〔RESEARCH〕

A Broadband Attenuation Measurement System in the Frequency Range from 4 GHz to 40 GHz

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A broadband attenuation measurement system based on parallel intermediate substitution technique has been developed in the frequency region of 4-GHz to 40 GHz. A performance comparison of the present system with mixer operation in fundamental and third harmonic modes has been presented. The dynamic range of the system is 60 dB in single step for the fundamental mixer mode and 40 dB in single step for the third harmonic mixer mode.

§1 Introduction

Operative frequency region of radio frequency (RF) waves based applications such as remote sensing, communications and navigation, is becoming broader and progressing up to millimeter wavelengths. This has led to increased demand for broadband measurement techniques in the radio frequency. The precise determination of radio wave attenuation plays an important role in quantitative functional tests on RF components and is an essential requirement for RF system performance. Increasing number of communication links and radars operation in frequencies region from 18-GHz to 40 GHz has emerged a requirement for precision attenuation calibration at millimeter-wave frequencies. Attenuation measurement systems reported in the literature [1-3] are mainly for lower frequency range. Stumper [4] reported an attenuation measuring equipment for frequencies 18-GHz to 40 GHz in the waveguide bands R220 and R320 for attenuation values un to 30 dB. In Electrotechnical Laboratory an attenuation calibration systems of 32-GHz to 37-GHz was developed by Iwase et al [5] but the frequency range was relatively narrowband and insufficient for present needs.

This paper describes a broadband attenuation calibration system with dynamic range of 60 dB and uses 2.92-mm diameter coaxial waveguide fitted with K connectors. A comparison of the system performance with mixer operation in fundamental and third harmonic mode has been carried out.

§2 Measurement Principle

Fig.1 shows a block diagram for a broadband attenuation calibration system working on the principle of parallel intermediate frequency (IF) substitution technique. It employs synthesized sources for RF measurement signal and local oscillator. A precision

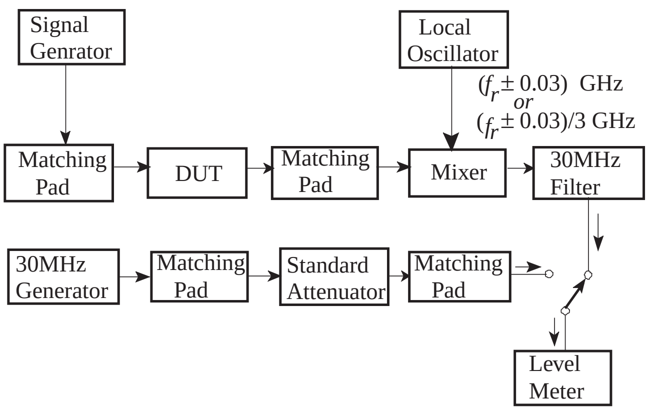

Fig.1 Experimental setup for precision attenuation measurement.

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piston attenuator operating at 30MHz is used as a standard. The measurement signal is passed through device under test (DUT) and mixed with a local oscillator signal to produce an intermediate frequency of 30 MHz. A linear mixer is operated either in fundamental mode or third harmonic mode. If fs is the measurement signal frequency, the local oscillator frequency f_L for the fundamental mixer operation is given by

$f_L = fs \pm 0.03$ (GHz)

The local oscillator frequency for the third harmonic mixer operation is given by

$f_L = (fs \pm 0.03)/3$ (GHz)

Mixer leakage is to be minimized for measuring high attenuation values as mixer ports isolations at millimeter wave frequencies is typically around 20 dB. This problem can be rectified by employing attenuation pads at mixer ports. The attenuation pads also dampen intermodulation products existing the mixer and masks any change in mixer port impedance with change in signal level. This practice however, introduces additional conversion loss and thereby reduces the dynamic range. Precision attenuation measurement can be performed using the system shown in Fig.1. In case of a step attenuator calibration, first a reference measurement is performed by connecting the DUT insertion points and the standard attenuator is adjusted until the reading on the 30-MHz level meter is same in both positions of the switch. The DUT is then inserted and a second measurement is made. The difference in the standard attenuator reading provides the measured attenuation. In case of a variable attenuator calibration, at each setting of the DUT, the standard attenuator is adjusted until the reading on the 30MHz level meter is same in both positions of the switch.

§3 Uncertainty Evaluation

The uncertainties in the present attenuation measurement system and calibration are evaluated based on Comite International des Poids et Mesures (CIPM) INC-1 recommendations using guide to expression of uncertainty in measurement [6)]. The sources of uncertainties in attenuation measurement system such as non-linearity of mixer, standard attenuator error, repeatability of switch, mismatch error contribute to Type B uncertainties for the system. Mixer non-linearity is less than 0.006 dB for a 60-dB attenuation step in fundamental mixer mode and less than 0.006 dB for a 40 dB attenuation step in harmonic mixer mode. The repeatability of the switch is found to be extremely good well below 0.001 dB and isolation better than 100 dB which makes its contribution to uncertainty as negligible. The uncertainty of attenuation measurement also depends on DUT insertion point VSWR performance and is generally termed as mismatch error[3)]. It is minimized by using attenuation pads with low VSWR at DUT insertion ports. The attenuation pads isolate the various devices used at the generator and detector ends. Measurement errors associated with repeatability of connectors used at the insertion point of DUT, IF signal fluctuation in the level meter reading contribute to Type A uncertainties for attenuation measurement and are evaluated by statistical analysis of series of observation. It has been observed that the repeatability of insertion point connectors mainly depends on proper alignment. A greater rigidity is obtained in the present system by magnetically clamping the source-end components while detector-end components are magnetically clamped on a rolling measurement bench. Repeatability better than 0.01 dB is observed with such an arrangement. The sources for IF signal fluctuation are frequency and power variation in the signal generators, noise and drift in the level meter. The synthesized sources allows higher accuracy, stability and repeatability of the system. The error caused by frequency variation is smaller than 0.001 dB. The amplitude stability of the signal sources is important in the present system. The power leveler removes fluctuation of about 0.005dB on the output of synthesized sources.

The attenuation calibration uncertainty contains the measurement system uncertainty described earlier and DUT contribution to mismatch uncertainty which is calculated as described by Warner [7] and Bayer et al [3]. **Table 1** presents the evaluated uncertainties for the present attenuation measurement system and for a typical 10 dB attenuation step calibration. The components of Type A and Type B uncertainties are expressed as one standard deviation and overall uncertainty is expressed as two standard deviation. The repeated measurement for same DUT has standard deviation below 0.006 dB. The mismatch uncertainty is evaluated for the 10-dB step attenuator having input and output VSWR as 1.05 and 1.04 at 40 GHz.

§4 System Performance

The attenuation measurement performance of the system has been experimentally investigated both in fundamental and the third harmonic mode mixer operation. The mixer is operated in the harmonic mode for measurement signal frequency from 12 GHz to 40 GHz with a lower local oscillator frequency 4.01 GHz to 13.0233 GHz. The frequency range for the fundamental mode is 4 GHz to 40 GHz with local oscillator frequency 4.030 GHz to 39.070GHz. Dynamic range of the system is an important parameter and depend on linearity of the mixer. At high measurement signal level, mixer drives into compression and causes measurement inaccuracy. Compression becomes a factor at measurement signal power level above -11 dBm for the harmonic mode and -2 dBm for the fundamental mode mixer operation. The conversion loss in the harmonic mixer mode is typically 10 dB higher than the fundamental mode. The dynamic range of the system for the fundamental mode mixer operation is 60 dB and for the harmonic mode mixer operation is 40 dB. The calibration uncertainty for a typical 10 dB step attenuator is 0.034-dB at two standard deviation level. The dynamic range of the system can be extended un to 100-dB using partial RF substitution technique where separately calibrated attenuators are connected in series with the device under test.

§5 Conclusion

A broadband attenuation measurement system based

Table 1 Uncertainty estimation for attenuation measurement system and calibrations. (10 dB attenuator measurement at 40GHz)

Source of uncertainty	Estimated bound of variability (±δ)	Assumed distribution	Standard deviation	Value of uncertainty
Type A				
Experimental standard deviation of mean		normal	u_1	0.0060 dB
Type B				
Standard attenuator attenuation constant resolution	 ±0.0020 dB ±0.0005 dB	 rectangular rectangular	u_2	0.0012 dB 0.0012 dB 0.0003 dB
Mixer linearity	±0.0018 dB	rectangular	u_3	0.0010 dB
Mismatch $20\log(1 \pm \lvert \Gamma_G \cdot \Gamma_L \rvert)$ $20\log(1 \pm \lvert S_{11} \cdot \Gamma_G \rvert)$ $20\log(1 \pm \lvert S_{22} \cdot \Gamma_L \rvert)$	 ±0.018 dB ±0.013 dB ±0.006 dB	U-shaped	u_4	0.016 dB
Resolution of level meter	±0.001 dB	rectangular	u_5	0.0006 dB
$u_2=u_3=u_5=\delta/\sqrt{3}$, $u_4=\delta/\sqrt{2}$ u_c: Combined standard uncertainty U:Overall uncertainty k:Coverage factor	$u_c^2=\Sigma u_i^2$ $U = k \cdot u_c$ $k = 2$			$u_c = 0.017$ dB $U = 0.034$ dB

on parallel intermediate substitution technique has been established in the frequency region of 4-GHz to 40 GHz. It has the advantage of higher dynamic range over homodyne reception based systems. The system allows attenuation measurement over wider frequency range by translating the attenuation measurement signal to a fixed intermediate frequency of 30 MHz of the standard attenuation. The third harmonic mode mixer operation allows millimeter wave attenuation measurement employing a lower frequency microwave local oscillator. The harmonic mode system needs a less broadband local synthesizer which makes the approach cost effective as a microwave synthesized source is less expensive compared to a millimeter wave synthesized source. It is suitable for organizations such as small industries, universities and technical colleges where cost is also an important factor.

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