ECE453 Lab 1. Spectrum Exploration

A spectrum exploration is our first lab exercise for ECE453. In this lab, you’ll have the opportunity to visualize signals from the many wireless transmitters that surround us. We’ll start working with the lab’s test and measurement equipment, including signal analyzers, signal generators, and oscilloscopes. You’ll be able to investigate RF emissions from both licensed sources and unlicensed Part 15 devices.

Learning Objectives

In this lab, we will learn to:

1) Setup frequency and power of unmodulated Signal Generator output
2) Relate power in linear units (mW) and log scale units (dBm) to voltage
3) View the chosen part of RF spectrum with MXA Signal Analyzer
4) Identify sources of RF emissions (e.g. radio station, WiFi, etc.)
5) “Catch” and display the spectra of bursts of signal
6) Resolve details of the spectra by adjusting MXA settings
7) Measure RF emissions from various common Part 15 devices

Background Information

Part I. Observing Signal Generator Output

Signal analyzers are used to measure and display signals in the frequency domain. The one we use in the 453 lab does so by taking many time-domain samples and performing a discrete Fourier Transform. The higher the resolution of spectral measurement (the lower the RBW), the more sample points are needed. The reduction of RBW also reduces the noise floor. Can you figure out why? The MXA has various detection options, which include max hold, useful for capturing bursts of signals, and averaging. To learn how to use these (and numerous other) measurement features of the MXA, you can refer to the Keysight “Spectrum Analyzer Mode Measurement Guide” posted in the Additional Information section of our lab website.

Signal generators are used to create high frequency signals. These signals can be modulated, but we will deal with unmodulated carriers today. The SG output can be connected to a cable or an antenna.

Oscilloscopes are probably familiar to you already. They are used to display signals in time domain. The scopes are neither as sensitive nor as accurate as MXAs, but are useful for signal visualizations. For triggering of the signal itself, it is helpful to have a periodic signal, such as an unmodulated SG output used today. The measurements of the signals, such as frequency and Vpp can be displayed on the scope. The power delivered to the scope port can be calculated by

\[
P_{ave} = \frac{V_{pp}^2}{8R}
\]
where V_{pp} is the peak-to-peak signal amplitude, in volts, and R is the scope input impedance, 50 ohms. (Note: most of the lab instruments we’ll work with have been designed around a 50 ohm reference impedance, which will simplify matching and power transfer calculations.)

When considering communication systems, power is often given in logarithmic units, dBm. One of the reasons for that convention is that it makes it easier to keep track of losses and gains. Also, displaying spectra in a logarithmic scale allows one to visualize weak signals in the presence of strong ones. The dBm units (dB with respect to 1 mW) are defined in the following manner:

\[ P_{dBm} = 10 \log_{10} P_{mW} \]

It is useful to remember that 1 dB is a factor of about 1.25, 3 dB is a factor of about 2, and 10 dB is a factor of 10. One can use these facts, for example, to quickly calculate that -14 dBm is 1 mW/(10*2*1.25) ≈ 40 µW. One can obtain the same result by inverting the formula above:

\[ P_{mW} = 10 \frac{P_{dBm}}{10} \]

**Part II. Observing Spectra from the Roof Discone Antenna**

A discone antenna (AOR DA3200) is positioned on the roof of the ECE building and attached to a cable that is dropped into the 453 lab. The antenna nominally covers the wide 25-3000 MHz frequency range, allowing us to observe many different signals available in our vicinity. Below 25 MHz, the emissions’ power is not captured as efficiently, but many peaks can still be observed. We can see (or hear, if you prefer) AM radio, FM radio, NOAA weather radio, TV signals, cell phone towers, air traffic control, municipal services, etc. They are operating in bands allocated by the FCC in accordance with ITU guidelines. See pages 15 and 16 of the ECE 453 course notes for a guide to these frequency bands.

The following Internet resources may help you in your efforts to identify signals:

1. radio-locator.com -- AM and FM broadcast radio stations
2. nws.noaa.gov/nwr/Maps/ -- NOAA weather radio
3. fcc.gov/media/engineering/dtvmaps -- television stations
4. radioreference.com -- aviation, municipal, public safety, and other miscellaneous

**Part III. Observing Spectra from Part 15 devices**

Part 15 of the FCC rules describes permissible use of unlicensed low power RF transmitters. Some of these devices act as transmitters by design (baby monitors, walkie-talkies, etc. can, of course, be operated without a license). Some devices (e.g. radio receivers) have accidental, or “spurious” emissions. All emissions must follow FCC rules and guidelines, which are readily available on the internet. Some of these rules only limit the field strength of the emission at a prescribed distance from the source. Others specify the time characteristics, such as intermittent transmissions.
Procedures

The different parts of the procedure below are independent and can be done out of order.

Part I. Observing Signal Generator Output

1. Turn on: Signal Generator (SG), Oscilloscope (scope), and MXA Signal Analyzer (login required)
2. Record the name, make, model numbers for each of the above instruments.
3. Setup the SG for an unmodulated carrier (sinusoidal) at \( f = 100 \text{ MHz} \), \( P = 0 \text{ dBm} \)
4. Connect the SG to the Scope (set 50Ω input) with a provided cable.
5. Fill in the table below by varying the SG output power (negative dBm!)

<table>
<thead>
<tr>
<th>P (dBm)</th>
<th>P (μW) (calculated from prev. column)</th>
<th>V_pp (mV) (measured on scope)</th>
<th>P_calc (μW) (calculated from prev. column)</th>
<th>P_MXA (dBm) (measured on MXA)</th>
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<tbody>
<tr>
<td>0</td>
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</table>

6. Adjust the MXA settings to measure the -100 dBm SG signal (with span > 2% of frequency)
7. Record MXA center frequency, span, RBW, # of points, duration of scan

Part II. Observing Spectra from the Roof Discone Antenna

1. Log into the MXA Signal Analyzer (if not done yet)
2. Attach the roof antenna to the input (consult lab instructor)
3. Set frequencies to measure from .3 MHz to 3 GHz (can break into parts)
4. Save a broad spectrum screenshot. In a table, identify the frequencies and sources of at least 5 peaks that can be seen – no more than two from the 88-108 MHz FM band.
5. Using your MXA and an Internet search, identify one example of each of the following transmissions. Zoom in to get a good look at the signal. (Don’t need to save/record data)
   a. Air traffic control
   b. 88-108 MHz FM
   c. NOAA weather radio
   d. Digital TV
   e. Municipal services/public safety
6. For your lab report, make a detailed presentation for two of the transmissions you found. (No more than 1 from 88-108 MHz broadcast FM)
   a. Measure and save (to a file) the best spectral representation
   b. Describe the MXA instrument settings (frequencies, RBW, averaging, etc.)
   c. Listen to the signal using the lab’s audio receiver. Record your observations.
   d. What is the center frequency, callsign (if available), modulation type, and content of the signal? Record your findings.
Part III. Observing Spectra from portable devices

1. Log into the MXA Signal Analyzer (if not done yet)
2. Attach a small antenna to the input (consult lab instructor)
3. Find the emission from three of the provided Part 15 devices. Record the frequencies.
4. Make a detailed presentation for the emission from one of your three devices
   a. Measure and save (to a file) the best spectral representation
   b. Describe the MXA instrument settings (frequencies, RBW, averaging, etc.)
   c. Describe the signal

Optional Explorations

Explore power vs. distance relationship
Explore emission from other portable devices
Identify more peaks on the spectrum from the roof antenna
Switch to the log-periodic antenna and observe differences in signal strength
Ask lab instructor for more ideas

Report Guidelines

1. Brief description of the lab (2 pts)
2. Brief description of instruments (3 pts)
3. Brief description of Part I. (2 pts)
4. Completed table of Part I. (6 pts)
5. Explanation of calculations (formulas) for the table. (3 pts)
6. Brief description of Part II. (2 pts)
7. Broad spectrum in 1-4 plots with 5 peaks identified in various bands. (4 pts)
8. Spectra and detailed descriptions (include source) of two given peaks. (6 pts)
9. Brief description of Part III. (2 pts)
10. List frequencies and source descriptions of 3 observed Part 15 emissions. (4 pts)
11. Spectrum screenshot and detailed description of one of the Part 15 emissions. (3 pts)
12. One paragraph reflections from each lab partner (include name). (3 pts)

   General report formatting, organization, clarity. (5 pts)

Total: 45 pts

Expected length of report is 4-7 (max!) pages, depending on graph format, line spacing, etc.