Digital communication exam

J.-M Friedt, April 8, 2023

Four signals are being broadcast in the 433.05 to 434.79 MHz Industrial, Scientific and Medical (ISM) band using the GNU Radio flowchart depicted in Fig. 1 provided for reference only. Two of these signals carry a frequency modulated sine wave, the other two broadcast an amplitude modulated sine wave.

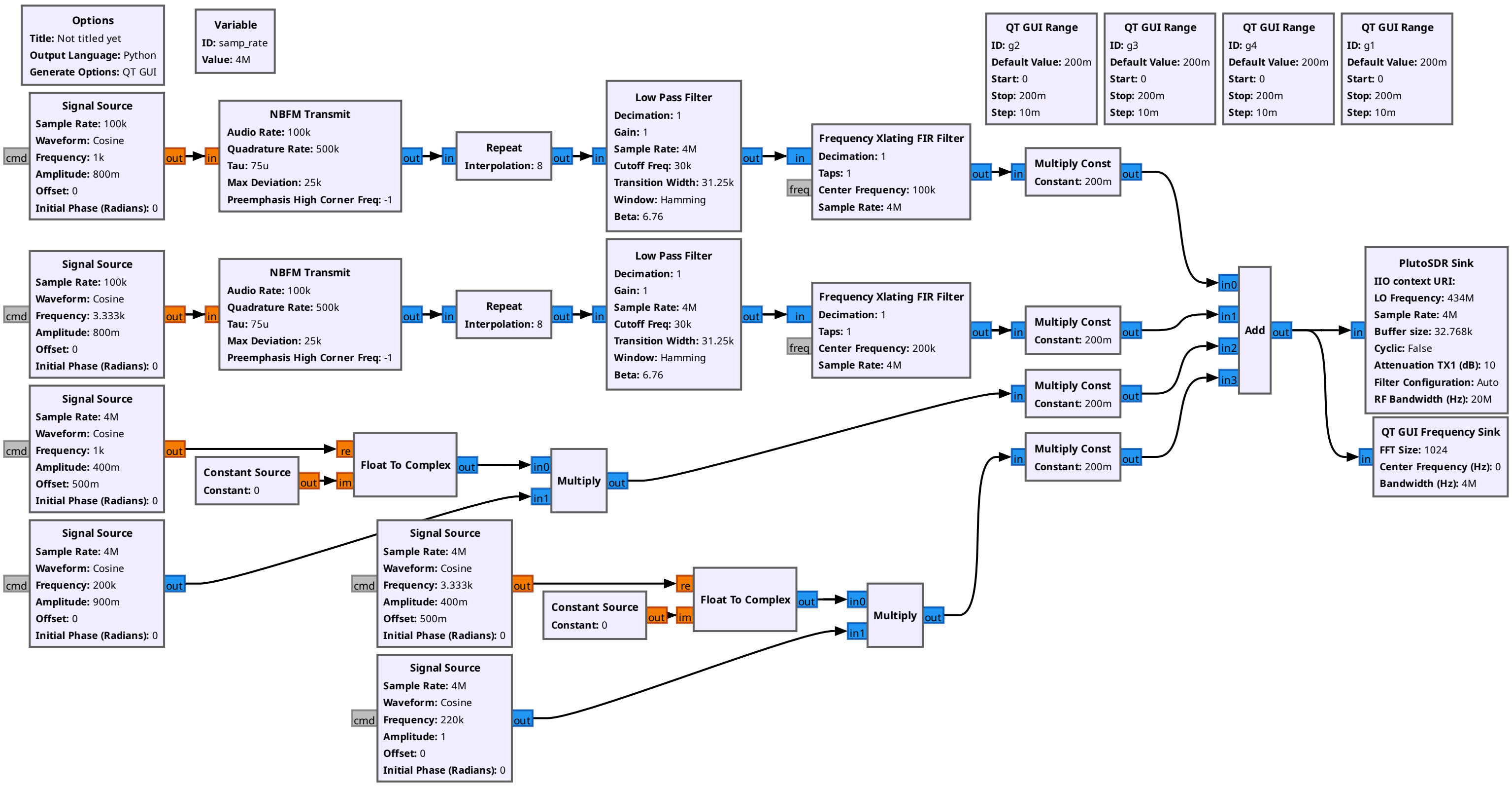


Figure 1: Transmitter flowchart executed on a PlutoSDR emitter.

1. Using the RTL-SDR dongle acting as a software defined radio receiver, investigate the ISM band and identify the four carrier frequencies. What are they?

2. Which carriers are amplitude modulated? which carrier are frequency modulated? Justify your selection.

3. What are the frequencies of the two amplitude modulated sine waves?

4. What are the frequencies of the two frequency modulated sine waves?

5. Set the receiver carrier frequency to the mean of the of AM modulated signal carrier frequencies and demodulate *both* signal simultaneously. How can you demonstrate that both sine waves have been demodulated simultaneously?

6. Try the same demodulation scheme with the FM modulated signals, setting the receiver local oscillator to a frequency at the middle of the two FM signal carriers and trying to demodulate both signals simultaneously? What do you observe?

The inability to demodulate *both* FM modulated signals is called the *FM capture* effect, in which the FM demodulation circuit locks on the strongest carrier and fails to track the weaker signal.

7. What is the analog circuit used for demodulating the AM signal? What is its equivalent implmentation in the digital domain?

8. What parameter of the RTL-SDR receiver defines the bandwidth of the reception channel and how many signals can be demodulated simultaneously. Where is this parameter defined in the GNU Radio flowchart? Draw a schematic of the reception chain indicating where this parameter is used.

9. Rather than using a single FM demodulator aimed at simultaneously demodulating both signals (which is not possibe due to the FM capture effect), demonstrate how you can nevertheless demodulate each FM signal independently using two FM demodulators on the same flowchart. What processing block allows for simultaneously analyzing two frequency bands?

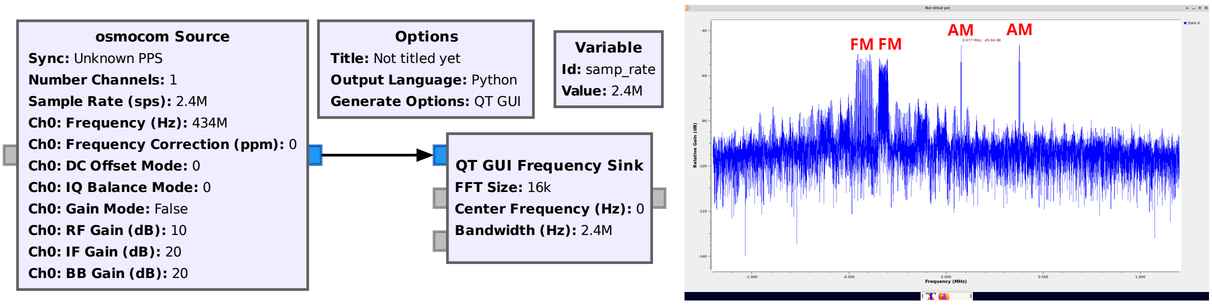
10. The PlutoSDR emitter is fitted with an antenna assumed to be isotropic and radiates -10 dBm. Considering your receiver fitted with an isotropic antenna is located about 6 m away from the emitter, what is the received power? How does it compare with the -90 dBm noise floor of the RTL-SDR receiver? What is the maximum communication range if keeping the same transmitter settings? How did you reach this conclusion?

11. How would this conclusion change if the frequency was raised to the 2.45 GHz ISM band? Justify.

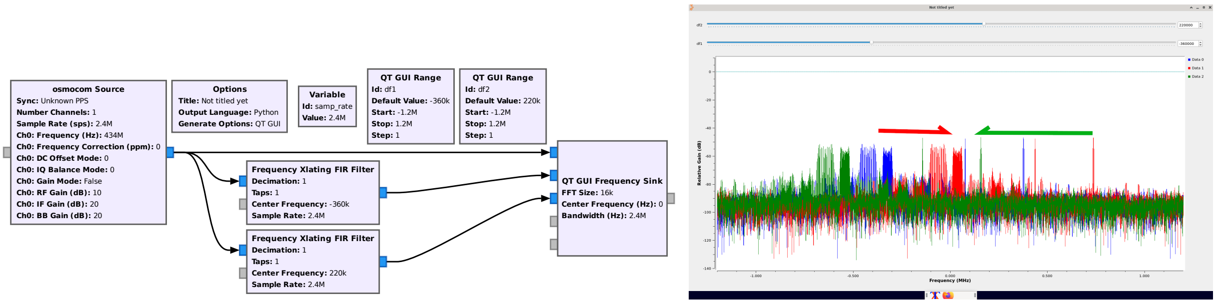
12. Considering the 2 MHz bandwidth available, what would the maximum communication rate (in bits/s) be at such a range? How would the conclusion change on a 4 MHz bandwidth? Justify.

Answers:

1. The sampling rate is set to its maximum frequency of 2.4 MS/s in the `samp_rate` parameter. The center frequency is set to 434 MHz. The gain is tuned to improve signal to noise ratio and exhibit a fine spectrum as shown below:

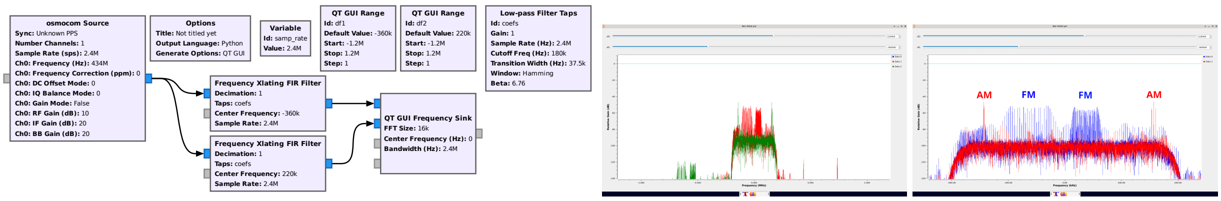


2. The narrow spectra are the amplitude modulated signals. The broader spectra are the FM modulated signals.



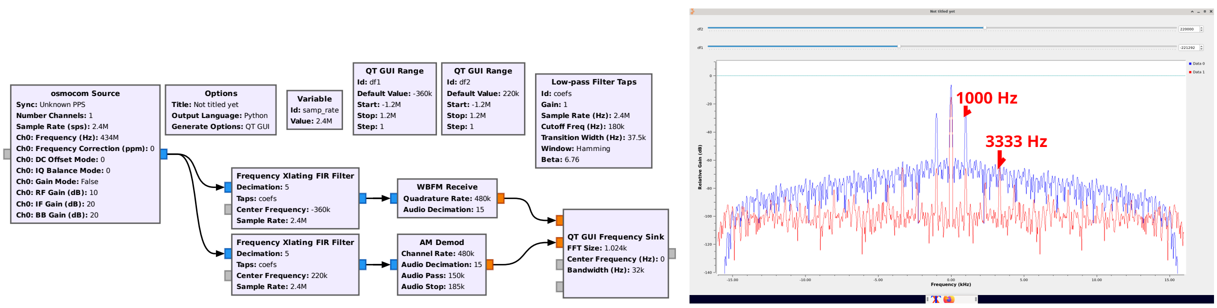
Here we have included two Xlating FIR filters to bring the amplitude modulated signals (green) and the frequency modulated signals (red) centered on zeros for demodulation in the next questions.

Each signal is isolated using a low pass filter (middle) and decimation (right).

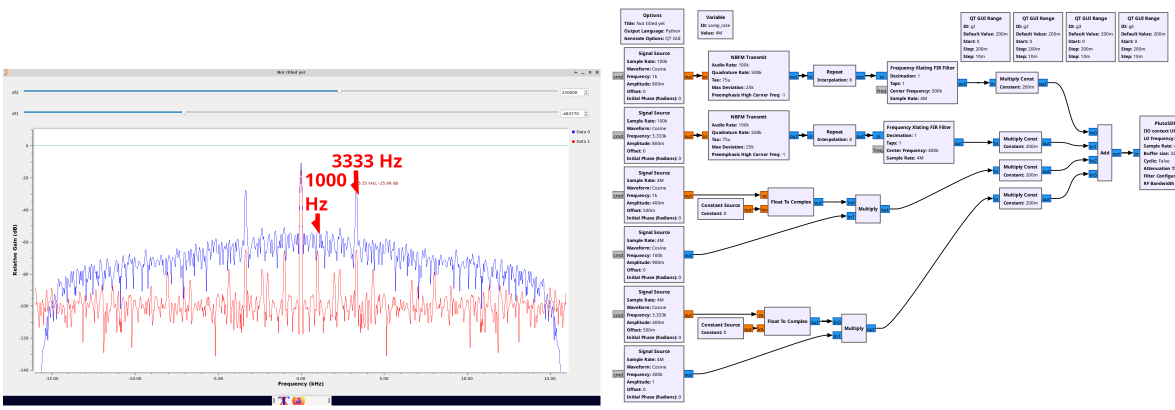


3.

4. The amplitude modulated signals are demodulated using the `AM demod` (red) and the frequency modulated signal is demodulated using the `WBFM Receiver` (blue)



Both amplitude and frequency modulated sine waves are at 1000 and 3333 Hz. The actual transmitted flowchart used during the second session exam is given on the right.



5. By setting the local oscillator frequency to the mean value of the frequencies carrying the amplitude modulated signal and running through the AM demodulator, we see on the spectrum of the demodulated signal both components at 1000 and 3333 Hz : both signals are demodulated simultaneously

6. By setting the local oscillator frequency to the mean value of the frequencies carrying the frequency modulated signal and running through the WBFM receiver, only one or the other spectral component at 1000 **or** 3333 Hz is observed. Both signals cannot be demodulated simultaneously.

7. AM signals are demodulated using a rectifier (diode + low pass filter). In the digital domain, rectifing is calculated using the absolute value, and low-pass filtering as a FIR filter.

8. `samp_rate` defines the ADC sampling frequency and hence the bandwidth in which the signals can be located around the carrier frequency set to the local oscillator.

9. Two Frequency Xlating FIR filters can select each FM band independently and feed two WBFM Receiver blocks,

10. $FSPL = 20\log_{10}(f) + 20\log_{10}(d) - 147.55 = 20\log_{10}(434 \cdot 10^6) + 20\log_{10}(6) - 147.55 = 41$ dB propagation loss and -10 dBm emitted power so the received power is -51 dBm, well above the threshold of the noise floor of the RTL-SDR. Multiplying by 100 the range to reach 600 m leads to 81 dB losses and the received signal at -91 dBm, just at the threshold of the RTL-SDR noise floor.

11. Raising the frequency decreases the wavelength and hence the aperture of the receiving antenna. The range is decreased 6-fold since the frequency was increased 6-fold.

12. At short range and hence high signal to noise ratio, Shannon capacity theorem stating that $C = B\log_2(1+SNR)$ states that the capacity doubles with bandwidth, with $SNR = \frac{P_R}{k_B \cdot T \cdot B}$. P_R being the received power of -51 dBm calculated above. The thermal noise power is $k_B \cdot T \cdot B = -174 + 10 \cdot \log_{10}(B) = -111$ dBm. The datarate is hence $B\log_2(1+SNR) = 2 \cdot 10^6 \cdot \log_2(1 + 10^{(-51+111)/10}) \simeq 2 \cdot 10^6 \log_2(10^6) = 4 \cdot 10^7$ bit/s