THE General Radio EXPERIMENTER

VOLUME XXVI No. 4 SEPTEMBER, 1951

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

AN OCTAVE-BAND ANALYZER FOR NOISE MEASUREMENTS

● **MODERN INVESTIGATIONS** in the field of noise measurements have shown the need for frequency analyses of the noise spectra. Problems that require calculation of the loudness or the speech interference of noise, the determination of the effect of manufacturing variations on product noise, the use of noise measurements to detect faulty operation in machinery, or the identification of sources of noise to aid in quieting can best be solved by using analyzers with the sound-level meter.

Over-all sound levels alone are an inadequate indication of the effect of complex noise on the hearing mechanism and on the ability of people to converse. Most sounds of a complex type impress the listener as interfering with his speech and hearing only when the intensity of the noise is high in the frequency range between about 500 and 5000 cycles per second. Similarly, studies of aviators' and boilermakers' deafness reveal that sounds in that frequency range cause the most damage.

Figure 1. View of the Type 1550-A Octave-Band Noise Analyzer with cover removed to show panel.

In buildings, on the other hand, noises which have traveled through partitions are in large part shorn of their higher-frequency components. The annoying effects of these sounds must frequently be judged by the intensity in the frequency range below 1000 cycles per second.

The acoustical engineer requires more information than simply the over-all noise level if he is to select acoustical materials, or if he is to design acoustical mufflers for reducing the noise of machinery and ventilating systems. He also needs to know the spectra of noises in vehicles if he is to isolate one type of noise from another, say, to isolate wind noise from engine noise.

The examples just cited show the necessity for knowing the distribution of intensities of a complex noise as a function of frequency. For some years, the General Radio Company has supplied the Type 760-B Sound Analyzer for determining in detail the spectrum of a complex noise. Having an effective band width of slightly more than three per cent, that instrument, continuously adjustable in frequency, effectively divides the frequency spectrum between 25 and 7500 cps into 180 separate bands, in each of which the intensity of the noise may be determined. Analysis in such detail as provided by the 760-B Sound Analyzer is often necessary when resonances in a device are being sought, or when the intensities of the several harmonic components of a sound with a low-frequency fundamental are desired. For many applications, however, much less detail is desired than is given by an instrument with the equivalent of 180 bands.

In response to the demand for an analyzer with fewer bands, the General Radio Type 1550-A Octave-Band Noise Analyzer has been developed. It divides the frequency range from 20 to 10,000 cps into eight bands so that the analysis is relatively simple. Yet it is sufficient in the great majority of cases to provide the information needed to solve the problems mentioned above.

This new portable instrument, pictured in Figure 1, combines versatility with superior filter characteristics. In addition to the filter set, as shown in the simplified schematic of Figure 2, it consists of an amplifier, an indicating meter, and a portable battery supply. The complete assembly, including batteries, weighs only 27 pounds. This design makes it possible for the user to connect the instrument, without concern over the availability of 60-cycle power, to the output of a sound-level meter, a magnetic-tape recorder, or any other source of audio-frequency signal. Furthermore, for economy in laboratory or plant use, the cabinet has been made large enough so that the battery can be replaced by a Type 1261-A A-C Power Supply.

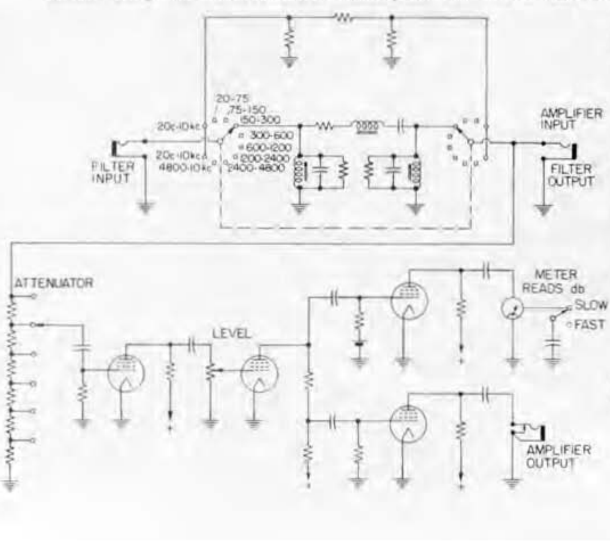

Figure 2. Elementary schematic circuit diagram of the analyzer.

FILTER DESIGN AND CHARACTERISTICS

The filter assembly itself is small and light in weight, with excellent selectivity characteristics. This combination is a result of taking advantage of design by modern filter theory. Good selectivity is not difficult to obtain by ordinary filter design, but the resulting filter is heavy, large, and expensive, because the inductors must have low losses. To avoid this excessive weight, the filter in the octave-band analyzer has been designed on an insertion-loss basis, rather than by the characteristic-impedance method.

A complete analysis of the effects of the loss in all the inductor elements showed that the desired filter could be obtained with all inductors having a Q (reactance-to-resistance ratio) less than 8, with a moderate insertion-loss in the pass band. This low Q made it possible to use small "postage-stamp" inductors, tapped for more than one range, without spoiling the filter characteristic because of high losses. Typical filter characteristics are shown in Figure 3.

The filter set has pass bands with the following nominal cut-off frequencies:

20 c — 75 c (low pass)
75 c — 150 c
150 c — 300 c
300 c — 600 c
600 c — 1200 c
1200 c — 2400 c
2400 c — 4800 c
4800 c — 10,000 c (high pass)

The six middle bands are an octave in width, and the other two are a low-pass and a high-pass filter. These eight bands has been found particularly useful for noise analysis, and they are standard in many applications. A straight-through or over-all connection is provided in addition to the eight filter bands.

The band-pass sections have an initial rate of attenuation beyond cut-off of about 50 decibels per octave of frequency. This high initial rate is important when the measured noises have energy levels that change rapidly as a function of frequency. When such a noise has appreciable energy extending over a wide-frequency range, the high level of over 50-decibels attenuation attained in this filter set at frequencies well beyond cut-off is also important. Without these features, the analysis of many noises encountered in practice would be seriously in error.

The filter is isolated by a resistance pad. This pad makes the filter characteristics essentially independent of the source used to supply the analyzer, provided the source impedance is constant over the audio-frequency range, or small compared to the 20,000-ohm input impedance of the analyzer.

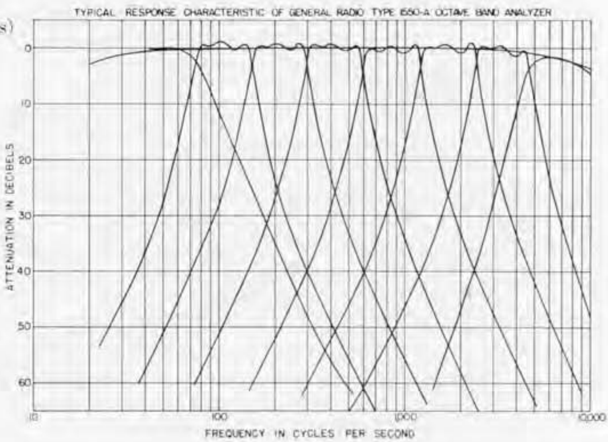

Figure 3. Typical response characteristic of the Type 1550-A Octave-Band Noise Analyzer.

MEASURING AND OUTPUT SYSTEM

The attenuator, amplifier, and indicating meter permit one to measure octave-band levels over a range of about 60 decibels. The attenuator is calibrated in 10-db steps from 0 to 50 db, and the indicating meter provides a range from −6 to +10 db. The amplifier compensates for the pass-band insertion loss of the filters and provides more than 50-db additional gain to obtain a meter reading for the 50-db range. A level control is provided to set the gain of the amplifier to the desired value.

In order to use the full range of analysis provided, an input level of about one volt is required across the 20,000-ohm input impedance of the analyzer. This level is readily supplied by the Type 1551-A[1] and Type 759-B Sound-Level Meters. Levels below one volt can be used with a correspondingly reduced range of analysis. Higher voltages can also be used, but above 10 volts the characteristics of the low-frequency filter changes with signal level and the amplifier may be overloaded.

Any amplifier or sound-level meter that is used to supply the input to the analyzer should be operated so that it introduces very little distortion, noise, or hum into the amplified signal. Any of these added effects will lead to incorrect results in analysis. The extent of the error will depend on the relative level of these added components. For example, a hum level 60 to 70 db below the total signal level is very satisfactory. Some sound-level meters have an inherently poor signal-to-noise ratio over much of the range, while others introduce appreciable distortion. The Type 1551-A[1] and Type 759-B Sound-level Meters are inherently superior in these respects, and are recommended for supplying the signal for analysis.

For the analysis of high-level sounds, the analyzer can frequently be connected directly to the output of a microphone system. The Type 759-P25 Dynamic Microphone[2] Assembly is a suitable type of microphone for the range from 70 to 140 db, and an Altec-Lansing Type M 11 Microphone System is another type suitable at levels from 60 to 135 db. A crystal microphone is not satisfactory for connection directly to the analyzer because its capacitance source impedance will lead to a response that increases with frequency over most of the audio range. For a particular microphone of known sensitivity, one can compute the level at which an analysis can be made, thus determining whether or not the simple combination of a microphone system and analyzer will be satisfactory for a given application. When the Type 759-P25 Dynamic Microphone Assembly is used, the absolute level can be set by the Type 1552-A Acoustic Calibrator.[3]

[1] To be described in a forthcoming issue of *Experimenter*.

[2] "A Dynamic Microphone for the Sound-Level Meter," *Experimenter*, April, 1951.

[3] E. E. Gross, "An Acoustic Calibrator for the Sound-Level Meter," *Experimenter*, December, 1949.

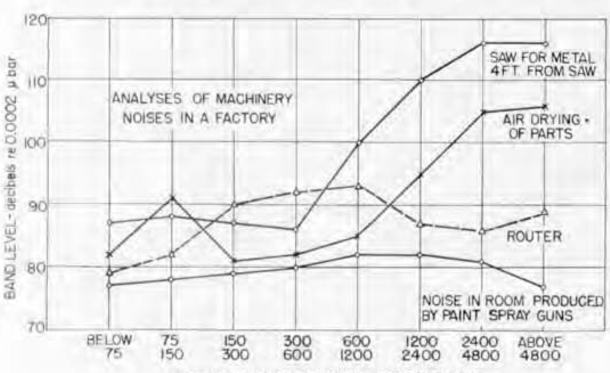

Figure 4. Octave-Band frequency analysis of noise produced by machines in a factory.

A separate, low-distortion monitoring output is provided for supplying a signal to a recorder or for listening to the filtered signal. It can also be used to supply a signal to a narrow-band analyzer, such as the General Radio Type 760-B Sound Analyzer, when more complete analysis within one band is desired, and when the selectivity provided by the octave-band noise analyzer is necessary to reduce strong interfering components to a low value.

EXAMPLES OF USE

Some problems that require analysis have been mentioned briefly in the introduction. For example, a value of loudness can be calculated from the results of an octave-band analysis.[4] This value will agree, in general, with subjective estimates much better than a value calculated from the reading of a sound-level meter.

Some further typical examples of the many possible uses of this instrument are given below.

ANALYSIS OF MACHINERY NOISE AND EAR PROTECTION

The General Radio Type 1550-A Octave-Band Noise Analyzer is particularly useful in measuring the noise spectra of many types of industrial machinery. Examples of noise spectra measured in a large factory are shown in Figure 4. From these data the management concluded that ear protection was required for operators of the air drying equipment and metal saws; that ear protection was desirable for operators of routers; and that ear protection was not required for operators of paint spray guns.

A comprehensive study of the deafening effects of noise has recently been made by Kryter.[5] His study has lead to tentative limits on levels that confirm the conclusions above.

ANALYSIS OF VEHICLE NOISE

Cities are showing an increased interest in the noise made by vehicles such as elevated trains, electric and steam trains, buses, automobiles, and motorcycles. Recent studies of noise in Chicago have used the octave-band method of analyzing vehicle noise.[6] Typical results of their measurements are shown in Figure 5. The data for this figure were measured at a distance of 20 feet from the vehicles.

ANALYSIS OF OFFICE NOISE

Forward-looking corporations are becoming increasingly aware of the advantages of satisfactorily low noise en-

[4]Leo L. Beranek, "Acoustic Measurements," New York, John Wiley & Sons, Inc., 1949, pp. 524-526, and Leo L. Beranek, J. L. Marshall, A. L. Cudworth, and A. P. G. Peterson, "Calculation and Measurement of the Loudness of Sounds," *Journal Acoustical Society of America*, Vol. 23, N. 3, May, 1951, pp. 261-269.

[5]Karl D. Kryter, "The Effects of Noise on Man," *Journal of Speech and Hearing Disorders*, Monograph Supplement 1, September, 1950.

[6]G. L. Bonvallet, "Levels and Spectra of Transportation Vehicle Noise," *Journal* Acoustical Society of America, Vol. 22, N. 2, March, 1951, pp. 201-205.

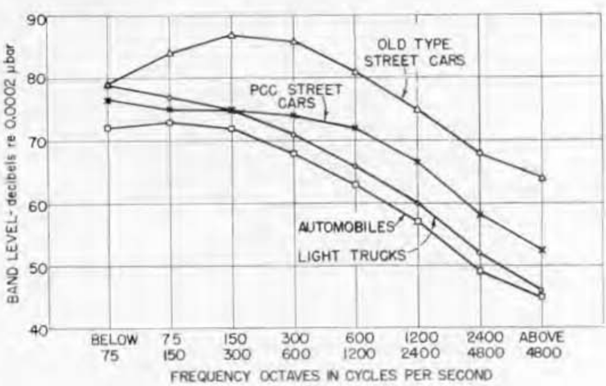

Figure 5. Results of analysis of vehicle noise made with an octave-band analyzer at a distance of 20 feet from the vehicles.

vironments for their employees. With charts made available recently, it is possible to measure the noise levels in offices using the General Radio Type 1550-A Octave-Band Noise Analyzer and to rate the office noise on an appropriate rating scale.[7] The procedure is to take a simple average of the noise levels in the 600-1200, 1200-2400, and 2400-4800-cps bands. This quantity is called the *speech-interference level*. Transformation from the speech-interference level to a rating of the noise condition in the office is possible with the aid of Figure 6.

ANALYSIS OF AIRCRAFT NOISE

The increased use of airplanes for long-distance travel by the general public has made the problem of noise in airplanes particularly important. Army-Navy specifications today require that aircraft noise be measured with an instrument possessing octave filter bands having the same cutoff frequencies as the General Radio Type 1550-A Octave-Band Noise Analyzer. In airplanes (and also in offices), the speech-interference level is a reasonable measure of the noisiness of the various compartments.[8] The relationship between the ability of passengers to converse at various voice levels and distances as a function of speech-interference level is shown in Table I.

[7] Leo L. Beranek and R. B. Newman, "Speech-Interference Levels as Criteria for Rating Background Noise in Offices," presented at June 22, 1950, Meeting of Acoustical Society of America, State College, Pa.

TABLE I

MAXIMUM VALUES OF SPEECH-INTERFERENCE LEVELS OF NOISE FOR WHICH ENTIRELY RELIABLE SPEECH INTELLIGIBILITY WILL BE OBTAINED FOR AVERAGE VOICES AND HEARING.

	Voice Level			
Distance ft.	*Normal*	*Raised*	*Very Loud*	*Shouting*
0.5	71	77	83	89
1	65	71	77	83
2	59	65	71	77
3	55	61	67	73
4	53	59	65	71
5	51	57	63	69
6	49	55	61	67
12	43	49	55	61

DETERMINATION OF ACOUSTICAL CHARACTERISTICS OF STRUCTURES

The sound-transmission loss of building walls, partitions, and floors is determinable in the field at eight points along the frequency scale with the octave-band analyzer, a sound-level meter, and a source of sound which produces either a random noise, an explosive sound, or a warble tone.

[8] Leo L. Beranek and H. Wayne Rudnose, "Sound Control in Airplanes," *Journal* Acoustical Society of America, Vol. 19, N. 2, March, 1947, pp. 357-364, and L. L. Beranek, "Airplane Quieting II—Specification of Acceptable Noise Levels," *Trans.* A.S.M.E., Vol. 69, February, 1947, pp. 97-100.

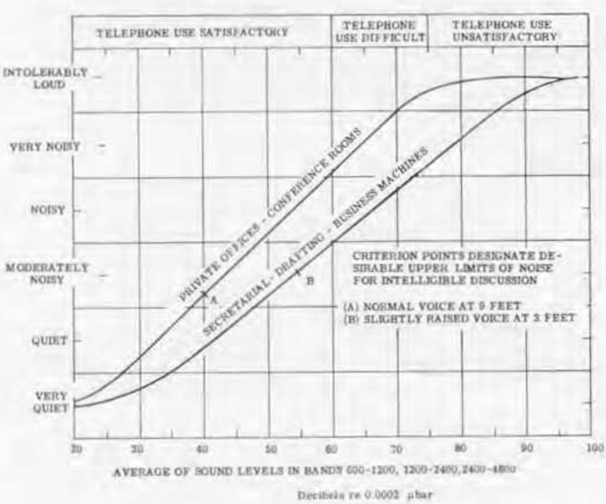

Figure 6. Rating chart for office noises. Data were determined by an octave-band analysis and correlated with subjective tests. (Courtesy Beranek and Newman.)

OTHER USES

These examples serve to show the variety of applications that can be handled in the field of noise analysis. The TYPE 1550-A Octave-Band Noise Analyzer, however, is not restricted to that field. It has been found useful as a selective bridge detector, particularly when used with headphones in the monitoring output. It can be used as a filter set for purposes other than analysis, for example, sound effects and speech studies. To increase further the general usefulness of the instrument, phone jacks are provided so that the amplifier or the filter can be used alone for various types of laboratory measurements.

— A. P. G. PETERSON

SPECIFICATIONS

Range: 20 cycles to 10,000 cycles in 8 bands:

20 c to 75 c (low pass)	600 c to 1200 c
75 c to 150 c	1200 c to 2400 c
150 c to 300 c	2400 c to 4800 c
300 c to 600 c	4800 c to 10,000 c (high pass)

In addition, a band with a flat characteristic from 20 c to 10 kc is available at two switch positions for convenience in calibration against the sound-level meter.

Input Level: Between 1 and 10 volts for normal range. Levels below one volt reduce the range of reading; those higher than 10 volts overload the filters.

Input Impedance: 20,000 ohms. Input is isolated by a resistance pad, so that performance is independent of source if source impedance is constant over audio range or is small compared to 20,000 ohms.

Source: Sound-level meter supplying analyzer input must have low hum, low internal noise, and low distortion. The TYPE 1551-A or the the TYPE 759-B Sound-Level Meter is recommended.

Direct Use with Microphone: TYPE 759-P25 Dynamic Microphone is recommended if the band levels exceed 70 db.

Level Indication: Meter calibrated in decibels from −6 to +10 db; attenuator covers 50 db in 10 db steps. Level is sum of meter and attenuator readings.

Attenuation: Except for the lowest and highest bands, at least 30-db attenuation is obtained at one-half the lower nominal cutoff frequency and twice the upper nominal cutoff frequency; at least 50-db attenuation is obtained at one-fourth the lower nominal cutoff frequency and at four times the upper nominal cutoff frequency. The 75-cycle low-pass filter has at least 30-db attenuation at 200 c and 50 db at 400 cycles. The 4800-cycle high-pass filter has at least 30-db attenuation at 2400 cycles and 50 db at 1200 cycles.

Tubes: Three 1U4 and one 1T4, all furnished.

Power Supply: Battery, Burgess 6TA60. Battery is included in price. For a-c operation, TYPE 1261-A Power Supply fits battery compartment.

Accessories Supplied: Shielded cable and plug assembly for connecting analyzer to sound-level meter.

Dimensions: (Width) 11⅝ x (height) 12$\frac{9}{16}$ x (depth) 9 inches, overall.

Net Weight: 27 pounds including battery.

Type		*Code Word*	*Price*
1550-A	**Octave-Band Noise Analyzer**	ABEAM	**$535.00**
	Replacement Battery for above	ABEAMADBAT	**5.79**
1261-A	**A-C Power Supply**	NUTTY	**120.00**

SERVICE DEPARTMENT NOTES

Our Service Department is now in a position to supply information on the modification of the following instruments to accommodate newer and more satisfactory vacuum tubes. More complete details will be forwarded upon request.

TYPE 1861-A MEGOHMMETER — Currently available 85 tubes do not operate satisfactorily because of high grid current. The 6AU6 tube can be substituted, but other changes are necessary.

TYPE 561-D VACUUM-TUBE BRIDGE—This bridge can be adapted to making measurements on noval tubes. Also, more complete shielding can be installed to eliminate spurious oscillation when tubes of high transconductance are being measured.

TYPE 805-C STANDARD SIGNAL GENERATOR—Stability of the output meter can be improved by replacing the 955 tube with a 6AU6 and making certain wiring changes.

When writing always mention the type and serial numbers of the instruments for which information is requested.

MISCELLANY

NEW PLANT UNIT IN CONCORD—Construction has been started by the General Radio Company on a new plant unit in the town of Concord, Massachusetts, to provide the additional manufacturing facilities necessitated by the nation's defense and rearmament program. The new plant will be a modern three-story brick-faced structure of 72,000 square feet and will provide facilities for about two hundred employees.

The executive offices and main manufacturing plant will continue to be at 275 Massachusetts Avenue, Cambridge. Present space at the Cambridge plant is about 145,000 square feet, with approximately 500 employees.

CREDITS—The Type 1550-A Octave-Band Noise Analyzer was developed by Dr. Arnold P. G. Peterson, author of the article appearing in this issue. Credit is also due to Dr. Leo L. Beranek, of M.I.T., consultant in the development, to Mr. Corwin Crosby for the mechanical design, and to Mr. Robert J. Ruplenas, who performed much of the experimental work on the circuit development.

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