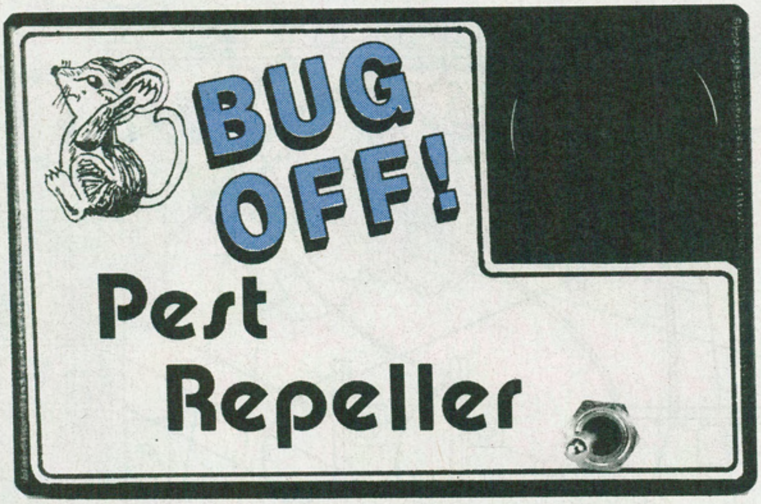
BUG-OFF: The Popular Electronics® Pest Repeller



Build a project to protect you from pests while hiking, or lounging 'round the pool, and learn something new about the 555 timer in the bargain!

BY JOHN YACONO

Ahhh, the great outdoors! It's so nice to get out in the fresh air and enjoy nature. Unfortunately, sometimes nature can turn a pleasant picnic into a please-the-ants picnic. Every camping trip I've been on has turned into a swat fest as night fell. As for me, I've never been too fond of rubbing malodorous ointments on myself and spraying ozone-eating aerosols in Mother Nature's face. Not being one to give up my enjoyment of the outdoors or my principles, I set to work to build a portable electronic pest repeller, affectionately called *Bug-Off.*

If you haven't heard of one before, or don't know what makes them tick, such pest repellers send out ultrasonic pressure waves (at 22–65 kHz) that are an annoyance to insects and certain small animals. Note that the version shown here is only powerful enough to affect insects, although it is an easy matter to amplify the output using a low-power, wide-band op-amp. For those interested in this, several suitable circuits were shown in "Using Wide-band Op-Amps" in the January, 1990 issue of **Popular Electronics**.

The basic Bug-Off unit is a very interesting little circuit. In it, a 556 dual-timer chip is suited-up with a few common components that turn it into a sweep-frequency oscillator. In the course of this article, I'll supply you with both construction and design details so that you can grant a 555 a 50% duty cycle and even use one as a voltage-controlled oscillator (something mentioned in text books, but never really covered).

Nuts, Bolts, and Paperwork. I have a commercially built, AC-powered pest repeller at home that works pretty well, so I decided to look inside of it before designing anything. To my surprise I found a lone 555 with support components that caused it to operate as a VCO (voltage-controlled oscillator). I had always known that was possible, but oddly enough I didn't remember ever seeing any design equations for VCO operation.

After checking two manufacturer's data books, and two 555-timer cookbooks, I realized my memory was not faulty (not this time anyway). Undaunted, I went on to figure out the equations for voltage-controlled operation for myself. Before giving you the results of my labor, a brief summary of 555-timer operation is a very good idea.

A 555 wired for astable operation is shown in Fig. 1. Let's ignore the control terminal for now, and just assume it's not connected. If you apply power to the circuit, capacitor C starts to charge through R_A and R_B, and the output is high. The FET in the 555 can initially be ignored as it is off. The rate of charge is thus determined by R_A, R_B, C, and V_{CC}.

The resistor network composed of R_{11}–R_{13} (all equal to 5 kilohms) divides the supply voltage (V_{CC}) into $1/3 V_{CC}$ and $2/3 V_{CC}$ (called the "trigger" and "threshold" voltages, respectively). Note that both comparators (C1 and C2) monitor the voltage stored in the capacitor; Comparator C1 compares the capacitor voltage to the threshold voltage and C2 compares it to the trigger voltage.

When the capacitor charges up to the threshold voltage, C1 goes momentarily high, toggling the flip-flop. That causes the internal FET to start draining the charge off the capacitor via R_B (without any of the discharge current flowing through R_A), and the output terminal goes low. The rate of discharge is thus determined by R_B, C, and V_{CC} (but not R_A). Once the capacitor voltage drops to the trigger voltage, C2 is triggered and toggles the flip-flop. The FET then turns off, the output goes high, and the capacitor begins to charge again.

There are a few interesting facts about the process. First, the timing is independent of the power-supply voltage (V_{CC}). That's because even though you may increase the charge rate by increasing the supply voltage, the threshold voltage is also increased, so it takes longer for the capacitor to reach that voltage (neat, huh?). The capacitor dissipates that higher voltage slower, but the trigger voltage is also higher, so the capacitor doesn't have to go as low. The time it takes for the capacitor to charge from $\frac{1}{3}V_{CC}$ to $\frac{2}{3}V_{CC}$, which is the time the output remains high, is given by:

$$t_h = 0.693(R_A + R_B)C$$

The time it takes for the capacitor to discharge from $\frac{2}{3}V_{CC}$ to $\frac{1}{3}V_{CC}$, which is also the length of time the output is low, is given by:

$$t_l = 0.693(R_B)C$$

Note the absence of R_A in the last equation. That's because only R_B is in the discharge path. Note also that that prevents us from attaining a 50% duty cycle (t_h can't equal t_l). Some may propose doing away with R_A, but that would short the power supply through the discharge pin at the beginning of the discharge cycle. However, there is another method for obtaining a 50% duty cycle, as you'll see.

Special Operation. A 50% duty cycle can be easily obtained by putting a diode pointing down (cathode toward the capacitor) in parallel with R_B, and setting R_A equal to R_B. That way R_B is bypassed during charging, but it is still in the discharge path.

Now let's upset the scheme a different way by applying a voltage (V_{CON}) to the control terminal (but without using the diode trick for now). Doing so doesn't change the characteristics of the basic charging circuit (composed of R_A, R_B, and C), but it does change the values of the threshold and trigger voltages. However, that does not affect the discharge time (t_l) of the capacitor for the same reason a different supply voltage doesn't affect it (go back to the previous section if you forgot why). It does change the charging time (t_h), which can be computed with the following formula:

$$t_h = (R_A + R_B)C(-0.693 + \ln[1 + 1/(1-V_{CON}/V_{CC})])$$

There are a few implications to all this: The first is that by changing the control voltage you can perform pulse-width modulation. You can also modulate the frequency and simultaneously modulate the duty cycle. In fact, using this technique, you can't change one without changing the other. By swinging the control voltage up and down, you can sweep a range of frequencies. That's exactly what the Bug-Off circuit does to ensure maximum effectiveness—it sweeps a range of frequencies to disturb the widest possible variety of species.

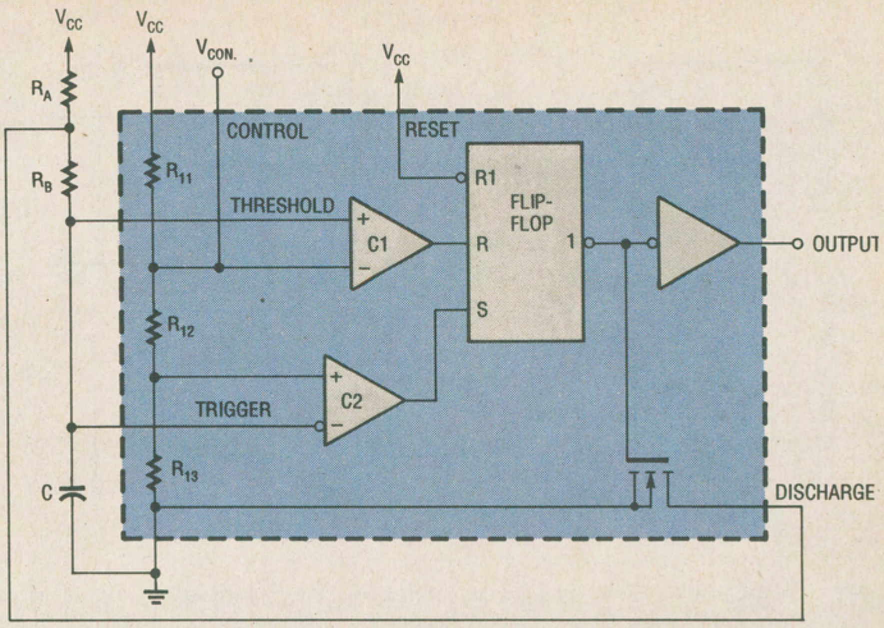


Fig. 1. This is a 555 timer IC (depicted in block-diagram form) connected to some support components to form a basic astable multivibrator.

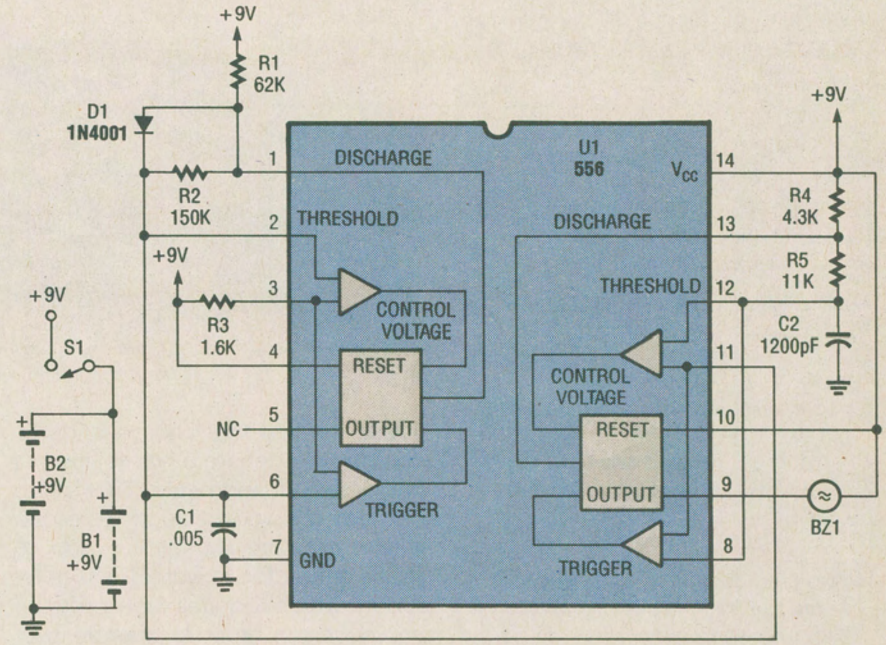
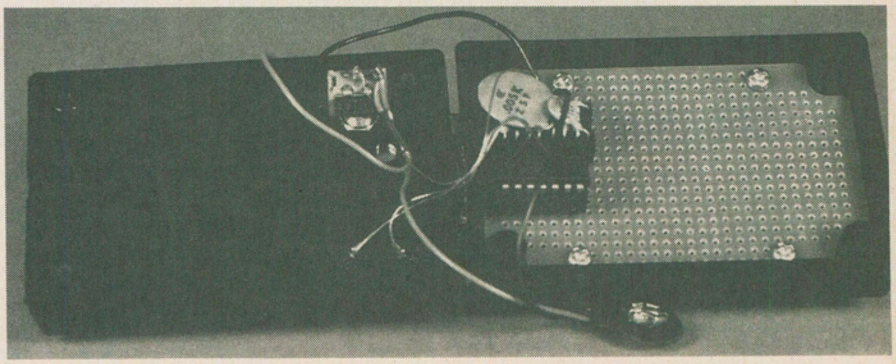


Fig. 2. The two timers in the full-blown project have some interesting characteristics. Both of them have their thresholds externally set, the oscillator on the left has a 50% duty cycle, and the oscillator on the right acts as a VCO.



Here's a peek under the hood of the pest repeller. Note the capacitors are neatly bent to permit the cover to be put on.

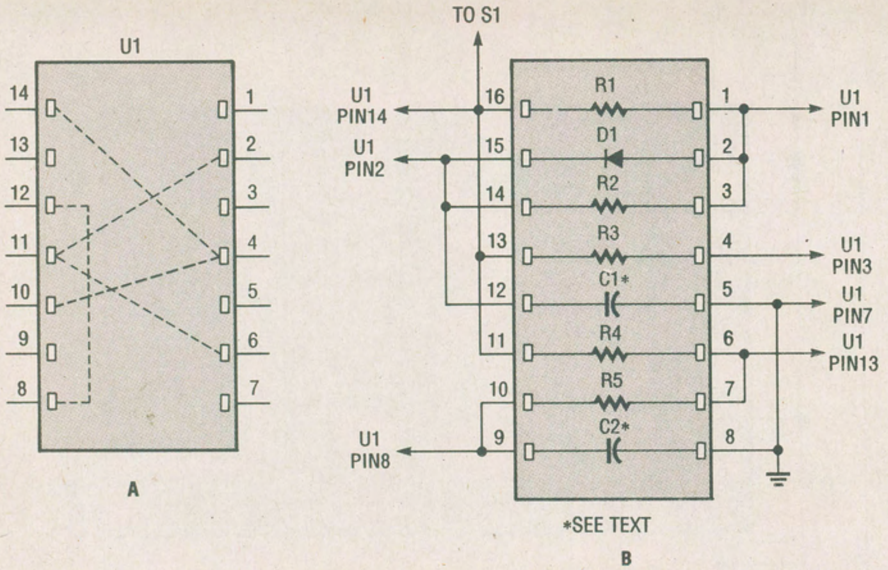


Fig. 3. If you wire the socket for U1 as shown in A, and the component socket as shown in B and interconnect them, you'll only have to connect the buzzer, battery, and switch to get your project up and running.

because a timers output simply swings between V_{CC} and ground, but the charging capacitor gradually moves between the trigger and the threshold voltages. The capacitor will thus cause the VCO to sweep a range of frequencies rather than jump between two of them.

The oscillator on the left has two interesting characteristics: a 50% duty cycle, and modified threshold and trigger voltage levels. The voltage levels are modified by R3 to cause C1 to charge from 4 to 8 volts. The reason that is done is to allow the VCO to have a wide voltage sweep (thus, a wide frequency range), without causing it to have a ridiculously high or low duty cycle.

The oscillator on the left is configured for a 50% duty cycle because of the exponential charging curve of the capacitor. When the capacitor (C1) starts to charge, its voltage changes rapidly, causing the VCO to rush through the frequencies generated during the beginning of the charging cycle. During discharge the opposite happens—the frequencies generated with the control pin near its maximum are rushed through. So over one complete charge/discharge cycle, the frequencies are given fairly equal treatment as long as the charge and discharge times are the same (*i.e.*, the duty cycle is 50%).

Note that R1 and R2 are not equal, though we mentioned they should be for a 50% duty cycle. That's because the use of R3 alters the duty cycle so that the values of R1 and R2 have to be adjusted to re-establish the 50% duty cycle.

The oscillator runs at a frequency of 980 Hz, sweeping the VCO twice (once up, once down) each cycle. That means a creature will be zapped at least around 1960 times a second

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PARTS LIST FOR THE BUG-OFF ELECTRONIC PEST REPELLER

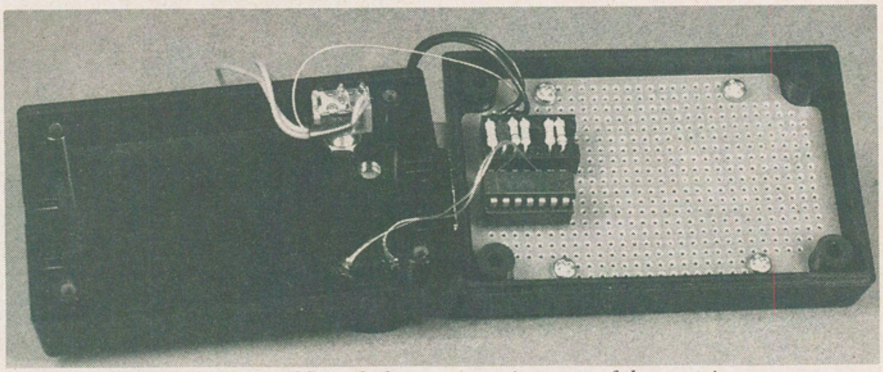
RESISTORS

(All resistors are ¼-watt, 5% units.)
R1—62,000-ohm
R2—150,000-ohm
R3—1600-ohm
R4—4300-ohm
R5—11,000-ohm

ADDITIONAL PARTS AND MATERIALS

BZ1—Piezo buzzer element
D1—1N4001 1-amp, 50-PIV, rectifier diode
U1—556 dual oscillator/timer, integrated circuit
C1—0.005-µF, ceramic-disc capacitor
C2—1200-pF, ceramic-disc capacitor
S1—SPST on/off toggle switch
B1, B2—9-volt transistor radio battery

Battery clips, perfboard, project case, 14-pin and 16-pin wire-wrap sockets, wire-wrap wire, solder, etc.



The components are more visible with the two capacitors out of the way. As you can see, using an IC socket keeps the project neat and small.

The Circuit. The Bug-Off circuit is shown in Fig. 2. The internal resistors are not shown for the sake of clarity. Note that it actually makes use of two 555 timers (both packaged in one 556 case). One timer circuit is shown on the left of the IC package, and the other is on the right. They are both set up as oscillators with some special features.

The oscillator on the right is a VCO and is used to sweep frequencies between 25.8 and 65.2 kHz. Its duty cycle varies from 40 to 76%. Keeping the duty cycle as close to 50% as possible is a good idea because it ensures that piezo element BZ1, which is the output transducer, will fully charge and discharge, and generate harmonics that are close to fundamental. Such piezo elements are great at creating pressure waves, and are sometimes used as sound generators in water (such as for sonar), which requires high-pressure transducers in order to operate over long distances.

One more thing should be mentioned concerning the transducer: get a high-efficiency type that operates with the highest resonant frequency possible. However, don't worry that the resonant frequency is not near the ultrasonic range. The voltage swing applied to the crystal forces it to electrostric (contraction due to an applied voltage) without the need for resonance; We are really concerned with generating noise in the form of pressure waves, not pure tones.

The VCO receives its control voltage from the oscillator on the left. Note that the voltage on capacitor C1 is used rather than the output from pin 3. That's

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(ouch!) no matter what its hearing range may be.

Also note the power supply; Two batteries in parallel are a good idea because, unlike common 555 circuits, the two oscillators are both supply-voltage dependent. A drop in voltage will reduce the unit's effectiveness. Besides, if you're out in the wild, you'll want the device to work a long time with little tending.

Construction. I wire-wrapped my Bug-Off because of the circuit's simplicity. I started by placing the IC socket for U1 on a small piece of perfboard sized to accommodate it, a 16-pin IC socket (which I'll explain in a little bit), and the two 9-volt batteries. I then wired the pins of the 14-pin socket as shown in Fig. 3A (note that the figure shows the wire side).

I used an unusual wiring technique for the rest of the Bug-Off circuit. I cut the leads of all the discrete components and inserted them into a 16-pin wire-wrap socket (see Fig. 3B). It makes for neat, and sparing use of perfboard surface area. That's important to make the unit easily portable. When preparing your own DIP socket, you might need to bend the capacitors back against the other components. It'll depend on the size of your project box. Once the components are in the socket, install the socket on the board. You can use Fig. 3B as a wiring-side diagram as long as you position D1 correctly. First wire the support-component jumpers, and then run the necessary wires to the IC.

Make appropriate holes in the unit's case for the switch and piezo element. Put them in place and wire them to the board and the battery clips (note that BZ1 goes to the switch and pin 9 on the IC). Before you close up the case, you should test the unit. Get two good batteries, preferably from the same package to help ensure their internal resistances are the same. Connect them to the circuit, and flip the power switch on. If you place your ear very close to the transducer, you should hear a hard-to-notice high-pitched whine.

If the tone is easily audible, then the VCO is not operating in the right range. That could be due to a poor battery, mis-wiring, poor component connections, or poor component tolerances. I would check for each in the order just listed. If you can't hear the tone at all, don't worry; your component tolerances might be pushing the frequency up, or, more likely, your hearing may be poor at such frequencies. That's very common and nothing worth worrying about. To make sure the unit is operating, press your finger against the leads of C2. That should cause its tone to drop to a more noticeable frequency.

Frills. You can soup-up the unit by running it off of a wall adapter for indoor use. However, without some amplification, the unit will have a limited range. You can use a good-size switching transistor running full-open to slam the crystal up and down at higher voltage levels to do just that. Just be sure you don't alter the operating voltage of the oscillators.

It's perfect for sleeping-bag use, especially if a clip or velcro is added to hold it in place. The pest repeller should provide you with many carefree hours to enjoy nature's bounty, or just a little patio R&R, without pesky bugs spoiling the fun. You can leave your battery of repellents and bite disinfectants home on that next family outing because you have Bug-Off. ■