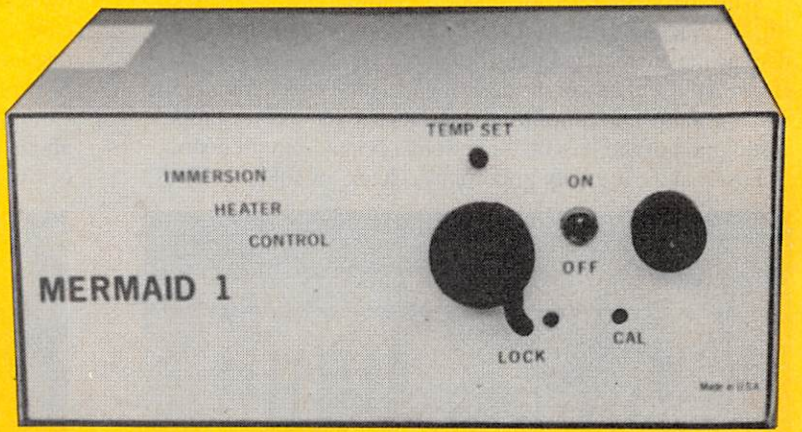
Build the MERMAID I



A submersible heater, made out of junkbox ½-watt resistors, for etchant, chemical baths, photoprocessing, fish, mermaids, etc...

By D.E. Patrick

□WHETHER YOU'RE INTO ETCHING PRINTED-CIRCUIT boards, photography, keeping coffee, fish, mermaids, or anything warm and at an exact temperature, the Mermaid I is a project made to order for you! Using an electronically-controlled submersible heater made from a power resistor or a string of ½-watt parallel-connected resistors, you can hold any liquid at an exact elevated temperature at a very low power cost.

In the case of etching printed-circuit boards, it's well-known that no matter what etchant you use, you can decrease the etching time required by raising the temperature and/or agitating more vigorously. However, when the etchant is cold or at room temperature, it can take a considerable amount of time to get a circuit board done. On the other hand, raising the temperature of the etchant, as the professionals do, will get your circuit boards done faster.

In film processing, holding chemical baths at a constant temperature is necessary. Here, the Mermaid I will hold temperatures constant up to 85 °C. However, as you'll see, you don't have to fork out big bucks for commercial units that don't approach the performance of this low-cost project.

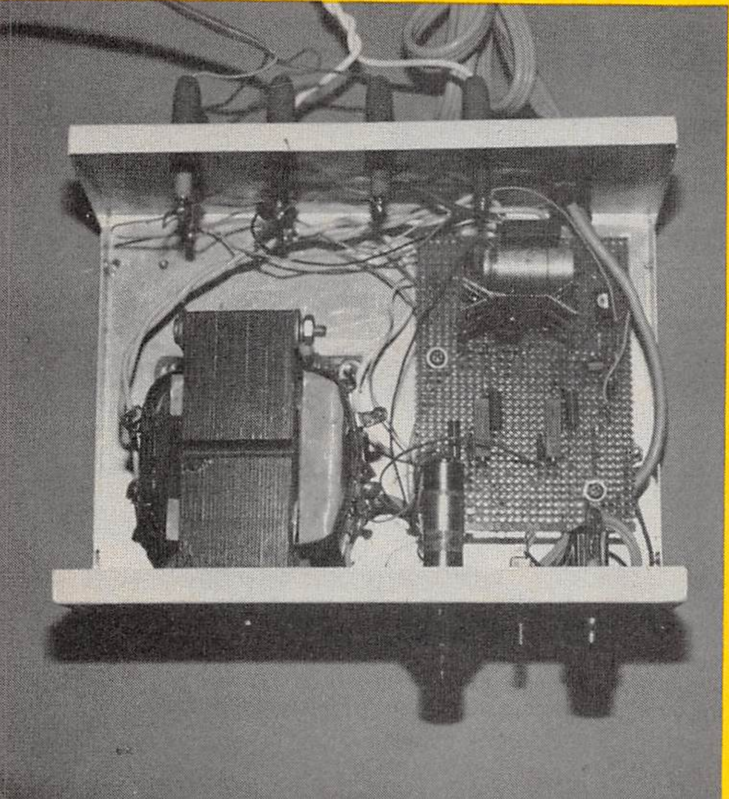
For those of you who aren't into etching printed-circuit boards or into photography, but happen to like their food or coffee at a given temperature: This project will do that, too. I happen to like my coffee at exactly 110 °F, which (while it might be a little odd) requires waiting around for it to cool. But the Mermaid I can keep a cup or even a pot at exactly the right temperature, which is more than you can say for even the most expensive electric coffee pots or food warmers.

Further, when the Mermaid I is used as an aquarium heater, there's no unsightly glass tube hanging down the side of the tank. You can bury its submersible heater under the rocks in the tank out of sight. Also, this unit runs off low voltages, so the chance of frying either you or your fish's fins is limited. And just considering the cost and construction of most commercial aquarium heaters operating off 117-VAC, with their inaccurate bimetal switches, which can stick and stew or break and scald anyone's mermaid, makes this project worth building.

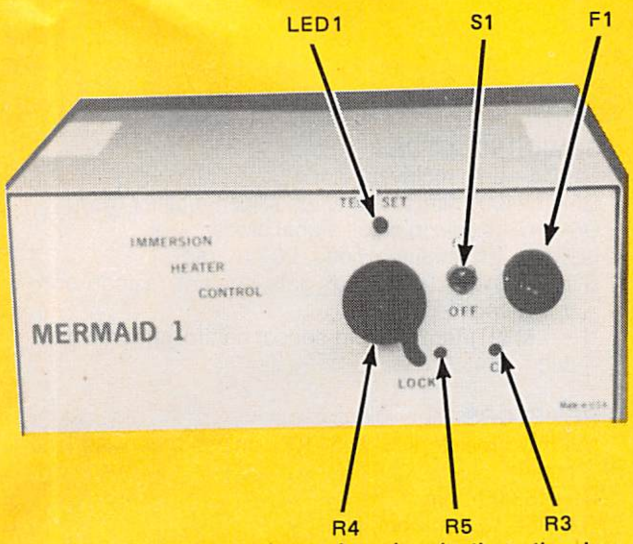
There are probably a thousand applications and I've only mentioned a few. So let your imagination be your guide.

How the Circuit Works

Step-down transformer T1 (Fig. 1) provides power-line isolation and a safe 20-VAC output, which is rectified by diodes D1 through D4 connected in a bridge network. The



With cover of Mermaid I removed, the wired perfboard circuit is revealed, with the power transformer (T1) occupying much of the space. All operating controls are front-panel mounted; interconnecting terminal points are brought to the rear apron.



The Mermaid I was designed as a showpiece by the author, however you need not indulge in so expensive or time consuming a fad.

positive output of the diode bridge drives the resistor heater consisting of R13 through R35, which consists of twenty-two 220-ohm, ½-watt resistors. Other resistive configurations are also possible to obtain a 10-ohm, 11-watt load. The positive output of D1 through D4 also provides power to drive light-emitting diode indicator LED1. That LED serves as a heater-on indicator. Diode D5 feeds filter capacitor C1 and integrated circuit U1, an LM3911N temperature sensor controller, which in turn controls the gate of SCR1, via emitter-follower Q1, applying power to the other side of the heater and LED1.

The LM3911N controller's comparator (U1) performs a balancing act, where the voltage at the plus input (pin 4) produced by its on-board sensor is compared with the reference voltage at the minus input (pin 1). The reference trip or turn-on point is determined by R2 through R6. Resistors R2 and R6 act in conjunction with optional R3 and R5 trimmer potentiometers to set maximum and minimum trip points respectively. Potentiometer R4 is a front-panel, 10-turn adjustable potentiometer with a vernier readout used to set the desired temperature in degrees C for the resistor values shown for R2 through R6.

When U1's output is low, SCR1, LED1, and the heater (resistors R13–R35) are off. If the temperature of the liquid bath in which U1 and the heater was immersed were to drop, the voltage change at the positive input of U1's comparator would be reflected at its output by going high. U1's output going high fires SCR1 via emitter-follower Q1, and the heater (R13–R35) and LED1 turn on. Since pulsating DC is applied to SCR1, when the temperature of the liquid rises so that U1's output goes low again, the heater and indicator will turn off. Hysteresis is provided by D6, R10, C4, and R11. It usually takes some time for the volume of liquid to both heat and cool.

Heating Things Up

The heating element proper could be anything from a commercial submersible heating element to a waterproofed, parallel string of composition resistors. The former can be expensive with most commercial heaters running off 117-VAC. The latter is generally cheaper and allows for a custom low-voltage design. Using a string of parallel resistors allows heat to be dispersed over a wider area for even heating, which may be handy for certain applications. If you prefer to concentrate the heat, a single power resistor could be used.

You can over-build a multi-resistor heater so that it will operate in free air. But the resistor array shown in Fig. 1 will handle approximately 11 watts in free air and four times that (44 watts) when immersed in a suitable volume of water or other low-viscosity liquid. Also, ½-watt resistors can be purchased for under three cents each for a cost-effective heating element under $1.50. Further, the transformer, diodes, and SCR will handle 6 amperes, driving a heater that you could push over 100 watts if the need arises.

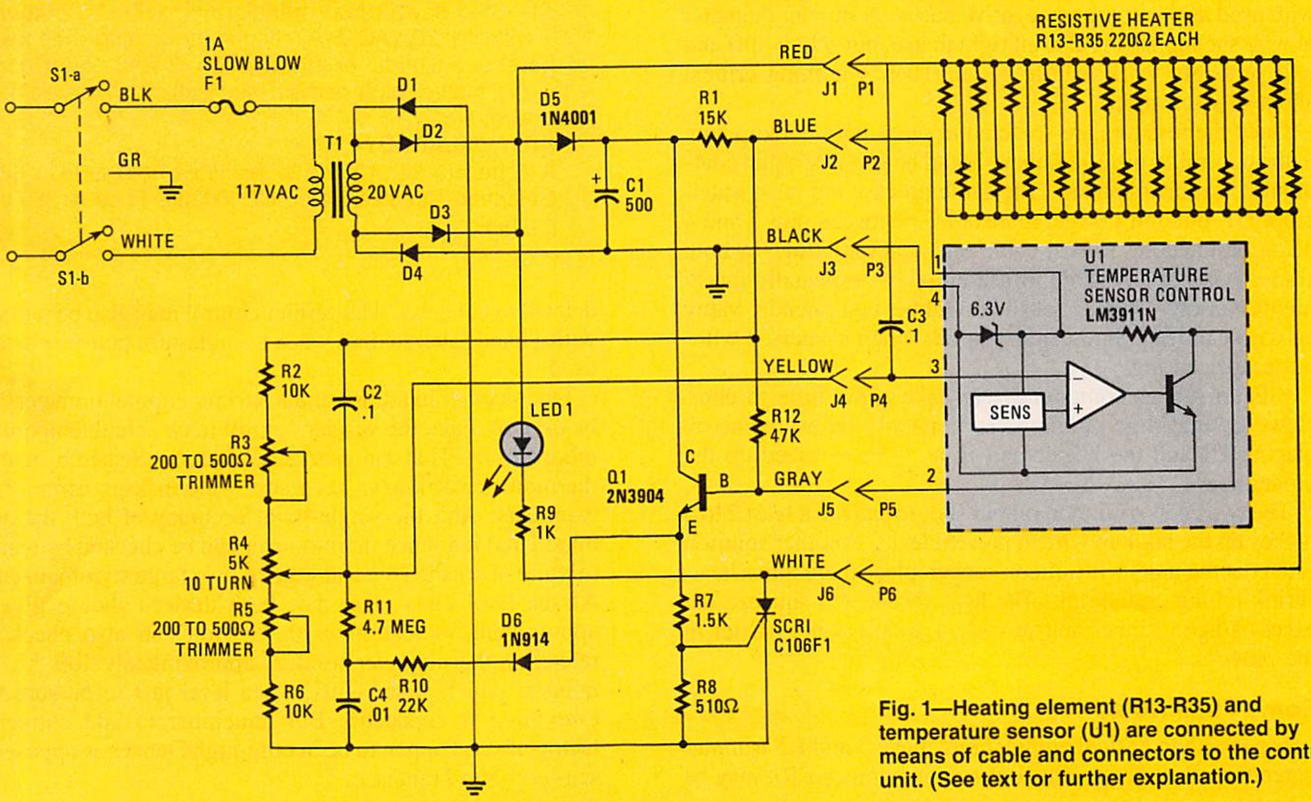
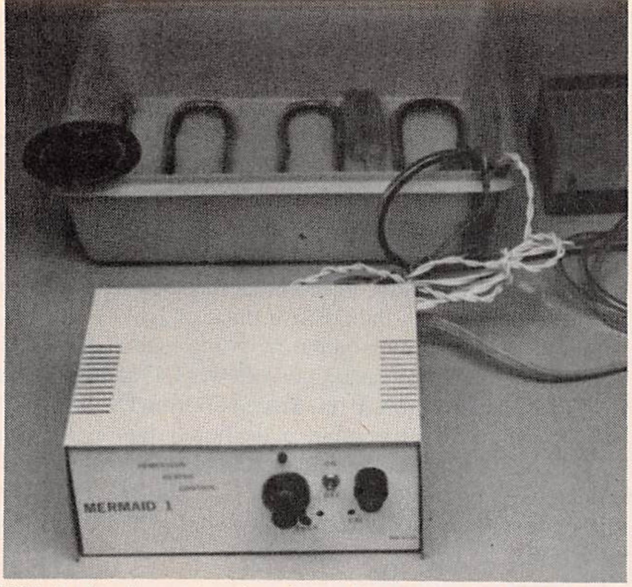


Fig. 1—Heating element (R13-R35) and temperature sensor (U1) are connected by means of cable and connectors to the control unit. (See text for further explanation.)



With the heating network resistors in place on the bottom of the pan, the Mermaid I is now ready to control temperatures for either film processing or etching circuit boards.

Construction Hints

There is nothing critical about construction. The circuit may easily be breadboarded as shown, with SCR1 mounted to a suitable heat sink, where even the aluminum case might have been used in place of the free-standing heat sink shown. Chip U1 can be connected to the rest of the electronics via flat-ribbon cable. For convenience, the author used pin-plugs and pin-jacks, but any six-terminal plug-and-jack mating combination could as easily have been used. Stranded hookup wire (#18 AWG) should be used to connect the heater. Teflon-coated wire is the best choice for interconnecting U1 and the heating element, where the Teflon properties will give long-life service.

The heating element can be constructed by placing half-watt or bigger resistors across two pieces of #12 solid copper wire used as positive and negative buses. A smaller diameter of wire such as #14 is also all right to use, but #12 is stiff and will probably work a little better. There's nothing critical about this selection.

Once the resistors are soldered in place with hookup wire to the controller installed, they should be given two thin coats of silicon rubber cement. The same process will also waterproof U1, but don't forget to install C3 between pins 3 and 4 before connecting ribbon cable and waterproofing. In both cases, it is not advisable to use epoxies—especially the 5-minute variety—in place of silicon rubber compounds. Many epoxies can leach into certain liquids when immersed without proper curing.

Silicon rubber compounds can take some time to cure. However, that time problem can generally be overcome by placing U1 and the heater unit in an oven to speed up the process.

The two coats of silicon rubber should extend at least 2 to 4 inches up the hookup wire to prevent leaks. Another solution is to coat the units with silicon rubber, place them into a heat-shrink tubing and shrink. The heat shrink will squeeze out excess silicon rubber and provide a double water-barrier in the process.

Some Final Notes

For less than critical applications, the R3 and R5 trimmer potentiometers along with 10-turn potentiometer R4 may be deleted to cut costs. The vernier control may also be replaced with a hand-lettered dial, when a single-turn potentiometer is used.

On the other hand, R3 and R5 trimmer potentiometers can be used to make the vernier control track actual temperature more closely. That can generally be accomplished by using a thermometer of known accuracy while making trimmer adjustments. And the single-point accuracy of both the Mermaid I and reference thermometer can be checked by using a mixture of crushed ice and water in two large styrofoam cups. At sea level on a clear day, both devices should give an approximate indication of 0 °C. You can also check the reference thermometer used at approximately 100 °C, the point at which water boils at sea level just to be sure that everything is copacetic. But remember to add correction factors if you happen to be in mile-high Denver as opposed to sea-level San Francisco. ■

PARTS LIST FOR MERMAID I

SEMICONDUCTORS

D1–D4—6-A, rectifying diode
D5—1N4001 diffused-junction silicon rectifier diode
D6—1N914 silicon small-signal diode
LED1—Light-emitting diode, 20-mA, red
SCR1—C106F1, 200-µA gate-current, silicon-controlled rectifier
U1—LM3911 temperature-sensor control integrated circuit

RESISTORS

(All fixed resistors ½ watt, 10% unless otherwise indicated)
R1—15,000-ohm
R2, R6—10,000-ohm, film
R3, R5—200- to 500-ohm, 10-turn trimmer potentiometers
R4—5000-ohm, 10-turn, linear-taper potentiometer
R7—1500-ohm
R8—510-ohm
R9—1000-ohm
R10—22,000-ohm
R11—4.7-Megohm
R12—47,000-ohm
R13–R35—220-ohm (see text)

CAPACITORS

C1—500-µF, 25- to 50-WVDC electrolytic
C2, C3—.1-µF, ceramic disc
C4—.01-µF, ceramic disc

ADDITIONAL PARTS AND MATERIALS

F1—Fuse, 1-A, slow-blow type
J1–J6, P1–P6—Tip jack and tip plug. Flat ribbon cable soldered directly may be used, or any six-connector mating jack and plug.
S1—DPDT, miniature toggle switch
T1—Step-down power transformer: 117-VAC primary winding; 20-VAC, 6-A. secondary winding (See text)
Fuseholder, metal or plastic case, 3-lead power cord with molded plug, cement (see text), hardware, solder, wire, etc.

KIT AVAILABLE

A complete kit of parts is available from E.T.C., 837 Galapago Street, Denver, CO 80204. Price is $50.00 postpaid.