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RF Attenuation Measurement System Using VNA at BSN

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Abstract **– Measurement of RF attenuation is required in determining the quality and effectiveness of telecommunication system. Measurement system of RF attenuation at 10 dB to 60 dB in the frequency range of 10 MHz to 3 GHz has been established at National Standardization Agency of Indonesia (BSN). The system was developed to support measurement of attenuation, particularly on equipment used by telecommunications industry. The measurement method in this system is IF substitution method. VNA works based on the principle of IF substitution method, so that VNA can be used for measuring RF attenuation. The measurement traceability can be achieved effectively by evaluating the VNA only at one frequency using a step attenuator that has been calibrated to the primary standard of RF attenuation. VNA has a linearity of 0.05 dB in the range of attenuation up to 60 dB and frequency up to 3 GHz. In the range mentioned above, the measurement uncertainty is 0.068 dB. Linearity of VNA and the uncertainty from standard are the dominant uncertainty source in this measurement.**

Keywords – Attenuator, IF substitution, RF attenuation measurement, VNA

I. INTRODUCTION

The performance of vector network analyzer (VNA) is improved significantly, therefore it can be used for precision radio frequency (RF) attenuation measurement. VNA is a device to measure S-parameter including attenuation of RF equipment [1]. In the VNA system, the measurement traceability can be achieved effectively by performing calibration only at one frequency. This study describes the investigation of VNA to ensure the capability and accuracy of RF attenuation measurement system. Various methods have been proposed in order to build RF attenuation measurement system [2, 3]. One of the method is intermediate frequency (IF) substitution method. VNA works based on IF substitution method [4]. Therefore, VNA can be used for RF attenuation measurement.

The fast growing of mobile phone and other telecommunication system require the precision measurement of RF quantities, including attenuation. The RF attenuation measurement is required to support telecommunication industries and to fulfil the regulation. The telecommunication industries in Indonesia still send their RF devices to abroad for calibration, because the RF attenuation measurement system is not established yet in Indonesia. National Standardization Agency of Indonesia (BSN) as National Metrology Institute (NMI) of Indonesia has responsibility to build RF attenuation measurement traceability in Indonesia. The measurement of RF attenuation is important for characterizing RF devices [5]. Therefore, the RF attenuation measurement in the frequency range of 10 MHz to 3 GHz should establish at BSN to calibrate attenuation of RF devices from telecommunication industries in Indonesia.

II. CONVENTIONAL IF SUBSTITUION METHOD

Many NMIs conduct the RF attenuation measurement using IF substitution method by using equipment as shown in Fig. 1. The system resulted an accurate measurement but it requires a lot of devices, that consist of RF sources, mixer, LO source, isolator, attenuator standard and IF receiver [6].

Measurement of RF attenuation using VNA system is new challenge to be conducted and it can be compared with the conventional IF substitution method. The VNA system only requires the attenuator standard and VNA itself.

III. MEASUEREMENT METHOD

IF substitution method is used by many NMI because the method provides an accurate result and wide frequency ranges [3]. Fig. 2 shows the block diagram of RF attenuation measurement using IF substitution method at VNA. The main devices in a VNA consist of signal generator, directional coupler, mixer and receiver. There are two types of signal generators, namely RF source as source for RF signal and Lo source as source for IF signal.

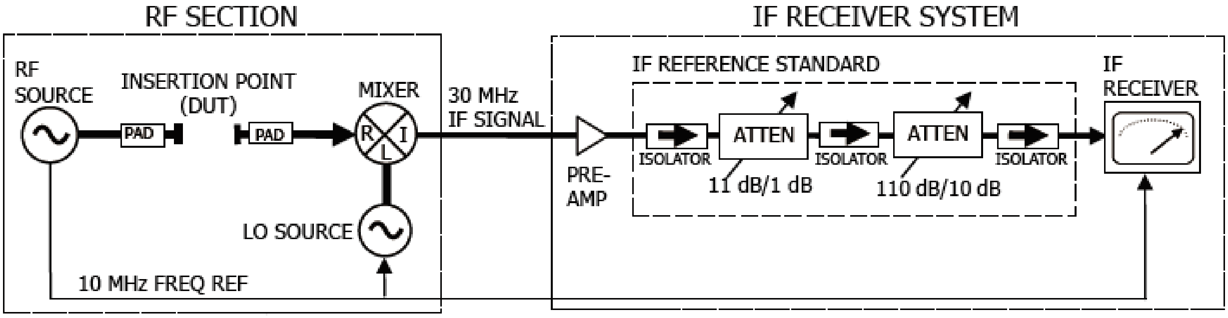

Fig. 1. Conventional IF substitution method [6]

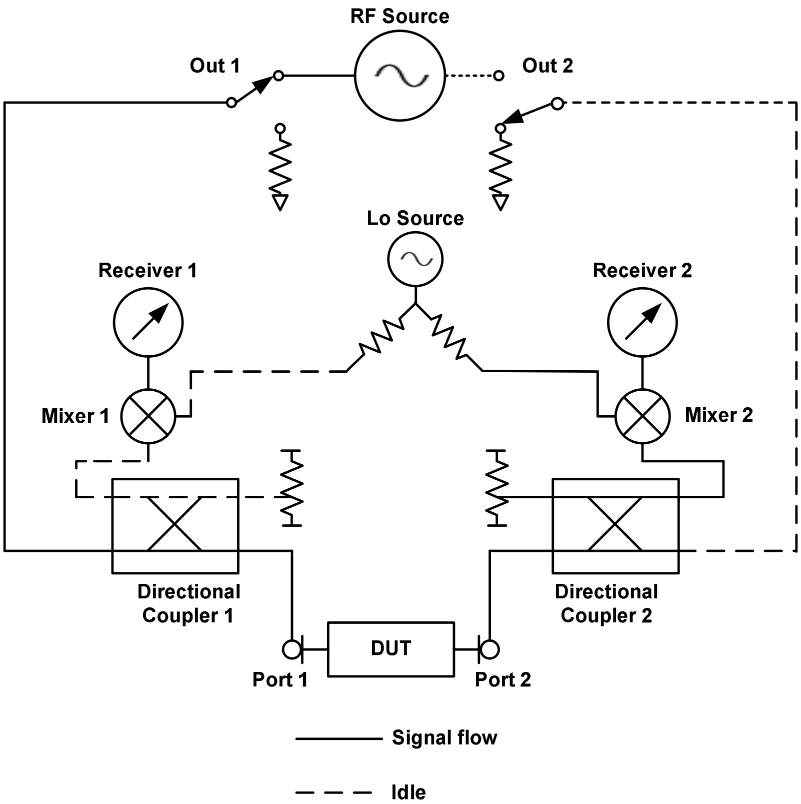

Fig. 2. Measurement system of RF attenuation using VNA

The directional coupler has function to separate a reflected signal and a transmitted signal to an output port. The RF signal is converted to an IF signal by a mixer. The receiver is used to measure the IF signal [7, 8].

Signal of the RF source flows through the directional coupler 1, enters the device under test (DUT) and passes directional coupler 2 to the mixer 2. The RF signal is mixed with signal from Lo Source to produce an IF signal. The IF signal is detected and measured by the receiver 2 in a ratio of the level against to its reference level. The attenuation of DUT is calculated using equation (1).

$$A = 20\ \log\left|\frac{S_{21}^{I}}{S_{21}^{F}}\right| \qquad (1)$$

where:

A = attenuation of DUT,

S_{21}^{I} = level ratio displayed on the VNA when DUT is not connected (initial value),

S_{21}^{F} = level ratio displayed on the VNA when DUT is connected (final value).

The attenuation of RF device is measured in a specific low frequency, it is based on the principle of IF substitution method in the VNA. According to the principle, the traceability of RF attenuation measurement can be achieved effectively by evaluating the linearity of the VNA only at single frequency using a calibrated attenuator. The frequency of 10 MHz is selected for evaluation of VNA. At the frequency of 10 MHz, the reference attenuator has a better repeatability and the directional coupler of VNA has a relatively small coupling loss. This is one of the advantages of RF attenuation measurement using VNA. A reference attenuator has been calibrated to other NMI at the frequency of 10 MHz to get the traceability to SI unit. The reference attenuator is used for evaluating of capability and accuracy of the VNA.

The block diagram of evaluation of VNA is shown as Fig. 3. A step attenuator is used to setup the level of power source. Measurement uncertainties are evaluated independently to ensure the contribution of each frequency measurement. The sources of uncertainty that being evaluated at each frequency consist of mismatch on the measurement ports, linearity of VNA, uncertainty of standard, resolution of VNA and measurement repeatability [9, 10, 11].

IV. RESULTS AND DISCUSSIONS

Fig. 4 shows the measurement result on the linearity of VNA system at 10 MHz. The VNA measured a nominal 10 dB attenuation of a calibrated reference attenuator. A step attenuator is used as level controller for measuring attenuation until 60 dB. The power levels were changed in the intervals of 10 dB. The blue lines show the standard deviation of linearity measurement at 10 MHz. The measurement results were obtained with the number of 10 data observation. Based on the results, the difference was less than 0.002 dB within the observation level up to -20 dBm, 0.01 dB within level up to -40 dBm and 0.02 dB within level up to -60 dBm. The values indicate the uncertainties limit related to the measurement traceability to the RF attenuation primary standard. The standard deviations of the measurement results increase significantly from the input level of -50 dBm, it is because of the noise effects. This problem can be minimized by increasing the number of observations, narrowing the IF bandwidth, and increasing the averaging number of the VNA.

Fig. 5 shows the comparison of linearity of the VNA system by measuring reference attenuator at 10 dB and frequency of 10 MHz, 100 MHz, 1 GHz and 3 GHz. The results are obtained by setting up the input power levels up to -60 dBm. The measurement results are normalized based on the results at the input level of 0 dBm. Based on the result, the linearity at 10 MHz is slightly different compared to the linearity at 100 MHz, 1 GHz and 3 GHz. It is because of the frequency characteristics of the directional couplers of the VNA. Related to the standard deviations in the results, the coupling loss of the directional coupler at higher frequencies is estimated larger than at 10 MHz. The standard deviation increases when the measurement frequency and the RF attenuation increase.

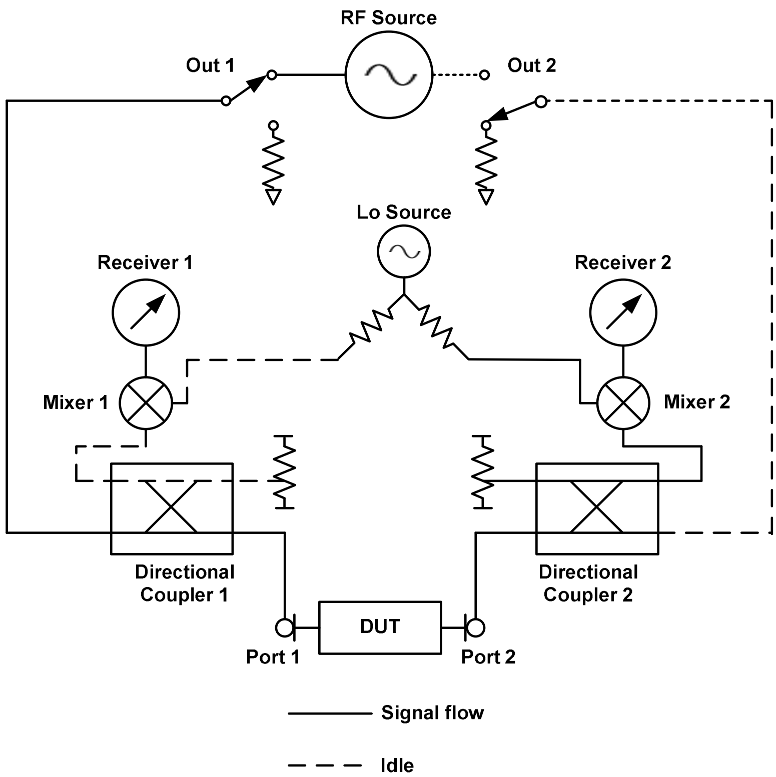

Fig. 3. Evaluation of the linearity of the VNA

Table 1 shows the uncertainty budget of RF attenuation measurement up to 60 dB and in the frequency range up to 3 GHz. Linearity of VNA becomes the major source of uncertainty in this measurement. The contributions of linearity to the measurement uncertainty are 0.007 dB for measurements up to 20 dB, 0.03 dB for up to 40 dB and 0.05 dB for up to 60 dB. The measurement uncertainties become larger according to the increasing of measured attenuation value and measurement frequency. Fig. 6 shows the established RF attenuation measurement system at BSN.

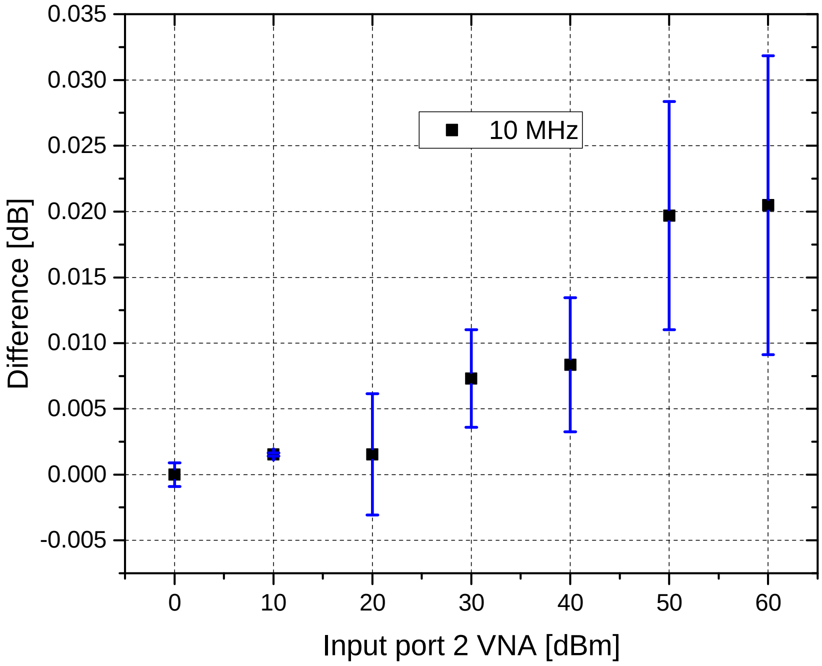

Fig. 4. The linearity of VNA system at 10 MHz

Tabel 1. Uncertainty budget of attenuation measurement up to 60 dB at frequency up to 3 GHz.

Uncertainty Source	**Standard Uncer-tainty**	**Probability Distribution**	**Sensitivity Coefficient**	**Uncertainty Con-tribution**
x_i	$u(x_i)$		$c(x_i)$	$u(x_i) \cdot c(x_i)$
Uncertainty of Attenua-tor Standard	0.015	Normal	1	0.015
Linearity of VNA	0.029	Rectangular	1	0.029
Mismatch	0.0049	Rectangular	1	0.0049
Resolution of VNA	0.00058	Rectangular	1	0.00058
Repeatability	0.0078	Normal	1	0.0078
Combined standard uncertainty, u_c				0.034
Expanded uncertainty (k=2), U				0.068

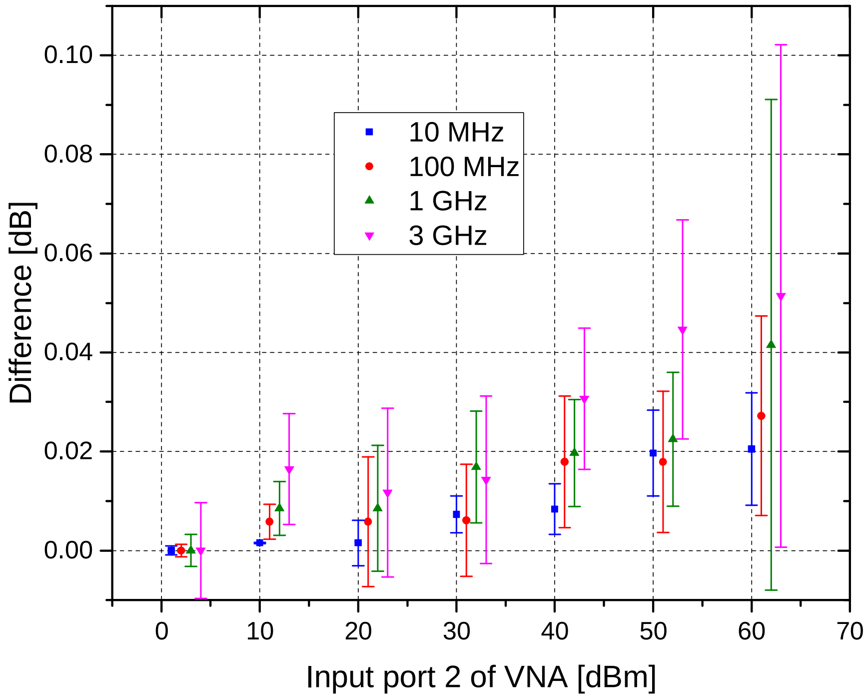

Fig 5. Comparison of linearity measurement of VNA

Fig 6. The established RF attenuation measurement system

V. CONCLUSIONS

RF attenuation measurement system using VNA has been established at BSN in the attenuation range of 10 dB to 60 dB and frequency range of 10 MHz to 3 GHz with the uncertainty of 0.068 dB. The measurement traceability of the system can be achieved effectively by evaluating the linearity of the VNA only at single frequency using a calibrated attenuator. The VNA system only requires the attenuator standard and VNA itself, and it is more efficient than the conventional method. These are the new added value of the system. The nonlinearity is the major uncertainty source for higher attenuation measurement, and it requires an improvement for future work.

VI. ACKNOWLEDGMENT

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