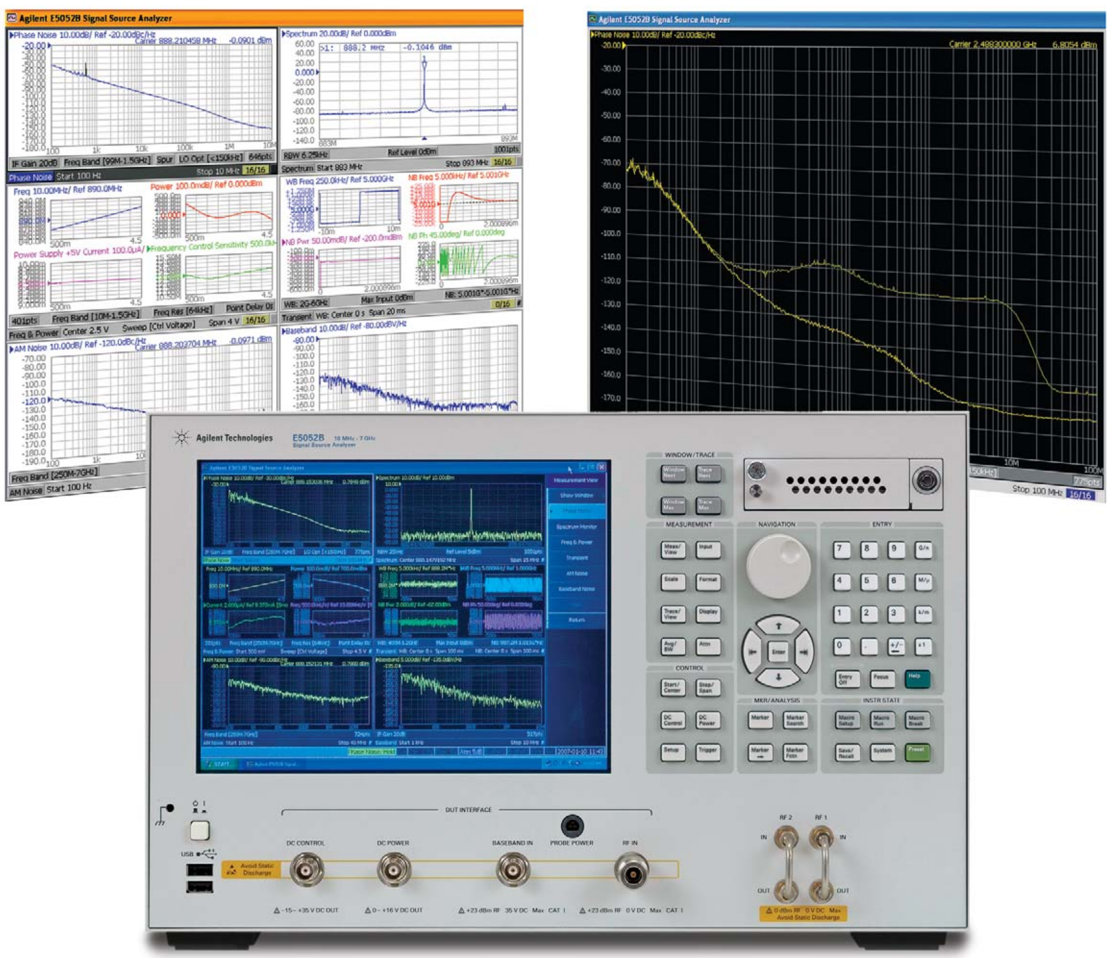
Agilent E5052B Signal Source Analyzer

Advanced Phase Noise and Transient Measurement Techniques

Application Note



Agilent Technologies

Introduction:

The Agilent E5052B Signal Source Analyzer (SSA) is designed to help R&D and manufacturing engineers across a wide range of electronic industries perform signal source tests more accurately, at higher throughput and lower cost, with unprecedented simplicity.

The SSA provides a complete set of measurement functions for full-characterization of signal sources in microwaves and RF. The SSA has six basic independent functions such as phase noise measurement, spectrum monitoring, frequency and power measurement (VCO test), transient measurement, AM noise measurement and baseband (LF) noise measurement. Each of the SSA's measurement functions delivers performance which is comparable to or exceeds that of conventional dedicated test instruments and systems.

This document describes two major advanced techniques of the SSA in phase noise measurement and transient measurement.

1. Phase Noise Measurement

1–1. Problems with conventional test solutions

For low phase noise measurement, the most commonly used method is a **PLL method** (Reference source / PLL technique) shown in Figure 1. This traditional method is widely used and works very well in general. However, it has several drawbacks in order to cover a wider range of phase noise level.

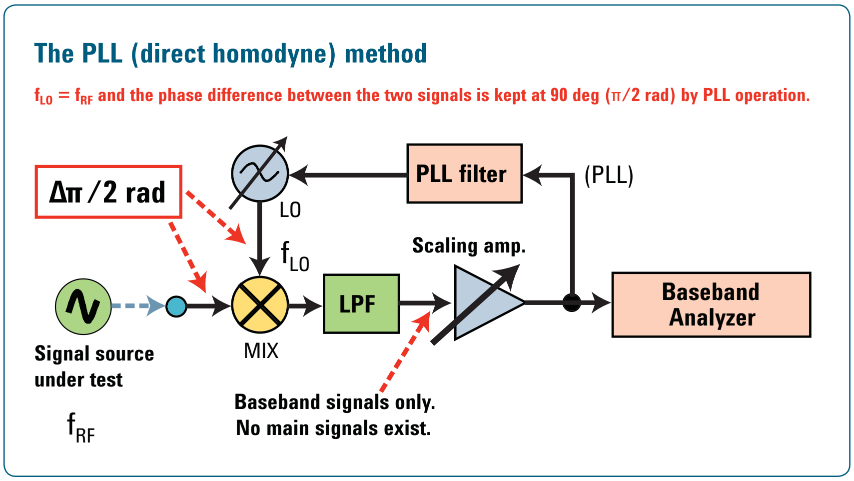


Figure 1.

The measurement process of the PLL method is relatively complicated. In order to configure the test system, an external reference source or local oscillator (LO) must be configured according to measurement needs so that it has sufficiently low phase noise compared to the signal source under test. It is not easy to configure a very low noise reference source for testing quiet oscillators, such as crystal oscillators and SAW resonator oscillators. In addition to this challenge, after the system is configured, a time-consuming set-up and calibration must be performed for accurate measurements.

The minimum sensitivity of the PLL method is determined by the noise floor of the reference source and the scaling amplifier. And the PLL method fails to measure phase noise of relatively drifty and noisy signal sources due to it's measurement principle. When the signal source under test is fairly noisy, phase-locking problems (PLL tracking failure) often occur, and it takes a long time to re-adjust the PLL's loop-bandwidth or loop-gain and re-calibrate the measurement system.

Another common method of conventional phase noise measurements is the **discriminator method** (analog delay line technique) shown in Figure 2. This method provides very high sensitivity at far from carrier offset frequencies. It satisfies, for example, the test requirement for GSM (<–165 dBc/Hz at 20 MHz offset). In addition, it can measure wider phase noise ranges for somewhat drifty sources, but the discriminator method has several disadvantages also.

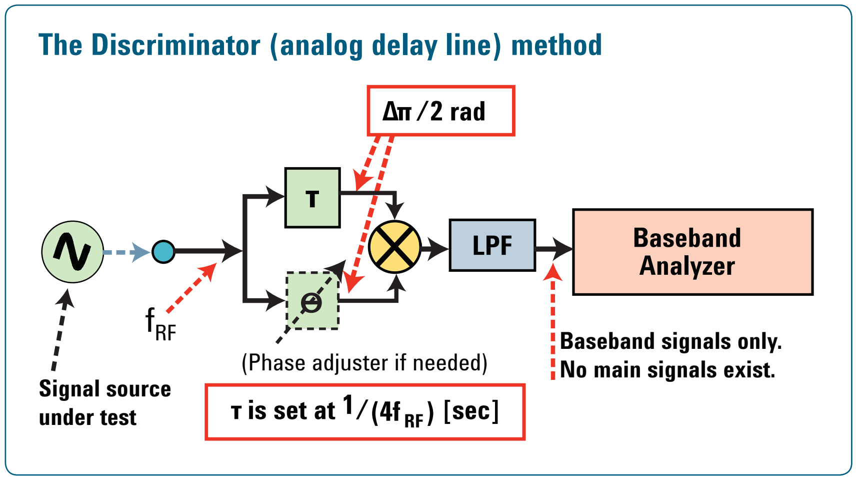


Figure 2.

The discriminator method is a fairly complex process. It is necessary to use several different analog delay lines according to the carrier frequency under test. Actually it is almost impossible to prepare appropriate delay lines at arbitrary test frequencies. In addition, a complicated calibration must be performed for each delay line.

Phase noise measurement at close-to-carrier offset frequencies by the discriminator method is not practical or accurate because a discriminator coefficient (shown in Figure 5b) limits a practical dynamic range at lower offset frequencies. To reduce discriminator coefficient's effect, longer delay lines are required at lower offset frequencies.

It is difficult to measure signal sources having low RF output power since the discriminator (phase detector) may not work properly due to insufficient driving power of the signal under test.

1-2. Innovative phase noise measurement techniques combined in the E5052B SSA

The E5052B signal source analyzer solves almost all issues mentioned above the phase noise measurement. It offers high sensitivity that surpasses conventional dedicated phase noise test systems with much faster measurement throughput and greater ease-of-use in actual operation.

The E5052B takes a unique combination of existing analog methods and newly-developed digital techniques, which can extend the effective range and reduce the noise floor significantly in phase noise measurements. The E5052B has two phase noise measurement modes, a normal capture range and a wide capture range, and a cross correlation technique with two independent measurement channels is available for both modes.

The **normal capture range** takes a PLL (direct homodyne) method shown in Figures 3a and 3b.

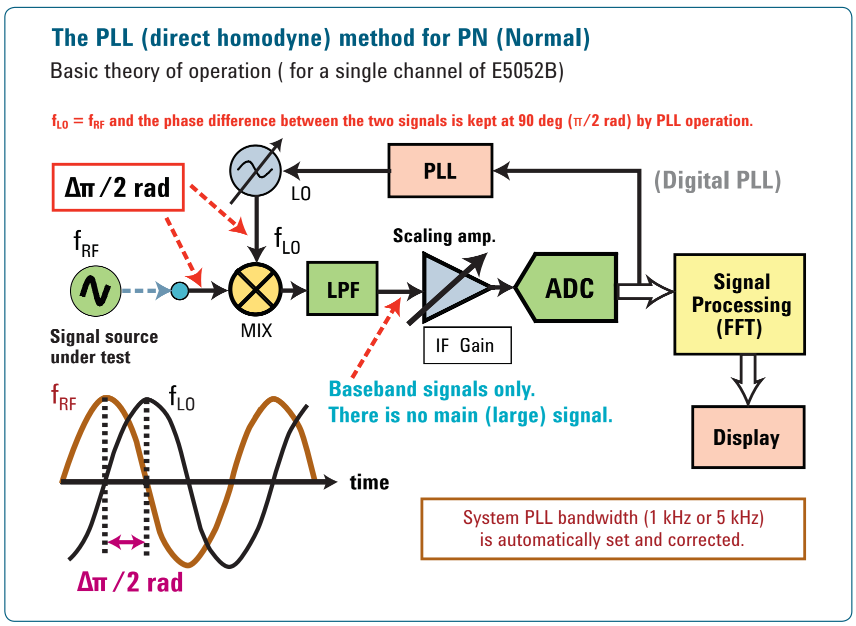


Figure 3a.

The PLL (direct homodyne) method for PN (Normal)

Basic theory of operation (for a single channel of E5052B)

$$v(t)=\sqrt{2}(1+\tilde{a})\cos(\omega_c t+\tilde{p})$$

$$v_{LO}(t)=\sqrt{2}\sin(\omega_c t+\tilde{q}) \quad \textit{where } \tilde{a}, \tilde{p} \textit{ and } \tilde{q} \textit{ are random variables.}$$

$$\textit{Assuming } |\tilde{a}|,|\tilde{p}|,|\tilde{q}| << 1$$

$$\begin{aligned} v(t)\cdot v_{LO}(t) &= 2\cdot(1+\tilde{a})\cos(\omega_c t+\tilde{p})\cdot\sin(\omega_c t+\tilde{q}) \\ &= (1+\tilde{a})[\sin(2\omega_c t+\tilde{p}+\tilde{q})+\sin(\tilde{p}-\tilde{q})] \\ &\rightarrow (1+\tilde{a})\sin(\tilde{p}-\tilde{q}) \quad \textit{after the LPF} \\ &\approx (1+\tilde{a})\cdot(\tilde{p}-\tilde{q}) \quad \textit{because } \sin x \approx x \textit{ if } |x| << 1 \end{aligned}$$

$$\textit{measured PM noise}: (\underline{\tilde{p}}\oplus\tilde{q})\cdot(1+\tilde{a})$$

Internal LO phase noise ($\tilde{q}$) **AM noise dependency** ($\tilde{a}$)

Figure 3b.

Two measurement channels with uncorrelated (phase noise) local reference oscillators are equipped in the instrument in order to implement a cross correlation technique.

For microwave phase noise measurements a heterodyne frequency-down converter (mixer) is used, and two mixers are necessary, as shown in Figure 4, for utilizing the same cross correlation technique.

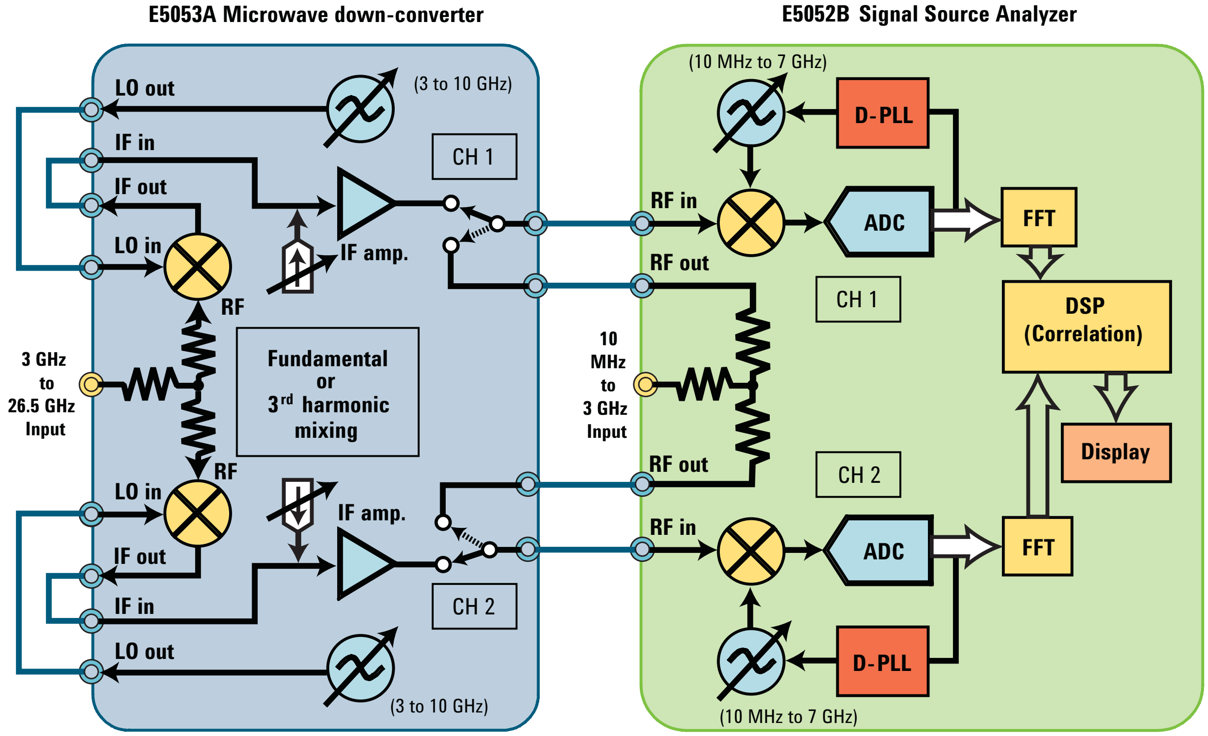


Figure 4.

The **wide capture range** takes a heterodyne (digital) discriminator method shown in Figures 5a and 5b, which is a modified version of an analog delay line discriminator method, to measure relatively large phase noise of unstable signal sources and oscillators. This method features wider phase-noise measurement ranges than the PLL method, and does not need re-connection of various analog delay lines at any frequencies. The total dynamic range of phase noise measurement is limited by that of the IF amplifiers and ADC's unlike the analog delay line discriminator method described above.

The heterodyne (digital) discriminator method also provides very easy and accurate AM noise measurements (by setting the delay time zero) with the same setup and RF port connection as phase noise measurement. An essential part of the AM detector is shown in Figure 5a.

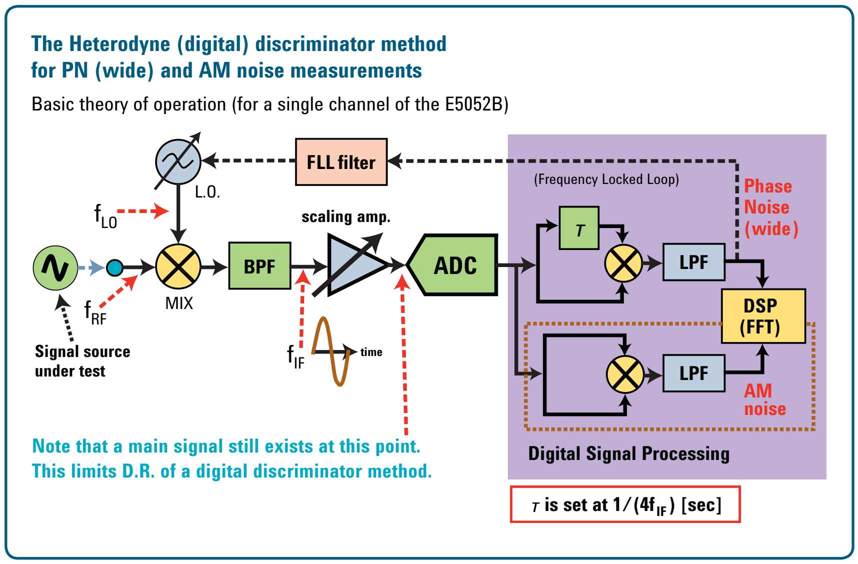


Figure 5a.

The Heterodyne (digital) discriminator method for PN (wide) and AM noise measurements

Basic theory of operation (for a single channel of the E5052B)

$$v_1(t) = \sqrt{2}\,(1+\tilde{a})\cos\{\omega_{IF}\,t + \tilde{p}(t)\},\ \ v_2(t) = \sqrt{2}\,(1+\tilde{a}(t-\tau))\cos[\omega_{IF}\,(t-\tau) + \tilde{p}(t-\tau)]$$

Where $\tilde{a}$ *and* $\tilde{p}$ *are random variables, and assuming* $|\tilde{a}|, |\tilde{p}| << 1$.

$$\begin{aligned} v_1(t)\cdot v_2(t) &= 2\cdot(1+\tilde{a})(1+\tilde{a}(t-\tau))\cdot\cos\{\omega_{IF}\,t+\tilde{p}(t)\}\cdot\cos[\omega_{IF}\,(t-\tau)+\tilde{p}(t-\tau)] \\ &= (1+\tilde{a})(1+\tilde{a}(t-\tau))[\cos\{2\omega_{IF}\,t - \omega_c\tau + \tilde{p}(t) + \tilde{p}(t-\tau)\} \\ &\qquad + \cos\{\omega_{IF}\tau + \tilde{p}(t) - \tilde{p}(t-\tau)\}] \\ &\to (1+\tilde{a})(1+\tilde{a}(t-\tau))\cdot\cos\{\omega_{IF}\tau + \tilde{p}(t) - \tilde{p}(t-\tau)\}\ \ \textit{after the LPF}. \\ &= (1+\tilde{a}+\tilde{a}(t-\tau)+\tilde{a}\cdot\tilde{a}(t-\tau))\cdot\sin\{\tilde{p}(t-\tau)-\tilde{p}(t)\}\ \ \textit{because}\ \omega_{IF}\tau = \pi/2 \\ &\approx (1+2\tilde{a})\cdot[\tilde{p}(t-\tau)-\tilde{p}(t)] \end{aligned}$$

$$\textit{Since}\ \ |\exp(-j\omega_m\tau)-1| = 2\cdot\left|\sin(\frac{\omega_m\tau}{2})\right|,\ (\textit{where}\ \omega_m = 2\pi\, f_m\ \textit{is the modulation frequency})$$

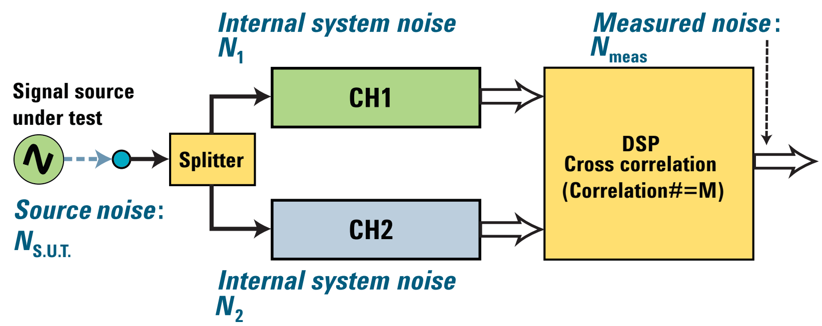
$$\textit{mesured PM noise}:\ \tilde{p}\cdot\sin(\frac{\omega_m\tau}{2})\cdot(1+2\tilde{a})$$

Discriminator Coefficient   **AM noise dependency**

Figure 5b.

The cross correlation technique for noise floor reduction is used widely in the E5052B. The basic theory of operation for cross-correlation calculation is traditionally well-known as shown in Figure 6. The E5052B implemented this principle by a highly sophisticated manner and enabled it's real time operation on display.

Two-channel Cross Correlation Technique



$$N_{meas} = N_{S.U.T.} + (N_1 + N_2)/\sqrt{M}$$ Assuming N_1 and N_2 are uncorrelated.

M (number of correlation)	10	100	1,000	10,000
Noise reduction on $(N_1 + N_2)$	–5dB	–10dB	–15dB	–20dB

Figure 6.

E5052B's flexible combination of these methods can extend phase noise measurement ranges. For very quiet signal sources, exceptionally stable local reference oscillators and the cross correlation technique in the normal capture range mode can satisfy any requirements of ultra-low phase noise or jitter measurement.

On the other hand, for noisy signal sources or drifty oscillators, the wide capture range mode provides reasonable measurement uncertainty and dynamic range in case the normal capture range mode does not work well.

E5052B's simplified functional block-diagram is shown in Figure 7.

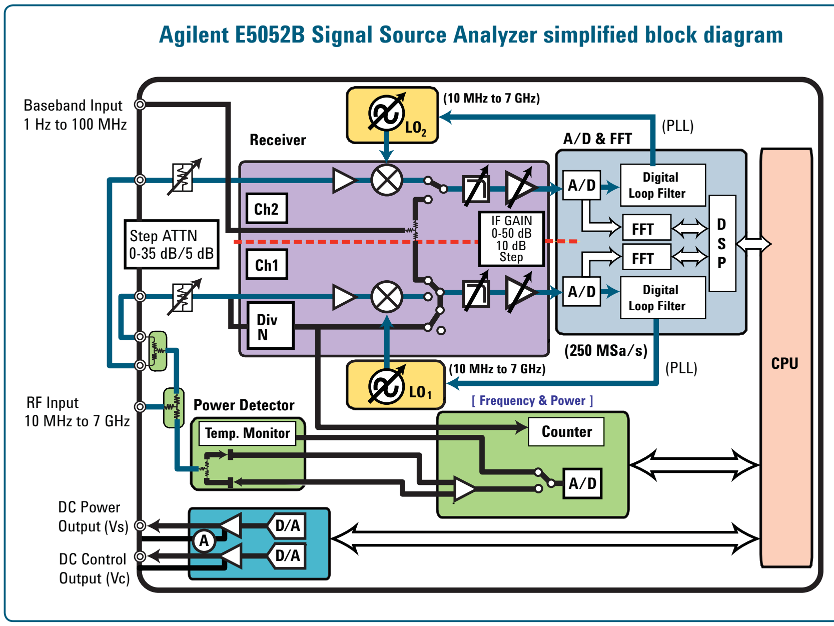


Figure 7.

1-3. Excellent phase noise measurement sensitivity

By using very clean built-in reference oscillators with the best performance time-base TCXO's, the E5052B achieves excellent SSB phase noise sensitivity or noise floor, as show in Figure 8.

The analyzer can accurately measure low phase noise at both close-in-carrier and far-out-carrier offset frequencies by just connecting the signal source under test and pushing a few buttons. Whereas the conventional test solutions require complicated procedures involving good reference sources or various delay lines.

E5052B SSB phase noise floor at 1 GHz (SPD)

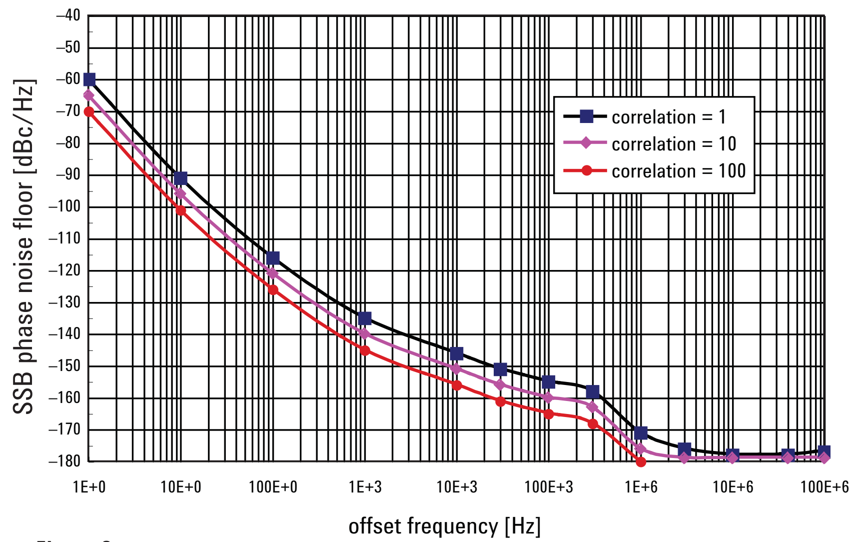


Figure 8.

Figure 9 shows a measurement example of phase noise and AM noise at a time in a single RF connection, without any reconnection of the RF signal.

PN and AM noise example of a quiet signal source

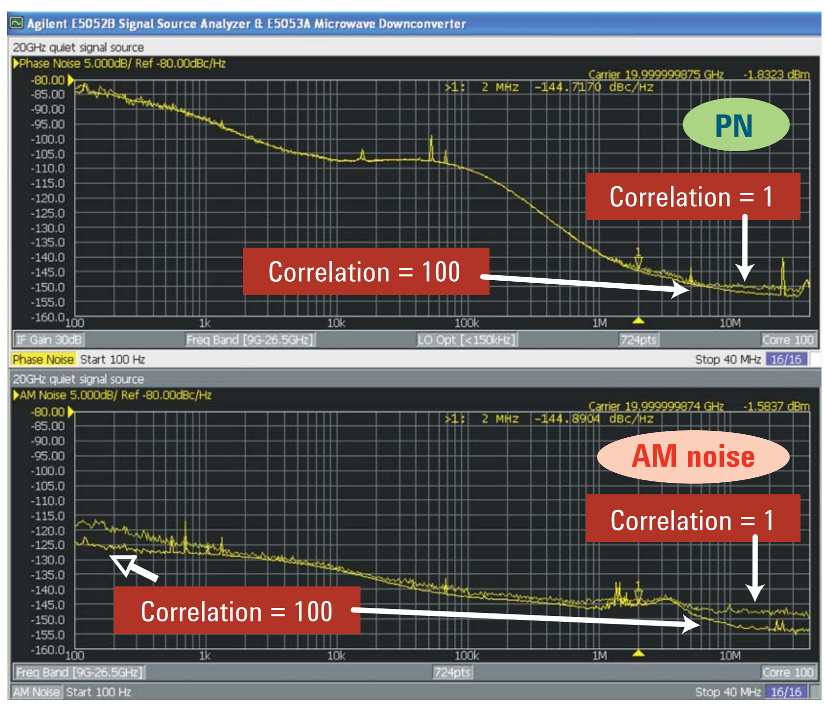


Figure 9.

Figure 10 shows a measurement example of a drifty signal source that can not be measured by the PLL method (normal capture range). The wide capture range mode could precisely measure large phase noise.

PN example of a drifty signal source (with 2 MHz deviation FM (2 kHz triangle waveform))

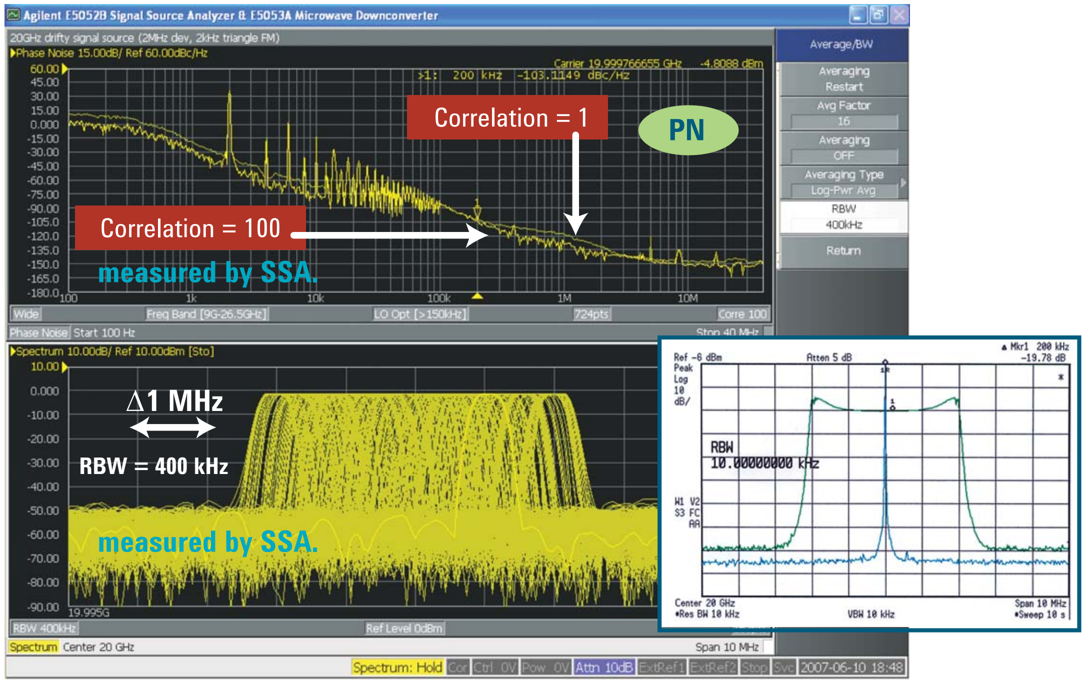


Figure 10.

Figure 11 suggests guidelines of phase noise level for proper measurements. (Note that this chart does not describe any specified or guaranteed limits. Allowable measurement conditions depend on phase noise shapes of the signal sources under test.)

Phase noise measurement range guide

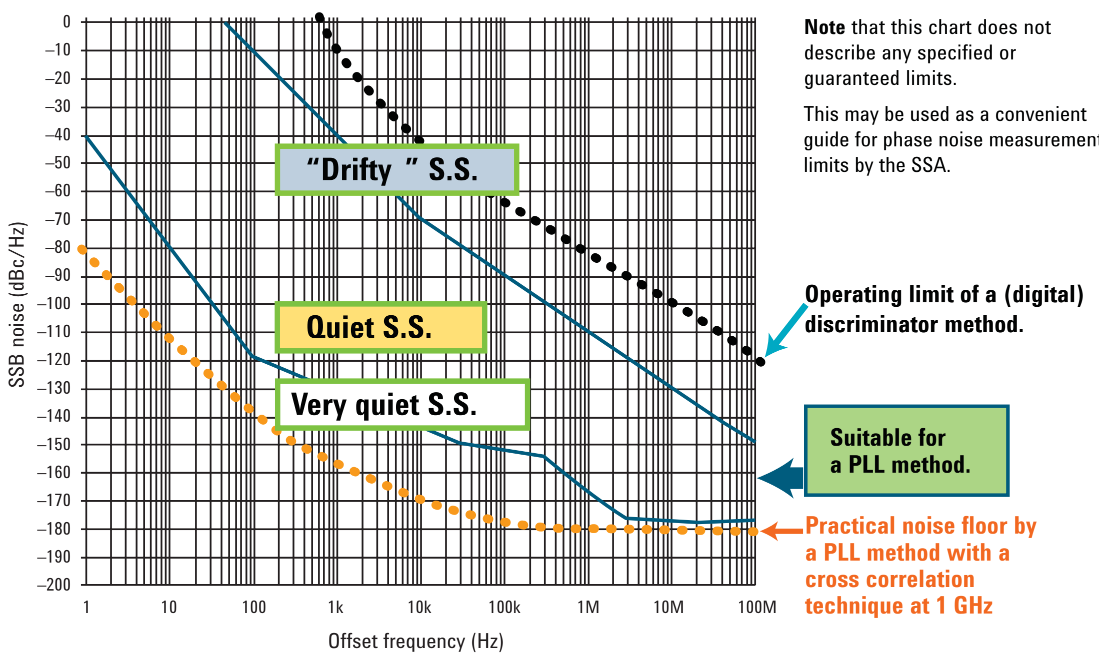


Figure 11.

1-4. Easy, one-step phase noise measurement

The signal source analyzer offers a true one-step phase noise measurement by eliminating time consuming procedures. With the SSA it is no longer required to perform tedious and complicated calibrations. The E5052B provides all necessary circuits and capabilities for phase noise measurements in one compact box, enabling users to automatically execute self-calibrations.

Besides traditional phase noise measurement capabilities, the E5052B has built-in frequency counter and power meter functions and utilizes them to perform internal self-calibrations including system PLL bandwidth correction. Compared to conventional solutions that usually require a lot of time to set up and calibrate the test system, SSA's self-calibration process is completed before making phase noise measurements within a negligible amount of time. Moreover, the analyzer provides better PLL tracking of source drift (with PLL bandwidth of 1 kHz or 5 kHz) than conventional PLL method solutions so that the built-in reference local oscillators (LO) are automatically controlled to maintain the same frequency of the carrier under test and keep the phase difference between RF and LO signals at 90 degrees exactly (for phase locking).

1-5. Comparison of phase noise measurement methods

Table 1 shows a comparison among conventional and newly developed methods in phase noise measurements. E5052B's innovative combination of appropriate measurement techniques offers the best performance and ease-of-use in practice. The signal source analyzer dramatically improves quality and efficiency in phase noise evaluation and characterization, as well as usability or friendliness for users. It can greatly diminish the frustration of phase noise measurements due to their complexity.

Comparison of PN measurement methods

PN measurement method	Advantages	Disadvantages
Spectrum Analyzer method (Direct Spectrum Analysis)	Easy operation Quick checking of phase-locked signals	Difficult to measure close-in-carrier PN of quiet signal sources such as crystal oscillators. Can not measure PN of drifty signal sources such as free-running VCO. Mixed results combined with AM noise and PN (Cannot separate AM noise from PN)
PLL method (Reference source / PLL technique)	Applicable to broad offset range. Can measure very low PN at close-in-carrier offset frequencies by using good L.O. Can separate PN from AM noise.	PN sensitivity is limited by L.O. noise Complicated set-up and calibration required.
Discriminator method (analog delay-line technique)	Can measure very low PN at far-out-carrier offset frequencies. Suitable for measuring relatively drifty signal sources such as YIG oscillators.	Not applicable to close-in-carrier PN because of gain degradation by a discriminator. Complicated set-up and calibration required. Difficult to get an appropriate delay-line at an arbitrary test frequency.
Signal Source Analyzer method (Dual channel PLL method with a cross-correlation technique)	Easy operation can eliminate complicated set-up and system calibration. Measures very low PN at broad offset ranges. Cross-correlation enhances PN sensitivity.	Longer measurement time for extremely low PN at close-in carrier offset frequencies.

Table 1.

2. Transient Measurement

E5052B's transient measurement capability satisfies almost all test requirements for current and future synthesized signal source evaluation in advanced high-speed communication systems.

2-1. Dual channel measurements for frequency/phase/power transient phenomenon

The signal source analyzer offers a major breakthrough in transient measurements for synthesized signal sources. It has two independent measurement channels and each channel takes a different method for measuring a signal's frequency simultaneously.

E5052B's **wideband mode (direct division mode) of transient measurement** contains a frequency divider at the very front end of the instrument and offers wider frequency hopping analysis range (maximum 4.8 GHz span) up to 7 GHz of carrier signal.

Another **narrowband mode (heterodyne mode)** shown in Figure 12, provides significantly fine resolution in frequency or phase transient measurement with reasonably wide frequency hopping range such as 80 MHz, 25.6 MHz, 1.6 MHz or smaller. Both wideband and narrowband modes operate completely in parallel, the E5052B enables observation of the entire picture of frequency changes and detailed transient response in frequency/phase/power at the same time.

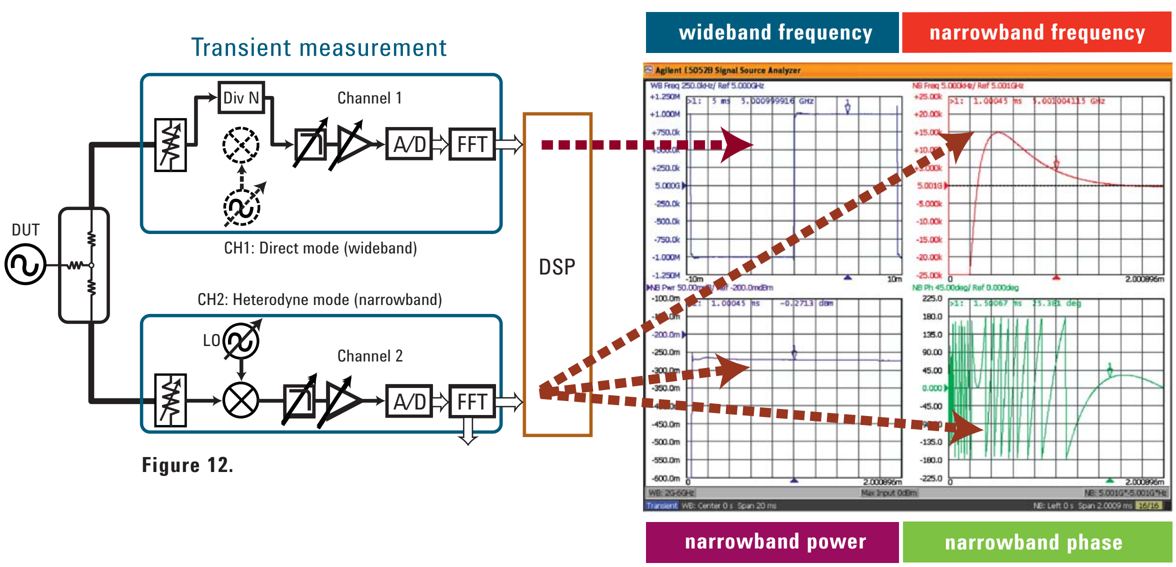


Figure 12.

2-2. Fast sampling and fine resolution in frequency/phase/power measurements

The E5052B takes 250 MHz sampling ADC (analog to digital converter) and the minimum time resolution is 8 ns in the narrowband mode while maintaining finer frequency resolution than any other instruments. It also covers long term observation up to 1,000 seconds (or 10,000 measurement points of the time resolution set).

Figure 13 shows a comparison of frequency resolution versus time resolution between the SSA and MDA (modulation domain analyzer), which has been commonly used for analyzing fast frequency transient in synthesized signal source design and evaluation. This comparison reveals that the SSA can provide far better performance, more than ten times in most cases, than an MDA.

Figure 14 shows actual transient measurement examples by the SSA and a MDA with the same time span. This figure illustrates SSA's superior and stable performance.

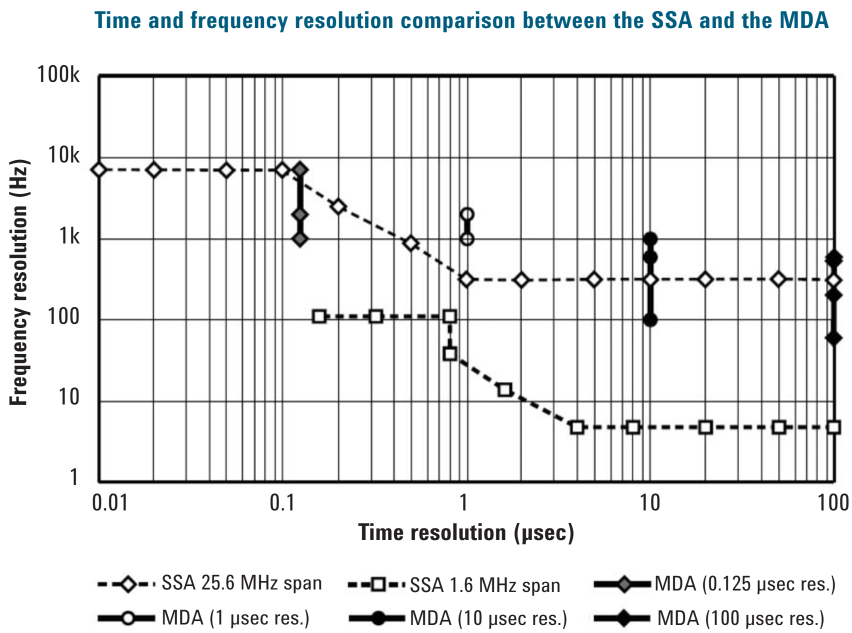
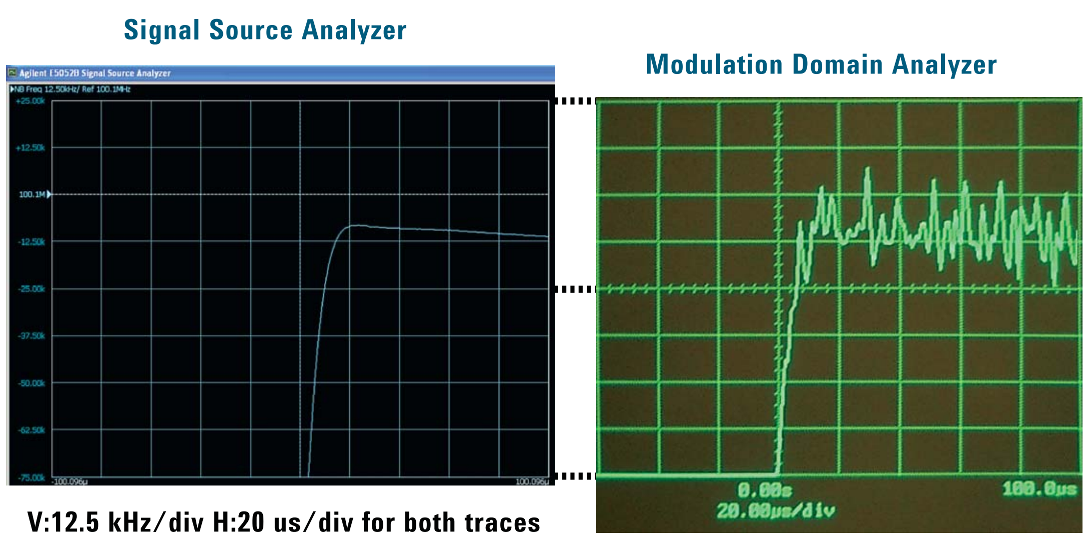


Figure 13.



V:12.5 kHz/div H:20 us/div for both traces

Figure 14.

Summary:

This document describes only two out of six major functions available on the E5052B illustrated in Figure 15.

The E5052B Signal Source Analyzer is designed to perform phase noise related measurements more accurately and efficiently, at a lower cost, with unprecedented simplicity. It provides almost all critical performance parameters to characterize any type of signal sources with incomparable measurement throughput by a factor of 10.

The SSA is, in fact, a single solution that replaces the need for large complex rack and stack test equipment.

Agilent E5052B: Six basic functions in one compact box.

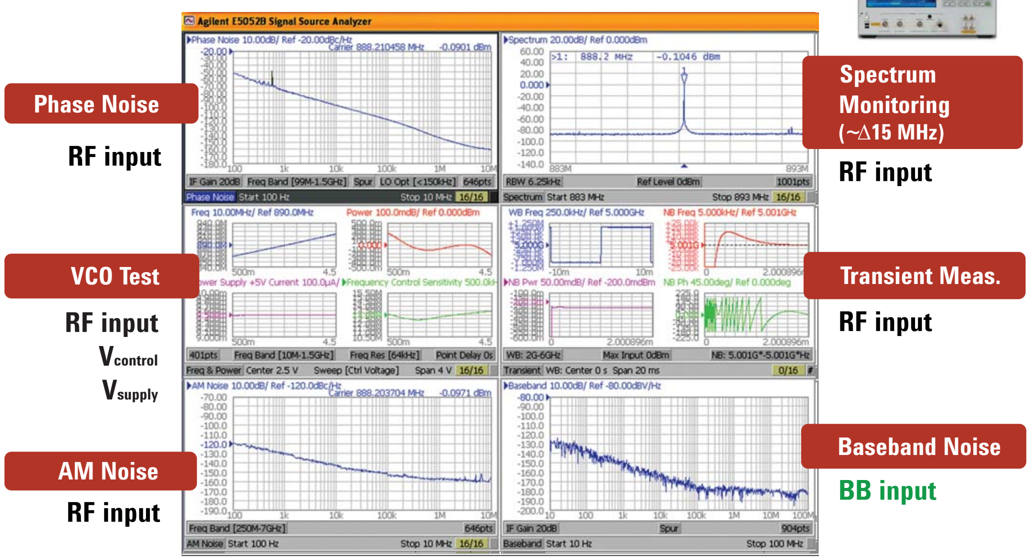


Figure 15.

Web Resources:

For the signal source analyzer and related options;
www.agilent.com/find/ssa

For jitter measurement applications;
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For test and measurement accessories in microwaves and mm waves;
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