

# TOI Measurement



## APPLICATION NOTES



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## 1 Revision history

Version number	author	Date of preparation /modification	Reason for change	Major changes (Just write the main points)
1.0	Yanfei Zhao	2026/4	first draft	TOI Measurement

## 2 Introduction

When two or more signals are simultaneously applied to the input of an active device (such as an amplifier or mixer), due to the nonlinear characteristics of the device, in addition to generating harmonics of each individual signal, the interaction between the signals also produces intermodulation products.

The relationship between the intermodulation product level and the input signal level follows the rule below: if the amplitude of two sinusoidal input signals changes by  $\Delta\text{dB}$ , the level of the corresponding N-th order intermodulation product will change by  $N \times \Delta\text{dB}$ . Here, the order N is defined as the sum of the absolute values of the frequency coefficients. For example, for the product at frequency  $2f_{in,1} - f_{in,2}$ , the order is  $N = 2 + |-1| = 3$ .

IM3 refers to the third-order intermodulation product. As shown in Figure 1, the third-order intermodulation products are located at frequencies  $2f_{in,1} - f_{in,2}$  and  $2f_{in,2} - f_{in,1}$ .

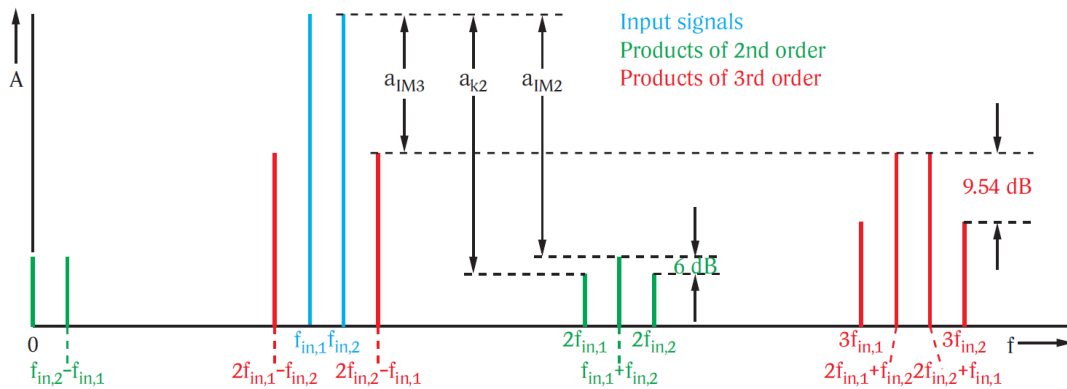


Figure 1 Spectrum diagram of dual-tone signal

The intercept point (IP) is a theoretical concept defined as the point at which the extrapolated fundamental output signal (assuming ideal linear amplification) and the extrapolated N-th order intermodulation product output signal (assuming ideal nonlinear extension) become equal in power, as illustrated in Figure 2. However, this intercept point cannot be physically reached in actual measurements, because the device output is typically limited by compression or saturation well before the input signal reaches that level. Among all intermodulation products, the second-order intermodulation product (IM2) and the third-order intermodulation product (IM3) generally have the most significant impact on measurements. Therefore, two intercept points are commonly defined: the second-order intercept point (IP2) and the third-order intercept point (IP3).

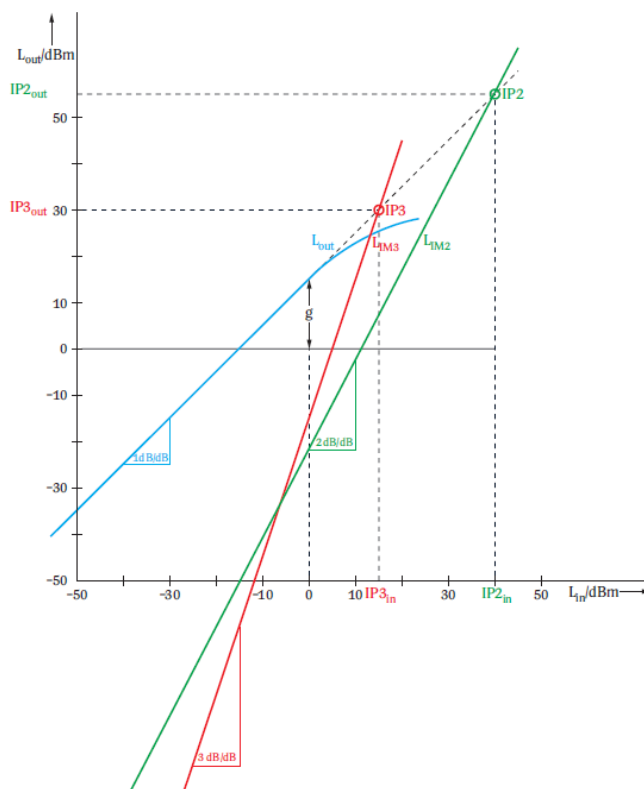


Figure 2 The relationship between IM3 and the input signal power

When testing the intercept point of the spectrum analyzer, it is necessary to ensure that the value of the attenuator is 0dB. The intercept point increases with higher attenuation. This is because the attenuator lowers the signal power into the first active stage, mitigating its nonlinear effects, but this comes at the cost of a degraded noise figure.

### 3 Difficulties and Challenges

Testing IP3 faces multiple challenges in both theory and operation. The difficulties mainly stem from the theoretical nature of IP3 and the nonlinearity of the testing system.

#### 3.1 Challenge 1 : Linearity and Extrapolation Errors

The IP3 is a theoretical intersection point derived by extrapolating the power of the fundamental signals and the third-order intermodulation (IM3) products. In practice, an actual device will saturate or enter compression long before reaching this power level, meaning it cannot physically operate at its IP3. Therefore, IM3 must be measured within the device's linear operating region, far from saturation, and then extrapolated based on the theoretical slope. If the test power levels are chosen improperly (e.g., too close to the compression region), the extrapolated result will be highly inaccurate, leading to an invalid measurement.

Solution:

Determine the linear operating region through a preliminary test. For example, measure the IM3 at multiple power points within a proposed input range, such as -30 dBm to -10 dBm. Use linear regression to

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verify that the power slope of the IM3 products relative to the fundamental tones is 3:1. This confirms that the measurements are being conducted within the device's true linear region.

### **3.2 Challenge 2 : Test System Induced Errors**

This challenge arises when using a test setup where two separate RF generators generate single-tone signals respectively, which are then passed through a combiner into the DUT (Device Under Test). If the signal generators themselves have significant harmonics or phase noise, the resulting spurious signals can overlap with and contaminate the IM3 measurement. Furthermore, if the combiner itself has poor linearity, it will generate its own IM3 products. This leads to a falsely high IM3 level and, consequently, an artificially low (i.e., worse) IP3 measurement for the DUT.

Solution:

Use a vector signal generator to generate the dual-tone signal to avoid introducing the combiner and affecting the test results. Or use a high-linearity combiner, preferably a resistive type. Be aware that resistive combiners have an inherent loss of at least 3 dB, so the power margin of the signal generators must be calculated in advance. Additionally, verify the harmonic distortion and phase noise performance of the signal generators before conducting the test to ensure they meet the required specifications.

### **3.3 Challenge 3 : High Dynamic Range Requirement for High-Linearity DUTs**

When a DUT exhibits good linearity, its IP3 is consequently high. Testing such a device presents two conflicting requirements: the input tones must be sufficiently strong to generate measurable IM3 products, yet the resulting IM3 products are inherently very weak. This combination is problematic because the strong input signals can drive other components in the test system (like the spectrum analyzer's front end) into their own nonlinear regions, generating interfering IM3 products. Simultaneously, the weak IM3 from the DUT can be easily masked by the large fundamental signals and the test system's own noise floor.

Solution:

Use a spectrum analyzer with a high dynamic range. This allows for the simultaneous and accurate measurement of the strong fundamental tones and the very weak IM3 products. Select a spectrum analyzer that has a high IP3 itself. This ensures the analyzer itself remains linear under high signal levels, preventing it from generating internal intermodulation products that would corrupt the measurement. Choose a spectrum analyzer with low phase noise. This prevents the "skirts" of the large fundamental signals from spreading and masking the adjacent, weak IM3 signals.

## **4 Solutions**

IP3 is typically tested by either using a vector signal generator to produce a two-tone signal or by combining two single-tone signals into the DUT. The IP3 value is calculated by measuring the power levels of the output tones and their resulting third-order intermodulation (IM3) products. For this procedure, a vector signal generator is employed to generate the two-tone test signal.



## 4.1 Step 1 : Test Topology

Connect the signal generator's RF output to the input of the DUT (e.g., an amplifier), and connect the DUT's output to the analyzer's input, as illustrated in Figure 3.

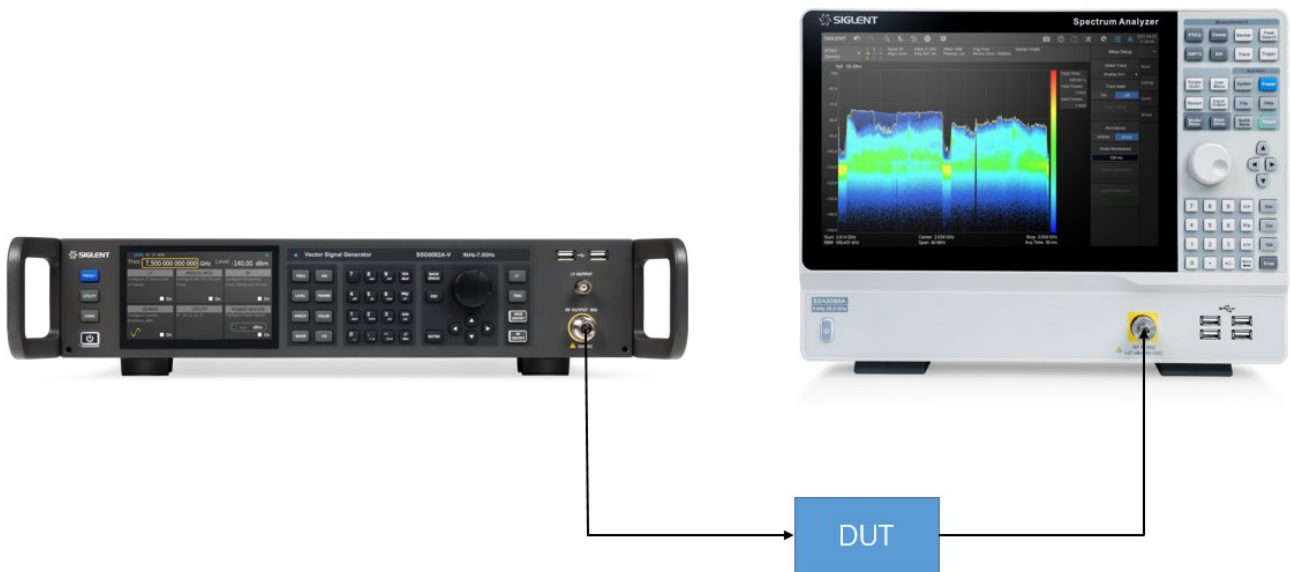


Figure 3 Test topology diagram

The physical connection diagram is as follows.

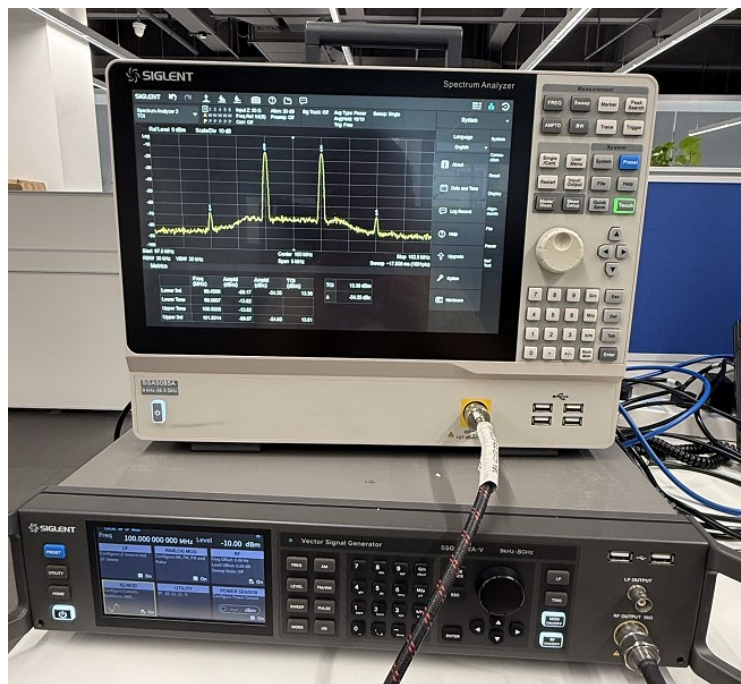


Figure 4 Physical connection diagram

## 4.2 Step 2 : Vector Signal Generator Settings

- 1) Set the frequency of the signal generator to 100MHz and the amplitude to -10 dBm.

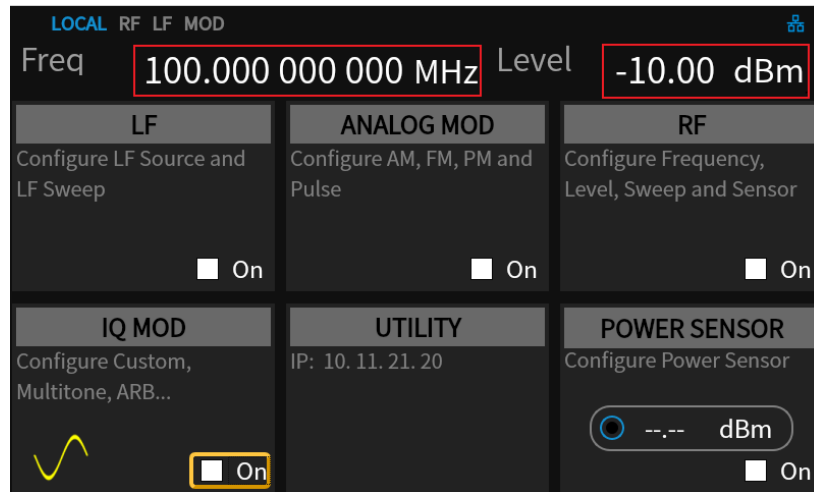


Figure 5 Schematic diagram of frequency and amplitude settings for the signal generator

- 2) Click IQ MOD > Multitone.

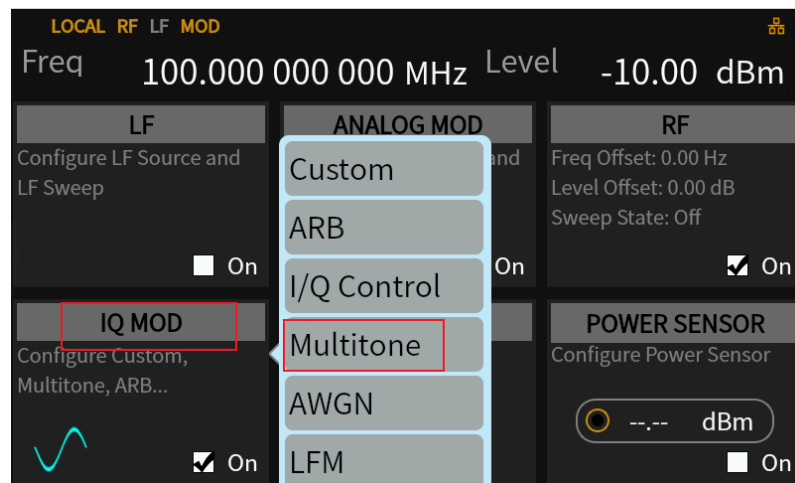


Figure 6 Schematic diagram of IQ MOD settings for signal generator

- 3) Set the Tone Number to 2 to send a two-tone signal. The Tone Spacing is set to 1MHz, and the frequency interval between two tones is 1MHz. Turn on the switch of Multitone State and click Update.

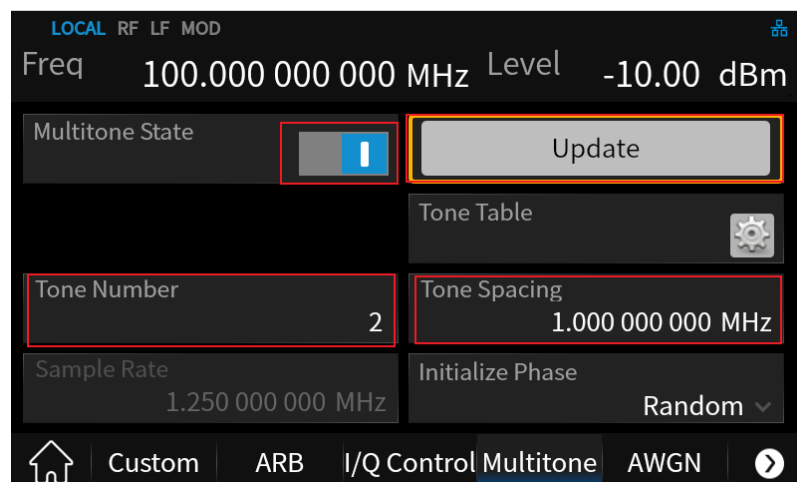


Figure 7 Diagram of multitone configuration for the signal generator

- 4) Return to the HOME page and turn on the switches of IQ MOD and RF.

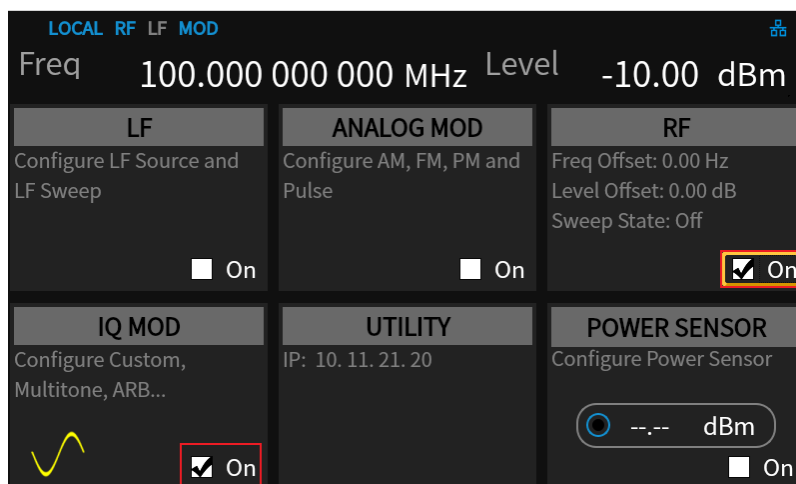


Figure 8 Schematic diagram of the switch settings for the signal generator

### 4.3 Step 3 : Spectrum Analyzer Settings

- 1) Click the Mode/Meas button and select TOI Measurement in Spectrum Analyzer Mode. Click the Add and OK buttons.

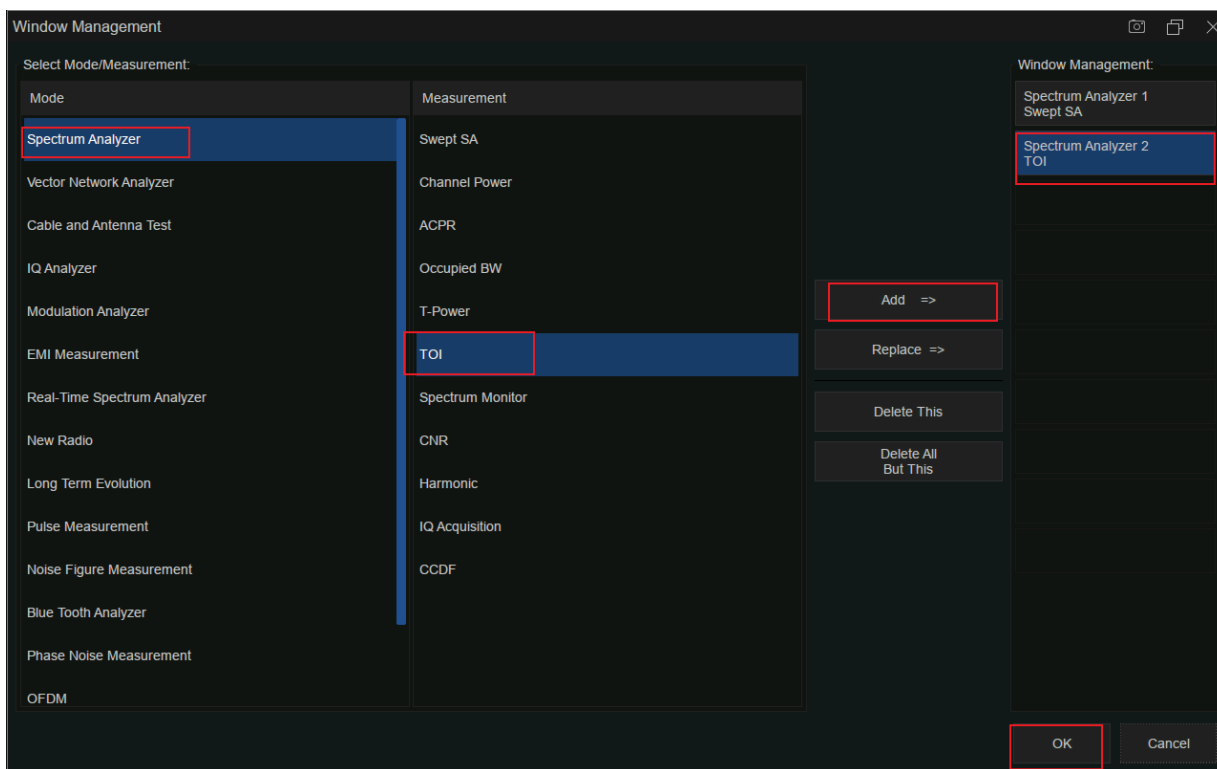


Figure 9 Schematic diagram of Mode Settings for spectrum analyzer

- 2) Center Freq is set to 100MHz.

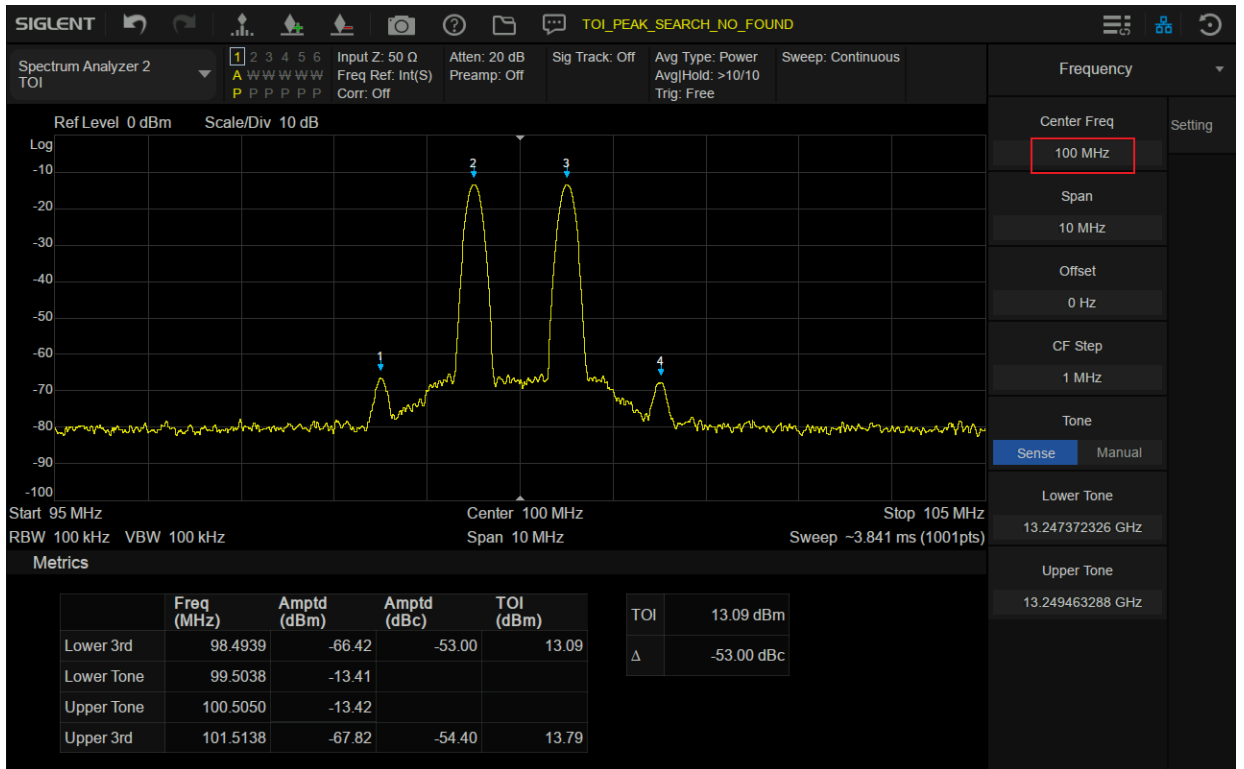


Figure 10 Schematic diagram of frequency setting for the spectrum analyzer

- 3) The third-order intermodulation measurement result is shown in Figure 11. The result window displays the fundamental frequency and power, as well as the third-order intermodulation frequency and power, and the calculated the third-order intercept value.

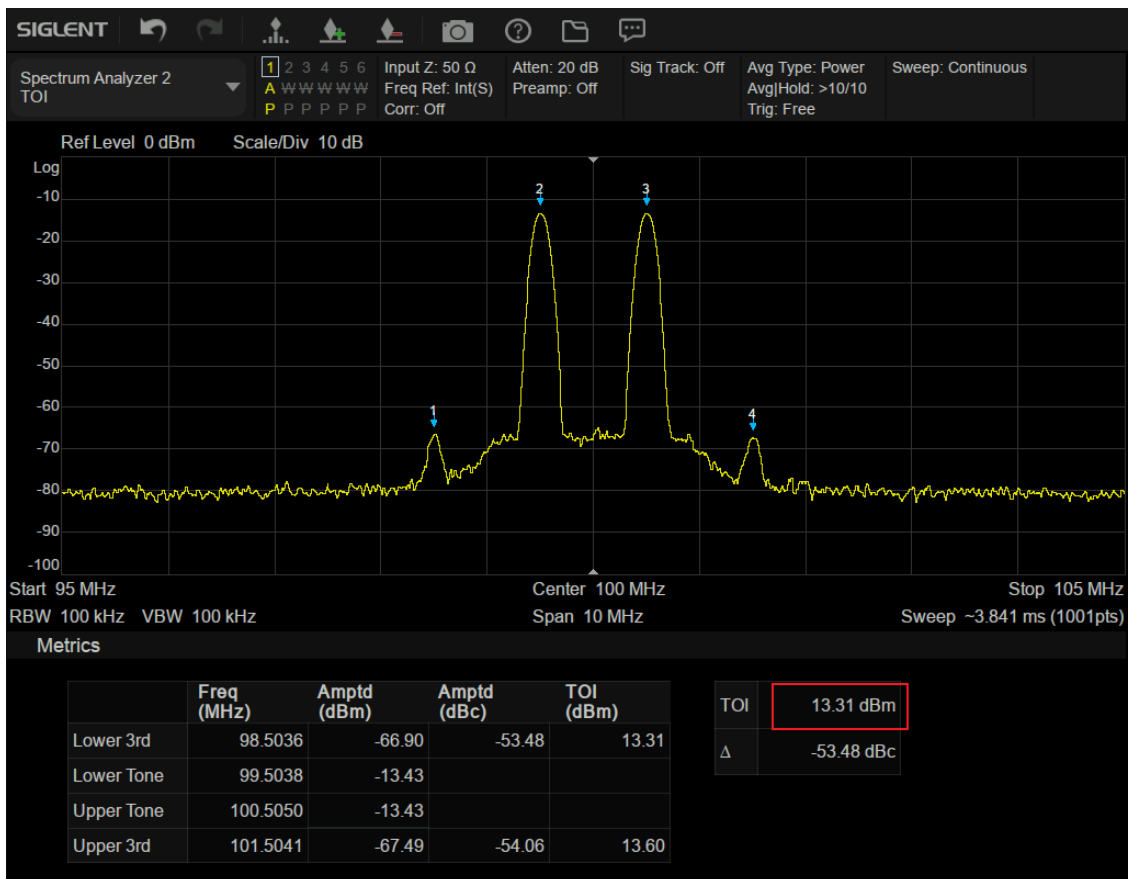


Figure 11 TOI measurement result

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#### 4.4 Step 4 : Verification Results

- 1) Change the attenuation of the spectrum analyzer and observe whether the level of the intermodulation products decreases or increases accordingly. If the level value changes, it indicates that the intermodulation products generated by the spectrum analyzer cannot be neglected, and the test result is invalid.
- 2) With all other conditions unchanged, compare the measured intermodulation product levels with and without the DUT. If the level measured without the DUT is much lower than that measured with the DUT, it confirms that the measured result represents the intermodulation products produced by the DUT; otherwise, the test result is invalid.
- 3) When the test result is invalid, you may try reducing the input level of the two-tone signal or increasing the attenuation of the spectrum analyzer's input attenuator to obtain a valid result.

### 5 Summary

SIGLENT provides a solution for third-order intercept point (TOI) testing, directly addressing the core challenges of strong signal masking and weak intermodulation products detection in high-linearity device testing. Through the spectrum analyzer, combined with high-precision signal generators and an intelligent measurement suite, TOI testing can be completed with a single click, greatly facilitating users in performing third-order intermodulation measurements.



## About SIGLENT

SIGLENT is an international high-tech company, concentrating on R&D, sales, production and services of electronic test & measurement instruments.

SIGLENT first began developing digital oscilloscopes independently in 2002. After more than a decade of continuous development, SIGLENT has extended its product line to include digital oscilloscopes, isolated handheld oscilloscopes, function/arbitrary waveform generators, RF/MW signal generators, spectrum analyzers, vector network analyzers, digital multimeters, DC power supplies, electronic loads and other general purpose test instrumentation. Since its first oscilloscope was launched in 2005, SIGLENT has become the fastest growing manufacturer of digital oscilloscopes. We firmly believe that today SIGLENT is the best value in electronic test & measurement.

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