POWER SENSOR: A MEASUREMENT COMPARISON

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Abstract: This paper presents the results of a comparative analysis of the calibration factor measurements of the power sensor model E4413A, manufactured by Agilent, which operates at frequencies from 50 MHZ to 26.5 GHz and power levels from -70 dBm to +20 dBm. The comparison takes into account the values of the calibration certificates provided by INPE's Integration and Testing Laboratory (INPE/LIT) and two others calibration laboratories: National Physical Laboratory (NPL) of United Kingdom and Brazilian Calibration Laboratory of Agilent. The normalised error is used to evaluate the performed power measurements. Conclusive analysis of the results presented in this paper shows the compatibility and the reliability of the measurement values provided by INPE/LIT.

Key words: radio frequency power measurements, power sensor, calibration factor, interlaboratory comparison.

1. INTRODUCTION

Aiming to provide traceability of the measurements performed under the Brazilian Space Program, the Integration and Testing Laboratory of the Brazilian National Institute for Space Research (INPE/LIT) has several facilities where metrology activities are developed:

- Electrical Metrology Laboratory: AC/DC voltage, AC/DC current, resistance, capacitance, inductance, time and frequency;
- Physical Metrology Laboratory: temperature, humidity, vibration, pressure; and
- Mechanical Metrology Laboratory: dimensional, mass and force.

Since 1991, the Electrical Metrology Laboratory is accredited by the Brazilian National Institute of Metrology, Standardization and Industrial Quality (INMETRO) to perform calibration services and is currently working on achieving technical capability to accomplish calibration services of power measurements at high frequencies. This effort aims to attend the growing demand to ensure the suitable qualification status of telecommunication systems by providing the traceability for electronic equipments used in Electromagnetic Compatibility (EMC) and Electromagnetic Interference (EMI) testing.

Interlaboratory comparisons are key criteria in the accreditation process, which allows assurance of compatibility and reliability of the results of a calibrating laboratory. Until now, INMETRO does not provide traceability and interlaboratory comparisons for power measurements at high frequencies.

To investigate the reliability of power measurements performed at high frequencies by INPE/LIT, this paper presents the results of a comparative analysis of power measurements. The comparison takes into account the values of the calibration certificates provided by INPE/LIT and two others calibration laboratories: NPL and Agilent, which have recognized technical competence and are accredited in accordance to ISO/IEC 17025.

3. METHODS

The power level is an important quantity which allows the performance characterization of telecommunication equipments. RF power sensor consists of two major elements: a structure that effectively terminates the waveguide through which power is being supplied and a device or method for measuring the power supplied to the termination. The resistive termination structure is designed to match the line, usually a coaxial one with 50 Ω [1].

Power sensors are used as a standard for the measurement of power levels at high frequencies. The most common types of power sensors are listed in Table 1 [2]:

Table 1 – Most common types of power sensors.

Type	Connector	Frequency Range	Power Range	Dynamic Range
Thermocouple	coaxial	DC – 50 GHz	1 µW – 100 mW	50 dB
	waveguide	8 GHz – 110 GHz		
Diode	coaxial	0,1MHz – 50 GHz	1 nW – 100 mW	90 dB
Thermistor	coaxial	1MHz – 18 GHz	10 µW – 10 mW	30 dB
	waveguide	2,6 – 200 GHz		

At thermocouples and diode power sensors, the radiofrequency (RF) power is detected or rectified to a DC voltage that is conditioned and displayed in a power meter, which has an internal power reference (1mW-50MHz) used to calibrate the power sensor.

Thermistor type sensor operates connected to a power meter with substitution technique, which is based on the thermistor heating effect due to RF power absorption. The thermistor forms one arm of a Wheatstone bridge, which is powered by a DC current that heats the thermistor until its resistance is such that the bridge balances.

The calibration of a power sensor aims to characterize its effective efficiency, being quantified by the value of the calibration factor and defined as the ratio of measured power to the RF incident power.

Calibration of a power sensor involves comparing an unknown power sensor against a standard power sensor. Rather than just connecting the two sensors in turn to a source, usually the calibration is done using a transfer standard (power splitter) with known small reflection coefficient [2]. The schematic of the measuring system is shown in Figure 1.

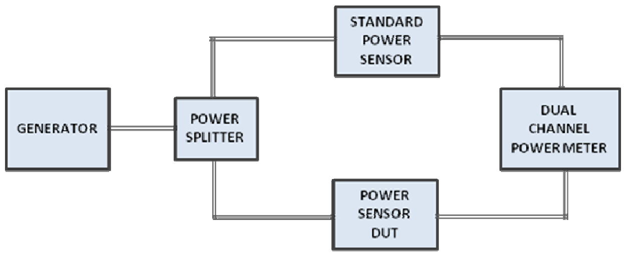

Figure 1 - Schematic of the measuring system.

The calibration factor of the DUT is determined from the ratio of the incident power at the reference frequency (50 MHz) to the incident power at the calibration frequency.

Four separate measurements were made, which involved disconnection and reconnection of both the unknown sensor and the standard sensor on a power transfer system. All measurements were made in terms of power ratios that are proportional to the calibration factor [2].

The power sensor and the power meter operation are not perfect and the calibration factor compensates for errors related to internal loss, which are different at each frequency.

The calibration factor of the power sensor under calibration (CF_x) is obtained by the Equation 1 [3]:

$$CF_x = p.\,(CF_{std} + \delta CF_{std})\,.\,c_r\,.\,c_f\,.\,M \qquad (1)$$

where:

$p = \dfrac{B_f/A_f}{B_r/A_r}$ = power measurement ratio when reference power sensor is connected to channel A and the power sensor under calibration is connected to channel B;

B_f/A_f = power ratio measurement when the standard power sensor is connected to channel A, while the power sensor under calibration is connected to channel B and the frequency of the applied power is 50 MHz (reference) to both sensors;

B_r/A_r = power ratio measurement when the standard power sensor is connected to channel A, while the power sensor under calibration is connected to channel B and a power of a given calibration frequency is applied to both sensors;

CF_{std} = calibration factor of the standard power sensor;

δCF_{std} = calibration factor drift of the standard power sensor;

c_r = correction due to non-linearity, resolution, zero set, zero drift, measurement noise, and power reference level of the power meter at the power ratio of the reference frequency;

c_f = correction due to non-linearity, resolution, zero set, zero drift and measurement noise at the power ratio of the calibration frequency;

$M = \dfrac{M_{xf}\,.\,M_{stdr}}{M_{stdf}\,.\,M_{xr}}$ = mismatch caused by the reflection coefficient between power sensors and source;

M_{xf} = mismatch factor due to power sensor under calibration at calibration frequency;

M_{stdr} = mismatch factor due to standard power sensor at reference frequency;

M_{stdf} = mismatch factor due to standard power sensor at calibration frequency;

M_{xr} = mismatch factor due to power sensor under calibration at reference frequency.

The uncertainties related to calibration factor measurement are related to signal-noise ratio, zeroing procedure, power reference level, power sensor linearity, calibration factor of the standard power sensor and mismatch.

Table 2 shows the calibration factor uncertainty budget for the measurements performed at 18 MHz for the power sensor E4413A, which is a diode sensor type. A comparison graph with the calibration results is shown in Figure 2.

Table 2 – Uncertainty budget for the power sensor E4413A at 18 GHz.

	Quantity X_i	Estimate x_i	Standard uncertainty $u(X_i)$	Probability Distribuition	Sensitivity Coefficient C_i	Uncertainty contribution $u(y)$
Power ratio measurement	p	0.99845	0.00759	normal	0.996	0.004367
Certificate of standard power sensor	CF_{std}	0.996	0.02949	normal	0.9984	0.014722
Drift do Cal Factor	δCF_{std}	1	0.002	rectangular	0.9984	0.000998
Resolution accuracy	P_{ref}	1	0.01	rectangular	0.9984	0.005762
Power reference drift	δP_{ref}	1	0.005	rectangular	0.9984	0.002881
Zero Set	Z_s	1	0.00000005	rectangular	0.9984	0.000000
Zero drift	Z_d	1	0.0000015	rectangular	0.9984	0.000001
Noise measurement	N	1	0.000007	rectangular	0.9984	0.000004
Linearity	L	1	0	rectangular	0.9984	0.000000
Mismatch Standard at 50 MHz	M_{stdr}	1	0.00064	U-shaped	0.9944	0.000451
Mismatch Standard at 18 GHz	M_{stdf}	1	0.00218	U-shaped	0.9944	0.001533
Mismatch DUT at 50MHz	M_{xr}	1	0.00666	U-shaped	0.9944	0.004686
Mismatch DUT at 18GHz	M_{xf}	1	0.02280	U-shaped	0.9944	0.016034
Cal Factor - DUT	CF_X	0.9944	Combined uncertainty			0.02326
			Expanded uncertainty (K=2)			**0.04651**

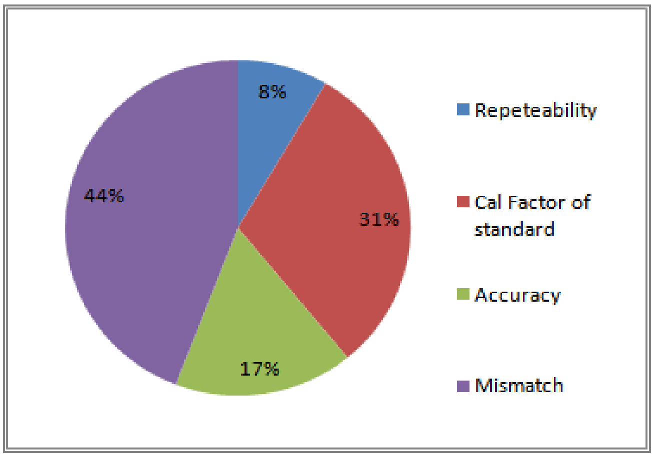

Figure 2 - Calibration factor uncertainties contributions for the power sensor E4413A at 18 GHz.

4. RESULTS

The comparison takes into account the values of the calibration certificates provided by NPL [4], Agilent [5] and INPE/LIT [6]. NPL and Agilent have recognized technical competence and are accredited in accordance to the ISO/IEC 17025 requirements. NPL is a National Metrology Institute and its calibration certificate values were taken as reference for this comparison.

The normalised error (En) is used to evaluate the consistence of the measurements performed by INPE/LIT. Equation 2 describes the expression used to determine the normalised error [7]. At each frequency, the calibration result is considered satisfactory if normalised error value is smaller than or equal to one ($E_n \leq 1$).

$$E_n = \frac{CF - CF_{ref}}{\sqrt{(U_{CF})^2 + (U_{CF_{ref}})^2}} \quad (2)$$

where:

E_n = normalised error;

CF = calibration factor at a given frequency;

CF_{ref} = reference calibration factor at a given frequency;

U_{CF} = expanded uncertainty value of the calibration factor;

U_{CFref} = expanded uncertainty value of the reference calibration factor.

The measured values and the uncertainties of the calibration factor declared at calibration certificates provided by NPL, Agilent and INPE/LIT for the power sensor model E4413A are shown in Table 3. The normalised errors values for the calibration factor values at each frequency are also presented in Table 3. A comparison graph with the calibration results is shown in Figure 3.

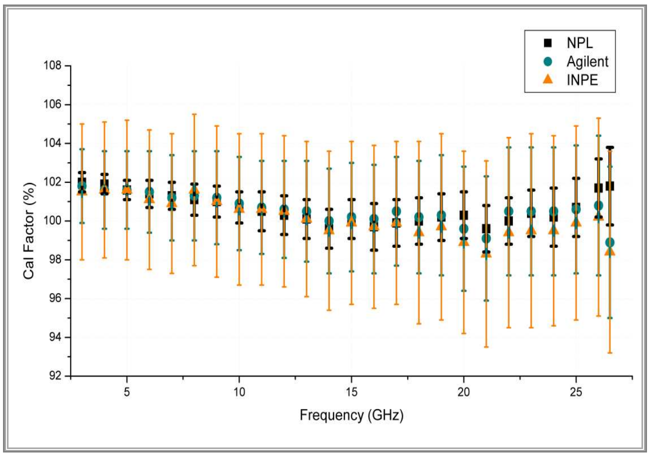

Figure 3 - Calibration results comparison.

Table 3 – Calibration Factor and normalised error results.

F (GHz)	NPL		AGILENT			INPE/LIT		
	CF_{ref} (%)	U_{CFref} (%)	CF (%)	U_{CF} (%)	En	CF (%)	U_{CF} (%)	En
0.05	100.0	-	100.0	-	-	100	-	-
0.1	101.0	0.3	100.9	1.8	0.05	100.9	3.7	0.03
0.3	101.7	0.3	101.4	1.8	0.16	101.3	3.5	0.11
1	102.2	0.3	102.2	1.8	0.00	102.0	3.5	0.06
2	102.2	0.5	102.2	1.9	0.00	102.2	3.5	0.00
3	102.0	0.5	101.8	1.9	0.10	101.5	3.5	0.14
4	101.9	0.5	101.6	2.0	0.15	101.6	3.5	0.08
5	101.6	0.5	101.6	2.0	0.00	101.6	3.6	0.00
6	101.4	0.7	101.5	2.1	0.05	101.1	3.6	0.08
7	101.3	0.7	101.2	2.2	0.04	100.9	3.6	0.11
8	101.1	0.8	101.3	2.3	0.08	101.6	3.9	0.13
9	101.0	0.8	101.2	2.4	0.08	101.0	3.9	0.00
10	100.7	0.8	100.9	2.4	0.08	100.6	3.9	0.03
11	100.5	1.0	100.7	2.4	0.08	100.6	3.9	0.02
12	100.3	1.0	100.6	2.5	0.11	100.5	3.9	0.05
13	100.1	1.0	100.5	2.6	0.14	100.1	4.0	0.00
14	99.6	1.0	100.0	2.7	0.14	99.5	4.1	0.02
15	100.1	1.0	100.2	2.8	0.03	99.9	4.2	0.05
16	99.7	1.2	100.1	2.8	0.13	99.7	4.2	0.00
17	99.9	1.2	100.5	2.8	0.20	99.9	4.2	0.00
18	100	1.2	100.2	2.9	0.06	99.4	4.7	0.12
19	100.2	1.2	100.3	3.1	0.03	99.7	4.8	0.10
20	100.3	1.2	99.6	3.2	0.20	98.9	4.7	0.29
21	99.6	1.2	99.1	3.2	0.15	98.3	4.8	0.26
22	100	1.2	100.5	3.3	0.14	99.4	4.9	0.12
23	100.4	1.2	100.5	3.3	0.03	99.5	5.0	0.18
24	100.2	1.5	100.5	3.3	0.08	99.5	4.9	0.14
25	100.7	1.5	100.6	3.3	0.03	99.9	5.0	0.15
26	101.7	1.5	100.8	3.6	0.23	100.2	5.1	0.28
26.5	101.8	2.0	98.9	3.9	0.66	98.4	5.2	0.61

6. CONCLUSION

This paper presents the results of a comparative analysis of the calibration factor measurements of the power sensor model E4413A, serial number MY41497662, manufactured by Agilent, which operates at frequencies from 50 MHz to 26.5 GHz and power levels from -70 dBm to +20 dBm.

Interlaboratory comparisons are key criteria in the accreditation process, which allows assurance of compatibility and reliability of the results of a calibrating laboratory. Until now, INMETRO does not provide traceability and interlaboratory comparisons for power measurements at high frequencies.

Aiming to investigate the reliability of power measurements performed at high frequencies by INPE/LIT, the comparative analysis takes into account the values of the calibration certificates provided by INPE/LIT and two others calibration laboratories: NPL and Brazilian Calibration Laboratory of Agilent, which have recognized technical competence and are accredited in accordance to ISO/IEC 17025.

The conclusive analysis of the results presented in this paper shows the compatibility and the reliability of the measured values of the calibration factor of the power sensor provided by the Electrical Metrology Laboratory of INPE/LIT.

ACKNOWLEDGEMENTS

The authors thank to the Brazilian National Institute for Space Research.

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