

Choosing The Right Signal Source for Reliable Measurements

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The primary goal when measuring a device under test (DUT) is that its measured parameters are unaffected by ambient conditions and unwanted influences from the test setup. While environmental influences are easier to compensate or correct, more effort and know-how may be required with the test setup. This effort increases disproportionately with how precisely the DUT performance is to be determined.

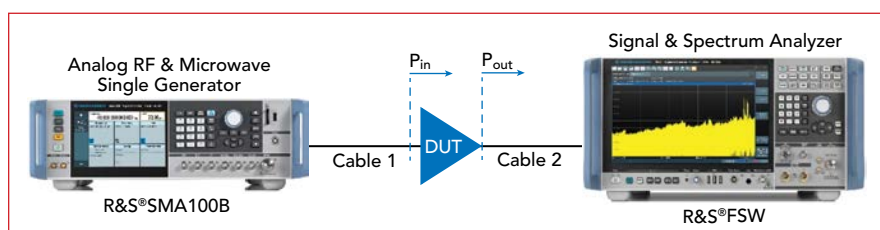
In principle, test and measurement (T&M) setups are often similar. A signal source provides the input signal to the DUT, and the output is measured with a spectrum analyzer, network analyzer or power sensor. For a quick test of the DUT performance, it may be sufficient to simply use this setup and record the measurement; however, more precise data requires more effort. Under certain circumstances, for example, losses or full S-parameters from the test fixture must be considered, as well as the performance of the T&M instrument itself (e.g., phase noise, power supply noise).

In this article we examine the role of the signal source, showing that unwanted influences from an “unsuitable” signal source never yield useful results. Using measurement examples, we show the actual performance of the DUT can only be determined with a “suitable” signal source, i.e., with performance that ensures accurate measurement results that are not falsified by the T&M instrument. As examples, we have selected several components and three typical measurements: harmonics, compression and single sideband (SSB) phase noise (PN). In each ex-

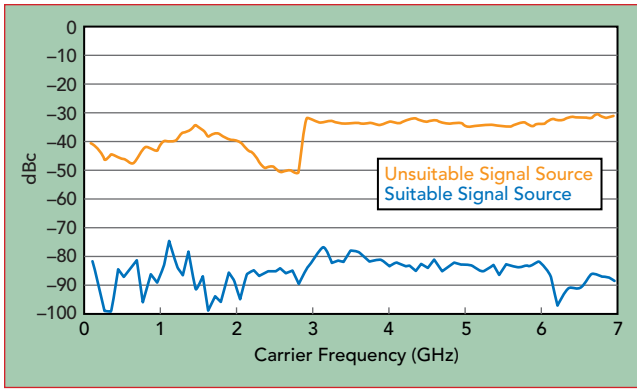
ample, the performance of the signal source is measured alone and its influence on the measurement result discussed. We refer to typical or measured performance to make it easier to understand how the actual performance of the DUT can be hidden by unwanted factors, such as insufficient harmonic suppression of the signal source.

HARMONIC MEASUREMENTS

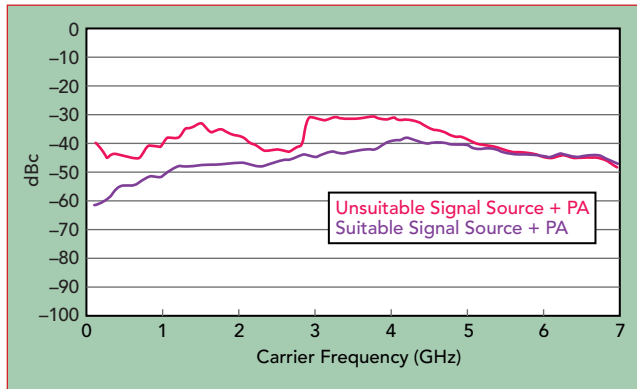
When a single CW tone is applied to a nonlinear component such as a power amplifier (PA), unwanted signals will be generated at n multiples of the original frequency, n being the order of the harmonic. To illustrate how the signal source will affect the harmonic performance of a PA, we used two signal sources: 1) an analog RF and microwave signal generator with high harmonic suppression, the suitable signal source. The R&S SMA100B was used for these measurements. 2) An “unsuitable”



▲ Fig. 1 Test setup for measuring the second harmonic.



▲ Fig. 2 Second harmonic of the suitable and the unsuitable signal sources.



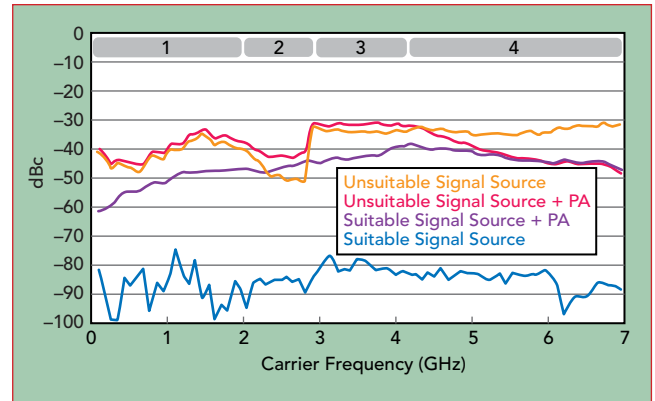
▲ Fig. 3 PA second harmonic measurements with the two signal sources.

source with harmonics greater than -30 dBc. The PA used for the measurements was a GaAs design covering 100 MHz to 7 GHz with 27 dBm saturated output power (P_{sat}) and 7 to 8 dB gain.

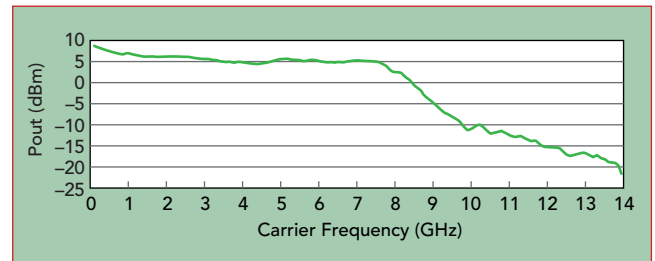
Figure 1 shows the test setup for the harmonic measurements, using an R&S FSW signal and spectrum analyzer to measure the second harmonic. The suitable and unsuitable signal sources were used to drive the PA, sweeping from 100 MHz to 7 GHz while keeping the output power (P_{out}) of the PA constant at approximately 7 dBm. The input power (P_{in}) was leveled to compensate for the cables and the frequency response of the PA.

The measured second harmonic performance of the two signal sources is plotted in Figure 2, showing a significant difference in harmonic suppression between the suitable and unsuitable sources. Inserting the PA and measuring the harmonic performance with each reveals how the harmonics from the unsuitable signal source make the apparent performance of the PA worse (see Figure 3). The effects of the harmonic performance of the signal sources is clearer by comparing the measurements of the individual sources with the combination in a single plot (see Figure 4), where the sweep is divided into four frequency ranges. Because the harmonic performance of the combination is the vector sum of the harmonics from the signal source and the PA, depending on the relative phase of the two signals, the combined performance is not simply the addition of the magnitudes of the two.

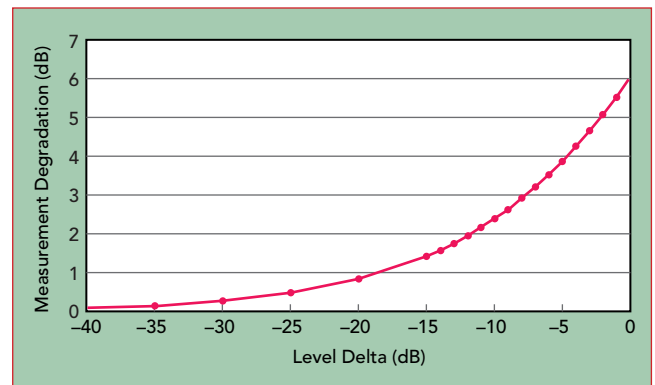
In ranges 1 and 3, the measurement reflects the



▲ Fig. 4 Comparing second harmonic measurements of the two signal sources and PAs driven by the respective sources.



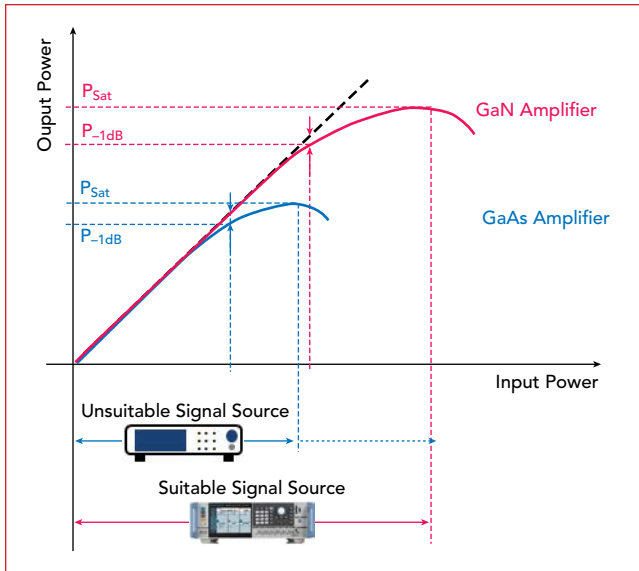
▲ Fig. 5 Measured PA frequency response.



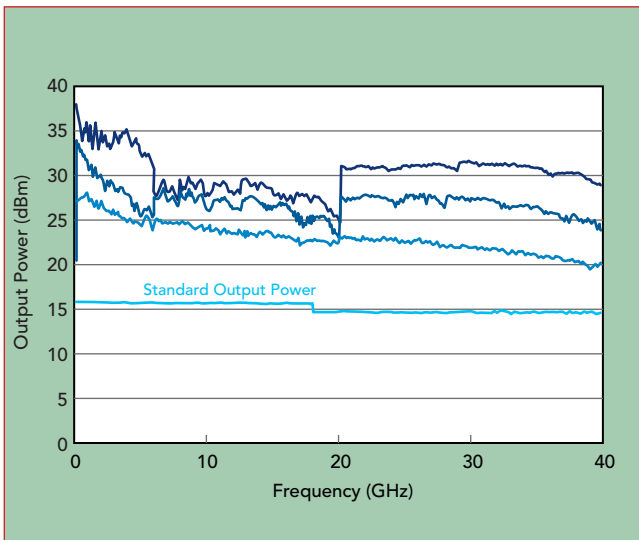
▲ Fig. 6 Measurement degradation caused by the second harmonic of the signal source.

performance of the unsuitable signal source rather than the PA's harmonics. In range 2, the measurement is closer to the PA's actual performance because the performance of the unsuitable signal source is slightly better than the PA's, so the contribution from the source is less. The interpretation of the measurement in range 4 is trickier. Why is the performance of the unsuitable signal source with the PA better than the source's, when the opposite is expected? The PA's frequency response provides the answer (see Figure 5). Above 8 GHz the gain drops; consequently, as the carrier frequency increases above 4 GHz, the second harmonic of the source is increasingly attenuated by the PA, and the measurement of the second harmonic from the combination gets closer to the PA's actual performance.

The conclusion of the test: to avoid harmonic contributions from the signal source, a source with low harmonics should be used to prevent the source from

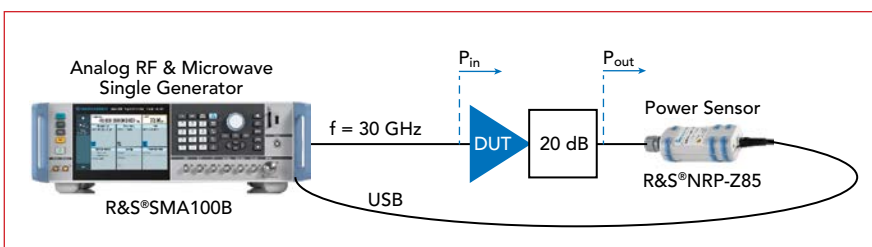


▲ Fig. 7 Input power range required for GaAs and GaN PAs.

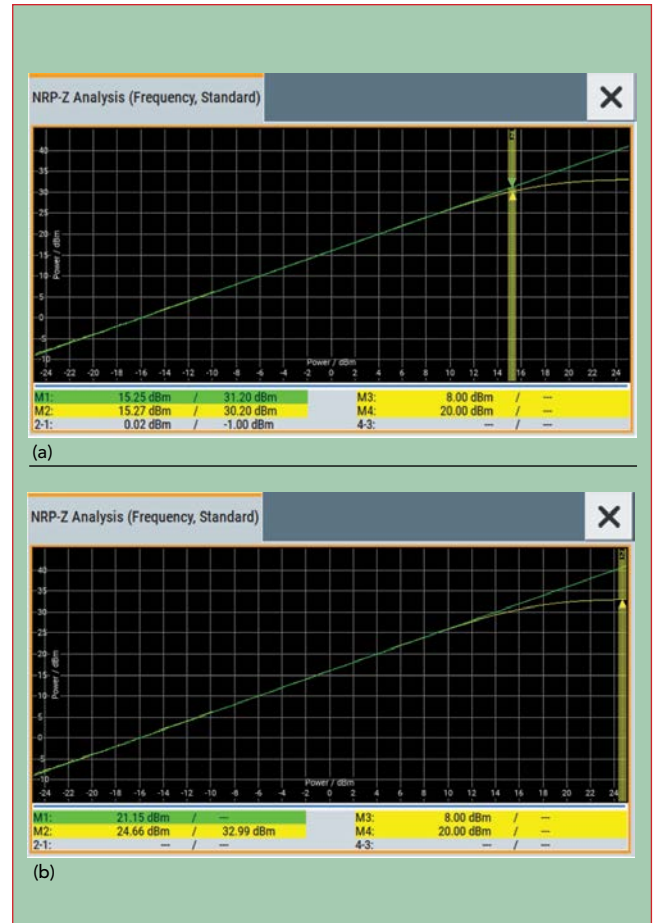


▲ Fig. 8 Output power options of the R&S SMA100B signal generator.

“distorting” the PA measurement. **Figure 6** quantifies how much better the signal source should be to obtain reliable measurements, assuming the worst case where the second harmonics of the signal source and the PA are in phase. For instance, if the second harmonic from the source is 30 dB below the PA’s actual performance, the second harmonic measurement of the PA will be degraded by approximately 0.3 dB, worst case.



▲ Fig. 9 Test setup for measuring 1 dB compression (P_{1dB}) and saturated (P_{sat}) power.



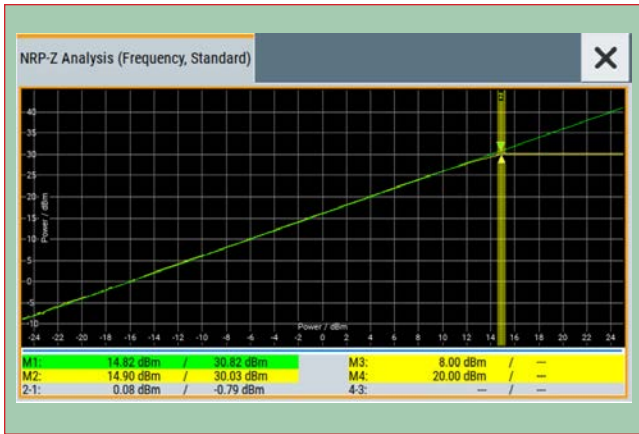
▲ Fig. 10 P_{1dB} (a) and P_{sat} (b) measurements using the suitable signal source.

COMPRESSION MEASUREMENTS

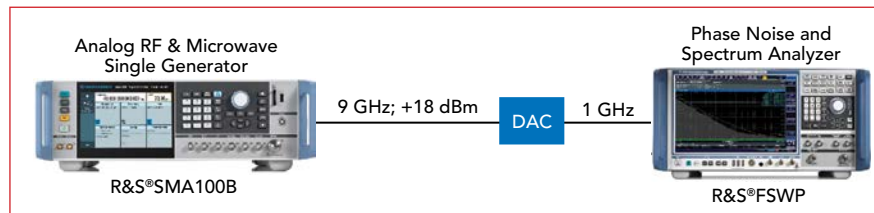
The 1 dB compression point (P_{1dB}) at the output of a PA defines the boundary between linear and nonlinear behavior. This is the input power where the small-signal gain of the PA is reduced by 1 dB. As the input power increases, the PA becomes increasingly nonlinear and produces significant harmonic distortion and intermodulation products.

GaN PAs have higher saturated output power capability than GaAs PAs. Assuming the same gain, the GaN PA will require higher input power to reach P_{1dB} and the maximum or saturated output power, designated P_{sat} (see **Figure 7**). For measuring the P_{1dB} and P_{sat} of a PA, the signal source must have suitable output power. Addressing this need, Rohde & Schwarz designed the R&S SMA100B to have four output power options (see **Figure 8**). From 20 GHz to approximately 38 GHz, the R&S SMA100B provides more than 30 dBm—compared to the 16 dBm available from traditional signal sources. Higher output power from the signal source may eliminate the need for an external amplifier at the output of the source to drive the PA into compression.

To illustrate this, **Figure 9** shows a typical test setup for measuring P_{1dB}



▲ Fig. 11 P_{1dB} measurement using the unsuitable signal source.



▲ Fig. 12 Test setup for measuring the SSB PN.

and P_{sat} . The power sensor measures the PA output power and feeds back the measurement result to the signal generator via USB, where it can be graphically displayed on the signal generator's display. The 20 dB attenuator after the PA ensures the power sensor is not overdriven. The DUT is a GaN PA covering 27 to 41 GHz with $P_{sat} = 33$ dBm and 16 dB gain. The input power (P_{in}) is swept from -25 to +25 dBm at a carrier frequency of 30 GHz. **Figure 10** shows the P_{in} versus P_{out} measurements of the PA using a suitable signal source, the yellow trace reflecting the output power and the green trace the linear gain. The y axis accounts for the 20 dB attenuator following the PA. **Figure 10a** shows a P_{1dB} measurement of 30.2 dBm, and **Figure 10b** shows a P_{sat} of 33.0 dBm. To measure the P_{sat} of the GaN PA requires $P_{in} = \sim 25$ dBm at 30 GHz, which is more power than the capability of many signal sources (see **Figure 11**). Using a signal source with lower output power, P_{1dB} and P_{sat} cannot be measured directly without an additional amplifier. **Figure 11** shows 30.0 dBm maximum output power from the PA, which reflects the shortfall of the signal

source rather than the performance of the PA.

These measurements show that using a signal source with sufficient output power simplifies the test setup, enabling higher power P_{1dB} and P_{sat} measurements without requiring an external amplifier that could introduce measurement errors.

SSB PN MEASUREMENTS

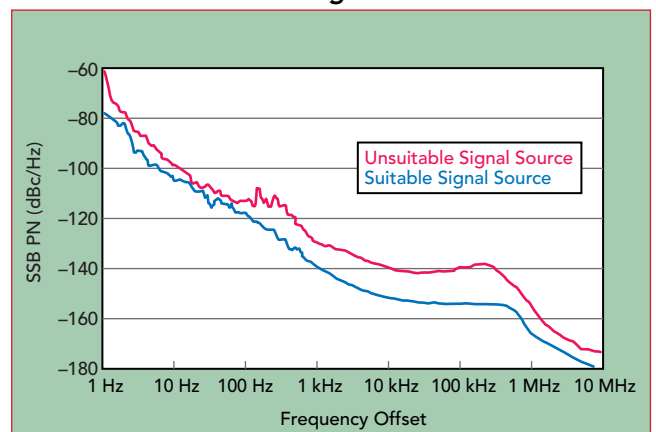
Analog and digital circuits rely on pure clock signals. Typical clock signal performance indicators are PN, jitter, wideband noise and spurs. Similarly, a low PN signal source is needed for measuring DUT performance. The residual PN of the DUT determines the PN added by the DUT to the PN of its input signal. Phase-locked loops in high speed digital applications require an input signal with excellent PN performance, i.e., negligible compared to the residual PN of the DUT.

How can designers ensure the signal source meets the requirements for SSB PN? First, the requirements for the DUT should be defined. Next, the data sheet of the signal source should be reviewed to determine whether the SSB PN performance meets the requirements

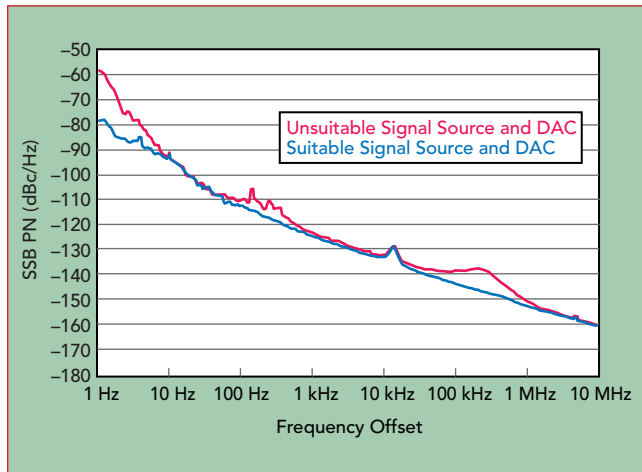
with enough margin to minimize the contribution from the signal source. We illustrate this with measurements showing how suitable and unsuitable signal sources affect SSB PN measurements. The R&S SMA100B is used as the suitable source, with the option for a maximum SSB PN of -128 dBc/Hz at 10 kHz offset from a 10 GHz carrier and typically providing -132 dBc/Hz. The unsuitable signal source has a specified SSB PN performance of -115 dBc/Hz at 10 kHz offset from a 10 GHz carrier. Although usable for many applications, this signal source may no longer be sufficient to for testing current generation analog-to-digital (ADC) and digital-to-analog (DAC) converters.

In this example, the DUT was a test board with a DAC. The best way to measure the residual SSB PN of the DAC is to generate a sinusoidal signal at its output, where the digital input is $I = Q = 1$. The DAC used here has a digital signal processing unit with a digital up-converter, enabling the digital input data to be resampled and shifted in frequency. The numerically-controlled oscillator of the DAC was set to $f_{out} = f_{sample}/9$, with $f_{sample} = 9$ GHz, so the DAC output signal was a 1 GHz sine wave.

As with the previous measurements, the setup comprised the two signal sources and the DUT; an R&S FSWP was used to measure the SSB PN (see **Figure 12**). The SSB PN was measured with the suitable signal source, with and without the DAC, and the unsuitable signal source, with and without the DAC. **Figure 13** shows the SSB PN



▲ Fig. 13 Comparing the SSB PN measurements using the two signal sources.



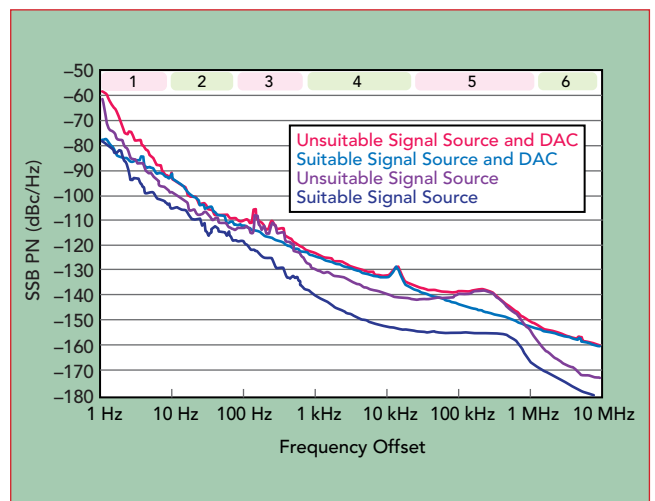
▲ Fig. 14 Comparing the SSB PN performance of the DAC using the two signal sources.

measurements of both signal sources at 9 GHz with +18 dBm output power and “downscaled” to 1 GHz by subtracting $20\log(9 \text{ GHz}/1 \text{ GHz})$ in dB. Downscaling is necessary to compare the SSB PN performance of the signal sources and the DAC.

Comparing the SSB PN performance of the DAC with the two signal sources, the difference in specific frequency ranges was high (see **Figure 14**), with the lower curve the SSB PN performance of the DAC measured with the lower PN source. The SSB PN measurement using the unsuitable signal source adds significant contributions to the DAC’s residual SSB PN. To show where the poorer signal source influences the SSB PN measurement, the offset frequency range was split into six bands (see **Figure 15**). In ranges 2, 4 and 6, the measured DAC SSB PN performance was nearly same with both signal sources, as the SSB PN of the unsuitable signal source was better than that of the DAC. In frequency ranges 1, 3 and 5, the SSB PN of the unsuitable signal source was worse than the DAC’s performance, so the SSB PN measurement reflects the performance of the unsuitable signal source, not the DAC.

These measurements show the importance of using a low PN signal source. To ensure accurate measurements, follow this process:

1. Measure the SSB PN performance of the signal source using the same frequency and power level as will be used for the DAC measurement. In this example, the DAC output frequency was 1 GHz, so the DAC clock input signal of 9 GHz was divided by 9 in the DAC.
2. Calculate the SSB PN performance of the signal source at 1 GHz to compare it with the DAC output frequency of 1 GHz: $\text{SSB PN}(1 \text{ GHz}) = \text{SSB PN}(9 \text{ GHz}) - 20\log(9 \text{ GHz}/1 \text{ GHz})$ in dB.
3. Ensure sufficient margin between the DAC measurement and the calculated SSB PN of the signal source.



▲ Fig. 15 1 GHz SSB PN comparisons.

| TABLE 1 | |
|---|------------------|
| SSB PN MEASUREMENT DEGRADATION | |
| Δ SSB PN: Signal Source vs. DAC (dB) | Degradation (dB) |
| +10 | 10.4 |
| +6 | 7.0 |
| +3 | 4.8 |
| 0 | 3.0 |
| -3 | 1.8 |
| -6 | 1.0 |
| -10 | 0.4 |

Table 1 shows how the SSB PN of the signal source will degrade the measurement of the DAC’s performance. The table shows if the SSB PN of the signal source is 10 dB better at a certain offset frequency than the DAC’s performance, the measurement will be degraded by 0.4 dB.

The instrument used to measure the SSB PN is another potential source of measurement error. Although not assessed in this article, a phase noise analyzer with low SSB PN should be used for these measurements to minimize any degradation.

SUMMARY

This article has examined how the harmonics, output power and SSB PN performance of the signal source can degrade measurement accuracy, often without the user realizing the unwanted effects. In each example, the performance of two signal sources was measured, showing the effect on a PA or DAC measurement. Guidelines for harmonics and SSN PN were provided to quantify the impact of the signal source, enabling users to determine the appropriate signal source requirements to achieve the desired accuracy for the application. ■