EE417 Winter 2015
Project Info: Satellite Downlink Modulator / Demodulator
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Project Description:

Working in teams of 1 or 2 students, you will implement a modulator and demodulator (modem) for NASA's "Automatic Picture Transmission" or APT data format. This data format is used by polar orbiting weather satellites to send live imagery to ground stations below. You will also implement a channel impairment test function that adds AWGN to the received signal so you can observe signal degradation with added noise.

Your modem will be formally evaluated by your ability to generate and decode APT format images from ideal (stored) data files. We will conduct informal testing using a live feed from the NOAA-18 satellite during the last class period on Friday March 13th.

Deliverables:
Three .m files implementing the following:

modulator.m - Accepts a JPEG image of width 909 pixels and height of 1-1818 pixels and produces an f_s = 16KHz and *nbits* = 16 .wav file output that is amplitude modulated with image data in APT format. This image should occupy both the "A" and "B" subimages of the APT frame. The APT telemetry data words shall be all zeros.

demodulator.m - Accepts a 16KHz / 16 bit .wav file input containing an arbitrary number of lines of APT data and writes an 8-bit grayscale image to a JPEG file. This JPEG image should have dimensions of 1818 x *n_lines* (presenting the "A" and "B" subimages next to each other) where *n_lines* is an arbitrary number of lines determined by the source .wav file.

impairment.m - Accepts a .wav file input along with a signal-to-noise power ratio in dB and writes a .wav file output including AWGN calculated to yield the requested signal-to-noise power ratio.

Note: I recommend implementing the modulator first so you will be able to generate additional test data sets for your demodulator.

Grading:
25% Correct operation of modulator - ability to encode APT images
25% Correct operation of demodulator- ability to decode ideal (stored) APT images
25% Correct operation of impairment tester
25% Code quality and documentation

WAV file specification:
Your modem implementation must use .wav files for input and output. This way your .wav files can be played and inspected on any computer, and you can trade .wav files with other teams to test interoperability. There are many possible .wav file formats but we will standardize on the following .wav format:

Sample Rate *Fs*: 16.0KHz
Number of bits per sample *nbits*: 16
Channels: 1 (mono)
Numerical Format: Wav file is int16, data range -32768<= y <= +32767
Note that wavread/wavwrite accepts vectors with a range of -1 to 1 and scales that range to the full int16 range of the wav file itself.

You must use the Matlab wavread/wavwrite files to import and export wav files into your code.

http://www.mathworks.com/access/helpdesk/help/techdoc/ref/wavread.html

JPEG Image file specification:
Images shall be read and written in 8-bit grayscale JPEG format using Matlab's imread and imwrite functions.

Your modulator function shall accept 909 x 1818 images and encode the same image into both the "A" and "B" subimages in the APT image.

Your demodulator function shall accept an arbitrary number of lines of APT data and write an 1818 x *n_lines* JPEG where *n_lines* is the number of lines in the APT data.

http://www.mathworks.com/help/techdoc/ref/imread.html

APT Data Format:
The following summary of the APT data format is an excerpt from the NASA/NOAA specification. The information presented here is sufficient to implement your modulator and demodulator but a great deal of additional info is available from NASA and NOAA.

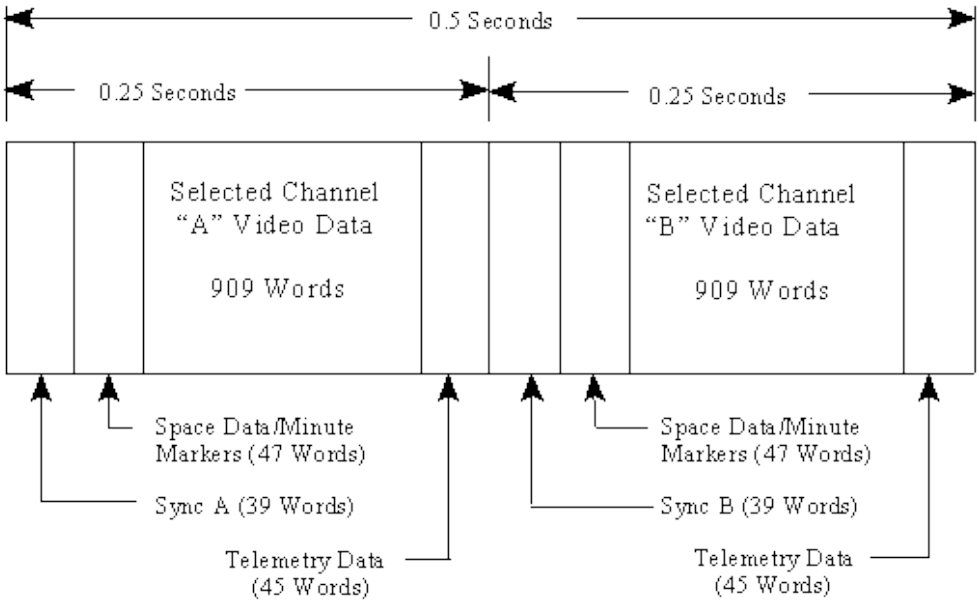
http://www.ncdc.noaa.gov/oa/pod-guide/ncdc/docs/klm/html/c4/sec4-2.htm

http://www.osd.noaa.gov/Spacecraft%20Systems/Pollar_Orbiting_Sat/NOAA_N_Prime/NOAA_NP_Booklet.pdf

APT Lines:
APT transmits images using pulse amplitude modulation (PAM) of a 2.4 kHz carrier. The fundamental unit of the APT image is the line. A received image from the satellite may consist of any number of lines because of varying amount of time the

satellite is visible above the horizon. Your demodulator shall function properly for any number of lines in the input APT data set. Your modulator need only accept up to 1818 lines as I will give you only 909 x 1818 JPEG images to encode.

Figure 4.2.3-2. APT Video Line Format.



Each APT line takes 0.5 seconds to transmit. Because you are receiving your data in .wav format with 16KHz sampling rate, each line will consist of 8000 samples. In the figure above, NASA has specified that each line is composed of a total of 2080 data words per line. Thus each data word period will be represented by 3.8462 samples in the .wav file. You will therefore have to account for the non-integer number of samples per data word period by resampling the input data to a sample rate of 16.640 KHz or 4.0 samples per word after resampling. If you do not resample, your images will appear striped or skewed because of the accumulated sample rate error.

http://www.mathworks.com/help/toolbox/signal/resample.html

APT Sync and Data Words

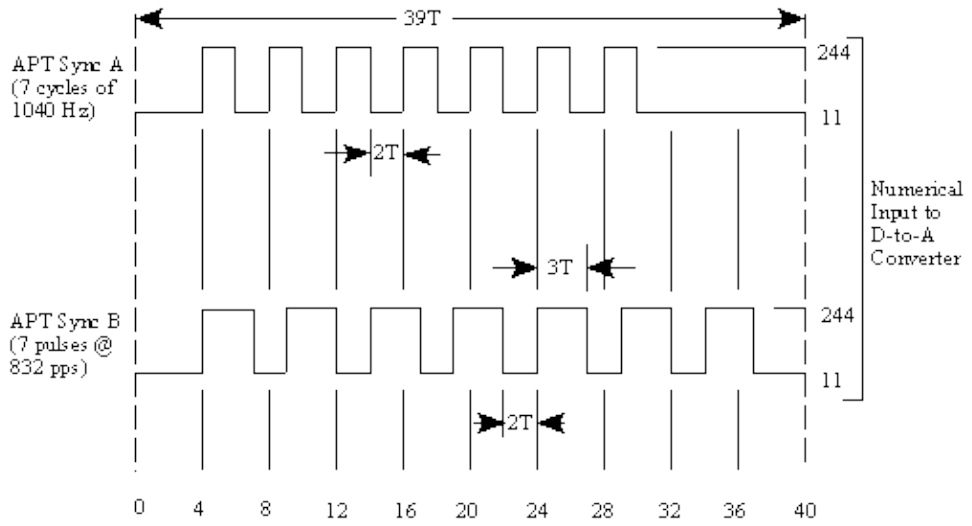
The modulation used for APT is pulse amplitude modulation (PAM) of a 2.4 kHz carrier. The magnitude of the signal power in each data word period encodes the word's value. APT data words are unsigned 8 bit words. Because your .wav files consists of 16 bit words (-32768 to +32767) you will have to scale the magnitude in your .wav file to yield unsigned 8-bit data words (0-255). Note that this scale factor cannot be fixed because the signal strength varies as the satellite moves. It must therefore be re-computed for each line based on the peak to peak amplitude of the Sync A pattern of each line (see below).

APT Sync Detection

Note that each line begins with the Sync A pattern that is used to identify the beginning of each line. Note that the .wav files you are given may not start exactly at the beginning of the first line of the image (for example, when the satellite comes over the horizon out-of-sync with respect to an image line). Your code must be robust to Sync A appearing at any time in the .wav file. You must therefore continuously check for the Sync A pattern in the input data and when it is detected begin accumulating that line's data. A correlator approach is recommended to perform the sync detection.

As mentioned earlier, the peak to peak amplitude of the Sync A pattern is used to calibrate the data scale factor for the remaining data words in that line. Referring to the NASA specification, the minimum of each sync pulse is defined as 11 decimal. The maximum of each sync pulse is defined as 244 decimal . This provides the scale factor for the remaining data words in each line.

Figure 4.2.3-3. APT Synchronization details.



Notes:

1) T=1/4160 second
2) Sync A precedes Channel A data
3) Sync B precedes Channel B data

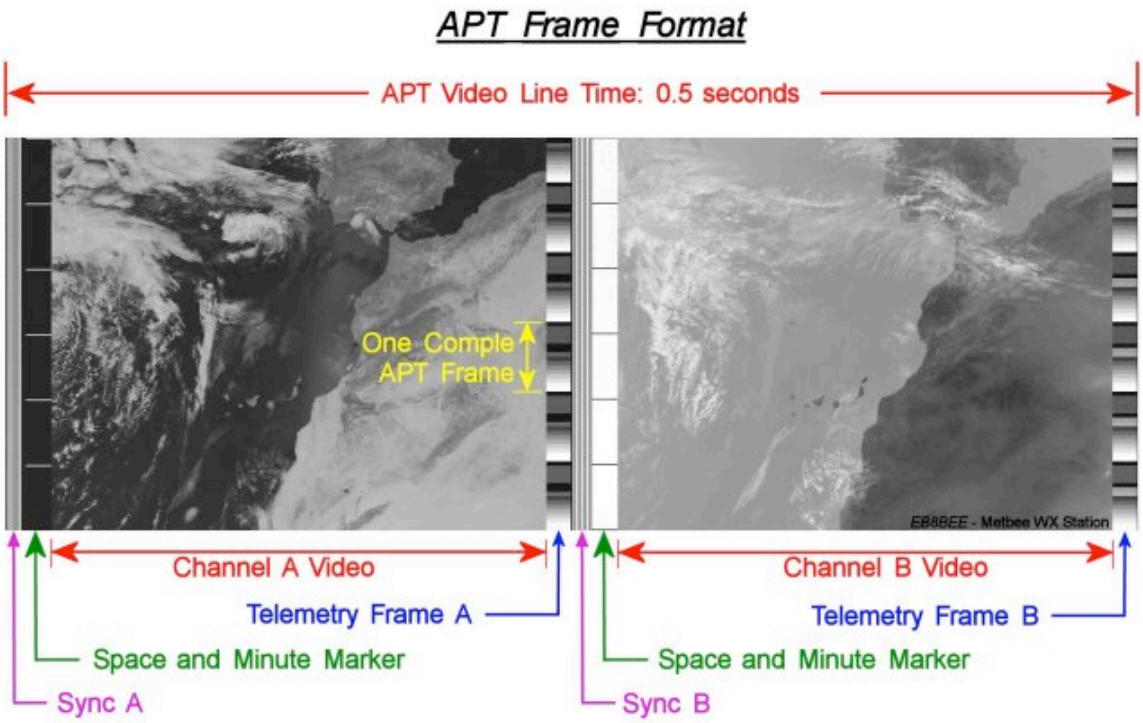
Note that you can and should ignore Sync B. If you have correctly started each line when Sync A is detected, Sync B and the "B" image data ("B Video Data") will appear at a fixed offset in sample number. So pulling out the 909 words of the A image and the 909 words of the B image is straightforward just by selecting the correct words out of the 2080 words in the line. If the word number starts at 1 for each line, words 87 through 996 form a line of the "A" image, while words 1127 through 2036 form a line of the "B" image.

When you write each line into the output JPEG image you should put the A image immediately to the left of the B image to form an 1818 pixel wide image. Ignore the space data and telemetry data words. The number of lines in your output JPEG image should be the same as the (variable) number of lines in the input .wav file.

APT Image Modulator
Note that your APT image modulator should generate the correct number of samples for the data words that are represented. I therefore recommend that you generate the APT lines at a sample rate of 16.640 KHz and resample to 16.0KHz immediately before writing the wav file.

Since we do not have any telemetry or space data to send, these fields should be set to zero.

Appearance of an APT Image
This figure shows how APT lines are assembled into an APT image. Note that the concept of "APT Frames" relates to the satellite telemetry and is not required for the purpose of this project since we are only interested in image encoding/decoding.



Impairment Generator Specification
The impairment generator shall add AWGN to the signal in the WAV file in such a way that the specified signal to noise ratio in dB is achieved.

For example, let us assume that a signal to impairment ratio of +10dB is to be generated. This means that signal power shall be 10X greater than noise power, averaged over the entire input file. Start by finding the RMS signal power in the input signal over the entire input file. Add AWGN on a per-sample basis with an appropriate variance chosen to yield the required noise power ratio. Now re-scale the resulting samples so they occupy the 16-bit range between -32768 and +32767 as required by the wavwrite function.