M3 Testing Procedures (DRAFT)

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SDR Testing Board

To test your subsystem, you will make use of the ECE295 SDR Test Board (also known as the main board), which is discussed in the ICD. A diagram of the main board appears in Figure 1. This is a large board which has connectors that mate with each of the subsystems. It not only powers and allows each of the subsystems to be connected to each other, but also "breaks out" relevant signals to BNC connectors located on the edge of the board. This allows individual subsystems to be plugged into the board and tested, with the connectors acting as either stimulus inputs to the subsystem, or outputs facilitating easy connection to test equipment.

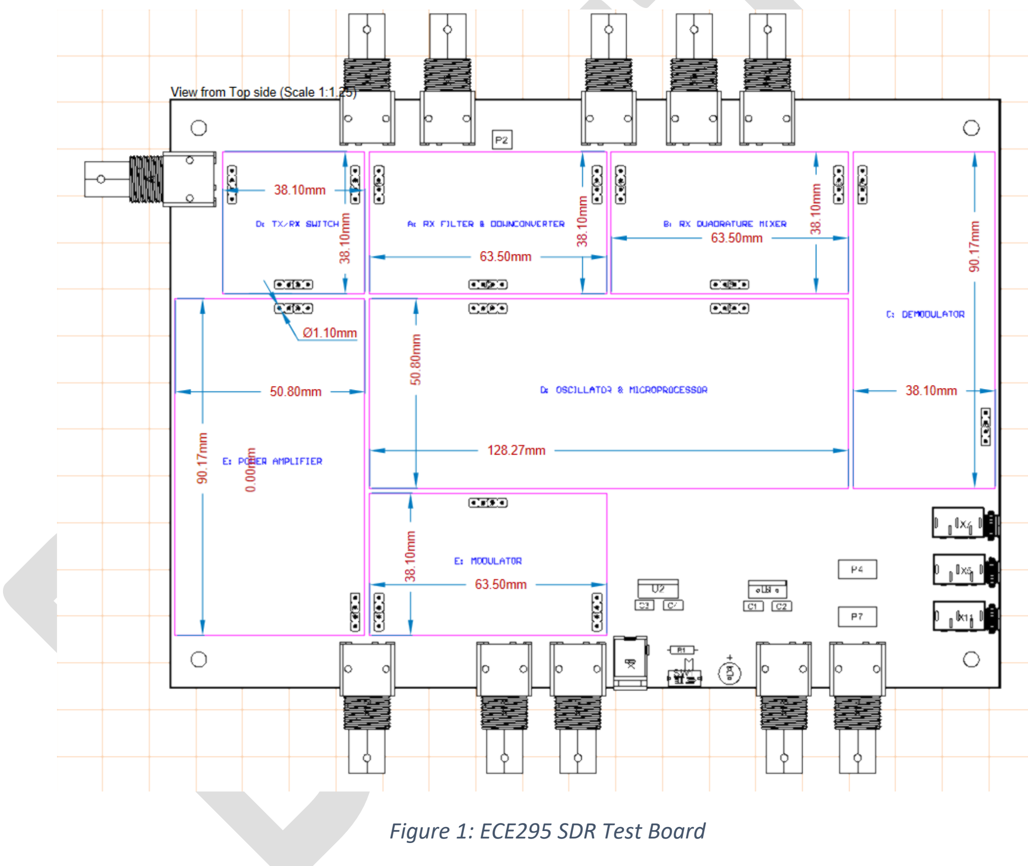

Figure 1: ECE295 SDR Test Board

The main board is available in the MY435 laboratory to be checked out and used. We now outline the important features of this board.

- Power to the board is supplied by a 2.1mm barrel jack at the bottom centre of the board (X1). You must obtain a 2.1mm coaxial cable from the lab staff in order to connect X1 to a power supply. **The polarity of the connection is extremely important**: if you look carefully at the end of the cable with the bare wire ends, you will see that one wire has a white stripe on it, while the other does not. **The wire with the white stripe is connected to the centre pin of the cable,**

which is the positive terminal: connect it to the positive output of Output 2 of the EDU36311A DC power supply. Output 2 should be set for 12V output. **If you connect this cable backwards, the main board will be damaged and rendered unusable**.

- There is a switch SW1 that is used to turn power on and off to the board, along with an LED D1 that indicates if the board is receiving power or not.
- At the bottom right corner of the board are three 1/8" audio jacks.
  - X7 (DEMOD OUT) is the output of the Subsystem C which is intended to go to a speaker. You can obtain speakers that plug into X7 in MY435.
  - X5 (IQ OUT) is for the I/Q outputs of Subsystem D, which can be optionally used by the SDR PC. The I/Q outputs are also available from BNC connectors X13 (RX_I) and X14 (RX_Q), so this jack should not be needed for M3 testing.
  - X11 (IQ IN) is for the I/Q inputs to Subsystem E. Like X5, this connector is for connection to the SDR PC and is not needed for M3 testing. Instead, I/Q signals for Subsystem E can be more easily applied to the BNC connectors X17 (TX_I) and X18 (TX_Q).
  - Associated with the audio jacks are jumpers P4 and P7, which should be fitted with shorting jumpers if jacks X5 and X11 are to be used. The positions of the jumpers can be used to determine how I and Q are routed to the left and right channels of the audio connector. You should not need to do anything with these jumper blocks for M3.
- The BNC connectors are as follows:
  - X6 (ANT) is usually for connecting to an external antenna, which is not used in M3. For M3, this connector can be used probe the output of the PA in Subsystem F, if the TX/RX switch is in the TX position. Since you may not have access to a TX/RX switch when doing M3 testing, you can simply insert a wire into the headers for the TX/RX switch to connect X6 to the PA output. See the specific test procedures below for details.
  - X2 (RX_SIG) is the received signal coming out of TX/RX switch when the switch is in the RX position. It can be used to stimulate Subsystem A directly without the need for the TX/RX switch in place.
  - X3 (LO_F2) is not used.
  - X4 (IF_SIG) is the output of Subsystem A. The connector can be used for two purposes:
    - To probe the output of subsystem A, to see if the filtering is working properly.
    - To stimulate the input of Subsystem B instead of using Subsystem A.
  - X9 (LO_F1_0) and X10 (LO_F1_90) are the 3.3Vpp LO signals.
    - If Subsystem D is installed on the test board, these connectors can be probed to see if the expected signals are present.
    - For other subsystems (Subsystems B and E): with Subsystem D absent, you can apply the desired LO signals here using a pair of signal generators to test your subsystems. See the specific testing procedure for details.
  - X13 (RX_I) and X14 (RX_Q) are the I/Q outputs from Subsystem B. They can be used as:
    - Probes to check the correct operation of Subsystem B.
    - Stimulus inputs for Subsystem C if Subsystem B is absent.
  - X17 (TX_I) and X18 (TX_Q) are the I/Q inputs to Subsystem E, which should be connected to signal generators for M3.
  - X12 (PA_IN) is the input signal to the PA. It can be used for two purposes:
    - If Subsystem E is installed, the output of Subsystem E can be probed here.

- If Subsystem F is installed alone, this connector can be used to apply a known stimulus to the PA without the need for Subsystem E.

There is an additional component that is needed for testing subsystems A and F: a 50 ohm dummy load. This is available in MY435 and resembles Figure 2.

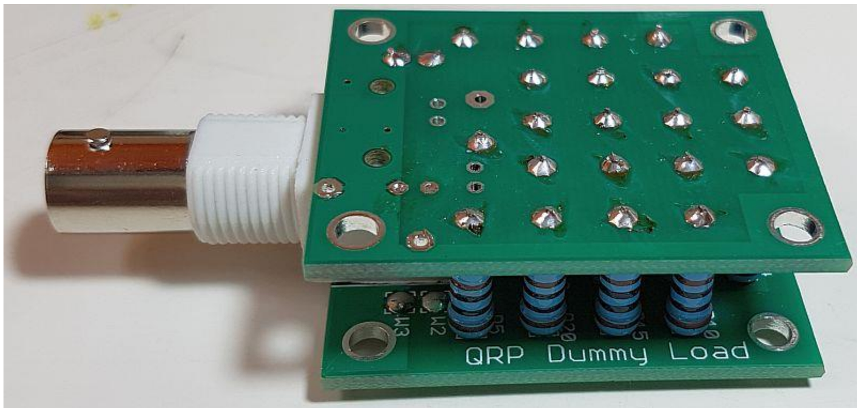

Figure 2: 50 ohm 20W dummy load

Subsystem Testing Procedures

In the subsystem testing procedures outline below, **you should only install one subsystem (PCB) in the testing board at once** (except for Subsystems A+B, and D, which each have two boards). These tests are written assuming all other PCBs are absent.

When doing initial subsystem testing, **you are strongly encouraged to initially set a current limit on the power supply** so that if there is a short circuit or other problem on your board, you may be able to limit the damage to your board. A current limit of 100-200 mA is sufficient for most cases. The output voltage of the power supply (Channel 2) should be set to 12V.

Detailed wiring diagrams of the tests below are available on Quercus as a separate file.

Subsystem A

NOTE: If testing Subsystem A without the TX/RX switch, no power needs to be supplied to the main board, since Subsystem A is passive.

Test equipment required

- Oscilloscope
- Function generator (optional if you use the one built-in to the oscilloscope)
- Two BNC T-junctions
- Three BNC cables
- 50 ohm dummy load
- Male/male BNC adapter

Procedure

1. Place one BNC “T-junction” at the output of the signal generator (GEN OUT) on the oscilloscope.
2. Connect one port of the T-junction to Channel 1 of the oscilloscope using a BNC cable. This way you can see the stimulus.
3. Connect the other T-junction port to X2 to a signal generator using a BNC cable.
4. We need to measure the output of Subsystem A as if it were terminated in a 50 ohm load. Connect the X4 to another BNC T-junction and place a 50 ohm dummy load on one half of the T-junction (you will need the male/male BNC adapter).
5. Connect the other T-junction port to the oscilloscope Channel 2 using a BNC cable.
6. Set the amplitude of the function generator to 1Vpp.
7. Set the frequency of the function generator to the desired frequency.
8. Measure the output of Subsystem A on the oscilloscope as the frequency is varied. Create a Bode plot of the filter. You may consider using the Frequency Analysis tool built into the oscilloscope to do this once you have things working.
9. Vary the amplitude of the input signal at a fixed frequency to check the operation of the limiter.

List of Measurements to Acquire to Reconcile with Requirements

☑ Bode plot showing frequency response of RX filter
☑ Oscilloscope trace(s) showing operation of limiter

Subsystem B

NOTE: Subsystem B can be potentially tested without Subsystem A installed. See instructions below.

Test equipment required

- Oscilloscope
- Two Function generators
- Power supply and coaxial power cable for SDR board
- Five BNC cables
- 50 ohm dummy load
- Hookup wire

Procedure

1. One signal generator will act as the RF signal source. You should use the internal function generator on the oscilloscope for this signal source. Set it up as follows. You should set the input signal to be small since you do not want to overload Subsystem B, since it has a very high gain.
    a. Signal amplitude: 50 mVpp
    b. Signal frequency: 14 MHz plus an offset, e.g. 10 kHz (or some other LO and offset frequency you want to test).
2. You may first want to probe the output of the signal generator on the oscilloscope prior to connecting it to the testing board, to be sure you are getting the correct signal going into the board.
3. Disable the function generator output and connect the RF signal source to the board.
    a. If Subsystem A is installed and functioning, the function generator can be connected to X2.
    b. If Subsystem A is not installed, connect the function generator to X4, which bypasses Subsystem A.
4. You will need two additional function generators: one to generate LO_F1_0 and the other to generate LO_F1_90. The settings on each are as follows:
    a. Output termination: High-Z (**it is very important to set this first, since all the parameters below will not be set properly if you do not**)
    b. Frequency: 14 MHz (or whatever LO frequency you would like to test)
    c. Waveform: Sine wave (**even if you want a square wave you must select a sine wave; the function generator cannot generate non-sinusoidal signals with a frequency higher than 10 MHz**).
    d. Amplitude: 3.3Vpp
    e. DC Offset: 1.65V – this will create a 0-3.3V amplitude signal with the above.
5. Connect both signal generators to an oscilloscope using identical BNC cables. Refer to Appendix B for addition procedures to synchronize the outputs of the function generator and place them 90 degrees out of phase with each other.
6. When you are happy with the two signals, disable the function generator outputs and connect them to X9 and X10 on the test board.
7. Connect the outputs of Subsystem B, X13 and X14, to oscilloscope channels 1 and 2.
8. If your board makes use of the /TXEN signal, you will need to set it low manually, since Subsystem D is absent. You can do this by using a piece of hookup wire. Refer to the wiring diagram. Plug in one wire end to the left-most pin of J9; this is the /TXEN signal. Plug the other end into the second pin of

J10 from the left; this is +3.3V, which should set the /TXEN signal high, thereby enabling receive mode.

9. Power up the test board an ensure the current draw seems reasonable. The subsystem should not output any signal with all the function generator outputs disabled.
10. Enable the two function generator outputs responsible for LO signal.
11. Enable the signal generator responsible for the RF signal.
12. Observe the output on the oscilloscope. If everything is working, you should have a signal whose frequency is equal to the offset frequency. If not, it is possible you have the phase relationship between the two LO signals backwards, e.g. one is lagging by 90 degrees when it should be leading.
13. Optional: try testing your board with the /TXEN signal low (transmitter enabled, receiver disabled). You can do this by plugging in the /TXEN wire into the left-most pin of J10, which is +GND.

Questions to consider relating to the specifications of the ICD:

1. What is the total gain from the RF signal to the IF signal?
2. Is there a way to test the gain of your amplifier introduced after the mixer?
3. What is the bandwidth of the mixer for a fixed LO frequency?

List of Measurements to Acquire to Reconcile with Requirements

- ☑ Oscilloscope trace(s) showing the I/Q signals obtained at the output, including measurements of:
    - o Amplitude balance between I/Q
    - o Phase difference between I/Q
- ☑ Oscilloscope traces or measurements showing the conversion gain of the entire subsystem, input-to-output
- ☑ Bode plot showing frequency response of RX mixer for a fixed LO frequency
- ☑ Optional: operation of the mixer when /TXEN is set to transmit mode

Subsystem C

Test equipment required

- Oscilloscope
- Two function generators
- Power supply and coaxial power cable for SDR board
- Four BNC cables

Procedure

SSB Demodulation Test

1. Place your Subsystem C in SSB demodulation mode.
2. Two function generators are used to generate the I/Q signals required for the demodulator: one for I and one for Q. The settings on each are as follows:
    a. Output termination: High-Z (**it is very important to set this first, since all the parameters below will not be set properly if you do not**)
    b. Frequency: 1 kHz (or whatever message frequency you would like to test)
    c. Waveform: Sine wave
    d. Amplitude: 100 mVpp (adjust as needed)
3. Connect both signal generators to an oscilloscope using identical BNC cables. Refer to Appendix B for addition procedures to synchronize the outputs of the function generator and place them 90 degrees out of phase with each other.
4. When you are happy with the two signals, disable the function generator outputs and connect them to X13 and X14 on the test board.
5. Power up the test board an ensure the current draw seems reasonable. The subsystem should not output any signal with all the function generator outputs disabled.
6. Enable the function generator outputs. You should observe a single-frequency sine wave at the output of Subsystem C (you will have to probe a suitable point on your PCB for this). If the amplitude (envelope) of the AC waveform is not constant, you likely are getting both the upper and lower sideband superimposed on top of each other, and you will have to debug the problem.
7. If you are satisfied with the signal, you can disable the function generators, turn off the power and connect a speaker to jack X7.
8. Turn on the power and enable the function generators. You should hear a tone from the speaker at 10 kHz (or whatever frequency you chose for the IF).
9. Experiment with the volume control on your subsystem to ensure it works as you intended.

AM Demodulation

1. Place your Subsystem C in AM demodulation mode.
2. Only one function generator is needed to produce an AM signal. The settings are as follows:
    a. Output termination: High-Z (**it is very important to set this first, since all the parameters below will not be set properly if you do not**)
    b. Frequency: 100 kHz (or whatever carrier frequency you would like to test)
    c. Waveform: Sine wave
    d. Amplitude: 100 mVpp (adjust as needed)
    e. Modulation: AM, with 1 kHz sinusoidal message signal, 100% modulation depth

3. Power up the test board an ensure the current draw seems reasonable. The subsystem should not output any signal with all the function generator outputs disabled.
4. Enable the function generator output. You should observe a single-frequency 1 kHz sine wave at the output (you will have to probe a suitable point on your PCB for this). If not, you may have the phase between the LO signals backwards, e.g. one is leading by 90 degrees when it should be lagging. In that case, you would be demodulating the wrong sideband (i.e. lower sideband [LSB] instead of upper sideband [USB]). This is still useful, as you will need to measure both.
5. Reverse the phase relationship between the LO signals to measure the other sideband. Compare the amplitudes of the USB and LSB signal.
6. If needed, switch the LO signals so that you are observing the USB signal. If you are satisfied with the signal, you can disable the function generator, turn off the power and connect a speaker to jack X7.
7. Turn on the power and enable the function generator. You should hear a tone from the speaker at 1 kHz (or whatever frequency you chose for the message).
8. Experiment with the volume control on your subsystem to ensure it works as you intended.

Questions to consider relating to the specifications of the ICD:

1. What is the bandwidth of your demodulator in each mode (AM and SSB-USB)?
2. What is the ratio of the upper sideband amplitude to the lower sideband amplitude (i.e. the *sideband rejection ratio*) of your demodulator in SSB mode?
3. Are you able to get a sufficiently loud signal from your subsystem?

List of Measurements to Acquire to Reconcile with Requirements

- ☑ Oscilloscope trace(s) showing the demodulated signals obtained at the output in
    - AM mode
    - SSB mode: LSB
    - SSB mode: USB
- ☑ Measurements illustrating the SSB sideband rejection ratio
- ☑ Plots illustrating the bandwidth of your demodulators as the frequency of the message signal is changed, for:
    - AM mode
    - SSB mode
- ☑ Be prepared to show the subsystem working with the speaker / volume control

Subsystem D

Test equipment required

- Oscilloscope
- Multimeter
- Power supply and coaxial power cable for SDR board
- Two BNC cables
- Two BNC-to-alligator cable

Procedure

Local Oscillator

1. Connect the oscillator outputs X9 and X10 to the oscilloscope channels 1 and 2 respectively, using identical BNC cables.
2. Connect your Subsystem D board to a PC using the USB-to-serial adapter.
3. Power up the test board an ensure the current draw seems reasonable.
4. Command your subsystem to produce a 14 MHz LO signal using your front-panel interface.
5. Check that you have two signals 90 degrees out of phase on the oscilloscope. You can check the frequency of the signal, as well as the phase difference between Channel 1 and Channel 2 using the Measure key. Do not worry if the amplitude of your clock signals is not exactly 3.3 Vpp.
6. Repeat steps 4-5 using suitable CAT commands issued from the PC.
7. Power down the test board.

TX/RX Switch

1. Connect one BNC-to-alligator cable to X6.
2. Connect the red alligator clip to the VΩ input on the multimeter using a test probe.
3. Connect one BNC-to-alligator cable to the X2.
4. Connect the red alligator clip to the LO input on the multimeter using a test probe.
5. Put the multimeter in Continuity Test mode (Cont key).
6. Power up the test board.
7. If your subsystem is configured to be in the RX state by default, the multimeter should signal continuity between the probes with an audible beep. If the subsystem is in the TX state by default, there should be no continuity.
8. Command your subsystem to go into TX mode using your front-panel interface and check for correct operation.
9. Repeat using suitable CAT commands issued from the PC.
10. If you wish, you can also check for continuity between the ANT port (X6) and the PA output from Subsystem F via J18. Refer to the ICD for the pinout of this connector.

List of Measurements to Acquire to Reconcile with Requirements

☑ Oscilloscope trace(s) showing the LO signals, including measurements of:
  - Amplitude balance the two LO signals
  - Phase difference between two LO signals
  - Frequency of the generated signals, for various settings as made through the front-panel interface and computer interface.

- ☑ Be prepared to demonstrate:
  - How the LO frequency is changed using your front-panel user interface
  - Correct operation of the TX/RX switch when controlled by either the front-panel interface or the computer interface
  - Correct operation of the “IF” command on the serial terminal

Subsystem E

Test equipment required

- Oscilloscope
- Power supply and coaxial power cable for SDR board
- Four function generators!
- Five BNC cables
- 50 ohm dummy load
- BNC T-junction
- Male/male BNC adapter
- Hookup wire

Procedure

1. Two function generators are used to generate the I/Q signals required for the mixer: one for I and one for Q. The settings on each are as follows:
    - Output termination: High-Z (**it is very important to set this first, since all the parameters below will not be set properly if you do not**)
    - Frequency: 1-10 kHz (whatever message frequency you would like to test)
    - Waveform: Sine wave
    - Amplitude: 1 Vpp (adjust as needed)
2. Connect both signal generators to an oscilloscope using identical BNC cables. Refer to Appendix B for addition procedures to synchronize the outputs of the function generator and place them 90 degrees out of phase with each other.
3. When you are happy with the two signals, disable the function generator outputs and connect them to X17 and X18 on the test board.
4. You will need two additional function generators: one to generate LO_F1_0 and the other to generate LO_F1_90. The settings on each are as follows:
    - Output termination: High-Z (**it is very important to set this first, since all the parameters below will not be set properly if you do not**)
    - Frequency: 14 MHz (or whatever LO frequency you would like to test)
    - Waveform: Sine wave (**even if you want a square wave you must select a sine wave; the function generator cannot generate non-sinusoidal signals with a frequency higher than 10 MHz**).
    - Amplitude: 3.3Vpp
    - DC Offset: 1.65V – this will create a 0-3.3V amplitude signal with the above.
5. Connect both signal generators to an oscilloscope using identical BNC cables. Refer to Appendix B for addition procedures to synchronize the outputs of the function generator and place them 90 degrees out of phase with each other.
6. When you are happy with the two signals, disable the function generator outputs and connect them to X9 and X10 on the test board.
7. Connect a BNC T-junction to the output of your subsystem, at X12. This way we can connect a 50 ohm load impedance across the output while also monitoring the output signal. This is not absolutely needed, but the PA, if designed correctly, is to present a 50 ohm load to your subsystem.
8. Connect the 50 ohm dummy load to one port of the T-junction using the male/male BNC adapter.

9. Connect the other port of the T-junction to the oscilloscope (Channel 1).
10. If your board makes use of the /TXEN signal, you will need to set it manually, since Subsystem D is absent. You can do this by using a piece of hookup wire. Refer to the wiring diagram. Plug in one wire end to the left-most pin of J9; this is the /TXEN signal. Plug the other end into the left-most pin of J10; this is GND, which should set /TXEN low and enable your subsystem.
11. Power up the test board an ensure the current draw seems reasonable. The subsystem should not output any signal with all the function generator outputs disabled.
12. Enable the LO function generators and check current draw again.
13. Enable the TX signal function generators and check the current draw again.
14. Have a look at the output signal on the oscilloscope. You should see a clean sinusoidal signal at 14.01 MHz. You may need to adjust the amplitude of the TX signal function generators if your output is saturated or otherwise unexpected in some way.
15. The FFT function on the oscilloscope can make it much easier to see the individual frequency components in the signal being measured. See the Appendix at the end of this document for details on how to set up the FFT. The following discussion assumes the message signal is at 10 kHz:
    - If you notice the lower sideband (LSB) signal at 13.99 MHz is larger in amplitude than the upper sideband (USB) signal at 14.01 MHz, you probably have the phase difference between the two LO signals backwards, i.e., one is lagging by 90 degrees when it should be leading.
16. Optional: test the functionality of your subsystem with /TXEN set high. (subsystem disabled)

List of Measurements to Acquire to Reconcile with Requirements

☑ Oscilloscope trace(s) showing the output signals, including measurements of:
  - Amplitude of the output signal
  - Frequency of the signal

☑ Oscilloscope traces or measurements showing the conversion gain of the entire subsystem, input-to-output

☑ Frequency purity of the output signal: there should only be one frequency (that of the upper sideband [USB], e.g. 14.01 MHz) present in the signal. Show the amplitude of other frequency components that may be present in the FFT, i.e. LO (14 MHz) and lower sideband (LSB, e.g. 13.99 MHz)
  - Calculate the SSB sideband rejection ratio, which is the ratio of the USB signal to the LSB signal amplitudes

~~☑ Bode plot of the frequency response of the PA and lowpass filter, for a small-signal input.~~

Subsystem F

Test equipment required

- Oscilloscope
- Power supply and coaxial power cable for SDR board
- Two BNC cables
- 50 ohm dummy load
- BNC T-junction
- Male/male BNC adapter
- Hookup wire
- Thermal camera (optional)

Procedure

NOTES BEFORE YOU BEGIN:

- It is very important that a 50 ohm load be present at the output of your PRA during tests, or else your power amplifier may be damaged! This is included in the steps below. Do not run your PA without the load attached.
- The transistors in your output stage may become hot during operation. Ensure you have attached appropriate heat sinks to them and do not touch them.
- The 50 ohm load will become hot when your PA is delivering power to them. They are designed to handle up to 20W of power. Do not touch them.
- Take care to begin testing your PA with small signals, and gradually build up to full-scale output. Your PA can be damaged if you push it too far.

1. As there is no TX/RX switch installed, you need to hard-wire the ANT connector (X6) to the output of the power amplifier so that you can observe the signal there. You can do this using the female connectors on the test board that normally mate with Subsystem D.2 (TX/RX switch). Use a short piece of solid-core 22 AWG wire to connect the right-most pin of J13 to the bottom pin of J11, as shown in the wiring diagram.
2. Connect a BNC T-junction to X6.
3. Using the male/male BNC adapter, connect one port of the T-junction to the 50 ohm dummy load. **It is very important that this load be present during tests, or else your power amplifier may be damaged!**
4. Configure the function generator on the oscilloscope (WaveGen) as follows:
    a. Output termination: High-Z (**it is very important to set this first, since all the parameters below will not be set properly if you do not**)
    b. Frequency: 14 MHz (or whatever RF frequency you would like to test)
    c. Waveform: Sine wave
    d. Amplitude: 0.1 Vpp
5. Connect the function generator temporarily to Channel 1 of the oscilloscope using a BNC cable, enable the output, and ensure the waveform is as you expect.
6. Disconnect the BNC cable from Channel 1 and connect it to the PA input X12.

7. Using another BNC cable, connect the other port of the T-junction to Channel 1 of the oscilloscope.
8. If your board makes use of the /TXEN signal, you will need to set manually, since Subsystem D is absent. You can do this by using a piece of hookup wire. Refer to the wiring diagram. Plug in one wire end to the left-most pin of J9; this is the /TXEN signal. Plug the other end into the second pin from the left of J10; this is +3.3, which should set /TXEN high and disable your PA.
9. Power up the test board current draw seems reasonable with your PA disabled. The subsystem should not output any signal with the function generator output disabled.
10. Now set the /TXEN signal low by plugging into the left-most pin of J10 (GND). Determine if the test board current draw seems reasonable with your PA idle (no input signal). The subsystem should not output any signal with the function generator output disabled.
11. Enable the function generator output.
12. Observe the resulting waveform on the oscilloscope. It should be a nice sinusoidal signal at 14 MHz.
13. Calculate the power delivered to the 50 ohm load and determine if this is what you expect for a 0.1 Vpp input.
14. Gradually increase the amplitude of signal input to the PA and track what happens to the output waveform in terms of power output (amplitude), clipping, etc. **Caution: the dummy load will get very warm for large output powers from the PA (more than 1 W)**.
15. Do not push your PA too far. This could damage your output transistors, especially if you do not have adequate heat sinking on them.
16. Using the FFT function of the oscilloscope, measure the amplitudes of the various harmonics (at least to the $n = 5$ harmonic) for various output powers. See the Appendix for more information on using the FFT function.
17. Optional: check out the temperatures on your board using the thermal camera.

List of Measurements to Acquire to Reconcile with Requirements

- ☑ Oscilloscope trace(s) showing the LO signals, including measurements of:
- ☑ Current and corresponding power consumption calculations of your board when:
    - /TXEN is high (PA disabled)
    - /TXEN is low but no signal applied (PA enabled but idle)
    - /TXEN is low but signal applied (try this for a few input signal levels including that needed for full rated output from your PA).
- ☑ FFT measurements including harmonic amplitudes up to $n = 5$
- ☑ Total harmonic distortion (THD) measurements carried out using measurements using the FFT
- ☑ Power output of the PA as a function of the applied signal amplitude (Vpp)
- ☑ Your assessment of the maximum power output of the PA given requirements
- ☑ Optional: thermal image of your PCB

Appendix A: FFT Measurements

The Fast Fourier Transform (FFT) is a powerful function on the oscilloscope that enables you to visualize the frequency spectrum of your input signal. While turning on and off the FFT function is easy (just use the FFT key on the oscilloscope), setting up the timebase and FFT settings for a meaningful measurement is another matter. This appendix discusses how to properly set these.

When you enable an FFT measurement, you must first select which Source you want to take the FFT of (Channel 1 or 2). Be sure to set this appropriately using the menu keys.

The frequency range of the FFT is determined by setting the *center* frequency and frequency *span* of the FFT. These are also set in the FFT menu using the menu keys and the knob. The FFT will determine the spectrum of the input signal between frequencies f_1 and f_2. The center frequency and span are related to f_1 and f_2 through:

$$\text{center frequency} = \frac{f_1 + f_2}{2}$$

$$\text{span} = f_2 - f_1$$

Inverting this relationship,

$$f_1 = \text{center frequency} - \frac{\text{span}}{2}$$

$$f_2 = \text{center frequency} + \frac{\text{span}}{2}$$

Clearly, the center frequency and span are set very differently, depending on what you are measuring. If you are looking at a modulated RF signal (e.g. output of Subsystem E), you only care about the carrier frequency and a relatively narrow band (span) around that frequency, perhaps only a tens of kHz wide, depending on the bandwidth of the message signal. On the other hand, if you are looking at the harmonics produced by mixer or power amplifier, then you are looking for frequencies at integer multiples of the carrier frequency, resulting in a very wide frequency range spanning many tens of MHz.

This is where the timebase (sec/div) setting of the oscilloscope comes in. Since the oscilloscope samples signals at a fixed rate (2 GSa/s), the timebase must be set so that the scope acquires a sufficiently long measurement (in seconds) to capture enough variation of the signal to provide usable FFT information over the frequency span you have requested. If the timebase is not set correctly, you will not have enough resolution in the FFT to see individual frequency components. The FFT may even not show any useful information at all, if the timebase is not set correctly.

Example 1: FFT of Modulated RF Signals

Consider an RF carrier signal at 14 MHz, AM modulated with a message signal at a frequency of 5 kHz. From our understanding of AM, we only expect frequency components at 13.995 MHz, 14 MHz, and 14.005 MHz at the output of an AM modulator. If the modulation depth is 100%, the 14 MHz carrier is suppressed, and only two frequency components will remain.

To see several periods of the AM signal, we actually need to set the timebase according to the period of the message signal, **not** the period of the carrier signal. The message signal has a period of $T = \frac{1}{5000} = 200\ \mu s$. Usually, we want to display several periods of a periodic signal on the oscilloscope screen. Say we want to show 5 periods. This would require us to acquire $5 \times 200 = 1000\ \mu s$ or 1 ms of samples. Since there are 10 time divisions on the oscilloscope screen, this requires a timebase setting of $\frac{1000\ \mu s}{10} = 100\ \mu s$/div. We can then set the FFT to compute the spectrum centered at 14 MHz and with an arbitrary span of 50 kHz, which should be more than enough to see our two frequency components at 13.995 MHz and 14.005 MHz. The result is shown in Figure 3.

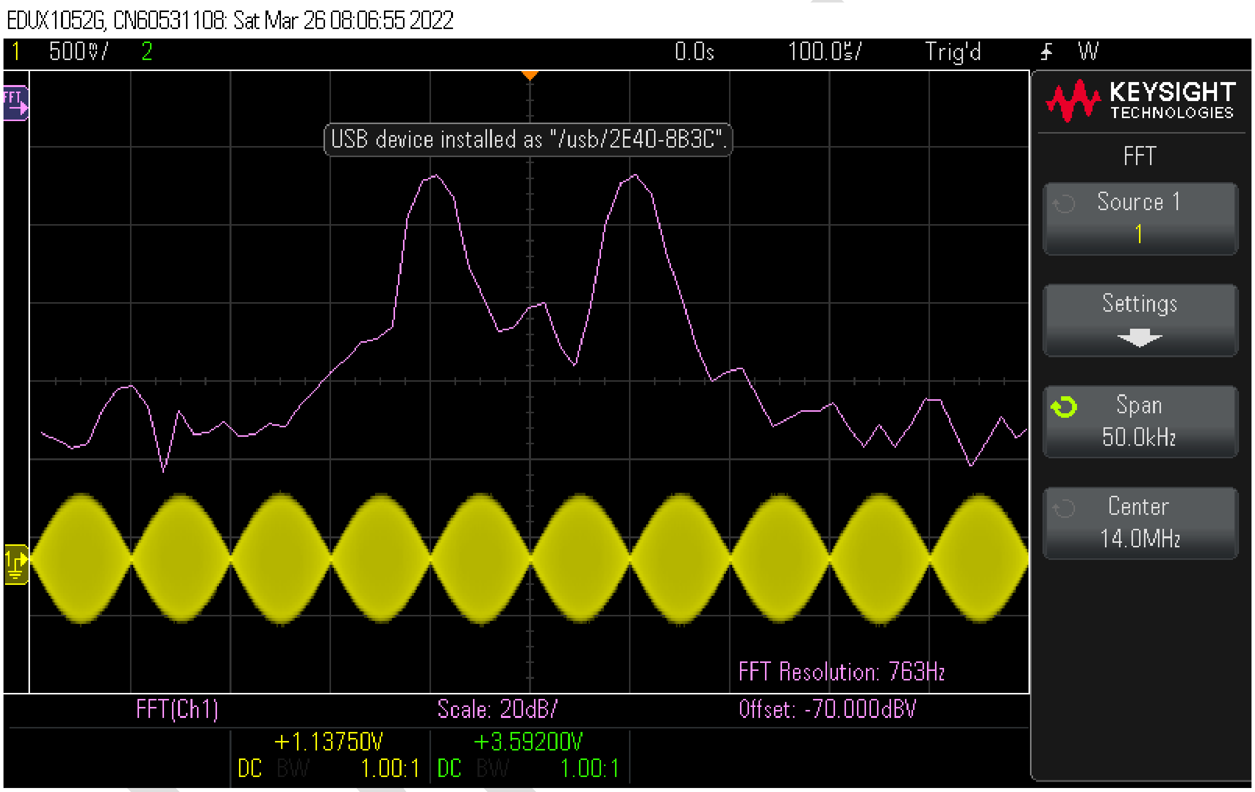

Figure 3: FFT of an AM modulated signal

As expected, we see two spikes in the frequency spectrum. If we use the cursors, we can see that they peak at the expected frequencies. One is the lower sideband and the other is the upper sideband. You may wonder why they are not very “spikey” or narrow like the delta functions we expect. The reason is that the FFT does not have infinite frequency resolution, because it depends on how many time samples were acquired to compute the FFT, which we have limited control over. Here the FFT resolution is reported to be 763 Hz; that means that we can only resolve frequency components more than 763 Hz apart from each other. Given that the “distance” between 13.995 MHz and 14.005 MHz is only 10 kHz, that’s only 13 frequency points separating the upper sideband and lower sideband in the plot; and remember the plot is on a dB scale (with a whopping 20 dB per division), so all things considered, the two frequency spikes are fairly close to delta functions given the limited resolution of our measurement.

Example 2: Harmonic Spectra of an CW Signal

In the second example, we assume that a single-frequency signal (also known as a continuous wave or CW signal) has gone through a nonlinear device like a mixer or power amplifier, resulting in the production of harmonics. If the fundamental frequency is 14 MHz, we expect harmonics at 28 MHz, 42 MHz, 56 MHz, etc. The frequency span we want to measure over is quite wide. The considerations for the timebase are totally different when the expected frequency span is very wide.

In this case, the timebase setting plays a strong role in setting the frequency resolution of the FFT (the spacing between the frequency points), because the timebase directly determines how many data samples are acquired by the scope for the FFT. The scope samples at a fixed rate of 2 GSa/s, so changing the timebase from 10 µs/div to 100 µs/div for example will result in 10 times more data samples being acquired. The number of data samples determines the frequency resolution: the larger the number of data samples (i.e. the higher the timebase setting in s/div), the greater the frequency resolution. If there is insufficient frequency resolution, it can be difficult to pick out various spectral components in the FFT.

Figure 4 shows one example. This is a distorted 14 MHz signal acquired with a timebase setting of 2 µs/div. We can see the 14 MHz fundamental on the left, a weak second harmonic signal, stronger third harmonic, and then a weaker 4th harmonic. The harmonics are hard to see, but they are resolvable. This is because the FFT resolution is only 30.5 kHz – that is, there is 30.5 kHz between individualk frequency points in the plot.

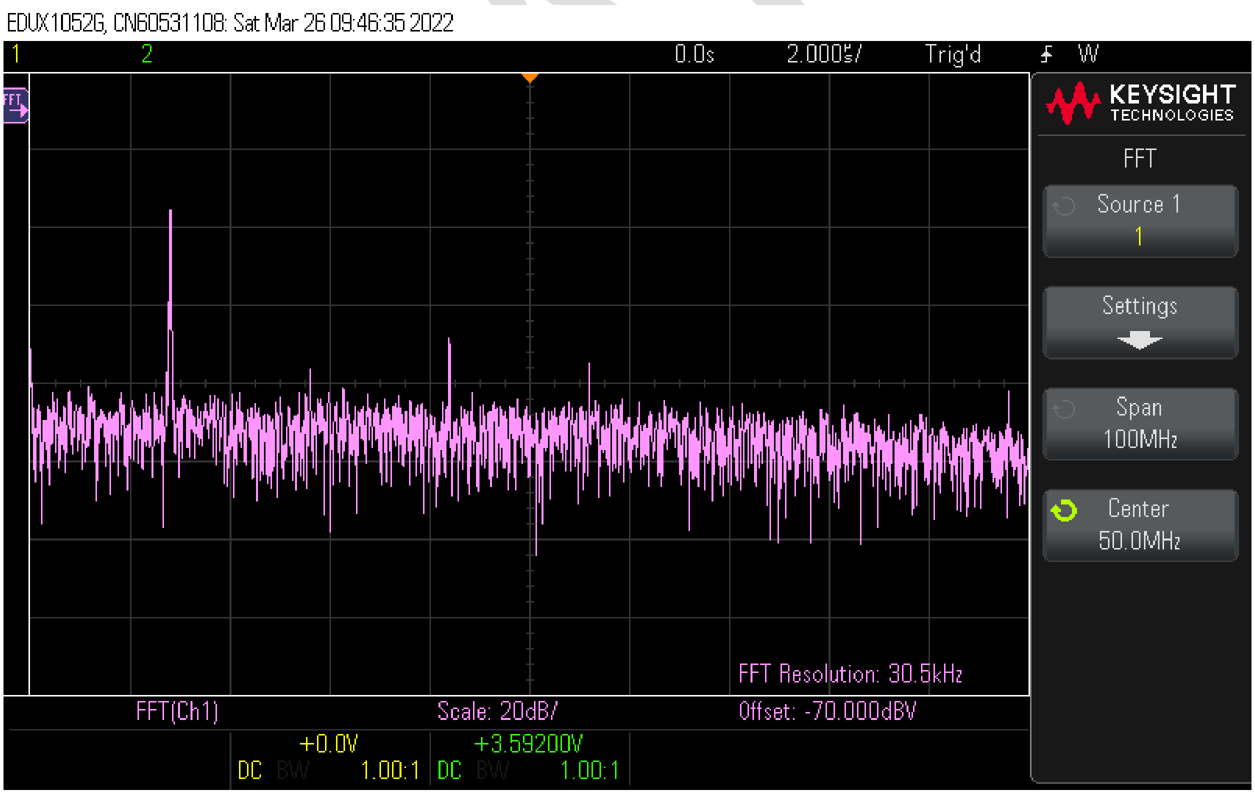

Figure 4: FFT of a distorted RF signal, 2 µs/div

When we increase the timebase to 5 µs/div, the FFT in Figure 5 results. Notice how it is easier to resolve the spectral components in the signal. The frequency resolution is also twice what is was previously:

now there is only 15.3 kHz between frequency points (the plot comprises many more points now, resulting in a more "dense" plot).

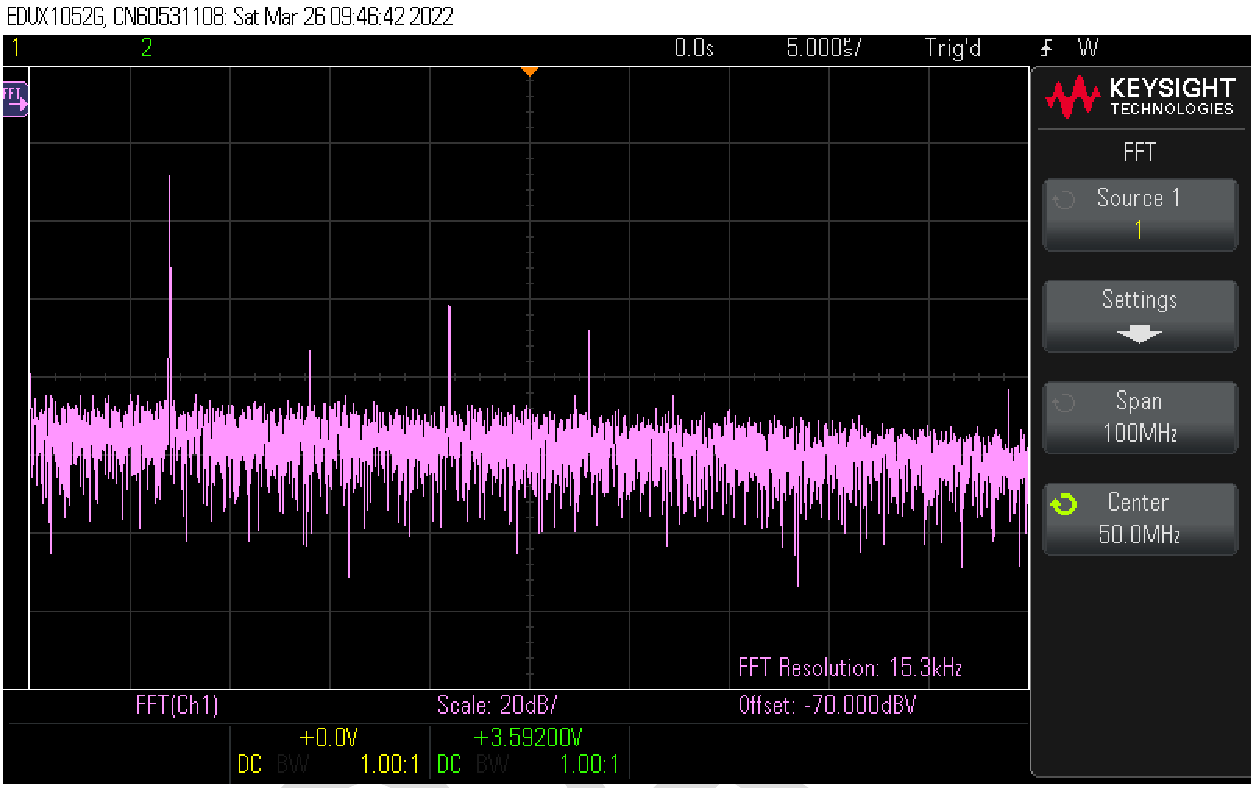

Figure 5: FFT of a distorted RF signal, 5 µs/div

Practically, both plots are usable; for example, they both show the same relative ratios of amplitudes between the fundamental signal and its harmonics. The second requires a longer acquisition time (and more memory), and so ultimately your needs will be determined by the exact requirements of your measurement.

Appendix B: Synchronizing Function Generator Outputs

Subsystems B, C, and E require two signals at the exact same frequency, 90 degrees out of phase with each other. Since two independent function generators are used to synthesize these signals, a problem arises with synchronizing the two generators so that they both produce identical frequencies with a phase-lock between them. This is in fact a common problem because the oscillators in each instrument are independent and hence cannot oscillate in exactly the same way (think of two vehicles with their turn signals on at an intersection and how they are not in time with each other). A way is needed to synchronize the two signal generators. Sophisticated instruments derive their signals from a common reference signal which can be shared between instruments, but that is not the case for the ECE295 lab instruments, so a workaround is needed.

1. Connect both signal generators to an oscilloscope using identical BNC cables.
2. One signal generator will be the MASTER. Connect a BNC cable to the SYNC / TRIGGER OUT connection on the front panel.
3. The other signal generator will be the SLAVE. Connect the other end of the cable in step 2 to the EXT TRIG / GATE / FSK / BURST connection on the front panel.
4. Configure the master signal generator to generate a sine wave with the desired amplitude, frequency, and phase.
5. Configure the slave generator waveform to be identical to the first one.
6. Enable the outputs of both generators and view the outputs on the oscilloscope. You should see two sine waves, but they will not be synchronized: one will appear to "slide" past the other one because they are not at identical frequencies (the stationary one is the one the scope is triggered off of).
7. On the master generator, press TRIGGER and select the SYNC menu option so that SYNC is ON. This produces the required synchronization signal at the SYNC / TRIGGER OUT port.
8. On the slave generator, press BURST and the following menu settings on the right side of the screen:
    a. "Burst" should be ON
    b. "N-cycle / Gated" should be set so that "N-cycle" is selected
    c. "# Cycles / Infinite" should be set so that "# Cycles" is selected
    d. Set the "Start Phase" to be the phase difference you want between the master and the generator: +90 or -90 degrees
    e. Set the "# of Cycles" to be a large number, such as 10000.
9. On the slave generator, press the TRIGGER button and choose the "Source" menu option. Change the source to "External".
10. Confirm that the two outputs are now synchronized. The slave signal should no longer "slide" past the master one, but it may appear jittery as the synchronization is only performed periodically. This is why this solution is more of a "workaround" rather than proper synchronization, but it should suffice for testing.
11. The outputs should be 90 degrees out of phase with each other; confirm this using the Measure button and feature on the oscilloscope to measure the phase difference between the two channels.