SEMICONDUCTOR INTERVAL TIMER

By DONALD E. LANCASTER

Semiconductor gate-controlled switch makes practical an all-electronic timer that can be set from 1 to 100 seconds in discrete 1-second steps.

THERE have long been available simple, low-cost timing devices of various types, ranging from mechanical egg timers, neon and thyratron devices, simple *RC* relay and SCR circuits, to others. Practically all of these devices leave much to be desired in the areas of convenience of operation, repeat accuracy, timing precision, life, resettability, and ease of external connections.

The new semiconductor gate controlled switch (GCS) makes practical an all-electronic digital timer capable of 1 to 100 second timing in discrete one-second intervals, to an over-all accuracy of better than 2 percent. The device is self-resetting, and has very quick recovery. It can be operated, read, and cycled in total darkness either manually or *via* external foot switches. There are no relays or other mechanical components in this circuit which will directly control 25 to 500 watts of 117-volt incandescent lamp load. Simple modifications allow the control of any load, either all-electronically or *via* an external relay. Operation is absolutely silent. No warm-up time is required and only a brief half-second recovery time is required for high repeat accuracy.

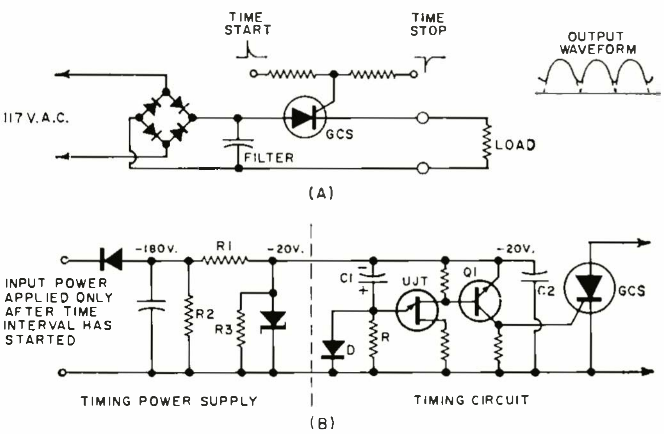
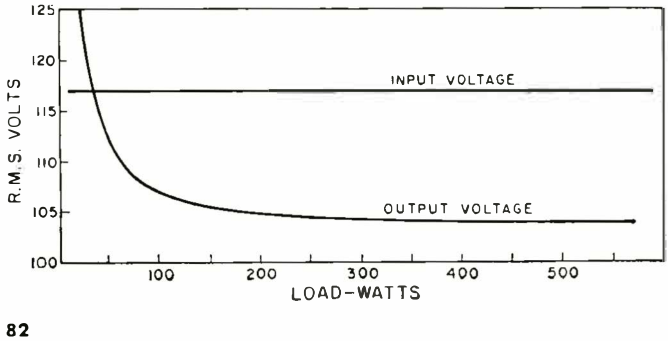


Fig. 1 (A) In simplified circuit, GCS is turned on by a positive and off by a negative pulse. (B) Basic timing circuit.

Fig. 2. The timer output voltage varies with the applied load. The minimum recommended load for proper operation is 25 watts.



This timer was specifically designed for use as an enlarger control center for a custom photo finisher and thus lends itself well to most darkroom applications. There are many non-photographic applications for this device, ranging from sequence timers for displays, electronic automatic checkout equipment, process control, to other applications requiring the accuracy and ease of operation not found in many other control devices.

Parts cost should not exceed $45 and no special tools or components are needed to build this unit.

Operation

The basic circuit consists of a bridge rectifier, a gate controlled switch, and a zener-stabilized transistor-unijunction timing circuit. This is combined with suitable switching that provides for momentary or sustained load power in addition to the normal time cycle.

A gate controlled switch is the new SCR-like device with the added advantage that the GCS may be turned off, as well as on, by gate pulses of the proper polarity. Since these are unilateral devices, a full-wave bridge rectifier is required for the GCS and the load. Fig. 1A shows the simplified power-control circuit, while Fig. 1B shows the timing circuit. The output of the rectifier is filtered only enough to provide holding current for the GCS during the zeros of the a.c. line. This produces the waveform shown in Fig. 1A across the load. Once the GCS is pulsed on, it latches on, and stays on cycle after cycle until a negative gate turn-off pulse appears. The amount of filtering used must be a compromise between providing enough holding current at high loads, and the rising output voltage that will be provided under light load operation. (With very small loading, the output would be pure d.c. at 1.41 times the normal line voltage.) When a 20-μF filter capacitor is used, loads of between 25 and 500 watts may be accommodated by the timer. The output voltage varies somewhat with large changes in load, as shown in the regulation curve of Fig. 2.

In operation, a "Time-Start" pulse turns on the GCS and the load. The GCS turn-on also provides power for the timing circuitry. At the end of the time interval, the timing circuit produces a turn-off pulse, shutting down the GCS, load, and timing power supply.

The timing circuit (Fig. 1B), consists of a zener-regulated power supply and a unijunction transistor. An *RC* network between the -20V line, the emitter of the UJT, and the circuit common provides the time function. In operation, the charge across *C1* (Fig. 1B) is zero at the start of the time period. Resistor *R* starts charging *C1* and the emitter voltage of the UJT gradually becomes more and more positive. When a critical emitter voltage is exceeded (the intrinsic stand-off ratio), the UJT abruptly turns on. This also turns on the gating transistor (*Q1*) which "dumps" the charge on *C2*

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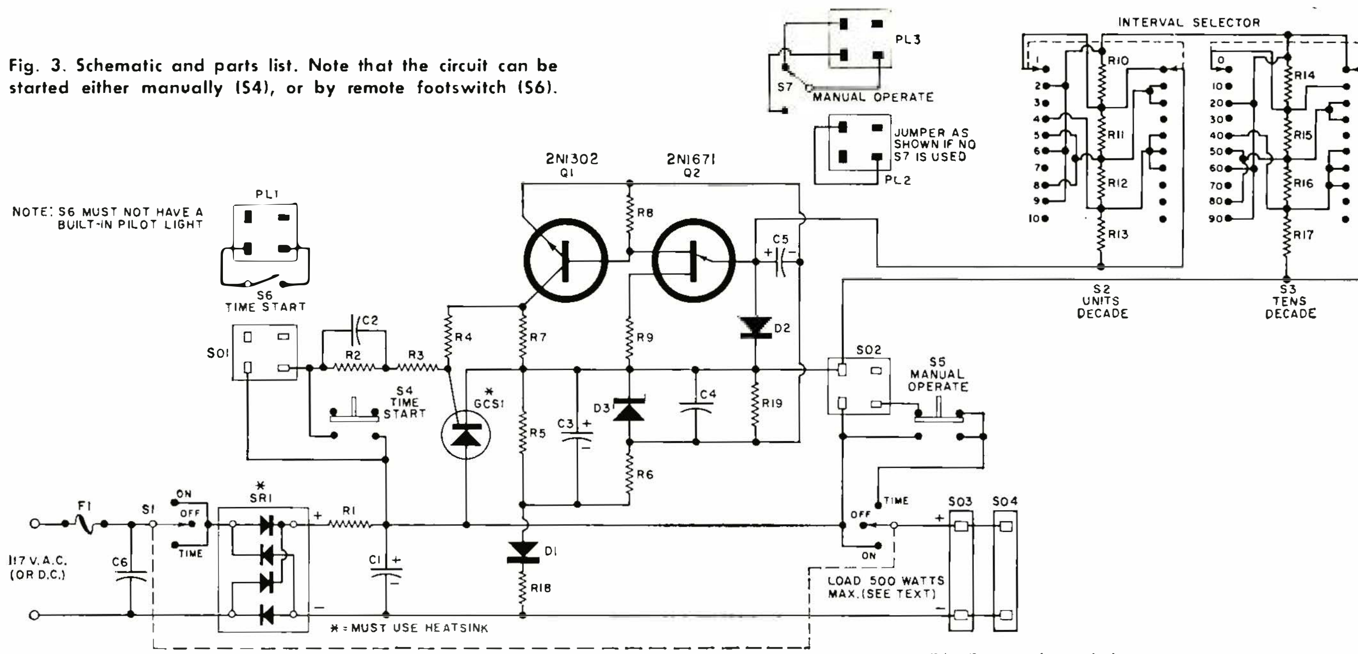
Fig. 3. Schematic and parts list. Note that the circuit can be started either manually (S4), or by remote footswitch (S6).



R1—1 ohm, 5 W wirewound power res.
R2—2.2 megohm. ½ W res.
R3—3300 ohm, ½ W res.
R4,R18—47 ohm. ½ W res.
R5—18,000 ohm, 2 W res.
R6—5000 ohm. 5 W res.
R7—470 ohm, ½ W res.
R8—39 ohm, ½ W res.
R9—510 ohm, ½ W res.
R10—Selected value to give exactly 1-sec time interval (approx. 17,000 ohms, ½ W, see text)
R11—2 × R10, ½ W res. ±1%, see text
R12—4 × R10. ½ W res. ±1%, see text
R13—3 × R10, ½ W res. ±1%, see text
R14—10 × R10, ½ W res. ±1%, see text
R15—20 × R10. ½ W res. ±1%, see text
R16—40 × R10, ½ W res. ±1%, see text
R17—30 × R10. ½ W res. ±1%, see text
R19—2400 ohm, ½ W res.
C1—20 μF, 250 V elec. capacitor
C2—0.1 μF, 200 V Mylar capacitor
C3—10 μF, 250 V elec. capacitor
C4—3 μF, 100 V Mylar capacitor
C5—68 μF, 15 V, 10% high-quality tantalum capacitor
C6—0.02 μF, 600 V disc ceramic capacitor
S1—D.p.d.t., 10 A center-off toggle sw.
S2,S3—D.p. 10-pos. non-shorting selector sw.
S4,S5—Two-circuit, 5A push-button sw.
S6—S.p.s.t. footswitch
S7—S.p.d.t. 5A footswitch
SO1.SO2—4-prong Jones socket
SO3.SO4— Chassis-mounting a.c. outlet
PL1,PL2,PL3—4-prong Jones plug
F1—1A fuse (for 100 W or less load) 2A fuse (200 W or less load), etc., see text
SR1—18A, 200 V press-fit bridge rectifier, 1N4436 or 4 3A, 200 V silicon diodes (Motorola MR1032B)
GCS1—Gate controlled switch (Motorola MGCS 924-4, 5A @ 200 V) or Texas Inst. TIC-12
D1.D2 750-mA, 200-V silicon power diode
D3—22V, 1W zener diode (Motorola 1N3028B)
Q1—2N1302 transistor
Q2—2N1671 unijunction transistor

into the GCS gate. This turns off the GCS, the timing circuit, and the load.

By switch-selecting *R* in a digital manner, the time interval may be selected. A "units" and a "tens" decade is used to give incremental one-second intervals between one and 100 seconds.

There is a major problem inherent in UJT timers that is eliminated in this upside-down circuit configuration. In a normal UJT, after turn-on and capacitor discharge, there is still a charge remaining on the timing capacitor. This charge slowly bleeds off and ultimately reaches zero after a long time period. The timing error introduced between starting with no charge and starting with some charge is considerable and can approach 40% of the time cycle. To overcome this problem, a set of mechanical contacts is almost always used to reset the UJT and its capacitor to zero charge. While this method is widely used, it is neither convenient nor practical to have to reset a timer mechanically each time cycle.

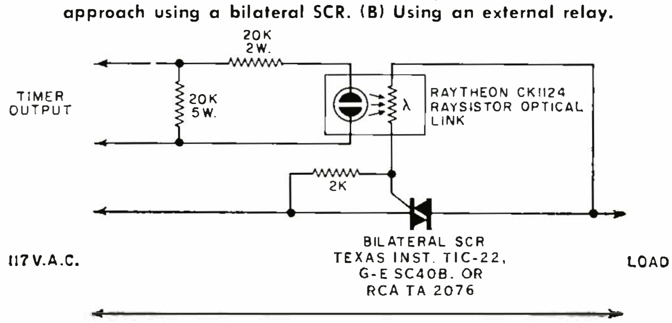
The fact that the supply voltage, but not the supply impedance, disappears at the end of the time cycle is used to automatically reset the timer. This is a function of diode *D* (Fig. 1B). When the 20-volt supply is operative, *D* is reverse biased and does not interfere with the normal time cycle. When the time cycle ends, the supply voltage disappears. Any charge remaining on *C1* now *forward* biases diode *D*, providing a discharge path through resistors *R1*, *R2*, and *R3*. Note that this is independent of the timing resistor, giving an equal recovery time regardless of the setting of the time interval selectors. The recovery time of the circuit is on the order of a half second to give a repeat accuracy error of less than 2 percent.

By careful selection of *R* resistance values, use of high-quality timing capacitors and zeners, and by waiting only a few seconds between cycles, this timer may be made to have an accuracy of better than 0.5 percent, and perhaps as good as 0.2 percent. This figure includes both repeat accuracy and long-time stability.

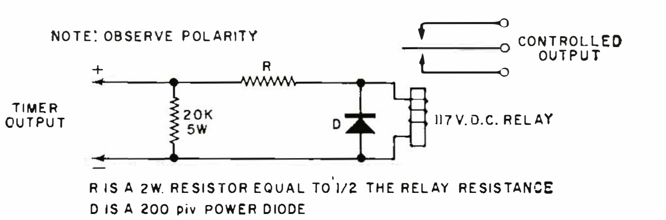
Final Circuit Arrangement

Fig. 3 shows the final circuit. The input power may be either conventional power line or d.c. between 100 and 130 volts. Fuse *F1* is rated slightly above the load power to protect the circuit. Capacitor *C6* is a filter to reduce AM radio noise during turn-on and turn-off of the time cycle. Switch *S1*

Fig. 4. Additional driver circuits may be added for loads that will not operate on inverted a.c. supply. (A) All-electronic approach using a bilateral SCR. (B) Using an external relay.



(A) ALL ELECTRONIC CONTROL



R IS A 2W. RESISTOR EQUAL TO 1/2 THE RELAY RESISTANCE
D IS A 200 piv POWER DIODE

(B) USING A RELAY

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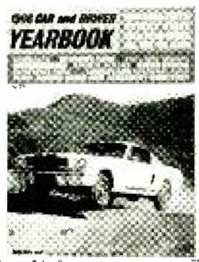

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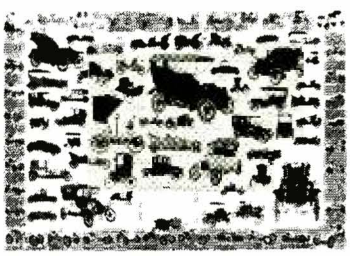

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is the power switch which also selects between timed and sustained ("on") operation of the devices.

The GCS used is the *Texas Instruments* TIC-12 rated at 5 amperes and 200 volts. (*Editor's Note: As this is written, the TIC-12 costs $9.60.*) It is in a diamond-shaped power transistor package and mounts in the usual manner. Both *SR*1 and the GCS must be mounted on a heatsink, with the GCS insulated from the heatsink.

The network consisting of *C*2, *R*2, and *R*3 provides the GCS positive gate pulse required for turn-on. This is a one-shot network, required to make the time cycle independent of the length of time the "Time-Start" push-button (*S*4) or foot switch (*S*6) is depressed.

The timer power supply consists of *R*5, *R*6, *R*18, *D*1, *D*3, *C*3, and *C*4. Unless GCS1 is conducting, there is no voltage drop across the load and no voltage across this power supply. This is a conventional zener supply except for its negative output. Unijunction transistor *Q*2 provides the time function when its emitter voltage exceeds the value required for breakdown. Timing is provided by a selected interval resistor charging up *C*5. A high-quality capacitor with low leakage must be used here; otherwise leakage and time degradation will affect timer performance.

The obvious way to select a time interval would be to use twenty precision resistors in values of 1, 2, . . .10 and 10, 20, 30 . . . 90, and switch these one at a time to obtain the desired time interval. By adding a second deck to each switch, and using the switching scheme shown in Fig. 3, only eight resistors are required. Note that at least one resistor must always be in the circuit. It is quite important that non-shorting selector switches are used.

The exact value of the resistors is determined by using an oscilloscope whose time base may be used for calibration. The one-second resistor value is then determined experimentally. All the other resistors are precision multiples of this original value. Once the "tens" decade series of resistors have been determined approximately, a conventional electric clock, equipped with a second hand, can be used to accurately trim the resistor values. Set the clock's second hand to 12, plug the clock into the timer output, and select the time values with the "tens" decade switch. Each "tens" decade switch position should cause the clock to indicate the correct number of seconds. The pertinent resistors can be trimmed as required.

The actual resistance may be obtained by several means. The simplest is to use all one-percent resistors. A second alternative is to use one- or two-watt carbon resistors and a file to raise them to the exact value. (Start with a resistor that gives you a time somewhat *shorter* than that desired.) The resistors must be resealed after filing to make them humidity and time stable. A third method is to use a large number of half-watt resistors and keep trying parallel combinations until the exact values are obtained. In all these cut and try methods, an accurate timing device (oscilloscope or other accurate timer) is required.

The final circuitry consists of gating transistor *Q*1 which is used to discharge capacitor *C*5 into the gate of the GCS *via* current-limiting resistor *R*4.

Two two-circuit push-buttons are used to provide the "Time-Start" and momentary bypass controls. Four-prong connectors bring these connections to the rear of the timer, allowing footswitch control. The "Time-Start" footswitch (*S*6) is in parallel with the "Time-Start" push-button (*S*4) while the momentary bypass footswitch (*S*7) is in series with the "Manual-Operate" push-button (*S*5).

Footswitch *S*7 must be a s.p.d.t. switch having heavy enough contacts to handle the load power. A jumper must be substituted for the normally closed connection of this switch if footswitch operation is not to be used. *S*6 is a s.p.s.t. footswitch and need only have a contact rating of half an ampere. This switch must not have a built-in neon pilot light because this type will not allow proper operation of the turn-on pulse network.

Reasonable size wire, at least #20, should be used for all internal connections that must carry the load current.

The timer is intended for use only with loads which will operate off inverted a.c. This includes all incandescent lamps, heaters, and most universal motors (motors with brushes). If a highly inductive load is used, a diode or varistor should be added to the output as a surge eliminator. The timer will not operate a fluorescent lamp directly or the "cold boxes" occasionally found on enlargers. The timer will not directly control an a.c. induction motor of any type.

Additional Drivers

If fluorescent lamp or induction motor operation is required, additional circuitry will be required to provide a switched a.c. output. Two possibilities are shown in Fig. 4. In Fig. 4A, the timer output actuates an optical link ("Raysistor") which in turn gates a bilateral SCR. Loads of between 10 and 600 watts may be switched with the bilateral SCR. The output waveform of this circuit is identical to the input powerline waveform, except for a drop of about one volt. Fig. 4B shows how a conventional mechanical relay may be coupled to the timer and used for special switching requirements. ▲

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