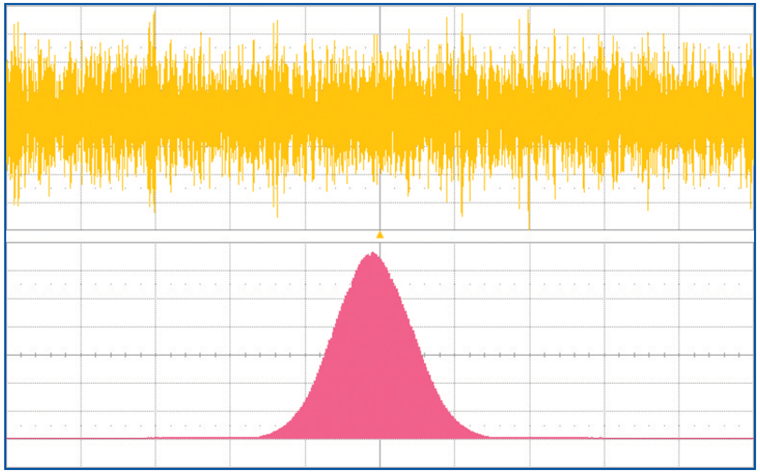
Noise Terminology:

An Overview of Noise Terminology and Applications

Author: Bob Muro, Applications Engineer

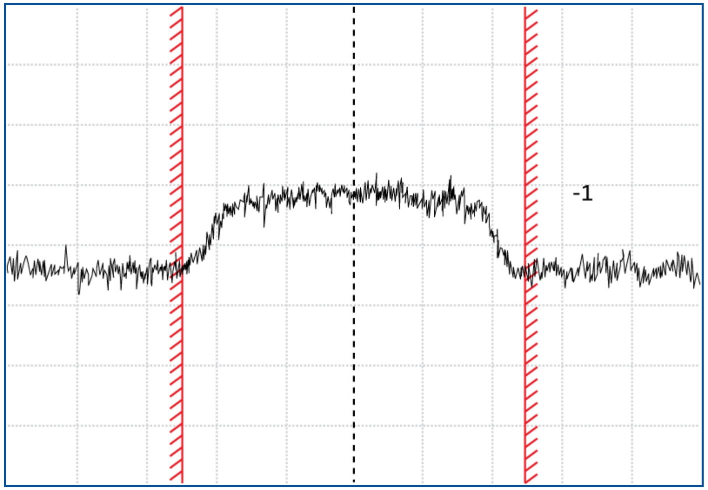


Today's Webinar

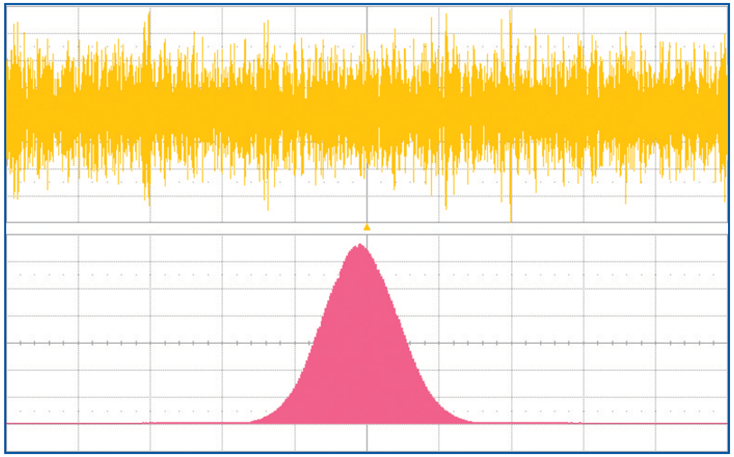
- Important noise characteristics
- Technologies effected by noise
- Noise applications and terms for this webinar
  - Np – noise power
  - NF – noise figure
  - Eb/No - the ratio of bit energy to noise density
  - NPR - noise power ratio
- Example calculations

Important Noise Characteristics

- Frequency Domain
  - Flat spectrum with uniform power spectral density
  - White noise contains all frequencies for a given BW



- Time Domain
  - Amplitude has a Gaussian distribution
  - Signal should have high crest factor (Pk/avg)



Technologies Affected by Noise

Wireless Communications

- Satellite links
- Mobile devices
- HDTV services

Radio Astronomy

- Reference source
- Calibration tool

Military & Commercial Radar Systems

- Calibration tool
- Reliability testing

Noise Terms & Applications

- Np – Noise power
- NF – noise figure
- Eb/No - the ratio of bit energy to noise density
- NPR - noise power ratio

Calculated Noise Power I

- Noise power, Np = kTB
  - K = Boltzmann's constant
  - T = temperature in Kelvin
  - B = noise bandwidth
  - Relationship between noise temperature and power

- An Example calculation at 290° K (62.6° F)(17° C)
  - The average temperature of the surface of the Earth
  - Np = (1.38065e-23)*(290° K)*(1 Hz)
  - Np = 4.004e-21 W/Hz
  - The BW selected depends on what you are calculating
  - Noise figure or receiver sensitivity
  - Watts per Hertz is not a common measure for communication engineers

Calculated Noise Power II

- More practical if normalized to 1mW in a 50Ω system
- Np (dBm/Hz) = 10log(4.004e-21/.001W) = -174 dBm/Hz
- Using this equation we can now relate the Np to a 50 Ω test system at 1 mW
- This is common standard for communication test equipment
- Therefore: -174 dBm/Hz is the output power of a 50 Ω resistor at the average temperature of the earth in a 1 Hz bandwidth
- This value cannot be measured with conventional communication equipment and is only used for comparison

Calculated Noise Power III

- -174 dBm/Hz, or thermal noise is used as the ultimate noise floor
- The value of -174 dBm/Hz is sometimes expressed as excess noise ratio, or ENR
- Simple equation to calculate ENR
  - ENR (dB) = 174 dBm / Hz – PSD (dBm / Hz)
- These values are used when measuring the noise figure of an amplifier
- The noise figure of an amplifier is necessary when calculating gain for a receiver system

Noise Terms & Applications

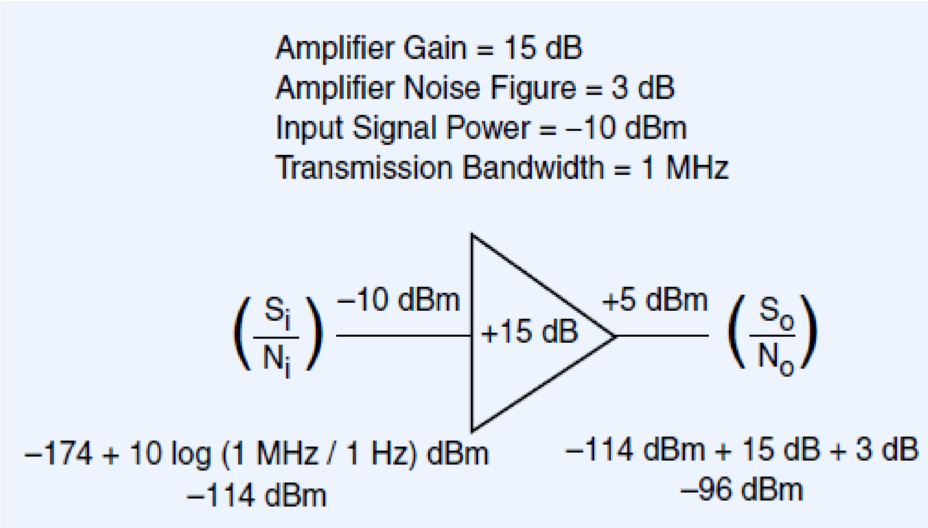
- Np – noise power
- NF – noise figure
- Eb/No - the ratio of bit energy to noise density
- NPR - noise power ratio

Example noise figure calculation

- Noise Factor (linear) and Noise Figure (dB)
- Noise Power vs. Noise Temperature
- Scalar Noise Figure Measurement I
- Scalar Noise Figure Measurement II

Noise Factor and Figure Equations

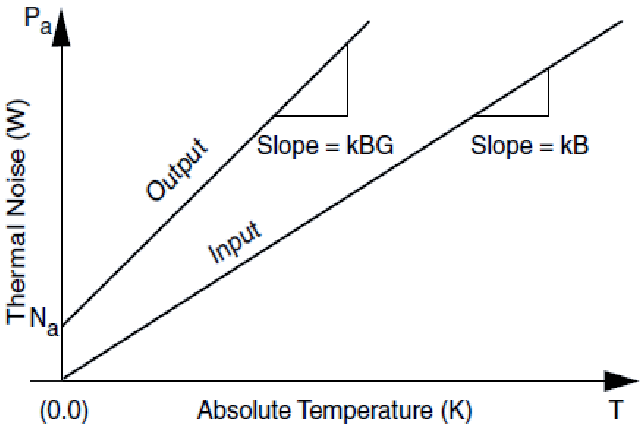
- The difference between SNR & SNR out excluding gain is noise figure
- Linear F is noise factor
- 10 log(F) is Noise Figure
- Example amplifier with
  3 dB noise figure
- Noise Figure is typically unknown and must be measured
- Noise figure is measured with
  - Noise Figure Analyzer
  - Spectrum Analyzer
  - Dedicated receiver



	Noise Figure Calculations in Power (dBm)
Terms	$F\text{ (dB)} = \left(\frac{S_i}{N_i}\right)_{dB} - \left(\frac{S_o}{N_o}\right)_{dB}$
S_i / N_i	–10 dBm – (–114 dBm) 104 dB
S_o / N_o	+5 dBm – (–96 dBm) 101 dB
Noise Figure	104 dB – 101 dB 3 dB

Noise Power vs. Noise Temperature

- The relationship between noise power and temperature is linear
- Graph of SNR without any signal power and zero return loss
- The slope m = kB; when b = 0° K

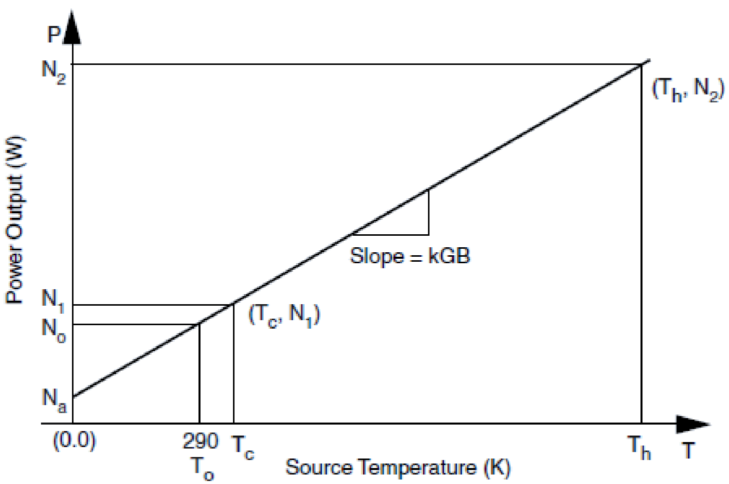


- Real amplifiers have gain and work above absolute zero
- The slope m = kGB above 0° K
- Na is intrinsic thermal noise generated by the amplifier
- b or the y-intercept (Na) is the noise figure of the amplifier
- The slope, or kGB is equal to the gain for a finite BW
- This is referred to as the “Y”- factor method

Scalar Noise Figure Measurement I

- The example uses a 15 dB ENR noise source
- 15dB ENR = T_{hot} = 9461° K
- Assume Tcold = T_{off} = 290° K
  - Simplify the equation
- F (dB)= ENR(dB) – 10log(Y–1)
- F (dB) = 15–10log[(N2/N1)-1]
- F dB = 15dB – 12.91dB
- F dB = 2.1dB

Conversion	Equation
T_h to ENR	$ENR = 10 \log (T_h - T_o)/T_o$
ENR to T_h	$T_h = T_o\, 10^{(ENR/10)} + T_o$



Scalar Noise Figure Measurement II

Conversion	Equation
T_h to ENR	$ENR = 10 \log (T_h - T_o)/T_o$
ENR to T_h	$T_h = T_o\, 10^{(ENR/10)} + T_o$

Term	Measured Noise Power
N_2	8.51×10^{-15} Watt
N_1	4.14×10^{-16} Watt

- If the T_c value does not equal T_o, or 290° K then must compute F using this method
- Assuming T_{cold} = Toff will be dependent on the estimated noise figure
- The larger the estimated value, the less critical the T_{off} value

$$F = \frac{\left(\frac{T_h}{T_o} - 1\right) - Y\left(\frac{T_c}{T_o} - 1\right)}{Y - 1}$$

$$F = \frac{(31.62) - 20.56\ (0)}{20.56 - 1}$$

$$F = 1.62$$

$$F = 10 \log (1.62) = 2.1 \text{ dB}$$

$$Y = (N_2 / N_1)$$

$$Y = 8.51 \times 10^{-15} / 4.14 \times 10^{-16}$$

$$Y = 20.56$$

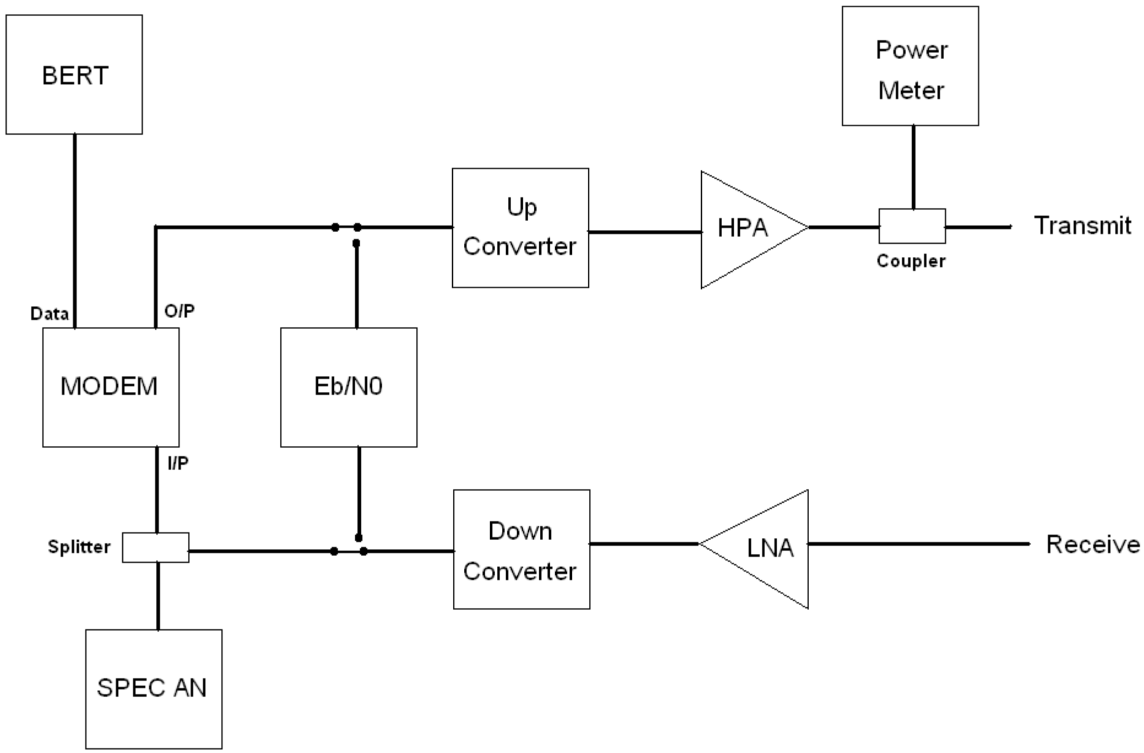
Noise Terms & Applications

- NP – noise power
- NF – noise figure
- Eb/No - the ratio of bit energy to noise density
- NPR - noise power ratio

Example SLE Calculation

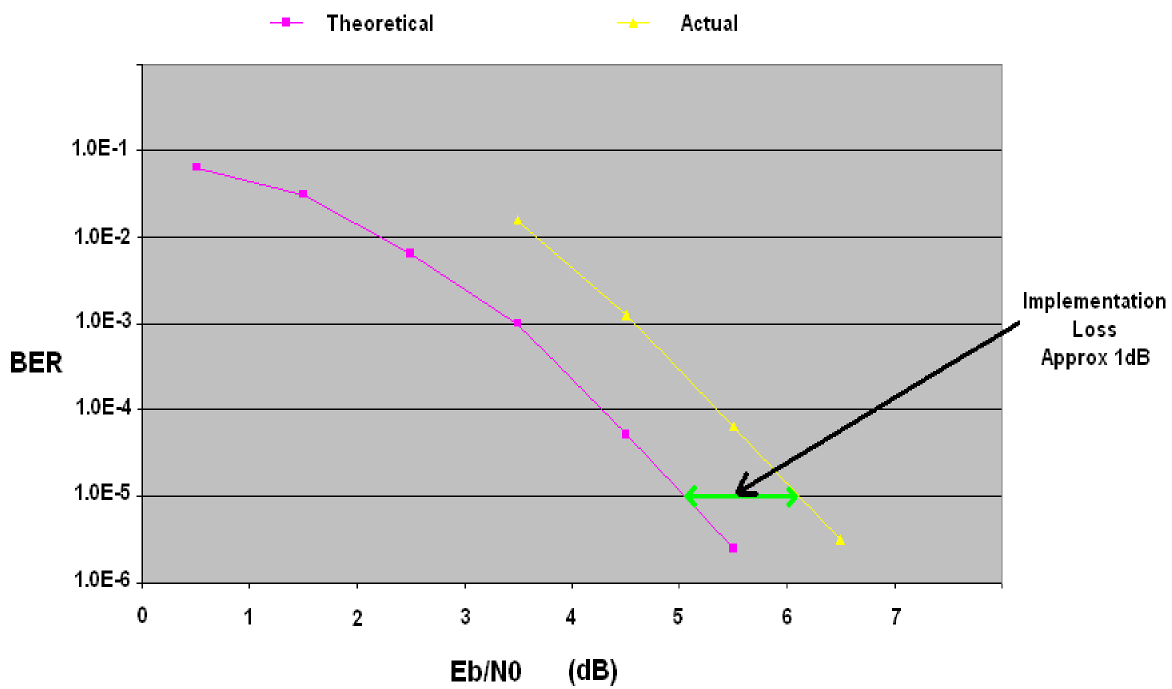
- Satellite Link emulation block diagram
- Waterfall diagram explanation
  - Example graph of different modulation schemes
- Calculate the amplifier noise floor
- Convert Eb/No value to C/N
- Calculate the required receiver sensitivity
  - The calculation does not include FEC, multi-path, or fading effects for simplicity

Satellite Link Emulation (SLE) Diagram



- Base band SNR measurement block diagram
- Eb/No can be measured on the up, or down link
- This example shows Eb/No at base band

Waterfall Diagram



- Waterfall diagram compares Eb/No (SNR) to BER
- Used to measure implementation losses
- Important for modulation comparisons

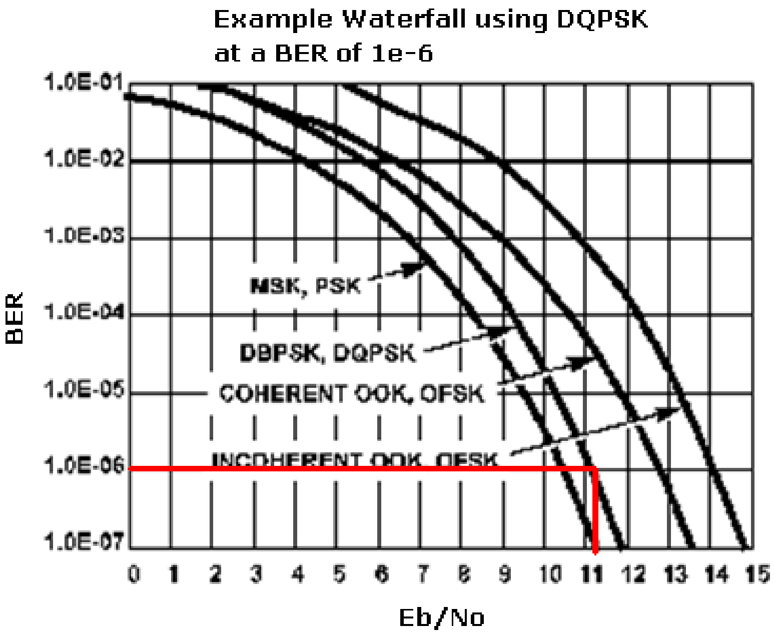
Amplifier Noise Floor

- Theoretical amplifier noise floor
- An amplifier with 1MHz BW at 290° K (17° C)
- Noise power = kTB
- = 1.38 x 10-23 J/K x 290K x 1e6 Hz s-1
- = 4 x 10-15W
- = -114dBm per 1 MHz
- NF of the amplifier in this example is 15dB
- = -114dBm + 15dB
- Real Receiver Noise Floor ≈ -99dBm
  - Will be slightly higher at room temperature 25° C

Convert Eb/No to SNR (C/N)

$C/N = (Eb/No) * (BR/BT)$

- Eb = Energy per bit
- No= noise density (per 1Hz)
- BR = system data rate
- BT= system bandwidth



Receiver Sensitivity

- Or, the required signal strength at the receiver input above the noise level
- The waterfall diagram from the previous slide requires an 11.1dB Eb/No for a BER of 10-6 using DQPSK modulation

C/N = (Eb/No) * (BR/BT)

- C/N = 11.1* 10log(2Mbps / 1MHz)
- C/N = 11.1dB + 3dB = 14.1 dB

Receiver sensitivity (Prs)

- Prs = Receiver Noise Floor + C/N (SNR)
- = -99dBm + 14.1dB
- = -84.9 dBm

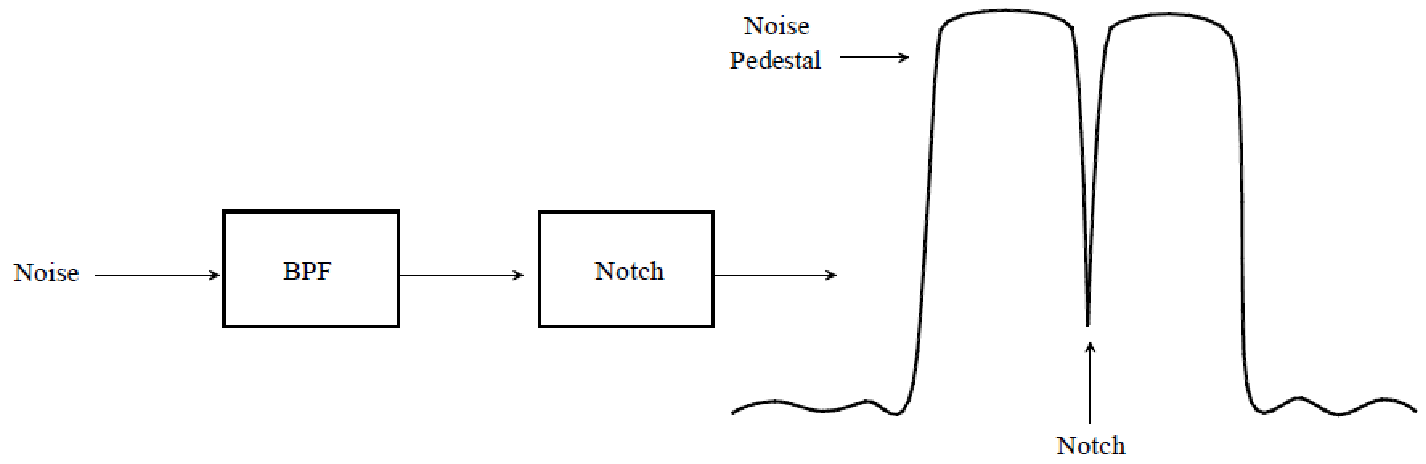
Noise Terms & Applications

- NP – noise power
- NF – noise figure
- Eb/No - the ratio of bit energy to noise density
- NPR - noise power ratio

NPR Noise Power Ratio Basics

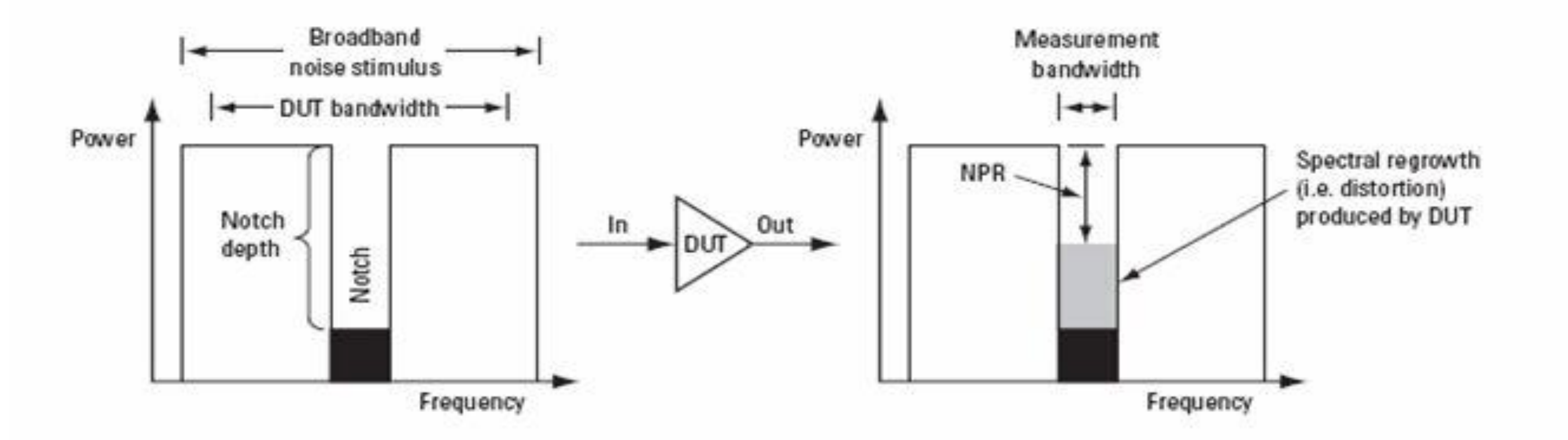
- White noise is used to simulate the presence of multiple carriers with random amplitude and phase.
- A finite BW notch is removed from the noise pedestal
- The notch is created using a band stop filter
- The power measurements are taken from inside the notch using a narrow band receiver
- The input signal power level is increased until the DUT is saturated
- The change in NPR is caused by spectral re-growth in the notch due to nonlinearities in the DUT

Noise Pedestal Generation



- NPR measurement used for high power amplifiers with > 10 carriers
- Pedestal is normally the width of a channel
- The notch is ≤ 1% of the pedestal
- The notch is typically ≥ 50dB in depth

NPR Notch Diagram



No Load Notch

- Without DUT
- NPR of test equipment

Loaded Notch

- With DUT

NPR vs Load

- Loading DUT

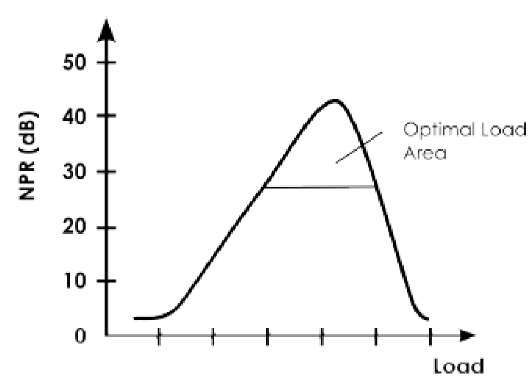


Figure 2: *Plot of NPR vs. loading condition to determine the optimum operating point for maximum SNR.*

Noisecom

NPR Summary

- NPR is a convenient method for evaluating the linear performance of amplifiers using multi-carriers ($\geq$ 10)
- Care must be taken in selecting the proper NPR test equipment.
  - Noise pedestal $\geq$ DUT BW
- NPR provides an accurate and repeatable measure of amplifier linear performance
- NPR represents the ratio of total output power to uncorrelated in-band distortion power

How Can You Use Our Instruments?

- From the bench top to a rack system we have several form factors

- Bench top instruments plug into a common lab outlet and require minimal operating instructions

- Computer controlled instruments are the solution for complex ATE system

- Instruments with power meters and filters provide advanced capability

How Can We Help You Today?

Noisecom has been working with industry leaders since 1985 that manufacture:

- Microprocessors
- HDD & Flash memory
- Radar equipment
- Satellite systems
- Radiometers
- Antenna systems
- Cellular service providers
- Calibration systems

Please visit our website for international locations: **www.wtcom.com**

Noisecom

Thank You for Participating in Today's Webinar

Any Questions?

WTG Regional Technical Contacts for Additional Questions

- Mr. James Lim - JLim@wtcom.com
- Mr. Steven Shaw - Manchester, UK - SShaw@wtcom.com
- Mr. Bob Muro - Parsippany, NJ - RMuro@wtcom.com