EE603 - Digital Signal Processing and Applications
Spectrum and Filtering of RTL-SDR FM radio data [1]
Assigned: 12/11/21, Due: 21/11/21
Indian Institute of Technology Bombay

In this assignment we will first look at the spectrum of time-varying RF signals obtained using a software-defined radio (SDR). Next we will demodulate the FM signal obtained, and filter it to listen to a recorded FM broadcast channel.
Download the files relevant to this assignment from here:
`https://drive.google.com/drive/folders/1lkvfmw8aimlqo4FUGq2gjw7OKgSP_WfE?usp=sharing`
The samples that are obtained by a software defined radio SDR represent a bandwidth of the spectrum around a center frequency. Hence, when demodulating to base-band (i.e. zero frequency) the signal must be imaginary since it has a non-symmetric Fourier transform. In this case, we would like to display both sides of the spectrum.
You can use a spectrogram like function to visualize the spectrum of the captured signal.
We will first look at radio FM spectrum. In India the broadcast FM radio band is $90 - 108$ MHz. It is split into 800 kHz slots [2]. This is a relatively large bandwidth and therefore it is also called wideband FM as opposed to narrowband FM which can be as low as 5 KHz. In FM radio the information is encoded by modulating the frequency of the carrier. See `http://en.wikipedia.org/wiki/FM_broadcasting` for more details. Also refer to this website for more information related to this simulation `http://www.aaronscher.com/wireless_com_SDR/RTL_SDR_AM_spectrum_demod.html`. You are also provided a commented python file that can be run to listen to one of the channels. Your task is to understand, uncomment the remaining parts, visualize the steps in the process and listen to a FM radio audio clip. You also need to pay attention to the parameters. Submit your python code with appropriate plots and comments.

Task 1: Spectrogram of FM signal

You are provided with the complex FM signal, already demodulated using the center frequency of a radio channel. For all the tasks, use one of the provided channels in your report. It is your choice to use either 91.89 MHz channel data or the 92.7 MHz channel data (corresponding to 5 s, 10 s, or 20 s). They have been obtained with a sampling rate of 2.5 MHz. Compute and display a spectrogram for this complex data. Include the spectrogram in your report, with appropriate labeled axes.
The spectrum of a FM demodulated signal $x(t)$ is shown in Fig. 1. The plot you created above does not resemble the broadcast FM spectrum in Fig. 1, since it is not yet FM demodulated. We can easily see that the signal is frequency modulated – because its frequency looks like the time-signal of speech or music.

Task 2: FM signal demodulation

The next step we are going to perform is to demodulate the FM signal and look at its spectrogram. For this we need to find the instantaneous frequency as a function of time. There are many ways to implement this. Since we have the digital samples it is very easy to compute the instantaneous frequency by taking the

[1] Adapted from lab by Michael Lustig
[2] Not sure of the accuracy. Source: `http://en.wikipedia.org/wiki/FM_broadcasting_in_India`

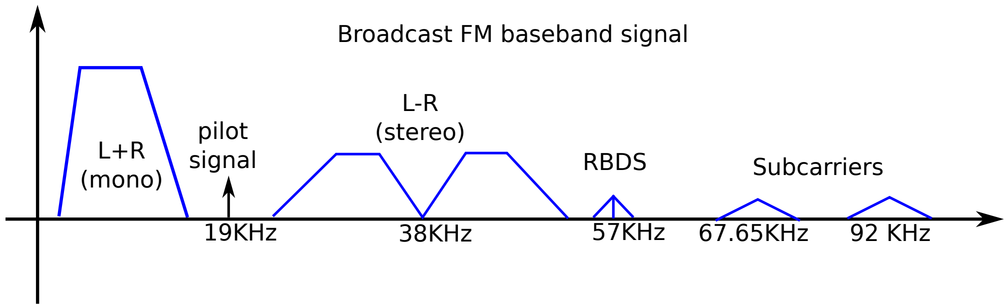

Figure 1: Broadcast FM baseband signal. Source: Prof. Lustig's manual.

derivative of the phase of the signal. We can approximate the derivative of the phase by computing finite differences of the phase of our signal,

$$\phi[n] - \phi[n-1] = \angle(y[n]) - \angle(y[n-1])$$

where $y[n]$ is the provided complex signal. The problem with phase is that it wraps. This will cause large finite difference values when the phase is around 0. An alternative, which is robust to phase wraps, is to compute the finite difference by computing the product $y[n]y^*[n-1]$ and then computing the phase.
FM demodulate the samples obtained using the SDR and display the spectrogram. Note, that after FM demodulating the signal should be real and hence it is sufficient to display only half the spectrum. Identify the mono audio, the pilot, the stereo and the RBDS signals. Note, that the radio broadcast data system (RBDS) signal may be too weak to detect or may need better spectral resolution. Can you identify any other sub-carriers ?

Task 3: Listen to radio

In this task we will play the mono signal of the demodulated FM station. The mono signal covers the frequency range of $0 - 16$ KHz. However, there are many other signals present. There's another problem. Our sampled signal is at a rate of 1 MHz. The soundcard on most modern computers can only deal with a sampling rate of 48 KHz. We will therefore need to filter our signal and downsample it before being able to play it.
To filter the signal you can use the `fdatool` in Matlab or equivalent tool in python. You can use it to design any type of filter. Design either a FIR or IIR filter and justify your choice. You can use any method that you are familiar with and obtain the filter parameters or coefficients. Create the filter and use it to filter the demodulated signal using `filter` or convolution. Plot the resulting spectrogram of the filtered signal. Include the filter details, along with a plot of the filter's magnitude response in your report.
In order to playout the audio you will need to change the rate of sampling. Resample it to have a rate 48 KHz, which the computer can play. What should be the maximum downsampling to avoid aliasing ? You can use Matlab's or python's `resample` to resample the signal. Scale it so that its range is between `-1` and 1 and play it. Plot the spectrogram after resampling. Make sure it makes sense. Do you see aliasing ? Do you hear radio ?