Signal-to-Noise, Carrier-to-Noise, EbNo on Signal Quality Ratios

by Wolfgang Damm, WTG
Agenda

- Signal Measurement Environment
- Ratios: S/N, C/N, C/No, C/I, EbNo
- Shannon Limit
- Error Correction
- BER & Coding Schemes
- Noisecom CNG-EbNo
- Questions - Answers
<table>
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<th>Technologies effeceted by Power Measurements</th>
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<td>Satellite Communication</td>
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<tr>
<td>Cable TV</td>
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<tr>
<td>Telecommunications</td>
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<tr>
<td>Chip Manufacturing</td>
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<tr>
<td>Wireless Data Networks</td>
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<td>Backbone &amp; Directed RF links</td>
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<td>mmWave applications</td>
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Signal Quality: Essential for Data Transmission

- Data transmission has to work under challenging circumstances: weak signals and high noise levels
- Requirement: High data rates, reliability, low BER
- Designers, developers and system engineers have to take less-than-ideal circumstances in consideration.
Signal Environment
Signal Measurement Environment 1

- High Signal Power

Diagram showing a signal spike with high power at a specific frequency.
Signal Measurement Environment 2

Signal Power Limitations
Signal Measurement Environment 3

Lower power level due to spread spectrum
Signal Measurement Environment 4

Intrinsic noise
(amplifier, demodulator)

P

Noise Floor

Signal

f
Signal Measurement Environment 5

- Intrinsic noise (amplifier, demodulator)
- Signal
- Neighbor channels
- Noise Floor
Communication Challenges

- Limited Power
- Limited Bandwidth
- Very low Signal Levels
- Noise
- Interferers
- Limited Data Processing Power
Shannon–Hartley theorem:
The limit of reliable data rate of a channel depends on bandwidth and signal-to-noise ratio according to:

\[ R < B \log_2 \left( 1 + \frac{S}{N} \right) \]

- **R** information rate in bits per second;
- **B** channel bandwidth in Hertz;
- **S** total signal power (equivalent to the carrier power **C**);
- **N** total noise power in the bandwidth.
**Forward Error Correction (FEC)**

**FEC** is a system of error control for data transmission. The sender adds redundant data to its messages (error correction code).

Example (2 Bit overhead):

<table>
<thead>
<tr>
<th>Triplet received</th>
<th>Interpreted as</th>
</tr>
</thead>
<tbody>
<tr>
<td>000</td>
<td>0</td>
</tr>
<tr>
<td>001</td>
<td>0</td>
</tr>
<tr>
<td>010</td>
<td>0</td>
</tr>
<tr>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>111</td>
<td>1</td>
</tr>
<tr>
<td>110</td>
<td>1</td>
</tr>
<tr>
<td>101</td>
<td>1</td>
</tr>
<tr>
<td>011</td>
<td>1</td>
</tr>
</tbody>
</table>

**Advantages:**
- High degree of fault tolerance
- No back-channel required
- Simple logic (cost efficient, fast)

**Disadvantages:**
- Adds data redundancy to link budget
Ratios

- **C/N**  Carrier to noise
- **C/No** Carrier to noise density
- **Eb/No** Energy per bit to noise density
- **C/I**  Carrier to interferer
Carrier to Noise Ratio (C/N)

What is it?
C/N is the ratio of the relative power level to the noise level in the bandwidth of a system.

Why:
Allows to analyze if a carrier can still be recognized as such, or if it is obliterated by ambient and system noise. C/N Provides a value for the quality of a communication channel.

How:
The quality of the system is usually determined through BER plots against C/N.

C and N may be measured in watts or in volts squared.
Example: Spectrum of a QPSK signal interfered by ambient white noise. The horizontal axis shows the frequency in Hertz, and the vertical axis the power in dBm. In this example, the C/N is \((-32.5 \text{ dBm}) - (-48 \text{ dBm}) = 15.5\)
Noise Spectral Density ($N_o$)

What is $N_o$?

Noise spectral density ($N_o$) is defined as the amount of (white) noise energy per bandwidth unit (Hz).

$$N_o = \frac{N}{B}$$

$N_o$ is often expressed as:

$$N_o = k T$$

where

- $k$ is the Boltzmann's constant in Joules per Kelvin [J/K], and
- $T$ is the receiver system noise temperature in Kelvin [K]

Units of $N_o$ are:

- Joules [J], Watts/Hz [W/Hz] or Watts * s [Ws].

All three units express the very same metric.

$$[J] = [W / Hz] = [Ws]$$
Carrier to Noise Spectral Density Ratio (C/No)

**What is it?**
C/No is the ratio of the power level to the noise power spectral density (normalized noise level relative to 1 Hz) in a system.

**Why:**
Similar as C/N but C/No does not factor the actual noise bandwidth in. This simplifies analysis of systems where variation of the (utilized) BW may apply.

**How:**
As C/N, C/No is usually determined through BER plots.
Energy per Bit (E_b)

**What is E_b?**

Energy per information bit (i.e. the energy per bit net of FEC overhead bits). Carrier power divided by actual information bits.

\[ E_b = \frac{C}{R} \]

where

- **C** is the carrier power, and
- **R** is the actual information bit rate.

**Why?**

Using the E_b rather than overall carrier power (C) allows comparing different modulation schemes easily.

Unit of E_b is:

- Joules [J], Watts/Hz [W/Hz] or Watts * s [Ws].

All three units express the very same metric.

Simplified depiction of E_b. Bits in modulation schemes are not as shown directly linked to a certain frequency.
**Energy per Bit to Noise Spectrum Density (E_b/N_0)**

**What is it?**

E_b/N_0 is the ratio of the Energy per Bit divided by the noise power density.

**Why:**

Allows comparing bit error rate (BER) performance (effectiveness) of different digital modulation schemes. Both factors are normalized, so actual bandwidth is no longer of concern.

**How:**

Modulation schemes are compared through BER plots against E_b/N_0.

E_b/N_0 is a dimensionless ratio.
BER, Coding Scheme and $E_b/N_0$

The diagram illustrates the relationship between BER and $E_b/N_0$ for different coding schemes.

- **Uncoded System**
- **FEC Coded System**
- **Ideal Coded**
- **Ideal Uncoded**

The diagram highlights the *Coding Gain* and *Residual BER*.

Coding improvement is noted at higher $E_b/N_0$ values for coded systems compared to uncoded systems.
**Eb/N₀**

**Eb / N₀** is commonly used with modulation and coding design for noise-limited rather than interference-limited communication systems, and for power-limited rather than bandwidth-limited communication systems. Examples of power-limited systems include spread spectrum and deep-space, which are optimized by using large bandwidths relative to the bit rate.

- **MSK**: Minimum shift keying
- **PSK**: Phase shift keying
- **DBPSK**: Differential binary phase shift keying
- **DQPSK**: Differential quadrature phase shift keying
- **OOK**: On-off-keying
- **OFSK**: Orthogonal frequency shift keying
Analyzing Ratios (EbNo)

Tuning carrier or noise level shifts \( E_b/N_0 \)
CNG EbNo

CNG Eb/No – does exactly this, it automatically sets the desired Eb/No quickly and very accurately. Based on the user-specified carrier output level, Eb/No ratio, and bit rate, the instrument calculates for example the maximum noise density.
Correlation: C/N, C/No and Eb/No

C/N, C/No and Eb/No are correlated.

\[
C / N = C / (N_o * B) = (E_b / N_o) * (R / B)
\]

\[
E_b / N_o = (C / N) * (B / R)
\]

\[
N_o = (N * E_b * R) / B * C
\]

\[
C / N_{dB} = 10 \log (Eb/No) + 10 \log (R / B)
\]

- \(R\) information rate in bits per second;
- \(B\) channel bandwidth in Hertz;
- \(C\) total carrier power;
- \(N\) total noise power in the bandwidth.
**Carrier to Interference Ratio (C/I, CIR)**

**What is it?**
C/I is the quotient between the average received modulated carrier power \( C \) and the average received co-channel interference power \( I \) (i.e. cross-talk, from other transmitters than the useful signal).

**Why:**
Allows analysis and rating of channel channel robustness against neighbor channels.

**How:**
As C/N and C/No, C/I is usually analyzed through BER plots.

\[
C / I = C / (I_1 + I_2 + I_n)
\]

\( C / I \) is a dimensionless ratio.
CNG EbNo Application

The CNG EbNo, simulates the transmitter-receiver link and measures relevant transmission quality parameters at the same time.
Product Specification Examples
## CNG EbNo Specs (excerpt)

### Carrier Path

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Power Range:</td>
<td>-55 dBm to +5 dBm</td>
</tr>
<tr>
<td>Max Input Power:</td>
<td>+21 dBm (with no damage)</td>
</tr>
<tr>
<td>Nominal gain:</td>
<td>+/-1.0 dB</td>
</tr>
<tr>
<td>Gain resolution:</td>
<td>0 to -60 dB in 0.1 dB steps</td>
</tr>
<tr>
<td>Gain flatness:</td>
<td>0.2 dB for 70 MHz +/-20 MHz</td>
</tr>
<tr>
<td></td>
<td>0.3 dB for 140 MHz +/-40 MHz</td>
</tr>
<tr>
<td></td>
<td>0.4 dB for others</td>
</tr>
<tr>
<td>Group Delay:</td>
<td>+/-0.20 ns/40 MHz for frequencies above 20 MHz</td>
</tr>
</tbody>
</table>

### Noise Path

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Power Range:</td>
<td>-55 dBm to +5 dBm</td>
</tr>
<tr>
<td>Flatness:</td>
<td>+/- 0.2 dB / 40 MHz</td>
</tr>
<tr>
<td></td>
<td>+/- 0.3 dB / 80 MHz</td>
</tr>
<tr>
<td></td>
<td>+/- 0.4 dB / 200 MHz</td>
</tr>
<tr>
<td></td>
<td>+/- 0.5 dB / 300 MHz</td>
</tr>
<tr>
<td>Attenuation range:</td>
<td>60 dB in 0.25 dB steps (0.1 dB opt)</td>
</tr>
</tbody>
</table>

CNG EbNos are available with a wide variety of frequency bands. Please check: [http://noisecom.com/products/instruments/cng-ebno-snr-noise-generator](http://noisecom.com/products/instruments/cng-ebno-snr-noise-generator) for more information or contact your next Noisecom representative.
CNG $E_b/N_0$ vs. Spectrum Analyzer

The CNG EbNo offers a variety of advantages over discrete instruments when measuring C/N, C/N$_0$, $E_b/N_0$ or C/I:

- Automated procedure, therefore repeatable measurements provided quickly
- Highest accuracy through substitution calibration method
- Automated calculation of results
- Customer specific configuration depending on the application
Conclusion

- Signal Measurement Environment
- Ratios: C/N, C/No, C/I, EbNo
- Shannon Limit
- Error Correction
- BER & Coding Schemes
- Noisecom CNG-EbNo
Questions – Answers
CNG EbNo Block Diagram (simplified)
Questions – Answers
THANK YOU!

Join us for our next Webinar:

Amplifier Testing: New Methods (Part I)

by Bob Muro, WTG

Date: 12/15/2010
Addendum