CornellEngineering
Electrical and Computer Engineering

ECE 4880: RF Systems

Fall 2016

Lab 1: RF Instrumentation and Spectrum Exploration

1 Learning Objectives

The students will learn to:

1) Set up frequency and power of unmodulated Signal Generator (SG) output
2) Relate power in linear units (mW) and log scale units (dBm) to voltage (V) and ratio (dB)
3) View the chosen RF spectrum with Spectrum Analyzer (SA)
4) Identify sources of RF emissions (e.g. radio station, WiFi, etc.)
5) "Catch" and display the spectra of bursts of signals
6) Resolve details of the spectra by adjusting SA settings

2 Background Information

2.1 Observing Signal Generator Output

Spectrum Analyzers are used to measure and display signals in the frequency domain. This is often done by taking many time-domain samples and performing a Discrete Fourier Transform (DFT). The higher the resolution of spectral measurement (the lower the resolution of bandwidth, aka, RBW), the more sample points are needed. Alternatively, this can be viewed as lower frequency behavior needing longer time of observation. The reduction of RBW most often reduces the noise floor. Can you figure out why? The SA has various detection options, which include "max hold", useful for capturing bursts of signals, and "averaging", useful for continuous-wave (CW) observation.

Signal generators (SG) are used to create high-frequency signals. These signals need to be *modulated* to carry data, but we will only deal with unmodulated carriers in Lab 1. Carrier frequency dictates the air protocol sharing and antenna designs, and its full understanding and characterization are important. The SG output can be connected to an RF cable or an antenna. RF cables are broadband waveguides that direct and confine the electromagnetic energy along the propagation line, while the antenna radiates electromagnetic energy to the air in all directions as a point source (but the energy will have some angular dependence, as isotropic waves cannot propagate), or selected directions as a beam.

Scopes are, likely, the most familiar instruments to your previous experience. They are used to display signals in the time domain. Because SA collects data from many cycles and performs DFT, the scopes are neither as sensitive nor as accurate as SAs, but are useful for signal visualizations. For triggering (or equivalently synchronization) 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 period and amplitude can be displayed on the scope. As shown in Fig. 1, there are several conventions for recording the CW voltage waveform of $V(t)=a\cos(\omega t)$ at a fixed spatial location with the angular frequency of $\omega = 2\pi f$ (Hz):

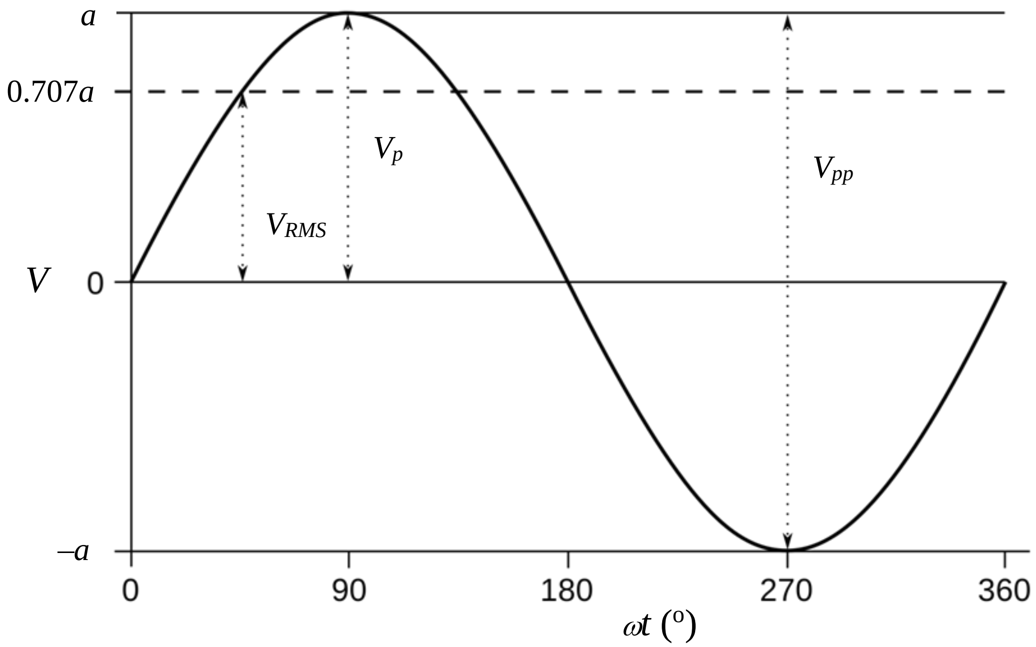

Fig. 1. Magnitude representation of a single-tone CW wave $V(t) = a \cdot cos(\omega t)$. This is similar to what will be displayed on an oscilloscope.

$$a = V_p = \sqrt{2} V_{RMS} = \frac{V_{pp}}{2} \qquad (1)$$

where $V_p = a$ is the amplitude, V_{pp} is the peak-to-peak voltage and V_{RMS} is the root-mean-square amplitude. The power delivered to the scope port with a characteristic input impedance of R (often at 50Ω) can be calculated by:

$$P_{av} = \frac{V_{RMS}^2}{R} = \frac{V_p^2}{2R} = \frac{V_{pp}^2}{8R}\,. \qquad (2)$$

When considering communication systems, power is often given in logarithmic units, dBm (decibel milliwatt, i.e., denote the ratio to 1mW by the unitless dB). One of the reasons for that convention is that it is easier to keep track of losses and gains in a signal chain where multiplication of gains in the linear unit becomes addition in the logarithmic unit. Also, displaying spectra in a logarithmic scale allows one to more easily visualize weak signals in presence of the strong ones. The dBm units (dB with respect to 1 mW) are defined in the following manner:

$$\begin{aligned} P_{dBm} &= 10\log_{10} P_{mW} \\ P_{mW} &= 10^{P_{dBm}/10} \end{aligned} \qquad (3)$$

It is useful to remember that 1 dB is a factor of about 1.25, 3 dB is 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 1mW/(10×2×1.25) ≈ 40μW. Although in other context, power can be denoted by dBW (decibel watt) or dBc (sideband power in ratio of the carrier), dBm is the most popular notation in the RF and acoustic context, which we will use consistently. Remember that dBm is a power unit (e.g., 20dBm is 100mW), while dB is always a unitless ratio (e.g., the ratio between 20dBm and –10dBm is 30 dB).

Now we will understand the spectrum analyzer (SA) a bit more in depth to understand its operations and limitations. There is only one RF input port RF_{in} for spectrum analyzer, which is by default set to R_{in} = 50Ω input impedance. Inside the SA, there is a RF source that outputs a monotone frequency which is called the local oscillator (LO). LO sweeps frequency in the bandwidth around the center frequency that you set. A mixer in SA then performs a signal multiplication of the RF_{in} and LO, and integrate over many periods to evaluate the frequency component of RF_{in} around the LO frequency f_{LO}.

From the Fourier analysis we know that RF_{in} can be decomposed into its frequency components, which is the measurement output we are seeking for:

$$V_{RF} = \sum_i v_i \cos(\omega_i t) \qquad (4)$$

where v_i is the voltage magnitude at the angular frequency $\omega_i = 2\pi f_i$. We have used the summation instead of the integral for the Fourier transform, and v_i should be related to the power contained around f_i within a frequency resolution of Δf_i, which is the RBW you set. The SA mixer performs the multiplication and integration:

$$\int_{t_0}^{t_1} V_{RF}(t)\cdot V_{LO}(t)dt = \int_{t_0}^{t_1}\left[\sum_i v_i \cos(\omega_i t)\right]\cdot A_{LO}\cos(\omega_{LO}t)dt \cong \frac{1}{2}v_{LO}A_{LO} \qquad (5)$$

where v_{LO} stands for the “average” Fourier component of RF_{in} around f_{LO} in terms of RBW Δf_{LO}. The spectral power density v_{LO}^2/R_{in} is then displayed as the SA output.

You can see that the spectrum analyzer is really a “broadband” radio receiver in many senses. As LO is a physical signal and the mixer contains realistic noises, where the noise power is proportional to the present setting of RBW, SA will have the following behavior:

1. When many sampling points in various LO frequencies are measured, the output refresh rate will be lower. This is mainly because the frequency synthesizer that generates LO will need time to change to the next value.
2. When you set a large sweeping frequency range with high RBW, there will be many sampling points and the refresh rate would be low.
3. When RBW is large, the noise floor will be higher, as the thermal noise, one of the main noise components, has a constant (white) noise spectrum. The larger the bandwidth you listen to, the higher the total noise power.
4. The frequency range that can be measured by SA is limited by the range of f_{LO} that can be generated. At the low and high ends, LO may not be of top quality as a monotone signal and accuracy will be somewhat compromised.

2.2 Observing Spectra from mobile devices

Mobile devices often have their wireless communication within Part 15 of the FCC (Federal Communication Commission) rules, which describes permissible use of unlicensed low-power RF transmitters. Some of these devices act as transmitters by design (baby monitors, walkie-talkies, cell phones, WiFi, speed radar, etc.). Some devices (e.g. radio receivers, transformers, displays, etc.) have accidental, or “spurious” RF emissions. As the free space is shared by everyone, to guarantee interference bounds, all emissions to free space 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. Transmission by cables is only limited by the leakage outside the ground shielding, while emission in an enclosed room (such as MRI) is governed by outside leakage as well. We will learn more FCC regulations throughout the semester.

3 Lab Procedures

3.1 Observing Signal Generator Output

1. Turn on: Signal Generator (SG), scope and Spectrum Analyzer (SA).
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 MHz, P_{av} = 0 dBm. Use the Frequency and Amplitude keys on the front panel for this purpose. The unit options are on the right side of the screen, access them using the corresponding menu keys close to the screen.
4. Connect the SG to the ‘RF Input 50Ω’ port in the Spectrum Analyzer with a RF cable.
5. Switch on the RF on/ off button on SG.
6. Set the center frequency of the SA with FREQ key. In this case, set it to 100 MHz. The frequency unit keys are placed close to the numeric keys on the front panel.
7. Adjust the span with SPAN key.
8. Use the BW key to adjust the resolution bandwidth (RBW). Current RBW is visible on top of the screen. Notice that it might be set to ‘Auto’ in the beginning (menu is displayed on the right side of the screen). Use the corresponding keys on the right of the screen to access the menu, and set it to ‘Manual’. Experiment with the RBW values and observe the changes. (Hint: Notice the change in noise floor level and the number of sampling points – as explained above).
9. Fill in the table below by varying the SG output power (negative dBm!). The third column is from the scope measurement. (Hint: you may need to adjust scope settings). When the signal is too noisy to record a meaningful number, state so. The fifth column is from the SA measurements.
10. In order to observe the maximum amplitude with marker, use MKR/ MKR–> keys. MKR–> key can directly assign the marker to the center frequency (use the menu option for this as well). You can also have additional marker keys from the menu to observe the noise floor levels. Rotate the round button to slide the marker.
11. In case the maximum power level goes beyond the screen level, change the Reference Level. It is the first option when you press the AMPT key.

Table 1. SG output to scope and SA.

P_{av} (dBm) from SG setting	P_{av} (μW) from SG (calculation)	V_{pp} (mV) from scope	P_{av} (μW) from scope	P_{av} (μW) from SA
0				
–10				
–20				
–30				
–40				
–90				
–100				

12. Adjust the bandwidth span from 2% to 10% to measure the signals.
13. Record SA center frequency, span, RBW, # of sampling points, and duration of scan. Use the SWEEP button to access option ‘Sweep Point’. This will give the number of sweep points (that can be user specified). The Sweeptime (SWT) is visible on top of the screen.

3.2 Observing Spectra from mobile devices

1. Turn on the SA.
2. Attach a small broadband antenna to the input (consult lab instructor).
3. Set frequencies to measure from .3 MHz to 3 GHz (can break into various parts).
4. Find the emission from your cell phone.
5. Make a detailed presentation for the above emission
   a. Measure and save (to a file) the best spectral representation. The SA has Windows environment. Data can be saved to the SA memory or external USB. Use the FILE key on the front panel to access the menu options. Go to More -> Export -> ASCII File Export. Select the Path, provide the file name and click on Save.
      The format of data storage is as follows: The details are at the top. The first (leftmost row) is frequency and the next (center row) gives the corresponding amplitude in dBm.
   b. Describe the SA instrument settings (frequencies, RBW, averaging, etc.).
   c. Describe the signal (include source of info, observation with receiver).

4 Optional Explorations

- Explore power vs. distance relationship for your cell phone
- Different emission spectra from cell phones in various status (dormant, in conversation, WiFi on, etc.)
- Identify more peaks on the spectrum, especially on the harmonic frequency
- Measure the drift of the signal generator output (zoom in RBW)
- Noise skirt around the center frequency of the signal generator

5 Report Guidelines

The main purpose of the lab report is to present findings (and enable people to trace, and repeat if necessary) of your results. Therefore, the ambient information is as important as the direct results from the instrument. The following content is suggested, but not meant as a template or limitation.

1. Brief description of the lab
2. Brief description of instruments
3. Brief description of the procedures
4. Measurement results in 3.1 (including filling of Table 1)
5. Check consistency in various columns at various SG output power levels in 3.1
6. Measurement results in 3.2, recognizing peaks in various bands
7. Records for the optional exploration

When you put your report together, two special things are worth your attention, which you may know before: figures and references. Your quantitative plots need to be readily readable with clear axis labels, units and tick marks. Do not just take the default settings. Make sure all of the fonts on the figure are readable. Non-readable numbers do not mean anything to the reader, except your negligence or your intention to hide something. For schematics, hand-drawn ones are acceptable for lab reports. However, if you use ANY artwork and direct figures from existing literature, an explicit quote is necessary.

References are usually not needed for lab reports. However, if you do need to quote one, please follow standard formats such as IEEE (preferred), ACM, APS or Harvard citation styles. You can use a footnote or a reference section at the end for the full citation information.

For report submission, please name your lab reports as: netid_netid_ECE4880_Lab1 for two students in a lab group. Submit your final report in Word or pdf to kan@ece.cornell.edu.