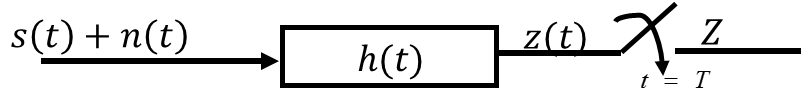
* **Matched Filter System Model**

where

Decision variable

Design Goal: Find which maximizes the signal to noise given as

* **Signal to Noise Ratio (SNR)**
* **Find Maximum of SNR**
* **Matched Filter**

The filter with an impulse response maximizes the signal to noise ratio. This filter is called ‘Matched Filter’.

* NSR of Matched Filter

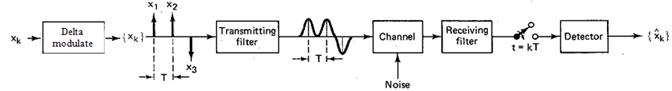
The matched filter is determined by the employed pulse shape. However, the performance (output SNR) of matched filter does not depend on the employed pulse shape. It depends only on the employed Energy.

* **Pulse Shaping Process**

Consider a system that transmit the consecutive data pulses with a pulse .

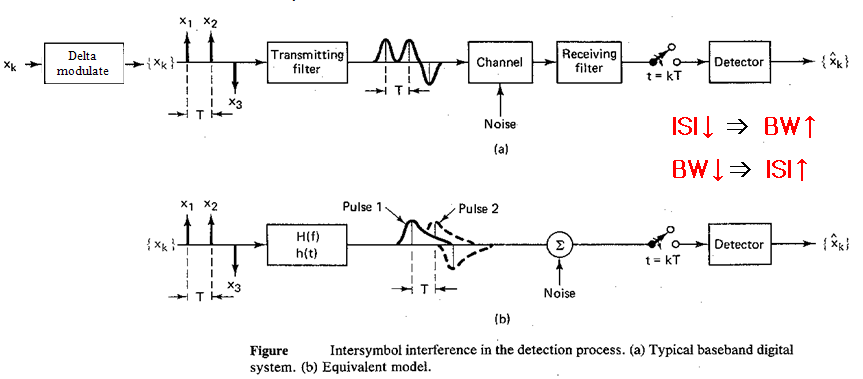
where are data symbol sequences and is symbol duration.

* **Delta(Impulse) Modulation**
* **Overall System: Tx, Channel and RX**

****

Impulse response from Transmitting filter and from Channel and from Receiving filter.

Therefore, equivalent system is



where is .

* **Inter-Symbol Interference (ISI)**

The pulses are overlapped and thus, the detected symbol sequence is

where the term is called ISI.

* **Pulse Shape Design**

Use a very short pulse to avoid ISI but large bandwidth (BW).

Pulse shape design issues are no ISI and BW as small as possible

Therefore, ISI free condition is (where ) are all 0, i.e. crosses 0 where is all integer (except 0) multiples of symbol duration .



* **Mathematical Setup for ISI Free Condition.**

where is ISI free pulse.

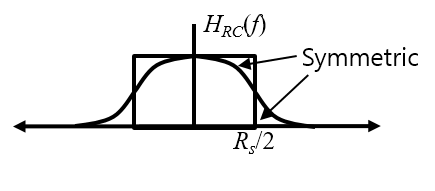
Then the spectrum of sampled is

where , i.e., symbol rate.

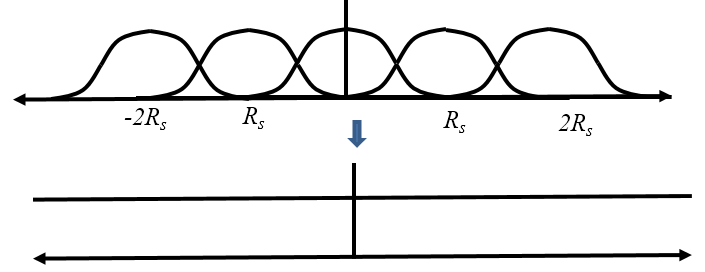
Consequently, ISI free condition in frequency domain should be equal to spectrum of impulse, i.e., a constant.

* **Raised Cosine (RC) Pulse**

where



* **Spectrum of RC Pulse**



RC pulse has a constant spectrum after sampling. So, RC pulse is most commonly used ISI free pulse.

* **RC Pulse Spectrums with Different Bandwidths**

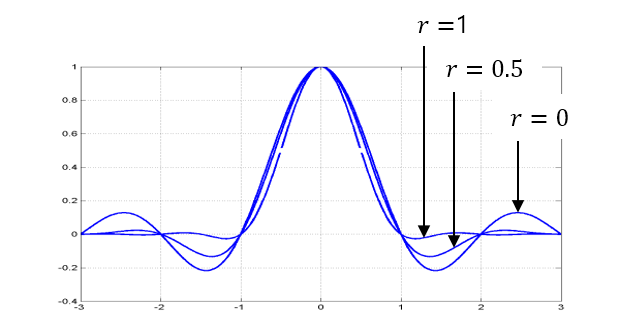
Minimum BW and  
Excessive BW

Roll off factor

where is Zero to Null Bandwidth.

Note that irrespective of the roll off factor that is 3dB BW which is 6dB in power spectrum.

* **BW vs. Truncation Error Tradeoff**



* + Small BW, Small , Large ripples, Large error.
  + Large BW, Large , Small ripples, Small error
* **Square Root Raised Cosine Pulse**

Assume the ideal channel, i.e.,

Then, to maximize output SNR of the receiver filter, should be the matched filter to the TX pulse , i.e.,

Substituting,

Note that we design , however, not should be ISI-free pulse. Hence, should be ISI-free spectrum.

where is called square root raised cosine (SRRC) pulse and is denoted by

* **Eye Diagram**

Partitioned and overlaid waveforms. Partition length is integer multiples of the symbol duration. Easy to see ISI and visually assess the signaling performance.

|  |  |
| --- | --- |
|  |  |
| Small roll-off factor:  narrow eye opening | Large roll-off factor:  wide eye opening |

* **Why and When the Waveform-level Simulation Needed?**
  + Accommodate the waveform-level effects such as:

Channel effects (multipath fading, clipping, etc.) / Synchronization error (phase, frequency, symbol timing)

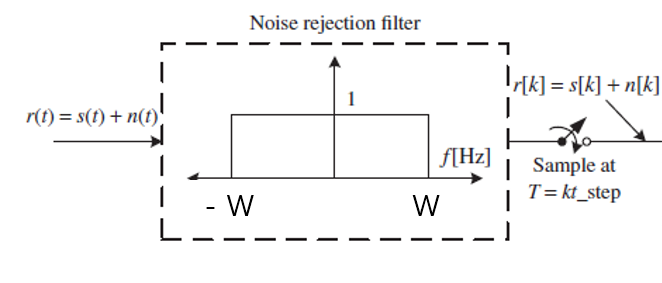
* + Accommodate the waveform-assisted (or waveform-level) algorithms such as:

Pulse shaping and matched filtering / Synchronization / Equalization

* + Observe the waveforms

Eye diagram / Constellation / Signal trajectory / Peak to average power ratio (PAPR)

* **Limitations of waveform-level simulation in the computers.**
  + Non-ideally continuous waveforms, i.e., we have to use the sampled versions of the waveforms
  + Careful setting needed for the sampling interval, variance for the sampled version of the noise signal.
* **Noise Rejection Filter**

To pass the signal as is and to reject white noise.

To make the output noise sequence be a white Gaussian process, the sapling frequency should be equal to 2W

* **Quaternary Phase Shift Keying (QPSK)**

then,

where

and and are BPSK signals. So, QPSK is the summation of two parallel BPSK signals that are orthogonal each other.

It is intuitive that BPSK and QPSK have the identical BER. With identical bandwidth, QPSK has twice data rate than BPSK.

|  |  |  |
| --- | --- | --- |
| 4-ary symbol index |  |  |
| 1 | 11 |  |
| 2 | 10 |  |
| 3 | 01 |  |
| 4 | 00 |  |

* **Pulse Shaped QPSK**
* **Offset QPSK (OQPSK)**

To avoid the simultaneous polarity changes of , and , simply insert a delay block into one of and signal before multiplying the sinusoids.

* **MPSK Signal Expression**

where

thus, in vector space,

* **Symbol Error of MPSK**

Minimum distance energy

where

As increases, decrease. Therefore, the symbol error rate increases.

* **Gray mapping**

Neighboring symbols have only 1-bit difference. This reduce bit errors.

* **BER of MPSK**

For large SNR, the errors between the closest symbol pairs in vector space is dominant. So,

There are three assumptions: large SNR, gray-mapped symbols and large .

As increase, BER of MPSK increases.

* **Bandwidth of MPSK**

Where

thus,

As increases with a fixed bit rate , the bandwidth of MPSK decreases.

As increases with a fixed bandwidth, the bit rate increases.

* **MPSK Demodulator**
* **16QAM Signal**

1

3

3

1

-1

-1

-3

-3

0000

0001

0010

0011

0100

0101

0110

0111

1000

1001

1010

1011

1100

1101

1110

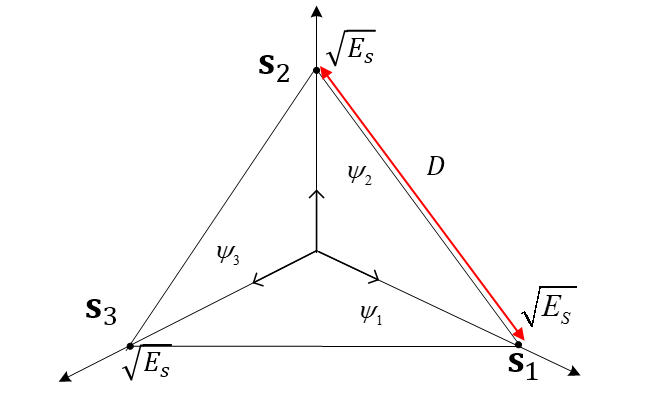
1111

* **16QAM Demodulator**
* **Bandwidth of QAM** as same as MSPK
* **Bandwidth Efficiency**
* **MFSK Signal**
* **MFSK Demodulator: Coherent**
* **MGSK Demodulator: Non-coherent**

This case when the phase of the local carrier is not synchronized to the received signal.

Mathematically equivalent to set

* **Error performance and BW of MFSK**



Note that as increases, increases. Therefore, better BER performance.

* **Bandwidth of MFSK**

Note that as increases, increases.

* **Rayleigh Fading**

where is complex plane representation for 2D modulated signal.

where is complex Gaussian noise.

and are independent each other.

where is signal scaling coefficient due to fading.

and are i.i.d. Gaussian.

* **Rayleigh Fading Decision Variable**

where signal term has the same phase as that of the original symbol .

* **PDF of**

****

This is called Rayleigh distribution.

* **Instantaneous Symbol Energy**

where is instantaneous symbol energy scaling term. Denote this scaling term as a new RV .

Under Rayleigh fading, instantaneous symbol energy is given by

* **PDF of**



This is called Exponential distribution

* **Average Instantaneous Symbol Energy**

where

So,

* **Average BER under Rayleigh Fading**

|  |
| --- |
| clear  syms c EbN0 positive  instantBER = 0.5 \* (1-erf(sqrt(c \* EbN0)));  BER\_fading = int(instantBER \* exp(-c), c, 0, inf);  Pretty((BER\_fading)) |
| >>  1 sqrt(EbN0)  - - --------------------  2 2sqrt(EbN0 + 1) |

if

in log scale,

* **Selection Diversity Combining (SDC)**

The branch with the largest fading coefficient is selected for detection and the rest are not used.

When are similar, the considerable symbol energies distributed in the unselected branches are missed.

* **Equal Gain Combining (EGC)**

The term prior to performing summation is required so that the fading coefficients are coherently summed.

The relatively noisy (=relatively small h) branches contribute rather destructively to the overall SNR of .

* **Maximum Ratio Combining (MRC)**

Large to the reliable branches.

Small to the noisy branches.

We can show that the optimal gains are proportional to the channel fading magnitude.

where is any arbitrary positive real number.

* **Optimal Combining Gain**

Inner product is maximized when two vectors have the same angle.