RF power calibration at Rohde & Schwarz

During development of its RF T&M equipment, Rohde & Schwarz takes great care to ensure that the displayed measurands are perfectly traceable to recognized national standards. This article* discusses the calibration of the measurand referred to as RF power. Since time is of the essence in a production environment, Rohde & Schwarz has developed a new technique that makes it possible to calibrate production systems significantly faster – with even higher accuracy.

RF power – an essential physical quantity for T&M equipment from Rohde & Schwarz

Spectrum analyzers, signal generators, radiocommunications testers, and network analyzers all have one thing in common: They can be used to measure the absolute power level of RF signals or to generate such signals with an exact level. Since high level accuracy – like high frequency accuracy – is a key property for many RF T&M instruments, power calibration plays an important role at Rohde & Schwarz. It must fulfill three conditions:

1. Power calibrations (like other calibrations as well) must be fully traceable to the standards of a national metrology institute.
2. When transferring power, the accuracy loss must be minimized at each stage of the calibration chain.
3. Power calibrations must be performed quickly but with the required accuracy since they represent the largest share of the total calibration effort.

All three conditions can be best fulfilled using power meters, which is why these instruments are encountered at many points in the production process. Calibration of the power of RF T&M instruments almost always involves a simple power comparison between the power meter and the device under test. In the case of sources, the power sensor is connected directly to the output. For receiver calibration, either a power divider is inserted or the measurement is made using a level control sensor from the R&S®NRP-Z28/-Z98 series. That is all that is actually involved in calibrating an RF T&M instrument. However, calibrating the power sensors themselves requires considerably more effort.

* An article by Germany´s National Metrology Institute (Physikalisch-Technische Bundesanstalt, PTB) starting on page 28 discusses how RF power, an important measurand for Rohde & Schwarz, is traced back to the national primary standard of the Federal Republic of Germany.

Traditional approach: the classic calibration chain at Rohde & Schwarz

The classic calibration chain for thermal power sensors of the R&S®NRV family has two stages (FIG 1): Depending on the frequency range, the sensor to be calibrated is tested using one or more calibration systems. These calibration systems are directly traceable to primary standards, e.g. to standards of Germany´s National Metrology Institute (Physikalisch-Technische Bundesanstalt, PTB) or the American National Institute of Standards (NIST). To ensure their traceability, these calibration systems are regularly compared with highly accurate reference standards which themselves are sent every one or two years to one of the national institutes where they are calibrated with considerable effort. Basically, this process is still in place today. Although this concept might sound appealing due to the short calibration chain, it is no longer up-to-date – mainly because of the reference standards that are used.

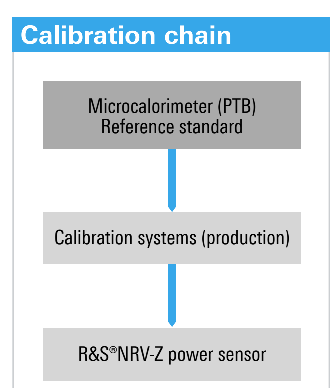

FIG 1 Calibration chain for power sensors of the R&S®NRV family. Microcalorimeter and reference standard form a national primary standard.

These reference standards must meet high requirements. First, they need to be reproducible, stable over the long term and compatible with the primary standards from national institutes. Second, they need to make it possible to test the company's internal calibration systems quickly and, most importantly, without major loss of accuracy. It is difficult to fulfill both requirements at the same time for two reasons: Compatibility with the calibration equipment used by national institutes means that only very specific types of power sensors can be used as reference standards, i.e. power sensors based on thermistors, which have not been used in industrial testing for many years now. Calibration of a production system also requires a large number of measurements in order to ensure the necessary process reliability or to cover wider frequency ranges. However, the slow thermistor power sensors need a great deal of time to accomplish these tasks. Another problem is that due to the close connection to the reference standards, each of the existing calibration systems only covers the frequency range of the reference standard. For example, to calibrate a 40 GHz R&S®NRV-Z55 sensor, the sensor had to be connected to three different systems.

In terms of accuracy, the result is also less than first-rate. Since thermistor power sensors are poorly matched by their very nature, relatively large mismatch uncertainties arise when calibrating production systems. This means that even immediately after calibration, these systems are significantly less accurate than the corresponding reference standards.

Faster and more accurate with gamma correction

In production, however, calibration time and achievable accuracy are both critical. To reduce the accuracy losses and calibration time, the only solution is therefore to test the calibration systems for power sensors using state-of-the-art power sensors instead of classic reference standards. However, this actually lengthens the calibration chain – an apparent paradox.

The key to solving this problem involves correcting the measurement errors caused by mismatch. These measurement errors can be computed with great accuracy if the complex reflection coefficients of the sensor and the calibration system are known. Then, the results only have to be taken into account in the final result. This technique is known as gamma correction – from the Greek uppercase letter gamma (Γ) that is the usual symbol for complex reflection coefficients. This technique makes it possible to rapidly perform power calibrations with extremely low loss of accuracy.

For an impressive example, see FIGs 2 and 3. If the output power of conventional RF or microwave generators is measured using a power sensor, the mismatch on both ends will normally make the largest uncertainty contribution, which is typically well above the measurement uncertainties specified in the sensor data sheet. Using gamma correction, this error source disappears almost completely, and the overall measurement uncertainty is equal to the power sensor's measurement uncertainty.

The obvious question at this point is: Why was gamma correction not used earlier for power calibrations? The reason is that not the actual correction but rather the determination of the complex source reflection coefficients caused problems. This measurement places specific demands on the source and

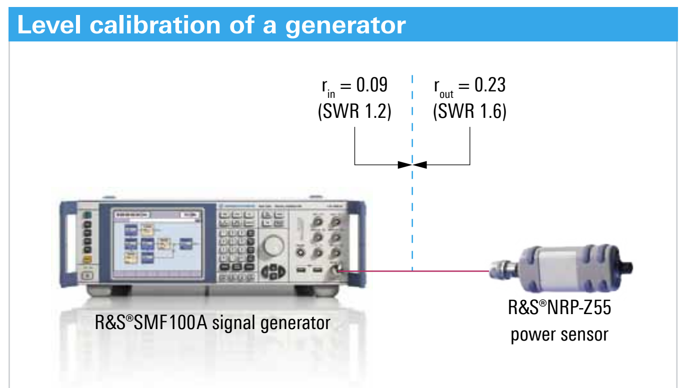

FIG 2 Level calibration of an R&S®SMF100A generator using an R&S®NRP-Z55 power sensor as the reference. The maximum measurement error due to mismatch is 0.18 dB at 18 GHz (without gamma correction).

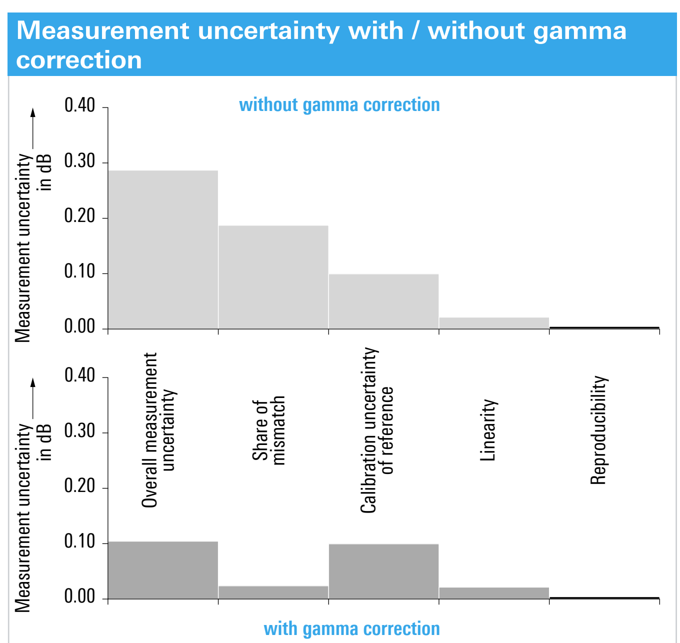

FIG 3 Measurement uncertainty with and without gamma correction for the example in FIG 2 (calibration level –10 dBm).

must also be performed with great accuracy since otherwise a contrary effect will occur. Rohde & Schwarz has managed to overcome this problem through its pioneering work. The power sensors of the R&S®NRP family can now be calibrated with great accuracy and at high speed using entirely redesigned calibration systems.

The new technique in detail: the calibration chain for power sensors of the R&S®NRP family

Through consistent correction of the mismatch influence, it is possible to introduce two additional calibration steps without causing an increase in the measurement uncertainty of the power sensors (FIG 4). The test systems are no longer calibrated using the old, time-consuming method involving reference standards with their associated loss of accuracy. Instead, company-internal transfer standards are used based on state-of-the-art power sensors. Since today's production systems are also designed to provide the entire frequency range of a sensor type on one test port, it is an obvious choice to also perform the calibration of the production system in one step. In the case of a 40 GHz system, for example, the benefit is that instead of three reference standards for the frequency bands from 10 MHz to 18 GHz, 18 GHz to 26.5 GHz, and 26.5 GHz to 40 GHz, only a single transfer standard needs to be connected for the entire frequency range.

A specially designed reference system has been developed to allow calibration of the highly accurate transfer standards based on the thermal sensors from the R&S®NRP family. This reference system is operated by German Calibration Service (DKD) laboratory 16101 at Rohde & Schwarz in accordance with purely metrological criteria (see box on right). The reference system contains a specially configured power reference for each reference standard. This is a source that can be calibrated and that has the same frequency range and the appropriate connector. Above 18 GHz, waveguides must be used. Currently, the system contains five power references covering the frequency range from 100 kHz to 75 GHz. The measurement uncertainties of the power references are only slightly above those of the reference standards since gamma correction is used in the calibration process and calibration is based on multiple reference standards of the same type. This increases the reliability of the process (keyword: outliers) and reduces the effects of stochastic influences.

Depending on the frequency range, the company's internal transfer standards are calibrated on one or more power references. Different adapters must be used depending on the connector type used by the coaxial transfer standard. However, since the adapter influences can be taken into account almost fully using an enhanced gamma correction, the transfer standards also achieve an extremely low measurement uncertainty. As a result, calibration of the production systems

Calibration chain for R&S®NRP power sensors

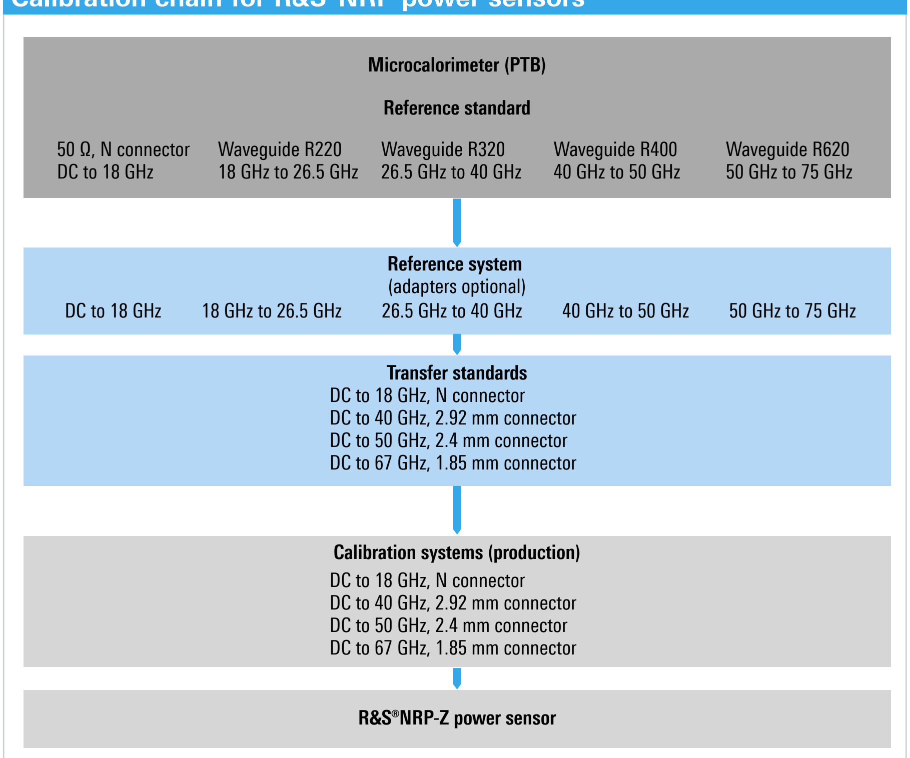

FIG 4 Calibration chain for power sensors of the R&S®NRP family. The calibration stages that are new in comparison to the classic approach are shown with a blue background.

for R&S®NRP sensors is fast and broadband and uses the connector type of the test system. This helps to considerably reduce downtime in production and also simplifies recalibration and improves reliability by eliminating the need for adapters. Moreover, the method is more accurate than the previous approach.

To prove the correctness of the calibration technique, the measurement method and the measurement uncertainties it produces were checked and confirmed by independent experts who performed comparison measurements as part of the accreditation process for the German Calibration Service (DKD).

Dr. Gerhard Rösel

Power references – highly accurate signal sources and one-port vector network analyzers all in one

The power references now used in DKD laboratory 16101 at Rohde & Schwarz have little in common with the systems used around the world until now as the standard setup for accurate power calibration. One-port vector network analyzers are used, and their output level is stabilized using built-in power sensors (FIGs 5 and 6). Accordingly, these systems are suitable for performing power comparisons and can also determine the reflection coefficient of the connected sensor and their own source reflection coefficient (both in complex notation). This means that everything needed for gamma correction is already available, helping to achieve the highest level of accuracy.

The RF power (measurand) is transferred from the reference standard to a company-internal transfer standard in four steps:

1. Determination of the complex reflection coefficients of the sensors and the source. The equivalent source reflection coefficient is determined using a Juroshek setup where a one-port calibration with OSM impedance standards is performed on the test port.
2. Calibration of the power reference using multiple reference standards of the same type, and averaging of the calibration factors.
3. Calibration of all four S-parameters of the adapter (if needed for the transfer standard).
4. Calibration of the transfer standard. To cover the entire frequency range of a transfer standard, the standard is connected to multiple power references in sequence.

FIG 5 Part of the reference system at Rohde & Schwarz.

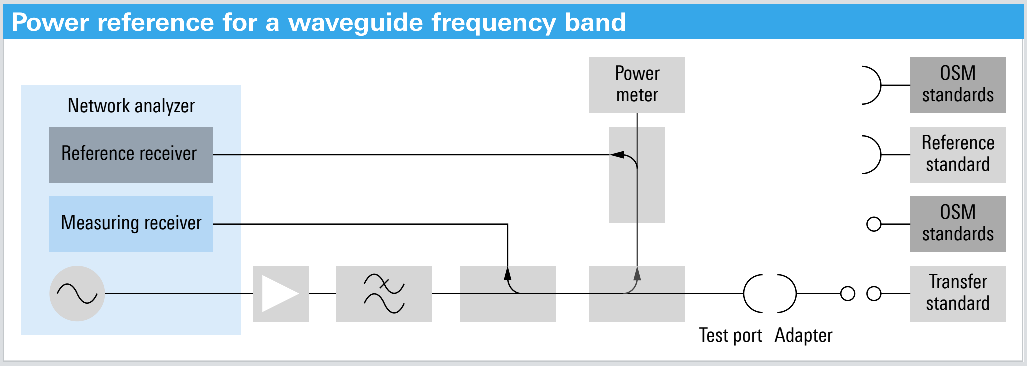

FIG 6 Block diagram of a power reference for a waveguide frequency band.