SDR Demonstration of QAM in mathematical and graphical forms

Contents

Source material used in this example

SDRForEngineers course material
Microwave journal
MIT Lectures on Modulation
ShareTechNote - Under Comm.Tech and SDR
Convolution example

Definitions/Script Configuration

```
% Include some packages (using minimal additions and
    functions hiding the maths,
% of what they're doing)
pkg load signal
pkg load communications

% Number of detection points (QAM is 4, one each quadrant
    )
mlevel = 4;

% Sample rate
samplerate = 100;

% Bit rate
bitrate = 2;

% Frequency of carrier signal should be higher than the
    bitrate! (x2-10 is useful)
fmod = 4;

% Bit length = 2pi * carrier freq
bitlen = fmod*2*pi;

% Input 'Bitstream' for modulation
inbits = [0, 1, 0, 1, 0, 1, 0, 1, 1, 1, 1, 1, 0, 1, 0, 1,
     0, 1, 0, 1, 1, 1, 1, 1];
```

Bitstream generation into quadrant components

```
% Some shorter inline equation $e^{ix} = \cos x + i\sin
    x$.

% Transform input bitstream so that 0's are -1
% this will make easier quadrant calculations below by
    pushing the sin/cos
% component out by 90 degrees (phase) if zero, as zero
    becomes -1,
% and if 1, it will stay 1.
inbits = (inbits .* 2) .- 1;

% Generate I/Q bit patterns for QAM (bit defines quadrant
     i=x q=y axis.
% Split every second bit between si/sq (QAM property)
```

```
si = inbits(1:2:end);
sq = inbits(2:2:end);
```

Lets look at the si sq I and Q multipliers

```
disp('si='); disp(si);
disp('sq='); disp(sq);
```

```
si=
  -1  -1  -1  -1   1   1  -1  -1  -1  -1   1   1
sq=
   1   1   1   1   1   1   1   1   1   1   1   1
```

Process into I and Q

```
% Pad last symbol for algorithm to work in octave/matlab
si = [si 0];
sq = [sq 0];

% The number of samples used in this example, go all the
    way to 2pi*length of bitstream
% 1 wavelength is 2pi
% 1 bit length is the bitrate
ft = 0:1:(2*pi*fmod*(length(si)-1));
```

QAM modulation (I/Q waveform phase generation)

Each bit is mapped onto a sin/cos waveform and phase(1/-1) of waveform
Equation for calculating the sin/I/real component 'bit' emphasis on phase

$$iy(t) = \cos(t) * Ibit(\frac{t}{2 * pi * fmod})$$

Equation for calculating the cos/Q/imaginary component 'bit' emphasis on phase

$$qy(t) = \sin(t) * Qbit(\frac{t}{2 * pi * fmod})$$

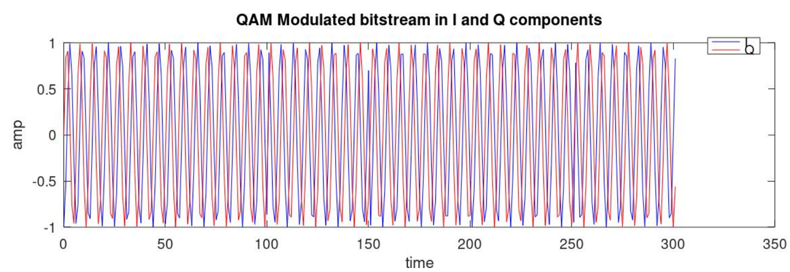
```
iy = cos(ft) .* si(floor(ft/(2*pi*fmod)) +1);
qy = sin(ft) .* sq(floor(ft/(2*pi*fmod)) +1);
```

Add the components of the wave together to get the output wave

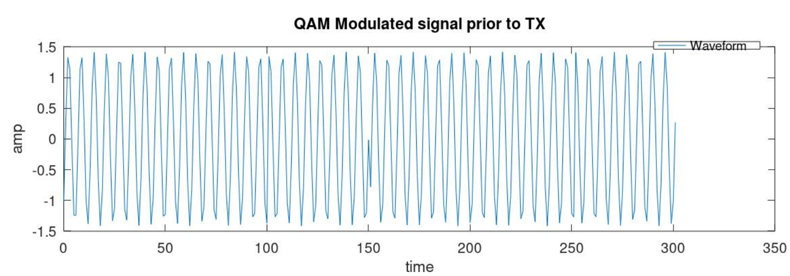
```
outwave = iy+qy;

% Putting the above equation together we get:
% $$w(t) = \cos(t) * Ibit(\frac{t}{2*pi*fmod}) + j * \sin
    (t) * Qbit(\frac{t}{2*pi*fmod})$$

% Plot the I and Q of the modulation
figure(1, "paperposition", [1 1 9 2.5]);
plot(ft, iy, "b", ft, qy, "r");
title('QAM Modulated bitstream in I and Q components');
legend('I', 'Q');
xlabel("time"); ylabel("amp");
```




```
% Plot the output wave
figure(2, "paperposition", [1 2 9 2.5]);
plot(ft, outwave );
title('QAM Modulated signal prior to TX');
legend('Waveform');
xlabel("time"); ylabel("amp");
```

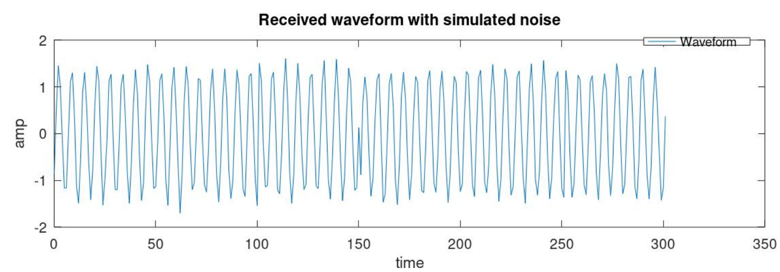


Process/simulate wave transmission (add noise etc)

What values of NOISE does QAM work down to, why does QAM have good noise immunity?

```
inwave = awgn(outwave,20,'measured');

% Plot the "received wave", noise included from above
figure(3, "paperposition", [1 3 9 2.5]);
plot(ft, inwave);
title('Received waveform with simulated noise');
legend('Waveform');
xlabel("time"); ylabel("amp");
```



Re-process signal into I and Q

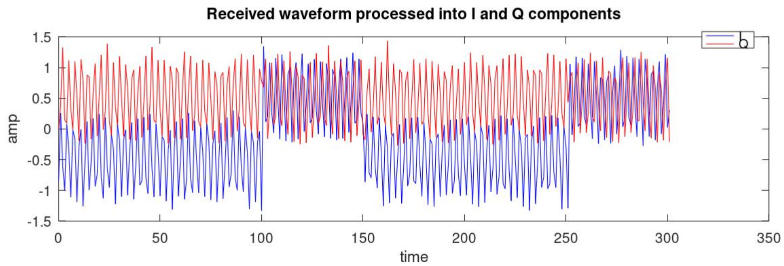
```
in_i = inwave .* cos(ft);
in_q = inwave .* sin(ft);

% Plot the waveform decomposed back into I and Q
figure(4, "paperposition", [1 4 9 2.5]);
plot(ft, in_i, "b", ft, in_q, "r");
title('Received waveform processed into I and Q
    components');
legend('I', 'Q');
xlabel("time"); ylabel("amp");
```

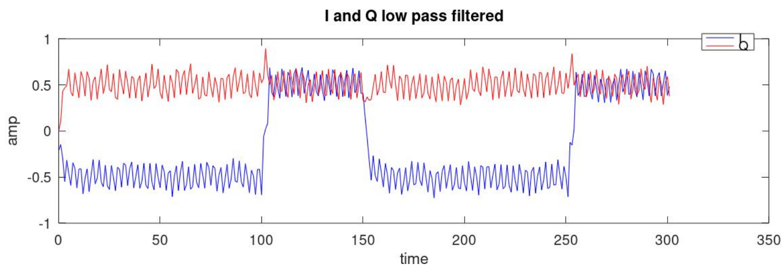
Window moving average/convolution low pass filter

this is essentially a simple convolution

```
windowsz = fmod;
filteredi = filter(ones(windowsz,1)/windowsz, 1, in_i);
filteredq = filter(ones(windowsz,1)/windowsz, 1, in_q);
```




```
% Averages of I and Q waveforms
figure(5, "paperposition", [1 5 9 2.5]);
plot(ft, filteredi, "b", ft, filteredq, "r");
title('I and Q low pass filtered');
legend('I', 'Q');
xlabel("time"); ylabel("amp");
```

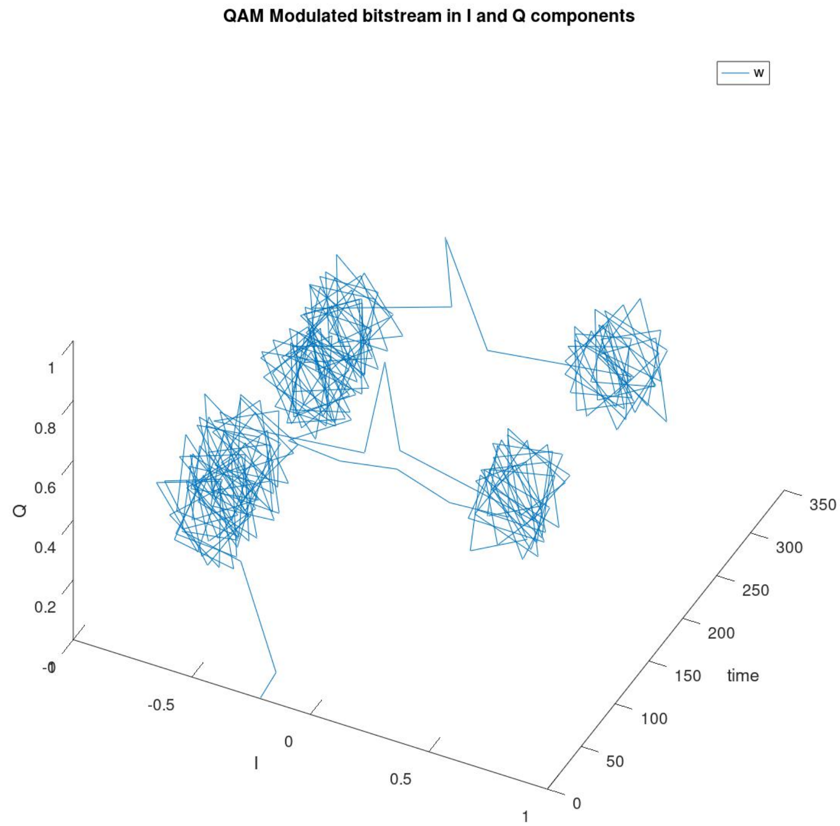



```
% Plot a constellation in 3d with time scale as the Z
    axis
figure(6, "paperposition", [1 6 8 8]);
plot3(ft, filteredi, filteredq);
view([8,-4,-10]);
title('QAM Modulated bitstream in I and Q components');
legend('w');
xlabel("time"); ylabel("I"); zlabel('Q');
```

Demodulation (quadrant detection)

We detect approx halfway into each symbol (bit length)

```
outbits = [];
for i = ft(floor(bitlen/2):floor(bitlen):end)
  if(filteredi(i) > 0)
    iret = 1;
  else
    iret = 0;
```



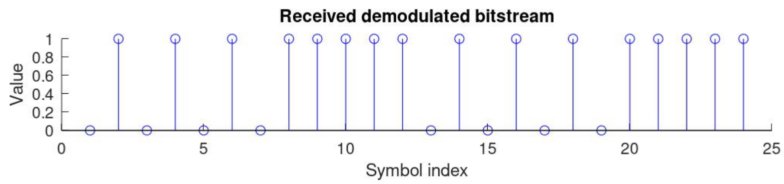

```
  endif
  if(filteredq(i) > 0)
    qret = 1;
  else
    qret = 0;
  endif
  outbits = [outbits iret qret];
endfor
```

Results

Output bitstream as received/filtered/demodulated

```
figure(7, "paperposition", [1 7 8 1.5]);
```

```
stem(outbits, 'b'); title('Received demodulated bitstream
    ');
xlabel('Symbol index'); ylabel('Value');
```



Input bitstream as modulated

```
figure(8, "paperposition", [1 8 8 1.5]);
stem(((inbits .+ 1) ./ 2), 'r'); title('Original
    modulated bitstream');
xlabel('Symbol index'); ylabel('Value');
```