Chapter III

GLOW LAMPS AS FREQUENCY DIVIDERS

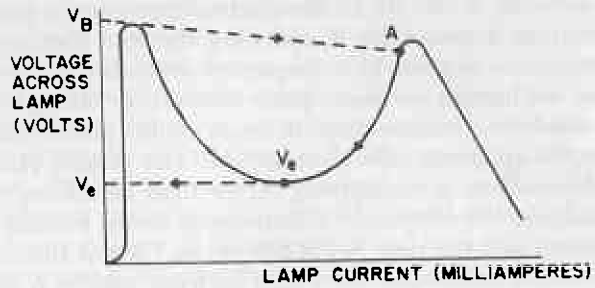
The basic characteristics of the neon glow lamp relaxation oscillators also lend themselves ideally to the function of frequency dividing. There are many applications in electronics for this classic glow lamp circuit. To illustrate how the glow lamp serves this function, we will use, initially a discussion of the electronic organ, a system which uses the glow lamp both as an oscillator and as a frequency divider.[1]

The electronic organ faithfully reproduces a variety of waveforms at different frequencies to simulate electronically the range of tones characteristic of other instruments, creating the same effect as is accomplished in a modern pipe organ. The frequency dividers have a division ratio of 2 to 1, so that the tone outputs are always one octave below the preceding stage. The sawtooth output waveform is rich in harmonic output, so that with proper filtering the tone characteristics of other instruments can be simulated.

When used as a relaxation oscillator in the organ, advantage is taken of the bistable characteristics of the glow lamp. That is, when it is off, it will stay off until a critical voltage is exceeded, then turn on. When it is on, it will stay on until the lamp current is reduced below a minimum current.

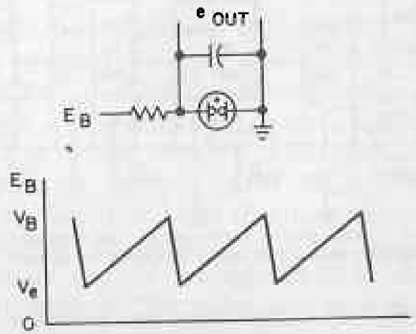
For the lamp to oscillate, the magnitude of the supply voltage, E_B, must exceed the breakdown voltage, V_B, of the lamp. For maximum stability, it should be as high as practicable. The value of the resistance should be 470K or more depending on the supply voltage. In operation, as the capacitor charges, the voltage across the lamp increases until point V_B is reached. (Figure 3-1) At this point the lamp fires, and the capacitor

1. Bauman, Edward, Signalite Inc. — "Neon Glow Lamps as Oscillators and Stable Frequency Dividers," *Signalite Application News*, Vol. 2, No. 3, and "Neon Glow Lamps: Stable Oscillators and Frequency Dividers." *Systems Design*, June 1965.



3-1 Bistable characteristics of glow lamps

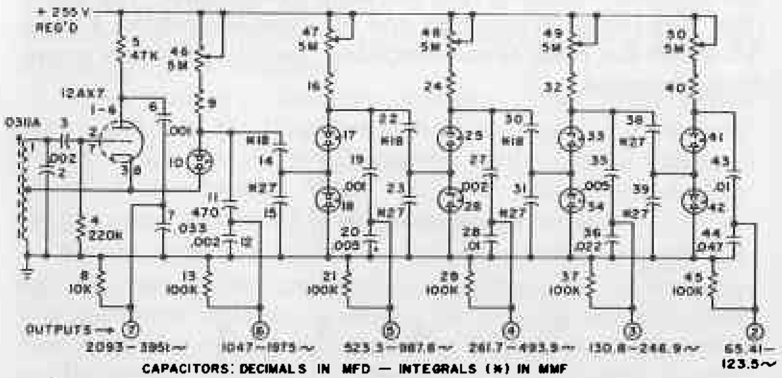
discharges through the lamp, increasing lamp current to point A. As the capacitor discharges rapidly, voltage and current follow the curve until point V_e is reached. At this point, since the current flowing from E_B through the resistor R is below the critical current of the neon lamps and there is no other means available for the voltage to rise, the lamp extinguishes. The capacitor then begins to recharge, and the cycle is repeated. Figure 3-2 shows the basic circuit simplified, and the sawtooth waveform generated.



3-2 Oscillator circuit and waveform

A refinement of this circuit is used to produce the frequency dividers which create additional octaves. Frequency dividers of this nature have worked successfully in divisions of any integral between 2 and 10. In the electric organ one is primarily interested in divisions by 2, reducing the tone frequency in each stage one octave. This frequency division must be exact because the human ear hears pitch intervals or changes in the same non-linear fashion that it hears audio power changes. That is, the apparent difference between two pitches (frequencies) depends on a multiplying rather than an adding factor. For example, the frequency difference between middle A (at 440 cycles) and the next A (at 880 cycles) seems the same to the ear as the interval of difference between middle A and the next lower A (at 220 cycles). Therefore, to create the next lower octave, once a stable frequency has been established, all that has to be done is to divide the frequency exactly in half.

In Figure 3-3 is shown a schematic diagram of a tone generator. One triode tube, half of a 12AX7, is used as the master oscillator for stability. This circuit is one whose stability has been proved for many years.



3-3 Electronic organ tone generator

A typical stage is one producing output 5 (523.3 cycles, C above middle C.) This consists of a classical neon lamp relaxation oscillator comprising a resistance (16 and 47 in series) in series with a neon lamp (actually two lamps in series) between

E_B and ground, with a capacitor (19 and 20 in series) across the lamps. The frequency of free-running oscillation for a given E_B voltage and lamp type is determined by the values of R and C and will be slightly lower than 523.3 cycles. The lamp used throughout is the circuit component, type AO 78, with a breakdown voltage of 66 to 74 vdc, and a maintaining voltage of 52 to 59 vdc. Its leakage resistance is extremely critical in this circuitry since variations in it would entail special selections of the timing resistor, R. Specifications call for a minimum leakage resistance of 8,000 megohms, and the average of the lamps obtained is about 20,000 megohms, giving a comfortable margin to work with.

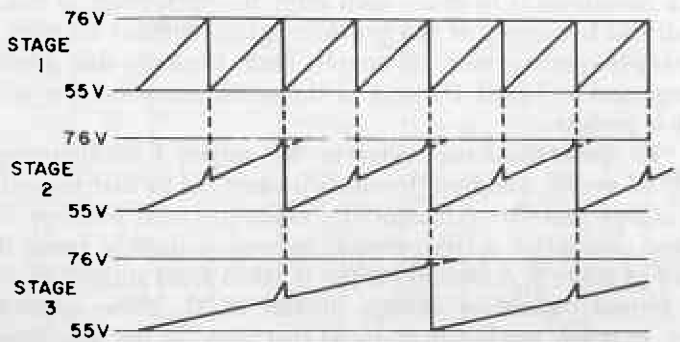
Output from this stage is taken through a capacitive voltage divider 19-20, which also acts as an impedance transformer. The output of terminal 5 is a low impedance output, therefore minimizing the loading effect on the relaxation oscillator.

In the specific circuit employed there are some significant deviations from the standard neon oscillator. The purpose of the deviations is to cause each stage to synchronize at exactly half the frequency of the previous stage, without causing the lower-frequency tone to couple back through the previous stage and be heard. Because of the synchronization, the stability is perfect.

To understand this, refer to the output 4 oscillator stage (261.7 cycles, middle C), which is identical to that for output 5 except that the values of the capacitors and resistors have been chosen for a free-running frequency slightly lower than half of stage 5. A second output is taken from stage 5 through a second capacitive voltage divider 22-23. These capacitors are so much smaller than 19-20 that they do not significantly affect the frequency of oscillator 5. When lamps 17-18 fire, a negative pulse is applied through 22-23 to the junction of lamps 25-26 in stage 4. This pulse voltage is divided approximately in two through capacitors 22-23.

Operation is as follows: the E_B voltage being applied to stage 4 starts the standard neon oscillator build up. When the negative pulse is injected from stage 5, this voltage plus the voltage across the lamp at the time is not great enough to fire the lamp. (See Figure 3-3) When the second pulse is injected the voltage across the lamp has built up to a point close to breakdown voltage of the lamp. The summation of the pulse peak voltage from stage 5 plus the existing voltage is sufficient to cause the lamp to break down. This transmits positive voltage to lamp 26 which also fires. Thus, the lamps fire on every alternate firing of the previous stage and at the point when the condenser is almost charged, thereby dividing the frequency exactly in half. This produces a tone one octave below stage 5. The same action takes place with every following stage.

The principle of frequency division in the tone generator is shown in a simplified form in Figure 3-4. Assuming breakdown voltage is 76 volts and maintaining voltage is 55 volts, the glow lamps in Stage 1 fire on each cycle, creating the sawtooth waveform indicated. The pulse from the lamp firing each cycle is injected to the following stage, increasing the voltage across



3-4 How frequency dividing is accomplished

the lamps by the incremental peak. The second pulse increases the voltage across the lamps to the breakdown voltage and the lamps fire. (Note that this must occur before the voltage build-up in the capacitor reaches the breakdown voltage of the lamp, as indicated by the continuation of the dashed line beyond the incremental peak, otherwise all synchronization would be lost.)

As shown here, stage 2 creates the same effect on stage 3, again dividing the frequency exactly in half. This process continues through the desired number of octaves in the organ.

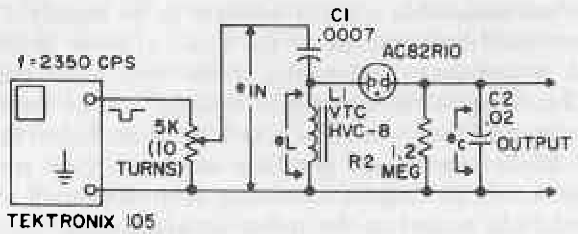
A special point about this circuit is important. It is most undesirable when playing a particular tone to hear anything of the tone an octave lower. While something of a higher octave tone is not noticeable since it appears to be merely a part of the harmonic development of the tone, a lower octave component is extremely noticeable. If the sync-pulse path from stage 5 to stage 4 could conduct equally well in the back direction, stage 4 tone would be heard in output 5. But for pulses at the 25-26 junction to get into output 5, they must pass through a voltage divider consisting of a very small capacitor (22 and 19 in series) as the series leg and a very much larger capacitor, 20, as the shunt leg. The voltage division is 5,000/22. Thus, the backfed tone is inaudible.

This organ is completely an electronic device. There are 12 tone generators of the type described above, one for each of the 12 notes of the chromatic scale. Through the use of a basic oscillator and five frequency dividers as described, it is possible to cover six complete octaves. The use of glow lamps as sawtooth oscillators and stable frequency dividers provides stable operation where, if there were variations in performance, the results would be noticeable and very unpleasant. This high reliability is obtained with a relatively inexpensive component. This application can be used in many other areas of operation, such as dividing a frequency standard, or as a source of accurate timing signals.

Very often in electronic systems, a need arises for an audio voltage to be divided into equal steps. Staircase generators normally used for this purpose generally involve 1 or 2 transistors and perhaps a dozen other components. It is possible through the use of neon glow lamps to reduce the number of components and produce a circuit which serves a double purpose—a staircase generator and a frequency divider.[2] When function-

2. Cistola, A. B., IBM Space Guidance Center, "A Unique Frequency Divider and Staircase Generator," *Signalite Application News*, Vol. 3, No. 4.

ing as a frequency divider the circuit separates out the odd number of pulses, for instance, 3's, 5's, 7's, etc. Thus the circuit eliminates the need for decoding logic usually associated with binary systems in order to separate out odd counts.

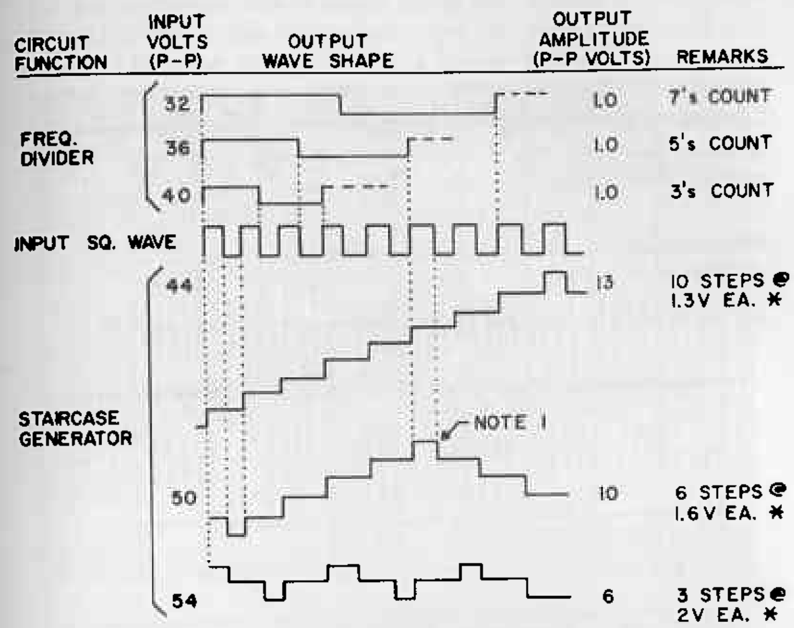


3-5 Staircase generator

The basic circuit is shown in figure 3-5. The input potentiometer R1 is a 10 turn pot controlled by a vernier dial. Its purpose is to supply a variable amplitude of the input square wave voltage to the series-resonant L1, C1 combination. The inductor L1 should have a high "Q" factor since the voltage which is developed across L1 must be high enough to fire the neon lamp. The combination of R2 and C2 serve as an integrator, aside from the normal duty of R2 as a current limiter.

The circuit is capable of operating in two distinctive modes: namely, as a frequency divider and as a staircase voltage generator. The mode of operation is determined by the range of the input voltage (See Figure 3-6)

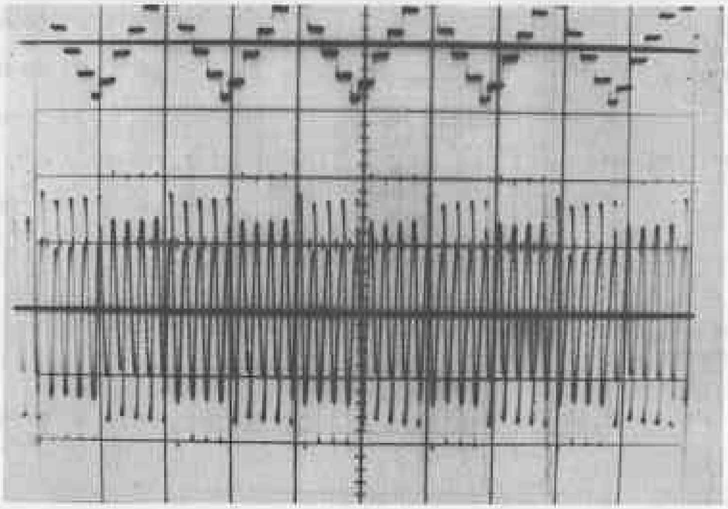
When a square wave voltage on the order of 54 volts or so is applied to resonant circuit L1, C1 the voltage across L1 is sufficiently high to cause current pulses to flow through R2 due to the firing of the neon lamp. Capacitor C2 will accumulate a charge of such polarity that it will be series-opposing the input voltage of breakdown to occur in the one direction, but series-aiding the input voltage for breakdown to occur in the opposite direction.



3-6 Mode of operation – Staircase Generator

Assuming that breakdown is occurring on the *positive going* pulses, the immediate result is that no current will flow through the lamp on negative going pulses. (See Figure 3-7) For every positive going input pulse an additional charge will accumulate on C2 until the voltage across C2 in series-aiding with the *negative going* voltage across L1 is enough to cause a discharge through the lamp in the opposite direction. When this happens all the negative going input pulses will reduce the accumulation of positive charges on C2, go through a zero level and build up in the negative direction until a point is reached where C2 will again discharge through the lamp, with the series-aiding *positive going pulses.* (See Figure 3-8)

This cycle will recur at a definite time interval. The number of step levels in a staircase is changed by changing the pot



3-7 Oscilloscope trace – positive going pulses

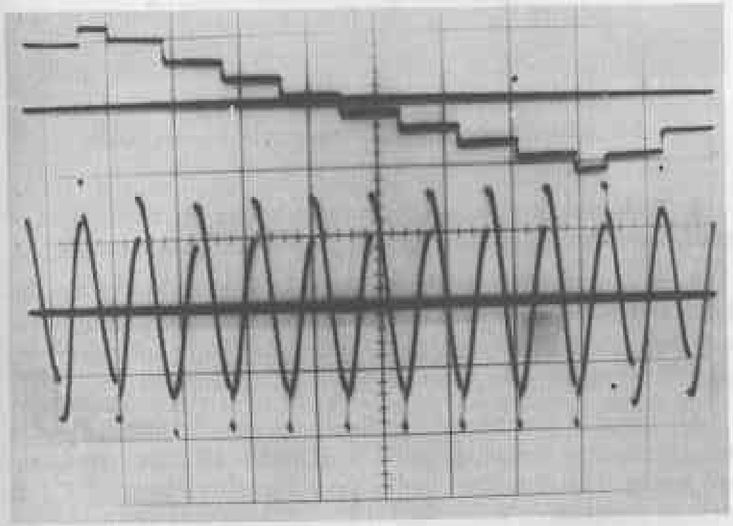
setting in *small* increments. (See Figure 3-6) As the input voltage is reduced various staircases of increasing step levels and peak-to-peak amplitudes will be generated. A point will be reached, however, where a further decrease of input voltage will not be sufficient to cause lamp current to flow on every positive or negative going cycle. This is the voltage at which the circuit will start operating in the frequency divider mode. (See Figure 3-9)

When the input voltage across L1 and C1 is in the order of 40 volts, the voltage across L1 will take a number of cycles to build up to a sufficient level to fire the lamp. The L-C circuit acts as a heavy load immediately upon application of the input signal and requires some time constant to build up. After about 1-1/2 input cycles have occurred the voltage across C2 will be sufficient to fire the lamp. A charge will develop across

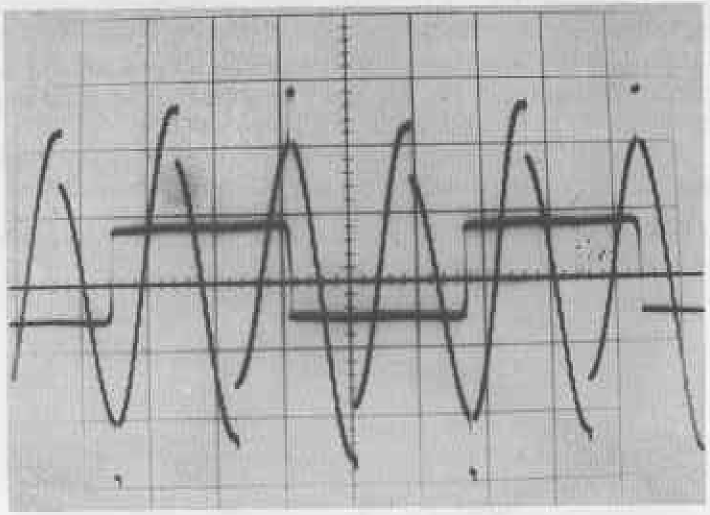
C2 due to current flow through R2, in the order of 1 volt (peak-to-peak). When the lamp discharges the voltage across L1 is lowered to some voltage which is below the maintaining voltage of the lamp. After 1-1/2 more input cycles have occurred again, the lamp will fire in the opposite direction causing a 3 to 1 count of the input square wave to be developed across C2. Frequency division by 5's, 7's, and 9's is obtained by reducing the input voltage through R1 in small increments.

In order to insure proper operation of this circuit the neon lamp characteristics should meet the following specifications:

1. It should have a large difference between breakdown and maintaining voltages.



3-8 Oscilloscope trace – generation of staircase



3-9 Oscilloscope trace – frequency divider mode

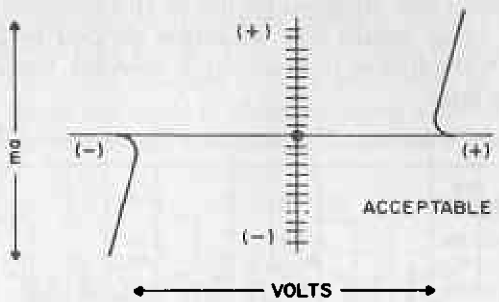
2. It should be checked on a curve tracer for cleanliness of breakdown curve. (It should not display an erratic curve.)

3. It should have as close tolerance as possible on breakdown and maintaining voltage levels in both positive and negative directions. Otherwise there will be a slight misalignment between positive going and negative going step levels.

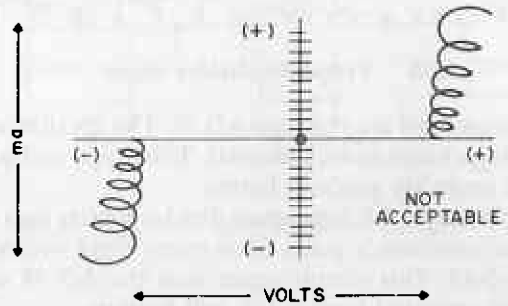
All three of the above specifications can be checked on a transistor curve tracer. Figures 3-10 and 3-11 show good and bad traces. The inductor should have a quality factor ("Q") as high as possible.

The signal generator should have a sufficient amount of drive to be able to handle loading of circuit.

An interesting variation on the conventional frequency dividers used in electronic organs uses transistors for coupling



3-10 Transistor curve trace – acceptable

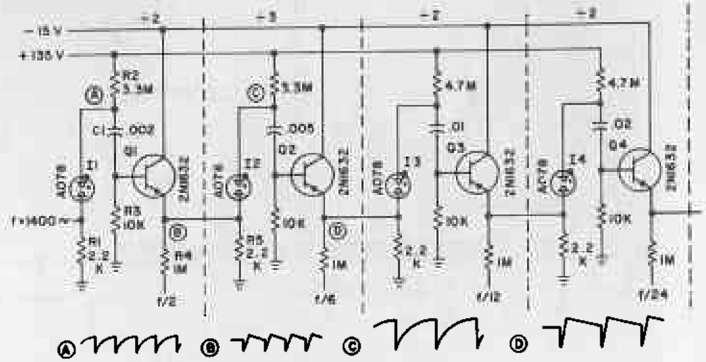


3-11 Transistor curve trace – unacceptable

the signals from one stage to the next and also for supplying an isolated output signal. (Figure 3-12) The first stage, a relaxation oscillator, has its natural frequency determined by R_2 and C_1. The familiar sawtooth waveform is shown at A. The synchronizing sine wave is a low impedance generator in series with I_1. The sine wave synchronizes the first stage by advancing or retarding the discharge of I_1 because it adds or subtracts itself to the ionizing potential.

Succeeding stages have natural frequencies lower than their synchronized frequencies because the negative pulse at B supplies an increased voltage to I_2, firing it prematurely.

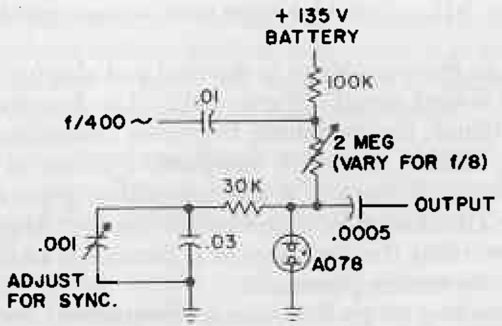
The circuit was intended for use as an electronic organ tone generator which would have all stages divided by 2. The second stage was adjusted to divide by 3, however, simply to prove it could be done.



3-12 Frequency divider circuit

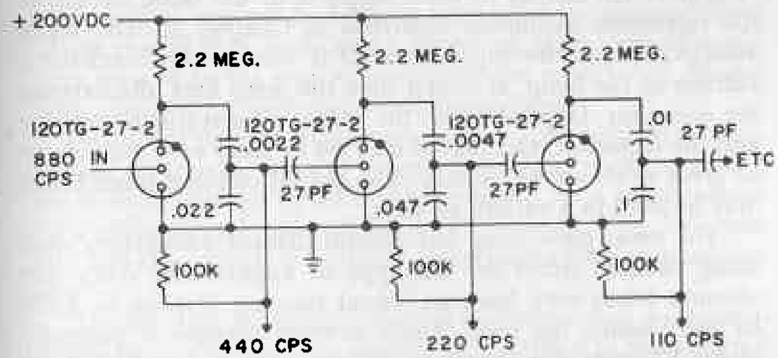
The lamps used are the type AO 78. The 2N1632 was selected for its high breakdown potential. Tube-type cathode followers would probably perform better.

A simple scale-of-8 frequency divider which uses a 400 cps source and produces a pulse once every eight cycles is shown in Figure 3-13. This circuit again uses the AO 78 neon lamp and can be operated from a 135 volt battery.



3-13 Scale-of-8 frequency divider

Another approach to frequency dividers using a 3-element trigger tube, the type 120TG-27-2 cold cathode triode, is shown in Figure 3-14. (See Chapter V for a discussion of 3-element lamps.) A linear sawtooth is obtained using a 200 vdc power supply which powers the master oscillator and other auxiliary circuits.



3-14 3-element lamp frequency divider