EE 133: Analog Communications Design Laboratory

Lab 0: Baseline Skillz Assessment

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DUE DATE: To be determined

DELIVERABLES:

1. Working single chip AM / FM radio
2. DMM measurements of an “unknown” gizmo
3. Set of working cables
    a. Two functional DuPont wires, approximately 6” long, one F/F and one M/F
    b. Two functional 18 AWG power cables:
        i. a red one approximately 24” long with banana plugs on both ends
        ii. a black one of the same length as the first with banana plugs on both ends
    c. 5 ns (± 50 ps) of RG-58A/U cable terminated with BNC connectors on both ends
4. An answer to the question “Where is the 50 Ω in the 50 Ω cable you just made?”
5. Determination of “unknown” cable type
6. Demonstration of power supply use (video)
7. Three pictures showing the three states of probe compensation
8. Measured results showing the effects of oscilloscope probe ground lead length
9. Catalog of time / frequency domain signal pairs (measured)

Time domain signal	Frequency domain signal
sine	???
cosine	???
square	???
pulse	???
triangle	???
sawtooth	???
the other sawtooth	???
???	sinc
???	sinc2
???	Gaussian
???	Lorentzian

Anything else that you find interesting!

10. Answer to the question – “How much 2nd harmonic and how much 3rd harmonic needs to be added to a sine wave before distortion is obvious to you on a ‘scope?” HINT: something in units of dBc.
11. Plan for learning anything you’re not comfortable doing

That’s ten (10) things / sets of things!

SUBMISSION: To be submitted via your class Github account.

Overall Objective

The objective of this lab (Lab 0) is to identify what you DON'T know and to formulate a plan to learn those skillz.

1 Introduction

First things first – If you know everything, you shouldn't be taking this course!

This is obviously true, so, that's why we're here to help you learn things that will help you become more comfortable in the lab. Since we all come from different backgrounds, we need to find out if there are any gaps in your knowledge and help fill those in. Unless you've been working around RF electronics, much of this may be new. So don't get discouraged! This is like so many other fields in that it has some specialized language (jargon, yuck!), some specialized techniques (you can master!) and some specialized measurement equipment (a pain to learn but makes things possible!).

If you're an "old hand" at this stuff, then please help other folks BUT remember that they need to do things for themselves! For example, DO NOT take a soldering iron out of someone's hand to "help" them learn to solder!! They need to hold the iron and solder things until they are comfortable and making good solder joints. So please help, please share your knowledge and experience, and PLEASE BE CONSIDERATE.

OK, enough of that (I hope), so on to the core of this lab, the SKILLZ assessment lab.

You're going to self-evaluate on several aspects of lab technique. Let's list them!

Can you –

1. Work safely in a lab
2. Solder well enough that you won't ride the struggle bus
3. Use a multimeter to get out of a jam
4. Build a cable if you need to
5. Use a power supply without damaging the thing you're interested in
6. Use a signal generator to apply an appropriate signal to your widget
7. Use an oscilloscope to make reliable measurements
8. Use a spectrum analyzer to measure things you need to know

If you don't know some of these things, YOU ARE IN THE RIGHT PLACE!! Soon you'll know and a little later you'll be comfortable, and in short order folks will look up to you and ask you to show them how to do stuff!

2 Lab Safety

In this course we will *not* be using high voltages or storing a lot of energy, but we still should work safely so we don't run into difficulties and / or damage things. It is required that you review the Basic Lab Safety Material and take (and pass!) the Basic Lab Safety Quiz. Once you have done this, you are qualified for lab access!

3 Soldering Assessment

3.1 Discussion

One of the skillz folks find super-useful is the ability to solder. Please start with the Intro to Soldering material unless you have previously gone through the soldering training.

Once you have reviewed the material, please take the Quiz at the end of the training so we can schedule a time to meet with you and do the soldering test.

3.2 Lab Work

During the soldering test you will complete the Soldering Qualification Board AND a small single chip radio (through hole version) OR the surface mount technology (SMT) version of the small single chip radio to demonstrate your soldering proficiency. Whichever you choose, you will need to complete the assembly in a set amount of time to demonstrate workmanship and competence.

Once you have passed the soldering test you are considered “qualified” and can access the department's soldering equipment and materials.

If you wish to do more soldering, for example join two wires and cover the joint with heat shrink tubing or do “ugly” / “dead bug” assembly, please ask the instructor.

DELIVERABLE: Completed Soldering Qualification Board AND a Working single chip AM / FM radio (either version)

4 Multimeter Use Assessment

4.1 Discussion

You have probably used a digital multi-meter (DMM) before, but you may not have fully appreciated its utility. The meter you have (Fluke 117) provides a convenient way to measure stuff that might interest you. For example, Vac, Vdc, Ω, AC current, DC current (to 10 A), capacitance, and frequency. The Fluke 117 has true RMS measurement capability. What do you think this means? When might this be important? Do you remember how to find the RMS value of something? If not, now is a wonderful time to ask your lab instructor for some refresher material!

Let's start with how a DMM operates. The fundamental measurement a DMM makes is voltage. This is to say that the meter is set up to measure voltage and so it has internal circuitry that converts the other quantities to be measured into a voltage.

Let's consider a DC voltage measurement. Well, that's going to be easy! The voltage "comes in" on the two test leads, gets scaled so that it is within the measurement range of the internal circuitry and is "measured". The result is displayed on the readout.

To illustrate the need for "scaling", let's imagine that we are going to measure a "48 volt" battery. The DMM itself runs from a nine volt battery but perhaps the internal IC is running from a stepped down voltage common for ICs; for example 3.3V. This means that the maximum input voltage the IC can withstand will be a bit over 3 volts, and consequently the "full-scale" input voltage at the IC is right around 3 volts too. But we want to measure a 48 volt thing! What should we do? That's right, we'll use some switches and resistor dividers to "scale" the 48 volts down. So, we need something that reduces the sampled voltage, presented to the IC input by a factor of ~ 16x.

To make the measurement, the voltage is digitized by comparison against a known reference voltage resulting in a digital code that is proportional to the input. That code is processed by the microcontroller portion of the DMM IC and the microcontroller sends the number to the display.

Great! Now what about AC voltages? Well, we can use the DC voltage measurement circuitry for this if we just rectify the AC to DC. The rest follows the earlier DC measurement pattern.

So far, so good… How might we approach measuring a DC current? Again, quite easy! We just use a known resistor to shunt the current and measure the voltage across the resistor. When measuring any significant current (something with units of amps, like 100 mA to 10 A) we need to be careful not to burn out the resistor! Manufacturers figured this out and usually there is an "in-line" fuse (in series with the shunt resistor) to protect it. Also, most handheld DMMs require that the leads be reconfigured to help avoid "burning out" the meter. So, if you try to measure current but the meter seems broken, what should you do?

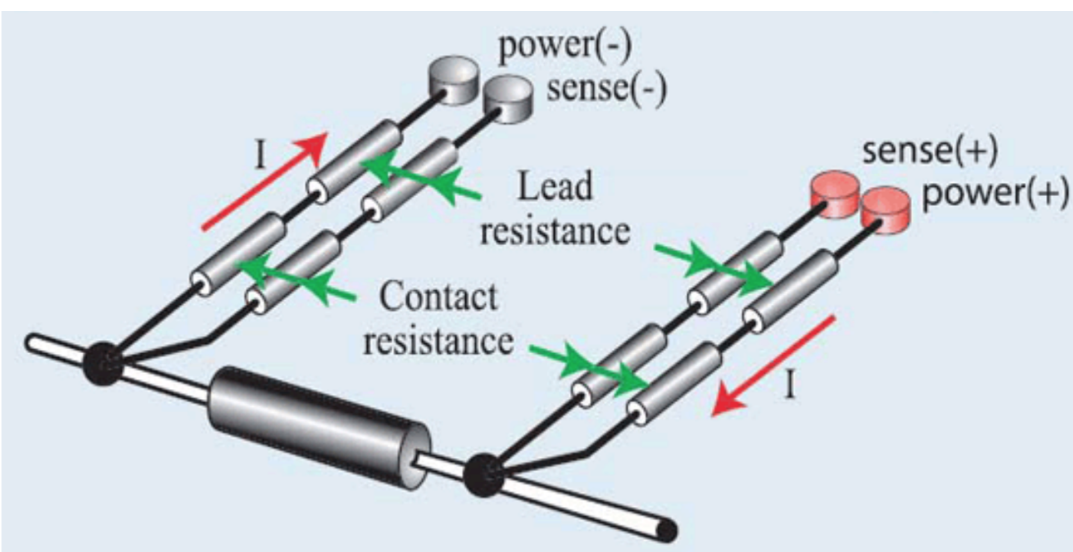
Fantastic, we have a pretty good understanding of this now. So, for AC current we would just rectify and follow the pattern again.

How about resistance? How is that measured? Well, we are going to measure voltage, so don't we just "turn around" the current measurement idea? Yes, that seems right. So, inside the DMM is a current source and we measure resistance by applying a small, known current between the leads and measuring the voltage generated by driving that current through the resistor.

BUT WAIT! Then that means the meter is going to drive a current through whatever circuit we try to measure the resistance of, right? RIGHT! And that means even though the handheld DMM is battery powered (and therefore line isolated), we shouldn't really use it on powered circuitry because it won't give the desired (correct?) reading and it might damage sensitive circuitry. If this isn't intuitive for you, find your lab instructor and ask to have it explained.

For the careful reader, the idea of sending a current through the leads while simultaneously measuring the voltage between the ends at the meter will sound some alarms! In this configuration we have placed the leads themselves in series with the very thing we are trying to measure! And we don't really know the voltage drop of the leads and any contact resistance, etc. This could lead to a very inaccurate measurement for low value resistances! What should we do?

Well, lucky for us, William Thomson (aka Lord Kelvin) needed to solve this very problem in 1861 when he was measuring very low resistances. His solution, called four-wire or Kelvin sensing, is that we use four leads; two to connect and drive the current through the device being measured and two more (high impedance) leads that measure the voltage differential across the device. This way the voltage drop of the drive leads does not effect the voltage measured across the device. More accurate (and expensive) bench DMMs have four jacks on the front panel just for these sorts of measurements. The figure below illustrates the concept.



From https://www.voltech.com/support/technical-articles/kelvin-connections/

4.2 Lab work

With all that in hand, let’s see if we’ve “got it” by working through some measurement scenarios and seeing if we get the expected results.

The very first thing to point out is that we should always check to see if the meter is working properly. This can be done very simply.

When we turn the meter ON, we look to make sure there is a visible display (and that it doesn’t have a LO BAT indication).
Next, we hold the leads in the air and see if the display reads as expected. What should we expect?

Next, we touch the probe tips together and see if the display reads as expected. What should the display read?

So what have we done here? We have checked that:

1) the meter has a working battery,
2) the display works (and the meter isn’t “shorted” internally), and
3) the leads are continuous (they are inserted fully into the meter and the wires are not broken)

All that in less than two seconds!

Should you do this every time you use a meter? YES!
Why? Because life is too short to waste your time with non-functional (dys-functional?) meters!

OK, now we're ready to measure the characteristics of the devices in gizmo to be tested. For this part of the lab, you’ll need to get a gizmo from your lab instructor. The gizmo will have different things to measure on each side. Measure your gizmo and make a table of your findings. Do you have any guesses as to what device is presented on each side? How can you confirm that you are correct (without opening the gizmo)?

DELIVERABLE: ID number of the gizmo you used and the table of your readings and your guesses about the type of “device” on each side of the gizmo.

As a final DMM exercise you are going to determine the connectivity of some cables and determine the “type” of cable each one is.

DELIVERABLE: Picture of the cable you used, cable ID number, and your conclusion of type of cable for the three cable styles provided.

5 Cables & Connections Assessment

5.1 Discussion

If you work around electronics for a while, you will probably run into a broken cable that needs repair or a time when you really need a cable and can only find the parts, so it is super helpful to be able to assemble your own cables, especially the common types.

Among the most frequently used cables are:

- DuPont (aka Zip) wires
- Banana cables
- BNC cables
  - BNC on both ends
  - those excellent cables with clips on the end
- SMA cables

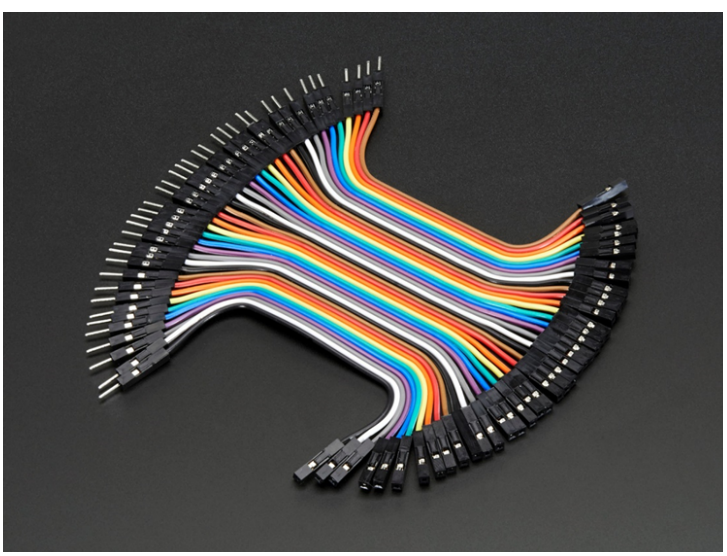
Although all of these are amenable to manual assembly, the SMA-style connector requires a bit more skill (and you can work up to that when you have more time), so we will show you how to build the first three cable types.

5.2 Lab work

5.2.1 DuPont Wires

The first thing we're going to do is assemble some DuPont wires. These are also known as "zip" or "jumper" wires and sold by a variety of vendors such as Adafruit, Jameco, Amazon, etc.

Here's a picture of some zip wires from the Adafruit web site where these are called "jumper wires" –



These particular “jumpers” are “male” on one end and “female” on the other.
Notice how there are pins and sockets that are crimped onto the wire ends and then inserted into the plastic housing. In this case housings are individual units, however housings with multiple positions can easily be purchased.

Since these are so nice, why wouldn’t we always just buy these beauties? Well, because sometimes we want a different wire length or color, or we want a housing that will allow us to group pins and maintain the wire order, etc. It can be quite handy to be able to make these for ourselves.

Let’s give it a try!

1. First step, cut the wire to the desired length.

2. Next, strip one end.

3. Now, find the pin or socket you want to crimp onto the end.

4. Position the pin / socket in the jaws of the crimping tool.

5. Insert the wire to the correct position to crimp onto the wire.

6. Squeeze the crimp tool to make the crimp, then release.

7. Inspect the crimp.

8. Now we’ll crimp the “ears” onto the insulation by positioning the crimped pin / socket in the jaws of the crimp tool such that the “ears” will be crimped.

9. Squeeze the tool again and release.

10. Inspect the crimp.

When you are doing this with a multi-position housing, you will need to make all the crimps BEFORE inserting the pins / sockets into the housing (otherwise the housing will be in your way when you’re crimping the rest of the pins / sockets).

Great! All done and look at those lovely crimps!

5.2.2 Banana Plug Terminations

Now let’s try our hand at making some banana terminated “power” leads.

The tricks here are:

1. Remember to take the banana plug apart.

   We need to unscrew the plastic part from the metal part so we can solder the wire into the metal part. Once you have these two separated, put the plastic part on the wire so you can screw it back in place when the time comes.

2. Strip and tin the wire you are going to connect.

   Strip and tin the wire you are going to solder into the back of the metal part. This will just make things easier.Find a way to hold the metal part so it will be easy to solder inside the hole where the wire goes.

3. You'll need to clamp it somehow.

   It turns out that to make a good solder joint, this part will get HOT!! So you will need a way to hold it such that you can work on it without being burned. There are many different ways to do this depending on what you have on your bench. Some folks like those clip things on stands; some folks try to use the "octopus" style clamps (those usually melt when I try that); some try to hold the metal part in a bench vise; It is all up to you and how you achieve success! The thing is that you want to hold it steady so you can work on it but you don't want to heat sink it so it is difficult to solder. I often go to the rubber band on the handles of my pliers method. I use the fat rubber bands that I get off broccoli bunches at the grocery store and I take a couple of turns around the handle of a pair of pliers; this "spring" loads the pliers closed and I can pry the jaws apart and use this as a clamp. I've had good success with this and it is easy and encourages me to eat broccoli (which is supposed to be good for you). If you can't figure this out, ask me and I'll try to help you.

4. OK, now stick the tinned wire end into the hole, heat the metal near the hole and feed solder when it gets to the proper temperature.

   Don't get carried away, because you'd like to have a bit of the wire that doesn't have solder amongst the strands. The part without solder will maintain some flexibility and your cable will last longer.

5. SUPER! Now hold it steady while it cools…
6. OK, once it is really cool, we can take the metal part out of the clamp and screw the plastic part back on.

YAY! You've made a banana cable end!! That's great! Let's do it a couple more times to get some practice. When we're done we'll have a "power" style cable thing to use to power our gizmos.

5.2.2 Making a BNC Cable

You're going to find BNC cables all over the place in this class. They're pretty popular for making all kinds of connections (both correctly and incorrectly, as we'll discuss). Since they are so ubiquitous and they are often in need of repair, let's learn how to assemble one. Our goal is to produce a 50Ω BNC cable that is 5 ns long. Simple enough, right?

AS I AM WRITING THIS IT COMES TO MIND THAT I SHOULD TELL YOU TO BE BRUTAL!!

As you work in the lab, you may come across a cable that isn't working properly. When this happens what should you do?

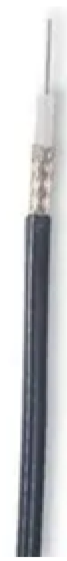
CUT ITS HEAD OFF!!

Why? Because again, we don't need to waste time with stuff that doesn't work! So cut its head off and save yourself and others the time and pain of finding it over and over. After this section, you'll be able to fix the cable but until you (or someone else) fixes it, make it OBVIOUS that it isn't working properly. Please!!

There are many different form factors of 50Ω coaxial cable. Some of them are shown below –

Really tiny
0.058" O.D.
flexible

Small
RG-178
stiffer



"Standard"
RG-58A/U
See for yourself

They all have a center conductor surrounded by a cylindrically shaped insulator and an outer conductor, either wire braid or foil or some fancy metal jacket. The point is that the cable has a cylindrical cross section consisting of a central conductor, then an annular insulating region (can be air!) and then the outer conductor.

For those folks that are familiar with transmission lines, this is one of the most popular transmission line configurations and when we make connections, we try to keep things coaxial as much as possible.

You are going to make a cable that is 5 nanoseconds long ± 50 picoseconds. You are going to do this for several reasons:

- it will emphasize the equivalence of length and delay
- it will enable you to build cables when you need them (super useful!)
- it's kinda fun, actually!

OK, let's get started!

First, we need to figure out how long a piece of coaxial cable we should cut.
Hint: We can't use the speed of light!

Now that we've got our lovely 5 nsec piece of coax, we need to get a couple of connectors and figure out how to put them on the cable.

Here's what one of the connectors looks like –

You should have two (2), one for each end!

Let's read the instructions… They can be found HERE and HERE.

For those more excited by video instruction, please watch THIS VIDEO, BUT **note that we have the luxury of the special tool that is referred to but not available in the video.**

Alrighty then! Please install a connector on one end.

Then use an ohmmeter to confirm that the outcome is as expected for a functional cable. If you have difficulty with this, check with the teaching staff.

Now let's install a connector on the other end!

YAY!! We've just made a 5 nsec BNC cable!!

Let's put that aside so we can measure its properties later.

Now that you have made a cable, you will be able to answer the question –
"Where is the 50Ω in the cable you just made?"

Again, if you have trouble finding the 50Ω, please ask one of the teaching staff for help.

DELIVERABLES:

a) Two functional DuPont wires, approximately 6" long, one F/F and one M/F
b) Two functional 18 AWG power cables:
   - a red one approximately 24" long with banana plugs on both ends
   - a black one of the same length as the first with banana plugs on both ends
c) 5 ns (± 50 ps) of RG-58A/U cable terminated with BNC connectors on both ends
d) An answer to the question "Where is the 50 Ω in the 50 Ω cable you just made?"

7 Power Supply Use Assessment

7.1 Discussion

In principle, power supplies are simply batteries that never run down; in practice, they provide some additional and quite useful capabilities. Let's start with a note about batteries and we'll come to understand how power supplies can be more "ideal" power sources.

Batteries change (or transduce) chemical potential energy into electrical energy. Each type of battery has a particular "chemistry", and therefore voltage, associated with it; for example, lead acid car batteries have a typical cell voltage of ~ 2 volts. But we all know car batteries are +12 volts, aren't they? Well, yes, that's right… When manufacturing the car battery six (6) cells are connected in series so the voltage across the battery terminals ends up being +12 volts. The lead acid cell is a "secondary" or rechargeable cell and the car alternator is constantly recharging it so it will be ready when you want to start the car, etc.

What is this battery's goal in life? To keep +12 volts across the terminals as well as it can. So if a battery were IDEAL it would be a voltage source! Always providing a +12 volt potential across the terminal regardless of the amount of current required. But they aren't ideal. They can supply a LOT of current (many 10's of amps!) when needed, but over time as the chemical potential becomes exhausted the voltage drops. But there is another aspect of this- they only supply many 10's of amps. Why don't they provide MEGA amps?!?! Well, how could they? Being made of normal metals and such there is an inherent series resistance that limits their ability to provide current (a gross oversimplification, but we're already in the weeds a bit). How big is this internal resistance? Well, 12 volts / 100 amps = 1/8 Ω. Just a rough guess, but an interesting number to keep in mind.

So how would we make something “better” than a battery? This seems pretty simple, right!?!? We’d make something that provides a constant voltage (maybe even adjustable, but stable once set) for all possible output currents. Wait, what? So, this gizmo must both source and sink current to keep the voltage constant? Yup! And then it should have a very low output impedance? Like less than 1/10 Ω. Yup! And it should do this without either long term fluctuations (drift) or short-term fluctuations (noise)? Yup! And since it’s going to run “forever” it should be line powered, right? Yup! But it should not let any of the line frequency energy “leak through” and contaminate the DC output, right? Yup!

Knowing this, we are in a better position to appreciate and use the lowly bench supply. We just “plug it in and use it” and hope some other engineer did a great job building this amazing device.

A practical note – Folks often want to use power supplies as “batteries” that never run down, meaning that the output terminals have NO GROUND REFERENCE. The jargon for this is that the “output is floating”. Thus, on many power supplies there are terminals marked + (positive) and – (negative) and then there is something called “com” or common. This “common” terminal is almost always connected to the supply chassis which is, in turn, connected to the “ground” terminal of the line cord and wall outlet. So, if you want the supply to provide a “negative” output, the com terminal can be connected to the + / positive terminal and the – / negative terminal will provide a negative output with respect to ground. BUT this only works up to the isolation voltage limit of the supply (which is determined by the insulation “strength”, etc. of the transformer). BE CAREFUL NOT TO EXCEED THIS RATING or you will have troubles.

Just one last thing before moving on – sometimes we want to limit the current provided by the supply. Why would we do that? Because sometimes we make mistakes and having a bunch of energy flow through our circuit can become an incendiary event. It is better to limit the current and avoid damaging something we are working on.

7.2 Lab work

Step 1. – Find the bench supply.
This shouldn’t be too difficult, but there are a bunch of boxes and stuff on the bench, so which one is the supply?

Step 2. – Take a careful look at the front panel of the supply.
Here we see that this is a triple output power supply, and it can only supply current up to a particular limit.

- What are the limits for the supply you have on the bench?

- What else do you notice about the terminals? There are more than three, right? Take a good look to see what they are labeled.
- OK, now what do you suppose the difference is between COM and the terminal with the upside-down dashed triangle?
- How can we confirm our suspicion?
- Talk to one of the teaching staff and then confirm your suspicion. Were you correct?

Step 3. – Let's see if it "powers up."
For this let's make sure the "LINE ON" switch is in the "downward" position and disconnect everything from the supply output terminals. Now let's plug the line cord into a bench outlet. Pick an outlet that is out of the way because you're going to just leave the supply plugged in and you don't want line cords in the way as you work.

GREAT! Now, let's turn any knobs fully CCW (counterclockwise) and toggle the "LINE ON" switch upward. Did anything happen? Hmmm…

So how will we tell if it's working?

Oh, let's turn one of the knobs slowly CW (clockwise) and see what happens. Hmmm…

Still nothing? Is the "METER" knob set to measure the thing you're adjusting? If not, turn it until is set to the voltage you're adjusting with the knob.

See it now? GREAT!

So play with this a little more until the controls make sense to you and you know what you're measuring and when.

Step 4. – Is this gizmo lying to us? How would we know?
Now let's find out if things "match-up" by using our old friend the DMM to measure the output voltages and confirm that they are as we expect. You've got this? Right?! If not, find one of the teaching staff and have them help you.

Step 5. – Let's revisit this "GROUND" vs COM thing.
Earlier you found out that the upside-down dashed triangle thing is connected to LINE GROUND. You should have done this by measuring this resistance from the BLACK upside done dashed triangle terminal to the round pin on the power plug and finding that they are continuous (low resistance). If you were being a bit fastidious, you may have checked to see that the COM terminal and the LINE GROUND are *NOT* directly connected. If you did this you should be proud, because even though it's not supposed to be connected the years of use (abuse?) may have shorted the COM to GROUND somehow. It's good to check this sort of thing before you count on it. THERE IS A LOT TO KNOW ABOUT "GROUND" THAT WE WON'T GET INTO HERE but perhaps we'll have time to talk about it later. For now just realize that the voltages are referred to the COM terminal and that everything you connect to the supply *WILL

BE “FLOATING” unless and until you connect COM to GROUND (using say, a short banana to banana cable).

Step 6. – OK let’s power some widget.
Right! With all that understood we’re ready to power our widget. Find a widget and connect it to the supply using some of those super cool banana cables. I can hear you already, “Isn’t there some better way?” Well, yes, kinda, but most folks never get there… Maybe we will in a bit, but for now what we want to focus on is that:

- We don’t draw too much current and cause the supply to shutdown
- We are getting the voltage we expect
- The “noise” isn’t “excessive
- The lead “loop area” is minimized

This last point is an important one: if the loop area “enclosed” by the leads is large, magnetic fields will pass through the loop and induce EMFs. But the whole point of a power supply is to act like a voltage source! But it can’t do that at very high frequencies (consider the lead inductance and this will be clear), so varying magnetic fields are *NOT OUR FRIENDS* and the way we avoid creating an antenna is to minimize the “loop area”. How can this be accomplished… Glad you asked! By simply twisting the leads together of course! So if you look at the power supply “rails” on your widget and find there is a bunch of 60 Hz or harmonics of 60 Hz, you should make sure there isn’t a loop that is causing some trouble.

Step 7. – Let’s watch the current meter part.
Take your widget and use it to draw more current from the supply. See that cute little meter go up and down, but the VOLTAGE meter should stay in the same position. What do you think? Is this working pretty well?

Step 8. – Turn everything off!
You’re ready to move on, so let’s turn the voltages down and then turn the supply off. If you don’t want someone to come along and burn your thing up, maybe you want to disconnect it from the supply… Just sayin’.

The **DELIVERABLES** for this section will be the notes and videos made about the power supply behavior.

8 Oscilloscope Use Assessment

8.1 Discussion

It is hard to know where to begin, but perhaps it is best to begin at the beginning and then jump forward. So in this spirit, I will start with some very basic things; for example, it is difficult to sense electricity with our five senses. While it is true that we can certainly perceive electrical shocks, it is much more difficult to taste, see, or smell electricity. This is generally not the case for physical objects; these are readily seen and felt, and thus “easily understood”. Hah! But the aspect to focus on here is that because we almost always have to use an instrument to sense electricity with a small amount of additional effort, we can quantify electricity. This naturally leads to the construction of meters, etc.

In the etc. category, it turns out to be super useful to be able to visualize voltage vs time. Simple enough, let’s just hook a pen up to some gizmo that move paper along at a pre-determined and relatively constant rate and voila! We have just re-invented the chart recorder.

GREAT! But what if the voltage changes are fast? Won’t the mechanics of the pen limit the speed of things we can measure? RIGHT AGAIN!

So what we need is a gizmo that can indicate voltages changes vs time with basically NO mass to limit the speed… What should we do?

Well, some clever folks thought about this and decided that we should use electrons because they’re pretty small and light. And they built this gizmo and called it an oscilloscope (from the Latin oscillare – to swing or vary and scope as in to be able to see or visualize).

So here it is in its essential aspect – a device that traces out a graph of relatively fast voltage changes vs time.

The one on the bench for your use might look like this-

Rather than plunge through the rich and exceptionally interesting history of oscilloscopes I am going to refer you to two places:

- For an overview of oscilloscope functions and controls – Wikipedia and / or Appendix O – The Oscilloscope in Horowitz and Hill AoE3
- For the fascinating history of oscilloscopes and their development – Professor Thomas H. Lee here at Stanford and anything he might tell you or to which he might refer you. This is one of his areas of interest and he is encyclopedic in his mastery of this area of human endeavor.

OK, so far, so good! But even with this sophisticated piece of measurement equipment you may be wondering, "How do we get the voltages we want to measure in there?". Glad you asked!

IT'S ALL ABOUT THE PROBES!

Seriously, it is ALL about the probes. To understand this let's look at a couple of resources – Let's watch Alan Wolke's video entitled Basic 1X and 10X Oscilloscope Probe tutorial to get a start on this.

Then we can read Professor Tom Lee's handout on Oscilloscope Probes.

For those that enjoy reading more than watching, there is Primer: The ABC's of Probes from Tektronix

To find out more about compensating 10x probes, let's watch this video, again from Mr. Wolke, called Importance of 10X Probe Compensation with your Oscilloscope. See how simple that is?

OK, so now you know some of the basic things to be aware of. Let's take the next step and watch another video from Alan Wolke where he shows the effects of those handy little ground lead clips. You can find that here: Oscilloscope Probe Ground lead length effects on signal quality.
Well, if that's the case, what are we to do?!?! NOT USE THE GROUND LEADS WHEN WE MAKE CAREFUL MEASUREMENTS. You saw this in the last video, but in case it went by too quickly, they look like this-

Mr. Wolke made one by just wrapping some “bus wire” around the probe tip body and that will work for a limited number of measurements. For a more durable solution a “ground spring” like the one shown is very handy.
Or you can make a “test socket” as Mr. Wolke shows in his video - [How to make a high performance oscilloscope probe socket.] Maybe you’ll have a method that you want to share; please DO!
There are lots more tips and tricks for using scope probes to make good measurements with oscilloscopes. Maybe we’ll have an opportunity to talk more about this later when it comes to high impedance probes and differential probes, etc.
But let’s review what we now know:

- We should use 10x probes whenever possible
- We should compensate the probes every time we go to use them
- If they won’t come into compensation, we’ve got the wrong probe for the ‘scope we’re trying to use
- If we want to measure “high frequency” signals, we should use a ground spring or make a “test socket”
- If we’re measuring something that might be sensitive to being loaded, the ~ 10 MΩ input impedance of a 10x probe may be too low!!
- Even with a 10x probe, we’re still what may be a significant capacitance!

So we need to consider a bunch of stuff when we “make a simple ‘scope measurement”!

BUT YOU DIDN’T SHOW ME HOW TO USE A ‘SCOPE!

Ok, ok, you caught me…
If ‘scopes are new to you, I think you might find this ~ 3 minute YouTube video “Collin’s Lab: Oscilloscope Basics” helpful. It recaps what we talked about in class.

There are basically three things we need to think about when using a ‘scope:

1. Vertical scale (voltage per division)
2. Horizontal scale (time per division)
3. When to start the horizontal sweep (how to trigger the sweep)

All three of these are pretty easy for most applications, especially monitoring repetitive waveforms. Things become more interesting when you want to look at waveforms that occur as a result of some “trigger” event (and especially when you don’t know what the “trigger event” is!).

This starts to get interesting when you are looking for the trigger event that gives rise to some condition that is troublesome. For example, you find that your processor is getting reset intermittently and you would like to track down any “glitch” that is causing the reset. But the only symptom is the reset… So you need a way to “look back” in time to see what was happening just before the reset. How might this be accomplished?

8.2 Lab Work

For now, let’s just check to see that we know how to properly compensate our probes.

Deliverable: You should make a set of pictures with the probe undercompensated, over compensated and, you guessed it, properly compensated.

If you have trouble with this, please ask one of the teaching staff about it.

9 Signal Generator Use Assessment

9.1 Discussion

We will frequently need “known” electrical signals to drive or test our circuits. Luckily almost everyone working on circuits needs this sort of thing, so there is a market for such devices and there are many signal generators commercially available.

Some of the most cost-effective generators available are the “2000-series” from Siglent. There are three models: SDG2042 40MHz generator, the SDG2082 80MHz generator, and the SDG2122 120MHz generator. In the EE labs we will find the 40MHz and 80 MHz versions which look almost identical –

The fancy model is shown because this came from Siglent’s web site and they want to show the most expensive version, of course.

Rather than dive into the theory of how these operate, let’s just imagine that they perform as advertised and see if we can get them to produce some signals for us. We can talk about how they do this later when we have more time.

9.2 Lab Work

Step 1. – Let’s be sure we understand what we’ve got here.

Looking at the front panel, we see the usual buttons and a (single) knob. These boxes have 4.3” touch screens, so we’ll check that out later. BUT WHAT IS THIS!?!? A pair of BNC connectors!! Hmmm… I bet the signal comes out of the center… But what about the barrels? Are those things grounded? How would we find out? You should be pretty good at this by now!

Step 2. – OK, let’s plug this in and see what happens!

Again, let’s find an outlet kinda “outta-the-way” because we’re gone to leave this plugged in and we don’t want to have to wrestle with the line cord.

Step 3. – Now we’ll turn it on!

OK, let’s first check to be sure nothing is connected to those Output BNC’s. Nothing there? Great, let’s turn it on (by pushing the button in the lower left corner). WOW! It makes a fan

sound. OH, and then it displays the Siglent logo. And then… and then… Maybe we should get something to drink…
Oh, wait, here it is! The first screen! How cute! A big ‘ol low frequency sine wave! I'm glad the outputs come up in the “disabled” state! Look at that thing! It's 4 Vpp!! Holy cow! That's a lot of power… This is meant to be able to drive 50Ω so let's see… 4 Vpp into 50Ω, that's +25dBm isn't it?
Well let's see if it does that… Let's take a coax and hook it up to the ‘scope.
What do we see?

Step 4. – Is that right?

Well, it certainly looks like 4Vpp at ~ 1kHz but is this really into 50Ω? Not if you're using the ‘scope I think you're using. Look again at the input BNC's on the ‘scope. What do you see?

Ah, yes, it says “All Inputs 1MΩ || 15pF 400Vpk”. So the sig gen is driving into a ~ 1MΩ load then.

Let's “fix” that by adding a tee and a 50Ω terminator. That should be OK, right? We aren't going to burn up our terminator with this are we? Does it matter where we attach the terminator? OK, let's do this!

Wow, what happens when we plug this on? Oh dear! Why is that?

Step 5. – Adjust the frequency to 10MHz

Now that was easy, wasn't it!

But isn't it still bugging you a little that the sig gen display says HiZwith an amplitude of 4Vpp and this doesn't match what you measure? Well, let's put this thing in 50Ω mode…
How do we do that? Hold the output button down for more than 2 seconds and it will toggle to display “Load 50 Ω” and now the amplitude display says 2.000 Vpp. Hooray! Everything now matches!

What do we learn from this? I guess that we need to be careful and use our sense of how things should work. Let's remember to take the time to track these sorts of things down since we'll save time and confusion!

Cool, so that's it right?

Oh sure, now let's look at a square wave. Can you do that?
And how about a “ramp” or triangle wave?
How would we generate a sawtooth waveform?
How about the other sawtooth waveform?

OK, so if you've got that, you're well on your way!! Congratulations!

10 Spectrum Analyzer Use Assessment

10.1 Discussion

It is often very useful to know the frequency components present in a signal. For example, imagine that you are using a signal source (like one of the generators you used in the last section) to generate a sine wave test signal. Maybe you're testing an amplifier, maybe an attenuator, but in any case, you are expecting to see a sine wave of a different amplitude at the output of the device under test (that's a DUT). But you seem to get a different result than expected so you want to see if there are any harmonics present in the signal driving your DUT. How should we approach this?

Well, there is a helpful device called a spectrum analyzer that measures and displays the relative amplitudes of the sine waves present when the signal is decomposed via Fourier analysis. Until recently, these devices were prohibitively expensive and despite their utility they were only available in corporate and well-equipped academic labs.

But within the last year or so an inexpensive spectrum analyzer called the tinySA has become available and you get to use one (and maybe compare it to the more expensive analyzer in our lab).

One of the best places to begin is the tinySA web page / wiki. Here one can find a variety of points to be cognizant about. You should read through the stuff on this site. Go ahead, I'll wait…

OK, now that you know everything there is to know about the tinySA, let's try it out!

10.2 Lab work

Step 1. – Find the tinySA

Step 2. – Look at it and make sure it's the thing you see in the wiki.

Step 3. – Appreciate the +10dBm input limit!
Got it? You sure?

Step 4. – No, **really** appreciate the +10dBm limit!

> How much is +10dBm? What is the voltage of a +10dBm signal level into a 50Ω termination?
> HINT: You might wish to refer to the dB handout. Just thinkin' out loud here…

Step 5. – Set the signal generator up to generate some "garden variety" thing… say a sine wave at ~ 1 MHz with an appropriate amplitude. Connect a "tee" so you can monitor the signal on your 'scope and then connect it to the tinySA. Go ahead, this won't hurt (much).

Step 6. – Take a look at the sine wave on the ‘scope and look at the tinySA display. What should you expect? What do you see? Were you expecting what you see on the tinySA?

Step 7. – FANTASTIC! Now let’s generate some time domain / frequency domain signal pairs. You’ll be recording these so you can make a little catalog and show your extensive understanding of this whole time / frequency thing. We’ll be expecting you to show:

Time domain	Frequency domain
sine	????
cosine	????
square	????
triangle	????
sawtooth	????
the other sawtooth	????
????	sinc
????	sinc2
????	Gaussian
????	Lorentzian

If you need a little help with this you may find The Fast Fourier Transform by E. Oran Brigham, Prentice Hall, Englewood Cliffs, N.J. [1974] (Stanford library QA403 .B74) helpful. Or ask to see my copy.

Deliverable: A catalog of actual tinySA spectra and the scope trace corresponding to each of the Fourier transform pairs listed above.

When I was goofing around with the signal generator and the tinySA looking at the output of the signal generator, I discovered some settings that allowed me to add harmonics to the waveform. Ooooo, how interesting! And when I was dialing harmonics into and out of the waveform, I was struck by how easy it is to see the effect of the third harmonic and how subtle the effect of the second harmonic is. There are a lot of folks that love music and they strive to get really good (that is low) total harmonic distortion. So I thought you might find it interesting to take a look and see how much 2nd harmonic and how much 3rd harmonic needs to be added to a sine wave before distortion is obvious to you on a ‘scope?” HINT: you can express this as something in units of dBc.

Deliverable: A couple of photos of the tinySA display showing the fundamental and

a) the second harmonic and its relative amplitude
b) the third harmonic and its relative amplitude

when the distortion becomes obvious to you on an oscilloscope.