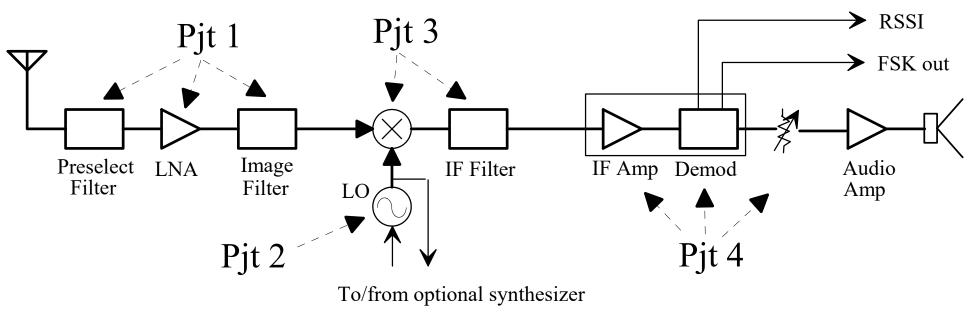
ECE662 Project 4

FM/FSK amplifier, demod, and Audio Circuits

Writeup due on or before Monday, Dec 9, 2019 (unless you drop this one)

Introduction:

In this last project, we will design, build, and test the IF and baseband functions of our semester goal - an FM/FSK broadcast-band receiver shown below.



Circuit topology:

Refer to the device data sheets and class notes to determine how to select external components and make the required connections.

Specifications:

♦ IF input impedance	300 Ω
♦ Minimum discernable signal MDS (at IF input)	< -100 dBm (5uV into 300 Ω)
♦ 30 dB quieting sensitivity (at IF input)	< -90 dBm (17uV into 300 Ω)
♦ Audio output power (< 10% THD)	> 1 Watt into 8 Ohm bridge-tie load
♦ Audio distortion (±75 kHz deviation, 100 mW out)	< 1% THD @ 1 kHz
♦ Audio-out de-emphasis	75 μs
♦ Audio response (assuming 75us pre-emphasis)	100 Hz to 15 kHz (+0, -3dB)
♦ Additional outputs for interface to Arduino Board	FSK out, RSSI out
♦ Power consumption (at minimum volume)	< 10 mA @ 5VDC

Teamwork:

As before, you should do your design and testing with your teammate to achieve the best product and to decrease your workload. It is recommended that one teammate concentrate on the IF subsystem design and the other on the audio portion.

NOTE: Even if you plan to drop this project score, it is <u>strongly recommended</u> that you draw a complete schematic (including part values) and do a very careful layout before beginning construction.

Design Suggestions

Study the datasheets for the FM IF Subsystem and the Audio Amp.

For the IF subsystem, decide how you will terminate the IF input port to satisfy the assumed load impedance for the IF filter in project 3. It is recommended that you use a second If filter within the middle of the IF amplifier cascade in project 4 to give better receiver selectivity. Assuming you do, be sure it sees appropriate source/load impedances as well.

Design the quadrature detector circuits in the IF subsystem using the procedures discussed in class. According to the IC datasheet, a 1pF value is recommended for the series C component when operating at 10.7 MHz. In addition, note that the input resistance to the phase-shifted quadrature input is about 40 K. Depending on the Q you design for, it may be possible to use the 22uH in your kit, together with one of the variable trim caps for alignment.

For the audio section, determine how much voltage gain you need to reach the specified audio output power. Your speaker is 8 Ohms, so determine what RMS and peak to peak voltage this corresponds to. Refer to the IF subsystem IC datasheet to find the output voltage, and then solve for the voltage gain needed. Implement it with basic opamp equations (see audio amp datasheet). Then plan for the potentiometer volume control and power switching. Check the IF subsystem output impedance and decide if you need any buffering/etc before the volume control.

Finally you will also need to compute capacitor values in the audio circuits to be sure that you can meet the audio frequency response specifications. And, don't forget the de-emphasis circuit. For commercial FM broadcast the in US, a 75 us de-emphasis is needed. Compute the associated lowpass corner frequency and implement that with an appropriate shunt C on the audio output. Do NOT just use a value mentioned in the datasheet - since neither value is appropriate for our FM broadcast application, and you may need to also consider the loading R of your audio amp.

IMPORTANT: Recall the need for appropriate DC blocks and bypass capacitors on all the circuits you design ! Look over the schematic you are making and the associated datasheets and be sure this is all OK before doing layout and construction.

Layout

Layout for this project is not critical, ***except*** in the IF amp portion of the circuit. Recall that the IF amp/limiter has on the order of 80 dB of gain. Hence, *oscillation **will** occur if you do not provide adequate grounds and supply bypass caps, and your final receiver's sensitivity will be significantly reduced. Keep your circuits reasonably compact, and keep the demodulator phase shift network away from the input* (these circuits are on opposite sides of the IC to help guarantee this). In addition, refer to the suggestions in the datasheet for ways to lower feedback with this IC.

If you have room, mount your pot on the edge of the board with enough clearance to be able to add a knob in the final assembly. Also, note the USB power jack and the pads dedicated to power. You can use these to provide power to your other boards, but may have to cut a trace to properly route power through the on/off switch...

Fabrication Tips

This project involves a significant amount of soldering, and some IC parts are very small pitch. *It is imperative that you construct your circuit carefully.* We do not have extra boards and debugging this circuit may be more difficult than the others. ***Avoid the need to debug by planning your layout and soldering your components carefully!***

Finally, an obvious word of advise. Do not wait to late to begin work on the project. The end of the semester is less than 3 weeks away...

Documentation:

As in previous projects, you and your teammate should document your design and measurements in your writeup (assuming this is not a project you drop). Even if you do intend to drop this one, you should get your circuit built and tested as outlined below well ***before exam week***.

Otherwise, it is ***virtually certain*** *you will not achieve a well-working receiver for the final exam.* As the saying goes, ***"if you don't test it, it will not work, guaranteed"***. This is true for any complex product/system ! Testing and revision is a key part of any development effort.

Measurements:

Initial Checkout

Power up your circuit and check for proper supply current. Record this current level and compare with what was expected based on the datasheets.

With a speaker connected, set the volume control at mid rotation. You should hear some "hiss", even without any input signal (unless you implemented the squelch). If you do not observe this, either your circuit is broken, it is oscillating, or the mute is active.

Debug. Do NOT rebuild !

Inject an FM modulated IF signal (frequency 10.7 MHz, reasonable amplitude) with a deviation of ±75 kHz (**use the internal 1kHz modulation function on the RF generator**). You should hear a loud tone from your speaker. If you do not, or if the tone is not pure, try adjusting your quadrature demod capacitor, AND ***search around for the quadrature circuit's resonance by changing the signal's frequency up and down a few MHz (in steps smaller than the filter bandwidth of course).*** If you still do not hear the tone, isolate the problem between the IF and audio circuits by checking for an audio sinewave (a few hundred mV) at the audio output of the demod, and then other points along the signal-processing path (pot, audio amp) to localize where things are going wrong.

Alignment

Observe the audio signal on a scope and align the quadrature phase shift circuit to get a large, pure audio sinewave. You should also vary the IF input frequency to be sure that a signal at 10.7 MHz provides the best audio output waveform. ***<u>Again, search around for the quadrature circuit's actual resonance by changing the 10.7 MHz signal up and down a few MHz (in steps smaller than the filter bandwidth of course). Find where the tone is loudest and purest.</u>*** If your circuit is off-frequency and you cannot get it centered on 10.7 MHz with the variable capacitor, you will probably not meet the audio distortion or other specs. Fix it!

Performance Testing:

Output power and distortion level:

First, increase the audio volume control until small to moderate distortion is heard. Record the *RMS* voltage delivered across the speaker and compute the audio power, assuming the speaker is an 8 Ω load. Since you're using a Bridge-Tie type amp, you will have to observe both speaker terminals' voltage to ground (e.g. using both input channels of the scope and the math function to do subtraction, or using the DMM in AC voltage mode) to get the real value across the speaker. Or, you can use the distortion analyzer which has a floating input capability :-)

Next, using the distortion analyzer, measure the total harmonic distortion (THD) at the audio output of your circuit with the ±75 kHz FM modulated IF signal applied as above.

Audio frequency response and de-emphasis:

Connect a function generator to the external modulation input of the RF signal generator and reconfigure it to use this audio source. Be sure to get the input amplitude correct (approx 1V) so the deviation is correct. Measure the frequency response of your circuit from 20 Hz to 20 kHz by observing the audio output voltage with an oscilloscope or the distortion analyzer. Plot the response (in dB relative to peak output) on a log frequency axis. Does your circuit show the proper de-emphasis curve? (i.e. Would the response be flat if the signal generator was using 75us pre-emphasis?) Try this looking at the FSK output as well. Since there is no de-emphasis there, you should notice a much higher audio frequency upper corner.

Threshold and 30 dB quieting sensitivity:

Next, using a 1 kHz modulation tone, decrease the RF generator's output level until you begin to hear a moderate amount of hiss together with the tone. Record this level as an estimate for the "30 dB quieting sensitivity". (Remember to use the 300 Ohm transformer board on the IF input!)

Finally, decrease the level further and record the input power at which the audio noise level roughly approximates the level of the audio tone. Record this as your "threshold sensitivity". If you like, use the distortion analyzer set to measure "SINAD" (Signal over

Noise-And-Distortion) and find the IF level where this equals 12 dB to get a better estimate of true 12dB SINAD sensitivity.

FSK and RSSI outputs:

Finally, locate the bench with the HP8648A signal generator and configure it to produce an FSK pager signal at 10.7 MHz with +/- 75 kHz deviation. Observe/record the waveform at your FSK output. What is the amplitude and the DC offset? Can you see the serial data properly? Change the frequency from 10.7 to 10.72 MHz and observe if the DC offset changes.

You should also try connecting the FSK out and RSSI out signals to the Arduino board and look at the data waveform after it has been "bit-sliced". You should see full 0 to 5V serial data waveform from the appropriate pin on the Arduino (see the code documentation handed out previously). Also vary the amplitude of the IF input signal and observe if the received signal strength (RSSI) is properly reported by the Arduino program.

Writeup and Final Exam Prep:

Document your design and measurement results as you have done before (assuming this is not the one you are dropping). At the end of your writeup for this project, provide a summary of your circuit, your measurements, and how measurements compare to the specifications. If you failed to meet any specifications, discuss possible reasons. Also, provide a 'photo' of your board.

Even if you're not documenting this design (e.g. planning to drop Project 4), you should understand all the measurements above, since your final exam score will be determined by your receiver performance, and your understanding of the circuits and full system.