Amplitude Noise Review and Phase Noise

- Sample noise calculations
- Phase noise

Noise Performance of Amplifiers

- When a signal of SNR, SNR_i, with noise power N_i enters an amplifier (any electronic device with gain) and exits with a new SNR, SNR_o with noise power N_o then we define the *Noise Factor (F)* of the network as,

$$F = \frac{SNR_i}{SNR_o}$$

- *Notice that SNR_i is always $> SNR_o$*.
- The *Noise Figure* is defined as,

$$NF = 10log_{10}(F)$$

- If the noise is **only** amplified then the NF is 0. In practice of course amplifiers make things worse.

The Noise Performance of Cascaded Amplifiers

- The noise factor of cascaded amplifiers is given by,

$$F_{TOT} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + ...$$

  where G_k are the power gains of the various amplifiers and F_k are the noise **factors**

- Provided that the amplifier gains are much larger than unity, the noise factor (and therefore the noise figure) of a receiver chain is dominated by that of the first amplifier.

Transfer Function, Insertion Loss (Conversion Loss) and Attenuation.

- *The Transfer function* of a four port network is the ratio of its output voltage V_o when terminated (in Z_o) to that when the network is replace by Z_o.
- **Transfer function must be unity if the network is lossless.**
- *Insertion loss* is the same as the transfer function.
- *Attenuation* only includes the loss from input to the output in terms of the voltage.

$$Transfer\ Function = \frac{2V_o}{Z_o}$$

$$Attenuation = \frac{V_o}{V_i}$$

$$Transfer\ Function = Attenuation \times (1 + \rho)$$

$$\rho = \frac{Z_i - Z_o}{Z_i + Z_o}$$

Noise Performance of Passive Networks

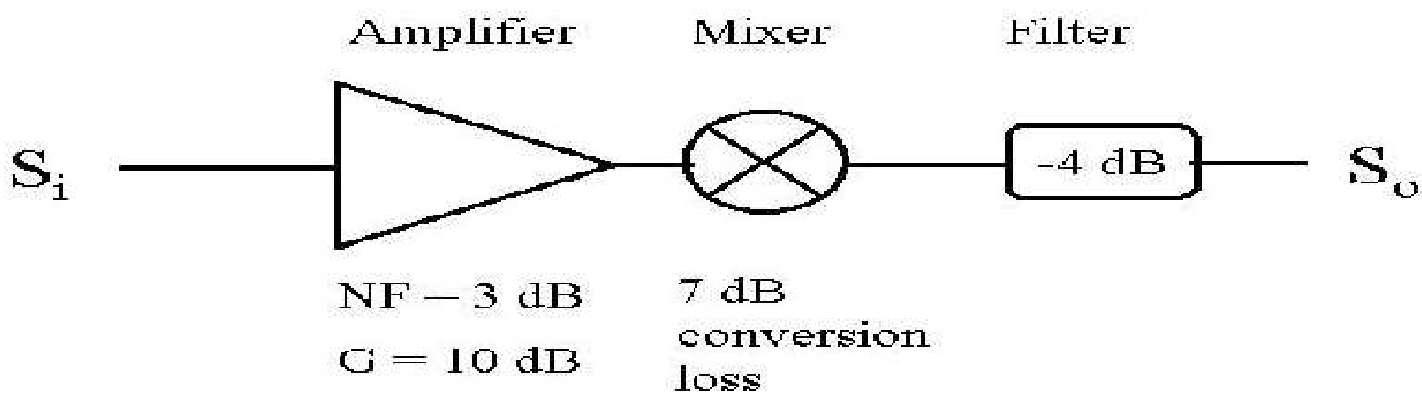
- If noise enters a passive circuit then the NF is equal to the *insertion loss* (IL) of the circuit.

$$NF = IL(dB)$$

- Insertion Loss (IL) refers to that fraction of the signal power which is dissipated in the network.
- Insertion Loss (IL) is the transfer function of a lossy network like an attenuator, a filter or a passive mixer.

Example Noise Power Calculation.

- Consider the following receiver chain which is typical of that in a wireless receiver.
- The noise figure of the mixer and filter (both passive devices with the given insertion losses) is 11dB.
- **Find the overall noise figure of the receiver**



Example Noise Power Calculation. (Contd)

- The noise factor of the amplifier is 2 (=$10log_{10}(3)$).
- The noise figure of the mixer and filter is 11 dB and so the noise factor is 12.6 (=$10log_{10}(11)$). Thus,

$$F_{TOT} = F_1 + \frac{F_2 - 1}{G_1} = 2 + (12.6 - 1)/10 = 3.16.$$

- Finally we obtain

$$F_{TOT} = 10log_{10}(3.16) = 5dB.$$

Receiver Noise Calculations

- The thermal noise added to a signal when passing through a system is given by,

$$N_o = k_B T B$$

- In dBm

$$N_o = 10 log_{10} \frac{k_B T B}{1 \times 10^{-3}}$$

- If N_o and the NF are known, then the required input signal level for a given output SNR can be calculated,

$$S_i = NF + N_o + SNR_o$$

Receiver Noise Calculations (Example)

- In the above example compute the required input signal level for a 10 dB output SNR and a 1.25 MHz bandwidth.

$$N_o = 10log_{10}\frac{(1.38 \times 10^{-23})(293)(1.25 \times 10^6)}{1. \times 10^{-3}} = -113dBm$$

- Therefore

$$S_i = NF + N_o + SNR_o = 5dB - 113dBm + 10dBm = -98dBm$$

- Notice that Johnson noise was assumed as the baseline input noise to the receiver. **This is rarely the case in practice**

Man Made Noise

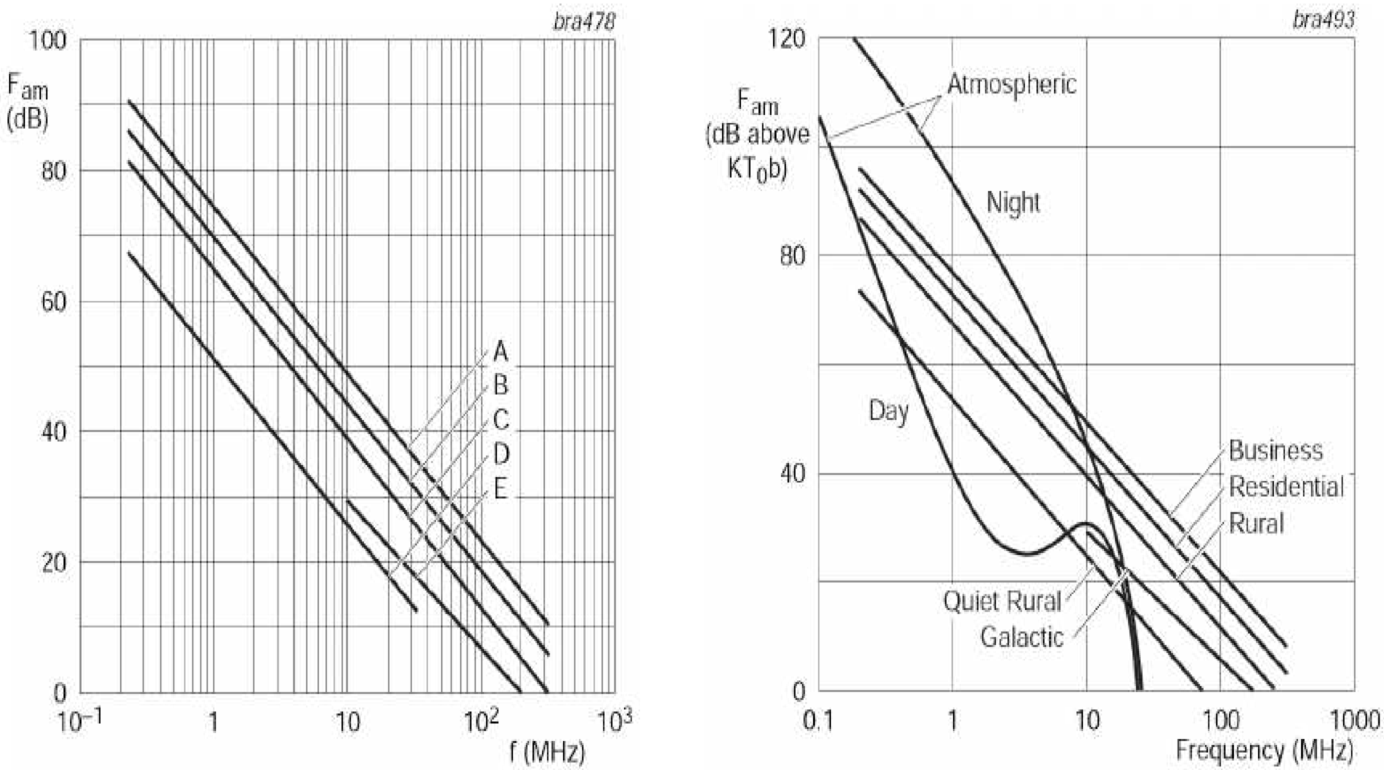


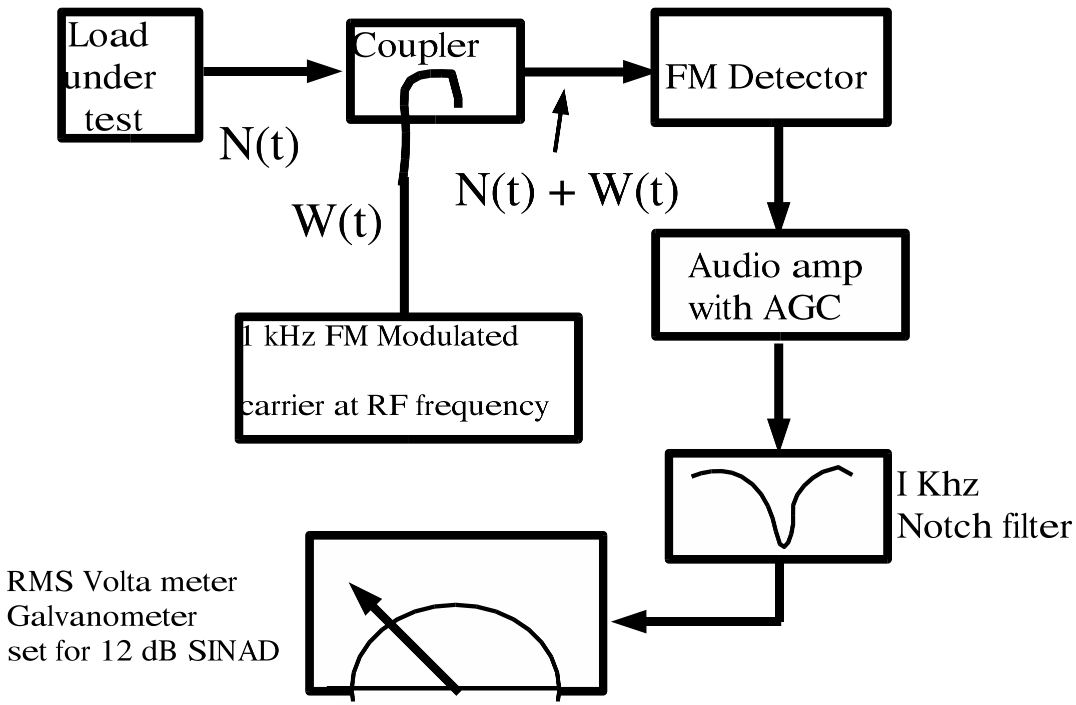
Figure 2.7: Ambient noise figures [4]. A: Business area, B: Residental area, C: Countrified area, D: Calm countrified area, E: Galactic noise.

Dealing with Noise

- In telecommunications the effects of noise are mitigated by the choice of receiver components that have a low NF. That is: NF is the parameter to look for in active component datasheets. Because it is that first amplifier in the receiver chain which determines the noise figure, it is usually chosen to be a Low Noise Amplifier (LNA) ($\ll 10dB$ NF).
- **To determine the sensitivity of a receiver in a particular application, one needs to measure the input noise from the antenna in situ and this will depend on the quietness of the site where the receiver is located.** *Site test*.
- In Radio astronomy, the antenna noise is the phenomenon under observation. Therefore one tries to minimise the receiver noise by judicious choice of components (NF) and cryogenics.

How to Measure Noise in Radio Receivers: SINAD (Signal to Noise And Distortion

- The method of measuring noise in arbitrary loads (e.g. antennas) and FM receivers



Phase Noise

- Phase noise corrupts the *argument* of an oscillator's sine wave...

$$V(t) = V_o[1 + A(t)]\sin(\omega t + \Delta\theta(t))$$

where $\Delta\theta$ is the R.M.S random phase noise.

- The following figure shows two types of phase noise. (i) Discrete spurious peaks and (ii) Continuous random phase noise.

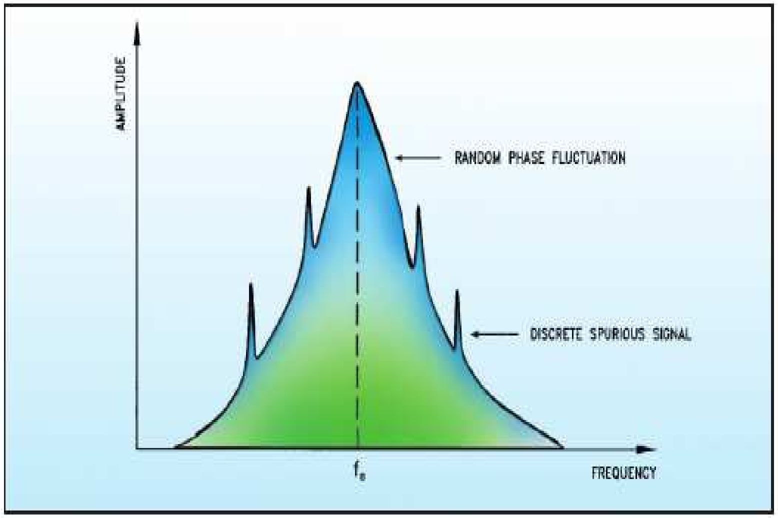
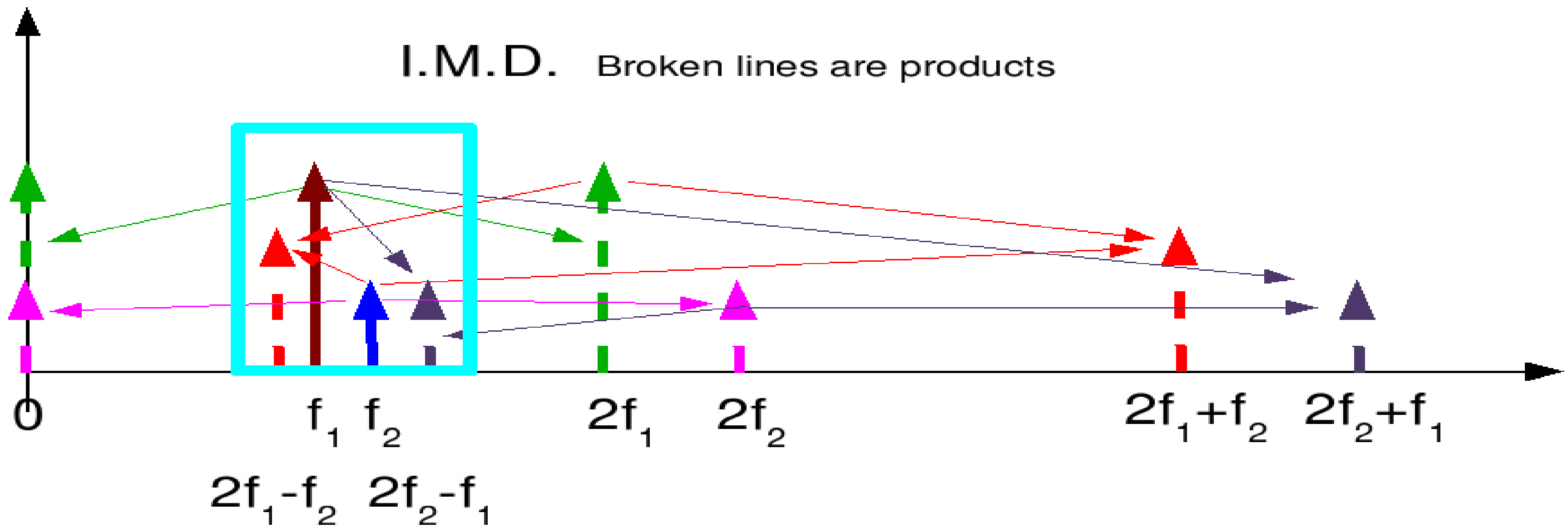


Figure 1. Spectrum analyzer display of phase noise

Sidetrack: Spurii and Intermodulation Distortion

- Spurious responses can be caused by oscillations of the PLL. Low frequency instability in the PLL will cause *frequency modulation*.
- Spurious peaks or spurs can also be caused by *second order Intermodulation Distortion (I.M.D.)*
- I.M.D. is caused by non-linear mixing of two tones f_1 and f_2 in the same passband. Products $2f_1 - f_2$ and $2f_2 - f_1$ are also in the same passband.



Characterising phase noise I

- The frequency domain information is contained in the *P.S.D* = $S_N(\omega)$.
- R.M.S. phase noise occurs in upper and lower sidebands.
- *Single Sideband Phase Noise is specified in dBc/Hz at a given frequency offset from the carrier*
- Let us see how this works.

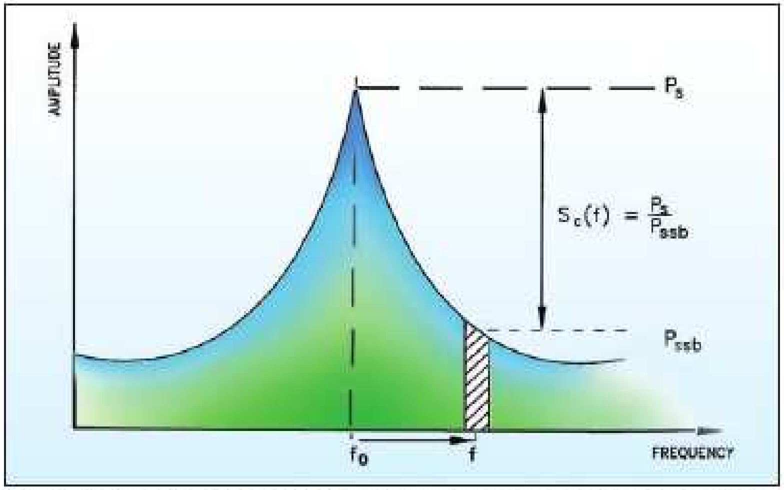


Figure 3. Single-sideband phase noise to carrier ratio

Characterising phase noise II

- If we consider an arbitrary carrier signal given by,

$$V(t) = V_o \sin(\omega t + \Delta\theta(t))$$

- Then provided the random variable $\Delta\theta(t)$ is small, $\cos(\Delta\theta) \approx 1$ and we may write,

$$V(t) \approx V_o (\sin(\omega t) + \Delta\theta(t) \cos(\omega t))$$

- Thus phase noise leads to double sideband modulation of the carrier.
- For example let $\omega = 0$ and we obtain,

$$V(t) \approx V_o \Delta\theta(t)$$

Some Basic Relationships

- The phase noise looks like amplitude noise,

$$V(t) \approx V_o \Delta\theta(t)$$

- Then the *spectral density* and *P.S.D* of a carrier are respectively defined by,

$$S_{\Delta\theta}(f) = \lim_{t->\infty} \frac{\tilde{\Delta\theta_t}^2}{t}$$

$$S_N(f) = \lim_{t->\infty} \frac{\left(V_o \tilde{\Delta\theta_t}\right)^2}{t}$$

where $\tilde{\Delta\theta_t}$ is the *Fourier transform* of $\Delta\theta$ limited to the time interval $[-t/2, t/2]$.

Specifying Phase Noise

- Common to specify phase noise as,

$$S_c(f) = \frac{S_N(\Delta f)/2}{Carrier\ Power}$$

where $S_N(f) = V_o^2 S_{\Delta\theta}(f)$ and the carrier power = V_o^2.

- The factor of 2 dividing the P.S.D. arises because we only consider one sideband in the definition of $S_c(f)$.

- $S_c(f)$ has the units of dBc/Hz.

$$S_c(f) = S_{\Delta\theta}(f)/2: \quad S_c(f)(dB) = 10log_{10}(S_c(f))$$

Specifying Phase Noise

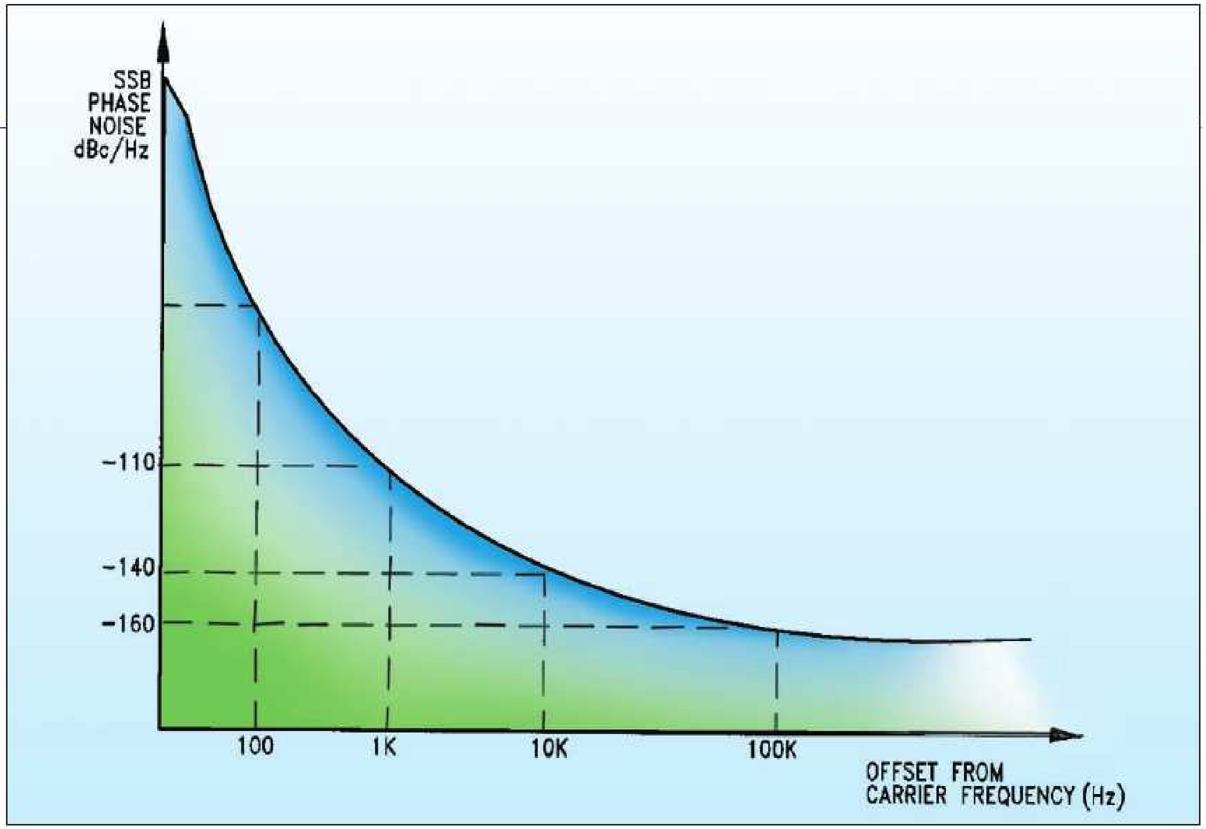


Figure 4. Single-sideband phase noise representation

Spectrum Analyser Revision

- LO Sweep generator is mixed with incoming signal
- IF signal is passed through two filters.
- *IF filter* : Resolution Bandwidth.
- *DC filter* : Video Bandwidth.
- **Thus be wary when measuring the phase noise with a spectrum analyser.**