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ELECTRICAL COMMUNICATIONS TECHNIQUE
AND ITS APPLICATIONS IN ALLIED FIELDS

WAVEFORM ERRORS IN THE MEASUREMENT OF FILTER CHARACTERISTICS

ENGINEERS whose work includes the design and manufacture of electric wave filters have often been concerned with the discrepancy that appears to exist between the calculated and actual performance. Given reasonably good data about the characteristics of the coils and condensers that are used, the frequency characteristics of a filter can usually be predicted fairly accurately, yet seemingly careful measurement often indicates a marked difference between the design data and the manufactured product.

While nearly all communication engineers are aware that waveform distortion in the power source will influence the measured characteristic of a filter, few take the trouble to make an actual calculation of how serious such errors may become.

Two of the usual circuits for observing filter characteristics are illustrated in Figure 1. With either method, the output voltage of the oscillator, which

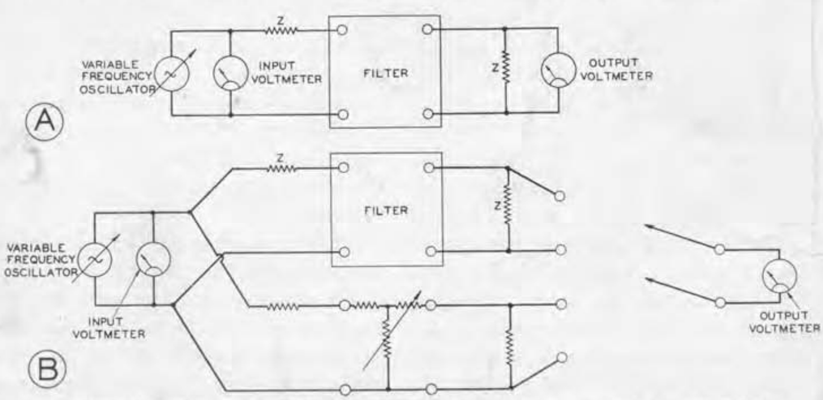

FIGURE 1. Schematic diagram of circuits for measuring wave filter characteristics

is usually kept constant, is applied to the filter through a resistance equal to the characteristic impedance of the filter. The filter is terminated in a second resistance of the same value, across which the output voltage is measured. Generally an amplifier preceding the output voltmeter is required, because the voltage after being attenuated by the filter is too low for direct measurement by voltmeters of ordinary

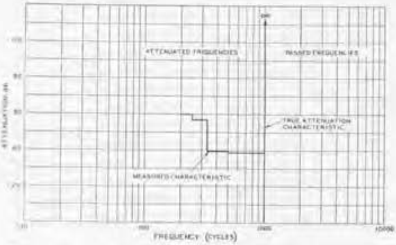

FIGURE 2. Error in measured characteristic of high-pass filter due to distortion in the power source

sensitivity. The loss is either read directly from the meter readings with the amplifier gain known, as in A, or a loss equal to the filter loss at the various frequencies is set up in a parallel variable attenuation network, and the losses balanced for equality by the method B. The latter circuit has the advantage that the gain of the amplifier need not be known for this comparison method. The impedance of the voltmeter or amplifier (if one is used) must, of course, be high with respect to the resistor Z.

If the output voltmeter has a uniform frequency characteristic (as with copper-oxide-rectifier or vacuum-tube types), trouble will occur when measuring band-elimination, band-pass, or high-pass filters. When a-c hum is present in the power source or is picked up in the circuit, even low-pass types may appear to possess characteristics which differ widely from those indicated by the calculated data.

A graphic illustration of the error of measurement of a high-pass filter is shown in Figure 2. An ideal high-pass filter with a cut-off at 1000 cycles is assumed. It eliminates entirely all frequencies below cut-off and passes without attenuation frequencies above cut-off. The power source in this case is a representative beat-frequency type of vacuum-tube oscillator which has relatively good waveform. The amplitudes of its harmonic components referred to the fundamental are as follows: second harmonic, 0.316% (–50 db), third harmonic, 1.0% (–40 db), fourth harmonic, 0.1% (–60 db), and fifth harmonic, 0.1% (–60 db) or a total distortion of about 1.06%.

At a measuring frequency of 200 cycles the fifth harmonic, or 1000 cycles, just falls in the passed band and is read on the output voltmeter. At 250 cycles the fourth appears, adding to the fifth, and so on up to the second, at 500 cycles. The result is the apparent attenuation curve shown by the heavy line.

So great a discrepancy between actual and measured performance cannot exist, because the ideal high-pass filter chosen for this example cannot be realized, but the better the filter the more pronounced the error will become.

With a low-pass filter, this error does not occur because the harmonics of the power source are attenuated in the filter by a greater amount than the fundamental frequency, but another error can occur if power line hum frequencies which lie below the cut-off frequency are present in the measuring circuit. For instance, when measuring a 1000-cycle, low-pass filter, one would expect a continually rising attenuation with increasing frequency above 1000 cycles. Actually, however, the attenuation would never exceed the r.m.s. level of the hum frequencies, all of which pass through the filter unattenuated. The discrepancy between actual and measured characteristics under such conditions can be very considerable. If the hum voltage amplitude is only one per cent of the amplitude of the power source, the measured attenuation cannot exceed a maximum of 40 db (one-hundredth of the amplitude of the measuring frequency). An r.m.s. output voltmeter has no means for distinguishing between measuring frequencies and extraneous hum.

Figure 3 is a comparison of the true characteristic of a band-pass filter with that obtained using the representative beat-frequency oscillator and r.m.s. output meter mentioned in the discussion of high-pass filter measurements. The accurate curve was obtained by a method described later, which eliminates the effects of the distorted waveform of the power source. The solid line represents the true attenuation curve, and the dotted curve is the indicated attenuation characteristic. The presence of the fifth harmonic, which is the highest one of any appreciable amplitude, shows up by the deviation of the measured from the true characteristic at a frequency of 200 cycles. The third harmonic has the greatest amplitude of all (1%). Thus at 333 cycles a big dip occurs in the measured characteristic as the third harmonic of 333 cycles falls in the passed band.

There are three methods that can be used to reduce the errors caused by power source harmonics:

(1) Improving the waveform of the a-c power source.

(2) Utilizing filters between the power source and the measuring circuit to reduce the harmonics to a negligible level.

(3) Using a tuned or selective output voltmeter, that is, one which responds to only *one* frequency at a time.

Vacuum-tube oscillators are universally used for the power source. The difficulty of reducing the harmonic content of their waveform below one, two, or three per cent is well known to anyone who has attempted it, therefore the method (1) above is impracticable. Of course, if the filter being examined has a maximum attenuation of only 20 db (10:1 ratio between

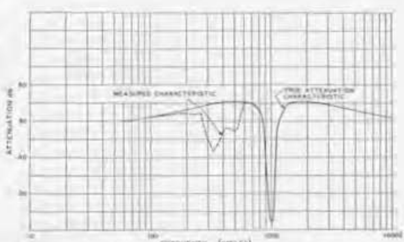

FIGURE 3. Error in measured characteristic of band-pass filter due to distortion in the power source

passed and cut-off frequencies), a three per cent harmonic will not bother the measurements seriously. Most wave filters, however, have a higher attenuation ratio than this, and too frequently vacuum-tube oscillators have much more than three per cent of harmonics.

Method (2), while often used, has

several practical disadvantages, principally that suitable filters for use with the power source are not always available, and, for a wide frequency range, they become too numerous and bulky to be handled conveniently.

Method (3) is, therefore, by far the most useful. If the measuring voltmeter is sufficiently sharply tuned so that it will respond only to the desired frequency, eliminating all others, and if its frequency response range is variable over wide limits, it will prevent the errors caused by harmonics and will still be flexible enough for making most audio-frequency measurements.

The TYPE 636-A Wave Analyzer* has these characteristics. Briefly, this instrument functions on the heterodyne principle. It has an internal variable-frequency oscillator covering the range from 34,000 to 50,000 cycles per second. The impressed voltage under measurement is heterodyned with the internal oscillator, which is set to the proper frequency so that the upper side band of the combined frequencies is 50,000 cycles. This fixed side-band frequency is passed through a two-stage quartz crystal filter of high selectivity. The internal or local oscillator is varied over its frequency range by means of a single large dial which is calibrated in terms of the frequency under measurement, *i.e.*, 16,000 to 0 cycles. The selectivity is so great that a frequency of only 30 cycles off resonance is attenuated by 40 db and one off 90 cycles is attenuated by 60 db. With such extreme selectivity, harmonics of the desired frequency do not produce a measurable reading, thus eliminating the errors from this cause; likewise hum frequency components that may cause errors in low-pass filter measurements are eliminated.

Our laboratories are frequently confronted with practical filter design

* *General Radio Experimenter*, June-July, 1933, pp. 12-14.

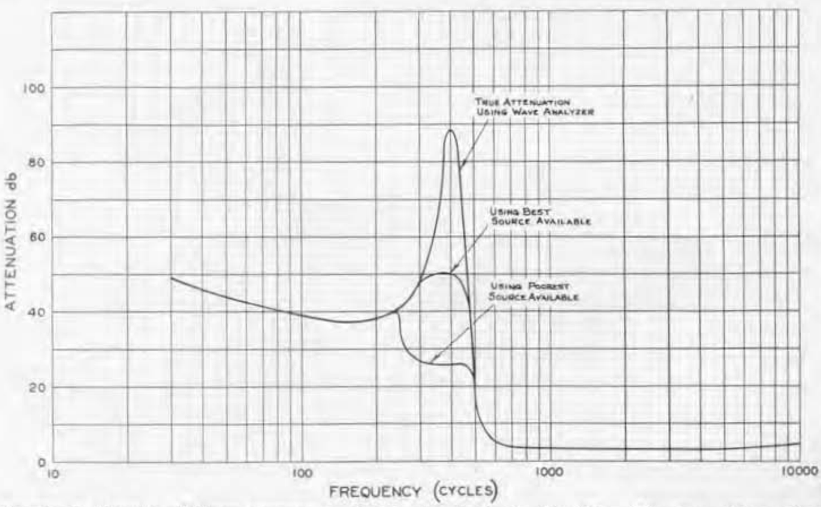

FIGURE 4. Results of three measurements on a band-elimination filter. The true attenuation characteristic is obtained when the TYPE 636-A Wave Analyzer is used as the detector. The two lower curves were taken using two different oscillators and a vacuum-tube voltmeter as the detector

problems requiring a careful measuring technique. For example, in two General Radio measuring instruments* a good combination high-pass and band-elimination filter is used to eliminate a 400-cycle fundamental frequency and pass only the harmonics of the impressed 400-cycle frequency, in order to measure the total residual harmonics in its waveform. The ratio of the amplitude of the total r.m.s. harmonic content to the fundamental amplitude is the "distortion factor," usually expressed as a percentage. Obviously the excellence of these instruments depends upon the use of a filter that will attenuate the 400-cycle fundamental frequency to such an extent that its amplitude after filtering will be entirely negligible compared to its harmonics. The frequencies below 400 cycles are also attenuated by the high-pass sections, so that errors due to extraneous noises, chiefly power line hum, will be eliminated.

Figure 4 shows the attenuation characteristic of this filter measured in three ways: First, an r.m.s. vacuum-tube voltmeter was used as the output meter, and an obsolete type of beat-frequency oscillator with high harmonic content was the power source. Instead of showing some attenuation at 400 cycles, the attenuation appeared actually to dip in the band-elimination region. Second, the best oscillator available was used with the same output meter. The new TYPE 713-A Beat-Frequency Oscillator was the power source in this case, which at 400 cycles had a harmonic content of only about 0.3% (–50 db). This time the attenuation curve showed a rising characteristic as it should, but its maximum was naturally limited to 50 db. For the third test a TYPE 636-A Wave Analyzer was substituted for the VT voltmeter. In addition to being highly selective, this has so great a sensitivity (one millivolt full-scale at its highest sensitivity) that the amplifier preceding the voltmeter in the two previous measurements was dispensed with. When the frequency selective wave analyzer was used, the true attenuation curve was obtained, showing, as it should, a maximum attenuation of 88 db. The curve obtained was practically the same, using *either* of the two oscillators for the power source.

—A. E. THIESSEN

*The TYPE 536-A Distortion-Factor Meter and the TYPE 732-A Distortion and Noise Meter.

USES FOR GENERAL RADIO INSTRUMENTS

THIS issue of the *Experimenter* is devoted mainly to uses for General Radio equipment. The filter measurement article by Mr. Thiessen describes one of the many laboratory measurement applications of the TYPE 636-A Wave Analyzer, and the article reprinted from *Norge News* on pages 6 and 7 shows an interesting industrial application of the Edgerton Stroboscope. We shall be glad to receive from our readers information regarding other interesting applications of General Radio apparatus, particularly those which are unique or of more than ordinary interest. We plan to publish those which are of general interest to our readers and full credit will, of course, be given to the source of the information.

THE STROBOSCOPE STOPS THE ROLLATOR

THE following article is an excellent example of the use of the Edgerton Stroboscope in observing the operation of rapidly-moving mechanical systems to check the performance of the finished product against the design data.

Our readers are undoubtedly familiar with the descriptions of the Norge Rollator in the manufacturer's advertising. This article (reprinted from *Norge News* by permission of the Norge Corporation) shows how these design features can be observed in operation.

ABOUT a year ago the Norge Engineering Laboratory obtained one of the very latest model Edgerton Stroboscopes developed by the General Radio Company. With this instrument, any motion up to as high as 10,000 vibrations or cycles per minute, so long as it was repeated in a regular cycle, could be slowed down or even stopped so that the parts could be studied with the eye the same as if they were standing still. For instance, if the tip of a fan blade is suspected of vibrating and making a noise, it may be viewed with the aid of the Edgerton Stroboscope the same as if the rapidly revolving blades were actually standing still, and if there are any vibrations imposed upon the ordinary rotation of the fan, they may be instantly detected. This instrument took care of the rapid movement of the parts, but the Engineering Department was still faced with the problem of being able to see into the cylinder.

They had previously built Rollators with glass inserts in the dome, simply to observe the effect on the oil when a job was in operation. Therefore, they were able from past experience to design a dome with a very large glass insert, so that the whole interior of the compressor would be easily illuminated by the flash from the lamp of the Edgerton Stroboscope. The cylinder bearing plate, as it is amply strong to support the shaft bearing, could be cut away sufficiently to expose the cylinder end plate, especially since additional available space for opening holes in the cylinder bearing plate could be obtained by moving the discharge valve from the cylinder end plate on to the side of the cylinder itself. This still left the problem of making a cylinder end plate from some transparent material.

The cylinder end plate is the flat plate which closes the end of the cylinder, and it must be absolutely flat to preserve the proper clearance between itself and the end of the roller. It was thought by the Norge engineers that it might be possible to construct this cylinder end plate out of glass with sufficient accuracy so that it would function properly. This problem was turned over to the engineers of the Bausch & Lomb Optical Company, who, after several weeks of work, were able to produce two plates ground flat with a sufficient degree of accuracy so that the compressor would function as satisfactorily as it would with the very accurately ground cast iron cylinder end plates produced in the Rollator plant at Detroit. Producing these glass end plates was a very unusual and painstaking job because bolt holes had to be drilled through the end plates the same as are in the regular cast iron end plate. However, at quite an expense, this problem was finally solved, and very tenderly the compressor was assembled to avoid any chance of a strain that would crack the precious glass end plates. It was finally put in operation and has revealed some very interesting and instructive facts about the interior of the Norge Rollator.

One of the first things that was checked was to see whether or not the statement was true that the Rollator actually rolled around the inside of the cylinder and did not itself revolve at shaft speed. The actual speed of revolution of the roller inside of the cylinder was observed and it was found that, for all practical purposes, it is almost stationary. On two separate occasions the roller was observed over a period of two hours, during which time it did not make even one complete revolution. However, it did creep about 10 to 15 degrees, proving that its position changes sufficiently to equalize any possible tendency to wear.

There are now under way further intensive studies of the action of the blade and the oil inside of the compressor cylinder as they are revealed through the glass compressor. With the aid of this visibly operated machine, some very interesting and pertinent

Norge engineers viewing the operation of the Rollator by means of the Edgerton Stroboscope

data are being obtained on the action of the oil in the cylinder, and especially the flow of the oil as it is forced past the ends of the roller and around the blade into the cylinder and out through the discharge valve.

Some studies also are to be made to see if there is any vibration of the blade during operation, and also of the action of the blade spring and the discharge valve under actual conditions of operation.

A NEW REACTANCE CHART

THE June, 1934, issue of the General Radio *Experimenter* announced that a considerable quantity of reactance-computation charts were available for distribution to readers. So many requests were received that our supply was very quickly exhausted.

We have recently prepared a new and improved chart which has a number of advantages over the older one and we shall be glad to forward a copy to everyone who requests it.

MODIFICATION OF BROADCAST FREQUENCY MONITORS FOR COMPLETE A-C OPERATION

For the benefit of those who are using frequency monitors composed of Type 575-D Piezo-Electric Oscillator and Type 581-A Frequency-Deviation Meter, the General Radio Company is prepared to rebuild this equipment for complete a-c operation. This service is being made available because most of the d-c monitors have been in continuous use for two or three years, and, in many cases, a general overhaul and readjustment may be desirable.

The modification of the piezo-electric oscillator into a Type 575-E includes installing a new panel and modification of the terminal strip, replacing the temperature control relay with an a-c unit, installing fusible protective links in the temperature-control circuit, replacement of the heat indicator lamp by one of the "bull's-eye" type, and such other minor changes as may be necessary.

The quartz plate will be readjusted to exact frequency, and bakelite bases will be replaced by isolantite.

The deviation meter, after modification, will be called Type 581-B and will supply the power for the Type 575-E Oscillator. The instrument will be given a complete overhauling and put in first-class electrical and operating condition.

The charge for the total modification is $125.00. The rebuilt instruments will carry the same guarantee as new equipment. The quoted price will include minor repairs not strictly a part of the reconditioning operation, but necessary major repairs will be subject to additional charge at a fair rate. The time required to do the work will be between ten days and two weeks.

The Federal Communications Commission will grant a permit to operate a broadcasting station for a period of three weeks without a visual monitor provided it is stated that the frequency monitoring equipment is being returned to the manufacturer for modification and calibration. It is, therefore, essential that the permit be granted before the equipment is returned to us.

Before returning instruments for this modification, write to the Service Department for shipping instructions.

—H. H. Dawes

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