Experimenter's Corner

DIGITAL TO ANALOG CONVERTERS, PART 2

By Forrest M. Mims

LAST MONTH, we saw how an *R-2R* resistor ladder network can be used as a rudimentary digital-to-analog (D/A) converter. We're now going to expand it into a full-fledged D/A converter and connect the converter to a few digital IC's. First, let's look at the circuit we'll be using to provide a binary input to the D/A converter.

A Simple Binary Input Circuit. A BCD (binary coded decimal) counter makes a convenient input circuit for the D/A converter. If you prefer, however, you can use a 4-bit RAM (such as the 7489) or any other chip with a 4-bit output. You can assemble both the binary input circuit and D/A converter on a plastic solderless breadboard.

Figure 1 shows the counter circuit along with a simple clock oscillator made from two of the inverters in a 74C04 hex inverter. I used CMOS chips, but you can use the TTL equivalents for the specified IC's. The pin numbers are the same for both.

If you use TTL chips, be sure to use a 5-volt power supply. If you don't have a suitable supply, use a 6-volt battery. Insert a IN4001 diode in series with the positive power supply lead to reduce the battery voltage to about 5 volts.

You can vary the clock frequency and count rate of the decade counter by varying the values of *R1* or *C1* or both. Increasing the capacitance of *C1* from 0.1 to 1.0 should give enough range.

The D/A Converter. Figure 2 shows how to add an operational amplifier to the *R-2R* resistor ladder network we experimented with last month. After you assemble the circuit, connect the binary inputs of the ladder network to the BCD counter outputs and then connect the probe of an oscilloscope between the output of the op-amp and ground. (If you don't have access to a scope, we'll shortly show you how to observe the operation of the circuit with a voltmeter.) With the clock running, you'll see a scope trace something like the diagram shown in Fig. 3. Obviously, the scope is showing the stepped voltage ramp coming from the op amp as the counter cycles through its 0000-1001 sequence.

Notice the ramp has not sixteen (as you would have expected from a 4-bit D/A converter), but ten, voltage levels. The reason for this, of course, is that the 74C90 is a BCD and not a pure binary (0000-1111) counter. Use a binary counter and you'll get a ramp with sixteen voltage steps.

The simple circuit in Fig. 2 can be used to synthesize waveforms digitally. A capacitor across the output will smooth the stepped waveform. The sequentially counting 74C90 will produce only ramps, but you can program a 7489 16-by-4-bit RAM to produce more complex waveforms.

Improving the D/A Converter. It's possible to improve the performance of the basic D/A converter by adding a second op-amp. The output voltage from the first swings from negative to positive as the ramp is created by the stepped voltage. It would be convenient to be able to adjust the ramp so that its baseline is ground, or any voltage you specify. The offset adjustment available to the first 741 isn't adequate for this purpose.

The second op amp (Fig. 4) makes adjusting the baseline of the ramp easy. In operation, the BCD counter is allowed to reach a count of 0000. The clock is then disabled to stop the count and the output of the second 741 is adjusted for any desired voltage. When the clock is reactivated, the output voltage will step through a ramp of ten voltage levels and automatically recycle as before.

You can set the 0000 count to equal 0 volt, so it's easy to use a voltmeter to

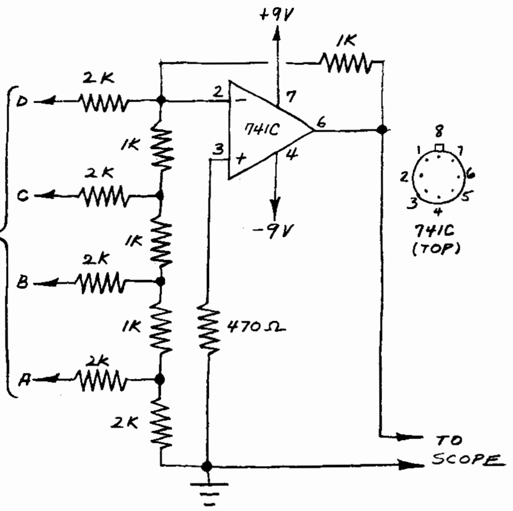

Fig. 2 How to connect an op amp to the resistor ladder D/A converter.

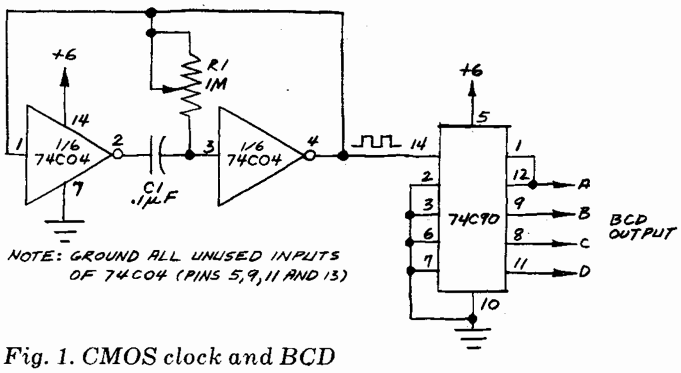

Fig. 1. CMOS clock and BCD counter for supplying binary inputs to D/A converter.

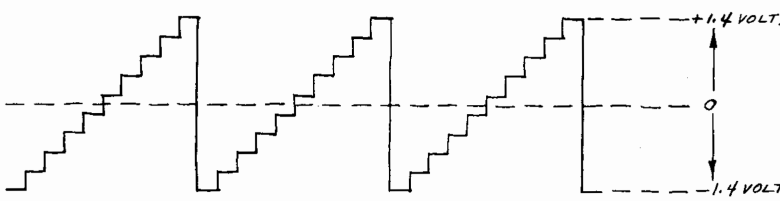

Fig. 3. Ramp voltage output from D/A converter in Fig. 2.

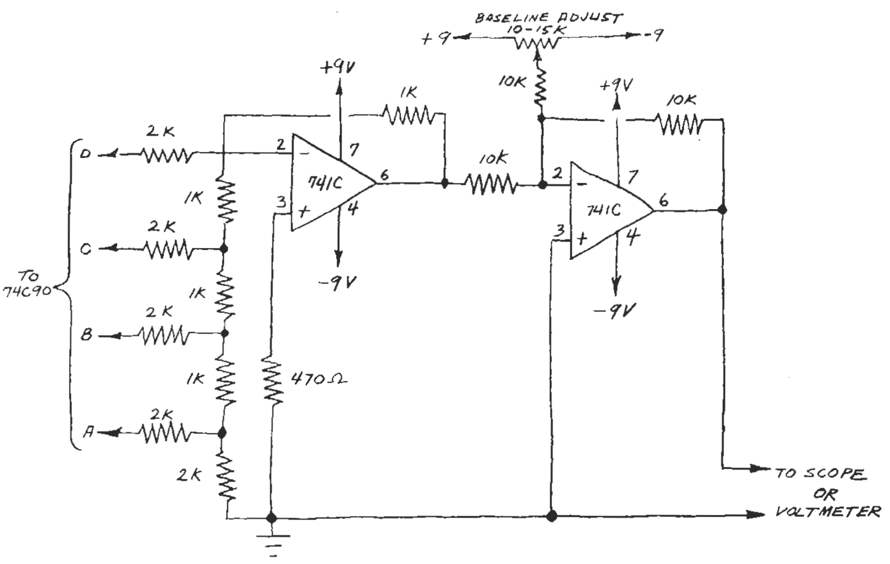

Fig. 4. Schematic of an improved D/A converter.

see the circuit in operation if you don't have access to a scope. First, insert a 10-μF capacitor in parallel with *C1* to slow down the clock to a few hertz. Then connect a voltmeter between pin 6 of the second 741 and ground. The needle on the meter will jump to about 3 volts and fall toward 0 volt in equally spaced increments. The cycle will then repeat.

Notice that the second 741 reverses the slope of the voltage ramp. The ramp from the first 741 goes from a low to a high voltage, while the ramp from the second 741 goes from high to low.

It's possible to reverse the slope of the ramp by inverting the binary input to the resistor ladder. The clock circuit uses only two of the inverters in the 74C04, so you have four uncommitted inverters, just enough to do the trick. Simply connect one inverter between each BCD counter output and the respective input to the resistor ladder.

Using the D/A Converter. By now, you should have a good understanding of the operation of a basic D/A converter. Let's use the circuit we've built in a practical application. Last month we noted that a D/A converter permits you to control the brightness of a lamp *digitally*.

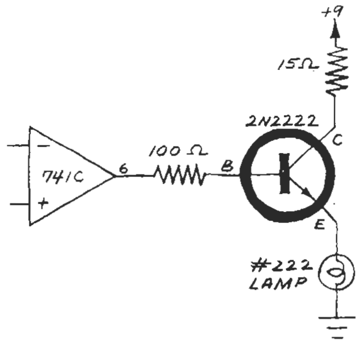

Fig. 5. Driver added to converter.

Figure 5 shows how a single driver transistor can be connected to the second 741 in our D/A converter to control the brightness of a 222 lamp.

Be sure to adjust the D/A converter so that a 0000 input gives an output of 0 volt. This will ensure that the lamp receives the highest voltage for a binary input of 1001. The lamp I used with the prototype circuit displayed six distinct brightness levels for binary inputs of 0100-1001. The counts 0000, 0001, 0010, and 0011 produced too little voltage to light the lamp.

You can also use the driver transistor circuit to power a small dc motor. In this mode, the D/A converter functions as a digital-motor speed controller. When the clock is slowed to a rate of less than a few Hz, you can easily observe the speed variations as the motor slows from a relatively fast clip to a full stop.

Remember, you can supply binary inputs to the D/A converter with a 4-bit memory such as the 7489 (see "Experimenter's Corner," December 1977 and January 1978). This means you can program any sequence of analog voltages you choose.

Further Reading. In a future column we'll explore the world of analog-to-digital (A/D) converters. Meanwhile, if you've found these experiments with D/A converters interesting, you'll want to read more on the subject. For starters, see "The How's and Why's of D/A and A/D Converters" by Robert D. Pascoe in the April 1977, POPULAR ELECTRONICS. For more details about resistor ladder networks, see "Fundamentals and Applications of Digital Logic Circuits" by Sol Libes (Hayden Book Company, 1975, pp. 131-138). ◇