APPLICATION NOTE

Fast RF Device Testing with Analog Sources

Analog signal generators with outstanding output power range, signal purity, and switching speed

KEYSIGHT

Introduction

Signal generators, also known as signal sources, provide a stable and reliable signal for testing and evaluating electronic circuits and devices. Portable, general-purpose analog signal generators with a wide output power range, low phase noise, and fast frequency and amplitude switching speed have many applications in R&D, manufacturing test, and field test.

This application note discusses several common applications of Keysight's compact RF and microwave analog signal generators, AP5001A and AP5002A. Though these signal generators consume low power, are lightweight (2.5 kg), and portable, they do not compromise performance (see Figure 1). For example, the AP5002A depicted in Figure 1 provides a wide output power range (-120 dBm to +23 dBm), excellent phase noise (-130 dBc/Hz at 1 GHz and 20 kHz offset), and fast switching speed (300 μs). These signal sources are ideal lower-cost alternatives for various applications we will cover next.

	AP5001A RF analog	AP5002A μW analog
Frequency range	9 kHz up to 6.1 GHz	9 kHz up to 26 GHz
Output power range	-30 to +17 dBm -120 to +17 dBm (Opt. 1E1)	-20 to +15 dBm -120 to +23 dBm (Opt. 1E1/1EA)
Phase noise at 1 GHz, 20 kHz offset	-124 dBc/Hz, -130 dBc/Hz typ.	-124 dBc/Hz, -130 dBc/Hz typ.
Harmonics at 1 GHz	-30 dBc, -40 dBc typ.	-30 dBc, -40 dBc typ.
Non-harmonics at 1 GHz	-55 dBc, -65 dBc typ.	-65 dBc, -75 dBc typ.
Frequency switching speed	200 μs	300 μs, 30 μs (Opt. UNQ)
Modulation capabilities	AM, FM, PM, pulse, frequency chirps	AM, FM, PM, pulse, frequency chirps

Figure 1. Compact analog signal generator, front (left) and rear (right) panels

Receiver Testing

It is important to test receivers to ensure that they operate efficiently in the real world, whether for consumer, military, or industrial use. Often, expensive laboratory-grade equipment is not required to characterize and test receivers. You just need to select the signal source that meets your requirements.

RF Blocker / Interferer

Verifying receiver operation under various test conditions often includes measuring performance under the influence of a nearby blocker or interferer. The blocker typically has a much larger amplitude than the desired signal; for example, an intentional jammer attempting to disrupt communications in a military operation. The blocker could be unintentional, as in the case of another wireless system operating in an adjacent frequency channel. In these cases, the R&D team verifies and tests the blocker rejection under various conditions.

Simulating real-world conditions that include high-power blockers often requires a signal generator capable of delivering high output power. The AP5002A with option 1E1/1EA can provide signals up to +23dBm and frequencies up to 26 GHz. The high output power is also helpful in overcoming the losses in test cables and switch matrices found in manufacturing test systems. You may choose a variety of modulation techniques, such as amplitude modulation (AM), frequency modulation (FM), phase modulation (PM), and pulse. Multiple modulations can be combined with up to three available internal modulation sources. External modulation signals are provided via the rear panel I/O, as shown in Figure 1.

Figure 2 shows a simple configuration for testing the receiver performance of a pulse-modulated signal under the influence of a large amplitude continuous wave (CW) blocker. We need two signal generators for this task — Keysight MXG and AP5002A generate the desired and the blocker signals, respectively. These signals are then combined using an RF signal combiner or coupler and sent to the receiver under test. The frequency and amplitude of the blocker and the desired signals can be adjusted to verify receiver performance. The measurement screen, in the bottom right of the figure, shows the spectrum of the combined signal — the desired pulse-modulated waveform and the larger amplitude CW blocker. It was recorded using a Keysight EXA signal analyzer. For a more dynamic test environment, the AP5002A can also sweep the frequency and amplitude of the output signal using either the “step sweep” or “list sweep” modes of operation.

The AP500xA (AP5001A and AP5002A) have a convenient “step sweep” mode, which enables the user to define the start and stop frequencies, the number of points across the desired sweep range, and the number of repetitions. The generator can rapidly sweep through the range, or a dwell time can be set at each frequency point, which is especially useful for measurements involving electrically long devices such as filters and long coaxial cables. The sweep can be triggered with an RF key on the front panel, externally, or via bus LAN, USB, or GPIB (Opt. GPB).

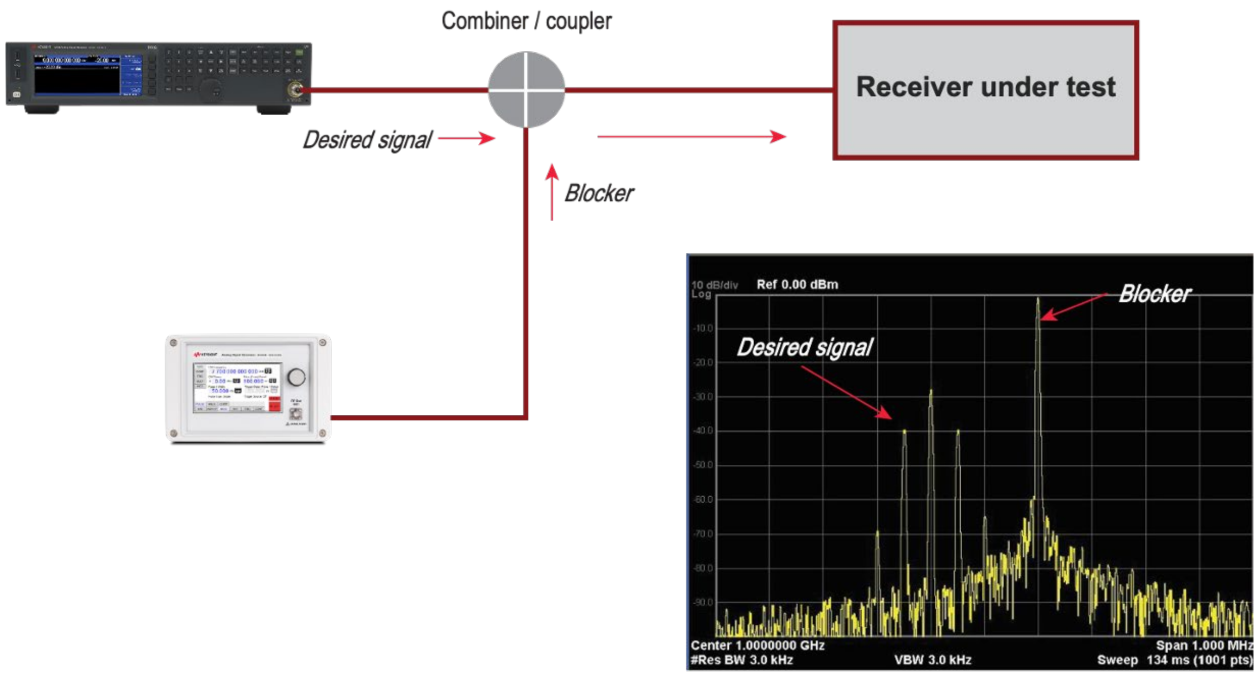

Figure 2. The AP500xA sends a blocker to the desired signal from another signal source to test a receiver

Power calibration / RSSI

Many receivers measure the level of the received signal and report the value to the system as a Received Signal Strength Indicator (RSSI). The RSSI value may be used to set the receiver gain or provide a visual indicator to the user, such as the number of “antenna bars” on a cell phone or a power value shown on a computer’s Wi-Fi® connection. Equipment manufacturers often perform this type of receiver testing in the late stages of R&D system verification and as part of the final manufacturing test.

When accurate RSSI measurement is a desired feature within a communication receiver, target accuracies could be as small as +/-0.1 dB. Due to losses in the measurement path and fabrication tolerances within the radio board, the RSSI measurements are often calibrated against an accurate signal source. The calibration is typically performed across multiple frequency channels and potentially across multiple frequency bands as the same radio may operate under different radio protocols, and each receiver subsystem is calibrated separately. The measured calibration coefficients as a function of frequency would be stored locally inside the wireless device.

Figure 3 shows the AP500xA signal generator used as the calibration source for a wireless device. During manufacturing test, the receiver may be connected through a switch matrix to a variety of other test equipment for rapid automated testing of the transmitter and receiver subsystems. Under the requirements for high accuracy and rapid testing, there are several key features that a signal generator must provide, including accuracy and repeatability of both amplitude and frequency and fast switching between frequency and amplitude changes. The AP500xA has these features and the capability of independently setting the frequency, power level, modulation, and dwell time in a “list sweep” mode of operation, as shown on the bottom right screen of Figure 3. As mentioned in the previous section, the signal generator can continually sweep through the list or start using a trigger signal.

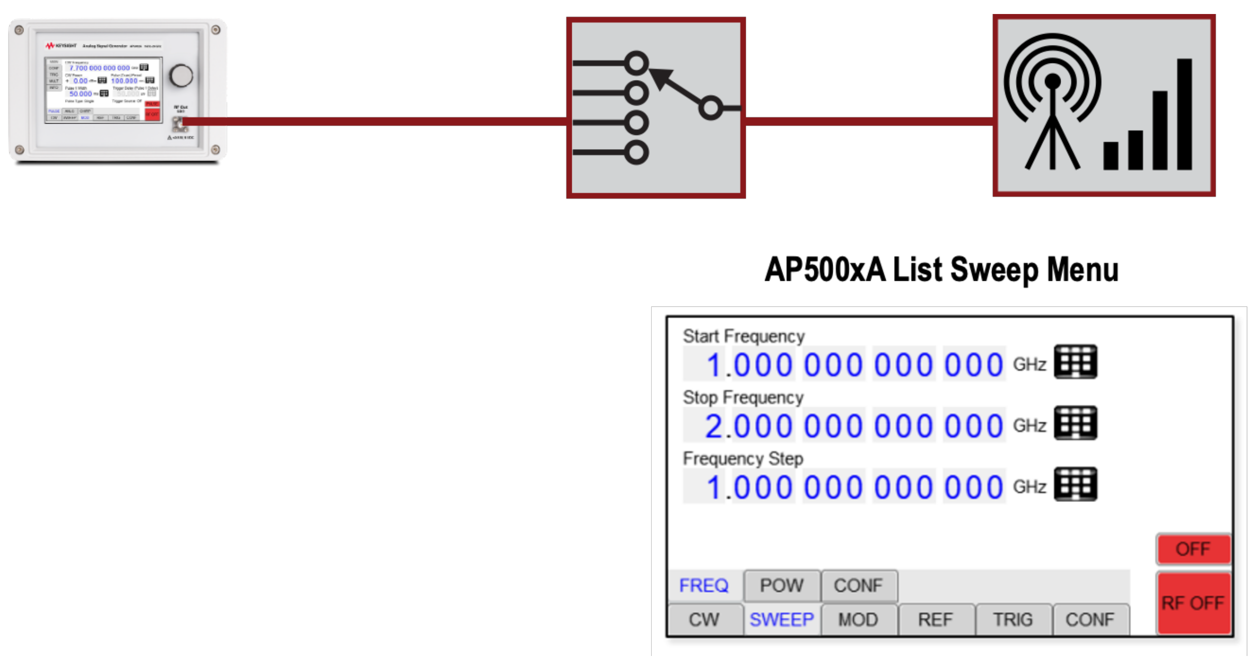

Figure 3. A user can connect the AP500xA to a switch matrix to calibrate the power of a receiver under test. The bottom right shows the list sweep menu of the AP500xA.

LO / Clock Substitution

During the product development phase, R&D engineers and technicians may use a signal generator to substitute for the system's local oscillator (LO) and clocking subsystems. Figure 4 shows a simple receiver where the AP500xA signal generators are the LO and clock substitutes for the case when the circuit prototypes for the LO and clock components have yet to be designed. The first signal generator connects to the mixer as an LO substitute. The output from the mixer then passes through a bandpass filter to capture the signal of interest. The signal of interest is then amplified before being sampled by an analog-to-digital converter (ADC) for additional signal processing inside a field-programmable gate array (FPGA). In this case, the ADC and FPGA clocks (the AP500xA as a substitute) are configured to run at different frequencies. These two sources are frequency-locked together by connecting their internal reference oscillators. It is also possible to frequency-lock the LO generator to these two sources if required.

One of the benefits of using signal generators as oscillator and clock component substitutes is to confirm the system's operation with signal sources that have excellent signal purity — low phase noise and low spurious signals. Phase noise is a measurement of the frequency stability of the RF source. It is often characterized by long-term stability, typically expressed in parts per million (PPM), and short-term stability, resulting from random fluctuations within the source. Spurious signals are undesired, non-harmonically related tones. As spurious and phase noise can harm receiver performance, selecting high-purity signal generators, such as the AP500xA, would allow a performance comparison to be made during the development of system components. The table in Figure 1 shows that the AP500xA provide excellent phase noise of -130 dBc/Hz at 1 GHz and 20 kHz offset.

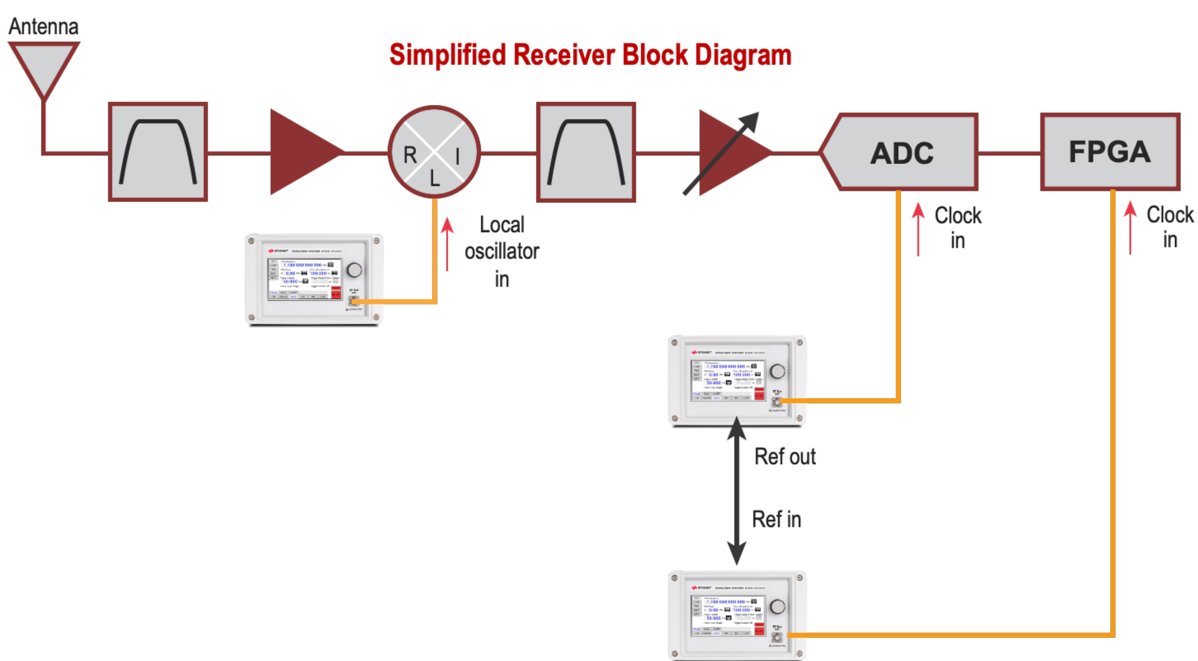

Figure 4. The AP500xA serves as LO and clock substitutes

Amplifier Testing

The goal of an amplifier is signal amplification. It should increase the output power of the signal without distorting the information that the signal carries. Otherwise, it defeats the purpose of an amplifier if it does not ensure signal integrity. In the next section, we will show how easy and efficient it is to characterize and verify some key amplifier parameters with the AP500xA.

Gain testing

Gain is a key amplifier characteristic. The gain factor is typically expressed in decibels (dB) or $10*\log_{10}(P_{out}/P_{in})$ in RF and microwave frequencies. P_{out} and P_{in} represent the output power coming out and input power going into the amplifier. Anyone manufacturing or using amplifiers must characterize and verify the amplifier gain. An RF / microwave engineer will tune and optimize the amplifier during the design process while observing the gain performance. Technicians may also fine-tune the amplifier for maximum gain and output power in manufacturing. These measurements are often performed over a range of test frequencies.

There are several ways to measure amplifier gain. One of the easiest and most accurate techniques involves a signal generator and a power sensor or signal analyzer. As the gain is a relative measurement or ratio between the output power and the input power, the signal generator power level is adjusted for a known power level, P_{in}, at the input to the amplifier, and the amplifier's output power, P_{out} is then measured using a power sensor or a signal analyzer. Adjusting for the P_{in} can be achieved during a preliminary calibration process where the power sensor is temporarily attached to the input reference plane of the amplifier. The amplifier gain is often measured over a range of frequencies. In manufacturing test where throughput is essential, the AP500xA provides a fast-switching speed of less than 300 microseconds for both frequency and amplitude.

Gain compression is another important characteristic of an amplifier. As Pin increases, the gain stays relatively flat over the small signal region until the amplifier goes into compression or "saturation," and the gain decreases. The output power where the gain drops by 1 dB is specified as the 1dB compression point or "P1dB." When measuring gain compression in high-power amplifiers, such as those with output powers greater than +30 dBm (1 watt), the signal generator must be capable of sourcing the high output power required to the amplifier under test with as little distortion as possible. As mentioned previously, the AP5002A can deliver up to +23dBm of output power with option 1EA. In manufacturing test, the high output power is helpful to compensate for signal losses in test rack cabling and switch matrix systems. The high power and fast switching speed make this an ideal choice for manufacturing test.

Figure 5 shows the test setup to measure the key performance metrics of an amplifier, such as gain. Placing attenuators before the input and after the output of the amplifier helps to reduce impedance mismatch and protect the instruments from damage. You may also consider placing an isolator before the input attenuator to terminate the reflected power going back to the signal generator due to a mismatch. The gain plot at the bottom left of the figure also depicts the operating regions of the amplifier, small signal and compression, as well as the P1dB point when the gain decreases by 1 dB.

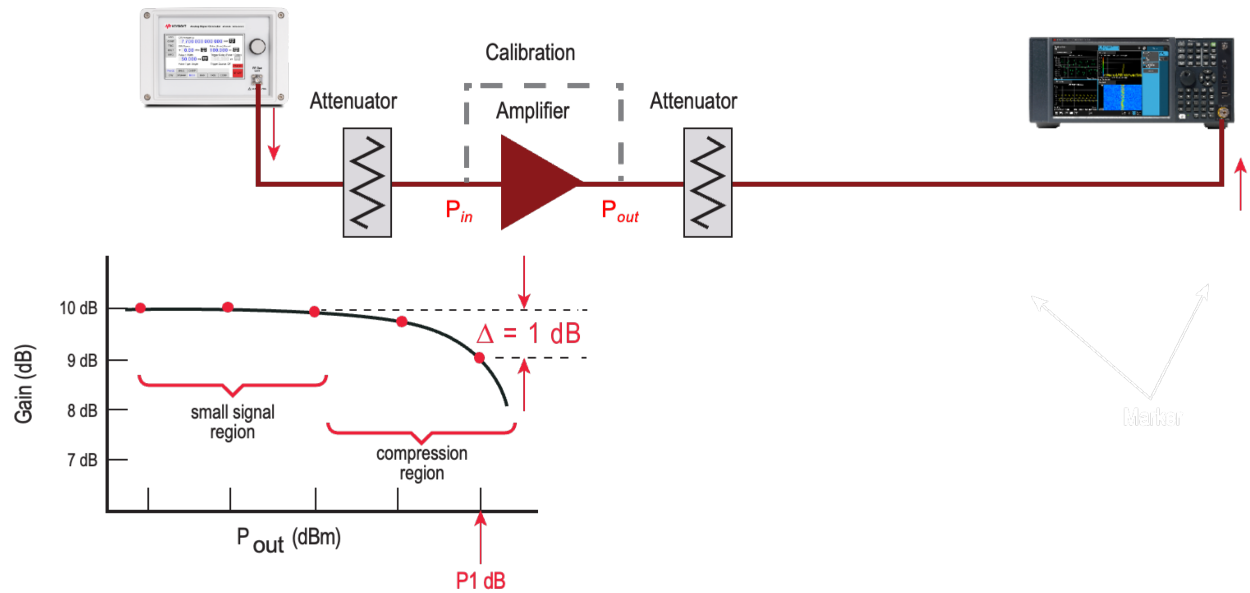

Figure 5. In the gain measurement setup, the AP500xA sources power to the amplifier, and a signal analyzer measures the amplifier's output power

Intermodulation (IM) testing

Amplifier datasheets usually include a specification for nonlinear distortion called the third-order intercept (IP3). You can perform distortion measurements using two or more CW signals and measure the frequency behavior of unwanted signals created by the amplifier's nonlinear effects. Distortion measurements are especially important to the radio and wireless communications industries as these unwanted signals may fall within the operating band or into an adjacent frequency channel, reducing overall system performance. Device manufacturers usually perform these tests during the design and manufacturing stages.

A typical configuration for measuring two-tone IM distortion requires two signal generators. Figure 6 shows two AP500xA signal generators, each operating at different frequencies, f_1 and f_2. The frequency spacing is often related to the channel spacing of the radio system. The combiner sums up the two signals generated from the AP500xA and applies the combined signal to the amplifier under test. When you work with higher output power, you will need a combiner with good isolation when working with higher output power.

Before the measurement, a signal analyzer, such as the EXA, calibrates the power levels of the two tones to ensure they are delivering the same power level in dBm at the input reference plane to the amplifier. The measurement screen on the bottom left shows the two tones provided to the input of the amplifier, while the bottom right screen shows the two tones, including the IM products, at the output of the amplifier. The IM products are due to the nonlinear effects of the amplifier. This distortion product is often displayed as a relative measurement in dBc, or the difference in dB as compared to the carrier amplitude. The distortion product is an important measurement as it shows the level of distortion that could be present in an adjacent radio channel.

These distortion products are called “third-order” because an increase in output power by 1 dB has an associated increase in the level of distortion by 3 dB. In other words, these undesired signals increase three times faster than the desired signals at f1 and f2. We will cover specifying third-order products in more detail in the next section.

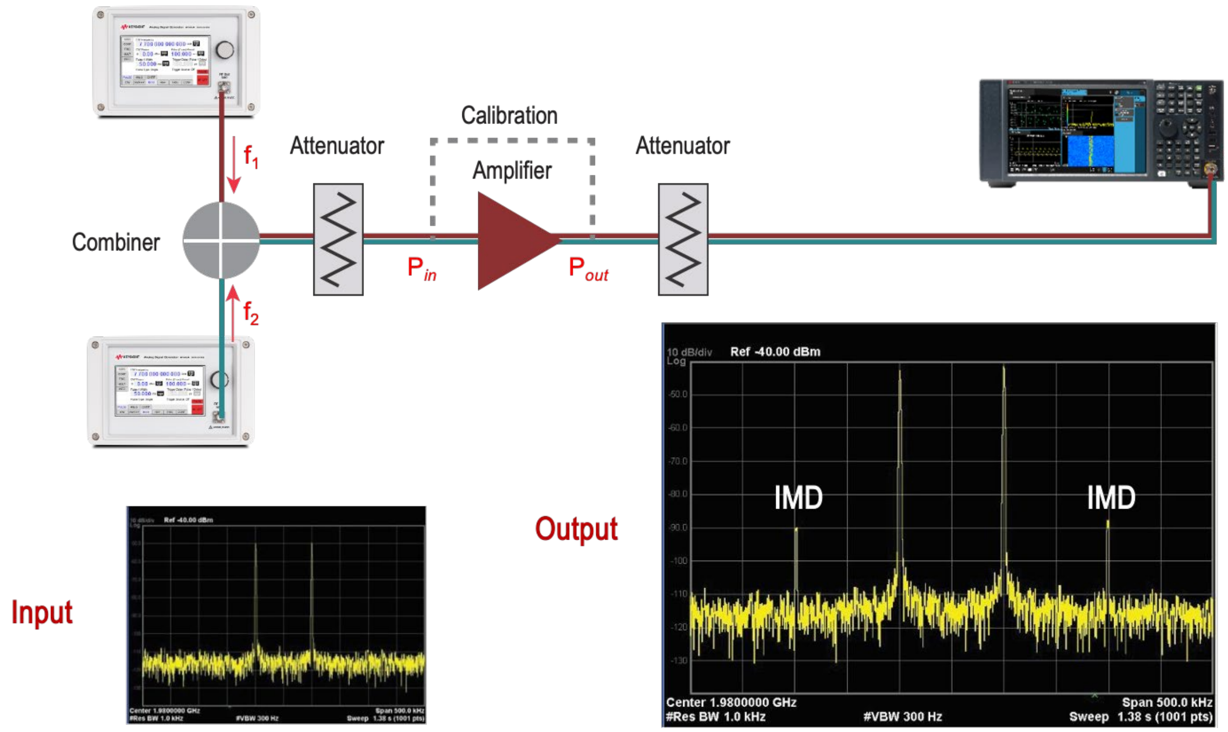

Figure 6. A test setup using two AP500xA to generate two-tone signals and a signal analyzer to make IMD measurements of an amplifier

Third-Order Intercept (TOI) testing

One challenge in specifying distortion products is that the input power levels may vary widely for different amplifiers and test configurations. A better way to specify IM distortion is to calculate the “intercept point” for the amplifier under test. The intercept point is the power level at which the fundamental carrier and the IM products are equal. This parameter can be used as a figure of merit when comparing the nonlinear performance between amplifiers and is a key parameter commonly found on amplifier manufacturers’ datasheets.

Intermodulation products have a slope equal to their order. For example, using the two-tone test from the previous section, the input power of the two fundamental carriers is equally varied over a power range, and the output power of the fundamental and IM products are measured. The power levels are plotted together on the same P_{in} versus P_{out} graph, as shown in Figure 7. The slope of the fundamental curve represents the gain of the amplifier, while the slope of the distortion curve represents the order of the IM product. For this measurement, a 1 dB change in the fundamental corresponds to a 3 dB change in the IM product, resulting in a third-order IM product. The amplifier will eventually enter compression or saturation as the input power increases. When these two lines are extrapolated from their linear range, they reach a theoretical intersection at the third order intercept (TOI) point, often labeled as “IP3” on amplifier datasheets. The IP3 is a key parameter for an amplifier, stating the relative suppression of the distortion products. Higher IP3 values result in lower distortion at a specified input power and provide the means to compare the performance of different amplifiers.

Note that the spectrum or signal analyzer is one of the few instruments that can measure the distortion products appearing at the output of an amplifier or other nonlinear devices such as a mixer. The signal analyzer displays the signal power measurement as a function of frequency. A power sensor does not provide any information concerning frequency content but makes a single combined measurement of all power across the entire sensor’s frequency range.

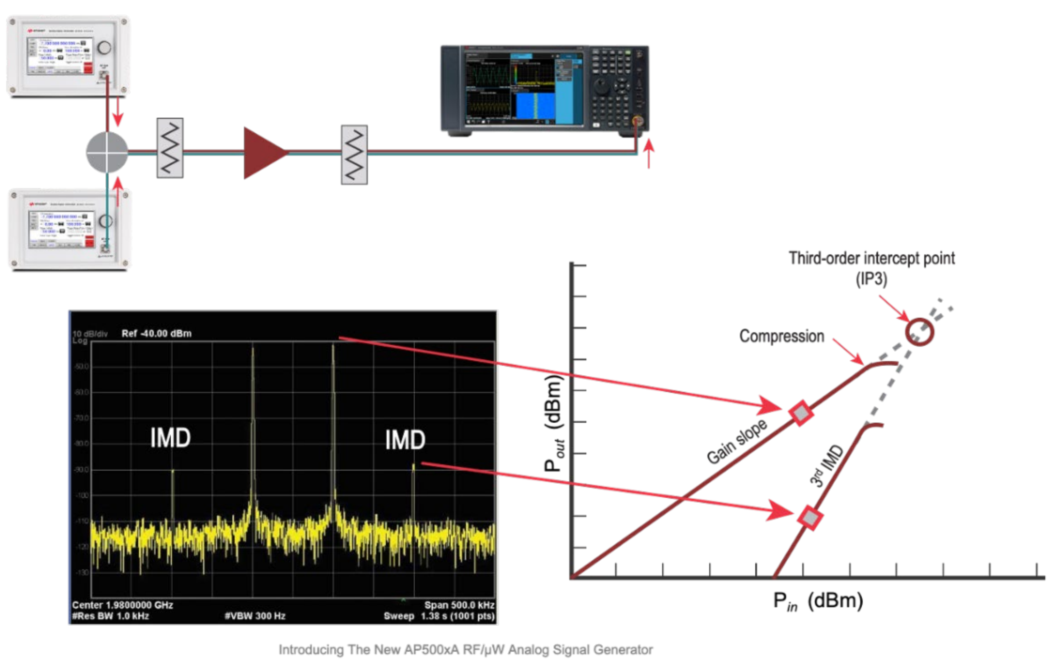

Figure 7. A key amplifier parameter, the third-order intercept point (IP3), is defined as the input power at the intersection of the gain and third-order IMD curves

Conclusion

To ensure success and accelerate product development, signal sources with faster switching speed, outstanding signal purity, and superior output power will enable you to quickly characterize and select components and submodules.

The Keysight compact analog signal generator AP500xA offers fast switching speed, outstanding signal purity, and high output power. Additional capabilities include AM, FM, PM, and pulse modulation, a high-performance oven-controlled crystal oscillator (OCXO), and excellent harmonic / non-harmonic performance.

Also, enjoy Keysight's three-year warranty and KeysightCare Technical Support to mitigate project risks.

Additional Resources

- AP5001A Product Page
- AP5002A Product Page