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The Ring-Centered Waveguide Flange for Submillimeter Wavelengths

A. R. Kerr and S. Srikanth

***Abstract* – The standard UG-387 waveguide flange (MIL-DTL-3922/67C) is not well suited for frequency bands above ~110 GHz. The proposed ring-centered flange has a precisely machined boss centered on the waveguide aperture and is aligned by a ring which centers the bosses of two mating flanges. The flange is compatible with the UG-387 type, allowing components with the new flange to be connected directly to older components without adapters. Like the UG-387 standard, it is sexless and the contact surfaces are not recessed, which facilitates cleaning and lapping to repair damage. The maximum misalignment between waveguides using the new flange should be < 0.001" (25 µm), corresponding to a worst-case return loss of 26 dB in the WR-1.9 band (400-600 GHz), or 16 dB in the WR-1.0 band (750-1100 GHz). A miniature version of the ring-centered flange is also proposed.**

***Index Terms* — Waveguide flanges, waveguide interfaces, waveguides, millimeter-wave, submillimeter-wave.**

I. Introduction

The MIL-DTL-3922/67C waveguide flange, commonly called "UG-387" or "750-round", shown in Fig. 1(a) is not well suited for frequency bands above ~110 GHz. The tolerances allow a misalignment between waveguides as large as 0.006", which can result in a return loss as low as 24 dB [1] at the upper end of the WR-10 band (75-110 GHz). Modified versions of the UG-387 flange, with tighter tolerances and smaller clearance between pins and pin holes, are in use for bands as high as WR-3 and beyond [2][3], but the practical limit of waveguide alignment using non-interfering pins appears to be about 0.0028" [3], which results in a return loss as low as 37 dB in WR-10 but only 19 dB in the WR-3 band (220-330 GHz) and 2 dB at the upper end of the WR-1.0 band (750-1100 GHz). This degree of misalignment is clearly unacceptable for many submillimeter applications.

A flange described by Lau and Denning [4] improved the alignment between waveguides by using a male flange with a boss and a mating female flange with a close fitting receptacle – Fig. 1(b).

Like the Lau-Denning design, the proposed ring-centered flange has a precisely machined boss centered on the waveguide aperture, but alignment is achieved by a ring which centers the bosses of two mating flanges – Fig. 1(c).

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2. Relative Merits

The alignment accuracy of the older UG-387 flange is determined by: (i) the clearance between the pins and the pin holes, (ii) the position of the pins and holes relative to the waveguide apertures, and (iii) the perpendicularity of the pins relative to the flange faces.

The Lau-Denning design does not rely on pins for alignment but on a boss and receptacle whose diameters need differ only by an amount sufficient to prevent jamming. The waveguide alignment accuracy depends largely on the precision with which the boss and receptacle can be centered on their waveguide apertures. The design has three shortcomings, however: it is not backward compatible with the UG-387 design, it is not sexless, and the contact surfaces are not accessible for lapping.

The ring-centered flange is compatible with the UG-387 type, allowing components with the new flange to be connected directly to older components without adapters. Like the UG-387 standard, it is sexless, and the contact surfaces are not recessed, which facilitates cleaning and lapping to repair damage. It also has an anti-cocking rim [5] which has been incorporated into many of the newer implementations of the UG-387 design. The maximum misalignment between waveguides using the new

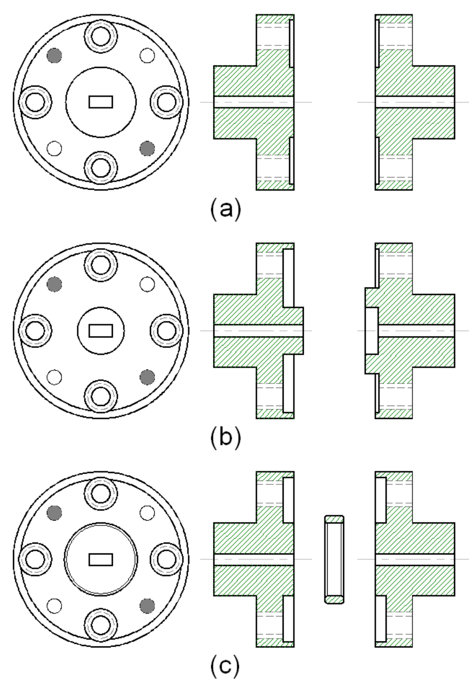

Fig. 1. (a) The standard MIL-DTL-3922/67C (or UG-387 or 750-round) flange. (b) The Lau-Denning flange. (c) The proposed ring-centered flange. Pins are omitted from the cross-sections for clarity.

flange should be <0.001" (25 μm), corresponding to a worst-case return loss of 26 dB in the WR-1.9 band (400-600 GHz), or 16 dB in the WR-1.0 band (750-1100 GHz).

2. Construction

The two most critical aspects of the ring-centered flange are: (i) the clearance between the coupling ring and the boss; and (ii) the alignment of the boss with the waveguide aperture. The coupling ring can be made from commercially available precision stainless steel shim bushing stock [6] which is available with outside diameter 0.3750" and inside diameter 0.3125" +0.0002/−0.0000. If the diameter of the boss is machined to 0.3125" +0.0000/−0.0002, the maximum misalignment of a pair of waveguides resulting from the tolerances of the ring and boss diameters is 0.0004" (10 μm).

The boss is machined on a CNC milling machine which has been centered on the waveguide aperture using an optical centering microscope fitted with a small video camera as shown in Fig. 2. The centering microscope is mounted in the spindle of the CNC milling machine and the flange positioned so the bottom right corner of the waveguide is centered in the cross-hairs. The machine coordinates (X_1, Y_1) are read. The centering microscope is then rotated 180° and the flange positioned so the top left corner of the waveguide is centered in the cross-hairs. The machine coordinates (X_2, Y_2) are read. The true center of the waveguide is (X_0, Y_0), where $X_0 = (X_1 + X_2)/2$ and $Y_0 = (Y_1 + Y_2)/2$. Rotating the centering microscope 180° between measurements eliminates any run-out in the spindle or offset in the microscope optics from the deduced center position (X_0, Y_0). The boss is machined, slightly over size initially, centered at (X_0, Y_0), and then reduced in diameter in small steps while a standard coupling ring is used as a gauge to determine the final diameter.

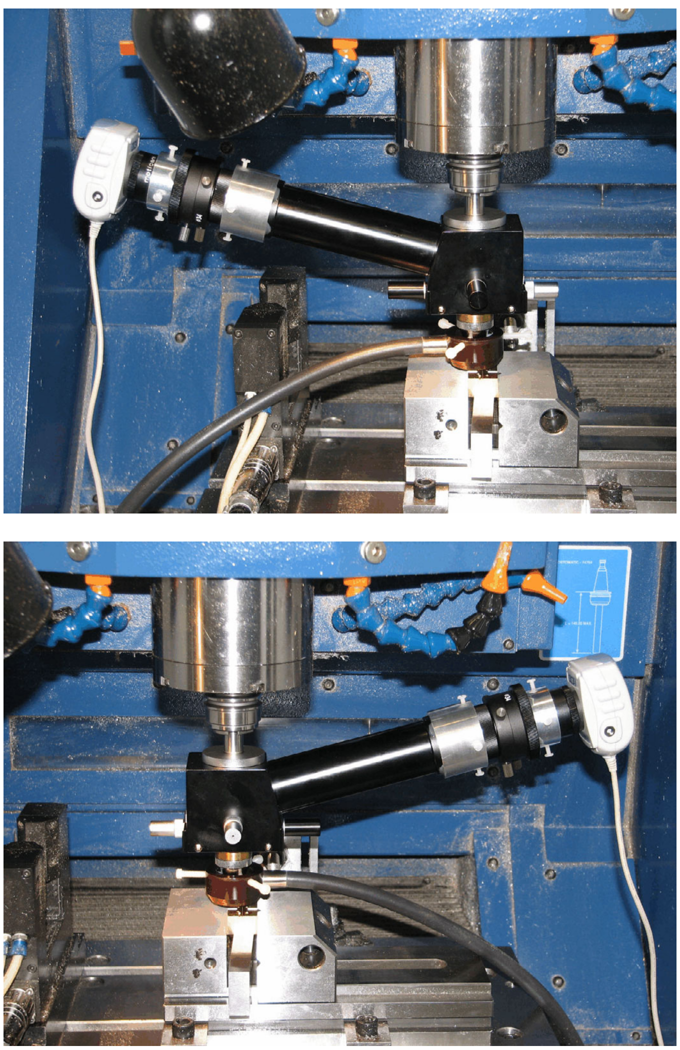

Fig. 2. Determining the center of the waveguide aperture using a centering microscope with video camera and ring illuminator. Top: Measuring the coordinates of the upper left corner of the waveguide. Bottom: Measuring the coordinates of the lower right corner of the waveguide.

Pins are required in the ring-centered flange only to prevent angular misalignment of the mating waveguides. To prevent the pins interfering with the centering function of the ring and bosses, oversize pin holes should be used. Holes of diameter 0.0670" with 0.0615"pins, as for the original MIL specification, would allow a maximum angular misalignment of 0.6° which has negligible effect (see next section).

3. Effects of Misalignment

The effects of lateral and rotational misalignment of waveguide flanges have been described in [1] where it was found that for rectangular waveguides of the usual 2:1 aspect ratio

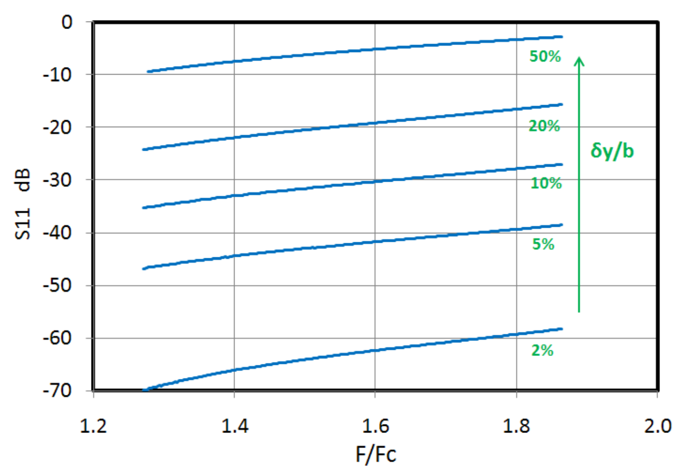

Fig. 3. Effect of a misalignment δy in the *b* direction as a function of frequency (simulated [7]).

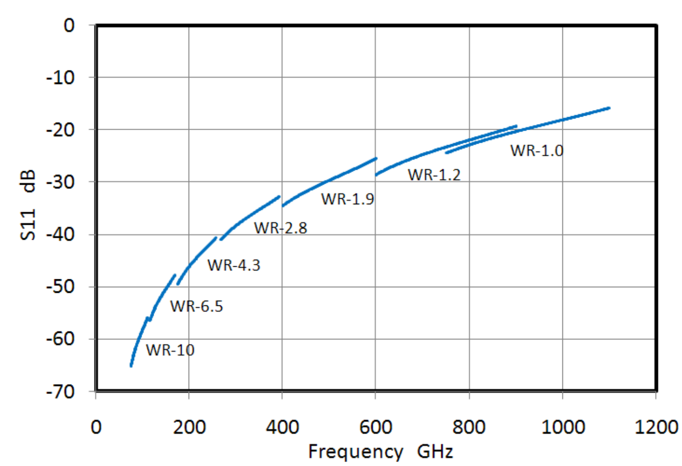

Fig. 4. Reflection at a waveguide joint with a 0.001" (25 μm) misalignment in the *b* direction, for several waveguide bands (simulated [7]).

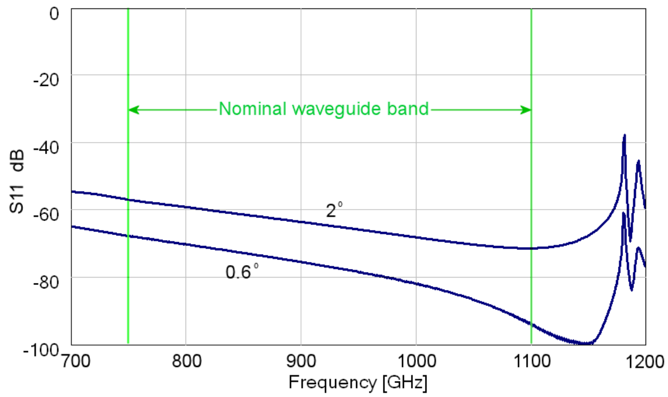

Fig. 5. The effect of angular misalignments of 0.6° and 2° at a waveguide joint. The results are independent of waveguide band (simulated [7]).

misalignment in the direction of the smaller dimension *b* is more serious than misalignment in the *a* direction or a diagonal misalignment. Fig. 3 shows the simulated [7] effect of a misalignment δy in the *b* direction as a function of frequency (normalized to the cutoff frequency). The expected maximum waveguide misalignment for a pair of ring-centered flanges is 0.001" (25 μm), and Fig. 4 shows the effect of such a misalignment in the *b*-direction in several waveguide bands.

The effect of a rotational misalignment at a pair of ring-centered flanges is independent of waveguide band and is shown in Fig. 5 for waveguides with a 0.6° rotation corresponding to the pin clearance in 0.067" holes, and a 2° rotation which would be clearly visible. Even with a 2° rotation the return loss is >56 dB across the band.

4. A Miniature ring-centered flange

In some applications a flange smaller than the UG-387 type is desirable. The Grammer miniature flange [3] was developed at NRAO for use in the ALMA project. With an outer diameter of 0.500", it is sexless and has no screw or pin holes in the E-plane, a desirable characteristic for split-block waveguide components. A ring-centered version of the Grammer miniature flange is shown in Fig. 6. The coupling ring is made from commercial precision stainless steel shim bushing stock [6] with ID 0.4375" +0.0002/−0.0000 and 0.500" OD. As for the larger ring-centered flange, alignment between the waveguide apertures depends on the clearance between the ring and bosses and the alignment of the bosses with the waveguide apertures. A total misalignment < 0.001" (25 μm) should be possible.

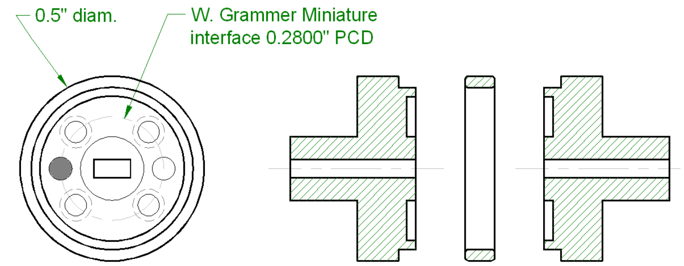

Fig. 6. The miniature ring-coupled flange based on the Grammer miniature flange. Pins omitted for clarity.

5. Conclusion

The proposed ring-centered flange offers a higher degree of precision than the older UG-387 type. Compared with the Lau-Denning design, the ring-coupled flange is inherently somewhat less precise because it has three mating parts as opposed to two in the Lau-Denning design.

We plan to make measurements of the reproducibility of waveguide joints using ring-centered flanges in the near future.

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[5] See, *e.g.*, http://www.flann.com/Sales/FMI_Catalogue.pdf, p. 119.

[6] McMaster-Carr: http://www.mcmaster.com/#shaft-shim-bushings/=1ch1xv

[7] QuickWave-3D, QWED Sp. z o.o., 02-010 Warsaw, Poland. http://www.qwed.com.pl/qw_3d.html