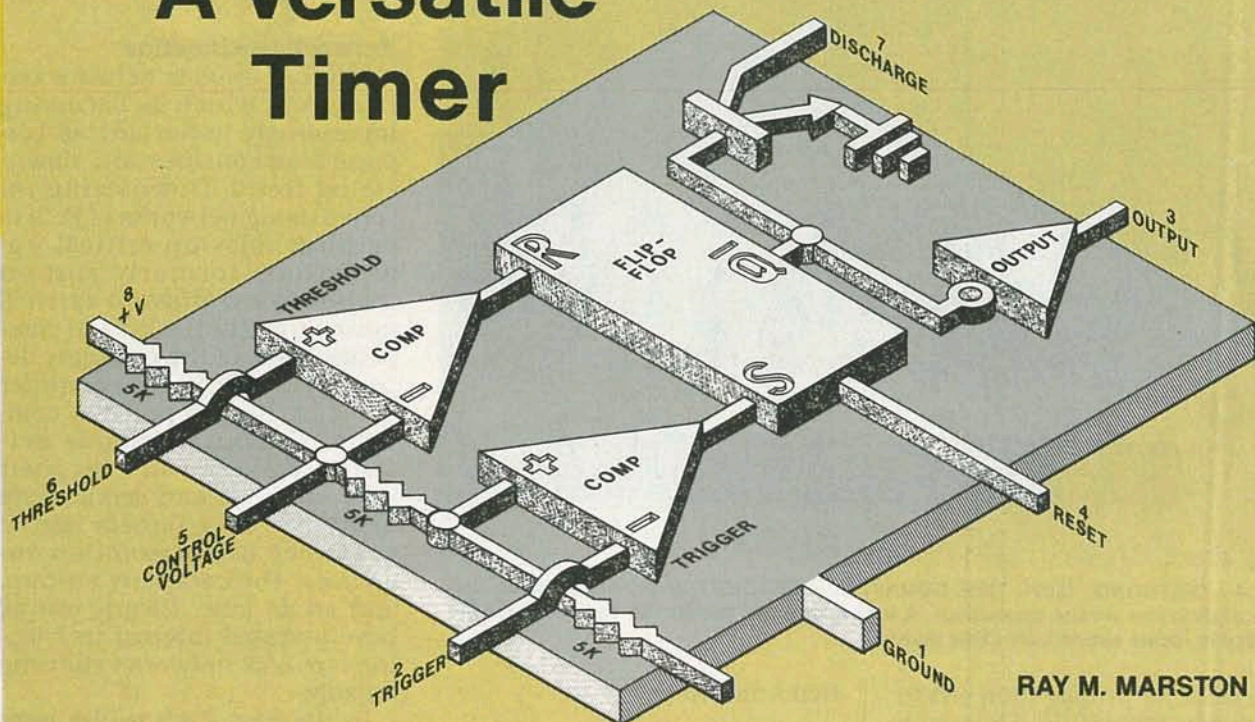# The 555 A Versatile Timer

RAY M. MARSTON

FIG. 1—FUNCTIONAL BLOCKS OF THE 555 TIMER with its pinout identified.

Learn to use the 555 and 556 timer IC in practical circuits to obtain accurate time delays and square waves

IN ANY ASSOCIATION TEST FOR those who know integrated circuits, the three digits 555 will summon up the instant response "timer IC." It's the short form generic designation for progeny of the NE555, a popular monolithic timer/oscillator IC first introduced by Signetics many years ago. Still widely second-sourced because of its versatility, the 555 ranks as a standard "building block."

The 555 and its derivatives can be found in thousands of different circuits, and its possibilities for further applications appear limitless. Although classed as a linear IC, it is often used in digital or "quasi-digital" applications because its inputs and outputs are essentially square waves

rather than sine or other complex waveforms. This article explains how the 555 works and shows you how to apply the IC in various practical control circuits.

A 555/556 overview

Figure 1 is a simplified block diagram of the 555 showing its principal functional blocks: threshold comparator, trigger comparator, R-S flip-flop, low-power complementary output stage, slave discharge transistor, and a voltage-reference potential divider. Both halves of a dual version of the 555 (two 555's on a single chip), the 556, have identical electrical characteristics. The 555/556 will run from 4.5 to 16 volts DC, although a typical

supply will be +12 volts DC or less.

The outstanding features of the 555/556 include:
- Timing adjustable from microseconds to hours
- Duty cycle adjustable
- Ability of output to source (supply) or sink (dissipate) 200-milliampere current
- Output can drive TTL logic circuits
- Temperature stability exceeds 0.005%/°C
- Normally "on" and normally "off" output

The 555 and 556 were designed for precision timing applications, with the timing interval controlled by an external resistor and capacitor (RC) network. The devices contain voltage dividers consisting of

ree 5000-ohm resistors in series between the supply voltage and ground so that one-third of the supply voltage is developed across each resistor. The internal flip-flop circuit provides a definite "on" or "off" response. Its timing intervals are independent of the supply voltage.

The 555 has two basic operating modes: *monostable* (one-shot—a single pulse is emitted), and *astable* (a stream of output pulses is generated). In the monostable mode when functioning as timers, time is precisely controlled by the external RC network. In that mode the 555 produces output pulses with rise and fall times measured in microseconds.

In the astable mode, the 555 can be an oscillator. It can maintain an accurately controlled free-running frequency and duty cycle with only two external resistors and one capacitor. In either monostable or astable modes, timing accuracy is essentially independent of variations in supply voltage or ambient temperature. The device can be triggered and reset on falling waveforms.

Typical applications for the 555 include precision and sequential timing, pulse generation, pulse-width and pulse-position modulation, and linear ramp generation. Moreover, it can directly drive loads such as relays, solenoids, low-power lamps, and high-impedance speakers.

The 555 is packaged in plastic and metal DIP's and 8-pin metal cans for operation in the commercial temperature range of 0 °C to +70°C. Some plastic DIPs can operate in the −40°C to +85°C extended temperature range.

Alternate-sourced 555's can usually be identified by the inclusion of the numbers 55 or 555 in their designations. Examples include Harris' CA555, Motorola's MC1455, and National Semiconductors' LM555C. Other sources include Exar, Goldstar, Raytheon, Samsung, SGS-Thomson, and Sharp Electronics. CMOS versions of the 555, such as Texas Instruments' TLC555 are also available. In addition to their low power consumption compared to standard 555's, their outputs are compatible with CMOS as well as TTL.

Table 1 presents some basic electrical characteristics for the 555. The 556 is housed in a 14-pin DIP package but the block diagram of each circuit is identical to that of the 555 shown in Fig. 1. The 556 is also alternate-sourced by many of the same firms that offer the 555. Examples are Motorola's MC3556 and Texas Instruments' TLC7556.

How the 555 works.

Figure 2 is a representative circuit schematic for the 555. It contains 21 transistors, 4 diodes, and 15 resistors. The voltage divider consisting of three 5000-ohm resistors (shown in Fig. 1) appears to the right of Q10 in the trigger comparator. It applies one-third of the supply voltage to the non-inverting input terminal of the trigger comparator and two-thirds of the supply voltage to the inverting input of the IC's threshold comparator.

The output of the two comparators controls the R-S flip-flop, which in turn controls the states of the complementary output stage and the slave transistor Q6. The flip-flop's state can also be set by signals at RESET pin 4.

When organized as a monostable timer, the TRIGGER pin 2 is held high by external resistor R_T in series with the DC supply voltage. Under that condition, Q6 is saturated, shorting external timing capacitor C_D to ground, and OUTPUT pin 3 is driven low. Timer action is started by applying a negative-going trigger pulse to pin 2. As this pulse falls below one-third of the DC supply voltage, the output of the trigger comparator changes state. That causes the R-S flip-flop to switch, turning Q6 off, and driving OUTPUT pin 3 high.

As Q6 turns off, the short is removed from the external capacitor C_D. The capacitor charges through the external resistor R_D until the voltage across C_D rises to two-thirds of the supply voltage. Then the threshold comparator changes state and switches the R-S flip-flop back to its original state, turning Q6 "on" and rapidly discharging C_D. At the same time, OUTPUT pin 3 reverts to its low state. The *timing cycle* is then complete.

A characteristic of the 555 is that, once triggered, it cannot respond to additional triggering until the timing sequence is complete. However, the sequence can be aborted at any time by feeding a negative-going pulse to RESET pin 4.

The output pulse is a square wave whose duration (time delay) depends on the values of R and C. The formula for this is: t_D (time delay) = 1.1 (value of R × value of C)

Simply stated, time delay is directly proportional to the

TABLE 1—ELECTRICAL CHARACTERISTICS

| Characteristics	Symbol	Min.	Typ.	Max.	Unit
DC Supply Voltage	V_{CC}	4.5	—	16	V
DC Supply Current (V+ =5V)	I_{CC}	—	3	6	mA
(V+ =5V)		—	10	15	mA
Power Dissipation		—	—	600	mW
Threshold Voltage	v_{th}	—	⅔	—	V
Trigger Voltage (V+ =5V)	V_T	—	1.67	—	V
(V+ =15V)		—	5	—	V
Reset Voltage	V_R	0.4	0.7	1.0	V
Reset Current	I_R	—	0.1	—	mA
Timing Error (Monostable)		—	1	—	%
Frequency Drift with Temperature		—	50	—	ppm/°C
Drift with Supply Voltage		—	0.1	—	%/V
Output Rise Time	t_r	—	100	—	ns
Output Fall Time	t_f	—	100	—	ns

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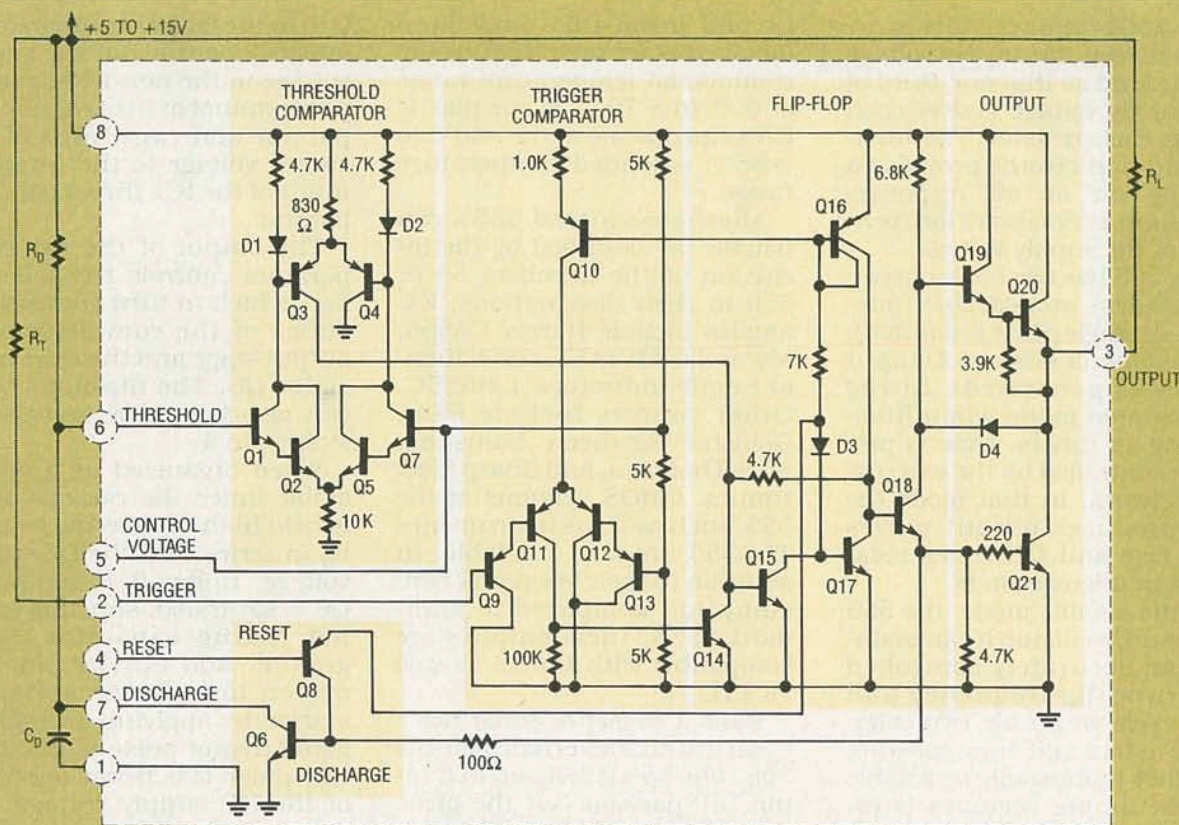
FIG. 2—REPRESENTATIVE CIRCUIT SCHEMATIC FOR A 555 timer with external resistive and capacitive components.
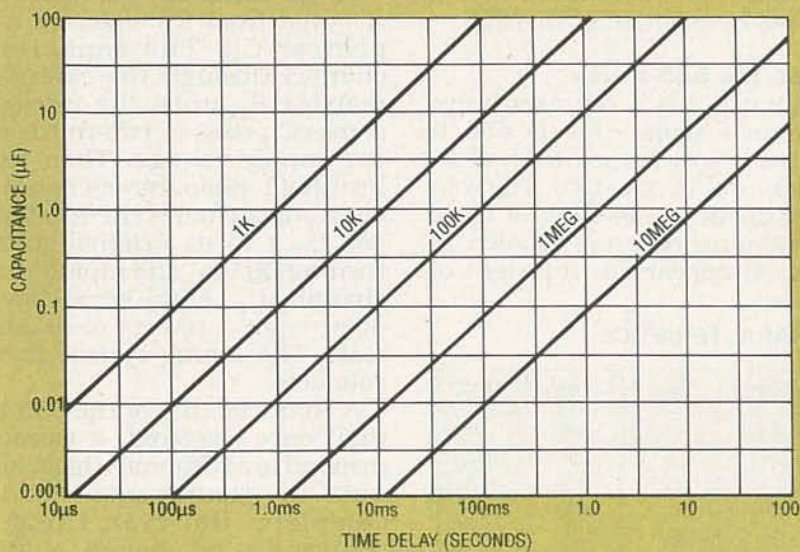

FIG. 3—COMBINATIONS OF RESISTANCE AND CAPACITANCE yield a range of time delays. The trigger pulse width must be less than the timing period.

product of R and C. Figure 3 is a plot of time delay vs. resistance and capacitance based upon the time-delay formula where t_D is in milliseconds, R is in thousands of ohms, and C is in microfarads. Figure 3 gives a family of time delay curves with variations in R_T and C_T. Delays from 10 microseconds to 100 seconds can be obtained by selecting suitable values of low-leakage capacitors from 0.001 µF to 100 µF and resistors from

1 thousand ohms to 10 megohms.

Figure 4-a is a simple fixed-period (approximately 50-second) manually-triggered time delay circuit, and Fig. 4-b shows the waveforms as they would appear on an oscilloscope. The sequence of events in Fig. 4-b is initiated by grounding TRIGGER pin 2 with momentary START switch S1. The CONTROL VOLTAGE pin 5 is decoupled by C2, and the output state can be determined by observing whether LED1 is illuminated or not. A square output pulse (whose fixed-period is determined by R1 and C1) appears at OUTPUT pin 3, while an exponential sawtooth (with the same period as the square wave) appears at DISCHARGE pin 7.

The fixed-period output of the circuit in Fig. 4 can vary from 1.1 to 120 seconds by making the changes shown in Fig. 5. Resistor R1 is replaced with a 10K fixed resistor and 1-megohm potentiometer R5 in series, as shown. A reset feature can be added by installing RESET switch S2, permitting
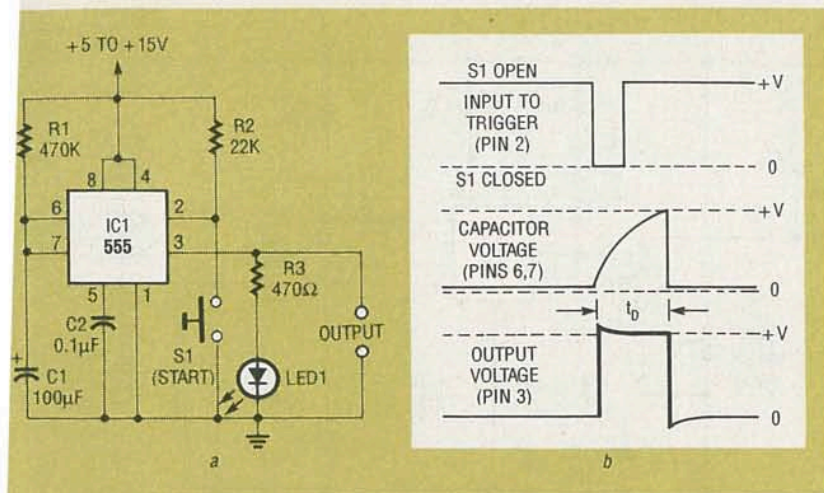
FIG. 4—FIXED-PERIOD TIMER produces a 50-second time delay (a). The waveforms at three pins are shown (b + a).
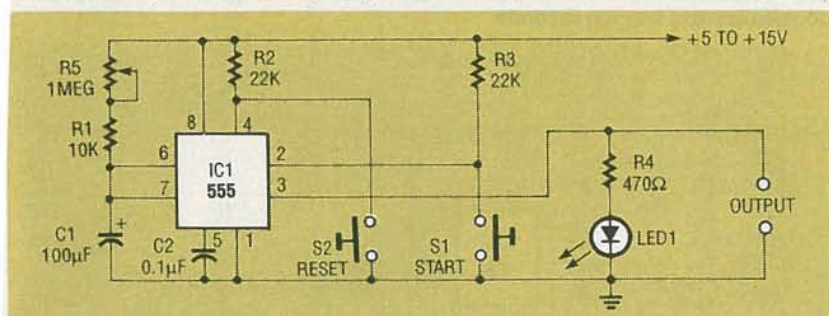

FIG. 5—VARIABLE-PERIOD TIMER CIRCUIT with reset capability produces time delays from 1.1 to 120 seconds.
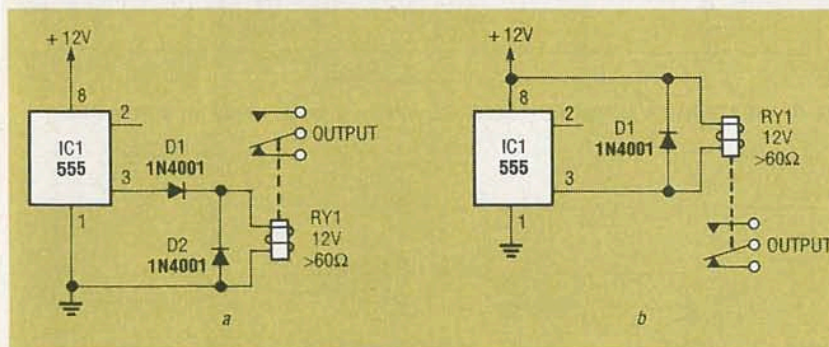

FIG. 6—ALTERNATE METHODS FOR ENERGIZING a relay from the output of a 555.
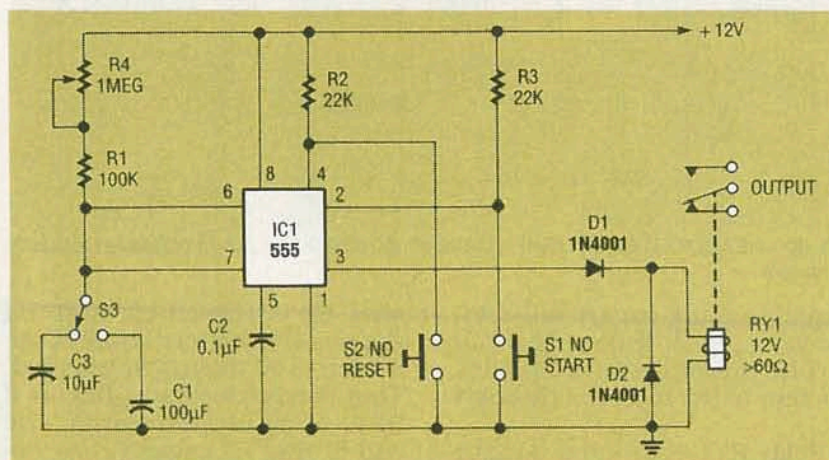

FIG. 7— TIMER WITH A RELAY OUTPUT provides time delays of 1.1 to 120 seconds.

premature termination of the timing period.

The 555 timer can drive non-inductive loads directly from pin 3 with currents as large as 200 milliamperes. However, if the circuit contains an inductive relay load, either of the schematics shown in Fig. 6 apply. In Fig. 6-a, the relay RY1 is normally off, but it goes on only when OUTPUT pin 3 goes high during the timing interval; in Fig. 6-b, RY1 is normally on, but it turns off during the timing interval. Diode D1 in both circuits protects the 555 against inductive-switching damage. The contacts of relay RY1 can control external circuits.

Figure 7 shows how a relay and a 555 can form a simple 1.1-to 120-second timer in two switch-selected decades. However, the general-purpose circuit has several drawbacks. First, it draws current continuously, even when the timer is off. Second, because of the wide tolerance variations in the electrolytic timing capacitors C1 and C2, potentiometer R4 needs two custom calibrated scales.

The schematic in Fig. 8 shows how to overcome these drawbacks. The RESET switch S2 and the set of relay contacts in parallel with the START switch S1, which are both normally open (N.O.) keep the circuit off so there is no current drain. The timing cycle is started by pressing momentary pushbutton switch S1, which connects power to the 555. At the instant of S1 closure, C3 is fully discharged. It therefore sends a start pulse to TRIGGER pin 2 through R4 and initiates a timing cycle.

As the timing cycle starts, RY1 is energized. The contacts in parallel with S1 close and keep the 555 powered even when S2 is released. At the end of the timing cycle RY1 is de-energized and its contacts re-open, disconnecting power from the 555.

The timing of the circuit in Fig. 8 is principally controlled by the values of resistor R1 and potentiometer R5, and either C1 or C2, which are switch-selected by S3-a. Note, however,

that timing is also influenced by the setting of potentiometers R6 and R7. They are selected with switch S3-b and connected to CONTROL voltage pin 5 of the IC. Those potentiometers effectively shunt the internal voltage of the 555, thereby altering timing periods.

That feature allows the circuit to produce precise timing periods even when capacitors with loose-tolerance values are in the circuit. It also allows a single calibrated timing scale to cover the two switch-selected timing ranges.

To set up the Fig. 8 circuit, first set potentiometer R5 to its maximum value, set switch S3 to position 1 and push START button S1. Then adjust potentiometer R6 for a precise period of 10 seconds. Next, set 3 to position 2, push START switch S1, and adjust potentiometer R7 for a precise period of 100 seconds. With those adjustments complete, the timing scale can be calibrated over its full 100-second range.

Timers for car lights

Figure 9 is a circuit that automatically delays the turn-off of an automobile's headlights, permitting them to function as safety lights at night after the ignition switch is turned off. It is a useful circuit if you want your car's headlights to remain on for 50 seconds after you have parked, turned off the ignition, locked the doors, and walked away. The headlights will stay on long enough to illuminate your route until you can reach the safety of your home. The circuit does not interfere with normal headlight operation.

When the car's ignition switch S2 is turned "on," RY1 is energized (through diode D3) closing its contacts and connecting the 12-volt battery to the 555 and headlights switch S1. In this state the headlights operate normally. However, because both sides of capacitor C2 are connected to the positive supply, it is fully discharged.

When S2 is turned "off," the voltage across R3 goes to zero, de-energizing the relay. However, at that time C3 applies a
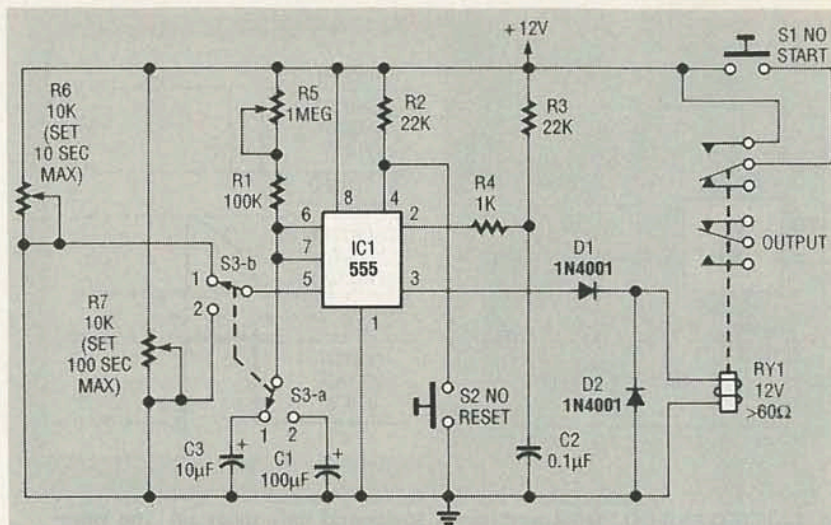

FIG. 8—PRECISION (COMPENSATED) TIMER with a relay output has two ranges: 0.9 to 10 seconds and 9 to 100 seconds.
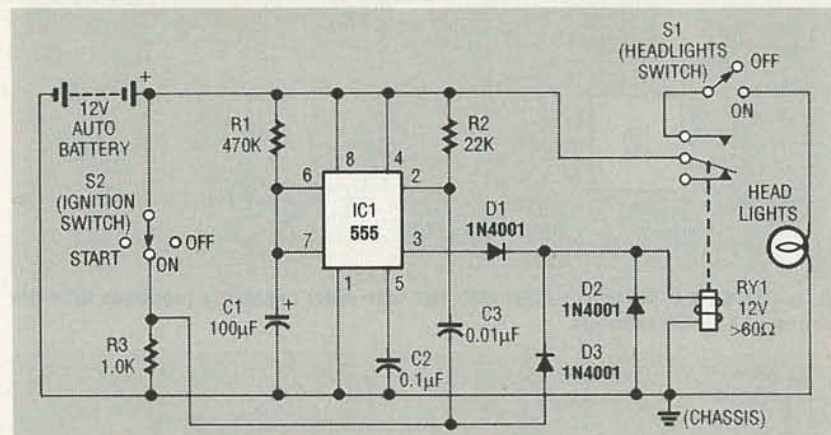

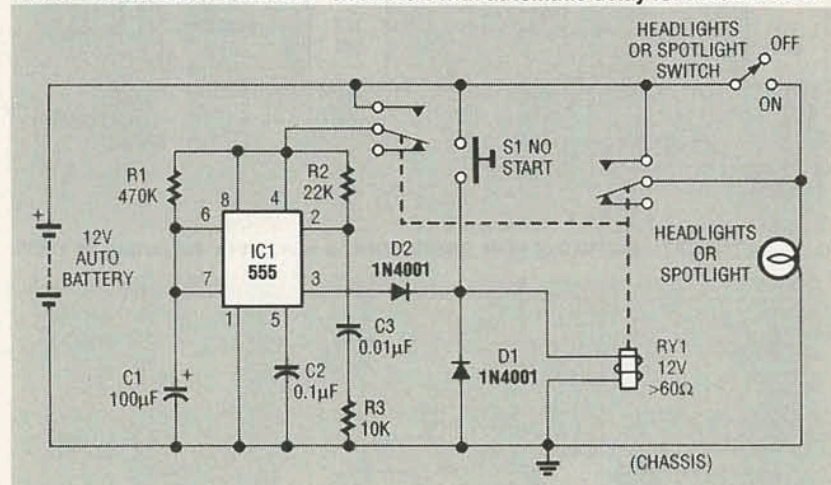FIG. 9—HEADLIGHT TURNOFF CONTROL with automatic delay for automobiles.

FIG. 10—HEADLIGHT/SPOTLIGHT TURNOFF CONTROL for automobiles is manually actuated.

negative-going trigger pulse to TRIGGER pin 2, initiating a 50-second timing cycle that applies current to the relay coil through D1.

Relay RY1's contacts remain closed for about 50 seconds after S2 is turned off, keeping the positive battery supply connected to S1 during this period. That keeps the headlights on if S1 is in its ON position. At the end of that 50-second time delay, RY1 de-energizes, its con-
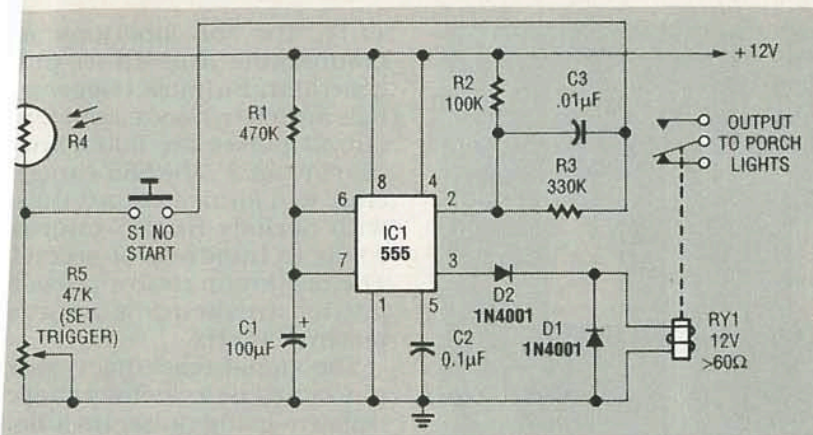
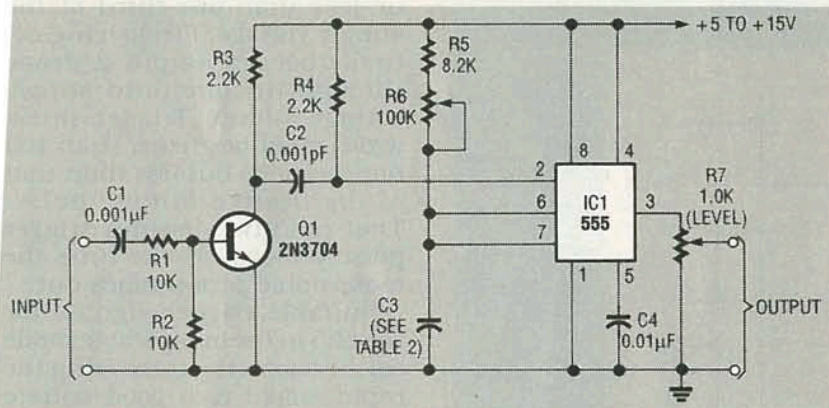G. 11—PORCH LIGHT CONTROL AUTOMATICALLY turns on a light for a preset period only when triggered at night.

FIG. 12—ADD-ON PULSE GENERATOR can supplement a stand-alone pulse generator. It is triggered by rectangular input signals. Table 1 gives output pulse widths for various values of C3.
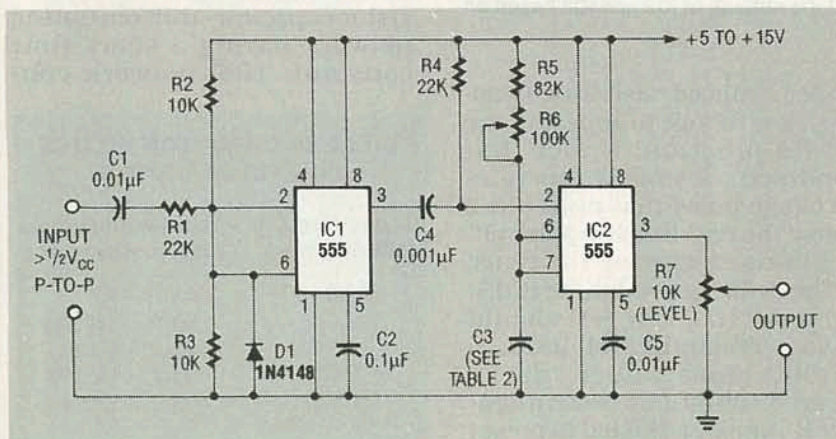

FIG. 13—MODIFIED ADD-ON PULSE GENERATOR can be triggered by any kind of input waveform including sine waves.

tacts open, and battery supply is disconnected from the 555 and S1.

The circuit in Fig. 9 is compatible with modern practice for powering the headlights switch S1 with ignition switch S2 so that headlights work only when the ignition switch is on. How-ever, the circuit shown in Fig. 10 is applicable to older vehicles whose headlights or spotlight are independent of the ignition switch. The circuit illustrates a manual delayed turn-off light control.

That circuit works if the vehicle is parked with its lights off.

They will be turned on for a pre-set 50-second period as soon as momentary pushbutton START switch S1 is pressed. When the delay period times out, the lights will be turned off again automatically.

The Fig. 10 circuit includes relay RY1 with two sets of nor-mally-open contacts. The timing sequence is started with the momentary closure of pushbutton switch S1. Normally, both S1 and the relay contacts are open, so the timer circuit is not powered and the lights are off. Capacitor C3 is discharged under this condition.

When S1 is momentarily closed, RY1's coil is energized. That action closes its first set of contacts, applying power to the car's lights while also closing its second set of contacts, applying power to the 555. However, TRIGGER pin 2 of the IC is briefly grounded through C2, so a negative trigger pulse is fed to it, and a timing cycle is begun.

Consequently, OUTPUT pin 3 of the 555 switches high when the relay contacts close, locking the relay into its "on" state (re-gardless of the subsequent state of S1), keeping the lights on for 50 seconds. At the end of the timing cycle, pin 3 of the IC switches to its low state, de-en-ergizing RY1. Then both sets of relay contacts open, discon-necting power from the 555 and the lights.

Automatic porch light

Figure 11 is an automatic con-trol circuit for a porch light. It will turn a porch light on auto-matically for a preset 50-second period when its sensor detects the presence of a person. How-ever, it performs that function only at night or under condi-tions of reduced visibility such as might occur during a storm. The circuit is activated with switch S1, which can be a microswitch triggered by a por-ch gate. It might also be a pres-sure-switch hidden under a porch mat and triggered by a person weighing perhaps 50 pounds or more.

Circuit operation depends on a negative-going pulse that falls below the internally controlled
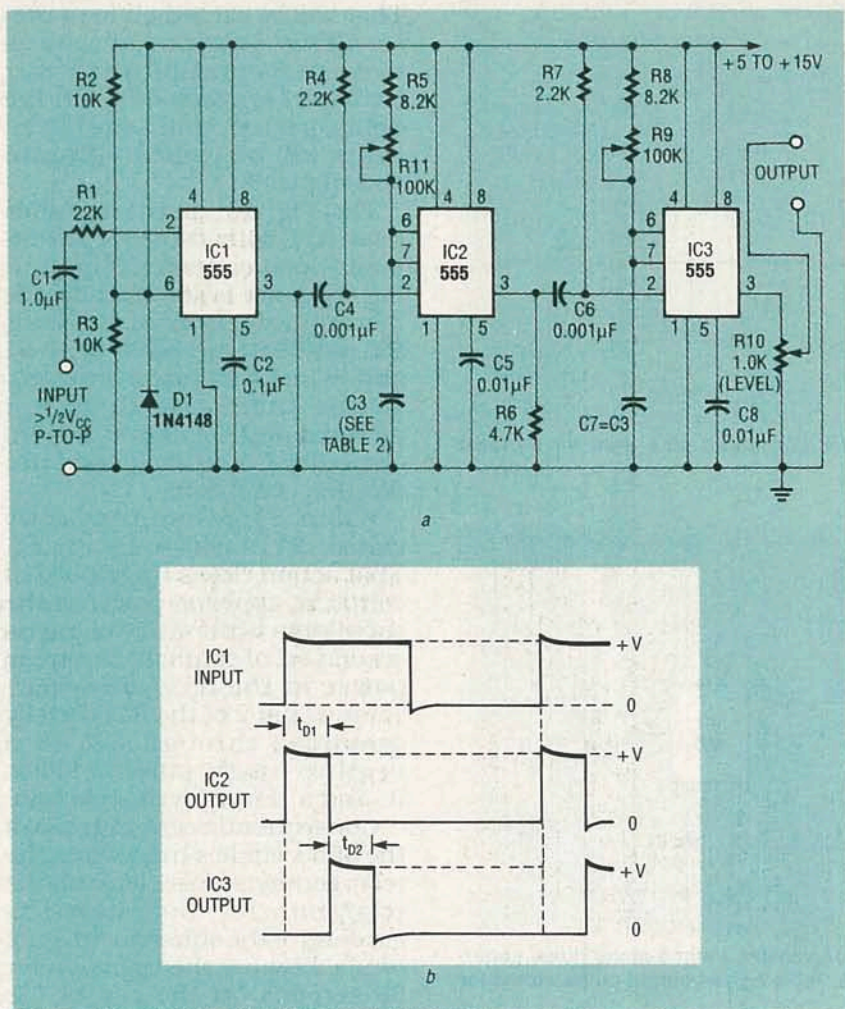
FIG. 14—ADD-ON DELAYED PULSE GENERATOR can be triggered by any input wave-form (a). Waveforms at input to IC1 and those at the outputs of IC2 and IC3 based on different values of R and C (b).

so far, the 555 functions as a monostable (one-shot) pulse generator. Suitable trigger signals are fed to TRIGGER pin 2 and output pulses are taken from OUTPUT pin 3. The 555 can generate well formed output pulses with periods from 5 microseconds to hundreds of seconds. The maximum usable pulse repitition frequency is approximately 100 kHz.

The signal reaching TRIGGER pin 2 must be a carefully shaped negative-going pulse. Its amplitude must switch from an "off" value greater than two-thirds of the supply voltage to an "on" value less than one-third of the supply voltage. (Triggering actually occurs as pin 2 drops through the one-third supply voltage value.) Trigger pulse width must be greater than 100 nanoseconds but less than that of the desired output pulse. That condition assures trigger pulse removal by the time the monostable period times out.

Suitable trigger signals for the 555 in the monostable mode can be formed by converting the input signal to a good square wave that switches between the full positive supply voltage and ground. The square wave is then coupled to pin 2 with a resistor-capacitor differentiating network having a short time constant. That network con-

TABLE 2—CAPACITOR VALUES FOR PULSE-WIDTHS

Capacitors C3 (Microfarads)	Pulse Width Range (Time in Seconds)
10.0	90 ms - 1.2
1.0	9 ms - 120 ms
0.1	900 μs - 12 ms
0.01	90 μs - 1.2 ms
0.001	9 μs - 120 μs

verts the leading or trailing edges of the square wave into suitable trigger pulses.

Figure 12 shows a timing circuit that accepts input signals already in the form of square waves or pulses. Transistor Q1 converts a rectangular input signal into a form that switches between the positive supply and ground. The output signal is

one-third supply voltage being fed to TRIGGER pin 2 of the 555. If the trigger pulse does not fall below that value, the timing cycles cannot be initiated.

In Fig. 11, the photocell (resistor R4) and potentiometer R5 are in series as a light-dependent voltage divider. One side of S1 is connected to the junction between R4 and R5, and the other side is connected to pin 2 through a the network of C2 and R3. In normal daylight the photocell's resistance is low, so a high voltage appears at the junction of R4 and R5. As a result, closing S1 sends a voltage pulse to pin 2 whose value is too low to pull pin 2 below one-third of the supply voltage. Thus, the timer cannot be triggered with S1 under those conditions.

However, the photocell's resistance value increases at night or

under reduced visibility, causing a low voltage to appear at the R4-R5 junction. Under that condition, closing S1 generates a voltage pulse that pulls pin 2 below the one-third supply voltage value, triggering the timer.

The cadmium-sulphide (CdS) photocell (resistor R4) should have a resistance of 1000 to 47,000 ohms under "dark" turn-on conditions. Potentiometer R5 can be adjusted to preset the minimum "dark" level for circuit triggering. The trigger signal is fed to pin 2 of the 555 through the C3 and R3, a network that shapes the trigger pulse and effectively isolates the DC component of the photocell-potentiometer network from pin 2.

Pulse generators
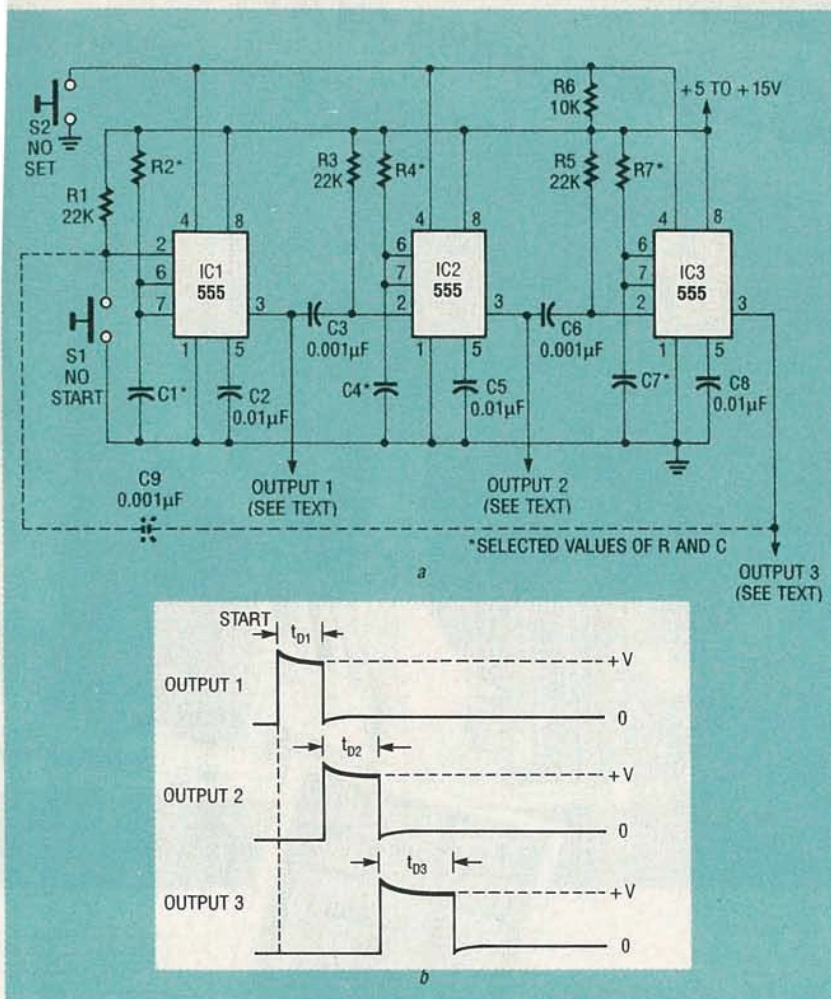
In all of the circuits presented

FIG. 15—THREE-STAGE SEQUENTIAL TIMER or pulse generator (a) and waveforms at three different output pins (b).

then fed to TRIGGER pin 2 through differentiating network C2-R4. The circuit can become an add-on pulse generator in combination with a separate square-wave or pulse generator. Variable-amplitude output pulses can be obtained from potentiometer R7.

The output pulse widths of the Fig. 12 circuit can be varied over more than a decade range with potentiometer R6, and they can be switched in overlapping decade ranges with the values of C3 listed in Table 2. With the component values shown, output pulse width is variable from 9 microseconds to 1.2 seconds. Capacitor C4 decouples CONTROL VOLTAGE pin 5 to improve circuit stability.

Figure 13 shows a modification of the circuit in Fig. 12 that can be triggered by any kind of input waveform, including sine

waves. Here the first 555 (IC1) is configured as a Schmitt trigger to convert all input signals into square-wave output signals. Those square waves trigger the second 555 (IC2) in the monostable mode in the same way as described earlier. The circuit can also become an add-on pulse generator in combination with any kind of stand-alone waveform generator that produces output signals with peak-to-peak amplitudes greater than one-half the IC's supply voltage.

Figure 14-a shows how two monostable circuits can be connected in series to make a delayed-pulse generator. As in Fig. 13, the first 555 (IC1) is configured as a Schmitt trigger. The second 555 (IC2) controls time delay width, while the third 555 (IC3) determines the output pulse width.

As shown in Fig. 14-b, the output pulse at pin 3 of IC3 appears at a time interval after the initial application of the trigger signal. This time delay width T_{D1} is determined by the product of the value of capacitor C3 and the sum of the values of resistor R5 and potentiometer R6, in accordance with the time delay formula given earlier. Similarly, output pulse width t_{D2} is determined with the values of C7, and R8 and R9.

This circuit can become part of a stand-alone pulse delay generator by building it into a square-wave generator case. The square-wave generator will provide the initial trigger signals needed.

A number of monostable pulse generators can be placed in series to operate in sequential form. Figure 15-a, for example, shows a three-stage sequential generator circuit. It can control lamps or relays in a pre-programmed time sequence after pushbutton switch S1 is pressed to give the START command. Note that the RESET pins (pin 4) of all three 555's are shorted together and positively biased by R6. Those pins can be shorted to ground with SET switch S2. When power is applied, S1 should be closed, ensuring that none of the 555's in the circuit are falsely triggered.

Figure 14-b shows the waveforms from the output pins of all three 555's (IC1 to IC3). The time delay t_{D1} is determined by the values of C1 and R2, t_{D2} is determined by the value of C4 and R4 and t_{D3} is determined by the values of C7 and R7 when inserted in the time delay formula given earlier.

Finally, three or more monostable circuits can be connected with capacitor C9 (shown in a dashed connection line) between S1 and pin 3 of the third 555 (IC3). This loop feeds a signal back from the OUTPUT pin of IC3 to the input TRIGGER pin of IC1, permitting infinite repetition of pulse sequence. The circuit can drive LED's and digital logic. The circuit also has the reset capability provided by S2 that clears the circuit when power is first applied. **R-E**