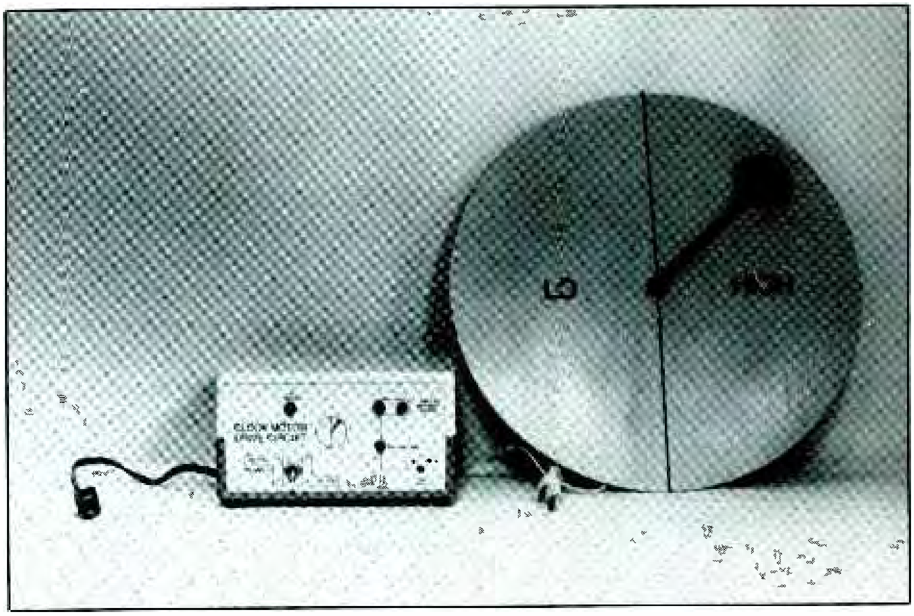
A Tide Clock

Keeps track of the rise and fall of water affected by ocean tides

By Joseph P. O'Connell



The ebb and flow of tidewater, being most influenced by the moon, ordinarily do not occur at the same rate as the standard 24-hour solar clock. Therefore, a different kind of clock is needed to keep track of high and low tides—a Tide Clock like the project presented here. It can be a highly valued indicator for people living near a shoreline. whether for swimming, boating or fishing.

At the heart of our Tide Clock is a 117-volt ac power supply that drives synchronous motors from either a 12-volt dc or 117-volt ac power source. The project produces up to 300 milliamperes, which is enough current to drive several small motors simultaneously. Frequency adjustment is accomplished with a potentiometer and either an external frequency counter or a clever beat-frequency display that especially simplifies calibration of the power supply at frequencies close to 60 Hz.

Although in this article we will concentrate on using the power supply, which comprises the major portion of the project, in a Tide Clock application, there are many other uses for it. These include operating small appliances and powering a telescope drive motor for stargazing. Astronomers should appreciate the variable frequency control the project affords, allowing them to temporarily convert from solar drive to sidereal tracking.

Making of a Tide Clock

Our Tide Clock works on the assumption that there are two equal tide cycles per day, each comprising a high and a low tide. For all but a few locations on Earth, where coastal features cause irregular tide intervals, this is a valid assumption.

Most areas on Earth can be represented as discrete points on a rotating globe that pass through two high and two low tides with every revolution. Locations of the high and low tides are fixed by the moon. If the moon stood still, each revolution of the lighthouse depicted in Fig. 1 would take 24 hours exactly and anyone in the lighthouse would see the tide change every 6 hours. If this were the case, an ordinary clock could be used to tell when the high and low tides would occur. However, because the moon revolves around the Earth in the same direction as the latter is rotating, each revolution of the lighthouse with respect to the tides takes 25 hours and 50 minutes.

One way to represent this cyclical event is with a specially designed synchronous motor that makes one revolution every 12 hours and 25 minutes. Using this approach, two revolutions of the motor would be needed to complete every cycle of four tides. This approach makes it easy to use a "clock-face" arrangement with a single hand to point to the condition of the tides depicted on the face of the clock at any given moment for a given location.

Another approach to obtaining the same effect is to drive a standard clock motor at a slightly lower frequency than the 60 Hz of the standard ac line. With proper selection of drive frequency, the hours hand will complete one revolution around the dial face in 12 hours and 25 minutes instead of the usual 12 hours.

Rather than being fixed to either an ac or a dc power source, our Tide

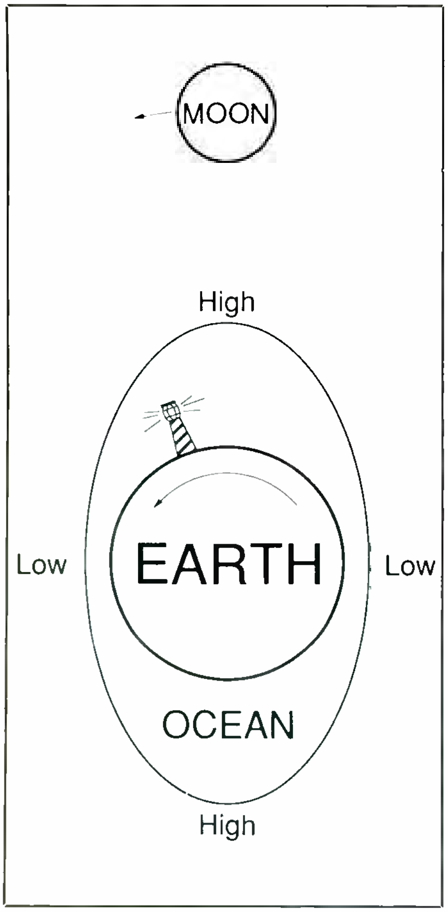


Fig. 1. With every rotation of the Earth relative to the moon, an observer in the lighthouse would see two high and two low tides.

Clock project incorporates both in a single electronics package. As can be seen in the lead photo, the Tide Clock actually consists of two units: a motor-driven clock mechanism with its special dial face and a separate electronics package that powers the motor. Though the project offers both powering options, the 12-volt dc electronic drive approach is likely to be of more widespread interest because it has uses beyond that of a simple Tide Clock application.

The unique characteristics of synchronous motors make this project possible and practical. Synchronous motors are employed in clocks and other electromechanical timing devices because their speed of operation depends on the ac line frequency used to drive them and on their reasonable immunity to wear, uneven loading and wide variations in powering voltage. Although designed to be driven by a 117-volt ac sine-wave signal, synchronous motors can operate satisfactorily with the square-wave drive the power supply in our Tide Clock delivers.

The dependence of synchronous motors on line frequency makes them both reliable in normal applications and easy to control in special applications. One such special application is the Tide Clock project presented here.

A synchronous motor can be thought of as a stepper motor whose output shaft advances a fraction of a revolution for every cycle of the ac drive signal. To complete a single revolution in 12 hours and 25 minutes instead of the 12 hours exactly it would normally require, a synchronous motor must be driven at a slightly slower frequency than normal. The new frequency must complete the same number of cycles in 12 hours and 25 minutes as the standard 60-Hz frequency completes in just 12 hours.

A frequency of 60 Hz completes 2,692,000 cycles in 12 hours. The frequency that completes the same number of cycles in 12 hours and 25 minutes is 57.9865772 Hz. A similar calculation for telescope drive motors reveals that the correct frequency to accurately accomplish sidereal tracking with a solar telescope drive is 60.1643 Hz. The power supply in this project offers more than this range of adjustment to meet a variety of application needs.

About the Circuit

The complete schematic diagram of the project's circuitry, including its ac-operated power supply but not including the drive motor, is shown in Fig. 2. Refer to this for the following explanation of circuit operation.

There are many ways to design an oscillator that will generate the required frequency for our Tide Clock. However, the simplest reasonably accurate approach is to build the circuit around an integrated-circuit oscillator chip. Of the oscillator chips that are commonly available, the Exar XR-2206CP was chosen for this project because it has the best thermal stability, rated at 20 ppm/°C.

The stability of the XR-2206CP chip is more than adequate for a clock with an analog display. This is because the error in reading the position of the hand against the clock dial alone is much greater than the oscillator would accumulate during weeks of worst-case operation.

Another advantage of the XR-2206CP shown for *IC2* in Fig. 2 is the low additional external component count required to configure a square-wave oscillator with this chip. In this circuit, the operating frequency of the oscillator built around *IC2* is determined solely by the capacitance of *C2* and series resistance of *R1* and FINE ADJUST potentiometer *R8*.

With a capacitance value of 1 microfarad, the resistance required is 17,425 ohms. A 16,000-ohm value for *R1* and 2,000-ohm value for the potentiometer permits the operating frequency of the oscillator to be adjusted over a range of 55.5 to 62.5 Hz, enough to allow for trimming purposes and to make up for slight discrepancies in component values.

The square-wave output at pin 11 of *IC2* is directly coupled to the input of *IC3* at pins 5, 7, 9 and 11. The unconnected pins of *IC2* provide a sine-wave output and some other functions that are not of interest here.

Capacitors *C1* and *C3* provide bypassing to ensure stable circuit operation. Their values are not critical to proper operation of the project.

Integrated circuit *IC3* contains six buffered inverter stages. The square-wave output from *IC2* that couples to pins 5, 7, 9 and 11 of *IC3* emerges inverted at pins 4, 6, 10 and 12 of the IC. Note that the output at pin 4 of *IC3* provides a means for monitoring

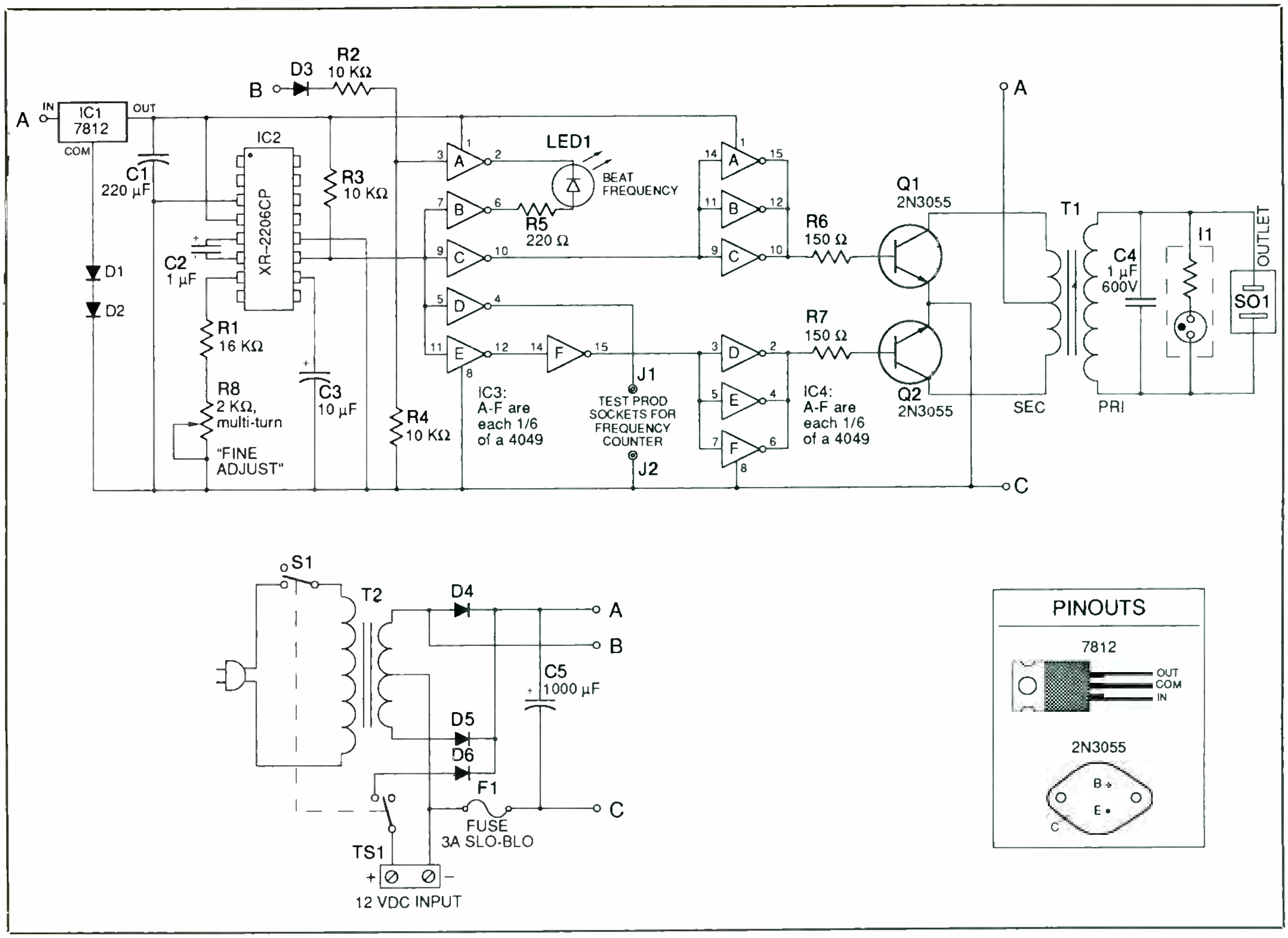


Fig. 2. Complete schematic diagram of Tide Clock electronic drive circuitry.

the frequency of the oscillator with an external frequency counter.

Inverters *IC3A* and *IC3B* drive light-emitting diode *LED1* at the beat-frequency (mathematical difference) of the oscillator and a 60-Hz pulse train obtained from the 117-volt ac line through *D3*, *R6* and *R7*.

The remaining inverters in *IC3* are used to obtain the alternating pulse trains needed to bias transistors *Q1* and *Q2*. One of these pulse trains passes through three such stages to reach *Q2*. This puts the drives to the two transistors out-of-phase with each other so that when one is conducting the other is held in cutoff, and vice-versa.

Integrated circuit *IC4* simply serves as a buffer between *IC3* and the two transistors. Note that there are two groups of three inverters connected in parallel in *IC4*, one for each transistor, to provide enough current to bias the transistors into saturation.

As *Q1* and *Q2* alternately conduct, each allows current to flow in alternating directions through the secondary of transformer *T1*. Capacitor *C4* suppresses switching transients, and the neon lamp *I1* provides visual indication when power is being delivered to ac OUTLET *SO1* into which the Tide Clock's display or other synchronous motor is plugged.

The ac/dc-driven power source, shown schematically at the lower-left in Fig. 2, is of conventional design. It permits operation from either a 12-volt dc or 117-volt ac source. A single double-pole, double-throw switch, *S1*, is provided for powering the project from the ac line and to switch between ac and dc modes.

The power supply provides a 60-Hz pulse train that is used to derive the beat frequency discussed above. During operation from a 12-volt dc source, the beat frequency display does not operate and *LED1* simply remains dark.

Although the power supply drives the inverter section of the main circuit directly, it passes through voltage regulator *IC1* before powering the more delicate timing and switching ICs. Using *D1* and *D2* in the return path of regulator *IC1* as shown increases the output of the chip by about 0.7 volt for every diode used.

PARTS LIST

Semiconductors

D1,D2,D3—1N4001 or any other silicon rectifier diode

D4,D5,D6—50-volt, 3-ampere (or more) silicon rectifier diode

IC1—7812 + 12-volt 3-terminal voltage regulator

IC2—XR-2206CP function generator (Exar Corp.)

IC3,IC4—4049 hex inverter

LED1—Red panel-mount light-emitting diode

Q1,Q2—2N3055 npn power transistor in TO-3 case

Capacitors

C1—220-μF, 16-volt electrolytic

C2—1-μF, 10% or better tolerance nonpolarized Mylar, propylene or polystyrene

C3—10-μF, 16-volt electrolytic

C4—1-μF, 400-volt or better nonpolarized

C5—1,000-μF, 16-volt electrolytic

Resistors (¼-watt, 5% tolerance)

R1—16,000 ohms

R2,R3,R4—10,000 ohms

R5—220 ohms

R6,R7—150 ohms

R8—2,000-ohm multi-turn pc-mount trimmer potentiometer.

Miscellaneous

F1—3-ampere slow-blow fuse

I1—Panel-mount neon-lamp assembly with current-limiting resistor

J1,J2—Panel-mount banana jack

S1—3-ampere or better dpdt toggle switch

SO1—Panel-mount ac receptacle

T1,T2—24-volt center-tapped, 2-ampere power transformer

TS1—Two-position panel-mount, screw-type terminal strip

Synchronous-motor analog clock (see text); printed-circuit board or perforated board with holes on 0.1-inch centers and suitable Wire Wrap or soldering hardware (see text); suitable enclosure (see text); solder-lug type terminal strip; sockets for all DIP ICs; fuse holder; materials for making clock face (see text); small-diameter heat-shrinkable tubing; suitable machine hardware; hookup wire; solder; etc.

The diodes used in this circuit assure that the power supply voltage for the ICs is at least 12 volts dc, even for a slightly out-of-specification regulator IC. If desired, *D1* and *D2* can be eliminated.

Construction

Most of the construction work for this project is entailed in wiring the Fig. 2 circuit and housing it in a suitable enclosure. What remains after that is taking apart an existing ac-line-powered analog clock to salvage the drive motor and fabricating a new face and hand to match its new function as a tide clock.

Owing to the fact that only low-frequency digital-level signals are used in this project, you can wire the Fig. 2 circuit on either a printed-circuit board or perforated board that has holes on 0.1-inch centers using suitable Wire Wrap or soldering hardware. A final alternative is to wire together the components on a Universal PC Board like the Radio Shack Cat. No. 276-168.

If you opt for printed-circuit construction, you can fabricate a suitable board using the actual-size etching-and-drilling guide shown in Fig. 3. From here on, we will assume pc construction. Once the board is ready to be populated, orient it as shown in Fig. 4. Begin wiring it by installing and soldering into place sockets for the DIP ICs. (Note that sockets for these chips are optional but highly recommended to ease replacement should any or all ICs fail during the life of the project.) Do *not* plug the ICs into their respective sockets until after preliminary voltage checks have confirmed that you have properly wired the project.

Continue wiring the circuit-board assembly by installing and soldering into place first the fixed resistors and then the diodes and capacitors. Make certain the diodes and electrolytic capacitors are properly oriented before soldering any of their leads into place. Next, install and solder into place multi-turn potentiometer *R8*, regulator *IC1* and the JUMPER wire. Use a cut-off resistor or capacitor lead or a solid bare hookup wire for the jumper.

Strip ¼ inch of insulation from both ends of eight 6-inch-long hookup wires. If you are using stranded hookup wire, tightly twist together the fine wires at both ends of all wires and sparingly tin with solder. Plug one end of these wires into the holes labeled Q1 BASE, Q2 BASE, FROM POWER SUPPLY "A" and "B" (two wires), LED1 CATHODE and LED1 ANODE (two wires), and TO J1 (two wires). Solder all wires into place.

Carefully examine all soldered connections. Solder any connection you missed and reflow the solder on any suspicious connections you encounter. Also, check for solder bridges, especially between the closely spaced pads for the IC sockets. If you locate any solder bridges, remove them with desoldering braid or a vaccum-type desoldering tool.

Now prepare the enclosure in which you will house the circuit-board assembly and power-supply circuitry. Make sure the enclosure you select is large enough to also accommodate POWER switch *S1*, power transformer *T2*, neon-lamp indicator assembly *I1*, power outlet *SO1*, screw-type terminal strip *TS1* fuse *F1* in its holder and a solder-type terminal strip on which to mount diodes *D4*, *D5* and *D6* and capacitor *C5*.

Machine the enclosure as needed to mount the circuit-board assembly, power transformer and diode/capacitor arrangement on a terminal strip and the fuse holder on the floor panel. Through the front panel, drill mounting holes for the LED, banana jacks, neon-lamp assembly and POWER switch. Also drill an access hole for *R8* in a location at the lower-right that provides easy access to the adjustment screw when the circuit-board assembly is mounted in place. Details for machining this panel,

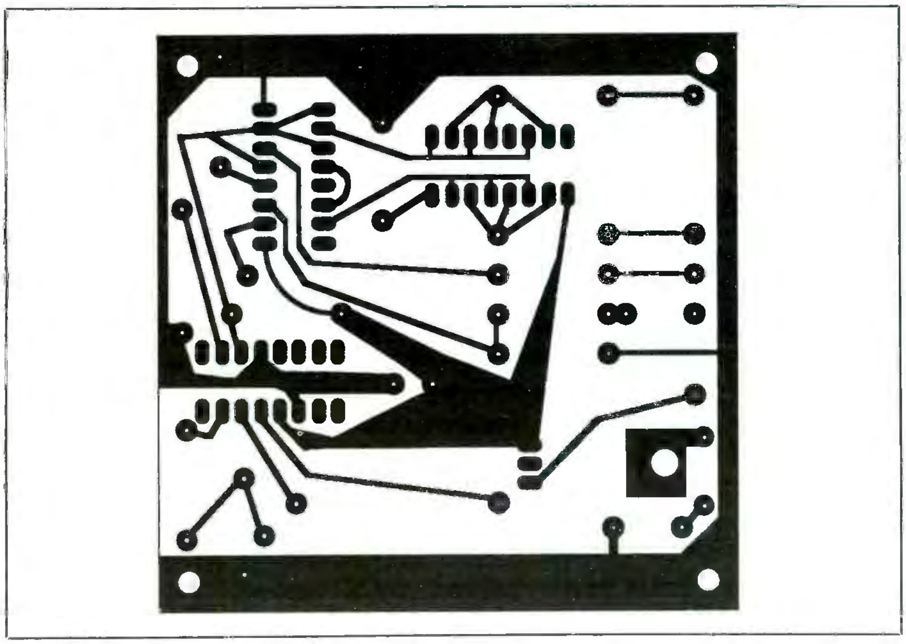


Fig. 3. Actual-size etching-and-drilling guide for project's printed-circuit board.

along with typical lettering, are shown in Fig. 5.

On the rear panel of the enclosure will be mounted the two-position screw-type terminal strip, power transistors *Q1* and *Q2*, transformer *T1* and receptacle *SO1*. Also, drill a hole to provide entry for the ac line cord. Machining details for this panel are shown in Fig. 6.

After all machining is done, deburr all holes and cutouts to remove sharp edges. Then paint the front panel, if desired. When the paint has fully dried, label the front panel with a dry-transfer lettering kit. Protect the lettering with two or more light coats of clear acrylic spray, allowing each to dry before applying the next.

When the enclosure is ready, mount the circuit-board assembly in place with suitable-length spacers and 4-40 machine hardware. Mount the power transformer, solder-type terminal strip and fuse holder into place. Then, referring to Fig. 2, carefully wire the power-supply circuit. Make certain that you do not mistake the primary leads of the transformer for the secondary leads and that the diodes are properly polarized.

Place a rubber grommet in the the ac line cord's entry hole in the rear panel. Then feed the unprepared end of the line cord through the hole and tie a strain-relieving knot in it about 8 inches from the free end inside the enclosure. Tightly twist together the fine wires in each conductor and sparingly tin with solder.

Mount the various components on the front panel. Then crimp and solder one line cord conductor to one lug of the POWER switch. Slip a 1-inch length of small-diameter heat-shrinkable tubing over one primary lead of the power transformer. Crimp the other line cord conductor to this lead and solder the connection. Slide the tubing over the connection to completely insulate it and shrink the tubing into place. Then crimp and solder the other transformer primary lead to the other POWER switch lug on the *same* side of the switch.

Crimp but do not solder the center-tap secondary lead of *T1* to one lug of the fuse holder. Then use a suitable length hookup wire to bridge between the same fuse holder lug and the negative (−) lug of the screw-type terminal strip on the rear panel of the enclosure.

Now wire the other half of *S1* as shown in Fig. 2. If the solder-lug ter-

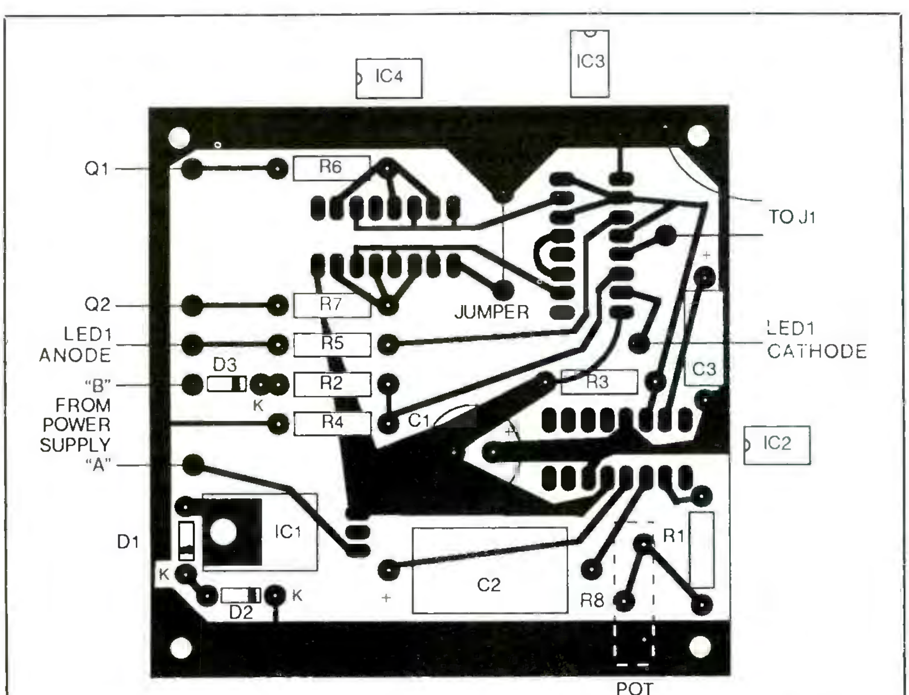


Fig. 4. Component-placement guide for pc board.

minal strip in the power supply is sufficiently close to *TS1*, simply bridge from the switch lug to the terminal strip lug to which the cathodes of all three diodes in the powering section connect. If not, lengthen the anode lead of *D6* with hookup wire (use heat-shrinkable or other tubing to insulate the connection). Make certain *D6* is properly polarized and that you wire the anode lead to *S1* so that when the ac powering option is off, the circuit from *TS1* is closed to *D6*.

Now wire *LED1*, *J1* and *J2* to the circuit-board assembly, using the wires you previously installed on the board. Use small-diameter heat-shrinkable tubing to insulate the connections to the LED, and make certain that the LED is properly polarized. When this is done, wire *I1* and *SO1* into the circuit.

Mount the two power transistors on the rear panel. If you are using a plastic utility box for the project's enclosure, you must use a $7 \times 4 \times \frac{1}{8}$-inch sheet of aluminum as a heat sink for the transistors. You can bend this into a U shape if the height of the enclosure is less than 4 inches. If you are using an all-metal enclosure, the enclosure itself will provide adequate heat-sinking for the transistors.

Make sure the transistors are insulated from the metal of the heat sink or metal enclosure. Once they are mounted, tie together their emitters with a length of hookup wire and connect them to circuit ground at the lug of the fuse holder to which the negative (−) lead of *C5* is connected. Crimp and solder the wire coming from hole A in the circuit-board assembly and the secondary center-tap lead of *T1* to the solder-lug terminal strip to which the cathodes of *D4*, *D5* and *D6* are connected.

Next, terminate the two wires coming from the Q1 Base and Q2 Base holes in the circuit-board assembly to the bases of the transistors. Mount transformer *T1* and ac outlet *SO1* to the rear wall of the enclosure. Crimp and solder the remaining secondary

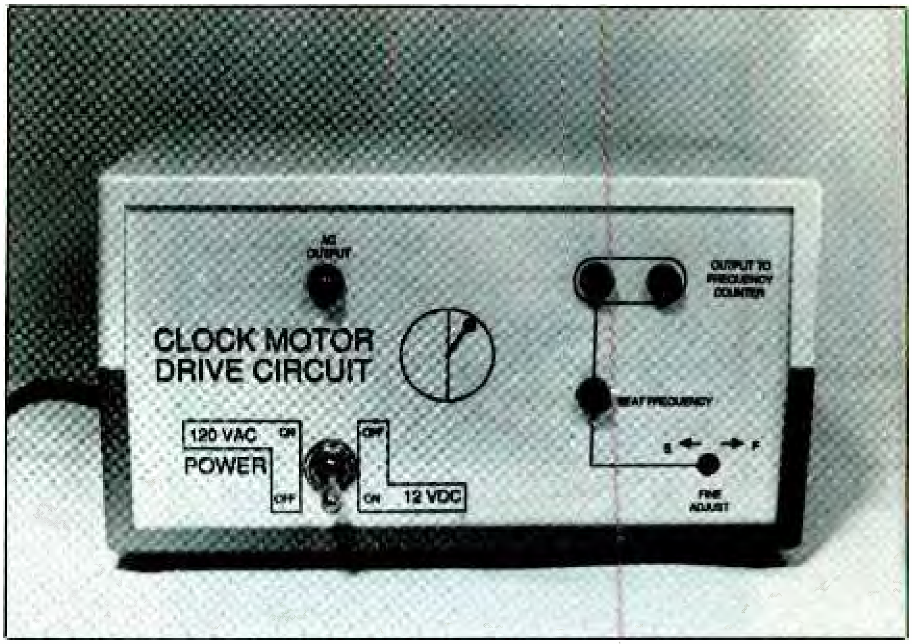


Fig. 5. Machining details for front panel of electronics-package enclosure.

leads of the transformer to the collectors of the transistors.

Mount *T1* and *SO1* in their respective locations on the rear panel of the enclosure. Slide suitable lengths of plastic tubing over the leads of non-polarized capacitor *C4* and crimp but do not solder the capacitor's leads to the lugs of the chassis-mounted ac outlet. Crimp but do not solder the primary leads of the transformer to the lugs of the outlet. Prepare two suitable lengths of hookup wire and crimp one end of each to the lugs of the ac outlet. Solder both connections.

Slide a 1-inch length of small-diameter heat-shrinkable tubing over the free ends of the two wires. Crimp and solder these wires to the leads of neon-lamp assembly *I1* on the front panel. When the connections cool, slide the tubing over them to completely insulate the connections and shrink the tubing into place.

Terminate the free end of the wire coming from hole B in the circuit-board assembly at the junction of *D4* and secondary lead of *T2*. Solder the connection. Then crimp and solder the free ends of the wires coming from holes J1 and J2 to the lugs on the jacks mounted on the front panel (observe polarity). Finally, plug a 3-ampere fuse into the holder.

This completes assembly of the power-supply portion of the project. Set this assembly aside until later and proceed to fabricating the Tide Clock's dial/motor assembly.

Modify an existing ac-operated analog clock is a simple procedure. Simply open the clock's case and remove all hands from the shafts of the drive motor. If you wish, you can save the hours hand for use as the pointer for the Tide Clock's display. The minutes hand (and seconds hand if there is one) can be discarded. Then dismount the synchronous motor from the clock case.

Building the clock hand and face depends on what materials are available. You can go elaborate, as was done for the prototype shown in the lead photo, or you can simply use the clock as-is, just replacing the existing dial face with a new one with appropriate markings to distinguish it from ordinary standard clocks.

If you decide to go the elaborate route, the dial face can be any sheet material—plywood, Masonite, hard-

Fig. 6. Machining details for rear panel of enclosure.

board, plastic sheet or metal sheet—you have handy and is thin enough to permit mounting the clock motor in its center with adequate clearance for the hours-hand ring on the motor's shaft to mount the hand. A ⅛-inch or less thickness is about right for most clock motors.

Mark the dial face to easily distinguish it from normal solar clocks. Instead of hours positions, divide the display into two sections, which you can label HIGH and LOW. When the clock face is ready, simply mount the motor mechanism to it, usually with small wood screws. Mount the motor to the clock face in any manner that works for you.

If you are making a large-size Tide Clock display, as shown in the photo of the prototype, the hours hand you removed from the clock mechanism is usually too small to be of use. Making a new hand is usually necessary in a case like this. However, give some thought to the material you will use. This must be light in weight to prevent loading down the clock motor. A thin piece of sheet plastic, brass or even balsa wood should work well here. Other materials may come to mind as well.

A car stereo knob is a good way to mount the new hand to the motor's shaft. An alternative is to use a small cork with a hole of the correct diameter drilled in it. Although the clock-motor shaft will have two to four concentric shafts that different hands were once attached to, only the shaft that formerly held the hours hand is to be used in this project. Fortunately, the shaft for the hours hand is usually the largest in diameter and most accessible since it is the outermost of the group, except for the removable alarm shaft that is featured on some clocks.

Checkout & Calibration

Before attempting to calibrate or put into service your Tide Clock, it is a good idea to check out voltage distribution throughout the system to make sure you properly wired the project. For this, you will need a dc voltmeter or a multimeter set to the dc-volts function.

Clip the meter's common lead to the negative (−) lug of *TS1* and leave it there until voltage measurements are complete. Plug the project's line cord into an ac outlet and set the POWER switch to the 120 VAC ON position. Touch the meter's "hot" probe to pin 16 of the *IC2* and pin 14 of the *IC3* and *IC4* sockets. The readings obtained should all be approximately +12 volts. If they are not, immediately power down the project and unplug it from the ac line. Rectify the problem before proceeding.

Once you are certain that the project has been properly wired, power it down and allow the charges to bleed off the electrolytic capacitors. Then plug the ICs into the various sockets on the circuit-board assembly. Make sure the correct ICs go into the sockets and that no pins overhang the sockets or fold under between ICs and sockets. Handle these ICs with the same care as you would use in handling any other MOS-type device.

Power up the project and calibrate it as follows. The easiest way to accurately calibrate the drive circuit to a particular frequency is with a frequency counter that has adequate resolution. Another method is to use the beat-frequency LED to indicate the difference between the oscillator frequency and the 60 Hz of the ac line. A third method is to use trial and error over a long period of time.

Before calibration, make sure the circuit is actually working by plugging the clock motor into the ac receptacle on the rear panel of the enclosure. Then allow the circuit to stabilize and the case to warm up by running the project for 20 minutes or so under load. If you have a frequency counter, connect it to the Tide Clock via *J1* and *J2*. While observing the counter's display, adjust the setting of the potentiometer for a precise 57.9865772-Hz output. Accuracy to two or three decimal places will be quite sufficient.

Without a frequency counter, calibration is more difficult but still possible. Using the panel-mounted LED, the output of the oscillator can be compared with the 60-Hz line frequency. The frequency of the flashes of the LED then represents the difference between the drive and ac-line frequency. This method will not tell

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you the sign of the difference, but this will be easy enough to figure out once the project is operating. Then you can mark the panel accordingly.

For a drive frequency of 57.987 Hz, adjust the setting of the potentiometer in the "slow" direction for a LED blink rate of about two times per second. For accuracy, you could use a stopwatch to time the beat frequency over intervals of about a minute. For a frequency of 60.1643 Hz, adjust so that the LED blinks once every 6.09 seconds. For frequencies close to 60 Hz, the beat-frequency LED can be a quite useful indicator.

Without a frequency counter or beat-frequency indicator, just set the potentiometer to about the middle of its range and hope for the best. Several corrections will probably be needed over a period of many days to accurately calibrate the Tide Clock. If this is your method of calibration, it helps to mark the potentiometer setting each time and write "S" or "F" next to the mark to indicate if the clock ran slow or fast at that setting. This will give you an idea of how much rotation is needed for a given change in speed. After a few resettings, you will notice the marks zeroing in on a point that has slow settings marked on one side and fast settings on another side.

Once the Tide Clock is calibrated, it can be set to the current tide by consulting a chart (check your daily newspaper). After making this initial setting, you can dispense with the need for the chart, unless the project should lose power for a prolonged period of time and where exact times are needed.

Even if you built this project to serve primarily as a Tide Clock, do not overlook its other uses. Away from home, it can be used as a low-power inverter for equipment that does not require a true sine wave as the drive signal. At home, the main application for this project will be its use as a means for changing the speed of synchronous motors. ME