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RF ATTENUATION CALIBRATION SYSTEM IN THE FREQUENCY RANGE OF 9 KHZ TO 10 MHZ

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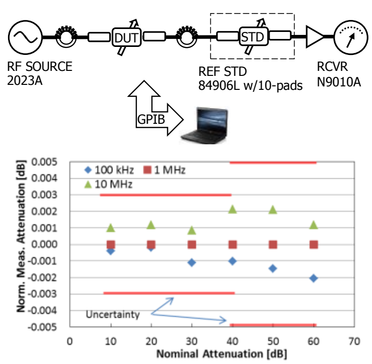
Graphical abstract



Abstract

An accurate RF attenuation calibration system in the frequency range of 9 kHz to 10 MHz is developed at NMIJ, to meet the demand in recent EMC regulations that require traceability of measurements to national standard. The system works based on the RF substitution technique, in which a resistive step-attenuator is used as a reference standard and a general-purpose receiver as a precision level detector. Attenuation values of the standard are determined by calibration at single frequency, i.e., 1 MHz using the NMIJ Primary Attenuation Standard system based on the voltage ratio of the IVD. The system is very simple and higher dynamic range (>100 dB) is obtained by introducing toroidal ferrite chokes in the circuit to minimize the common mode current effects.

Keywords: RF attenuation; resistive attenuator; EMC; standard; traceability

1.0 INTRODUCTION

Attenuation is one of the fundamental measurement quantities that characterize electromagnetic waves propagating in transmission lines of radio frequency (RF) and microwave (MW) networks [1],[2],[3]. At the National Metrology Institute of Japan (NMIJ), an accurate attenuation calibration system operated in the frequency range of 10 MHz to 50 GHz has been developed. The system is built by using the simple intermediate frequency (IF=30 MHz) receiver technique using a calibrated resistive step-attenuator, as an IF attenuation reference standard and a general-purpose receiver, as a level detector [4], [5]. The standard provides accuracy and traceability for measurements and calibrations of transfer standards used in a variety of applications such as communications, radar and navigation. On the other hand, the traceability of measurement to national standard is also required in recent electromagnetic compatibility (EMC) regulations for both national and global recognition purposes [6]. However, since the EMC covers the electromagnetic measurements from several kilohertzs, it is necessary to extend the coverage frequency range of the system. This paper presents an improvement of the attenuation calibration system at NMIJ in order to establish the attenuation calibration system in the frequency range of 9 kHz to 10 MHz dedicated for meeting the demand in recent EMC regulations that require traceability of measurements to national standard. The system is built based on the RF substitution technique, by applying a resistive step attenuator used as a reference standard and a general-purpose receiver as a precision level detector. Attenuation values of the standard are determined by calibration using the NMIJ Primary Attenuation Standard System based on the voltage ratio of the IVD operated at 1 kHz [7]. Since the resistive step attenuators in general have a good frequency response at frequencies below 10 MHz, then calibration to the standard in single frequency, i.e., 1 MHz is sufficient to cover the entire frequency range. Higher dynamic range is obtained by introducing toroidal ferrite chokes on the test ports of the system to minimize the leakage effects which increase due to deterioration in the isolation of the skin effect of the coaxial transmission line used in the low frequency range.

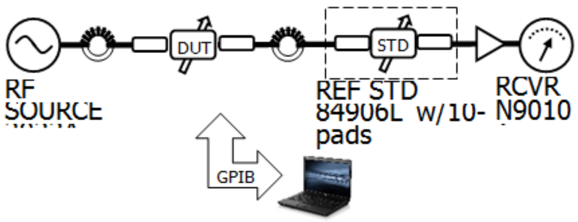


Figure 1 Simplified block diagram of the proposed attenuation calibration system in the frequency range of 9 kHz to 10 MHz.

2.0 MEASUREMENT SYSTEM

2.1 Measurement System

Figure 1 shows the simplified block diagram of the proposed attenuation calibration system in the frequency range of 9 kHz to 10 MHz. The system is constructed with very simple consisting of a RF signal source, test ports, a reference standard and a receiver as a level detector. A resistive programmable step attenuator of 84906L with 10 dB pads mounted on both ports is applied as a set of a reference standard. The RF signal from the source passes through the device under test (DUT) installed in the test ports, where each port consist of a 10 dB matching pad and a toroidal ferrite choke. The matching pads are used to minimize the mismatch uncertainties, however, the toroidalferrite chokes minimize the leakage effect which increases due to deterioration in the isolation of the skin effect of the coaxial transmission line used in the low frequency range. The attenuation of the DUT is compared with the attenuation of the reference standard using the receiver which acted as a sensitive signal comparator. An amplifier is installed before the receiver for adjustment of signal level to the specifications of the receiver. The power level difference of the signals which entered the receiver is kept for less than 1 dB by adjusting the reference standard before and after setting of the DUT.

Letting the attenuation of the standard attenuator is S (dB) and the power level displayed at the receiver be D_i (dBm) at initial setting and be D_f(dBm) at final setting, respectively, then the attenuation value of the DUT is determined in decibel by

$$A = S + (D_i - D_f) \quad (1)$$

A personal computer is used to control the RF source levels and frequencies, reference standard attenuation settings, read the power level measured in the receiver and calculate the calibration value as expressed in equation (1). For programmable step attenuator calibrations, the system can be fully operated automatically.

2.2 Traceability

Traceability route of the system is ensured by performing periodic calibration to the attenuation of the reference standard using the NMIJ Primary Attenuation Standard System based on the voltage ratio of the IVD operated at 1 kHz [7]. In principle, it should be calibrated in the entire frequency range, however since resistive step-attenuators such as 84906L, etc., have good frequency response at frequencies below 10 MHz, thus calibration at a single frequency, e.g.,1MHz, can be considered to represent the attenuations throughout the frequency range of 9 kHz to 10 MHz. The expanded uncertainties of these calibrations are better than 0.004 dB per 20 dB. The matching pads mounted on both test ports function to keep these calibration values from the mismatch effects when the standard is set back to the system.

3.0 RESULTS AND DISCUSSION

Figure 2 shows the evaluation results to the 84906L step-attenuator with 10-dB pads mounted on both ports which was nominated as a reference standard of the system. Attenuations with nominal values of 10 dB to 60 dB in 10 dB intervals (x-axis) were measured

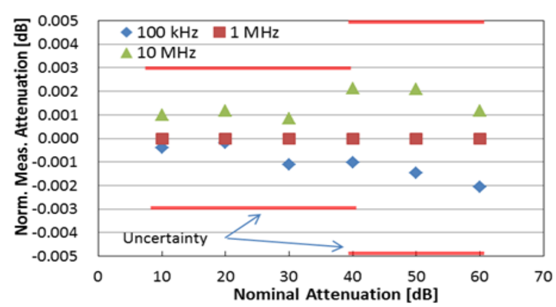


Figure 2 Comparison of attenuation values of the reference standard (84906L w/10 dB pads) at frequency 100 kHz, 1 MHz and 10 MHz, calibrated using the NMIJ Primary Attenuation Standard System based on the voltage ratio of the IVD.

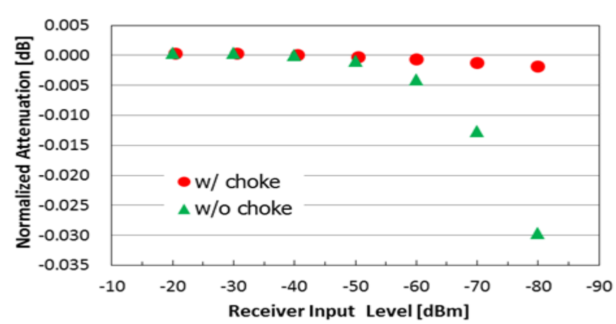


Figure 3 Linearity of the system at frequency 100 kHz

Table 1 Measurement results and uncertainties of a particular step attenuator (84906K)at 300 kHz.

Nominal Value	Proposed System			NMIJ Primary Attenuation Standard System [7]			Difference
	Mean of Measurements *P*	Standard Deviation of the Mean	Expanded Uncertainty (*k*=2)	Mean of Measurements *Q*	Standard Deviation of the Mean	Expanded Uncertainty (*k*=2)	*P-Q*
[dB]	[dB]	[dB]	[dB]	[dB]	[dB]	[dB]	[dB]
10	10.061	2.0E-04	0.004	10.059	2.2E-04	0.004	0.002
20	19.864	1.9E-04	0.004	19.863	1.5E-04	0.004	0.001
40	40.145	1.6E-04	0.004	40.144	2.4E-04	0.004	0.001
60	60.189	8.3E-04	0.006	60.188	1.5E-03	0.005	0.001
80	80.053	3.7E-04	0.007	NA	NA	NA	NA
90	90.110	8.1E-04	0.016	NA	NA	NA	NA

using the NMIJ Primary Attenuation Standard System [7] at frequencies of 100 kHz, 1 MHz and 10 MHz. The results were normalized and plotted based on the measurement results of 1 MHz (y-axis). From the figure, the differences in the results due to the frequency are quite small, smaller than the expanded uncertainties of the measurements as indicated by the horizontal lines. This suggests that a single frequency calibration, i.e., 1 MHz, to the applied reference standard, is sufficient to cover the entire frequency range.

Figure 3 shows the linearity experiment results of the system at frequency of 100 kHz. The results as shown by the filled circles were obtained by measuring 10-dB step of a variable attenuator, where the input level on the receiver is swept from -20 dBm to -80 dBm. From these results, it is found that the system has a dynamic range more than 70 dB with the accuracy of better than 0.002 dB. By applying the double step technique [8], it can be extended up to 100 dB. For comparison, the linearity measurement of the system in which the toroidal ferrite chokes were removed from the circuit, were also performed and the results are shown by the filled triangles. Significant differences in the results can be seen from the receiver input level is equal to -60 dBm, and increase with the decrease in the receiver input. This proves the effectiveness of the use of the toroidal ferrite chokes on thetest ports of the system to minimize the leakage effects which increase due to deterioration in the isolation of the skin effect of the coaxial transmission line used in the low frequency range.

The effectiveness of this technique was investigated by measuring a particular 84906Kstep attenuatoras a DUT. Table 1 shows the results for the nominal values of 10, 20, 40, 60, 80, and 90 dB, respectively, measured at frequency of 300 kHz. The double-step technique [8] was applied to the DUT with a nominal value greater than 60 dB.The results were obtained by the number of observation was ten. The measurement uncertainties were evaluated using the Guide to the Expression of Uncertainty in Measurement [9], includethe type A standard uncertainty, i.e., the standard deviation of the mean, and the type B standard uncertainty,which consists mainly of the systemic uncertainties as follows:Calibration uncertainty and frequency response of the reference standard. Linearity, stability, noise and leakage effects of the measurement system. The mismatch error that occurs between the test ports and the DUT. Gage block attenuator calibration uncertainty when the double step technique is appliedin the higher attenuation measurements.The expanded uncertainty is obtained by multiplying the combined standard uncertainties by the coverage factor k = 2 which for a normal distribution corresponds to a coverage probability of approximately 95 %.For comparison, attenuation measurementsusing the NMIJ Primary Attenuation Standard System [7]were also performed. Both the measurement results and uncertainties showed very good agreement.

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4.0 CONCLUSION

Improvement of the attenuation calibration system at NMIJ was carried out in order to establish the attenuation calibration system in the frequency range of 9 kHz to 10 MHz dedicated for meeting the demand in recent EMC regulations that require traceability of measurements to national standard. A very simple system was constructed based on the RF substitution technique, in which a calibrated resistive step-attenuator is used as a reference standard and a general-purpose receiver as a precision level detector. The traceability route of the system is ensured by performing periodic calibration to the reference standard using the NMIJ Primary Attenuation Standard, however, the results showed that calibrations at a single frequency, i.e., 1 MHz, represent the calibration values throughout the frequency range. Higher dynamic range was realized by introducing toroidal ferrite chokes in the circuit to minimize the common mode current effects. Normal measurement capability of this system is up to 60 dB, however, by applying the double-step technique it can be extended to 100 dB. The expanded uncertainties of the system are 0.004 dB, 0.007 dB and

0.016 dB for attenuationmeasurement range up to 40 dB, 80 dB and 100 dB, respectively.

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