Simple metronome uses two transistors

Basic Electronics

Over the past 12 months or so we have had quite a few requests for a simple metronome circuit. This new circuit has low current drain and drives a loudspeaker as well as a LED indicator and even at maximum volume from the loudspeaker the current drain is still less than one milliamp.

by PAUL DE NOSKOWSKI

Some five years have elapsed since we last published a design for an electronic metronome – in the July, 1976 issue, to be precise. That unit featured an accented beat, wherein certain clicks in the sequence are accentuated to simulate the down-beat at the beginning of each musical bar. However, this increases the complexity of the circuit, and is reflected in both increased expenditure for parts and increased battery consumption.

In our new simplified design, we have been able to keep the battery drain down to less than 1mA!

Most readers will at some time or other have heard or seen a conventional mechanical metronome, which is built into a pyramidal shaped case containing a clockwork escapement mechanism. A spindle emerging from the base end supports an upright pendulum, carrying a brass weight, which can be locked into the desired position. When set in motion, the pendulum oscillates from side to side producing an audible click.

Both the visual movement and audible click serve as a guide to musical tempo, or beat. The tempo range covered by a mechanical metronome is usually between about 40 and 170 beats per minute, and is varied by sliding the brass weight up and down the pendulum, with the rate being displayed on a calibrated scale on the body (behind the pendulum).

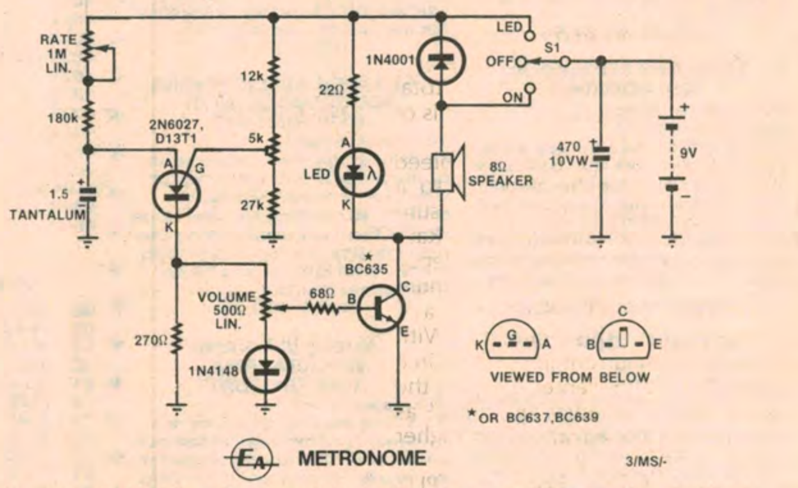
The two main requirements in a metronome are that the rate at which the clicks occur should be constant and repeatable, and that the clicks should be "non-musical" in character.

In this latest design we have used a programmable unijunction transistor (PUT) as the basic oscillator, since it can perform almost as well as a 555 timer in the areas of temperature and voltage stability, yet consumes far less supply current (which is about 5mA in the case of the 555). We also considered using a 7555 (the "CMOS" version of the ubiquitous 555), which only draws some 100μA, but rejected it on the grounds of increased cost and somewhat limited availability.

A PUT is really not a unijunction transistor at all but is actually a special low current type of silicon controlled rectifier (SCR) which has an anode gate instead of a cathode gate. A conventional SCR with cathode gate requires that its gate be raised about 0.5 volts above its cathode in order for it to conduct.

An anode gate SCR is different in that it requires that its anode be raised above its anode gate by about 0.5 volts (or thereabouts) for it to conduct. This enables it to be used in relaxation oscillator circuits and give improved performance compared to a unijunction transistor.

In our circuit the PUT has its gate connected to a preset voltage provided by an adjustable divider consisting of a 5kΩ trimpot and two resistors. When power is applied to the circuit, the 1.5μF capacitor begins to charge via the 180kΩ



The circuit uses a 2N6027 programmable unijunction transistor as the oscillator.

Our new metronome features a level control and has an output of between 30 and 160 beats per minute.

resistor and 1MΩ "rate" control potentiometer. When the voltage across the 1.5μF capacitor rises just a little above the preset gate voltage, the PUT suddenly breaks into conduction and dumps the capacitor charge across the 270Ω resistor connected to its cathode. When the capacitor is fully discharged (in about one millisecond) the PUT switches off and the cycle can repeat itself. Thus the circuit is a classic example of a relaxation oscillator, with the voltage waveform being a sawtooth (slowly rising ramp and rapid decay) with an amplitude controlled by the preset voltage. At the same time, there is a string of positive pulses appearing across the 270Ω cathode load resistor.

By varying the setting of the rate control, we can vary the frequency of the sawtooth waveform across the capacitor and the rate of the pulses across the cathode resistor. At the same time, the 5kΩ trimpot allows us to accurately set the sawtooth frequency for a particular setting of the rate control. The accompanying oscilloscope photograph shows the voltage waveforms at the anode and cathode of the PUT.

Virtually no current is drawn by the PUT during the charging segment of the oscillator cycle; and when the PUT conducts, the stored charge in the tantalum capacitor provides the anode/cathode current flow. Thus the current drawn from the supply is the sum of charging current and the "bleed" current flowing through the gate biassing network. Charging current will be dependent on the setting of the Rate control, varying between approximately 6μA and 35μA – typically about 20μA. As bleed curent is some 200μA, the total current drawn by the PUT oscillator is of the order of 220μA.

It should be noted that the bleed current has been deliberately set to a relatively high value in order to ensure satisfactory PUT oscillation with the Rate control set to the highest frequency (minimum resistance), when minimum performance PUT devices are encountered in this circuit. With insufficient bleed current (ie, high source impedance being presented to gate) the oscillator will commence "misfiring" as the Rate control is advanced to higher repetition rates.

The output pulses from the PUT cathode are used to drive a single transistor which acts as a rudimentary amplifier stage to drive a LED and a small loudspeaker. The volume of this amplifier stage is controlled by feeding the pulse waveform into the transistor base via a 500Ω volume control potentiometer and 68Ω limiting resistor.

A 1N4148 diode is connected in series with the volume control. If this diode was omitted, there would be a noticeable "dead spot" at minimum settings of the control due to the fact that the transistor does not begin to conduct until the voltage applied to its base exceeds around 0.6V. The diode compensates for this in the following way:

PARTS LIST

1 "zippy" box, 130 x 68 x 41mm
1 Scotchcal panel label
1 printed circuit board 81mi11, measuring 57 x 35mm
1 "small" 8Ω loudspeaker (57mm diameter)
1 9 volt battery,
1 battery retaining clip
1 clip lead set for battery
1 SPDT (centre "off") toggle switch
2 knobs

SEMICONDUCTORS

1 small red LED (3mm diameter)
1 1N4001 diode
1 1N4148 doide
1 2N6027 (D13T1) programmable unijunction transistor
1 BC635 (or BC637, BC639) small signal transistor

CAPACITORS

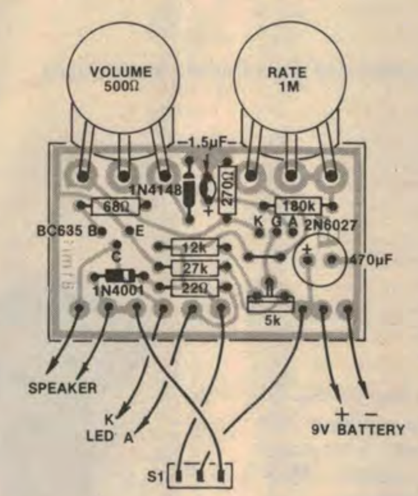
1 470μF 10 volt PC electrolytic
1 1.5μF 16VW tantalum electrolytic

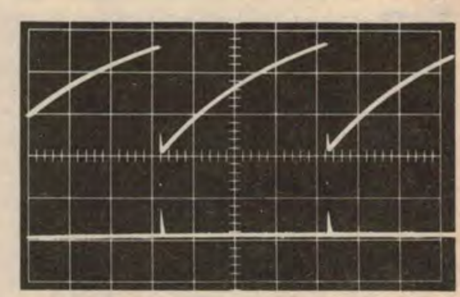
RESISTORS

(¼ watt, 5% carbon film)
1 x 180kΩ, 1 x 27kΩ, 1 x 12kΩ, 1 x 270Ω, 1 x 68Ω, 1 x 22Ω
1 1MΩ linear potentiometer
1 5kΩ vertical mount trimpot
1 500Ω linear potentiometer

MISCELLANEOUS

1 metre hook-up wire, screws, nuts and solder lugs etc.





This photograph shows the waveform at the anode and cathode of the PUT.

LEFT: the component overlay diagram. The volume and rate potentiometers are soldered direct to the PCB.

When the output pulse voltage appears at the cathode of the PUT, it is divided so that about 0.6V appears across the 1N4148 diode and the remainder of the pulse voltage appears across the 500Ω volume pot. This means that when the volume control is set fully anticlockwise, the transistor will barely conduct when each pulse appears but the loudness of the clicks from the loudspeaker will increase progressively as the volume control is advanced. And this system works well no matter how "sick" the battery becomes and how weak the PUT output pulses become.

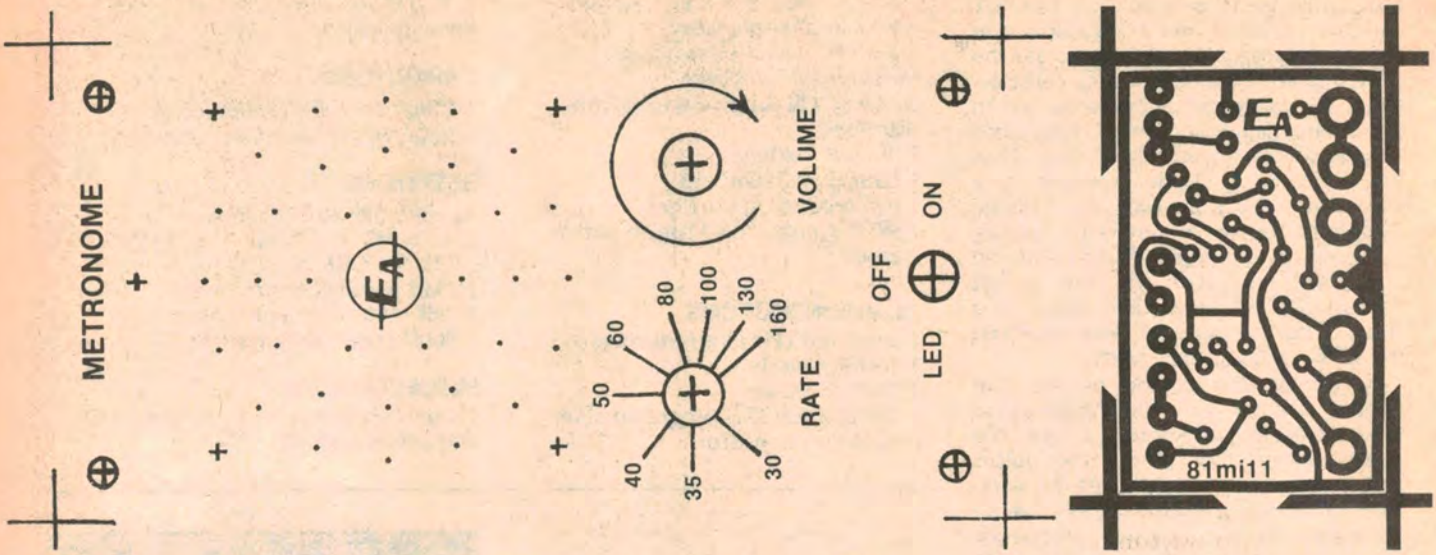
As a matter of fact the PUT will continue to oscillate at battery voltages down to about four and a half volts although at this level, the available loudness from the loudspeaker is quite restricted.

We arranged the on/off switch to select either the LED alone or both LED and loudspeaker. When the on/off switch feeds the power directly through to the loudspeaker load for the transistor, the rest of the circuit is fed via the 1N4001 diode, so that the LED flashes each time a click sounds from the loudspeaker. When the LED is selected, the diode blocks current to the loudspeaker which is silenced. The on/off switch is a single-pole, double throw type with a "centre-off" position.

Readers may wonder why the 470μF capacitor is connected directly across the battery instead of on the circuit side of the on/off switch. The capacitor is intended to supply the brief pulses of current to the loudspeaker which the battery becomes increasingly incapable of doing as it ages. In other words, the capacitor ensures a low supply impedance. But the reason the capacitor is connected directly across the battery is an interesting sidelight to this project.

In our original prototype the capacitor was wired between the junction of the diode and loudspeaker, and the 0V side of the circuit. However, we found that when the LED only function was selected by the on/off switch, the loudspeaker continued to produce clicks. At first we could not understand how this could happen since the loudspeaker was supposedly isolated from the supply. But in actual fact, it wasn't!

What was actually happening was that in the comparatively long "off" time

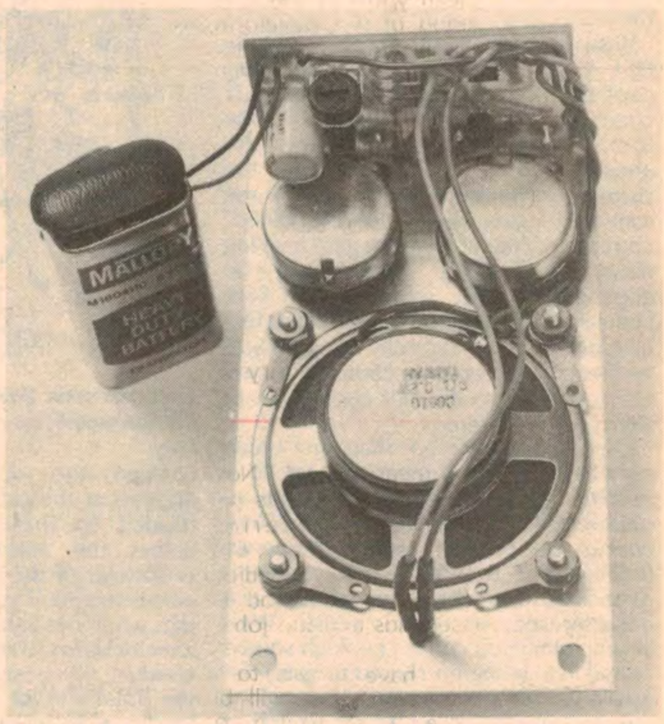


Here are actual size artworks for the front panel and the printed circuit board.

between each click, the 470μF capacitor was able to charge via the LED and loudspeaker, since the transistor was turned off. Then, when the transistor turned on, ostensibly only to light the LED, the capacitor was able to deliver a pulse of current to the loudspeaker. Very tricky! Therefore, the capacitor now resides permanently connected to the battery. The leakage current of the capacitor, by the way, can normally be expected to be around one microamp or so, which is hardly likely to reduce the battery life by a significant amount.

Current drain of the unit varies with volume control settings; at minimum setting only the PUT oscillator is functional, drawing some 220μA. At 120 beats (crotchets) per minute the average current consumption is around 850μA with the volume turned to maximum, and the metronome simultaneously driving LED and loudspeaker.

Having considered the operation of the circuit, let us now turn to its assembly.



View of the completed PCB and front panel assembly. Note how the loudspeaker is secured.

CONSTRUCTION

Our unit was built into a small plastic zippy box measuring 68(W) x 130(H) x 41(D)mm. The printed circuit board is coded 81mi11 and measures 57 x 35mm.

Commence construction by assembling the components onto the PC board. Install smaller components first, finishing with the capacitors and transistors. Follow the overlay provided to assist in the orientation and positioning of the components. Make sure that polarised items are correctly oriented, and that the resistor and capacitor values are as per the circuit. At this stage do not solder the potentiometers to the board.

The next step is to affix the self-adhesive Scotchcal label to the front panel, and drill the holes for the controls and loudspeaker.

Straighten the connecting lugs of the potentiometers so that they lie at right angles to the pot shafts and can be fed into the appropriate holes on the PC board. Note that it will probably be necessary to slightly crimp the ends of each lug to enable them to pass through the 3mm diameter holes in the PC board.

Now install the two potentiometers in the front panel, remembering that the 1MΩ pot is used for the Rate control, and the 500Ω for the Volume control. Ensure that the pots' connecting lugs are positioned to face towards the lower edge of the panel. Fit the assembled board to the pot lugs, and solder together.

The toggle switch, LED and loudspeaker may now be fitted to the panel. Note that four solder lugs, each secured with a screw and two nuts, hold the loudspeaker in position.

Wire up the LED, switch, loudspeaker and battery clip leads to the PC board, as per the component overlay diagram. Connect the battery, and switch the unit on. Providing the volume control is partly advanced, you should hear clicks at a rate set by the Rate control. Advance the Volume control further and check that the LED is flashing in time with the audible clicks. Switch to LED only, noting that the LED continues flashing but the clicks are suppressed.

Assuming that your metronome is functioning as described above, you can now calibrate the Rate control. Firstly, fix its knob so that it can rotate equally past the 30 and 160 marks. There should be about 10 degrees of rotation past both marks. As this is a relatively simple instrument, we have only included a preset for adjusting the basic rate, and have omitted facilities for presetting end limits for the Rate control. Thus the "tracking" of the Rate control on your unit will be dependent on the tolerance match of the 1MΩ potentiometer and associated series 180kΩ resistor. For this reason it is desirable to perform the calibration at a rate which is in the centre of your most used range.

There are two ways to calibrate your metronome. First, if you have a frequency meter which can measure period (the latest EA design described last month is ideal) you can use it to measure the period of the waveform. Connect the frequency meter across the 270Ω cathode load resistor for the PUT and set the frequency meter mode control for period measurements. Now set the rate control for 100 beats per minute and note the period measurement. It should be 600 milliseconds or not far off. Now adjust the 5kΩ trimpot to get a period of exactly 600 milliseconds and the job is complete.

Should you not have access to a suitable frequency counter, it will be necessary to use a stopwatch or wristwatch with sweep second hand. As previously, set the pointer to "100", turn the metronome on and count the clicks in, say, a one-minute period. Adjust the preset to obtain exactly 100 clicks (Hint: for coarse adjustment, count the clicks in, say, a 12-second period – should be 20 clicks – then use the one-minute period for the final fine adjustment).

The unit may now be screwed into its box, and is ready for use. One final thought: readers interested in photography can set the Rate control to 60 (one click per second), and use the audible clicks to tick off the seconds for "time" exposures at night or for printing sessions in the darkroom.

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

$17.00

including sales tax and battery