Measuring RF Power Sensor Nonlinearity

RF power sensor linearity is a commonly misunderstood topic. To obtain the most accurate power measurements, though, you need to understand what linearity is, the sources of nonlinearity, and how to measure the linearity of your RF power sensors.

Types of RF power sensors

There are three main types of RF power sensors:

Diode sensors have the fastest response times (microseconds) and the largest dynamic range (-70 to +20 dBm), but have the worst linearity specs. Nonlinearity ranges from 1.5% to 5%, depending on design. They are best used for making peak power measurements and very wide dynamic range measurements.

Thermoelectric sensors have response times in the millisecond range and typically a 50 dBm dynamic range (-30 dBm to +20 dBm). Their nonlinearity is negligible over most of their range, but may be up to 3% at the top end of the range. They are best used for making true average power measurements.

Thermistor sensors are the most accurate and most linear of the three RF power sensor types. Typically, the nonlinearity of a thermistor RF power sensor is 0.1%. this makes them ideal for use as transfer standards.

What is linearity?

A perfectly linear RF power sensor is one whose output varies in direct proportion to a change in input power. That is to say the output voltage of a perfectly linear RF power sensor will double when the input power is doubled. The linearity specification describes the extent to which a sensor's actual response can vary from the ideal response.

RF power sensors exhibit two primary types of nonlinear behavior:

Ranging nonlinearity is a symptom of multi-path sensors, which effectively combine a number of sensors with different sensitivities.

Design-related nonlinearity is caused by either a diode sensor being operated over a wide range without multiple paths, or by nonlinearities in the thermopile and other thermal responses of thermoelectric bolometer sensors. These tend to be related to some exponent applied to the power input, but probably not exactly the square.

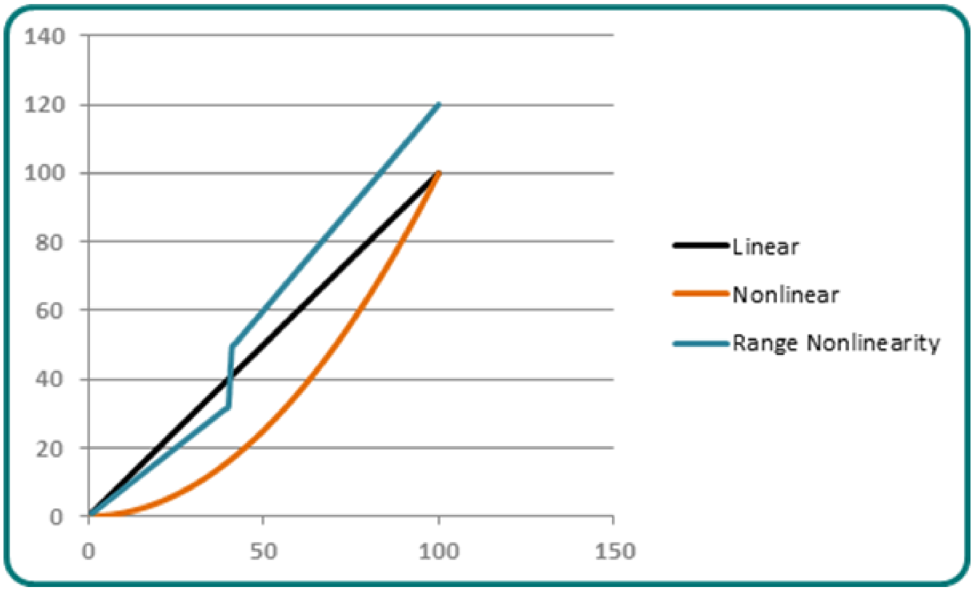

Figure 1: Types of Linearity

The nonlinearity of an RF power sensor is a combination of both types of nonlinearity, and when you measure the nonlinearity of a sensor, your measurements will include both types of non-linear behavior.

Compensating for nonlinearity
The most common way to compensate for RF power sensor nonlinearity is to measure the nonlinearity over the power range of the sensor and then build a lookup table. These values are then used to correct for nonlinearity by retrieving a correction value from the table based on the input power level. The metering system then adjusts the measured value and displays the corrected value.

Measuring nonlinearity
There are several methods that you can use to measure RF power sensor nonlinearity, including:

1. Direct comparison to an RF thermistor standard such as the TEGAM M1130A.
2. Use the internal step attenuator in a highly accurate RF source such as the Fluke 9640A.
3. Use a programmable attenuator such as the Agilent 8494G with an 11713B switch driver to precisely adjust signal level.
4. Use a vector network analyzer.

Each of these methods typically uses a test frequency of 50 MHz, and while each method is reliable, there are some tradeoffs. These include equipment specifications, reusability, and cost.

The best method for your application will depend on the equipment available and the specification that you need to achieve.

This application note explains the process with a TEGAM M1130A due to the highly linear nature of thermistor power sensors. A linearity accuracy of 0.004 dB is cost effectively achievable with equipment already owned by many calibration laboratories.

Another approach is to use the precision step attenuators in the Fluke 9640A with an accuracy of 0.02 dB at 50 MHz. This test can be performed over a range of 55 dB and is suitable for many diode and thermoelectric sensors.

A third method employs a variable step attenuator such as the Agilent 8494G whose rated accuracy is 0.2 dB for a 20 dB step. However, specific attenuators can be characterized at a national lab like NPL in the UK to achieve a linearity approaching 0.001 dB. These characterizations can be expensive and time consuming.

A final common option is to use a vector network analyzer as the linearity standard. VNA receiver amplitude accuracy is currently about 0.05 dB and test levels may be limited by the network analyzer's signal sources which are typically lower than those of most signal generators.

Example - measuring the nonlinearity of an R&S NRP-Z51

In this example, we will use the TEGAM M1130A to directly compare a change in power level with that measured by a Rohde & Schwarz NRP-Z51. The NRP-Z51 is a thermal power sensor that has the following specifications:
Measurement range: -35 dBm to + 20 dBm
Frequency range: DC to 18 GHz
Nonlinearity: 0.02 dB (0.5%)

For this example, we will measure the nonlinearity of the sensor at -3, 0, 3 ,5 ,7, 9, 11, 13, 15, 16, 17, 18, 19, and 20 dBm. Since we will not be measuring below -3 dBm, we will not need additional attenuation for this particular sensor.[1]

To make these measurements, the following equipment is required:

- A signal source with the capability of delivering 24 dBm (250 mW) at 50 MHz into a 50 Ω load. Since we are measuring a ratio of absolute power an amplifier may also be used.
- A splitter which will typically have about 6 dB of loss.
- Three attenuators:
  - 10 dB for the standard
  - 3 dB (level dependent)
  - 30 dB for DUT levels including and below 0.05 mW
- A variable attenuator may be used on the DUT side of the splitter
- A harmonic Filter may be required for sources with higher levels of frequency distortion
- TEGAM M1130A Thermistor RF Power Sensor

[1] 30 dB of attenuation will be shown as optional attenuation for sensors that may require testing below -3 dBm.

TEGAM 1830A RF Power Meter
R&S NRP-Z51 Power Sensor
R&S NRPII Power Meter

Equipment Configuration

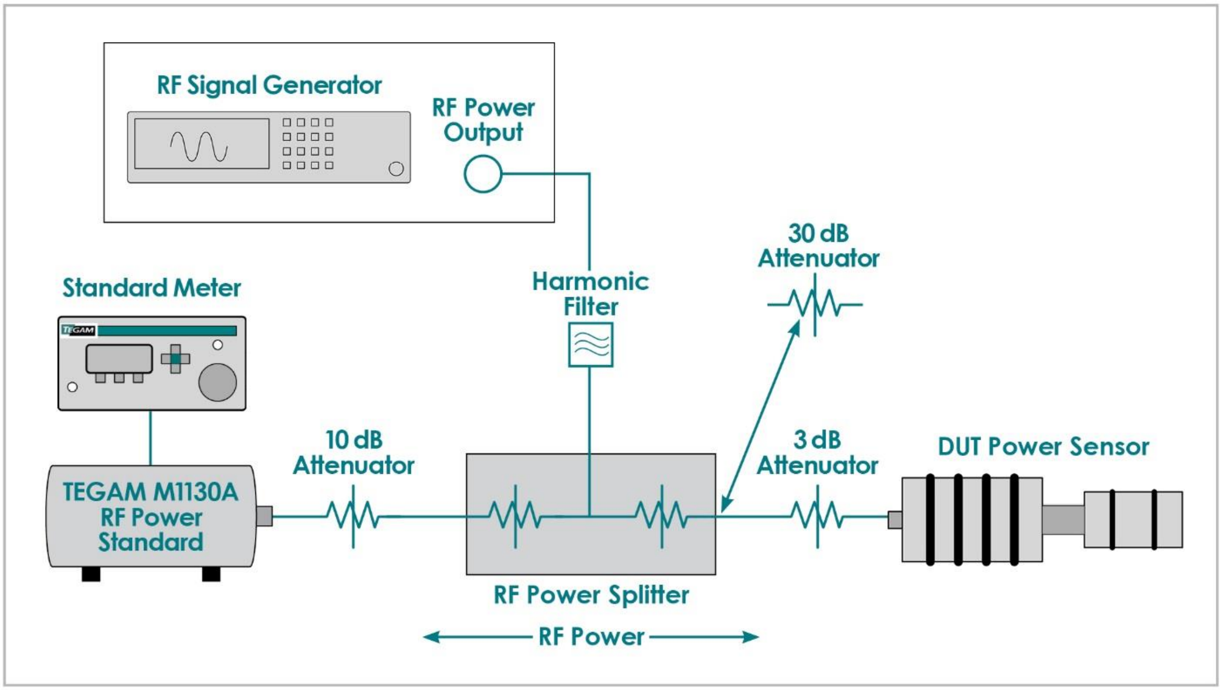

Figure 2 Complete Linearity Verification Configuration

The TEGAM M1130A RF Standard has excellent linearity from -10 dBm to +10 dBm (0.1 mW to 10.0 mW). By adding a 10 dB attenuator between the splitter and standard we cover all power ranges for this particular example. Although Figure 2 shows an attenuator between the splitter and the R&S NRP-Z51, they are not used for this example.

Figure 2 shows a harmonic filter connected between the RF source and the splitter to filter out unwanted signal source noise. It is advisable to use a harmonic filter for all linearity testing.

Running the test
After connecting the equipment as shown in Figure 2:
Set the signal source frequency to 50 MHz.
Set the signal source output level so that the reading on the R&S NRPII reads -3 dBm ± 0.5 dBm.
Record the results.

Repeat steps 2 and 3 for each of the required levels. Note that the output power of the RF source need only be within ± 0.5 dBm of the specified test level. This is because we are comparing the readings of the device under test to an accurate standard.

After making all of the measurements, the nonlinearity is calculated the using the following formula:

Linearity = ABS((DUT Power (dBm) A – DUT Power (dBm) B) – (REF Power (dBm) A – REF Power (dBm) B))

where:
DUT Power is the value measured by the R&S NRPII
REF Power is the value measured by the TEGAM 1830A
A = current measurement
B = previous measurement

Our test results are shown in Figure 6. Note that there are power on and a power off reference measurements. These measurements are made to prevent any zero drift from affecting the calculations.

Verification levels Z51	DUT Power (dBm)	DUT Power (W)	Ref RF/Off (W)	Ref RF/On (W)	REF Power (W)	REF Power (dBm)	Linearity (dB)
-3	-2.95	0.000506991	0	5.07E-05	5.07E-05	-12.94992041	NA
0	0	0.001	1.00E-07	1.01E-04	1.00E-04	-9.982662872	0.017257535
3	3	0.001995262	-1.10E-06	2.00E-04	2.01E-04	-6.974526275	0.008136597
5	5.02	0.003176874	-1.10E-06	3.19E-04	3.21E-04	-4.941719661	0.012806614
7	7.07	0.005093309	-1.10E-06	5.12E-04	5.13E-04	-2.900519835	0.008800173
9	9.03	0.007998343	-1.10E-06	8.03E-04	8.04E-04	-0.949060317	0.008540482
11	11.04	0.012705741	-1.20E-06	1.28E-03	1.28E-03	1.072099696	0.011160013
13	13.08	0.02032357	-1.00E-06	2.05E-03	2.05E-03	3.111390583	0.000709114
15	15.11	0.032433962	-1.00E-06	3.26E-03	3.26E-03	5.132842045	0.008548537
16	16.1	0.040738028	-3.00E-07	4.10E-03	4.10E-03	6.125507581	0.002665536
17	17.11	0.051404365	-3.00E-07	5.18E-03	5.18E-03	7.142542966	0.007035385
18	18.12	0.064863443	-1.00E-07	6.53E-03	6.53E-03	8.147136127	0.005406839
19	19.13	0.081846479	-1.00E-07	8.24E-03	8.24E-03	9.159324822	0.002188695
20	20.12	0.10280163	1.00E-07	1.03E-02	1.03E-02	10.14516339	0.004161436

Figure 3 - Linearity Test Results

Conclusion
Using the inherent linearity of a thermistor standard is an accurate and cost effective way of verify power sensors. Thermistor power sensors such as the TEGAM M1130A are generally only used in situations where their excellent linearity and repeatability is important such as calibration. Even though they are much slower and have a smaller dynamic range than thermocouple or diode-based sensors, thermistor power sensors are still the sensors of choice for power transfer standards because of their DC power substitution capability. In addition, we can now conclude that a thermistor power standard is a competitive method for measuring power sensor nonlinearity.