First Lab – Scope Exercises, Equipment Introduction, Ohms Law and Voltage Dividers

January 7, 2009

Lab Introduction

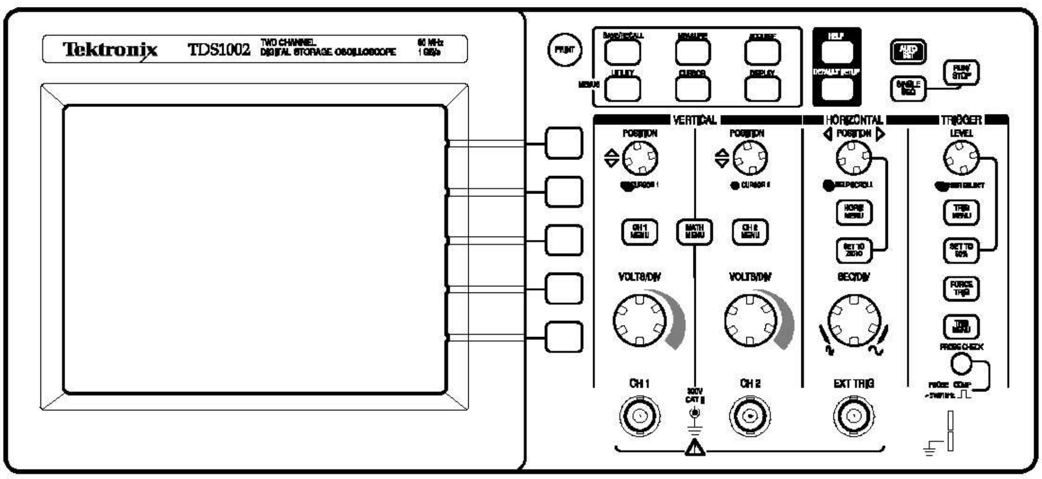
1 Scope Exercises

The Oscilloscope, or 'scope for short, is probably the most ubiquitous and generally useful piece of equipment in almost any science lab. Whatever your field of study, you will probably find that having good 'scope skills is an invaluable asset in the lab. You will have lots of time to get familar with the scopes this quarter. Here are a few exercises that will help you start.

You will be using a digital scope this quarter and it can make many measurements for you. But don't assume that a digital scope is any better or worse than an analog scope just because it has a pretty multicolored screen. The best piece of equipment depends on the measurement at hand, and in other circumstances, an analog scope may be as good, or even better, than a digital scope. In fact, for some applications, analog scopes have features that are difficult to find on a digital scope. As one example, when viewing scintilator pulses for high energy physics experiments, using an analog scope is far superior to a digital scope in certain circumstances.

We'll be using Tektronix 2xxx series scopes in this lab. Start you scope by pushing the power button on the top of the scope in the upper right hand corner. The scope will start up, and if all goes well after several seconds give you a message to this effect and ask you to press a key to continue. Do so.

Here's the front panel of your scope:



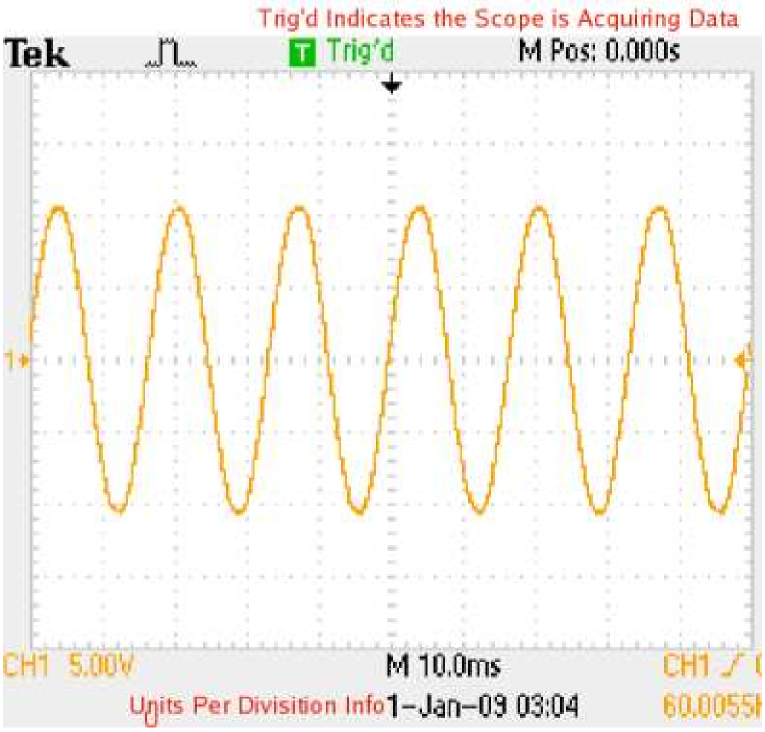
Note the vertical (Volts/Div) and horizontal (Sec/Div) controls for the scope. The inputs for the scope are the circular BNC connectors at the bottom for Channel 1 (CH1) and Channel 2 (CH2). The unlabeled keys to the right of the screen are software defined keys or “softkeys” and their function changes depending on the context of the measurement being made at any given point in time. Their function at any point in time is indicated on the screen at the right hand side just to the left of the keys. For example if you press the CH1 button, you’ll see the top softkey will change the input coupling for the channel. If you press the Trigger Menu button, it’s function changes and now pressing it will change a trigger edge parameter setting. More on this later... but for now let’s just get started with the scope.

We’ll start by looking at the output of a transformer. Use a BNC cable and a double banana plug adapter to connect the scope to the output of the transformer box, shown below.

A Circular BNC Connector (Left)

A BNC or Double Banana Plug Adapter

In connecting the BNC connector, slide it gently onto the mating equipent connector and give it about a quarter turn clockwise to lock it into place, ensuring a good contact. Do similarly with the BNC to banana adapter before plugging into the transformer. Take a moment to note that there is a little “tab” on one side of the banana adapter. This tab indicates the Ground side of the BNC adapter, which corresponds to the outer conductor of the cable. Because of this, you should also keep in mind that these banana plugs are not completely equivalent. In some cases this will matter. In this case, not so much so.



A useful first step when aquiring a signal can often be simply hitting the autoset key located in the upper right corner in the top bank of keys. Press it. You should see something like the preceeding scope trace.

The autoset feature is quite useful. Don't depend on it all the time, though. There are times that it will fail you. For example, anytime you have a non-periodic signal, autoset will get all screwed up. So learn how to use the other scope features too.

Get familiar with some of the other buttons on the scope. Try the following:

- Press the Blue and Yellow Channel 1 and Channel 2 buttons. These will turn on and off each channel. Note the arrows on the left side of the screen indicating each channel. These are useful if you turn a channel on, but can't find it. If this is the case, often, you've "rolled it off the screen" and the indicator arrows will help you get it back into view.
- Change the Timebase (Sec / Div) – Note the changes at the bottom of the screen. Often these values are expressed in milli, micro, or nano seconds,
- Change the Volts/Div – Again note changes at the bottom of the screen.
- Scroll left and right. Notice the "trigger" position marked by the "T". More on this later.

Note the information at the bottom of the screen. Two pieces of information will be of constant use to you:

- The timebase, in seconds per division. This is the amount of time that passes between each set of "X axis ticks"
- Volts per division – The voltage between each set of "Y axis ticks"

But, a big "gotcha" – You can scale the Y axis for "probe attenuation": The oscilloscope probes you will use sometimes attenuate, or lessen by a fixed factor, the signal voltage. (The reason this is useful will become clear later) You can tell the scope to account for this by setting the scope attentuation setting, then you don't have to do the math every time you make a measurement. *However, if you forget to check the attenation factor, all your measurements may be off by that same factor.* Some scope probes are able to communicate their attenuation factor to the scope. Others cannot. You should always check, in any case, that it is set correctly.

Since we're making a direct connection with a BNC cable, there is no attenuation. So, check that the probe attenuation factor is set to 1x by selecting: Channel 1 and press the 2nd from the bottom softkey until it reads "Probe 1X" This means a scaling factor of unity is chosen for the Y scale. Generally, you should select 1X for any direct connection via a BNC cable to the scope, but a 10X anytime you are using a scope probe. Scope probes usually attenuate the signal to 1/10th it's size. Selecting 10X selection multiplies the value the scope sees at its input by 10, so you your scope screen reflects the voltage AT THE TIP OF THE PROBE, which is what you usually care about. (Not the voltage at the input to the scope)

Measure the peak to peak voltage. Do it 2 ways:

- Use the Y axis and volts / division at the bottom of the screen for the channel you are using as an input to measure between the two peaks of the waveform. You may find it useful to use the vertical adjustment knob (above the Volts/Div knob) to line up your waveform with a convenient mark to make your measurement easier.
- Press the Measure button and select Pk-Pk volts as a measurement.

Do the two match? They should be reasonably close. Keep in mind that any noise on the signal can slightly influence measured values.

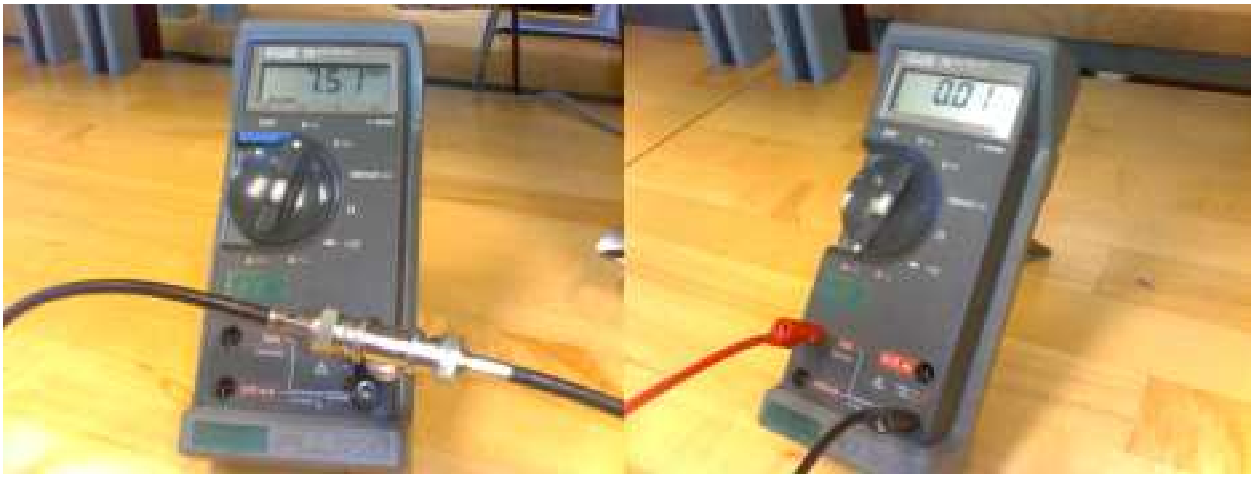
Also measure the frequency. Similarly, compare two ways of getting this value:

- Use the X axis and time/division indicator at the bottom of the screen for the channel you are using as an input to measure between the two consecutive high or low peaks of the waveform.
- Press the Measure button and select Frequency as a measurement.

2 Using the Digital Multimeter

A frequently used piece of equipment in the lab and all the rest of the world is the digital multimeter or DMM. We'll be using Fluke 75 and 77 multimeters primarily in this class. There are many other manufacturers and flavors.

Your multimeter can make many of the same measurements your scope can. Both have advantages and disadvantages, depending on application.



These pictures show two multimeters. One is cabled to measure a current, the other a voltage. Note there are 4 connection points on each DMM. The "Common" connection point is used for all measurements. Your multimeter can measure Alternating Current (AC) and Direct Current (DC) voltages (V - in Volts) and currents (I - in Amps). In addition, the DMM can measure resistance values (R - In Ohms) and check the function of diodes and check for continuity of a circuit. All are useful at points. You select the function of the DMM by dialing the selector switch, of course. In each case, the squigley sine wave symbol indicates an AC measurement, the straight line a DC measurement.

It is very important to use the correct connection points on the DMM to make a reading, or you'll get the wrong result and potentially damage your equipment or the multimeter. Note that we always need two connection points to measure voltage and current. Voltage is the potential difference between two points, so you always need two. Similarly, current is the flow of electrons through the multimeter, so again you need two: an "in" and and "out" cable. In addition, ALWAYS be sure you have have some resistance in series when measuring a current. If you don't... bang. This is probably the world's favorite way to fry a multimeter.

In making a connection to a multimeter, the grounded side of a connection typically goes to the common input of the DMM. Use the two rightmost input plugs to measure a voltage. In later sections, we will want to measure a current, in which case we must use the "common" input and the input labeled "10 Amp". Again, ALWAYS be sure any current measurement you make has some resistance in series with a voltage source before trying to measure a current because an ideal current meter has ZERO resistance. Therefore, if you hook an ideal voltage source to an ideal current meter an infinite current will flow and BOOM! byebye current meter or voltage source. We will use 10 Amp input first for ALL current measurements in this course, as it gives us a higher level of protection in case we accidently would create a short.

Make a measurement of the AC voltage from the transformer. Does it agree with the value you measured with the scope? Which is right?

They both are! The DMM makes an RMS (Root Mean Square) measurement of the voltage. We measured Peak to Peak values. Use the fact that $V_{RMS} = \frac{V_{Pk,Pk}}{2\sqrt{2}}$ (for sine waves only) and compare.

3 Using the Function Generator

Often it will be useful to "tickle" our circuits with a known signal to see how they respond to a stimulus. This is most commonly done with a function generator.

Below is the front panel of your function generator in the lab.

The function generator we will use can generate any frequency from DC to about 5 MHz, which will be adequate for our needs this quarter. There are two output BNC connectors: One labeled OUTPUT, the other labeled SYNC OUT. This quarter we'll mostly use the OUTPUT output :) – The Sync Output ALWAYS puts out a square wave with digital logic levels, which is useful, but less so this quarter than next.

Turn off and disconnect the transformer. Use a BNC cable to hook the OUTPUT connection of the function generator to channel 1 of the oscilloscope in place of the transformer.

Select a waveform type (Sine, Square, or Triangle). You can change it's amplitude with the amplitude control, of course. To change the frequency, set a range with the buttons to the right of the display, then fine tune the frequency with the frequency dial. The offset adjusts the level of the entire waveform relative to ground. The symetry dial allows you to change the shape of the waveform. Try it, but be sure you turn it off when you're done.

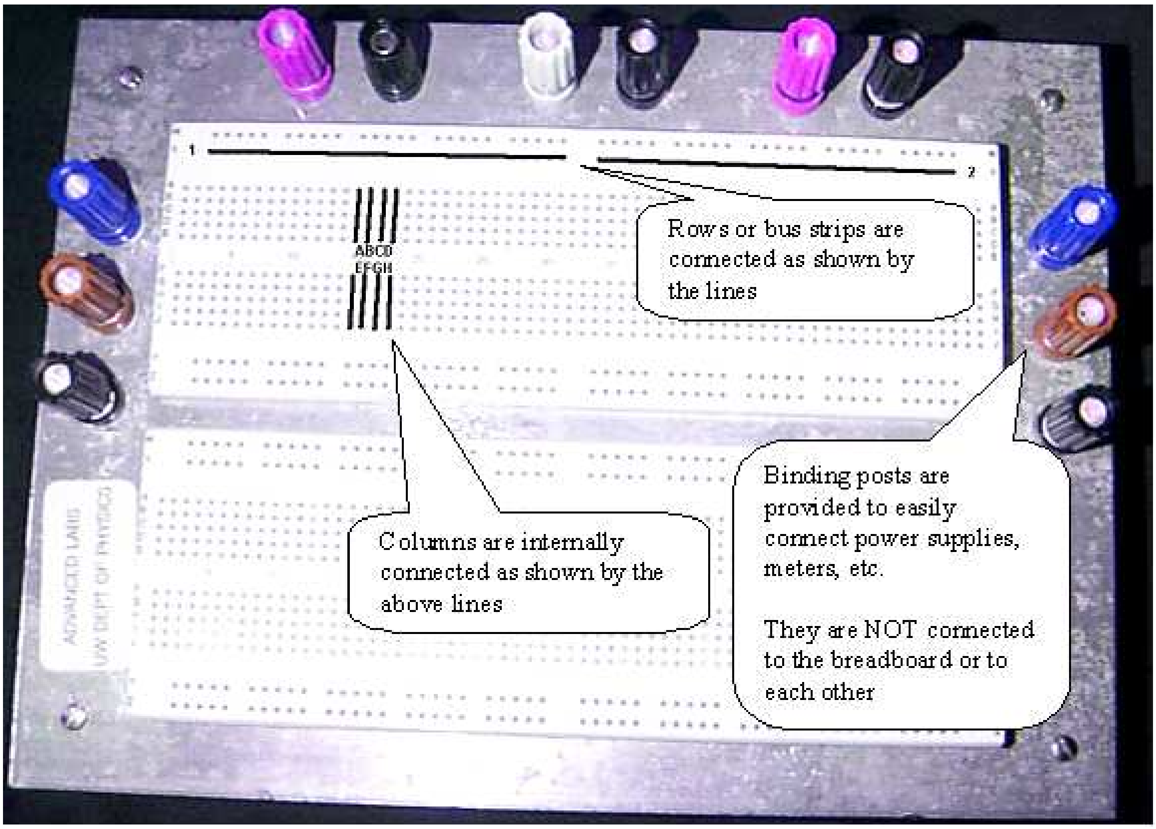
ALWAYS check the output of the function generator with your scope BEFORE hooking it up to your circuit. In fact, because we often use the function generator as a stimulus for a circuit we are studying, it's often useful to put it's output on scope channel 1, and the output of our circuit under test on channel 2. We then can see the input and output to the circuit simultaneously.

There are a couple things that are sometimes confusing about these generators when you first start using them. First, these generators can be used both as a function generator, or they may be used as a frequency counter as well. To use them as a frequency counter, the internal input to the numeric displays must be disconnected. If you do this accidentally, you get garbage numbers on the frequency display digits. So be sure for this course, the EXT COUNTER button to the far left is always pushed in.

Second, it is possible to have these units sweep through a range of frequencies automatically, as if you were changing them with the dial. Be sure the sweep function is turned off if you're not expressly intending to use it. The buttons and dials in the upper right hand side control the sweep function. Again, they should be off in most cases.

4 The Solderless Breadboard

A useful way to prototype circuits is to use a so-called breadboard, which allows connections to be made and removed quickly and easily. A diagram of the breadboard is shown below. Lines indicate breadboard holes which are interconnected with conductive strips, and these in turn can be used to make common connections between them with wires or other components.



The columns labeled ABCD and EFGH are internally connected with tiny copper strips along the lines as shown. Note, however, that they are not connected across the "gap". (i.e. A is not connected to E).

The rows or "bus strips" are connected internally as well. All the points in the row labeled "1" are conneted, as are those in row "2" and similarly throughout the board. Again, note that they don't span the largest "gap" so Rows 1 and 2 are not connected to each other.

Remember: If you ever get confused as to how the breadboard is connected internally, you can always check it with a multimeter. Connected points should have a very low resistance between them.

5 A Word about "Ground"

Throughout electronics, a common convention is to speak of "Ground", or in much of Europe "Earth". We'll often speak of a voltage as +10V DC with respect to ground, or if we just say +10 Volts, the "above ground" part is often just assumed. When we do this, we're just saying we have an agreed upon voltage that all other voltages can be referenced to. Often this is established in just the way you might expect by it's name: A conducting copper rod is driven into the ground near an electrical panel. A conducting wire attached to this rod is then wired throughout the house or lab and can be referenced at will.

In our lab, anytime you use a piece of equipment that has a BNC adapter, you can pretty well assume that the outer conductor of the BNC cable is that ground voltage, and the inner conductor is a signal voltage. This is true of your function generators and oscilloscope, for example, in the lab. This is also why it's important to keep track of any signal to which you attach a banana type adapter on a BNC cable – One of the banana plugs coming off this adapter has the signal, one has ground. You have to keep track of which is which.

Sometimes, you'll even hear people talk about multiple "grounds", such as a "Signal Ground" or a "Power

Ground". In all cases, though, the idea is the same – People have an agreed upon voltage to which they compare other voltages. We do an anologous thing with heights often. If you say, "I live at 500 ft.", "Above Sea Level" is assumed. But in some other context, such as if I were to speak of the height of the Physics Astronomy Building, another reference point would probably be assumed, such as the high of some nearby road, rather than sea level. In our electronics class, when we don't specify, ground means the voltage wall plug ground, which for convenience is pulled to the front of the power supply panel on a banana connector, and is also, as previously noted, connected to the outer conductor of the BNC connectors of both the scope and the function generator.

6 Power Supplies

We have triple supply power supplies in the lab. There is one Fixed 5 Volt supply and two variable supplies each with separate voltage and current adjustments. 5 Volts is a common supply voltage for digital electronics and since our focus this quarter is analog electronics, We will rarely use the 5 volt supplies this quarter. Next quarter, we'll use it almost exclusively.

The variable supplies have two knobs that control their operation. One sets the maximum voltage, the other the maximum current. The supplies will hold whatever voltage is dialed in with the voltage set knob unless it draws a lot of current. When it reaches a certain value of supplied current, set by the current setpoint the supply will lower the voltage supplied so that it does not exceed the maximum current setpoint. Most often this quarter, we'll want a fixed value voltage supply, so we'll set the current limit setpoint to " a little more than we need" . For us, that means about 1/3 or a bit more of it's maximum value. If, after wiring your circuit, you notice the voltage drops to a value below the setpoint, it's likely you've accidently miswired your circuit, possibily accidentally wiring a short somewhere in it! If so, turn off the supply and fix your circuit, then reapply power.

One thing to note, and this relates to the previous section about ground: Our supplies are "Floating" supplies. This means that if I set a voltage for channel A to say 7 volts, this means the difference between the two Channel A banana plugs is 7 volts. It says NOTHING, however, about how those voltages relate to our predetermined ground point. In fact, we can tie either one of these points (but not both!) to ground – It's only the difference the power supply monitors and controls. In this way, with our two variable supplies we can make two positive, two negative, or a positive and a negative supply with respect to ground. This turns out to be quite handy. Usually, we will tie one side or the other to ground, though, since many of our measuring instruments also make measurements relative to ground.

7 Parts Cabinets, Lab Organization

You've seen several of your instruments now. In addition, we'll have quite a number of small parts we'll examine during the quarter. These small parts are organized in the parts cabinets. PLEASE help to keep them organized, for your own sake and that of your classmates. If you need and take a part from a parts cabinet, please return it to the same location. It can be a headache to find parts if people do not make an effort to keep them in order, so please do your "part" (groan!). At the end of each lab, please be sure to dewire all circuits and your breadboard and return the station to the condition in which you found it.

Always check your circuit carfully before turning on any power supplies or function generators. After doing so, if you wire a circuit, power it up and and it doesn't work, *turn off the power and double check your wiring. You've probably made a small wiring mistake.* If, after checking, it still doesn't work *check your wiring again.* Seriously. While this may sound silly and it's tempting to blame something else, most of the time a minor wiring mistake is the culprit.

If after double checking a circuit you and your partner still have not found any errors, it's time to start some serious trouble shooting. The first thing to check if you have any integrated circuits is to be sure ALL chips have power and ground properly applied. Visually check your wiring and use a scope probe to check. After this, trace the any inputs on the circuit step by step through the circuit, making sure they look like you expect them to at each step. If you can't explain what an input looks like, try to figure out why. I can almost guarante that until you provide the correct input, the output probably won't make sense either. In this way, the trouble location in your circuit can be isolated.

If you still cannot figure out the problem, ONLY AT THIS TIME is it appropriate for you to call in the TA or professor. If you must enlist their help, please be patient. You will have wired your circuit in a slightly different way than whatever circuit s/he was last looking at, so it may take a moment or two to figure out. In addition, remember that you do, after all, have her or him outnumbered 20 to 1 and your TA gets called in on all the "tough stuff". You should struggle a bit to try to find the problem yourself. Struggling a bit is a part of the process of learning electronics. It turns out, most of the time, we fail on our first attempt at anything. Get comfortable with it. This class, as with many others, is often about you learning how to find your mistakes and fix them.

If all of you finally conclude that every power input and output pin are hooked up correctly, and it still does not work, then it may be appropriate to try replacing the chip. While you will occassionally find a bad component, it is a far less common problem than other problems and mistakes. However, in the event this is the problem or is suspected, a bin is provided in front near the sink for any parts you think may be defective. Please do not return a defective part to your cabinet. You're just leaving a frustrating problem for someone else.

8 Cables, Potentiometers, and Wiring Your Circuits

You'll use several types of cables this quarter. Here are a couple pointers:

- Banana Plugs – Use banana plugs for power supplies or DC signals only.
- BNC cables – Use BNC cables for DC and AC signals. For example, they can and should be generally be used from the output of the function generator and as the input in preference to using banana plug type cables.
- Scope Probes – Scope probes are ONLY used as an input to the oscilloscopes. DO NOT use them from the output of the function generator. Scope probes have intentionally added internal resistance and capacitance and only make sense to use as an oscilloscope input cable.

Take care this quarter to wire neatly. Often, it will make sense to color code your circuits. A frequently used color convention is to use Red for a positive supply voltage, black for a negative, and green for a ground connection. Some other color can be used for other connections such as input and output signals. While this is not set in stone, using some common conventions will make debugging your circuits easier.

We'll use Potentiometers in a number of our circuits. Potentiometers are nothing more than variable resistors. Usually, they have three leads coming out of them. If you measure the resistances, two of these leads always have the nomial poteiometer resistance value between them. The the resistance between the third lead (sometimes called the "wiper") and either of these previous two leads varies between zero and the nominal potentiometer resistance. If you ever get confused, remeber you can always use your DMM to measure the resistance between any two leads by setting it to the resistance (Ω) setting.

9 A Few Sections in the Book

We will do a couple sections in the Horowitz Lab Manual today. Do Section 1-1, 1-2, 1-3 and 1-4. See the notes below for some helpful hints. If you need graph paper, .pdf's of linear and semilog paper are available on the course website.

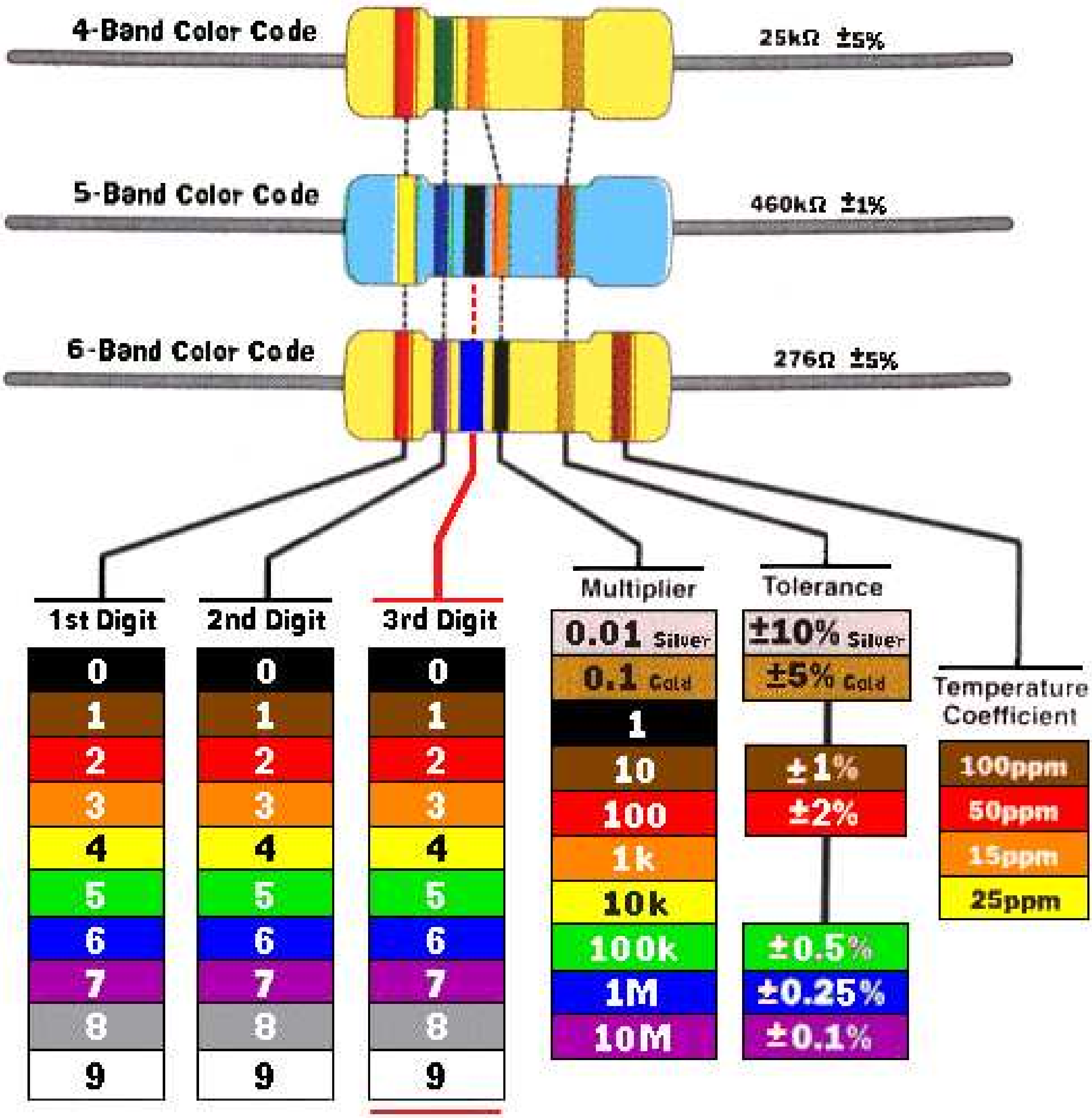
Section 1-1

Do 1-1 as indicated. You won't use an old fashioned VOM, but one of your DMMs as the ammeter.

Your very first step when assembling a circuit is to verify you have the correct compoenents. So first, check that you have the correct value resistor either by reading the resistor color code, or by measurement with your DMM. After this, measure I and V for a 20k (or two 10k's in series) and for a 10 k for 5 points each with the power supply set at about 1 volt intervals. Make a data table and then plot (by hand is OK). Put values for both resistors on the same plot. From the slope of each line, you should get the corresponding resistance if you plotted it right.

Think about all thee questions in "Effects of instruments on your readings", but answer the quantitaive part in your lab report. Assume you really do have a VOM in the circuit, with an internal resistance of 200,000 Ω (20,000 Ω / V on the 10 V scale). Our DMMs have a much higher resistance than this; typically between 1 and 100 MΩ.

Here's a chart that will remind you of how to read a resistor's color code:



Section 1-2

Repeat the procedure in 1-1: measure 5 points spaced about 1 volt apart, and make a plot. You should see a definite curve to your plot.

On the question of "resistance", think about the difference between the *static* resistance, defined as V/I and the *dynamic* resistance defined as dV/dI, each associated with a point on the V vs. I plot. What is the dynamic resistance approximately at V=1V? What is it at V=5V?

Section 1-3

Again, you don't need more than about 5 points (in the forward direction) to see the curve. Since the current increases exponentially with the voltage across the diode, space your measurement out by *doubling* the current at each point. Note: What current does the 1k resistor limit you to? To make things easier, start with the variable resistance R equal to zero, and then add resistance into the circuit.

Then reverse the diode and see what happens for R = 0.

Section 1-4

Show all calcuations and measurements. You may only be able to make a resistance that is approximately the correct R_{Th}.