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Study of the Long Term Performance on the Calibration Data of the Coaxial Thermistor Mounts up to 18 GHz

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Abstract

National Physical Laboratory (NPL) India is the premier research and development center and the National Metrology Institute (NMI), which provides traceability in measurements by calibration throughout the country. Radio frequency (RF) power is one of the most important quantities in RF metrology. The calibration of the reference standard thermistor mount and the unknown thermistor mounts in the frequency range of 50 MHz to 18 GHz has been carried out using coaxial microcalorimeter and direct comparison technique respectively. The long term stability performance study carried out on the reference standard thermistor mount and the unknown thermistor mounts is reviewed in this paper. The results show that the maximum deviation in the calibration results of the reference standard thermistor mount and the three unknown thermistor mounts over the period of seventeen years is within ± 0.4% and ± 1.5% respectively from 50 MHz to 18 GHz.

1. Introduction

Coaxial microcalorimeter system established, as the primary standard of RF power is an absolute method for the determination of effective efficiency of the coaxial thermistor mounts. The effective efficiency (η_e) of the coaxial thermistor mount is directly proportional to the calibration factor (K_b) of the thermisator mount and their relationship at a particular frequency is given by;

$$K_b=\eta_e(1-|\Gamma|^2) \quad (1)$$

where, Γ is the reflection coefficient of the thermistor mount.

The uncertainty in assigning the effective efficiency to the reference standard thermistor mount using coaxial microcalorimeter lies within ± 0.8% up to 18 GHz. The uncertainty in measurement of the calibration factor for the unknown thermistor mounts is within ±1.5% up to 18 GHz using direct comparison technique. This paper summarizes direct comparison technique, which is one of the oldest and the most basic technique for microwave power transfer for the measurement of calibration factor of the thermistor mount over the specified frequency range. In this technique, calibrated thermistor mount acts as a reference standard and is used for calibrating [1] the unknown thermistor mounts used in RF power measurements. The direct comparison technique is based on connecting the reference standard thermistor mount (STD) and an unknown thermistor mount (DUC) alternately to a matched source of RF power. The purpose of calibration of thermistor mount is to determine the calibration factor, which is the ratio of substituted DC power to the total incident RF power on the thermistor mount at the desired frequencies. To ensure the quality of measurement, a study on the long-term stability of the unknown thermistor mounts has been carried out, which is spread over seventeen years from 1991 to 2007.

2. Direct Comparison Technique

Direct comparison technique [2] is applicable for the calibration of thermistor mounts for their calibration factor. The reference standard thermistor mount (STD) and unknown thermistor mount (DUC) are used in conjunction with Self-Balancing Bridge (SSB) [3] for the measurement of RF power. The photograph of the measurement setup for this technique is shown in Fig. 1. Coaxial thermistor mounts, which are assigned calibration factors using coaxial microlacorimeter system, are used as reference standards to calibrate unknown thermistor mounts using direct comparison technique. VSWR of the DUC is measured at all the desired frequencies with the help of a slotted line method. The calibration factor K_b of the DUC is calculated using the relation;

$$K_{b(DUC)}=(P_{DUC} / P_{STD})xK_{b(STD)} \tag{2}$$

where, $K_{b(DUC)}$ is the calibration factor of the DUC and $K_{b(STD)}$ is the calibration factor of the reference standard thermistor mount. P_{DUC} is the DC substituted power measured by the unknown thermistor mount and P_{STD} is the DC substituted power measured by the reference standard thermistor mount.

P_{DUC} is calculated as follows;

$$P_{DUC} = K_1 \text{ x } (Vu_1^2 - Vu_2^2) \tag{3}$$

where, K_1 =0.025 x R, 'R' is the constant, which depends upon the resistance of the thermistor mount used, Vu_1 and Vu_2 are respectively the SBB voltages for RF power OFF and RF power ON conditions applied to the DUC.

P_{STD} is calculated using the relation;

$$P_{STD} = K_2 \text{ x } (Vs_1^2 - Vs_2^2) \tag{4}$$

where,

$$K_2 = \frac{1}{R\left(1+\frac{100}{R}\right)^2}$$

'R' is the constant, which depends upon the resistance of the thermistor mount used and Vs_1 and Vs_2 are respectively, the SBB voltages for RF power OFF and RF power ON conditions applied to the STD.

Power is measured by connecting the STD on Port 1 and DUC on Port 2 of the coaxial switch as shown in Fig. 2. First, Vs_1 and Vu_2 the SBB voltages for RF power OFF and RF power ON conditions applied to the STD and DUC, respectively are measured. After measuring these voltages, switch is transferred to Port 2. Then, Vu_1 and Vs_2 the SBB voltages for RF power OFF and RF power ON conditions applied to DUC and STD respectively are measured. P_{DUC} is power measured by the DUC and P_{STD} is power measured by the reference standard thermistor mount using Eqs. 3 and 4, respectively. From Eq. 2 the value of calibration factor of DUC on port 1 of the coaxial switch is calculated. Then the ports of STD and DUC are interchanged i.e. reference standard thermistor mount (STD) is connected on Port 2 and the unknown thermistor mount (DUC) on Port 1 of the coaxial switch. The measurements as described above are repeated and the value of calibration factor of the DUC on port 2 of the coaxial switch is calculated. The results are recorded automatically in an excel format as shown in Table 1. The average of these two values is calculated in order to compensate the losses of both the ports and to phase out the effect of asymmetry in

Fig. 1. Photograph of the measurement setup for determining the calibration factor of DUC using direct comparison technique

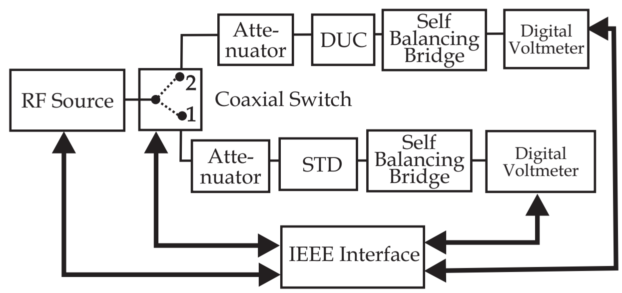


Fig. 2. Block diagram for determining the calibration factor of DUC using direct comparison technique

Table 1
Data recorded in an excel format

Microsoft Excel - Data

LF & HF Voltage, Current & RF Power Standard
Electrical & Electronic Standard
National Physical Laboratory

Frequency : 100 MHz — DUC : Unknown Thermistor mount

Power Level: 10 mW — STD : Reference Standard thermistor mount

Observations:

Forward Direction :

Port 1 (STD)	Power (mW)	Port 2 (DUC)		Power (mW)	Calibration Factor	
V2 (ON)		V1 (OFF)	V2 (ON)		Kb (STD)	Kb (DUC)
1.37828	9.498	2.52814	2.12722	9.332	99.78	98.03
1.37813	9.496	2.52812	2.12700	9.336	99.78	98.10
1.37814	9.496	2.52813	2.12714	9.334	99.78	98.07
1.37803	9.495	2.52813	2.12713	9.334	99.78	98.09
1.37821	9.497	2.52811	2.12733	9.329	99.78	98.01

Reverse Direction :

Port 1 (DUC)		Power (mW)	Port 2 (STD)	Power (mW)	Calibration Factor	
V1 (OFF)	V2 (ON)		V2 (ON)		Kb (STD)	Kb (DUC)
2.52786	2.12471	9.378	1.37269	9.421	99.78	99.32
2.52785	2.12476	9.377	1.37226	9.415	99.78	99.37
2.52785	2.12487	9.375	1.37252	9.419	99.78	99.31
2.52785	2.12457	9.381	1.37249	9.419	99.78	99.38
2.52784	2.12478	9.376	1.37180	9.409	99.78	99.43

Calibration Factor (Kb)
98.68
98.74
98.69
98.74
98.72
98.71

the value of VSWR at the two ports of the coaxial switch. A set of ten such measurements is taken at each frequency of calibration to estimate the measurement uncertainties.

3. Calibration of Reference Standard Thermistor Mount

The reference standard thermistor mount has been calibrated for absolute determination of effective efficiency using coaxial microcalorimeter. In this method, the effective efficiency of the reference standard thermistor mount is determined by simultaneous measurements of the total RF power dissipated in the reference standard thermistor mount and the substituted DC power of the reference standared thermistor mount. The effective efficiency (η_e) [4] of the reference standard thermistor mount is determined as follows;

$$\eta_e = g\eta_e' = g\left[\frac{1-(\nu_2/\nu_1)^2}{(e_2/e_1)-(\nu_2/\nu_1)^2}\right] \tag{5}$$

where,

g total correction factor

η_e' effective efficiency without correction

ν_1, ν_2 SBB voltage for RF power OFF and ON conditions respectively

e_1, e_2 thermopile output voltage corresponding to ν_1, ν_2 respectively at steady state condition

There are three major factors that influence the measured effective efficiency of the reference standard thermistor mount due to the design of the microcalorimeter [4]. These are RF loss in the thermal isolation section of the calorimeter (L), RF loss in the wall of the reference standard thermistor mount (A) and non-linear thermopile response of the calorimeter (Q). These parameters L, A and Q are determined by the Eqs. 6, 7 and 8, respectively.

$$L = 1 + \left[\frac{e_L / e_1}{(e_2 / e_1) - (\nu_2 / \nu_1)^2} \right] \tag{6}$$

where, RF loss causes an additional thermopile emf as e_L, which is estimated as 0.8 $\sqrt{f/18}$; f is frequency of operation

$$A=1+(1-\eta e')xW \tag{7}$$

where, W is the local heating effect difference of coaxial thermistor mount. A figure of 2 percent is arbitrarily assigned to this effect.

$$Q = 1 - x \tag{8}$$

where, $x = (0.001 / 14)\,\Delta e$, $\Delta e = e_2 - e_1$ and $p = (\nu_1-\nu_2) / \nu_1$

The total correction factor 'g' is determined as follows;

$$g = LAQ \tag{9}$$

The value of the factor 'g' for the coaxial thermistor mounts ranges from 1.000 to 1.008 depending upon the frequency and the thermistor mount used [4]. The correction factor g for the reference standard thermistor mount is within the specified range. At 1 GHz, the value of g is 1.0034 and its uncertainty is 0.00085.

The uncertainty in determining the effective efficiency using coaxial microcalorimeter depends upon the uncertainty in the correction factor g and the instrumentation uncertainty, which consists of uncertainty in measuring the biasing voltages of the reference standard thermistor mount using SBB and digital voltmeter (DVM) and uncertainty in measuring the thermopile emf using nano voltmeter.

To study the stability of reference standard thermistor mount, the mathematical average of the measured values of the effective efficiency at the specified frequencies are calculated over the period of calibration, spread over seventeen years. For the deviations from the mean value we have taken the average reference value equal to zero so that these measurement results are compared and analyzed against a common reference line.

The calibration results of the reference standard thermistor mount using coaxial microcalorimeter in terms of effective efficiency are shown in Table 2 and its uncertainty budget at 1 GHz is shown in Table 3.

Table 2
Calibrated results of the reference standard

Coaxial Thermistor mount (Reference Standard)				
Frequency (GHz)	Effective efficiency (1991)	Effective efficiency (1997)	Effective efficiency (2002)	Effective efficiency (2007)
0.05	99.89	99.86	99.82	99.81
0.10	98.52	97.86	97.96	98.35
0.50	98.30	97.80	97.76	98.13
1.00	98.00	97.45	97.58	97.94
2.00	97.36	96.91	96.86	97.24
4.00	96.64	96.00	96.10	96.50
6.00	96.10	95.37	95.52	95.93
8.00	95.44	94.85	94.89	95.27
10.00	95.32	94.80	94.82	95.18
12.00	95.26	94.78	94.77	95.13
14.00	95.15	94.70	94.70	95.08
16.00	94.90	94.60	94.50	94.84
18.00	94.51	93.95	94.03	94.35

Table 3
Uncertainty budget for determining the effective efficiency of the reference standard thermistor mount using coaxial microcalorimeter

Uncertainty budget of the reference standard at 1 GHz							
Source of unertainty	Estimates (A)	Limits x_i (A)	Probability Type A or B Factor	Standard uncertainty $u_i(x_i)$ A	Sensitivity coefficient c_i	Uncertainty contribu-tion $u_i(y)$ ***A***	Degree of freedom (n_i)
Correction Factor "g"	0	0.0017	Normal Type B	0.000850	1	0.000850	∞
Thermopile Non Linearity	0	0.0001	Rectangular Type B	0.000058	1	0.000058	∞
Nano-voltmeter Unstability	0	0.0004	Rectangular Type B	0.000231	1	0.000231	g
DVM Unstability	0	0.0007	Rectangular Type B	0.000404	1	0.000404	∞
SBB Unstability	0	0.0006	Rectangular Type B	0.000346	1	0.000346	∞
Repeatability			Normal Type A	0.000097	-	0.000097	4
Combined Standard Uncertainty $u_c(\eta_e)$						0.001035	∞
Expanded Uncertainty $U(\eta_e)$			k=2			0.00207 0.21%	51397

4. Calibration of Unknown Thermistor Mount

Three unknown thermistor mounts A, B and C of the same manufacturer have been calibrated against the reference standard thermistor mount for their calibration factor under the environmental conditions of (25 ± 1) °C and (50 ± 10) % RH using direct comparison technique. These mounts have been calibrated from 50 MHz to 18 GHz spread over seventeen years from 1991 to 2007.

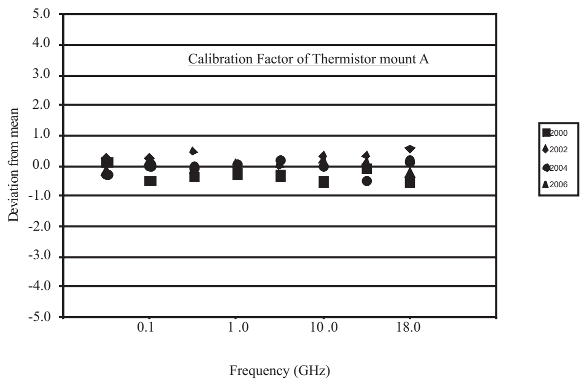
To study the long-term stability of these unknown thermistor mounts, the mathematical average of the measured values of the calibration factor at the specified frequencies are calculated over the period of calibration, spread over several years. For the deviations from the mean value we have taken the average reference value equal to zero so that these measurement results are compared and analyzed against a common reference line. The calibration factor of the thermistor mounts A, B and C is given in Tables 4-6, respectively.

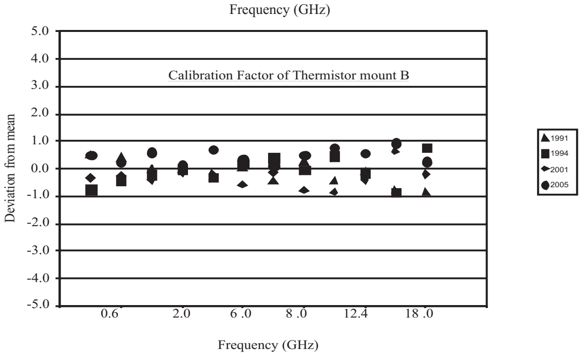
5. Analysis of the Results

Analysis of the results shows that the drift in the

Table 4
Measured values of the calibration factors for the Themistor mount A

Frequency	Calibration Factor (k_b)			
(GHz)	2000	2002	2004	2006
0.05	98.3	98.2	98.7	98.6
0.10	98.7	98.0	98.2	98.1
0.30	98.0	97.2	97.7	97.8
1.0	96.4	96.1	96.1	96.1
3.0	94.9	94.6	94.4	94.5
10.0	91.7	90.9	91.2	91.0
15.0	89.8	89.4	90.2	89.6
18.0	88.2	87.1	87.5	87.9





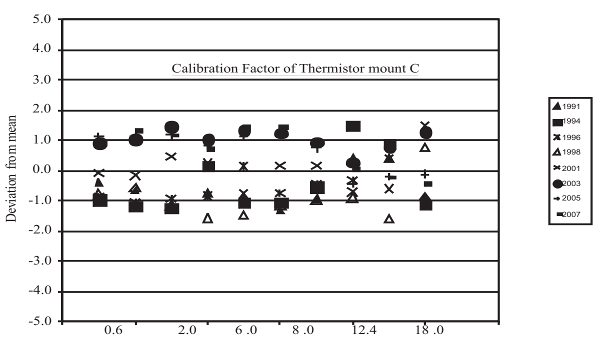


Fig. 3. Analysis on the measurement of the Calibration Factor of the themistor mounts A, B, & C

Table 5
Measured values of the calibration factors for the Themistor mount B

Frequency	Calibration Factor (k_b)			
(GHz)	1991	1994	2001	2005
0.10	98.0	99.3	98.9	98.0
0.60	97.7	98.5	98.4	97.9
1.0	97.4	97.6	97.9	96.8
2.0	96.4	96.3	96.5	96.2
4.0	94.8	94.8	94.7	93.8
6.0	93.7	93.6	94.3	93.4
8.0	92.6	91.7	92.3	92.0
10.0	91.1	91.4	92.2	90.9
12.4	90.3	89.4	90.8	89.1
14.0	90.2	90.2	90.5	89.5
16.0	89.2	89.3	87.8	87.5
18.0	86.4	84.8	85.8	85.3

measurement results from the mean value obtained by calibrating the reference standard thermistor mount over the period of seventeen years lies within ± 4%. The maximum drift in the measurement results from the mean value obtained by calibrating the unknown thermistor mounts over a period of seventeen years lies within ± 1.5%, for all the three cases [5]. The contributing factors of uncertainty in measurements are :

1. Uncertainty in the calibration factor of the reference standard thermistor mount,
2. Uncertainty due to drift in reference standard thermistor mount,
3. Uncertainty due to mismatch between the RF signal source and the reference standard mount,
4. Uncertainty due to mismatch between the RF signal source and the thermistor mount under calibration, and
5. Uncertainty due to repeatability.

The expanded uncertainty in determining the calibration factor of the unknown thermistor mount C at 18 GHz using direct comparison technique is shown in Table 7.

Calibration results are presented as a drift from the reference value, which is obtained by taking the mathematical average of the results at a particular frequency, as shown in Fig. 3. The statistical analysis for all the three cases from Fig. 3, shows that the

Table 6
Measured values of the calibration factors for the Themistor mount C

Frequency (GHz)	Calibration Factor (k_b) 1991	1994	1996	1998	2001	2003	2005	2007
1.0	97.0	97.6	97.5	97.4	96.7	95.7	95.5	95.7
2.0	95.5	96.0	95.9	95.4	95.0	93.8	93.7	93.5
4.0	95.4	95.5	95.2	95.4	93.8	92.8	93.1	93.1
6.0	93.6	92.7	93.7	94.4	92.6	91.8	92.0	92.1
8.0	93.6	93.8	92.6	94.2	93.5	91.4	91.6	91.3
10.0	93.7	93.4	93.1	93.5	92.2	91.1	91.1	90.9
12.0	91.1	90.7	90.6	91.1	90.0	89.2	89.4	89.2
14.0	89.7	88.6	90.4	91.0	90.8	89.8	90.5	90.0
16.0	88.5	88.0	88.5	90.5	89.5	88.1	89.1	89.1
18.0	89.0	89.3	89.3	87.4	86.7	86.9	88.3	88.6

Table 7
Uncertainty Budget for determining the Calibration factor using direct comparison technique

Uncertainty Budget for the thermistor mount C (2007) at 18 GHz							
Source of unertainty	Estimates (A)	Limits x_i (A)	Probability Type A or B Factor	Standard uncertainty $u_i(x_i)$ A	Sensitivity coefficient c_i	Uncertainty contribu-tion ui (y) A	Degree of freedom (n_i)
Referece Standard	0.9435	0.0032	Normal Type B	0.001600	1	0.001600	∞
Due to Drift in Cal. Factor of the Standard	0	0.0020	Rectangular Type B	0.001155	1	0.001155	∞
Due to Instrument Linearity	0	0.0010	Normal Type B	0.000707	1	0.000707	∞
Mismatch w.r.t. Source to STD	0	0.0041	U Shape Type B	0.002899	1	0.002899	∞
Mismatch w.r.t. Source to DUC	0	0.0054	U Shape Type B	0.003818	1	0.003818	∞
Repeatability			Normal Type A	0.000050		0.000050	4
Combined Standard Uncertainty $u_c(K_b)$						0.005232	∞
Expanded Uncertainty		*k*=2				0.01047	
$U(K_b)$						1.05 %	

deviation in the calibration results from the mean value obtained by calibrating the unknown thermistor mounts are:

i) Thermistor mounts A over the period of six years is ± 0.5%

ii) Thermistor mounts B over the period of fourteen years is ± 1.0%

iii) Thermistor mounts C over the period of seventeen years is ± 1.5%

The inconsistency present in the calibration results in terms of repeatability is due to the mismatch between the RF source and the unknown thermistor mount. This is due to wear and tear of the coaxial N type connector, which has a severe impact on reflection coefficient measurements.

6. Conclusion

Coaxial microcalorimeter system is the fundamental method for assigning the effective efficiency or the calibration factor to the reference standard thermistor mounts at the desired frequencies. Direct comparison technique is discussed and used for calibrating the unknown thermistor mounts against the reference standard thermistor mount. The measurement results of the reference standard thermistor mounts and the unknown thermistor mounts obtained over a periodof seventeen years indicate that no major drift in the values of the calibration results has occurred in the frequency range of 50 MHz to 18 GHz.

The calibration data analysis of the reference standard thermistor mount shows that the maximum drift in the effective efficiency from the mean value over the period of seventeen years of calibration is within ± 0.4%. A study on the long-term stability of the unknown thermistor mounts for their calibration factor is done and result analysis of these thermistor mounts shows that the maximum drift in the calibration factor from the mean value over the period of seventeen years from 50 MHz to 18 GHz is within ± 1.5%.

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References

[1] NIST Document, Good Measurement Practices for Assignment and Adjustment of Calibration Intervals for Laboratory Standards by NIST (2003).

[2] M.P. Weidman, NIST Technical note 1379 on Direct Comparison Transfer of Microwave Power Sensor Calibrations by NIST (1996).

[3] Operating and Service Manuals of Equipment Used (1990).

[4] N.S. Chung, J. Shin, H. Bayer and R. Honigbaum, Coaxial and Wave Guide Microcalorimeters for RF and MW Power Standards, IEEE Trans. on Instrumentation and Measurements, Instrum. Meas. IM-30, **2** (1989) 460-464.

[5] APMP Comparison of Radio Frequency Power Standard (APMP-IC-3-95) APMP. EM. RF-S2 (APMP Project No. 95) in (1997).