THE UNIVERSITY OF BRITISH COLUMBIA
Department of Electrical and Computer Engineering

ELEC 391 – Electrical Engineering Design Studio II

# Lab Assignment 1 – Spectrum Analyzers

## 1 Objectives

This lab consists of four experiments that demonstrate the use of a spectrum analyzer to:

- measure the power spectrum of selected periodic signals,
- (in conjunction with a signal generator) measure the frequency transfer function (both magnitude and phase) of a low pass filter,
- measure the frequency spectrum of an FM signal that has been modulated by a sinusoidal signal, and,
- measure the RF spectrum of the AM and FM broadcast bands.

## 2 Lab Preparation

Before the lab session, please solve the following problems *on your own* and submit the answers to your teaching assistant at the beginning of the lab session. Although the pre-lab assignments will not be formally marked, they will be checked for completeness and correctness and will be considered when your mark for the lab assignments are assigned.

### 2.1 Fourier Series Expansions

Using Fourier series expansions, determine the power spectrum of each of the signals $s_1(t)$, $s_2(t)$, $s_3(t)$ that are described in the Procedure section of Experiment 1.

### 2.2 Plot the Magnitude and Phase Responses of Butterworth Filters

The transfer function of an $n$th order Butterworth filter was given in the lecture notes. Use MATLAB or a similar free package (*e.g.,* Octave or Scilab) to find and plot the magnitude and phase responses of Butterworth filters with a corner frequency of 5 MHz for $n = 1, 2, \ldots, 6$. In each case, plot the location of the poles and zeros in the $s$-plane. (Hint: Even an all-pole filter has zeros. Where are they?)

# 3 Lab Schedule

1. *Before your assigned lab period:* Review the lab assignment and begin the prelab assignment in Section 2 on your own! Although the assignment will not be formally marked, it will be checked for completeness and correctness and will be considered when your mark for this lab assignment is assigned.

   Meet with your lab partners to discuss the lab assignment and to assign responsibilities during the lab session.
2. *During the scheduled lab period:* Submit your individual prelab assignment and work with your lab partners to complete the four experiments described in the lab assignment handout.
3. *During the few days after your assigned lab period:* Meet with your lab partners to plot and/or reduce your data, to draw conclusions, and to the group lab report.
4. *Three days after your assigned lab period:* Submit your group lab report for marking.

# 3 Test and Measurement Equipment

The following equipment and accessories will be used in this lab session. Where applicable, please record the serial numbers of each item.

1. RF Signal Generator (Agilent, model 8648B, 9 kHz – 2 GHz)
2. Function/Arbitrary Waveform Generator (Rigol, model DG1022, 2 Channel, 20 MHz, 100 MSa/s)
3. Spectrum analyzer (Rigol, model DS 815), 9 kHz-1.5 GHz)
4. Dual-channel oscilloscope (Tektronix, model TDS 2012C, 100 MHz)
5. 2-input combiner (Mini-Circuits, model ZSC-2-1, 0.1-400 MHz)
6. 20 dB attenuator (Mini-Circuits, HAT-20 (DC-2 GHz))
7. Low-pass filter (Mini-Circuits BLP-5)

In order to protect the input of the spectrum analyzer, please make absolutely certain that the signal at the output of the signal generators does not exceed 5 $V_{p\text{-}p}$

# 4 Experiment 1: Power Spectrum of a Periodic Signal

## 4.1 Procedure

Using the experimental setup shown below, please find the power spectrum of the following signals:

1. $s_1(t)$ - a square wave with a frequency of 1 MHz, a duty cycle of 50% and a peak-to-peak amplitude of 2 V across a load of 50 Ω.
2. $s_2(t)$ - a square wave with a frequency of 1 MHz, a duty cycle of 20% and a peak-to-peak amplitude of 2 V across a load of 50 Ω.
3. $s_3(t)$ - a triangle wave with a frequency of 250 kHz and a peak-to-peak amplitude of 2 V across a load of 50 Ω.

In each case, **verify the shape and amplitude of the signal using the oscilloscope**, select and justify appropriate spectrum analyzer settings, including the center frequency, frequency span, resolution bandwidth, and sweep time, then estimate the spectrum.

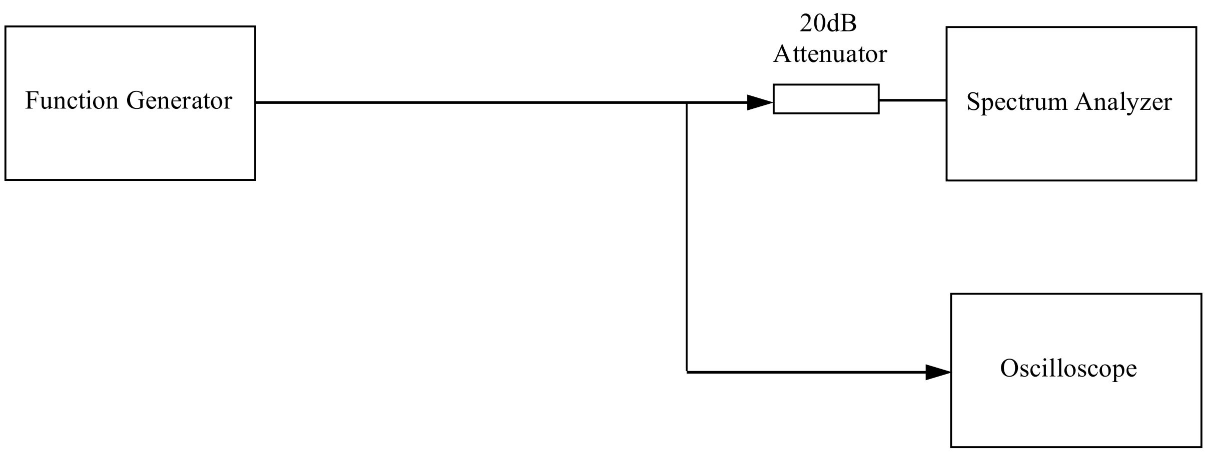


Figure 1: Experimental setup – measurement of the power spectrum.

## 4.2 Issues for Discussion

In your discussion section, please address the following issues:

1. How do the measured power spectra of the above signals compare with the theoretical results that you obtained before coming to the lab? How large is the difference between the measured and theoretical results?
2. Which of the three signals has the greatest high frequency content? Why?
3. What considerations guided your selection of appropriate spectrum analyzer settings?

# 5 Experiment 2: Frequency Response of Filters

## 5.1 Procedure

Using the experimental setup shown below, please find and plot the frequency response (magnitude and phase) of the Mini-Circuits BLP-5 low-pass filter. List the spectrum analyzer settings used, including the center frequency, frequency span, resolution bandwidth, and sweep time.

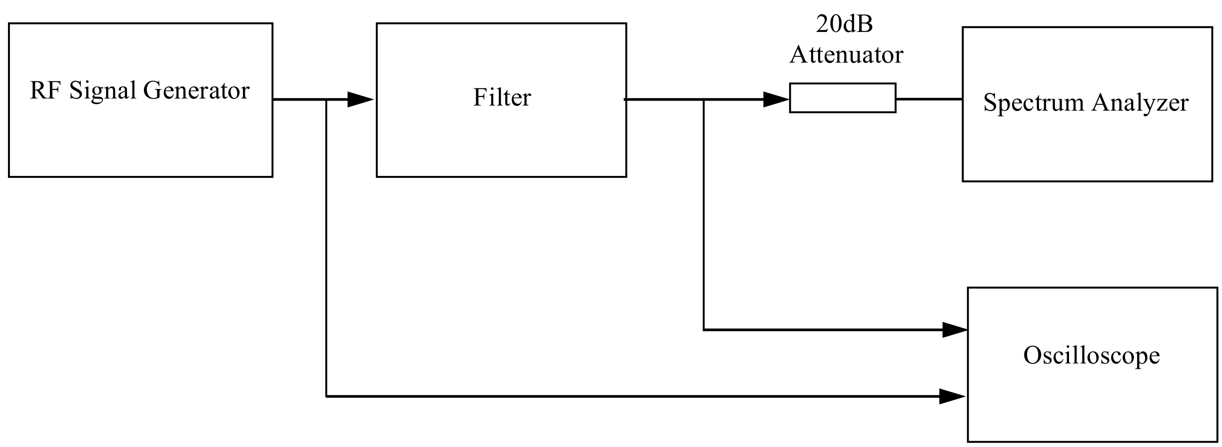


Figure 2: Experimental setup – Measurement of the frequency response of a filter.

1. Apply a 1 MHz sinusoidal signal with an amplitude of approximately 2 V peak-to-peak to the filter input. Use:
   a. the oscilloscope to measure the signal amplitude at the input of the filter.
   b. both the oscilloscope and the spectrum analyzer to measure the signal amplitude at the output of the filter.
   c. the oscilloscope to measure the phase difference between the input and output signals by direct measurement of the time delay.
2. In order to determine the overall frequency response of the filter, repeat the above for twenty frequencies over the range 1 – 10 MHz. Verify the assumption that the output of the function generator varies only minimally with frequency. Determine the precise frequency at which the power at the filter output falls half of its maximum value, *i.e.*, the 3-dB point in its frequency response.

### 5.2 Issues for Discussion

In your discussion section, please address the following issues:

1 How does the measured frequency response of the filter compare with the theoretical results that you obtained before coming to the lab? How large are the differences between the measured and theoretical results?

2 What is a tracking generator? How might one be used to facilitate measurement of the frequency response of a system?

3 Could one measure the complete frequency response of the filter (magnitude and phase) using only a conventional swept-tuned spectrum analyzer? Explain.

4 What are the tradeoffs between using an oscilloscope-based *vs*. using a spectrum analyzer-based frequency response test set.

# 6 Experiment 3: Frequency Modulation

## 6.1 Procedure

Prepare the experimental setup shown below. When measuring the FM signal, please pay particular attention to appropriate selection of the spectrum analyzer settings, including the center frequency, frequency span, resolution bandwidth, video bandwidth, and sweep time.

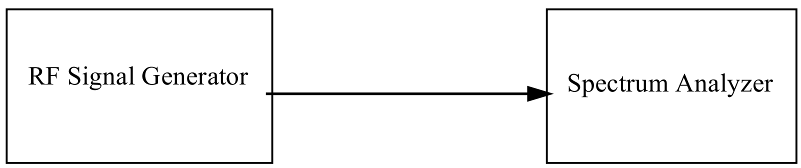


Figure 3: Experimental setup – Analysis of FM signals.

1. Configure the RF signal generator to output an unmodulated carrier of frequency 100 MHz and amplitude -10 dBm.
2. Configure the spectrum analyzer to have a centre frequency of 100 MHz, a span of 50 kHz, and a resolution bandwidth of 1 kHz. The video bandwidth and sweeptime will be set automatically.
3. Activate FM modulation using the internal 3 kHz modulating signal. Increase the frequency deviation in seven steps from 0 Hz to 100, 200 500, 1000, 2000, 5000, and 10,000 Hz. In each case, observe the resulting spectrum, adjust the spectrum analyzer settings as required, then record the position and amplitude of the peaks and estimate the bandwidth of the FM signal.

## 6.2 Issues for Discussion

In your discussion section, please address the following issues:

1. In general terms, describe the function and operation of FM modulators and demodulators.
2. Was it difficult was it to estimate the position and amplitude of the peaks in the spectrum of the FM signal? If so, why?
3. Based upon your observations, suggest a relationship between the bandwidth of the FM signal $W_B$ and the frequency deviation $\Delta\omega$. How does the frequency of the sinusoidal modulating signal $\omega_m$ affect this relationship?

# 7 Experiment 4: Wireless Spectrum – AM and FM Broadcast Band

### 7.1 Procedure

Connect one of the long-wire antennas that are deployed on the roof of the MCLD building to the input of the spectrum analyzer.


Figure 3: Experimental setup – Analysis of Over-the-Air signals.

1 Configure the spectrum analyzer to measure signals over the range from 530 to 1700 kHz. Observe how spectrum analyzer settings, including the RF attenuation resolution bandwidth, video bandwidth, and sweep time, affect the display.
2 Attempt to resolve individual broadcast stations and match them to particular broadcasters. Note the strength, frequency, bandwidth and station call sign associated with each signal.
3 Demonstrate use of the spectrum analyzer demodulation function to recover audio from a few stations.
4 Configure the spectrum analyzer to measure signals over the range from 88 to 108 MHz. Observe how spectrum analyzer settings, including the RF attenuation resolution bandwidth, video bandwidth, and sweep time, affect the display.
5 Attempt to resolve individual broadcast stations and match them to particular broadcasters. Note the strength, frequency, bandwidth and station call sign associated with each signal.
6 Demonstrate use of the spectrum analyzer demodulation function to recover audio from a few stations.

### 7.2 Issues for Discussion

In your discussion section, please address the following issues:

1 Comment on the number, density and strength of broadcast stations visible in the AM and FM broadcast bands.
2 Was it difficult was it to estimate the position and amplitude of the peaks in the AM and FM broadcast spectrum? If so, why?
3 Was it difficult was it to estimate the bandwidth of the signals in the AM and FM broadcast spectrum? If so, why?

## References

[1] Agilent Technologies, "Back to Basics Seminar - Spectrum Analyzers," 1998.

[2] Agilent Technologies, "Spectrum Analyzer Basics - A Self-Paced Tutorial," 1998.

[3] A.D. Helfrick, *Electrical Spectrum and Network Analyzers*. San Diego: Academic Press, 1991.

[4] M. Engelson, *Modern Spectrum Analyzer Theory and Applications*, 2nd ed. Dedham, MA: Artech House, 1984.

[5] R.A.Witte, *Spectrum and Network Measurements*. Engelwood Cliffs, NJ: Prentice Hall: 1991.