# THE DIGITAL ELECTRONICS COURSE

## MULTIPLEXED DISPLAYS

**Multi-digit displays can add considerable cost to electronic equipment, but display multiplexing—a process by which the number of discrete components and IC drivers is reduced—can cut the cost to a minimum.**

BY ROBERT A. YOUNG

The vast majority of seven-segment displays used commercially are housed in packages containing one or more individual digits (either common anode or common cathode), each configured for "direct drive." Direct drive means that each segment of each digit is provided with one terminal for connection to external driver circuitry. Such displays may be driven by a standard decoder/display driver (such as the 7447 and 7448 unit covered in a previous exercise).

However, when the number of digits in a display panel reaches four or more, the circuit becomes too complex, bulky, and expensive for direct drive—too many external connections and too many individual drivers are needed, which adds considerably to the cost.

To reduce the hardware needed to implement a four or more digit display a technique known as *multiplexing* is used. Multiplexing is accomplished using a special type of circuit known as (what else?) a multiplexer.

**Multiplexer Basics.** A multiplexer is actually a signal-selector circuit (like a multi-position switch) that allows what is best termed as a form of time sharing of current paths. Several signals are fed to the multiplexer and by using control inputs, the selected signal is made available at the output.

The concept of multiplexing can best be illustrated using a couple of single-pole double-throw switches, as shown in Fig. 1 (simplistic though it may be), where two input signals and two output devices share a single current path. For the sake of discussion, let's assume the A input signal is applied to switch S1 and switch S2 is connected to the A output device. After a period, the control signal causes both S1 and S2 to toggle to the B positions, passing the B input signal to the B output device. Display multiplexing requires slightly more complex circuitry to reduce the number of connections to the display, however the concept is pretty much the same.

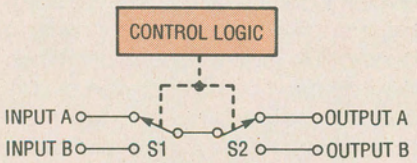


*Fig. 1. To reduce the hardware needed to implement multi-digit displays, a technique known as* multiplexing *is used. A multiplexer is actually a signal selector circuit (or multi-position switch) that allows a form of time sharing of current paths.*

**Display Multiplexing.** Multiplexed, multiple-digit displays require special decoder/drivers. Such drivers connect all like segments of each digit in parallel, forming a matrix of seven segment by N (N being the number of digits in the display).

The task of the multiplexed decoder/driver is to logically select the appropriate segments and digit of the display, illuminating each at the proper time. Only one digit is actually activated at a time, however, due to the rapid switching action—sequential strobing—of the multiplexed decoder/driver, all digits appear constantly on.

A block diagram of a generic multi-digit display with multiplexed seven-segment decoder/driver is shown in Fig. 2. The multiplexer consists of a decoder (which accepts a 4-bit BCD input), segment drivers (which either sink or source current to light the LED segments), digit-drivers (that, like their counterparts, the segment drivers, either sink or source current), and the control-logic circuit (that controls the multiplexer's switching). Note that the multiplexer provides only one set of segment drivers and

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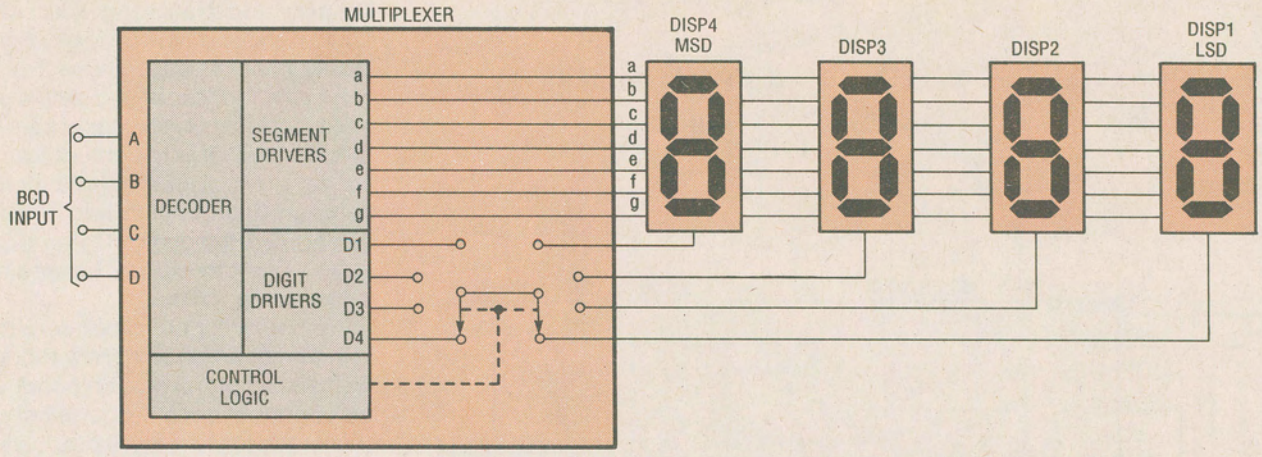


*Fig. 2. This generic multiplexer consists of a decoder, segment drivers, digit-drivers, and a control-logic circuit.*

that all like segments are tied together.

When a valid BCD input is received, it is decoded and fed to the driver circuits. Let's assume that 1111 (decimal 15) is applied to the BCD input of the multiplexer. Ignoring the decimal point, decimal 1 (the most-significant digit or MSD) is placed on the segment lines. The multiplexer activates DISP4 for a set period of time. And after that time has elapsed, the segment drivers output a signal to produce a decimal 5, while the control logic circuit activates the second MSD (DISP3).

The control logic then returns to the first position again lighting the first digit with a 1, and then switches back to the second MSD, displaying a 5. The actual switching takes place so fast that eye does not detect any blinking. The multiplexer may also include circuitry for the positioning of a decimal point (which is not included in our example, but positioning is handled in pretty much the same manner as the digit drivers).

**Timing is Key.** In all multiplexing operations, timing is critical; if, for instance, data intended for the most-significant digit is on the segment outputs, but the least-significant digit (LSD) is activated, or the control logic is in the process of deactivating the LSD and activating the MSD, it's obvious that you'll get an incorrect readout.

Many multiplexing circuits come equipped with an internal clock generator, and require a minimum of external components to set the proper clock rate (often nothing more than a resistor or two, a couple of capacitors, and a crystal to stabilize the clock frequency). Such all-encompassing IC's have gained in popularity in recent years. In fact, with the advent of large-scale integration (LSI), it is quite common to find complete systems of many types packaged in a single chip—Intersil's ICL7107 3½ digit, single-chip A/D converter, for example.

The ICL7107—a pinout diagram of which is shown in Fig. 3—contains seven-segment decoders, display drivers, a reference, and a clock circuit. That low-power, high-performance chip boasts a guaranteed zero reading for a 0-volt input, true polarity at zero for precise null deflection, a typical input current of 1 pA, direct-display drive capabilities (no external limiting components are required) low noise (less than 15 μV peak-to-peak), and low power dissipation (typically less than 10 mW).

## PARTS LIST FOR THE DEMONSTRATION CIRCUIT

**RESISTORS**

(All resistors are ¼-watt, 5% units, unless otherwise noted.)
R1—24,000-ohm
R2—47,000-ohm
R3—100,000-ohm
R4—1000-ohm trimmer potentiometer
R5—1-megohm

**CAPACITORS**

C1—0.1-μF, ceramic-disc
C2—0.47-μF, ceramic-disc
C3—0.22-μF, ceramic-disc
C4—100-pF, ceramic-disc
C5—0.01-μF, ceramic-disc

**ADDITIONAL PARTS AND MATERIALS**

U1—ICL7107 3½-digit A/D converter, integrated circuit
DISP1—Common-anode display, see text
Breadboard materials, ± 5-volt power supply, low-voltage variable power source, voltmeter, etc.

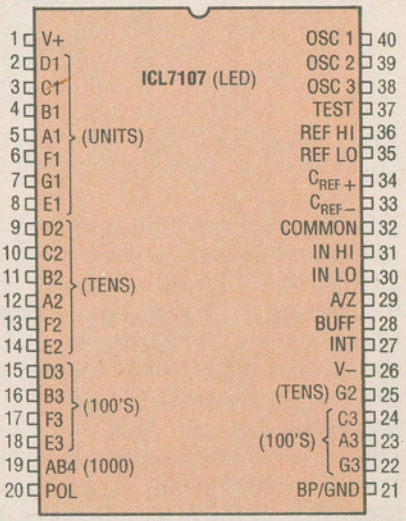


*Fig. 3. The ICL7107 contains seven-segment decoders, display drivers, a reference, and a clock circuit.*

**Operational Characteristics.** Each measurement cycle of the ICL7107 is broken down into three phases: auto zero (A-Z), signal integrate (INT), and de-integrate (DE). During the auto-zero phase three things happen: input high and low (pins 31 and 30, respectively) are internally disconnected from their external pins and shorted to analog common (pin 32); the reference capacitor (connected between pins 33 and 34) is charged to the reference voltage; and a feedback loop is closed around the system to charge the auto-zero capacitor to compensate for offset voltages in the ICL7107's internal buffer/amplifier, integrator, and comparator. Since the comparator is included in the loop, the auto-zero accuracy is limited only by the noise of the system. In any case, the offset referred to the input is less than 10 μV.

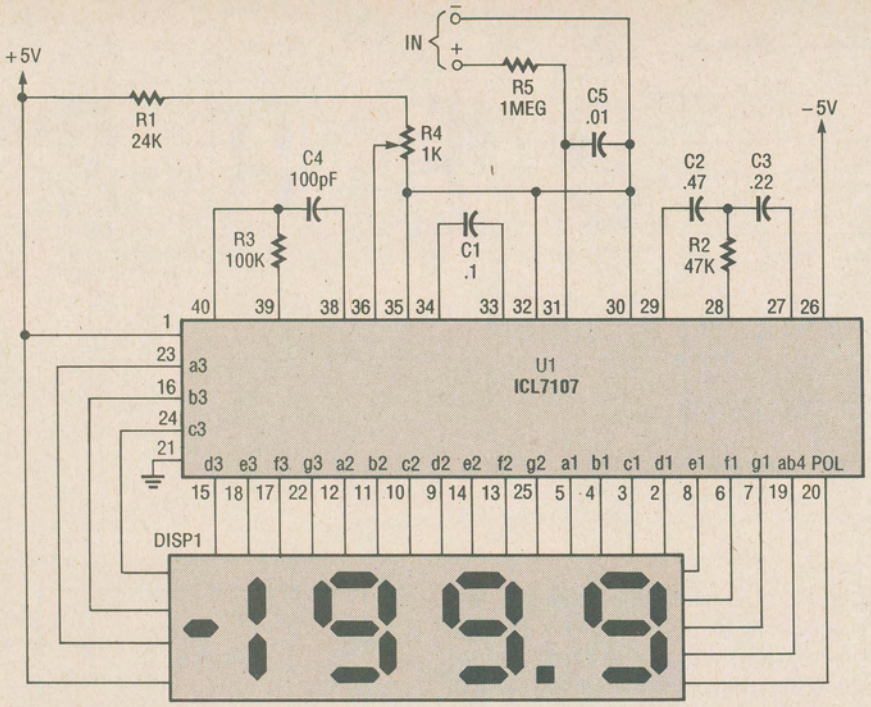


*Fig. 4. The ICL7107 3-1/2-digit single chip A/D converter can be used as the basis of a simple voltmeter capable of readings of from 0–2 volts.*

During the signal-integrate phase of operation, the auto-zero loop (initiated during the auto-zero phase) is opened, the internal short (to analog common) is removed, and the high and low inputs are reconnected to their respective pins. The converter then integrates the differential voltage—which can be within a wide common-mode range (within 1 volt of either supply)—between pins 30 and 31 for a fixed time. If, on the other hand, the input has no return with respect to the converter power supply, input low can be tied to analog common to establish the correct common-mode voltage after which the polarity of the integrated signal can be determined.

In the final phase, deintegrate (or reference integrate), input low is initially connected across analog common and input high is connected across the previously charged reference capacitor. Circuitry within the chip ensures that the reference capacitor is connected with the correct polarity to cause the integrator output to return to zero.

For critical applications the integrator swing can be reduced to less than the recommended 2-volt full-scale swing with little loss of accuracy. The integrator output can swing within 0.3 volt of either supply without loss of linearity.

The differential reference voltage can be generated anywhere within the power-supply voltage of the converter. The main source of common-mode error is a roll-over voltage caused by the reference capacitor losing or gaining charge due to stray capacitance at its nodes. If there is a large common-mode voltage, the capacitor can gain charge (increase in voltage) when called upon to deintegrate a positive signal, but lose charge (decrease in voltage) when called upon to deintegrate a negative input signal. That difference in reference for a positive or negative signal voltage gives a roll-over error. However, by selecting—in comparison to the stray capacitance—a large reference capacitor, the roll-over error can be held to less than 0.5 of the count for the worst-case condition.

Analog common (pin 32) is included primarily to set the common-mode voltage for battery operation, or for any system in which the input signal is floating with respect to the power supply. Pin 32 sets a voltage that is about 2.8 volts more negative than the positive supply voltage, which is selected to give a minimum end-of-battery-life voltage of about 6 volts. However, pin 32 has some of the properties of a reference voltage. When the total supply voltage is large enough to cause the ICL7107's internal Zener diode to regulate, the common voltage will have a low-voltage coefficient, a low output impedance, and a temperature coefficient of less than 80ppm/°C.

**Display Multiplexing Exercise.** Figure 4 shows a typical application of the ICL7107 3½-digit, single-chip A/D converter. That circuit is a simple voltmeter capable of readings of from 0–2 volts, and will serve to demonstrate the concept of multiplexing. Note that our demonstration circuit uses only two components (R3 and C4) to set the IC's internal oscillator, while C1 is used as a reference capacitor.

The display for our circuit consists of four common-anode display modules (we used whatever was on hand) with the anodes of each tied together and connected to the +5-volt bus. The individual segment of each module is then connected to the appropriate segment driver. (You will note that this circuit differs slightly from the description above. That's because our circuit is designed to use the cheaper direct-drive display modules, rather than a multiplexed display. However the basic concept is the same.)

When breadboarding the circuit shown in Fig. 4, it will be necessary to provide a negative (−) 5-volt power source in addition to the +5-volt source that has been used throughout this series. You'll also need a low-voltage power supply and an accurate voltmeter to adjust the circuit for the proper readout.

Breadboard the circuit that is shown in Fig. 4, and connect the voltmeter and power source across the input of the circuit. With a 0-volt input the circuit should give a 0-volt reading. If not, adjust potentiometer R4 until a 0-volt reading is obtained.

Now bring the power supply voltage up to 1-volt as indicated on your voltmeter readout. If the demonstration circuit gives the proper response, vary the power supply voltage while observing the readout of the demonstration circuit. If not, re-adjust R4 for the proper readout. The demonstration circuit's readout should vary accordingly; *i.e.*, count up or down.

Our demonstration circuit can be expanded to read voltage many times its basic 2-volt range by the addition of a resistor voltage-divider network and a range switch, providing a useful piece of test equipment. For those who wish to take the basic circuit a step further, select the resistors in the divider network to provide decade steps. In other words, since the basic range of the circuit is 2 volts, the next higher ranges should be 20 volts, 200 volts, 2000 volts, and so on. ■