Based on the 555 timer IC:

# Square wave oscillator

## A simple circuit for checking audio gear & for IC experiments

**Here's an ideal project for beginners: a really simple and easy to build multi-frequency square wave oscillator. The parts will cost you less than $10, and you should be able to put it together in one evening. But you can use it for all sorts of things — from testing amplifiers and radios to experimenting with digital ICs.**

**by GERALD COHN and JAMIESON ROWE**

A square wave oscillator can be a very handy gadget to have on the experimenter's workbench — particularly if it can be used to produce a number of different frequencies. You can use it as a source of test signals, to test audio amplifiers, loudspeakers, headphones and other equipment. And because a square wave is rich in harmonics, you can also use such an oscillator as a "signal injector" to test radio receivers.

It can also be used as a simple pulse generator, to provide a train of pulses for operating counters, shift registers and other digital circuitry. This makes it just the thing if you are experimenting with digital integrated circuits (ICs).

The little square wave oscillator described here is about as simple as you could get. It uses only a single low-cost IC, the well known 555, with a handful of other parts, and operates from a small nine volt battery. This makes it very low in cost, easy to build and completely safe even for the really young experimenter.

Yet it will deliver any of five handy test frequencies: from a low 1Hz (one hertz, equal to one cycle per second) up to 10kHz (10 kilohertz), in multiples of 10 or "decade" steps. So you can get low frequencies for checking digital circuits, and higher frequencies for checking audio gear and radio sets — all at the flick of a switch.

The output is virtually a perfect square wave at all five frequencies, with short "rise" and "fall" times to ensure that there are plenty of harmonics. And the output is a healthy 8 volts peak-to-peak, able to drive just about any likely circuit. You can of course cut it down, by using an external series resistor or a variable "pot".

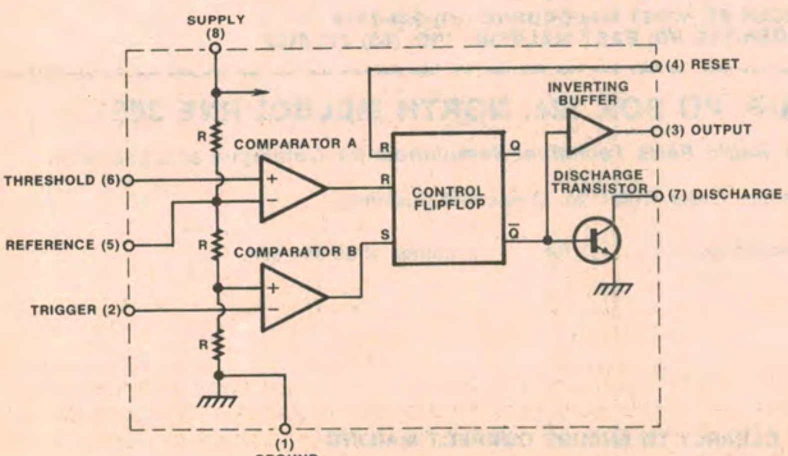



FIG. 1 : INSIDE THE 555

The oscillator is also provided with a light-emitting diode (LED) output indicator, so you can see that it is working. On the low frequencies you can actually see the LED flashing on and off; on the higher frequencies it flashes too rapidly for the eye to see.

Well then, how does it work? The circuit diagram may not give you much of a clue at this stage, particularly if you're not too familiar with the 555 IC. So let's look a little closer at this device and how it works.

Inside the 555 there are really quite a few parts — something like 28 transistors and 12 resistors, depending upon the particular brand of device you get. We're not going to worry about all the fine details of its internal circuitry, though; just the basic functions it performs.

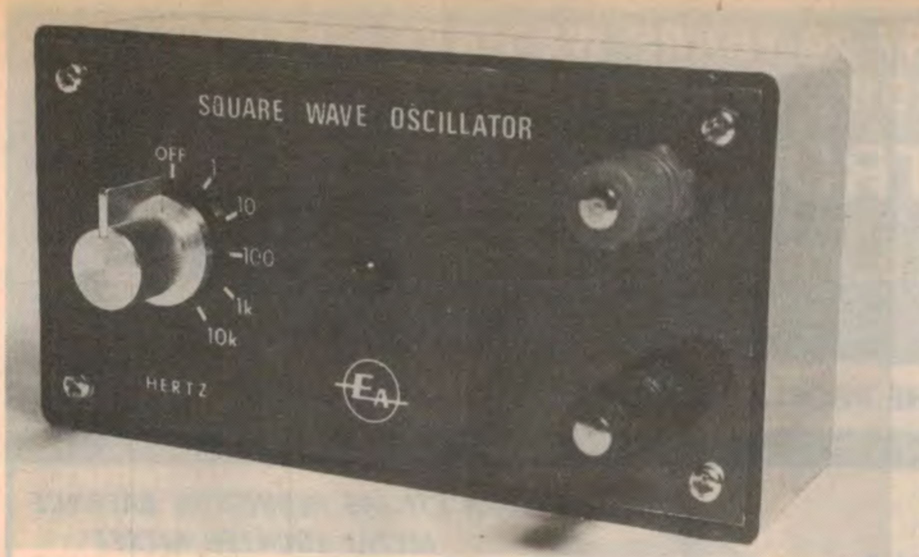
The diagram of Fig. 1 shows the story. At the heart of the IC is a control flipflop, a circuit which can "flip" from one of two different sets of voltage and current levels to the other, in response to pulses fed to its R (reset) and S (set) inputs. The flipflop also has outputs Q and Q-bar, whose voltages show which of the two possible states the flipflop is in. The voltage at Q is high for one state, and low for the other; the voltage at Q-bar is always the opposite of that at Q.

When the flipflop receives a pulse on one of its R inputs, it flips to the state where Q is low and Q-bar high. On the other hand when it receives a pulse on its S input, it flips to the other state where Q is high and Q-bar low. And in

We estimate that the current-cost of parts for this project is approximately

**$8.50**

This includes sales tax




*We built our unit into a low-cost plastic Zippy box. The light emitting diode (LED) indicates when the unit is on and flashes in sympathy with the output frequency.*

each case it stays at the state concerned until it is deliberately forced to flip to the other state by an input pulse.

So if you like, the flipflop has a memory: it "remembers" which sort of input pulse it received last.

Attached to the flipflop's Q-bar output is an "inverting buffer" — basically an amplifier whose output moves in the opposite direction to its input. The output of the buffer is connected to pin 3 of the 555, to become the output of the whole device. So when the Q-bar output of the flipflop is high, pin 3 goes low, and vice-versa.

Also connected to the Q-bar output of the flipflop is the base of an NPN transistor, known as the discharge transistor. The emitter of this transistor is grounded, while the collector is connected to pin 7 of the IC and labelled "discharge". The idea being that when the flipflop's output is high, the transistor is driven into conduction, and effectively shorts pin 7 to ground. This can be used to discharge an external capacitor, as we shall see shortly.

The rest of the 555 consists of two voltage level comparators, which are used to generate the input pulses for the control flipflop. The comparators are high-gain amplifiers, which each have two inputs and an output. The output goes high whenever the "+" input is connected to a voltage which is more positive than the "-" input. On the other hand if the "-" input is more positive than the "+" input, the comparator's output goes low.

Hence the name comparator: a circuit which compares two voltage levels, and indicates with its output which one is more positive.

As you can see from Fig. 1, one input of each of the comparators is taken to a tapping on a voltage divider, made up of three resistors R connected across the 555's power supply pins 8 and 1. The "-" input of comparator A is connected to the upper tap of the divider, while the "+" input of comparator B is connected to the lower tap. As the three resistors in the divider all have the same value, this means that comparator A's input is fed with a voltage of 2/3 the supply, and comparator B's input a voltage of 1/3 the supply.

The remaining input of each comparator is connected to an external IC pin: comparator A's "+" input to pin 6, labelled "threshold", and comparator B's "-" input to pin 2, labelled "trigger".

So what comparator A does is compare the voltage at pin 6 with 2/3 the supply voltage, and feed a pulse to the R input of the control flipflop if the voltage at pin 6 is more positive. Similarly comparator B compares the voltage at pin 2 with 1/3 of the supply voltage, in this case feeding a pulse to the S input of the flipflop if the voltage at pin 2 is less positive.

So much for what's inside the 555 IC. Now let's look at the main circuit again, to see how we turn all of this into a square wave oscillator.

As you can see, pins 2 and 6 are actually tied together in this case, and connected to the moving arm of switch SW1b. This in turn connects them to ground via one of the capacitors C2-C6. Pins 2 and 6 are also taken up to the +9V supply line, via series resistors R1 and R2.

Note that the junction of R1 and R2 is connected to pin 7, the collector of the 555's internal discharge transistor.

Let's consider what happens when the circuit is first turned on, with SW1a connecting the 9V supply from the

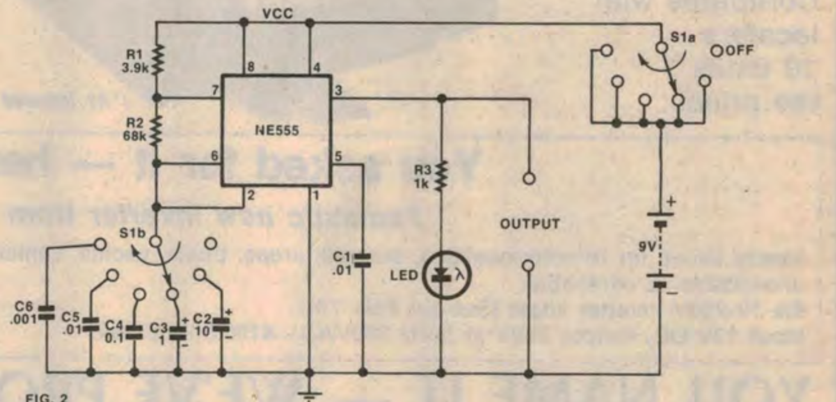
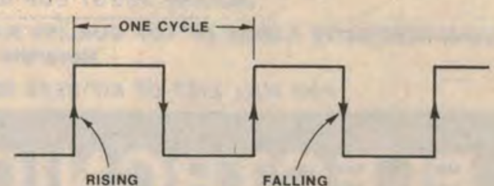



FIG. 2

*The complete circuit. It provides 5 switched frequencies from 1Hz to 10kHz.*

## WHAT THE TERMS MEAN

**SQUARE WAVE:** In electronics, a square wave is an alternating voltage or current which does not reverse direction smoothly and gradually like a sine wave, but suddenly and sharply. A graph of voltage or current against time thus looks like the following:



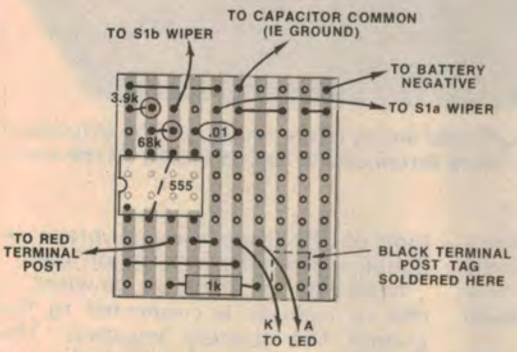

**OSCILLATOR:** In electronics, an oscillator is a circuit which generates a continuously alternating voltage or current. So that a square wave oscillator is a circuit which generates a continuously alternating voltage or current which has a waveform as shown above.

battery and SW1b turned to connect say C3 into circuit between pins 2-6 and ground.

At first, C3 will contain no electric charge, so the voltage across it will be zero. As a result, comparator B inside the 555 will feed a pulse to the S input of the control flipflop. The flipflop will accordingly flip to its "set" state, with the Q output high and Q-bar low. The internal discharge transistor connected to pin 7 will be turned off, while the buffer amplifier will take the output pin 3 up to a voltage very close to the 9V supply rail.

With the discharge transistor off, C3 is able to charge up from the 9V rail via voltage across C3 has fallen to the point where it is just slightly below 1/3 of the supply voltage. Then the 555's comparator B triggers once again, causing the control flipflop to switch back to its set state. Then the output pin 3 goes high again, the discharge transistor turns off, and C3 begins charging again via both R1 and R2.

So the circuit settles down to a continuous cycle of events, with capacitor C3 (or whatever other capacitor is switched into circuit) being alternately charged and discharged under the control of the 555. While ever the capacitor is charging, the voltage at output pin 3 is high, and while ever it is discharging




*The components are assembled onto stripboard as shown in this component overlay diagram. Cuts along the copper strips are best made with a drill bit. Simply place the point of the drill in the hole closest to the required break and twist by hand so as to cut away the copper.*

resistors R1 and R2. The voltage across C3 thus begins to rise, as it charges. The voltage rises in so-called "exponential" fashion: fast at first, then gradually slower and slower. The time it takes to reach 63% of the supply voltage will be found by working out the "time constant", which is equal to the product of the capacitance and the total series resistance:

$$T = C3. (R1 + R2)$$

where T is in seconds, C3 is in Farads and R1 and R2 in ohms.

The capacitor will be able to charge up in this exponential fashion just a little longer than this time T — until the voltage across it reaches 2/3, or 67% of the supply voltage. What happens then is that comparator A inside the 555 triggers, resetting the control flipflop. Its Q-bar output goes high, turning on the discharge transistor and effectively shorting the junction of R1 and R2 to ground. At the same time the buffer transistor takes the output pin 3 down to ground potential as well.

What happens now is that with the junction of R1 and R2 shorted to ground, C3 stops charging and begins to discharge via R2 and the 555's discharge transistor. So its voltage begins falling, rapidly at first and then slower and slower in the same exponential fashion that it charged.

The discharging continues until the the voltage at pin 3 is low.

Each time it charges, the capacitor voltage rises from 1/3Vcc to 2/3Vcc. When it discharges, the voltage falls by the same amount: from 2/3Vcc to 1/3Vcc. And since R1 is small compared with R2, the resistance in series during the charging (R1 + R2) is really quite close to the resistance in series during the discharging (R2 alone). As a result, the charging and discharging times are very close to the same.

So what happens as a result of all this is that the 555's output pin 3 switches up and down, producing a continuous square wave. The rate at which it switches up and down will depend upon which capacitor we have in circuit — a large capacitor will produce a low rate (low frequency), while a small capacitor will produce a high rate (high frequency).

Hence the largest capacitor C2 gives an output frequency of 1Hz, while the smallest capacitor C6 gives an output frequency of 10kHz. Capacitors C3, C4 and C5 give intermediate frequencies of 10Hz, 100Hz and 1kHz respectively.

As you can see, the indicator LED is simply connected in series with a 1k current-limiting resistor from pin 3 of the 555 to ground. The resistor limits the LED current to about 7 milliamps, giving adequate brightness. This leaves the 555 output with plenty of current capability to drive external circuitry.

At this stage there's only one circuit component we still haven't explained: the .01uF capacitor (C1) connected between pin 5 of the 555 and ground. What does this do?

Well, as you can see from Fig. 1, pin 5 is actually connected to the upper tapping point on the 555's internal voltage divider. By connecting this point to ground via a capacitor, we filter out any hum or noise that might otherwise find its way into the divider and disturb the operation of the two comparators.

C1 isn't essential for circuit operation, and if you try leaving it out you'll probably find that the circuit seems to work just as well — at least most of the time. But by putting the capacitor in we ensure that the circuit works as it should all the time, even when the battery gets tired and noise gets into the circuit.

As you can see, the oscillator is housed in a small low-cost "Zippy" box. The box measures 130 x 68 x 71mm, and is available from most suppliers; the one we used came from Dick Smith Electronics, who list it as catalog number H-2753.

Inside the box, most of the components are mounted on a small piece

## Simple oscillator

of drilled strip conductor board (Veroboard or similar), which measures 28 x 28mm. As the board strip and hole spacing is both 2.5mm, this means that the board is 10 strips wide and 10 hole spaces long.

The timing capacitors are not mounted on the board, as these can vary quite significantly in size and it is easier to mount them on the switch. You can see how they are mounted from the internal photograph; similarly you should be able to get a good idea of the way the board is wired from the wiring diagram.

Before mounting the IC and other components on the board, cut the tracks where we have indicated. The easiest way to do this is to use a twist drill of about 6-7mm (¼in), placing the tip in a suitable hole and turning it so that it "countersinks away" the copper strip around the hole. Continue until you are sure that the copper strip has been completely cut.

When wiring up the board, fit the resistors and capacitors on first, then add the 555 IC. Take care when soldering all of the components to the board not to overheat them — especially the IC.

The next step is to drill holes in the front panel for the switch, LED and output terminals. Use the front panel artwork we have reproduced in these pages as a guide in placing the holes, and choose the hole sizes to suit the parts. Those for the LED and terminals will be around 6mm, while the hole for the switch will be about 9.5mm.

Having drilled the holes, you can then provide the panel with suitable lettering. If you are adept at photography, you might be able to make a paper print of the artwork and stick it to the panel. Or you may have access to some "Scotchcal" photosensitive adhesive-backed aluminium, in

## Parts List

*1 555 IC*
*1 red LED*
*1 1k ¼W resistor*
*1 3.9k ¼W resistor*
*1 68k ¼W resistor*
*1 .001uF polyester capacitor*
*2 .01uF polyester capacitor*
*1 .1uF tantalum capacitor*
*1 1uF tantalum capacitor*
*1 10uF tantalum capacitor*
*1 piece of Veroboard, 28mm x 28mm*

*2-pole six-position rotary switch*
*Zippy box, 130 x 68 x 41mm*
*Hookup wire, solder, terminal posts, knob for switch, etc.*

*This view inside the case shows the general layout of the oscillator. The stripboard assembly is soldered directly to the black terminal post tag, as shown on the component overlay diagram.*

which case you could use this to make a replica of our own unit. Alternatively you could make up your own version using "Letraset" or similar rub-on lettering.

With the panel suitably prepared, you can mount the switch, terminals and LED to it. Don't forget to insulate both terminals from the panel with fibre washers, and to fit solder lugs under the nuts for the inside connections.

The LED mounts on the panel via a small clip-together plastic bezel, and if you haven't assembled one of these before you might find it a little tricky.

You'll find the bezel consists of two parts: an inner sleeve, with the bezel proper at one end, and a locking ring which is of larger diameter and has "teeth" moulded inside. To assemble these with the LED, you first push the sleeve through the hole in the panel from the front, until the bezel portion meets the panel. Then push the LED through the sleeve from the rear of the panel, until it "clicks" into place (the front will now be protruding from the front of the bezel). Finally push the locking ring on the rear of the sleeve, working it forward until it meets the rear of the panel. The whole assembly should then be locked fairly securely in place.

You can now solder the component board to the solder lug on the rear of the "earthy" output terminal, as shown in the photograph. It is quite small and light, and this is adequate to hold it in place. Then add the wiring to the other terminal, the LED and the switch, and of course the battery lead wiring. The battery itself can be fastened to the bottom of the case using a piece of double-sided adhesive tape or foam.

Note that the LED must be wired so that its cathode is connected to the ground line (battery negative). The cathode lead of most LEDs is the one nearest the "flat" on the side of the LED, or else the shorter of the two (if they are of different length).

To complete the actual wiring, fit the various timing capacitors to the switch — wiring them as shown in the photograph. Then add a knob to the front of the switch, and your square wave oscillator should be ready to try out. But before you connect up the battery, just check that you haven't made any mistakes.

Have you got the 555 round the right way? The LED connections right? The polarised capacitors C2 and C3 round the right way? The battery connections right? These are all important.

If all seems well, connect up the battery and switch to the 1Hz position. You should be greeted by the LED flashing on and off, once a second. If not, switch off and check your wiring again for errors.

Switching to the 10Hz position should cause the LED to flash somewhat faster — 10 times per second. And if you switch to the three higher positions, it should flash so fast that your eye won't be able to respond. The LED will appear to be glowing continuously.

Your oscillator will now be completed and ready for use. Next month we'll start showing you how to use it for some simple experiments with digital ICs.