

## Power Spectral Density of Line Codes

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### Introduction

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In this lab you will measure the Power Spectral Density (PSD) of three common line codes: NRZ, Manchester, and 4B5B combined with MLT-3 (the line code used by 100 Mb/s Ethernet).

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### Generating the Test Signals

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Matlab is a convenient language for generating test signals. We will use Matlab or Octave<sup>1</sup> to generate the signals in .RAF format suitable for loading into the AWG. The file `linecodes.zip`, available on the course web site, contains the files `linecodes.m` and `rafwrite.m`. The `linecodes.m` script generates 10,000 random bits and encodes them using the three line codes.

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### Pre-Lab Report

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Read through the Matlab code (particularly the comments) to learn how it works and answer the following questions. You can also use the `help` command and evaluate expressions in Matlab to answer questions about operators and functions.

- What does the `rand(1, n)` function return? Is it a row or column vector? (try the command `help rand`).
- What values result from applying the `>` operator? (`doc gt`).
- How many rows and columns does a matrix defined as `[ 1 0 ; 1 0 ; 1 0 ]` have? (`help size`)
- What is the effect of subscripting the above matrix with `(:)`? (`help colon`)

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<sup>1</sup>Matlab is available through Apps Anywhere however Octave is compatible with Matlab, can be downloaded for free and may be easier to use in the lab.

- What does the `.'` operator do? What is the effect of applying it to the above vector? (`help transpose`)
- What do the `cumsum()` and `mod()` functions return?
- How does the expression `mod(cumsum([1 0 1 1 0 0 1]), 4)` perform MLT-3 encoding?
- What is the bit rate at the input to the encoder if the sampling rate is set to 1 MHz?

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### Procedure

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#### Generate Waveforms

Run the Matlab script to generate the three .RAF files. You may want to copy the script to your working directory (or flash drive) and `cd` to this drive/directory<sup>2</sup> before running the script so that all the files end up in the same folder.

Load the `nrz.raf` file into the AWG using the instructions in previous labs. Set the sample rate to 1 MHz, HiLevel to 1 V and LoLevel to -1 V.

#### Capture Waveforms

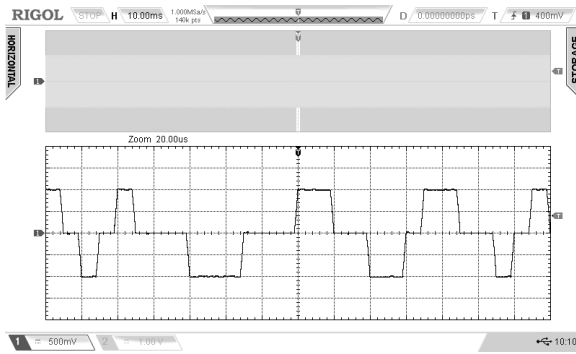
Connect the signal generator to the 'scope and look at the waveform. Measure the amplitude and bit period and confirm it's what you expected.

As in a previous lab, use the Acquire menu to set the memory Depth to 140 kSamples and use the Scale control in the Horizontal controls section for a sampling rate of 1 MHz.

As in a previous lab, press the Horizontal scale knob to switch to delayed trigger mode and "zoom in" on a portion of the waveform. For the MLT-3 line code it might look like:

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<sup>2</sup>e.g. `cd 'f:'`



Capture a 'scope screen shot for your report.

Use the Storage menu to save the captured data to your flash drive. Under "Storage" select CSV for the file type, Channel 1 for the source, "Maximum" for the Data Depth and disable Parameter Save.

Press Save to select the folder (directory) and file name under which to save the file. If you wish, you can create a new folder on the flash drive and a new file name.

Repeat the steps above for the data encoded using the Manchester and 4B5B-MLT3 line codes (`manchester.raf` and `4b5mlt3.raf` respectively).

You should now have three screen captures and three `.csv` files on your flash drive.

### Analyze Waveforms

As in the previous lab, run Octave (or Matlab) and read the samples from the `.csv` file for the NRZ-encoded data using the `csvread()` function. As before, remove the first two lines and convert to a real signal. For example:

```
x=csvread('f:nrz.csv');
x=real(x(:,2));
```

Now compute the power spectrum using the following Matlab function:

```
[nrzpsd,f]=pwelch(x,hamming(256),[],256,1e6,'onesided');
```

This will compute the (one-sided, i.e. positive) power spectrum over 256 frequencies assuming a sampling rate of 1 MHz using a "Hamming" window.

You can then plot the power spectrum (in dB) versus frequency using the command:

```
plot(f,10*log10(nrzpsd))
```

Check your results by comparing to the spectra given in the lecture notes.

Compute the spectrum for the Manchester- and 4B5B-MLT3-encoded signals and plot them together for comparison<sup>3</sup>:

```
plot(f,10*log10([nrzpsd,manchesterpsd,mlt3psd]))
```

As in the previous lab, save this plot to an image file so that you can include it your report.

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### Lab Report

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Your report should include the usual identification information, three 'scope screen captures showing your waveforms, one plot showing the computed spectra of the three line codes in dB and the values of the following parameters for each line code<sup>4</sup>:

- data rate
- baud rate
- the 10 dB bandwidth (the frequency at which the PSD has dropped by 10 dB compared to the maximum value)
- frequency of first (lowest frequency) null above DC ( $f = 0$ )
- PSD at DC (0 Hz), in dB relative to the maximum

<sup>3</sup>Substituting the variable names you used for the other power spectra.

<sup>4</sup>Formatted as a table might be a good idea.