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the AEROVOX Research Worker

The Aerovox Research Worker is a monthly house organ of the Aerovox Corporation. It is published to bring to the Radio Experimenter and Engineer authoritative, first hand information on condensers and resistances for radio work.

VOL. 11, NO. 4 APRIL, 1939

50c per year in U.S.A.
60c per year in Canada

Sweep Circuits

By the Engineering Department, Aerovox Corporation

THERE are several types of sweep circuits, such as the sinusoidal and the linear sweep circuit; and there are sweep circuits which make the spot trace a more complicated pattern such as an ellipse, a zig-zag line, a circle or a spiral. This article is restricted to the familiar linear sweep circuit.

The requirements for a linear sweep circuit are:

1. The spot must move at a constant speed in the forward stroke.

2. The return stroke must be as fast as possible, occupying only a small part of the entire cycle.

3. The frequency must be easily adjustable.

4. The arrangement must lend itself to synchronization with the observed signal or with any other alternating voltage.

Most linear sweep circuits derive their "saw-tooth" wave-form from the charge and discharge of a condenser. During the forward stroke the voltage across the condenser is made to rise at a uniform rate by charging it through a constant-current device. When the charge reaches a certain magnitude the condenser is discharged suddenly by means of a gaseous tube or a vacuum tube. One of the oldest and simplest forms of such a circuit is shown in Figure 1. The condenser, C, is charged from a d.c. source

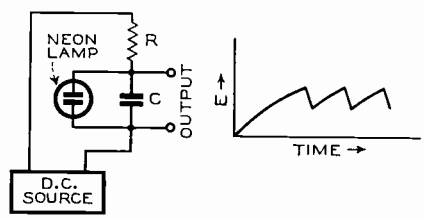

Figure 1

through a high resistance, R. The voltage drop across the condenser then increases according to the well-known relation

$$e = E\left(1 - \epsilon^{-\frac{t}{Rc}}\right) \qquad (1)$$

where e is the voltage across the condenser

E is the voltage of the power supply

ϵ is the base of the natural logarithmic system, 2.718...

t is the time in seconds, the duration of the charge

C is the capacity in microfarads

R is the resistance in megohms

When the voltage drop across the condenser reaches the striking voltage of the neon tube, the tube ionizes and discharges the condenser to the extinction potential of the tube. Then the condenser charges again and the cycle is repeated. The waveform of the voltage across the condenser is shown in Figure 1.

In this case the neon lamp can be any one of the commercial neon lamps without a resistor in the base. The popular ¼-watt, ½-watt, 1-watt and 2-watt sizes are suitable; of course, such tubes as the 874 and the VR-150 may be employed.

The required d.c. potential must be at least large enough to reach the striking voltage of the tube but a somewhat higher voltage is advantageous as shall be shown presently.

This old circuit has several defects: (1) The forward stroke is not exactly linear but follows a logarithmic curve. (2) The output voltage is restricted to the difference between the striking and extinction voltage. (3) The tube constants are subject to variation with age and temperature so that the same circuit constants will not always result in the same frequency.

Some of these difficulties are overcome when the neon lamp is replaced by a gaseous triode such as the 884 or the 885; this circuit is shown in Figure 2. The striking or firing voltage of the 884/885 depends on the grid bias. Thus the peak voltage of the condenser and the amplitude of the output wave can be fixed by the design of the circuit. Synchronization is easily obtained by feeding a small

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portion of the synchronizing signal to the grid of the triode. The resistors R_2 and R_3 have to be provided in order to limit the plate and grid currents to within the rating of the tube. The values given in Figure 2 are typical for this service.

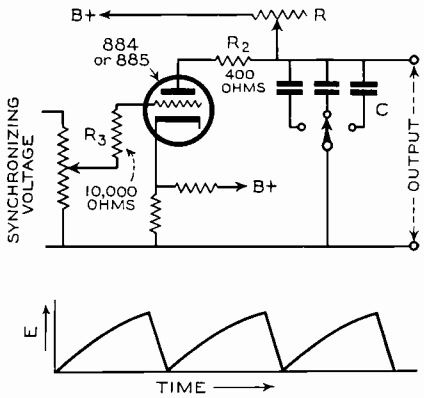

Figure 2

Linearity of the forward stroke is still not obtained, the curve being again logarithmic according to the equation (1). There are two ways of making the forward stroke practically linear. The easiest one consists in utilizing only a small part of the logarithmic curve. A close study of the curve reveals that the lower portion of the curve—up to about 20 percent of the full charging voltage—is very nearly straight. The difference is so small that one must make a rather large drawing to show it up. Thus, if the charging voltage (B-supply) is rather high and the tube is adjusted to discharge the condenser when it is charged to 20 percent of the B-voltage, a practically perfect saw-tooth wave-form is obtained.

The second way of obtaining a linear forward stroke is by using a constant current device instead of R in Figure 1 and Figure 2. Such a constant-current device consists of a tube which has been limited to give no more than a definite small amount of plate current regardless of the plate voltage. Originally, a saturated diode was used for the purpose. In its simplest form it is shown in Figure 3.

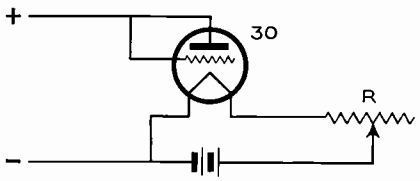

Figure 3

This may be a 201-A or a 30 or any filament type triode connected as a diode. If the filament rheostat, R_1, is adjusted to give less than rated filament voltage the plate current is limited by the reduced emission. The plate current cannot be more than the emission of the filament and becomes independent of the plate voltage. The whole circuit may be regarded as a resistance and may be substituted for R in Figure 1 and 2 with due regard for polarity. The magnitude of this "resistance" and the charging rate and the frequency are adjustable by means of the rheostat R_1.

In practice the saturated diode is less satisfactory because the plate potential, when it becomes high can actually pull electrons out of the filament and increase the emission. The current then increases and the device fails in its purpose.

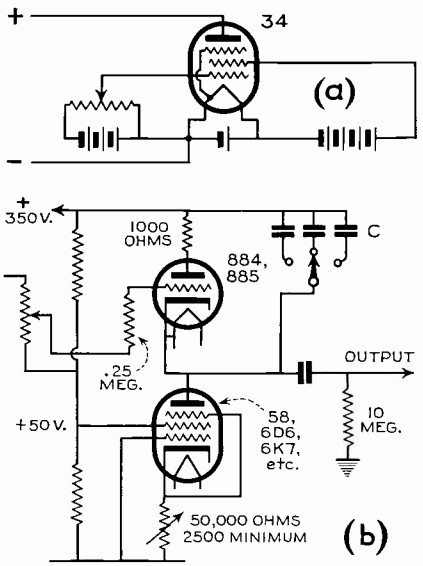

Figure 4

Better regulation is had by the use of a pentode. Such a tube has the peculiar characteristic that the plate current is determined by the screen voltage and grid bias and is independent of the plate voltage over part of the voltage range. Figure 4 shows a pentode with proper connections for this purpose. Either a battery tube (type 34) or an indirectly heated type can be employed but the battery tube is superior in performance because it permits the 885 to be at ground potential which reduces hum and cathode-to-heater leakage. The magnitude of the charging current can be regulated either by the screen voltage or the grid bias. Usually the charging current is very low—below 0.5 ma.

The time required for a single cycle in the case of a simple resistance in the charging circuit, is

$$T = t - RC \log \left(1 - \frac{e}{E}\right) \text{ SECONDS} \qquad (2)$$

where t is time required for discharge

R is charging resistance in megohms

C is capacity of condenser in microfarads

e is maximum voltage across the condenser

E is the supply voltage

log is the natural logarithm.

The frequency in cycles per seconds is then $f = 1/T$.

The value of t depends on the tube and on the charge in the condenser and is in the neighborhood of 1/50,000 of a second. This quantity may be neglected at low frequencies. The equation then becomes the simple one of a condenser charged through a resistor. This subject was discussed in the Research Worker for January 1938 where graphs are shown for the finding of T.

If a current limiter is used, the value of f is

$$f = \frac{1}{t + \frac{Ce}{I}} \text{ CYCLES PER SECOND} \qquad (3)$$

where t is the time for the discharge in seconds

C is the capacity of the condenser in microfarads

e is the peak of the condenser voltage

I is the charging current in microamperes

There are an infinite number of combinations of R, C and e or I, C and e to obtain a given frequency.

In order to make the time of the return trace as short as possible, the condenser C should be small since the maximum discharge rate is limited. A low voltage, e, also results in a shorter discharge time. There is a limit, however, to the reduction of capacity. When the condenser becomes too small compared to the capacity of the wiring and the tube the operation of the circuit becomes erratic resulting in a distorted waveform.

In general then, it is desirable to make the tube fire at a plate voltage which is relatively low—10 to 30 percent of the B-supply—to make the resistance R large and the condenser small. The following constants were used in one successful design. The B-supply was 370 volts, the resistor R consisted of a fixed 1 megohm resistor in series with a 5 megohm variable resistor, the latter being linear. The capacity for the lowest frequency, 15 cycles, was .1 mfd. and for the highest frequency, 20,000 cycles, C was 20 mmfd. The 885 had a bias of 5 volts obtained from the bleeder.

In most cases the sweep voltage will have to be amplified. This is generally done with a resistance-capa-

city coupled amplifier. A few practical wrinkles may be pointed out here. The amplifier must faithfully reproduce the saw-tooth wave. This means that the phase relations between the fundamental and the various harmonics making up the saw-tooth form

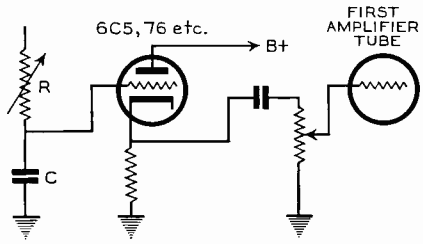

Figure 5

must remain the same. Such a requirement is not met by the usual audio amplifier especially at the lower frequencies.

A phase shift-free amplifier can be made but will probably be uneconomical for the average oscillograph. The distortion can be minimized by making the coupling condensers large and omitting the condenser across the bias resistor. In addition, it is recommended by Mezger (IRE Proceedings, March 1939)* that a direct-coupled matching stage be employed directly after the oscillator to prevent distortion from a grid-leak and condenser across the high resistance R. A suitable circuit is shown in Figure 5.

The sweep circuit as shown in Figure 2 still has limitations due to the time required for the discharge which becomes a problem at frequencies above 10,000 cycles. Since this is near a frequency employed in tele-

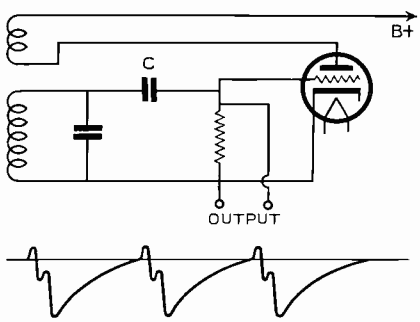

Figure 6

vision, considerable work has been done to find a circuit which will work reliably at higher frequencies and will use regular vacuum tubes.

One of the oldest ones along this line is the self-quenching oscillator shown in Figure 6. It is a simple r.f. oscillator with a grid-leak-and-condenser of too large a time constant so that the tube blocks periodically. When the tube blocks, the condenser has a charge making the grid negative to beyond plate current cut-off of the tube. The charge leaks off through the resistor according to the logarithmic law until the condenser charge reaches a certain critical value. Then the bias has returned to a value which allows oscillations to start again. The waveform is shown in Figure 6; it is of course not a perfect saw-tooth the forward stroke being non-linear.

An improved type of circuit, now employed in the RCA television re-

	60 CYCLES	13230 CYCLES
R	2 Meg.	0.6 Meg.
C	0.25 Mfd.	0.001 Mfd.
R_1	0.22 Meg.	30000 Ohms
R_2	1.2 Meg.	27000 Ohms
C_1	3300 Mmfd.	820 Mmfd.

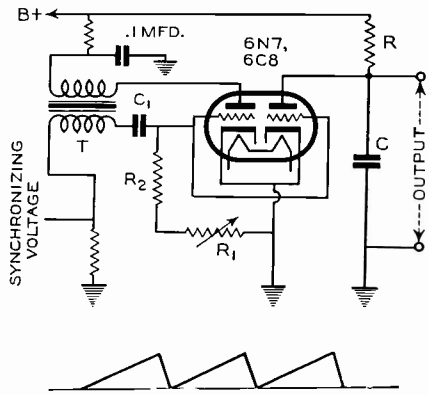

Figure 7

ceivers is shown in Figure 7. It requires two tubes but they may be in a single envelope as in the 6N7 or 6C8.

The circuit consists of a blocking oscillator and a discharge tube. The first section of the tube is a blocking oscillator similar to the one in Figure 6. Its natural period is in the lower radio frequencies and depends on the transformer. The waveform produced across the grid-leak is not used. However, it is seen that the grid of the tube is negative and beyond plate current cut-off for nearly the whole blocking cycle and becomes positive for only a short pulse. Since the grid of the second section is connected to the grid of the first section, this second section is also beyond plate current cut-off except for one pulse at every blocking cycle. During this time, when the tube is non-conducting, the condenser C charges through the resistor R again according to the logarithmic law (equation 1) but the values of R and C are such that it can only charge to a fraction of the B-voltage before the tube becomes conducting for a short time and discharges the condenser. The cycle then repeats; the frequency of the saw-tooth wave is dependent on the grid-leak and condenser constants of the blocking oscillator while R and C determine the amplitude and the waveform. The higher the ratio $RC/(R_1 + R_2)\ C_1$ the higher the amplitude and the less the linearity.

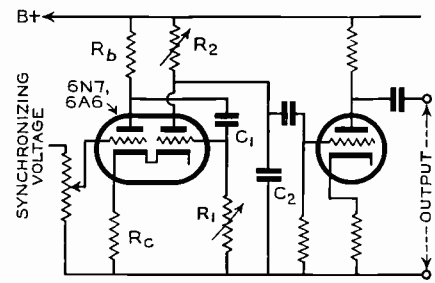

Figure 8

Synchronization is easily obtained by supplying a small synchronizing voltage across R_3.

Sweep circuits which can operate at frequencies from a few cycles to 100 kc. and more have been made employing vacuum tubes. One such circuit was described by Potter in the Proceedings of the IRE for June 1938*; it is shown in Figure 8. It uses again a double tube but requires no transformer. The last tube shown is just an amplifier stage and does not take part in producing a saw-tooth wave-form. The action is somewhat complicated; briefly it is as follows. When the switch is closed, the condenser C_1 charges through R_b and R_1 but this makes the grid of the second section positive and the charge continues through R_c and the grid-to-cathode resistance rather than through R_1. During this time, since the grid is positive, the second section is drawing plate current, the plate-to-cathode resistance of the second section is low and C_2 has no chance of being charged. If it had a charge it is now discharged. This period represents the return sweep, the discharge of C_2.

During the forward sweep the condenser C_1 is fully charged and is now discharging. This makes the grid voltage of section two highly negative and C_2 charges; the cycle then repeats. The voltage across C_2 is practically a perfect saw-tooth. The frequency is approximately $f = 0.4/R_1C_1$ while the amplitude again depends on R_2 and C_2. Therefore, for oscillograph use, R_1 and R_2 should be varied simultaneously so as to keep the amplitude constant. Mr. Potter reports a maximum frequency of 100 kc. with this equipment.

*G. Robert Mezger, Allen B. Dumont Laboratories, Inc., Passaic, N. J.

*J. L. Potter, State University, Iowa City, Ia.

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● Above: A study in extremes—heavy-duty porcelain-case mica capacitors with the smallest or "postage stamp" molded bakelite capacitor—showing at a glance the wide selection available. The porcelain-case units are intended for transmitters, oscillators and electronic equipment in general requiring high-voltage capacitors with minimized r.f. losses. In the small bakelite-molded units, AEROVOX offers a wide choice of types for transmitting and for receiving requirements to meet all electrical and mechanical considerations.

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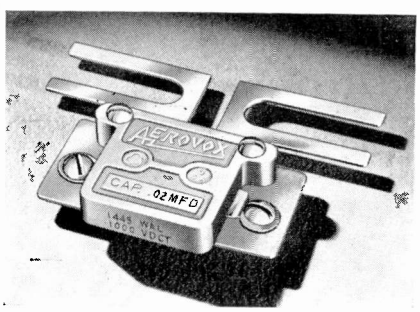
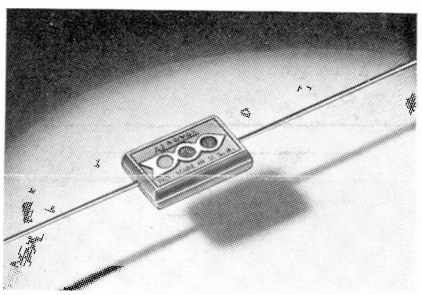
● TO an already extensive choice of mica capacitors, several new types have been added in rounding out the AEROVOX line, in keeping with the latest requirements of the radio and electronic arts. Typical of these latest additions to the AEROVOX line are:



● Left: Meter-mounting brackets fitted to the 1445-47 types of molded bakelite mica capacitors, permit such units to be used in shunting meter windings. Also, low-loss or mica bakelite (yellow finish) units are now available at an additional 25 cents to list prices. Such units carry the same type designations as standard (brown-finish) bakelite items, plus the XM suffix. Thus 1650-XM indicates a 1650 type in low-loss bakelite.

Despite low cost, each AEROVOX molded-bakelite capacitor is built of selected mica and foil—silver deposit in the silver-mica types—with the clamped section finally imbedded in a molded bakelite casing that is impervious to moisture, heat and mechanical damage. Capacity values are closely maintained by micrometer test for thickness of every sheet of mica used. Thus values are precisely maintained throughout years of service.



● Above: For the most critical applications where precise capacity values must be attained and maintained, AEROVOX silver-mica capacitors are now made generally available. Encased in molded XM bakelite and similar in external construction and dimensions to standard units. Unique silver-mica construction. Plus .0022 per degree F.—a remarkably low temperature coefficient. Practically no capacity drift. Exceptionally high "Q". Closest tolerances. Ideal for push-button tuning, etc.

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