

AN AUTOMATIC AUDIO-FREQUENCY GRAPHIC RECORDER*

A. D. MACLEOD**

In designing and engineering equipment to be used for recording and reproducing speech and music there are many different problems. Of these, the most neglected is the measurement of the electrical to mechanical translation. It is quite common to find a radio set manufacturer, for example, who produces a large number of receivers, testing and checking them as far as the voice-coil of the reproducer, but neglecting the acoustical measurements of the cone. Sound-pressure measurements that are made are, in general, rather limited. In reality, these measurements are of great importance to the manufacturer, as acoustical fidelity is probably an important factor in the public's acceptance of a receiver. Perhaps the reason why more acoustical measurements are not made is that the time involved is too great. It was this problem that prompted development of the *Audi-O-Graph* (Fig. 1), a self-contained unit that enables an overall fidelity curve to be taken in approximately two minutes.

After setting up the tentative design features, it was found advisable to make the equipment adaptable to as many kinds of audio-frequency measurements as possible without limiting its usefulness for specific service. The result was a unit that could be used for comparing loud speakers, microphones, audio amplifiers, and filters. It was found necessary, for the radio manufacturers, to include a small signal generator which could be modulated over the audio spectrum to obtain an overall curve without tying up the use of a standard signal generator. The unit, from a production engineering standpoint, is extremely valuable, as changes in any part of a particular system can be readily checked for comparison with the original set-up. Although it is possible to make all the measurements mentioned above by other methods, the time required for setting up the apparatus is usually as great as that required to make the measurements.

There has long been a need for an instrument that would record transmission level in some permanent form, while automatically sweeping the audio spectrum. The art is well acquainted with motor-driven oscillators and hand-operated recorders, but automatic curve-tracers, while used in a few laboratories, have not been generally found satisfactory. Various methods have been tried, but most of them possess disadvantages that overbalance any possible advantage from the standpoint of automatic recording.

The problem was to develop a recorder that would handle changes up to 40 db. per second, produce a permanent ink record, be of rugged construction, and sweep the audio spectrum while recording the level of the system under test. The components of the complete unit should consist of an audio oscillator, a microphone amplifier, a rectifier-control amplifier, and recorder of the control-motor-driven type.

* Presented at the Spring, 1937, Meeting at Hollywood, Calif.; received June 10, 1937.

** Tobe Deutschmann Corp., Canton, Mass.

OSCILLATOR

The audio oscillator was designed so that two separate tuning condensers would be used for manual and automatic control, switching from one to the other as desired. The condenser for automatic control is fastened directly to the shaft of the recording drum. The plates are so shaped that the low frequencies up to 100 cps. are spread out on the curve sheet, and above 100 cps. the scale is approximately logarithmic. This arrangement shows the cone resonance of a loud speaker readily, and allows comparison of the finished curve with any standard curve of the log-scale type. Fig. 2 shows a typical curve. Since the instrument was to cover a number of applications it was necessary to provide output impedances in several steps, from 50 to 5000 ohms, selected by a switch. A small oscilloscope is provided in the unit for checking the frequency against the 60-cycle supply.

The output level of the oscillator was held fairly low, because the increased output tube capacity and the associated power supply developed more heat, which increased the problem of stability in the beat-frequency oscillator. De-

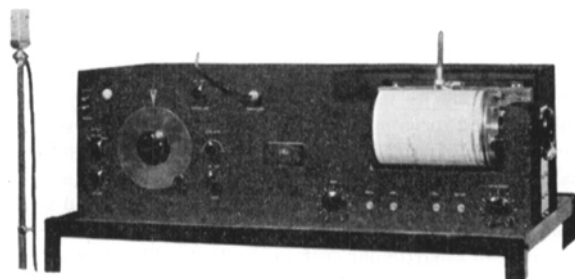


FIG. 1 The *Audi-O-Graph*.

generation in the audio amplifier was found necessary to hold the level within $\frac{1}{2}$ db. over the recording range of 30 to 12,000 cps.

MICROPHONE AMPLIFIER

The amplifier used to produce sufficient gain to operate the control tubes of the recorder is more or less of the conventional design, using high-gain pentode stages, resistance-coupled and heavily by-passed. The amplifier contains also any compensation necessary for the microphone used in sound pressure measurements. A manually operated, calibrated attenuator, having 20 steps of 2 db. each, is connected in the grid circuit of the second stage. This controls the deflection of the recorder arm to position the graph upon the paper. The automatic attenuator of the recorder is connected in the grid circuit of the last stage, and controls the input to the rectifier-control amplifier, holding it to a constant value. As this type of amplifier and recorder-control produces amplitude variations that are linear with decibel changes of the input, it was not necessary to resort to the logarithmic type of amplifier as used with linear-voltage recording systems. For the range covered by the *Audi-O-Graph* a logarithmic amplifier would be complex and necessitate considerable adjustment at each set-up.

RECTIFIER

The problem of rectifying the audio input to the recorder was found to be very interesting and more complex than was anticipated when work was first begun. We soon learned that if the rectifier output were to be filtered to any great extent, the recording speed of the pen would be greatly reduced. At that stage of the development it became necessary to ascertain the required recording speed of the various systems that the unit was to measure. A large number of speaker curves, taken by the Bostwick method and carefully checked, revealed that a speed of 15 db. per second would cover all transitions in speaker curves. After a number of measurements on audio amplifiers and filters it was found that at 25 db. per second one could plot the curve of practically any system that might be encountered. As work progressed on the recorder, speeds up to 40 db. per second were found to be reasonable and accurate enough to be retraced several times with a deviation of less than one step of the attenuator, which in the case of the audio unit is 0.5

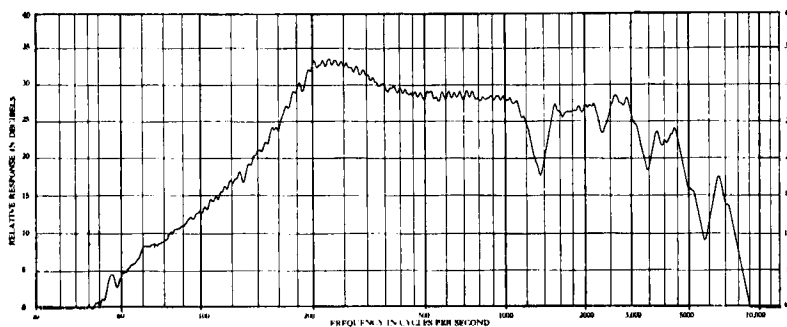


FIG. 2. Curve of 6-inch permanent-magnet dynamic loud speaker, taken at high speed.

db. Using full-wave rectification enabled us to produce a filter for the double-frequency component that would remove the chatter from the dynamic relay and still allow maximum recording speed. The output of the rectifier was fed through an elaborate filter system to a high-conversion d-c. amplifier operating the dynamic relay.

RECORDER

The first step in designing the recorder was to decide the size of the graph sheet. Shortly after work was started upon the recorder it was found that the greater the length of the sheet could be made the more accurately changes could be recorded. The length finally decided upon was one that would fold double into a standard $8\frac{1}{2} \times 11$ -inch binder. The length of the sheet determined the diameter of the recording drum. The recording drum was found to be more convenient for audio measurements than a continuous feed, as it made it possible to calibrate the graph in terms of frequency and to record upon the same sheet as many as six different curves in differently colored inks so that comparisons could be made.

After checking all the available recorders it was decided that we should eliminate the meter and the magnetic clutch types of movement, and, finally, the only type that remained for development was the controlled-motor type.

It was then found necessary only to choose an actuating switch and motor that would operate within the limits set by our previously determined recording speed.

From the first, a dynamic relay has been used for controlling the drive motor. Many attempts were made to discard this unit only to find that it presented the most durable and readily adjustable switch that could be obtained. In earlier experiments the recorder drive motor was of the universal type with two series fields, the direction of rotation being determined by the position in which the dynamic relay operated.

Again we learned that the recording speed was determined by the braking and coasting of the motor after cessation of excitation. The final choice settled down to a two-phase induction motor with dynamic braking, which enabled uniform

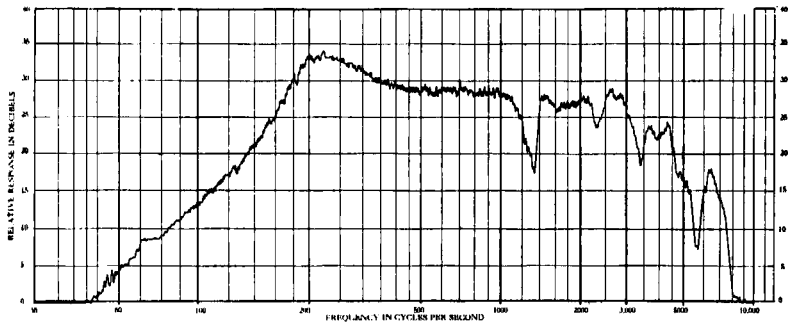


FIG. 3. Same as Fig. 2, taken more slowly.

integration at any level. The two-phase motor is operated from the single-phase line, the second phase being supplied by a condenser. The latter phase determines the rotation of the motor and when both windings are connected to the same phase dynamic braking takes place.

The pen arm also carries the attenuator arm which operates in the microphone amplifier to balance the control system. The final choice for the drum drive motor was a series type of motor with a field speed control. This was found to be most convenient, and running a quick curve to determine the general trend of the system, it was found that the accuracy of the trace could be improved by a longer recording period. Fig. 2 is a curve of a 6-inch permanent-magnet dynamic loud speaker run at high speed, while Fig. 3 is a curve on the same unit taken more slowly. The completed recorder was then supplied with switches that would cut the power supply when the curve was finished. After the recorder was completed it became obvious at once that a complete unit that would contain the beat-frequency oscillator, the microphone amplifier, the audio rectifier, the recorder control, and the recorder and associated power supplies would provide a unit that would permit running practically any audio curve automatically.

DISCUSSION

The following is a discussion held jointly of five papers presented at the Convention of the Society at Hollywood, Calif., on May 25, 1937, constituting a symposium on transmission meters and including the following papers:

"A Transmission-Measuring System Utilizing a Graphic Recording Meter"; W. W. Lindsay, Jr.

"A New Instrument for Producing Automatically a Graphic Record of Audio-Frequency Characteristics"; A. D. MacLeod

"A Continuous Level Recorder for Routine Studio and Theater Measurements"; G. M. Sprague and J. K. Hilliard

"A Curve-Plotting Transmission Meter"; L. A. Aicholtz

"A Curve-Plotting Transmission Meter"; L. D. Grignon

The first paper, that by W. W. Lindsay, Jr., was published in the July issue of the Journal; the four other papers appear in this issue immediately preceding this discussion.

MR. SKINNER: Has anything been done about using photographic methods in this work? I have done some work of that sort, but did not have an amplifier that would produce a logarithmic scale. I have used a three-element oscillograph, one element of which recorded the input; another element recorded the frequencies shown on the dial; and a third made the curve of the equipment, all photographed simultaneously on a piece of bromide paper. A loud speaker could be measured in seven seconds. The method was described in *J. A. I. E. E.* in 1929. There was no possibility, however, of completing the run before the formation of a standing wave.

MR. HAWKINS: Since many tests are routine, has anyone thought of using for such tests the cathode-ray oscilloscope with a wide-range warble? The whole spectrum would be covered in a twenty-fourth of a second, and a suitable sweep circuit could fix the curve upon the screen of the oscilloscope. That would enable a simple positive or negative report as to whether the circuit were satisfactory. If satisfactory, you could go over the curves with a slow-speed machine, perhaps a hand-operated set, of sufficient accuracy to find out where the trouble lay.

Another point relates to the matter of obtaining a logarithmic scale from a linear function by using two dissimilar tubes in parallel, to produce either characteristic required. I was able to get a fairly accurate logarithmic scale over a range of 40 db. by using two 6C6 pentodes in parallel, with different screen voltages, which, of course, gave each of the tubes a different amplification factor.

MR. HILLIARD: Another method of making loud speaker acoustic measurements is to impress the output from the loud speaker upon a light-valve. By rotating the oscillator at a very fast rate the effect of standing waves is reduced. That seems to be a very logical method, as it is not necessary to use a warble tone.

MR. TASKER: It should be noted, as mentioned by one of the speakers, that when the oscillator is changing frequency rapidly, frequency modulations are present and there is a tendency to get a false result.

MR. SKINNER: In agreement with that statement, when we took only the seven seconds to check the standing waves, the loud speaker runs were made under a condition in which there were no standing waves. However, fast methods of testing a speaker are of interest in finding out whether the speaker will respond.

MR. TASKER: It might be interesting to know the relative speeds of the several instruments described. With the Deutschmann device something like 50 seconds were required—

MR. LINDSAY: Sixty seconds for a complete run.

MR. SPRAGUE: Thirty-five seconds.

MR. AICHOLTZ: Exactly 60 seconds.

MR. GRIGNON: Seventy-five seconds.

MR. TASKER: The figures vary considerably, but are somewhere around a minute. What are the input levels to the recording meter amplifiers at full-scale deflection?

MR. LINDSAY: Plus 10 db. for the full scale.

MR. MACLEOD: Minus 85 db. for the full scale of the instrument.

MR. SPRAGUE: Plus 10 db. for full-scale deflection without amplification, and -92 db. with amplifiers included in the unit.

MR. AICHOLTZ: Minus 13 at full-scale deflection.

MR. GRIGNON: Under normal conditions, ± 6 db. for the maximum level on the linear portion of the scale.

MR. POWERS: I think it was said that it might be desirable to keep permanent records of the test of overall peaks of each shot made. Have any of these instruments been used for that purpose?

MR. LINDSAY: We made some records of that sort, and found them useful under certain conditions. However, we do not generally make them.

MR. HAWKINS: I had occasion to be associated with the construction of apparatus for recording the peaks and checking the mixing, and we electrically counted the peaks of 90 per cent modulation with a peak relay. Another measured the time during which the modulation was in excess of 35 per cent to give an estimate of the time in which there were no signal peaks present.