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ELECTRICAL COMMUNICATIONS TECHNIQUE
AND ITS APPLICATIONS IN ALLIED FIELDS

WAVEFORM STUDIES WITH THE CATHODE-RAY OSCILLOGRAPH

THE absence of any appreciable inertia in a beam of fast moving electrons gives the cathode-ray oscillograph an inherent advantage over all other types for the study of waveforms involving a wide range of frequencies. However, linear frequency response does not, in itself, guarantee a useful oscillograph, and it is only recently that tube limitations have been overcome and satisfactory auxiliary equipment developed to make possible exacting study of periodic phenomena up to 50,000 or 100,000 cycles per second.

The General Radio cathode-ray oscillograph tube is of the low-voltage type, employing anode potentials of 500 to 2000 volts to accelerate the electrons emitted by the alternating-current heated filament. The arrangement of the tube elements is shown in Figures 1 and 2.

There are two pairs of electro-static deflecting plates: one to produce horizontal deflection, and the other to produce vertical deflection. If an alternating voltage is applied to either pair, the beam will be deflected rapidly so that a straight line appears upon the screen.

Obviously, some means of providing a time axis so that phenomena may be seen in their true amplitude-time relationship is most desirable. The rotating mirror has been used with vibrating-element oscillographs, and is also useful with the cathode-ray instrument. When the line produced by voltage across one pair of plates is viewed in a rotating mirror arranged with its axis parallel to the line on the fluorescent screen, the waveform may be seen, if the mirror is turning at a suitable speed.

The use of the rotating mirror with the cathode-ray oscillograph is somewhat limited in its applications since careful observation of the higher frequency phenomena to which the cathode-ray tube will respond would involve very high mirror speeds.

But probably the most serious disadvantage of the rotating mirror is its inability to keep in synchronism when the frequency shifts. Although the mirror speed may be adjusted so that a stationary pattern is obtained of the

FIGURE 1. The General Radio cathode-ray oscillograph tube. The inside of the glass at the large end is coated with a fluorescent substance on which the moving beam of electrons traces patterns

constant-frequency phenomena, any change in the frequency will cause the pattern to move. If the frequency changes appreciably, the pattern will probably move too quickly to be of any value.

Another method of obtaining a time axis is the moving-film camera. Where a photographic record of a non-recurrent phenomenon is desired, this undoubtedly is the most satisfactory equipment. The General Radio Company has perfected moving-film cameras for various uses which will operate satisfactorily at film speeds up to 15 feet per second, giving a reasonably clear representation of any phenomenon involving frequencies in the audible spectrum.

The camera is, of course, limited by mechanical and photographic factors, including maximum velocity at which the film can be driven without tearing, and the maximum film "speed" at which proper photographic records can be obtained. The latter depends to a great extent upon the optical system and the type of film or sensitized paper, as well as upon the brilliancy of the cathode-ray spot and the speed with which it moves. In this connection, it is obvious that higher frequencies will produce fainter records than lower frequencies, since the actual length of the record will be considerably greater for a given length of film, consequently reducing the amount of light to which any particular spot of the film is exposed.[1]

It is evident that some other means of visual waveform examination is desirable. Since the oscillograph is arranged with deflecting plates so that two dimensional figures may be seen upon the screen, the possibility of being able to

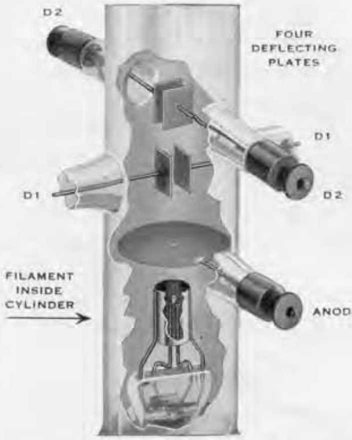

FIGURE 2. Electrode structure of the oscillograph tube. The negatively charged cylinder concentrates the electrons emitted by the filament so that practically all pass through th small hole in the anode. The beam passes between each pair of deflecting plates

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[1] The General Radio cathode-ray oscillograph tube is characterized by the unusual brilliance of the spot. With plate voltages of the order of 1500 to 2000 volts, the patterns on the fluorescent screen may easily be seen by a large group of persons in a lighted room. The fluorescence is unusually actinic, thus facilitating photography.

FIGURE 3. A record of speech made with sensitized paper traveling at 6¼ feet per second. Each of the dots in the line above the trace represents one millisecond. The reproduction suffers from the halftone screen required for the preparation of a printing plate, but the original is more than satisfactory for any purpose of analysis

see a waveform without the use of external mechanical equipment suggests itself.

If alternating voltages are applied simultaneously to both pairs of deflecting plates in the cathode-ray tube, Lissajou's figures will be formed, remaining stationary when one applied frequency is an exact multiple of the other. By proper interpretation of these figures, frequency comparisons can be made, but except to a skilled observer, little knowledge as to any deviation in the waveforms from a pure sinusoidal form can be gained.

This type of pattern can frequently be made more useful when the wave being observed has a high frequency compared with the other or timing wave. If, for instance, a low-frequency timing wave, say 60 cycles, is impressed across the horizontal deflecting plates, and another recurring 600 times a second is impressed on the vertical plates, a pattern will be formed upon the screen which, with a little imagination, can be visualized as the 600-cycle wave.

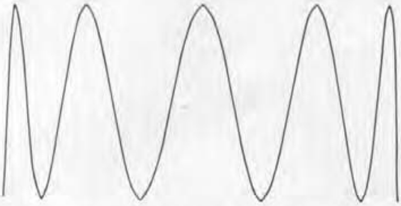

FIGURE 4. Characteristic Lissajou figure from applying a voltage E_h across horizontal plates having exactly $\frac{1}{10}$th the frequency and twice the amplitude of the voltage E_v applied to the vertical pair. Note that the pattern near the center is an approximation to the true shape of E_v since the spot velocity due to E_h is nearly constant in this region. The "back trace" coincides with the forward sweep for this particular phase difference (90°)

If some system is used whereby the cathode-ray beam can be deflected across the screen at a constant velocity, an actual representation of any wave may be seen in linear relation with respect to time. Furthermore, if the beam can be made to traverse the screen at the desired speed, in one direction only, and then return instantaneously to its starting position, only a single representation of the waveform will be seen, whereas, with the sinusoidal timing wave previously mentioned, two views of the wave are seen, one going in each direction. The frequency at which the cathode-ray beam sweeps across the screen must, of course, coincide with the frequency of the observed wave or some submultiple of it, or the pattern will appear to move.

To provide a source of a controlled linear timing wave or "sweep," the

Figure 5. Output waveform of one Type 506-A Sweep Circuit as shown on the cathode-ray oscillograph using another to supply the linear time axis. Note the close approach of each trace to the ideal straight line

General Radio Company has developed the new Type 506-A Sweep Circuit, which was announced in last month's issue of the *Experimenter*. The sweep circuit provides a timing wave having a saw-tooth form, as shown in Figure 5 by means of a circuit which is shown diagrammatically in Figure 6.

The condenser *C* and the current limiter tube are connected in series across a source of 500 volts, d.c. Current flows in the circuit, charging the condenser, but since the current is limited to a certain maximum value, the voltage rises at a constant rate rather than exponentially, as would otherwise be the case.

Across the condenser is connected a mercury-vapor discharge tube (Type 506-P1). This tube is provided with a control grid so that it can be arranged to break down at any predetermined value of plate voltage. When this voltage is reached, the discharge tube flashes, discharging *C*, and reducing the voltage across its terminals to practically zero. The flash in the discharge tube is then extinguished and the condenser charges again, going through the same cycle as before.

The voltage across the condenser terminals, accordingly, has the waveform shown in Figure 5, and if the horizontal deflecting plates of the cathode-ray oscillograph are connected across the terminals of *C*, the fluorescent spot will have a periodic horizontal movement, crossing the screen at a constant velocity and then returning quickly to its original position.

The amplitude of the saw-tooth wave, that is, the horizontal length of the path traversed by the fluorescent spot, is determined by the voltage at which the discharge tube operates, which is controlled by the d.-c. bias on the grid of this tube. This bias is adjustable, so that the sweep may be long or short, as desired, and may be kept within the limits of the fluorescent screen, regardless of the anode voltage used on cathode-ray oscillograph tube.

By varying *C* and the maximum current passed by the current limiter tube, the speed at which the voltage across the condenser rises may be controlled. These two adjustments are used in the General Radio sweep circuit to adjust its natural frequency.

Since it is desirable to be able to cen-

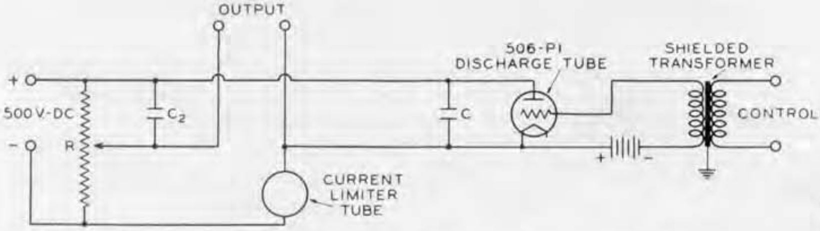

Figure 6. Schematic diagram of the Type 506-A Sweep Circuit

ter the pattern on the fluorescent screen of the oscillograph, an auxiliary position control is provided on the sweep circuit which consists of the voltage divider *R*. It will be seen from Figure 6 that the horizontal deflecting plates of the oscillograph are so connected to the sweep circuit through *R* and the C_2 that a variable direct voltage bias is impressed upon the deflecting plates in addition to the saw-tooth wave. This makes it possible to move the entire pattern horizontally in either direction on the fluorescent screen.

Probably the most important feature of the General Radio sweep circuit is the manner in which the instrument is made to synchronize with any observed recurrent phenomena. A voltage of the frequency of the observed wave, usually obtained by direct connection to the vertical deflecting plates, is impressed across the terminals marked CONTROL. A shielded transformer transmits this voltage to the grid circuit of the discharge tube. If, without the control voltage connected, the circuit is adjusted to operate at approximately the desired frequency, introduction of the source of control voltage will cause the sweeping action to synchronize exactly with the observed wave. Not only is the transformer shielded, but it is so designed that, in connection with a resistance network, it reduces to a negligible value any interference which might be transmitted from the discharge tube back through the control circuits. A volume control is also included for varying the amount of control voltage applied to the discharge tube grid so that the best operating point may be secured without the use of external equipment.

The sweep circuit is completely shielded to minimize interference, and designed so that the mercury-vapor discharge tube operates at the correct temperature. The instrument includes power-supply equipment, so that it operates entirely from the 115-volt, 60-cycle lines.

FIGURE 7. The TYPE 506-A Sweep Circuit is shown at the right of the mounted oscillograph tube and its a-c operated power supply equipment

Because of the automatic control feature of the sweep circuit, this equipment may be used for visual and photographic examination of all types of recurrent phenomena occurring at audio frequencies, as well as certain types of transients and recurring waveforms involving frequencies up to approximately 100 kc. Since the sweep circuit may be controlled by the waveform under examination, it may be made to lock in step, not only on absolutely recurrent phenomena, but on many types of phenomena involving shifts in frequency and amplitude. For instance, complex audio-frequency waves, such as are emitted by musical instruments or an orchestra, may be observed while music is being played, since a stationary pattern will be obtained on any tone which is sustained long enough for observation.

The photographs of Figure 8 were taken with a small pocket-type of camera (Ansco Memo) using 16-millimeter sensitized paper. The camera was equipped with an f/3.5 anastigmat lens, and 1/10th second exposure was allowed for each oscillogram.

Because of the linear frequency response of the oscillograph, the detail with which the various harmonic components of a sound are shown depends only upon the excellence of the microphone and amplifiers employed. The amplifying system used had an excellent frequency characteristic and no noticeable harmonic distortion.

—H. H. Scott

Figure 8. Sustained notes from a B♭ clarinet (left) and a C-melody saxophone (right) as they appear on the oscillograph screen using the Type 506-A Sweep Circuit. Exposure: 0.1 second for each record

VARIABLE INDUCTORS FOR BRIDGE MEASUREMENTS

IT is a peculiarity of bridge measurements practice that, while variable (continuously adjustable) capacitance standards are almost universally used in preference to fixed standards, a general preference for fixed inductance standards over variable standards has prevailed. There are, as a matter of fact, many cases where measurement methods can be improved by the use of a continuously adjustable inductor or variometer.

The use of such an instrument permits the use of equal arm bridges for inductance measurements. Equal arm bridges have very distinct advantages, particularly at higher frequencies, over bridges where adjustable bridge arms are relied upon for a bridge balance.

The whole technique of precision capacitance measurements has been developed around equal-arm bridge substitution methods. The same technique can be adapted for inductance measurements with advantage in many cases, although variable inductance standards have not been developed to as high a degree of precision as have variable standards of capacitance. The variometer balance is of particular value where repeated measurements are made on units of approximately the same size, as this type of standard is very well adapted to a limit bridge.

A variometer for laboratory bridge work should have an inductance which will remain constant to within narrow limits over a wide frequency range. The resistance should be low. In some applications ruggedness and ability to stand large currents are important.

Undoubtedly one of the reasons why the substitution method has not been more generally adopted for inductance measurements is the limitations of the available types of laboratory variometer. The General Radio line of laboratory variometers, TYPE 107, has recently been rather extensively redesigned and improved with this type of application in view. The new variometers are now available in stock.

One of the new TYPE 107-M Variable Inductors with rotor and stator connected in parallel

The new TYPE 107 Variable Inductors are wound with stranded wire having individual strands separately insulated from each other in order to keep down high-frequency resistance. The coils are impregnated and baked in a high-melting-point material so that the variometers can be run 40 degrees centigrade above room temperature without damage. The mechanical arrangement of windings has been changed so as to provide a more nearly linear calibration and a new type of slow-motion dial has been provided.

In order to provide the maximum inductance range for each variometer, provision is made for connecting the coils either in series or in parallel. The rotor and stator inductances are made equal so that there is no circulating current when the coils are connected in parallel. The parallel inductance at any setting is one quarter of the series inductance at the same setting. The inductance is nearly constant over a wide frequency range and is increased by only 2% at 1/10 the natural frequency of the coil.

Values of maximum and minimum inductance and d.-c. resistance for the series connection are marked on the nameplate of each instrument. Calibrations, accurate to 1%, for the entire range of the series connection at 1000 cycles per second may be obtained at a small additional charge.

The resistance is of course a function of frequency and varies approximately with the square root of frequency. The direct-current resistance which is substantially the same as the 1000-cycle resistance is measured for each variometer and this value is supplied with the instrument. The table here lists the value of Q[1] at that frequency for which it is a maximum for each coil. These values are for the coil at full inductance setting.

All of the new variometers have a 15-watt dissipation for a 40 degree centigrade rise. At this wattage and temperature there is a 16% increase in the direct-current resistance.

The table below lists new Type 107 Variable Inductors. Ranges have been generally readjusted and a new instrument has been added so that variometers are now available for inductances from 0.005 millihenrys to 500 millihenrys. The values listed below are average values for the several ranges of variometer. The resistance given is the direct current resistance measured at room temperature. The current value is that producing 40 degree temperature rise. Maximum and minimum inductances are given for the series connection. The natural frequency for maximum setting of each variometer is given. The maximum value of Q and the frequency at which it occurs are also listed for each coil at maximum inductance setting.

Qty.	R_o	I	Lmin.	Lmax.	f_o	Q at f	
Unit	Ω	a	mh	mh	kc		kc
107-J	0.17	8.5	0.005	0.05	5900	110	400
107-K	0.7	4.0	0.05	0.5	1500	140	200
107-L	4.0	1.7	0.5	5	500	125	60
107-M	40	.60	5	50	150	65	20
107-N	64	.14	50	500	30	20	7

The price of the new Types 107-J, K, L and M Inductors is $30; that of Type 107-N is $40.

—Charles T. Burke

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[1] Q is the quantity, sometimes called dissipation factor, that expresses the excellence of a given inductor when used as a tuning element. It is the ratio of reactance to resistance $\left(\frac{\omega L}{R}\right)$ at the frequency in question.

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