

SNA Calibration For Use In Your Shack

Dave Collins - AD7JT

13 February 2015

Introduction

SNA calibration has been described as confusing and frustrating and its purpose is often misunderstood. The objective of this white paper is to remove some of the confusion by outlining the objectives of SNA calibration and to clear up some of the misunderstanding.

Background

It is often thought that the objective of SNA calibration is to be able to accurately measure power levels in dBm to two or three decimal places. This level of precision is not only unnecessary for ham radio applications, it is virtually impossible for those of us who lack the laboratory-grade instruments required for precise calibration. Instead we should concentrate on calibrating our SNA to produce meaningful and easy to interpret results. To accomplish this objective, the typical SNA has three areas that need attention:

- Reference RF signal power level
- Power meter slope and zero intercept point
- DDS output variation with frequency

None of these need super precision but first we must decide on a frequency for the reference RF power source.

Selecting the Reference Signal Frequency

The output level of most DDS devices varies with frequency and that variation may not be linear. Typically the power level decreases as the frequency increases. This problem can be handled separately and need not be considered for the other calibrations. To avoid the frequency dependant output affecting the initial calibrations, the reference frequency must be fixed at one frequency during these calibrations. I recommend using 1 MHz for reasons that will be explained later.



Setting the Reference Power Level

An SNA injects a reference RF signal into the device under test (DUT) and measures the DUT output power level. Generally the absolute value of the power levels involved are totally irrelevant to the results we are looking for. Instead, we are mainly interested in the ratios between power levels and can usually assume the power ratios will remain the same independent of the actual power levels. In other words, the transfer functions are linear with respect to input power levels. These ratios are really a measure of the signal gain or loss of the DUT.

We use the following formula to express power gain in dB:

$$\text{gain/loss in dB} = 10 \cdot \log(P_1/P_0)$$

Where P_1 is the DUT output power level and P_0 is the input or reference power level. When P_0 is equal to one milliwatt in a 50 ohm system, the gain or loss is said to be in units of dBm the "m" signifying the power level is relative to one milliwatt. When P_1 is greater than P_0 , the result is positive and the network has gain. When P_1 is less than P_0 , the result is negative and the network has loss. Since the power transfer function is linear, P_0 can have nearly any value and P_1 will change such that the network gain or loss will remain the same. **Thus it is not necessary to accurately set our reference power level to get accurate results.**

Instead, the reference power level should be set for convenience and to maximize dynamic range. To illustrate what these terms mean in this context, let's look at the transfer function of the AD8307 Logarithmic Amplifier^[1] used in many RF power meters including the PHSNA and the NAT-SNA^[3].

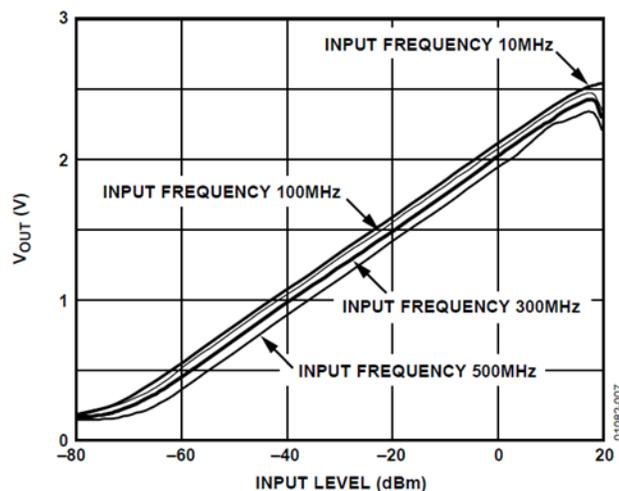


Figure 7. V_{OUT} vs. Input Level (dBm) at Various Frequencies

The output voltage (V_{OUT}) is relative to the input power level and is very linear over a range of from about +15 dBm to about -70 dBm. Since most of the DUTs we will be interested in are passive (e.g., filters, return loss bridges, crystals, etc.), we should set our reference power level fairly high on this curve to give us maximum range in the negative direction. We should also try to avoid the non-linear

ends of the curve. Setting the reference power source to approximately Zero dBm (1 milliwatt) looks like a good choice.

Question: How do you set the reference power level without an accurate power meter?

Answer: Use an inaccurate power meter!

An inaccurate power meter that many of us have is an oscilloscope. A one milliwatt sine wave terminated with a 50-ohm load has a peak-to-peak voltage of 0.632 volts. This is equivalent to $0.224 V_{\text{rms}}$ if you have an RF volt meter.

Determining the RF Power Meter Slope and zero Intercept

The typical SNA must deal with a number of inaccuracies that affect the accuracy of power readings. The AD8307 data sheet claims the above curve is accurate within about 0.5 dBm over the linear portion of the curve. The typical SNA measures the power meter output voltage using an analog-to-digital converter (ADC) input to a microcontroller which relies on a reference voltage which may not be a *precision* reference voltage. Last but not least, there is possible inaccuracy in our reference power source.

The SNA must compute the power level based on the ADC voltage reading. The ADC voltage reading is expressed as a count. To compute the ADC voltage, the count is multiplied by the reference voltage and divided by the number of steps in the ADC voltage range (1024 for a 10-bit ADC and 4096 for a 12-bit ADC). All of the inaccuracies listed above are linear, as is the power meter transfer function. Therefore, these factors can be included in the form of a single linear equation defining the relationship between ADC count and power ratio in dBm. Consider the general linear equation:

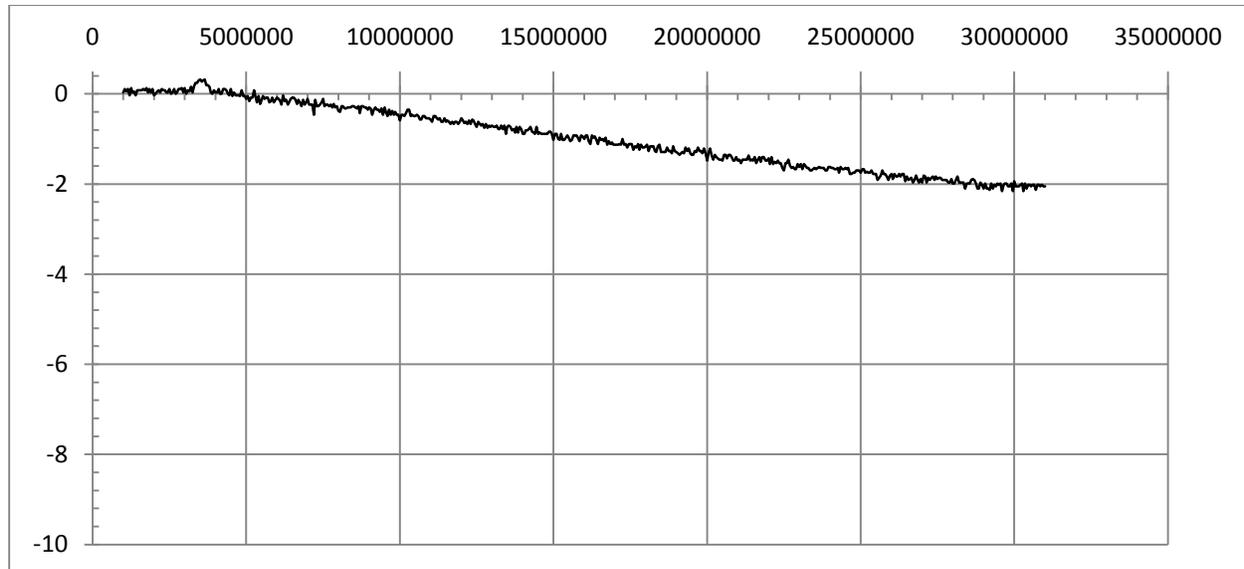
$$P = S * C + I$$

Where P is the power ratio in dBm, S is the slope of the power curve in dBm per ADC count, C is the ADC count, and I is the zero intercept point which is the dBm reading at zero volts ADC output assuming linearity down to the zero level. We have two unknowns (S and I) so we need two points on the curve to calculate them.

One point can be our reference signal which is approximately 0 dBm. The second point can be generated using the reference signal and an attenuator (e.g., -20 dBm). This determines the second point. We now have two simultaneous equations that can be solved to derive values for S and I. Actually, the SNA controller firmware usually solves them for us and saves the results to be used for all future power meter readings. Both the PHSNA controller and the NAT-SNA firmware (Version 3 and beyond) provide this functionality.

Compensating for DDS Output Variation With Frequency

After the above two factors have been addressed, a plot of the DDS output will probably look something like this:



This plot illustrates typical DDS output power level variation for frequencies from 1 MHz to 31 MHz. The curve is typically non-linear so a simple linear equation cannot be used to generate correction factors. The **PHSNA firmware** uses a curve fitting function in Excel^[2] to generate six coefficients for a polynomial equation. The coefficients are then manually entered and the PHSNA firmware uses them to adjust all future power meter readings. However the **NAT-SNA** accomplishes the same thing by saving the results of a scan of the power output over the frequency range and uses the results to adjust all future power meter readings. The adjustment consists of subtracting the calibration value for that frequency from the power meter reading. Remember that we are dealing with logarithms of ratios here so subtracting from the result has the same effect as scaling down the input power level.

The shape of the above curve is the reason I recommend using 1 MHz as the reference signal frequency. Calibrating everything to 0.0 dBm at 1 MHz pretty much assures us the calibration data points will all be negative and, for me anyway, easier to visualize what's going on. When the SNA adjusts the power readings to a 0.0 dBm base line across the frequency spectrum we are using means the DUT gain or loss can be read directly from the adjusted output without having to remember to do any further adjustments.

Conclusion

Recognizing that a high degree of precision in SNA power level readings is not necessary greatly simplifies the task of calibrating an SNA. We can, instead, simplify the process and eliminate the need for expensive test and calibration equipment. This allows us to concentrate on maximizing the dynamic range available and on making the results easy to interpret and easy to use.

^[1] AD8307 Low Cost, DC to 500 MHz, 92 dB Logarithmic Amplifier by Analog Devices
<http://www.analog.com>

^[2] Adding calculations to compensate for SSNA output change with frequency by Jim Giammanco, N5IB
<https://groups.yahoo.com/neo/groups/PHSNA/files>

^[3] The NAT website is located at <http://midnightdesignsolutions.com/nat/>