ENGS 110 Final Project
SDR Wideband FM Stereo Receiver

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Abstract

This report details the implementation of a Software Defined Radio (SDR) Wideband Stereo FM Receiver using the GNU Radio Companion (GRC) software suite. The receiver was based upon a NBFM demodulator designed in a previous homework assignment, but was reconfigured to interface with an SDR USB dongle in order to receive wideband FM signals. Details of standard FM demodulation will not be covered in this report. The stereo audio signal was obtained from the demodulated FM data using Stereo Multiplexing (SMPX), a type of Frequency Division Multiplexing (FDM) using a single sideband suppressed carrier modulation (SSBSC). The end result of the project was a successful implementation and demonstration that was able to tune to any FM station and extract the stereo audio with excellent quality.

note: a high-resolution digital copy of this report can be found at the url listed in section 6

1 Theory of Operation

SMPX is the standard technique used to transmit stereophonic (stereo) audio over FM VHF broadcast bands. Stereo audio consists of two separate (L and R) signals, rather than just the single signal characteristic of monophonic (mono) audio. One of the main design requirements of SMPX during its development in the 1950's was that it must retain backwards compatibility with existing mono FM radios. The current FM radios only utilized the 0-15 kHz range for audio transmission, despite a channel spacing of 100 kHz. SMPX capitalized on this extra bandwidth by using the 0 to 15 kHz band to transmit the ordinary monophonic "sum" (L+R) signal, and then amplitude modulating the L-R information onto a suppressed 38kHz subcarrier in the 23-53 kHz region of the baseband spectrum[1]. In order to detect the phase of the suppressed 38 kHz carrier, a 19 kHz pilot tone is added to the difference (L-R) signal to allow for the exact phase of the carrier to be obtained by a coherent detector (a phase-locked loop in this case). This allows regular mono FM receivers to get the full audio signal in mono form from the 0-15 kHz range, and stereo-capable receivers to combine this information with the difference frequency to obtain a stereo signal. Figure 1 shows the spectrum of a stereo FM signal.

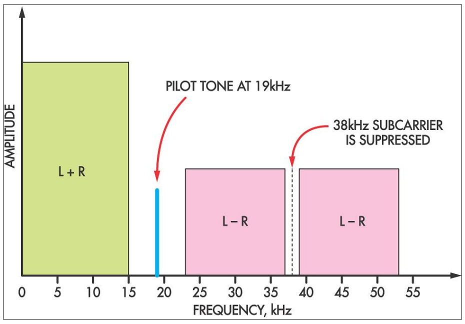

Figure 1: Stereo Multiplex Spectrum

2 Mathematical Analysis and Derivations

2.1 Multiplexed Signal

The equation for the transmission of a stereo multiplexed signal, m(t) is given by...

$$m(t) = C_0[L(t) + R(t)] + C_1[L(t) - R(t)]cos(2\pi 2f_c t) + C_0 cos(2\pi f_c t) \quad (1)$$

where $L(t), R(t)$ are the left and right audio signals, $f_c = 19kHz$ pilot wave frequency, and C_0, C_1, K Are gain values such that the signal is properly scaled and the pilot wave is between 8% and 10% peak frequency deviation.[1]

The demultiplexer built utilizes three filters: a low pass filter with cutoff frequency of 15kHz to recover the L+R signal, and two band pass filters. One band pass filter recovers the modulated L-R signal in the 23-53 kHz band, and a NB filter (often a high-Q filter) is used to recover the pilot carrier at 19 kHz.

The 38 kHz sub-carrier is then obtained by doubling the frequency of the pilot carrier, or in the case of this project, the frequency of a phase-synchronized reference signal generated by a PLL. The L-R signal can then obtained from the 38 kHz sub-carrier and modulated L-R signal using a a phase-coherent detector. The sum and difference signals are then input to a matrixer (adder/subtractor) to reconstruct the individual L and R signals.

The equations[3] for the individual sum and difference signals are given by...

$$sum_{L+R} = \frac{(L(t) + R(t)) + (L(t) - R(t))}{2} \quad (2)$$

$$difference_{L-R} = \frac{(L(t) + R(t)) - (L(t) - R(t))}{2} \quad (3)$$

The L and R signals are then de-emphasized to attenuate the boosted high frequencies using a single pole LPF[3] given by...

$$H(z) = 1 + j2\pi f\tau z \quad (4)$$

3 Block Diagrams

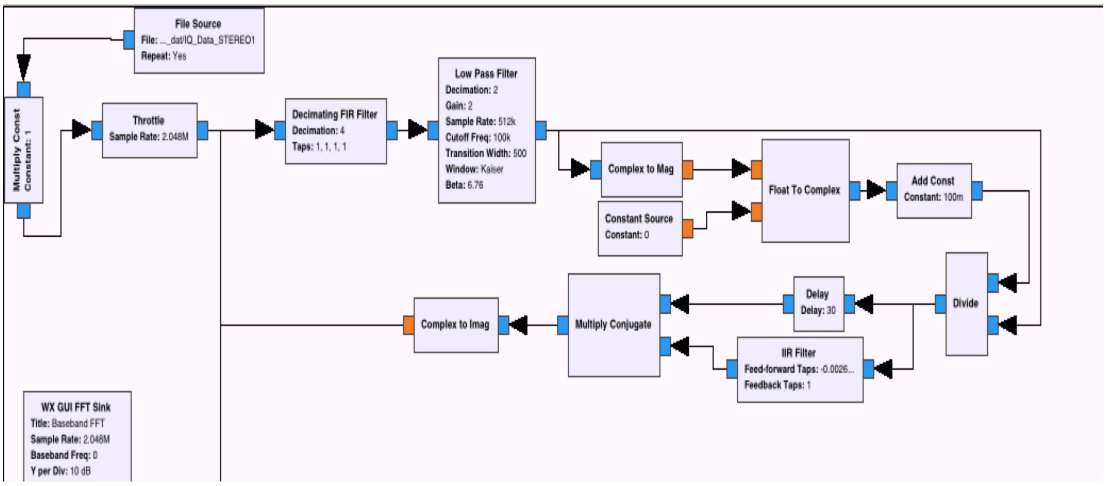

Figure 2: WBFM Demodulator

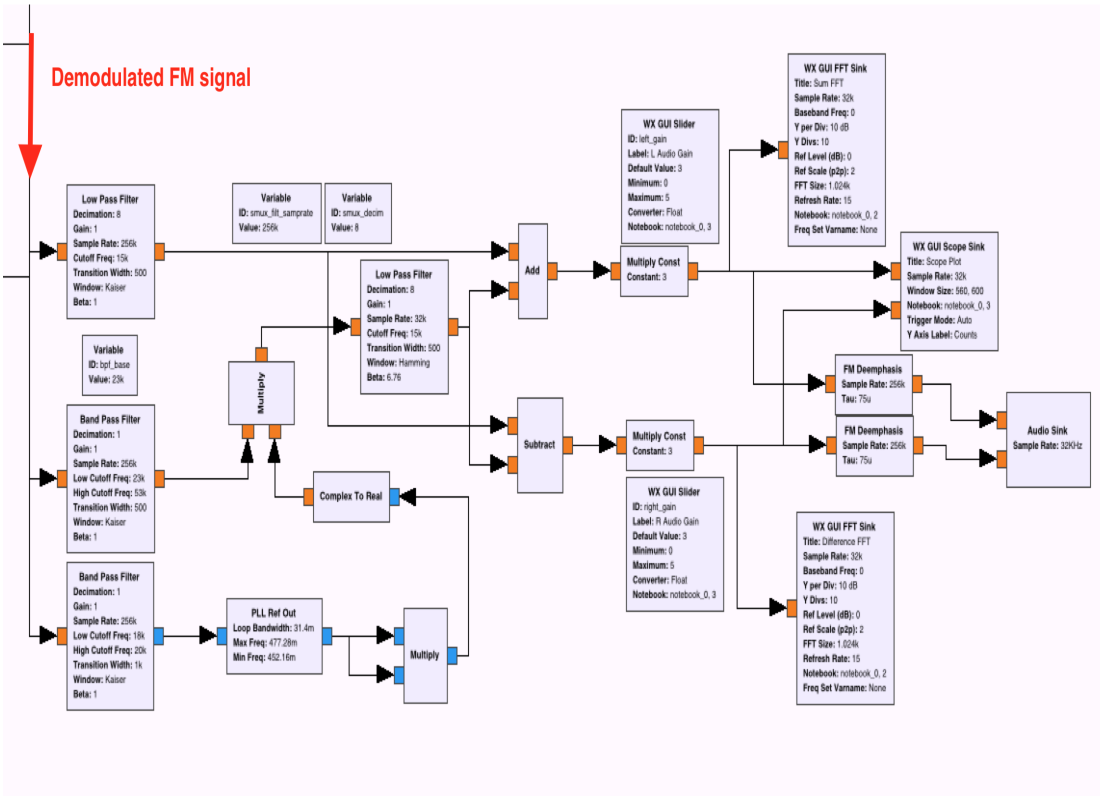

Figure 3: Stereo Demultiplexer

4 Results

As mentioned in the abstract, this project was successful in its implementation, delivering clear stereo audio at 32 kHz sample rate. Figure 4 shows an FFT and waterfall plot of the input spectrum directly output from the antenna, with 99.3 MHz mixed to baseband. Figure 5 shows the FFT of the demodulated signal at the output of the differentiator. Note the pilot frequency presenting as the strong peak at 19 kHz.

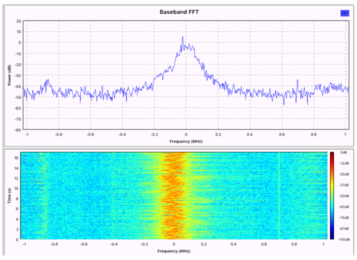

Figure 4: Baseband Spectrum

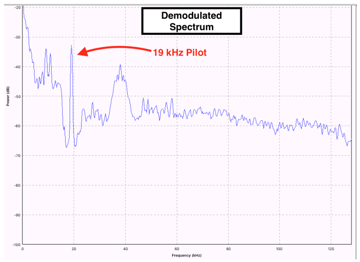

Figure 5: Demodulated Spectrum

Figure 6 shows the demultiplexed spectra after they have passed through the matrixer. The top plot is the FFT of the difference signal, and the bottom plot is the FFT of the sum signal. Note that they are not identical, but are both bandlimited to 15 kHz like a normal FM signal.

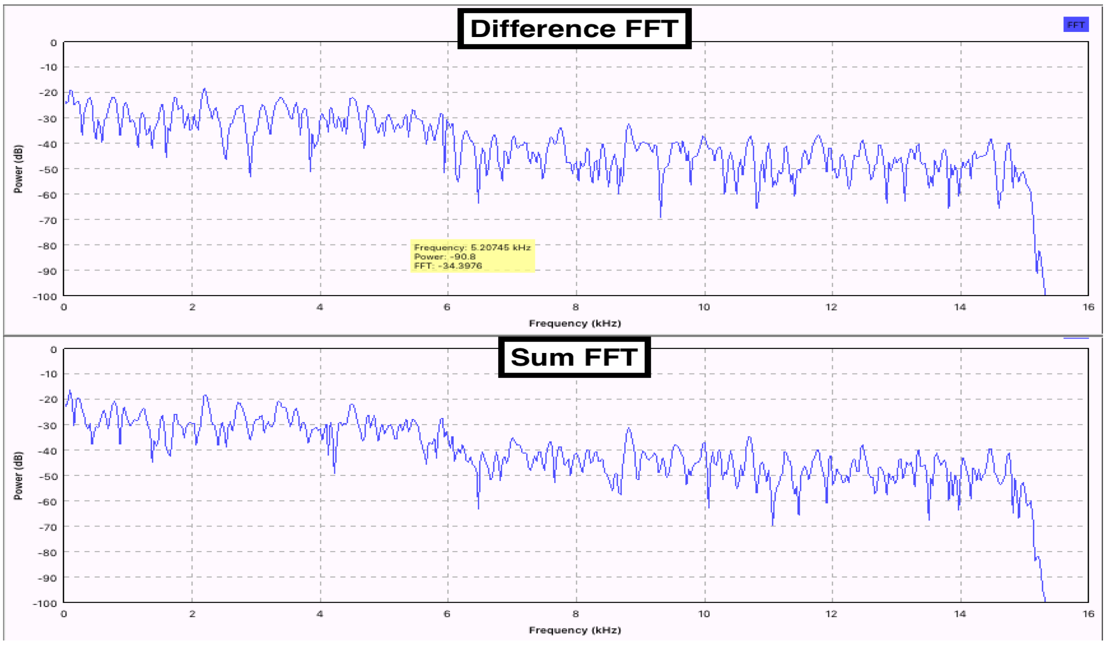

Figure 6: Sum and Difference Spectrum

Finally, Figure 7 shows the L and R audio signals at the input to the audio sink. Notice how the two signals (blue and green) are different, reflecting the two different audio channels.

Figure 7: Left and Right Audio Signals

5 Discussion

Overall, the project went smoothly, thanks to plenty of last minute help from Professor Hansen. One of the most difficult parts of building the SMPX was debugging the PLL reference output, since the block does not have much documentation. Once the block was functional, the rest of the design fell into place rather quickly.

One of the biggest struggles with the project was dealing with the various idiosyncrasies of the GNU Radio companion software. Glitches, such as audio underrun errors and fatal crashes occurred fairly frequently, especially when the scope of the design grew large, and when asking the computer to multitask on top of running GNU Radio. Many problems were alleviated by reducing the order of the implemented filter lengths to a reasonable level (i.e. setting kaiser filter values of $\beta \leq 2$. In addition, there were a number of problems that arose when switching between host operating systems. The source of these errors was never resolved, however they ceased to be an issue once recognized and worked around.

6 Source Code

GNU Radio companion source code, as well as a high-resolution digital copy of this report can be found at
`https://github.com/bigbrett/engs110_FM_stereo`

References

[1] Lawrence Der, Ph.D., *Frequency Modulation (FM) Tutorial.* Silicon Laboratories Inc.

[2] AllSyllabus Resources *FM Stereo Multiplexing.*

`http://www.allsyllabus.com/aj/note/ECE/Analog_Communication/Unit6/FM%20Stereo%20Multiplexing.php#.V05BqJMrKHq!`

Accessed May 29, 2016

[3] J. Kean, *FM Stereo and SCA Systems.* National Association of Broadcasters Engineering Handbook, 9^{th} Edition, NAB, 1999

[4] Wikipedia contributors. *FM broadcasting* Wikipedia, The Free Encyclopedia.

`https://en.wikipedia.org/w/index.php?title=FM_broadcasting&oldid=721844643.`

Accessed May 28, 2016.