

Laboratory Demo 1: Software radio receiver and noise

EE161: Digital Communication Systems
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1 Introduction

The purpose of the experiment is to become familiar with the ADALM-PLUTO SDR module (henceforth referred to as APR). In particular, to investigate some of the effects that sampling rate, gain and DC offset of the APR have on the baseband signal and its spectrum. For this purpose, a MATLAB Simulink spectral analysis model is used. In addition, the functionality of the spectrum analyzer block is explored.

2 Prelab work

2.1 The APR receiver block in MATLAB Simulink

Investigate the functionality of the APR receiver block in MATLAB Simulink. In particular:

1. What types of DC offset compensation are available?
2. What types of automatic gain control (AGC) modes are supported?

2.2 Notes on earlier MATLAB versions

1. If you have your own APR and want to run the model in an earlier version, use the command `Simulink.exportToVersion`.

Example: Export model `APR_ISM915_spectrum.slx` to version R2019a with command:

```
Simulink.exportToVersion(bdroot, 'ISM915_spectrum_R2019a', 'R2019a')
```

2. The factory default transceiver chip in the APR is the AD9363 with an RF frequency range from 325 MHz to 3.8 GHz.

To run the radio at relatively lower or higher RF frequencies, you may need to click on the “Configure Pluto Radio” link that appears in the Diagnostics Viewer window.

To switch to the wider band transceiver chip you can also run the command:

```
configurePlutoRadio('AD9364', 'usb:0')
```

The AD9344 has an RF frequency range from 70 MHz to 6.0 GHz.

3 Bandwidth and gain

Download file `APR_ISM915_spectrum_2020b.slx` from Canvas directory `Files/Laboratory/Demo1`. You may need to copy and paste the file from your computer to the remote computer. Double-click on the file to start MATLAB Simulink.

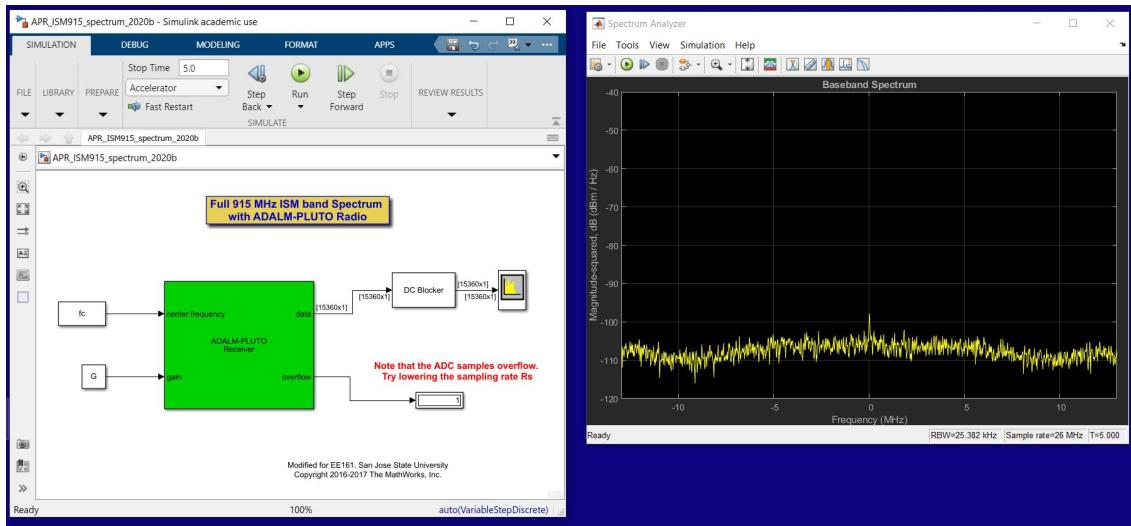
The APR receiver block has center frequency $fc = 915$ MHz, bandwidth of 26 MHz, set via the sampling rate $Rs = 26000000$ samples/second, and receiver gain of $G = 10$ dB. *For the report: What is the baseband signal bandwidth?*

The model uses variables for the parameters so that it is not necessary to open and close the model every time a change is made. You simply go to the command window and type the new parameter values. This is useful in models where many blocks share the same parameter value. It is important to note that in this mode you must first stop the model, type in the new variable values and then start the model again.

3.1 Overflow and sampling rate

- Run the model. The bandwidth covers the entire ISM band centered at 915 MHz so you should be able to observe many signals. Notice the presence of a “noise floor” that “jitters” about an average. This is the result of thermal noise with a Gaussian distribution. Also notice that there are overflows in the received samples (the overflow output port of the APR block is always equal to 1).

An example of the model results is shown in the figure below:



~~Stop the model. In order to estimate the noise floor value (or average power spectral density of the noise), open the *Spectrum Settings* subwindow and under *Trace options* change the value of *Averages* from 10 to 100. Close the subwindow, run the model again and record the noise floor value at around 1 MHz. For the report: What is the shape of the noise floor? Take a note (capture or sketch) as a reference.~~

- Stop the model. Now change the sampling rate to 4 MHz. Run the model and observe the spectrum. *For the report: What is the shape of the noise floor now? Take a note (capture or sketch). What happens to the overflow output?*
- Repeat with the sampling rate equal to 1 MHz. *For the report, in addition, measure the noise floor at 100 kHz.*

3.2 Gain

- Stop the model. Without modifying the other settings, change the gain from 10 dB to 30 dB. Run the model and observe the spectrum. *For the report: Take a note (capture or sketch) of the shape of the noise floor. Measure the noise floor at 100 kHz.*
- Stop the model. Change the gain from 30 dB to 50 dB. Repeat the same measurements and in addition measure the noise floor at 100 kHz ~~use averages set equal to 300~~.

4 DC offset

The default algorithm of the *DC blocker* Simulink block is *Subtract mean*. In this section we investigate the effect of other methods of DC offset compensation, including those built in the APR.

- Stop the model. Set the gain to 40 dB and the *averages* value to 100 and run the model. Observe the resulting spectrum. *For the report: Take a note (capture or sketch) of the spectral shape near 0 Hz.*
- Stop the model. Double-click on the *DC blocker* block and change the algorithm to FIR with *Number of past input samples for FIR algorithm* equal to 128. This number is the order of a high-pass filter with cutoff frequency near 0. You can see the frequency response by clicking on the *View Filter Response*. Run the model. *For the report: Take a note (capture or sketch) of the spectral shape near 0 Hz. Also include a plot or sketch of the FIR filter amplitude frequency response.*
- Stop the model. Remove the *DC blocker* block and reconnect *data* output port of the APR receiver block to the *Spectrum Analyzer*. Double-click on the APR receiver block and go to the *Advanced* tab.

Note that both RF and baseband DC correction are enabled by default. Close the window and run the model. Observe the resulting spectrum. *For the report: Take a note (capture or sketch) of the spectral shape near 0 Hz.*

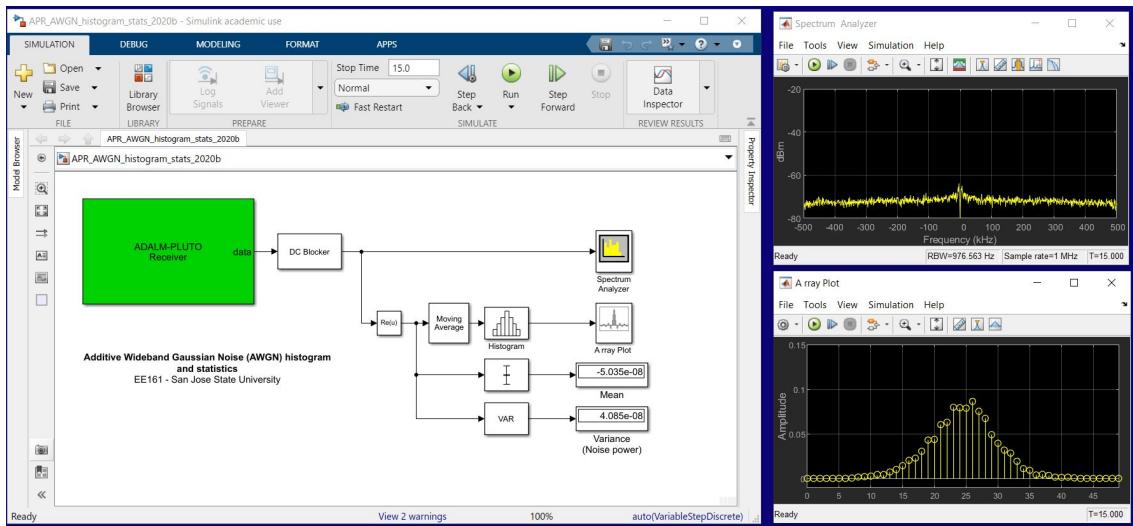
- Stop the model. Open the advanced parameters of the APR receiver block. Uncheck the *Enable RF Correction* box. Close the window and run the model again. *For the report: Take a note (capture or sketch) of the spectral shape near 0 Hz.*
- Stop the model. Open again the advanced parameters of the APR receiver block. Uncheck both the *Enable RF Correction* and *Enable baseband Correction* boxes. Close the window and run the model again. *For the report: Take a note (capture or sketch) of the spectral shape near 0 Hz.*

For your report: Finalize this section of the report with a summary and discussion on the effects that different DC offset algorithms have on the spectrum.

5 Receiver noise

Download MATLAB Simulink model `APR_AWGN_histogram_stats_2020b.slx` from Canvas directory `Files/Laboratory/Demo1`. The model displays both the spectrum as well as the histogram of the real part $r_I[n]$ of the received samples. A running average over 22 samples is computed prior to each histogram block in order to remove the effect of the DC offset.

- Run the model with the default receiver gain value $G_R = 0$ dB. Wait for the model to stop. Capture or sketch the histogram and attach it to your report. Take note of the variance (or noise power) measurement. An example of the model results is shown in the figure below:



- The noise power is given by $P_n = N_0 W$, where W is the demodulated signal bandwidth. Calculate the noise floor density $S_n = N_0/2$ in dBm with $S_n = 10 \log_{10} [(P_n/(2W))/10^{-3}]$ and attach the result in your report.
- Now change the **Baseband sample rate** from 1 MHz to 700 kHz and repeat the procedure above for each case. *For the report: Explain the effect, if any, that the sampling rate has on the histogram. You must justify carefully your explanation.*