F-M Broadcast Transmitters*

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THERE are two generally well known methods of producing wide-band frequency modulation; one, the phase-modulation method and the other, direct frequency modulation. The latter is also frequently referred to as the reactance-tube method. As both methods and the circuits employed have been described and analyzed mathematically by others in IRE and AIEE papers, only a brief comparison of the two methods is given here.

First, it seems appropriate to explain that phase modulation and frequency modulation are interrelated. We always have phase and frequency modulation simultaneously. Here again this relation has been explained and analyzed mathematically by others.

Phase-Modulation Method

The usual transmitter circuit arrangement to produce wide band f-m by the phase-modulation method starts with a relatively low-frequency crystal-controlled oscillator, say around 200 kc. The output of this oscillator is divided into two parts. One part is passed through a network which shifts the phase by 90 degrees. The second part of the original oscillator output is amplitude modulated by means of a balanced modulator which suppresses the original carrier frequency, leaving only the side bands. When these side bands are recombined with the first part of the r-f signal, there is produced a phase modulated signal which can be modulated up to a phase shift of about ±30° with good linearity.

This corresponds to a very narrow frequency swing and a great many stages of frequency multipliers are necessary to produce wide-band frequency modulation. (Wide band f-m is now standardized by FCC at swing ±75,000 cycles about the mean carrier frequency.) In fact, the signal frequency variations are multiplied more than 3,000 times. To obtain a multiplication as great as this value, without increasing the mean carrier frequency to an undesired high value, it is necessary to multiply the frequency several times, then heterodyne down to a lower carrier frequency and multiply again to produce the desired frequency swing and mean carrier frequency. Each multiplication increases the frequency shift by the same amount as the mean carrier frequency. Heterodyning down decreases the mean carrier frequency, but not the frequency shift.

Phase modulation must undergo additional treatment before it becomes true frequency modulation of the desired type. Its shift is proportional to the modulating frequency and, therefore, a corrective network must be inserted in the audio input channel to make the amplitude of the applied audio signal inversely proportional to frequency, thus resulting in a flat overall frequency response.

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One-kilowatt frequency-modulation transmitters in various stages of completion at G-E Schenectady works.

The limitations of this method are:

(1) It is difficult to fully modulate the transmitter at audio frequencies less than 50 cycles.
(2) Frequency stability is not that of the first crystal oscillator; it is a combination of the error of the first crystal, the multiplications employed, and the error of the second crystal.
(3) The high multiplication factor requires elaborate shielding of the circuits and special filtering of the leads between the power supplies and the various units.
(4) The shielding and filtering (3) are usually accomplished at considerable sacrifice of accessibility.
(5) Many tubes are required and even though a number of them are receiver type, the possibility of failure with program interruption exists.
(6) The circuit is comparatively complicated.

Direct Frequency Modulation

The usual transmitter circuit arrangement to produce wide-band f-m by the direct frequency modulation method employs a reactance-tube frequency modulator and its associated oscillator followed by a relatively few multiplier and amplifier stages. The oscillator operates in a conventional oscillator circuit, across which is connected the plate and control grid of the reactance-tube frequency modulator. The insertion of a properly chosen network, consisting of a capacitor between the plate and grid and a resistor between the grid and cathode of the modulator tube, results in a change in modulator plate current which is 90 degrees out of phase with the plate current drawn by the oscillator.

Thus the modulator functions as a capacitance connected across the frequency-determining circuits of the oscillator and varying in accordance with the voltage impressed on the grid of the modulator. Therefore, if we apply an audio-frequency voltage to the grid of the modulator, the oscillator will be

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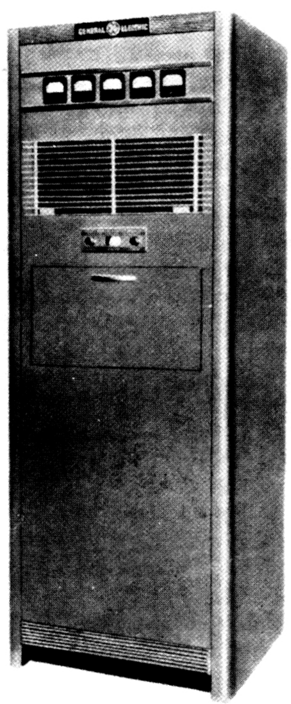
subjected to the effect of a varying capacitance across its frequency-determining circuit, causing the oscillator frequency to swing above and below the mean carrier frequency at the rate determined by the applied audio frequency.

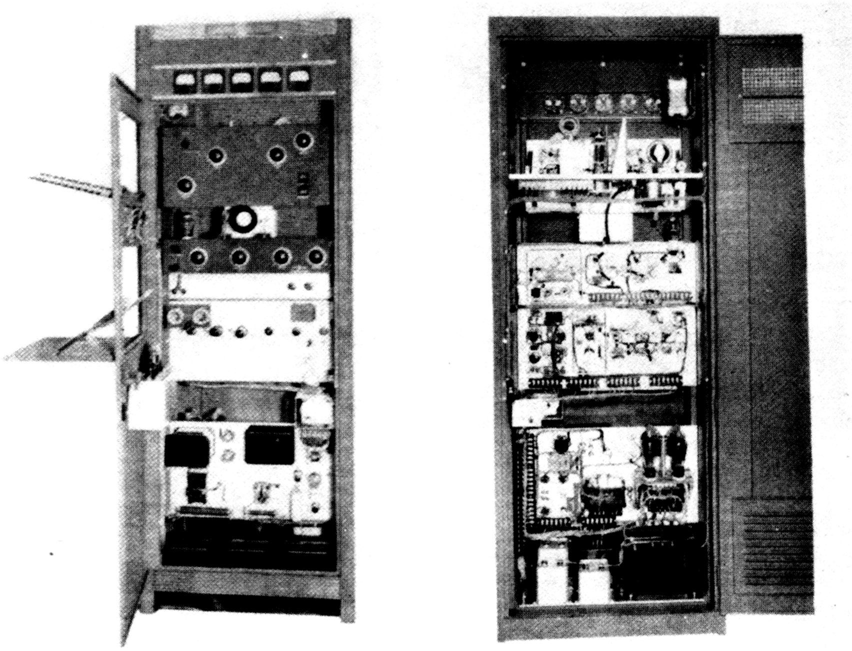
In this method, the magnitude of frequency shift depends only on the amplitude of the modulating signal. Hence, unlike the phase-modulation method, no corrective network is needed in the audio input channel. Direct frequency modulation is almost ideal for producing wide-band frequency modulation, but it will not provide the desired stability of the mean carrier frequency until another circuit is added.

Two types of circuits are now employed for mean carrier frequency stabilization, both using the feed-back principle. One comprises a crystal oscillator, converter, and discriminator and the combination of these develops a corrective voltage for the modulator tube when there is any change in the mean carrier frequency. The other circuit comprises several stages of frequency dividers, crystal oscillator, and amplifiers. It includes also a synchronous motor which varies a capacitor in the frequency-determining circuit of the oscillator by the proper amount to correct any change in the mean carrier frequency. The first method of frequency stabilization is electronic, and the second mechanical. Inherent advantages are claimed for each method.

About the only limitation of the direct frequency-modulation method of producing wide-band frequency modulation is the necessity for indirect frequency control. However, with careful design the stability of direct crystal control can be closely approached.



A front view of the 250-watt f-m transmitter.



Front and rear views (doors open) of a 250-watt 42 to 50 megacycle f-m transmitter.

Problems of FM Broadcast Transmitter Design

The electrical problems of f-m broadcast transmitter design are chiefly frequency stability, low noise level, low distortion, modulation linearity, and proper audio-frequency response. With the exception of frequency stability, which we covered earlier in this paper, all of the problems are handled more readily with f-m than with a-m.

The low noise level problem may be divided into two parts—i.e., f-m noise level and a-m noise level. Low f-m noise level may be obtained by separating the d-c and a-c wiring in the transmitter cabinet, employing a regulated power supply for the modulator-oscillator stage, careful r-f shielding and bonding, using low-microphonic tubes, and by shock mounting the modulator and oscillator stages, etc. Incidentally shock mounting, as mentioned, did not prove to be as essential as our initial development work indicated.

With these precautions, an f-m noise level in the order of 60 db below ±75 kc swing is consistently possible with production transmitters. This value can be lowered to 70 db by using a small amount of stabilized feed back. Low a-m noise may be obtained by the same precautions employed in a-m transmitters. In addition, care must be exercised in the design of the phase-shifting network of the modulator stage and proper saturation of the amplifier stages. An a-m noise of 60 db below 100% amplitude modulation is consistently possible in production 1 kw transmitters without employing feed-back and with a-c filament excitation.

Low distortion, modulation linearity, and flat audio-frequency response are obtained by careful circuit design and I should add that extensive experience in such design work is of great help.

General Electric FM Broadcast Transmitter

General Electric's 250-watt f-m broadcast transmitter Type GF1B will be described in more detail than the larger GE transmitters since the unit serves also as an exciter for the transmitters of higher output rating. The radio-frequency circuits of this transmitter consist of the modulator-oscillator, frequency multipliers, r-f amplifiers and the frequency stabilizer. The modulator-oscillator is really the heart of the transmitter. In this stage, wide-band frequency modulation is generated directly by means of a master oscillator and a reactance-tube modulator.

The circuit may be described in greater detail by referring to the block diagram (Fig. 1) and the simplified schematic diagram (Fig. 2). The block diagram shows every stage in the transmitter and its function, the crystal oscillator and frequency stabilizing circuit. power supplies and modulation monitor. The simplified schematic shows the audio stage, pre-emphasis network, modulator-oscillator circuit, and the frequency stabilizing circuit.

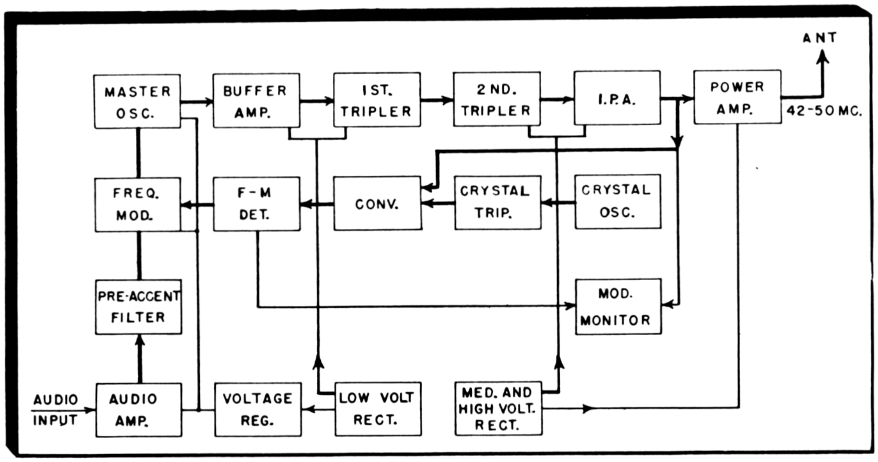


Fig. 1. Block diagram of the f-m transmitter.

Components of Simplified Schematic

R 124	L 121	Pre-emphasis network
C 102	R 101	Phase shifting network
L 101	C 109	Frequency determining circuit of oscillator
L 119		Oscillator plate choke
L 120		Oscillator grid choke
C 107		Oscillator grid capacitor
C 103		By-pass capacitor
R 102		Oscillator grid resistor
L 102		Oscillator plate inductor
L 101		Oscillator grid inductor
R 194	C 137	Filter network to permit passage only of corrective voltages having frequencies considerably lower than the lowest audio frequency it is desired to transmit.
L 134		Feedback to lower f-m noise level
C 195		Discriminator filter r-f bypass capacitor
C 101		Modulator grid by-pass capacitor.

A comparison of this circuit with the circuits of other f-m broadcast transmitters will emphasize its simplicity. There are fewer circuits and tubes and only two tripler stages are required. The frequency stabilizing circuit is extremely simple. Aside from the crystal oscillator and its tripler stage, only two tubes are used for the entire frequency stabilizing circuit. Furthermore, it is completely electronic.

A description of the frequency stabilizing circuit follows:

By referring to the simplified schematic, we see that part of the r-f output voltage is taken from the output of the IPA stage and combined in a converter or mixer tube along with the frequency-multiplied output from a temperature-controlled crystal oscillator. The crystal frequency is such that the resulting difference in frequency in the output of the converter tube is very much lower than either the crystal or IPA frequency.

Since the crystal-oscillator frequency is extremely stable, any variations in the IPA or transmitter output frequency will result in the same number of kilocycles variation in the "difference" or intermediate frequency. By this arrangement, changes representing a very small percent of the output frequency, become a very much larger percent of the intermediate frequency appearing in the plate circuit of the converter. Thus we obtain a great magnification in percent of any change in the output center frequency.

The intermediate frequency is applied to a form of f-m detector which converts frequency changes into amplitude changes. This f-m detector, also called discriminator or slope filter, is so adjusted by tuned circuits that when the i-f is exactly the correct value, no output voltage is obtained from the discriminator rectifier to be applied to the frequency-modulator grid. Hence, nothing happens to change the M.O. frequency.

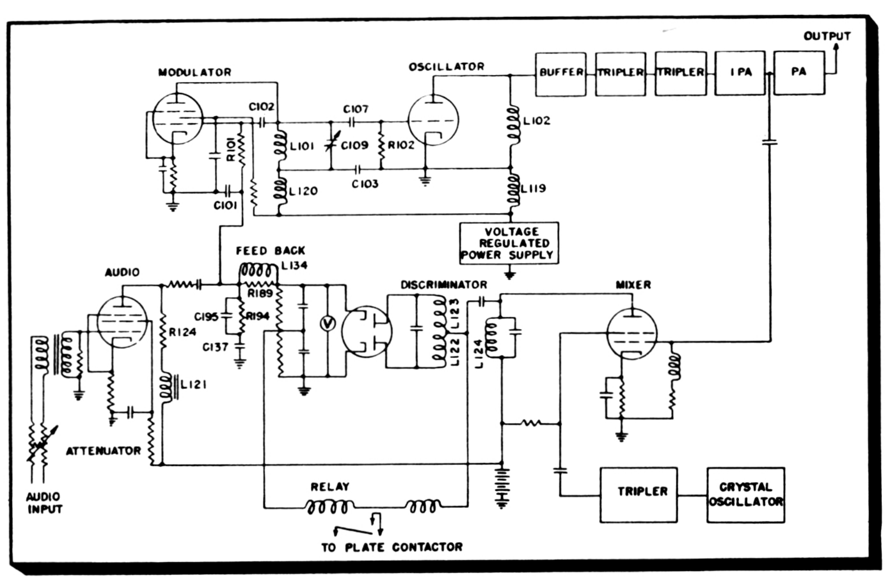
If the output frequency becomes slightly *higher* than the assigned carrier frequency, the intermediate frequency follows and the discriminator instantly produces a voltage of the correct polarity to force the output carrier back on its assigned frequency. If the output frequency should become slightly *lower* than the assigned carrier frequency, a voltage of the opposite polarity derived from the discriminator would immediately cause the frequency modulator tube to correct the M.O. frequency in the opposite direction. By proper selection of intermediate frequency and frequency modulator characteristics, it is possible to obtain a very rapid and forceful correction of any change in mean carrier output frequency.

Since the intermediate-frequency circuit operates at very low frequency as compared to the output carrier, instability in this circuit has relatively small effect on output stability. Even so, these intermediate-frequency circuits have been very carefully designed and stabilized to minimize such effects, however small. Thus, it should be evident that the transmitter stability is completely controlled by the highly stable crystal oscillator.

The stabilizer circuit exerts such a great corrective force on the output carrier that it would effectively oppose the desired frequency modulation, completely demodulating the output signal, were it not for the fact that a filter network is placed between the discriminator rectifier output and the grid of the modulator tube. This permits passage only of corrective voltages having frequencies considerably lower than the lowest audio frequency to be transmitted.

Provision is made in this transmitter

Fig. 2. Simplified schematic of frequency-modulation transmitter.



for mounting two temperature-controlled crystal cells with a switch for changing from one to the other during operation.

Since the voltage output of the discriminator rectifier due to any frequency drift, bears a linear relation to the amount of such drift, a d-c voltmeter placed across the rectifier output will indicate the magnitude of this drift. Such a mean-frequency indicator has been built into this transmitter to furnish the operator with a positive check on mean carrier frequency at all times. Two degrees of sensitivity are provided, one for tuning operations and a second for normal operation.

The main audio amplifier supplies the audio signal, through the pre-accentuation filter, to the grid of the frequency modulator. Very little gain is required of this amplifier stage for complete modulation, and its main function is to permit obtaining the proper action of the pre-accentuation filter.

The pre-accentuation filter at the transmitter has a very definite purpose in obtaining high-fidelity noise-free reception of broadcast transmissions, when receivers having the proper characteristics are used. It has been found that when high-fidelity transmission and reception systems are used in any type of modulation, a great proportion of the accompanying noise lies in the higher audio frequencies between 5,000 and 15,000 cycles. In all types of broadcast programs, the relative amplitude of these high frequencies is very low compared to frequencies from 30 to 5,000 cycles. Consequently, any reception of these high frequencies is usually covered up by the high noise level. Now, if by means of a pre-accentuation filter, the relative modulation of the transmitter is "stepped up" at these higher frequencies, while the receiver is made correspondingly less sensitive for the same frequencies, there will be a noticeable improvement in signal-to-noise ratio. The advantage of using such filters in frequency-modulation transmitters and receivers is even more pronounced than in case of amplitude-modulated systems.

Modulation Indicator

An electronic modulation-level indicator of the cathode-ray type is built into this transmitter. It operates by means of a combined application of both audio and frequency-modulated r-f, and serves to indicate to the operator the percentage modulation or frequency swing taking place in the transmitter output.

Rectifiers

Two rectifiers of conventional single-phase full-wave type are employed. The low-voltage rectifier supplies all plate voltages to the low-level stages, both r-f and audio. The second rectifier has two output voltages, one supplying plate power to the final frequency multiplier and IPA stages, and the other supplying high-voltage plate power to the power amplifier.

Automatic Voltage Regulator

A refinement which contributes materially to the stability and high-quality transmission of this transmitter is the electronic voltage regulator which maintains a constant plate voltage on the modulator and oscillator stages regardless of variations in supply line voltage.

A regulating-type of transformer supplies constant filament voltage to the modulator and oscillator tubes, relatively independent of line voltage fluctuations.

Power and Control Circuits

The 115-volt, single-phase, 60-cycle power supply is supplied to the transmitter through a circuit-breaker type of hand-operated switch. Power for the crystal and modulator-oscillator compartment heaters is furnished by a separate fused circuit, usually connected to the station lighting supply.

Control circuits, unusually simple in design, provide for complete protection and efficient operation of the equipment. Relays of different types guard against such things as severe overloads and premature application of plate voltage.

Several conveniently located instruments on the front panel indicate such information as plate voltage, filament voltage, and plate currents.

Larger Size Transmitters

In addition to the 250-watt unit, General Electric now offers transmitters in the 1-kw, 3-kw, and 50-kw sizes. The 1-kw amplifier is built in the same size and type of cabinet as its 250-watt exciter. The tube complement consists of two GL-833A tubes in a single Class C amplifier stage, while the rectifier employs four GL-872A tubes. In addition to the previously described features of the exciter unit, the 1-kw amplifier, when tied in with the 250-watt controls, provides an automatic "off-on" control circuit.

The 250-watt unit serves as an exciter for either the 1-kw or 3-kw amplifiers, and these respectively serve as drivers for the 10-kw and 50-kw units. The 3-, 10-, and 50-kilowatt amplifiers all employ new ultra-high-frequency tubes developed by General Electric especially for frequency modulation and television.

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