PCB Test

Introduction

Now that your PCBs have been manufactured, it's time to test your designs. You will first complete the assembly by soldering the SMA connectors to the PCB, as well as the surface-mount components. After that, you will use the FieldFox to test your circuits and determine if they work as expected. You will also be asked whether there is anything you would change about your design if you could refine it further.

Overview of your PCB

The PCB you designed has two circuits that attempt to match a test load (using a stub matching network and a quarter-wave transformer matching network), as well as a 1 GHz RF gain block. The board circuit is shown in Figure 1.

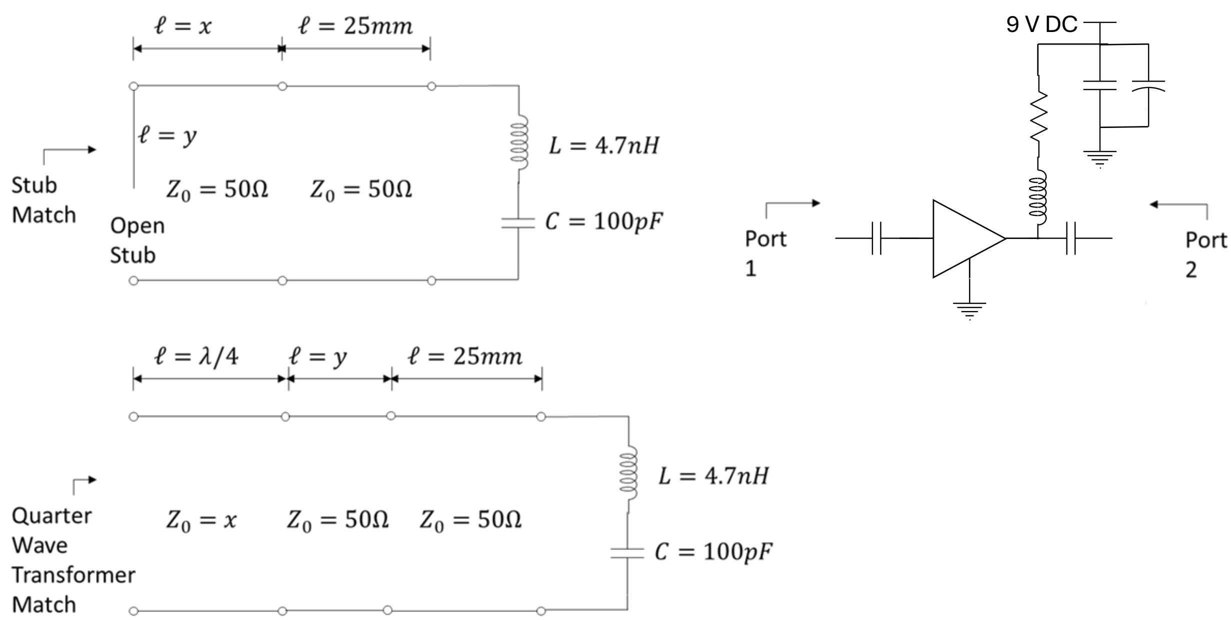

Figure 1 – Your PCB circuits. The stub matching network shown is an open-circuit version, but a short-circuit version is also possible.

Assembling your board

As a result of the fabrication of your design, you will receive 5 copies of the PCB. These are yours to keep. If you have not submitted a design to be fabricated, you can either ask for another group to share one of their PCBs with you, or ask for one from the lab technician. If you will test someone else's board, it is important you familiarize yourself with how the board is laid out and what the design choices were.

Before you can test your board, you will need to complete its assembly by soldering onto it the surface mount components and SMA connectors. Proceed to the supply room of the lab to access the equipment to be used to solder the components. Only one board per group will be assembled in this lab, so the remaining 4 PCBs will be spares. It is important to understand that the soldering will take place in two stages:

1. In the first stage you will solder only the surface mount components (resistors, inductors, capacitors, RF integrated circuit amplifier). It is important to do this first, as this step requires the bottom of the PCB to be a flat surface. These components are too small to be easily soldered by hand, so we will do this using solder paste and a hot plate.
    a. Make sure the hot plate is on and pre-heated to 250 C.
    b. Use the soler paste syringe to dispense a very small amount of solder paste on each pad (just enough to cover the pad). Don't worry if you accidentally put solder paste outside of the pad or bridge the pads, as long as there is a small amount of solder paste, the solder will flow and surface tension will pull the solder only where the metallic pads are exposed.
    c. Use tweezers to gently put the components on the paste. You can gently push the components down. Don't worry about perfectly aligning the components, the surface tension will straighten them into place. The paste is tacky enough that the components will not shift while you move the PCB. <u>NOTE</u>: the large electrolytic capacitor has a polarity, so it should be placed in the correct orientation. The red band indicates the negative terminal.
    d. Use tweezers to place the PCB on the hot plate, which is pre-heated to the desired temperature. Do not place the PCB near the edge of the hot plate, otherwise the board will not heat up evenly. Within about 1 minute, the solder paste will melt and the components will be soldered. Watch closely to determine when the process is complete. You should see shiny wet metal on all pads bridging the pads to the components.
    e. Use tweezers to gently push the PCB to the edge of the hot plate and pick it up, placing it gently on a heat-resistant surface to cool it. Warnings: Careful not to touch the hot plate or the PCB shortly after you remove it, they are very hot! Handle the PCB very gently while it cools – the solder is still wet and parts can fall off easily before it solidifies.
2. In the second stage, you will solder the SMA connectors and the 2-pin header for the 9V supply. These are through-hole components and being larger these can be soldered by hand using a soldering iron and solder wire.

More information on how to solder and soldering a surface mount component can be found in the following two videos:

Soldering surface-mount components using solder paste: – Link (short demo) – Link (our test)
Basic soldering of through-hole components – Link

Testing your board

The FieldFox will now be used to make measurements on your board. We will first set it up similarly to when you made measurements on the test board.

1. Set up the FieldFox to operate on the external power supply. Start up the FieldFox and after it has loaded and launched the default CAT application, press the Mode button and then the NA

soft key to load and launch the Network Analyzer application. If they are not already present, install a Type-N to SMA adapter on port 1 and port 2 of the FieldFox.

2. The NA application starts up showing the S_{11} parameter over the full frequency range of 30 kHz to 4 GHz and presents this in a log-magnitude format.
3. Connect one end of a 24-inch long coaxial cable with SMA connectors to port 1. We will now perform the port extension to remove the effect of the length of the cable.
4. Set the frequency range between 0.9 and 1.1 GHz by pressing Freq/Dist and entering the desired values under Start and Stop menus. Set the marker at 1 GHz by pressing Marker and typing 1 GHz.
5. Press Measure, Format, and select Smith. The Smith chart should show a trace revolving several times around the screen (see Figure 2).
6. Press Measure Setup, Port Extensions, then the Port Extensions menu to activate the port extension feature.
7. Select Port1 Extension, then type 3 ns. This will reduce the trace length. However, the load does not appear to be a open circuit, and we need to fine-tune the port extension.
8. Select Port1 Extension again, and rotate the selector knob until the trace reaches the open circuit location on the Smith Chart and the trace collapses to a small circle and the equivalent reactance of the load is minimized (the equivalent reactance is shown as an inductance or capacitance on the top-right of the screen) – see Figure 2. Finally, press the Back button.
9. Attach another 24-inch ling coaxial cable with SMA connectors to port 2, select Measure, S22.
10. Repeat steps 4-8 to make a port extension on port 2. The Fieldfox now measures the characteristics of the networks connected to the cables without including the effect of the cables.
11. Make a note of the time delays used for port extensions on ports 1 and 2.

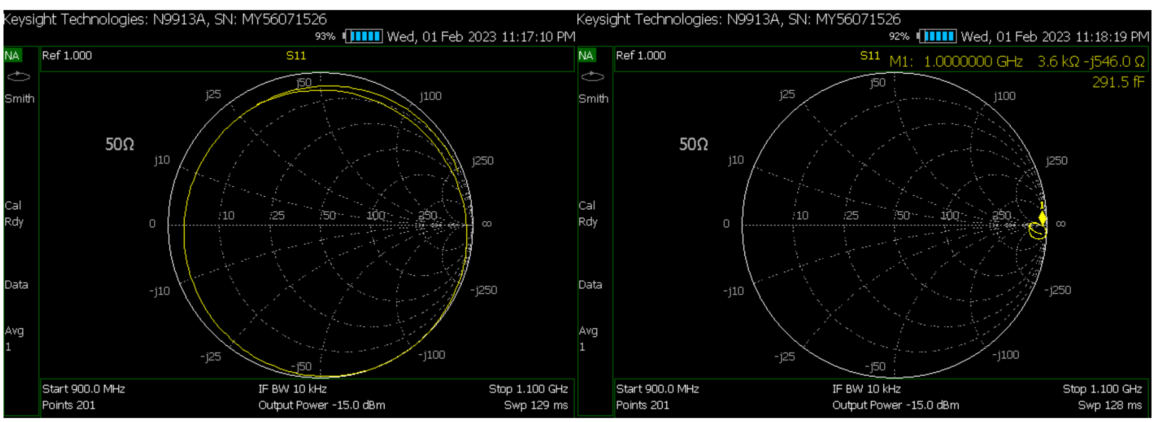

Figure 2 – Smith Chart of the S11 measurement between 0.9 and 1.1 GHz on the 24-inch cable before and after port extension.

You are now ready to make measurements of your board. Let's first check if the impedance matching networks have worked as expected. As we do this, think about where the Smith chart's marker should be located for a perfectly matched load.

1. Set the measurement to S11, and connect the cable to the input ports of your PCB, first for your stub-matched network, next for the quarter-wave transformer-matched network.
2. For either of those networks, where is the marker located on the Smith chart? If it is somewhere near the center of the chart, congratulations, you matched the test load to the 50 Ohm line of the Fieldfox!

If the marker was not located near the center, there may have been something unaccounted for, either in the design of the matching network, the layout of your design in the PCB, the fabrication of your board, or even in the measurements done on the test PCB. Perhaps, there was even some lack of repeatability giving rise to a difference between the load to be matched on the test PCB and your PCB (hint: are all components created equal?).

Reflect on the results of your measurement and the process you followed to get to this point, and list anything that could have gone wrong and the reason why you suspect this.

A likely scenario is that your design is just a bit off the target. To check this, let's expand the frequency range of the FieldFox to see if the curve on the Smith chart gets closer to the center at a different frequency.

1. Set the marker to report the magnitude of the reflection coefficient by pressing Marker → More → Marker Format → More → "Mag & Phase". Now you should see the marker reporting magnitude and phase of the voltage reflection coefficient along with the frequency.
2. Widen the frequency span by pressing Freq/Dist → Start → Enter 500 MHz → Stop 2 GHz.
3. Select Marker again, and use the rotary knob to scroll through the frequencies while observing the magnitude of the reflection coefficient. If you find a minimum, <u>make a note of this value and the associated frequency, and calculate the fraction of power that your matching network returns to the generator.</u> You may find that your network does a decent job, although at a different frequency.
4. Do this for both matching networks.

Now that you have isolated the frequency where you impedance matching networks work, let's look at the S parameters.

1. Press Measure → Format → "Log Mag"
2. Use the marker to measure the S11 parameter at the frequency where the best match is achieved (ideally a perfectly matched load with have an S11 parameter with a high negative number in dB units, indicating a small amount of power being reflected) Make a note of the S11 parameter for both of your impedance matching networks.

Let's now have a look at the RF gain block. We will set the FieldFox to make measurements using a different calibration to take into account losses in the cables, not just the delays as we did previously:

1. Set the FieldFox to measure the full frequency span from 30 kHz to 4 GHz, displaying the S_{21} parameter in Log Mag format.
2. Press Measurement Setup and set the Output Power mode to manual, then specify the output power to be -20 dBm. This ensures that we are not using too much input power. If we do so, the RF amplifier could deliver too much power and damage the FieldFox. <u>**WARNING: Never let the output power go above -10 dBm!!!**</u>
3. Select Cal → Quick Cal → Start Calibration, then follow the prompts
    a. In step 1 the instrument measures the cables open-ended, so make sure both ports 1 and 2 of the FieldFox are connected to the 24" cables and leave them open circuit. Hit Measure when ready.
    b. In step 2, connect a 50 Ohm load to the end of the cable on port 1, hit Measure when ready. You can use a 50 Ohm SMA load with female connector.
    c. In step 3, move the 50 Ohm load to the end of the cable on port 2, hit Measure when ready.

   d. In the last step, join the two ends of the SMA cables together using a female-female barrel connector, hit Measure when ready.
   e. Once finished, the instruments stores this calibration for the following measurements.
4. Connect the RF in port of your PCB to port 1 of the FieldFox (RF out), and connect the RF out port of your PCB to port 2 of the FieldFox (RF IN). This way the FieldFox generates a signal, which will go to the PCB amplifier, and once amplified the signal goes in the appropriate port of the FieldFox for measurement. At this point you should see an S_{21} plot at about -20 dB throughout the frequency spectrum. This indicates that some RF power makes it through your RF amplifier even though it is not yet powered on.
5. It is now time to provide power to the RF amplifier. **Warning: do not power the amplifier before making the RF connections, do not enable the DC power supply output before setting the appropriate voltage and current limits.**
6. Turn on the bench DC power supply, set it to 9 V DC, and if possible set a current limit to no more than 50 mA. This will ensure that the current delivered does not exceed a level that could break the RF IC. Do not enable the output yet.
7. Connect the output of the DC power supply to the correct pins of the 2-pin header of your PCB, making sure you have the correct polarity. If you did not mark the polarity on your PCB silkscreen, note the polarity of the electrolytic capacitor (red band marks the negative terminal).
8. Once you have verified the DC and RF connections, you can enable the output of the DC supply. When doing so, the current should be near 20 mA. If the supply provides significantly more current, something is wrong. In that case, disable the output of the supply and check your circuit and connections.
9. If everything is ok, observe how the S_{21} trace now shows gain instead of loss. Use the marker function to read the gain at 1 GHz, it should be near 20 dB. Congratulations, your amplifier works!
   a. What are the powers at the input and output of your amplifier at 1 GHz? Report these on eClass.
   b. Using the gain you obtain at 1 GHz as a reference, determine the -bandwidth of your amplifier by determining the frequency range within which the gain stays within 3 dB below the value at 1 GHz. Report this bandwidth on eClass.
   c. Ideally, this amplifier will yield a constant gain for all frequencies and all input power levels. However, the bandwidth and output power are limited. We want to characterize this output power limitation.
   d. Change the output power of the FieldFox to -45 dBm, then using the marker function, read the S_{21} parameter at 2 GHz. Measure the S_{21} parameter as function on the output power of the FIeldFox. Use 5 dB increments from -45 dBm to -25 dBm, then proceed to 1 dB increments up to -10 dBm. **Never let the output power go above -10 dBm!!!**
   e. Based on your measurements, deduce the output power from the gain, and plot output power versus input power. Use this plot to determine the output power at 1 dB compression, and compare this to the data sheet. The 1 dB compression point is when the gain of the amplifier is 1 dB lower than the ideal value obtained when the input is small. This is where the amplifier starts to struggle to provide the desired gain since the output is becoming large. Report these observations on eClass.

Grading scheme

This lab is out of 15 marks.

- 4 marks for completing the assembly of your PCBs
- 8 marks for answering the questions about the PCB testing section
- 3 marks for INDIVIDUALLY answering additional questions about this lab found on eClass

All questions can also be found on eClass, where you will enter your answers. Note that all group members may have similar answers, EXCEPT for the questions indicated that are to be answered INDIVIDUALLY, where each group member is expected to have their own answer.