Traceability Chain for the Improvement of The Attenuation High Frequency

NADIA FEZAI, ABDESSATTAR BEN AMOR
University of Carthage Tunisia (INSAT)
Computer Laboratory for Industrial Systems (LISI)
Tunis, Tunisia
nadiafezai@yahoo.fr; mrdssrst@yahoo.fr

Abstract: - The ISO/CEI 17025 standard requires to validate the testing and analytical methods when they are standardized or after amplification or modification of these methods. A measurement uncertainty must also be associated with the results. Metrology is the science of measurement associated with the evaluation of uncertainty. The metrologist is interested in the quality of measurements and in particular to two factors. The first of these factors is to ensure that the measurement is connected to reference standards. The second factor in the quality of the measurement is the calculation of uncertainty. To evaluate the sources of measurement uncertainty, the so-called 5M method is commonly used (Manpower, Machines, Materials, Methods, Management);

In High Frequency metrology, all measurement devices are linked to a standard. In High Frequency attenuation, there are no physical standards in this area for most of the national metrology laboratories. Thus, a large number of theoretical measurement methods are adopted for the attenuators calibration.

Thus, this paper improves the feasibility of a developed method HF attenuation, called Power variation, realized within the laboratory of electrical metrology DEF-NAT in close collaboration with Computer Laboratory for Industrial Systems LISI to ensure traceability to the International System of Units SI according as the requirements of ISO/CEI 17025.

The obtained results by the adopted method are compared against to those of the traceable Intermediate Frequency method for fixed and variable attenuators to prove the chain of metrological traceability according to the attenuation parameter.

Key-Words: - Fixed attenuation, Variable attenuation, Intermediate Frequency, Bolometric Bridge, power sensor, Power Variation.

1 Introduction

Metrology is defined by the International Bureau of Weights and Measures (BIPM) as "the science of measurement, embracing both experimental and theoretical determinations at any level of uncertainty in any field of science and technology"[10].

At present, the metrology has an indisputable role and their applications are multiple according to the type of the considered metrology, Fig.1.

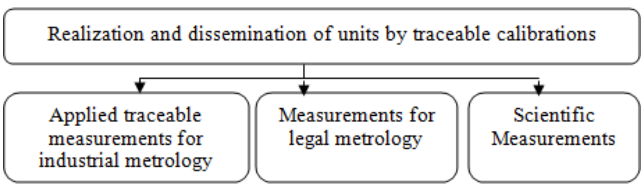

Fig. 1. Dissemination of units by traceable calibrations for all types of metrology

The measure is a comparison using a reference to express the result of this comparison with a numerical value associated with a unit that reminds the nature of the reference. This value is associated to uncertainty that depends on the quality of the experiment performed and the knowledge that the operator has on the reference and the conditions of use [7].

Indeed, the company relies on a vast infrastructure of services, often invisible, as transportation and communication network which presences are familiar and which functioning is essential for daily life.

In the area of high frequency (HF), the wavelength λ is small compared to the physical dimensions of a transmission line length, where current and voltage are not constant and so we are interested by the power measurement.

In all civil and military applications, we need to measure input and output power levels by a power meter device. But in HF we cannot measure the power directly; it can be possible by an intermediate bolometric mount.

At high frequencies, the power becomes the reference value. The International System of Units (SI) has defined the Watt (W) as the power unit. In our case, to quantify the relative levels of power, the decibel (dB) and the decibels relative to one milliwatt (dBm) can be used.

These units are dimensionless and have an advantage in the calculation of gain or attenuation measurement systems.

The high frequency attenuation (HF) is usually measured using a heterodyne receiver intermediate frequency. The most commonly used frequency is 30MHz.

The idea is to achieve in a linear manner, the transposition of attenuation in high frequency to attenuation in low frequency.

As part of our works on traceability of measurements of attenuation, we propose a method to determine the desired attenuation by measuring HF power using bolometric method.

This new method is developed for several reasons.

First, the heterodyne receiver requires annual expensive calibration and generates instrumentation and drift problems.

Second, it is necessary for a metrology laboratory, according to the requirements of ISO / IEC 17025 [10], to possess several references to a same parameter.

And finally, some types of commercial receivers, used in the tester, have seen their production stopped as the evanescent wave receiver VM3.

All these reasons have guided us towards verification methods as efficient and less costly according to the requirements of ISO / IEC 17025.

2 Intermediate Frequency Substitution Method

The attenuation is a reduction of amplitude and a phase change of the voltage or current at the terminals of a load when a circuit element inserted between the source and the load.

There is confusion between the definitions of the attenuation-related in the insertion loss, the attenuation constant, and the intrinsic attenuation. Consequently, it would be interesting to begin by establishing a precise definition of the quantity considered.

Among the different variables that can be defined to characterize a measure of attenuation, we retain, for reasons of simplicity, the two ones that seem most important and which defined as:

- Insertion loss.
- Notion of attenuation.

2.1 Insertion loss/ Attenuation

If a source of any impedance delivers a power P1 to any impedance load and if the power delivered to the same load is reduced from P_1 to P_2, when the attenuator is inserted into the line, the insertion loss expressed in dBm (compared to 1milliwatt), is described by:

$$Insertion\ Loss = 10\log\left(\frac{P_1}{P_2}\right) \quad (1)$$

Thus defined, insertion loss can be a positive or negative quantity. It is not an exclusive characteristic quantity of the attenuator because it depends on the source and load impedances.

Then, attenuation is a special case of the insertion loss. By definition, attenuation in dBm, is the correlation between powers P_1 and P_2 [16].

Where:

-P_1: The power delivered to a load perfectly adapted from a source perfectly adapted.

-P_2: The power delivered to the same charge from the same source when the attenuator is inserted between them.

In contrast to the insertion loss defined above, attenuation is a specific amount that is characteristic of the attenuator.

It is important to note that a transmission line element can produce attenuation without power dissipation produced in this element. For example, a purely reactive component inserted in a line will change the power delivered by a source to a load. If the load and source are mismatched, this change can be either a decrease or an increase in the power delivered to the load.

While, if the source and the load are adapted, the attenuation can only be a positive quantity with a maximum power delivered.

The attenuation produced by N purely reactive elements is sometimes called reflection losses.

In this case, the reflection losses are different depending on the direction in which it is used and, therefore, attenuation of this element will be different according to the direction of propagation.

2.2 Principle

Attenuation Radio Frequency is often measured using a heterodyne receiver. This receiver is an attenuator operating at a standard intermediate and commercially frequency (IF) 30MHz.

By IF method, fixed attenuators, variable attenuators and customer equipments are calibrated. Then, it is possible to reach up to 90dBm according to the characteristics of the used equipments.

The Intermediate Frequency method of substitution is frequently used at LNE in France and at DEF-NAT Laboratory in Tunisia. The (IF) method can be performed in serial or parallel forms.

In this paper, we limit ourselves to the presentation of the serial substitution since the parallel one is rarely used. The block diagrams of the serial substitution intermediate frequency is illustrated in Fig.2.

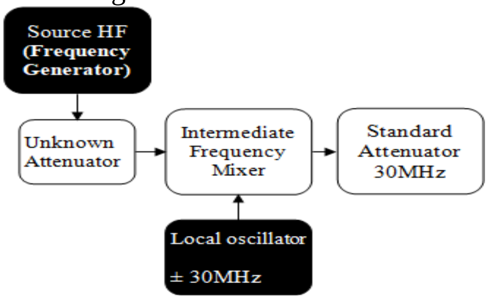

Fig.2. Blocks Diagram of Intermediate Frequency substitution (IF)

The goal of the practical test of the proposed method, Fig3, is to determine the value of the unknown attenuator.

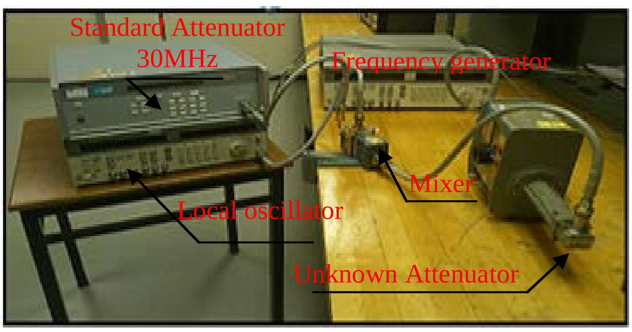

Fig.3. Practical tests of the Intermediate Frequency substitution (IF)

Indeed, the intermediate frequency substitution method performs a linear transposition of the H.F attenuation into 30 MHz intermediate frequency attenuation. It has a relatively large measurement range, generally of the order of 60 to 90 dB, depending on the characteristics of the devices used and the type of heterodyne receiver used.

The exploitation of this method is approached by national and international laboratories but it remains limited for higher frequencies than 7GHz where it generates troublesome fluctuations for reading, [8, 9].

3 Fixed Attenuation By Power Variation Method

The power variation method is used as a crossover method to validate the results obtained by the intermediate frequency substitution method F.I in the attenuation range [0-20 dB].

The standard ISO / IEC 17025 require the uses of multiple verification methods to validate the same accredited metrological parameter. So, the power variation method is used as a verification method to validate the results obtained by the intermediate frequency substitution method (IF) in the attenuation range [0-20 dB], [9] [3], [20].

3.1. Principle

The idea is to measure by a power meter the power dissipated before and after insertion unknown attenuator using continuous voltage DC.

Then, the signal generated by the HF source before and after insertion according to the figure4, is applied to the Coupler which, according to its coupling coefficient, channels a ratio of the signal to the main line to generate the incident power (Pij) which crosses the Bolometric Bridge. The rest of the signal will be the lateral power (Plj) of the main line that will be displayed on the digital milli-wattmeter,[18],[19].

The value of attenuation A is the ratio between P1 and P2 obtained by power ratio between P_{ij} and P_{lj}:

$$A = 10\log\left(\frac{P_1}{P_2}\right) \quad (2)$$

Where:

$$P_1 = \frac{P_{l1}}{P_{i1}} \quad (3)$$

**P_1(without attenuator);P_2(with attenuator)

$$P_2 = \frac{P_{l2}}{P_{i2}} \quad (4)$$

3.2 Diagram measurement and operatory mode

The corresponding measurement setup according to the method DC Power Variation is shown by Fig.4:

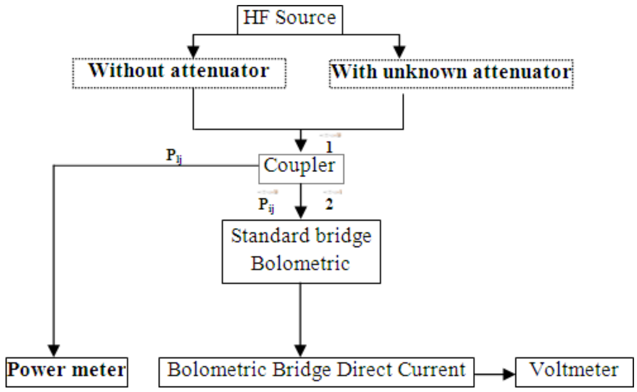

Fig. 4. Blocs diagram of DC Power Variation for fixed and variable attenuator

**P_i: incident power; P_l: lateral power; P: power of the source.

The realization test of the adopted method of Fig.4 is shown in Fig.5.

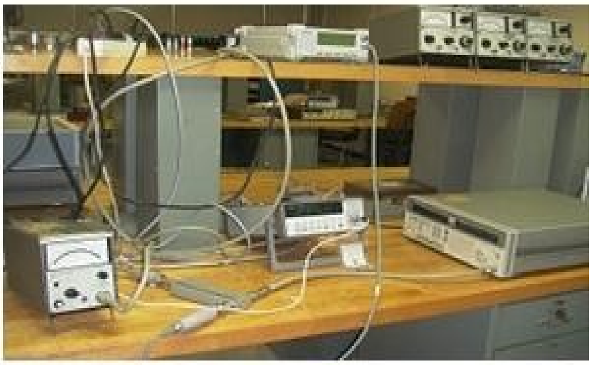

Fig. 5. Realization test of the Power Variation for fixed and variable attenuator

To determine the power substituted measurement two cycles are needed. The first one is done without High Frequency power followed by a second one with HF power.

From one cycle to another, the Wheatstone bridge is used to hold the bolometer thermistor in the same value.

4 MEASUREMENT RESULTS

Within laboratory, we realize a series of measurements for fixed attenuators 10 dBm and 20dBm in specified experimental conditions.

We usually determine reflection factor Γ of the attenuator by exploiting the Vector Network Analyzer and each time the corresponding curves are traced by comparing with FI method.

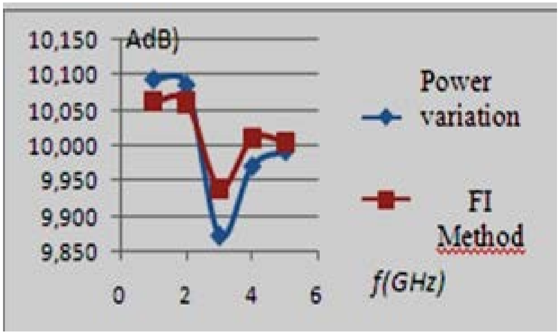

Fig. 6.a. for 10dBm

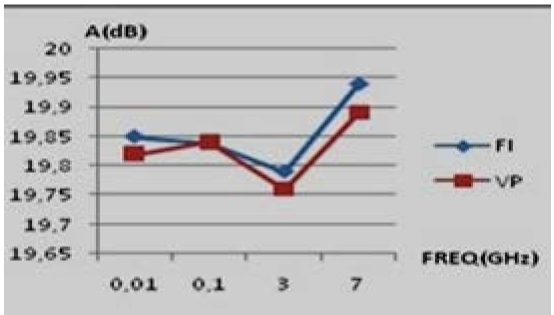

Fig.6.b. for 20dB

Fig. 7. Experimental results for 10 and 20dBm attenuators by FI and VP methods.

The observations show that the maximum deviation between the values measured by VP (power variation) and the values obtained by the FI method does not exceed 5.10^{-2}dBm.

These obtained results within VP method compared to FI one satisfied the requirements of the standard ISO/CEI 17043[6].

To determine the uncertainty of each attenuator, we must determine the reflection factor Γ using the software network analyzer of the used VNA.

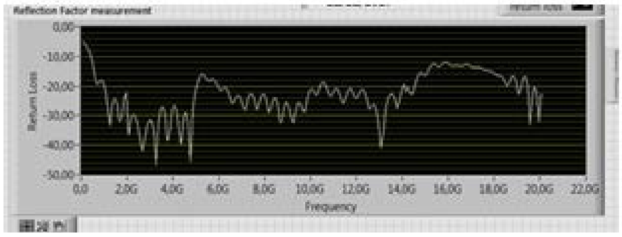

Fig.7. Return Loss (RL) for attenuator 10 dBm in the range of frequencies from 1GHz to 20GHz

Where the Return Loss (RL) is expressed by:

$$-20\log(|\Gamma|) = RL_{dBm} \quad (5)$$

The values of reflection factor are increasing since the frequency 7GHz, Fig.7, that's why the measurement attenuations are affected.

Therefore, it's essential to use the masking attenuators (usually two attenuators) in operational mode; before the calibration operation and whatever used HF method; to minimize the losses by mismatch.

4.1 Estimation of measurement uncertainty

The uncertainty budget is the process leading to estimate the measurement uncertainty [10] [7]. This process takes into account the full analysis of the measurement process: obviously measured quantities, factors of influence and corrections to the result announcement [9].

In the absence of mismatch terms, the expression (2) of the attenuation A will be:

$$\underbrace{\left|\frac{\left[2V_{1comp}(\Delta V_1-\Delta V_{01})-\Delta V_1^2+\Delta V_{01}^2\right]/(4.R_2.K_2)}{\left(V_4^2-V_3^2\right)/(4.R_1.K_1)}\right|}_{(term1)}\cdot\underbrace{\frac{P_{l1}}{P_{l2}}}_{(term2)}=A_{rapport} \quad (6)$$

The second term of equation (6) is the ratio of lateral powers; it's very near to unity. The only considered uncertainty (term 2) is related to the fluctuations of the voltmeter. This term is statistically (type A) estimated.

The partial derivatives of (term 1) gives:

$$\underbrace{\frac{\Delta A_1}{A_1}}_{(term3)}+\underbrace{\frac{\Delta(R1/R2)}{(R1/R2)}}_{(term4)}+\underbrace{\frac{\Delta(K1/K2)}{(K1/K2)}}_{(term5)}=\frac{\Delta P_{i2}/P_{i1}}{P_{i2}/P_{i1}} \quad (7)$$

The term3 is the uncertainty related to the measurement reports of tensions.

The term 4 represent the change of equilibrium of the bridge resistance as a function of the RF power.

Then the term5 is the uncertainty due to the linearity of the calibration factor of the bridge according to the RF power

The (term3) is extended by:

$$\frac{\Delta(\left[2V_{1comp}(\Delta V_1-\Delta V_{01})-\Delta V_1^2+\Delta V_{01}^2)/\left(V_4^2-V_3^2\right)\right])}{\left[2V_{1comp}(\Delta V_1-\Delta V_{01})-\Delta V_1^2+\Delta V_{01}^2\right]/\left(V_4^2-V_3^2\right)}=\frac{\Delta A1}{A_1} \quad (8)$$

Considering the uncertainty due to the mismatch influence in case of a fixed attenuator, the expression of the standard deviation σ is:

$$[2\Gamma_m^2\Gamma_g^2(1+1/A_0)^2+2(\Gamma_m^2+\Gamma_g^2)\Gamma_x^2]^{1/2}=\sigma \quad (9)$$

With:

Γ_x: is the measured reflection factor relative to the unknown equipement.

Γ_m: is the measured reflection factor relative to the load.

Γ_g: is the reflection factor relative to the HF source.

For variable attenuator, the expression of the standard deviation σdB ,from the initial attenuation position Ao to the unknown attenuation Ax relative to another position is expressed by:

$$4.34[2\cdot\Gamma_g^2\left(\Gamma_1^2+\Gamma_1^{'2}\right)+2\cdot\Gamma_m^2\left(\Gamma_2^2+\Gamma_2^{'2}\right)+2\Gamma_m^2\Gamma_g^2\left((1/A_x)^2+(1/A_0)^2\right)]^{1/2}=\sigma_{dB} \quad (10)$$

With:

Γ_1, Γ_2: are the reflection factor magnitudes according to the initial position A_0.

$\Gamma_1^{'}$, $\Gamma_2^{'}$: represent the magnitudes of reflection factor according to the position A_x.

Besides, measurement is repeated to obtain the best uncertainties, due to stability, repeatability and reproducibility, generated by changing the operator.

The composed uncertainty Uc is the quadratic sum final result to estimate the measurement uncertainties given by.

$$\sqrt{A_1^2+A_2^2+A_3^2+BL_1^2+BL_2^2+BL_3^2+BL_4^2}=U_c \quad (11)$$

With:

A_i: Type A evaluation of measurement uncertainties. It consists on the evaluation of a component of measurement uncertainty by a statistical analysis of measured quantity values obtained under defined measurement conditions [5].

BL_i: Type B evaluation of measurement uncertainties. It consists on the evaluation of a component of measurement uncertainty by other means than Type **A** evaluation of measurement uncertainties [5].

Practically, the obtained absolute uncertainties for fixed coaxial attenuators are illustrated in table 1 by two methods.

Table 1: MAGNITUDE UNCERTAINTIES FOR FIXED ATTENUATORS

Frequency (GHz)	**Magnitude uncertainties**		
	Range(dB)	***Absolute uncertainty***	***Method***
[10MHz-18GHz]	0;3;6;10 and 20	$0.017+0.366\Gamma_x$	by VP method
		$0.025+0.410\Gamma_x$	by the IF method

It shows that the adopted method VP is a comparable measurement uncertainty compared to the conventional method FI for fixed attenuators. These multiple methods are satisfied the requirement of the standard ISO/CEI 17025.

4.2 Validation for fixed attenuators

The standard ISO/IEC 17025 [7] requires validation method when the laboratory uses a non-standard or outside of scope of the used standard.

We must therefore show that the implemented method in the laboratory is suitable for intended use.

Method performances can be expressed using some validation parameters such as selectivity, linearity, repeatability and robustness. In the studied case, we are interesting by the selectivity as a principal characteristic.

To interpret the results, a standard deviation "E_n" is calculated following the methodology described in paragraph "A 2.1.4.e ISO / IEC 43-1" of [6], to achieve the selectivity of the adopted method.

$$E_n = \frac{x - X}{\sqrt{U_{lab}^2 + U_{lref}^2}} \quad (12)$$

Where:

U_{lab} is the expanded uncertainty set associated with the value of the participant x and

U_{ref} is the expanded uncertainty associated with the values X of the reference laboratory [7] [9].

Applied to the present case for the 3 dB attenuator at 10MHz, formula (15) becomes:

$$E_n = \frac{A_{VP} - A_{FI}}{\sqrt{U_{VP}^2 + U_{FI}^2}} \quad (13)$$

Where:

A_{VP} : Attenuation by PV method.

A_{FI} : Attenuation by the IF method.

U_{VP} : Obtained uncertainty by PV method.

U_{FI} : Obtained uncertainty by FI method.

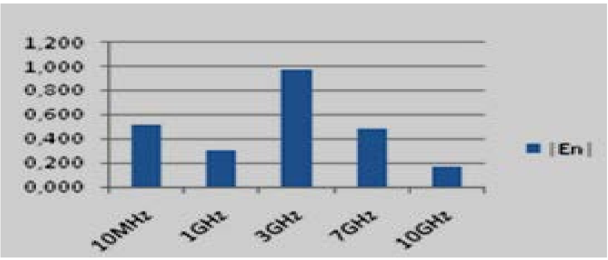

Fig. 1. Statistical test "E_n" of attenuator 10dB For different frequencies

When the value (E_n <1), according to the guide LAB-GTA and the standard ISO/CEI 17043, the uncertainty estimate is consistent with the definition of the expanded uncertainty given in the guide GUM [7] [6], [23], [21].

The performance statistic allows us to conclude that the results obtained by PV are validated regarding the conventional method FI,[19], [20].

5 Conclusion

The goal of this paper is to improve the establishment of diversified methods for fixed and variable attenuator to insure the chain of metrological traceability to the attenuation parameter regarding to the requirements of ISO/CEI 17025.

The comparison of the IF method, which is non-standardized but frequently used, by the PV method, gives a satisfactory statistical coherence.

Since the inter-comparison Inter-laboratories internationally are scarce and quite heavy costs, this work could be a local inter-comparison for considering the PV method as a verification method according to the international system of unity SI.

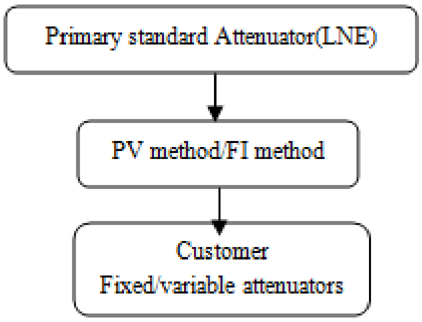

Fig. 2. Metrological Traceability Chain of "attenuation" parameter

In operatory mode, the PV method used as verification method presents difficulties of practical realization, on the one hand, and is limited by the dynamics of the Bolometric Bridge used, on the other hand. In this study the level of the used bolometric bridge is bounded by [-30dBm to +20dBm] limiting the validation of the FI method up to 20 dBm.

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