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

Technologies effected by Power Measurements

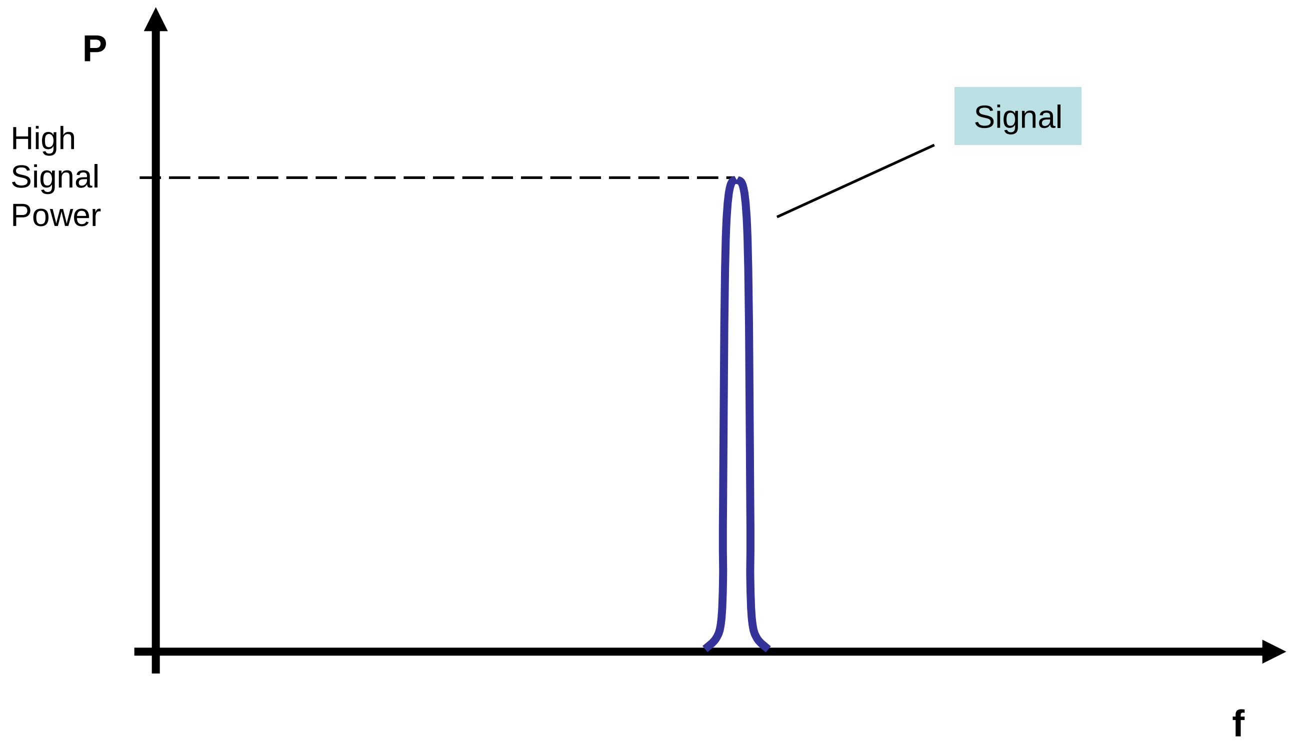
Satellite Communication	R&D, System Monitoring
Cable TV	R&D, bandwidth analysis, throughput optimization, amplifiers,
Telecommunications	R&D, QoS, amplifiers,
Chip Manufacturing	Amplifiers, Receivers, Transmitters
Wireless Data Networks Backbone & Directed RF links	R&D, System Monitoring, Optimization, Monitoring
mmWave applications	e.g. 60G

Signal Quality: Essential for Data Transmission

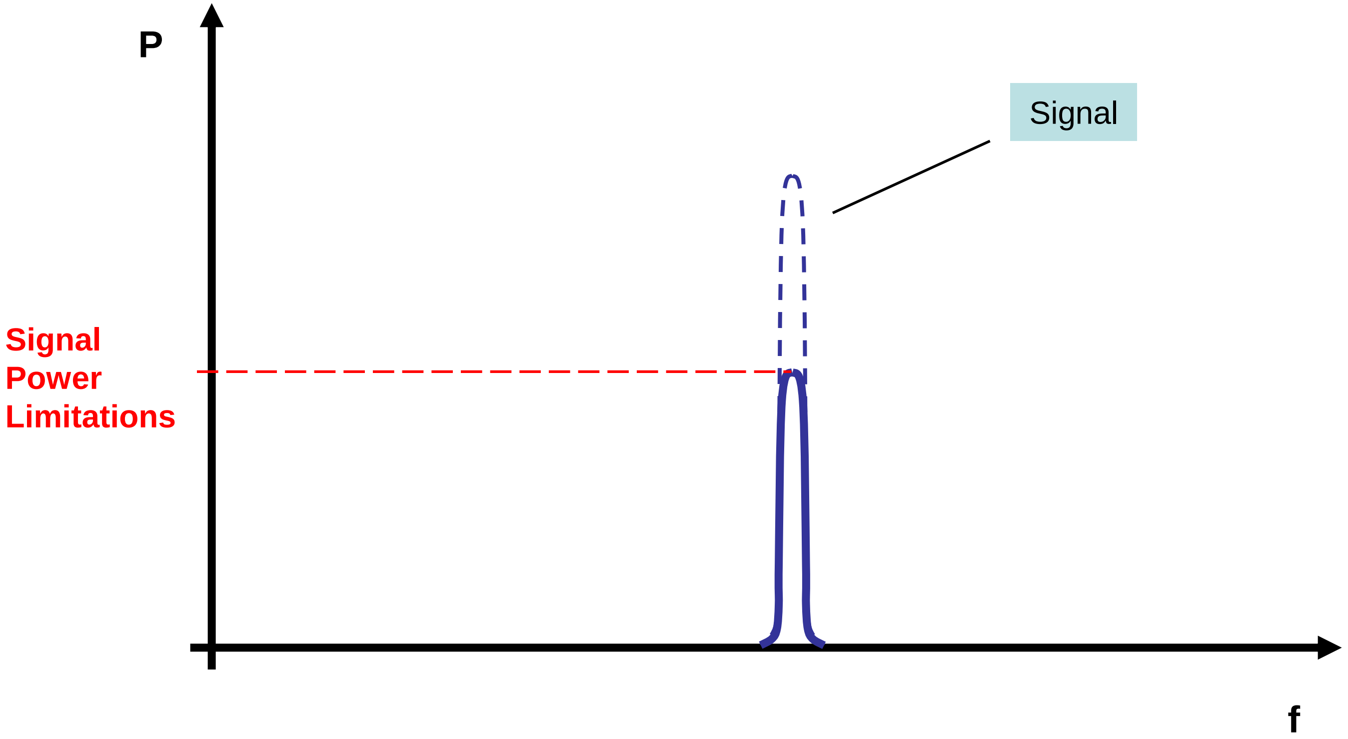
- Data transmission has to work under challenging circumstances: weak signals and high noise levels
- Requirement: High data rates, reliability, low BER
- Designers, developers and system engineers have to take less-than-ideal circumstances in consideration.

Signal Environment

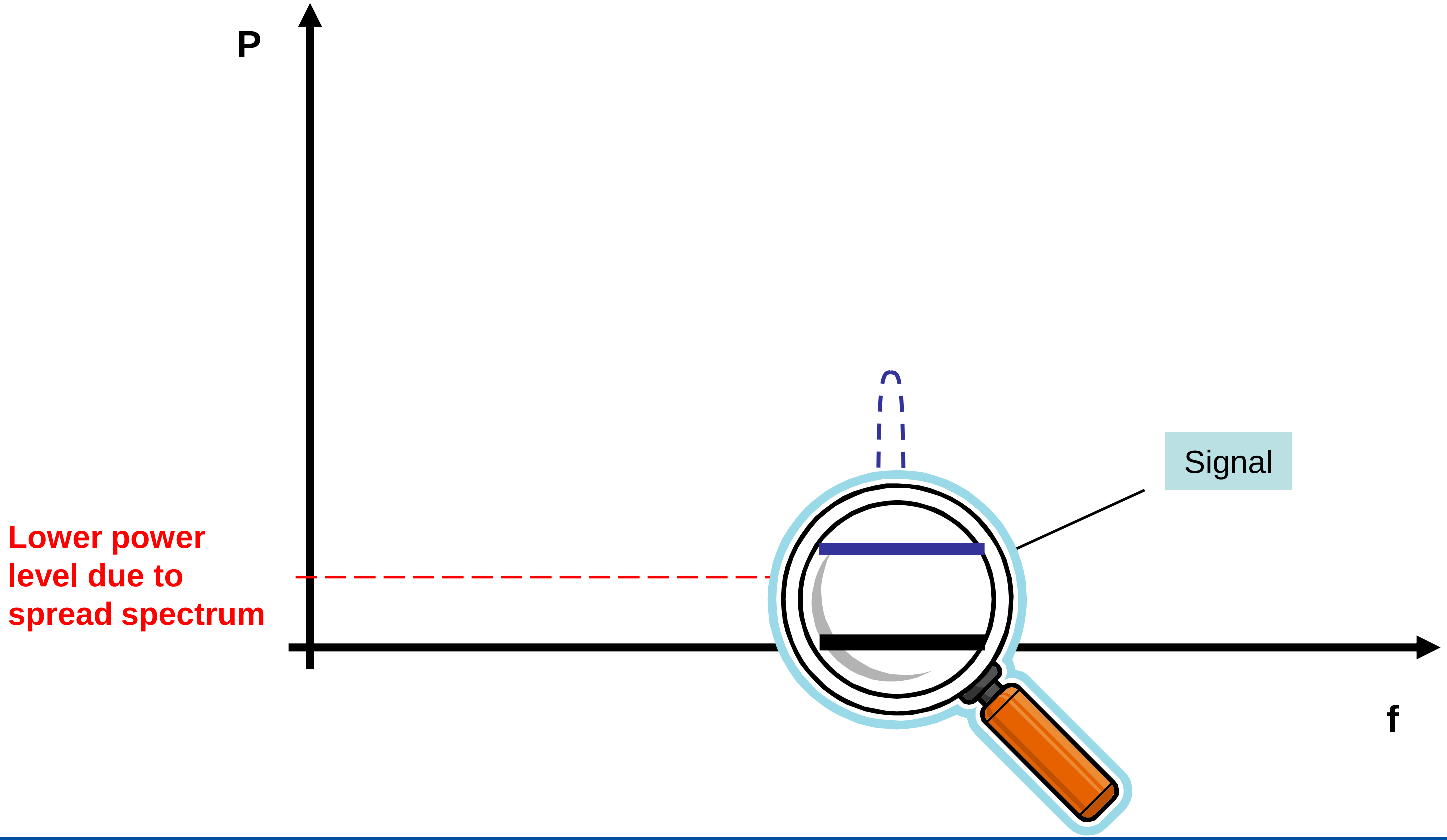
Signal Measurement Environment 1



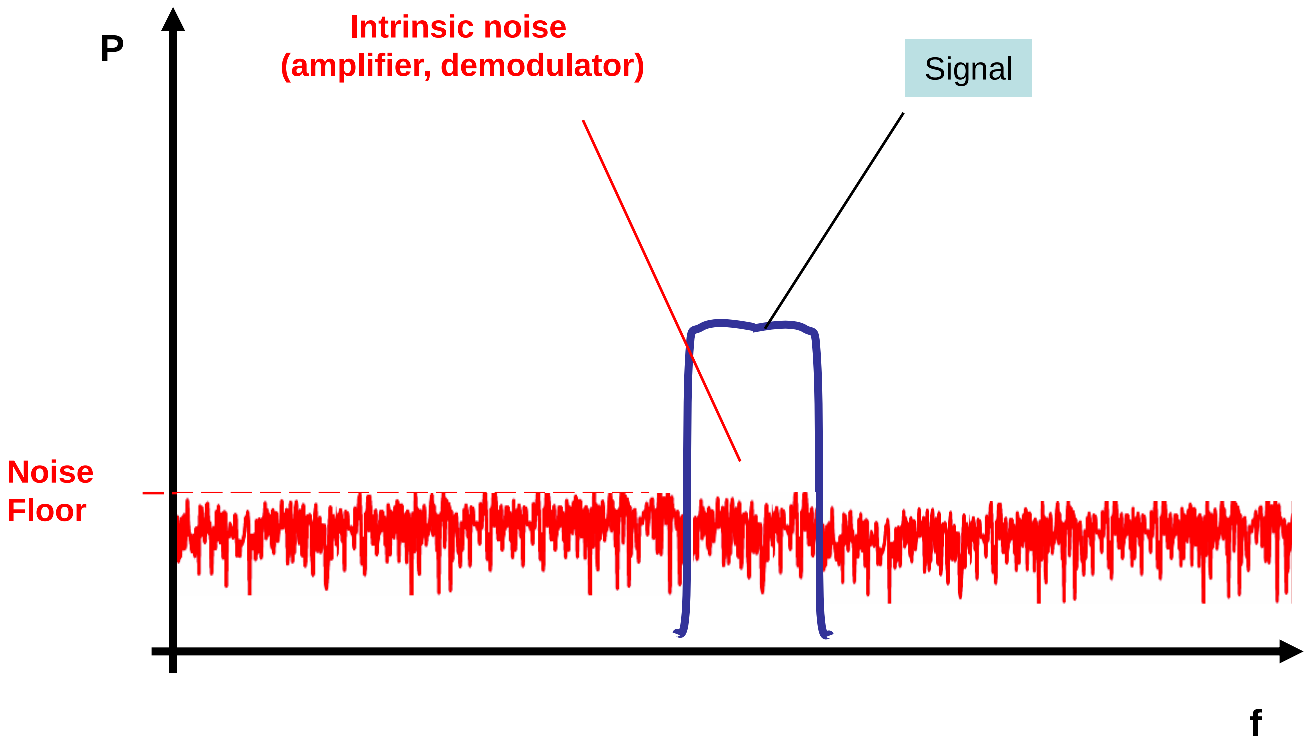
Signal Measurement Environment 2



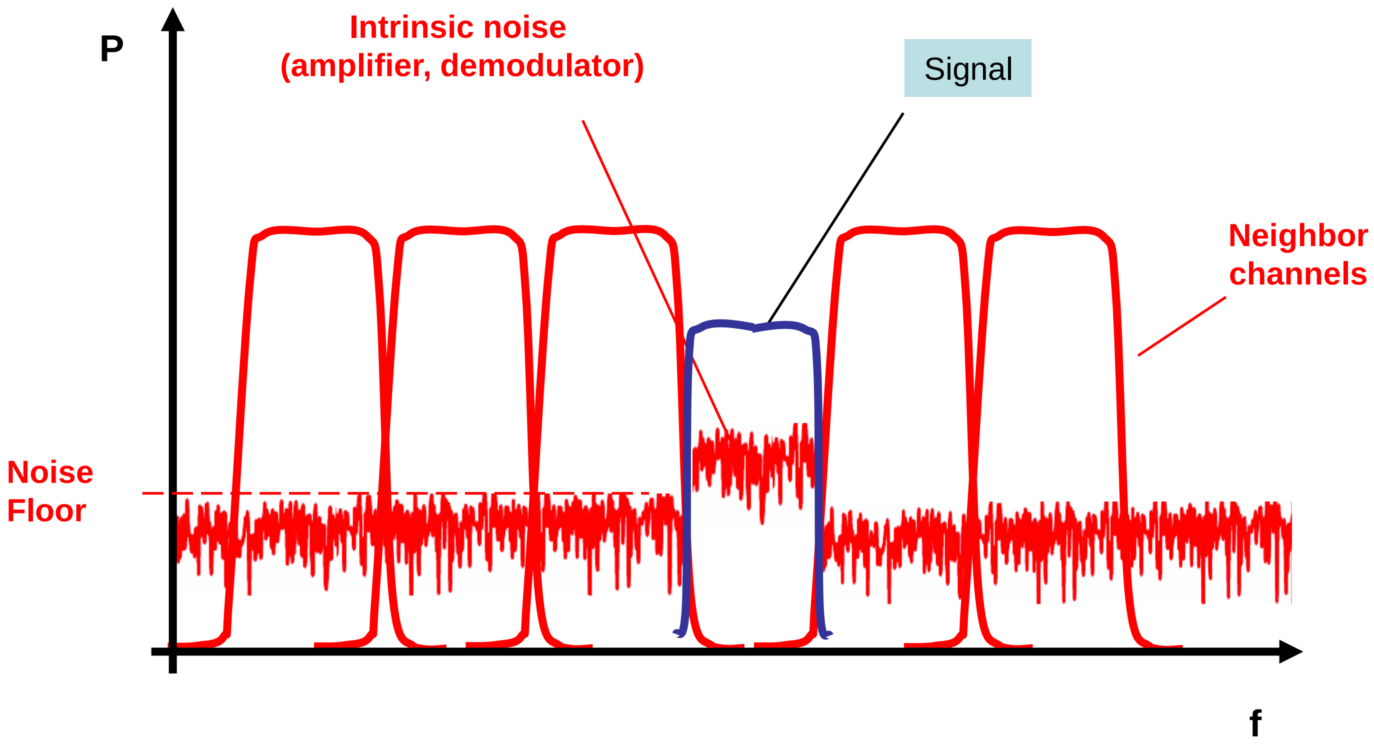
Signal Measurement Environment 3



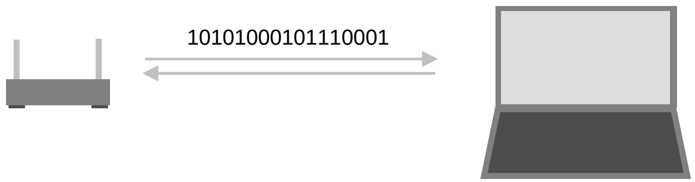
Signal Measurement Environment 4



Signal Measurement Environment 5

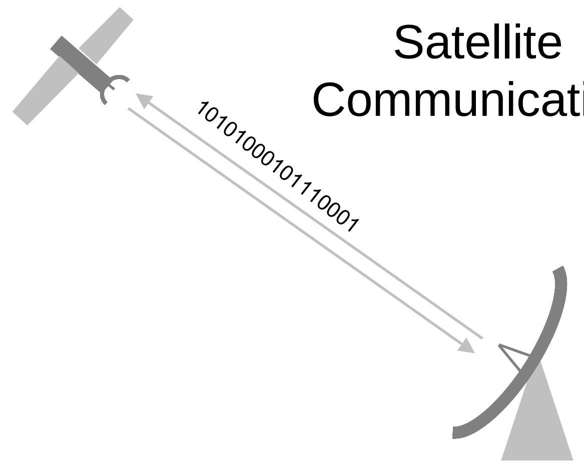


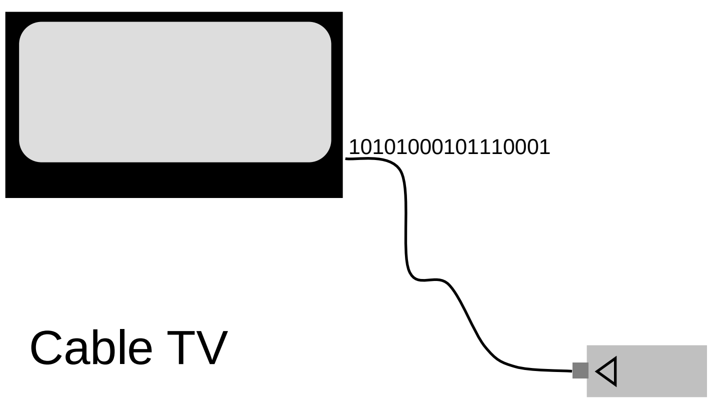
Communication Challenges



Wireless Data

Satellite Communication





Cable TV

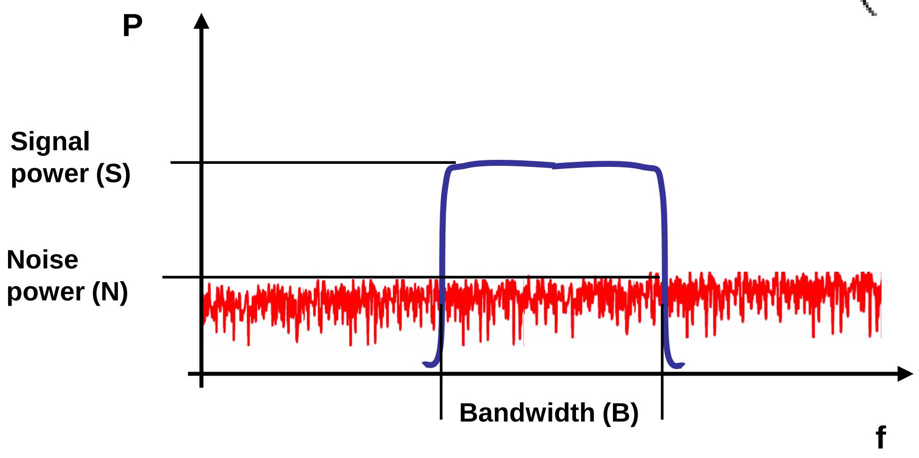
- **Limited Power**
- **Limited Bandwidth**
- **Very low Signal Levels**
- **Noise**
- **Interferers**
- **Limited Data Processing Power**

Shannon Limit

Shannon–Hartley theorem:

The limit of reliable data rate of a channel depends on band-width 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):

Triplet received	Interpreted as
000	0
001	0
010	0
100	0
111	1
110	1
101	1
011	1

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?

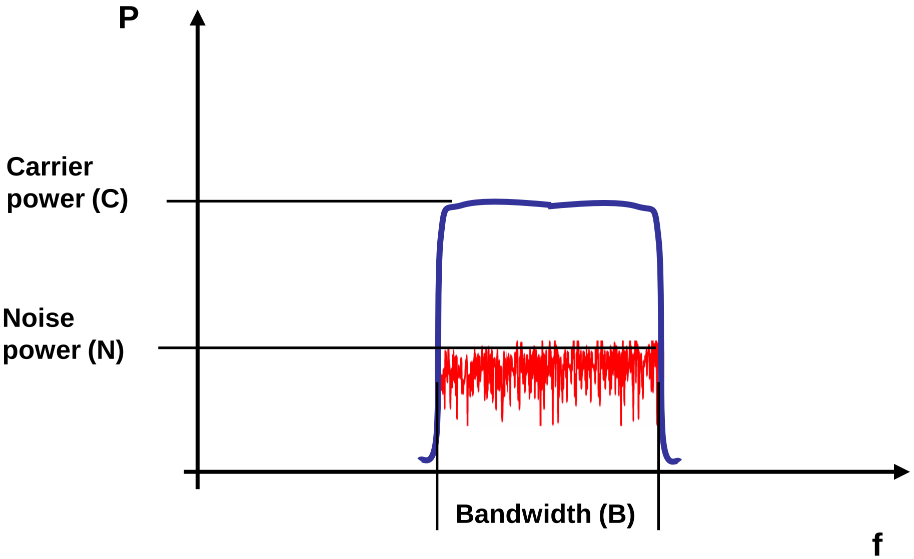
C/N is the ratio of the relative power level to the noise level in the bandwidth of a system.

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.

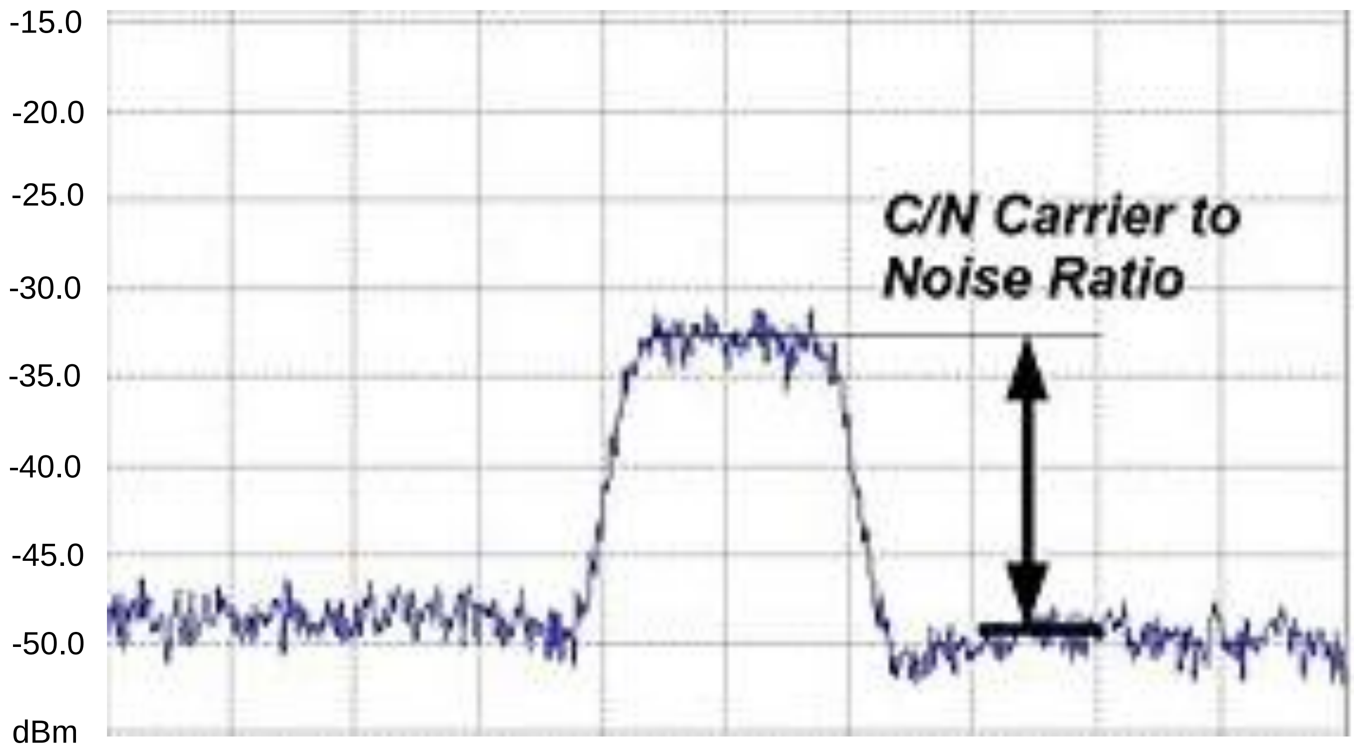
How:

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

C/N Example



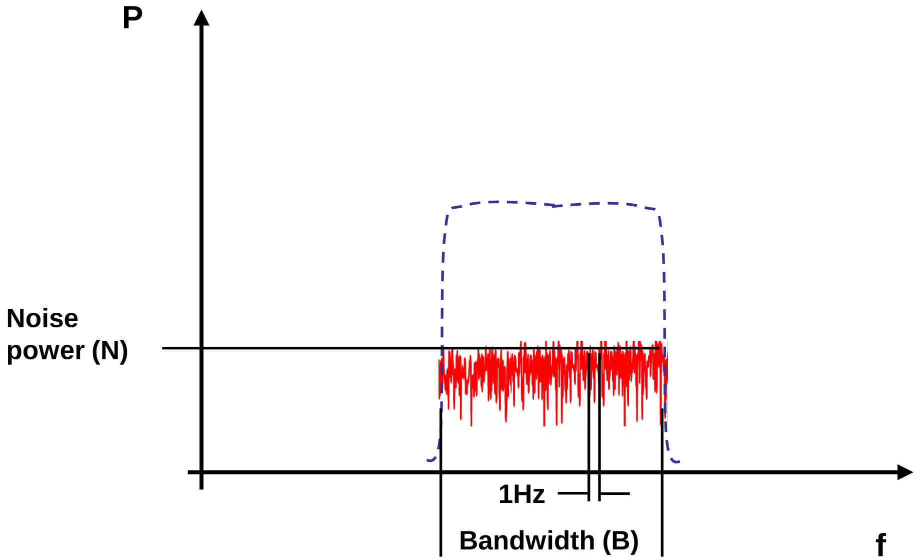
Example: Spectrum of a QPSK signal interfered by ambient white noise. The horizontal axis shows the frequency in Hertz, and the vertical axis the power in dBm
In this example, the C/N is (−32.5 dBm) − (−48 dBm) = 15.5

Noise Spectral Density (N_o)

What is N_o?

Noise spectral density (No) is defined as the amount of (white) noise energy per bandwidth unit (Hz).

$$No = N / B$$



N_o is often expressed as:

$$No = k\,T$$

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?

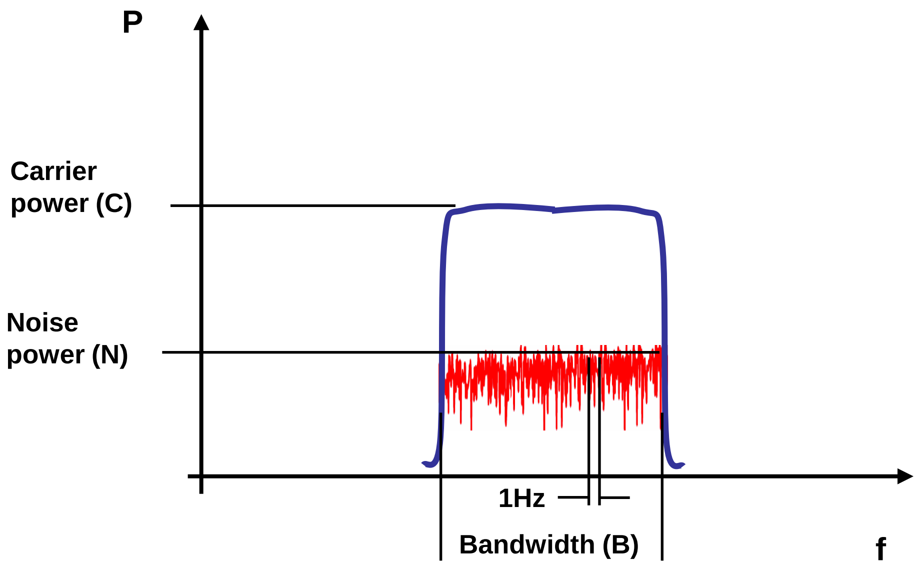
C/No is the ratio of the power level to the noise power spectral density (normalized noise level relative to 1 Hz) in a system.

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?

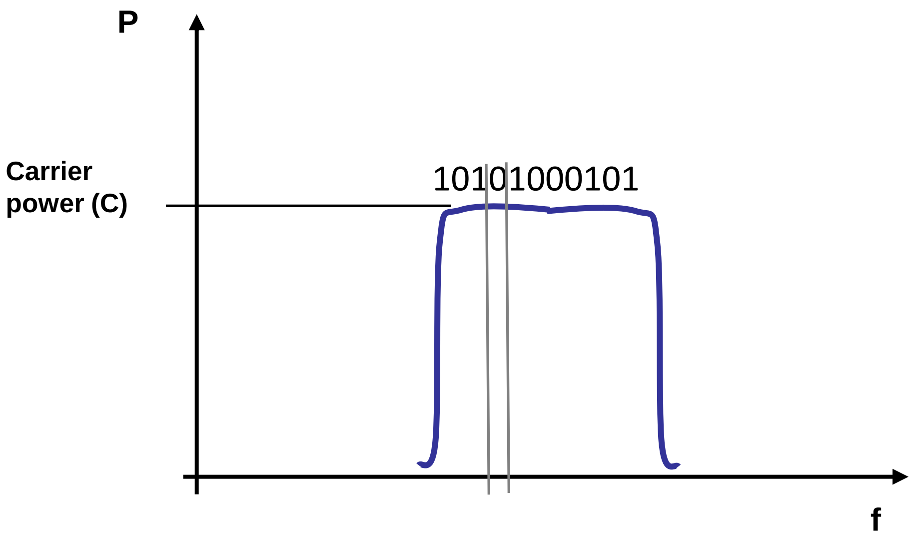
Energy per information bit (i.e. the energy per bit net of FEC overhead bits). Carrier power divided by actual information bits.

$$E_b = C / R$$

where

C is the carrier power, and

R is the actual information bit rate.



Simplified depiction of **E_b**. Bits in modulation schemes are not as shown directly linked to a certain frequency.

Why?

Using the Eb 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..

Energy per Bit to Noise Spectrum Density (E_b/N_o)

What is it?

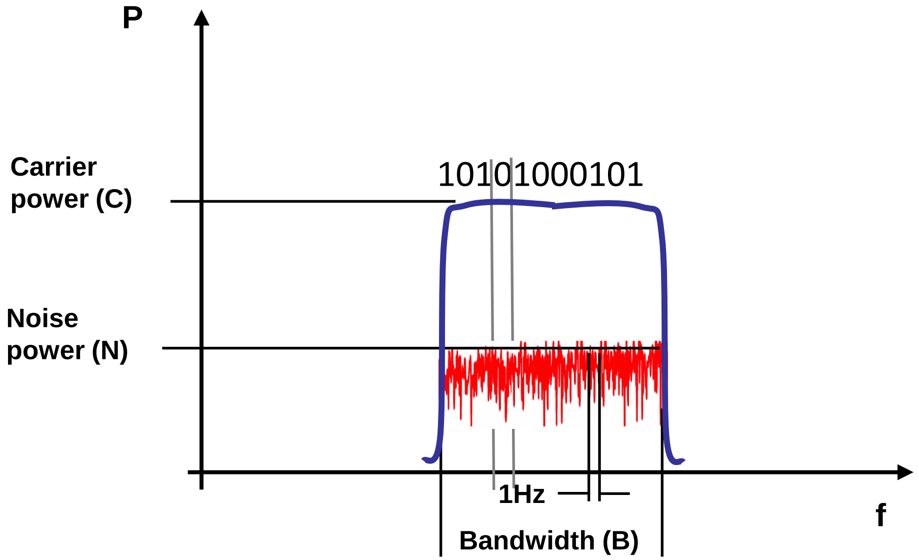
E_b/N_o is the ratio of the Energy per Bit divided by the noise power density.

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.

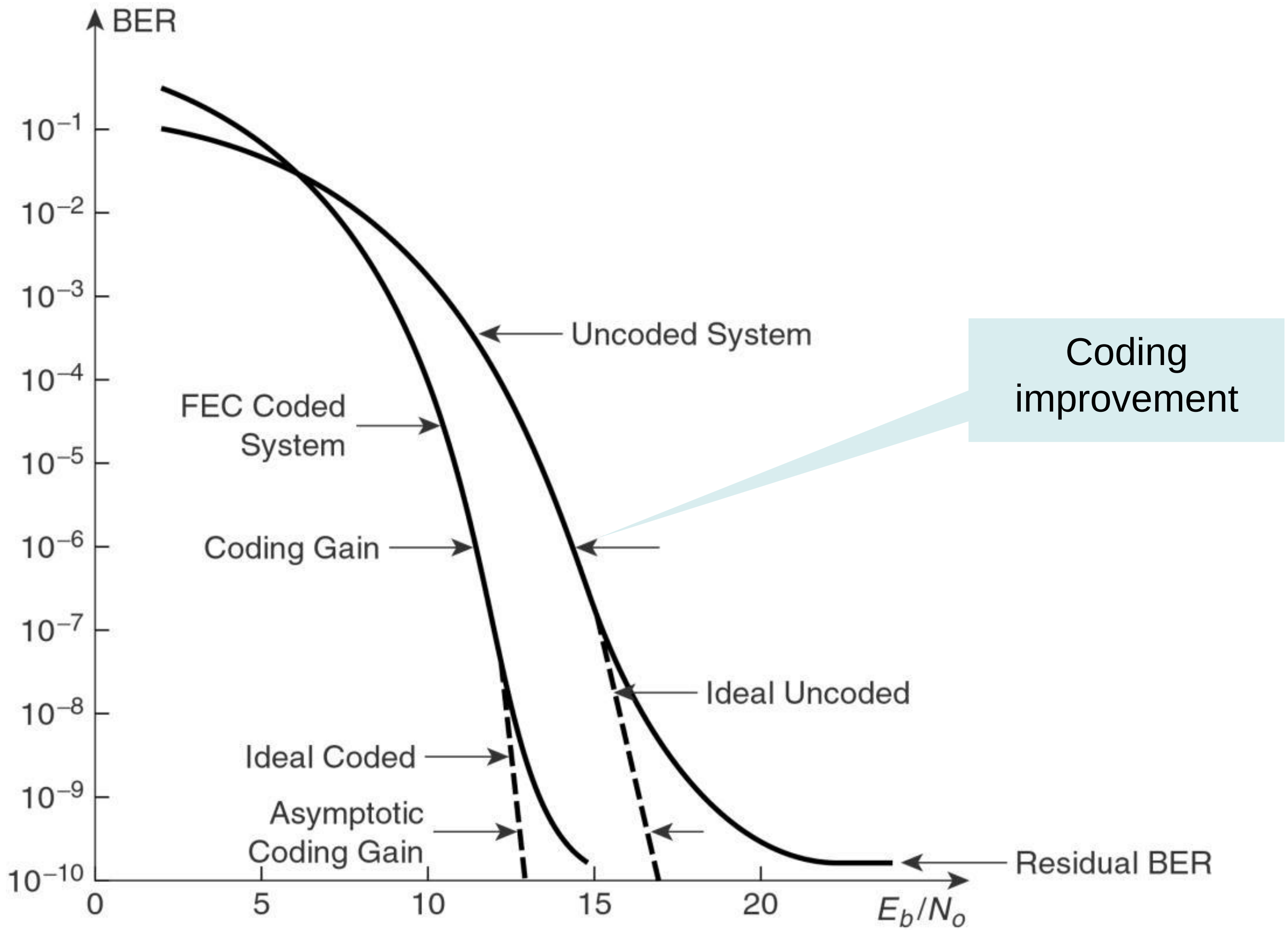
How:

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



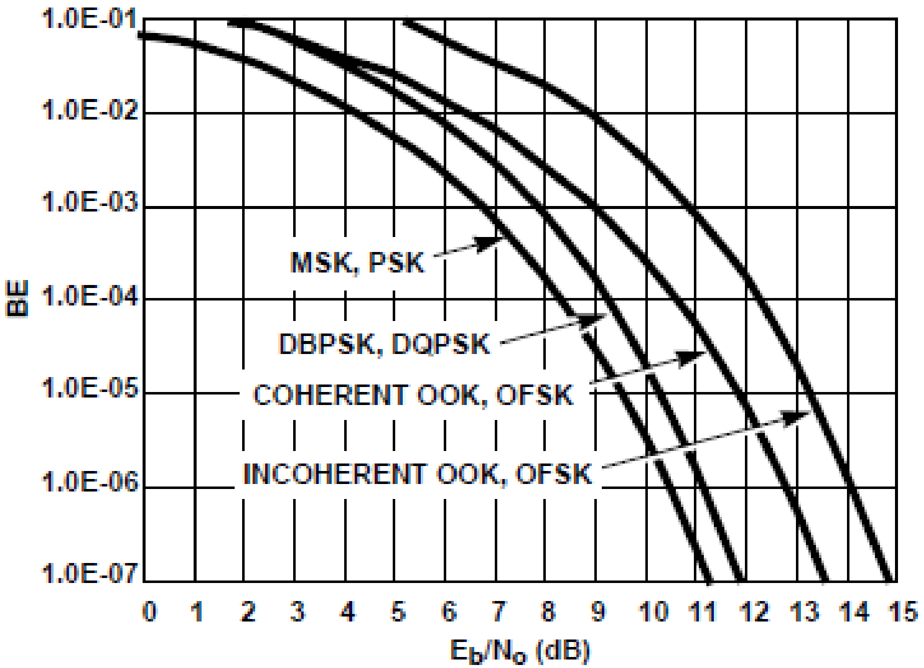
E_b/N_o is a dimensionless ratio.

BER, Coding Scheme and E_b/N_o



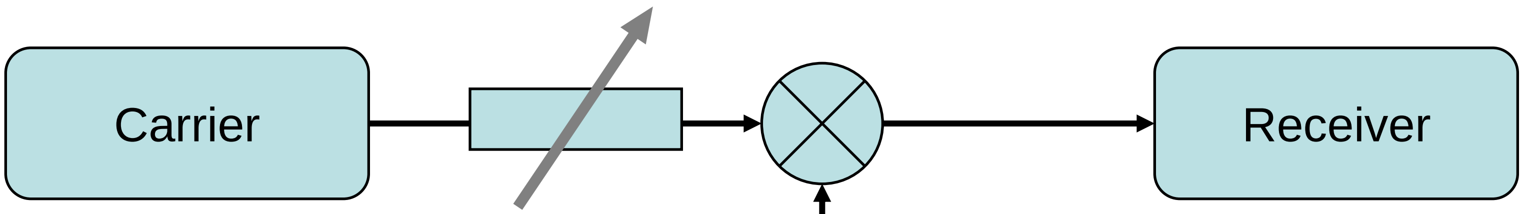
E_b/N_o

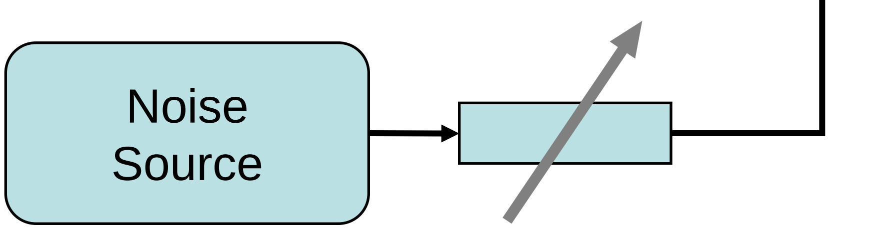
E_b / N_o is commonly used with modulation and coding design for noise-limited rather than interference-limited communication systems, and for power-limited rather than bandwidth-limited communication systems. Examples of power-limited systems include spread spectrum and deep-space, which are optimized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



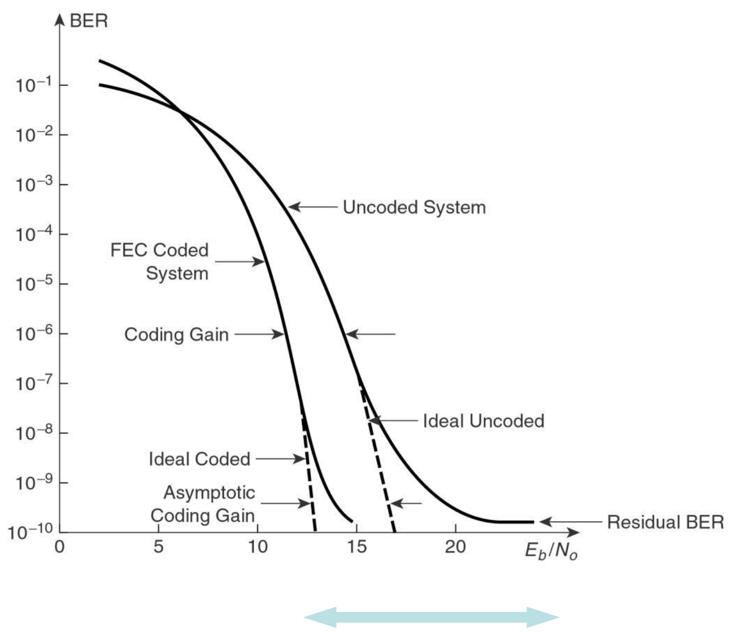
MSK: Minimum shift keying
PSK: Phase shift keying
DBPSK: Differential binary phase shift keying
DQPSK: Differential quadrature phase shift keying
OOK: On-off-keying
OFSK: Orthogonal frequency shift keying

Analyzing Ratios (EbNo)

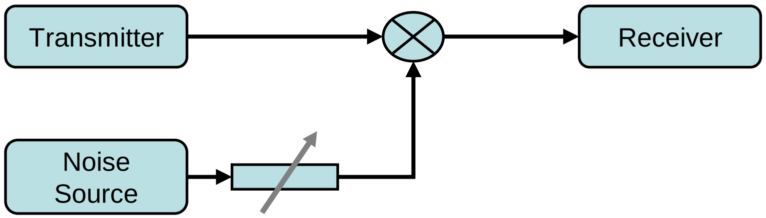




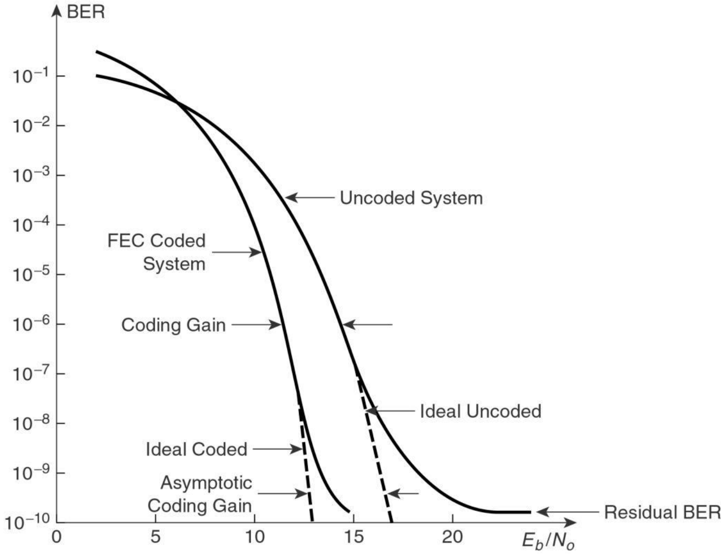
Tuning carrier or noise level shifts E_b/N_o



CNG EbNo



CNG E_b/N_o – 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/N_o and E_b/N_o

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

$$C / N = C / (N_o * B) = (E_b / N_o) * (R / B)$$

$$E_b / N_o = (C / N) * (B / R)$$

$$N_o = (N * E_b * R) / B * C$$

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

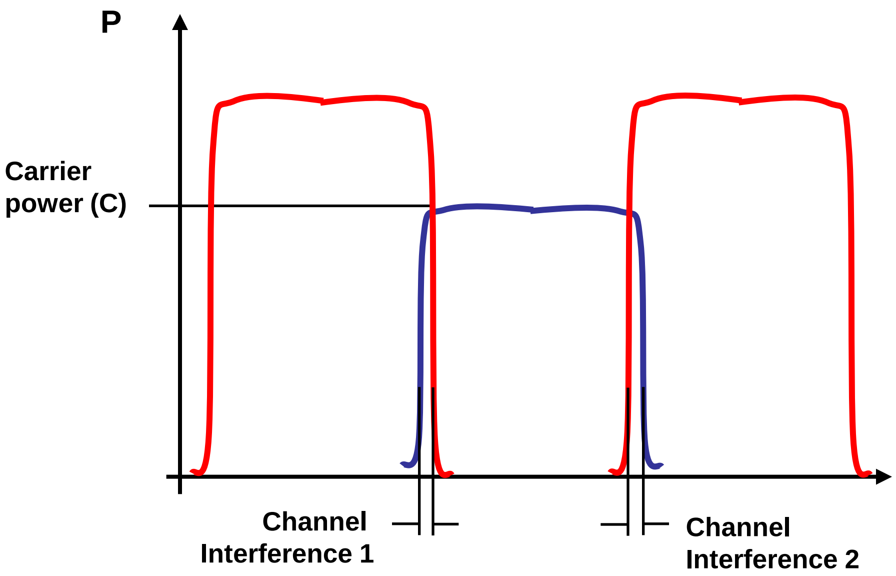
R information rate in bits per second;
B channel bandwidth in Hertz;
C total carrier power
N total noise power in the bandwidth.

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.

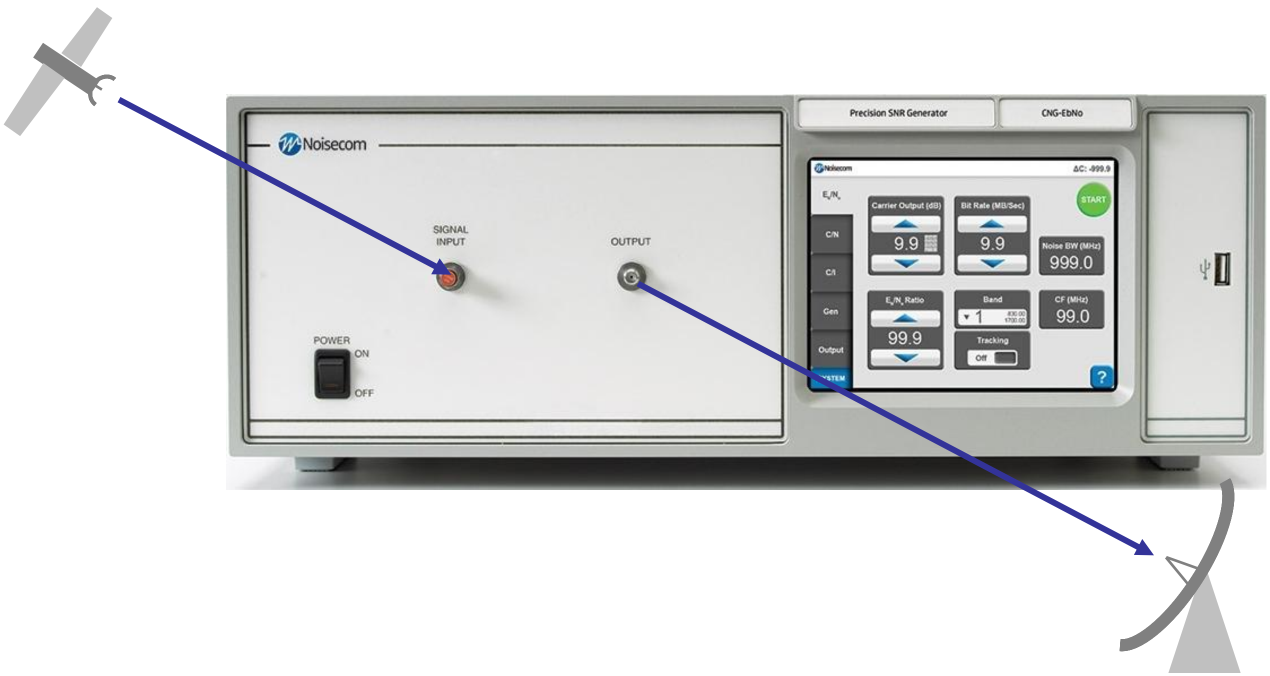
How:
As C/N and C/No, C/I is usually analyzed through BER plots.



$$C / I = C / (I_1 + I_2 + I_n)$$

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	
Input Power Range:	-55 dBm to +5 dBm
Max Input Power:	+21 dBm (with no damage)
Nominal gain:	+/-1.0 dB
Gain resolution:	0 to –60 dB in 0.1 dB steps
Gain flatness:	0.2 dB for 70 MHz +/-20 MHz 0.3 dB for 140 MHz +/-40 MHz 0.4 dB for others
Group Delay:	+/-.20 ns/40 MHz for frequencies above 20 MHz

Noise Path	
Output Power Range:	-55 dBm to +5 dBm
Flatness:	+/- 0.2 dB / 40 MHz +/- 0.3 dB / 80 MHz +/- 0.4 dB / 200 MHz +/- 0.5 dB / 300 MHz
Attenuation range:	60 dB in 0.25 dB steps (0.1 dB opt)

CNG EbNos are available with a wide variety of frequency bands. Please check: http://noisecom.com/products/instruments/cng-ebno-snr-noise-generator for more information or contact your next Noisecom representative.

CNG E_bN_o vs. Spectrum Analyzer

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

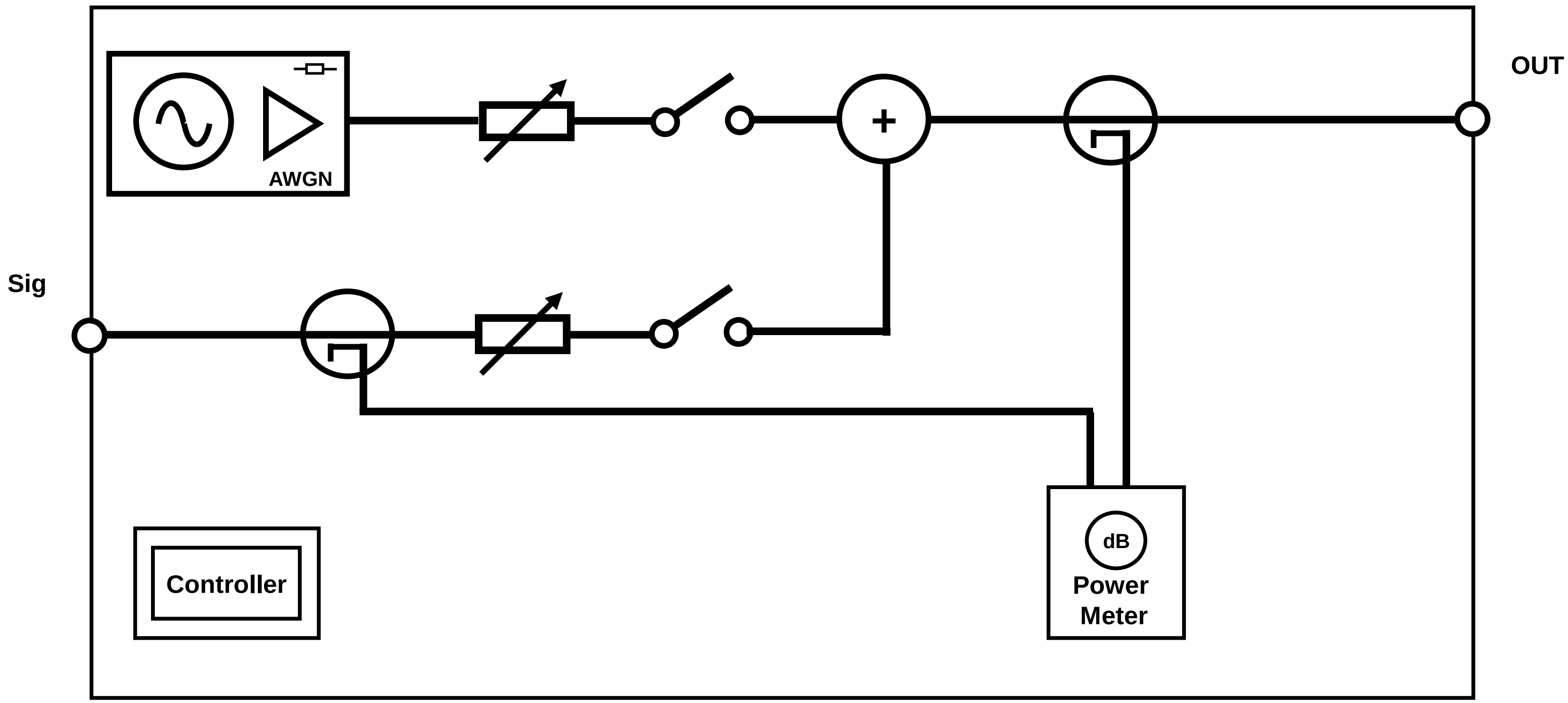
- Automated procedure, therefore repeatable measurements provided quickly
- Highest accuracy through substitution calibration method
- Automated calculation of results
- Customer specific configuration depending on the application

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

Wireless Telecom Group
Boonton Microlab Noisecom

THANK YOU !

Join us for our next Webinar:

Amplifier Testing: New Methods (Part I)

by **Bob Muro, WTG**

Date: 12/15/2010

Addendum