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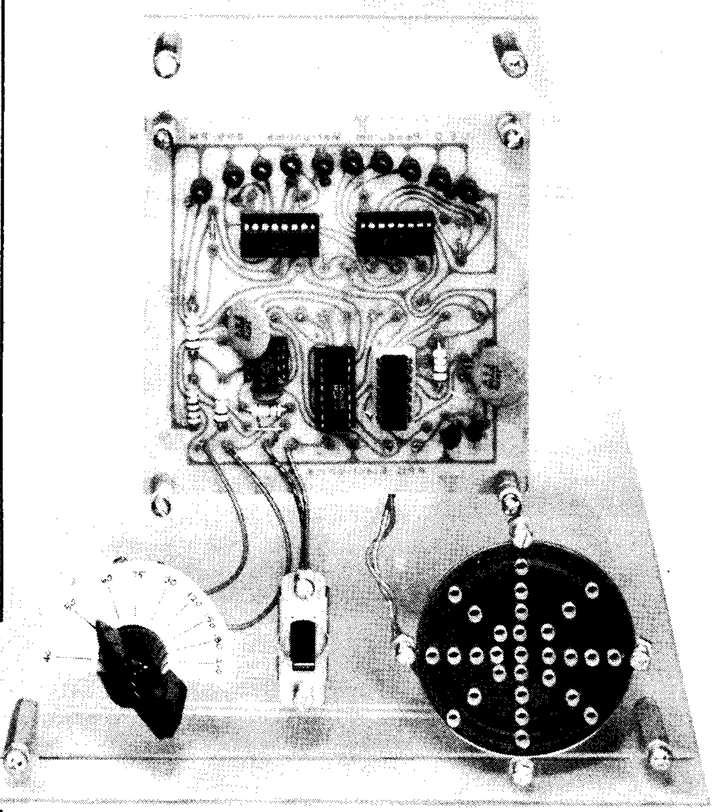
A LED PENDULUM METRONOME

An electronic replacement for the old mechanical music timer

The mechanical metronome, reputedly invented by Maezel in the 19th century, has been a familiar sight around musicians and music students for many years. It uses a wind-up clock mechanism to swing a weighted arm, generating a series of clicks as the escapement gears make contact. The clicking rate is conventionally adjustable from 40 to 210 beats per minute by positioning the weight on the calibrated oscillating arm to change the moment of inertia and the rate of the swing.

Redoubtable though it may be, Maezel's brainchild suffers from defects common to all mechanical devices: wear, drift of calibration, and the need for fairly frequent maintenance. In addition, it must be wound often. A battery-operated, solid-state electronic design, such as the LED Pendulum Metronome described here, circumvents or alleviates the problems of the mechanical metronome. It is stable in calibration and reliable.

Partly for nostalgic reasons, the pendulum movement of the mechanical metronome is simulated in the project as a flashing sequence of LEDs arranged in an arc. (A click from a loudspeaker occurs as the LED at either end of the string fires.) However, the LEDs offer the user the option of "reading" the metronome signal visually in circumstances where a click might be inaudible or objectionable to the user.



Circuit Operation. The "beats" are generated by *IC1*, which is used as an oscillator (Fig. 1). Resistors *R1*, *R3*, and capacitor *C1* limit the frequency of operation that can be set by means of potentiometer *R2*. Capacitor *C2* decouples the *IC1* modulation input. Each cycle of operation of *IC1* results in a positive-going pulse at pin 3, which is fed to the clock input of up-down counter *IC4*. This counter can be set to count from 0 to 9 (10 counts) or 0 to 15 (16 counts), depending on the status of pin 9. With pin 9 positive (as shown), *IC4* counts from 0 to 15. Counting up or down is controlled by pin 10; positive for up-counting, ground for down-counting. The A, B, C, and D outputs of *IC4* (pins 6, 11, 14, and 2) go positive in a 4-bit binary sequence with the D output (pin 2) low during counts 0 to 7 and high during counts 8 to 15.

Both *IC2* and *IC3* are identical 1-of-8 switches. Depending on the 3-bit binary input, one of eight outputs is connected to pin 3 through a low resistance (typically 120 ohms). This is called the "on" condition for this pin. The A, B, and C inputs to *IC2* and *IC3* (pins 11, 10, and 9) are addressed by the output pins (6, 11 and 14, respectively) of *IC4*. However, *IC2* or *IC3* must be enabled by a low on pin 6. For counts 0 to 7, pin 2 of *IC4* is low, enabling *IC2*. Notice, however, that pin 6 of *IC3* is high because of *IC5A*, one section of a quad 2-input NAND gate, wired as an inverter. This disables *IC3* while *IC2* is enabled.

As *IC4* counts from 0 to 7, the outputs of *IC2* are turned "on" in sequence. In this case, on is *not* ground, but is an internal low resistance to pin 3, which is grounded. This low resistance to ground allows the LED connected to an on pin to glow.

Only five LEDs are connected to the eight outputs, with *LED1* connected to three outputs, *LED2* to two outputs, and *LED3*, *LED4*, and *LED5* to one output each. This is done to simulate the swinging motion of a pendulum, which is fastest near the center but slows down near each end of its swing as it finally stops and reverses. By using multiple counts for the LEDs farthest from the center, the apparent motion of the pendulum seems to slow down, stop, and reverse at each end of its swing. This same technique is used for the five LEDs connected to *IC3*.

As *IC4* counts from 0 to 7, only *IC2* is enabled, with *IC3* cut off. When *IC4* reaches the count of 8, the D output at pin 2 goes high. This turns off *IC2*, but, via the inversion by *IC5A*, *IC3* is enabled, lighting LEDs 6 to 10 in sequence. Therefore, the first eight counts of *IC4* are used to command the *IC2* outputs, and the next eight counts command *IC3* outputs.

Up to this point, *IC4* was counting up since its pin 10 was high. This is controlled by the output of a flip-flop formed by NAND gates *IC5B* and *IC5C*. When power is first turned on by closing switch *S1*, pin 9 of *IC5B* is pulled high through *R6*, and pin 5 of *IC5C* is pulled low by pin 13 of *IC2*. Pin 4 of *IC5C* is therefore high since it has a low on at least one input. Pin 4 is connected to *IC4* pin 10, so *IC4* counts up. The flip-flop holds this high on pin 4 of *IC5C*, even though the first count changes pin 5 of *IC5C* to a high. On count number 15 (actually the sixteenth count, if you start at 1 instead of zero), pin 4 of *IC3* is switched on (low resistance to ground). This pin is directly connected to pin 9 of *IC5B*, pulling it low, so output pin 10 of *IC5B* goes high. This provides a high input to pin 6 of *IC5C*. Since pin 5 is already high, pin 4 of *IC5C* goes low to switch *IC4* to the down-counting mode. Even though *IC5B* pin 9 goes high on the next count, the flip-flop logic keeps pin 4 of *IC5* low.

When *IC4* gets down to the zero count, pin 13 is turned on, and pin 5 of *IC5C* is pulled low, making pin 4 of *IC5C* high, and thus putting *IC4* in the up-counting mode. The top count of *IC4* then causes the flip-flop to again change the output at pin 4 of *IC5C*. This flip-flop action keeps occurring at each end of the pendulum, causing it to "swing" back and forth. Capacitors *C4* and *C5* prevent noise from accidentally changing the up/down mode of *IC4*.

The clicking sound occurs at each end of the pendulum swing (as counts 0 and 15 are reached) by changing the state of *IC5D*. Pins 12 and 13 of *IC5D* are normally high, so pin 11 is in a low

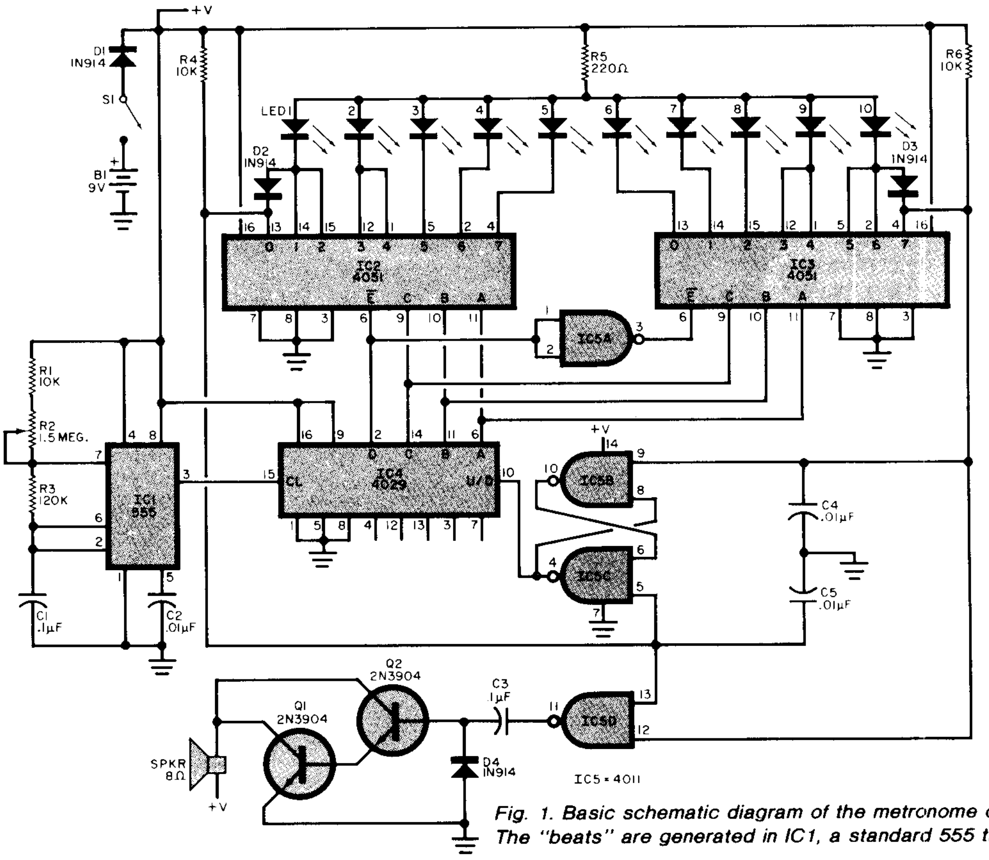


Fig. 1. Basic schematic diagram of the metronome circuit. The "beats" are generated in IC1, a standard 555 timer.

PARTS LIST

B1—6-to-9-volt battery (see text)
C1,C3—0.1-µF disc capacitor
C2,C4,C5—0.01-µF disc capacitor
D1 through D4—1N914 diode
IC1—555 timer
IC2,IC3—4051 1-of-8 switch
IC4—4029 up down counter
IC5—4011 quad 2-input NAND
LED1 through LED10—Jumbo red LED
Q1,Q2—2N3904 or similar transistor
R1,R4,R6—10-kΩ, ¼-W, 10% resistor
R2—1.5-MΩ, liner-taper potentiometer
R3—120-kΩ, ¼-W, 10% resistor
R5—220-Ω, ¼-W, 10% resistor
S1—Spst switch
SPKR—Miniature 8-Ω speaker
Misc.—IC sockets (optional), battery holder, knob, suitable enclosure, mounting hardware, etc.

Note: The following is available from PPG Electronics Co., Inc., Dept. B, 14663 Lanark St., Van Nuys, CA 91402 (213-988-3525): complete kit of parts including pc board (PM-K) at $14.95. Also available separately: plastic "cabinet" (PM-C) at $9.95; etched and drilled pc board (PM-B) at $5.95. Add $2 shipping and handling. California residents, add 6% sales tax. No foreign orders.

state. When *IC2* pin 13 or *IC3* pin 4 is pulled low, on counts 0 or 15 respectively, pin 12 or 13 of *IC5D* is made low, and pin 11 of *IC5D*, following NAND logic, goes high. This positive voltage swing charges *C3*, causing a small positive pulse to forward-bias transistors *Q1* and *Q2*, which are arranged in a Darlington circuit. The small current pulse through the series-connected base-emitter circuits of *Q1* and *Q2* enables a larger current flow from the power source, through the speaker and the collector-emitter circuit of *Q1*. This is heard as a click. When pin 13 of *IC2* or pin 4 of *IC3* goes high on the next count, a high is put back on pin 12 or 13 of *IC5D*. Pin 11 goes low again, and capacitor *C3* is discharged through diode *D4*. Since transistor *Q2* is now reverse-biased, there is no sound from the speaker until the pendulum "swings" to the other end.

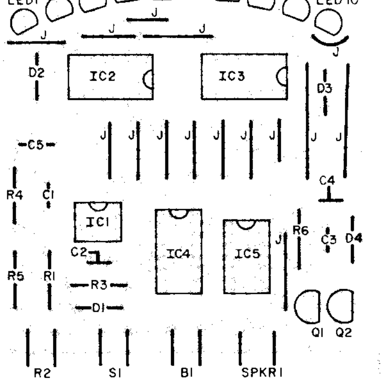
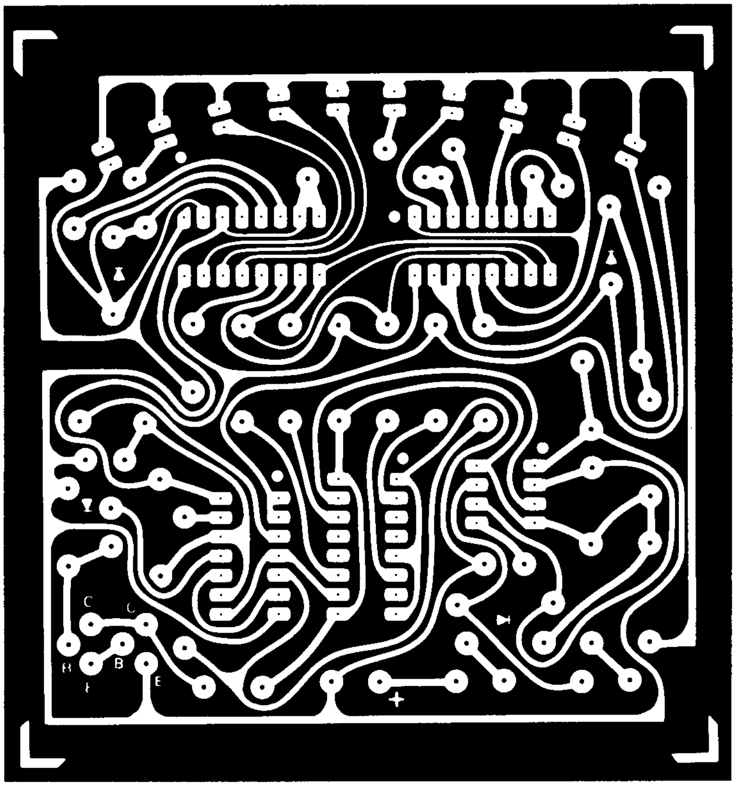


Fig. 2. An actual-size foil pattern for a printed-circuit board is shown below. Above is the component layout diagram. Install jumpers first.



Diodes *D2* and *D3* block the low voltage from pins 14 and 15 of *IC2* and pins 5 and 2 of *IC3* so the count is not prematurely reversed. Diode *D1* prevents damage to the circuit from reversed power leads, or from inserting the battery backwards.

Construction. The LED Pendulum Metronome circuit can be built on a perforated board with point-to-point wiring. However, there are 120 terminations for the ICs, resistors, capacitors, diodes, and transistors—and this doesn't count the external speaker, potentiometer, switch, and battery wiring. Thus, it is more convenient to use the printed-circuit pattern and parts layout shown in Fig. 2.

If you use the pc board, assembly is straightforward. A small 25-watt soldering iron and resin-core solder should be used. First, install the 15 jumpers shown in Fig. 2, cutting wires to the appropriate length and trimming about ¼″ of insulation from each end. Insert through the top of the board and solder on the foil side. Next, install and solder the resistors and diodes, making certain the bands (cathodes) on the diodes are properly oriented. Next, solder in the five sockets, but do *not* install the ICs yet. Now, solder in the three capacitors. The LEDs must be installed in the proper orientation. The cathode (bar of arrow symbol) is identified by a flat-spot or notch at the base of the LED, and the cathodes of all LEDs face the main portion of the circuit board. Next, solder in the transistors, with the flat side facing as shown, so the E, B, and C leads are properly placed. Solder two leads each for the speaker, switch, battery, and potentiometer, and your circuit board wiring is completed.

Your final packaging will dictate the placement of the external parts and the lengths of the leads. Double-sided tape can be used to mount the speaker to the foil side of the board. Potentiometer *R2* should be located below the circuit board to allow room for a calibrated scale and knob on whatever front panel you use. The switch and battery leads can be located wherever convenient.

A unique, modern package is provided by using two sheets of Plexiglas with spacers and screws used to mount the circuit board sandwich-fashion, as shown in the photo.

Since all the ICs have a broad voltage operating range (roughly 3 to 15 volts), you have a choice of what battery configuration to use. At 9 volts, the circuit draws an average of 30 mA, so it's practical to use a standard 9-volt transistor radio battery. Used 4 hours daily, a standard 9-volt zinc-carbon battery (such as Burgess 2V6) should last about 5 hours; an alkaline 9-volt cell should run at least 20 hours. For long, hard use, it would be less expensive to use four "AA" pen cells, "C" or "D" cells wired in series to provide 6 volts initially. Although the LEDs will not be quite as bright and the clicking not as loud, the average current drain is only about 20 mA. Four regular zinc-carbon pen cells should run the metronome for almost 50 hours, used 4 hours a day. Using zinc-carbon "C" cells under the same conditions you can expect 125 hours of use. Alkaline batteries will provide from 4 to 10 times as much useful life. Actually, the circuit will operate with as little as 3 volts, and only uses an average of 4 mA at that voltage—but it's not very loud or bright, so not as effective!

Testing & Calibration. It's a good idea to test and calibrate the unit before final installation in whatever cabinet you're using. Install the ICs carefully in their sockets, making sure they are oriented properly and that no pins are bent out or under. Since all the ICs except *IC1* are CMOS devices, take precautions to avoid static electricity when handling them. Solder the speaker, switch, potentiometer, and battery connector (if used) to the leads from the circuit board and don't forget the jumper across two of the potentiometer terminals.

Connect the battery power and turn on switch *S1*. If nothing happens, make sure that *D1* is not connected "backwards" and that battery polarity is correct. If any individual LED does not light, it may be soldered to the board backwards. If only one LED lights, the 555 (*IC1*) may not be operating. Check for the presence of positive voltage on pins 4 and 8, and see that pin 1 is grounded. Also make sure the values for resistors *R1* and *R3* and capacitor *C1* are correct. As always, solder connections should be checked. If the LEDs swing properly, but you hear no sound, check transistor installation and diode *D4* polarity. If you encounter problems beyond that, an ohmmeter, logic probe, and the circuit description should allow you to pinpoint the problem.

Calibration ideally requires a stopwatch, but a sweep-second watch or seconds-counting digital watch will do. You'll also need patience. The major calibration points are 60, 120, and 180 beats per minute (bpm), since these are 1, 2, and 3 beats per second. You can tell pretty closely in a 15-second timing period what the minute-rate will be for a particular pointer setting by just multiplying the number of beats by four. By trial and error, mark the pointer scale at these points. Next find the 90, 150, and 210 bpm points. Once you've found these points, space the other points equally between the calibrated points and you'll be close enough for all but precision use. If the clicking sound is too loud, add a resistor (up to 100 ohms) in series with either speaker lead. (A 100-ohm potentiometer or variable resistor can be used as a volume control if desired.)

The LED Pendulum Metronome is not intended to be used in precision-timing applications, but is a modern version of an established musical teaching aid. ◇