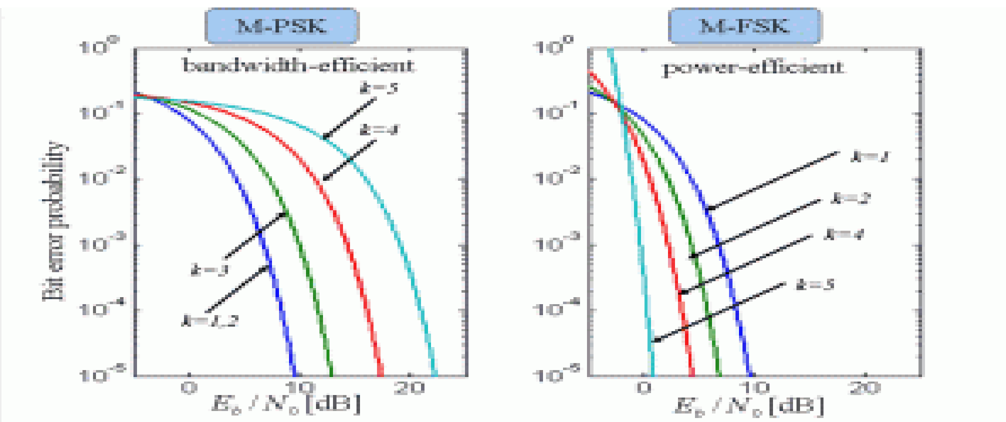
# NYQUIST AND SHANNON THEOREM

### More on Power and Bandwidth Efficiency:

- Power Efficient system
- Bandwidth Efficient system

Bit error Probability Vs Eb/N0 graph is shown here (at your right) to illustrate the difference between the two.




Bandwidth and Power Efficient Modulations

The variable K indicates the number of bits in a symbol. In digital communication, bits are clubbed together to form symbols. I we would like to represent all the Alphabets in English, we need 5 bits (if we follow Binary representation) . Meaning that every 5 bits in the data stream is clubbed to represent an alphabet.

**What is BER or Bit Error Probability ?**

Bit error probability is a term used to measure the reliability of a system. Suppose if 100 bits are transmitter and out of which 1 bit gets corrupted on receiving it (after detection, decoding and estimation), then BER is 1/100 (i.e $10^{-2}$). If BER is $10^{-5}$ it means that 1 out of 1,00,000 bits will be erroneous after receiving. So one of goal will be reducing BER as minimum as possible.

In the graph for PSK the required power increases when we stuff more and more bits. For example the required Eb/N0 to achieve a Bit Error Probability of $10^{-5}$ for 3-PSK signal is 12dB approx. For acheiving the same Bit Error Probability ( $10^{-5}$) 4-PSK (i.e our QPSK) needs 22dB Eb/N0 (i.e it requires 10dB more signal power to counter the effects of noise). This can also be evident from the constellation plot. If we compare the constellation plot for QPSK (4-PSK) and 16-PSK , the plot for 16 PSK will be bigger in size than 4-PSK. This is because the Eb/N0 has increased which determines the diameter of the constellation plot. Thus PSK is power-limited in other words it is Bandwidth efficient (since it can stuff more bits at same frequency at the expense of power).

If we consider the graph of M-FSK , the required power decreases when we modulate more bits over different frequencies. For example the required Eb/N0 to achieve a BER of $10^{-5}$ for 1-FSK signal is 10 dB and for achieving same BER it requires just 1 dB Eb/N0 for 5-FSK (here 5 frequency carriers are used to carry the 5 bits separately). Since 5 frequencies are used for 5 bits the bandwidth increases but it requires minimum power. Thus FSK is bandwidth-limited or it is power effiecient (since it can stuff more bits at minimized power level at the expense of bandwidth).

## Nyquist Theorem :

In a previous [article, Channel capacity Shannon-Hartley theorem] was discussed. Now its time to explore Nyquist theorem and understand the limit posed by the two theorems.

Goals in Designing a Digital Communication System

- Maximizing the transmission bit rate
- Minimizing probability of bit error
- Minimizing the required power
- Minimizing required system bandwidth
- Maximizing system utilization
- Minimize system complexity

## Effect of Pulse shape:

One of the goals in designing Digital Communication System is to minimize the BER. The bits that we transmit over the channel will not be just voltages representing ’1′s and ’0′s rather they can also take some shape. ’1′ can be mere a +ve voltage and ’0′ can be a -ve voltage occupying some time duration. For example I can define ’1′ as +3V for 0.125 seconds and ’0′ as -3V for another 0.125 seconds. In this case they will form rectangular shape (imagine a sequence – ’010′) . We can also have other pulse shapes according to the design criteria. One of the most important theorem that influences the BER and determines the pulse shape is Nyquist Criterion for minimum bandwidth requirement.

Source: http://www.gaussianwaves.com/2008/04/nyquist-and-shannon-theorem-2/