Applied Radio Labs

Phase Noise Reference

How LO Phase noise affects received SNR - Frequency Modulation

A signal which has sinusoidal frequency modulation has general form (1.8)

$$s(t) = A \sin(w_c t + b \cos(w_m t))$$

if this signal is mixed with a local oscillator somewhere in the signal chain, then the resultant signal has the phase modulation of both the initial signal and the local oscillator.

signal $s(t) = A \sin(w_c t + b \cos(w_m t))$

local oscillator $S(t) = B \sin(w_{LO} t + f(t))$

mixing gives

$$s(t) * S(t) = A \sin(w_c t + b \cos(w_m t))\, B \sin(w_{LO} t + f(t))$$

$$= 0.5*AB \cos((w_c - w_{LO})t + b \cos(w_m t) - f(t)) \quad \text{plus sum term}$$

So the phase noise on the local oscillator is added the phase modulation on the wanted signal. This happens at each frequency conversion process during the entire signal chain, both in the transmitter and receiver. Any frequency translation that occurs in between can also contribute (e.g. repeaters).

This phase noise will produce a residual background noise when the signal is demodulated, that will be present regardless of the system external S/N ratio. If the signal is added in the transmitter chain, then the signal transmitted is transmitted with built-in noise that cannot be removed.

The actual effect of this noise on the system depends on the frequency response of the demodulator, and whether any de-emphasis is provided.

The Residual FM is the rms frequency deviation of the signal, as measured in a particular specified audio bandwidth.

$$\text{Residual FM (Hz)} = \sigma_f = \sqrt{2\int_{f_1}^{f_2} L_\phi(f)^2 f^2 df} \qquad \text{.. (2.2)}$$

where f_1 and f_2 are the lower and upper frequency limits of the audio output filter. For other than a brick-wall filter, the filter response can be included under the integration sign in

Example: An oscillator has phase noise of -70dBc/Hz at 1kHz, and the phase noise is varying at 20dB/decade. Determine the residual FM in a band 300Hz to 3kHz.

As the phase noise is varying at 20dB/decade, $L_f(f) = a/f^2$ *and to get -70dBc/Hz at 1kHz, gives* $a = 0.1$*. The integral may be performed exactly to get*

residual FM = $\text{sqrt}(2\, a\, (f_2 - f_1)) = 23.2\text{Hz}$

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If you are designing a synthesizer using SimPLL and wish to determine the residual FM, simply select **Edit / Report Options** in the main menu and enter the frequency bounds f_1 and f_2 , SimPLL will automatically calculate the residual FM by numerically integrating the phase noise curve and will display the result on the Report page.

The residual FM is the FM that is left when there should be no modulation - that is why it is called *residual*. So when there is no modulation on the transmitter, some residual noise voltage comes out of the demodulator in the receiver with RMS amplitude v_n. The residual FM is the RMS frequency deviation of the transmitter needed to produce v_n.

The residual FM limits the signal to noise ratio achievable in a system. The S/N ratio for sinusoidal modulation with peak deviation f_d, on a carrier with residual FM s_f is given by

$$S/N = 20\log_{10}\left(\frac{f_d}{\sqrt{2}\sigma_f}\right) \quad \text{.. (2.3)}$$

Some people remember this as the RMS deviation over the residual FM

Example: If the previous oscillator was used in an FM system with 3kHz deviation, what would be the best S/N ever achieved in the system in the absence of all other sources of noise?

The residual FM is 23.2 Hz, the PEAK frequency deviation is 3kHz, so the S/N ratio is

*S/N ratio = 10 $\log_{10}$(peak deviation / (sqrt(2) * residual FM)) = 39.2dB*

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Users of SimPLL and can easily determine the residual FM and the S/N, simply select **Edit / Report Options** in the main menu and enter the frequency bounds f_1 and f_2 and the deviation. SimPLL will automatically calculate the residual FM and S/N and will display the result on the Report page.

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