Contactless Flanges and Rail System for mmW and THz Testing

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***Abstract* — In millimeter-wave (mmW) component engineering and manufacturing processes, it can be a constant struggle to achieve good calibration and measurement accuracy and repeatability. Furthermore, it is even more challenging to accurately and consistently characterize devices in a volume production setting where testing speed and data reliability are essential. The contactless flange is a good solution to this problem. It can be electrically connected to a device under test (DUT) without full mechanical contact and without tightened screws. There are two types of contactless flanges, i.e., the choke flange and the pin-array flange. In this paper the performance of three typical contactless flange designs is presented and compared, especially in consideration of possible misalignment. Additionally, a rail positioning system integrated with contactless flanges is proposed to minimize the alignment efforts during waveguide component testing. The rail positioning system has been successfully integrated with mmW frequency extenders for vector network analyzers (VNAs) to ease and improve mmW and THz testing.**

***Keywords* — contactless flange, rail, mmW, THz.**

I. Introduction

The standard approach for connecting mmW waveguide components utilizes screws to hold two waveguide flanges together. If the screws are not tightened carefully with good balance and proper torque, calibration and measurement results may be inaccurate or unreliable due to waveguide cocking. In addition, screw insertion and adjustment are a tedious process that can make calibration and testing times long or result in poor data quality over an extended period. Furthermore, this process could damage the waveguide flanges if not done properly. To avoid these challenges, the contactless flange was proposed and developed. There are two types of contactless flanges that have been reported, i.e., the choke flange and the pin-array flange. It has been experimentally demonstrated that both the choke flange and the pin-array flange have comparable performance in mmW and THz measurements [1]. In [2], WR-03 contactless non-leaking waveguide flanges were realized by using a pin-array to suppress signal leakage. A dispersion diagram was presented to illustrate the stopband introduced by the bed of pins. In [3], a removable contactless flange adapter that uses a magnetic fastening solution instead of screws is described. In [4], an egg-choke flange for contactless waveguide joints was designed and analyzed in terms of linear and rotational misalignments. In [5], a contactless flange with a combination of choke flange and pin-array flange was proposed and manufactured for mmW and THz measurements. The flange was implemented in a mmW VNA measurement system with frequency extenders.

Contactless flanges are particularly useful when using a VNA with frequency extender modules for mmW and THz measurements. In general, the mechanical tolerances of the extender flange locations and orientations are not always well-controlled, as extenders are typically designed and manufactured for occasional manual use in a laboratory environment. At higher mmW and THz bands the alignment of two VNA frequency extenders becomes more critical for obtaining consistent results from a two-port network test setup. The entire effort is vulnerable to flange misalignments during the calibration and measurement phases.

In this paper, three typical contactless flange designs at E-band (60 to 90 GHz) are investigated. They include a choke flange, a pin-array flange with a quarter-wavelength transformer, and a pin-array flange without a transformer as shown in Figure 1. Their performance is compared when linear misalignment exists between flanges during measurements. The contactless flange is used with VNA frequency extenders to ease the calibration and test processes. To minimize linear misalignment, a rail positioning system is proposed and fabricated to integrate with VNA frequency extenders for rapid mmW and THz measurements.

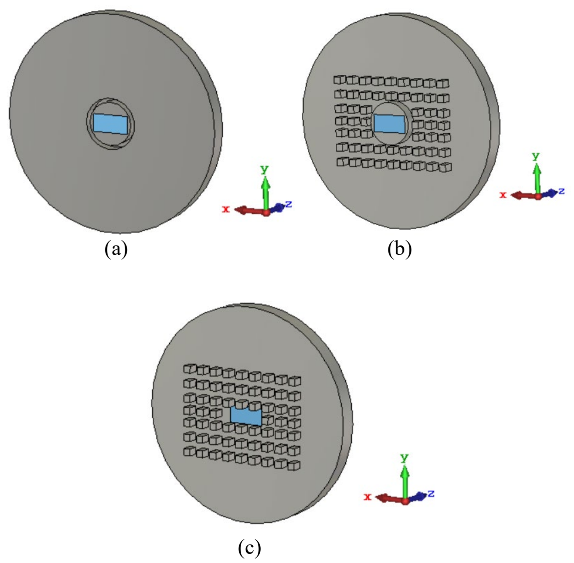
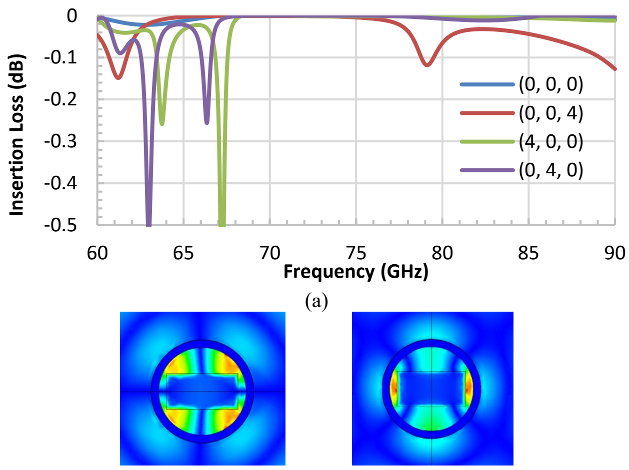


Fig. 1. (a) choke flange; (b) pin-array flange with transformer; (c) pin-array flange without transformer.



(a)

(b) (c)

Fig. 2. (a) Insertion loss for a choke flange with misalignments of (Δx, Δy, Δz) shown in mils. (b) Maximum E-field at the resonance frequencies when misalignment is (4, 0, 0) mils. (c) Maximum E-field at the resonance frequencies when misalignment is (0, 4, 0) mils.

II. Contactless Flange Comparison

A. Choke Flange

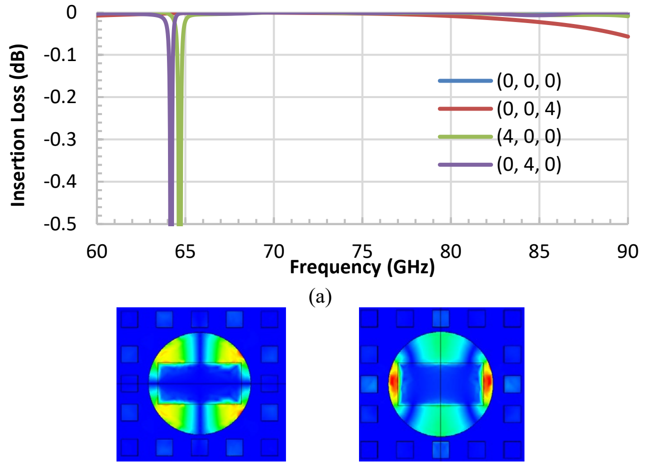
The CST model of an E-band choke flange is shown in Fig. 1(a). The inner wall of the slot is $\lambda_0/4$ away from the broad wall of the waveguide, and the depth of the slot is $\lambda_0/4$ as well, where λ_0 is the guided wavelength at the frequency of interest. In this case, it is the mid-band frequency at 75 GHz. The diameter of the outer wall of the slot is λ_0. Since the slot is shorted at the bottom, it presents high impedance after the $\lambda_0/4$ depth. Another $\lambda_0/4$ across the flange surface produces low impedance at the broad wall of the waveguide.

For the analysis, the air gap between the choke flange and a standard waveguide flange is selected as 4 mils. The linear misalignments in the *H*-plane, *E*-plane and longitudinal directions are indicated as Δx, Δy, and Δz, respectively. Fig. 2 (a) shows the simulation results of a choke flange with various misalignments in the setup. When the offset is (0, 0, 4) mils, i.e., the air gap is increased by 4 mils, the insertion loss is higher. When there is an offset in the *E* or *H* planes, resonances show up and a standing wave is excited at the choke flange, as shown in Figs. 2 (c), (d). The egg-choke contactless flange is proposed for wideband operation and greater robustness against misalignment between flanges [4]. However, it can hardly cover a full waveguide bandwidth.

B. Pin-array Flange with Quarter-Wavelength Transformer

The CST model of an E-band pin-array flange with a quarter-wavelength transformer is shown in Fig. 1(b). The pin dimensions can be scaled from existing designs in [2]. The pin array generates an Artificial Magnetically Conductive (AMC) surface, which forms parallel plates with the standard mating waveguide flange [6]. The parallel plates exhibit a stopband when the plates are separated by less than a quarter-wavelength. The dispersion diagram can be used to decide the air gap and pin dimensions for the design. A quarter-wavelength transformer surrounds the waveguide port, similar to the choke flange. The edge of the transformer is $\lambda_0/4$ away from the broad wall of the waveguide. The open boundary condition at the transformer's outer edge is transformed to a short boundary condition at the waveguide wall.

The pin-array flange with transformer was simulated using an air gap of 4 mils between the flange and a standard waveguide flange. Fig. 3 (a) presents the simulation results with various misalignments in the setup. An offset in the E or H plane will introduce a resonance in the contactless transition. The standing waves excited at the transformer surface are shown in Figs. 3 (b), (c).



(a)

(b) (c)

Fig. 3. (a) Insertion loss for a pin array choke flange with transformer and misalignments of (Δx, Δy, Δz) mils. (b) Maximum E-field at the resonance frequencies when misalignment is (4, 0, 0) mils. (c) Maximum E-field at the resonance frequencies when misalignment is (0, 4, 0) mils.

C. Pin-array Flange without Transformer

The CST model of an E-band pin-array flange without transformer [5] is shown in Fig. 1 (c). The pins are distributed around the waveguide port, which provides a wide stopband at the edge of the waveguide. The air gap between the pin-array flange and standard waveguide flange is 4 mils. Fig. 4 presents the simulation results of the pin-array flange with various misalignments in the setup. It is observed that no resonance is introduced, and no obvious deterioration occurs, when there are linear misalignments in the *E* or *H* planes. The pin-array flange without transformer demonstrates robust performance in the presence of linear misalignments for the full waveguide bandwidth. The pin-array flange without transformer has been used in many other mmW and THz components [7-9].

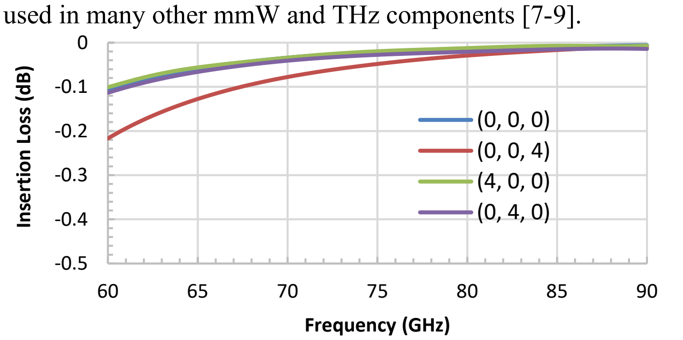
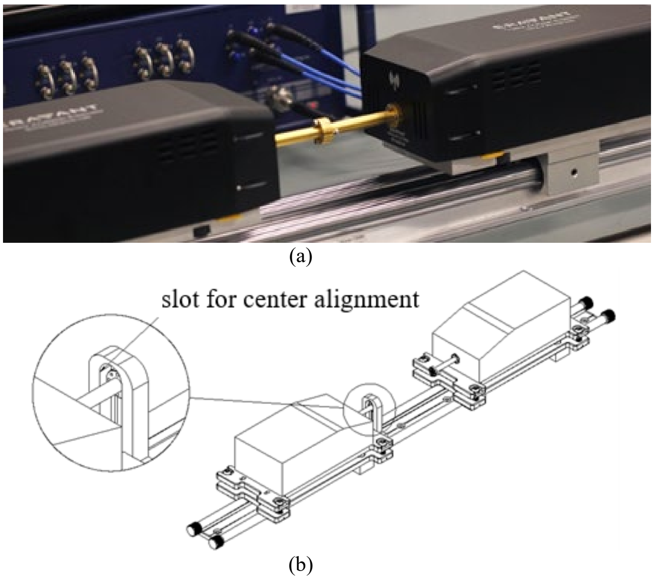


Fig. 4. Insertion loss for a pin-array flange without transformer

III. Rail Position System

To minimize the alignment efforts of utilizing mmW frequency extenders with a VNA setup, a rail positioning system was developed to streamline component testing, as shown in Fig. 5 (a). It provides a fast and reliable system for connecting DUTs with waveguide frequency extenders that are mounted on sliding rail platforms. Contactless waveguide flanges are especially effective when used with the rail positioning system. To ease the alignment process and accommodate variations in the extender geometries, a combination of pitch, yaw and roll adjustment is necessary. To aid this requirement, an adjustment mechanism has been developed which consists of two plates separated by screw-guided springs. The screws are easily accessible and can be tightened or loosened causing the springs to contract or extend, thus providing the adjustment required along the *x*, *y* or *z* axis. An additional fixture is provided to aid the alignment of the mating waveguide flanges, as well as to have the flanges parallel and centered with respect to the rails, as shown in Fig. 5 (b). The sliding plates have mounting holes that are compatible with several common VNA extender modules.

Once a good alignment is achieved, the calibration process is swift and repeatable. Measured return loss for a through-line standard is a good indicator of calibration quality. For a mmW VNA test system spanning 60 to 90 GHz, through-line return loss is typically better than -55 dB when pin-array contactless flanges are used as shown in Fig. 6. Repeated calibrations show similarly low levels of through-line return loss, indicating that reliable calibrations are achieved without engaging waveguide screws. When a bandpass filter was measured three times with complete removal and reinsertion, the test results were unchanged as shown in Fig. 7. This measurement consistency makes it possible to test large numbers of waveguide components quickly and accurately, with each measurement taking a few seconds to complete.



(a)
(b)

Fig. 5. (a) Rail position system for streamlined component testing. (b) fixture used for contactless flange alignment.

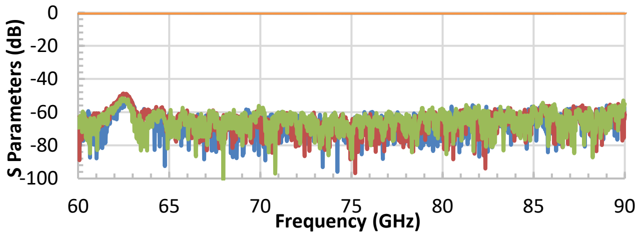


Fig. 6. Return loss and insertion loss for a calibration standard. The two-port calibration was repeated three times.

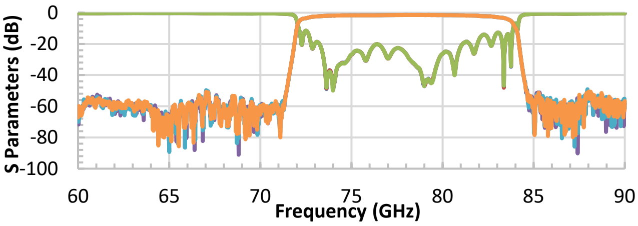


Fig. 7. Return loss and insertion loss for a bandpass filter. The measurement was repeated three times with complete removal of the DUT between tests.

IV. Conclusion

In this paper, 3 types of contactless flanges are simulated and compared with misalignment in the setup. The pin-array contactless flange without transformer was shown to be the most robust design. The flange was adapted for a VNA test system with mmW frequency extenders to demonstrate reliable and repeatable calibration and testing processes. To enhance the measurement system and control misalignment between flanges further, a rail positioning system is designed and implemented. The adjustment mechanism of the rail system provides an easy alignment process to accommodate the dimensional tolerance of the VNA frequency extenders. The performance and efficiency of the contactless-flange and rail test system has been validated with multiple calibrations and component tests at frequencies up to 220 GHz.

References

[1] 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.

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

[3] 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.

[4] B. Pyne *et al.*, "Robust contactless noncircular choke flange for wideband waveguide applications," *IEEE Trans. Microw. Theory Techn.*, vol. 67, no. 3, pp. 861–867, March 2019.

[5] C. Mayaka *et al.*, "Robust contactless waveguide flange for fast measurements," *IEEE MTT-S Int. Microw. Symp. Dig.*, June 2021.

[6] Per-Simon Kildal, "Three metamaterial-based gap waveguides between parallel metal plates for mm/submm waves," *3rd Eur. Conf. Antennas Propag* (*EUCAP*), March 2009.

[7] D. Sun *et al.*, "Flexible rectangular waveguide based on cylindrical contactless flange," *Electron. Lett.*, vol. 52, no. 25, pp. 2042–2044, Dec. 2016.

[8] D. Sun, and J. Xu, "Real time rotatable waveguide twist using contactless stacked air-gapped waveguides," *IEEE Microw. Wirel. Compon. Lett.*, vol. 27, no. 3, pp. 215–217, Feb. 2017.

[9] J. Tayebpour *et al.*, "A waveguide switch based on contactless gap waveguide technology," *IEEE Microw. Wirel. Compon. Lett.*, vol. 29, no. 12, pp. 771–774, Dec. 2019.