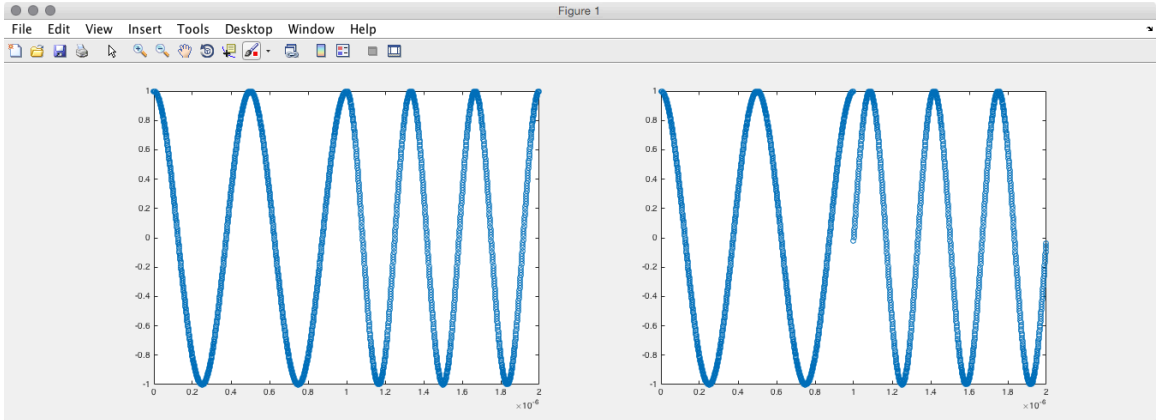
EE194/EE290C HW3 -- Simulating radio basics in Matlab -- Spring 2017

In this HW we will:
1. Generate a data signal: a random binary vector representing frequency vs time where 0 means -250kHz and 1 means +250kHz. The binary values should change at 1Mbit/s (for GFSK modulation, this is the same as 1Msymbol/s), so each binary value in your original vector represents 1us of time. Be sure to oversample it so you get at least 256 points per bit.
2. Use that to modulate the frequency of an oscillator (performing up-conversion via direct modulation). In the chip this will be ~2.4GHz but in this HW it'll be 24MHz to make the matlab processing faster.
3. Pretend the signal travels over the air perfectly (for now); pass that signal through a mixer by multiplying by a sinusoid just a bit less than 24 MHz. We want $f_{IF}$=2.5MHz and the receiver's Local Oscillator frequency is $f_{RF}$-$f_{IF}$. (performing down-conversion).
4. Filter with an appropriate low-pass filter. Multiplying two cosines yields the sum and difference of their frequencies; we need to get rid of the sum component.

**Assignment 1:** Write a matlab script that performs these functions, and plot at the time-domain waveforms (amplitude vs time) and frequency-domain spectrum (including negative and positive frequency) at each of these 4 steps to see how the signal evolves at each point. Then plot freq vs time at step 1 and step 4 to make sure the input and output match!

Spec details:
The oscillator should be modulated at 24MHz +/- 250kHz at 1Msymbol/s (in BLE this is the same as saying 1Mbit/s or the frequency shifts at 1MHz -- the frequency could change every 1us.). In reality, this will be 2.4GHz + BLE channel offset +/- 250kHz. You can accomplish this however you want, but make sure it doesn't have any phase discontinuities. For instance, here's a 1V amplitude time-domain signal transitioning from 2MHz to 3MHz at t=1us:

```
t=0:1e-9:2e-6-1e-9;
subplot(1,2,1)
plot(t,[cos(2*pi*2e6*t(1:end/2-1)) cos(2*pi*3e6*t(end/2:end))],'o')
subplot(1,2,2)
plot(t,[cos(2*pi*2e6*t(1:end/2)) cos(2*pi*3e6*t(end/8:5*end/8-1))],'o')
```




On the left there is a smooth transition but on the right there's an abrupt phase jump. Both switch from f=2MHz to f=3MHz but the phase jump will result in all sorts of noisy emissions in the frequency domain and a real circuit will have a hard time jumping so abruptly besides.

We suggest starting with random binary sequence, switching at 1Mbit/s, then writing a loop to go through that sequence to generate a time-domain waveform with something like `cos(2pi*(f_RF+f_modulation)).`

Another good way is to calculate the phase of the signal over time and take `cos()` of that afterward.

FFT:

The code included with the matlab help page on setting up FFT works great:
`https://www.mathworks.com/help/matlab/ref/fft.html`
But try to plot double-sided instead of single-sided FFT. There's some sample code in `http://inst.eecs.berkeley.edu/~ee290c/sp17/hw/MatlabSignalsAndNoise.m` too -- but most of that file isn't applicable to this homework.

Filtering:

Any low-pass (bandpass?) filter should be fine; experiment with what you can generate with matlab's `fdatool` GUI. A good place to start is the Butterworth. Once you design a filter, export it with File > Generate MATLAB Code > Filter Design Function. Save the .m, open it, and copy that code into yours.

Visualize a filter with `fvtool(Hd)`, where `Hd` is the object created by `dfilt.dffir()`. Apply it to a signal with `filter(Hd,mySignal)`.

Getting started:
If you're lost, here's the first few lines of our sample program:

```
% Simulation parameters
N=2^13;                      % Number of points to simulate
fs=256e6;                    % Sampling frequency (N/(fs/datarate) must
be integer)
deltat=1/fs;
deltaf=fs/N;
time=0:deltat:(N-1)*deltat; % Simulation time vector
datarate=1e6; % 1Msymbol/s
deltafsk=0.5*datarate/2;
f_RF=24e6;

% Generate random binary bits
bits=round(rand(1,N/(fs/datarate)));
```

**Assignment 2:** Redo #1 with a Gaussian filter applied to the bit stream. This means a freq vs time plot would look like a smooth change from one freq to another instead of sudden jumps between +250kHz and -250kHz. Note this is different from *phase discontinuities* -- now you're trying to eliminate *frequency discontinuities* too. One way to do this is take your vector of frequency vs. time representing 0101... and apply a Gaussian filter.

Matlab's Gaussian filter can be invoked with `gaussdesign()`. The first parameter for this function is BT, or B*T -- this is the filter bandwidth times the bit period. Bit period you already know, and the filter should be the total +/- frequency spacing. The second parameter is "span" and we suggest leaving it at its default of 3. The third parameter depends on your code.

A huge demo of Gaussian filters for various bandwidths and ideal vs nonideal approximations will pop up if you run `GaussianFilterExample`. FYI the "a" term in Figures 2 and 4 is b*t.

**Assignment 3:** Add noise to your Gaussian bitstream after step 2 (the signal doesn't get transmitted perfectly anymore), then redo #2. Make some noise with:

```
noise = sigma*randn(size(mySignal));
```

And add it to your Gaussian signal:

```
newsignal = mySignal+noise;
```

This is called AWGN -- additive white Gaussian noise. Try a few different `sigma` values (0.1 is a good place to start). How large can it be before you can't see the signal in your freq vs time plot after step 4 anymore? What should sigma be for the bandwidth we need to use with our IF?

IMPORTANT NOTE:

This is a plot-heavy writeup so use plots and axis labels efficiently, e.g., `subplot()` -- I don't want to see a 50-page word doc with 1 barely-labeled plot per page.