**ASSIGNMENT COVER SHEET**

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| --- | --- |
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| Date of submission | / / 2020 |

Please complete your details above and include this cover sheet as the first page on your assignment submission.

Please also remember to upload your source file (Matlab or otherwise), in a format that can be executed to confirm functionality, i.e. ensure all support files are included, and files are logically names and commented. A ‘zip’ file with subdirectories for each question and/or a ‘README’ file is highly recommended.

The allocation of marks will be:

|  |  |  |
| --- | --- | --- |
| Question | Max [%] | Mark [%] |
| **Transmitter/20** | |  |
| a | 5 |  |
| b | 5 |  |
| c | 5 |  |
| d | 5 |  |
| **Receiver/40** | |  |
| e | 10 |  |
| f | 10 |  |
| g | 20 |  |
| **Equaliser/40** | |  |
| h | 20 |  |
| i | 10 |  |
| j | 10 |  |
| **TOTAL** | **100** |  |

a) In this case, a throughput of 1Mb/s is required, with a bandwidth of 500kHz. Three modulation types are available:

* Bipolar Signalling, or 2 PAM sends a stream of raised cosine shaped pulse of amplitude -1 or 1, representing the state of each individual bit. Hence, Rs = Rb. The essential bandwidth of the signal is therefore 1Mb/s. However, the transmitted signal of this method has only two voltage levels, making resilient to Inter-Symbol Interference (ISI).
* 4 PAM, like Bipolar Signalling, sends a series of shaped pulses. These are of amplitude -3, -1, 1, 3 however, representing the value of each set of two bits. Hence, two bits are transmitted for each pulse, so Rs=2Rb, giving an essential bandwidth of 500kHz for this case.
* 8 PAM is similar to 4 PAM, but with a symbol size of 8, giving a data rate of 1.5Mb/s for a symbol rate of 500kHz. Because of the decreased margins between levels in the transmitted signal, this is significantly more susceptible to ISI than 4 PAM.

Considering these characteristics, 4 PAM is considered the most suitable method of modulation as it’s bandwidth of 500kHz for a bit rate of 1Mb/s meets requirement. If 8 PAM were used, it would also meet these requirements, and would occupy less bandwidth than 4 PAM. However, its increased susceptibility to channel noise makes it less reliable than 4 PAM, and would thus require a greater transmitted power to achieve the same Signal to Noise Ratio (SNR).

b) Mathematically, 4 PAM is defined as follows in the time domain:



Where defines the pulse shape, which is then convolved with a series of impulses of height ak, representing the data to be modulated and sent over the channel.

To find the Power Spectral Density (PSD) function:



Where |YT(f)|2 is the energy density function of the Fourier transform of y(t). By convolution theory:

Where is the Fourier transform of:



Thus, the PSD becomes:

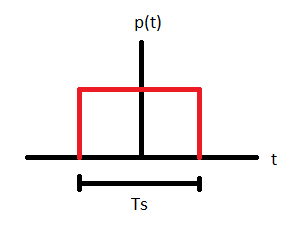


Rearranging gives:



Where is the PSD function of, and is the Fourier transform of . In this case, no pulse shaping is used. is therefore a square sided rectangle function:

In graphical form:

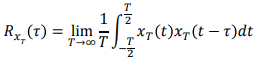


Therefore:

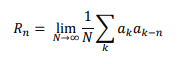
)

To find the energy spectral density, this is squared:

Using the autocorrelation properties of , , the autocorrelation of x(t), where:



Because x(t) is a discrete function, the integral will be zero for all values of tau that do not cause the xT functions to align. This will occur at tau = 0 and every other multiple of the signal period, Ts. For the purpose of explanation, these two cases are defined separately as:





Where N represents the number of symbols transmitted in the time T, given a constant symbol rate of Ts. Given that an infinite number of symbols are transmitted, and that a symbol values of -3, 3, 1, and -1 are equally likely to occur, R0 becomes:

Therefore:

To calculate Rn, all 16 possible combinations of must be considered:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  | | | |
|  | -3 | -1 | 1 | 3 |
| -3 | 9 | 3 | -3 | -9 |
| -1 | 3 | 1 | -1 | -3 |
| 1 | -3 | -1 | 1 | 3 |
| 3 | -9 | -3 | 3 | 9 |

Table 1; All possible combinations of an autocorrelated 4 PAM signal

From table 1, it is clear that the autocorrelated values of -3 and 3 each occur ¼ of the time, whereby -1, 1, -9 and 9 occur 1/8 of the time. As Rn assumes an infinitely long symbol stream, Rn becomes:

Therefore:

,

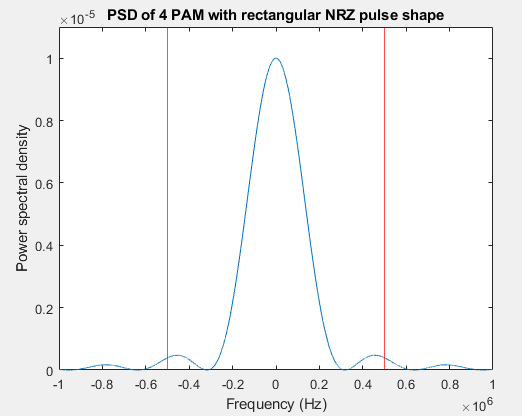
As is an even function:



Substituting for Ro and Rn gives:

Correlating this with in the time domain gives the overall PSD:

Given this, a PSD was generated using Matlab:



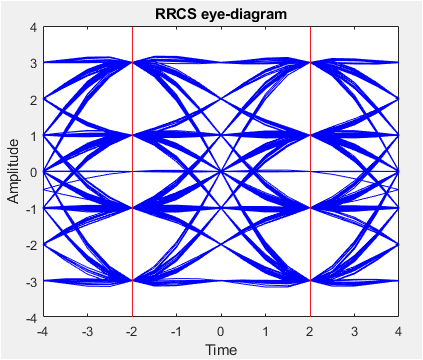
c)

d) With an input bit sequence of:

The symbols to be transmitted with 4 PAM are:

Modulated using a root raised cosine pulse shaping gives the time domain output below:

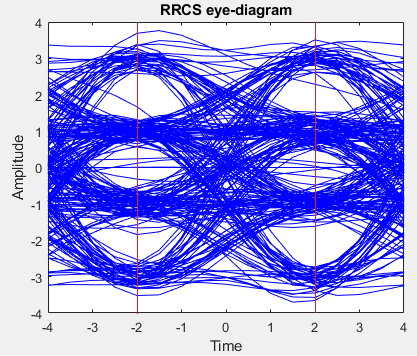
e) Using an alpha value of 1, and a random set of data, the following eye diagram was produced, showing two symbol periods:



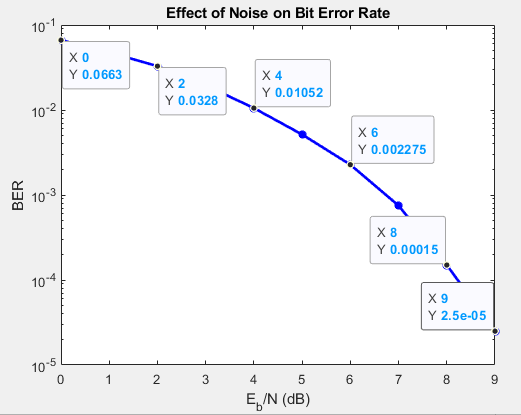
Ideal sampling points are shown in red, as no ISI is exhibited at these points.

f) When affected by an Eb/N0 or Signal to Noise Ratio (SNR) of 10dB, the eye diagram of the receiver matched filter output will have the following characteristics when compared with its noise free counterpart:

* The eye opening will be slightly closed, meaning the ISI will have increased.
* At the optimum sampling point, the individual signals will have differing values, introducing some uncertainty in the decoder.
* Despite the effect of noise, the maximum eye opening will remain at the same point during the symbol period.



g)



h)

Taken from assignment specification:

The received signal can be represented in discrete time as

Where w[i] is a sample of AWGN noise. Using the definition of the autocorrelation coefficients

We can derive the autocorrelation expression using the following steps:

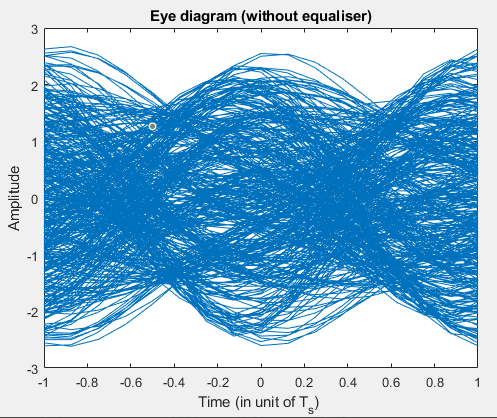
Assuming sampling at the ideal sampling instants

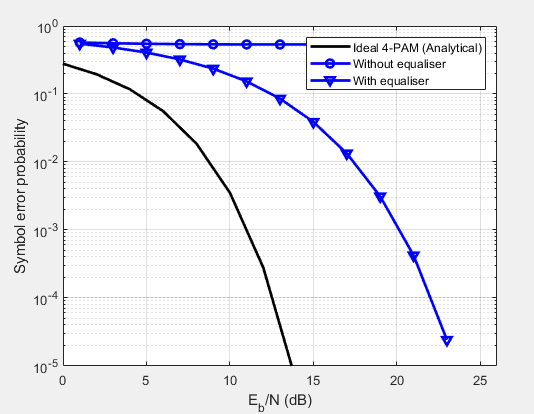


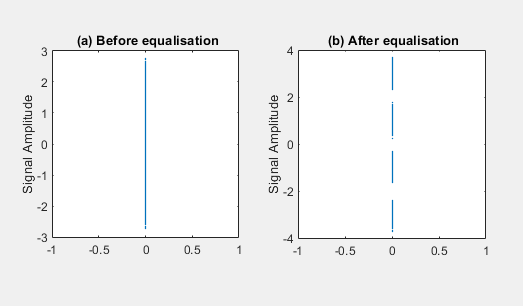




i)







j)

First, the signal output must be fed into the oscilloscope. This is done by using a BNC lead to connect the output if the PAM generator to input 1 on the scope.

To display the signal, input 1 is tuned on. Creating an eye diagram requires the input signal to be triggered at the start of each symbol. Because of the variable level of PAM at the start of each symbol, an external trigger source must be used. A signal clock output is used for this.

Using a BNC lead, the clock signal is plugged into the external trigger input of the oscilloscope, which is then set to source its trigger signal from the external trigger input.

At this point, each symbol would be shown on the screen independently. To attain an eye diagram the persistence of an analogue oscilloscope must be simulated. To achieve this, the persistence setting is set to ‘high’ to show multiple modulated symbols overlayed, creating an eye diagram.