ROHDE & SCHWARZ

Test and Measurement
Division

Manual

Thermal Power Sensor

NRV-Z51 (0 ... 18 GHz)

0857.9004.02/.04

NRV-Z52 (0 ... 26.5 GHz)

0857.9204.02

NRV-Z55 (0 ... 40 GHz)

1081.2005.02

Printed in the Federal
Republic of Germany

ROHDE&SCHWARZ
EC Certificate of Conformity

CE

Certificate No.: 9502231

This is to certify that:

Equipment type	Order No.	Designation
NRV-Z1	0828.3018.02/.03	Power Sensor
NRV-Z2	0828.3218.02/.03	"
NRV-Z3	0828.3418.02/.03	"
NRV-Z4	0828.3618.02/.03	"
NRV-Z5	0828.3818.02/.03	"
NRV-Z6	0828.5010.02	"
NRV-Z15	1081.2305.02	"
NRV-Z31	0857.9604.02/.03/.04	Peak Power Sensor
NRV-Z32	1031.6807.04/.05	"
NRV-Z33	1031.6507.03/.04	"
NRV-Z51	0857.9004.02/.04	Thermal Power Sensor
NRV-Z52	0857.9204.02	"
NRV-Z53	0858.0500.02	"
~~NRV-Z54~~	~~0858.0800.02~~	~~"~~
NRV-Z55	1081.2005.02	"

complies with the provisions of the Directive of the Council of the European Union on the approximation of the laws of the Member States

- relating to electromagnetic compatibility
  (89/336/EEC revised by 91/263/EEC, 92/31/EEC, 93/68/EEC)

Conformity is proven by compliance with the following standards:

EN50081-1 : 1992
EN50082-1 : 1992

Affixing the EC conformity mark as from 1995

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Contents

1 Characteristics

1.1 Application

Power sensors NRV-Z51, NRV-Z52 and NRV-Z55 are thermal power sensors for basic instruments NRVS, NRVD, URV35 and URV55. They permit power measurement from 1 µW to 100 mW within the frequency ranges DC ... 18 GHz (NRV-Z51), DC ... 26.5 GHz (NRV-Z52) or DC ... 40 GHz (NRV-Z55) in systems having a characteristic impedance of 50 Ω.

The thermal conversion principle always permits measurements of the RMS value independently of the waveform and modulation of the test signal. Depending on whether the measured value is output as a power and/or a power level or as a voltage, the average power (and/or the equivalent power level) or the RMS value of the voltage is displayed.

All measuring heads are d.c. coupled so that even power in the audio-frequency range can be measured.

1.2 Design and Functioning

The power sensor contains a thermo-electric transducer made of silicon by means of semiconductor technology. Due to the power supplied, the 50-Ω termination situated on it heats up. Immediately next to this resistor there is a thermoelement generating a direct voltage proportional to the heating. As termination and thermoelement are dc-decoupled, the power sensors do not contain coupling capacitors. This means that even d.c. powers can be measured, and there is no lower cut-off frequency below which matching and frequency response deteriorate again.

The direct voltage generated by the thermoelement is amplified by a low-noise amplifier of high sensitivity within the sensor and supplied to the basic unit for further processing.

All power sensors contain a data storage in which the parameters obtained during calibration in production are stored in a non-volatile memory. The basic instrument reads out these data and takes account of them when indicating the power measured.

Linearity correction of the measured values is effected automatically with the aid of the correction coefficients stored. For temperature correction, the temperature of the measuring head is evaluated additionally via a temperature sensor. For measurements with frequency response correction, the measuring frequency must be entered via keyboard, remote control interface or an analog control input.

2 Preparation for Use

The measuring head is connected to the basic unit by inserting the plug-in adapter into the opening of the basic unit and locking it into position. This can be done with the unit being switched off or on. Each turn on of the basic unit with the measuring head connected or connecting the measuring head to the basic unit when it is switched on results in the calibration data being read out from the data memory of the measuring head.

Notes for Operation:

- Maximum input power 100 mW
- Ambient temperature 0 ... 50 °C
- Connect RF connection to the signal source only by hand and without fitting it askew
- Avoid condensation. Should condensation occur nevertheless, the power sensor is to be dried before switching on the unit.
- Overloading up to 300 mW is permissible, however, the power is not indicated any more.
- When measuring power below 300 µW, let sensor warm up (approx. 10 min), avoid heating up of the measuring head due to heated RF connections of the signal source.
- Calibration applies to power at the RF connector of the power sensor. Adapters situated between sensor and signal source result in additional attenuation and measuring errors due to worse matching with higher frequencies.

3 Operation

3.1 Measuring by means of Power Sensors NRV-Z51, NRV-Z52 and NRV-Z55

3.1.1 Power and Voltage Measurement

Thermal power meters measure the arithmetic mean value of the product of the instantaneous values of voltage and current. This exactly corresponds to the definition of electric true power.

$$P = \frac{1}{T} \int_0^T u \cdot i \cdot dt$$

This means that in the entire control range always the actual true power is measured independently of the waveform of the signal.

If a voltage display is selected at the basic unit, the voltage is calculated from the power measured:

$$U = \sqrt{P \cdot Z_0} \qquad (Z_0 = 50\ \Omega \text{ for NRV-Z51/-Z52/-Z55})$$

V is calculated as the RMS value of a sinusoidal voltage generating the power P at the effective resistance Z_0.

3.1.2 Power Measuring Ranges

The entire measuring range is divided up into five subranges with power sensors NRV-Z51/-Z52/-Z55:

0 ... 10 µW

10 ... 100 µW

0,1 ... 1 mW

1 ... 10 mW

10 ... 100 mW

Basic instruments NRVD and NRVS allow measurement using automatic or manual range selection.

Using automatic range selection (AUTO RANGE) the unit itself sets the suitable measuring range depending on the test level. In the case of manual range selection (FIX RANGE) the user can set a fixed measuring range. Thus the automatic resetting of the most sensitive measuring range with each temporary taking away the measured power can be prevented.

3.1.3 Measurement Rate and Noise

The smaller the test signal, the greater the effect of noise inevitably occurring in electronic circuits. It results in fluctuations of the indicated value. In order to achieve a high measuring accuracy, a filtering of the test signal is necessary. However, the more effective this filtering has to be, the more the measuring rate decreases.

Basic units NRVD and NRVS offer the possibility of measuring by means of automatic or manual filter setting.

With automatic filter setting it is guaranteed that the optimal filter is set depending on the measuring range and the display resolution the user has selected. The measuring rate results from filter setting. Very small test signals (that is to say, a low measuring range) and a high display resolution require the most effective filtering and thus result in the smallest measuring rate.

If automatic filter selection does not seem to be optimally adapted to a specific measurement, that is to say, e.g., a higher measurement rate (deteriorating display noise) is demanded, another filter can be set manually.

The connection between filter number, measuring period and noise can be taken from the Specifications.

3.1.4 Zeroing

When measuring low power, an additive offset - of positive or negative polarity -, as it results, e.g., due to thermo-electromotive force at the measuring head, can invalidate the measurement result. In zeroing the offset is measured, stored and subtracted from the following measured values.

Notes for Zeroing

- No power to be measured must be applied to the measuring head.
- After measuring large powers, wait until the indicated value has become stable before starting zeroing.
- Do not move the sensor cable to a large extent during zeroing.
- In the case of changing ambient temperatures or when the instrument has not yet warmed up completely, check zeroing without a power to be measured applied from time to time and repeat if necessary.
- Ground loops can result in external offsets. If these cannot be completely eliminated by means of correct grounding, the sensor remains connected to the signal generator (with the power to be measured switched off) also during zeroing. In doing so, the external offset is recorded as well and considered in calculating the indicated value.
- The zero offset is not stored after switching off the instrument. Thus it should be carried out after each switching on.

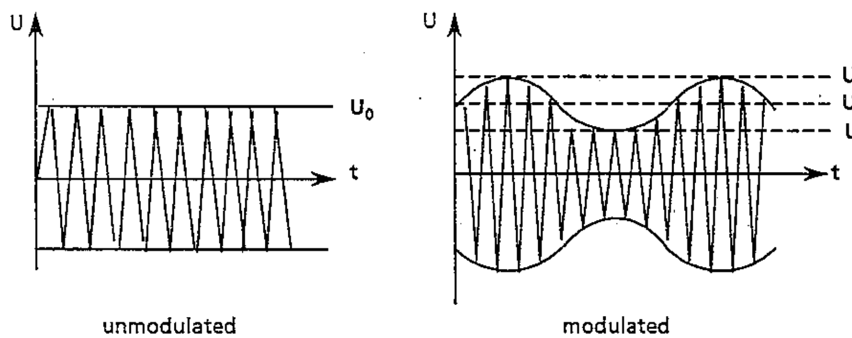
3.1.5 Frequency Response Correction

The frequency response of every power sensor is individually measured in calibrating and stored as a calibration factor (ratio of indicated power to power supplied) in the data memory of the sensor for a plurality of frequencies. Frequency response correction is considered by entering the test frequency into the basic unit. If the frequency entered is between two calibration frequencies, the respective calibration factor is calculated by means of linear interpolation. For power sensors NRV-Z51/-Z52/-Z55 the calibration factors refer to the sensor sensitivity at 50 MHz. If measurement is carried out without frequency response correction, the measured value is indicated as if measurement was carried out at 50 MHz.

3.1.6 Measurement of Modulated Signals

The capability of thermal measuring heads of measuring the average power also in the case of arbitrarily modulated signals allows, together with the basic unit NRVD, to determine the modulation depth in the case of amplitude-modulated carriers (only NRVD) and the pulse power with pulse-modulated RF (NRVD, NRVS, URV55).

Determination of Modulation Depth:



Time characteristic of signal voltage

Modulation depth is calculated from:

$$m = \frac{(U_2 - U_1)/2}{U_0}$$

In the case of amplitude modulation, two sideband frequencies having the amplitude

$$U = \frac{m}{2} \cdot U_0$$

are formed above and below the carrier frequency, which corresponds to an increase in power.

Unmodulated Power:

$$P_{unmod} = \frac{U_0^2}{Z_0}$$

Modulated Power:

$$P_{mod} = \frac{U_0^2}{Z_0} + 2 \cdot \frac{(U_0 \cdot m/2)^2}{Z_0} = P_{unmod} \cdot \left(1 + \frac{m^2}{2}\right)$$

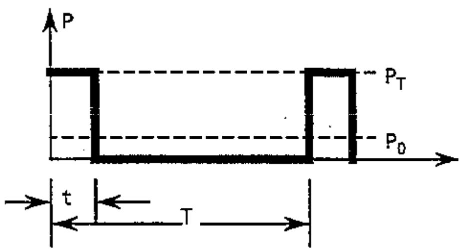
From the power measured using modulation or not, the modulation depth is calculated:

$$m = \sqrt{2 \cdot (P_{mod}/P_{unmod} - 1)}$$

In order to measure the modulation depth exactly it is necessary for the carrier mean value V_0 to remain constant in modulation and for the modulation to be exactly sinusoidal.

Measurement of pulse-modulated power:

The carrier power can be calculated from the pulse duty factor (Duty Cycle) with pulse-modulated signals. To distinguish it from the maximum envelope power to be measured physically (PEP) this value is designated as pulse power.



P_T=Carrier power

P_0= Power measured

For calculating the carrier power it is taken for granted that the energy of the average power P_0 measured during the time T is as large as the energy of carrier power P_T during the time t:

$$P_0 \cdot T = P_T \cdot t$$

$$P_T = \frac{T}{t} \cdot P_0$$

When measuring modulated signals, it has to be noted that the thermal power sensors contain a chopper amplifier whose chopping frequency is approx. 575 Hz. Modulation using this frequency, half, two or three times the value, can result in periodic display variations. In this case the modulation frequency should be slightly varied.

3.2 Measuring Accuracy

Every measurement will inevitably have measuring errors of various causes. The error value actually resulting in any measurement is almost never known. It is only possible to indicate the possible maximal values of the individual errors and calculate limits from these between which the total error can be.

3.2.1 Mismatch

Thermal sensors NRV-Z51/-Z52/-Z55 serve to measure the power a source can supply to a load having the ohmic resistance Z_0. In general, however, the impedance of the source as well as the impedance of the power sensor acting as a load are different from the value Z_0. The error in the power measured resulting from this mutual mismatch is calculated from:

$$E_p = \frac{1 - |\Gamma_l|^2}{|1 - \Gamma_g \cdot \Gamma_l|^2} - 1$$

Γ_g: complex reflection coefficient of the source
Γ_l: complex reflection coefficient of the load

The numerator $1 - |\Gamma_l|^2$ in the above equation results in a fraction defective which is only caused by the load. It is determined by measurement during calibration with the power sensors and is included in the calibration factor (see Section 3.2.2).

A second fraction defective is caused by the denominator $|1 - \Gamma_g \cdot \Gamma_l|^2$. As Γ_l and Γ_g are complex a.c. parameters, the error can become positive or negative depending on their phasing. In general, the amount and phase of reflection coefficient Γ_g of the source are not known, thus the size of this error cannot be indicated in the data sheet and not be calculated in practice either.

However, the error limits can be determined from the maximal values of the amounts of the reflection coefficients. The mismatch uncertainty M_u resulting from mismatch between source and load is calculated in percent of the power:

$$M_u\,[\%] = 100 \cdot [(1 \pm r_g \cdot r_l)^2 - 1]$$

By approximation, the following is true:

$$M_u\,[\%] \approx \pm\, 200 \cdot r_g \cdot r_l$$

r_g: Amount of reflection coefficient of the source
r_l: Amount of reflection coefficient of the load

3.2.2 Calibration Uncertainty

Due to the fact that the reflection coefficient of a power sensor is inevitably larger than zero (and its SWR $>$ 1), part of the power offered to the sensor is reflected. Hence all power sensors are individually measured at a plurality of calibration frequencies during production. The power measured is compared with the one supplied by the calibration system and the relation of both values is stored as calibration factor. When frequency response correction is switched on, the measurement result is set off against the calibration factor belonging to the measuring frequency entered.

All measuring systems for calibrating power sensors used by R&S can be traced to the corresponding primary standards by the Physikalisch-Technische Bundesanstalt PTB (Federal Office for Weights and Measures).

In spite of this, even the determination of the calibration factor includes mismatch uncertainties resulting from mismatch, errors in transmitting power and the mismatch uncertainty of PTB primary standards. The error limits of the calibration factor are - depending on the frequency and the respective sensor - indicated as RSS error in the data sheet (see Section 3.2.7).

3.2.3 Linearity Error

An ideal power meter is expected to show a strictly proportional connection between the measured power applied and the measured power indicated over the entire measuring range. The behaviour of real power meters is more or less different from this ideal behaviour, the result is a linearity error which depends on the control.

In the case of the thermal power sensors, the linearity error is very small, because the control characteristic of each sensor is individually measured in production and stored in the non-volatile data memory of the sensor. On the basis of these data, the power indicated by the basic unit is mathematically corrected to result in an almost perfect linearization. The remaining residual error is specified in the Specifications of the power sensors.

3.2.4 Display Noise

The noise superimposed on the output signal generated by the power sensor causes slight variations of the indicated value which result in a measuring error. As the build-up of noise is a statistic process, it is useful to describe the amount of noise using the methods of probability calculus.

R&S states twice the value of the standard deviation for noise power. This means that this value of the noise power is not exceeded in 95% of a statistically sufficiently large number of measurements.

Display noise is an additive value, i.e. the error caused by noise becomes the smaller, the larger the power measured is.

The value of display noise can be influenced by the filter setting (see Section 3.1.3). Each additional doubling in averaging reduces the display noise power by approx. 30%.

3.2.5 Zero Error

A zero error is induced when a power different from zero is displayed without a power measured. Most of the time variations in temperature the measuring head is subjected to are the cause of this offset. In zeroing (see Section 3.1.4) the offset is measured and subtracted from the measured value in the successive measurement.

Zero error as well is an additive value whose error effect becomes the smaller, the larger the power measured is. When measuring small power, it is thus recommended to keep variations in temperature, as they can be induced by the warmth of the hand imparted to the measuring head or heated RF connections of signal generators, small and to repeat zero adjustment from time to time.

3.2.6 Temperature Effect

The temperature effect is an additional error resulting at a temperature which is constant but other than 23 °C.

By means of cyclic temperature measurement, the influence of changing ambient temperatures can be mathematically corrected up to a very small residual error with the aid of the thermal characteristic stored. It is approx. 0.1 %/grd, with respect to a calibration temperature of 23 °C.

3.2.7 Errors of the Basic Unit

The analog unit of the basic instruments basically consists of a precise DC amplifier and a high-resolution A/D converter. The error indicated is only caused by the drift of gain factors (time, temperature) and, like all other errors, refers to the measured value. As the typical error is still substantially smaller in general, the error of the basic instrument can be neglected compared to the other mismatch uncertainties.

3.2.8 Maximum and RSS Error

A correct error indication must contain two pieces of information:

- How large are the error limits and
- how large is the confidence level, i.e. how many measuring results out of a large number of measurements do not exceed the error limits.

In the case of the maximum error the confidence level is 100 %: The error limits are exceeded in no measurement. The maximum error E_{max} is the sum of all individual maximum errors $(E_{max})_i$:

$$E_{max} = \sum_{i=1}^{N} (E_{max})_i$$

In practice, one sees that the maximum error is only rarely achieved. If the total error is composed of many individual errors which have causes independent of each other (and this is the case with the individual errors described up to now), it is, statistically, a very rare event that all individual errors occur with their maximal value and same sign at the same time in a measurement.

In power measurement it has thus become customary to state the RSS error (RSS: Root Sum of the Squares), which is closer to practice.

It is the square root of the sum of the squares of the individual RSS errors $(E_{RSS})_i$:

$$E_{RSS} = \sqrt{\sum_{i=1}^{N} (E_{RSS})_i^2}$$

The RSS error of a sum of individual errors is the error which is generally not exceeded in 95 % of all measurement results.

3.2.9 Total Mismatch Uncertainty

The total mismatch uncertainty is calculated (as an RSS value) by an example under the following measurement conditions:

- Power sensor — NRV-Z51
- Power measured — 5 mW
- Frequency — 6.5 GHz
- Ambient temperature — 24 °C
- SWR of source — 1.35 (r=0.15)
- NRVD filter — 4

The following example shows that the greatest individual error is caused due to mismatch between source and measuring head. The measuring accuracy can thus be increased most lastingly by means of better SWR values of the source.

Cause of Error	Description in Section	Indiv. Error (RSS) in %
Matching $r_g = 0.15$ $r_l = 0.07$	3.2.1	2.1
Cal. uncertainty	3.2.2	1.3
Linearity	3.2.3	0.3
Zero ±60 nW	3.2.5	≈ 0
Noise ±240 nW	3.2.4	≈ 0
Basic instrument NRVD	3.2.7	0.3
Temperature	3.2.6	0.1
RSS total mismatch uncertainty		**±2.51%**

4 Maintenance and Troubleshooting

4.1 Maintenance

Power sensors NRV-Z51/-Z52/-Z55 are maintenance-free. The RF plug should be cleaned from time to time. Sticking dirt can be removed by means of a pencil and alcohol.

4.2 Troubleshooting

Troubleshooting can only be limited to the clarification of whether a power sensor is defective. Repair requires a new calibration in almost all cases, which must be carried out by the manufacturer.

If the rated values of the following tests are not observed, the measuring head is defective and should be had repaired.

4.2.1 Testing Sensor Sensitivity

Test Setup:

- Directly connect power sensor (without RF cable) to the testing generator of the NRVD. Enter 50 MHz correction frequency at the NRVD, carry out zero adjustment, switch on testing generator.

Rated Value of Power Readout:

- 0.98 ... 1.02 mW (18 ... 23 °C)

4.2.2 Testing SWR

Test Setup:

- Directly connect power sensor (without RF cable) to an SWR network analyzer.
  The measurement inaccuracy of the network analyzer has to be taken into account for the measured SWR value.

Rated Values SWR:

Frequency	Maximum SWR (r)
DC...2 GHz 2...12.4 GHz 12.4...18 GHz	1.1 (0.048) 1.15 (0.07) 1.2 (0.09)
18...26.5 GHz (NRV-Z52, NRV-Z55)	1.25 (0.11)
26.5...40 GHz (only NRV-Z55)	1.30 (0.13)

5 Checking Rated Specifications

Due to the multifarious sources of error, power and reflection measurements in the frequency range of up to 40 GHz require a large amount of apparatus, experience and special care.

A remeasurement of the characteristics guaranteed in the Specifications should thus only be carried out with appropriate calibrating facilities or in the service shops of R&S.

For the power sensors NRV-Z51, NRV-Z52 and NRV-Z55 an annual check, if necessary including calibration, with the manufacturer is recommended.