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Contactless Flange Made the Sub-THz VNA Calibration and Testing Faster and More Accurate

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***Abstract* — This paper presents contactless flanges designed for sub-THz VNA calibration and testing. Compared to standard waveguide flanges, no electrical contact is necessary between two flanges, which allows for a faster calibration and testing process. This type of contactless flange has the same exact mechanical dimensions as the standard waveguide flange and can be secured by using waveguide screws if needed, making it compatible with the standard waveguide flange. Both TRL and SOLT calibrations were performed on the VNA to compare the calibration speed with and without fastening screws. Multiple tests using contactless flanges were conducted on sub-THz components to demonstrate the repeatability of accurate measurement. It has been experimentally verified that accurate and reliable results can be obtained without tedious and time-consuming waveguide alignment and the careful waveguide screws attachment and adjustment during testing of sub-THz components.**

***Keywords* — contactless flange, VNA, calibration, sub-THz.**

I. Introduction

The sub-THz (90-330 GHz) components usually have waveguide ports with standard flanges. Currently, VNA extenders must be used with the VNA to test these components operating above the W-band frequency range. Reliable waveguide connections between two VNA extenders are crucial for accurate sub-THz measurements. This presents challenges in the testing of sub-THz components. To obtain reliable and accurate test results, the interconnections between waveguide flanges must be aligned and tightened carefully, and no gap should be present between the two flanges. Otherwise, the leakage and reflection at the waveguide ports will result in unreliable and inaccurate device under testing (DUT) performance. There are other challenges in testing sub-THz components. Normally, experienced technicians or engineers are needed to perform the test, even for fastening the screws between flanges to ensure the adequate flange alignments and connections. Waveguide cocking could occur if the screws are not properly tightened evenly, causing the mating faces to pull apart with small gaps. In addition, the waveguide flanges could wear out or deform after intensive use. VNA extenders need to be moved around, and waveguide flange misalignment could occur during the test, resulting in leaking, reflection, and inaccurate readings.

To address the issues of waveguide flange cocking, fastening, and wear out, researchers have proposed contactless waveguide flanges for millimeter wave and sub-THz measurement. In [1], a contactless flange working between 190 and 320 GHz was realized using a bed of nails on the waveguide flange, and simulation results were presented to validate the design. [2] proposed a contactless flange adapter for interconnecting two standard waveguide flanges. The contactless flange adapter can be mounted on a standard waveguide flange with a magnetic fastener ring attached to it. In [3], a contactless flange with a combination of choke flange and pin-array flange was proposed, and measured results of E-band components were presented to verify the design. In [4], contactless flanges with pins and choke flanges were fabricated, measured, and compared up to 325 GHz. To avoid waveguide flange misalignment during calibration and testing, a rail positioning system was proposed in [5]. This setup improves the efficiency and speed of calibration and measurement.

This paper proposes contactless flanges for sub-THz component measurement in the frequency range of 90-330 GHz. Compared with the contactless flanges proposed in [1] and [2], this design has a pin array embedded in a choke flange. This flange can work in a contactless manner and also mate with standard waveguide flanges using waveguide screws. This work extends the efforts in [3] and [5] and realizes fast calibration of VNA with extenders and measurement of sub-THz components up to 330 GHz. It was experimentally verified that sub-THz components can be readily tested without the effort of fastening waveguide screws for both system calibration and component data collection.

Fig.1. Fabricated WR-3 straight waveguide with contactless flanges.

II. Contactless Flange Design

The working principle of the proposed contactless flange is the same as the ones proposed in [1]. The pin array at the waveguide flange forms a high impedance surface, which functions as an artificial magnetically conductive (AMC) surface. There is no tangential magnetic field present at the AMC surface, while the other mating waveguide flange is a perfect electric conductor (PEC), which means there is no tangential electrical field at the surface. When the distance between the two flange surfaces is less than a quarter wavelength of the operating frequency, a stopband is created, and no waveguide modes propagate between these two flange surfaces. The difference between the proposed contactless flange and other designs is that the pin array is engraved on a choke flange on the surface. The choke is a ring with a depth of a quarter wavelength of the operating frequency, and the distance between the inner circle of the choke and the waveguide broadside is also a quarter wavelength. Therefore, the contactless flange can mate with standard waveguide flanges using waveguide screws and serve as a contactless flange adapter.

The fabricated WR-3 straight waveguide with contactless flanges is shown in Figure 1. The WR-3 waveguide size is 0.032” x 0.017”. The inner diameter of the choke is 0.068”, and the outer diameter of the choke is 0.212”. The pin array height and the choke depth are the same, both being 0.012”. In contrast to the design in [3], where only two rows of pins are used, the WR-3 contactless flange is equipped with four rows of pins, which enhances the stopband created by the pin array. All the pins are arranged along concentric circles with a thickness of 0.008”, and the spacings between two adjacent circles are also 0.008”. There are ten groups of pins arranged along the radial line of the flange surface, with a central angle of 24 degrees, while the central angles between two adjacent groups are 12 degrees. It covers the full WR-3 frequency range from 220 GHz to 330 GHz. The WR-3 straight waveguide with contactless flanges is used with WR-3 VNA extenders for fast calibration and component test.

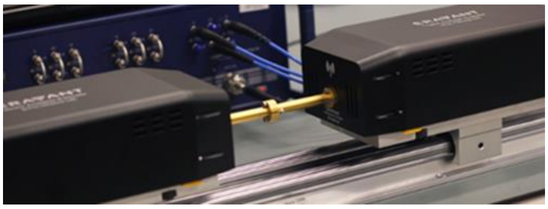

Fig.2. VNA with extenders on the rail position system after [5]. Each extender is equipped with a straight waveguide using contactless flanges.

III. Experimental Verification

To make VNA calibration and testing faster, the two VNA extenders are equipped with straight waveguides using contactless flanges at their waveguide ports. In this way, the two VNA extenders will slide on the rail systems and mate with each other directly during the VNA calibration process. The device under test can be placed directly between the two contactless flanges of the VNA extenders during the sub-THz component test process. There is no need to fasten waveguide screws at the waveguide interconnections. The VNA with extenders on the rail positioning setup is shown in Fig. 2. This kind of equipment setup applies to the VNA covering the frequency range of 90-330 GHz.

The contactless flange, in combination with the rail positioning system, makes sub-THz VNA calibration and testing much faster. To validate the statement, the calibration time needed for VNA were recorded and compared in Table. 1. Two most common calibrations were used, which were SOLT (short, open, load, through) and TRL (through, reflect, line). SOLT calibration is based on shorts, opens, loads, and through standards. TRL calibration normally uses a zero-length through, reflect standards such as open or short, and a longer through line. TRL calibration was performed on the WR-3 VNA, while both SOLT and TRL calibrations were performed on the WR-10 VNA. A timer was used to record the time of calibrating the VNA by an experienced engineer.

Table 1. Time recorded to perform calibrations on VNA.

	SOLT Calibration	TRL Calibration
WR-3 VNA with screws	-	3 minutes 15 seconds
WR-3 VNA without screws	-	44 seconds
WR-10 VNA with screws	3 minutes 15 seconds	1 minute 57 seconds
WR-10 VNA without screws	1 minute 3 seconds	42 seconds

When WR-3 VNA was calibrated with TRL, it took 42 seconds to finish without fastening the waveguide screws of flanges, while it took 3 minutes and 15 seconds to finish with all the waveguide screws tightened up. The time spent on calibration was reduced by 77% using contactless flanges compared with normal flanges. When WR-10 VNA was calibrated with SOLT, the time spent on calibration was reduced by 67% using contactless flanges compared with normal flanges. When WR-10 VNA was calibrated with TRL, the time spent on calibration was reduced by 64% using contactless flanges compared with normal flanges. It was experimentally verified that the VNA calibration could be performed with more than 60% time reduction by using the contactless flanges.

The return losses of the WR-3 VNA after TRL calibration with and without engaging waveguide screws were compared in Fig. 3, which demonstrated the same levels after each calibration. The return losses of WR-10 VNA after SOLT and TRL calibrations were presented in Fig. 4 and Fig. 5, respectively. The difference between using waveguide screws and using contactless flange was within the tolerance of calibration for both cases. It was experimentally verified that VNA calibration was sped up without compromising the accuracy.

To validate the performance of the contactless flange for fast sub-THz component testing, measurements were conducted on one WR-3 10 dB coupler using the WR-3 VNA, and on one WR-10 E-plane filter using the WR-10 VNA. For both cases, one test was performed when waveguide screws between the waveguide flanges were tightened up, and the other 5 tests was done without engaging the waveguide screws. The measured couplings of the WR-3 coupler were compared in Fig. 6, and the measured insertion loss the WR-10 filter were compared in Fig. 7. The difference between testing with and without waveguide screws was within the VNA test tolerance range. This confirmed that the contactless flange enabled faster testing and repeatable measurements without compromising the accuracy of the test.

The validation above was performed with the assistance of the rail system to be more quantitative so that conclusion drawn is more subjective. In the average test lab or production settings, the rail system is not available. The calibration made without the aid of the rail systems shows much longer time to proper align the mating waveguides and fasten even performed by a skilled and experienced engineers and technicians. The required time to perform a full VNA calibration can be more than 10x of that of using contactless flanges if standard flange is used.

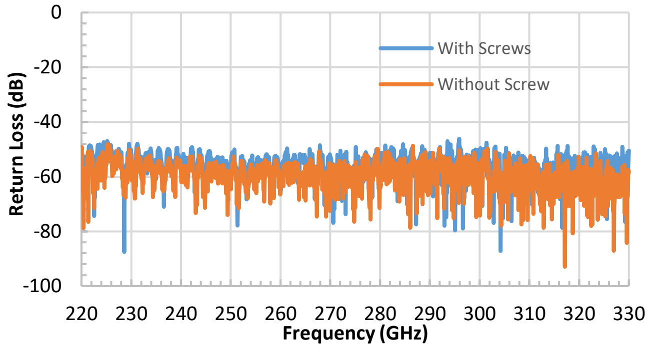

Fig.3. Return loss of WR-3 VNA after TRL calibration.

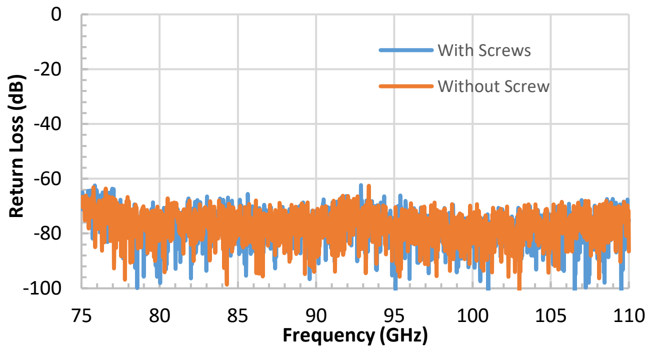

Fig.4. Return loss of WR-10 VNA after SOLT calibration.

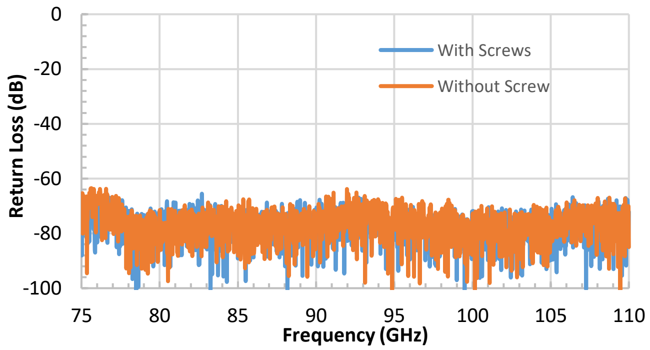

Fig.5. Return loss of WR-10 VNA after TRL calibration.

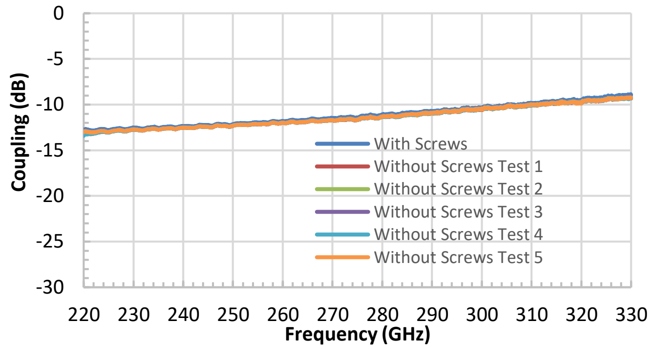

Fig. 6. Comparison of coupling of one WR-3 coupler when screws of contactless flanges were tightened up and when no screws used.

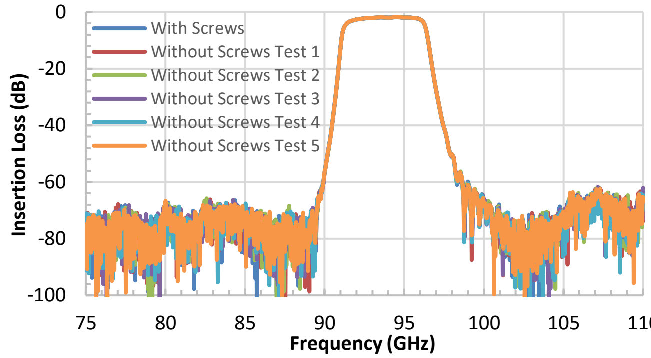

Fig. 7. Comparison of insertion loss of one WR-10 E-plane filter when screws of contactless flanges were tightened up and when no screws used.

IV. Conclusion

Contactless flanges are designed to improve the speed and reliability of the mmW and Sub-THz VNA calibration and component measurements. They are suitable for VNAs operating in the frequency range of 90 to 330 GHz. The proposed contactless flanges are versatile, as they can be used as both a contactless adapter without screws and a standard waveguide flange with screws. One specific example, the WR-3 band (220 to 330 GHz) contactless flanges, were selected to verify the calibration speed improvement of VNA calibration. By eliminating the need for waveguide screws attachment and waveguide alignment during calibration, the contactless flanges can significantly reduce the time needed for the process. To demonstrate the consistent and repeatable of the contactless flanges, the WR-10 band was considered and a bandpass filter was tested.

References

[1] E. Pucci and P.-S. Kildal, "Contactless non-leaking waveguide flange realized by bed of nails for millimeter wave applications," *6th Eur. Conf. Antennas Propag* (*EUCAP*), March 2012.

[2] E. Alfonso, S. Carlred, S. Carlsson, and Lars-Inge Sjoqvist, "Contactless flange adapters for mm-wave measurements," *11th Eur. Conf. Antennas Propag* (*EUCAP*), March 2017.

[3] C. Mayaka, Y. Shu and D. Doshi, "Robust contactless waveguide flange for fast measurements," *IEEE MTT-S Int. Microw. Symp. Dig.*, June 2021.

[4] S Rahiminejad, E Pucci, S Haasl and P Enoksson, "Micromachined contactless pin-flange adapter for robust high-frequency measurements," *J. Micromech. Microeng*., vol. 24, no. 8, p. 084004, 2014.

[5] L. Ren, D. Doshi, and Y. Shu, "Contactless flanges and rail system for mmW and THz testing," *52nd European Microwave Conference* (*EuMC*), September 2022.