APPLICATION NOTE

Metrology-Grade Measurement Challenges

Easily measure RF power accuracy using the N5531X

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Introduction

Overview of tuned RF level in Keysight N5531X measuring receiver

This application note analyzes the sources that contribute to measurement uncertainties and summarizes how to achieve the most accurate measurement results with the Keysight N5531X. A measuring receiver is an effective tool for calibrating signal generators and RF attenuators. It is widely used in metrology and calibration lab environments across industries including aerospace, defense, and commercial telecommunications.

Accurately quantifying the output signal strength (RF power) of signal sources is one of the most crucial tasks for measuring receivers. The Keysight N5531X measuring receiver's linearity and sensitivity enables metrology users to calibrate signal generators and step attenuators with wide dynamic range at different frequencies (from RF to millimeter wave frequencies) to meet strict specifications demanded by customers. Due to the nature of metrology services, even a fraction of a decibel in RF power measurements can significantly impact the quality of the services.

Tuned RF Level Measurement

Tuned RF level measurement block diagram

The N5531X is available in two configurations:

1. The primary configuration in Figure 1 consists of an N9030B PXA signal analyzer with the N9091EM0E MMR application, and a U5532C USB sensor module which has a USB power meter built in. This gives you a one-box solution.
2. An alternative configuration combines a PXA/N9091EM0E MMR application, an external power meter, and an N5532A/B legacy power sensor.

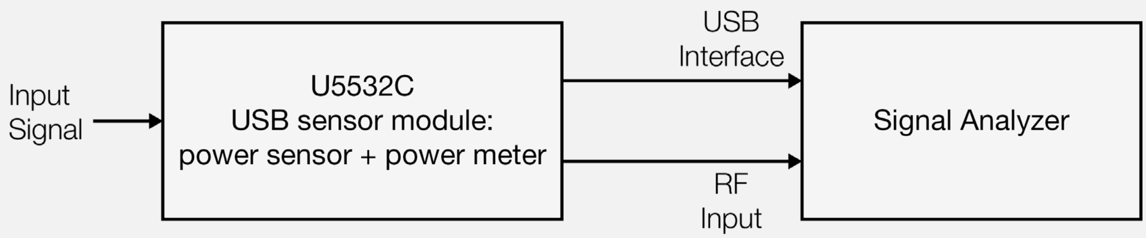

Figure 1. Primary configuration for the N5531X measuring receiver

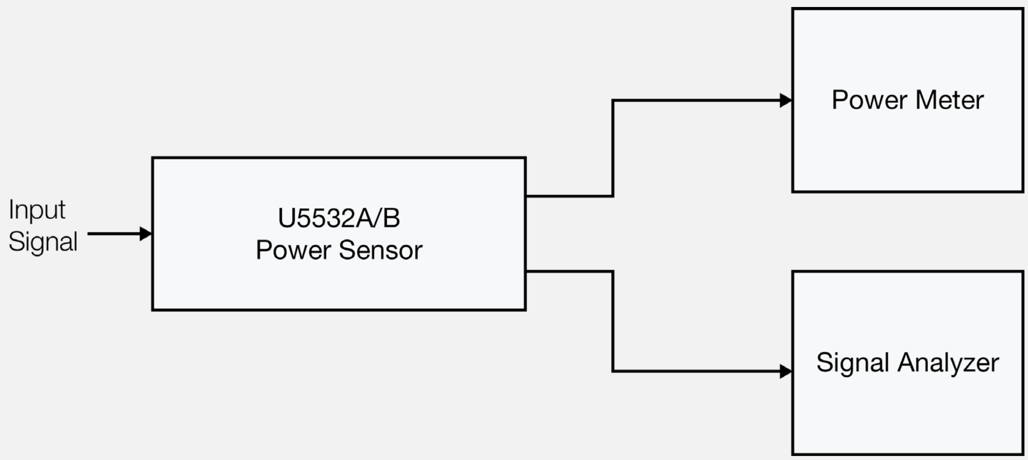

Figure 2. An alternative configuration for the N5531X measuring receiver system

Our discussions will focus on the *alternative configuration.* The *primary configuration* is covered as well since the measurement sciences and algorithms used in both configurations are exactly the same.

From Figure 2, N5532A/B sensor module, captures incoming signal from the DUT. In N5532A/B Sensor module, the input signal will split between EPM (or P Series) power meter and PXA. The TRFL power measurement will use the power meter to make measurement in a high-input power (i.e. not less than -20 dBm) condition and this measured signal by power meter. Then, signal analyzer (PXA) will make measurement at the similar high input power. The difference in power between power measured by power meter and by PXA will then be computed. This difference is later used for compensation/correction purposes for the measurement to enable TRFL to provide measurement with good sensitivity.

Purpose

The TRFL application is targeted to make power measurements with exceptional accuracy and sensitivity. To measure extremely low input power level in order to meet the desired sensitivity, TRFL measurement is required to tune the PXA to the frequency of interest with a very narrow IFBW setting. TRFL application is widely used for signal generator and step attenuator calibration. It is particularly useful in verifying step attenuator linearity and step accuracy.

It is important to note that for each measurement frequency, the instrument must be aligned and needs to perform range calibration to correct for frequency-dependent measurement variations. The range calibration remains valid for any CW signal at that frequency +/-5% (or above 100 MHz +/-5 MHz, whichever is smaller).

Measurement Technique

Types of ranging calibration

Unlike RF Power measurements which measure total power across a wide frequency band, Tuned RF Level measurements tune to the frequency of interest and can measure extremely low levels of power. This is particularly useful when a step attenuator or a signal generator is tested for step accuracy of power output with incremental changes.

The Measuring Receiver System can accurately measure the absolute or relative power of low level, continuous wave (CW), RF signals. At each measurement frequency, the instrument must be calibrated to correct for frequency-dependent measurement variations.

Calibration over the full dynamic range requires calibration at three different levels. The calibration remains valid for any CW signal at that frequency +/- 5% (or above 100 MHz +/- 5 MHz, whichever is smaller).

The System offers two ways of supporting ranging calibration: automatic ranging calibration and manual ranging calibration, which both have different calibration procedures.

1. Automatic ranging calibration

With automatic ranging calibration, the Measuring Receiver can make automatic ranging calibration without user intervention. The Measuring Receiver will perform ranging calibration automatically depending on the SNR of input RF signal; if SNR is lower than 35 dB, the Measuring Receiver will perform a range-to-range calibration.

2. Manual ranging calibration

With manual ranging calibration, the Measuring Receiver performs ranging calibration with user intervention manually, depending on the input RF signal level and the signal frequency. If the power of the signal of interest is close to a range calibration level, the Measuring Receiver will perform a range-to-range calibration by displaying the “Recal” indicator. The calibration must be initiated by pressing TRFL Cal.

Ranging calibration in Tuned RF Level measurement

As the PXA measures the Tuned-RF-Level in three distinct ranges, as shown in Figure 3, it can maintain a favorable signal-to-noise ratio as the signal level decreases toward the noise floor of the PXA. The actual range switching involves changing the setting of the internal mechanical attenuator and either turning on or off internal preamp of the PXA. See Table 1.

Range	PXA attenuation (dB)	Pre-amp
1	30	OFF
2	10	OFF
3	4	ON

Table 1. N5531X TRFL measurement ranges

The SNR threshold at which range switching occurs depends on various factors of the PXA, including analyzer's attenuation, IFBW, the mixer's level, and DANL performance of the frequency at which the measurement is performed.

Initial power calibration

An initial absolute power level calibration is made by applying a signal to the Measuring Receiver via a calibrated sensor module. The signal must be within both the sensor module's and Measuring Receiver's power and frequency range. The absolute power is first measured by power meter and stored as the reference level. Then the PXA makes a power measurement at the same frequency. The input signal level must not change during this re-calibration and the signal level must be constant during the calibration. Then the two levels (reference level and PXA level) are compared to get a ratio (noted as CF1, Cal Factor for Range1). The ratio of the two measurements is stored as a calibration factor.

First RF input ranging calibration

When the power of the input signal is lowered to the 2nd range (which varies by different frequency band in the PXA), the Measuring Receiver creates a second calibration factor (as CF2, Cal Factor for Range2) by comparing the power level measured before and after the range changes. (The input signal level must not change during this recalibration.) The new calibration factor CF2 is multiplied by the calibration factor CF1 made previously (with the reference) and used in all subsequent measurements in RF Range2 at that frequency.

Second RF input ranging calibration

When the power level of the input signal is lowered to the 3rd range (which varies by different frequency band in the PXA), the Measuring Receiver creates a third calibration factor (as CF3, Cal Factor for Range3) by comparing the power level measured before and after the range changes. The input signal level must not change during this recalibration. The calibration factor CF2 multiplies the new calibration factor CF3, and CF1made previously (with the reference) to be used in all subsequent measurements in RF Range3 at that frequency.

Calibrating the calibrated level

The two Cal factors can be obtained for three ranges, Range1, Range2, and Range3 as CF1, CF2, and CF3 (linear unit instead of dB). If we let P1, P2, and P3 (linear unit instead of dBm) be the levels for Range1, Range2 and Range3 from PXA separately, the P is the actual power, we have:

P = P1 * CF1, If P1 is in Range1

P = P2 * CF1 * CF2, If P2 is in Range2

P = P3 * CF1 * CF2 * CF3, If P3 is in Range3

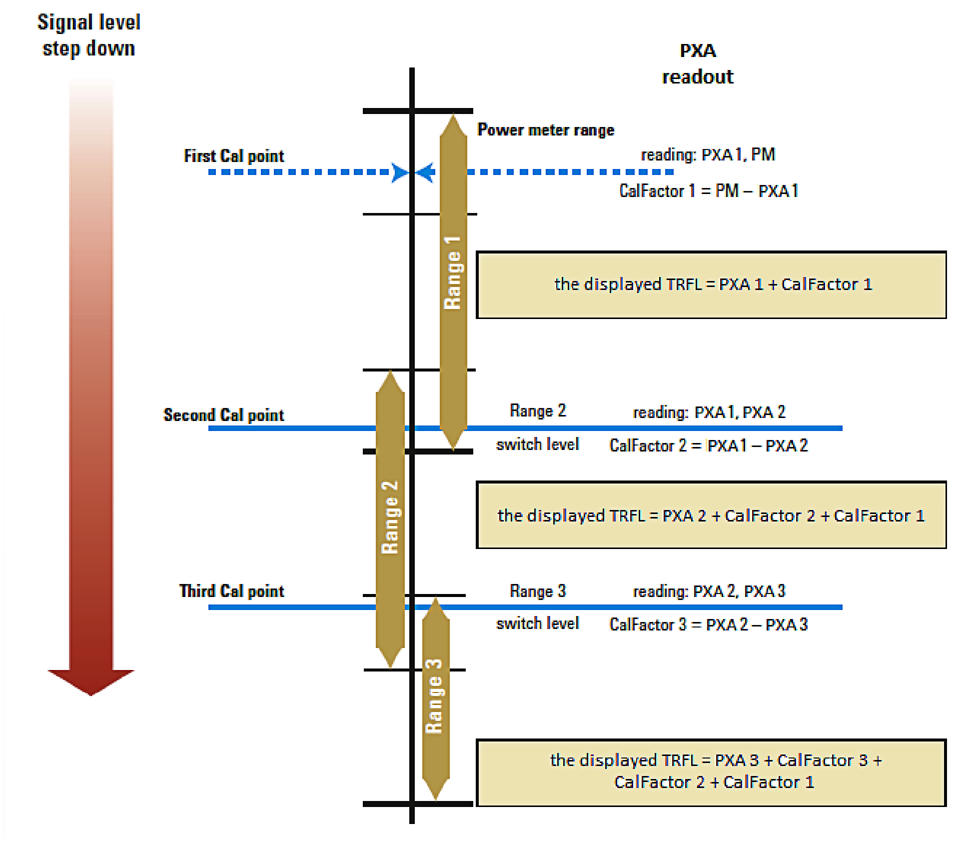

Figure 3. TRFL ranging calibration

Sources of Tuned RF Level Measurement Uncertainty

Measurements made in TRFL mode utilizing the PXA signal analyzer

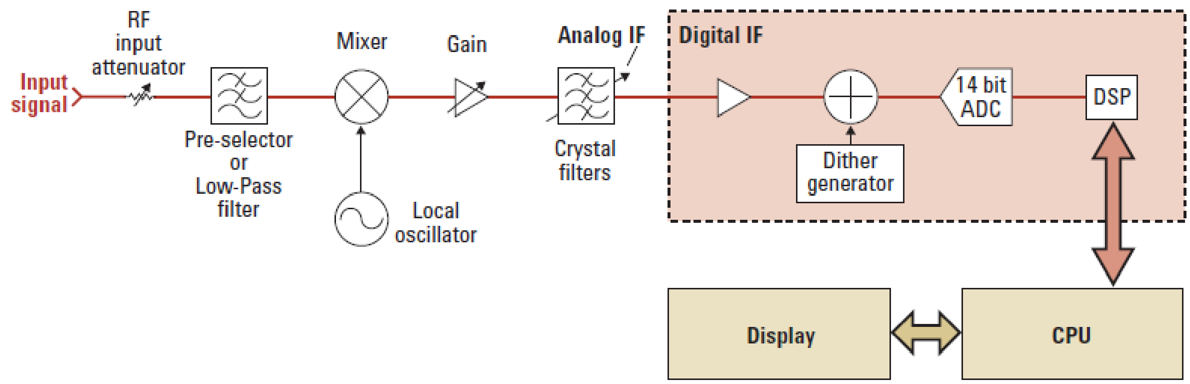

Figure 4. Simplified block diagram of the PXA signal analyzer

The critical blocks that determine the relative TRFL accuracy of the PXA are the Analog IF and Digital IF. The most important performance characteristics of the PXA for amplitude measurement is “detector linearity.” The detector in the PXA is a 16-bit, an analog-to-digital converter (ADC) coupled with a digital processing (DSP) chip. This detection method is far more accurate than the traditional method employing analog logarithmic amplifiers and analog detectors.

Detector linearity applies throughout the entire TRFL amplitude measurement range. When the signal level drops below about –70 dBm, residual noise and range-changing in the PXA become the main contributors to the uncertainty of the TRFL measurement.

Absolute power measurement by the N5531X below the range covered by the power meter (below –10 dBm), requires the TRFL measurement mode using the PXA. The PXA’s absolute power reference is established by the power meter. Consequently, in TRFL mode, there are two contributors to the value of the absolute RF power accuracy specification:

- The absolute reference measurement made by the power sensor/power meter combination.
- The relative TRFL measurement made by the PXA.

The combined uncertainty of these two separate contributing measurements becomes the specified performance limit (i.e., the specification) for absolute TRFL power accuracy.

$$u^2(P_{ABS\_TRFL}) = u^2(P_{REF}) + u^2(P_{TRFL})$$

where $u(P_{ABS\_TRFL})$ = uncertainty of absolute TRFL measurement by PXA;

$u(P_{REF})$ = uncertainty of absolute reference power measurement by power sensor/power meter;

$u(P_{TRFL})$ = uncertainty of relative TRFL measurement by PXA

When operating as a measuring receiver in the TRFL mode, the PXA amplitude accuracy (uncertainty) is dominated either by the PXA linearity or by the residual noise level, as shown in Figure 5. These two regions are separated by the line labeled Residual Noise Threshold which marks the power level below which the signal-to-noise ratio (SNR) becomes the dominant contributor to the accuracy of the TRFL measurement. As indicated in the N5531X measuring receiver data sheet:

$$Residual\ noise\ threshold = minimum\ power + 30\ dB$$

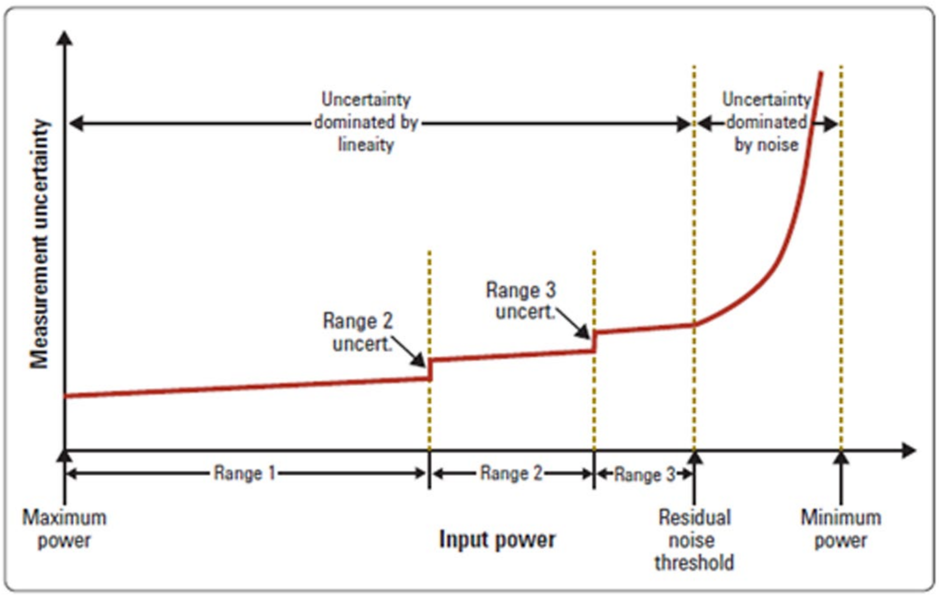

Figure 5. Measured uncertainty vs. input power relationship

“Minimum Power” is specified in the N5531X data sheet for various frequency bands, resolution-bandwidth settings, and pre-amp settings.

Throughout the power ranges shown in Figure 5, the power indicated by the PXA, P_{TRFL}, is subjected to the following sources of measurement uncertainty:

- $u_{LIN}(P_{TRFL})$ = Uncertainty due to the detector linearity
- $u_{SNR}(P_{TRFL})$ = Uncertainty due to the residual noise
- $u_{RANGE}(P_{TRFL})$ = Uncertainty of the range-to-range cal factor

This section will describe the derivation of these uncertainties which contribute to the TRFL accuracy specifications.

Detector Linearity

For the PXA, there are no factory or field adjustments for detector linearity. Its value depends directly on the accuracy of the analog-to-digital converter (ADC) in the PXA.

The uncertainty due to the detector "nonlinearity" arises from five distinct mechanisms in the PXA system:

a. Single-tone compression in the conversion chain

The nonlinear behavior of the front-end of the signal/spectrum analyzer can be described as compression. Compression begins when the plot of output level vs. input level begins to deviate from a linear relationship. As the input power level increases, the output level begins to flatten out, and it takes significant increases in input level to produce steady increments in output level. Compression in the PXA is caused primarily by the conversion chain (mixers and amplifiers). If the power level at the first mixer is limited to ≤ -28 dBm, the uncertainty created by compression has been determined to be less than 0.002 dB.

$$u_{COMPR} = 0.002\ dB$$

The N5531X measurement algorithm adjusts the amount of PXA input attenuation to maintain input mixer level at or below –28 dBm.

b. Crystal filter hysteresis

The PXA uses single-pole crystal filters of different bandwidths in the final analog IF stage. Crystal filters suffer from a "hysteresis effect", wherein their loss depends on their signal-level exposure history. This problem is well known, and designers take precautions to keep the drive level to the crystal filter low enough to minimize this effect. This hysteresis effect decreases as the bandwidth of the crystal filter increases. In the worst case, a crystal filter can have hysteresis as large as 0.04 dB. This level is assured by the factory and field-calibration testing of the scale fidelity.

The effect of hysteresis models as "ΔESR with drive", the change in the crystal filter's equivalent series resistance with drive level. When the bandwidth of the analyzer increases from the narrowest settings, the effect of the ΔESR decreases proportionately. The linearity of the PXA is tested with the narrowest crystal-filter bandwidths.

Due to the uncertainty caused by the hysteresis effect, the crystal filter paths in analog IF are not selected in TRFL measurement mode. Instead, the PXA is controlled to apply LC filters in analog IF to the measurement. The resulting uncertainty is due to crystal filter elimination.

$$u_{HYST} = 0.000\ dB$$

c. Processing resolution

Trace processing in the PXA generates an error due to quantization that can be as large as 0.001 dB.

$$u_{TRACE} = 0.001\ dB$$

d. ADC-range rain alignment

The ADC input conditioning in PXA is a single fixed gain stage; there is no error due to gain switching in front of the ADC.

$$u_{ADC\_GAIN} = 0.000\ dB$$

e. ADC linearity

The ADC is guaranteed by its manufacturer to have an integral linearity error of less than six-part in 2^{16}. The PXA employs a “dithering signal” technique to enhance the ADC linearity. The dither signal is a triangular wave with pseudo-random frequency modulation at 18.75% of a full-scale level. The effect of this dither signal can be modeled as a transfer function that is the convolution of the ADC transfer function with the probability density function of the dither signal. The ADC transfer function in the worst case has a positive linearity for a signal just above zero and a negative linearity for signals just below zero. Even with this nonlinearity, the slope variation of the effective ADC transfer function does not exceed 0.004 dB. This is illustrated in the figures below.

$$u_{ADC\_LIN} = 0.004\ dB$$

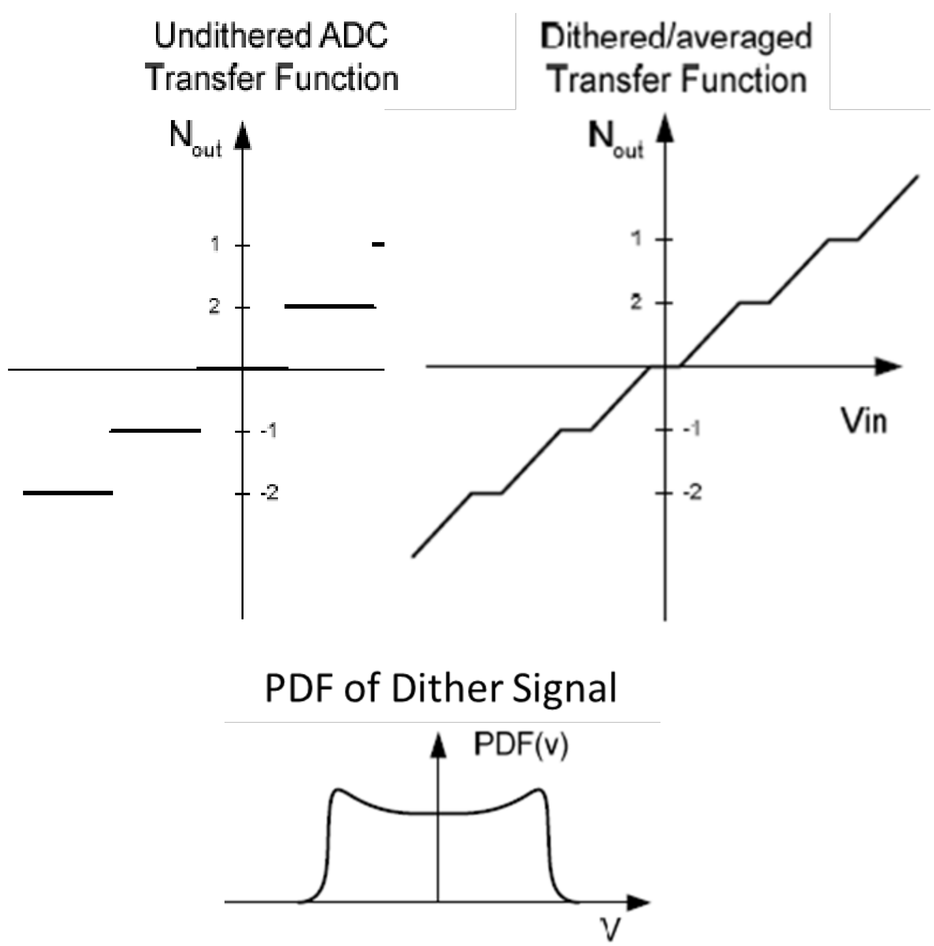

Figure 6. ADC linearity

f. Combined uncertainty for detector linearity

As a conservative estimate of the total uncertainty due to the detector linearity, the worst case linear sum of the contributors listed above is:

$$u_{LIN}(P_{TRFL}) = u_{COMPR} + u_{HYST} + u_{TRACE} + u_{ADC\_GAIN} + u_{ADC\_LIN}$$

$$u_{LIN}(P_{TRFL}) = 0.002\ dB + 0\ dB + 0.001\ dB + 0\ dB + 0.004\ dB = 0.007\ dB$$

When the uncertainty is computed, as shown, instead of demonstrated, there is always the risk that additional error contributors exist but have not been discovered or included in the sum. To minimize risk, many analyzers were tested against calibrated reference attenuators. These reference attenuators had errors of their own that increased with the amount of attenuation. This verification technique still allowed risk that unknown errors might exist in the PXA that are not included in this analysis. To cover that risk, the PXA is specified to have another component of error. That component is ±0.003 dB/10 dB. To be conservative, we added margins to both terms discussed above. The final combined linearity specification appears below:

$$u_{LIN}(P_{TRFL}) = 0.009\ dB\ \pm 0.005\ dB/10\ dB$$

The specification also meets the linearity specification of the legacy N5531S, the predecessor of the N5531X, ensuring the smooth migration from the N5531S to the N5531X.

Residual Noise

The indicated TRFL power is due to the sum of the signal power at the frequency of interest and the noise power within the selected resolution bandwidth. For high values of signal-to-noise ratio (≥ 40 dB), the noise has a negligible effect on the displayed amplitude of the signal. When the signal-to-noise ratio (SNR) drops below about 20 dB, the noise becomes a significant component of the indicated value of the signal.

At low SNR, the instantaneous, indicated value of a steady CW signal is continually changing due to the additive and subtractive effects of the noise. The PXA indicates the combined power of the signal plus noise: P_{S+N}. To make a precise estimate of just the signal power, P_S, we need to eliminate the mean error due to noise and minimize the fluctuation due to the noise.

The PXA acts to minimize the fluctuation due to the residual noise by averaging the combined $P_S + P_N$ and to eliminate the mean error due to the noise by performing a subtraction:

$$P_S = P_{S+N} - P_N\,[dB]$$

where: P_{S+N} is the power in the signal plus noise

P_N is the power in the residual noise alone

After the mean error is subtracted, the fluctuations remain. The mean error subtraction process has errors due to the imperfect estimation of the noise, but these errors are much smaller than the errors due to noise fluctuations even with large amounts of averaging. Therefore, the rest of this section will deal with the noise fluctuations only.

The analyzer is set up in various ways according to the signal-to-noise ratio. Our interest here is in the most difficult, low signal-to-noise ratio cases. In these cases, the measurement is made by averaging a zero-span sweep with a sweep time computed as 10/RBW, and with the maximum number of such traces averaged automatically selected by the software (to keep the measurement time from growing without bound), which is 900.

The signal-to-noise ratio can be used to compute the standard deviation of the averaged traces. First, you must calculate the standard deviation of each trace. To do that, start with the standard deviation of the instantaneous measurement of a CW signal with noise. The noise added to a CW signal is random. Therefore, its phase relative to the CW component is random. We can describe this noise in several ways —one takes into account its magnitude and phase distribution, another involves its real and imaginary components. The most useful way is to look at a rotated version of its real and imaginary components in which we can decompose it into two random components—one component is in-phase with the CW signal, and one is in quadrature. Each of these components has the same average power. Therefore, each one has 3 dB less power than the total noise. When the signal-to-noise ratio is large, the quadrature component adds negligibly to the variation in measured level. So the relevant noise is the in-phase component with half the total noise power.

The standard deviation of the envelope voltage of the in-phase component is equal to the voltage computed from its total power. With this information, the standard deviation of the instantaneous envelope voltage calculation. Let's start with a noise voltage sinusoid, of level v, that expresses in decibels relative to the signal power that may either add to or subtract from the carrier power. The error associated with v is:

$$Error_{dB} = 20 \cdot log_{10}\left(1 \pm 10^{v/20}\right)$$

For small values of v, the error linearly relates to v. You can do a Taylor-series expansion for the error equation:

$$Error_{dB} \approx \Delta v \cdot \frac{d}{dv}\left(20 \cdot log_{10}\left(1 + 10^{v/20}\right)\right)$$

The latter term, 20log(e), is 8.69 dB, also known as 1 neper.

Substituting in the voltage error (from the signal-to-noise ratio) for v, we can compute the standard deviation of our measurement:

$$\sigma_{CW} = (8.69\, dB) \cdot 10^{-\frac{SNRatio + 3.01}{20}}$$

This expression is slightly conservative compared to a full statistical treatment using Rician distributions, but it is useful for our purposes. This standard deviation is reduced by filtering. The filtering comes from averaging the result for a duration of 10/RBW. How much filtering does that give us?

The distribution of the noise of the detected signal description with a noise bandwidth of half of the predetected signal. The noise bandwidth of the predetected signal is 1.056 times the RBW for our very close to Gaussian RBW filters. The noise bandwidth of the averaging process is $1/(2 \cdot t_{INT})$, where t_{INT} is the integration time.

The standard deviation of the filtered envelope is reduced by the square root of the ratio of the noise bandwidth of the signal to the noise bandwidth of the averaging process. Therefore:

$$\sigma_{TRACE} = \frac{8.69\ dB}{\sqrt{t_{INT} \cdot NBW_{RBW}}} \cdot 10^{-\frac{SNRatio+3.01}{20}}$$

Given that t_{INT} = 10/RBW, and that NBW_{RBW} = 1.056 · RBW, we get:

$$\sigma_{TRACE} = 2.67\ dB \cdot 10^{\frac{SNRatio+3.01}{20}}$$

When we average this 900 times, the standard deviation improves by the square root of 900, which is a factor of 30:

$$\sigma_{AVG} = 0.0891\ dB \cdot 10^{\frac{SNRatio+3.01}{20}}$$

We can express the total error in this format instead:

$$Error = 0.0012 \cdot (SNRatio - 30)^2$$

SNRatio − 30 dB is the same as input power minus residual noise threshold power. For SNRatio values in the 0 to 30 dB range, the 3σ result is under 0.01 dB, or the error expression is conservative relative to three standard deviations.

The table below demonstrates the numerical relationship:

Range	3 x Standard deviation (dB)	Error expression (dB)
30	0.006	0
25	0.011	0.03
20	0.019	0.12
15	0.034	0.27
10	0.060	0.48
5	0.106	0.75
0	0.189	1.08

Table 2. Signal to noise ratio error

This error expression is used as an error component of both the absolute and relative TRFL accuracy expressions as shown in N5531X Measuring Receiver Chapter of the PXA Specifications Guide.

Range-to-Range Cal Factor

As we discussed previously (in section 3.3.2), the TRFL measurement with the PXA spans three amplitude ranges. This section will explain the errors in each of those three ranges. The allocation of measurement ranges is according to the input signal level; Figure 3.

The power level at the first mixer of the PXA stays at ≤ -28 dBm. Optimized power level is achieved by manipulating the input attenuator of the PXA and internal preamplifier settings to avoid error due to signal compression.

Example: If the signal power level at the input of the N5532A/B sensor module is 0 dBm, then the nominal power level at the PXA input will be −7 dBm (due to the power splitter loss). The internal attenuator of the PXA must be set to 21 dB or more to ensure that the power level never exceeds −28 dBm at the mixer. By maintaining this attenuator setting, the PXA mixer always identifies a level that is 28 dB lower than the level at the sensor module input.

Range-to-range cal factor uncertainty

Cal factor 1

Cal factor 1 applies in Range 1, Range 2, and Range 3. It accounts for the difference in reading between the power meter and the PXA for a fixed power level measured in Range 1. Cal factor 1 is determined as follows:

1. The power level of the signal is measured in Range 1 by the N5532A/B sensor module and the P-Series or EPM Series power meter. The value is stored as $P_{PM\,1}$ (in dBm);
2. The PXA is set to Range 1 (the internal attenuator is set to 30 dB) and the same power level is measured by the PXA, via the N5532A/B connection. The value is stored as P_{PXA1}.
3. $CalFactor1 = P_{PM1} - P_{PXA1}[dB]$

The uncertainty of Cal Factor 1 is

$$u^2(CF1) = {C_1}^2 \cdot u^2(P_{PM1}) + {C_2}^2 \cdot u^2(P_{PXA1})$$

where C_1 and C_2 are sensitivity coefficients given by:

$$C_1 = \frac{\partial(CF_1)}{\partial P_{PM1}} = 1 \text{ and } C_1 = \frac{\partial(CF_1)}{\partial P_{PXA1}} = 1$$

Therefore, $u^2(CF1) = u^2(P_{PM1}) + u^2(P_{PXA1})$

The uncertainty value $u(P_{PM1})$ is given as 0.086 dB.

$$u(P_{PM1}) = 0.086\ dB$$

The uncertainty value $u(P_{PXA1})$ is dependent only on the marker readout resolution. All other PXA uncertainties are eliminated by the comparison of the power meter reading to the PXA reading.

So, $u(P_{PXA1})$ can be expressed as:

$$u(P_{PXA1}) = u(MKR)$$

Where, *u(MKR)* is the marker readout accuracy (?). From the PXA datasheet, u(MKR) = 0.001 dB, with averaging ON.

Because this parameter is specified in dB, we will assume that it was determined from data taken in dB. The marker readout value is a quantized value that is assigned to the power level within a distinct vertical-scale "bucket". Any value that falls within the boundaries of this "bucket" will be assigned the same amplitude value. Conversely, the probability that any value within the bucket boundaries caused the reading is the same. This situation is best described by a uniform probability distribution (i.e., every value in the "bucket" interval is equally likely and will be assigned the same value by the PXA).

For a uniform distribution, the standard deviation is:

$\sigma_{UNIFORM} = \frac{w}{\sqrt{12}}$, where w is the width of the uniform distribution.

So, the standard uncertainty of a true value that falls within a particular amplitude bucket is equal to:

$$u(MKR) = \sigma_{MKR} = \frac{0.001\ dB}{\sqrt{12}} = 0.0003\ dB$$

The uncertainty of the Range 1 Cal Factor is then:

$$u^2(CF1) = u^2(MKR) + u^2(P_{PM1})$$

$$U_C{}^2(CF1) = (0.0003\ dB)^2 + (0.086\ dB)^2$$

$$U_C(CF1) = 0.086\ dB$$

If a relative TRFL measurement is being made, then Cal Factor1 is 0 dB.

Cal factor 2

Cal factor 2 applies in Range 2, and then contributes in Range 3 as well. It accounts for the change from Range 1 to Range 2. Cal factor 2 is determined as follows:

1. The power level of the signal is measured in Range 1 and the value is stored as P_{R1}(in dBm);
2. The PXA is switched to Range 2:
   a. The preamp remains OFF
   b. The internal attenuator is changed from 30 dB to 10 dB
3. The power level of the signal (unchanged) is measured again, now in Range 2, and is stored as P_{R2} (in dBm).

$$CalFactor2 = P_{R1} - P_{R2} [dB]$$

The uncertainty in Cal factor 2 is due entirely to the noisiness of the pair of measurements that compare Range 2 and Range 1.

The transition between ranges is constrained to occur at a signal-to-noise ratio of 22 dB or more, therefore, 22 dB is the worst case. We have offered a brief computation of uncertainty due to this noise here because the computation process was thoroughly explained in the "Residual Noise" section. With 22 dB signal-to-noise ratio, the in-phase noise is 25 dB below the CW signal, giving a standard deviation error of:

$$\sigma_{single} = 8.69\ dB \cdot 10^{-\frac{25}{20}}$$

This standard deviation is reduced by the square root of the number of averages (900) to give a standard deviation of 0.0158 dB. The signal is measured again in Range 2, but the signal-to-noise ratio is 100 times better, so when the standard deviation of that measurement is combined with the standard deviation of this measurement, the effect is negligible.

To compute the 95% confidence interval due to this noise, we multiply the standard deviation by 1.96 and get an interval of ±0.031 dB. Therefore, ±0.031 dB can be said to be the 95% confidence result for the worst-case signal-to-noise ratio. The signal-to-noise ratio is likely to be any value between 22 and 32 dB. When we compute the probability of the noise causing an error outside the range of ±0.031 dB, we find the result is within this error 99.3% of the time. Unlike other specifications for this product which are worst-case specifications, this one is 99.3% confidence specification. This specification is suitable because it is never used by itself, only in combination with other terms which are themselves quite large, so that statistical combining leaves very little risk of failing to meet specifications.

Cal factor 3

Cal factor 3 applies in Range 3 only and accounts for the change from Range 2 to Range 3. Cal factor 3 is determined as follows:

1. The power level of the signal is measured in Range 2 and the value is stored as P_{R2} (in dBm);
2. The PXA is switched to Range 3:
   a. The preamp is turned ON;
   b. The internal attenuator is changed from 10 dB to 4 dB.
3. The power level of the signal (unchanged) is measured again, now in Range 3, and is stored as P_{R3} (in dBm).

$$CalFactor\ 3 = P_{R2} - P_{R3} [dB]$$

The derivation of Cal factor 3 is the same as that of Cal factor 2. The only difference is that the noisiness of the measurement in Range 3 is nominally 40 times lower than the noisiness of Range 2, compared with a factor of 100 in the former derivation. Both these noise ratios give negligible contribution to the uncertainty.

A measurement made in Range 3 will involve CF1, CF2 and CF3. The uncertainty of these combined cal factors will be:

$$u_{RANGE}(P_{TRFL}) = \sqrt{u^2(CF1) + u^2(CF2) + u^2(CF3)}$$

Measurements made in Range 2 or Range 1 will have smaller values of overall range-to-range uncertainty.

Combined uncertainty for P_{TRFL} measurement

Since the effects of linearity, range offset, and signal-to- noise ratio are independent of one another, the combined uncertainty can be expressed as:

$$u_C{}^2(P_{TRFL}) = u_{LIN}{}^2(P_{TRFL}) + u_{SNR}{}^2(P_{TRFL}) + u_{RANGE}{}^2(P_{TRFL})$$

The worst case combined uncertainty is linear summation of all the error sources above.

$$u_C(P_{TRFL}) = u_{LIN}(P_{TRFL}) + u_{SNR}(P_{TRFL}) + u_{RANGE}(P_{TRFL})$$

From this equation, it is clear that the overall uncertainty of an indicated TRFL measurement made by the N5531X is dominated by the PXA linearity and range offsets until the signal level nears the level of the noise.

Summary

Tuned RF Level measurement is one of the most crucial functions that a measuring receiver offers. The Keysight N5531X measuring receiver integrates the N9030B PXA high performance signal analyzer with a specially designed USB sensor module or alternatively, with a precision P-Series or EPM Series power meter and a legacy N5532A/B sensor module to achieve excellent measurement accuracy capable of meeting the challenging requirements of metrology/calibration applications. The exceptional sensitivity of the N5531X TRFL measurements enables users to calibrate step attenuators and signal generators with the widest dynamic range within the required measurement uncertainty and speed.