the carrier and they are separated by the amount of the modulating frequency. A carrier of 1000 kc. being frequency-modulated at 1000 cycles would have side bands at 1001, 1002, 1003, etc., as well as at 999, 998, 997 kc., etc. When the carrier is being swung, for instance 10 kc. either side, the side bands situated between 990 kc. and 1010 kc. only are of importance, the others becoming very weak. Therefore, the band-width of a frequency-modulated signal is equal to twice the frequency deviation employed and has no connection with the audio frequency.

The side bands again have a definite phase relationship with the carrier. When the upper and lower side bands are in phase, they are 90 degrees out of phase with the carrier.

NOISE REDUCTION

It was shown by Major Armstrong that frequency modulation could be used for noise-free high-fidelity transmission when the frequency was swung wide, a limiter being employed, and when the signal was at least twice as strong as the noise.

If one is to eliminate noise from the transmitted signal, it is first necessary to find one characteristic wherein these two differ. Then it is possible to make a device which will discriminate between the two. Most types of interference: static, man-made static, tube hiss and thermal agitation are similar to amplitude-modulated sig-

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nals. Therefore, they might be eliminated by a system of frequency modulation if the receiving system is made insensitive to amplitude modulation. This is accomplished by the "limiter", a tube in the i.f. amplifier which is adjusted so the signal will overload it. All waves are then cut down to the same size, removing all amplitude modulation, if the signal exceeds a certain minimum.

Armstrong showed the following properties of noise in sharp and broad-tuning receivers.

In amplitude modulation receivers, the noise at the detector is proportional to the band-width of the receiver as long as no carrier is being received. As soon as a carrier appears, the various noise components beat with the carrier only and not with each other. The noise is then proportional to the band width up to a 32 kc. band-width. Any further broadening of the receiver will have no audible effect.

In a frequency-modulated system, in the presence of a limiter, the noise is inversely proportional to the band width. Thus a system with a frequency deviation of 100 kc. each side of the carrier would have one-tenth of the noise of a system employing only 10 kc. frequency deviation each side of the carrier.

Due to the wide band required, frequency-modulated signals have to be restricted to the high frequencies. At present there are some stations near 40 mc. just below the television band. There is also an experimental station on 110 mc. Receivers must be made for this reception range. The remainder of this paper will be devoted to a description of receiving equipment and its adjustment.

RECEIVERS

Since the present transmitters employ a frequency deviation of 80 kc., the receivers are superheterodynes with a band width of 200 kc. so that there will be some leeway for possible fluctuation of the signal frequency or the local oscillator frequency due to heat or voltage variation.

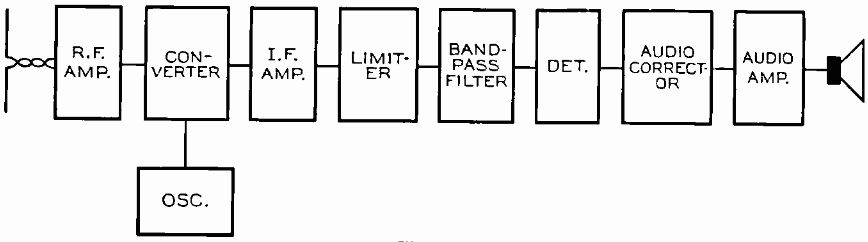


Fig. 1

The receiver is shown in block diagram form in Figure 1. There is an oscillator and a converter with or without an r.f. stage. This is followed by a 200 kc. wide i.f.-amplifier usually at about 3 mc. Then there is the limiter followed by another set of band-pass circuits so as to cut out the harmonics it created. Next comes the detector and an audio corrector circuit. This audio corrector is needed because the stations are using a speech amplifier with a rising characteristic at the high frequency end so as to get a better signal to noise ratio at this frequency. The corrector, a type of tone control, reduces these high frequencies to normal.

This tuner is followed by a high-fidelity audio amplifier and a good speaker.

Since the r.f. end of the receiver is no different from that of an amplitude modulation receiver of the same range, it may be dismissed briefly, with this additional observation: the range of the receiver is usually from 39 to 44 mc. When the oscillator frequency is chosen above the signal frequency it will fall within the television band. It has proven to blot out completely the image on a neighboring television receiver. If any constructor wishes to incur the undying gratitude of his neighbor looker-in, let him make the oscillator frequency below the signal frequency.

I.F.-AMPLIFIER

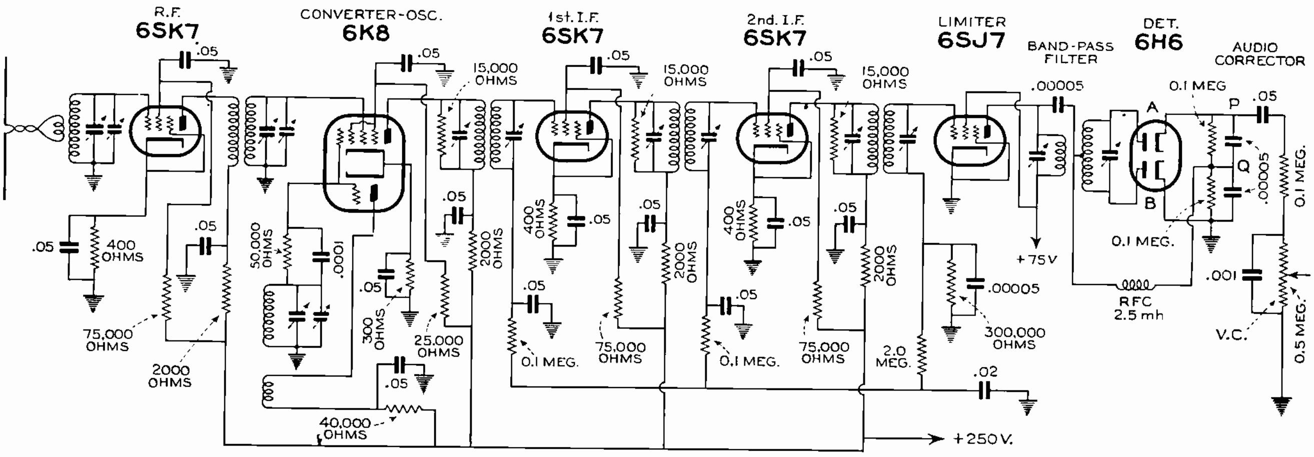
The intermediate frequency seems to be little standardized. It is roughly between 1500 kc. and 5 mc. with most of them about 3 or 4 mc. At these frequencies it is rather simple to obtain the required band-width since a 200 kc. width at 4 mc. corresponds to a 20 kc. width at 400 kc.

Figure 2 is a schematic diagram of a receiver with as many of the values as possible. The i.f. coils are now commercially available from some of the coil companies. They could also be made from standard 3 mc. variable selectivity coils by setting them for the required width and connecting a resistor of 15,000 ohms across the tuned circuits.

There should be plenty of gain in the i.f. amplifier. The signal arriving at the limiter must be large enough to start grid current flowing, else the limiter does not help in noise reduction. Regeneration should be avoided for it will cause distortion.

THE LIMITER

This device consists of a sharp cut-off pentode of the 6J7 type with a low plate and screen voltage while the bias is provided by a grid leak as in Figure 2. There will be a voltage drop across the grid leak and this may be used as a.v.c. for the preceding i.f. stages. The action of the limiter is illustrated by Figures 3A and 3B. Figure 3A shows how the signal looks before it enters the limiter, and 3B shows how it looks in the plate circuit.



The flat-topped waves contain harmonics which are removed in the transformer following the limiter.

DETECTION

There are several detectors for frequency-modulated waves. The old system consisted in changing the frequency modulation to amplitude modulation by means of a "slope filter" and then detecting it normally. The slope filter can consist of nothing but a tuned circuit which is slightly out of tune with the incoming carrier. In Figure 4 such a circuit is shown with its resonance curve. If the circuit is tuned so that the carrier falls at X, a frequency variation of the carrier between A and B will cause the current in the circuit (and the voltage drop across C) to vary between P and Q. So the signal now is also amplitude modulated. There are several disadvantages to this type of detector. If there is to be no distortion, the frequency can be varied only over the range where the side of the resonance curve is approximately straight. Also, a frequency-modulated signal results in less than 100 percent amplitude modulation.

Armstrong first used a slope filter of a more complicated type where he was able to change frequency modulation into 100 percent amplitude modulation. This circuit has been superseded by a simpler one.

The detector now generally employed for frequency modulation produces an audio frequency directly without first changing the signal into an amplitude modulated one. The circuit is the old familiar "discriminator" of a.f.c. systems. A complete description of this detector was given in the Research Worker of February, 1937.

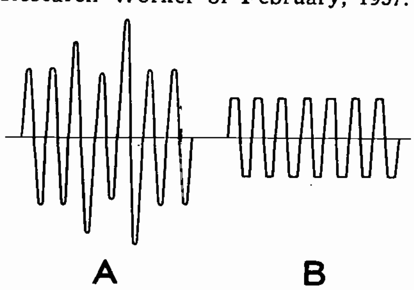


Fig. 3

There are two diodes which are so connected to the special transformer that their diode currents are equal when the carrier is at its normal frequency. When the carrier frequency deviates in one direction, the current in diode A is larger than in diode B, while if the frequency deviates the other way, the diode current of diode B is larger than that of diode A. The two equal load resistances are so connected that their voltage drops buck each other. So, the voltage drop between point P and chassis is equal to the difference between the voltage drops across the two diode loads. When the carrier is at its normal frequency, there is no potential difference between P and the chassis while a frequency modulated signal will cause the voltage at P to vary in accordance with the frequency modulation.

The output voltage at P is proportional to the frequency deviation as well as to the strength of the signal in the previous transformer. Since the limiter cuts all signals down to the same size, the output at the detector is practically independent of the strength of the incoming signal as long as it is above a certain minimum level. The characteristic of frequency-versus-output of this detector is shown in Figure 5. This is the kind of curve one would get with a wobbulator. To avoid distortion, the sloping middle

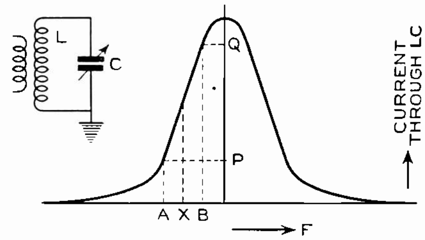


Fig. 4

part of the curve should be straight and long enough to accommodate the 200 kc. swing. The curve should also be symmetrical.

The separation of the two peaks or the length of the sloping part depends on the Q of the tuned circuits. In order to have a wide enough curve, it may be necessary to employ resistance loading. The symmetry depends on the correct tuning of both tuned circuits.

AUDIO-FREQUENCY CORRECTOR

The transmitters are being designed to emphasize the high notes so that there may be a better signal-to-noise ratio at these frequencies. It is necessary to employ a corrector circuit to neutralize this effect. It is a rather simple resistance-capacity network consisting of two resistors and one condenser. This resembles an ordinary tone control of fixed adjustment.

AUDIO AMPLIFIER

The circuit of Figure 2 does not show the audio amplifier since it can be of conventional design. In order to take advantage of the high-fidelity possibilities, the best audio amplifier is none too good. The output stage should be preferably a set of triodes such as type 6A3 or 6A5G. If pentodes or beam tetrodes are employed, inverse feedback should be used with it. The speaker and its mounting should also be designed for best fidelity.

ALIGNMENT

The problem of alignment may seem considerable at first glance but it should not be so great if the circuit is well understood. There are several

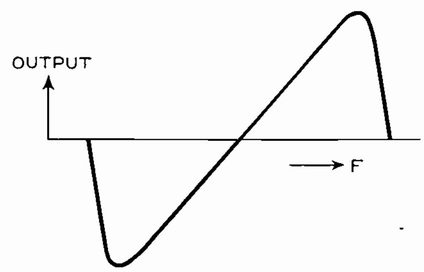


Fig. 5

possible procedures. The following is perhaps easiest for the average man who is not blessed with an oversupply of expensive test equipment.

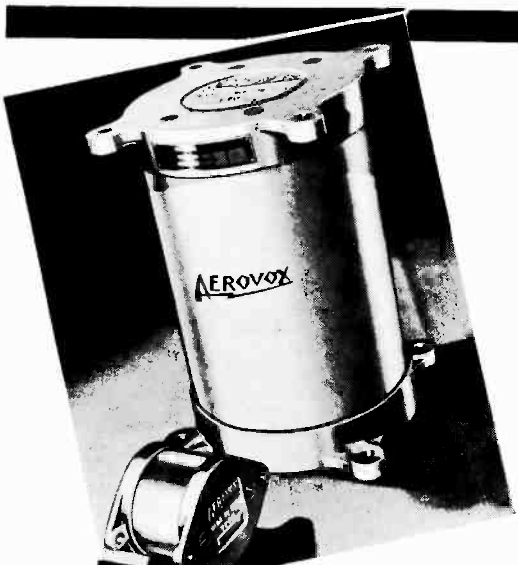
The i.f. amplifier plus the limiter forms an amplifier which acts nearly like an ordinary i.f. amplifier plus detector. If a.v.c. is used, a milliammeter can be inserted in an a.v.c.-controlled i.f. stage and used as an indicator. The system may be aligned as any other i.f. amplifier. If no a.v.c. is used, an electronic type d.c. voltmeter might be connected across the limiter grid leak, or, if necessary, the audio amplifier could be fed from there.

The alignment should not prove difficult but if there is trouble with double peaks connect a 20,000 ohm resistor from grid to ground at the transformer to be aligned, then adjust the grid circuit. Remove the resistor and adjust the plate circuit. In a.v.c.-controlled circuits it should be a 20,000 ohm resistor in series with a .1 mfd. condenser.

Assuming that the i.f. amplifier is in line up to the limiter, the problem is now to align the detection transformer. If you have a d.c. electronic voltmeter connect it at the detector load from the point Q to the chassis. Otherwise, disconnect the audio amplifier from the point P and connect it at Q. Now the circuit is an amplitude-modulation detector and both primary and secondary can be adjusted for maximum output using the electronic voltmeter in the first case and an output meter in the second case. Of course, the signal generator should have remained undisturbed since the aligning of the i.f. amplifier.

When the alignment is completed, return the audio amplifier connection to the point P or connect the electronic voltmeter from P to chassis. Readjust the condenser of the secondary circuit slightly so as to obtain zero output, or, at least, minimum output. The alignment of the receiver is now finished.

The performance may be checked by making several measurements of the output at different frequencies and plotting output versus frequency as in Figure 5. Lack of symmetry may be corrected by a slight re-adjustment of the detection-transformer primary.



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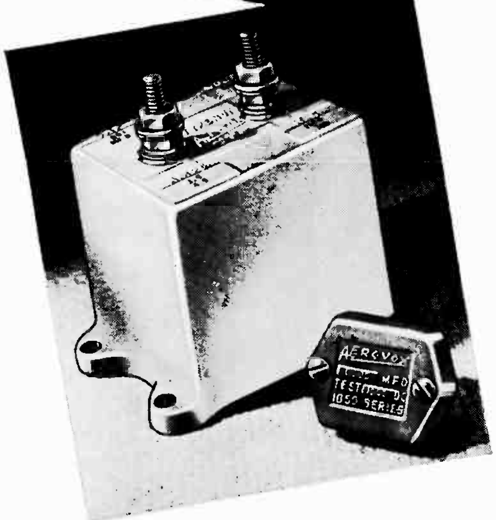

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