CHAPTER II

OSCILLATORS

A relaxation oscillator may be defined as an oscillator whose frequency is determined by the time constant of a resistance-capacitance network rather than the resonant frequency of an inductance-capacitance network. The basic principle of operation is the charging of a capacitor at a given rate. When the voltage across the capacitor reaches the breakdown voltage of the switching device, the switch turns "on," rapidly discharging the capacitor. When the capacitor is discharged, the switch turns "off," and the capacitor starts charging over again. This cycle is repeated as long as there is source energy to charge the capacitor. The resultant output is a sawtooth waveform available in frequencies from as low as one cycle in 45 minutes to as high as 20,000 cycles per second.

Among the many circuit component applications for neon glow lamps, their use as switching elements in relaxation oscillators is certainly among the most common, as well as one of the earliest. The neon glow lamp relaxation oscillator served as the time base generator for the first cathode ray oscilloscopes where capacitors were switched for frequency range changing and the resistor was varied for "fine" adjustment. The high level of output voltage simplified the horizontal deflection amplifier requirements and was one of the important advantages that the neon glow lamp offered for this early application. Another advantage was the ease and simplicity of synchronizing the oscillator frequency to input signal frequency.

This circuit was, in time, replaced by the "hard tube" and later by transistorized sweep circuits, as cathode ray instrumentation became more advanced. It is interesting to note, however, that in these days of highly sophisticated components, the neon glow lamp relaxation oscillator is being "re-discovered" as a time function generator, especially where time bases of up to an hour or more are required.

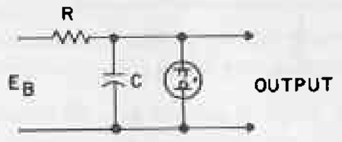
The neon glow lamp is a cold cathode diode with bistable characteristics. In its non-conducting state it comprises a very high resistance until its ignition, or breakdown, voltage is reached. At this point it rapidly becomes a low resistance path and maintains this condition until the voltage across the lamp drops below its extinguishing voltage. When this occurs, the lamp abruptly ceases to conduct and again becomes a high resistance element. This ability to stay "off" until a critical voltage point is reached, and to stay "on" until another, lower critical voltage point is reached, makes it uniquely well suited for use as the "switching" component in an oscillator circuit.

With no resonant circuit, a minimum number of components, and its elementary simplicity, the neon glow lamp relaxation oscillator circuit constitutes an approach of outstanding practicality, economy, and reliability. The advent of "tight tolerance" neon glow lamps, which might more properly be referred to as cold cathode diodes rather than lamps, has permitted a new degree of reliability and control in this particular circuit configuration.

Consequently, we find that oscillator circuits utilizing these units are being widely used in a variety of circuit applications. In the electronic organ, for example, the basic circuitry consists of cold cathode diode relaxation oscillators and frequency dividers. (See Chapter III) The ability to construct oscillators with time bases that range from less than 0.0005 cps to over 20,000 cps has resulted in their use in many oscillators and time delay applications. (See Chapter IV) In addition they have been used in a variety of audible and visual alarms, plus a host of different applications too numerous to cover here.

Theory of Operation

The basic circuit for a relaxation oscillator is shown in Figure 2-1. As mentioned above, when the supply voltage E_B, is applied to the RC network, C begins charging until the voltage reaches the ionization voltage of the neon glow lamp. At ionization, the glow lamp abruptly switches from a high resistance to a low resistance, discharging C rapidly through the lamp. When the voltage across the lamp decreases to the extinguishing point of the lamp the lamp extinguishes and reassumes its high resistance characteristic. The capacitor, C, again charges through R toward the E_B potential, repeating the cycle, thus producing oscillations which continue as long as E_B is maintained.



2-1 **Basic circuit for relaxation oscillator**

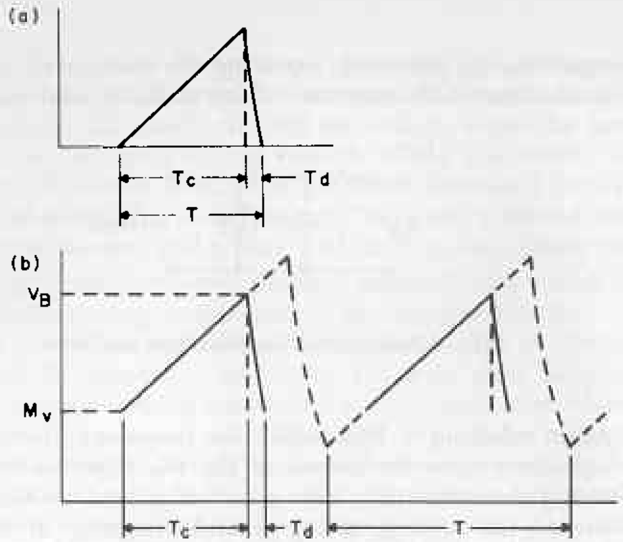
Again referring to Figure 2-1, the frequency of oscillation is dependent upon the values of the RC time constant, the operating characteristics of the glow lamp (i.e. specific breakdown and maintaining voltages) and the value of E_B. The peak-to-peak output level will be the difference between the glow lamp's breakdown and maintaining voltages.

The primary limitation on the high-frequency capabilities of such a relaxation oscillator lies in the finite ionization and deionization times of the particular neon glow lamp. This limitation restricts the use of a glow lamp to a practical maximum of about 20 kilocycles per second. Only the leakage of the capacitor in the RC network, the neon lamp and the associated circuitry, restrict the low-frequency capability of the circuit.

Circuit Design Considerations

In the design of a relaxation oscillator in which the output characteristics are not particularly critical, elaborate computation is not really necessary. The output level is established by the selection of the particular type of glow lamp (ignition voltage minus the maintaining voltage approximate the peak-to-peak output amplitude). As for determining frequency a familiarity with the principles outlined below will enable the designer to create a circuit having the desired general characteristics.

In instances where the frequency is more critical a number of factors must be taken into consideration.



2-2 Period of cycle in oscillator

The solid curve is the calculated frequency. The broken line represents the actual frequency attained because of ionization and deionization time factors.

As shown in Figure 2-2, the period of a cycle T in a relaxation oscillator's output is equal to the total charge, T_C, and discharge times, T_D. For low frequency oscillators (below approximately 20 cps) the discharge time is such an insignificant portion of the cycle that it can normally be ignored. At higher frequencies, however, the discharge time, in addition to the ionization and deionization times of the glow lamp, become factors to be reckoned with.

Low-Frequency (<20 cps) Design

In oscillators intended for use below approximately 20 cps, the resistance and capacitance required for the desired frequency may be determined as follows:

Determine K_1 from the following expression. K_1 should be 0.63 or less for optimum stability.

$$K_1 = \frac{V_B - M_V}{E_B - M_V}$$

Where E_B = Supply voltage
M_V = Maintaining voltage of the glow lamp
V_B = Breakdown voltage of the glow lamp

If K_1 is greater than 0.63 and the E_B is fixed, then another neon lamp must be chosen whose V_B and M_V will yield a K_1 of 0.63 or less. If E_B is not fixed, then increase E_B until K_1 is equal to 0.63 or less. Then from the graph of Figure 2-3, determine K_2.

Then the value of the RC time constant is determined from the expression:

$$RC = \frac{K_2}{f}$$

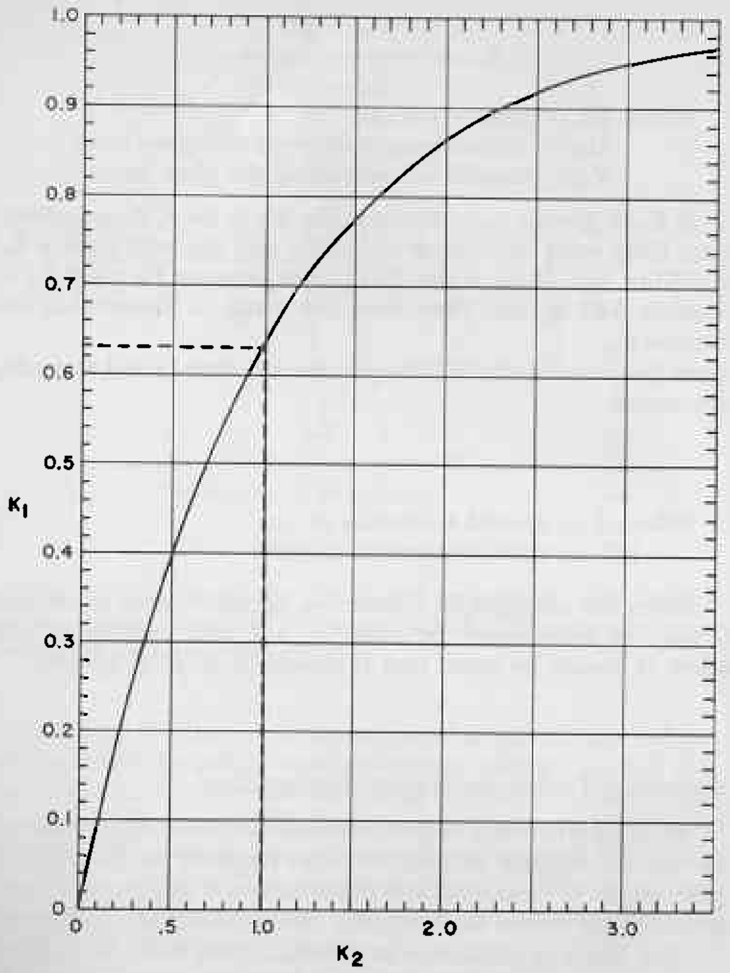
Where f = desired frequency in cps
RC = time constant in seconds

From the nomograph, Figure 2-4, specific values for R and C may be determined by selecting one and reading off the other. It should be noted that R should be 470K or greater.

Correction Factors for Higher Frequencies

In cases where the output frequency is above approximately 20 cps, and is fairly critical, the times required for the physical phenomena of ionization and deionization of gas must be compensated for before the foregoing computations are performed.

The effect of ionization and deionization times is to lower the frequency from that computed from theoretical values. As can be seen from Figure 2-2b, the times required for the firing and extinguishing of the lamp add to the total period of the cycle. The higher the frequency, the greater a portion of the total cycle these time lags occupy. In addition, the non-linearity in the fall-time similarly assumes increasing importance as it (T_D) becomes a significant portion of the total cycle.



2-3 K_1 versus K_2

It is also obvious from Figure 2-2b, that overshoot effects resulting from the ionization and deionization times of the gas result in the oscillator's operating at a somewhat higher output level than that calculated from the difference between the firing and maintaining voltage of the particular neon glow lamp.

Example:

Let us assume we wish to construct an oscillator whose frequency is .5 cycles per second. The supply voltage, E , is 90 volts and the neon lamp is the close tolerance AO 59-6 with a breakdown voltage, V , of 70 volts and a maintaining voltage of 56-57 volts.

Substituting these values in the formula:

$$K_1 = \frac{B_V - M_V}{E_B - M_V}$$

$$K_1 = \frac{70 - 56.5}{90 - 56.5}$$

$$K_1 = .4$$

Since this is less than 0.63 we then refer to the chart in Figure 2-3, where we find that a factor of $K_1 = .4$ *yields a value of .5 for* K_2*. Inserting these values in the formula:*

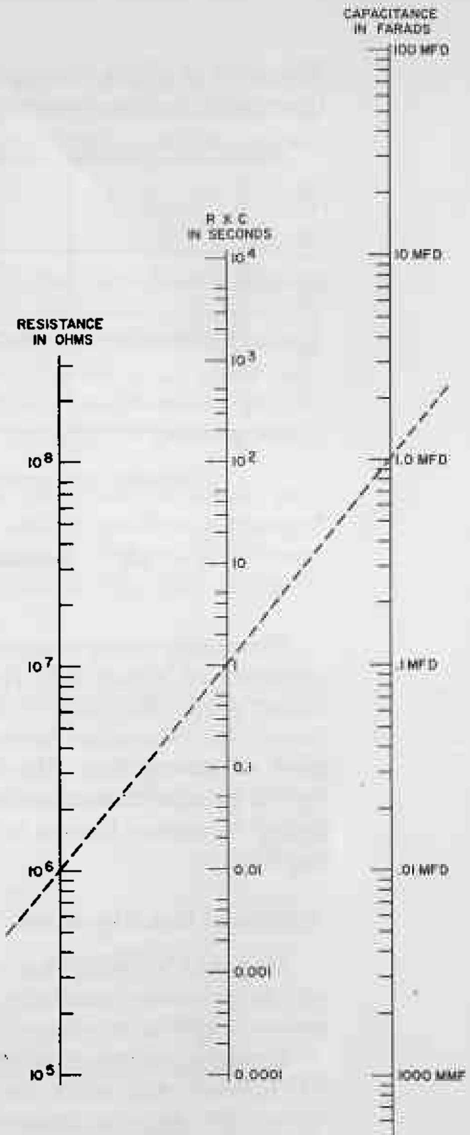
$$RC = \frac{K_2}{f}$$

$$RC = \frac{.5}{.5}$$

$$RC = 1$$

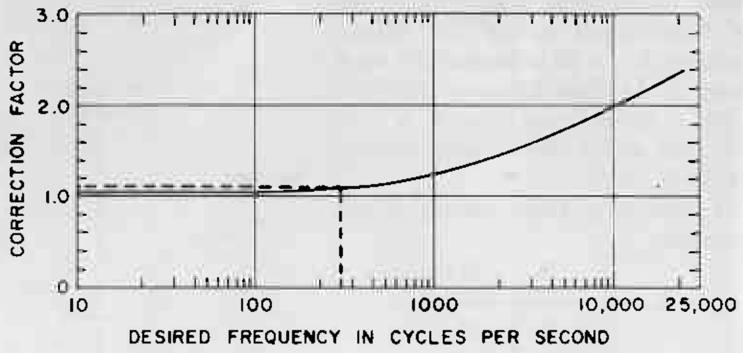
From the nomograph, Figure 2-4, we can then determine values for the resistor and capacitor. Thus our components in this low frequency oscillator are:

R = 1 megohm
and C = 1 microfarad



2-4 RC monograph

The point at which the capacitor begins to recharge is similarly lowered by this phenomenon.



2-5 Frequency correction factor

Frequency compensation may be easily accomplished by reference to Figure 2-5. To locate the appropriate correction factor read vertically from the desired frequency to the curve. The correction factor then read horizontally from this point of intersection. The desired frequency should be multiplied by this correction factor in order to obtain the "calculating" frequency for use in the above expression for determining RC.

Additional Considerations

It should be noted that variations in supply voltage will result in frequency instability. If this is of concern, a regulated power supply or a voltage regulator should be used.

Similarly variations in the resistance and capacitance of the RC network will affect the frequency. Therefore components having low or zero temperature and voltage coefficient characteristics should be used for optimum frequency stability.

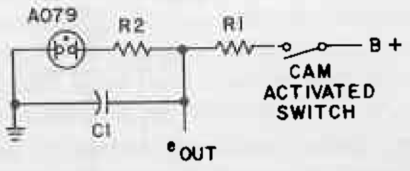
Finally, the active element, the cold cathode diode, is of critical importance. It should be recognized that a glow lamp intended primarily for indicator applications does not provide the type of reliable performance required in a precision switching device used in an oscillator having critical output characteristics.

Circuit Examples

The variety of individual circuits that have been designed using neon glow lamps for relaxation oscillator applications is virtually unlimited. A few typical examples are included here to demonstrate some of the variations possible. A quick perusal of these circuits shows that minor modifications can be made to the basic oscillator circuit in order to perform many different tasks.

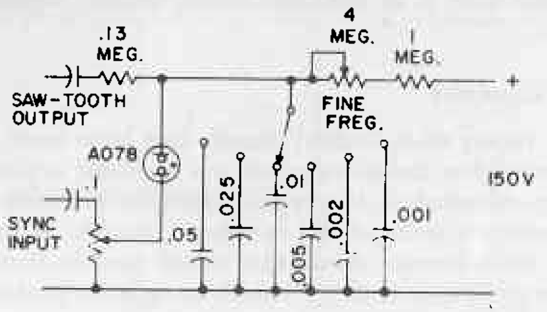
The addition of a cam activated switch and a resistor to a relaxation oscillator circuit can be used to produce a triangular waveform. (Figure 2-6) The symmetry of the output is seen if we let F equal the rotational speed of the cam activated switch.

Then, $F = \dfrac{1}{T}$ where R_1C_1 and C_1R_2 are equal to T. The switch could readily be replaced by any gating circuits such as multivibrators, phantastrons, and so forth. The lamp is our AO 79.



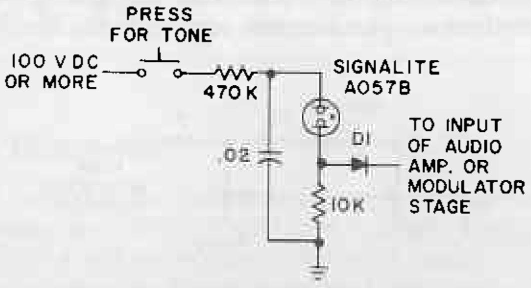
2-6 Circuit for symmetrical triangular waveform

A circuit producing a sawtooth waveform ideally suited for inexpensive, moderately linear time bases is shown in Figure 2-7. This specific circuit has been used as a source of time base voltage for the horizontal sweep of a small oscilloscope. With the components given, the frequency range is from about 5 cps to over 1,500 cps, which is well suited for oscilloscopes.



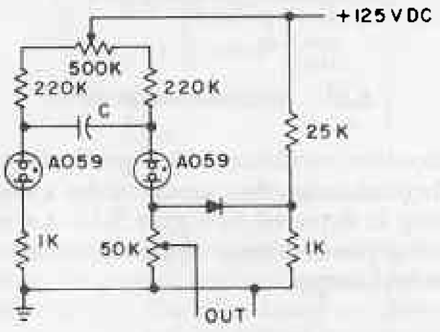
2-7 Circuit for inexpensive, moderately linear time base

Many variations on this circuit are possible and most of the parts are not critical. Changing the resistance or the capacitance, for example, would change the oscillator frequency. If only a small range of frequency is to be covered, a single capacitor could be used across the AO 78 neon lamp. If no synchronization is desired, the sync control could be left out, and the neon lamp connected to ground.



2-8 Simple tone generator

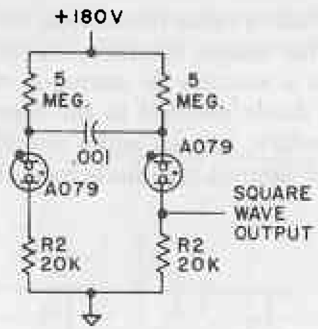
While neon lamp relaxation oscillators have been widely used as tone generators in electric organs, the circuit in Figure 2-8 shows a simple and inexpensive tone generator which could be incorporated into a radio transmitter for fast on-the-air tone identification. This simple oscillator easily may obtain operating power from a suitable dc source in the transmitter. The audio output is diode coupled to the input of the modulator stage, or if necessary, into an audio amplifier stage preceding the modulator. If desired, the diode may also be replaced by a capacitor.



2-9 Low frequency oscillator

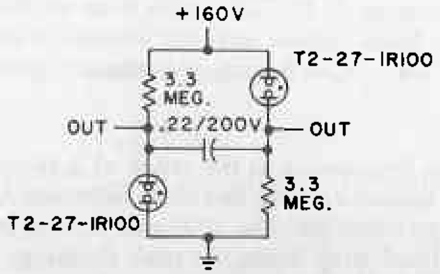
For very low frequencies in the range of 1-10 cps, the circuit shown in Figure 2-9, using two close tolerance AO 59 type lamps, does an excellent job. The 1000 ohm resistor in the cathode of the left hand lamp limits the peak discharge of the capacitor, C. The right hand lamp is adequately protected via the 50K resistor and the clamping diode with the 1K resistor.

Another dual relaxation oscillator, which operates as a multi-vibrator type oscillator, is shown in Figure 2-10. It can be used as a sequence flasher or as a source for square wave output. Output is obtained across resistor R_2. The positive peak is slightly curved, but with a diode clipper across R_2 the output is near a perfect square wave. With the components shown, the frequency is approximately 300 cps, but this can be changed by altering either the resistance or the capacitance.



2-10 Multivibrator oscillator

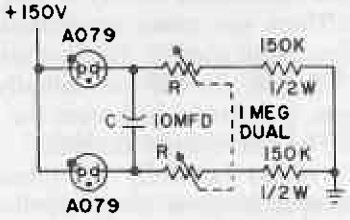
A dual relaxation oscillator which produces a differential saw-tooth voltage of twice that produced by a circuit using a single neon lamp is depicted in Figure 2-11. An advantage of this circuit is that power supply ripple and noise are reduced by the symmetrical output.



2-11 Dual relaxation oscillator

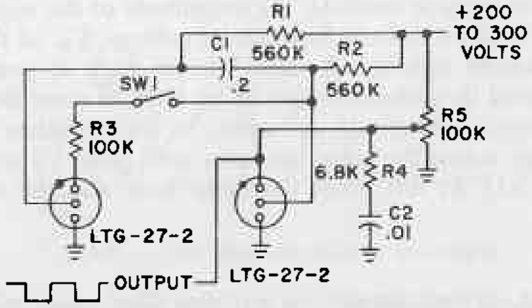
Another approach to generating a triangular waveform is produced with a dual neon astable oscillator as shown in Figure 2-12. The voltage across C closely approximates a linear triangular waveform. With the values shown the frequency is variable from approximately 0.005 cps to 0.5 cps, providing an extremely low frequency oscillator. The upper frequency limit is set by the ionization time of the neon glow lamps. The lower

frequency is limited mainly by the leakage resistance of capacitor, C, which should be a high quality paper or mylar capacitor. Using type AO 79 neon lamps the circuit operates reliably over a range of at least three decades with a single control. Capacitor, C, may be switched to obtain a very wide range circuit.



2-12 Dual astable oscillator

The circuit in Figure 2-13 is an interesting variation on the oscillator theme for several reasons. It produces a square wave output at about 50 cps. The neon lamps are three-element cold cathode tubes instead of the standard two-element type. (For a discussion of three-element lamps, see Chapter V). The cycle is self-completing when the switch SW1 is closed. Should neon #2 be in conduction when switch SW1 is closed, neon #2 will continue to time out and turn on neon #1. Neon #1 will then inhibit neon #2, thus preventing the beginning of the next cycle.



2-13 3-element lamp oscillator