

VOLTAGE

Learn how to build a variety of voltage integrated circuits and put them

THIS ARTICLE EXPLAINS THE DESIGN of a many different low-power electronic voltage converters. These circuits generate higher-value supply voltages from low-voltage DC sources and negative DC voltages from positive DC voltage sources. The circuits in this article include the popular 555 industry-standard timer IC and the Harris Semiconductor ICL7660 voltage converter IC, devices that simplify the design and construction of a variety of voltage converter circuits.

Low-voltage generation.

The easiest way to increase the voltage level of a DC source voltage or reverse its polarity is to apply that DC voltage to a free-running, squarewave generator whose output is fed to a multisection capacitor-diode voltage-multiplier network. Figure 1 shows block diagrams for positive and negative output voltage converters.

If a positive output voltage is desired, the multiplier must provide a noninverting response, as shown in Fig. 1-a. But if a negative output is required, the multiplier must function as an inverter, as shown in Fig. 1-b.

Voltage converters are based on a variety of multivibrator circuits. These converters can include free-running, square-wave-generating multivibrators based on bipolar or field-effect (FET) transistors or CMOS or TTL integrated circuits. In general, the square-wave generators should oscillate at frequencies between 1 kHz and 10 kHz so that the multiplier section can operate efficiently. This frequency range permits the use of multiplying capacitors with low values.

An easy way to build a voltage converter is to design it around an industry-standard 555 timer IC. (This versatile device and many practical circuits that include it were discussed in the November and December issues of *Electronics Now*, starting on pages 61 and 62, respectively.) The 555 can source or sink up

to 200 milliamperes when set up as a free-running square-wave generator.

Figures 2, 3, 4, and 5 are voltage-converter circuits based on the 555. The 555 is configured

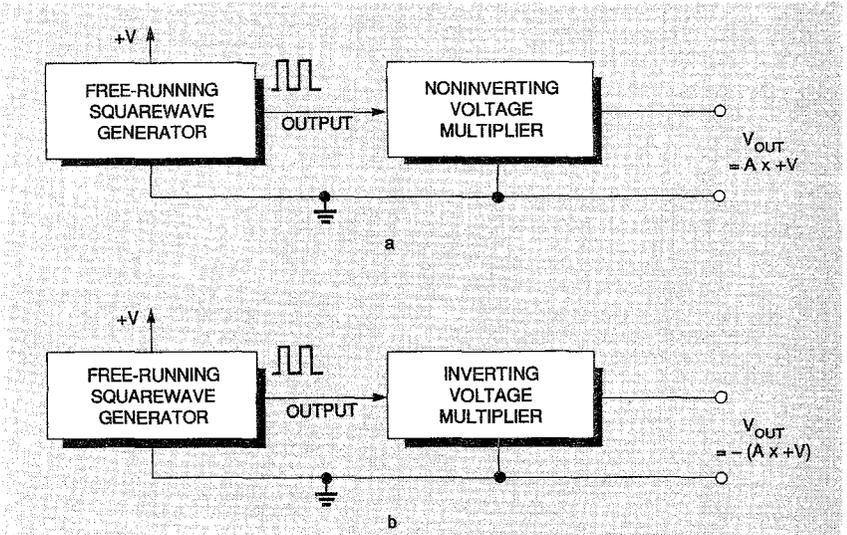


FIG. 1—VOLTAGE CONVERTER BLOCK DIAGRAMS: positive output (a) and negative output (b).

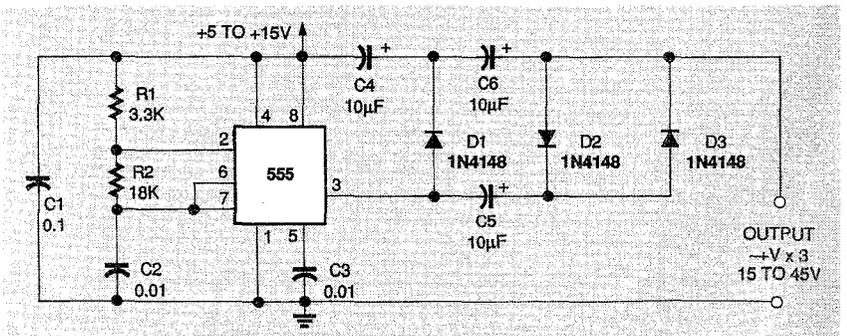


FIG. 2—DC VOLTAGE-DOUBLER circuit based on the 555 timer IC.

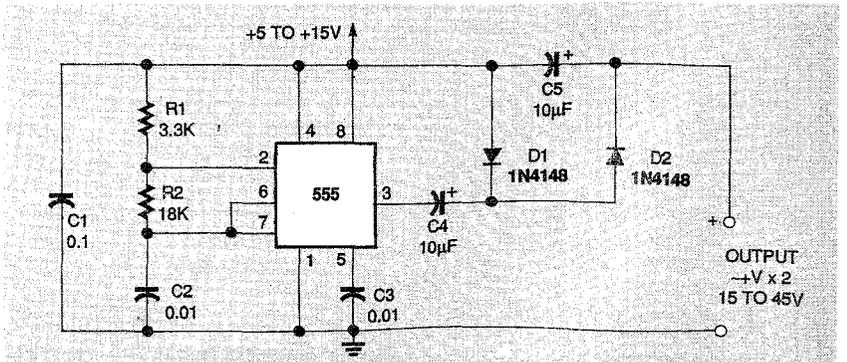


FIG. 3—DC VOLTAGE-TRIPLER circuit based on the 555 timer.

CONVERTERS

-conversion circuits from popular to work in your own circuit designs.

as a free-running astable multi-vibrator (squarewave generator) operating at about 3 kHz in all of these circuits. The 3-kHz frequency is determined by the values of resistors R1 and R2 in series with capacitor C2. Supply-line capacitor C1 prevents the 3-kHz output of the 555 from feeding back into the device, and capacitor C3 enhances circuit stability.

The circuit in Fig. 2 is a DC voltage-doubler that generates a DC output voltage with a value that is approximately twice that of the supply voltage. The 555's output is fed to a voltage-doubler network made up of capacitors C4 and C5 and diodes D1 and D2. The network produces the approximate *two times supply voltage output* when that output is unloaded.

The precise output value is:

$$2 \times V_{\text{peak}} - (V_{\text{fd1}} + V_{\text{fd2}})$$
 Where: V_{peak} is the peak output voltage of the squarewave generator V_{fd1} and V_{fd2} are the forward voltage drops (about 600 millivolts) of multiplier diodes D1 and D2.

The output voltage of the circuit decreases when the output is loaded.

The Fig. 2 *voltage doubler circuit* will work with any DC supply of 5 to 15 volts. Because of its voltage-doubling response, it can provide voltage outputs over a range of about 10 to 30 volts. Higher voltage can be obtained by adding more multiplier stages to the circuit.

The Fig. 3 *DC voltage tripler circuit* can provide output voltages from 15 to 45 volts. The Fig. 4 *DC voltage quadrupler circuit* can provide output voltages from 20 to 60 volts.

Figure 5 is the schematic for a *DC negative-voltage generator*, capable of producing an output voltage that is approximately equal in amplitude but opposite in polarity to that of the power supply. It also operates at 3 Hz, and it drives an output stage consisting of capacitors C4 and C5 and diodes D1 and D2. This circuit's *split-supply* output is useful for powering ICs that require both positive and negative power from a single-ended source.

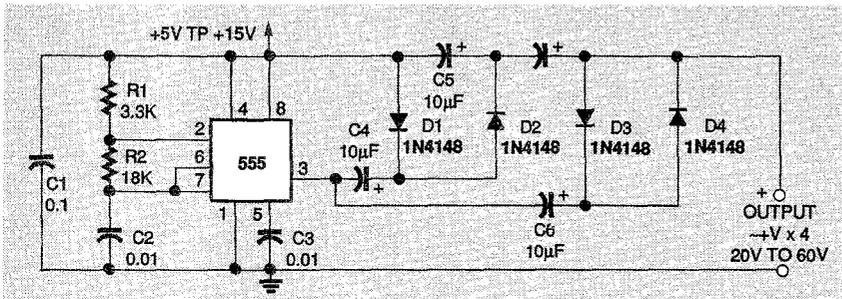


FIG. 4—DC VOLTAGE-QUADRUPLER circuit based on the 555 timer.

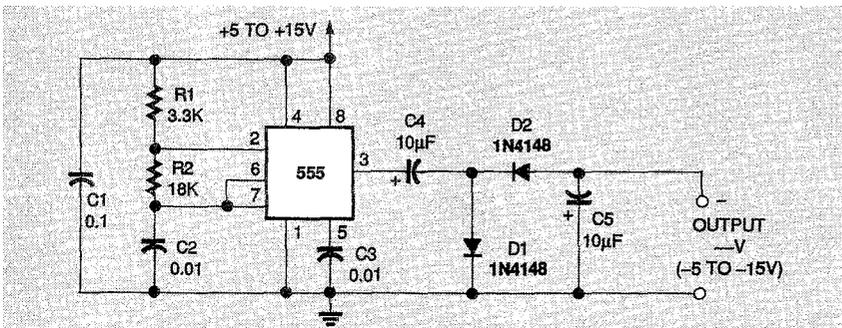


FIG. 5—DC NEGATIVE VOLTAGE generator based on the 555 timer.

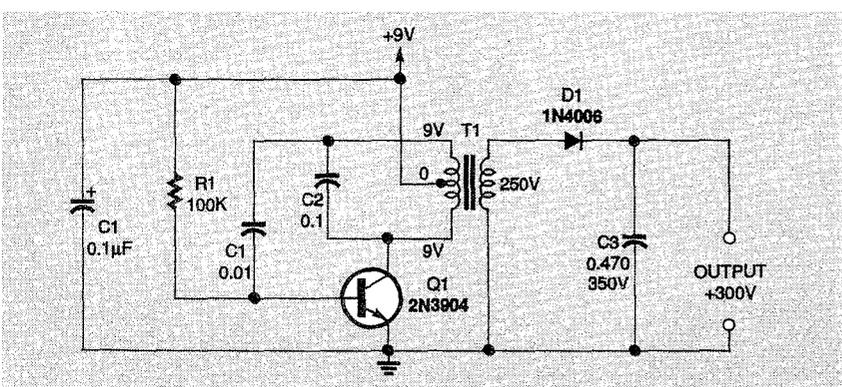


FIG. 6—NINE-VOLT-TO-300-VOLT DC-to-DC converter.

High-voltage generation.

The generation of higher output voltages with voltage multipliers is usually cost-effective only when the values of the required voltages are less than six times the supply voltage. Where very large step-up ratios are required (e.g., hundreds of volts generated from a 12-volt supply), other circuit designs are recommended.

It is usually cost-effective to apply the output of the low-voltage oscillator or squarewave generator as the input to a suitable step-up voltage transformer. The required high AC output voltages appear across the transformer's secondary winding.

This AC voltage can easily be converted back to DC with a

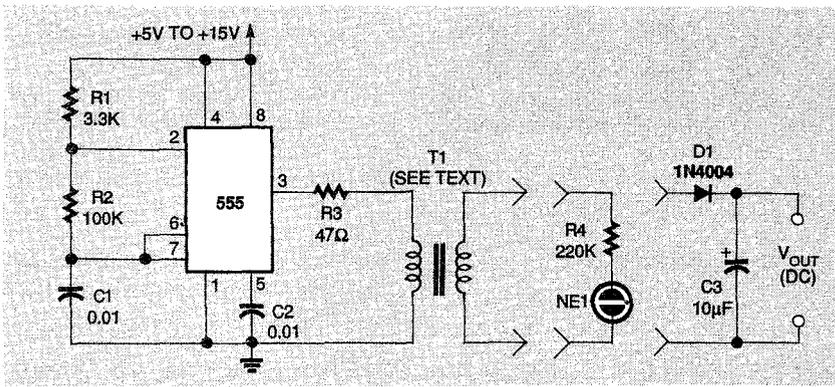


FIG. 7—HIGH-VOLTAGE GENERATOR that can also be a neon lamp driver.

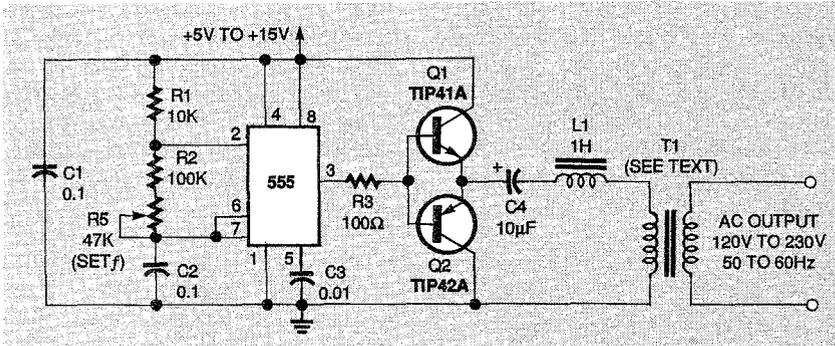


FIG. 8—DC-TO-AC INVERTER based on the 555 IC.

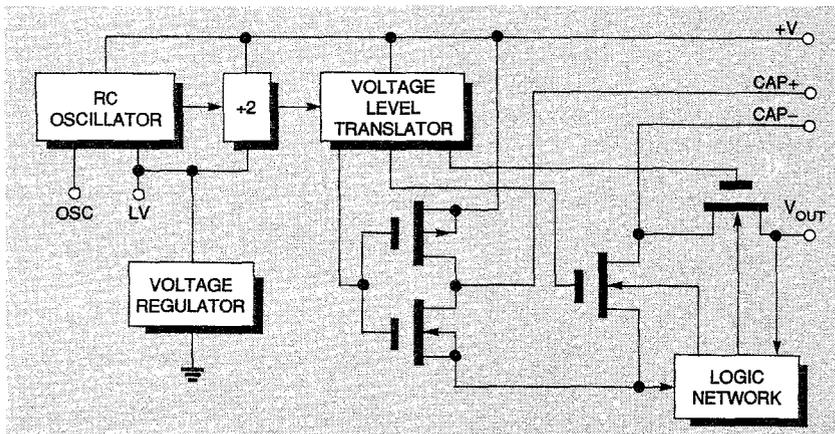


FIG. 9—FUNCTIONAL DIAGRAM for the ICL7660 CMOS voltage converter.

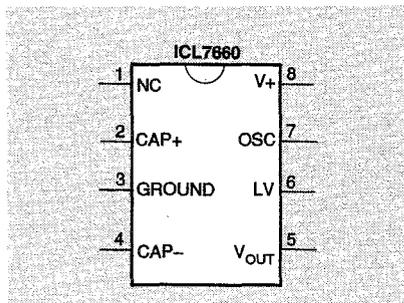


FIG. 10—PIN CONFIGURATION for an ICL7660 in an eight-pin miniDIP.

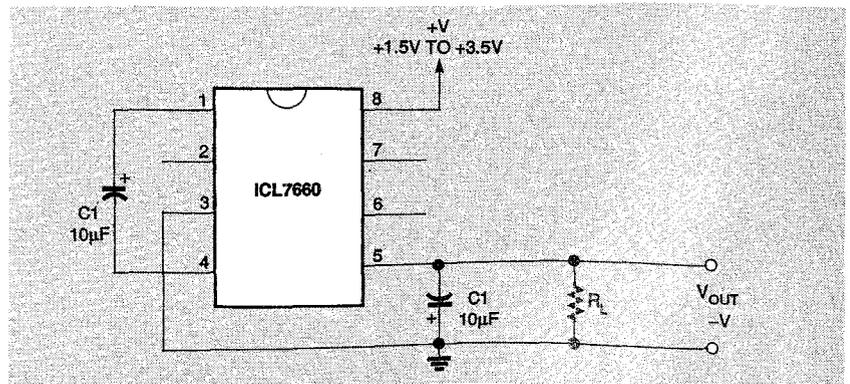


FIG. 11—NEGATIVE VOLTAGE CONVERTER for a 1.5- to 3.5-volt supply.

Figure 6 is a DC-to-DC converter circuit that can generate a 300-volt DC output from a 9-volt DC power source. In this circuit, transistor Q1 and its associated circuitry form a Hartley inductive-capacitive (LC) oscillator. The voltage on the primary winding that swings between zero and 9-volts is applied to 250-volt transformer T1. The inductance of the primary is the inductive element in the LC oscillator, which is tuned by capacitor C2.

The supply voltage is stepped up to about 350 volts peak at the secondary of T1. This output is half-wave rectified by diode D1, and it charges capacitor C3. Without a permanent load on C3, the capacitor can deliver a powerful but non-lethal electrical shock. With a permanent load, the output drops to about 300 volts at a load current of a few milliamperes.

The Fig. 7 circuit can either drive a neon lamp or generate a low-current DC voltage of up to several hundred volts from a 5- to 15-volt DC supply. The 555 is configured as a 3-kHz astable multivibrator whose square-wave output is fed to the input of transformer T1 through the resistor R3.

In this circuit, T1 is a small audio transformer with a turns ratio necessary to give the desired output voltage. In this circuit, a 10-volt supply and a transformer with a 1:20 turns ratio will give an unloaded DC output of 200 volts peak. This AC voltage can easily be converted to DC with a half-wave rec-

simple rectifier-filter network, if required. Figures 6, 7 and 8 show schematics for low-power,

high-voltage generation circuits based on of this principle.

tifier and filter capacitor, as shown in Fig. 7.

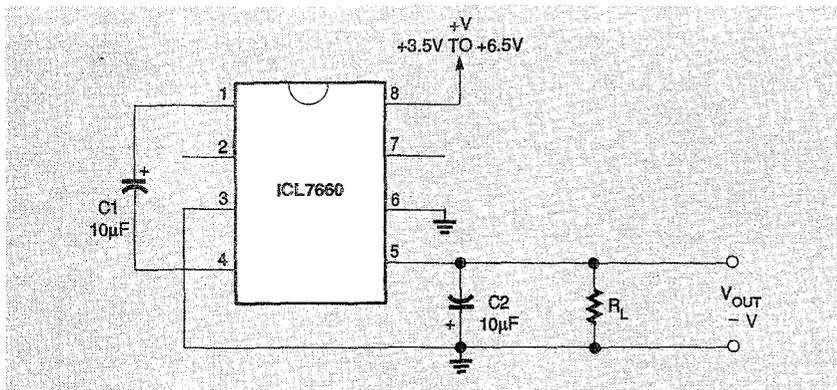


FIG. 12—NEGATIVE VOLTAGE CONVERTER for a 3.5- to 6.5-volt supply.

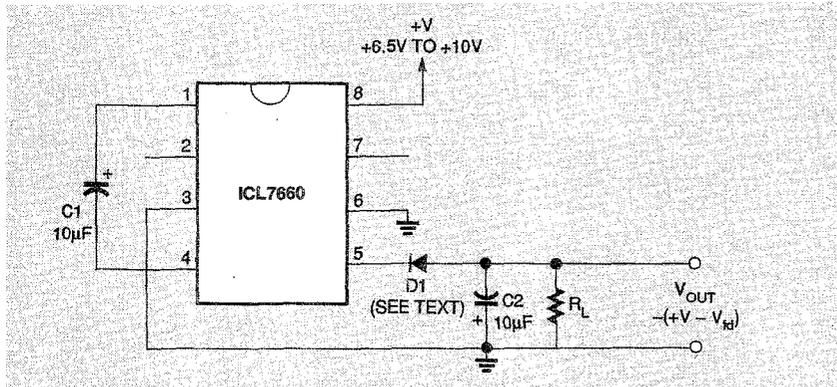


FIG. 13—NEGATIVE VOLTAGE CONVERTER for a 6.5- to 10-volt supply.

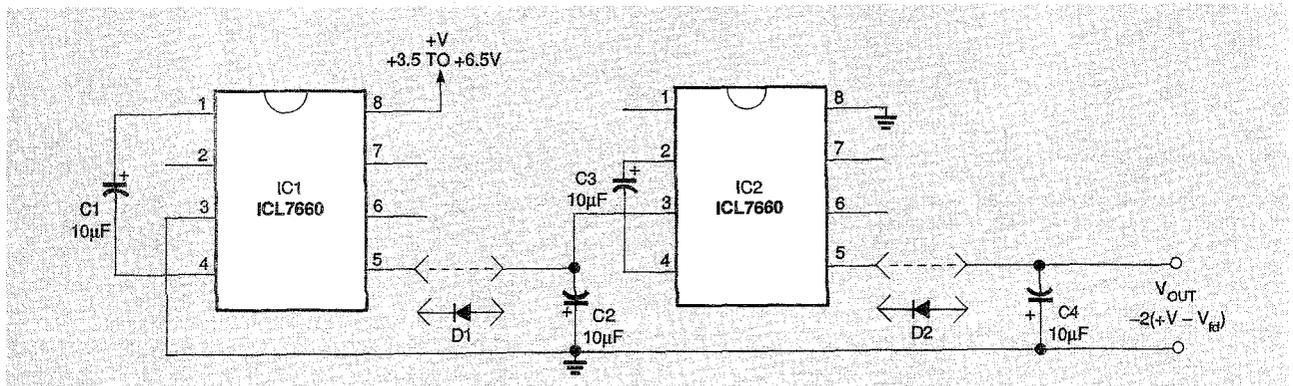


FIG. 14—METHOD FOR CASCADING voltage converter ICs for increased voltage.

The DC-to-AC inverter circuit in Fig. 8 will produce an AC output at line frequency and voltage. The 555 is configured as an astable multivibrator whose output frequency can be adjusted over a range of 50 to 60 Hz by trimmer potentiometer R5.

The output of the 555 is fed to the paired NPN and PNP bipolar transistors Q1 and Q2, and their output is fed into the low-voltage side of reverse-connected filament transformer T1. It has the necessary step-up turns ratio. Capacitor C4 and coil L1 filter the input to ensure

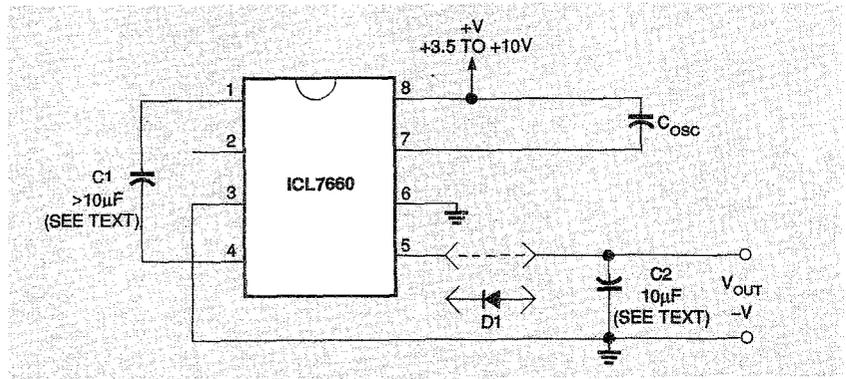


FIG. 15—CAPACITOR SUBSTITUTION for reducing the voltage converter's oscillator frequency.

that the transformer input is essentially a sine wave.

CMOS voltage converter

The Harris ICL7660 is a monolithic CMOS voltage converter that converts its supply voltage from positive to negative for an input range of +1.5 volts to +10 volts. This results in complementary output voltages of -1.5 volts to -10 volts. For example, if powered from a +5-volt source, the device will generate a -5-volt output.

The ICL7660 has a typical open-circuit voltage conversion efficiency of 99.9% and a typical power efficiency of 98%. When the output is loaded, the ICL7660 acts like a voltage source with an output impedance of about 70 ohms. It can supply maximum currents of about 500 microamperes.

Only two external capacitors are needed to perform the charge pump and charge reservoir functions. The ICL7660 can also be configured as a voltage doubler and it will generate output voltages up to +18.6 volts with a +10-volt input.

Figure 9 is the functional block diagram of the ICL7660.

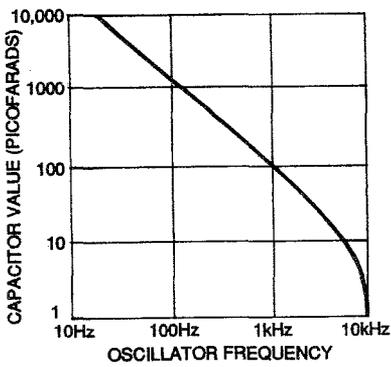


FIG. 16—FREQUENCY OF OSCILLATION as a function of external oscillator capacitor value (+V = 5 volts).

It contains an RC oscillator, divide-by-2 circuit, voltage-level translator, voltage regulator, four output power MOS switches, and an unusual logic network. The logic network senses the most negative voltage in the device and ensures that the output N-channel switch source-substrate junctions are not forward biased. This is intended to ensure latchup-free operation.

The unloaded oscillator oscillates at a nominal frequency of 10 kHz when the input supply voltage is 5.0 volts. This fre-

quency can be lowered by the addition of an external capacitor to the osc terminal, or the oscillator can be overdriven by an external clock.

The LV terminal can be tied to GROUND to bypass the internal series regulator and improve low voltage (LV) operation. At medium to high voltages (+3.5 to +10.0 volts), the LV pin is left floating to prevent device latchup.

The ICL7660 is available in eight-pin miniDIP and small-outline IC (SOIC) packages as well as TO-99 cases. Figure 10 is the drawing of pin configurations for the eight-pin miniDIP package, the least expensive version. Power dissipation of this package is 300 milliwatts. The ICL7660S, an enhanced direct replacement for the ICL7660, is now available and can be substituted if desired.

The operation of the ICL7660 is similar to that of the oscillator and voltage-multiplier shown in Fig. 2, but it performs that function more efficiently. As stated earlier, the use of conventional silicon multiplier diodes causes the circuit's unloaded output voltage to drop by about 1.2 volts—the sum of the forward voltage drops of the two diodes.

The ICL7660 eliminates the voltage drop by replacing the diodes with MOS power switches. These switches are driven by the logic network so that each switch automatically closes when it is forward biased and opens when it is reverse biased. This feature accounts for its high operating efficiency.

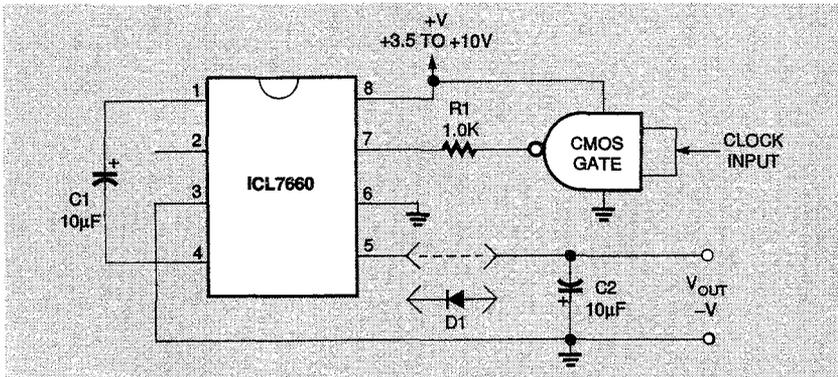


FIG. 17—EXTERNAL CLOCKING METHOD for reducing the internal oscillator frequency of the ICL7660.

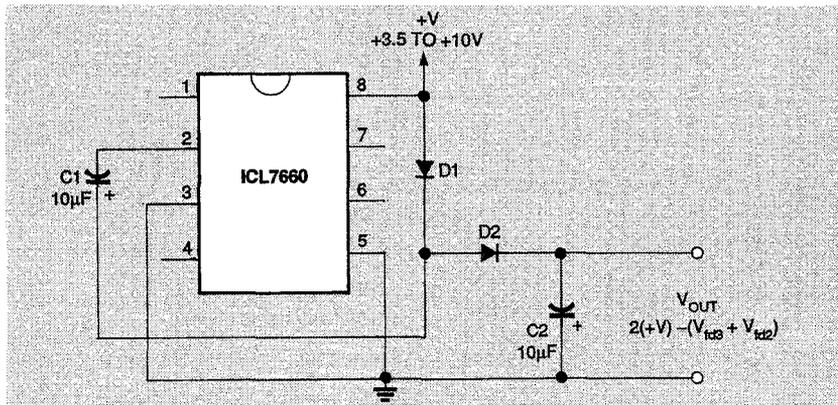


FIG. 18—POSITIVE VOLTAGE MULTIPLIER based on the ICL7660.

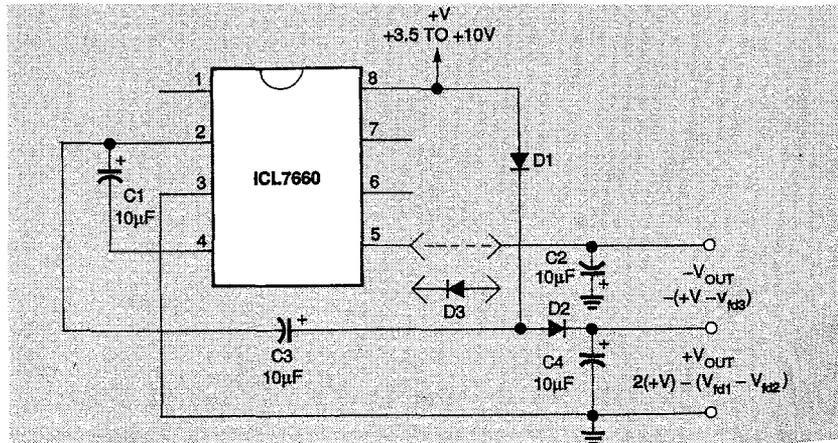


FIG. 19—COMBINED NEGATIVE VOLTAGE converter and positive doubler.

Do's and don'ts

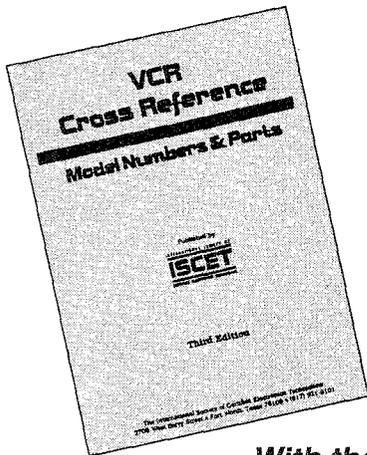
The manufacturer recommends some *Do's and Don't's* to assure reliable device operation:

1. Do not exceed the device's maximum supply voltage.
2. Do not connect any pins to voltages greater than +V or less than ground.
3. If the IC is operating in the power supply range of 1.5 to 3.5 volts, ground the LV-SX pin 6; at supply values greater than 3.5 volts, leave pin 6 open circuited.
4. Do not short circuit the output to the +V supply for out-

Continued on page 62

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VOLTAGE CONVERTERS

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ages above 5.5 volts for extended periods.

5. When installing polarized capacitors, connect the positive lead of the capacitor to the CAP + pin 2 and the negative lead to the CAP - pin 4 of the ICL7660. Connect the positive terminal of capacitors to V_{OUT} pin 5 to ground.

6. Be sure that pin 5 does not swing more positive than GND pin 3 to prevent latchup

7. If the supply voltage is greater than 6.5 volts, put a protective diode in series with pin 5.

Practical ICL7660 Circuits.

The most popular application for the ICL7660 is as a negative voltage converter. Figures 11, 12, and 13 are three basic negative converter circuits. In each circuit, capacitors C1 and C2 are *multiplier* capacitors with a value of 10 microfarads.

The negative voltage converter circuit in Fig. 11 is designed to be powered from a 1.5- to 3.5-volt supply, and it requires only two external electrolytic capacitors, C1 and C2. The circuit in Fig. 12 is similar, but it is designed to be powered in the 3.5- to 6.5-volt range and its LV pin 6 grounded.

The negative voltage converter circuit in Fig. 13 is designed for a 6.5- to 10-volt supply. Diode D1 is in series with +V_{OUT} pin 5 to protect the IC from excessive reverse biasing by C2 when the power supply is removed. Diode D1, which should be a Schottky diode, reduces the available output voltage by V_{fd}.

Up to ten cascading ICL7660s will give increased output voltage. For example, if three ICs are cascaded, their final output voltage will be -3 volts. Figure 14 shows how to make the connections for cascading two of these stages. Connect all additional stages in the same way as shown in the schematic.

Output frequency change

In some applications there might be a reason for reducing the operating frequency of the

IC's RC oscillator. This can be done by inserting an external oscillator capacitor C_{OSC} between osc pin 7 and +Vpin 8, as shown in Fig. 15.

The relationship between the value of C_{OSC} in picofarads and the oscillator frequency f_{OSC} is shown in Fig. 16. For example, a C_{OSC} of 100 pF reduces the operating frequency by a factor of ten, from 10 kHz to 1 kHz.

However, it will be necessary to alter the values of capacitors C1 and C2 to compensate for this 10 to 1 reduction of frequency if circuit efficiency is to be kept high. Increase the values of C1 and C2 (both 10 microfarads) by the inverse of the reduction function. For example, if the oscillator frequency is to be 1 kHz, both C1 and C2 should have values of about 100 microfarads.

Oscillator frequency can also be reduced by connecting osc pin 7 as shown in Fig. 17 so that an external clock input overrides the internal oscillator. Feed the clock signal to pin 7 through 1-kilohm series resistor R1. The clock signal should switch fully between the two power supply values. The CMOS NAND gate is connected as an inverting buffer stage to ensure reliable switching between those values.

The ICL7660 can also be a positive voltage multiplier. It can produce a positive output voltage that is nearly double the initial supply voltage value when set up as shown in Fig. 18. The oscillator output signal at CAP+ pin 2 drives a capacitor-diode voltage-doubler network. It is the same network as the one shown in Fig. 2.

The two diodes, D1 and D2, reduce the available output voltage by an amount equal to their combined forward volt drops. Consequently, both D1 and D2 should be low-loss germanium diodes.

Figure 19 shows how the circuits of Figs. 12, 13, and 18 can be combined to form a positive voltage multiplier and negative voltage converter that provides dual output voltages. Each voltage source has an output impedance of about 100 ohms. Ω