Relaxation Oscillators

By Forrest M. Mims III

Relaxation oscillators are common in nature and in living systems. Consider a branch hanging in a swift-moving stream. As the end of the branch is carried downstream, the tension in the branch is increased. Eventually, the tension exceeds the force of the moving water. The branch then relaxes by swinging back to its original position. The cycle is then repeated. Another example is a leaf that gradually fills with rain water. When the weight of the water exceeds the ability of the stem to hold the leaf upright, the leaf tilts over and dumps its liquid cargo. It then returns to its original position and begins collecting yet another load of water until the cycle is repeated.

On a grander scale, a lightning stroke is the visible evidence of the natural relaxation oscillator formed by a thunderstorm. The lightning stroke dissipates the electrical charge accumulated within the cloud. As the charge again builds up, another stroke occurs, and the cycle continues.

Electronic Relaxation Oscillators

The electronic analog of these natural oscillators is the relaxation oscillator, one of the most important basic electronic circuits. Most textbooks define a relaxation oscillator as a circuit that automatically switches between two stable states. Unlike sinusoidal oscillators, relaxation oscillators generate square or sawtooth waves. If the square waves are very brief in duration, they are usually called spikes.

Relaxation oscillators are used to generate repetitive pulses that can control a simple flashing light or a complex sequential logic circuit. They are also used in electronic music, laser pulse generators, television sweep circuits, and function generators to name just a few.

There are many kinds of electronic and optoelectronic relaxation oscillators. The ruby laser is one of the most interesting. When light from a flashlamp stimulates more than half of the chromium atoms within the ruby to a higher-than-normal energy level, optical amplification can occur. This happens when photons, which are emitted when excited atoms fall back to their normal energy level, stimulate additional atoms to release photons. The result is a brilliant burst of red light through one of the laser's feedback mirrors. Soon there are fewer excited than unexcited atoms, and the laser stops emitting light until light from the flashlamp stimulates additional atoms to repeat the cycle.

Most ruby lasers are excited by a flashlamp pulse lasting a few milliseconds. A close examination of the laser output during this period will reveal a series of closely-spaced spikes, demonstrating that this laser is indeed a relaxation oscillator.

The simplest purely electronic relaxation oscillators have a period determined by the values of a single charging resistor and a single capacitor. In this column several of these very simple RC relaxation oscillators will be examined. Then both hardware and software versions of digitally-synthesized relaxation oscillators will be presented.

Basic Relaxation Oscillator

Figure 1 shows a minimum configuration RC relaxation oscillator. In operation, capacitor *C1* is gradually charged through series resistor *R1*. When the voltage stored in the capacitor reaches the switching potential of an electronic switch connected across the capacitor, *C1* discharges through switch *S1* and load resistor *R2*. The circuit is said to have "relaxed." The capacitor now begins charging again until the cycle repeats, with *R1* controlling the charging time of *C1* and, hence, the circuit's frequency of oscillation.

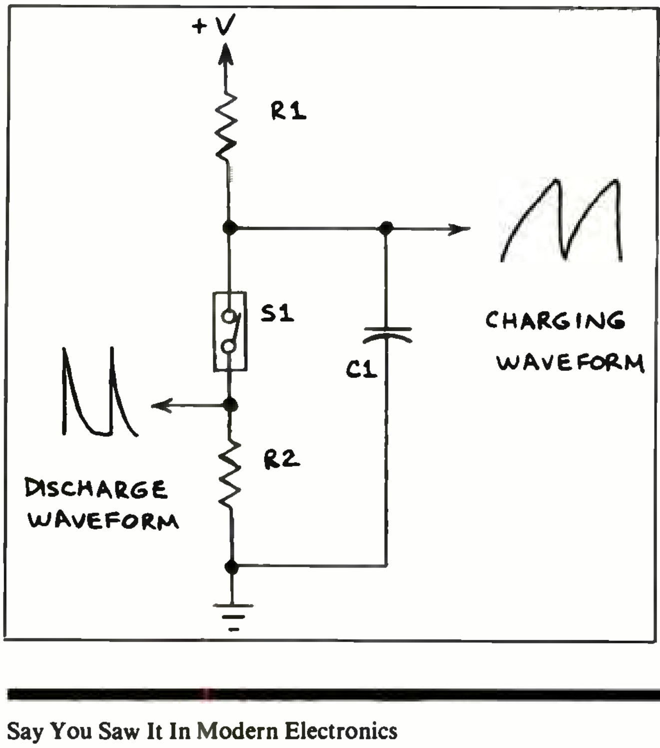
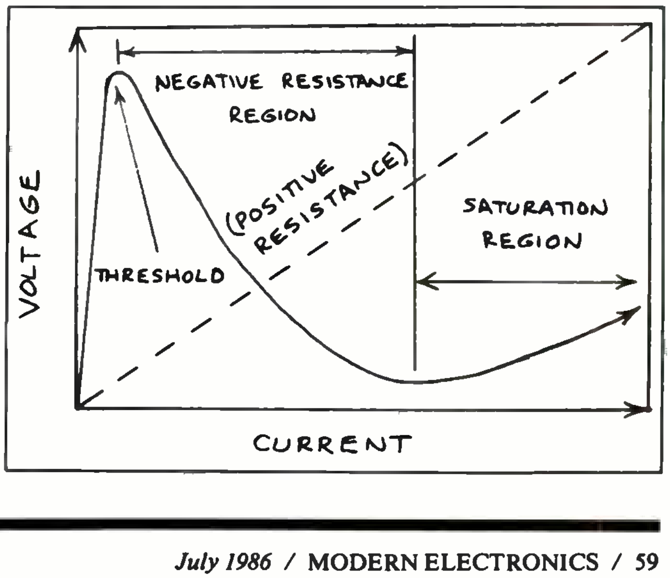


Fig. 1. Basic relaxation oscillator circuit.

Fig. 2. Negative-resistance properties.



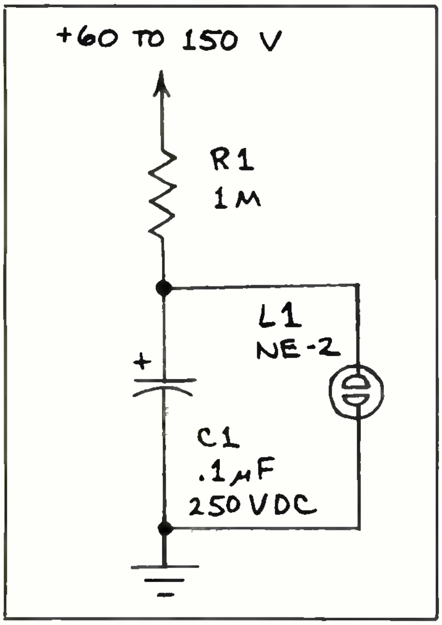


Fig. 3. Neon-lamp relaxation oscillator.

Figure 1 also shows the waveforms generated by an RC relaxation oscillator. The charging waveform, which resembles a ramp or sawtooth, is a standard capacitor charging waveform. The discharge waveform is a fast risetime spike. If the on-resistance of switching element *S1* is low, current switched through *S1* and *R2* can be as high as 10 amperes or more. If *C1* is very small in value, the duration of the spike across *R2* can be as brief as a few tens of nanoseconds (50 nanoseconds when *C1* is 0.01 microfarad).

A simple way to monitor the parameters of a relaxation oscillator is to insert a 1-ohm current-monitoring resistor between *R2* and ground. An oscilloscope probe can then be connected across the resistor. According to Ohm's law, the current through a resistor is the voltage across the resistor divided by the resistance of the resistor in ohms (I = E/R). Therefore, when *R* is 1 ohm, the current through *R* equals the voltage across *R*. In other words, a 5-volt spike across a 1-ohm current monitor means a current of 5 amperes through the resistor during the spike.

Incidentally, an oscilloscope is very helpful when adjusting most relaxation oscillators or evaluating their performance, particularly those oscillators with adjustable parameters. Simply by watching the shape of the waveform(s), it is possible to easily optimize the performance of a particular oscillator circuit.

Negative Resistance

The switching device in Fig. 1 was d scribed above as turning on when the a plied voltage exceeded a certain value. Th characteristic is known as *negative r sistance*. Several classes of electronic con ponents exhibit negative resistance. No mally, their resistance is very high, but becomes very low when the potenti across the device reaches a point variou ly known as the breakdown, avalanche, c switching voltage.

Figure 2 illustrates the electrical prope ties of a typical negative resistance devic From this curve it is clear that the curre through the device remains very small a the voltage across the device is increase In other words, the resistance of the devic is very high. When the voltage reaches critical threshold point, however, the cu rent through the device rapidly increase Now the resistance of the device fal dramatically. This is the negative-r sistance region. If the forward curre through the device increases beyond a ce tain point, the device is said to be sa urated. The resistance of the device the begins to increase. Contrast this actic with that of a positive-resistance devic such as an ordinary resistor, illustrated b the dashed line in Fig. 2.

Negative resistance is a feature share by various electronic components tha have little else in common. For exampl the neon glow lamp, four-layer diod SCR, and unijunction transistor all exhib negative resistance.

Neon-Lamp Oscillator

Figure 3 is the schematic diagram for th familiar neon-lamp relaxation oscillat circuit. Here, the neon lamp serves as th switching element. A typical neon lam has an ionization (turn-on) potential c about 60 volts. When the charge on C reaches this value, the gas inside the lam ionizes and provides a low-resistance pat for the charge stored in *C1*. The lam glows until the charge on *C1* falls below th point at which ionization is sustained.

The power supply for this circuit can b one or two 67.5-volt batteries or a dc-to-c converter. The latter can be made by switching a current through the 6.3-volt winding of a filament transformer. Use a 1N4004 or similar diode to transform the alternating current at the transformer's secondary to pulsating direct current. For additional information, see *Engineer's Mini-Notebook: 555 Circuits* (Forrest M. Mims, III, Radio Shack, 1984, p.32).

With the values shown in Fig. 3, the neon lamp will flash a few times a second. Increasing the value of *R1* or *C1* will slow the repetition rate. Several flasher circuits can be powered by the same power supply. If slightly different values for *R1* and *C1* are used, the lamps will flash at different times, creating an attention-getting effect.

Caution: Use care when operating this circuit and any circuit powered by a high voltage supply. See the caution note under the avalanche transistor oscillator circuit described below.

Four-Layer Diode Oscillator

The four-layer diode is a pnpn device that closely resembles a silicon-controlled rectifier (SCR) without a gate electrode. Normally, the device exhibits a very-high resistance. When the forward voltage across the diode exceeds a certain threshold, the diode switches on and permits a current to flow. The diode will remain switched on even when the forward voltage falls below the threshold value so long as the forward current exceeds a value called the holding current. Depending on the device, the holding current can range from 0.1 to 50 milliamperes.

A simple four-layer diode relaxation oscillator configured as an LED driver is shown schematically in Fig. 4. Depending on the setting of *R2*, this circuit will oscillate at a frequency of up to a few tens of kilohertz. In operation, *C1* charges through *R1* and *R2* until its charge reaches the avalanche voltage of *D1*. When *D1* switches on, *C1* discharges through *D1* and the LED. Then *D1* switches off and the cycle is repeated. Current pulses through the LED will have a duration of around 50 nanoseconds at up to an ampere or more.

An advantage of the Fig. 4 circuit is its extremely small size. Excluding the power supply, the entire circuit can be assembled in a space the size of a thimble. A possible

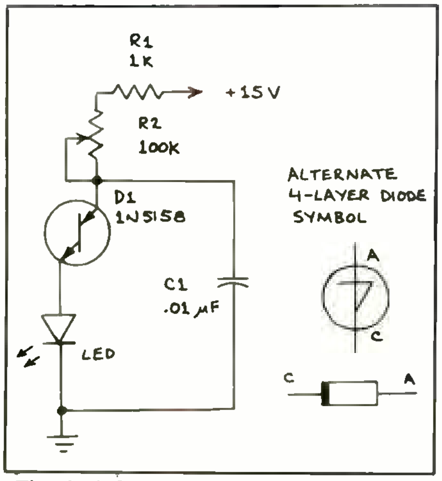


Fig. 4. A four-layer-diode relaxation oscillator.

disadvantage is that the four-layer structure of *D1* offers a somewhat higher on-resistance than that of a transistor operated in the avalanche mode. Unless the highest possible current is required, this should not normally pose a major drawback. Another possible disadvantage is that four-layer diodes can be hard to find. Many different four-layer diodes will work in this circuit. Of course the supply voltage will have to exceed the breakdown voltage of the selected diode or the circuit will fail to oscillate. I have used four-layer diodes made by Motorola, ITT and American Power Devices. You will have to contact electronics distributors that represent these companies.

SCR Oscillator

Normally, the SCR is triggered by an external pulse at its gate electrode or, in the case of the light-activated SCR (LASCR), by a flash of light. Figure 5 shows an SCR that is self-triggered and operates as a relaxation oscillator. Though the gate lead is used, the gate does not trigger the SCR in this circuit. Instead, the pnpn SCR is operated much like a four-layer diode.

In operation, *C1* charges through *R1*. When the SCR's anode-cathode breakdown voltage is reached, the device suddenly switches on and permits *C1* to discharge through itself and the LED. After *C1* is discharged, the SCR switches off, and the cycle is repeated.

When this circuit is first operated, *R2* should be set to its center point. After power is applied, *R2* should be rotated in either direction until the circuit begins to oscillate. This setting can be optimized with the help of an oscilloscope connected across *C1* or a small-value resistance between the LED and ground. The frequency of oscillation can be made variable by substituting a 100,000-ohm (100k) potentiometer for *R1*.

I have used various SCRs and LASCRs in this circuit. Since different SCRs may have differing avalanche voltages, you may have to experiment with the supply voltage to make sure the circuit will oscillate when a particular SCR is used.

UJT Oscillator

The unijunction transistor (UJT) bears little resemblance to a conventional bipolar (pnp or npn) transistor. Though both have three leads, the bipolar transistor has two pn junctions, the UJT only one. A UJT is formed from a small bar of n-type silicon. Leads attached to opposite ends of the bar are designated base 1 and 2 (B1 and B2). A third lead, the emitter (E), is attached to the side of the silicon bar near the base-2 electrode. Where the emitter joins the silicon bar a pn junction is formed.

Normally, the resistance of the silicon bar (base 1 to base 2) ranges from around 4,000 to 10,000 ohms. When the voltage applied to the emitter terminal exceeds a critical point, the emitter-to-B1 junction conducts and the resistance of the silicon bar falls to a few tens of ohms. This negative-resistance characteristic makes the UJT well-suited for relaxation-oscillator applications.

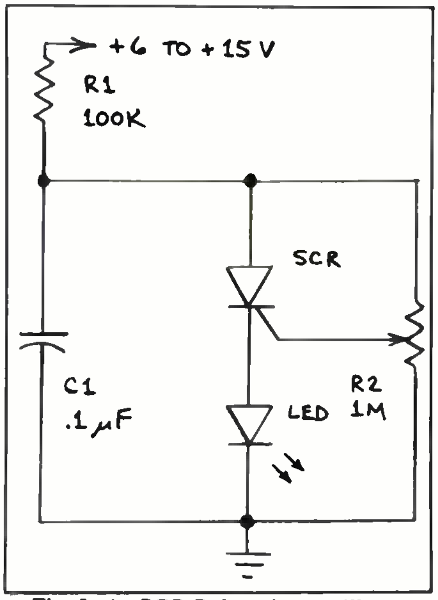


Fig. 5. An SCR Relaxation oscillator.

A simple UJT oscillator that drives a small 8-ohm speaker is shown schematically in Fig. 6. In operation, *C1* charges through *R1* until *Q1*'s emitter-to-B1 junction switches on and discharges *C1* through the speaker. The emitter-to-B1 junction then resumes its high resistance state until *C1* is again charged and the cycle repeats. The frequency of oscillation can be altered by varying *R1*.

Besides the small speaker shown in Fig. 6, the UJT oscillator can flash an LED, function as a pulse generator, actuate a relay, or trigger and SCR. By using a very-large-value capacitor for *C1*, the circuit can function as a timer having a period of half a minute or so.

Avalanche Transistor Oscillator

When the voltage across the collector-to-emitter junction of an npn transistor reaches a certain threshold, the device will switch on without the need of a base signal. What's more, it will switch so fully on that its resistance may be as little as an ohm or so. This is significantly lower than any of the solid-state negative-resistance devices described above. When a transistor is switched in this fashion, it is referred to as an avalanche transistor. Certain transistors are designed specifically for operation in the avalanche mode. Many ordinary silicon switching transistors can also be operated in the avalanche mode.

A relaxation oscillator designed around a 2N2222 transistor operated in its avalanche mode is shown schematically in Fig. 7. The avalanche (or breakdown) voltage of the 2N2222 is very close to that of the NE-2 neon lamp, which is generally around 60 volts. When the charge on *C1* reaches this value, the 2N2222 will switch on and dump the capacitor's charge through the LED. The transistor will then resume its high-resistance state until *C1* is again charged to its avalanche voltage.

Since this circuit requires a fairly high supply voltage, its practical applications are limited. Among its most important applications is service as a high-current driver

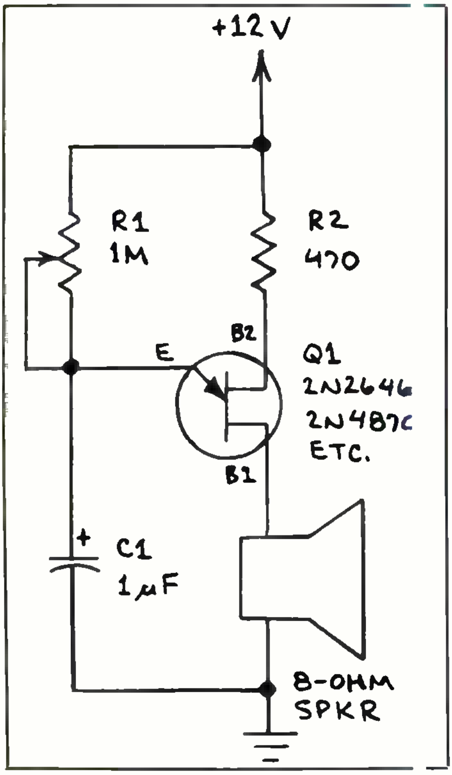


Fig. 6. A UJT relaxation oscillator.

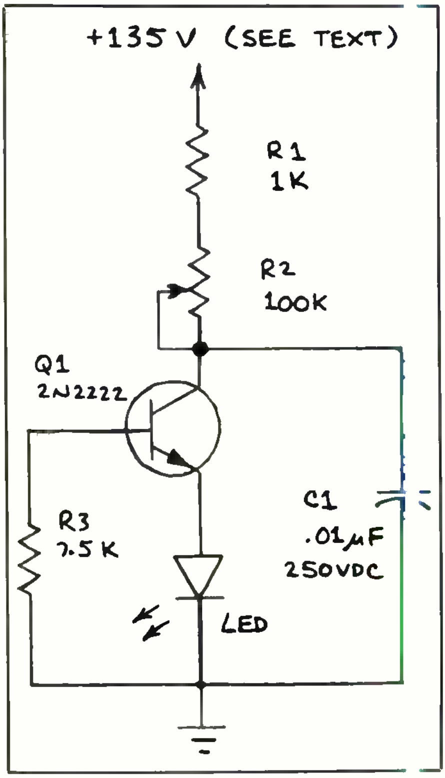


Fig. 7. An avalanche transistor relaxation oscillator.

for single-heterostructure laser diodes. These lasers emit up to several watts of near-infrared radiation when driven by current pulses having an amplitude of 10 amperes or more. These lasers cannot be operated continuously at room temperature but must be driven by pulses having a duration of no more than a few hundred nanoseconds. The circuit in Fig. 7 delivers 50-nanosecond pulses having an amplitude of up to 10 amperes at a rate of up to a few thousand hertz.

Caution: Use care when powering this circuit. Two 67.5-volt batteries in series will provide a good power source. A single 67.5-volt battery might work if the switching voltage of the 2N2222 happens to be below around 60 volts. A simple dc-to-dc converter, such as the one mentioned under the neon-lamp oscillator above, will also work. Whether a battery or dc-to-dc converter supply is used, it is important to remember that the supply voltage is capable of delivering an electrical shock. While the shock alone might not necessarily be dangerous, muscular contraction caused by the shock might cause an injury.

Optoelectronic Oscillator

The circuit in Fig. 8 is included here to illustrate how negative resistance can be simulated by combining two or more components. The key to the circuit is an optoisolator. Initially, the phototransistor within the optoisolator is off. As the charge on *C1* gradually increases, current through *Q1* and the LED in the optoisolator increases. Eventually, the radiation emitted by the LED is sufficient to switch on the transistor in the optoisolator, causing *C1* to discharge, and the cycle begins anew.

The Fig. 8 circuit can be a little tricky to adjust at first. For best results, use a 1-microfarad capacitor for *C1* and set *R1* to about 5,000 ohms (5K). Then adjust *R3* until the circuit begins to oscillate. Connect an oscilloscope across *C1* to monitor oscillation. If you don't have a scope, you can verify that the circuit is working by inserting a small 8-ohm speaker between the emitter of the optoisolator transistor and ground.

Digital Logic Oscillator

A simple feedback loop can transform a

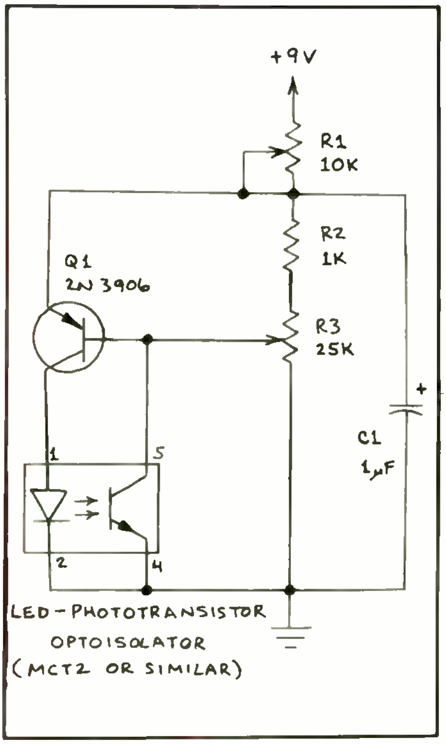


Fig. 8. An optoelectronic relaxation oscillator.

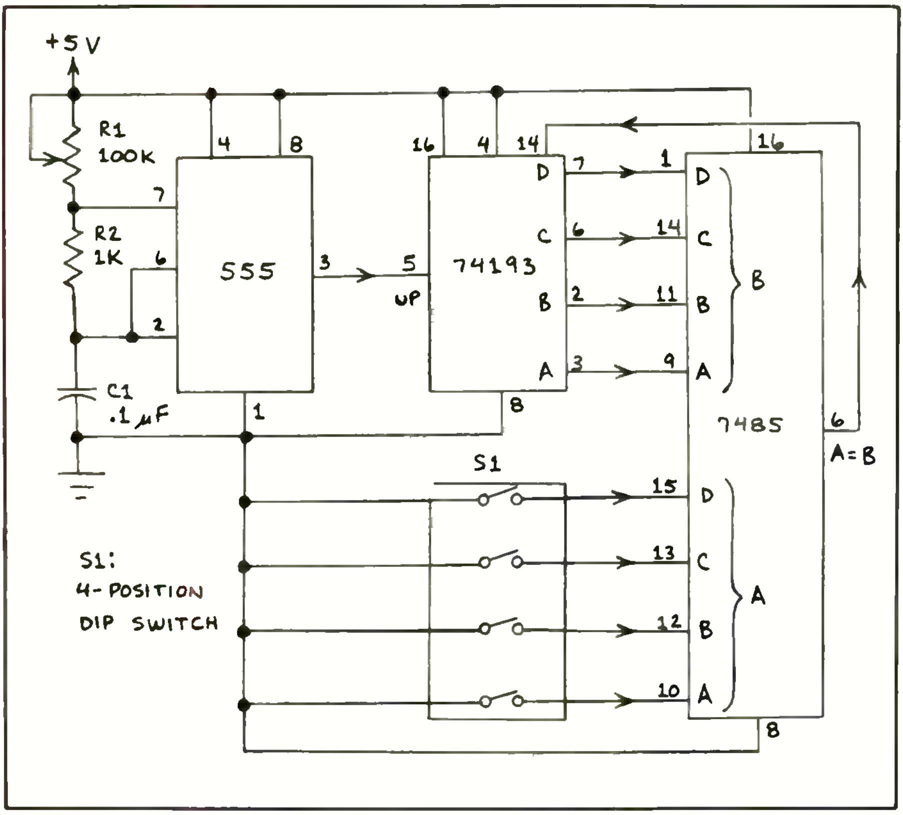
logic circuit into the digital equivalent of the relaxation oscillator. For example, consider the programmable 4-bit counter shown schematically in Fig. 9. The binary equivalent of the desired count is entered into a 4-position DIP switch. The 74193 counter advances one count for each arriving pulse from the 555 clock. The 7485 compares the count at the 74193's outputs with the desired count entered in the DIP switch. When a match occurs, the 7485 clears the 74193, and the count-compare cycle is repeated.

The clear signal from the 7485 corresponds to the threshold point of a negative-resistance switch. And the clearing of the 74193 is much like the discharging of the capacitor in the previous circuits. An added advantage of the logic circuit is that the threshold point, hence the frequency of oscillation, can be quickly adjusted to any of 16 values.

Software Oscillators

Any computer language that has a looping command permits establishment of the functional equivalent of the relaxation

Fig. 9. Digital logic analogy of relaxation oscillator.



oscillator. For instance, consider this simple BASIC listing:

```
10 BEEP
20 GOTO 10
```

This listing will cause a computer to emit a continuous series of beeps. The program can be easily modified to alter the frequency at which the beeps occur, simulating the variation of the RC values in the circuits given above. For example, this listing permits the delay between beeps to be selected:

```
10 INPUT "ENTER DELAY BETWEEN BEEPS"
20 BEEP
30 FOR Z = 1 TO N:NEXT Z
40 GOTO 20
```

Going Further

By now, it should be apparent that relaxation oscillators play a key role in both natural and electronic systems. You can find out more about this subject and specific kinds of relaxation oscillators by referring to electronics textbooks and data sheets that describe the characteristics of various negative-resistance devices. ME