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Primary RF-Power Standard Realization in a Single-step Measurement Process

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***Abstract* – The RF power standard realized by the microcalorimeter technique has many problems related to the measurement time and the necessity of operating the measurements in two steps, measurement and calibration. In the paper, a new type is proposed of dry microcalorimeter, which has hardware facilities that allow a self-calibration of the system through convenient algorithms and without dismounting/mounting operation. A shorter measurement time without accuracy loss is the most significant result obtainable, provided that the manner changes in which the primary broadband RF-power standards are considered and designed.**

Keywords* – *RF power standard, twin microcalorimeter, thermoelectric sensor, adiabatic transmission line

I. INTRODUCTION

The coaxial microcalorimeter is a measurement system having the specific role of determining the effective efficiency of the power sensors at small power levels (1-10 mW). Such a system is operative in the most important National Metrology Institutes, NMIs, which implement different technical solutions with the aims to obtain high accuracy, wide bandwidth and limited measurement time.

The realization of the core system may be seen based either on a thermostatic water bath or an active thermostatic shield, which create a very stable thermal environment for single or more often for twin thermal loads. Fig. 1 shows the basic scheme of this structure.

How this system works has been widely described in the specialized literature, even of the same authors [1-8]. However, independently of the technical solution adopted in each laboratory, the effective efficiency of the power sensor used as calorimetric load is a rational function of the temperatures measured by the differential thermometer in two different conditions of thermal equilibrium, that is, with and without RF injection into the measurement channel. The critical points of the microcalorimeters are the temperature stability of the thermostatic shields, the degree of the twin symmetry, if this configuration is used and mainly the dismounting/mounting operation requested by the microcalorimeter calibration step. This last can produce a calibration data set non coherent with the power sensor measurements, indeed. Other weak points are, a large number of test frequencies and an intrinsic time consuming of the measurements.

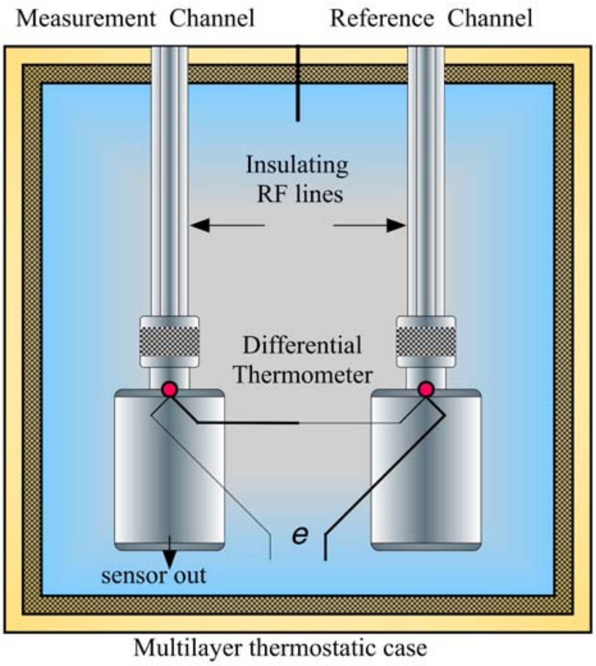


Fig. 1. Scheme of a classic coaxial microcalorimeter based on the twin architecture

II. ACTUAL STAGE

A part of NMIs, as PTB, INRiM and KRISS, are realizing the RF power standard by using thermoelectric power sensors mainly, whereas NIST and AIST prefer the bolometric power sensors. In any case, a progress in this field is possible if a right answer will be given to each of the following technical questions:

- twin loads or single load
- compensations or corrections
- direct results or separately data
- medium-term or long-term measurements
- power switching between channels in the twin architecture
- thermal conduction or thermal insulation
- inner thermal shunt or high thermal resistance
- thermocouples or bolometers as thermal load

Unfortunately, few of the listed points have been thoroughly considered up to now by the scientific community especially for dry microcalorimeter fitted with a thermoelectric twin load.

III. SINGLE STEP MEASUREMENT PROPOSAL

For determining the power sensors effective efficiency through microcalorimeter measurements, a supplementary step is necessary, mainly to discover the error contribution due to the microcalorimeter feeding lines. A lot of problems appear in this step. Microcalorimeter dismount/mount operation, long-term thermal equilibrium, inherent changes in the thermal pats, high number of test points, different levels and small measured values, complicate the determination for both effective efficiency and its uncertainty [1-5].

The switching power method already proposed in [6], by the same authors, allows to obtain the final result without corrections and microcalorimeter dismounting/mounting operations, of course, but the involved quantities are still obtained in different measurement phases and by changing the instrumentation set-up. This contributes to generate non-coherent data and therefore possible strong measurement errors.

Only with new design of the feeding lines complex, the classical twin microcalorimeter [4-5] will allow true single-step measurements and therefore to obtain direct effective efficiency values. The technical solution we propose is that of duplicating the classical twin line inset [4] according to the scheme of Fig. 2. Of course this proposal requires major change in the microcalorimeter core design and furthermore, important changes are needed in the instrumentation set-up and in the measurement algorithms.

IV. NEW TWIN LOADS MICROCALORIMETER

At every channel A and B of the classical twin configuration [5], also shown in Fig. 1, an additional transmission line is coupled, so that both A and B have an own thermal reference channel. These additional reference channels are permanently terminated with dummy loads that from the electromagnetic point of view behave as broadband short-circuit. Fig. 2 shows two schematic cross sections of the new coaxial microcalorimeter, took on two orthogonal planes.

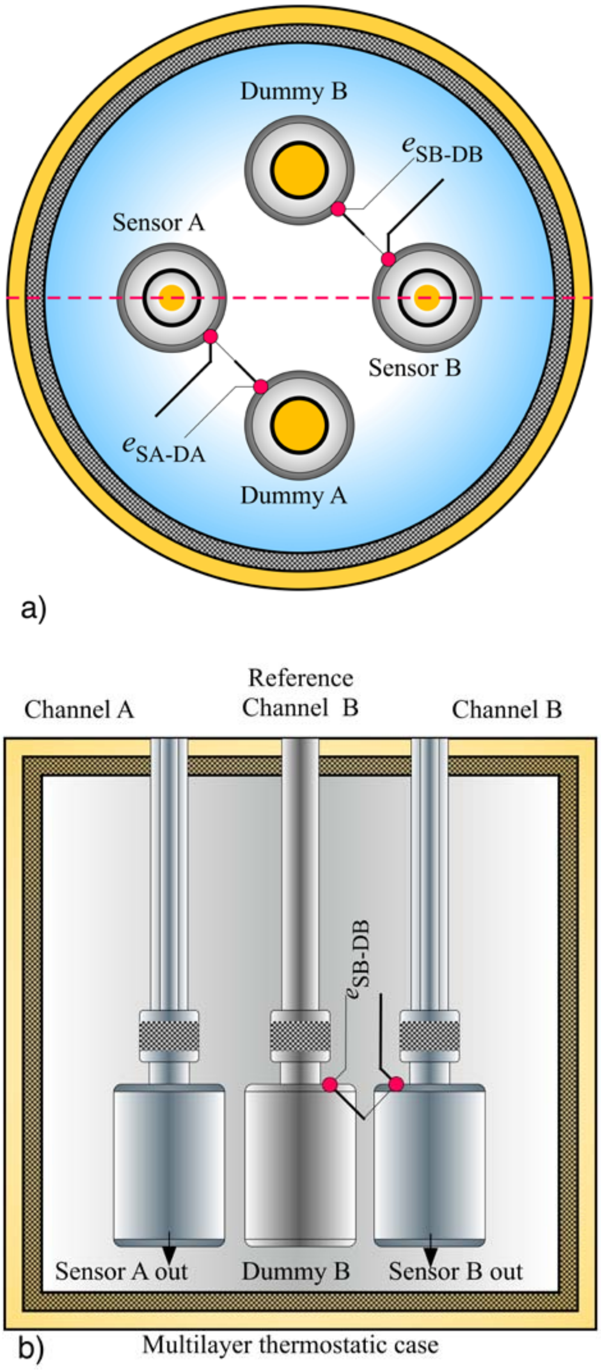


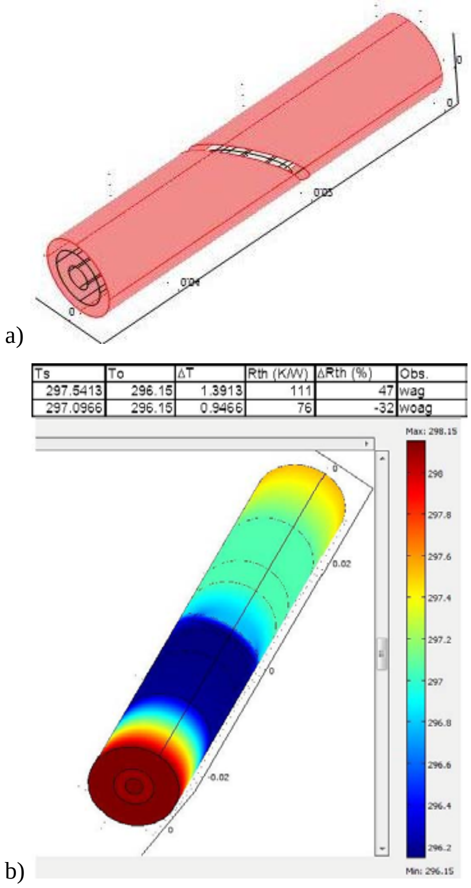
Fig .2. a) Scheme of cross-section of the new coaxial microcalorimeter inset at the base of power sensor input connector, where thermometers measure the temperature differences; b) Schematic vertical cross section of the new microcalorimeter

The channels A and B will be feed by the RF power and reference power, respectively, whereas the new reference channels will be feed only with RF power. This scheme should allow compensation for the RF losses in the feeding lines that supply the sensor A and B. In this manner, we obtain a virtual isotherm reference plane at the sensors input connectors, like in a lossless ideal feeding line case.

V. MICROCALORIMETER COMPONENT DESCRIPTION

The most important components of a microcalorimeter are described in the following order with more detail:

A) The feeding lines are surely the most critical component of the system, because they introduce the dominant error term in all the measurement process. The general criteria for designing suitable feeding lines are good thermal and electrical pairing, good adjustable thermal insulation, inner thermal shunt at the reference plane and small reflection coefficient at the test port. A new profiled machinable air-gap insulating line, as shown in Fig. 3, is proposed in order to fulfil these goals. The device is different than that described in [9] and further incorporates improvements.



Ts	To	ΔT	Rth (K/W)	ΔRth (%)	Obs.
297.5413	296.15	1.3913	111	47	wag
297.0966	296.15	0.9466	76	-32	woag

Fig. 3. a) A profiled machinable air-gap insulating line; b) the improvements in the thermal isolation (COMSOL). wag = with air gap; woag = without air gap

Table 1. The behaviors of a 2.92 mm insulating line with and without air gap. Inner thermal shunt: Boron Nitride, ε' = 2.

Parameter	Value	Type of IL	Frequency
S_{21}	0.9900	wag	1GHz
S_{21}	0.9901	wag	20GHz
S_{21}	0.9875	wag	40GHz
S_{21}	0.9885	woag	40GHz
S_{11}	0.0297	wag	1GHz
S_{11}	0.0186	wag	20GHz
S_{11}	0.0686	wag	40GHz
S_{11}	0.0687	woag	40GHz
Lumped ports situation			
S_{21}	1.0028	wag	1GHz
S_{21}	1.0022	wag	20GHz
S_{21}	0.9992	wag	40GHz
S_{21}	0.9960	woag	40GHz
S_{11}	0.0205	wag	1GHz
S_{11}	0.0190	wag	20GHz
S_{11}	0.0860	wag	40GHz
S_{11}	0.0836	woag	40GHz
Z_{11}	51.62	wag	1GHz
Z_{11}	53.91	wag	20GHz
Z_{11}	47.29	wag	40GHz
Z_{11}	57.43	woag	40GHz

The increasing of about fifty percents in the thermal insulation, as result of an 1 mm air-gap, do not have any significant changes of *S* parameters values, Table 1, in entire working bandwidth for a 2.92 mm coaxial line. Besides the 45° angle of the air-gap section and four DC thin-wall bridges, the inner thermal shunt is also present, [10-13].

B) Other important components are the dummy loads. They must be a good “imitation” of the power sensors under calibration in terms of mechanical dimensions and thermal properties [1]. They must be fitted with metrology grade RF connector, and from the electrical point of view must behave as perfect as possible short circuit. The sensors output wires must be also electrical connected in order to reproduce the same thermal ways and bridges as in the real sensors under test.

C) The thermal sensing devices of the microcalorimeter consist of two differential thermopiles having two balanced asymmetric outputs of the same polarity. This allows measuring directly both the thermal load response of each channel and their difference.

D) Due to the low power levels normally used in the measurements, the thermostatic case must maintain a temperature stability of some mK of the microcalorimeter kernel.

VI. INSTRUMENTATION SETUP AND MEASUREMENT PROCESS

As Fig. 4 shows, the instrumentation set-up consists of a thermostat implemented with a nested structure of active and passive thermal shields, two RF generators, two AF current generators, two DC millivoltmeters, a two DC nanovoltmeters. Basically this set-up duplicates the number of the instruments normally requested for running the classic coaxial microcalorimeter [1], [2], [4]. The number of instrument can be reduced if dual channel instruments are available, provided that each channel had the same performances.

A switching box allows supplying both the loads and dummy loads with correct RF/AF power levels according to the sequences requested both by the microcalorimeter calibration and by the power sensor calibration.

The dedicated computer controls the temperature inside the thermostat by means Peltier elements, whereas a second computer performs the operations and the controls requested during all the measurement processes.

The measurement procedure starts when the microcalorimeter thermal loads are in thermal equilibrium, a status detected by measured temperatures. The first phase consists in the determination of the sensors pairing in three conditions: same AC reference power, same sensors output voltage and same sensor temperatures, these last calculated or measured at the connector reference plane. These data allow computing three ratios for the next measurement phases.

In the second phase, the channel A is fed with RF power level that produces the same microcalorimeter thermocouple output as AC reference power, meanwhile with a second RF source half power is applied to the thermal reference line of channel A. This operation allows extracting the feeding line contribution. The effective efficiency is given by the ratio between the AC and RF thermopile outputs, for every test frequency. Another algorithm can be applied so to achieve the thermopiles balance. This can eliminate the thermopiles nonlinearities in the transfer function, though the balance will increase the measurement time.

The effective efficiency is given by the equations that basically have the same form for both algorithms, (1) and (2). They contain microcalorimeter thermopile outputs or power sensors output voltage ratio, respectively, and two coefficients which define the pairing of the sensors and of the feeding paths:

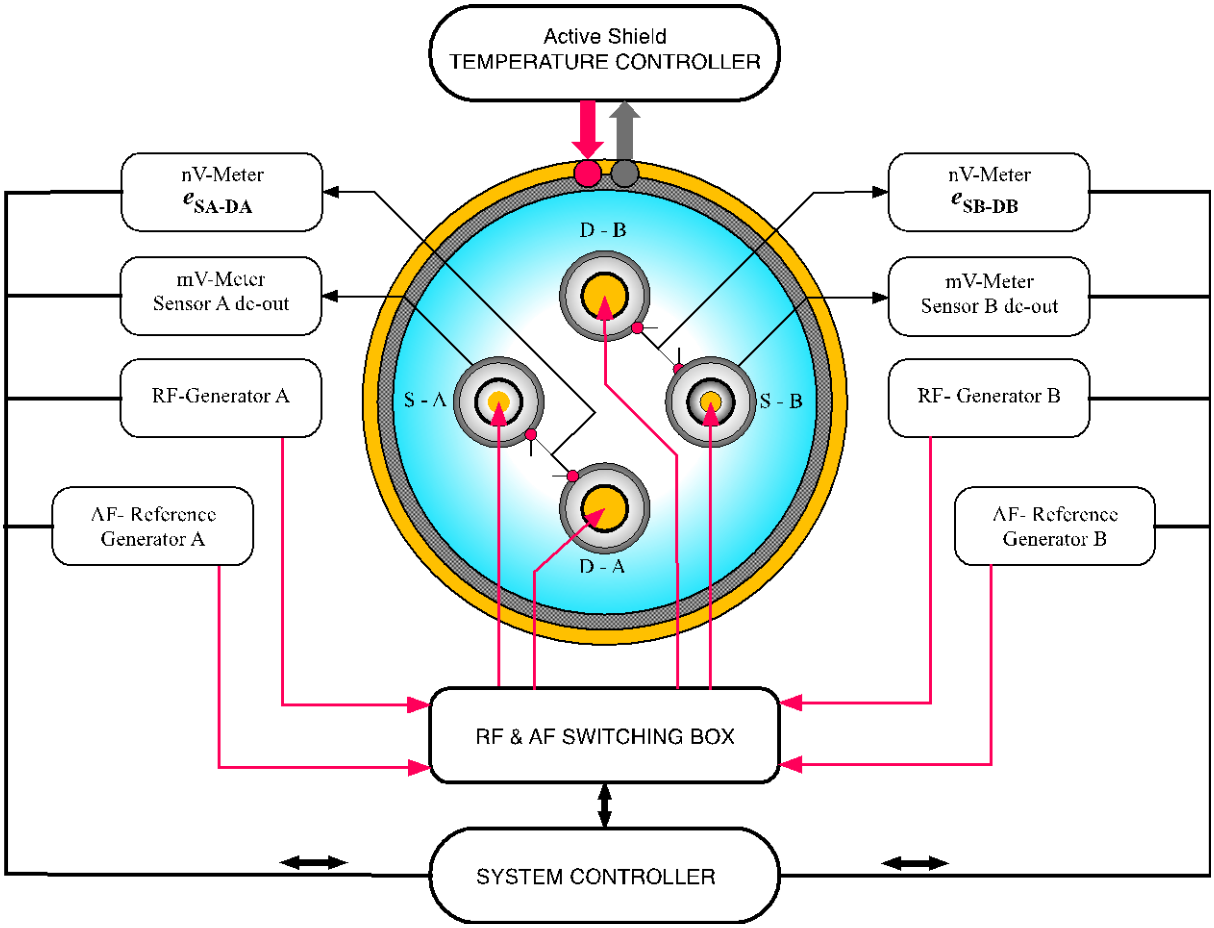


Fig. 4. Scheme of the instrumentation set-up proposed

$$\eta_{eff_A} = \frac{e_{SB-DB}\,|_{REF,\,E_B=E_A}}{e_{SA-DA}\,|_{RF,\,E_A}}\frac{K_{S_{B-A}}}{K_{1_{B-A}}} \tag{1}$$

$$\eta_{eff_A} = \frac{E_B\,|_{REF,\,E_B=E_A|_{RF}}}{E_B\,|_{REF,\,e_{SB-DB}=e_{SA-DA}|_{RF}}}\frac{K_{S_{B-A}}}{K_{1_{B-A}}} \tag{2}$$

where:

- η_{eff} is the wanted main quantity, [1], [4], [5];

- e_{SA-DA}, e_{SB-DB} are the thermopiles differential output voltages;

- E_A, E_B are the thermoelectric power sensors output voltages;

- $K_{1_{B-A}}$ define the insulating lines balance in the thermal transmission coefficients, [1], [5], [6], [10];

- $K_{S_{B-A}}$ characterizes the power sensors pairing in the power conversion sensitivity, [7].

At the end of the measurement frequencies list, the whole process must be reiterated according to the uncertainty computing requirements. A successfully finish, proved by the same behaviours in the first phase of the measurement, will allow to start, immediately, the measurements for the channel B sensor. The equations will be, of course, similar with (1) and (2).

The overall measurement time for a RF power sensors pair, and for the same degrees of freedom number in the data computation, will be half as for a single sensor consumed in the actual microcalorimeter measurement case, about 18 hours/frequency test point.

VII. CONCLUSION

The doubling of the channels in the classical twin - microcalorimeter seems to be a better way in solving the problems still related to this architecture. Such a microcalorimeter and the new measurements methods possible to be applied, overpass the problems treated in the other research paper dedicated to the thermoelectric RF power standards, [4-6], [14-16]. The complications related by the realization of a true two channels RF microcalorimeter are completely justified by the fact that a pair of two sensors can be calibrated in a single measurement step and the computation involves data acquired at the same time.

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