Eb/N0 Explained

Few subjects in RF design elicit as many blank looks as Eb/N0. Read the article and associated links below to find out more about this important subject!

What's All This E_b/N_o Stuff, Anyway?

By Jim Pearce (With Apologies to Bob Pease)

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Anyone who has spent more than ten minutes researching digital communications has run across the cryptic notation E_b/N_o. Usually this shows up when discussing bit error rates or modulation methods. You may have a vague feeling that it represents something important about a digital communication system, but can't really put a finger on what or why. So let's take a look at just what this E_b/N_o thing is and why it's important.

First of all, how do you pronounce E_b/N_o? Most engineers that I know say "E bee over en zero," though some of the more fastidious ones say "E sub bee over en sub zero". At any rate, even though "No" is usually written with an "Oh" instead of a zero, it is not pronounced as the word "no".

E_b/N_o is classically defined as the ratio of Energy per Bit (Eb) to the Spectral Noise Density (No). If this definition leaves you with a empty, glassy-eyed feeling, you're not alone. The definition does not give you any insight into how to measure E_b/N_o or what it's used for.

E_b/N_o is the measure of signal to noise ratio for a digital communication system. It is measured at the input to the receiver and is used as the basic measure of how strong the signal is. Different forms of modulation -- BPSK, QPSK, QAM, etc. -- have different curves of theoretical bit error rates versus E_b/N_o as shown in Figure 1. These curves show the communications engineer the best performance that can be achieved across a digital link with a given amount of RF power.

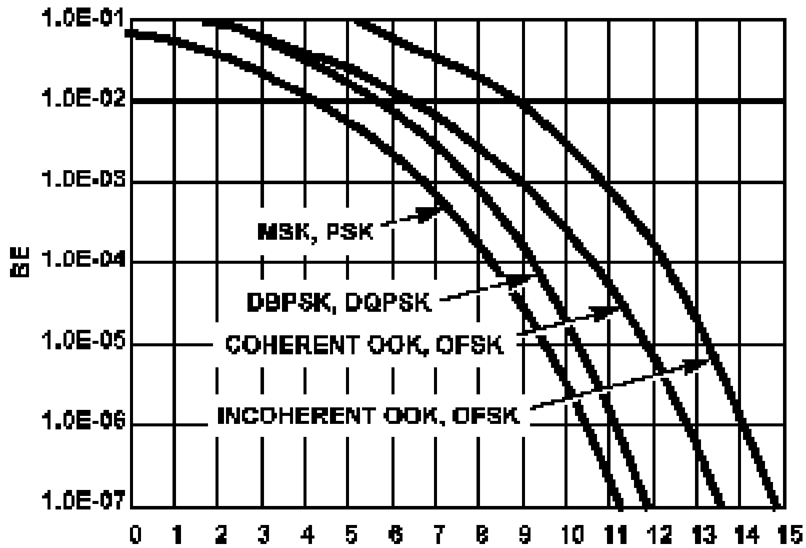

Figure 1. BER vs E_b/N_o
(Thanks, Intersil for this figure)

In this respect, it is the fundamental prediction tool for determining a digital link's performance. Another, more easily measured predictor of performance is the carrier-to-noise or C/N ratio.

So let's pretend that we are designing a digital link, and see how to use E_b/N_o and C/N to find out how much transmitter power we will need. Our example will use differential quadrature phase shift keying (DQPSK) and transmit 2 Mbps with a carrier frequency of 2450 MHz. It will have a 30 dB fade margin and operate within a reasonable bit error rate (BER) at an outdoor distance of 100 meters. Hold on to your hat here! Remember that when we play with dB or any log-type operation, multiplication is replaced by adding the dBs, and division is replaced by subtracting the dBs.

Our strategy for determining the transmit power is to:

- Determine E_b/N_o for our desired BER;
- Convert E_b/N_o to C/N at the receiver using the bit rate; and
- Add the path loss and fading margins.

We first decide what is the maximum BER that we can tolerate. For our example, we choose 10^{-6} figuring that we can retransmit the few packets that will have errors at this BER.

Looking at Figure 1, we find that for DQPSK modulation, a BER of 10^{-6} requires an E_b/N_o of 11.1 dB.

OK, great. Now we convert E_b/N_o to the carrier to noise ratio (C/N) using the equation:

$$\frac{C}{N} = \frac{Eb}{No} \bullet \frac{fb}{Bw}$$

Where:

fb is the bit rate, and
Bw is the receiver noise bandwidth.

So for our example, C/N = 11.1 dB + 10log(2x106 / 1x106) = 11.1 dB + 3dB = 14.1dB.

Since we now have the carrier-to-noise ratio, we can determine the necessary received carrier power after we calculate the receiver noise power.

Noise power is computed using Boltzmann's equation:

$$N = kTB$$

Where:

k is Boltzmann's constant = $1.380650\text{x}10^{-23}$ J/K;
T is the effective temperature in Kelvin, and
B is the receiver bandwidth.

Therefore, N1 = ($1.380650\text{x}10^{-23}$ J/K) * (290K) *(1MHz) = $4\text{x}10^{-15\text{W}}$ = $4\text{x}10^{-12}$mW = -114dBm

Our receiver has some inherent noise in the amplification and processing of the signal. This is referred to as the receiver noise figure. For this example, our receiver has a 7 dB noise figure, so the receiver noise level will be:

N = -107 dBm.

We can now find the carrier power as C = C/N * N, or in dB C = C/N + N.

C = 14.1 dB + -107dBm = -92.9 dBm

This is how much power the receiver must have at its input. To determine the transmitter power, we must account for the path loss and any fading margin that we are building in to the system.

The path loss in dB for an open air site is:

$$PL = 22 \text{ dB} + 20\log(d/\lambda)$$

Where:

PL is the path loss in dB;
d is the distance between the transmitter and receiver; and
λ is the wavelength of the RF carrier (= c/frequency)

This assumes antennas with no gain are being used. For our example,

$$PL = 22 \text{ dB} + 20\log(100/.122) = 22 + 20*2.91 = 22 + 58.27 = 80.27 \text{ dB}$$

Finally, adding our 30 dB fading margin will give the required transmitter power:

$$P = -92.9 + 80.27 + 30 = 17.37 \text{ dBm} = 55 \text{ mW}$$

Our result, 55 mW, is well within a reasonable power level for spread spectrum links in the 2.4 GHz band. So we see that, in this example, our 100 meter range is a very reasonable expectation.

So, what is all this E_b/N_o stuff? Simply put, it's one of the "secrets" used by top RF design engineers to evaluate options for digital RF links, and is a crucial step in the design of systems that will meet performance expectations.