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VOL. 20, NO. 7 JULY, 1950 Subscription By Application Only

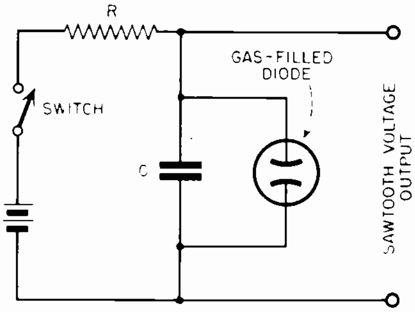
Non-Sinusoidal Wave Forms

Part 2, Generators and Non-Linear Shapers

By the Engineering Department, Aerovox Corporation

In the preceeding article, the response of four-terminal passive wave-shaping networks to various types of applied waveforms was discussed without regard to the actual generation of these waveforms. The present issue will be concerned with a description and discussion of several of the more basic methods of generating non-sinusoidal waves.

Pulse generators as a general class fall into two rather loosely defined categories: the self-excited or self-sustaining generators such as the gas tube relaxation oscillator, the block oscillator, the multivibrator, etc., and the "driven" generators such as the squaring amplifiers, limiters and rectifiers. The self-excited generators require no input other than the usual d.c. operating potentials (plus a synchronizing or triggering signal if desired for improved stability), and are self sustaining as long as the d. c. power is applied. They operate on the rather simple principle that any system—electrical, acoustical, or mechanical—having two stable states of equilibrium may oscillate between these states if a sufficient amount of its output energy is fed back to the input in the correct phase. Thus, it will be readily seen that the escapement of a watch movement satisfies these conditions and is therefore a mechanical relaxation oscillator. The primary source of energy in this case is the potential energy stored in the spring.



RELAXATION OSCILLATOR
FIG.1

Among the electronic pulse generators to be discussed is the familiar gas tube relaxation oscillator first used in the "dark ages" of electronics as an oscilloscope time-base generator. Briefly, the sequence of action in such a device, shown diagramatically in Fig. 1, is as follows. After switch closure, condenser C charges exponentially through resistor R, the condenser voltage at any time being given by:

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

Where:

e is the instantaneous condenser voltage
E is the battery voltage
ϵ is the base of Naperian logarithms
t is the time in seconds after switch closure
R is the resistance in ohms
C is the capacitance in $\mu\mu$fds

If the gas tube were not in the circuit, the condenser voltage would in time be equal to the full battery voltage. However, when a gas diode having an "ignition" potential somewhat lower than the battery voltage is connected as shown in Fig. 1, the condenser voltage at some point on the charging curve will be sufficient to ionize the gas, rendering it conductive. In this condition the tube serves as a discharge path for the charge stored on the condenser. The condenser voltage will decay exponentially toward zero until it reaches the "extincition" voltage of the gas tube permitting deionization to take place, where upon the condenser voltage again charges toward the ignition potential and the cycle repeats. The output voltage for large values of the RC time constant is the distorted sawtooth shown as the solid line of Fig. 2. Also shown (dotted lines) is the output voltage for identical battery voltage and gas tube conditions but with a small time constant (RC). With this simple relaxation generator, the output must be limited to about 5 or 10 percent of the supply voltage if a linear sawtooth is desired.

As a refinement, the gas diode of Fig. 1 may be replaced by a gas-filled triode, or *thyratron*, and the charging resistor by a constant current source such as the plate resistance of a pentode[2]. With these modifications, a much larger portion of the supply

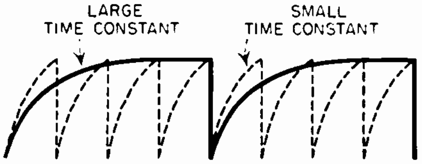


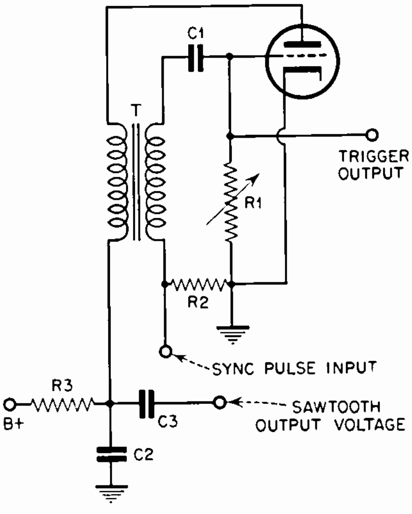
FIG. 2

voltage appears as linear sawtooth at the output of the generator. In addition, it is relatively easy to inject a synchronizing pulse into the grid circuit to insure that the sawtooth generator will "lock in" synchronously with some desired repetition frequency.

A pulse of very short duration may be obtained from the gas tube type of generator by inserting a resistor into the cathode circuit of the thyratron. The voltage pulse across this resistor is, of course, proportional to the discharge current pulse of the condenser, and may be made of short duration by the proper choice of tube and circuit parameters.

The blocking oscillator[3], Fig. 3, has been widely used in television receivers as a pulse generator for accurately timing the sweep generator. Here again the *modus operandi* is the relaxation principle, with an iron core transformer serving as the feedback coupling mechanism. The transformer must of necessity be so phased that an increase in plate current causes an increase in grid voltage in the positive direction, and vice versa. Under these conditions the slightest fluctuation of plate current is sufficient to drive the tube either to cutoff or plate-saturation, depending on the polarity of the initial disturbance. For a positive-going disturbance, the plate current will increase until the rate of rise of plate current decreases sufficiently to make the rate of change of net grid voltage negative, at which time the plate current falls to zero. During the fall of plate current, as well as during the rise, the transformer phasing dictates that the rate of change of current shall be extremely rapid. Since the grid draws appreciable current during a portion of the cycle, once the plate current has fallen to zero, it will remain cut off until the accumulated negative charge on the grid condenser (and consequently the net grid voltage) becomes sufficiently small to again permit the flow of plate current. As may be seen, the cycle is repetitive and self-sustaining.

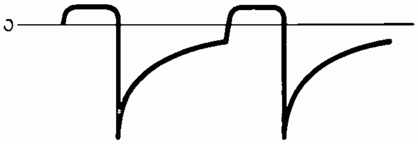
Fig. 4 depicts typical grid and plate voltage waveforms observed in blocking oscillators. The grid voltage may be used as the trigger pulse to fire a discharge-tube type of television sweep generator which will be discussed later, or the plate output may be used directly as the shaped sweep waveform. Both methods have been used sasisfactorily in commercial television receivers.



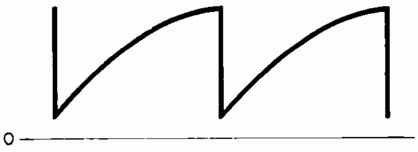
BLOCKING OSCILLATOR
FIG. 3

Synchronization of a blocking oscillator may be accomplished by injecting a positive sync pulse into the grid circuit as shown in Fig. 3. For best results, the free-running frequency of the blocking oscillator (controlled by R_1 of the above figure) should be slightly lower than the frequency of the sync pulses, although synchronization with multiples or submultiples is possible.

Several modifications of the free-running blocking oscillator should also be mentioned. For example, if sufficient negative bias is applied to the grid, self-sustained oscillations may be prevented. This circuit, called a "driven blocking oscillator", will oscillate for only one cycle each time a trigger pulse is applied. Another useful variation is the "positive grid blocking oscillator," in which the grid is operated with a slight positive bias to reduce randon pulse-to-pulse time "jitter".



(a)
GRID VOLTAGE OUTPUT

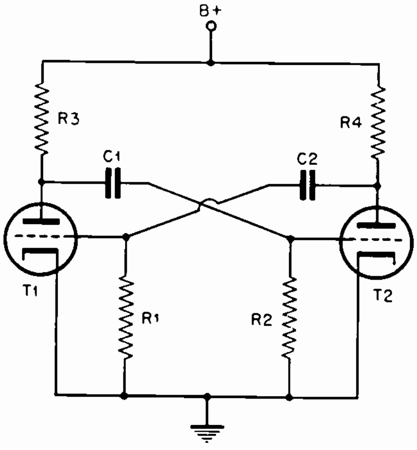


(b)
PLATE VOLTAGE OUTPUT

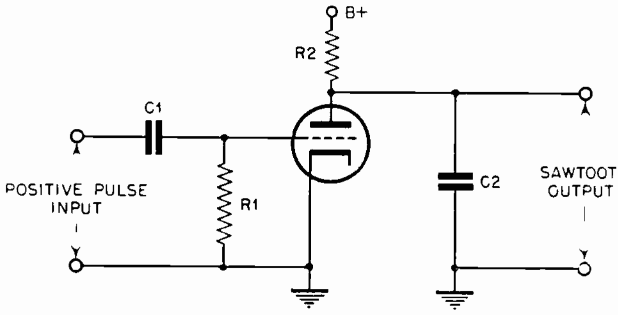
BLOCKING OSCILLATOR WAVEFORMS
FIG. 4

Closely related to the ordinary blocking oscillator is the generator first referred to in British literature as the "squegging" oscillator. In this circuit, the feedback mechanism is an r.f. transformer. The action of this type is similar to that of the blocking oscillator, with the significant exception that, instead of the single burst of plate current normally occurring in the blocking oscillator, there may be several cycles of r.f. oscillations generated before sufficient charge accumulates on the grid condenser to cut the tube off. This action, incidentally, is identical with that occurring in superregenerative detectors. Squegging oscillators have been tried as rather primitive radar transmitters, but the synchronization problems involved have precluded their wide usage.

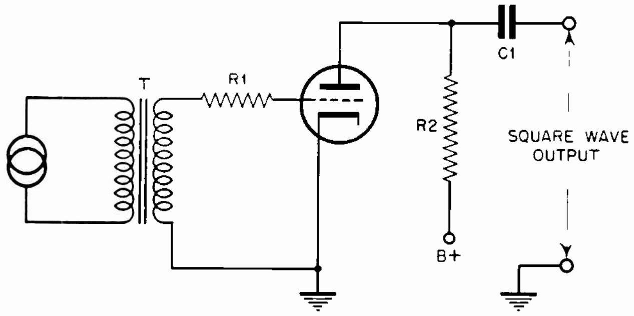
Another circuit which may be used as a non-sinusoidal wave generator is the multivibrator[4]. In its simplest form (Fig. 5), this may be thought of as a two stage, resistance coupled amplifier whose output and input are regeneratively coupled. The circuit operation may be readily understood by recognizing that two stable states are possible; tube No. 1 conducting when tube No. 2 is cut off, and vice versa. The tube that is cut off will remain in that condition until the negative voltage charge accumulated on its grid condenser during the grid conduction period has decayed suf-



MULTIVIBRATOR
FIG. 5



DISCHARGE-TUBE SWEEP GENERATOR
FIG. 6



OVERDRIVEN AMPLIFIER
FIG. 7

ficiently to permit plate current to flow. The light feedback coupling makes the build-up of current extremely rapid. When this occurs, the phasing is so arranged that the other tube will be cut off, and the cycle repeats. Like the blocking oscillator, the multivibrator may be synchronized by injecting a sync pulse into either grid circuit.

As mentioned above for the blocking oscillator, the free-running multivibrator may be altered in several ways from varying applications. If, for example, the circuit is arranged so that one tube is permanently biased to cutoff, and a positive trigger pulse is applied to its grid, the circuit will complete only one cycle of multivibrator action and return to the most stable state — that of the permanently biased cutoff condition. This type of multivibrator, called a Kipp relay, may be further modified by removing the condensers and providing conductive feedback paths. With this circuit, the tube that is cut off will remain in that condition until triggered by a positive pulse. The circuit will flip to the other equilibrium condition with the other tube cut off, and will remain that way until it too is triggered similarly. The shift occurs only once for each triggering impulse applied.

The output of a symmetrical multivibrator will be the square wave illustrated in Fig. 1b of Part 1. The term "symmetrical" implies that the values of resistance and capacitance in the grid and plate circuits of one of the tubes are equal, part for part, to those of the other tube. For this circuit, the frequency of oscillation is given by:

$$F = \frac{1}{2RC} \qquad (2)$$

Where:

F = frequency in cycles per second

R = resistance of the grid resistor in ohms

C = capacitance of the coupling condenser in ohms

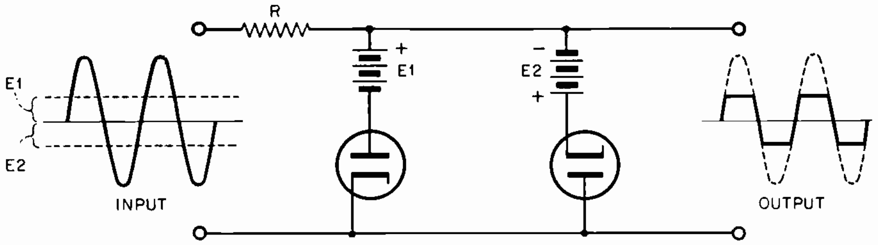
A convenient method of varying the frequency is by using a dual potentiometer as the grid resistors.

In the unsymmetrical multivibrator, i.e., one in which *unequal* values of grid resistors and coupling condensers are employed, the output waveforms will resemble Fig. 1g of the previous article.

The sawtooth sweep generator referred to as the "discharge tube" in commercial television practice is a simple circuit (Fig. 6) whose operation is quite similar to that of the gas tube relaxation oscillator discussed above. Here, however, the discharge occurs when the grid potential is made positive enough to reduce the plate resistance of the tube to a small value. Between pulses, of course, the voltage across the storage condenser rises more or less linearly and, if limited to about 5% of the supply voltage, may be used as the sweep voltage waveform of a television receiver.

In conclusion, a brief description of typical *driven* waveform generators, such as the overdriven amplifier and the limiting diode circuits, will be given. The overdriven amplifier (Fig. 7) consists of a conventional amplifier tube and associated circuit which is operated in such a manner that both plate and grid limiting occur. If a large sinusoidal voltage is applied to the input, the tube is driven beyond cutoff during most of the negative excursion of the sine wave. During the positive portion, however, the grid will draw current, which is limited by the series grid resistor. Under these conditions, it is impossible for the grid voltage to rise more than just a few volts positive, no matter how high the input signal goes. Thus, the plate current is also limited. The output will be a square wave. By properly choosing the values of the circuit elements, the limiting action may be made to occur over a wide range of signal amplitudes. Thus, it is possible to convert any complex waveform into a flat-topped waveform.

The circuit of Fig. 8, variously termed a diode clipper, clamper, or limiter, performs a similar function. Any waveform applied at the input terminals will be clipped at a voltage level determined by the bias voltage in series with each diode. This circuit provides a simple method of converting a sine wave to a square wave. Diodes of either the vacuum tube type or the crystal type[5] may be employed.



DIODE CLIPPER
FIG. 8

REFERENCES

1—Aerovox Research Worker, June 1950.

2—RCA Publication, "Cathode Ray Tubes and Allied Types."

3—"Principles of Television Engineering", D. G. Fink. Page 155.

4—Aerovox Research Worker, Nov. 1940.

5—Aerovox Research Worker, May 1950.

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