

# EE 4440 – Comm Theory

## FM (Frequency Modulation)

### **Purpose:**

The purpose of this lab is to investigate FM. FM signals will be explored in the time and frequency domains. The bandwidth of FM signals will be studied. Demodulation of simple FM signals using an approximated differentiator and envelope detector are implemented in the lab.

*Note:* For this lab, a **formal** lab report is due. The requirements of the formal lab write up are provided on a separate handout. I would like a very detailed and formal report including a theory section. For example, explain the frequency domain signal for FM tone modulation and how the demodulation circuit works.

### **Equipment:**

The lab will utilize a variety of equipment. The first piece is the Agilent 54622D mixed-signal oscilloscope used in the first two labs. The Agilent 33120A function generator will be used to create the FM signals. The computers with LabVIEW and the Data Acquisition Cards (DAQs) serve as a spectrum analyzer for the lab. The Agilent E3631A triple-output power supply will be used to power the approximate differentiator circuit.

### **Procedure and Questions:**

#### **Notes:**

- Use the function generator's "sync" output as the external trigger input for the oscilloscope (on the back). Be sure to select this trigger source on the oscilloscope (Edge button -> Ext softkey)
- A trigger level of 180 mV worked successfully for most of the lab
- For time domain sketches and observations, 500  $\mu$ s/division or 1.00 ms/division were adequate time bases. For frequency domain sketches and observations, 1.00 ms/division provided a better spectrum
- Measure all bandwidths as frequency content within -20 dB of the carrier amplitude
- Set the function generator's output impedance to high impedance
- All LabVIEW modules can be stopped by pressing the escape (ESC) key
- The input channels for the DAQs are channel 7 (red wire) and channel 15 (blue wire)
- Both the oscilloscope and LabVIEW can save waveforms. If you do not wish to sketch diagrams (and since this is a formal report), feel free to use these features. Ask the TA for help if you are having problems. Note: LabVIEW only provides a  $\Delta t$  and  $\Delta f$  value, you will need to generate the time and frequency reference columns manually.

## Part 1: FM Tone Modulation

The Agilent Function Generator will generate the FM signal for this lab. To enable FM, press the SHIFT key and then the Square Wave key. Carrier frequency and amplitude are determined using the Freq and Ampl keys. To change the message frequency, press the SHIFT key once and then the Freq key. Frequency deviation ( $\Delta f$ ) is adjusted by pressing the SHIFT key once and then the Ampl key. The FM message shape is located under the modulation menu (Menu On/Off, Mod Menu $\downarrow$ ,  $\rightarrow$  $\rightarrow$ FM Shape,  $\downarrow$ choose shape).

The first signal generated will be a basic FM signal. The carrier frequency should be a 16 Vpp sinusoid with 10 kHz frequency. The message signal should be a sinusoid with 1 kHz frequency and 2 kHz frequency deviation ( $\Delta f$ ).

Observe the time domain signal on the oscilloscope. Use the scope's FFT function to observe the signal in the frequency domain.

Adjust the displays so both are easily visible on the oscilloscope at the same time. A recommended setting for the FFT is a 50 kHz span with a 25 kHz center, 20 dB scaling, and a 15.6 dB offset.

- i) Sketch the signal in the frequency domain. Carefully label the frequencies and the relative amplitudes of the significant components.
  - What is the approximate bandwidth of the FM signal? How does this compare with the theoretical bandwidth?
  - For your laboratory report, read pages 264-267 in the text and review the related class notes, and explain the observed frequencies and amplitudes. Use Figure 4.7 and the Bessel function table provided in class notes.
- ii) Gradually increase the message signal frequency to 2 kHz and observe the changes in the time and frequency domains. What happens to the bandwidth of the FM signal?
- iii) Reset the message signal frequency to 1 kHz and gradually decrease  $\Delta f$  to 1 kHz observing the changes in the time and frequency domains. What happens to the bandwidth of the FM signal?

## Part 2: FM modulation with a square message signal

- i) Change the FM message pulse shape to "square" and reset  $\Delta f$  to 2 kHz using the directions from Part 1.
  - Ensure the message frequency is still set for 1 kHz and the carrier frequency is set to 10 kHz.
  - Observe the change in the frequency domain and estimate the bandwidth of the FM signal. Give some justification for the change in the FM signal's bandwidth.
- ii) Sketch the signal in the time domain. Carefully label the time axis. Also, label the frequency of the carrier at various portions of the time domain signal.

- iii) Increase  $\Delta f$  to 4 kHz. Sketch the signal in the time domain. Carefully label the time axis.
- Again, label the frequency of the carrier in various portions of the time domain signal.
  - What happens to the bandwidth of the FM signal? How does this compare with the approximate theoretical FM signal bandwidth?

### **Part 3:** FM demodulation using an approximate differentiator and envelope detector

#### **Approximate Differentiator**

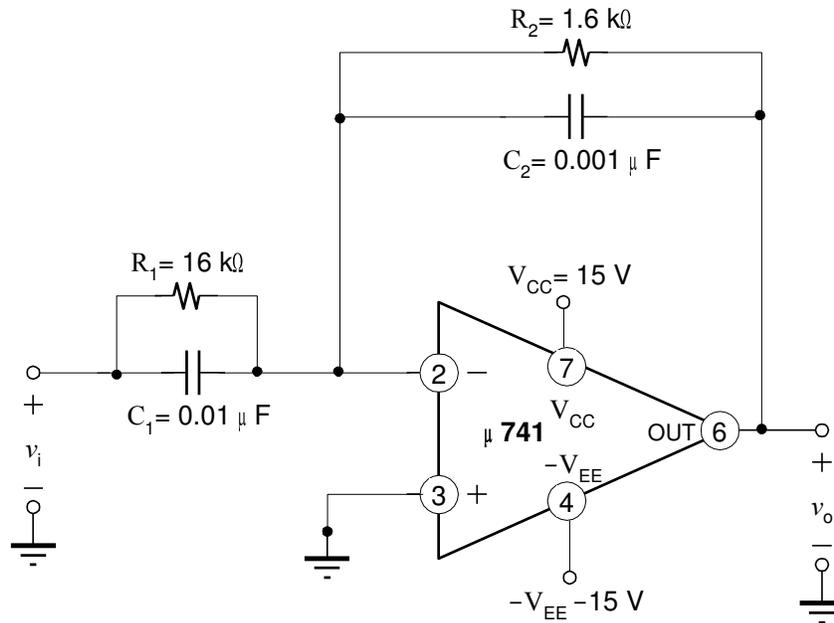
Construct the circuit shown in Figure 1 on the next page. As part of the lab report, draw a Bode plot for the response of the circuit (magnitude and phase). What is the gain of this circuit at 8 kHz, 10 kHz, and 12 kHz? How do these gains relate to the output?

*Note: Ensure no power is connected to the breadboard and be sure the DC power supply is off before making any connections. Double check your circuit before applying power.*

For the DC supply, you may use the older DC power supplies or the newer Agilent E3631 Triple Output DC power supply. Instructions for the Agilent power supply are outlined here. The older power supply is fairly intuitive, but if you want to use it and have questions, don't hesitate to ask.

To setup the Agilent power supply

- 1) Turn on the power supply
- 2) Press the +25 button. Then press the Display/Limit button.
- 3) Adjust the voltage to read 15-volts.
- 4) Press the Voltage/Current button under the adjustment knob. Adjust the current limit to be 0.030 A (30 mA).
- 5) Press the -25 button and repeat the process for the negative supply (-15 V 30mA).
- 6) When ready to use the supply, press the Output On/Off button. This enables/disables the power supply.
  - If LMT is flashing on the display, press the Display/Limit button to toggle to the measurement (actual output) mode.
  - Verify the supply is working correctly by pressing the +25 key and the -25 key. Under both displays, the voltage should be 15 V (or -15 V) and the current should be miniscule.
  - If the CC indicator on the right hand side of the display toggles on, immediate turn the output off (Output On/Off) and check your connections. This means the supply is operating in constant current mode (as a current source) and typically indicates a short or other fault in the circuit we are using for this lab.



**Figure 1 – Approximate Differentiator Circuit**

- On the function generator, reset  $\Delta f$  to 2 kHz and the message signal frequency to 500 Hz.
  - Adjust the carrier signal to 7 V<sub>pp</sub> and 10 kHz. Leave the message signal as a square wave initially. You may turn off the scope's FFT function if you wish to free up some space on the oscilloscope display.
  - Also for this portion of the lab, hook the LabVIEW spectrum analyzer to the input and output of the system and observe the frequency content. The module is named 'Dual Channel Spectrum Analyzer.vi' and should be on the desktop of the machine.
  - Recommended options for the module are to set the sampling rate to 40000 samples/sec, 4096 Frame size, 4096 FFT size, a Von Hann (Hann, Hanning) window, and an averaging factor of 4. You are free to adjust the settings to better settings if you wish to obtain better results.
- i) Observe the input on channel 1 of the scope and one channel of the LabVIEW spectrum analyzer. Do the same for the output with channel 2 of the oscilloscope and the other analog channel of the DAQ.
- Turn on the circuit power and run the LabVIEW module.
  - What observations can be made about the input and the output from the oscilloscope? Sketch the output from the oscilloscope.
  - Observe the input and output on the LabVIEW spectrum analyzer and roughly sketch the frequency of the output shown by LabVIEW. Which spectrum is better, the oscilloscope or the spectrum analyzer? Why?
- ii) Change the message shape to sine and observe the changes. Sketch the output spectrum from either the oscilloscope or LabVIEW.

- iii) Gradually increase  $\Delta f$ . How does the waveform change? Describe the changes for both a square wave message signal and a sine message signal.

#### **Part 4:** Envelope detector

If not done in the prelab, design a basic envelope detector using a diode, resistor, and capacitor (as in the AM lab. Refer to Figure 4.12a on page 168 of your text for connections). Let the capacitor value be  $0.01 \mu\text{F}$ . Choose a resistor value given a carrier frequency of 10 kHz and a message frequency of 500 Hz.

On the function generator, reset  $\Delta f$  to 2 kHz. Ensure both the message and carrier signal are sinusoidal. Remember to turn off the power supply output and apply the output of the approximate differentiator to the envelope detector. Connect channel 1 of the oscilloscope and one channel of the LabVIEW spectrum analyzer to the output of the differentiator. Connect channel 2 of the oscilloscope and the other channel of the LabVIEW spectrum analyzer to the output of the envelope detector.

- i) Sketch the output from the oscilloscope and label it carefully.
- ii) Change the message signal shape to a square and sketch the output.
- iii) Does the envelope detector work? If so, how well does it work? If not, what problems does it appear to have and how may you go about fixing them?

## EE 4440 – Comm Theory – Prelab for Lab 3

The following questions are to be answered **before** coming to lab. The prelab will be due at the beginning of the lab period.

- 1) Design an envelope detector (see your AM lab) for a signal with a 10 kHz carrier and a 500 Hz message frequency. Use a capacitor value of 0.01  $\mu\text{F}$ . The equations used so far in class require us to know the modulation coefficient. However, we don't know the modulation coefficient here. Instead, you can use the equation:  $RC \gg \frac{1}{\omega_c}$ .
  
- 2) Given a simple wide band FM system with a 10 kHz carrier wave at 8-volt amplitude, a message frequency of 1 kHz, and a frequency deviation of approximately 12566.3 rad/s, what is the theoretical bandwidth of the FM signal? Assume both carrier and message signal are sinusoidal in nature. Be sure to show your work.