

# A Review of the IEEE 1785 Standards for Rectangular Waveguides above 110 GHz

N M Ridler\* and R A Ginley<sup>†1</sup>

\*NPL, Teddington, UK; <sup>†</sup>NIST, Boulder, CO, USA

**Abstract**—A new series of standards has recently been published by IEEE defining waveguide for use at millimeter-wave and terahertz frequencies. The series comprises three standards covering different aspects of this technology: (i) frequency bands and waveguide dimensions; (ii) waveguide interfaces; and (iii) recommendations for performance and uncertainty specifications. This paper describes each of these standards.

**Index terms** — IEEE 1785, millimeter-wave, rectangular waveguides, submillimeter-wave, terahertz, waveguide apertures, waveguide interfaces, waveguide tolerances.

## I. INTRODUCTION

Until recently, no international document standards existed for defining sizes and interfaces for rectangular metallic waveguides used at submillimeter-wave frequencies (i.e. at frequencies above 325 GHz). Some proposals for sizes and interfaces had been published (e.g. [1-5]) but these had not been adopted by any of the international standards-making bodies (e.g. ISO, IEC, IEEE). This situation was recognized in 2007 by the IEEE Standards Association, and this led to a project being initiated to put in place IEEE standards for both waveguide sizes (i.e. the aperture dimensions) and their associated interfaces (i.e. flanges) suitable for use at all frequencies above 110 GHz. Although some standards already existed for waveguides in the 110 GHz to 325 GHz range (see, for example, [6, 7]), it was decided that these waveguides should be included in the new IEEE standards to allow their tolerances to be re-evaluated in the context of contemporary manufacturing capabilities.

The development of the new standards was sponsored by the Standards Committee of the IEEE's Microwave Theory and Techniques Society (MTT-S). A working group was set up (and assigned the project number P1785) to write the standards. This working group held its first meeting during the IEEE MTT-S International Microwave Symposium in Atlanta, GA, USA, in June 2008. The working group then met regularly (approximately every six months) in order to develop the necessary standards.

It was decided to publish the standard in three parts: Part 1 – frequency bands and waveguide dimensions [8]; Part 2 – waveguide interfaces [9]; Part 3 – recommendations for performance and uncertainty specifications [10]. Part 1 was published in 2013, and Parts 2 and 3 were published in 2016. This paper gives an overview of all three parts.

## II. IEEE STD 1785.1-2012

Part 1 of the IEEE 1785 series of standards [8] gives specifications for the waveguide (including aperture dimensions, frequency range, cut-off frequency, etc). The standard considers the tolerances of the waveguide aperture dimensions and the impact these have on the electrical properties (in terms of return loss, transmission loss, etc) of the waveguide. The standard lists a series of waveguide sizes for use at frequencies up to 3.3 THz – see Table 1. The shaded region of Table 1 corresponds to sizes that have already been defined in previous standards [6, 7]. Table 1 also shows the naming convention that has been introduced by this standard. Since the waveguide sizes given in the standard are defined in terms of metric units, the letters WM are used to indicate that the size refers to Waveguide using Metric dimensions. The numbers that follow these letters correspond to the broad wall dimension of the waveguide specified in micrometers ( $\mu\text{m}$ ). For example, WM-250 refers to waveguide with a broad wall dimension of 250  $\mu\text{m}$ .

The standard gives a procedure for extending the series of waveguide sizes to produce waveguides for use at frequencies above 3.3 THz. The standard also defines different grades of waveguide based on the tolerance for the height and width of the waveguide aperture. Grades are established based on the tolerances being less than a certain percentage of the aperture broad wall dimension. For example, if the dimensional tolerances are less than  $\pm 0.2\%$  of the broad wall dimension, then this waveguide is graded as 0.2. The worst-case reflection coefficient for several grades of waveguide are also given in the standard, along with a table showing the dimensional tolerances needed to achieve selected waveguide grades (and hence worst-case reflection coefficients).

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<sup>1</sup> N M Ridler and R A Ginley are the Chair and Vice Chair, respectively, of the IEEE P1785 Working Group that developed the IEEE 1785 series of standards.

Part 1 also contains two annexes. Annex A gives plots of reflection coefficient caused by tolerances in the waveguide aperture height, width and corner radii. Annex B gives calculated values of attenuation constant (in dB/cm) due to loss in the waveguide conductor, assuming the classical skin effect and the waveguide walls are perfectly smooth.

TABLE I  
FREQUENCY BANDS AND WAVEGUIDE DIMENSIONS [8]

Name	$a$ ( $\mu\text{m}$ )	$b$ ( $\mu\text{m}$ )	$f_c$ (GHz)	$f_{\min}$ (GHz)	$f_{\max}$ (GHz)
WM-2540	2540	1270	59.014	75	110
WM-2032	2032	1016	73.767	90	140
WM-1651	1651	825.5	90.790	110	170
WM-1295	1295	647.5	115.75	140	220
WM-1092	1092	546	137.27	170	260
WM-864	864	432	173.49	220	330
WM-710	710	355	211.12	260	400
WM-570	570	285	262.97	330	500
WM-470	470	235	318.93	400	600
WM-380	380	190	394.46	500	750
WM-310	310	155	483.53	600	900
WM-250	250	125	599.58	750	1100
WM-200	200	100	749.48	900	1400
WM-164	164	82	913.99	1100	1700
WM-130	130	65	1153.0	1400	2200
WM-106	106	53	1414.1	1700	2600
WM-86	86	43	1743.0	2200	3300

### III. IEEE STD 1785.2-2016

Part 2 of the IEEE 1785 series of standards [9] gives specifications for waveguide interfaces (also known as flanges). The standard considers the tolerances of the waveguide interface dimensions and the effect these have on the electrical properties (in terms of reflection coefficient) of the waveguide. The standard defines three waveguide interfaces that are suitable for use with waveguides used at 110 GHz and above. The three interfaces are called IEEE 1785-2a (“Precision Dowel”), IEEE 1785-2b (“Ring-Centered”) and IEEE 1785-2c (“Plug and Jack”). A generic engineering drawing for all three interfaces is shown in Figure 1.

The primary alignment mechanism for the Precision Dowel interface is two dowels (of different diameters) that are inserted into the holes labelled “D” in Figure 1. The Precision Dowel interface is shown in Figure 2.

The primary alignment mechanism for the Ring Centered interface is a centering ring that fits over the central boss section of the interface – see Figure 3.

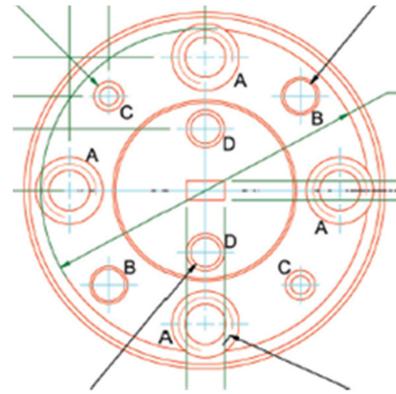


Fig. 1: Waveguide interface containing 4 screw holes (A), 4 alignment holes (B and D) and 2 fixed alignment pins (C)

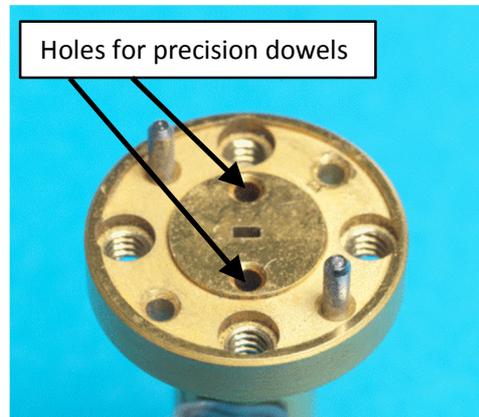


Fig. 2: IEEE 1785-2a “Precision Dowel” interface, showing holes for inserting the precision dowels

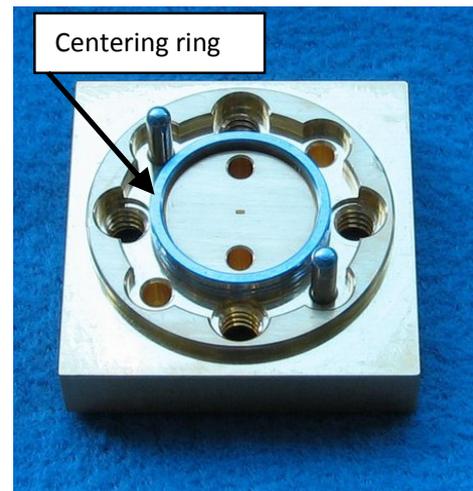


Fig. 3: IEEE 1785-2b “Ring Centered” interface, showing detachable centering ring

The Plug and Jack interface is a male/female design and relies on this feature as the primary alignment mechanism – see Figure 4.

All three interfaces are mechanically compatible with each other, and with the interface commonly known as UG-387 [11] and most of its common variants (e.g. [3, 12, 13]). However, the resulting electrical performance when mated with these UG-387 type interfaces is not as good as when mating the interfaces in the standards with themselves.



Fig. 4: IEEE 1785-2c “Plug and Jack” interface, showing both male and female halves of the interface

Part 2 also contains detailed engineering drawings for all three interfaces, as well as the accessories (alignment dowels and centering ring) used with the interfaces. It also gives values of worst-case reflection coefficient due to the interface dimensional tolerances given in the standard. This allows end-users to predict the performance from a mated pair of interfaces for each waveguide size given in Part 1 of the standard [8]. Part 2 also contains an annex giving plots of reflection coefficient caused by both linear ( $x$ ,  $y$ ) interface misalignment and angular interface misalignment.

#### IV. IEEE STD 1785.3-2016

Part 3 of the IEEE 1785 series of standards [10] gives recommendations for summarizing the performance and the expected uncertainty of the reflection coefficient of the rectangular waveguide apertures and interfaces given in Parts 1 and 2 of the standard [8, 9]. The information provided also facilitates the development of a complete uncertainty analysis for the performance of rectangular waveguide interfaces. For example, it includes the dimensional information necessary for calculating the uncertainty in both reflection and transmission coefficients for interfaces provided by different manufacturers, if both manufacturers follow the guidance give in this standard [10].

The standard lists the dimensional data (with associated uncertainty) that is needed to undertake the uncertainty analysis. These include: the height, width and corner radius of the waveguide aperture; and, the lateral displacement of the

aperture due to linear and angular interface misalignment. Guidance is given on the propagation of uncertainty from the dimensional data to electrical performance data (i.e. reflection coefficient). This guidance is in line with appropriate internationally agreed recommendations [14, 15].

Finally guidance is given on summarizing and reporting the information. This includes example plots (graphs) showing expected electrical performance, an example uncertainty budget, and details of analysis software that adheres to the recommendations given in the standard.

#### V. DISCUSSION

Part 1 of these standards [8] has, for the first time, provided standardized sizes for waveguides used to 1 THz and beyond. This is more than adequate for the current state of the art for test instrumentation operating in this frequency range (e.g. [16]). Information on aperture tolerances given in the standard indicates that a 5  $\mu\text{m}$  tolerance for an aperture used at 1 THz will give rise to a worst-case reflection coefficient of the order of -20 dB.

Part 2 of these standards [9] has introduced three new types of waveguide interface that enable waveguide technology to be used, with acceptable electrical performance, across the whole of the submillimeter-wave band (to 3 THz). For example, worst-case reflection coefficient due to interface dimensional tolerances for these interfaces, when used at 1 THz, is of the order of -20 dB.

Part 3 of these standards [10] has, for the first time, given guidance necessary to estimate the uncertainty due to the combined effects of both waveguide aperture and waveguide interface. For example, for the above situations (a 5  $\mu\text{m}$  aperture tolerance and nominal tolerances for the interfaces given in part 2 of the standard at 1 THz) an overall expanded uncertainty [14] in reflection coefficient is expected to be of the order of -15 dB.

#### VI. CONCLUSION

This paper has reviewed three new IEEE standards [8-10] that have recently been published relating to rectangular metallic waveguides used at millimeter-wave and terahertz frequencies. These standards provide a reference for all organizations using rectangular waveguides at these frequencies. This will enable efficient trade between customers and suppliers, and common design criteria and practices for component, systems, and design engineers, and, all other end-users. It is therefore expected that these standards will have a major impact on science, engineering and technology employing the use of these frequencies, for many years to come.

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