7

3-Digit Counter and Display

This final lab brings together much of what we have done in our lab experiments this quarter to construct a simple tachometer circuit for measuring and displaying the speed of the fan used in lab 5. We will explore the use of 7-segment LED displays and associated decoder circuits, combined with a 3-digit BCD counter and timing circuit. We will also show how a simple LED/phototransistor pair can be used to create a chopper circuit for monitoring the speed of the fan.

Pre-lab Preparation

Before Coming to the Lab

Read through the lab experiment to familiarize yourself with the components and assembly sequence. Before coming to the lab, each group should obtain a parts kit from the ECE Shop.

Parts List

The ECE2 lab is stocked with resistors so do not be alarmed if you kits does not include the resistors listed below. Some of these parts may also have been provided in an earlier kit.

Laboratory #7

3-Digit Counter and Display

Qty	Description
1	MC14511 BCD-7-segment latch/decoder/driver
1	MC14553 3-digit BCD counter
1	3-digit common-cathode multiplexed display
1	CD4011 Quad 2-input NAND
1	CD4093 Quad 2-input NAND Schmitt
3	2N3906 PNP transistor
1	555 timer
1	IR LED T1 3/4
1	IR phototransistor T1 3/4
3	Tactile pushbutton switch, SPST PCBPB1
1	Ceramic capacitor 0.01uF (10nF)
2	Ceramic capacitor 0.1uF (10nF)
1	220-Ohm 1/4 Watt resistor
7	330-Ohm 1/4 Watt resistor
1	2.2-KOhm 1/4 Watt resistor
3	4.7-KOhm 1/4 Watt resistor
2	47-KOhm 1/4 Watt resistor
1	10-KOhm 1/4 Watt resistor
1	100-KOhm 1/4 Watt resistor
2	1-MOhm 1/4 Watt resistor

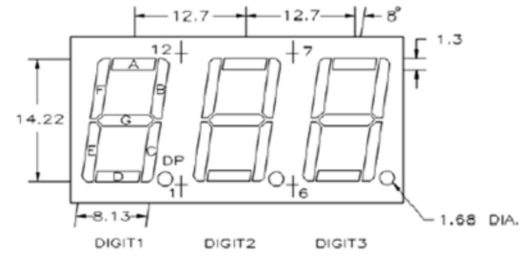
In-Lab Procedure

Follow the instructions below CAREFULLY.

☐ Each critical step begins with a check box like the one at the left. When you complete a step, check the associated box. Follow the instructions below and carefully document your results for inclusion in your lab report.

7.1 7-Segment Displays and Drivers

3-digit display



LM56X3-11
COMMON CATHODE
PIN NO. FUNCTION
1.ANODE E
2.ANODE D
3.ANODE DP
4.ANODE C
5.ANODE G
6.NO CONNECTION
7.ANODE B
8.DIGIT 3 COMMON CATHODE
9.DIGIT 2 COMMON CATHODE
10.ANODE F
11.ANODE A
12.DIGIT 1 COMMON CATHODE

Figure 7-1 – 3-digit multiplexed common-cathode display.

In this lab we will build a digital counter with a 3-digit numerical display. Historically, LED 7-segment displays have been commonly used for this purpose, although liquid-crystal (LCD) displays enjoy wide use in modern applications. Figure 7-1 shows the pin descriptions for the three-digit display used in this lab. Each digit has seven segments marked “A” through “G”, with an additional decimal point marked “DP”. This particular unit is a so-called “common-cathode” display, because all seven of the light-emitting diodes comprising each digit are connected together at their cathode terminals. In this way, we can ground all the cathodes simultaneously with a single connection. In addition, this unit is called a “multiplexed” display because the corresponding segments in each digit also share common connection. For example, the three “G” segments all have their anode’s connected to pin 5. Multiplexed displays are designed to be driven sequentially, with each digit illuminated briefly in sequence. If the digits are scanned rapidly enough, they appear to be continuously “on”.

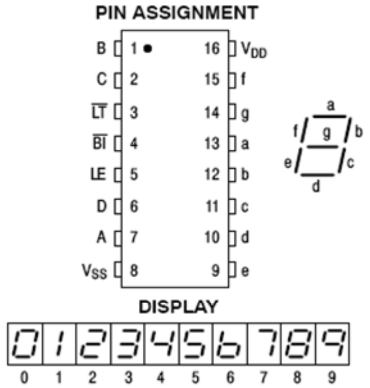
☐ Connect your 3-digit display to your proto-board. Ground the cathode of just one digit (one of pins 12, 9, and 8). Using a 5-volt supply and a 330Ω current-limiting resistor, test each segment to verify the operation.

☐ Configure your circuit to display the number “777” continuously.

Note: we will not use the decimal point indicators in this lab.

BCD-7-segment Decoder

To display each number requires a different group of pins to be activated. This is accomplished with a “decoder” circuit, which translates a binary number representation into the appropriate logic levels on each of the display segments. Decoder circuits can be constructed from combinational logic elements, but this is such a common requirement that there are many dedicated integrated-circuits on the market to perform this function. We will use the 4511 (or MC14511) chip, labeled a “BCD-7-segment latch/decoder/driver”. The pinout and truth table for this circuit are shown in Figure 7-2. This circuit has a built-in 4-bit latch (a set of flip-flops like we used in the previous lab) that can permanently retain a binary-coded decimal (BCD) input. When the latch-enable (LE) pin 5 is low and the blanking ($\overline{BL}$) and lamp-test ($\overline{LT}$) pins are high, the display is a base-ten representation of the 4-bit BCD number applied to pins 7-1-2-6. When the latch-enable pin is brought high, the 4-bit input is latched and displayed, such that any subsequent changes to the 4-bit BCD inputs have no effect.



TRUTH TABLE

Inputs							Outputs							
LE	$\overline{BI}$	$\overline{LT}$	D	C	B	A	a	b	c	d	e	f	g	Display
X	X	0	X	X	X	X	1	1	1	1	1	1	1	8
X	0	1	X	X	X	X	0	0	0	0	0	0	0	Blank
0	1	1	0	0	0	0	1	1	1	1	1	1	0	0
0	1	1	0	0	0	1	0	1	1	0	0	0	0	1
0	1	1	0	0	1	0	1	1	0	1	1	0	1	2
0	1	1	0	0	1	1	1	1	1	1	0	0	1	3
0	1	1	0	1	0	0	0	1	1	0	0	1	1	4
0	1	1	0	1	0	1	1	0	1	1	0	1	1	5
0	1	1	0	1	1	0	0	0	1	1	1	1	1	6
0	1	1	0	1	1	1	1	1	1	0	0	0	0	7
0	1	1	1	0	0	0	1	1	1	1	1	1	1	8
0	1	1	1	0	0	1	1	1	1	0	0	1	1	9
0	1	1	1	0	1	0	0	0	0	0	0	0	0	Blank
0	1	1	1	0	1	1	0	0	0	0	0	0	0	Blank
0	1	1	1	1	0	0	0	0	0	0	0	0	0	Blank
0	1	1	1	1	0	1	0	0	0	0	0	0	0	Blank
0	1	1	1	1	1	0	0	0	0	0	0	0	0	Blank
0	1	1	1	1	1	1	0	0	0	0	0	0	0	Blank
1	1	1	X	X	X	X	*							*

X = Don't Care

*Depends upon the BCD code previously applied when LE = 0

Figure 7-2 – Pinout of the 4511 chip and truth table.

Figure 7-3 illustrates the basic connections and use of the 4511 chip. Here we ground the latch-enable pin and tie the blanking and lamp-test pins high, so that one of the 7-segment display digits will continuously display the BCD input applied at pins 7-1-2-6.

☐ Construct the circuit of Figure 7-3. Note that we have just grounded one of the cathodes, so only one digit will be illuminated. Using logic switches or jumper wires, apply the appropriate BCD input to display the numbers 0-9.

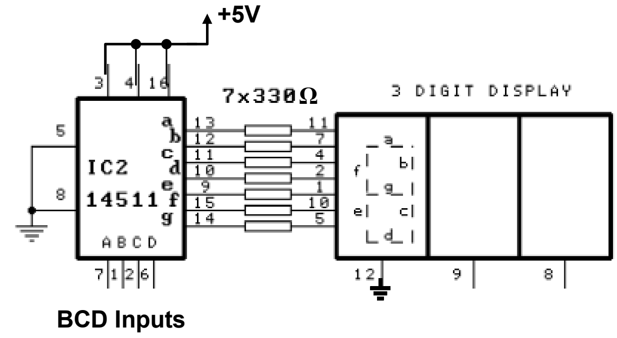


Figure 7-3 – Using the 4511 BCD-7-segment decoder.

7.2 BCD Counter

In the previous lab we built a 4-bit (divide-by-16) ripple counter using D-flip-flops. Using similar techniques and adding a bit of combinational logic we can create divide-by-N counters where N is any integer. A common choice is N=10, which gives a base-ten counter that is appropriate to most human-friendly displays.

To create a 3-digit base-ten counter and display, we would basically need a cascade of three separate divide-by-ten counters, a BCD-to-7-segment decoder, and a scan oscillator and mutiplexer that would allow us to rapidly scan each digit of the multiplexed display in sequence. Much of this circuitry is collected together in a single chip, the 4553 (or

MC14553) 3-digit BCD counter. This chip was designed specifically to work with multiplexed displays, so it only requires a single external decoder circuit. Figure 7-4 shows the basic configuration for creating a 3-digit counter using the 4553, the 4511 decoder, and a multiplexed common-cathode display.

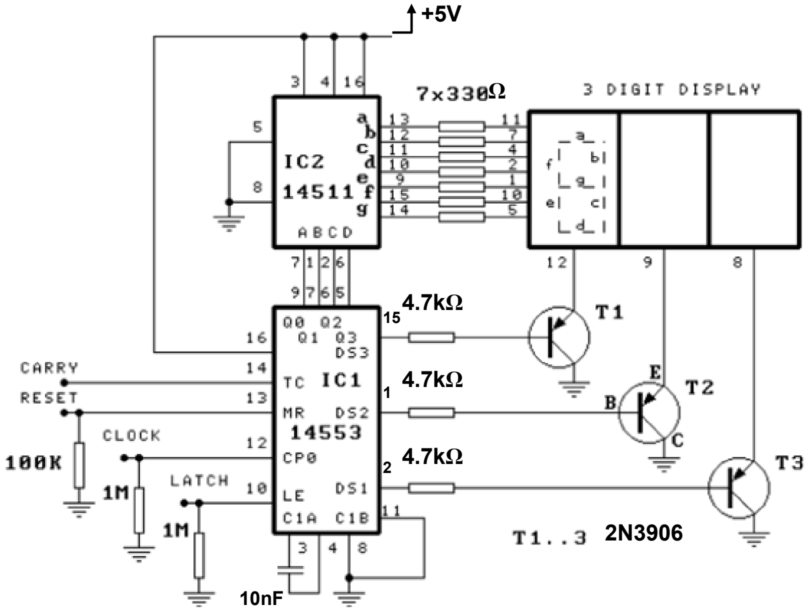


Figure 7-4 – Using the 4553.

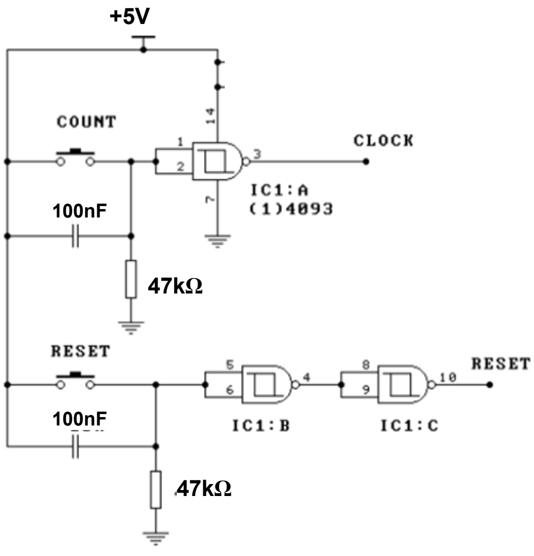


Figure 7-5 – Debounced switches.

□ Build the circuit of Figure 7-4 using the 4553. Note that the 4511 decoder/display circuit is identical to the one you built in the last step, so the only new part here is the use of the 2N3906 PNP transistors to drive the cathode connections of each digit.

Note that the 10nF capacitor between pins 3-4 sets the scan rate of the LED display.

□ To test the 3-digit counter we need debounced clock and reset signals. Figure 7-5 describes suitable circuits that are similar to the ones used on our previous lab, using the 4093 quad-NAND Schmitt devices. Build this circuit on your protoboard, and connect the clock and reset connections to the appropriate places on the 4553 counter circuit of Figure 7-4.

☐ Now test the 3-digit counter. Pressing the clock button should increment the counter. Pressing the reset button should clear it. Do not continue with the rest of the lab until your circuit is functional.

Note: this counter circuit is probably the most complex circuit we have constructed in ECE2 to date. If your circuit doesn't work the first time, don't panic! It is rare for any circuit to work the first time. The more complex the circuit, the easier it is to make mistakes in assembly. To debug a circuit problem, it may help to build some simple LED-based logic indicators on your board, much like we did in the last lab, and use these to monitor the logic levels at various pins. Common mistakes are forgetting to apply power and ground connections to each chip (check this first), or mounting the transistors incorrectly, or simply misidentifying a pin on an integrated circuit.

☐ Configure your bench function generator to produce a 0-5V square wave at a frequency of 1Hz. Apply this to the clock pin of the counter in place of the debounced switch. Your counter should be incrementing one per second. Experiment with the frequency; what happens when the counter goes past 999? Note that you can reset the counter at any time with the reset button.

Monitoring Events

Counters like the one we have just built are useful for monitoring many real-world events. The trick is to add enough circuitry to generate electrical pulses for each event to be counted.

For example, in the fan speed control circuit we constructed in Lab #5 it might be nice to monitor the fan speed directly. To use our counter we just need a digital pulse train that is proportional to the fan speed. One way to do this is shown in Figure 7-6, which uses an LED-phototransistor combination. The LED generates a small beam of light that is directed at the fan blade. The phototransistor on the opposite side is sensitive to this light beam, such that when the light strikes the phototransistor, it conducts. As the fan rotates, the blade periodically interrupts the light beam, turning off the phototransistor. Thus the phototransistor stage acts like a simple light-sensitive switch. By coupling this to a spare inverter, we can generate a nice CMOS-compatible pulse train to drive our counter.

☐ Build the circuit of Figure 7-6, adding these components to your fan speed control circuit of lab #5. Consult the datasheets for the infrared LED and phototransistor devices. Bend the leads of the LED and phototransistor so that the plastic lenses of each face each other through an opening in the fan housing. The devices should be aligned and positioned such that the blades of the fan block the path of the light as they rotate.

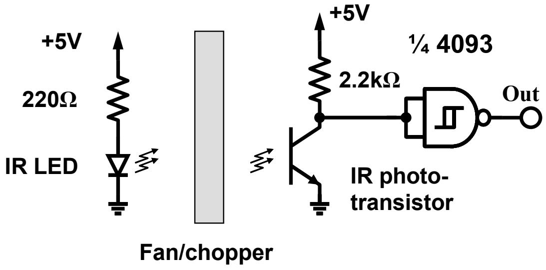


Figure 7-6 – Chopper circuit for generating a pulse train at a frequency proportional to the fan speed..

☐ Test the chopper circuit first by monitoring the output on your oscilloscope. Do not continue until you can generate a nice clean pulse train.

7.3 Tachometer Circuit

The circuit you just build will just count digital pulses. The speed of the fan is related to the frequency of the pulses. How can we display a number that is proportional to the frequency? The trick here is to simply count for a certain interval of time. For example, if we count 100 pulses in a tenth of a second, that means the frequency is 1 kHz.

If you look at the data sheet for the 4553, you will see that there are a couple of pins we could use to force the device to count for a specific interval in time. For example, on page 5 it says "*The Disable input, when high, prevents the input clock from reaching the counters, while still retaining the last count.*" So all we need to do is apply a logic low signal to the disable pin (pin 11) for a fixed period of time. The counter will advance only during the period when pin 11 is low.

We can generate a suitable timing pulse using a 555, configured as a monostable multivibrator. A circuit for doing this is shown in Figure 7-7. Here the pushbutton switch triggers the device. The output goes high for a time period given by $T = 1.1RC$. We use an inverter at the output to invert the pulse, so that the output is normally high, and goes low for the period T.

So, the next question is, how do we choose T? That depends on what we want to measure and display, and also on how the fan is constructed. Suppose we want to display the fan speed in "revolutions per second", and there are N blades on the fan. Then we should choose $T = 1/N$ seconds.

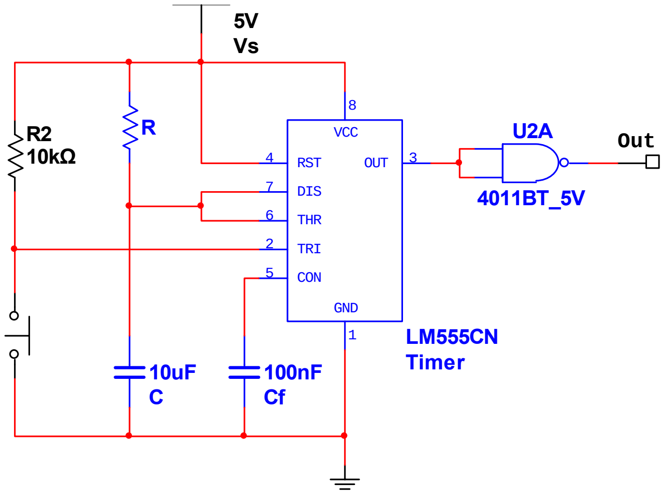


Figure 7-7 – Monostable "one-shot" for triggering the counter.

☐ Build the monostable in Figure 7-7. Choose the resistor R to give the appropriate pulse duration for displaying revolutions per second as described above, and verify on an oscilloscope (note you can use your bench function generator to trigger the device periodically to very the operation).

☐ Now, remove the grounding wire on pin 11 of the 4553, and apply the output of your monostable circuit. Reset the counter, and then trigger the monostable to count the output of the fan chopper circuit for the duration you choose. Your display should read a number that is roughly the number of revolutions per second of the fan.

☐ Vary the fan speed using your pulse-width modulator circuit, and retest the tachometer circuit. Record your observations.

Congratulations!
You have now completed Lab 7