

EE133 - Lab 2

Using Oscillators to Generate FM Signals

1 Introduction

In this lab, you will be experimenting with a number of different oscillators. These circuits build up to two forms of FM transmission: One using discrete components and one using chips. Once you have characterized the different methods, you will decide which one you want to use in your final project (you can simply disconnect the other). These are your design choices:

- **Discrete Design** - The colpitts oscillator you have designed in the prelab is capable of doing frequency modulation at 24.3 MHz without the use of a multiplier (we say 24.3 MHz because we wish to use an intermediate frequency of 300kHz). Using one transistor and a few passive components, you get all the functionality of a VCO, multiplier and local oscillator all rolled into one. In addition, this colpitts transmitter gives much better power gain (can you guess why?) than its chip version. However, all this comes at a cost of frequency drift and general fickleness of the circuit, as you'll find out in lab.
- **Chip Design** - The other option is to build the transmitter using the VCO and Multiplier chips you've been working on in the prelab and Lab 2. In this implementation, you will modulate the 300kHz VCO signal and then use one of two crystal oscillators to multiply it up to 24.3 MHz. You can decide which crystal oscillator (the on-board 612 fundamental-mode crystal oscillator or the packaged oscillator chip) you want to use in your final design (think about the advantages/disadvantages of each as you characterize them). Although this version has better stability, it has its own drawbacks as well. It will be up to you to characterize both of these circuits and decide for yourself which will give the best performance.

A Note about Oscillator Interference: Starting with this lab, you and your lab mates will have oscillators running at 24MHz for a good portion of the time. When you are making measurements, this translates to 24MHz signals being sprayed all over the room. Therefore, you have to be careful about your measurements, and make sure that the signals you are recording are actually coming from your circuit (sometimes, even your own circuit can cause interference - e.g. the SA612 oscillator can couple into your LNA signal, etc.).

2 Mathematics of Frequency Modulation

In your lab preparation, you generated FM signals using MATLAB. Now, you will be using the signal generator to generate FM signals, and examine them in both the time and frequency domains.

- Set channel A to be a 10kHz sinewave carrier with 1V amplitude to output 1.
 - Set channel B to frequency modulate this carrier with $f_m = 1kHz$ and a frequency deviation (bandwidth) of 5kHz. This is equivalent to $m=5$.
 - Set channel C to be a 1kHz, 1V sinewave to output 2.
1. View both outputs simultaneously on the oscilloscope. This should allow you to clearly see the frequency variations in the time domain. Sketch or plot the output as seen on the oscilloscope.
Now you will look at an FM signal in the frequency domain. (on the HP3561A Spectrum Analyzer)
 2. Set up an FM signal with a center frequency of 30kHz, an amplitude of 1V, and a modulating frequency of 1kHz with a 1kHz bandwidth ($m=1$).
 3. Use the signal analyzer to obtain the spectrum of the signal. Use a linear scale for the vertical axis in order to make a comparison to your Matlab plots (give percent error). Plot or sketch the results.

- Now increase the frequency deviation in increments until you cause the zeroth order Bessel function to go to a minimum value. What is this frequency?
- Keep increasing the frequency deviation until you reach the zeros for the first and second order Bessel functions. What are these frequencies? How do these frequencies compare to your prelab results?

3 The LM566 Voltage Controlled Oscillator

Build the LM566 VCO on your transmitter board as designed in the prelab using the datasheet for reference. You will be characterizing this chip in a fashion similar to the Colpitts VCO, so that you may compare the two topologies.

- Basic Functionality:** Measure the power consumption and center frequency and compare with your prelab results. Use the high-frequency spectrum analyzer with the high-impedance active probes for your frequency measurements. Keep in mind that this probe has a 10:1 ratio, or 20dB of loss.
- Frequency Characterization:** Measure the center frequency vs. tuning voltage. You will need to make several measurements over the range of frequencies that you want. If the resulting curve looks at all linear, what is tuning constant, k , for your oscillator (in Hz/V)? We eventually want a 100kHz total bandwidth, what ΔV gives this ± 50 kHz deviation? How does this compare to the Colpitts version?
- Modulation Bandwidth:** Apply a 1V, 1kHz modulating signal to the VCO input. View the output on the spectrum analyzer. Adjust this input voltage until you get a 100kHz bandwidth. What is this voltage?
- Demodulation on the Spectrum Analyzer: Now you can use the FM demodulation function of the spectrum analyzer to demodulate and listen to your signal.
 - Use the 'Aux Control' key and turn the demodulation on. Make sure that the demodulation type is FM, that your marker is on your center frequency, the frequency span is 1MHz, and the speaker is on.) Do you hear the 1kHz tone? The volume knob is on the front, under the screen.
 - Using the same 1kHz input to the VCO, view the output on the spectrum analyzer. How does the output power compare with your prelab result? (Don't worry if there is a large error.)

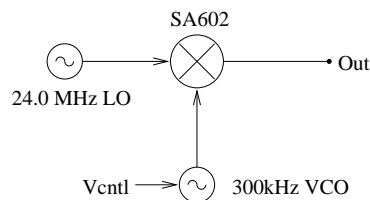


Figure 1: Block Diagram of Transmitter

4 Using the Oscillator on the SA612

One of the great things about integrated circuits is that they allow designers to cut costs by putting multiple functions on a single chip. One such example is the extra transistor attached to pin 6 of the SA612. This transistor allows you to create a simple, reliable oscillator to use as the input to the upper pair of the mixer.

- Build the Colpitts Oscillator on the SA612 using a fundamental-mode crystal configuration.
- Add the necessary components to the SA612 on your transmitter. Measure the output power using the active probe. How clean is the signal? Do you see any harmonics?

3. Nerd Bonus Questions: Feedback and Phase Noise

- Can you identify the different elements of the feedback system? Which one is the gain element? What part(s) make up the feedback path? Which component plays the role of the LC Tank?
- Now look at how the crystal is situated in the circuit. Drawing on your knowledge about crystal resonators, are you using the crystal in its series or parallel resonant mode? A schematic model of a quartz crystal appears in Figure 2.
- Phase Noise** - Look at the base of the 24 MHz peak. You should see some “skirts” that extend out from the base. These are due to noise in the system, which manifests itself as low-power sidebands. This is known as *phase noise*, and is measured in dBc, or “decibels relative to carrier” and specified a fixed distance (in frequency) away from the carrier frequency. A possible phase noise measurement might be -90 dBc at 100 kHz offset, meaning that the noise level was 90 dB below the carrier signal power 100kHz away from the carrier frequency.
- Pick an appropriate offset (between 50 and 150 kHz) and measure the phase noise using the spectrum analyzer.

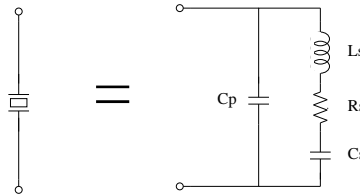


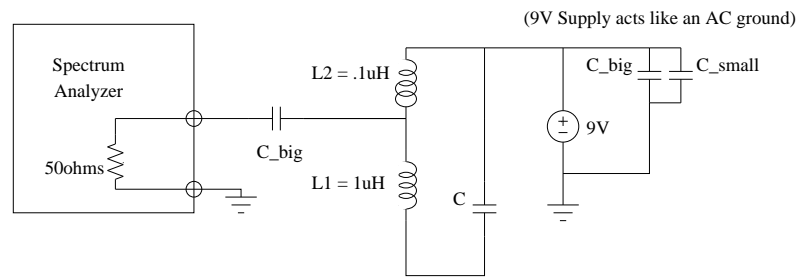
Figure 2: Equivalent Circuit for a Quartz Crystal)

5 Transmission with the LM566 and SA612

Now we're ready to create FM signals and transmit them. Connect the output of the VCO to the lower input of the SA612 four-quadrant multiplier on the transmitter board.

- Using the a 1V, 1kHz input to the VCO, view the multiplier output on the spectrum analyzer. Note the output power and bandwidth. Does this agree with your prelab calculations?
- Connect an 11' wire to the output of your multiplier. This will act as your makeshift antenna (why did we choose 11'?) Connect the other antenna to the spectrum analyzer and make sure your labmates' oscillators are off at the moment. Repeat the above step and listen to the 1kHz tone. You are now, by all RF standards, one cool dude (or dudette). Turn the modulation off for a moment and note the power into the spectrum analyzer.
- Now, take the antenna off of your spectrum analyzer and attach it to a spectrum analyzer on the other side of the room. With the modulation still off, what is the received power now? (Record the distance and orientation of the antennas.) Turn the modulation on and listen to the 1kHz tone.
- Connect the output of the microphone circuit (if you built one) to the input of the LM566. Reset the center frequency of the spectrum analyzer to 24.3 MHz. Speak into the microphone and listen to yourself on the spectrum analyzer. Congratulations, you have just made your first audio broadcast. :-)

Lab Implementation of LC Tank Circuit



(This node is floating but will connect to the collector of your amplifier)

Figure 3: LC Resonator

6 The LC Tank

After carefully reviewing Figure 3, solder your LC circuit to the same board as the LM566. This board will eventually become the transmitter for your final project. Remember: **If a lead can be shorter, then it is not short enough!** Instead of connecting your LC tank to ground, please connect your tank to V_{dd} , using bypass capacitor on the power supply lines (see Figure 3). Note that the power supply is an AC ground for high-frequency signals.

- **Estimating Q with the spectrum analyzer:** In HSPICE, we were able to apply a current source input to our circuit in order to measure the impedance versus frequency of our tank circuit. We don't have access to an AC current source in the lab, so we will have to improvise.

We will want to hook up the tap between the inductors to the spectrum analyzer. At this point, ask your TA for a solder-on BNC connector. Solder one ground wire and one signal wire to the connector and twist the pair of wires together (why do we use twisted pairs?). Solder the BNC connector across the smaller of the inductors, as shown in Figure 3.

Make an antenna out of a small straight wire and attach it to the BNC output of the high-frequency signal generator. We will use this antenna to couple energy into the tank and measure the Q. Bring the antenna near the capacitor in your circuit (trying to keep it away from your output) and fix this setup so nothing moves. Using the high-frequency spectrum analyzer at your bench, make a table of output power (in dBm) versus frequency.

1. Estimate the Q of your circuit and compare this to your prelab results.
2. Verify that the resonant frequency of your tank is approximately 24MHz.

7 The Colpitts Oscillator

Build the colpitts oscillator designed in the prelab. Use a 30pF capacitor in parallel with a variable capacitor (0.5pF to 30pF) to realize C_1 . Remember, the combination of C_1 and C_2 along with the varactor will act as your tank capacitor. You will be using the Toshiba 2SC3302 bipolar transistor which has an $f_t = 7GHz$. Remember, the collector and base leads are opposite one another with the collector being the longer lead. The other two leads are both connected to the emitter.

Notice that the schematic in Figure 4 includes a potentiometer at the input to the varactor. If you choose to use this colpitts design as your transmitter, this input will come from the output of your audio amplifier, which already includes the potentiometer and coupling capacitor. Therefore, you should connect a wire from your varactor input to the output of your audio amplifier. If you have not built the audio amplifier yet,

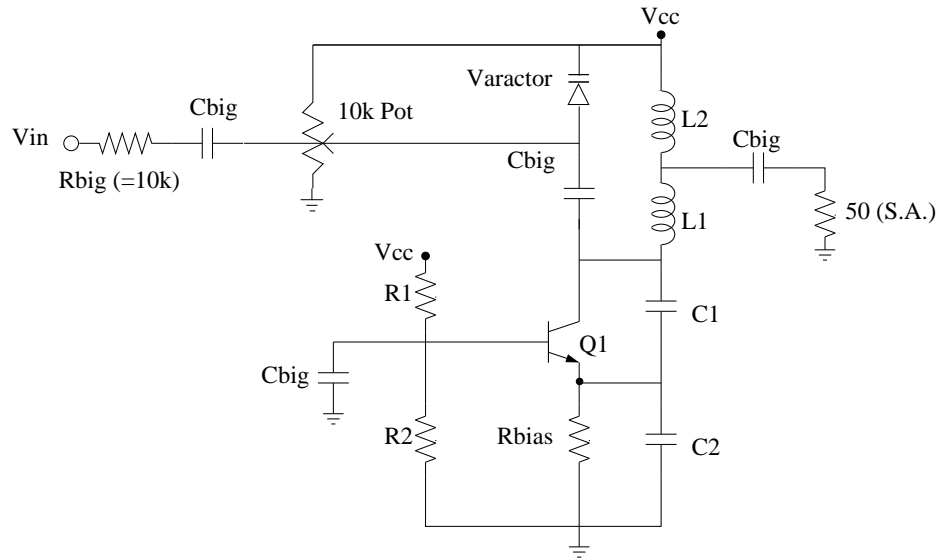


Figure 4: Colpitts Oscillator (somewhat simplified lab version)

you can just wire up a potentiometer in a position near where you will build it. You will want to keep the audio amp output flexible (keep a movable wire attached to it) so that you can use it to test your chip-based transmitter as well. (Since the input to the varactor is in the audio frequency range, you will need a large coupling capacitor - around 22 μ F. An electrolytic cap will work here; just be sure to get the polarity right!).

7.1 Characterizing the Colpitts

Now we will look at some of the functional characteristics of the Colpitts oscillator.

1. **Power Up** - For now, do not give an input to your circuit. Simply connect the potentiometer in the correct place and bias the varactor to have 2.25VDC across it (i.e. bias the varactor such that its DC voltage is about 6.75V). Power up your oscillator and view the output on the high frequency spectrum analyzer. If your oscillator doesn't behave correctly, check to make sure that you have bypassed your power supplies very close to the circuit. Also make sure your varactor (the reverse-biased diode) is still operational.
2. **Basic Functionality** - Power up and tune your oscillator to some frequency around 24.3MHz by adjusting the variable capacitor (C1). When using the high frequency spectrum analyzer, make sure you set the frequency span to 1MHz in order to get an accurate frequency measurement. You can also use the bandwidth key (BW) to adjust the resolution to smaller frequency increments. Play around with changing the resolution and video bandwidths.
3. **Output Measurements** - What is the power output of your oscillator into 50 Ω ? What is the output in volts? What do you calculate to be the voltage at the top of the tank? How does this compare with your prelab value?
4. **Power Output vs. Current** Decrease the bias resistor you have chosen to be around 1k Ω . You can do this by placing resistors in parallel, if you don't want to desolder. What is the new output power into 50 Ω ? What is the new tank voltage? Does this agree with the expression given in the prelab?
5. **Frequency Characterization** - Tune the oscillator by adjusting the potentiometer. Take a few data points and plot the center frequency versus voltage. What are the upper and lower frequency bounds? If the curve looks at all linear, what is the tuning constant, k, for your oscillator (in Hz/V)? We eventually want a 50kHz bandwidth on either side of the center frequency (total bandwidth of 100kHz);

what ΔV (relative to the varactor bias voltage) gives this $\pm 50\text{kHz}$ deviation?

7.2 Modulation with the Colpitts

Now we will investigate how we can produce frequency modulation with this oscillator. We will be applying the modulating signal to the center of the potentiometer which biases the varactor. In order not to load the tank with a low impedance, be sure to place a $10\text{k}\Omega$ resistor in series with the input as well as a large coupling capacitor (about $22\mu\text{F}$).

1. **The Colpitts as a VCO** - Apply a 1V, 1kHz modulating signal to the VCO input, making sure you use a $10\text{k}\Omega$ resistor in series with a large coupling capacitor (We do this so that the 50Ω output impedance of the signal generator does not load the oscillator. View the output on the spectrum analyzer. Increase or decrease the input voltage until you get a 200kHz bandwidth. What is this voltage? (You will want to directly measure the voltage at the varactor, since the signal might be attenuated through the $10\text{k}\Omega$ resistor.)
2. **FM Demodulation** - Use the FM demodulation function of the spectrum analyzer to demodulate and listen to your modulating signal.
 - Use the 'Aux Control' key and turn the demodulation on. Make sure that the demodulation type is FM, that your marker is on your center frequency, the frequency span is 1MHz, and the speaker is on.) Do you hear the 1kHz tone? The volume knob is on the front, under the screen.
 - Using the same 1kHz input to the VCO, view the output on the spectrum analyzer. How does the output power compare with your prelab result? (Don't worry if there is a large error.)
3. **Now for some fun** - Disconnect the probe that connects to the spectrum analyzer and replace it with an 11' wire (this is an antenna) that the TA's will provide. (Why did we choose 11'?) Connect the other antenna to the spectrum analyzer and make sure your labmates' oscillators are off at the moment. Repeat the above step and listen to the 1kHz tone. You are now, by all RF standards, one doubly cool dude (or dudette). Turn the modulation off for a moment and note the power into the spectrum analyzer.
 - Now, take the antenna off of your spectrum analyzer and attach it to the same spectrum analyzer on the other side of the room that you used before. With the modulation still off, what is the received power now? (Note the distance and orientation of the antennas.) Turn the modulation on and listen to the 1kHz tone (again, revel in your coolness).
 - Connect the output of the microphone circuit (if you built one) to the input of the Colpitts varactor. Reset the center frequency of the spectrum analyzer to 24.3 MHz. Speak into the microphone and listen to yourself on the spectrum analyzer. How does the sound quality compare to the 566/Multiplier topology?