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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also

IN THIS ISSUE

THE NOISE PRIMER

PART VI

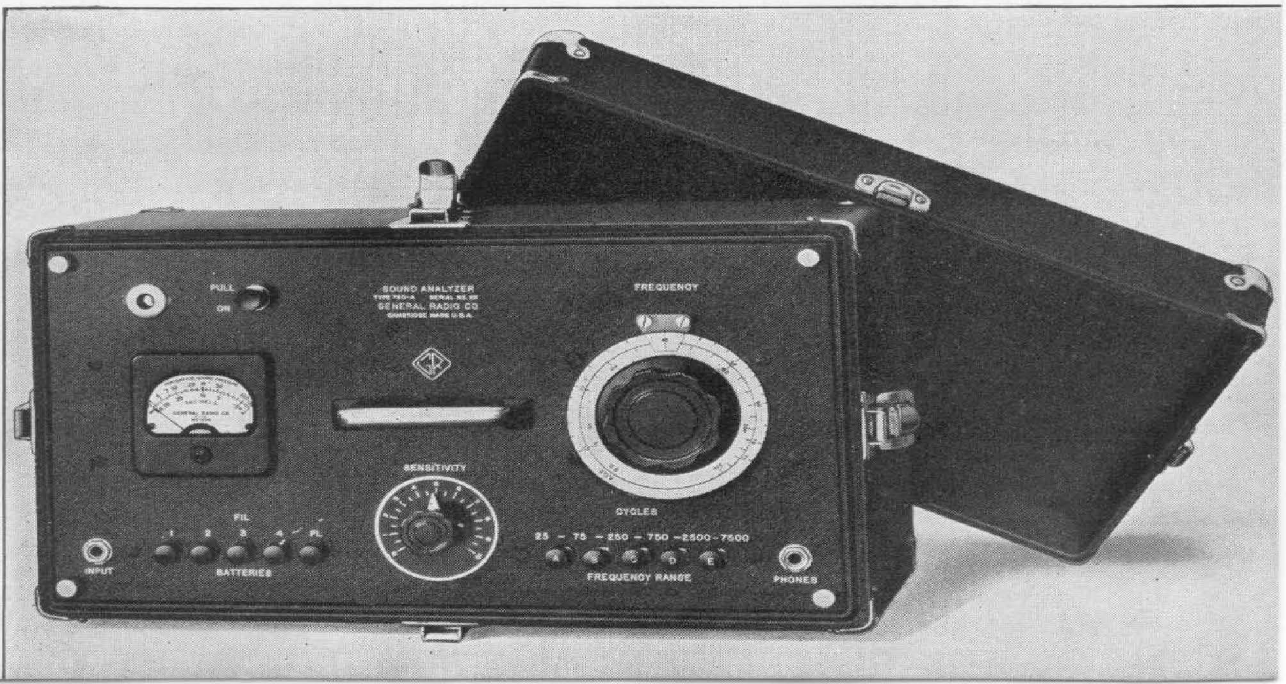
ANALYSIS OF NOISE

Why Analysis?

The sound-level meter measures only weighted or unweighted sound pressure. For a more complete description of the sound, measurements involving pitch and quality are also needed. The usual mathematical concept of a complex sound or vibration is based upon the Fourier system of analysis, which divides any complex waveform into a series of sinusoidal, or pure, waveforms of different pitch or frequency and of definite amplitude and phase relationship. Each of these sinusoidal waveforms contributes to both the loudness and the quality of the sound.

In general, what the ear recognizes as pitch is the frequency of the lowest-frequency sinusoidal component in the complex waveform. The higher-frequency components are generally, but not always, harmonics

Figure 12. View of the Type 760-A Sound Analyzer with cover removed.



(that is, integral multiples) of this frequency, and determine the quality or timbre of the sound.

For instance, steady-state notes of the same pitch, but played upon different musical instruments, have the same fundamental frequency and differ only in their harmonic structure or overtones. Similarly, two noises of the same intensity and the same pitch may vary appreciably in the annoyance they cause because of different harmonic makeup or "quality."

A sound analyzer measures the amplitude of each individual frequency component.[15] For steady-state sounds, therefore, measurement of level with the sound-level meter and analysis of harmonic structure with the sound analyzer give a substantially complete description of the sound itself. There are other characteristics which may affect slightly the quality of a sound, but for general purposes it may be said that two steady-state noises of the same level and harmonic structure will sound alike.

The analyzer shows clearly why different kinds of musical instruments playing the same note do not sound alike. Each has its characteristic timbre, which depends upon the resonances of the instrument itself.

Similarly, the noise generated by any mechanical device depends upon its own resonances. The sound produced by a machine includes not only a fundamental frequency, depending generally upon the machine's speed, but also many other components of higher frequencies, usually determined by the various resonant frequencies of the machine parts and structural elements. Many of these resonances are calculable[16] or measurable by various methods. Hence an analysis of the noise will provide many clues to the source of the various components. When the source of the noise is found, the problem is half solved. Often relatively simple modifications will entirely eliminate the noise.

Therefore a sound analysis is useful for two important reasons. In the first place, it provides definite information, which can be recorded for later reference, as to the makeup of the sound. In the second place, the sources of the sound can be identified through their corresponding frequency components, so that definite steps can be taken to reduce the sound through proper redesign of the mechanism.

Classification of Noises

Machinery noises may be divided roughly into two classes. The first includes the fundamental frequency at which the machine is operating and various harmonics thereof, as well as any other components which vary in frequency proportionally with the fundamental. Sounds of this class are generally characterized by the harmonic relationship between the various components and are characteristic of most types of rotating or reciprocating mechanisms, particularly those operating at high speeds. These are the noises commonly referred to as "pitched."

The second class of noises contains those components which are *not* definitely related in frequency to the fundamental speed of the machine. These vibrations are generally caused by shock excitation at the machine fundamental speed or some harmonic of it. They produce a series of damped waves whose components correspond to the natural frequency or harmonics of the vibrating

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[15] Except under unusual conditions the phase of the components does not affect the ear and hence is unimportant for purposes of noise measurement.

[16] For instance, see J. P. Den Hartog, "Mechanical Vibrations," published by McGraw-Hill, 1940; S. Timoshenko, "Vibration Problems in Engineering," Van Nostrand, 1937; I. B. Crandall, "Theory of Vibrating Systems and Sound," Van Nostrand, 1926.

parts, rather than to the machine speed or its harmonics.

The actual frequencies involved in such sounds are seldom clearly defined, since the effects of shock excitation, the natural damping of mechanical parts, the movement of the parts, and the variation of forces impressed upon them cause appreciable frequency variations. Such sounds are commonly referred to as "unpitched" and include rattles, buzzes, and similar noises. Their sound energy is generally spread over bands of frequencies rather than being confined to discrete frequencies.

The noise of most machines contains both pitched and unpitched components, but usually most of the important sound energy falls into one class or the other. For example, the whine of a dynamo is almost entirely a pitched sound in Class 1. A typewriter, on the other hand, produces noise almost entirely through shock excitation, and hence this noise is an unpitched sound, falling into Class 2.

Unpitched sounds, except in those few cases such as the typewriter, are characteristic mainly of machines which are poorly designed or in poor repair. The presence of strong Class 2 components in the noise produced by a machine to which they are not characteristic is generally an indication of trouble.

Analyzer Characteristics

It is well known that the ease with which a frequency-selective electric circuit can be adjusted to resonance with any particular signal component depends upon the steadiness of pitch of that component. Fluctuation, or frequency modulation, of the pitch beyond the band width of the selective circuit produces an attenuation of the response dependent upon the type and extent of the frequency modulation and upon the characteristics of the selective circuit.[17]

Most users of sound-measuring and -analyzing equipment are in agreement that in the ideal noise analyzer the band width of the selectivity curve should be proportional to the frequency to which the device is tuned. For Class 1 sounds this will provide the minimum error, since any attenuation caused by frequency modulation of the sound will be equal for all components, and they will then be measured in their true relative proportions.

For Class 2 sounds it is obviously more difficult to determine the ideal selectivity characteristic, but the constant-percentage type, which widens out in band width proportionally as the frequency is increased, is far more suitable for measuring the unpitched components than an analyzer with razor-sharp selectivity in the high-frequency region. The degenerative type of sound analyzer which has inherently a constant-percen-

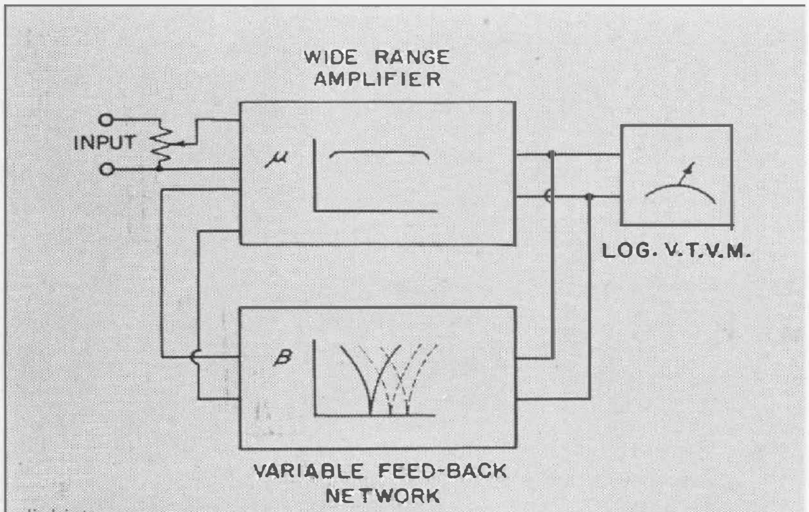

FIGURE 13. Functional block diagram showing the operation of the TYPE 760-A Sound Analyzer. It consists of a high gain amplifier and a frequency-selective feedback network, so designed that the feedback is degenerative at all frequencies except that to which the network is tuned.

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[17] From the mathematical standpoint, frequency modulation produces side bands, just as amplitude modulation does. In frequency modulation strong side bands cover a band width equal to the total frequency swing. These side bands, however, are spaced apart in the frequency spectrum by intervals equal to the modulation frequency, which in machinery sound and vibration problems is generally very low, so that the side bands cannot be measured separately with any practical analyzer now available.

tage band width characteristic,[18] has been developed for noise analysis and is generally better adapted for that purpose than the many modifications of heterodyne and other types of analyzers which are also in use. Figure 13 shows the principle of operation of the degenerative-type analyzer.

The General Radio TYPE 760-A Sound Analyzer[19] is of the degenerative type and, because of its unusual circuit, it is both inexpensive and easily portable. Because of the absence of inductances in the design of this instrument and the complete electrostatic shielding of the case, this instrument is quite unaffected by ordinary electromagnetic and electrostatic fields.

Where a heterodyne-type analyzer, such as the General Radio TYPE 736-A is available, it also can be used for noise analysis of sounds where the pitch is constant and no important unpitched components are present. Where new equipment is to be purchased, however, the TYPE 760-A Noise Analyzer is recommended because of its greater general usefulness and the lesser possibility of error.

The following instructions apply to the TYPE 760-A Noise Analyzer.

PART VII—HOW TO USE THE SOUND ANALYZER

Relative Readings

The TYPE 760-A Noise Analyzer is completely self-contained and operated from dry batteries. No battery adjustments are required. Push buttons and a neon lamp on the panel indicate whether or not the batteries have sufficient voltage for satisfactory operation. Complete instructions covering testing and replacement of the batteries will be found in the cover of the instrument.

The analyzer is tuned by means of the large knob and the row of push buttons beneath it. The buttons select the particular frequency range and the knob provides tuning over that range. The calibration is direct reading in cycles per second and may be converted to rpm by multiplying by 60.

To analyze a sound, connect the input of the analyzer to the output of the sound-level meter by means of the cord

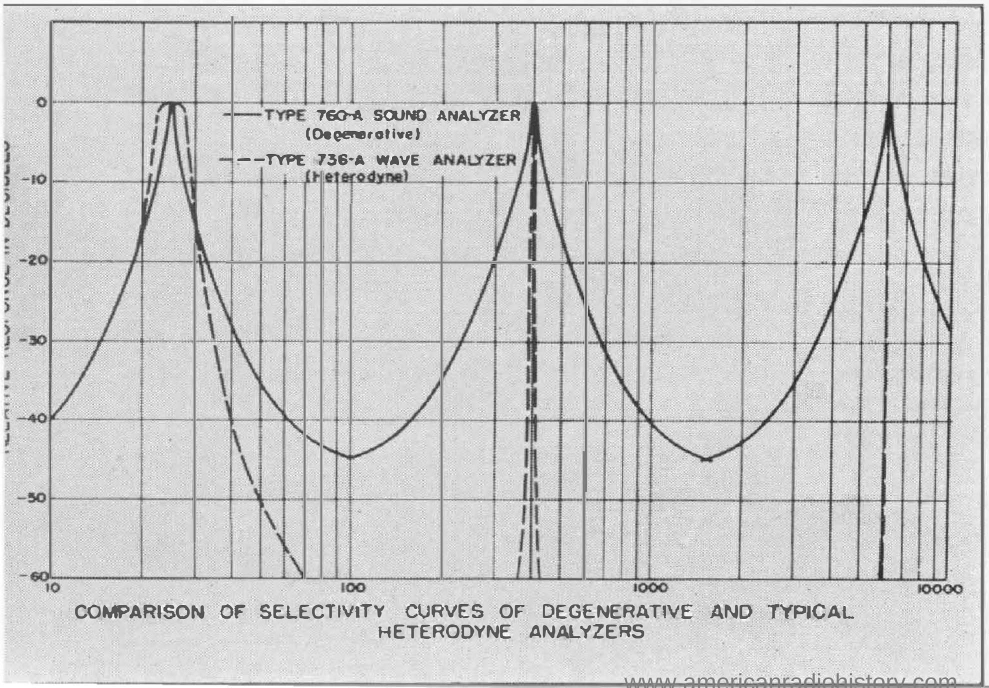

FIGURE 14. Comparison of the selectivity curves of a degenerative and a heterodyne analyzer. The degenerative analyzer, because of its constant percentage selectivity, is to be preferred for noise analysis.

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[18] The theory of this circuit was described in "A New Type of Selective Circuit and Some Applications," by H. H. Scott, Proc. I.R.E., Vol. 26, No. 2, February, 1938.

[19] This analyzer was described in "The Degenerative Sound Analyzer" by H. H. Scott, The Journal of the Acoustical Society of America, Vol. 11, No. 2, October, 1939; also "An Analyzer for Noise Measurement," *General Radio Experimenter*, February, 1939.

provided. Both instruments should be turned on. The level of the sound which strikes the microphone will be indicated directly on the meter on the panel of the sound-level meter. This reading is the total sound pressure. Press Button A on the sound analyzer, which selects the 25-to-75-cycle range, and turn the main dial slowly from 25 to 75 cycles, noting the deflections of the meter on the sound analyzer. Repeat this process, covering the entire range of the instrument by successively depressing Buttons B, C, D, and E and turning the dial around. The instrument is so constructed that the dial may be rotated continuously in one direction, thus facilitating rapid scanning of the entire frequency range.

During this process the sensitivity control of the analyzer should be turned down whenever a component is found which deflects the meter above the 100% (0 db) point, so that the meter reads exactly at this point. This sets the sensitivity such that the analyzer will read 100% on the loudest component in the sound. *Do not change the setting of this control before the analysis is completed.* The analyzer should then be carefully tuned for maximum amplitude on each component (without touching the sensitivity control) and the results recorded. This provides an analysis directly in terms of the loudest component, which is generally, but not always, the fundamental.

The sensitivity control on the analyzer is intended only for use in making the initial setting and it should not be used as a multiplier for the meter or to extend the scale of the meter

The vacuum-tube voltmeter circuit is so arranged as to provide a semi-logarithmic scale characteristic, in order that components varying in amplitude over a range exceeding 40 db may be read directly from the scale, and with an accuracy proportional to the importance of the components. That is, the strongest components are read with the highest degree of accuracy. The meter is equipped with two scales, one in decibels and one in percentage of full scale, so that measurements may be made in whatever units are most convenient to the operator. The accuracy of the voltmeter calibration is maintained by means of a neon ballast tube.

The analyzer is equipped with an output jack for operating a pair of phones, thus allowing the user to listen directly to the particular component being measured. The semi-logarithmic characteristic of the tube voltmeter circuit provides an automatic volume control effect at the phones output jack, thus avoiding the possibility of acoustic shock to the operator.[20]

Absolute Readings

Relative readings are generally sufficient for practical analyses, but if it is desired to have the readings in terms of the absolute sound level rather than referred to the strongest component, proceed as follows:

Plug the sound-level meter into an alternating-current power line and adjust all controls as when calibrating. This will provide a deflection on the indicating meter of approximately +5.

Connect the analyzer to the sound-level meter, tune the analyzer to the power-line frequency and adjust the SENSITIVITY control so that the indicating meter on the analyzer reads 10 db lower than that on the sound-level meter. For instance, if the sound meter reads +5 the analyzer meter should read —5. *Do not readjust the SENSITIVITY control further.* The dial may

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[20] Because of these avc characteristics, the output at the phones jack is not a pure sine wave, but it is adequate for all listening purposes.

be marked with a pencil to show the proper setting, if desired.

Disconnect the sound-level meter from the power line and adjust the DECIBELS control of the sound-level meter for normal measurement of the sound with the indicating meter showing a deflection between 0 and 10 (except, of course, for levels below 30 db). The analyzer may then be tuned to each individual component in the normal manner. Do not change the setting of the sensitivity control on the analyzer. The absolute level of each component will be indicated directly by the algebraic sum of the setting of the DECIBELS switch on the sound-level meter and the decibels reading of the indicating meter on the analyzer, plus 10 db. The DECIBELS switch on the sound-level meter should not be used to increase the deflection of the meter on the analyzer on low amplitude components since this would overload the output circuits of the sound-level meter and cause distortion.

Choice of Network

Before making an analysis one decision must be made. Which is desired—a measurement of the amount which each component contributes to the sound as heard by the ear, or a direct physical measurement of the relative intensity of each component? If the first is desired, the same weighting curve should be used as when measuring the noise with the meter alone. If a direct physical measurement is desired, however, the C curve (flat) should always be used.

—H. H. SCOTT

(To be continued)

METHODS OF OBTAINING LOW DISTORTIONS AT HIGH MODULATION LEVELS

● **UNDISTORTED SIGNALS** at high modulation levels are sometimes quite useful in the laboratory for testing purposes, but distortionless output is not easily obtained from low-powered testing equipment. In general, these devices tend to produce appreciable distortion when operated at high modulation levels.

With standard-signal generators, there are two convenient methods by means of which low distortion at high modulation levels can be obtained. These are described below, together with their application to the TYPE 805-A Standard-Signal Generator.

(a) Carrier Amplitude Reduction

If a modulated r-f voltage be combined in the proper manner with an unmodulated r-f voltage of the same carrier frequency but of opposite phase, the resultant output will have a higher percentage modulation and lower amplitude than the original. Thus it may be seen that, starting with a source of modulated carrier-frequency voltage of relatively low modulation distortion, and reducing the amplitude of the carrier component, it is possible to increase the percentage modulation with no increase in modulation distortion.

When the TYPE 805-A Standard-Signal Generator is operated at 50% modulation, the modulation distortion is very small. Using this instrument as a source of modulated carrier frequency, it is merely necessary to provide two linear r-f amplifiers and to operate their output circuits in parallel and 180 degrees out of phase. Since it is necessary to obtain unmodulated r-f voltage from the signal generator, one of the linear r-f amplifiers must be directly coupled to the r-f oscillator in the Type 805-A, but through an isolating impedance (Z_1) in order to avoid reaction on the oscillator frequency. The second r-f amplifier may be connected directly to the output terminals of the signal generator. This system is shown in schematic form at the lower right of Figure 1.

There are several precautions to be observed if satisfactory results are to be obtained with this system. The two r-f amplifiers should be identical in construction and have very nearly the same phase shift. Because exact phase balance cannot be conveniently obtained unless a variable element is introduced into one of the r-f amplifiers, some such means of adjustment should be provided. Control of the amplitude of either or both amplifiers provides a means of adjusting the percentage modulation at the output of the system. It is also quite important to isolate the two r-f amplifiers to prevent cross-modulation between them, which would tend to introduce distortion and, under certain conditions, would prevent a symmetrically modulated wave from being obtained. The inability to adjust the modulation to 100%, without clipping negative modulation peaks, is another indication of trouble of this sort.

Further circuit precautions involve the use of a voltage-regulated supply, especially on those units which do not have internally regulated power supplies. This has been found necessary in order that the voltage and phase balance of the system be maintained within the degree of accuracy required.

A suitable means for determining the exact percentage modulation level when operating in the vicinity of 100% is desirable. Any of the conventional methods employing a cathode-ray oscillograph could be used. It is quite difficult to determine, with any degree of accuracy, the exact point at which 100% modulation is reached, however, and some form of an indicating meter seems more useful. The Type 726-A Vacuum-Tube Voltmeter has proved to be quite convenient for this purpose. When used in low impedance circuits at voltage levels above 15 volts, the peak-response characteristics of this instrument are excellent.[1]

A Type 805-A Standard-Signal Generator, used as a source of modulated

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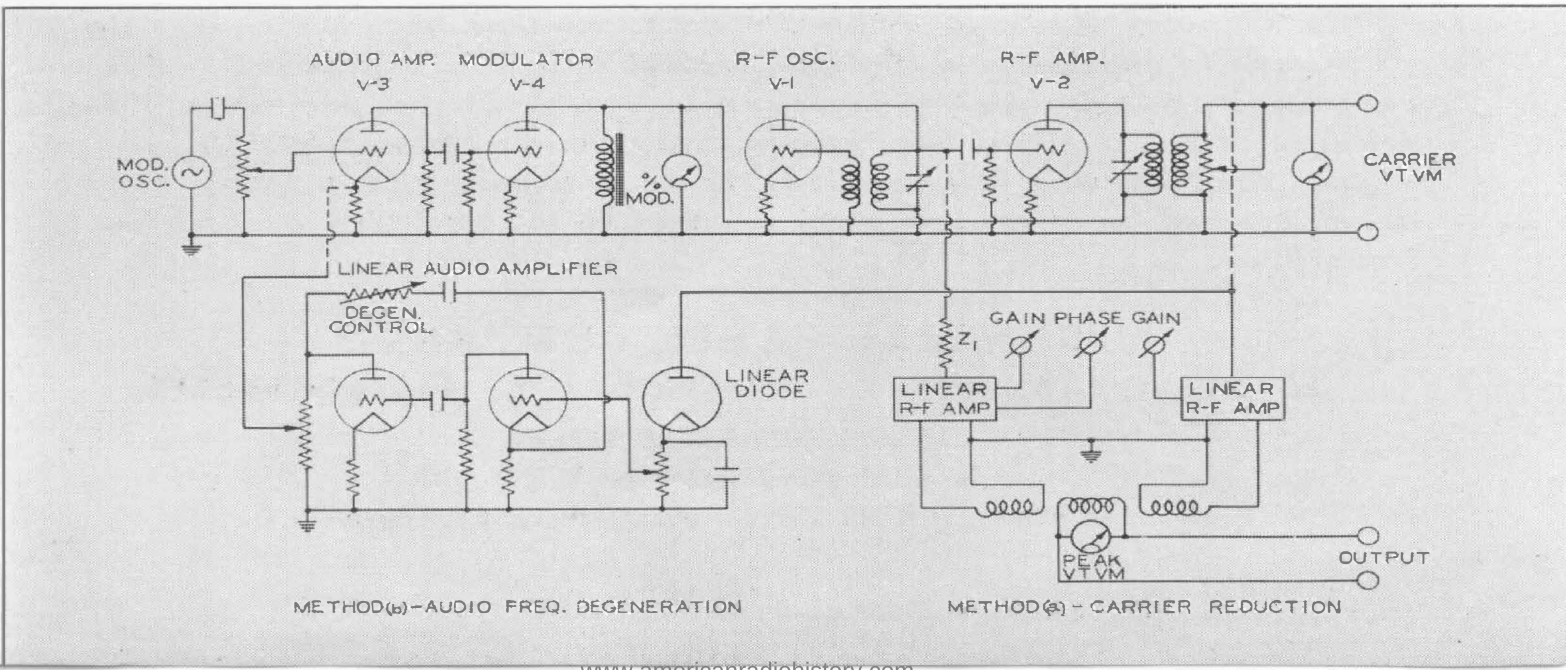
[1] The Type 726-A Vacuum-Tube Voltmeter will indicate peak amplitudes of repetitive transients, provided the peak amplitude is maintained for at least .001 of the period. The scale readings should be multiplied by 1.4 to obtain true peak values.

Figure 1. Schematic diagram showing both methods of reducing distortion as applied to the Type 805-A Standard-Signal Generator. The signal generator is shown at the top of the diagram. Below, at the right, is the carrier reduction system; at the left, the audio-frequency degeneration system.



carrier frequency to drive the two amplifiers, has resulted in measurements as low as ½% modulation distortion at 100% modulation. The tests were made at carrier frequencies between 500 and 2000 kc and at modulation frequencies of 50 to 7500 cycles. The instrument was externally modulated, using a TYPE 608-A Oscillator as a source of audio frequencies of very low distortion.

(b) Audio-Frequency Degeneration

If distortion of the order of 1½% can be tolerated, a considerably simpler method than that described above can be used. This system, which is used in broadcast transmitters, is based on inverse feedback of the modulating frequency as it appears in the envelope of the output voltage. The modulated output of the generator is rectified in a linear detector and the audio-frequency components are then amplified and degeneratively coupled to the internal modulating amplifier of the signal generator. This results in a reduction of both the amplitude and the distortion of the modulation or side-band components. Loss in amplitude may be compensated for by increasing the output from the modulating oscillator.

The arrangement at the lower left of the schematic diagram of Figure 1 shows how this system can be used with the TYPE 805-A Standard-Signal Generator. In this circuit it is desirable to operate the diode at the maximum voltage obtainable from the instrument. Connecting the diode to the output system, directly ahead of the output control, will work satisfactorily with little or no reaction upon the internal r-f amplifier. Sufficient voltage to operate the diode on the linear portion of its characteristic will be obtained on all but the highest frequency range of the instrument. A suitable non-distorting audio-frequency amplifier should be coupled to the diode and used to provide the necessary feedback voltage. This, for convenience, may consist of a single duo-triode tube. The output of this linear amplifier should be coupled into the cathode circuit of V-3 in the TYPE 805-A. For proper operation, the linear audio-frequency amplifier should be provided with means of controlling the output amplitude, and the amount of local degeneration, which should be adjusted for minimum distortion. Best results are obtained by modulating the TYPE 805-A from an external audio oscillator of good waveform, such as the TYPE 608-A.

—C. A. CADY

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