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Test and
Measurement Division

Manual

100-V Insertion Unit

URV5-Z4

0395.1619.02/.05

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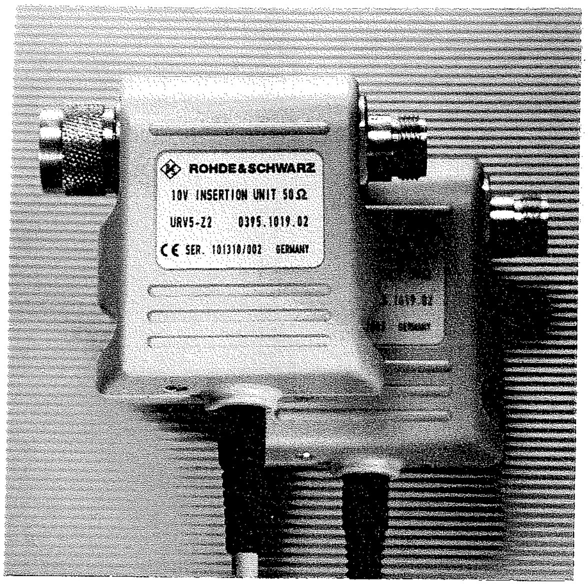

Insertion Units URV5-Z2 / URV5-Z4

Voltage, power and level measurements up to 3 GHz

Coaxial voltage measurement probes are among the standard accessories of RF voltmeters and power meters. Coming as insertion units, they are particularly versatile as they can be connected into a test circuit without interrupting the signal flow. The new products can thus be used for a wide variety of applications, such as monitoring tasks of any kind as well as level control and terminated power measurements.

Compared to the successful predecessor models (of same name) the frequency range has been extended, whereas most other features remained essentially the same.

- 9 kHz (100 kHz) to 3 GHz frequency range
- 93 dB dynamic range (200 µV to 10 V for URV5-Z2, 2 mV to 100 V for URV5-Z4)
- Both insertion and terminated measurements
- Absolute power measurements with well-matched load
- Low insertion loss and reflection
- Compatible with URV35/55, NRVS/D and URV5
- Calibration data memory: Plug in and measure

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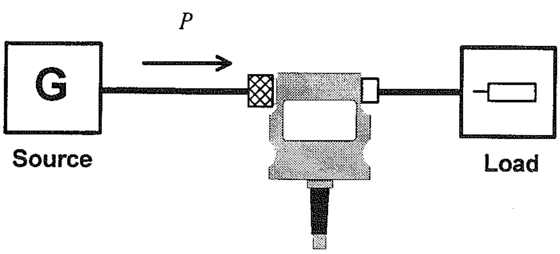
Preliminary

Applications

The Insertion Units URV5-Z2 and URV5-Z4 are used for uninterrupted level measurements between source and load and for terminated power measurements on the basic units of type URV35/55, NRVS/D and URV5. Due to their wide frequency range they are ideal especially for the measurement of EMC test levels as well as many general-purpose applications.

Compared to the terminating power sensors of the NRV line the URV5-Z2 and -Z4 insertion units offer a larger dynamic range, a much lower frequency limit (9 kHz with URV5-Z2) and the possibility of using them during operation of the load.



Insertion Units URV5-Z2 and URV5-Z4 are operated on the transmission line between source and load. With small load SWR the power incident on the sensor can be measured.

Characteristics

Both units are made up of a short, coaxial line between the two RF connectors, in the middle of which the voltage is tapped: directly with URV5-Z2, and via a capacitive 20 dB divider with URV5-Z4. If the insertion units are match-terminated, the voltage is constant over the whole length of the line, so a fixed relationship is obtained between applied RF power and test voltage: $P = V_{rms}^2 / 50\ \Omega$. In this configuration, the insertion units provide precise absolute power and level measurements.

The insertion units are calibrated so that the power incident upon them is indicated. With a poorly matched load, precise absolute-value measurements are not possible, but relative measurements can be performed and system applications implemented in which subsequent calibration of the complete test setup takes place. Switchover between voltage, level and power indication is made at the basic unit.

The built-in detectors offer a dynamic range of more than 90 dB for spectrally pure sinusoidal signals with an unmodulated envelope (CW, FM, φM, GMSK, FSK, etc). This gives a voltage measurement range of 200 µV to 10 V (-60 dBm to +33 dBm into 50 Ω) for URV5-Z2, and 2 mV to 100 V (-40 dBm to +53 dBm into 50 Ω) for URV5-Z4. With modulated envelope or high harmonic content, the insertion units should be operated only within the square-law region of the detectors, which for URV5-Z2 ends at approx. 22 mV (-20 dBm into 50 Ω) and for URV5-Z4 at 220 mV (0 dBm into 50 Ω). In this region, the behaviour of the insertion units is similar to that of a thermal power meter, ie the rms voltage or the equivalent average power is measured.

Thanks to the high decoupling of the detector from the RF connectors, insertion loss of URV5-Z4 is very low, ie not exceeding that of a line of equivalent length. URV5-Z4 is therefore truly transparent and can be inserted into any test circuit without influencing the measured parameters.

Both insertion units are equipped with a calibration data memory that contains information about the individual sensor characteristics like frequency response, linearity, temperature coefficient etc. The stored data are automatically considered by the basic unit during operation so that the user can plug the sensor in and immediately start measuring.

Specifications

	URV5-Z2	URV-5-Z4
Frequency range	9 kHz to 3 GHz	100 kHz to 3 GHz
Voltage measurement range	200 µV to 10 V [1]	2 mV to 100 V [2]
Power measurement range	1 nW to 2 W [1]	100 nW to 200 W [2]
Level measurement range	-60 dBm to +33 dBm [1]	-40 dBm to +53 dBm [2]
Max. rating		
V_{rms} $[P_{avg}]$ [3] up to 1 GHz	15 V [4 W]	150 V [400 W]
V_{rms} $[P_{avg}]$ [3] from 1 GHz to 3 GHz	15 V / $(f$ / GHz$)$ $\left[4\,\text{W} / (f / \text{GHz})^2\right]$	150 V / $\sqrt{f / \text{GHz}}$ $\left[400\,\text{W} / (f / \text{GHz})\right]$
V_{peak}	22 V	220 V
V_{DC}	50 V	1000 V
Nominal impedance	50 Ω	50 Ω
RF connector	N (male / female)	N (male / female)

Matching and insertion loss (max. values)

	URV5-Z2 SWR	URV5-Z2 Refl. coeff.	URV5-Z2 Ins. loss [4]	URV-5-Z4 SWR	URV-5-Z4 Refl. coeff.	URV-5-Z4 Ins. loss
DC to 200 MHz	1.04	0.02	0.07 dB	1.04	0.02	0.05 dB
200 MHz to 500 MHz	1.10	0.048	0.20 dB	1.04	0.02	0.05 dB
500 MHz to 1.0 GHz	1.22	0.10	0.50 dB	1.07	0.035	0.10 dB
1.0 GHz to 1.6 GHz	1.35	0.15	1,00 dB	1.07	0.035	0.10 dB
1.6 GHz to 2.0 GHz	1.35	0.15	1.50 dB	1.07	0.035	0.15 dB
2.0 GHz to 2.4 GHz	1.35	0.15	2.50 dB	1.10	0.048	0.15 dB
2.4 GHz to 3.0 GHz	1.35	0.15	3.50 dB	1.10	0.048	0.15 dB

Measurement uncertainty [5][6]
at 18°C to 28°C

(values in parentheses for URV5 and NRV)

	URV5-Z2 up to 1 V 0.02 W / +13 dBm	URV5-Z2 above 1 V 0.02 W / +13 dBm	URV-5-Z4 up to 10 V 2 W / +33 dBm	URV-5-Z4 above 10 V 2 W / +33 dBm
	uncertainties in dB		uncertainties in dB	
9 kHz to 20 kHz	0.35 (0.45) [7]	0.20 (0.30) [7]	---	---
20 kHz to 50 kHz	0.20 (0.20) [7]	0.17 (0.20) [7]	---	---
50 kHz to 100 kHz	0.17 (0.17)	0.17 (0.17)	---	---
100 kHz to 200 kHz	0.13 (0.13)	0.13 (0.13)	1.50 (2.20) [7]	0.50 (0.80) [7]
200 kHz to 500 kHz	0.13 (0.13)	0.13 (0.13)	0.60 (0.80) [7]	0.25 (0.40) [7]
500 kHz to 1 MHz	0.13 (0.13)	0.13 (0.13)	0.20 (0.25) [7]	0.17 (0.20) [7]
1 MHz to 3 MHz	0.13 (0.13)	0.13 (0.13)	0.17 (0.17)	0.13 (0.13)
3 MHz to 100 MHz	0.13 (0.13)	0.13 (0.13)	0.13 (0.13)	0.13 (0.13)
100 MHz to 200 MHz	0.17 (0.20)	0.17 (0.20)	0.13 (0.13)	0.13 (0.13)
200 MHz to 500 MHz	0.20 (0.25)	0.25 (0.30)	0.17 (0.17)	0.20 (0.20)
0.5 GHz to 1.0 GHz	0.25 (0.35)	0.30 (0.40)	0.20 (0.25)	0.25 (0.30)
1.0 GHz to 1.6 GHz	0.30 (0.45)	0.40 (0.55)	0.30 (0.45)	0.40 (0.55)
1.6 GHz to 2.0 GHz	0.35 (0.55)	0.50 (0.65)	0.35 (0.60)	0.50 (0.70)
2.0 GHz to 2.4 GHz	0.40 (0.65)	0.60 (0.80)	0.45 (0.80)	0.70 (1.00)
2.4 GHz to 3.0 GHz	0.50 (0.85)	0.75 (1.05)	0.65 (1.15)	1.05 (1.50)

Effect of temperature on meas. uncertainty [8]

	URV5-Z2	URV-5-Z4
18 °C to 28 °C	included in measurement uncertainty specifications	
10 °C to 18 °C and 28 °C to 40 °C	0.17 dB	0.17 dB
0 °C to 10 °C and 40 °C to 50 °C	0.44 dB	0.44 dB

	URV5-Z2	URV-5-Z4
Effect of zero offset on meas. uncertainty [9]	0.0009 dB / $(P_{meas}$ / µW$)$	0.09 dB / $(P_{meas}$ / µW$)$
Effect of display noise on meas. uncertainty [10]	0.0005 dB / $(P_{meas}$ / µW$)$	0.05 dB / $(P_{meas}$ / µW$)$
Measurement time	depending on filter setting (see specifications of basic units)	
Compatible basic units	URV35, URV55, NRVS, NRVD, URV5 and NRV	

General Data

Operating temperature range	0 °C to 50 °C (without condensation)
Storage temperature range	-40 °C to 70°C
Other environmental conditions	see specifications of URV35/55, NRVS/D and URV5

[1]) Up to 1.5 GHz. Above this frequency the measurement range is limited by the maximum rating.

[2]) Up to 2 GHz. Above this frequency the measurement range is limited by the maximum rating.

[3]) Permissible input power for matched loads (must be reduced by factor ×0.5 for 3.0 SWR and ×0.25 for open/short circuit).

[4]) Insertion loss of URV5-Z2 is level-dependent above 0.5 GHz. The given values apply to low levels where insertion loss is maximum.

[5]) Expanded uncertainty with a coverage factor k = 2 (except for the frequencies stated in footnote 7). An expanded uncertainty with k=2 corresponds to a coverage probability of approximately 95 % for a normal distribution of combined errors.

[6]) With reflection-free load at the female connector, frequency correction switched on, measurement results referred to incident wave. The given measurement uncertainty includes the effects of calibration uncertainty, nonlinearity and temperature (18°C to 28°C), the influences of the basic unit, load mismatch, zero offset and display noise are to be considered separately.

Due to standing waves, mismatch of the load can lead to an additional measurement uncertainty that can be approximated by ±4 dB × (SWR-1) for the maximum deviation and 2.8 dB × (SWR-1) for the standard uncertainty (both formulas are valid for 1.0 SWR to 1.25 SWR).

[7]) Max. deviation from nominal value. Measurement deviation is highly dependent on level and temperature in this frequency range. Therefore much larger deviations must be expected above 28 °C: The values given from 9 kHz to 20 kHz (URV5-Z2) and 100 kHz to 500 kHz (URV5-Z4) approximately double with every 5 K increase of temperature.

[8]) Residual uncertainty (approximately two standard deviations) after internal temperature correction, taking into account the temperature characteristics of the sensor and its actual temperature. Not valid for the frequency and temperature ranges stated in footnote 7.

[9]) Residual uncertainty (approximately two standard deviations) within 1 hour after zeroing, at constant ambient temperature; basic unit with sensor run in for about 2 hours. P_{meas} is the value measured in terms of power.

[10]) Two standard deviations, valid at 18°C to 28°C sensor temperature (double at 0 °C) and filter setting 7 of URV55/NRVS/NRVD or filter F2 of URV5. With other filter settings, multiply specified uncertainty by factor ×0.25 (11/F0), ×0.5 (9, F1), ×2 (5, F3), ×4 (3, F4) or ×13 (0, F5). P_{meas} is the value measured in terms of power.

Display noise of URV35 is specified in the relevant data sheet.

Ordering Information

10 V Insertion Unit 50 Ω (with 1.3 m cable)	URV5-Z2	0395.1019.02
10 V Insertion Unit 50 Ω (with 5 m cable)	URV5-Z2	0395.1019.05
100 V Insertion Unit 50 Ω (with 1.3 m cable)	URV5-Z4	0395.1619.02
100 V Insertion Unit 50 Ω (with 5 m cable)	URV5-Z4	0395.1619.05

Recommended extras

Precision Termination 50 Ω, 0 to 18 GHz, 1 W	RNA	0272.4510.50

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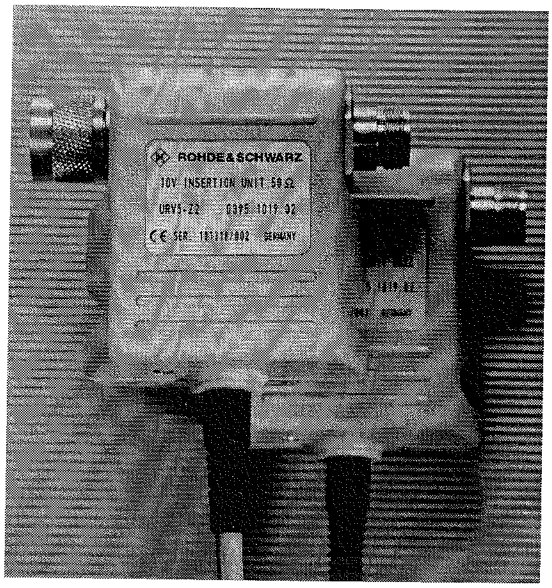
Technical Information



Insertion Units URV5-Z2 / URV5-Z4

Voltage, power and level measurements up to 3 GHz

Coaxial voltage measurement probes are among the standard accessories of RF voltmeters and power meters. Coming as insertion units, they are particularly versatile as they can be connected into a test circuit without interrupting the signal flow. The new products can thus be used for a wide variety of applications, such as monitoring tasks of any kind as well as level control and terminated power measurements.

Compared to the successful predecessor models (of same name) the frequency range has been extended, whereas most other features remained essentially the same.

- 9 kHz (100 kHz) to 3 GHz frequency range
- 93 dB dynamic range (200 µV to 10 V for URV5-Z2, 2 mV to 100 V for URV5-Z4)
- Both insertion and terminated measurements
- Absolute power measurements with well-matched load
- Low insertion loss and reflection
- Compatible with URV35/55, NRVS/D and URV5
- Calibration data memory: Plug in and measure

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Applications

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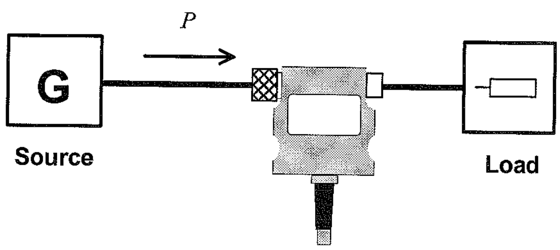

Insertion Units URV5-Z2 and URV5-Z4 are operated on the transmission line between source and load. With small load SWR the power incident on the sensor can be measured.

Characteristics

Both units are made up of a short, coaxial line between the two RF connectors, in the middle of which the voltage is tapped: directly with URV5-Z2, and via a capacitive 20 dB divider with URV5-Z4. If the insertion units are match-terminated, the voltage is constant over the whole length of the line, so a fixed relationship is obtained between applied RF power and test voltage: $P = V_{rms}^2 / 50\ \Omega$. In this configuration, the insertion units provide precise absolute power and level measurements.

The insertion units are calibrated so that the power incident upon them is indicated. With a poorly matched load, precise absolute-value measurements are not possible, but relative measurements can be performed and system applications implemented in which subsequent calibration of the complete test setup takes place. Switchover between voltage, level and power indication is made at the basic unit.

The built-in detectors offer a dynamic range of more than 90 dB for spectrally pure sinusoidal signals with an unmodulated envelope (CW, FM, φM, GMSK, FSK, etc). This gives a voltage measurement range of 200 µV to 10 V (-60 dBm to +33 dBm into 50 Ω) for URV5-Z2, and 2 mV to 100 V (-40 dBm to +53 dBm into 50 Ω) for URV5-Z4. With modulated envelope or high harmonic content, the insertion units should be operated only within the square-law region of the detectors, which for URV5-Z2 ends at approx. 22 mV (-20 dBm into 50 Ω) and for URV5-Z4 at 220 mV (0 dBm into 50 Ω). In this region, the behaviour of the insertion units is similar to that of a thermal power meter, ie the rms voltage or the equivalent average power is measured.

Thanks to the high decoupling of the detector from the RF connectors, insertion loss of URV5-Z4 is very low, ie not exceeding that of a line of equivalent length. URV5-Z4 is therefore truly transparent and can be inserted into any test circuit without influencing the measured parameters.

Both insertion units are equipped with a calibration data memory that contains information about the individual sensor characteristics like frequency response, linearity, temperature coefficient etc. The stored data are automatically considered by the basic unit during operation so that the user can plug the sensor in and immediately start measuring.

Specifications

	URV5-Z2			URV-5-Z4		
Frequency range	9 kHz to 3 GHz			100 kHz to 3 GHz		
Voltage measurement range	200 µV to 10 V [1]			2 mV to 100 V [2]		
Power measurement range	1 nW to 2 W [1]			100 nW to 200 W [2]		
Level measurement range	-60 dBm to +33 dBm [1]			-40 dBm to +53 dBm [2]		
Max. rating						
V_{rms} [P_{avg}] [3] up to 1 GHz	15 V [4 W]			150 V [400 W]		
V_{rms} [P_{avg}] [3] from 1 GHz to 3 GHz	$15\,V/(f/GHz)$ $[4\,W/(f/GHz)^2]$			$150\,V/\sqrt{f/GHz}$ $[400\,W/(f/GHz)]$		
V_{peak}	22 V			220 V		
V_{DC}	50 V			1000 V		
Nominal impedance	50 Ω			50 Ω		
RF connector	N (male / female)			N (male / female)		
Matching and insertion loss (max. values)	SWR	Refl. coeff.	Ins. loss [4]	SWR	Refl. coeff.	Ins. loss
DC to 200 MHz	1.04	0.02	0.07 dB	1.04	0.02	0.05 dB
200 MHz to 500 MHz	1.10	0.048	0.20 dB	1.04	0.02	0.05 dB
500 MHz to 1.0 GHz	1.22	0.10	0.50 dB	1.07	0.035	0.10 dB
1.0 GHz to 1.6 GHz	1.35	0.15	1,00 dB	1.07	0.035	0.10 dB
1.6 GHz to 2.0 GHz	1.35	0.15	1.50 dB	1.07	0.035	0.15 dB
2.0 GHz to 2.4 GHz	1.35	0.15	2.50 dB	1.10	0.048	0.15 dB
2.4 GHz to 3.0 GHz	1.35	0.15	3.50 dB	1.10	0.048	0.15 dB

Measurement uncertainty [5][6] at 18°C to 28°C (values in parentheses for URV5 and NRV)	up to 1 V 0.02 W / +13 dBm	above 1 V 0.02 W / +13 dBm	up to 10 V 2 W / +33 dBm	above 10 V 2 W / +33 dBm
	uncertainties in dB		uncertainties in dB	
9 kHz to 20 kHz	0.35 (0.45) [7]	0.20 (0.30) [7]	---	---
20 kHz to 50 kHz	0.20 (0.20) [7]	0.17 (0.20) [7]	---	---
50 kHz to 100 kHz	0.17 (0.17)	0.17 (0.17)	---	---
100 kHz to 200 kHz	0.13 (0.13)	0.13 (0.13)	1.50 (2.20) [7]	0.50 (0.80) [7]
200 kHz to 500 kHz	0.13 (0.13)	0.13 (0.13)	0.60 (0.80) [7]	0.25 (0.40) [7]
500 kHz to 1 MHz	0.13 (0.13)	0.13 (0.13)	0.20 (0.25) [7]	0.17 (0.20) [7]
1 MHz to 3 MHz	0.13 (0.13)	0.13 (0.13)	0.17 (0.17)	0.13 (0.13)
3 MHz to 100 MHz	0.13 (0.13)	0.13 (0.13)	0.13 (0.13)	0.13 (0.13)
100 MHz to 200 MHz	0.17 (0.20)	0.17 (0.20)	0.13 (0.13)	0.13 (0.13)
200 MHz to 500 MHz	0.20 (0.25)	0.25 (0.30)	0.17 (0.17)	0.20 (0.20)
0.5 GHz to 1.0 GHz	0.25 (0.35)	0.30 (0.40)	0.20 (0.25)	0.25 (0.30)
1.0 GHz to 1.6 GHz	0.30 (0.45)	0.40 (0.55)	0.30 (0.45)	0.40 (0.55)
1.6 GHz to 2.0 GHz	0.35 (0.55)	0.50 (0.65)	0.35 (0.60)	0.50 (0.70)
2.0 GHz to 2.4 GHz	0.40 (0.65)	0.60 (0.80)	0.45 (0.80)	0.70 (1.00)
2.4 GHz to 3.0 GHz	0.50 (0.85)	0.75 (1.05)	0.65 (1.15)	1.05 (1.50)

	URV5-Z2	URV-5-Z4
Effect of temperature on meas. uncertainty [8]		
18 °C to 28 °C	included in measurement uncertainty specifications	
10 °C to 18 °C and 28 °C to 40 °C	0.17 dB	0.17 dB
0 °C to 10 °C and 40 °C to 50 °C	0.44 dB	0.44 dB
Effect of zero offset on meas. uncertainty [9]	$0.0009\,dB/(P_{meas}/\mu W)$	$0.09\,dB/(P_{meas}/\mu W)$
Effect of display noise on meas. uncertainty [10]	$0.0005\,dB/(P_{meas}/\mu W)$	$0.05\,dB/(P_{meas}/\mu W)$
Measurement time	depending on filter setting (see specifications of basic units)	
Compatible basic units	URV35, URV55, NRVS, NRVD, URV5 and NRV	

General Data

Operating temperature range	0 °C to 50 °C (without condensation)
Storage temperature range	-40 °C to 70°C
Other environmental conditions	see specifications of URV35/55, NRVS/D and URV5

[1]) Up to 1.5 GHz. Above this frequency the measurement range is limited by the maximum rating.

[2]) Up to 2 GHz. Above this frequency the measurement range is limited by the maximum rating.

[3]) Permissible input power for matched loads (must be reduced by factor ×0.5 for 3.0 SWR and ×0.25 for open/short circuit).

[4]) Insertion loss of URV5-Z2 is level-dependent above 0.5 GHz. The given values apply to low levels where insertion loss is maximum.

[5]) Expanded uncertainty with a coverage factor k = 2 (except for the frequencies stated in footnote 7). An expanded uncertainty with k=2 corresponds to a coverage probability of approximately 95 % for a normal distribution of combined errors.

[6]) With reflection-free load at the female connector, frequency correction switched on, measurement results referred to incident wave. The given measurement uncertainty includes the effects of calibration uncertainty, nonlinearity and temperature (18°C to 28°C), the influences of the basic unit, load mismatch, zero offset and display noise are to be considered separately.

Due to standing waves, mismatch of the load can lead to an additional measurement uncertainty that can be approximated by ±4 dB × (SWR-1) for the maximum deviation and 2.8 dB × (SWR-1) for the standard uncertainty (both formulas are valid for 1.0 SWR to 1.25 SWR).

[7]) Max. deviation from nominal value. Measurement deviation is highly dependent on level and temperature in this frequency range. Therefore much larger deviations must be expected above 28 °C: The values given from 9 kHz to 20 kHz (URV5-Z2) and 100 kHz to 500 kHz (URV5-Z4) approximately double with every 5 K increase of temperature.

[8]) Residual uncertainty (approximately two standard deviations) after internal temperature correction, taking into account the temperature characteristics of the sensor and its actual temperature. Not valid for the frequency and temperature ranges stated in footnote 7.

[9]) Residual uncertainty (approximately two standard deviations) within 1 hour after zeroing, at constant ambient temperature; basic unit with sensor run in for about 2 hours. P_{meas} is the value measured in terms of power.

[10]) Two standard deviations, valid at 18°C to 28°C sensor temperature (double at 0 °C) and filter setting 7 of URV55/NRVS/NRVD or filter F2 of URV5. With other filter settings, multiply specified uncertainty by factor ×0.25 (11/F0), ×0.5 (9, F1), ×2 (5, F3), ×4 (3, F4) or ×13 (0, F5). P_{meas} is the value measured in terms of power.

Display noise of URV35 is specified in the relevant data sheet.

Ordering Information

10 V Insertion Unit 50 Ω (with 1.3 m cable)	URV5-Z2	0395.1019.02
10 V Insertion Unit 50 Ω (with 5 m cable)	URV5-Z2	0395.1019.05
100 V Insertion Unit 50 Ω (with 1.3 m cable)	URV5-Z4	0395.1619.02
100 V Insertion Unit 50 Ω (with 5 m cable)	URV5-Z4	0395.1619.05

Recommended extras

Precision Termination 50 Ω, 0 to 18 GHz, 1 W	RNA	0272.4510.50

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1 Putting the Unit into Operation

Unpacking

When unpacking the unit, check that nothing is missing and carefully inspect all parts for any damage. If there is any damage, you should immediately inform your carrier and keep the packing material to safeguard your claims under the warranty.

Connecting the Insertion Unit to the Basic Unit

Insertion Unit URV5-Z4 is fully compatible with Power Meters/Voltmeters NRVS, NRVD, URV35 and URV55. For operation with RF Millivoltmeter URV5 or Dual-Channel Power Meter NRV, it should be taken into account that there are certain restrictions regarding measurement accuracy (see Specifications and ***Notes on Basic Units URV5 and NRV*** in section 2). The insertion unit is connected to the basic unit by inserting the plug-in adapter into the slot in the basic unit until it locks. When connected to NRVD, NRVS and URV55, the cable connector must point outwards, and when connected to URV35, URV5 and NRV, downwards. The basic unit may be on or off when connecting the insertion unit. Initialization of the insertion unit and reading-out of the calibration data are indicated in the display by the texts ***READ SENSOR*** (NRVS, NRVD, URV55), ***readPRB*** (URV35) or ***Init*** (URV5, NRV). The insertion unit is then ready for use.

Operating instructions:

- The maximum measurable voltage is 100 V (200 W / +53 dBm into 50 Ω), and the voltage limit is 150 V (400 W / +56 dBm into 50 Ω). It should be noted that with modulation or mismatch, this limit may be attained with powers much smaller than those specified, for example at 80 W (+49 dBm) with an SWR of 3.0 and 80% amplitude modulation. If necessary, an appropriate attenuation pad should be used.
- For power and level measurements, mismatch of the load considerably affects measurement accuracy (see ***Connecting the Insertion Unit into the RF Circuit,*** section 3). For this reason, SWR should not exceed 1.2 if accurate measurements are required.
- Below 220 mV (1 mW / 0 dBm into 50 Ω), true rms measurements are performed, ie URV5-Z4 indicates correct values also with modulated signals and signals containing harmonics. Above 220 mV, the insertion unit should be used only for spectrally pure signals with an unmodulated envelope (CW, FM, φM, FSK, GMSK or similar).
- The permissible ambient temperature range is 0 to 50°C. Outside the temperature range 18 to 28°C, greater measurement uncertainty is to be expected due to the temperature dependence of the RF sensor (see data sheet).
- Avoid condensation. Tarnished insertion units, and especially the interior of RF connectors, are to be dried before connection.
- Connect the RF connector to the signal source only by hand. Make sure that the RF connector is not at an angle.
- The unit should, if possible, be connected directly to the signal source as adapters or cables will increase measurement uncertainty due to mismatch and additional attenuation.

Function Test

When the insertion unit connected to the basic unit is being initialized, a function test is performed on the calibration data memory and the temperature sensor. If there are no error messages, these components are operating correctly. The RF sensor can be checked using a number of simple tests with no major equipment requirements (see section 5).

If the basic unit does not respond when the insertion unit is connected or indicates an error after initialization, disconnect the insertion unit and connect it again. Make sure that the insertion unit is locking properly: the last 1 to 2 mm of travel require a considerably greater insertion force. With the insertion unit connected, switch the basic unit off and on again. If the response is still the same, repeat the procedure with another insertion unit. For further information on troubleshooting refer to the manuals for the basic unit or get in touch with your local R&S representative.

2 Operation

Insertion Unit URV5-Z4 for the frequency range 100 kHz to 3 GHz permits voltage, level and power measurements from 2 mV (100 nW / -40 dBm into 50 Ω) to 100 V (200 W / +53 dBm into 50 Ω).

When measuring high power levels, the following instructions should be strictly observed to avoid damage to the sensor or injury to persons:

Do not exceed permissible continuous loading (see data sheet).

Switch sensor into test circuit only with the RF power switched off.

Tighten RF connector by hand.

Non-observance may cause injuries, eg skin burns, damage to the instruments used and premature wear of the RF connectors.

In the following sections, the most important operating functions for the insertion unit when used with Power Meters/Voltmeters NRVS, NRVD, NRV, URV35, URV55 and URV5 are described. For details, eg remote control commands or designation of keys, please refer to the manual for the basic unit in question.

Connecting the Insertion Unit into the RF Circuit

Insertion Unit URV5-Z4 can be connected into the line between the source and the load (Fig. 2-2) or - with a precision termination at the output - used for terminated measurements (Fig. 2-1). Each of the two RF connectors can be selected as input. The insertion unit physically measures the voltage in the middle of the line between its two RF connectors. It has been calibrated to indicate, with match-termination, the voltage of the incident wave or the forward power at the RF input. With a matched source, the incident power is identical to the source power available into 50 Ω.

With a matched load, the voltage on the line between the source and the load is approximately constant, ie independent of the measurement point, so that a fixed relationship is obtained between the voltage and the power:

$$P = \frac{V^2}{50\Omega}$$ **Equation 2-1**

$$V = \sqrt{P \cdot 50\Omega}$$ **Equation 2-2**

The basic units automatically perform voltage/power conversion according to the above equations.

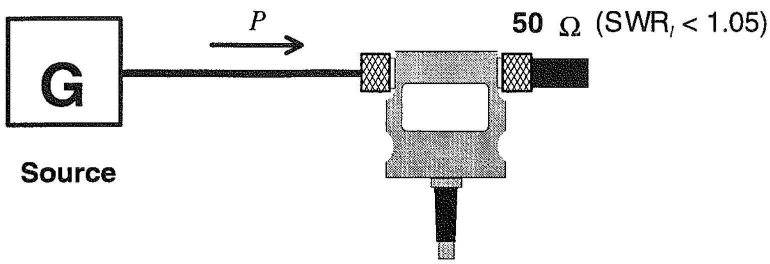

Fig. 2-1 **Configuration of Insertion Unit URV5-Z4 for terminated measurements**

With a mismatched load, the voltage on the line between the source and the load is variable, ie dependent on the measurement point, and SWR increases as mismatch increases. Therefore, depending on the position of the test point, the measured voltage may deviate to a varying degree from the average value which represents the forward power. To avoid significant measurement errors, it should therefore be ensured that the SWR of the load is sufficiently small (max. 1.25 for a measurement error of ± 1 dB).

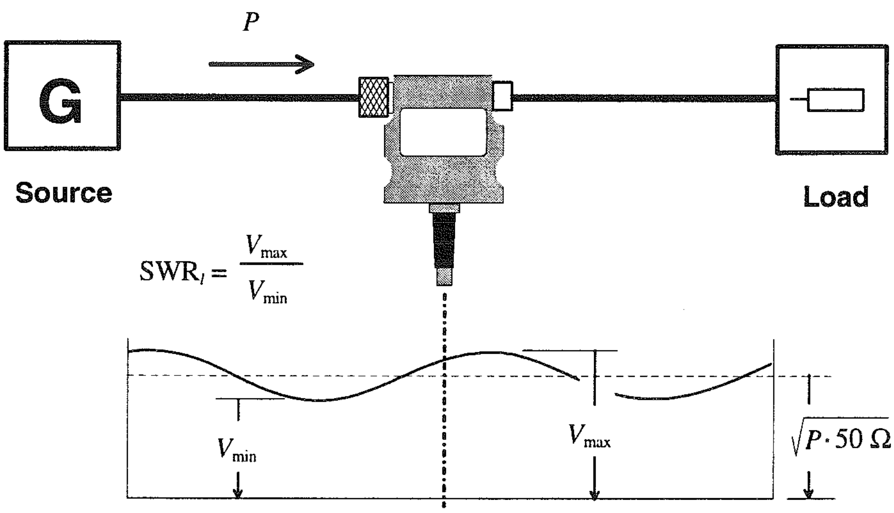

Fig. 2-2 **Configuration of Insertion Unit URV5-Z4 for feedthrough measurements**
(diagram in lower half: voltage characteristic with mismatch)

Zeroing

After being connected to the basic unit or switched on, Insertion Unit URV5-Z4 may give a small voltage or power reading without any test signal being applied. This zero offset, which shows in the power reading as a constant offset independent of the power level, may lead to relatively large measurement errors at the lower measurement limit.

Therefore, URV5-Z4 should always be zeroed before any measurements are performed. The test signal must be switched off during zeroing.

Note: **After switching off the test signal, wait until readout has stabilized before performing zeroing.**

Immediately after zeroing, the reading should not be greater than 1 mV (25 nW / -46 dBm). The zero point of Insertion Unit URV5-Z4 is relatively stable so, as a rule, zeroing does not have to be repeated.

Entering the Measurement Frequency

Insertion Unit URV5-Z4 has been calibrated to indicate, with match-termination (Fig. 2-1), the voltage of the incident wave or the forward power (for conversion see equations 2-1 and 2-2). To ensure that the frequency-dependent correction coefficients determined during calibration of the insertion unit are taken into account, the frequency response correction must be activated on the basic unit and the precise carrier frequency entered. The entry can be made numerically from the keypad or via the IEC/IEEE bus or by applying a DC voltage. With the frequency response correction switched off, the instrument assumes a carrier frequency of 50 MHz.

Selecting the Measurement Range

Due to the short response time of Insertion Unit URV5-Z4, it is best to use autoranging. All basic units except for URV35 also feature manual range selection to avoid unwanted changes in the result format due to autoranging and/or to increase measurement speed even further.

The following ranges can be selected:

10 mV (only URV55, NRVS and NRVD), 100 mV, 1 V, 10 V and 100 V

Display Smoothing and Measurement Speed

All basic units have display smoothing facilities to reduce noise and display fluctuations at low modulation frequencies. Smoothing is obtained by averaging a number of consecutive measured values. The greater the number of measured values averaged, the more stable the readout and the more the measurement speed decreases. With low powers, more smoothing is generally required as display noise is more noticeable.

URV35 has an automatic averaging filter which adapts to the measured voltage/power and the selected resolution (HI or LO), so giving optimum display stabilization. NRVS, NRVD and URV55 feature both automatic filter setting as a function of the measurement range and display resolution and manual filter setting for fine adjustments. URV5 and NRV feature manual filter setting only.

Measuring Modulated Signals

Insertion Unit URV5-Z4 can be used without restrictions for measurements on RF signals with unmodulated (constant over time) envelopes. These include all carriers that are completely unmodulated or just frequency- or phase-modulated (CW, FM, φM, FSK, GMSK, etc).

With all other signals, including modulation modes such as AM, x-QAM, π/4-DQPSK, spread-spectrum methods and pulse-modulated RF (bursts), major deviations from the average power may occur with measured values above 1 mW / 0 dBm. It depends on the signal amplitude and the type of modulation whether the reading is higher or lower than the true value.

It is only for measured values below 1 mW / 0 dBm that the deviation or measurement error is small and approximately proportional to the measured power, ie at a tenth of the measured power level, a tenth of the error would be expected. As a rule of thumb, a measurement error of approx. ±0.1 dB should be assumed for a power of 1 mW.

Remote Control

Insertion Unit URV5-Z4 and the associated basic units are matched such that settled measured values are output even if the measured voltage, level or power changes immediately before triggering. Only if there are very large level steps (40 dB or more) - from higher to lower levels - it might become necessary to provide a certain trigger delay in the application program.

Notes on Basic Units URV5 and NRV

Basic units URV5 and NRV are not capable of evaluating all correction data stored in the memory so that, especially at the limits of the frequency range, measurement errors are to be expected that will not occur with basic units URV35, URV55, NRVS or NRVD. Relevant measurement uncertainties are specified in the data sheet.

3 Sources of Error Affecting Measurement Accuracy

Like any other type of measurement, voltage and power measurements in the RF and microwave range are subject to errors from various sources that may reduce measurement accuracy. As voltmeters and power meters must meet very stringent accuracy requirements, the main sources of error should be known. They will be discussed in the following sections in the order of their significance.

Function Description of Insertion Unit

Insertion Unit URV5-Z4 physically measures the voltage in the middle of the short coaxial line between its two RF connectors. For this, two full-wave diode rectifiers are capacitively coupled to the inner conductor. Their output voltages are taken via the cable of the insertion unit to the basic unit, where they are amplified, filtered and digitized. The insertion unit contains a nonvolatile data memory for the coefficients determined during calibration. The basic unit reads these coefficients and takes them into account in the display of results.

Nonlinearity of measured values is corrected automatically using the stored correction coefficients. To compensate for temperature effects, the temperature of the insertion unit is measured with a temperature sensor. The frequency response is taken into account using the stored calibration coefficients and the test frequency, the latter being entered on the basic unit. The entry can be made from the keypad, via a remote control interface or an analog control input.

The insertion unit has been calibrated to indicate, with match-termination, the voltage of the incident wave or the forward power at the RF input. With a matched source, the forward power is identical to the source power available into 50 Ω.

Mismatch of the Load

Mismatch of the load is the error source that as a rule has the greatest effect on measurement accuracy since it leads to a standing wave with a location-dependent voltage distribution on the line (Fig. 2-2). Depending on the phase angle of the reflection coefficient and the position of the insertion unit, a positive or negative measurement error relative to the average value is obtained. The relationship between the average value V and the forward power P is expressed by equations 2-1 and 2-2. The maximum deviation of the measured value from the average value for an SWR up to 1.25 is obtained from the approximate equation below:

$$\frac{\varepsilon_{SWR}}{\text{dB}} \approx 4 \cdot (\text{SWR}_l - 1)$$

Equation 3-1

The index "l" is used to distinguish the load SWR from other types of SWR. Since variation of the measurement error as a function of the URV5-Z4 position takes the shape of a sine curve, the "effective" measurement error (standard deviation) is only 0.71 times the maximum value specified. This value is to be taken into account in calculating the total measurement uncertainty (see relevant section).

Mismatch of the Source

Mismatch of the source becomes apparent by the fact that the forward power P can be influenced by matching the load. Its effect is proportional to the reflection coefficient of the source and should be taken into account in all measurements where the source power into 50 Ω, ie the nominal power, is to be measured. Depending on the phase angles of the reflection coefficients of the source and the load, positive or negative measurement errors (mismatch uncertainties) are obtained. The maximum measurement error up to approx. 1 dB is obtained from the approximate equation

$$\frac{\varepsilon_m}{\mathrm{dB}} \approx 8{,}7 \cdot \left|\Gamma_g\right| \cdot \left|\Gamma_l + \Gamma_m\right| \qquad \textbf{Equation 3-2}$$

where $\left|\Gamma_g\right|$ is the magnitude of the reflection coefficient of the source, and $\left|\Gamma_l + \Gamma_m\right|$ is the magnitude of the reflection coefficient at the input of the insertion unit. The latter is made up of the reflection coefficients of the insertion unit (Γ_m) and the load (Γ_l). For calculating the total measurement uncertainty (see relevant section), two factors should be taken into account:

1. Since the relationship between the measurement error and the phase angles of the reflection coefficients is a sine function, the "effective" measurement error (standard deviation) is only 0.71 times the maximum value specified.

2. Since in general only the magnitudes $\left|\Gamma_l\right|$ and $\left|\Gamma_m\right|$ are known but not the vector sum $\left|\Gamma_l + \Gamma_m\right|$, the effects of Γ_l and Γ_m are calculated separately so that two values are obtained as measurement uncertainty. For calculation, the other reflection coefficient is set to zero in equation 3-2 in each case (also see example in section ***"Calculation of Total Measurement Uncertainty"***).

If the magnitudes of the reflection coefficients are not known but only the equivalent SWRs, these can be converted by means of the following formula:

$$\left|\Gamma\right| = \frac{\mathrm{SWR} - 1}{\mathrm{SWR} + 1}$$

Insertion Loss

For accurate feedthrough measurements (Fig. 2-2), it should be taken into account that the power at the output of the insertion unit is reduced relative to the input power by the insertion loss. With URV5-Z4, however, this effect can in most cases be neglected because of the unit's extremely low insertion loss (max. 0.15 dB).

Calibration Uncertainty

All Insertion Units URV5-Z4 are individually calibrated at a large number of frequencies during production. The measured power is compared with the power supplied by the calibration system (approx. 1 mW), and the ratio of the two values is stored as calibration factor. However, even the determination of calibration factors is subject to measurement uncertainties resulting from mismatch, errors in installing the characteristics of the transfer standard on the calibration system and the measurement uncertainty of the transfer standard itself. Due to the large number of error sources, the resulting measurement error can only be handled in terms of random distributions.

Calibration uncertainty together with nonlinearity and temperature effect yields the measurement uncertainty specified in the data sheet.

All measuring systems used by R&S for calibrating Insertion Units URV5-Z4 are traceable to the national standards of the Physikalisch-Technische Bundesanstalt PTB (Federal German Bureau of Standards). The reference standards used by R&S are calibrated directly at the PTB, so calibration uncertainties are kept to a minimum.

Nonlinearity

An ideal meter is expected to show a strictly proportional relationship between the measured quantity and the indicated value across the entire measurement range. The behaviour of real meters deviates more or less from this ideal behaviour; as a result, level-dependent nonlinearity is obtained.

To minimize these errors, the transfer characteristics of each Insertion Unit URV5-Z4 are measured during calibration, stored in the data memory of the insertion unit and later used to make corrections. With this method of linearization, residual nonlinearities are small and, between 3 MHz and 500 MHz, negligible. Above 500 MHz, additional nonlinearities are caused by the voltage dependence of the junction capacitance (varactor effect), below 3 MHz by the voltage dependence of the input impedance of the diode rectifiers. Although both effects can be compensated to a certain degree by means of the frequency response correction function, nonlinearity is to be expected especially at the lower limit of the frequency range if the temperature of the insertion unit deviates from the calibration temperature (23°C).

Further nonlinearity may be obtained with envelope modulation, that is to say if measurements are made outside the square-law region, ie above 220 mV (1 mW / 0 dBm) (see section ***"Measuring Modulated Signals"***). Moreover, significant nonlinearity may occur at the temperature range limits due to level-dependent temperature coefficients.

Nonlinearity is not separately specified in the data sheet but stated together with nonlinearity, calibration uncertainty and temperature effect under the common parameter of measurement uncertainty for unmodulated signals.

Display Noise

Noise on the output signal of the insertion unit causes slight variations in the reading which may result in significant measurement errors especially with small signal amplitudes. As noise is a random process, noise levels are best described in statistical terms.

R&S specifies display noise in terms of twice the standard deviation. This means that for 95% of measured values the measurement error will be smaller than the specified value.

Display noise can be influenced by averaging consecutive measured values via smoothing facilities (see ***"Display Smoothing and Measurement Speed"***): Doubling of the number of measured values to be averaged reduces display noise by approx. 30%.

Zero Offset

A zero offset exists if a reading different from zero is obtained without any test signal being applied. The offset is usually caused by non-uniform heating of the insertion unit, eg at the RF connector. By zeroing the NRV-Z4, the offset can be measured and subtracted from the measured value in the subsequent measurements.

The zero offset, like display noise, is an error whose relative effect becomes the smaller the larger the measured power. It is, therefore, advisable to zero from time to time when measuring very small powers.

Temperature Effect

For almost all RF sensors, the ratio of output voltage to input voltage/power is temperature-dependent. This means that without a certain amount of temperature compensation, significant measurement errors may result. The temperature effect is level-dependent and occurs in addition to the above-mentioned zero offset.

Therefore, the temperature of the RF sensor of URV5-Z4 is cyclically measured and the result used for measured-value correction. Residual errors above 3 MHz are small; they are stated in the Specifications. As the temperature characteristics of the RF sensor, and therefore temperature compensation, are level-dependent, residual errors can lead to nonlinearities of the same order. They are, however, noticeable only in the case of major level differences of the order of several dB or greater.

In the frequency range 100 kHz to 3 MHz, a strong temperature effect is to be expected for voltages below 3 V (approx. 0.2 W / 23 dBm) - especially at the lower frequency limit -, which shows by increased measurement uncertainty (see data sheet) and reduced display linearity. This is due to the strongly temperature-dependent input impedance of the rectifier circuit, which causes the lower limit frequency of the insertion unit to vary as a function of temperature.

Harmonics and Nonharmonics

Diode sensors such as Insertion Unit URV5-Z4 perform true rms measurements below 220 mV (1 mW / 0 dBm), ie they indicate the correct value irrespective of the waveform applied. Above 220 mV this is not generally true, only applying to spectrally pure, unmodulated sinusoidal signals, ie the waveform used to calibrate the sensors. Deviations from the sinusoidal waveform caused, for example, by harmonics or nonharmonics, may result in significant measurement errors. In the case of harmonics, it depends on the phase of the harmonic relative to the fundamental whether the sensor indicates a value higher or lower than the rms value of the total voltage or the sum of the individual powers, respectively.

Fig. 3-1 shows maximum measurement errors. Because of the sinusoidal relationship between the measurement error and the phase difference between the fundamental and the harmonic, the "effective" measurement error (standard deviation) is only 0.71 times the maximum value specified. This value is to be taken into account when calculating the total measurement uncertainty (see relevant section).

Note: **Basically there are no measurement errors due to harmonics for measurements made at the outputs of radio equipment since such equipment must have very good harmonics suppression in order to avoid interference with other frequency bands.**

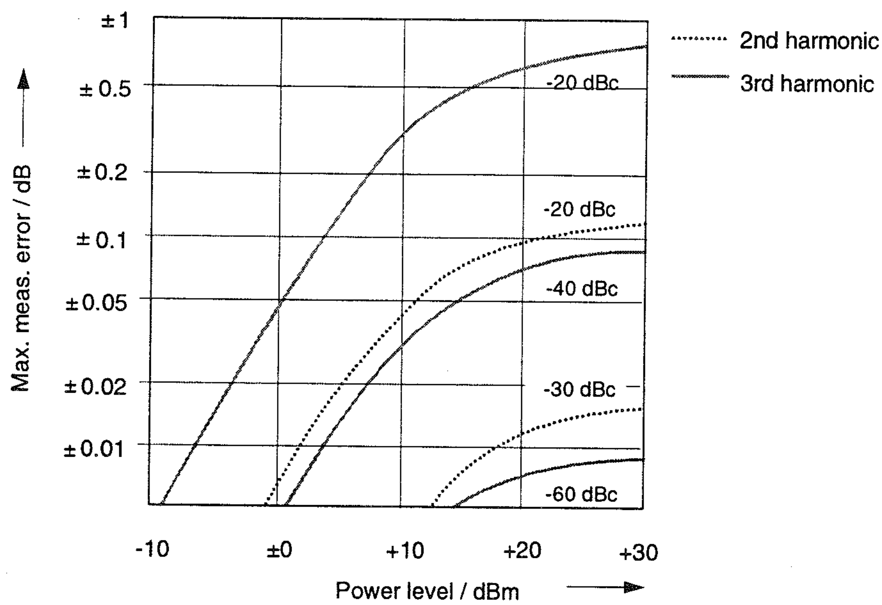

Fig. 3-1 **Effect of harmonics on measurement accuracy of Insertion Unit URV5-Z4 (parameter: harmonics)**

Basic Unit

The analog section of the basic units comprises a precision DC amplifier and a high-resolution A/D converter. Uncertainties specified in the data sheet include calibration uncertainties for these components as well as drift (time, temperature). The effect of the basic unit on measurement accuracy is in general so small that it can be neglected in comparison with other types of measurement uncertainty.

Calculation of Total Measurement Uncertainty

When calculating measurement uncertainty it has become metrological practice to assume not the worst case but a random distribution of the individual measurement errors, which means that the specified uncertainty is smaller but reflects much more closely what is actually the case.

As accuracy in power measurements in particular is influenced by a multitude of error parameters, this approach is fully justified, and for many years uncertainty has been expressed in terms of rss values (rss: root sum of the squares).

New international provisions [1] stipulate specification of the standard deviation taking into account all error parameters (combined standard uncertainty u_c) or of a multiple of the standard deviation (expanded uncertainty $U = ku_c$). In most cases, expanded uncertainty with a coverage factor $k = 2$ is specified, which approximately corresponds to the old rss values. With a normal distribution, the confidence level in this case is 95%, which means that the specified value would be exceeded in only 5% of all measurements.

The combined standard uncertainty u_c is calculated by squaring the standard uncertainty u_v of each error parameter, summing the squares, and taking the square root of the sum::

$$u_c = \sqrt{\sum_v u_v^2}$$

Standard uncertainties u_v should be estimated as accurately as possible using measurements, specifications or assumptions otherwise derived. Where no standard uncertainties but only error limits are available, the distribution function of the error parameter would have to be known in each case in order to determine the standard uncertainty. With symmetrical error limits it is in most cases sufficient to assume half the value of the error limit, ie from a specified error limit of ±4% a standard uncertainty of 2% would be derived, for example.

[1] See, for example, "Guide to the Expression of Uncertainty in Measurement" issued by IEC, ISO, BIPM and other organizations

In the following example, measurement uncertainty is determined for a source power into 50 Ω measured with Insertion Unit URV5-Z4:

• Insertion unit	URV5-Z4
• Test signal	220 mV (1 mW / 0 dBm) CW
• Frequency	120 MHz
• Ambient temperature	26°C
• SWR_g of source	1.5 $\left(\lvert\Gamma_g\rvert = \frac{SWR-1}{SWR+1} = 0.2\right)$
• SWR_l of load	1.05 $\left(\lvert\Gamma_l\rvert = \frac{SWR-1}{SWR+1} = 0.025\right)$
• Smoothing filters (NRVD, NRVS, URV55)	5
• Harmonics (3rd harmonic)	20 dB

Error parameter	Standard uncertainty u_v	Remarks
Mismatch of load	0.140 dB	$2.8\,dB \cdot (SWR_l - 1)$
Mismatch of source	0.031 dB 0.025 dB	$6.2\,dB \cdot \lvert\Gamma_g\rvert \cdot \lvert\Gamma_l\rvert$ $6.2\,dB \cdot \lvert\Gamma_g\rvert \cdot \lvert\Gamma_m\rvert$
Insertion loss	0.000 dB	Not relevant for this measurement
Measurement uncertainty specified in data sheet	0.065 dB	Calibration uncertainty + nonlinearity + temperature effect in the range 18°C to 28°C
Display noise	0.000 dB	Not relevant for this signal level
Zero offset	0.000 dB	Not relevant for this signal level
Temperature effect	0.000 dB	Included in measurement uncertainty specified in data sheet
Harmonics	0.035 dB	0.7×max. measurement error (±0.05 dB acc. to Fig. 3-1)
Basic unit	0.009 dB	0.5×max. measurement error (±0.017 dB acc. to data sheet specifications URV35, URV55, NRVS)
Combined standard uncertainty u_c	**0.163 dB**	

Expanded uncertainty U with a coverage factor k = 2 is 0.33 dB.

4 Maintenance

Insertion Unit URV5-Z4 requires no maintenance. Only the RF connectors should be regularly checked for any damage and cleaned if required. Contamination inside the coaxial connector or on the contact areas may cause significant measurement errors. Remove contamination cautiously with a brush or a cotton bud soaked in alcohol. How to check the most important functions of the insertion unit is described in section 5. Defective units should be returned to the manufacturer for repair.

Calibration

Voltage and power are among the most fundamental measured quantities. The measuring instruments used for determining these quantities are, therefore, often found right at the beginning of a measurement chain and determine the absolute accuracy of complete measurement systems. We, therefore, recommend that you have your insertion unit recalibrated at regular intervals. If an insertion unit is subject to low wear and tear (eg when used in a measurement system), a calibration interval of two years will be sufficient.

Calibration can be performed at the factory or at a competent calibration center. Calibration Kit NRVC is available for program-controlled measurement of absolute accuracy and linearity.

5 Function Test

Complete calibration of Insertion Unit URV5-Z4 requires a wide range of equipment, experience and great care. The following tests allow the correct functioning of the insertion unit to be checked using simple equipment. Function tests performed at regular intervals can be used as checks between two calibrations and are stipulated by the standard DIN ISO 10012, for example. Results can be entered into the test report form at the end of this section.

Measuring and Auxiliary Equipment

Item	Characteristics	Type	Purpose
1	Basic unit with test signal generator	R&S NRVD or R&S NRVS / URV35 / URV55 with option NRVS-B1	Power-up sequence Zeroing Measurement accuracy at 50 MHz
2	Precision termination SWR <1.02 at 50 MHz	R&S RNA	Measurement accuracy at 50 MHz

Test Procedure

- All tests should be carried out with autoranging and automatic filter setting (for smoothing) and with **high** resolution. Attenuation correction must be switched off.

Power-up Sequence

- Connect insertion unit to basic unit.
- After reading the data of the insertion unit (***READ SENSOR***, ***readPRB***), measured values should be indicated. If the insertion unit is defective, one of the following error messages is displayed:

  **** INVALID SENSOR ****
  **** DEVICE-ERROR* 0100***
  **** DEVICE-ERROR* 0400***
  ErrPRB
  ErrHRD

For details refer to the manual for the basic unit in question.

Zeroing

- Disconnect insertion unit from signal source and terminate with precision resistor at one end.
  Wait until reading has stabilized. Then trigger zeroing (ZERO key).
- On completion of zeroing, measured values should be displayed. Watch readout for a few seconds and check for compliance with limits specified in test report. Error messages ***ERROR ZERO*** or ***ErrZRO*** indicate a defective insertion unit.

Measurement Accuracy at 50 MHz

- Switch on frequency response correction, set frequency to 50 MHz.
- Connect insertion unit to test signal generator of basic unit. Switch test signal generator on (NRVD).
- Check readout for compliance with limit values specified in test report.

Test Report

Function Test

100 V INSERTION UNIT URV5-Z4

Stock No.: 0395.1619.02/05

Name:

Serial No.:

Date:

Item No.	Test	Min.	Actual	Max.	Unit
1	Power-up sequence	-------		------	------
2	Zeroing	-25		+25	nW
3	Measurement accuracy at 50 MHz	0.97		1.03	mW