

Use the 555 to generate sawtooth waves, detect missing pulses, convert DC to AC, boost DC voltage and more.

THE VERSATILE 555

RAY M. MARSTON

THE POPULAR 555 TIMER IC HAS been the star of three previous **Electronics Now** articles (September 1992, page 58, October 1992, page 69 and November 1992, page 61.) Just when you thought that all possible applications for that versatile 555 had been exhausted—surprise! This article takes the 555 into new territory—a sawtooth generator, a “ramp” generator, a time-base generator, a frequency meter, and even a tachometer for your car.

But that's not all—there is a missing-pulse detector, and DC voltage doubler, tripler and quadrupler. There are also negative and high-voltage generators and a DC to AC inverter!

If you've been following the previous articles and (we hope) building some or all of the circuits presented in them, you'll be all set for the circuits presented here. Who said the microprocessor was the most versatile IC, anyway?

The last three articles on the 555 explained its basic operating principles. You would have learned (or refreshed your memory) about how to place external components so the timer functions either as a monostable or astable multivibrator. You might want to reread the introductory sections of those articles to brush up on the unusual features of the 555. A complete schematic of the circuitry contained in the 555 is given as Fig. 2 on page 64 of the September 1992 issue.

Figure 1 is another functional block diagram and pinout of the bipolar 555 with a different ar-

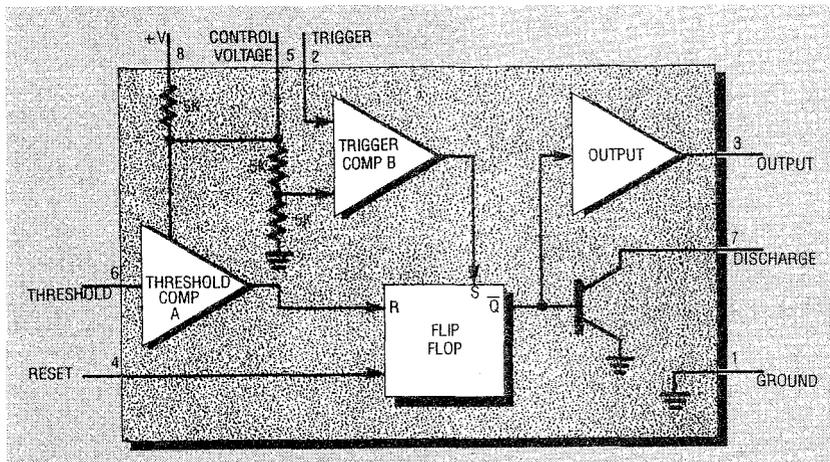


FIG. 1—FUNCTIONAL BLOCK DIAGRAM and pinout for the bipolar 555 timer IC.

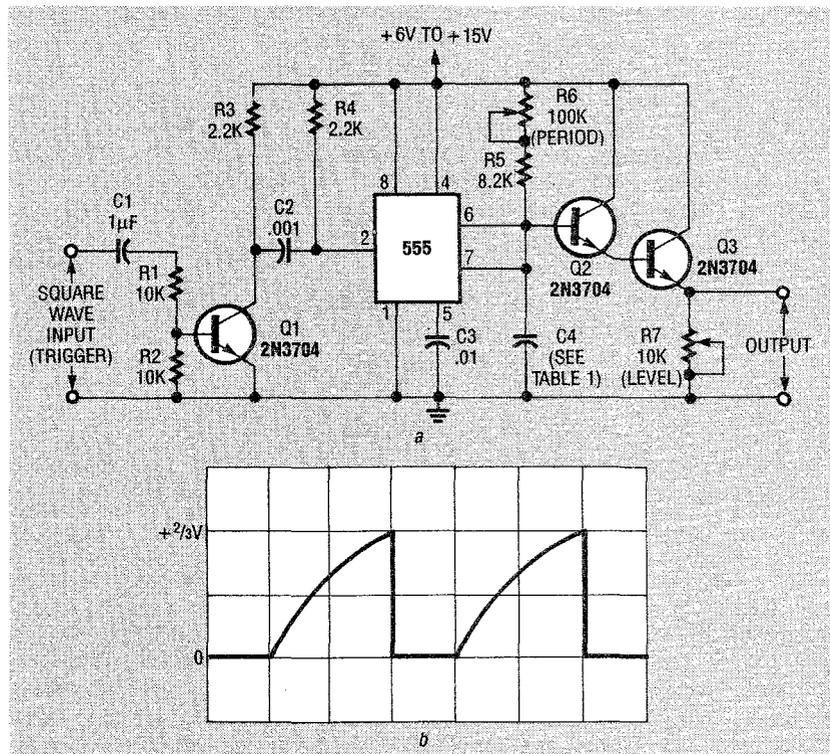


FIG. 2—TRIGGERED SAWTOOTH GENERATOR based on the 555, a, and typical output waveform, b.

range of functional blocks than the others given earlier, illustrating yet another manufacturer's preferred data book presentation. Neither diagrams nor data sheets on the 555 have been standardized.

Sawtooth-wave generators

The 555 with external components can become a triggered nonlinear (exponential) sawtooth waveform generator, as shown in the schematic Fig. 2-a. The circuit is a modified

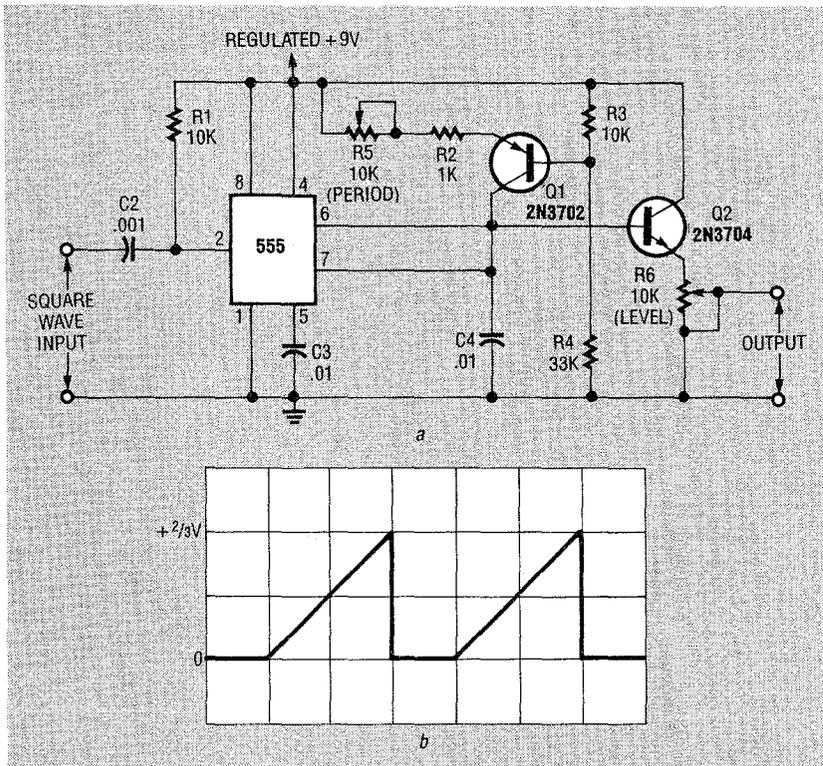


FIG. 3—LINEAR SAWTOOTH OR RAMP waveform generator based on the 555, a, and "ramp" waveform, b.

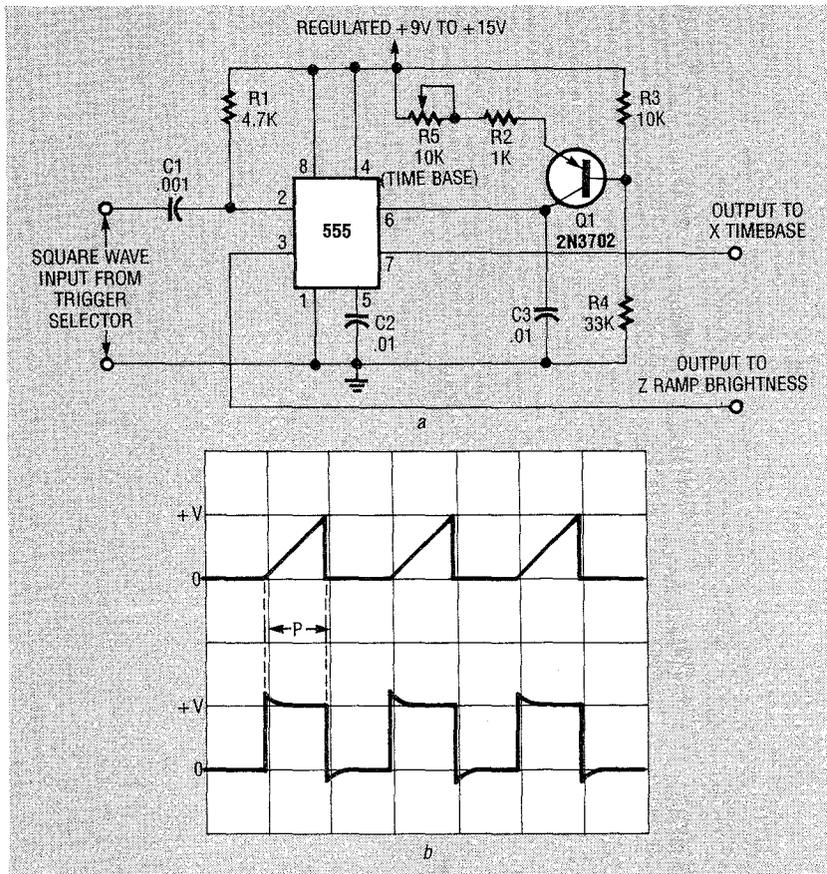


FIG. 4—OSCILLOSCOPE TIME-BASE GENERATOR circuit based on the 555, a, and ramp and ramp brightness pulse waveforms for an oscilloscope's X and Z axes.

monostable multivibrator that is triggered by an external square wave TRIGGER pin 2 obtained through capacitor C2 from the collector of transistor Q1. Note that OUTPUT pin 3 of the 555, used in most of the 555-based circuits presented earlier is unused here.

The voltage across C4 (the timing component) is normally zero, but whenever the circuit is triggered, C4 charges exponentially through resistor R5 and PERIOD potentiometer R6 to two-thirds of the supply voltage. At that time, the monostable period ends and the voltage across C4 drops abruptly to zero. The output sawtooth waveform (Fig. 2-b) is taken across capacitor C4 through buffer transistors Q2 and Q3 and LEVEL potentiometer R7.

The period of the sawtooth or width can be varied from 9 microseconds to 1.2 seconds with the capacitance values for C4 listed in Table 1. The circuit's maximum usable repetition frequency is approximately 100 kHz.

The generator must be triggered by rectangular input waveforms with short rise and fall times. Potentiometer R6 controls the sawtooth period over a decade, and potentiometer R7 controls the amplitude of the output waveform.

Figure 3-a shows a triggered linear sawtooth or ramp waveform generator. Capacitor C4 is charged by a constant-current generator that includes Q1. The output waveform (Fig. 3-b) is taken at the wiper of LEVEL potentiometer R6, which is coupled to the voltage across C4 through Q2. Note that the curved ramps of Fig. 2-b have been flattened.

When a capacitor is charged from a constant current source, its voltage rises at a predictable linear rate that can be expressed as:

Volts/second = amperes/farad
 By introducing more practical values, alternative expressions for the rate of voltage rise are:
 $V/\mu s = A/\mu F$, or
 $V/ms = mA/\mu F$

Those formulas state that voltage rate-of-rise can be in-

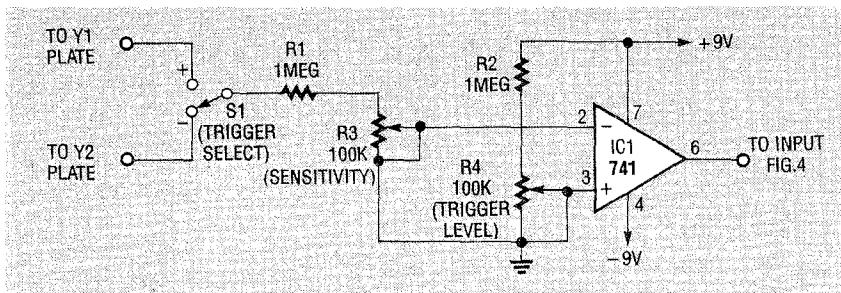


FIG. 5—TRIGGER SELECTION CIRCUIT for the Fig. 4 circuit

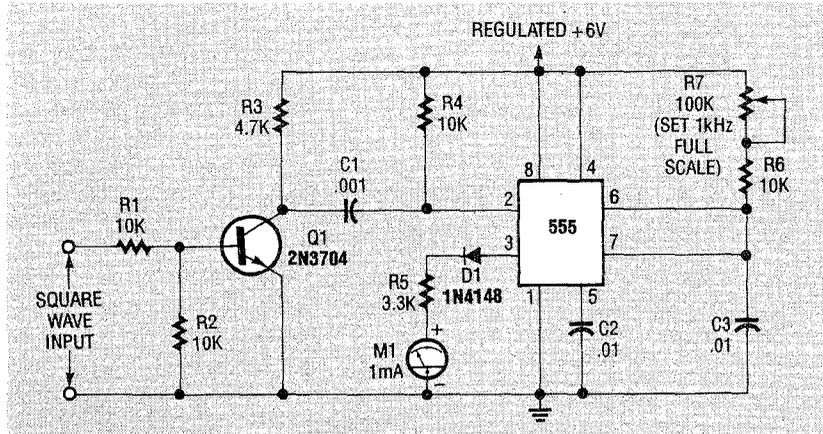


FIG. 6—A 1-kHz LINEAR-SCALE ANALOG FREQUENCY meter circuit based on the 555.

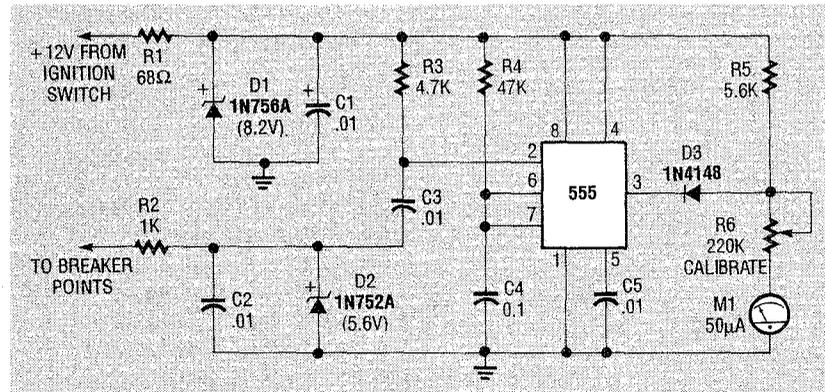


FIG. 7—VEHICULAR TACHOMETER CIRCUIT based on the 555.

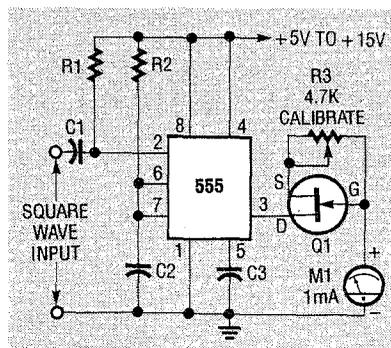


FIG. 8—ALTERNATIVE ANALOG TACHOMETER CIRCUIT to Fig. 6.

creased either by increasing the charging current or by decreasing

The sawtooth cycles of the circuit have periods variable from 666 microseconds (2/3 millisecond) to 60 microseconds (6/100 millisecond).

Periods can be increased beyond those values by increasing the value of C4, or reduced by reducing the value of C4. In this circuit, stable timing periods depend on a stable voltage source.

Fig. 4-a shows how the circuit in Fig. 3-a can be modified to become an oscilloscope timebase generator. It can be triggered by external square waves through a suitable trigger selector circuit. The ramp output waveform (top of Fig. 4-b) is fed to the X plates of an oscilloscope with a suitable amplifier stage. The pulsed output from pin 3 of the 555 (shown in the lower half of Fig. 4-b) is fed to the CRT's Z axis to trace the ramps with higher brightness.

The shortest useful ramp period that can be obtained from the circuit in Fig. 4-a (with a 0.001 microfarad capacitor C3) is about 5 microseconds. That value, when expanded to give full deflection on an oscilloscope with a ten-division graticule, yields a maximum timebase rate of 0.5 microsecond per division.

The timebase circuit of Fig. 4-a can synchronize signals at trigger frequencies up to about 150 KHz. At higher frequencies, the input signals must be divided by a single- or multi-decade frequency divider. With that approach, the timebase can be used to view input signals at megahertz frequencies.

ing the capacitance value.

The charging current in the Fig. 3-a circuit can be varied over the range of about 90 microamperes to 1 milliampere with PERIOD potentiometer R5, thus giving the 0.01 microfarad timing capacitor rates-of-rise of 9 volts per millisecond to 100 volts per millisecond.

Each one-shot or monostable cycle of the 555 ends when the voltage across C4 reaches two-thirds of the supply voltage. As shown in Fig. 3-a, the supply is 9 volts, so two-thirds of 9 volts is 6 volts, the amplitude of the ramp waveforms in Fig. 3-b.

Figure 5 illustrates a simple but versatile trigger selector circuit for the timebase generator in Fig. 4-a. Operational amplifier IC1 (a μ A741) has a reference voltage fed to its non-inverting input pin 3 by TRIGGER LEVEL potentiometer R4. The signal voltage is then fed to IC1's inverting pin 2 through switch S1, resistor R1 and SENSITIVITY potentiometer R3.

Switch S1 selects either in-phase or out-of-phase input signals from the Y-driving amplifier of the oscilloscope, permit-

ting the selection of either the plus or minus trigger modes. The output of the circuit in Fig. 5 is coupled directly to the C1 input of Fig. 4.

Analog frequency meters

Figure 6 shows the 555 IC organized as a linear-scale analog frequency meter with a full-scale sensitivity of 1 kHz. The circuit's power is obtained from a regulated 6-volt supply, and its input signals can be pulses or square-wave signals with peak-to-peak amplitudes of 2 volts or greater. Transistor Q1 amplifies this input signal enough to trigger the 555. The output from pin 3 is fed to the 1-milliamperere full-scale deflection moving-coil meter M1 through offset-canceling diode D1 and multiplier resistor R5.

Each time the monostable multivibrator is triggered, it generates a pulse with a fixed duration and amplitude. If each generated pulse has a peak amplitude of 6 volts and a period of 1 millisecond, and the multivibrator is triggered at an input frequency of 500 Hz, the pulse will be high (at 6 volts) for 500 milliseconds in each 1000 milliseconds. Moreover, the *mean* value of output voltage measured over this period is 500 milliseconds/1000 milliseconds \times 6 volts = 3 volts or half of 6 volts.

Similarly, if the input frequency is 250 Hz, the pulse is high for 250 milliseconds in each 1000-millisecond period. Therefore, the mean output voltage equals 250 milliseconds/1000 milliseconds \times 6 volts = 1.5 volts or one quarter of 6 volts. Thus, the circuit's mean value of output voltage, measured over a reasonable total number of pulses, is directly proportional to the repetition frequency of the monostable multivibrator.

Moving-coil meters give *mean* readings. In the circuit of Fig. 6 a 1-milliamperere meter is connected in series with multiplier resistor R5, which sets meter's sensitivity at about 3.4 volts full-scale deflection. The meter is connected to give the mean output value of the multi-

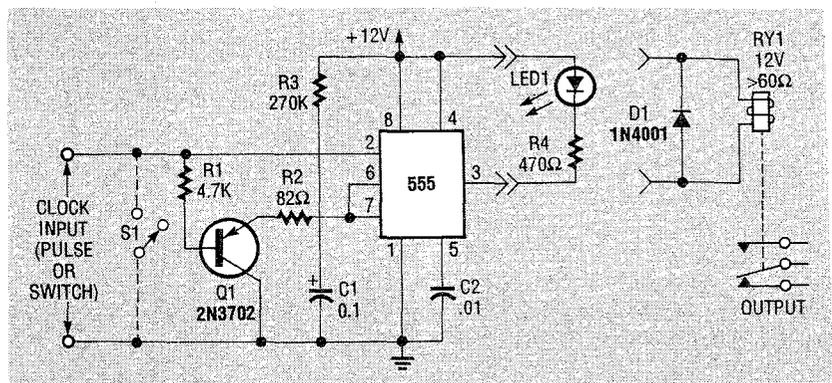


FIG. 9—MISSING-PULSE DETECTOR with LED or relay output.

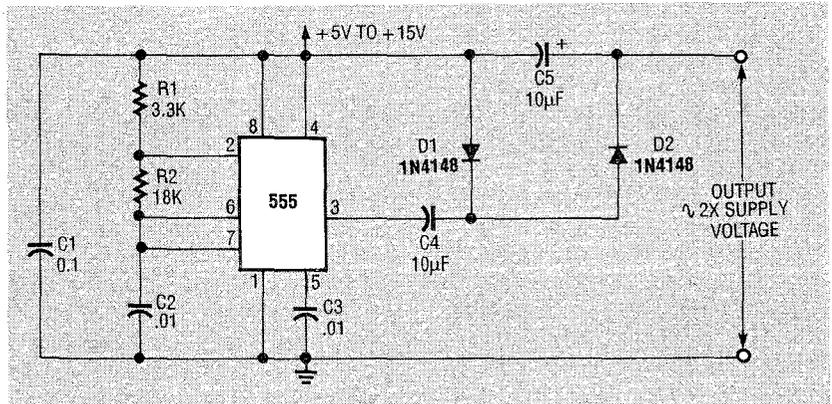


FIG. 10—DC VOLTAGE-DOUBLER based on the 555.

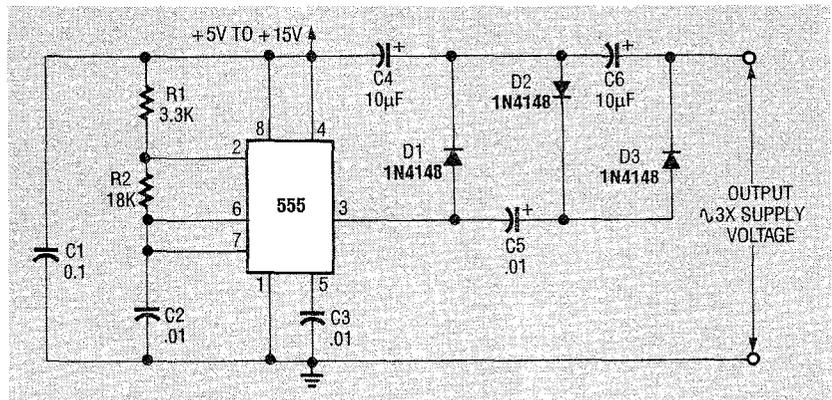


FIG. 11—DC VOLTAGE-TRIPLER based on the 555.

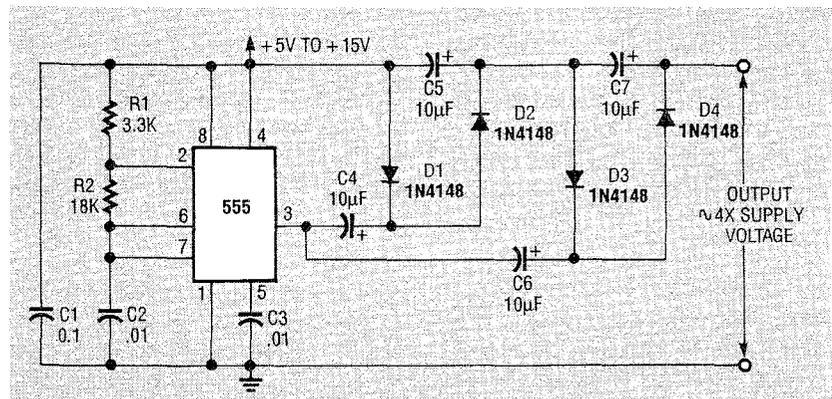


FIG. 12—DC VOLTAGE-QUADRUPLER based on the 555.

vibrator, and its reading is directly proportional to the input frequency.

With the component values shown, the circuit is organized to read full-scale deflection at 1 kHz. To set up the circuit initially, a 1-kHz square-wave signal is fed to its input, and full-scale-adjust potentiometer R7 (it controls pulse length) is set to give a full-scale reading on the meter.

The full-scale frequency of the circuit in Fig. 6 can be varied from about 100 Hz to 100 kHz by selecting the value of C3. The circuit can read frequencies up to tens of megahertz by introducing the input signals to the monostable multivibrator through either a single or multi-decade digital divider. The dividers can reduce the input frequencies to values that can be read on the meter.

Figure 7 shows how the circuit in Fig. 6 can be modified to become an analog tachometer or revolutions per minute (rpm) meter for motor vehicles. The circuit is powered by a regulated 8.2 volts derived from the vehicle's 12-volt battery with resistor R1, Zener diode D1, capacitor C1, and the ignition switch. The 555 is triggered by a signal from the vehicle's breaker points conditioned by the network of resistor R2, capacitor C2, and Zener diode D2.

The 50-microampere moving-coil meter M1, the rpm indicator, is activated from OUTPUT pin 3 of the 555 through diode D3. Current is applied to the meter through series-connected resistor R5 and CALIBRATE potentiometer R6 from the power supply when the 555's output is high. But current is dropped nearly to zero by diode D1 when the 555's output is low.

Both the circuits of Figures 6 and 7 are powered from regulated sources to ensure a constant pulse amplitude and provide accurate, repeatable readings from the meter. The meter is actually a current-indicating device, but it is connected as a voltage-reading meter with suitable *multiplying* resistors. They are R6 and R7 in Fig. 6 and R5 and R6 in Fig. 7.

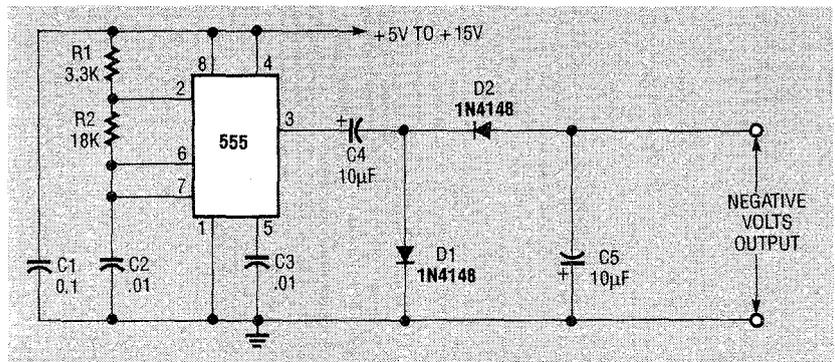


FIG. 13—DC NEGATIVE-VOLTAGE GENERATOR based on the 555.

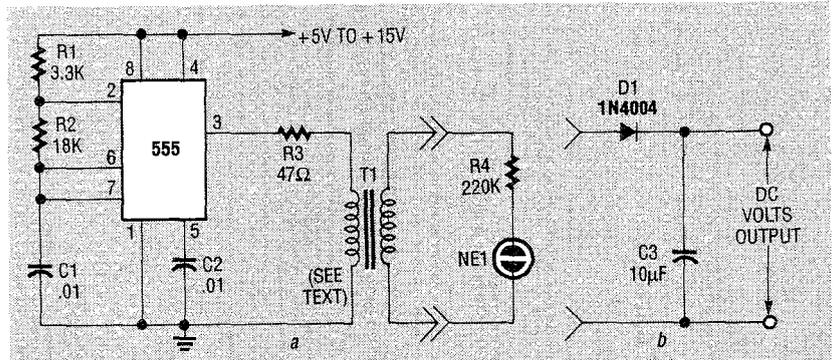


FIG. 14—NEON-LAMP DRIVER based on the 555, a, and DC-to-DC converter with rectifier and filter replacing lamp, b.

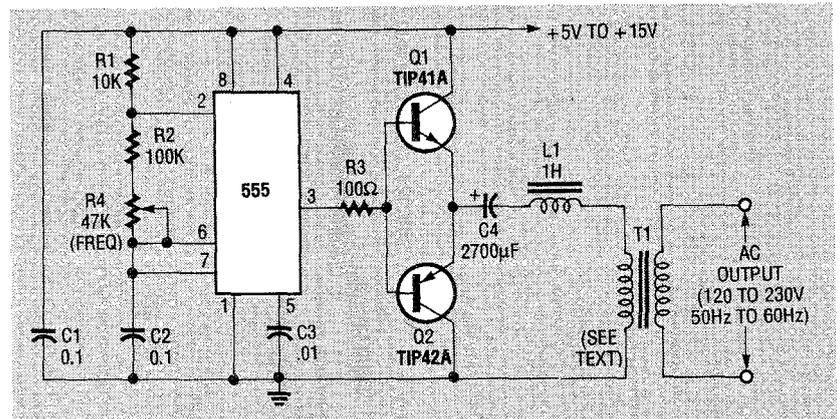


FIG. 15—DC-to-AC INVERTER based on the 555.

The diagram of Fig. 8 shows the outline schematic for an alternative analog frequency meter that requires neither a multiplier resistor nor a regulated power supply. In this circuit, OUTPUT pin 3 of the 555 is connected to the meter through JFET transistor Q1. Configured as a constant-current generator through potentiometer R3, it sends a fixed-amplitude pulse to the meter regardless of variations in the supply voltage.

Missing-pulse detector

Figure 9 illustrates how the

555 can become the key component in a *missing-pulse detector* that closes a relay or illuminates a LED if a normally expected event fails to occur. The 555 is connected as a monostable multivibrator except that Q1 is placed across timing capacitor C1, and its base is connected to TRIGGER pin 2 of the IC through R1.

A series of short pulse- or switch-derived clock input signals from the monitored event is sent to pin 2. The values of R3 and C1 were selected so that the natural monostable period of

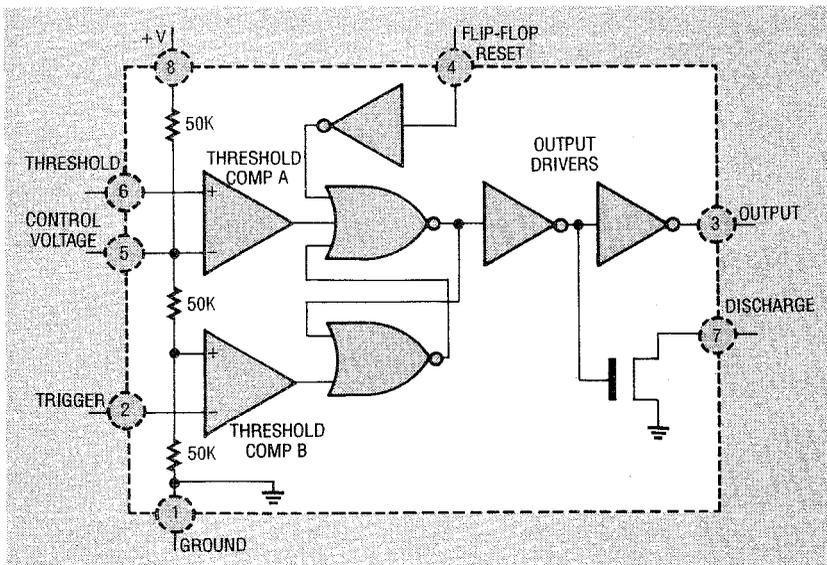


FIG. 16—FUNCTIONAL BLOCK DIAGRAM and pinout of the CMOS 7555.

the IC is slightly longer than the repetition period of the clock input signals.

Thus, each time a short clock pulse arrives, C1 is rapidly discharged through Q1, and simultaneously a one-shot timing period is initiated through TRIGGER pin 2 of the IC, forcing OUTPUT pin 3 high. Before each monostable period can terminate naturally, however, a new clock pulse arrives and starts a new timing period. Therefore OUTPUT pin 3 remains high as long as clock-input pulses continue to arrive within the preset time limits.

If a clock pulse is missing or its period exceeds the pre-set limits, the monostable period will end on its own. If that happens, pin 3 of the IC will go low and drive either the relay or LED "on." As a result, the circuit becomes a missing-pulse detector. It will produce a pulse output when an input pulse fails to occur within the timer delay.

Missing-pulse detectors like this can automatically warn of gaps or one or more missing pulses in a stream of pulses at the input. They are used in communications systems, continuity testers, and security systems. With the component values shown, the timer has a natural period of about 30 seconds. This period can be changed by changing R3 or C1 to satisfy specific needs.

Voltage converters.

The 555 IC can be instrumental in converting a DC voltage to a higher DC voltage, reversing the polarity of a DC voltage or converting it to an AC voltage. Figures 10 to 15 show variations of those circuits.

Figure 10, for example, shows how the 555 functions in a DC voltage doubler. The 555 is organized as a free-running astable multivibrator or square-wave generator that oscillates at about 3 kHz. (The oscillation frequency is set by the values of R1, R2 and C2.) The circuit's output is sent to the capacitor/diode voltage-doubler network made up of C4, D1, C5, and D2. That network produces a voltage that is about twice the supply voltage. Capacitor C1, across the supply, prevents the 3-kHz output of the 555 from being fed back to the IC, and C3 stabilizes the circuit.

The voltage-doubler circuit of Fig. 10 will operate from any DC supply offering from 5 to 15 volts. As a voltage doubler it can provide outputs from about 10 to 30 volts. Higher output voltages can be obtained by adding more multiplier stages to the circuit circuit. Figure 11 is the schematic for a DC-voltage tripler that can supply from 15 to 45 volts, and Fig. 12 is the schematic for a DC voltage quadrupler that supplies from 20 to 60 volts.

The DC negative-voltage generator is a particularly useful 555-based converter circuit. It supplies an output voltage that is almost equal in amplitude but opposite in polarity to that of the IC supply. This circuit can provide both positive and negative voltages for powering op-amps and other IC's with dual power requirements from a positive supply. The DC negative-voltage generator in Fig. 13, like that shown in Fig. 10, is a 3-kHz oscillator that drives a voltage-doubler output stage made up of C4, C5, D1, and D2.

Figures 14-a and 15 show DC to AC inverters that change input DC voltage to output AC voltage by means of transformer coupling. The AC voltage from these inverters needs no further conditioning, and it can be converted back into higher DC voltages with the addition of only a half-wave rectifier and a capacitor filter.

The inverter shown in Fig. 14-a can drive a neon lamp with its AC output. If the lamp and resistor R4 are replaced by the diode and capacitor filter as shown in Fig. 14-b, the AC output can be converted back to a low-current, high-voltage DC output. For example, with a 5- to 15-volt DC input, the inverter can produce an output of several hundred volts DC.

The 555 in Fig. 14-a is configured as a 4-kHz oscillator and its square-wave output from pin 3 is fed back to the input of audio transformer T1 through resistor R3. Transformer T1 has the necessary ratio of primary to secondary turns to produce the desired output voltage. For example, with a 10-volt supply and a 1:20 turns ratio on T1, the unloaded output of T1 will be 200 volts, peak.

The DC-to-AC inverter schematic of Fig. 15 produces an AC output at line frequency and voltage. The 555 is configured as a low-frequency oscillator, tunable over the frequency range of 50 to 60 Hz by FREQUENCY potentiometer R4. The 555 feeds its output (amplified by Q1 and Q2) to the input turns of transformer T1, a reverse-connected filament trans-

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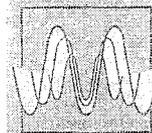
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former with the necessary step-up turns ratio. Capacitor C4 and coil L1 filter the input to T1, assuring that it is effectively a sinewave.

A CMOS version of the 555

The standard bipolar 555 timer IC is still one of the most popular and versatile IC's today, but it has some drawbacks that were overcome by a CMOS version. For example, the 555 will not operate from voltages less than about 5 volts. Moreover, it typically draws 10 milliamperes of quiescent current when run from a 15-volt supply. This rather large current drain makes it unsatisfactory for most battery-powered circuits.

In addition to those shortcomings, the 555 produces a massive 400-milliamperere current spike from the supply as its output is switched from one state to the other. A spike, lasting only a fraction of a microsecond, can cause lost bits in digital circuits near the 555 or powered from the same supply.

The CMOS version of the 555 timer, also able to operate in both monostable and astable modes, is known generically as the 7555. Figure 16 shows the functional block diagram and pinout of the 7555. This can be compared with the functional block diagram of Fig 1. Note that the pinout is identical.

Harris Semiconductor's version of the 7555, for example, is designated the ICM7555. In common with all other 7555's, it will run from a +2- to +18-volt DC supply. Notice that the resistors in its internal voltage divider are 50 K rather than the 5K of the 555. Other sources of the 7555 are Maxim (ICM7555) and Sanyo (LC7555).

Supply current to the 7555 is typically only 60 microamperes when run from an 18-volt supply. In addition, typical TRIGGER, THRESHOLD, and RESET currents are 20 picoamps, orders of magnitude lower than those of the bipolar 555. Those low currents permit the use of higher impedance timing elements for longer

RC time constants. The 7555 can be organized to time out in periods from microseconds to hours.

Table 2 compares the characteristics of the 7555 to those of the 555. The 7555 permits:

- Lower supply current
- Wider supply voltage range
- Lower power dissipation
- Lower current spikes in output transitions
- Higher switching frequency performance

These improvements must be balanced against the higher cost of the 7555. The 7555 should be specified only if:

- It is to be used in a battery-powered circuit where power economy is critical
- Available power is 5 volts or less (too low for the 555)
- It is to be in digital circuitry whose signal output could be degraded by noise.

The 7556 is the dual CMOS counterpart of the bipolar 556. The 7555 can directly replace any 555 in all the circuits presented in this series.

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