

Make Your Measurements More Accurate When Using RF Signal Generators

You can improve the accuracy and consistency of your test measurements by properly adjusting your signal source.

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Signal sources provide precise, highly stable test signals for a variety of components and system test applications. Signal generators add precision modulation capabilities, and are used to simulate system signals for receiver performance testing. They must simulate not only ideal transmissions, but also faulty transmissions, noise, and out-of-channel interference signals.

There are many parameters, settings, and other factors involved in using these tools to their best advantage. Knowing how to optimally adjust an RF analog signal source will enable you to improve the accuracy and consistency of your measurements. This article describes

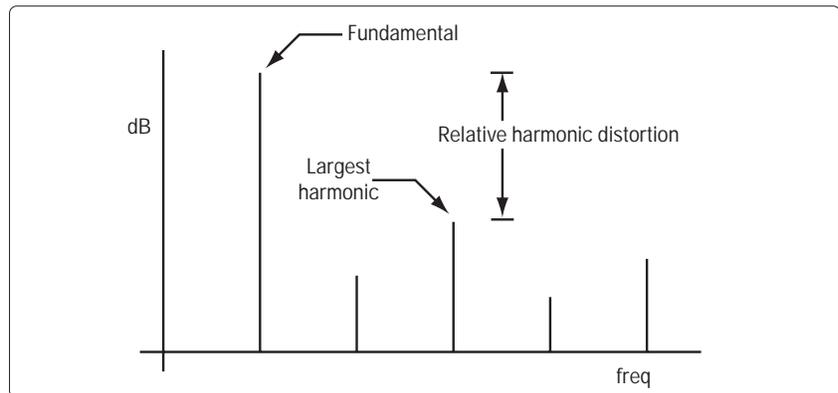


Figure 1. A typical harmonic-distortion measurement

several methods and techniques you can use to make better RF signal generator measurements.

Decrease Harmonic Distortion

Accurate harmonic-distortion measurements require a spectrally pure signal source and a spectrum analyzer. The harmonic distortion of the

signal source and the dynamic range of the spectrum analyzer limit the quality of a measurement. However, the signal source is often the limiting factor, with harmonic-distortion performance on the order of 30 dB below the fundamental. Figure 1 shows a typical harmonic-distortion measurement. The



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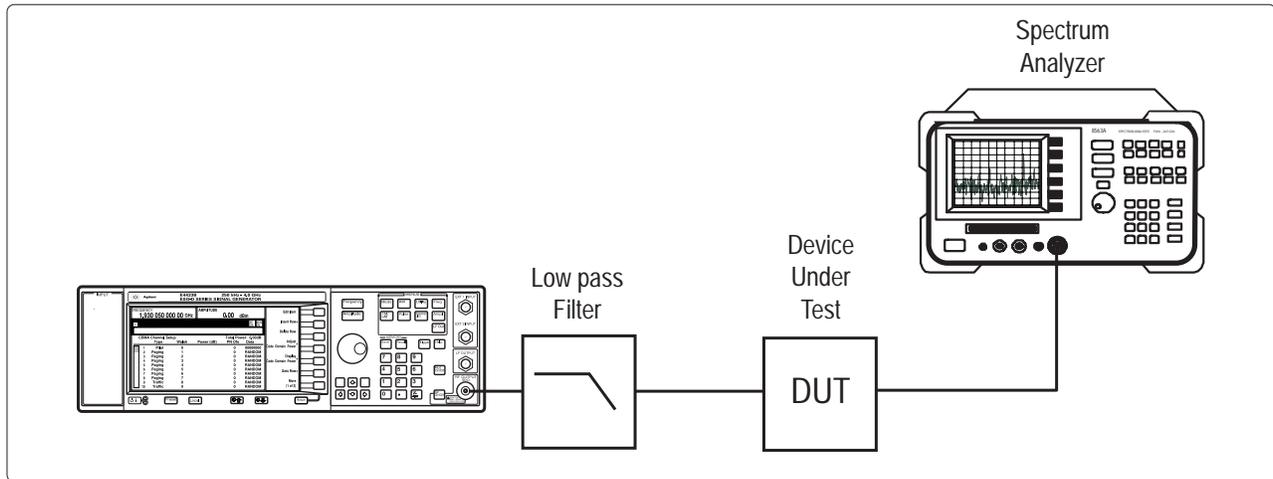


Figure 2. The harmonic distortion of a signal source can be improved by installing a low-pass filter at the source's output.

harmonic distortion of a signal is often specified by stating the amplitude of the largest harmonic in dB relative to the fundamental.

You can use a low-pass filter to improve the source's effective harmonic distortion, as shown in figure 2. The cutoff frequency of the low-pass filter should allow the fundamental frequency to be passed largely intact, while the harmonics are attenuated significantly. You can verify the performance of the source/filter combination directly with the spectrum analyzer.

If the loss through the filter at the fundamental frequency is significant, the loss should be accounted for when setting the source output level. Use the spectrum analyzer to check the fundamental level at the output of the filter.

You can calculate the percent distortion for a particular harmonic (mth harmonic) as:

$$\%d_m = 100 \times 10^{\frac{(\Delta dB)}{20}}$$

To calculate total harmonic distortion, calculate the distortion for each harmonic as above and find the root sum of the squares:

$$\%THD = \sqrt{\sum(\%d_m)^2}$$

Increase Power-Level Accuracy

In your test setup, you are likely to use passive devices such as cables, filters, or switches between the source and the device under test (DUT). The accuracy of the signal level at the DUT is affected by these components. In some applications such as receiver sensitivity measurements, the accuracy of the input signal level is critical. To have the desired power applied to the DUT, perform the following test prior to making your measurements. The setup

consists of the signal generator, a power meter with a power sensor, and any cables or switches that are necessary for the measurement (figure 3).

You need to calibrate the power meter to the power sensor for an accurate power measurement. The accuracy of the power-meter measurement depends on the calibration factors of the sensor, so these must be entered into the power meter prior to calibration.

Once you have completed calibration of the power meter, set its measuring frequency to the signal frequency. Connect the sensor in place of the DUT as

indicated in figure 3 and measure the power level. If there is a difference between the power meter's reading and the indicated level on the source, use the source's amplitude-offset feature to make the necessary adjustments. Match the displayed power level of your source to the power meter's reading. Once you adjust the amplitude at a particular frequency, the source will automatically display the correct value for different amplitudes at that same frequency. Because the accuracy of the power meter is very high (uncertainty in the range of tenths of a dB), you can have confidence that the power level is accurate.

Improve Frequency Accuracy

For certain measurements, the absolute frequency of the stimulus signal is most important, but other measurements require accurate relative-frequency spacing between multiple signals. For instance, to create multitone inputs with known frequencies, more than one signal generator is often used. The frequency accuracy of each source relies on its internal frequency standard. It is possible for these standards to be slightly off in frequency, thereby causing relative-frequency errors in the measurement.

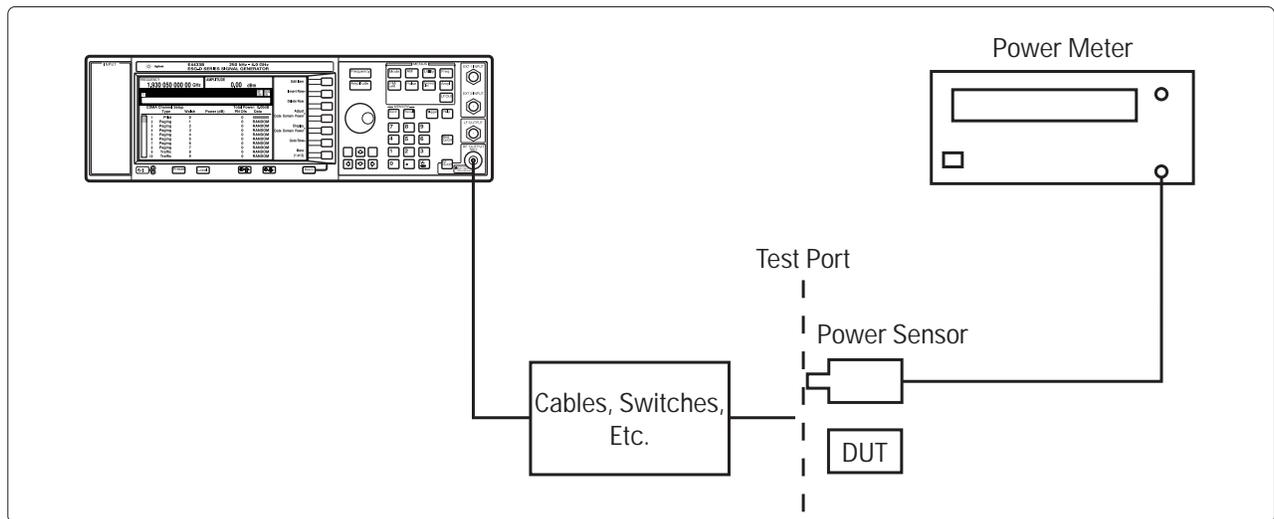


Figure 3. Setup for improving the level accuracy of the signal

For example, assume you are trying to set a 1-kHz separation between two signals centered at 200 MHz, and your sources have an aging rate of $\pm 1 \times 10^{-6}$ /year. Your sources' frequency error in this case is $200 \text{ MHz} \times 1 \times 10^{-6}$, or $\pm 200 \text{ Hz}$. The separation could be anywhere from 600 Hz to 1400 Hz (figure 4). To increase the relative-frequency accuracy, you can connect the time bases of the two sources together. Take the reference-signal output of one source, usually located on the back panel of the box, and connect it to the reference-signal input of the other source. Now the uncertainty of the separation is $1 \text{ kHz} \times 10^{-6}$ or 0.001 Hz.

When the absolute frequency of the signal is important, increase the frequency accuracy of your source by finding the most accurate external frequency reference available. Choose the instrument in your setup with the most accurate time base and connect all the other equipment to this reference. Some instrument manufacturers offer high-stability ovenized reference oscillators as an option. These frequency and time standards are extremely accurate, but can be expensive.

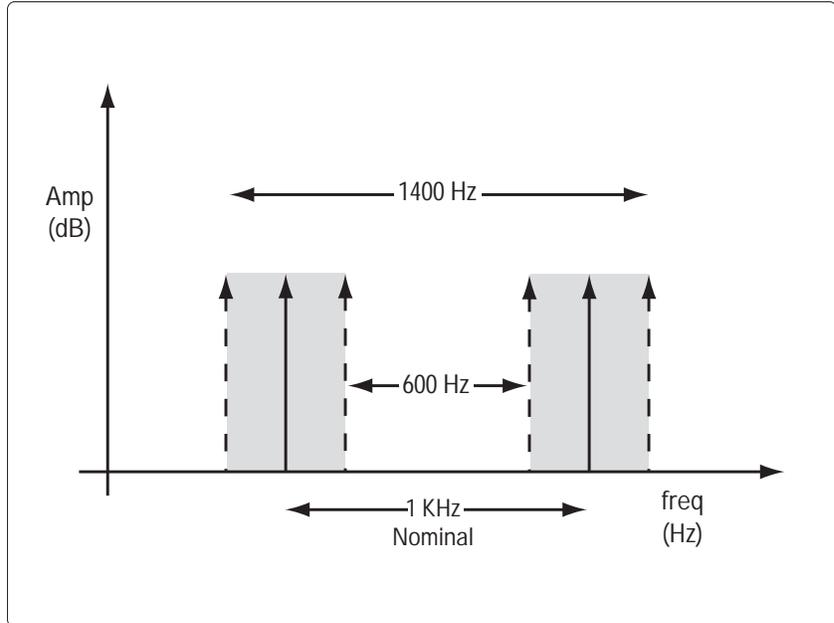


Figure 4. The shaded area shows the range of the relative-frequency error.

You can also improve frequency accuracy by using a house standard (a high-accuracy frequency reference distributed throughout your facility). If one is available, connect your signal generators and all your other equipment to this reference. A distribution amplifier may be needed to maintain proper levels and impedance matching.

Improve Source Impedance Match

Source match is important because mismatch between the source and the load impedance changes the effective signal input level to the DUT. When a load is not well matched, there is a reflection from the load, which travels back toward the source. Instead of being completely absorbed at the source, some of it is re-reflected back toward the load. This re-reflected wave adds constructively or destructively at the load, depending on the phase of the signal.

Complicating the picture, the DUT is seldom connected directly to the source. You may be using adapters to accommodate the connector type of the test device, filters to eliminate source harmonics, and so forth. These cables and components degrade the source match as seen by the DUT.

This mismatch may be reduced in several ways. The simplest

way is to insert a fixed attenuator with good match at the input of the DUT. This improves the effective source match by twice the value of the attenuator in dB (figure 5). From a measurement point of view, concentrate on the maximum and minimum power transfer, which represents the maximum and minimum error that can be incurred due to impedance matching problems.

Combine Source Outputs for TOI Measurements

When combining two sources to make a third-order-intercept (TOI) measurement, it is important that your sources are terminated properly (50-Ω termination) and well isolated from each other. If they are not isolated, the sources can intermodulate with one another, producing intermodulation products at the input of the DUT. This condition can mask the device's true intermodulation performance.

When using resistive combiners, be sure to use the three-resistor, not the two-resistor, type (figure 6). Two-resistor combiners/splitters are used for leveling applications where one side of the splitter connects to a power meter for accurate level control. For TOI applications, two-resistor combiners don't provide a 50-Ω match on all ports. In addition to providing proper termination at all three ports, three-resistor combiners provide 6 dB of isolation between the two sources.

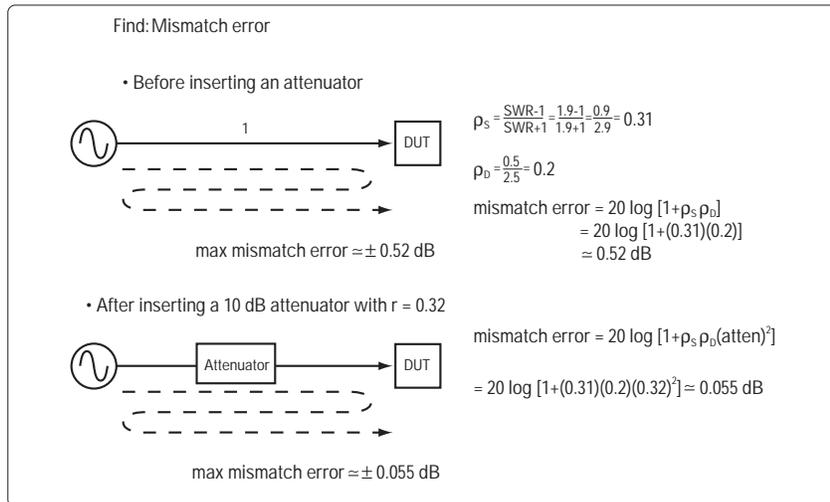


Figure 5. Inserting a fixed attenuator improves the effective source match by twice the value of the attenuator in dB.

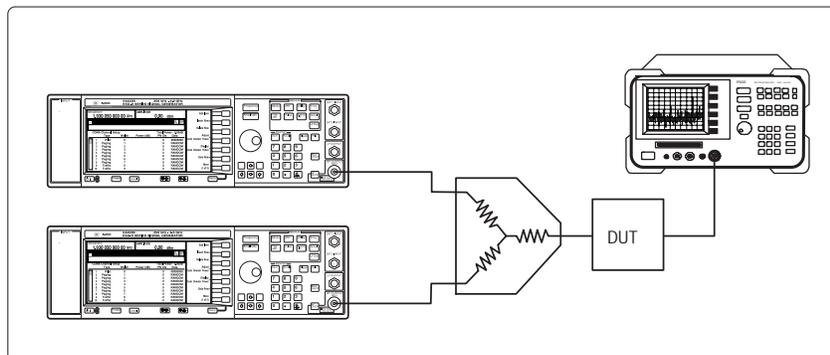


Figure 6. A three-resistor combiner is used to isolate the outputs of two sources.

The best way to combine two sources is to use a directional splitter or directional coupler. They provide good port matches and extra isolation.

Regardless of what type of combiner is used, you can improve isolation between the sources by adding attenuators at the output of each source (before the signals are combined). You need to increase the source power to compensate for the extra attenuation. Adding a 10-dB attenuator to the output of each source increases the isolation by 20 dB.

Another way to increase isolation is to place an amplifier after each source. The reverse isolation of the amplifiers typically provides plenty of isolation between the two sources.

For some sources, turning off the output automatic level control (ALC) will decrease intermodulation products. This prevents conflict in power-level control between the two sources. This is less of a problem for wide frequency offsets (100 kHz and higher) since most ALC bandwidths are fairly low when AM is turned off.

Improve FM Deviation Accuracy

You can use the carrier-null method to set a signal generator's frequency deviation precisely. With frequency modulation, the spectral components (including the carrier component) change their amplitudes when the modulation index is varied. Bessel function curves (figure 7) show the relation between the carrier and sideband amplitudes of the modulated wave as a function of the modulation index, β . The carrier component J_0 and the various sidebands J_N go to zero amplitude at specific values of β . The formula for the modulation index is:

$$\beta = \frac{\text{peak frequency deviation}}{\text{modulation frequency}}$$

You can adjust your signal generator to a precise frequency deviation with a spectrum analyzer and a frequency counter. Use one of the carrier zeros to

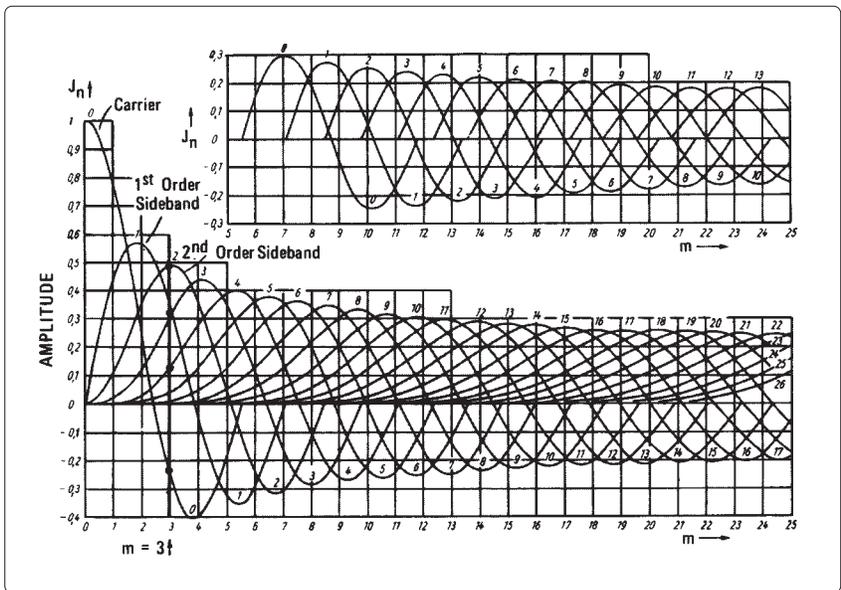


Figure 7. Bessel function curves show the relation between the carrier and sideband amplitudes of a modulated wave as a function of the modulation index β .

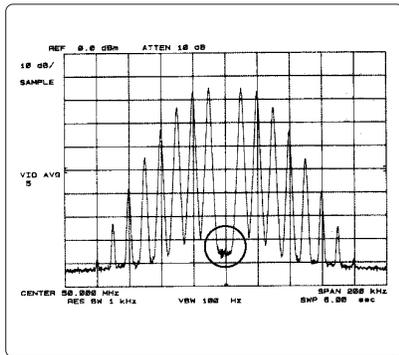


Figure 8. The spectrum of an FM signal at 50 MHz with the deviation adjusted to the first carrier null

select the appropriate modulation frequency. For example, in figure 8 the deviation is adjusted for the first carrier null. The modulation frequency is 10 kHz and β is 2.4 (the first carrier null). The modulation-index formula gives a carrier peak frequency deviation of 24 kHz. Table 1 provides the modulation frequency for common values of deviation for the various orders of carrier nulls. The procedure for setting up a known deviation is:

1) Select the column with the required deviation (for example, 250 kHz).

2) From the table, select the carrier null that corresponds with the modulation bandwidth normally used. For example, if a deviation frequency of 250 kHz is chosen to test an audio modulation circuit, it is necessary to go to the fifth carrier null to get a modulation frequency within the audio passband of the generator (16.74 kHz for this example).

Order of Carrier Zero	Modulation Index	Commonly Used Values of FM Peak Deviation									
		7.5 kHz	10 kHz	15 kHz	25 kHz	30 kHz	50 kHz	100 kHz	150 kHz	250 kHz	300 kHz
1	2.40	3.12	4.16	6.25	10.42	12.50	20.83	41.67	62.501	04.17	125.00
2	5.52	1.36	1.18	2.72	4.53	5.43	9.06	18.12	27.17	45.29	54.35
3	8.65	.87	1.16	1.73	2.89	3.47	5.78	11.56	17.34	28.90	34.68
4	11.79	.66	.85	1.27	2.12	2.54	4.24	8.48	12.72	21.20	25.45
5	14.93	.50	.67	1.00	1.67	2.01	3.35	6.70	10.05	16.74	20.09
6	18.07	.42	.55	.83	1.88	1.66	2.77	5.53	8.30	13.84	16.60

Table 1.

3) Use the frequency counter to set the modulation frequency to 16.74 kHz, and monitor the output spectrum of the generator on a spectrum analyzer. Increase the deviation of the carrier until the carrier amplitude has gone through four zeros and stop when the carrier is at its fifth minimum. This setup provides a unique 250-kHz deviation for a modulation frequency of 16.74 kHz and the spectrum at its fifth zero.

As the modulation frequency can be set accurately using the frequency counter, and the modulation index is also known accurately, the frequency deviation generated will be equally accurate.

Extend the Amplitude Range

An important specification of any signal generator is the output power range. If you need to go beyond this specified range, you can use an amplifier to increase the output power or an attenuator to decrease it. When you extend the output amplitude range of the source by using one of these devices, there are some important factors to be aware of.

The amplifier gain uncertainty affects the output signal level directly. If you need to drive the device too close to the 1-dB compression point, use a low-pass filter at the output to reduce the added harmonic distortion, as described earlier.

There are also uncertainties to consider when using an attenuator, such as attenuator flatness and accuracy. For the most accurate measurements, you can characterize the attenuator using a network analyzer and correct the source power to compensate for any attenuator error.

Interfering signals are a significant source of error, especially at very low amplitude levels. These signals come from either external radiation (such as a nearby radio station), or even leakage from the source itself. Leakage from the source affects the level input to the DUT and external noise affects the measurement data. To reduce these inaccuracies, place the DUT in a shielded environment such as a metal box or a shielded room. A TEM (transverse electromagnetic wave) cell may work as well. This reduces the effect of the external radiation and any signal leakage from the attenuator or source provided they are outside of the cell.

Select the Appropriate Phase-Noise Profile

Random noise within the source causes the power to be spread over a small range of frequencies. This spread is referred to as phase noise and is often mathematically modeled as random phase modulation. The units of phase noise are dBc/Hz: dB down from the carrier in a 1-Hz bandwidth. Phase noise is specified at a frequency offset from the source's

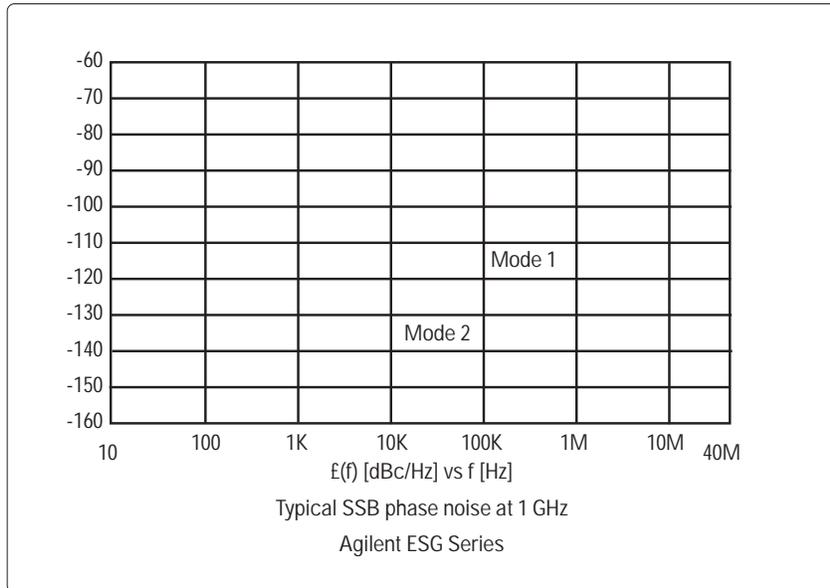


Figure 9. Displaying phase noise on a log-log axis allows both close-in and far-out phase noise to be examined on one plot.

output. For example, the phase noise of a source may be specified as -97 dBc/Hz @ 100 kHz offset from a signal frequency at 20 GHz.

Some recently designed signal generators have a choice of two phase-noise modes; you can tailor performance to either in-channel or out-of-channel measurements. Widening the phase-lock-loop bandwidth of the synthesizer internal to your signal generator yields the minimum phase noise at lower

offsets (such as < 10 kHz) for in-channel measurements, but at the expense of increased phase noise at higher offsets. Conversely, using a narrow phase-lock-loop bandwidth achieves optimum phase noise at higher offsets (such as > 10 kHz) for out-of-channel measurements. Now, the trade-off is increased phase noise at lower offsets.

Phase noise is generally displayed on a log-log axis. This enables both the close-in phase noise (offsets < 1 kHz) and the far-out phase noise (offsets > 10 kHz) to be easily examined on one plot (figure 9).

Optimize ACLR for CDMA Receiver Testing

When generating a signal to measure the ACLR (adjacent channel leakage power ratio) of a CDMA receiver and verify that it meets the CDMA requirement, you must use a signal generator that can create a very complex signal. The signal generator must create a clean base-station signal along with the appropriate interference signals.

A common problem with signal generators if used in the standard mode for this application is that their power amplifier may be set at a power level that is not optimum for this type of measurement. Typically, the power amplifier is set in a range that is optimized for the power amplifier. The signal generator then attenuates this signal to the desired level. In many cases, this is the preferred method, but under certain conditions it results in a distorted signal.

When making ACLR measurements, it is critical that you verify that the signal generator is creating the complex CDMA test signal properly. If the signal generator is creating a distorted signal, the receiver will have a difficult time passing the test. Instead of allowing the signal generator to select the power amplifier and attenuator levels, you have to manually control these settings. This is done by using the attenuator hold function to manually control the power amplifier and the attenuator.

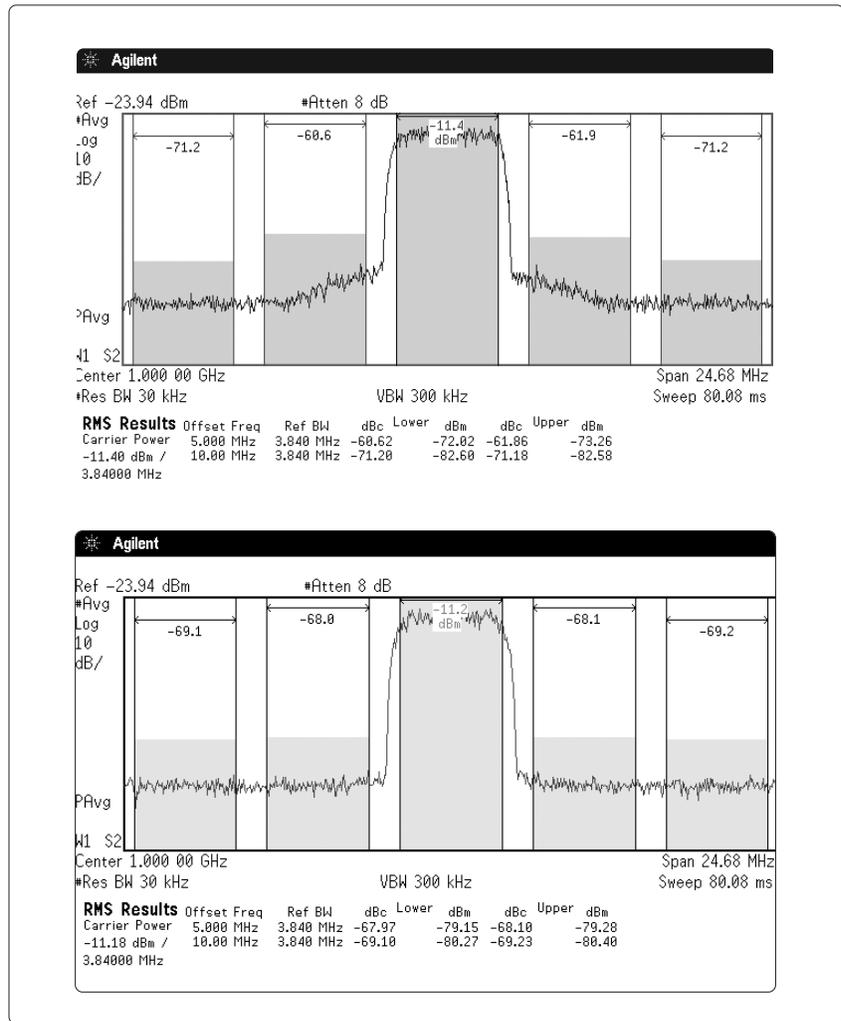


Figure 10. W-CDMA Test Model 1 with 64 DPCH signals generated (a) in the standard mode and (b) optimized with the attenuator-hold function

You should set the power amplifier to the lowest level possible and then adjust the attenuator to provide the desired signal level. For example, to provide a -5-dBm signal, the signal generator in the standard mode may set the power amplifier to +15 dBm and the attenuator to -20 dBm, resulting in a -5-dBm output. This may overdrive the power amplifier and create a distorted signal. Instead, you should manually set the power amplifier to -5 dBm and the attenuator to 0. You will get the same output level without overdriving the power amplifier.

Consider the W-CDMA Test Model 1 with 64 DPCH (Dedicated Physical Channel) signals shown in figure 10. The signal in figure 10a was generated in the standard mode while the signal generated in figure 10b was optimized. Notice the 8-dB improvement from -60 to -68 dBm.

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