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USES OF THE CATHODE-RAY OSCILLOGRAPH IN TRANSMITTER ADJUSTMENT AND CONTROL

By S. H. Coombs

INTRODUCTION.

The established methods for transmitter adjustment and control require the use of d'Arsonval meters. Since these methods are generally satisfactory, any supplement to them must be in keeping with their simplicity, speed, and effectiveness. A supplement fulfilling these requirements is the cathode-ray oscillograph; for this versatile instrument can be employed in transmitter aligning, neutralizing, monitoring, and trouble shooting.

The oscillographic patterns, or oscillograms, as they are called when permanent records are made, which are useful for adjustment and control of radio transmitters can be classified into five types: (a) the audio sine-wave pattern, which provides a means for testing the a-f channel; (b) the r-f unmodulated wave pattern, which is used for adjustment of the r-f channel of the transmitter; (c) the Lissajous pattern which serves as an indicator for neutralization and for adjustment of frequency-multiplier stages; (d) the modulated-wave pattern, which furnishes a check on over-all performance and an index of the source of trouble in the transmitter; (e) the trapezoidal pattern, which has the same functions as the modulated-wave pattern, and is also a valuable modulation monitor.

PATTERN THEORY

Examples of the foregoing patterns and the methods for tracing them on the screen of the cathode-ray oscillograph are given below.

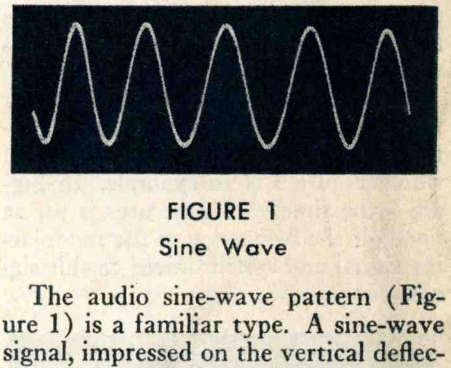

FIGURE 1

Sine Wave

The audio sine-wave pattern (Figure 1) is a familiar type. A sine-wave signal, impressed on the vertical deflection plates of the cathode-ray tube, moves the electron beam up and down in accordance with the components of the signal. Horizontal deflection is accomplished by the saw-tooth signal which is generated by the oscillograph's time-base generator. The combination of the sine-wave and saw-tooth signals on the deflection plates causes a pattern to be traced by the electron beam. To obtain a stationary pattern the two signals must be synchronized by feeding a small portion of the vertical deflection signal to the grid of the time-base oscillator tube.

The unmodulated-wave pattern is produced on the screen of the cathode-

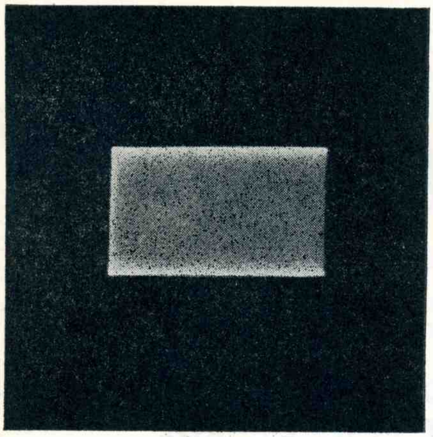

FIGURE 2
Unmodulated-Wave Pattern

ray tube in the same manner as is the sine wave pattern. In this case, however, the frequency of oscillation of the vertical signal is so high above the frequency range of the saw-tooth generator that synchronization is meaningless and unnecessary. An unmodulated-wave pattern is shown in Figure 2.

Amplitude modulation of the carrier wave will change the carrier wave pattern into a modulated-wave pattern, of which Figure 3 is an example. In Figure 3 the time-base generator is set at one-half the frequency of the modulating signal and synchronized to this signal.

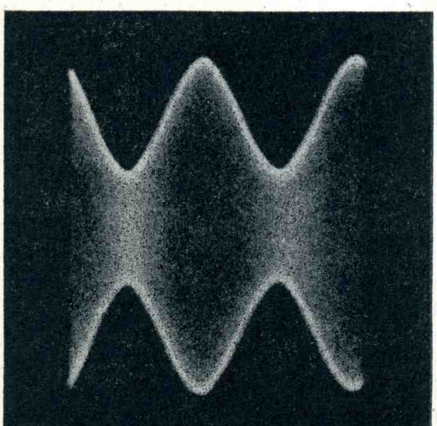

FIGURE 3
Modulated-Wave Pattern

When it is desired to check the neutralization of an r-f stage of a radio transmitter, a Lissajous-type pattern may be employed. The Lissajous pattern used for neutralization has a 1:1 frequency relationship which yields various elliptical shapes. To obtain a Lissajous pattern which will be an aid in neutralizing a transmitter stage, it is necessary to feed the r-f signal, as it appears on the grid of the stage to be neutralized, to the horizontal deflection plates of the cathode-ray tube, and to connect the r-f signal as it appears on the plate of the stage to be neutralized to the vertical deflection plates. If the stage to be neutralized is also a modulated stage, the modulating signal must be turned off to get an intelligible Lissajous pattern.

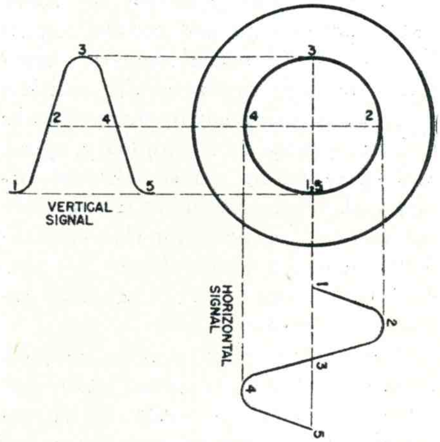

FIGURE 4
Lissajous Pattern Showing 90° Phase Difference Between Signals

For a complete understanding of the information contained in a Lissajous figure, the phase relationship of the two signals, as they appear at the deflection plates, must be considered. For example, Figure 4 shows the pattern resulting from two signals of the same amplitude but with a 90° phase difference connected to the deflection plates of a cathode-ray tube. The position of the electron beam, and thus the trace on the screen, is determined by the instantaneous deflecting voltage which is vectorially resolved from the two signals. Figure 4 shows how the trace resulting from the deflecting signals on the deflection plates is controlled by instantaneous resultants of both signals. Projections drawn from similar timed positions on the two signals illustrate the combined influence of the horizontal and vertical signals on the electron beam. That is, position 1, on the elliptical pattern, is determined by the instantaneous resultant of the potentials at time 1 of each of the two input signals, as indicated by the projections from these points. Also positions 2, 3, 4, and 5 on the elliptical pattern are determined by the instantaneous resultants of the deflection potentials at times 2, 3, 4, and 5 respectively of the two signals. All other points on the elliptical pattern can be determined in the same manner.

Lissajous patterns are also useful in transmitter adjustment when it is necessary to check the performance of frequency-multiplier stages. The equipment arrangement and connections in this application are similar to those employed when obtaining a Lissajous pattern as a neutralization indicator.

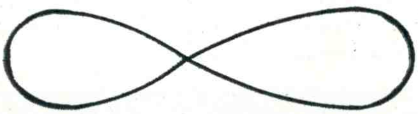

FIGURE 5

Typical Lissajous Pattern Encountered at a Frequency-Doubler Stage

A type of Lissajous pattern which may be observed when checking the performance of frequency-multiplier stages in this case a frequency-doubler stage, is illustrated in Figure 5. In actual practice, the signal at the plate of the frequency-doubler stage contains the fundamental frequency as well as one or more harmonics. Thus, it may not have all of its peaks at the same height, the fundamental being of greatest amplitude. The Lissajous pattern, therefore, will appear somewhat distorted; but this will not destroy the accuracy or utility of the indication required to determine the integral frequency relationship.

The frequency ratio of the two signals which are connected to the horizontal and vertical deflection plates is determined by comparing the number of contacts which the pattern makes with a horizontal side and with a vertical side of an imaginary rectangle enclosing the pattern. For example, the pattern of Figure 5 makes contact with a horizontal side of an imaginary rectangle twice while the pattern contacts a vertical side only once. In this case the frequency ratio is 2:1.

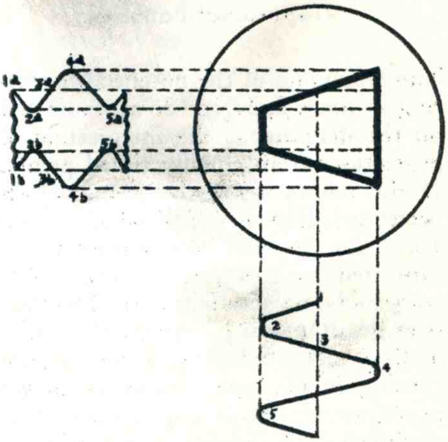

FIGURE 6

Graphic Explanation of Trapezoidal Pattern

Presentation of a trapezoidal pattern on the screen of a cathode-ray oscillograph requires that the modulating signal be connected to the horizontal deflection plates in place of the usual sawtooth signal. An analysis of the trapezoidal pattern can be made in a manner similar to that used to develop a Lissajous pattern. For example, Figure 6 shows, in diagrammatic form how the signals on the deflection plates cause the electron beam to trace a trapezoidal pattern. Point 2 on the modulating signal and points 2a and 2b of the modulated carrier-wave occur, for illustration purposes, at the same time.

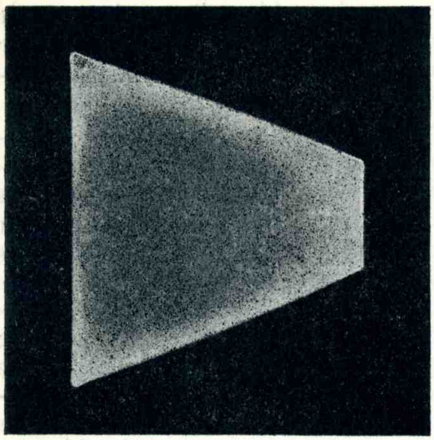

FIGURE 7

Trapezoidal Pattern

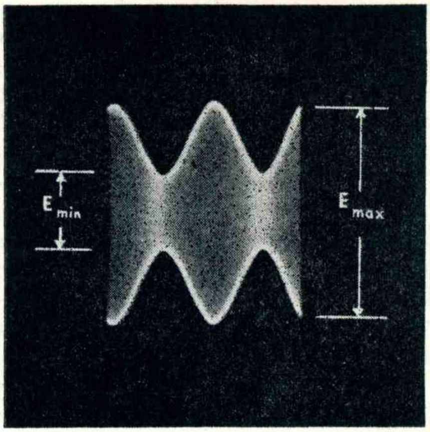

FIGURE 9

Calculating Modulation Percentage (Modulated-Wave Pattern)

The resultants of the potentials occurring at times 2, 2a, and 2b are indicated on the diagram as the intersection of projections from equally timed points. If the points along the signal which occur simultaneously, of which 1, 1a, 1b, 2, 2a, 2b, etc., are examples, are projected to meet, the outline of a trapezoidal pattern is traced. The electron beam, moving between the limits of these potentials, traces the pattern, causing it to appear solid as shown in Figure 7. Since the frequency of modulation of the carrier wave is the same as the frequency of the signal impressed on the horizontal deflection plates, the two signals are automatically synchronized, and the trapezoidal pattern appears stationary.

Phase distortion of the signals which is exemplified by the pattern of Figure 8, results when the modulating signal and the modulated carrier wave are presented out of phase at the deflection plates. This may be due to phase distortion arising in the transmitter or to distortion arising in the connecting link between the transmitter and the cathode-ray oscillograph.

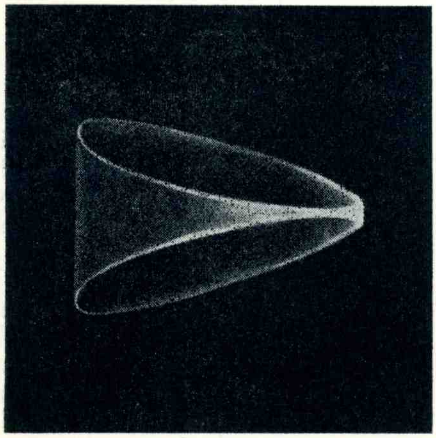

FIGURE 8

Phase Distorted Trapezoidal Pattern

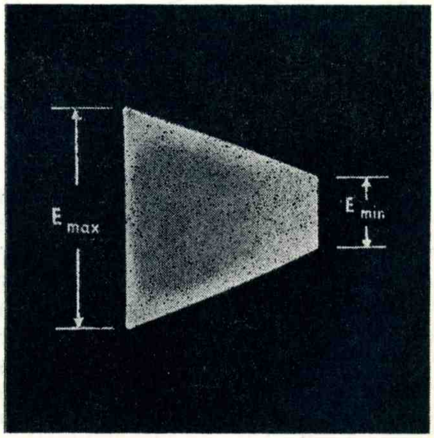

FIGURE 10

Calculating Modulation Percentage (Trapezoidal Pattern)

In connection with the modulated-wave and the trapezoidal patterns, the modulation percentage may be expressed as

$$\text{Modulation percentage} = \frac{E_{max}-E_{min}}{E_{max}+E_{min}} \times 100$$

This percentage is readily obtained by measurement of the maximum and minimum vertical deflections of the pattern. For example, in Figures 9 and 10

$E_{max}=1.2''$ approx.
$E_{min}=0.4''$ approx.

$$\% \text{ mod.} = \frac{1.2-0.4}{1.2+0.4} \times 100 = 50$$

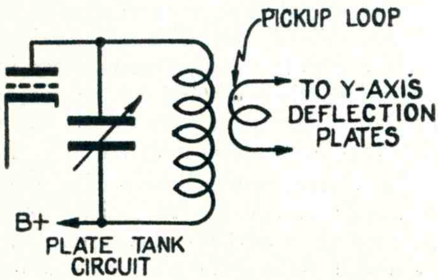

FIGURE 11

Method of Coupling RF Signal From Transmitter to Cathode-ray Oscillograph

METHODS FOR OBTAINING PATTERNS

Coupling a sample of the carrier wave signal to the vertical axis of the oscillograph must be done in such a manner that the resonant condition of the tank circuit is not altered. By loosely coupling two or three turns of wire to the coil of a tank circuit, the resonant conditions will not be seriously disturbed. The leads from this pick-up loop are then connected to the vertical-axis deflecting plates of the cathode-ray oscillograph. The connections will resemble those illustrated in Figure 11.

The pick-up loop method for coupling the carrier wave sample to the vertical-deflection plates is recommended because of its simplicity. The signal obtained by this method, however, may be insufficient for the desired vertical deflection of the electron beam. Thus, a high-Q tank circuit often must be connected in parallel with the vertical deflection plates and coupled inductively to a link coil which in turn is coupled, through a low-impedance line, such as a coaxial cable, to a link coil at the transmitter tank circuit, as shown in Figure 12. The length of the line must be considered carefully since the amount of signal attenuation in the line is directly proportional to the length of the line. The tank circuit, consisting of a coil and a capacitor with a high Q will by resonance increase the signal amplitude sufficiently to obtain the required deflection.

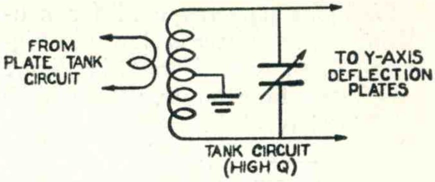

FIGURE 12

Method of Coupling Very Weak RF Signal to Cathode-ray Oscillograph

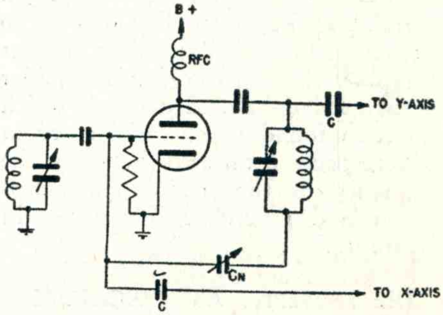

FIGURE 13

Method of Coupling Signals to Cathode-ray Oscillograph for Neutralization Patterns

A satisfactory method for obtaining the Lissajous patterns used for neutralizing a transmitter is shown in Figure 13. If the capacitors C in Figure 13 are 0.01 mfd or larger, there will be negligible phase shift.

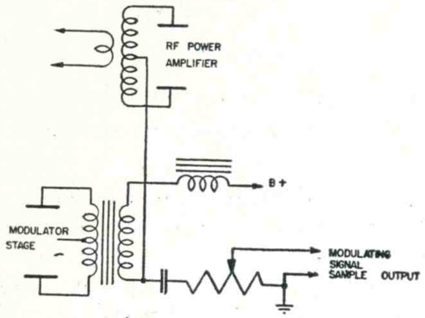

FIGURE 14

Method of Obtaining a Sample of the Modulating Signal

The method for coupling a sample of a modulated-wave to the oscillograph demands the same considerations as those which are observed in the case of the unmodulated wave. To obtain a stationary modulated wave pattern, however, the linear time-base generator must be synchronized to the modulating signal, which means feeding the modulating signal to the grid of the time-base generator. The final modulating signal which is used to modulate a radio-frequency amplifier stage is generally too large to feed directly into the cathode-ray oscillograph. It is often necessary, therefore, to employ a modulating-signal-sampling network to attenuate this signal and thus prevent it from overloading the X-axis amplifier of the oscillograph. A network which has been found to be satisfactory in this respect, connected between the secondary of the modulation transformer and ground, is illustrated in Figure 14.

THE PATTERNS AS INDICATORS

Each of the patterns described in the foregoing can be used as an indicator for transmitter adjustment or control. The unmodulated-wave pattern serves as an indicator for tuning the r-f section of the transmitter. The alignment process consists of loosely coupling the pick-up loop to the coil of each tank circuit in succession, starting with the oscillator stage of the transmitter. Then the tuning of each tank circuit is adjusted until the carrier-wave pattern indicates maximum deflection. With this adjustment, the tank circuit is tuned to resonance. Proceeding in order through the transmitter, the other tank circuits are tuned to resonance in the same manner. The tank circuits of frequency-multiplier stages are aligned similarly but the desired frequency of resonance is determined by the method described in the foregoing.

The method for neutralizing a transmitter stage is to adjust the neutralizing capacitors to balance and cancel the signal which is fed back from the plate to the grid circuit. Therefore, without plate voltage on the stage to be neutralized, but with all previous exciter circuits of the transmitter in operation, there should be no signal present in the plate-tank circuit when the stage is correctly neutralized.

For correct neutralization of a given transmitter stage, the transmitter must be properly tuned and neutralized up to, and including, the grid of the stage in question. After the connections described above are made, the stage can be neutralized by observing the proper pattern.

Since a parallel tuned circuit, tuned to resonance at the frequency of the applied signal, acts as a pure resistance, there is no phase shift present other than the 180° phase inversion between grid and plate circuits. Two signals, therefore, one picked up at the grid, the other at the plate, would be just 180° out of phase. If the plate signal were fed to the vertical deflection plates of a cathode-ray tube, and if the grid signal were fed to the horizontal deflection plates, the pattern on the screen would resemble Figure 15A since the grid signal is larger in amplitude than the plate signal when no plate voltage is present. This figure illustrates a typical pattern which is obtained when the plate circuit is tuned. A detuned plate circuit, however, would act as an inductance or as a capacitance, depending upon the

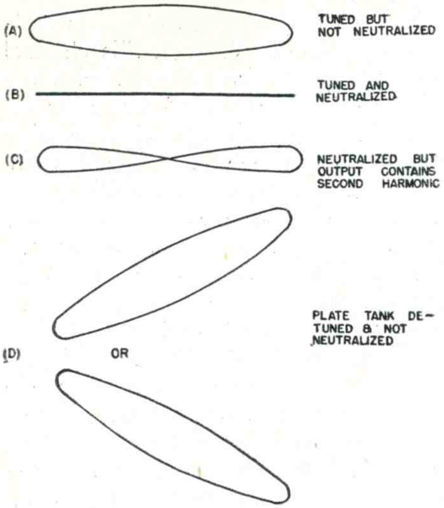

FIGURE 15

Examples of Patterns Encountered in Neutralizing a Transmitter Stage

particular side of resonance to which the plate tank is detuned. Under these conditions, the phase shift would be different from 180° which would cause the pattern to be tilted as shown in Figure 15D.

The indication of a correctly tuned plate tank, using the suggested connections, for a transmitter stage which must be neutralized, is a horizontal ellipse. If the ellipse is found to be inclined, the tuning of the plate-tank circuit should be adjusted until the ellipse becomes horizontal.

A correctly neutralized transmitter stage has effectively no signal appearing at the plate circuit. One concept considers a correctly neutralized transmitter stage as having two signals appearing at the plate, but these signals are at all times exactly opposite in phase resulting in the two signals completely cancelling each other.

After the stage to be neutralized is properly tuned, the neutralizing capacitor, or capacitors, is adjusted until the ellipse becomes a straight horizontal line as shown in Figure 15B. This line indicates that there is no signal present on the vertical deflection plates, or, in other words, there is no signal at the plate. Then, the stage is correctly neutralized because any signal which is fed into the plate-tank circuit through stray capacitance is neutralized by the signal fed through the neutralizing capacitor.

To properly tune frequency multiplier stages, the same connections for the cathode-ray oscillographs are employed as those described previously in connection with tuning and neutralization. Also, as in neutralizing a transmitter stage, the grid-tank circuit is first tuned to resonance by the pick-up coil method. The plate of the frequency-multiplier stage is then tuned by adjusting the plate-tank circuit until the pattern becomes a clearly discernable Lissajous pattern with a frequency ratio corresponding to the desired multiplier-stage frequency ratio.

MONITORING TRANSMITTER PERFORMANCE

The trapezoidal or the modulated-wave patterns may be used as indicators of over-all performance of a radio transmitter. The trapezoidal pattern is particularly well suited to modulation

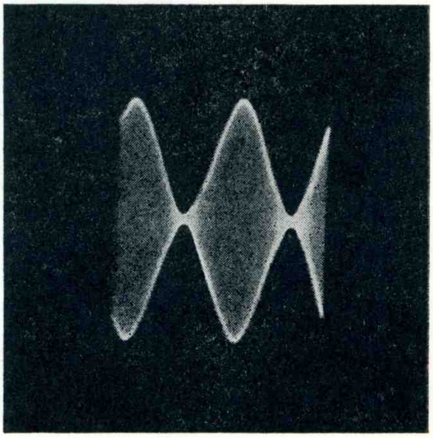

FIGURE 16

Modulated Wave Pattern Showing 100% Modulated Carrier Wave monitoring. Such an indication gives more modulation information than any meters which depend upon a mechanical movement. For example, an audio signal which is rapidly varying in amplitude can overmodulate the carrier wave and yet not be indicated by an ordinary modulation meter because of the inertia of the pointer. Under the same conditions overmodulation will be revealed by the presence of a "tail" on the clearly pulsating trapezoidal pattern.

TROUBLE SHOOTING THE TRANSMITTER

Included under the general heading of checking over-all performance of the transmitter, but important enough to deserve separate mention is trouble shooting with the cathode-ray oscillograph. The use of this instrument for trouble shooting is based upon the premise that the location of many defects is revealed by proper interpretation either of the trapezoidal or the modulated-wave pattern. The trapezoidal pattern will indicate one trouble more readily in one case and the modulated-wave pattern in another. Figures 16 through 28 are representative of the patterns encountered when using these methods to locate the source of trouble. A sine-wave modulation signal is recommended to simplify the interpretation of the pattern which is obtained.

When it is indicated that the trouble lies in the audio channel, this channel may be further investigated with the cathode-ray oscillograph by using an audio sine-wave signal and by tracing this signal through the audio system. For trouble shooting the audio channel, an audio oscillator which is fully capable of producing signals at the high and low extremes of the audio range is required, since the a-f channel must be tested for both low- and high-frequency response. The general procedure for trouble shooting the audio channel is to compare the input signal from the signal generator to the output signal of each successive amplifier stage for amplification and fidelity. Faults can be isolated to a particular stage in this manner and the defect readily located. A closer check on amplifier performance may be accomplished with an electronic switch or with a double-beam cathode-ray tube in either of which cases both input and output signal can be compared or superposed on the screen of a single cathode-ray tube.

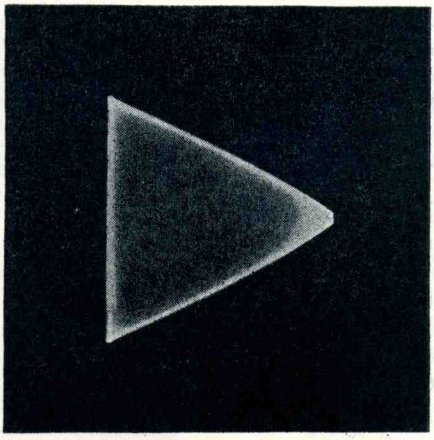

FIGURE 17

Trapezoidal Pattern Showing
100% Modulated Carrier Wave

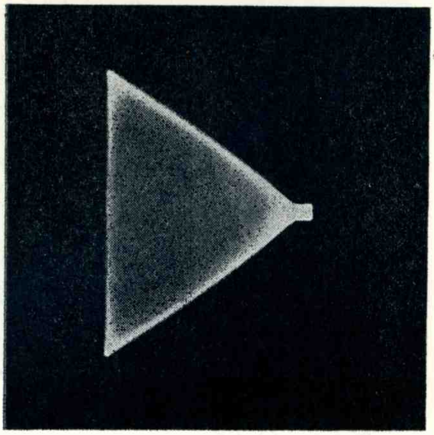

FIGURE 18

Trapezoidal Pattern Showing Over-modulated Carrier Wave

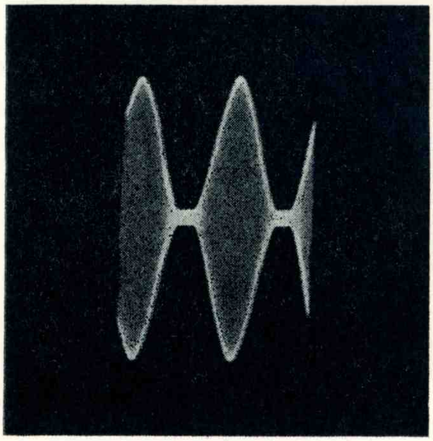

FIGURE 19

Modulated-Wave Pattern Showing Overmodulated Carrier

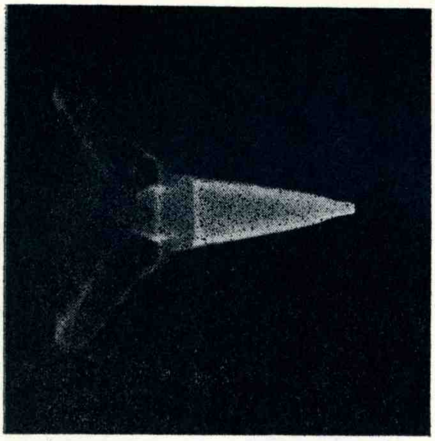

FIGURE 20

Trapezoidal Pattern Showing:

1. Phase Distortion Due to Incorrect Pick Up of Signals
2. Overmodulation
3. Parasitic Oscillations Caused by Incorrect Neutralization of Output Stage of Transmitter

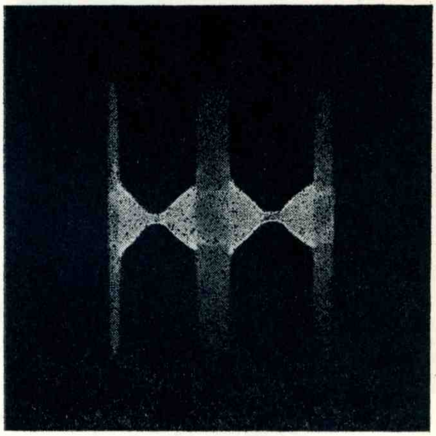

FIGURE 21

Modulated-Wave Pattern Showing:

1. Overmodulation
2. Parasitic Oscillations Caused by Incorrect Neutralization of Output Stage of Transmitter

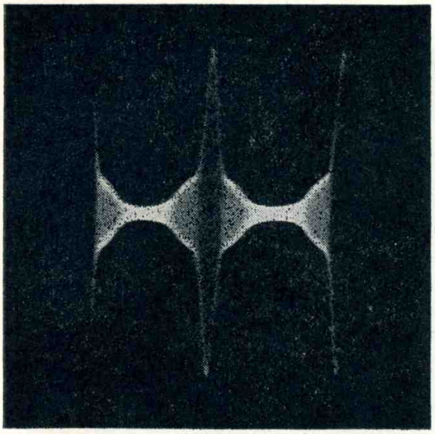

FIGURE 22
Modulated-Wave Pattern Showing:
1. Excessive Grid Bias of Output Stage of Transmitter
2. Incorrect Neutralization of Output Stage of Transmitter
3. Overmodulation

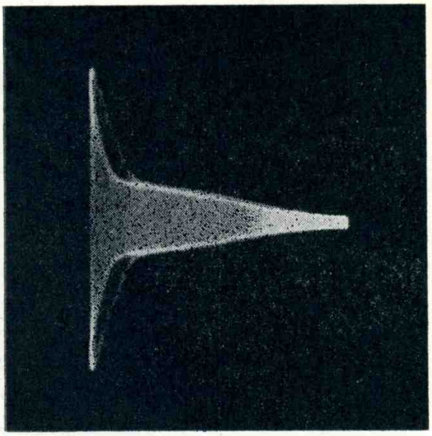

FIGURE 23
Trapezoidal Pattern Showing:
1. Excessive Grid Bias of Output Stage of Transmitter
2. Overmodulation
3. Incorrect Neutralization of Output Stage of Transmitter
4. Phase Distortion Due to Incorrect Pick Up of Signals

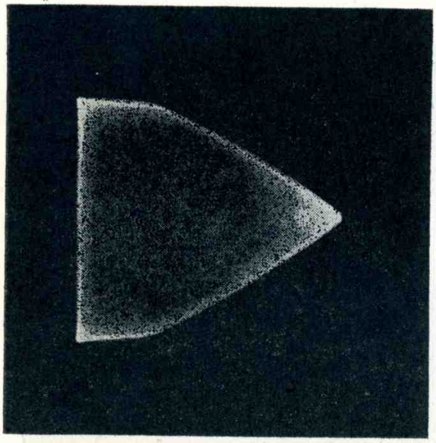

FIGURE 24
Trapezoidal Pattern Showing:
1. Insufficient Excitation of Output Stage of Transmitter
2. 100% Modulation

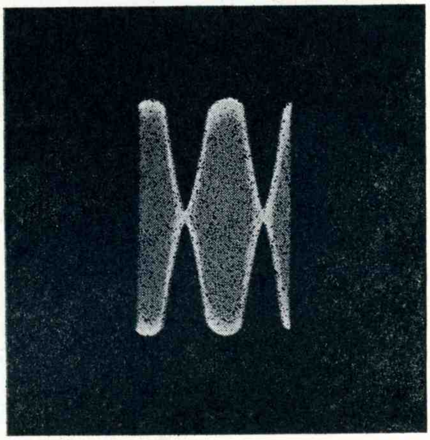

FIGURE 25
Modulated-Wave Pattern Showing:
1. Insufficient Excitation of Output Stage of Transmitter
2. 100% Modulation

CONCLUSION

The cathode-ray oscillograph is indeed an important supplement to existing instruments for adjustment and control of radio transmitting equipment. The patterns which appear on the screen of the cathode-ray tube will serve as useful indicators for tuning, neutralizing, monitoring and trouble shooting the transmitter.

The methods for aligning the r-f channel and neutralizing r-f stages of a transmitter by using the unmodu-

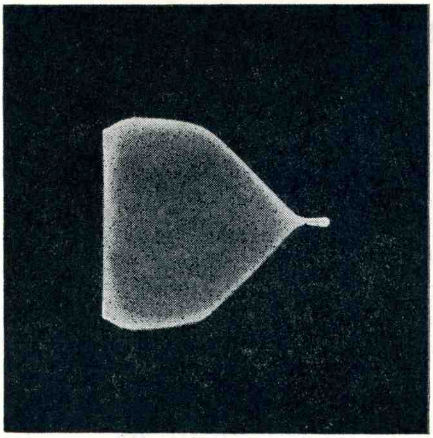

FIGURE 26
Trapezoidal Pattern Showing:
1. Insufficient Excitation of Output Stage of Transmitter
2. Overmodulation

lated wave pattern and the Lissajous pattern as indicators are extremely accurate and simple. Monitoring overall performance of a transmitter, by means of a cathode-ray oscillograph, particularly modulation monitoring, appears in many respects superior to other methods. The use of a cathode-ray oscillograph for servicing and maintaining a radio transmitter can

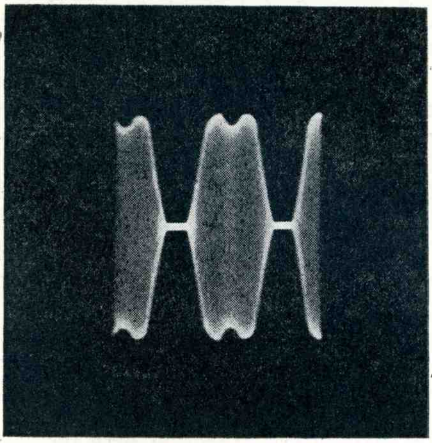

FIGURE 27
Modulated-Wave Pattern Showing:
1. Insufficient Excitation of Output Stage of Transmitter
2. Overmodulation

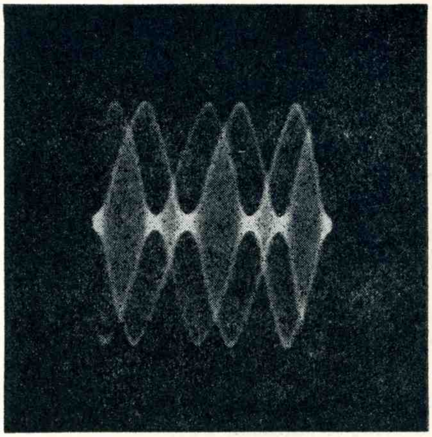

FIGURE 28
Modulated-Wave Pattern Showing:
1. 100% Modulation
2. Incorrect Setting of Oscillograph Time-Base Generator Controls

be developed into a fast, effective method which permits the operator to locate faults by tracing waveforms.

THE DU MONT TYPE 213-A MODULATION MONITOR

The Allen B. Du Mont Laboratories, Inc., has developed a special-purpose cathode-ray oscillograph for use with radio transmitter equipment. The instrument is known as the Type 213-A Modulation Monitor. The Type 213-A has a multi-band, tuned tank circuit which is connected in parallel with the Y-axis deflection plates of its cathode-ray tube to produce substantially uniform Y-axis frequency response from 400kc to 40 mc. The unit is also provided with a co-axial, shielded, six-foot cable to which a pick-up loop may be connected.

The type of indication may be shifted quickly from a modulated-wave pattern to a trapezoidal pattern by operating a single switch, for speed in operating with the proper input signal coupled to the terminals.

The Type 213-A is housed in a steel case with black wrinkle finish. The weight of the instrument is forty-five pounds. The dimensions are: 14-1/4″ high x 8-13/16″ wide x 19-1/2″ deep. The cathode-ray tube is a Type 5LP1 which is operated at 2000 volts accelerating potential.

SIMULTANEOUS PRESENTATION OF TWO SIGNALS

A very interesting application using instruments that have two free vertical deflection plates is to combine two signals for simultaneous presentation. The independently connected deflection plates of this type of oscillograph are extremely valuable when it is required to measure the time duration of the signal being presented, or to examine the time relationship between two related signals.

When it is required, for example, to measure the time duration of a signal, the signal under observation is fed into the vertical amplifier and the timing signal from a signal generator may be connected to one of the vertical deflection plates (either D_3 or D_4 on the Type 208-B oscillograph). Of course, the overall gain of the vertical amplifiers will be reduced by 50%, since one side of the final push-pull amplifier is rendered inoperative. However, since most instruments have sufficient gain, this is not a serious drawback. Figure 1 illustrates the connections for this application. Capacitors "C_1 and C_2" (Figure 1) are large enough to pass the timing signal without attenuation, and the resistor R_9 acts to provide both a d-c return for the deflection plate and full positioning voltage. If the signal generator is a square-wave generator, then the combination C_1 R_9 (Figure 1) can be made a differentiating circuit to produce sharp pulses on the screen.

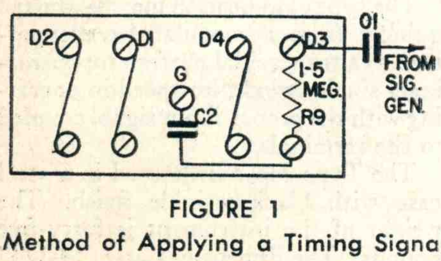

FIGURE 1

Method of Applying a Timing Signal to One Vertical Deflection Plate

To examine the time relationship between two signals the same procedure as in the previous case is used, but the application is not limited to placing one of the signals through the vertical amplifier. The illustration given in Figure 2 shows the method of connecting both of these related signals

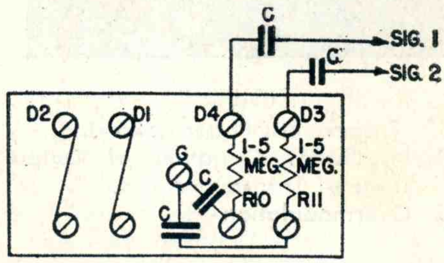

FIGURE 2

Method of Applying Two Related Signals Directly to the Deflection Plates

directly to the deflection plates. As in the previous examples, capacitors "C" (Figure 2) are large enough for adequate a-c by-pass and resistors R_{10} and R_{11} act to provide a d-c return and to connect the internal positioning circuits of the instrument to the deflection plates.

The presentation on the screen of the cathode-ray tube for both of the special cases just mentioned will be the algebraic sum of the two signal components. Neither signal will appear in its true form, but rather the presentation will be a point by point addition (taking into account relative polarity and amplitude of the signals). Often this will not be objectionable but discretion must be used in interpreting the results. Also, it must be pointed out that although this method of combination through direct deflection may be able to replace an electronic switch in some applications, this is not always the case.