EE283 Electrical Measurement Laboratory
Laboratory Exercise #7: Digital Counter

Objectives:

1. To familiarize students with sequential digital circuits.
2. To show how digital devices can be used for measurement of frequency.

The purpose of this laboratory exercise is to familiarize students with digital sequential circuits in general, and the “counter” in particular. Counters are very useful for a number of purposes, ranging to simply counting events, to serving as tachometers or frequency counters, and as a component in an Analog to Digital converter which converts an analog signal into a digital form suitable for further processing in a computer. This exercise will explore those three applications.

Background:

There are several new components that are used which are described below.

1. LM555 timer:

The LM555, in its many variations, has been perhaps the most widely produced integrated circuit in the world. It really is just a Voltage controlled switch. It is generally used to alternately charge and discharge a capacitor through a resistor network. When the Voltage on the “threshold” input (pin 6) reaches down to (or below) about 1/3 of the power supply Voltage, and output “Discharge” (pin 7) turns off. That allows the capacitor to charge. When the Voltage at the “trigger” (pin 2) reaches about 2/3 of the power supply Voltage or above, the “Discharge” turns on, starting discharge of the capacitor. A second output (pin 3) indicates whether the capacitor is charging (high) or discharging (low). There is also a reset pin (pin 4) that we won’t use (leave it tied to the positive supply), Considerable material about the LM555 timer can be found online. Figure 7.1 illustrates a typical timer circuit that can drive LEDs. The timer frequency and duty cycle (proportion of time high) depends of component values for R1, R2, and C.

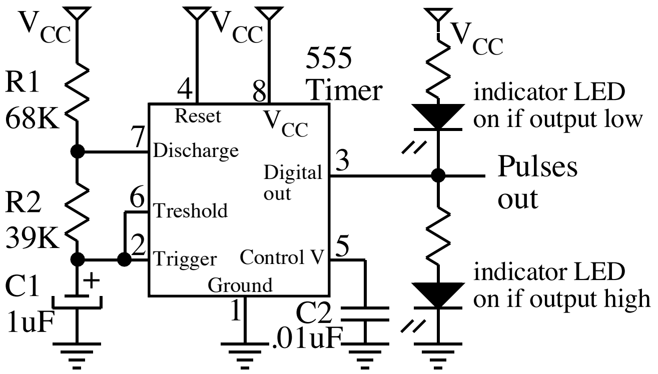


Figure 7.1 The LM555 timer used as an oscillator.

The LM555 can be operated at various Voltages, but the frequency and timing is determined by the RC time constants as C1 charges through R1 and R2, then discharges through R2. These component values determining frequency and duty cycle. The time constants are independent of Voltage, so the behavior of the circuit is independent of the power supply Voltage. Useful formulas are given below:

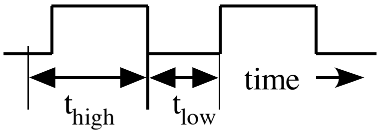
The frequency in Hz is given by:

$$f = 1 / (.693\ C\ (R1 + 2\ R2)) \qquad (7.1)$$

The Duty cycle (percentage of time the signal is high) is given by:

$$D = (R1 + R2) / (R1 + 2R2) \qquad (7.2)$$

Notice that the duty cycle D cannot fall below 50%, and getting to 50% requires that R1 have the value 0, which is very undesirable since setting R1 to 0 will cause large currents to flow into the discharge pin (pin 7). If R2 is much larger than R1, the duty cycle will approach 50%. Figure 7.2 below illustrates these timing parameters.



$f = 1/ (t_{high} + t_{low})$

$D=t_{high} / (t_{high} + t_{low})$

Figure 7.2 Information about timing

2. The 74LS160 decimal counter:

This is an integrated circuit of the 74LS family, similar to those you worked with in laboratory Exercise #2. However, it is a “sequential” device. The state of the outputs (called Q_D,Q_C,Q_B, and Q_A) depends not just on the current inputs, but on their past history. The outputs Q_D,Q_C,Q_B, and Q_A give the binary representation of a number, 0000 for 0, 0001 for 1, and so forth up to 1001 for 9. Each time a “clock” input makes a negative to positive transition, the outputs change to the next positive integer. When nine is hit, they next roll back over to zero. A “clear” input, if held low, resets the device to zero. An “Enable T” input can be hooked to the “Ripple Carry Output” of another counter so that it counts only when the previous device is on “9”, allowing these counters to be cascaded for a multi-digit timer. The “Load” and “Enable P” inputs won’t be used. See Figure 7.3 for the pinout diagram for this device.

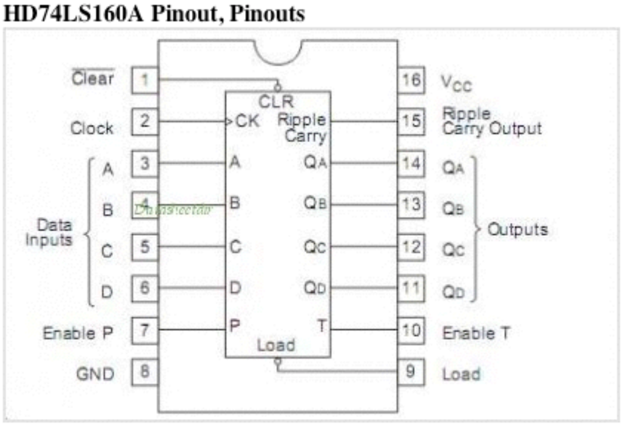


Figure 7.3 74LS160 pinout diagram, top view

3. **The 74LS47 seven segment decoder-driver:**

This single device does the job that your Laboratory #2 circuit performed: it converts binary signals into the segment a to g outputs needed to drive a common anode LED display. Unlike your circuit, it also works for “8” and “9”, so that makes it a good device to use to show the output of a 74LS160 counter. Furthermore, it can sink about 48mA per output (unlike 8mA peroutput for normal digital 74LS devices) so it can make your display bright. (You can use 220 Ohm resistors.) Figure 7.4 shows the pinout diagram. The D, C, B, and A inputs are the binary number. We won’t use the other inputs; they can simply be tied “high”. (Note that there are lots of different 7 segment decoder devices for different kinds of applications.) Figure 7.5 shows the pin connections for the LED display.

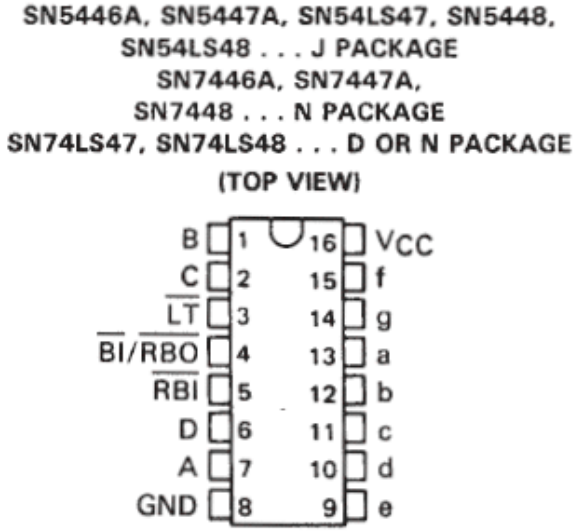


Figure 7.4 74LS47 Seven Segment decoder device pinout diagram (top view)

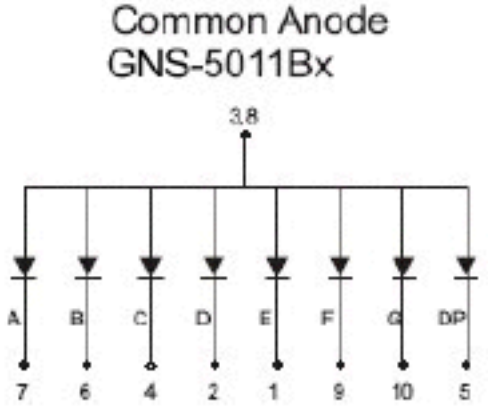


Figure 7.5 Common Anode LED display for Counter project

4. **Op-amps (For extra credit part):**

Using the digital counter as an A/D converter requires the use of an op-amp to compare the Voltage of the input to be measured with a Capacitor Voltage. The capacitor is slowly charging from a current source. (We will use a resistor to power as an approximation of a current source.) The op-amp is used as a "comparator", so that when the Capacitor Voltage rises to the same value as the measured Voltage, the comparator will "flip" from being close to the positive supply Voltage to being close to the negative supply Voltage (feedback isn't used). You can read about op-amps in the Lab #9 material. The idea is that the comparator, referencing the Voltage at the measured input, determines how long the counter counts.

Figure 7.6 below illustrates in principle how an "integrating" A/D converter works. The current source into the capacitor produces a "ramp" Voltage that climbs linearly with time. How long does it take to get up to the same Voltage as the input to be measured? You use a digital timer for that. The timer's digital value is in a form that can be either displayed (as a DMM) or used by a computer (as a 12 bit signal, for example).

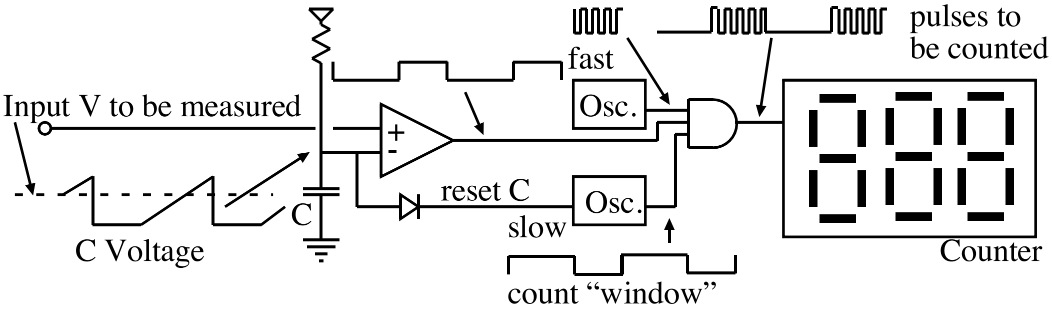


Figure 7.6 Integrating A/D Converter

The problem is that the LM741 or equivalent op-amp requires a second power supply. We'd like to operate it at +5V and -2V. When operated at +5V and ground, the output cannot go low enough. The circuit shown later requires "help" for the output to be able to turn off the counter at the appropriate time. Also, the input is not sensitive below about 2 Volts, so it is not possible to measure low Voltages with a 0V negative supply. Using a power supply lower than 0 Volts mitigates both of these problems. However, not only is having a second power supply inconvenient, but it also becomes necessary to make sure that the signal going into digital circuits don't swing much below ground, or that can cause problems. While the material here shows the 741 op-amp being used, a supplement is expected to be promulgated showing how to use a "single ended" op-amp (either the LM3900 or the LM386, probably) instead. Figure 7.7 shows, for reference, the LM741 op-amp pinouts.

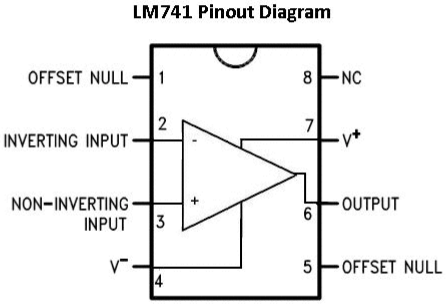


Figure 7.7 LM741 Op-Amp pinout diagram

The Laboratory Exercise: Procedure

7.1 Build an LM555 Timer circuit.

We want a timer that will give a waveform like that shown in Figure 2 above, having a .10 second low time and a high time of 1 second or more (the exact value is unimportant). Connect pin 3 to an LED (in series with a resistor) to V_{CC}, and you should see the LED blink at a bit over 1 Hz, staying lit for only .10 second at a time. Measure the waveform with the oscilloscope to make sure the low phase is very close to .10 sec. You can use a “trimpot” (small variable resistor) as one of the timing resistors in your circuit, “R2”, so that you can adjust the low time to be exactly what you want. Or use a regular pot. The time low is used to determine the interval over which the timer counts.

7.2 Build a three-digit digital decimal counter.

Build a counter using 74LS160’s, 74LS47’s, and LED seven segment display devices that will count 000 to 999. Figure 7.8 below shows the schematic. You can toggle it to count single pulses with the “debounce” circuit shown; each time you flip the input on and off (by alternately grounding the “set” and “reset” inputs, the counter will count up one. Grounding the (active low) “Clear” input to the sets the counter back to zero. All unused inputs can be pulled high with shared 1.0KΩ resistors. (Use a resistance 220Ω - 470Ω for the segments.)

Note: You need to be careful with power supply arrangements for the 74LS160 counter devices. Take the power and ground for each device to the same bus strip, and “bypass” the power supply (as close as possible to the power connections) using a small (4.7 µF) tantalum capacitor. The point is to short out any high frequencies that appear on the power supply. Be careful to get the polarity correct; these capacitors will burst into flames if reversed.

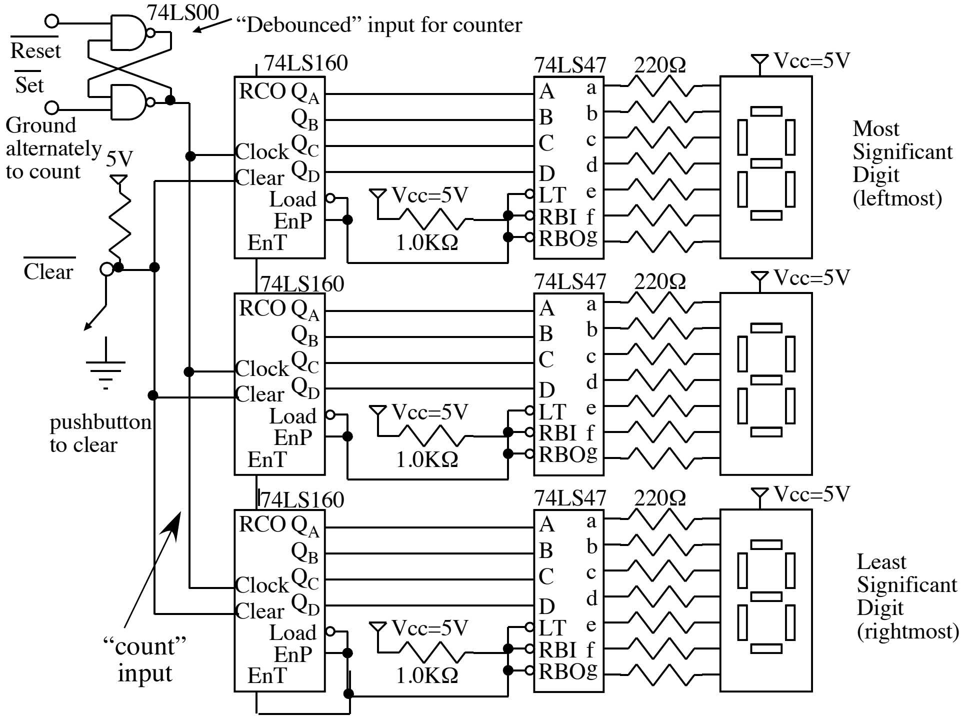


Figure 7.8 Digital Counter with Debounced Input

The NAND gates shown are found in the 74LS00 device. It is similar to the 74LS08, having the same pinouts, but with inverted "NAND" outputs rather than un-inverted "AND" outputs. The "/Clear" signal should be held high with a 1.0K Ohm resistor.

7.3 Count stuff:

As the digital counter counts, you can either count occurrences of events or frequencies. After you use the alternate grounding of "/Set" (active low signal "Set"), and "/Reset" to count one at a time, try counting by getting rid of the NAND gate and directly contacting the "count" input (the signal going to the 74LS160 inputs) with a ground wire after disconnecting it from the 74LS00 gate output. Can you get it to count only one step at a time? Pretty hard to do that! This is the "bounce" that we need to get rid of to count cleanly. All switches have some degree of bounce (generating multiple pulses instead of just one) unless circuitry has been added to "debounce" them.

Now, take an input from the signal generator. Set the output to 2V amplitude and 2V offset. Confirm with the oscilloscope that the waveform is square between 0V and 4V. (We don't want Voltages below 0V!) Connecting the signal generator ground to the counter's ground, and the signal to the count input, you should see the counter count: rapidly at high frequencies (say, 1KHz), slowly at slow frequencies (say, 1Hz).

7.4 Frequency counter:

Add the 555 timer (and a bit of additional circuitry), from part 1 earlier, to your circuit, to turn it into a frequency counter, as shown in Figure 7.9. The 555 output time low will be the "count" time, the time high will be the "hold" time. We will count for 1/10 second, and hold for a second or more. (Adjust or substitute for R1 in the timer circuit to get a hold time that you like.) The NAND gate turns the source of pulses from the Frequency source to be measured on or off: On for .1 seconds, and off for your hold time. (The fact that the output is inverted really doesn't matter.) The output of the LM555 timer is inverted (using a NAND gate as an inverter) so that the .1 second low phase is a high signal to the NAND letting pulses through. The high pass filter resets the timer by putting a pulse on "/Clear" very briefly each time it starts to count.

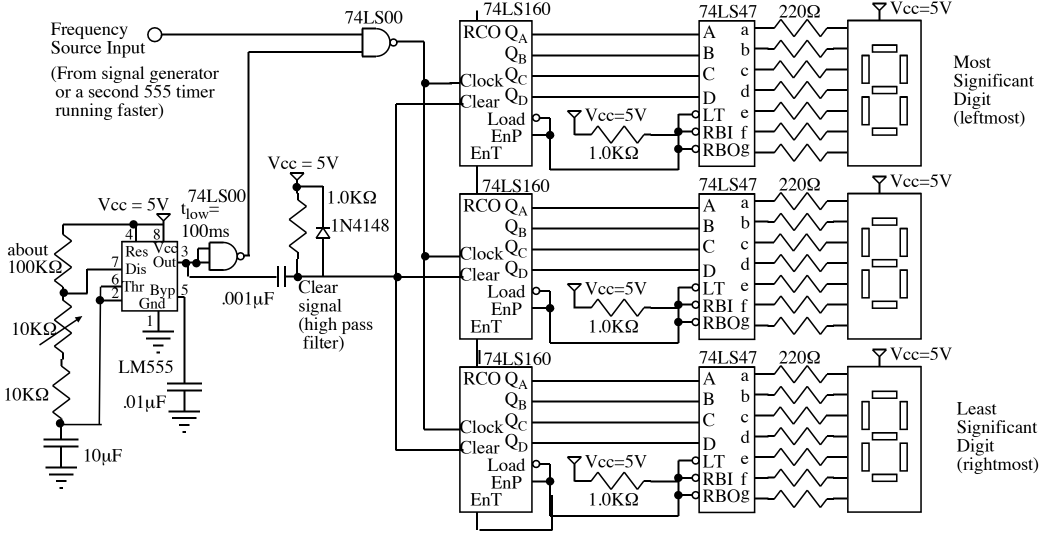


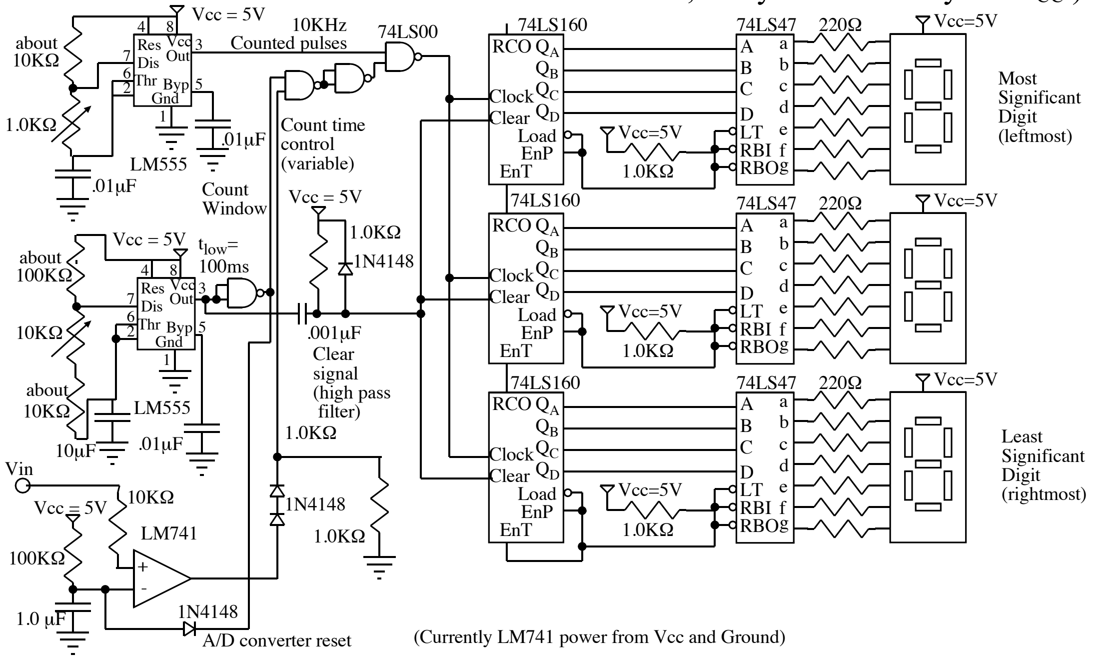
Figure 7.9 Frequency Counter

Use your frequency counter to count pulses from the signal generator. When the signal generator is set to 1 KHz, you should see "100" displayed. At 10KHz it should "roll over" to display 000 since we can't count to 1000. Try various frequencies. You can use this to adjust the variable timing resistor of your LM555 to get exactly 000 at 10KHz. (That's called "calibration".)

Now, add a second LM555 timer to be a signal source. Use a smaller capacitor so that it counts fast. You can use a 1KΩ potentiometer for R2 and make R1 relatively small, maybe 470Ω, so you can get a range of different frequencies, an octave or more. If you use a 10KΩ pot with 1KΩ for R1, you can get an even wider range of frequencies. To hear the sound, you can connect pin 3 of the LM555 to a small speaker using a series resistor of about 47 Ohms. (Too much smaller, and you may overdraw the LM555.) You now have a frequency counter with something built-in to count, and if you hook it to a speaker or earphone, you could conceivably use it to tune musical instruments!

7.5 Make it a digital Voltmeter (extra credit):

Set the second LM555 to get an appropriate frequency. (You can tweak it later.) Figure, by how many Volts will the capacitor Voltage rise in 100 milliseconds? That's the maximum Voltage you will be able to display. (It depends on R and C choices.) The circuit below in Figure 7.10 then lets you measure an input Voltage. Put the Voltage source between ground and the "Vin" input. You don't need the signal generator; the second LM555 serves that purpose. You can use a potentiometer to generate a Voltage to measure. Note that a diode is used to discharge the capacitor during the "hold" time. To save having to use a different logic device, we use three NAND gates together as a 3 input NAND. The two diodes at the op-amp output and 1K resistor "fix" the problem with the LM741, with its negative power supply at ground, not being able to go low enough to generate a good logic "0" to shut off the NAND gate. (The power connections to the LM741 are not shown. If you use a negative supply of about -3V, this circuit should behave better. You can use 2 small cells for that, and your 6V battery for V_{CC}.)



(Currently LM741 power from Vcc and Ground)

Figure 7.10 Digital Voltmeter circuit

EE283 Measurement Lab
Project #7 (Digital Counter / Timer) Report

Student Group Names:

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Date: ____________________

Section:____________________

Lab Station:________________

Report:

7.1: LM555 timer circuit:

Show schematic for timer circuit used to produce the 100 millisecond "counter window" signal. Specify resistor nominal values used, and measured value of variable resistors.

Show Timer circuit capacitor and output waveforms (seen on Pins 3 and 6 of the LM555). Show them as a properly annotated graph:

7.2, 7.3: Counter operation:

Was your counter able to count individual steps from the debounce circuit?

Without the debounce circuit, how many steps did the counter step for one switch touch? (Give several samples)

7.4: Frequency counter:

With a 100 Hz signal from the signal generator into your frequency counter, graph the waveform seen at the counter input (the clock to the 74LS160 counter devices). We want to see the windowing effect, so the time axis should show at least 150 milliseconds.

What counter value is seen for the following signal generator settings?
Counter value

100 Hz: ____________

1000 Hz: ____________

5000 Hz ____________

10,000 Hz ____________

12,000 Hz ____________

Show the circuit for your second (signal source) 555 timer, and the information asked:

LM555 Circuit (with component values):

Frequency from oscilloscope:______

Count by your counter: ______

Part 5: Digital Meter (extra credit)

Show the circuit (with power sources) used for your counter Voltage measurement circuit. (Do not include the counter itself.)

What are the counter values for:

a. 0 Volts in ________(counter value)

b. minimum value of Voltage that causes counter value to rise:__________ (Volts)

c. maximum count ______ and Voltage where that count is seen ____________(Volts)

d. Meter sensitivity (counts per Volt): ______

e. Anything else you may do to modify / improve the meter: