Recommendations for Waveguide Interfaces to 1 THz

J.L. Hesler, A.R. Kerr, W. Grammer, and E. Wollack

***Abstract* — The existing waveguide interface standards are generally found to be unsatisfactory above 110 GHz. An improved interface is proposed which is backward-compatible with the MIL-DTL-3922/67C standard and most of its higher-frequency variants. As there are currently no standard waveguide bands above 325 GHz, an extended set of bands is recommended for operation to 1100 GHz.**

***Index Terms* — Waveguides, millimeter-wave waveguides, rectangular waveguides, submillimeter-wave waveguides, standards.**

I. INTRODUCTION

The existing waveguide interface standards above 110 GHz, from WR-8 (90-140 GHz) to WR-3 (220-325 GHz), have long been known to have significant limitations. Over the years, efforts to modify and improve the standards have been made at companies such as Aerowave, Agilent (HP), Custom Microwave, Flann, Maury Microwave, Millitech, and Oleson Microwave Laboratories, as well as at various research institutions [1-3]. These efforts lead to the creation of competing and often incompatible interface standards. Furthermore, for frequencies above 325 GHz there are no universally supported waveguide standards at present, although at least one new set has been suggested [4].

In the 1960s and early 1970s, the industry wrestled with standardization issues remarkably similar to those under discussion today. As organizations developed interfaces to meet their own needs, multiple flange variants were developed complicating progress toward a universal standard [5]. This anarchy persisted until the 1975 release of MIL-F-3922/67B, which specified round millimeter-wave flanges for use through 110 GHz. Most notable in that specification was the explicit definition of the alignment pins and pin-holes. Several studies have shown that the flange works as designed through 110 GHz [1]. Used with WR-15 and smaller waveguides, the 0.750" diameter flange is commonly called the "750-round" flange (round flanges are still often referred to by their outdated 1950s AN nomenclature: UG-383, UG-385, UG-387). The current version of the Military Specification is MIL-DTL-3922/67C. Above 110 GHz, the so-called *mini-flange*, MIL-F-3922/74, was specified to operate up to 325 GHz (WR-3), but with experience it was found to have poor repeatability, as well as being difficult to machine. The community became dissatisfied with the mini-flange, preferring instead variations of the 750-round flange with tightened tolerances. Different groups developed different variants of this standard, with a resulting loss of cross-compatibility. For these reasons, it is important to establish a new standard which allows the development of compatible components for the THz community.

This paper presents recommendations for a standard waveguide interface and also a set of frequency bands for use from 110 to 1100 GHz. These recommendations are based in large part on work carried out for the multi-national ALMA project [6]. The interface has been successfully implemented for substantial numbers of both passive and active waveguide components at frequencies ranging from 31- 950 GHz. A number of factors in the choice of a waveguide interface are discussed, including tolerances, interface size and pattern, backward compatibility, English vs. metric units, and the use of anti-cocking flanges. For frequencies above 325 GHz, we propose defining waveguide bands in a manner consistent with the existing set of overlapping waveguide bands specified in MIL-DTL-85/3C.

II. GOALS OF A WAVEGUIDE INTERFACE STANDARD

The main reason for developing a waveguide interface standard is to ensure compatibility of components from different groups. The following features and goals are desirable:

1) Repeatable operation to ~1 THz with low reflection.
2) Backward compatiblility with existing interfaces and waveguides below 325 GHz.
3) Ease of machining.
4) Applicability to extruded waveguide and to electroformed and machined blocks.
5) Asexual, to avoid the need for male and female flanges.
6) Anticocking, but should not require surface relief on machined blocks.

Backward Compatibility

Over the past 30+ years, a large amount of waveguide hardware has been developed for 75-325 GHz using either the 750-round flange or the mini-flange. In that time, laboratories have accumulated many components while manufacturers have made a substantial investment in tooling (fixtures, mandrels, jigs, *etc*.) to produce these parts, and in inventory. Because of this broad infrastructure, backward compatibility is an important practical consideration when developing a new interface standard. While backward compatibility may not be possible with all variations of the old interface, it should not

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be ruled out; rather, the cost benefits of backward compatibility (not having to replace existing equipment) must be weighed against the potential performance advantages of a new but incompatible interface. The waveguide and interface standards proposed here are compatible with most existing hardware, and as such offer an appropriate path forward.

One important aspect of backward compatibility is the use of metric as opposed to English units. From a scientific viewpoint it would be desirable to have a metric interface standard, but backward compatibility precludes this. For this reason, the interface and waveguide sizes proposed here are based on English units.

III. Waveguide Interface Recommendation

A diagram of the proposed waveguide interface is shown in Fig. 1. This interface is an extension of MIL-DTL-3922/67C interface with tightened tolerances and anti-cocking characteristics. A number of factors must be considered.

Interface Tolerancing

The tolerancing of the interface, particularly the alignment pins and pin-holes, is crucial to accurate mating of two waveguides, and thus to minimizing the reflection at the interface. However, there is a tradeoff between interface alignment, machinability, mating force, and binding at the interface. The common use of drilling jigs for manufacturing waveguide interfaces sets limits to the achievable angular alignment of the pins, and so interfaces made using drilling jigs are likely to be limited to use below 325 GHz. By using CNC machines to fabricate the interface as an integral part of a waveguide component it is possible to maintain tighter tolerances, thus minimizing reflections at higher frequenices. In order to provide the greatest flexibility, a multi-tiered tolerancing scheme is proposed, as specified in the *Tiered Tolerancing Table* in Fig. 1. The tightest tolerances, labeled *Submm*, represent the strictest tolerance specification that can reasonably be achieved using a standard high-precision CNC milling machine.

By using the waveguide interface misalignment simulations described in [1], we can link the tolerances given in Fig. 1 to a worst-case reflection due to interface misalignment. Table 1 shows the calculated return loss for the three tolerancing schemes. As can be seen in the table, even the tightest tolerance yields only marginal worst case performance at 825 GHz (7 dB return loss). This is an indication of the practical limit of a machined interface: to achieve a satisfactory return loss near 1 THz is extremely difficult. To date, above ~1 THz, nearly all devices have avoided waveguide interfaces by using integral feedhorns to couple power into or out of the component.

Alignment Pins

No changes are proposed to the pin originally specified in the MIL-F-3922/67B interface. The waist shown in the drawing was found to improve the grip of the dowel when it is pressed inplace, and so it should be retained.

One additional consideration related to the pin is its height above the plane of the interface. In general, the pin height should be minimized to reduce binding and to ease the angular tolerance. However, the pin must also be tall enough to keep the interface in place while the screws are being engaged. As a compromise, a pin height of 0.156" above the interface face is recommended, as in MIL-DTL-3922/67C.

Annular Recess and Relief Around Pin Holes

The annular recess is used to minimize the contact area of the interface and thus to ensure greater pressure in the vicinity of the waveguide aperture while preserving the anti-cocking nature of a flat flange without a central boss. At sub-millimeter wavelengths, a gap of only a few microns between flange faces can introduce significant loss and reflection, and the annular recess also helps to avoid gaps caused by bumps

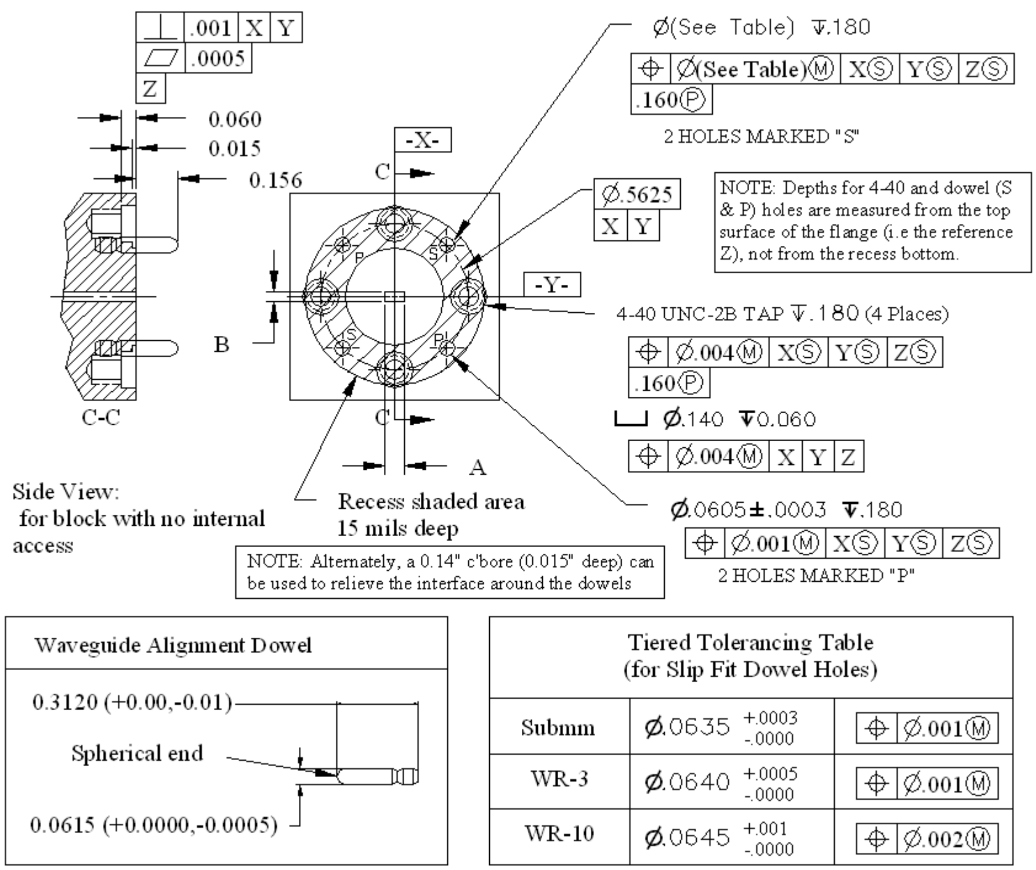

Figure 1. Drawing of the recommended waveguide interface from WR-10 to WR-1.0.

on the mating surfaces from metal displaced when the alignment pins are pressed in place (after inserting the pins, the flange surface can not be lapped). The proposed 0.015" deep annular recess provides the necessary relief.

Because of the complexity of machining the annular recess, the simpler alternative of a 0.14" counterbore (0.015" deep) around the pin holes may be preferred, and this is included in the interface drawing as an option.

A Miniature Interface

At millimeter and submillimeter wavelengths, the geometry of the 750-round interface can force a component to be larger than required electrically. For this reason, it is desirable to have an alternative miniature interface, preferably one which fits within the proposed interface so that parts with miniature interfaces can be tested using components with the larger standard interface. Such a miniature interface, shown in Fig. 2, has been developed at NRAO for use in the ALMA project. Similar in size to the mini-flange, it is asexual, and has no screw or pin holes in the E-plane, a desirable characteristic for split-block waveguide components.

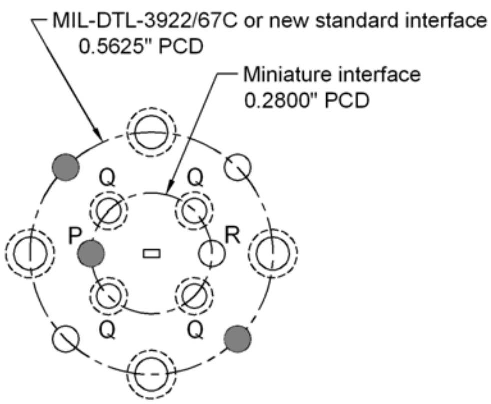

Figure 2: The Grammer miniature interface fits within the larger MIL-DTL-3922/67C pattern. Each side of the interface contains one captive pin (P) and a clearance hole (R) for the mating pin. The bolt holes (Q) can be either #2-56 or M2. Tolerancing for the miniature interface should follow that of the proposed larger interface.

TABLE 1: PIN AND PIN-HOLE DIMENSIONS AND TOLERANCES

	Submm (in.)	WR3 Tol (in.)	WR10 Tol (in.)
Min. Pin Diameter	0.061	0.061	0.061
Max. Pin Diameter	0.0615	0.0615	0.0615
Min. Hole Diameter	0.0635	0.064	0.0645
Max. Hole Diameter	0.0638	0.0645	0.0655
Pin Tolerance Range (PLTZF)	0.001	0.001	0.001
Hole Tolerance Range (PLTZF)	0.001	0.001	0.002
Pin Tolerance Range (FRTZF)	0.001	0.001	0.001
Hole Tolerance Range (FRTZF)	0.001	0.001	0.002
Maximum Total Offset	0.0024	0.0028	0.0038
Fit Tolerance	0	0.0005	0
	Frequency of Min Return Loss Due to Misalignment (GHz)		
	Submm	WR3 Tol	WR10 Tol
Minimum RL (23 dB) at	275	240	176
Minimum RL (7 dB) at	825	720	528

IV. WAVEGUIDE BANDS

The current standard series of waveguide bands starts in the microwave region at 320 MHz (WR-2300), and extends in two overlapping series to 325 GHz (WR-3), as specified in MIL-DTL-85/3C. If the number following the dash in the WR-## nomenclature is divided by 100, the result is the waveguide broad-wall width in inches (certain band designations, particularly the higher frequency ones, have been rounded for convenience). In order to cover many decades of frequency, the lower frequency series is extended by decades. So, for example, there are waveguide bands at 2.2-3.3 GHz (WR-340), 22-33 GHz (WR-34), and 220-325 GHz (WR-3), with broadwall widths of 3.4", 0.34", and 0.034". This progression can be continued upwards, as shown in Table 2 starting at WR-10 and extending to 1100 GHz. In order to avoid confusion caused by rounding of the band numbers, we have added an extra significant digit, and thus WR-3 becomes WR-3.4 in this nomenclature.

TABLE 2: CURRENT AND PROPOSED WAVEGUIDE BANDS

Proposed Band Designation	EIA Band Designation	Internal Dimensions (mils)	Internal Dimensions (mm)	Frequency Range (GHz)	TE(10) Cutoff (GHz)
WR- 10	WR- 10	100 x 50	2.540 x 1.270	75.0 - 110.0	59.0
WR- 8	WR- 8	80 x 40	2.032 x 1.016	90.0 - 140.0	73.8
WR- 6.5	WR- 6	65 x 32.5	1.651 x 0.826	110.0 - 170.0	90.8
WR- 5.1	WR- 5	51 x 25.5	1.295 x 0.648	140.0 - 220.0	116
WR- 4.3	WR- 4	43 x 21.5	1.092 x 0.546	170.0 - 265.0	137
WR- 3.4	WR- 3	34 x 17	0.864 x 0.432	220.0 - 330.0	174
WR- 2.8	n/a	28 x 14	0.711 x 0.356	265.0 - 400.0	211
WR- 2.2	n/a	22 x 11	0.559 x 0.279	330.0 - 500.0	268
WR- 1.9	n/a	19 x 9.5	0.483 x 0.241	400.0 - 600.0	311
WR- 1.5	n/a	15 x 7.5	0.381 x 0.191	500.0 - 750.0	393
WR- 1.2	n/a	12 x 6	0.305 x 0.152	600.0 - 900.0	492
WR- 1.0	n/a	10 x 5	0.254 x 0.127	750.0 - 1100.0	590

In certain circumstances it is necessary to use a waveguide band which overlaps standard bands. In practice, the choice of a non-standard band may be dictated by a scientific application (e.g., an atmospheric window or a group of molecular lines) or by a particular component (e.g., a frequency multiplier whose output range does not fit within a standard band). In such cases, the proposed WR-## nomenclature is easily modified by the user with results which are immediately clear to other engineers.

V. Discussion and Future Development

The proposed waveguide interface and set of waveguide bands cover 110 GHz to 1.1 THz. They are compatible with existing standards while offering greater precision and repeatability. For more than five years they have been used successfully for hundreds of components made for the multi-national ALMA project. However, the relatively poor return loss at the highest frequencies leaves much to be desired. It has been suggested [7] that alignment tolerances could be tightened significantly by using shorter alignment pins. By reducing the protrusion of the pin above the plane of the interface from 0.156" to 0.070", a pin hole diameter of 0.0625" could be used with a pin tolerance range of 0.0005". This would improve the worst-case return loss below 1.1 THz to 10 dB.

The effect of the specified interface flatness on loss and return loss is not well understood. Non-flat flange pairs could be investigated, either experimentally or by electromagnetic simulation, to determine the necessary flatness tolerance.

VI. Acknowledgment

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