FM MONITOR HAS PULSE-COUNTER DISCRIMINATOR

General Radio FM Monitor for FM Broadcast and Television Sound Transmitters

BY CHARLES A. CADY*

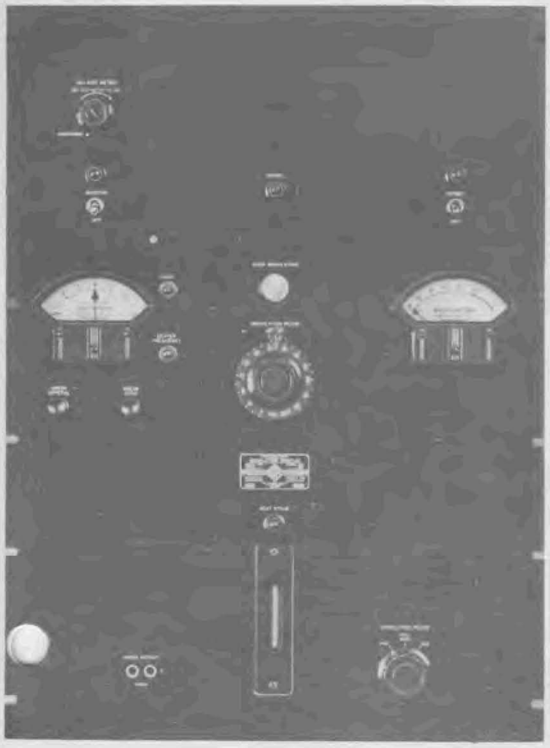

FIG. 1. FRONT PANEL OF THE MONITOR

THE General Radio Company has provided monitoring instruments for AM broadcast transmitters for many years. Their outstanding characteristics are ease of installation, reliability in operation, and stability of indication. These features were also the objectives for the new General Radio 1170-A FM monitor to be described here.

In this design, Figs. 1, 2, and 11, continuous indications of center-frequency deviation, modulation percentage, and overmodulation peaks are available at all times, without the need of calibration adjustments during the operating day. When remote indicators are used, the operator need not leave his position at the transmitter desk for the purpose of making any adjustments or calibrations. Without this feature, remote indicators are nearly useless.

Input power requirements are very low; only 1 volt into a high-impedance circuit is needed. This greatly simplifies the coupling problem and facilitates installation. The assembly is designed to dissipate the heat generated by the tubes and to make all parts accessible, as can be seen in Fig. 2. All circuits have undergone tests to prove their reliability and suitability for long-period service.

With one exception, vacuum-tube diodes are used rather than crystal rectifiers. Our experience indicates that crystals are not yet commercially available with characteristics as uniform as those of vacuum tubes, for tests on both types of diodes showed that only with vacuum tubes could the desired stability be achieved in this application.

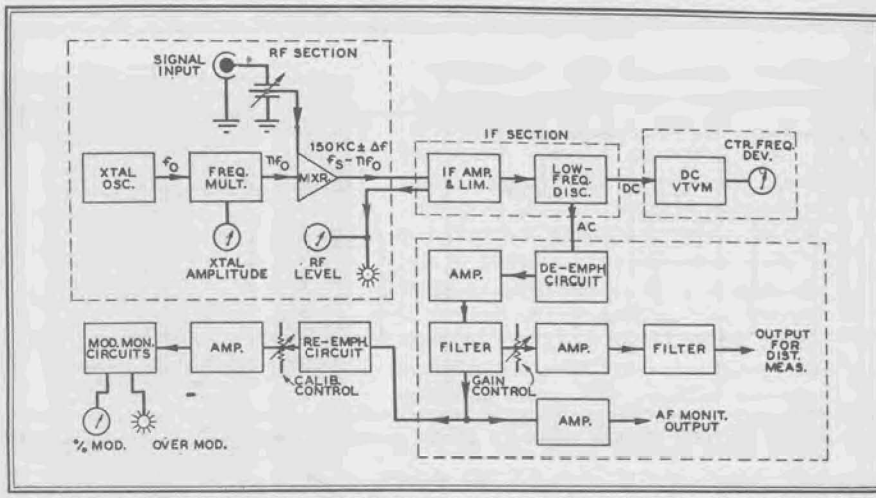

FIG. 3. THIS BLOCK DIAGRAM SHOWS THE CIRCUIT ELEMENTS OF THE FM MONITOR

Design Considerations ★ The problems of flexibility were considered in the initial design stage of the new FM Monitor. It was planned for television audio service as well as FM broadcasting, and as a measuring device for the laboratories of transmitter manufacturers. These services require a high degree of adaptability to suit the many changing requirements. For example to shift the operating frequency with a minimum of effort, the tuning adjustments have been made readily accessible, and they cover a wide range without the necessity of removing components. Further, as the same calibration for the modulation swing is not employed in all FM services, a single adjustment is provided to permit rapid changes in this setting.

The RF sensitivity of the monitor is high enough to permit remote monitoring over short distances. Most transmitters are provided with a direct connection to the monitor, but the high impedance RF input and the 1-volt RF sensitivity of this instrument indicate that, with tuned RF amplifiers, remote installations are possible.

Two of the most important features of any monitor are the accuracy and stability of the center frequency indication. The first of these can be readily obtained through the use of crystal oscillators and precision metering circuits. However, the overall stability of an FM monitor is very closely dependent on the characteristics

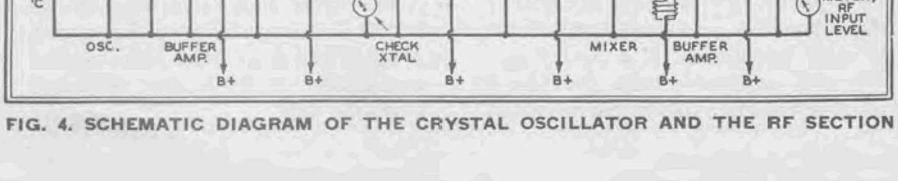

FIG. 4. SCHEMATIC DIAGRAM OF THE CRYSTAL OSCILLATOR AND THE RF SECTION

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of the discriminator employed. Early attempts to design a suitable tuned-circuit type of discriminator involved a frequency of several megacycles in order to obtain a linear characteristic. Operations at these frequencies resulted in a relatively unstable discriminator and required the use of a second, or calibrator crystal, in order to provide the required overall accuracy. While this arrangement might simplify the design, the result would be more of a measuring device than a true monitor, since continuous calibration checks would be necessary.

By employing a pulse-counter type of discriminator, it was found possible to operate at the relatively low frequency of 150 kc. This resulted in a considerable improvement in the ratio of desired frequency stability to discriminator center-frequency. In the case of the tuned-circuit discriminator operating at 10.7 mc., with the required stability of the center-frequency indicator arbitrarily chosen as 100 cycles, the ratio is 100/10,700,000 or .001%, while in the case of the pulse-counter discriminator the ratio is 100/150,000 or .066% for the same stability.

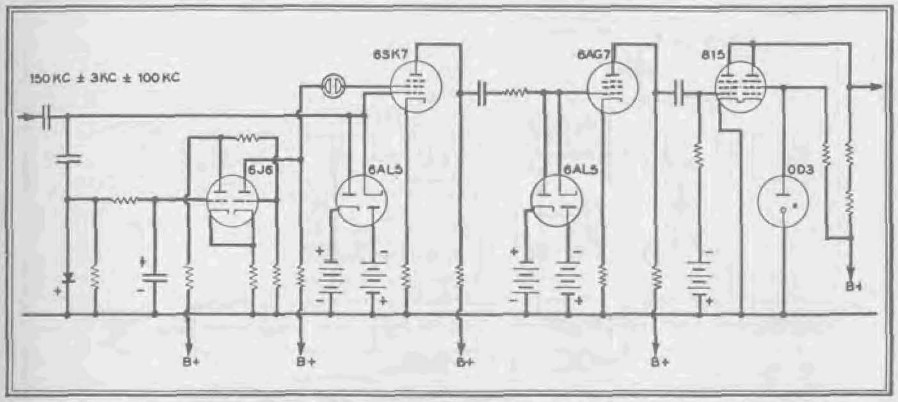

FIG. 5. MIXER OUTPUT SIGNAL GOES TO DIODE CLIPPERS AND LIMITING AMPLIFIERS

In order that the center frequency of the discriminator remain within 100 cycles of its nominal value for long periods, and thus eliminate auxiliary crystal calibrators, the choice was decidedly in favor of the low-frequency discriminator operation. With standard circuit components, a stability of .066% in center frequency of the discriminator can be far more readily obtained than the .001% figure.

Pulse counters are inherently linear devices, with circuit simplicity a direct result. Distortion measurements made with this type of discriminator do not depend upon critical adjustments, which may exhibit serious ageing effects or drift with changes in climatic conditions.

The pulse-counter type of discriminator is not without limitations, but these are more readily overcome than their counterparts of the tuned-circuit type. The inherent lack of sensitivity of the pulse-counter discriminator made additional amplification necessary. This increased the size of the monitor, but the added components are simple, and the freedom from critical adjustments justifies a larger instrument. The second factor to be overcome was noise produced in the square-wave amplifier and discriminator. Extraneous signals resulting from beats between the crystal oscillator and harmonics of the square-wave intermediate-frequency are eliminated through judicious selection of the crystal operating frequencies. High-frequency noise, resulting from the pulse-type waveform of the discriminator output, is removed by low-pass filters. A high signal-to-noise ratio is achieved by operating the discriminator at a high input level.

Operating Circuits ★ Fig. 3 shows the operation of the monitor in simple block form. A crystal oscillator is used to drive a series of simple tuned-circuit amplifiers to produce a signal at the mixer which differs from the transmitter channel frequency by 150 kc. This 150-kc. signal is the center frequency of the IF system. A series of diode limiters and limiting amplifiers convert the signal into a high-level square wave that operates the pulse-counter discriminator. The DC output of the discriminator actuates a meter that indicates shift in the center frequency of the transmitter from the assigned frequency. The AC output of the discriminator is de-emphasized and passed through filters to remove unwanted high-frequency components. At this point, the audio signal divides into three systems: 1) a simple amplifier provides an output for local aural monitoring, 2) a second amplifier, with adjustable gain, provides a signal to operate an external distortion and noise meter, and 3) a third amplifier system includes a standard pre-emphasis characteristic to restore the flat frequency response for the modulation metering circuits. These provide for indicating positive and negative modulation peaks simultaneously, or either one alone as selected on a panel switch. Also, an over-modulation lamp flashes whenever the dial setting has been exceeded.

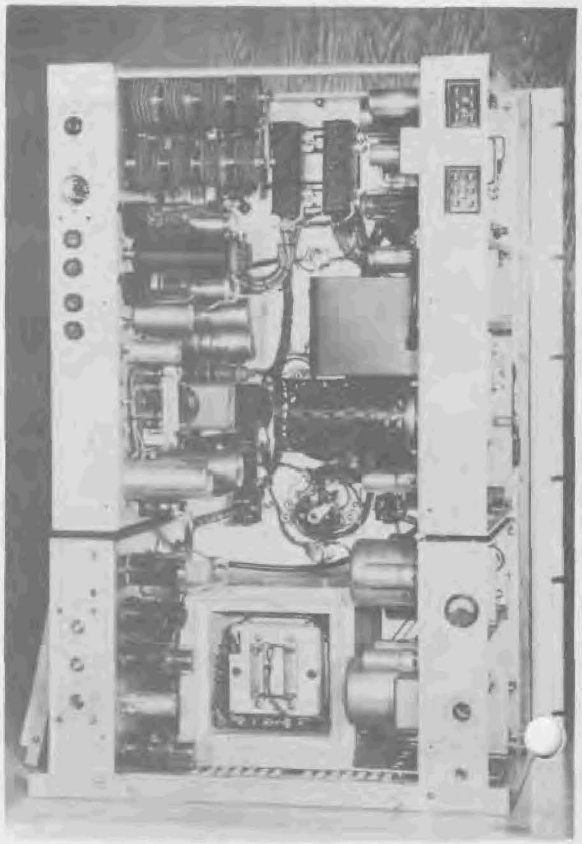

FIG. 2. REAR OF THE MONITOR CHASSIS

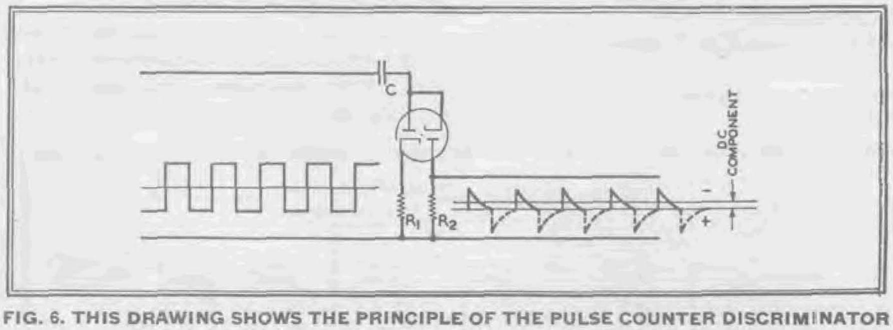

FIG. 6. THIS DRAWING SHOWS THE PRINCIPLE OF THE PULSE COUNTER DISCRIMINATOR

Auxiliary circuits are provided for checking monitor operation. These include:

1. An indication of crystal oscillator output level,
2. An indication of the RF input level,
3. A monitoring signal lamp to indicate normal transmitter input,
4. A heat-cycle pilot lamp to show the action of the crystal oven thermostat,
5. A panel switch to check the electrical zero-setting of the center frequency indicator, and

6. Connections for external meters and an external over-modulation lamp.

Crystal Oscillator & RF Section ★ The crystal oscillator is one developed at General Radio specifically for frequency monitoring. There are no tuning inductances, and the crystal operates very close to its true resonant frequency. High stability is obtained without critical circuit adjustments. Crystals can be interchanged with ease. The oscillator circuit is shown at the left of Fig. 4.

Circuit capacitance can be changed by as much as 4% before the frequency will change by 1 part per million. The crystal has a temperature coefficient of less than 2 parts per million per degree Centigrade, and is enclosed within a temperature-controlled oven operated at 60° ± 0.15° C. For maximum stability, low-frequency crystals are used, with fundamentals between 1.4 and 2.2 mc. Amplitude of the crystal oscillator output is indicated on a panel meter when a panel switch is depressed.

The crystal oscillator is followed by an aperiodic buffer amplifier and 3 harmonic multiplier stages. Fig. 4 shows the circuit arrangement.

The crystal frequency is chosen so as to result, after passing through the multipliers, in a 150-kc. offset from the assigned transmitter frequency. The multipliers are operated at high levels to minimize phase-shift effects which would appear in the monitor output signal as residual FM noise. Because these stages are individually tunable over a considerable range, it is a relatively simple matter to change the operating channel frequency of the monitor. It is merely necessary to insert the new crystal and make three simple tuning adjustments of the multiplier stages.

It is possible to extend the RF range of the monitor down to 30 mc. by replacing one or more of the fixed inductances in the multiplier system. The high-frequency operation can be extended above 162 mc. by replacing a removable section of the multiplier assembly with a VHF unit.

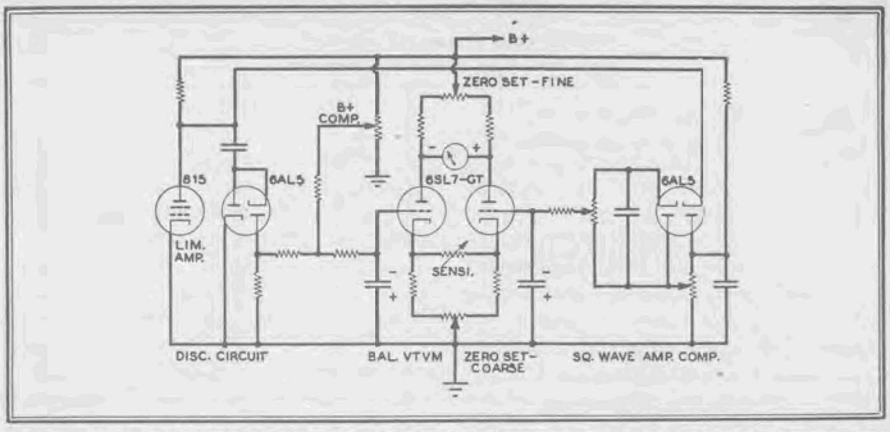

FIG. 7. CIRCUIT OF THE PEAK-RESPONSE DIODE VOLTMETER AND ZERO ADJUSTMENTS

FIG. 11. VIEW OF THE REAR PANEL

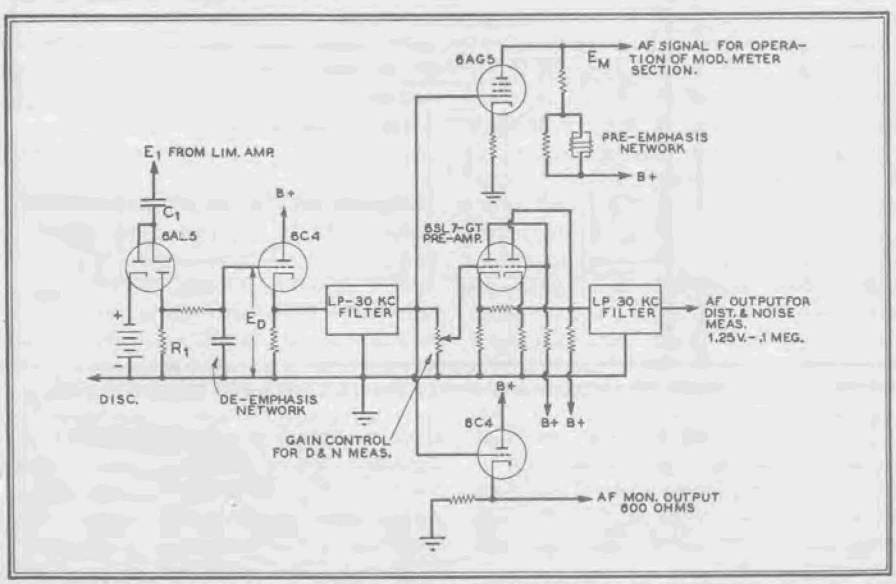

FIG. 8. THE AUDIO SYSTEM IS DIVIDED INTO 3 SEPARATE CIRCUITS, AS SHOWN HERE

RF input from the transmitter is fed to the mixer stage through an adjustable capacitive attenuator. This is a high-impedance circuit, operating with a nominal signal level of 1 volt. No appreciable power is taken from the transmitter, and there are no loading resistances subject to burnout. The RF input level is continuously indicated by a small meter at the rear of the monitor. This meter is operated by the IF signal, which is proportional to the RF input over the normal operating range. The amplifier saturates at higher levels, making it impossible to burn out the meter through overloading. Since the RF level is not critical, this meter is normally used only during the initial installation procedure. A panel pilot lamp provides a continuous indication of the required minimum transmitter signal level.

Limiter-Amplifier ★ The mixer output signal is amplified and passed through a series of diode clippers and limiting amplifiers to convert it into a square wave. These are shown in Fig. 5. To operate the limiters, a minimum input voltage level is required. A control tube keeps the final amplifiers inoperative until the output of the mixer is sufficient to provide a saturation signal to the limiters. Erratic behavior at low RF input levels is thus avoided, since the monitor automatically ceases operation when the signal level falls below a critical value.

The pulse-counter type of discriminator depends for its operation upon a uniform charge and discharge of a condenser through a series resistance during each half-cycle. For this reason, those characteristics of the square wave which influence the condenser charges must be rigorously controlled. Anode and limiter-bias potentials in the clipper-limiter sections are closely regulated. A power tube, operating as a limiter, is used to drive the discriminator at a high level.

Discriminator Operation ★ Fig. 6 illustrates the principle of the pulse counter discriminator. The series condenser is alternately charged through the left diode, and discharged through the right diode.

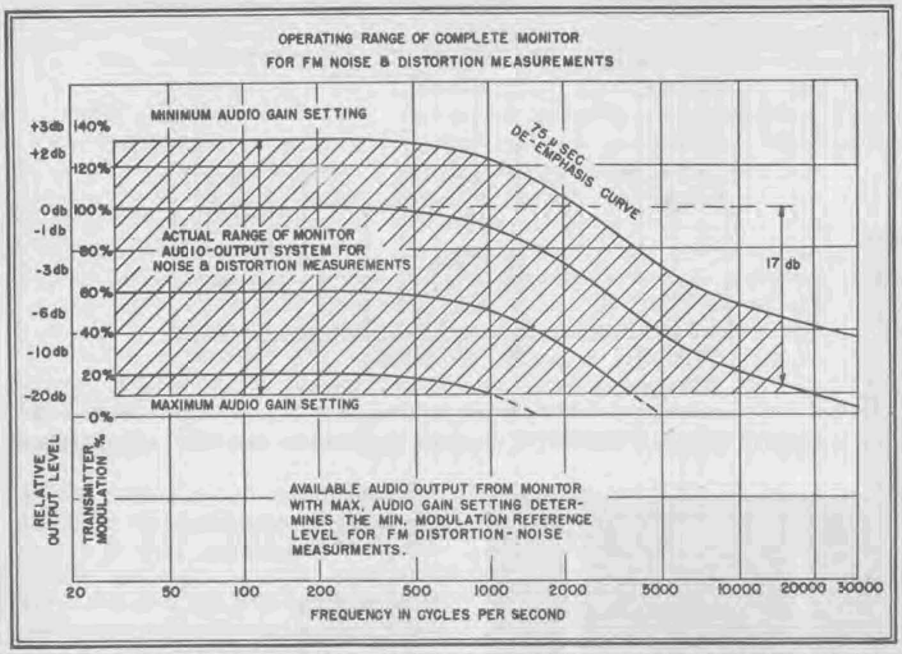

FIG. 9. OPERATING RANGE FOR MAKING FM DISTORTION-NOISE MEASUREMENTS

Thus a series of short, uni-directional current pulses flow through the resistance at the rate of 1 per IF cycle. When the transmitter is unmodulated, these pulses occur at a uniform rate. When modulation is applied, the pulses occur at a varying instantaneous rate, dependent upon the modulation signal. A DC potential is developed across the resistance which is proportional to the average rate of the pulses. This is used to operate a balanced DC vacuum-tube voltmeter, calibrated to read average center-frequency-shift from the assigned transmitter channel frequency.

To minimize the effects of minor variations in the amplitude of the discriminator input signal, a compensating circuit is used. This consists of a peak-response diode voltmeter, whose output is applied to one side of the balanced DC vacuum-tube voltmeter. Amplitude changes affect both circuits equally, and hence do not affect the meter indication. Frequency changes are detected only by the discriminator, and hence appear as deflections on the meter. The metering circuit is shown in Fig. 7.

The AC components of the pulse voltage appearing across the discriminator resistance contain the modulation signal, the fundamental pulse repetition frequency, and a series of harmonics. The high frequencies are above the upper limit of the audio measurement band (i.e., 30 kc.), and a high-pass filter is used to separate the desired modulation signal.

Audio System ★ The entire audio system is coupled to the discriminator by a standard 75-microsecond de-emphasis network. This reduces the reactance load across the discriminator to improve the linearity, and is an effective low-pass filter which attenuates the pulse repetition frequency and its harmonics. This is followed by an impedance-transforming amplifier and a low-pass filter section which provides a uniform frequency-response up to 30 kc. At this point, the audio system divides into three separate circuits, as in Fig. 8.

A cathode-coupled amplifier provides an audio signal for direct connection to aural monitoring lines at a level of 0 dbm for a modulation swing of ±75 kc. The image impedance is 600 ohms, and has one side grounded.

A second amplifier is provided with an input gain control. This is intended for fidelity measurements, and has been designed for very low residual noise and distortion. It has a low-pass filter section on the output to reduce further the noise resulting from IF and RF interference. The residual distortion level is less than .1% with a noise level of approximately −80 db, and is intended for use with an external distortion and noise meter such as the GR 1932-A. Input gain control permits the output of the amplifier to be set for a constant level of 1.2 volt with transmitter modulation swings ranging from ±100 kc. to ±6 kc. In the standard FM broadcast band, this corresponds to a range of 133% to 8% modulation. For television aural transmitters, the range is 133% to 24% modulation. Due to the de-emphasis characteristic, the available signal level for a given modulation swing decreases at the higher audio frequencies. This limits the minimum modulation swing, or percentage modulation, at which measurements can be made when the audio frequency approaches its upper limit. Fig. 9 shows the operating range for these measurements.

The third audio circuit comprises the modulation measuring system. An amplifier with a standard pre-emphasis characteristic is used to restore a flat frequency-response, since the modulation swing must be measured without de-emphasis. Following this is an amplifier with continuously adjustable gain. To change the calibration of the entire modulation system it is only necessary to reset this one control. It has a range slightly in excess of 3 to 1. Hence the instrument can be shifted readily from a calibration level of 100% modulation for ±75-kc. swing to a value of 100% modulation for ±25 kc. swing, as required for monitoring television aural transmitters.

The output of this amplifier feeds two modulation indicating circuits. One of these consists of an over-modulation peak indicator, which flashes a panel lamp whenever the instantaneous modulation peaks exceed a given setting of a dial indicator. A thyratron tube is employed to flash a lamp connected in its anode

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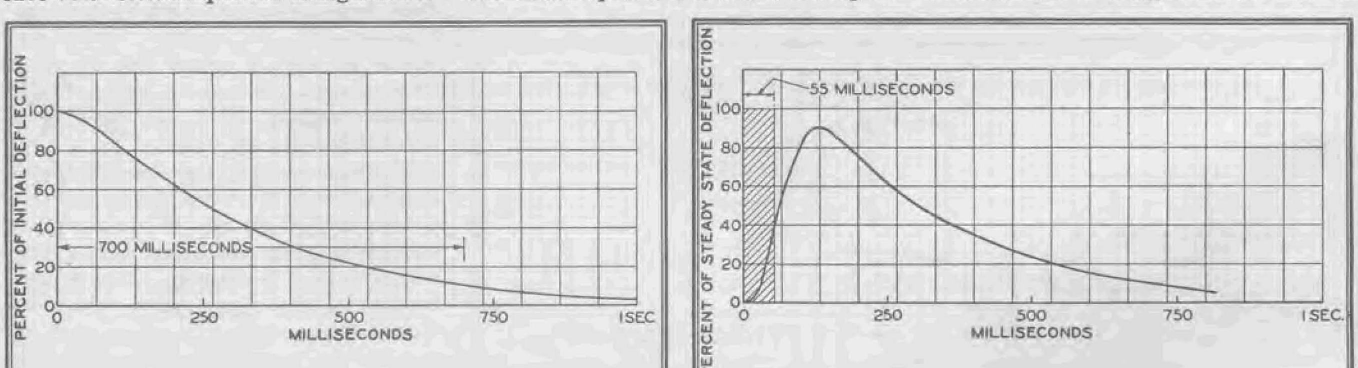

FIG. 10. PERCENTAGE OF INITIAL DEFLECTION AND STEADY STATE DEFLECTION ARE IN ACCORDANCE WITH FCC REQUIREMENTS

FM MONITOR

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circuit. The thyratron is tripped by a triggered amplifier tube which has the modulation signal impressed on its control grid, together with a given amount of negative bias voltage as determined by the dial-potentiometer setting. Whenever a modulation peak exceeds the applied DC bias, a pulse of plate current is generated in the amplifier, which is then used to trip the thyratron. The lamp operates on positive modulation peaks. This is not significant, except when asymmetrical modulation is present, at which times the agreement between the modulation meter and the over-modulation lamp will depend upon the meter polarity used.

The second modulation indicator consists of a semi-peak response meter circuit, which can be set to respond to negative or positive modulation swings, or both simultaneously. There are two semi-peak response diodes, each used to operate an independent VT voltmeter tube. An R-C network is placed in the grid circuits of each of these tubes. This permits a rapid rise in the grid potential with increasing modulation amplitude, and a slow response to decreasing a-m plitudes. During modulation, the meter indications appear to float along the peaks of the modulation signal. This dynamic-response characteristic meets FCC requirements. It is illustrated by Fig. 10.

For FM applications, there is no preference for monitoring any one polarity of the modulation signal, as is the case in an AM transmitter. Operators are mainly interested in the maximum modulation swing regardless of polarity. Hence, the ability to monitor both simultaneously is advantageous. This is especially true when asymmetrical program material is encountered. The maximum modulation peaks may shift from one polarity to the other as the program changes, thus requiring continual shifting of the meter polarity to assure an indication of the true maximum peak swing. By setting the meter to respond to both polarities simultaneously, this operating complication can be avoided.

Center-Frequency Indicator Characteristics ★ The stability and accuracy of the center-frequency indications are dependent upon several circuits. The monitoring crystal affects the center frequency meter directly. After the initial installation and the usual frequency check and adjustment, it has been found that long-term stabilities in the order of 1 part per million can be expected. This will account for a change in the center-frequency indicator of 100 cycles.

A second factor to be considered is the discriminator center-frequency stability. This includes the discriminator, compensating circuits, and associated diodes. These circuits will not cause an effective shift in discriminator center frequency greater than .066%, or an indication of 100 cycles on the center frequency indicator.

These account for errors in the center-frequency indicator, and will amount to only 2 parts per million, or 200 cycles.

Changes in meter circuit sensitivity can be neglected, since they are proportional to the full-scale deflection of the meter, and are negligible by comparison with other factors.

Since a balanced DC vacuum-tube voltmeter is used to drive the center-frequency meter, any change in the zero setting will affect the meter directly. This has been reduced to a value of less than 200 cycles for extended periods. A panel switch has been provided so that this zero setting can be checked (once a day is adequate), and hence drift in the zero does not influence the ultimate accuracy of the center-frequency indicator. If this check is not made, the overall instability will approach a maximum of 400 cycles. Continuous recordings of the center frequency are feasible, a feature which is not possible without this high overall stability, regardless of the ultimate accuracy.

The extreme linearity of the discriminator results in a negligible shift in indicated center frequency under full modulation conditions. Therefore, the monitor can be used to test transmitters for this characteristic.

External Indicators ★ Arrangements are provided for connecting to remote indicators. The meters used are currently available types, with a minimum of special requirements, and can be connected without affecting the calibration. The remote over-modulation-peaks indicator is a standard 3- to 6-watt, 115-volt mazda lamp.

Test Equipment ★ One of the most difficult problems associated with the development of the monitor was that of determining the overall performance characteristics in the absence of a perfect test source. Each component was first tested separately. The discriminator was checked statically, using a precisely calibrated potentiometer. A characteristic was obtained which indicated a maximum of .05% departure from linearity over a range of ±100 kc.

The audio fidelity measuring system was considered satisfactory when overall tests resulted in a residual distortion below 0.1%, and the residual noise measured less than −80 db.

Other portions of the instrument were given long-term calibration tests. To ascertain its stability characteristic for extended periods, the discriminator was operated from a 150-kc. signal derived from our primary-frequency standard.

By operating the IF system from a stable, noise free, 150-kc. source, the residual equivalent FM noise level was measured to be less than −80 db for the combined IF, discriminator, and audio output systems.

Overall tests of the complete monitor were made with a specially developed phase-modulated FM test-source, operated from the 50-kc. output of the primary frequency standard, multiplied to 102.4 mc. This provided a source of extremely stable FM signals, and was very useful for determining the shift in the indicated center frequency of the monitor with applied transmitter modulation. It further served as a comparison test source for fidelity measurements. A second test source employed a local FM oscillator for overall tests of residual noise and distortion. It was obviously impossible to construct a perfect test source, and there were practical limits imposed upon the two test units. By comparing the results obtained from each of these two different types of modulators, a relative measure of the monitor performance was obtained. Consistent results showed a measured distortion level of 0.25% over a wide range of modulating frequencies and transmitter modulation levels for both test sources. The modulating oscillator was known to have 0.1% distortion. On the basis of the tests on the monitor, made by insertion of an IF signal, it was adjudged that most of the remaining distortion was actually generated within the test sources. While these tests cannot be used to define rigorously the residual distortion within the monitor, they are indicative of the results that may be expected.

The same is true for the noise measurements, where the results indicated a noise level of −70 db for the entire system, with the conclusion that the FM test sources were again the limiting factor.

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