Agilent PN 894400-2

Measuring Phase Noise with the Agilent 89400 Series Vector Signal Analyzers

Product Note

The characterization of phase noise is increasingly important in modern communications systems. In the past, it has been a very difficult and time-consuming measurement. The Agilent Technologies 89400 Series vector signal analyzers (VSAs) greatly facilitate phase noise characterization measurements for designers of systems with all but the most demanding requirements. The power of these vector signal analyzers is in their ability to make very fast direct phase noise measurements in any domain. For example, transmitter designers are often interested in the actual spectral density around the carrier or inte-grated band power in adjacent channels, whereas users interested in the recovery of digitally modulated information may be most concerned with peak or RMS phase deviation of the recovered vectors. The 89400 Series VSAs quickly and easily produce results in any of these domains. They are also capable of mathematically locking to unlocked or drifting carriers, allowing fast and accurate averaged measurements even under these conditions. This is a powerful feature, not available in other spectrum analyzers, that allows the recovery of close-in phase noise information even for drifting carriers.

For many situations, measurements which previously had taken minutes or tens of minutes to complete can be performed in seconds. Expect measurement speed improvements of 10X to 100X.

89410A dc-10 MHz vector signal analyzer

The 89410A has an input bandwidth of 0 to 10 MHz, and intrinsically lower phase noise than other RF spectrum analyzers due to its baseband implementation. Practically, the instrument's input noise makes up the fundamental phase noise measurement's dynamic range limitation, and will be discussed later.

The user needs to downconvert the signal-under-test into the 0 to 10 MHz input bandwidth. The phase noise bandwidth of interest dictates how close the carrier can be to either dc or 10 MHz. If possible, the instrument should be phase locked to the signal-under-test, although it is not necessary.

89440A dc-1.8 GHz vector signal analyzer

While most of the following discussion applies to all the 89400 Series VSAs, some differences apply. The 89440A can directly measure input signals up to 1.8 GHz. However, since the RF section is essentially a heterodyned receiver, its local oscillator phase noise will reduce the phase noise measurement's dynamic range below the raw capability of the 89410A itself. Refer to the Agilent 89400 Series VSA data sheet for specifications on phase noise performance of each specific analyzer.

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Direct $\mathit{\mathcal{L}(f)}$ measurements

$\mathcal{L}(f)$, the *single-sided phase noise density* in units of dBc/Hz, is a common phase noise measurement. In the 89400 Series VSAs, $\mathcal{L}(f)$ is facilitated by trace math and/or an Instrument BASIC program to normalize the noise density to carrier power, and as with all measurements the instrument performs *very* fast averaging for *very* accurate noise measurements. In fact, the 89400 Series VSAs produce complete spectral results for 401 frequency points with averaging in less time than traditional spectrum analyzers take to measure noise density for a single frequency point using noise markers.

Using the instrument's built-in trace math, define a function F1 = PSD/K1, where K1=10 $^{((\text{carrier power in dBm})/10)}$. (This is easily automated using an I-BASIC program). This function is the desired result $\mathcal{L}(f)$, assuming the noise density is dominated by phase noise rather than AM or input noise. The *"f"* in $\mathcal{L}(f)$ is generally understood to be the frequency offset from the carrier frequency. Figure 1 shows an example of this measurement; although the annotation shows units of dBm/Hz, the actual units are dBc/Hz due to the normalization to carrier power.

If the signal-under-test is unlocked and drifting too much to make a satisfactory averaged measurement, an alternate method is to use an 89400 Series VSA with demodulation and auto-carrier functions. See "Phase Perturbation Measurements" later in this note.

Adjacent-channel power measurement

This is an important variation of the phase noise measurement. The 89400 Series VSAs have an explicit "C/N" feature which accomplishes the adjacent-channel power measurement in cases where the carrier is distinguishable as a single tone.

In cases where the carrier is heavily modulated or defined over a frequency band, trace math solves the problem. Again let F1 = PSD/K1, where K1 = $10^{((\text{carrier power in dBm})/10)}$, but this time carrier power is measured using band-power markers. The entire measurement can be executed with a single keystroke using an I-BASIC program. Figure 2 shows an example of this measurement.

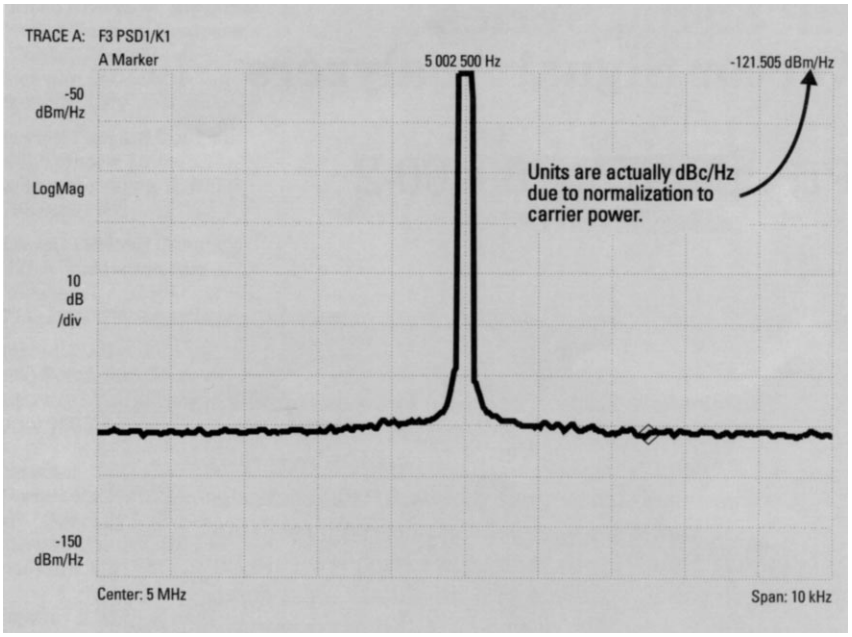

Figure 1. $\mathcal{L}(f)$ measurement

Phase perturbation measurements

Phase perturbation measurements include phase jitter, time jitter, phase deviation, peak-phase deviation, and RMS-phase deviation. They all refer to the phase or time deviation from ideal of the *information*, due to phase noise or phase distortions in the system. The 89400 Series VSAs greatly facilitate these measurements with demodulation and time-domain features.

Select PM Demodulation for the instrument mode. If the signal-under-test is not phase locked to the VSA, simply turn Auto-Carrier on ("Phase and Frequency" PM auto type). This built-in function mathematically phase-locks the signal to the instrument. Note that this causes the lowest two demodulated frequency points to be invalid due to the phase-servo effect of the Auto-Carrier function. (Phase-locking with hardware phase-lock loops implicitly does the same thing, although it is less obvious in the measurement.) When possible, physically phase-lock the signal to the instrument using the external reference input and change "PM auto type" to "Phase"; then the measurement itself will be valid over the entire demodulated frequency span.

The Auto-Carrier function can also handle the problem of drifting carriers, even when using averaging (use "Phase and Frequency" PM auto type). Close-in phase noise can be accurately measured despite the drifting carrier, even with averaging. The only limitation is that a severely drifting carrier can result in desired noise sideband information falling out of the measurement span. For instance, if the carrier drifts ±5% from the specified center frequency during the measurement, then 5% of each end of the spectrum drifts out of the measurement span and will not be correctly demodulated. This would correspond to the upper 10% of the demodulated frequency span being invalid.

A typical measurement situation is illustrated in Figure 3. The top trace shows the phase-demodulated power spectral density (PSD), while the bottom trace shows the time waveform of the demodulated information (in this case, noise). Considerable information can be obtained directly from this measurement:

- Peak-phase deviation during a given period is read directly from the time trace.
- RMS-phase deviation is obtained by applying band-power markers to the time trace.
- Frequency selective determination of RMS phase deviation is obtained by applying band-power markers to the PSD trace.
- Variance of the measurement is reduced by averaging the PSD trace.
- Measurements are presented in any engineering unit of interest: degrees or degrees^2, radians or radians^2, normalized per Hz or $\sqrt{\text{Hz}}$, etc.
- Time gating can be applied to the time trace to produce time-selective frequency spectra, for cases where the demodulated information is not necessarily stationary.

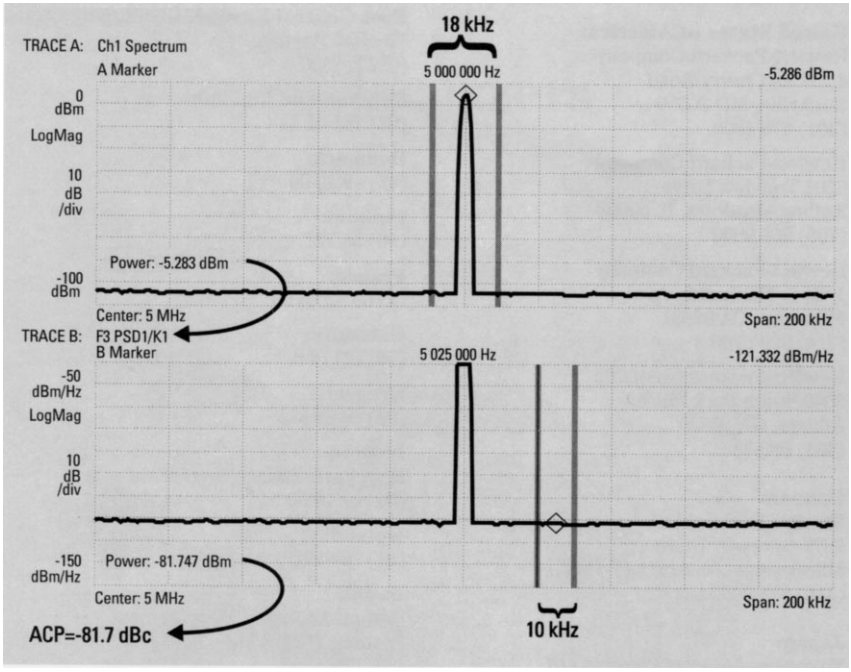

Figure 2. Agilent channel power

In addition, measurements can be paused at any time, and any or all of the above features applied after the fact to the data record. By now, it is probably clear that the features in the Agilent 89400 Series VSAs provide unprecedented measurement speed and ease of use.

Conversion between $\mathit{\mathcal{L}(f)}$ and phase perturbation domains

There is a simple relationship between $\mathit{\mathcal{L}(f)}$ and the phase demodulation PSD for the majority of cases where the noise modulation satisfies the "narrowband FM" assumption. Specifically,

$\mathit{\mathcal{L}(f)}$ (dBc/Hz) =
{Phase demodulated PSD ($dBrad^2_{rms}$/Hz)} – 3 dB,
for $\mathit{\mathcal{L}(f)} < -30 - 10 * LOG_{10}(f)$(dBc/Hz)

Dynamic range considerations

The 89400 Series analyzers' input noise is usually the practical limitation for the dynamic range of these measurements. Therefore, for maximum dynamic range, the user should range the instrument as low as possible without causing ADC overloads. This will typically result in a dynamic range of better than –120 dBc/Hz, or analogously,

57 $microdegrees_{rms}/\sqrt{Hz}$

However, the instrument's input noise is neither a desired nor necessary pail of the phase noise measurement. At least 10 dB more dynamic range can be achieved simply by using the features of the 89400 Series VSAs to subtract the measured input-noise density from the desired phase-noise density measurement.

For improved $\mathit{\mathcal{L}(f)}$ dynamic range, let F2 = F1–D1, where D1 is a stored trace of F1 measured with the input terminated in 50 ohms. Again, this can be automated with an I-BASIC program that utilizes internal relay configurations to switch the input path to an internal termination. The amount of averaging applied to both measurements primarily determines the amount of improvement in dynamic range. Figure 4 shows the comparison of $\mathit{\mathcal{L}(f)}$ measurements of a low phase noise source with and without the dynamic range improved by input noise subtraction.

For improved phase perturbation measurement dynamic range, the relationship between $\mathit{\mathcal{L}(f)}$ and phase demodulated PSD is used. Again, the input noise is measured in Vector mode and stored into D1. Now select the instrument's Demodulation mode, and define F2 = PSD-D1/K2, where K2 = 20 and provides a conversion between the two domains. Use I-BASIC to make this a single keystroke

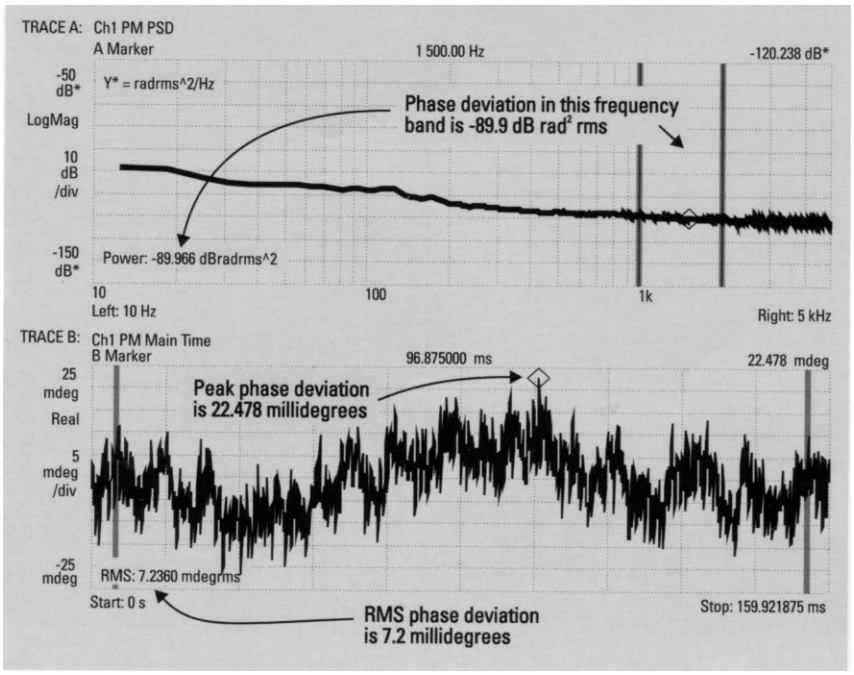

Figure 3. Phase perturbation measurements

measurement. Figure 5 shows a comparison of the measurement of a low phase noise source with and without the dynamic range improvement. Dynamic range of better than

–130 $dBrad^2_{rms}/Hz$ or

20 microdegrees$_{rms}/\sqrt{Hz}$

is achievable with this method; however, the improvement applies only to the spectral results, and cannot be applied to the time domain data.

State-of-the-art phase noise measurements

For state-of-the-art in features, speed, and ease of use for all but the most demanding phase noise requirements, nothing surpasses the Agilent 89400 Series VSAs.

For systems with the most demanding phase noise requirements, choose the world standard Agilent 3048A phase noise measurement system.

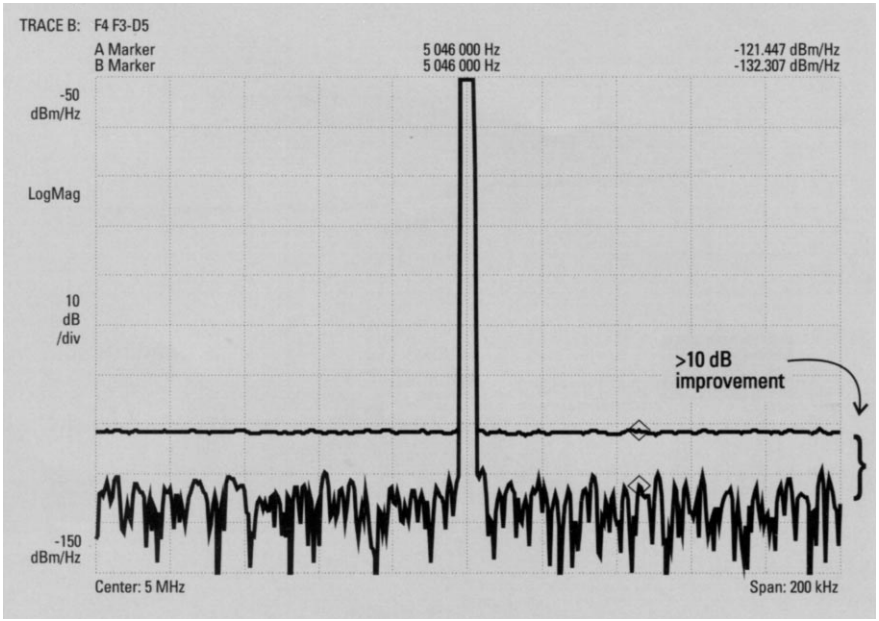

Figure 4. Dynamic range enhancement for $\mathcal{L}(f)$ measurement

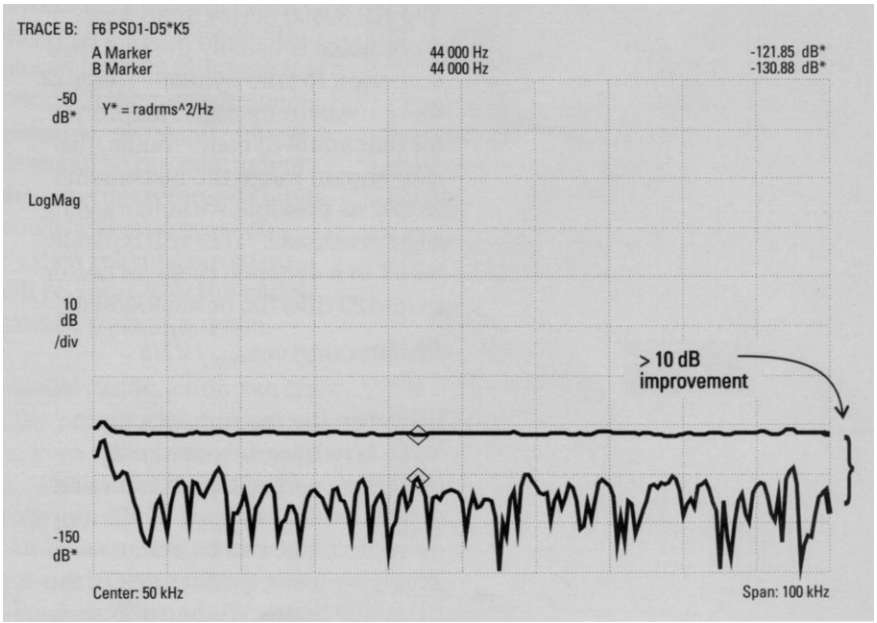

Figure 5. Dynamic range improvement for phase perturbation measurements

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Printed in U.S.A. 9/00
5091-7193E

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