전력과 임피던스표준을 이용한 RF전압의 정밀 자동측정

정회원 신 진 국*

The Automatic Precision Measurement of RF Voltage using Power and Impedance Standards

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요 약

본 논문에서는 50-1000 MHz의 주파수 범위에서 전력과 임피던스의 표준을 이용하여 RF전압을 자동으로 정밀 측정을 하였다. RF-DC차를 결정하기 위하여 동축형 미소열량계와 자동 회로망 분석기가 이용되었으며, 총불확도는 약 1 % 이다. 써미스터 마운트의 실효효율과 열전압 변환기의 RF-DC차를 측정하기 위하여 HP 컴퓨터와 Commodore 컴퓨터, 그리고 IEEE-488 인터페이스 버스를 이용하고, 측정하는 전체과정이 자체 개발한 프로그램에 의해 자동으로 수행되었다.

Key Words : RF voltage, Microcalorimeter, Thermistor mount, Effective efficiency, RF-DC difference

ABSTRACT

In this paper, the automatic precision measurement of RF voltage has been done using the power and impedance standards [1] in the frequency range of 50 to 1000 MHz. A coaxial microcalorimeter and an automatic network analyzer were used for the determination of the RF-DC differences and the total uncertainty is about 1.0 %. A HP computer, a commodore computer and IEEE-488 interface bus were used for measuring the effective efficiency of thermistor mount and the RF-DC difference of thermal voltage converter, All processes of measurement were accomplished by self-developed program automatically.

Ⅰ. Introduction

The accurate RF voltages are measured by comparing unknown RF voltage to DC voltage using thermal voltage converters (TVC's) whose RF-DC differences are calibrated by RF voltage standards. The RF-DC difference is calculated from the difference between RF and DC voltages to get the same thermoelement(TE) output voltage.

In order to establish our own RF voltage standards, the effective efficiency and RF equivalent parallel resistance of a coaxial thermistor mount were measured using a microcalorimeter and a network analyzer, respectively. The RF-DC differences of a TVC were obtained and compared to the values calibrated from the National Institute of Standards and Technology (NIST).

Ⅱ. Theory

The details of a TVC connected with a thermistor mount are shown in Fig. 1. The characteristics of the transmission line between the plane A and C were analyzed using the S-parameters of

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section BC and those of section AB calculated from BC section data [3]. The characteristic impedance of section AB and the susceptance due to the change of the outer conductor radius at B were considered [4].

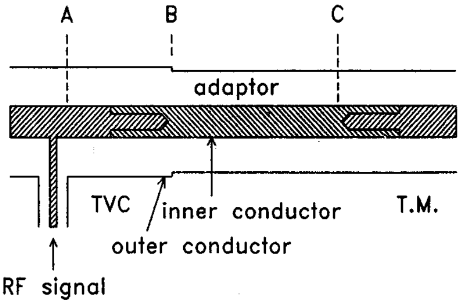


Fig. 1. Details of a TVC connected with a thermistor mount.

The transmission line between the T-junction of the TVC and the thermistor mount is assumed to be of no reflection. The S_{12} value of the transmission line is determined from the loss of the female-female adaptor used for connection and the electrical length of the line.

The RF voltage at plane *C* is given by

$$V_{RF}=\sqrt{P_{NET}R_p}=\sqrt{\frac{P_{DC}}{\eta_{eff}}R_p} \qquad (1)$$

where P_{net} is the net power delivered to plane *C*, R_p is the RF parallel resistance at plane *C*, and η_{eff} is the effective efficiency of the thermistor mount. The ratio of the voltage at plane *B* to that at plane *C* is given by

$$\left|\frac{V_B}{V_C}\right| = \left|\frac{S_{12}\,(1+\Gamma_{in})}{S_{12}{}^2+(\Gamma_{in}-S_{11})(1+S_{11})}\right| \qquad (2)$$

where Γ_{in} is the reflection coefficient looking into the thermistor mount at plane *B*.

After determining the RF voltage, the DC voltage to get the same TE output from the TVC under test is measured and the RF-DC difference δ is calculated by equation (3). The polarity of the DC voltage is changed to reduce the DC reversal error and the average value is used.

$$\delta=\frac{2V_{RF}}{|V_{DC+}|+|V_{DC-}|}-1 \qquad (3)$$

When the TE output is assumed to be proportional to the square of DC input voltage, the ratio given by eq. (4) should be constant at all frequencies and this can be used as a consistency check for RF voltage transfer. In eq. (4) subscripts x,s represent the DUT and the standard TVC, respectively.

$$R=\frac{V_{TEs}}{V_{TEx}}\left(\frac{1+\delta_s}{1+\delta_x}\right)^2 \qquad (4)$$

Ⅲ. Experimental results

3.1 Test setup

The accurate measurement of the microwave power is based on the use of bolometer mounts which are calibrated in a microcalorimeter. The calibration is the determination of the effective efficiency which characterizes the substitution error of the bolometer mount. The effective efficiency is defined as the substituted DC bias power divided by the total RF power dissipated in the bolometer mount.

Generally, the bolometer mounts used in a microcalorimeter method are thermistor mounts which have large thermal capacities. Usually several hours are needed to measure at thermal equilibrium state. The effective efficiency of a coaxial thermistor mount was calibrated using a microcalorimeter which is the primary standard of RF and microwave power [2].

Fig. 2 shows the relationships of the effective efficiency of thermistor mount, calibration factor, incident power, reflected power, and net power. The effective efficiency of thermistor mount is written by

$$\eta_{eff}=\frac{P_{DC}}{P_{\neq T}} \qquad (5)$$

where P_{DC} is the substituted dc power and $P_{\neq T}$ is the RF net power.

When the reflection coefficient of thermistor mount is Γ, the amount $P_r = |\Gamma|^2 P_i$ of incident power P_i is reflected for signal source, so the incident net power $P_{\neq T}$ is written by

$$P_{\neq T} = P_i - P_r = (1-|\Gamma|^2)P_i \qquad (6)$$

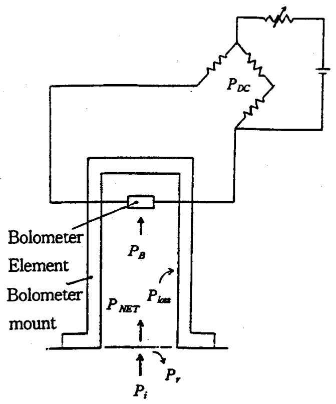
and the incident power is

$$P_i = \frac{1}{(1-|\Gamma|^2)\eta_{eff}} P_{DC} = \frac{1}{K_b} P_{DC} \qquad (7)$$

where $K_b = (1-|\Gamma|^2)\eta_{eff}$..

In the eq. (5) and (6), $P_{\neq T}$ is the RF power delivered into the thermistor mount, P_{DC} is the substituted DC power calculated by DC output voltage of thermistor mount.

The parallel resistance R_p was determined from the reflection coefficients measured and compensated by the residual impedance at plane *B* and *C*, and HP 8510 Network Analyzer was used for measurement.



$\eta_{RF-DC} = \frac{P_{DC}}{P_B}$: RF−DC substitution efficiency

$\eta = \frac{P_B}{P_{NET}}$: Efficiency of mount

$\eta_{eff} = \frac{P_{DC}}{P_{NET}}$: Effective efficiency

$K_b = \frac{P_{DC}}{P_i}$: calibration factor

Fig. 2. Illustration showing components of power and related terminology in power measurement.

Fig. 3 is the block diagram of the microcalorimeter system for the effective efficiency measurements. The thermopile EMF and the bridge voltage are measured at 1-min intervals by a nanovoltmeter and a digital voltmeter(DVM) interfaced to a computer. The computer also sets the frequency and the power level of the signal generator so that the automatic measurements can be continued for several frequencies. The effective efficiency η_{eff} is determined by

$$\eta_{eff} = g\eta'_{eff} = g\frac{1-(V_2/V_1)^2}{(e_2/e_1)-(V_2/V_1)^2} \qquad (8)$$

where

g overall correction factor,

η'_{eff} effective efficiency without correction,

V_1, V_2 bridge voltage when the RF power is not applied and when it is applied, respectively,

e_1, e_2 thermopile EMF corresponding to V_1 and V_2 at the steady state.

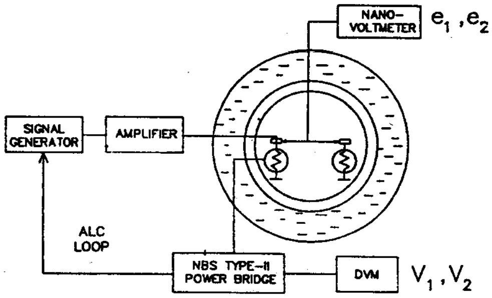
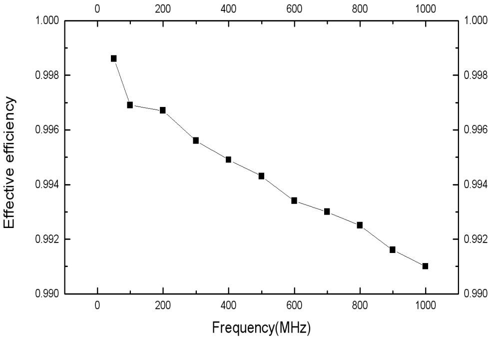


Fig. 3. Block diagram of the microcalorimeter system

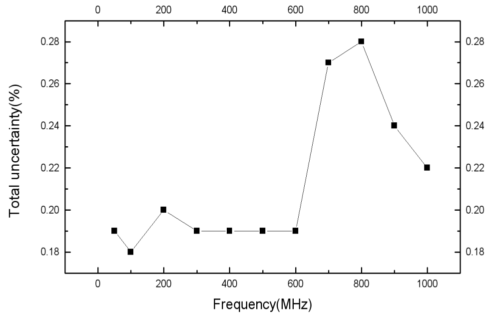
The results are shown in Fig.4. The uncertainties in determining η_{eff} of (7) consists of the uncertainty in the correction factor *g* and the instrumentation in determining the second term η'_{eff}. The instrumentation uncertainty due to the self- balancing bridge and the uncertainty in measuring V_1, V_2, e_1, and e_2 is about 0.05 %.

The impedances are measured at reference plane B and reference plane C of Fig.1 with a network analyzer to determine the impedance of thermistor mount. The values measured at reference plane C are the impedance of thermistor mount and the values measured at reference plane

B are the impedance of the state connected with type N female-female adaptor and thermistor mount. The measurement results are shown in Fig.5 and impedances of thermistor mount compensated by residual impedance at plabe B and plane C are shown in Fig.6.



(a) Effective efficiency



(b) Total uncertainty(%)

Fig. 4. Measurement results of effective efficiency(η_{eff}) of thermistor mount (HP478A,ser.80464).

The ratio of the voltage at plane A to that at plane C is given by

$$\left|\frac{V_A}{V_C}\right| = \left|\frac{S_{12}\,(1+\Gamma_d\,)}{S_{12}{}^2+\Gamma_d}\right|\Bigg\} \qquad (9)$$

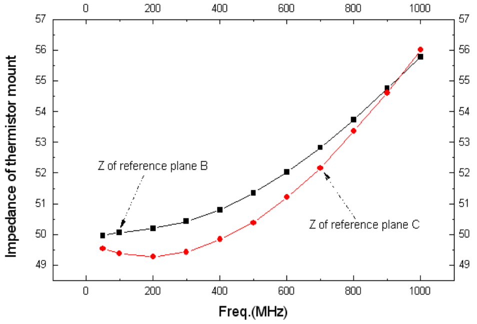
where Γ_d is the reflection coefficient looking into the thermistor mount at plane C [3].

$$S_{12} = 10^{-loss/40}e^{-j2\pi fl/C} \qquad (10)$$

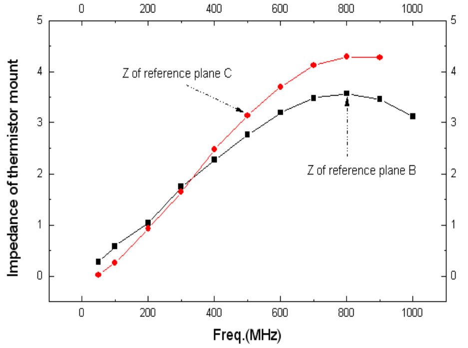
where $loss = \dfrac{10l\ \times\log(e)}{C\ Z_0}R\ \sqrt{f}$

R : resistance [Ω/m]

l : length between T-junction and thermistor mount



(a) real part



(b) imaginary part

Fig. 5. Measurement results of impedance of thermistor mount.

The calculation results of voltage ratio between T-junction and thermistor mount are shown in Fig.7.

Fig.8 shows the schematic diagram of the test setup including the simplified circuit diagram. The DC source outputs an adjustable DC reference voltage which can be measured accurately. The substituted DC power for the determination of P_{net} is measured using an NBS type-II power bridge. All the instruments including switches are controlled by a personal computer via IEEE-488 BUS.

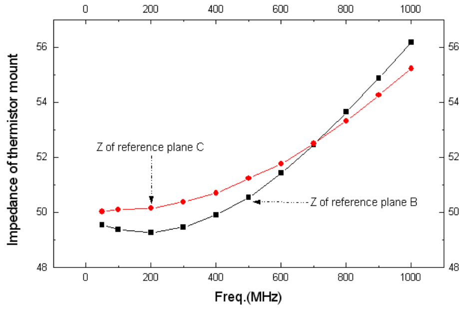


Fig. 6. Impedance of Thermistor Mount compensated by residual impedance.

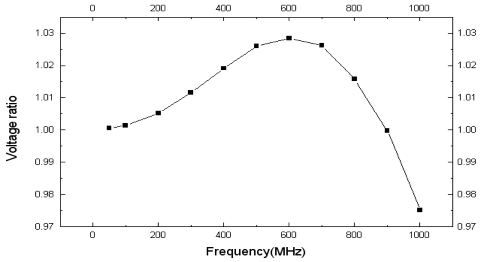


Fig.7. Calculation results of voltage ratio.

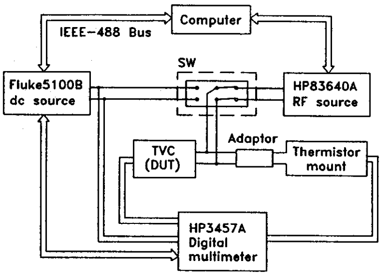


Fig. 8. Test setup.

3.2 Results and uncertainties

The RF-DC differences of a UHF TVC (Ballantine 1396H-1) were measured and the results are shown together with the values from NIST in Fig. 9. The difference between the values is 0.01 to 1.43 %. The difference between the results from the two impedance data was less than 0.5 %.

The results of a TVC (1396H-2.4) calibrated with a KRISS standard TVC (1396H-1) and a TVC calibrated at NIST (1396H-7) are shown in table 1. The difference between the results is less than 0.5 % and the transfer consistency was less than 0.5 % when normalized with the ratio of TE outputs.

Ⅳ. Conclusion

The RF voltage standards in 10 to 1000 MHz frequency range have been established using power and impedance standards. The overall uncertainty is about 1.0 %.

Improvement of the impedance measurement accuracy, determination of the reference plane, and more accurate characterization of the S-parameters of the transmission line used for connection are needed to reduce the uncertainty. The use of a self-developed program, computers and IEEE-488 interface bus reduced a measuring time.

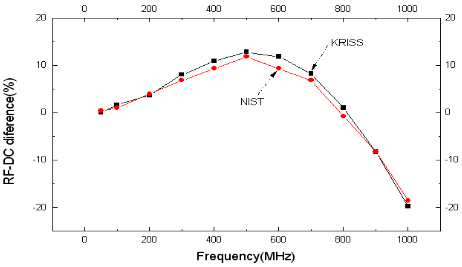


Fig. 9. Measurement results of δ (%)

Table 1. The calibrated results.

Freq.(MHz)	DUT	
	δ_K	δ_N
50	-	-
100	5.17	5.68
200	-	-
300	5.41	5.29
400	-	-
500	0.79	0.87
600	-	-
700	-1.46	-1.37
800	-	-
900	-	-
1000	5.55	5.76

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