Design of Verification Standards for S-parameter Measurements from 110 GHz to 170 GHz

Beijing Institute of Radio Metrology and Measurement

Abstract

This paper describes a new waveguide verification kit has been introduced recently to provide high repeatable and high stable scattering parameter measurements in the frequency range from 110 GHz to 170 GHz. The verification kit consists of three two-port mismatches with flat frequency response, two precision fixed attenuators and a new designed waveguide section. The verification kit can be used as a primary standard for *S*-parameters. Traceability to the International System of units (SI) is achieved via dimensional measurements of the waveguide aperture or precision calibration by the national attenuation standards. This paper describes the design method of the verification kit, both simulation and measurement results are presented. Furthermore, the uncertainty of measurement results is estimated in this paper.

Ⅰ. INTRODUCTION

- Vector-network-analyzers (VNA) are widely used to measure components and sub-assemblies. It can measure S-parameters rapidly with a great accuracy.
- When a calibration has been performed, we need to use verification kits to check the performance of the VNA.
- In the frequency range below 110 GHz, commercial verification kits are available, such as W11645A provided by Keysight and 27710 provided by Flann. However, in the frequency beyond 110 GHz, there is no specific model available in the catalog.
- In this paper we designed a new verification kits for VNA in the frequency range from 110 GHz to 170 GHz.

Ⅰ. INTRODUCTION

- The verification standard can provide accurate, stable and repeatable S-parameters, it can trace to the International System of units (SI) by precision calibration by the national standards and dimensional measurements of the waveguide sections.

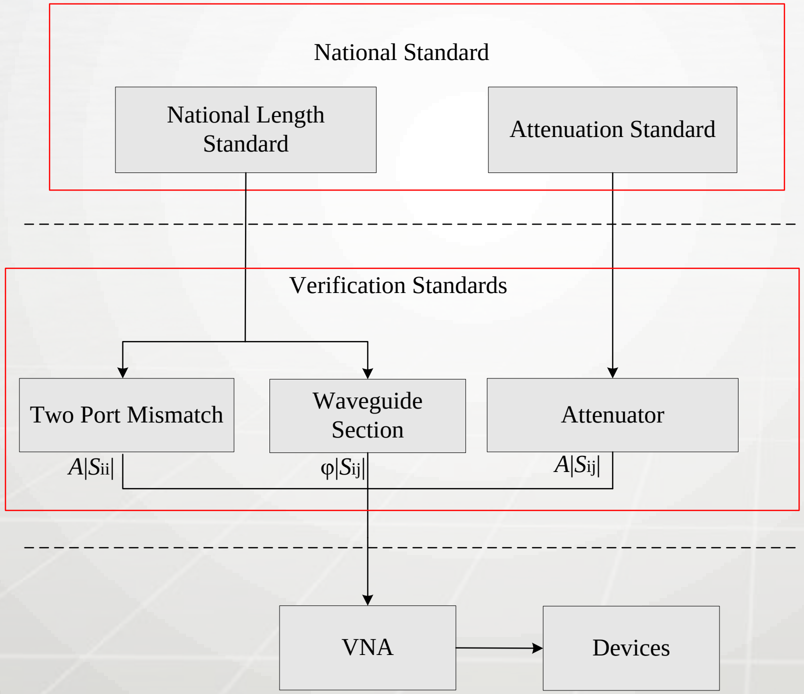


Figure 1. Traceability path of the 110GHz~170GHz S-parameter.

II.DESIGN OF VERIFICATION STANDARDS

- The primary standard for S-parameter measurement can be traced to International System of units, which is the most important requirement.
- The verification standards designed in this paper consists of three simple waveguide two-port mismatches with different VSWR, two precision attenuators with different attenuation and a matched waveguide section with the shortest length.
- The two-port mismatch and matched waveguide section are used as the reflection amplitude standard ($A/S_{ii}|$) and transmission phase standard ($\varphi/S_{ij}|$), respectively, which can be traced to the national length standard. The precision attenuator is used as the transmission amplitude standard ($A/S_{ij}|$), which can be traced to the national attenuation standard.

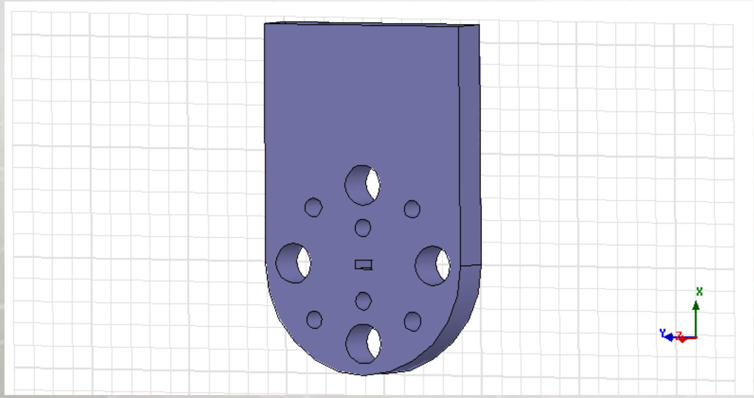
II.DESIGN OF VERIFICATION STANDARDS

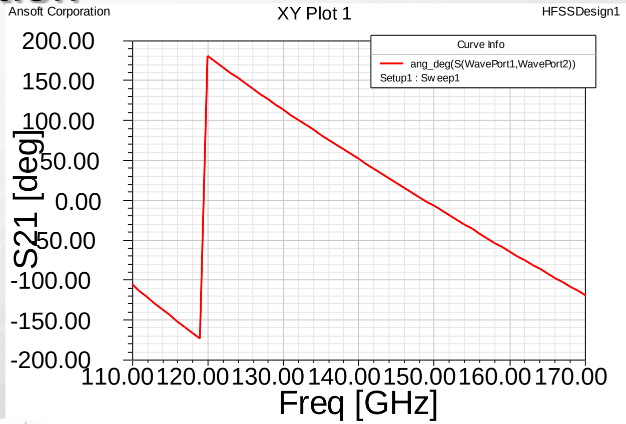
- **Transmission Phase Standard**

- The matched waveguide section is used as the transmission phase standard, which should cover the phase range from -180°to +180°.
- The phase introduced by the phase standard can be calculated as follow:

$$\varphi = 2\pi l / \lambda_g$$

- Machining model of the transmission phase standard and the Simulation results of the match waveguide section





II.DESIGN OF VERIFICATION STANDARDS

- **Reflect Magnitude Standards**

- The three two-port mismatches waveguide sections with nominal VSWR 1.1, 1.5 and 2.0 are working as the reflect magnitude standards.
- The corresponding reflection coefficient, S_{11} can be calculated as follow:

$$S_{11} = \frac{(1+r-jBr)(1-\frac{1}{r}-jB)e^{-2\gamma l}+(1-r-jBr)(1+\frac{1}{r}+jB)}{(1-r+jBr)(1-\frac{1}{r}-jB)e^{-2\gamma l}+(1+r+jBr)(1+\frac{1}{r}+jB)}$$

Table 1. Dimensional design of the mismatch with the traditional method

VSWR	*a*	*b*	*l*
1.10	1.6510	0.784	0.640
1.50	1.6510	0.660	0.640
2.00	1.6510	0.580	0.640

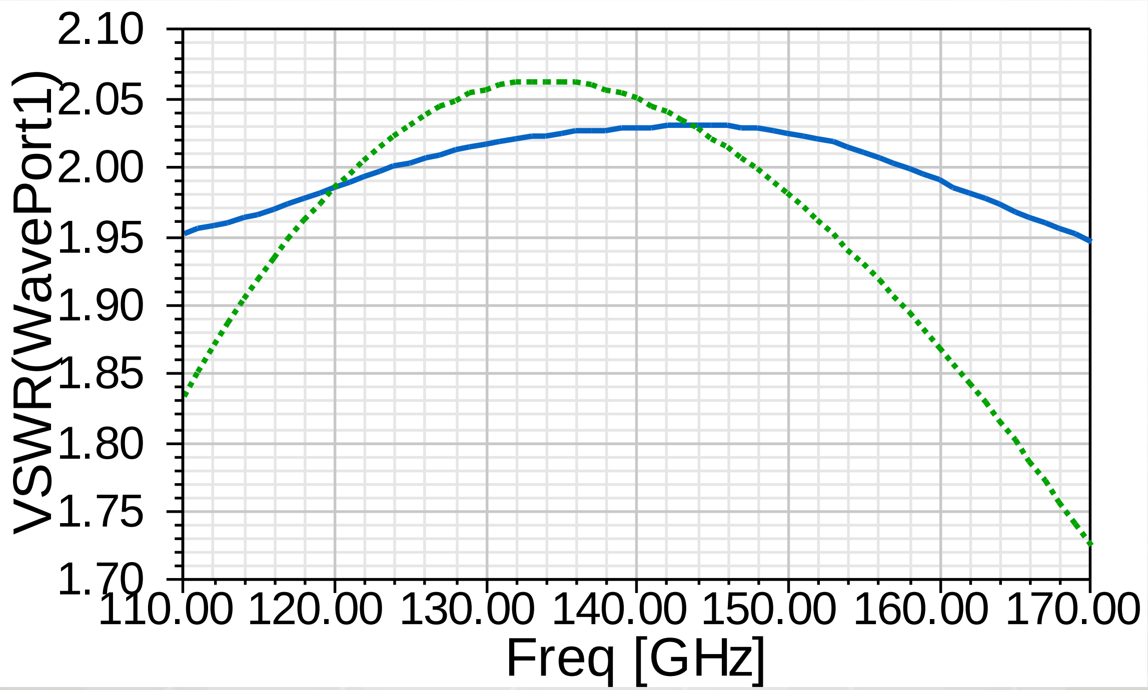
Table 2. Dimensional design of the mismatch with the new method (Unit: mm)

VSWR	a	b	l
1.10	1.656	0.787	0.640
1.50	1.795	0.690	0.473
2.00	2.140	0.620	0.488

II.DESIGN OF VERIFICATION STANDARDS

- **Reflect Magnitude Standards**

➢ The three two-port mismatches waveguide sections with nominal VSWR 1.1, 1.5 and 2.0 are working as the reflect magnitude standards.



II.DESIGN OF VERIFICATION STANDARDS

- **Transmission Magnitude Standards**

- The two precision fixed attenuators with nominal insert loss of 20dB and 40dB are working as the transmission magnitude standards.
- It realized by a directional coupler, and the aperture of the coupling hole conforms to the Chebyshev distribution.

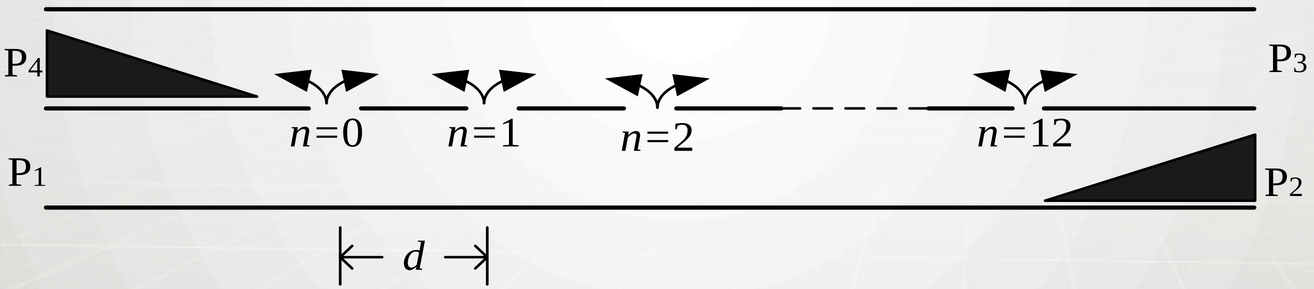


Figure 6. The internal structure of the attenuator.

Ⅲ. DETERMINATION OF THEORETICAL VALUE

- The verification standard after processing is shown in Figure 7, including the mismatch waveguide designed by the two methods, the new designed matched waveguide section and two precision attenuators with different attenuation. Send the mismatch waveguide and the matched waveguide to National Institute of Metrology, China, for dimension traceability.

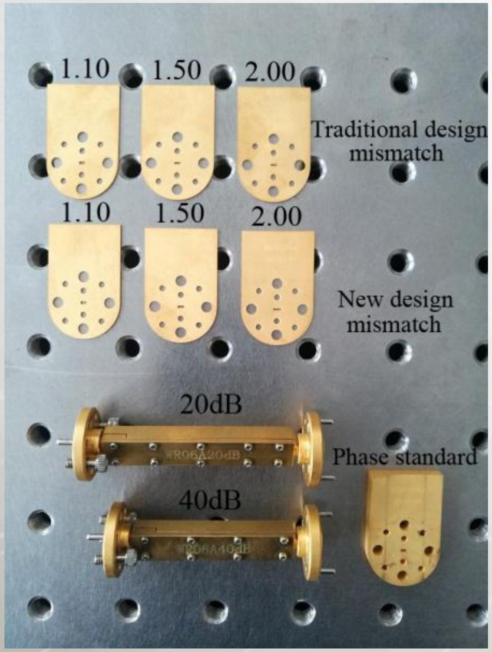


Figure 7. Photos of the processed verification standard.

Table 3. Dimensional measurement results of aperture size and thickness of the mismatch waveguide and match section (Unit: mm)

Device	*a*	*b*	*l*	*U*（*k*=2）
Match section	1.657	0.822	3.834	0.003
1.10 N-mismatch	1.649	0.784	0.644	0.003
1.50 N-mismatch	1.788	0.684	0.473	0.003
2.00 N-mismatch	2.136	0.618	0.501	0.003
1.10 T-mismatch	1.647	0.779	0.661	0.003
1.50 T-mismatch	1.646	0.655	0.654	0.003
2.00 T-mismatch	1.648	0.574	0.649	0.003

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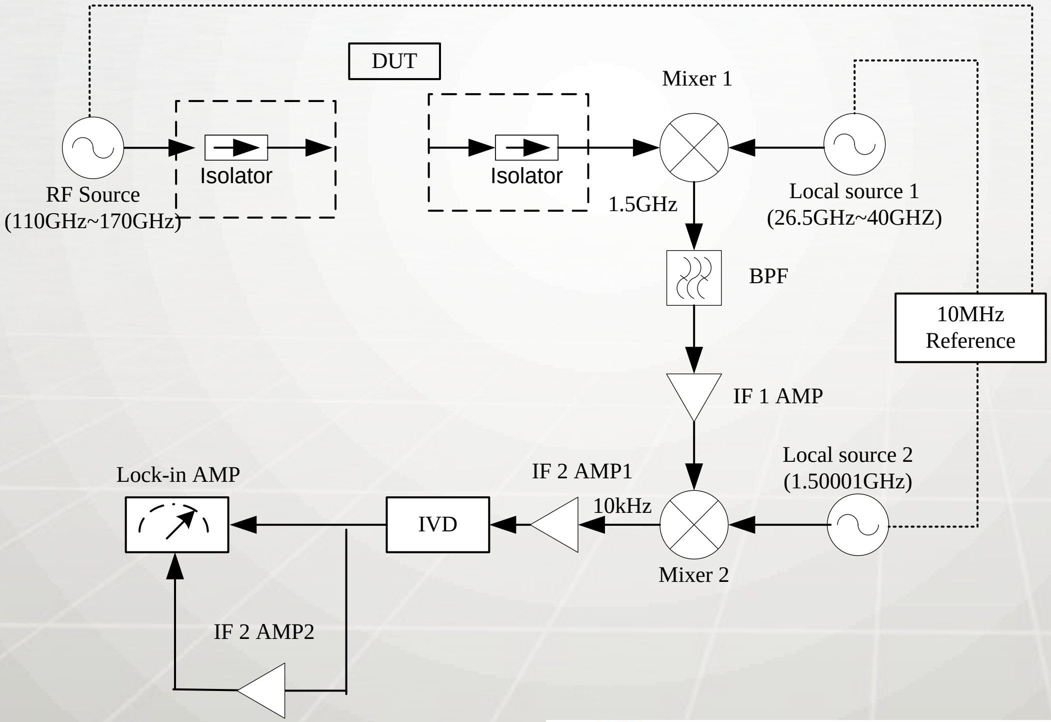
Ⅲ. DETERMINATION OF THEORETICAL VALUE

- The theoretical value of the transmission amplitude standard is obtained from the attenuation measurement system, which based on the IF substitution method as shown in Figure 8, it employs an inductive voltage divider (IVD) working at 10 kHz as a reference standard.



Ⅳ. UNCERTAINTY ESTIMATES

- The dominate source of the transmission phase and reflection amplitude uncertainty contains worst-case errors due to aperture height tolerance, worst-case errors due to aperture width tolerance, worst-case errors due to length tolerance.

- The dominate source of the transmission magnitude uncertainty contains receiver nonlinearity, detection noise, leakage, inductive voltage divider (IVD) error and repeatability.
- We assumed that the factors were uncorrelated. Uncertainties are combined using root-sum-of-the-squares (RSS) method to yield the standard system uncertainty.

Ⅴ. SYSTEM VERIFICATION FOR VECTOR NETWORK ANALYZER

- Using verification standards achieves system verification for a VNA from Keysight Technologies and a ZC-170 frequency extension module from Rohde&Schwarz Company, which sent by customers for calibration.

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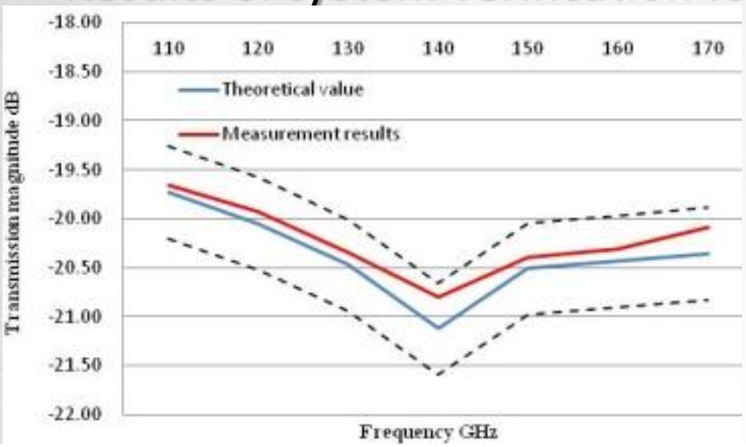
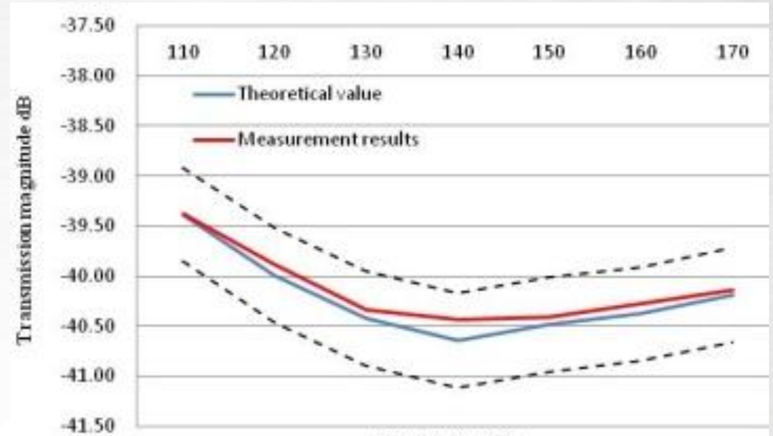
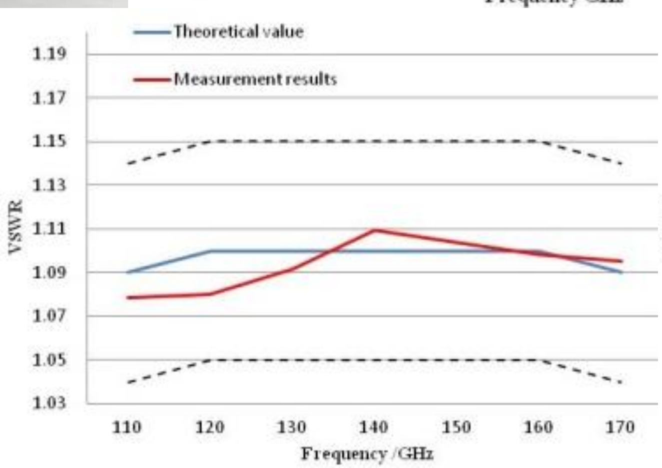
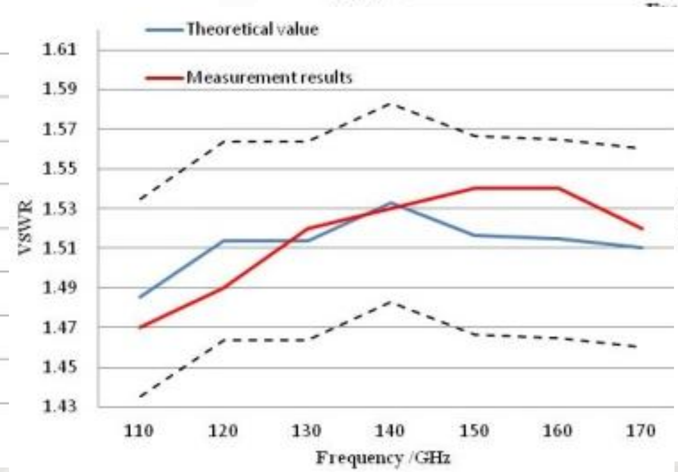
Ⅴ. SYSTEM VERIFICATION FOR VECTOR NETWORK ANALYZER

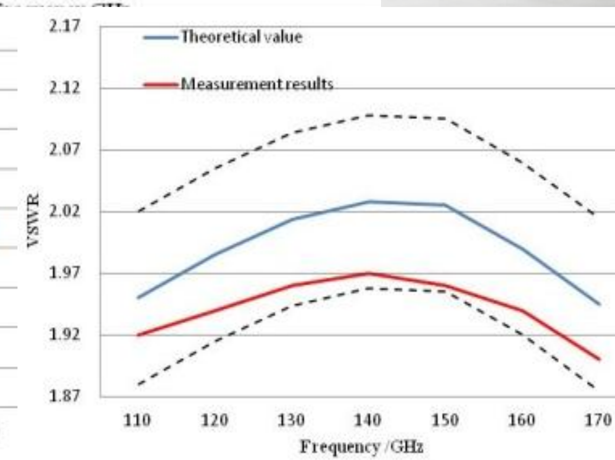
- Results of system verification for VNA

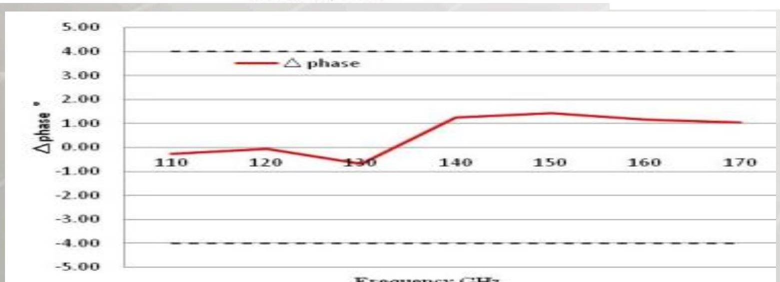












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Ⅵ. CONCLUSION

- This paper describes the new designed waveguide verification standards in the frequency from 110GHz to 170GHz. It can provide accurate, stable and repeatable S-parameters, it can trace to the International System of units (SI) by dimensional measurements of the waveguide sections and precision calibration by the national standards. By using the verification standards, the performance of a VNA can be verified.