Terahertz Waveguide Standards

John Ward

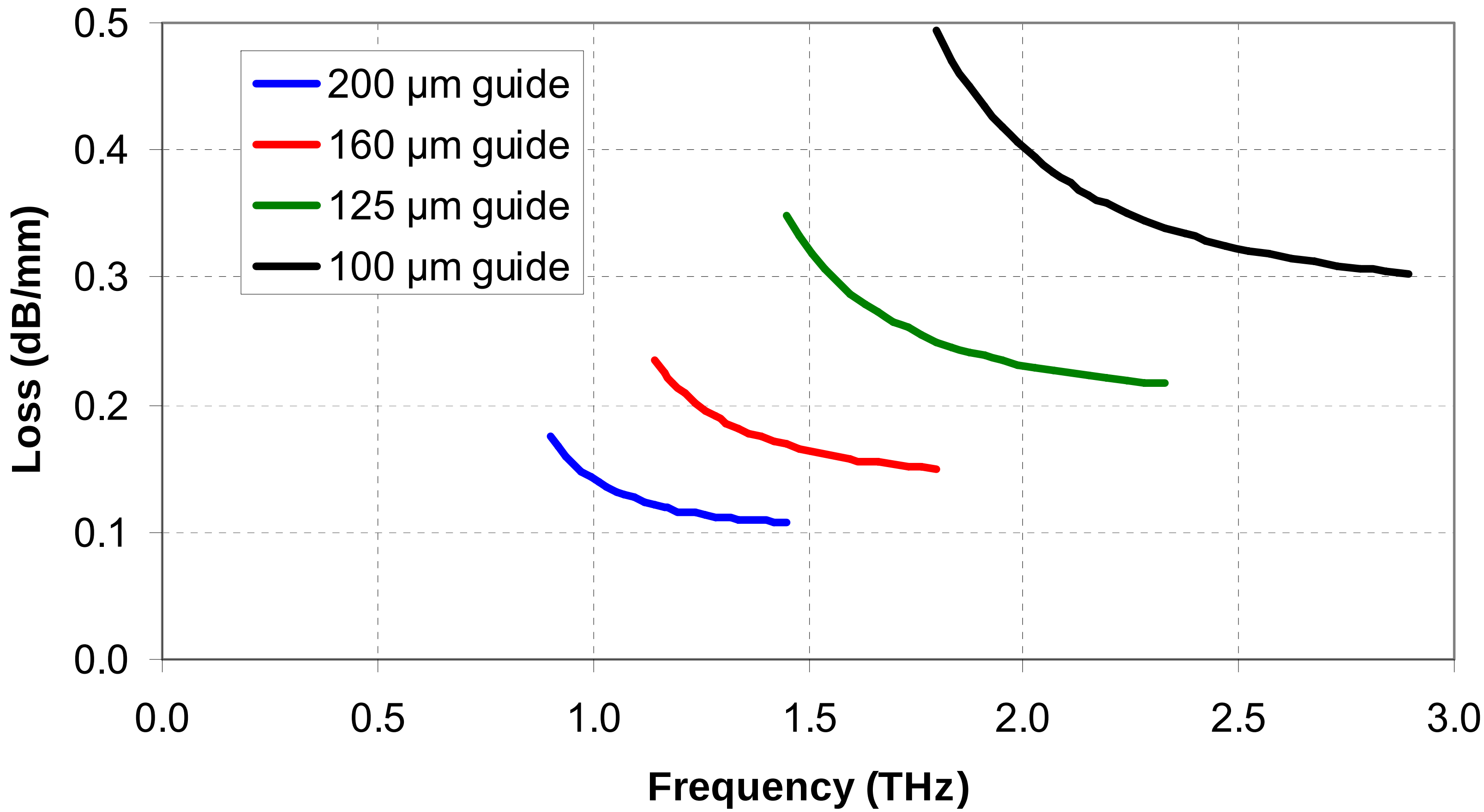
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive Mail Stop 168-314
Pasadena, CA 91109, USA

Outline

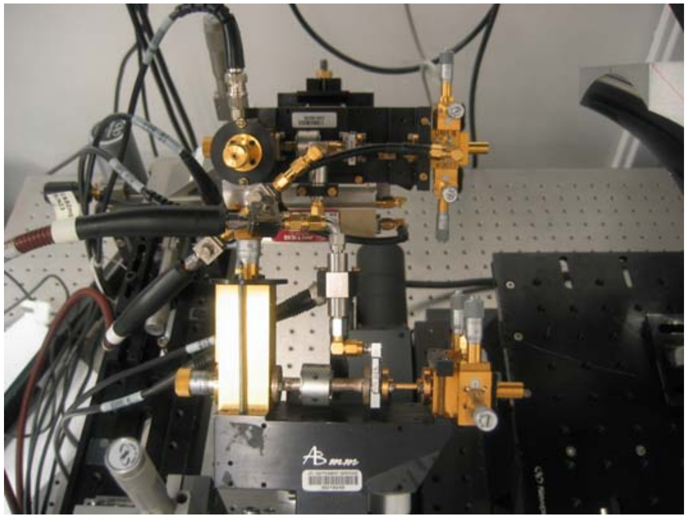
- Why new standards are needed
- Rectangular waveguide sizes
- Waveguide flanges

Interchangeable terahertz waveguide hardware? You must be crazy!

Waveguide Losses



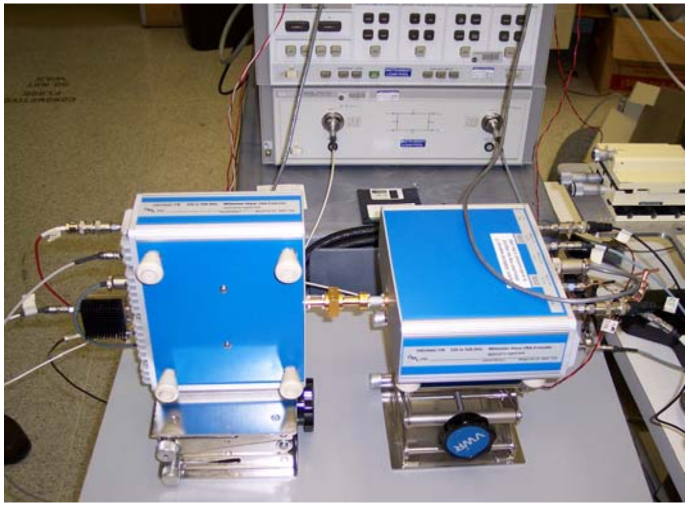
Vector Network Analyzers



AB Millimetre

Paris, France

Up to 1.9 THz



Oleson Microwave Labs

Morgan Hill, CA

Up to 500 GHz

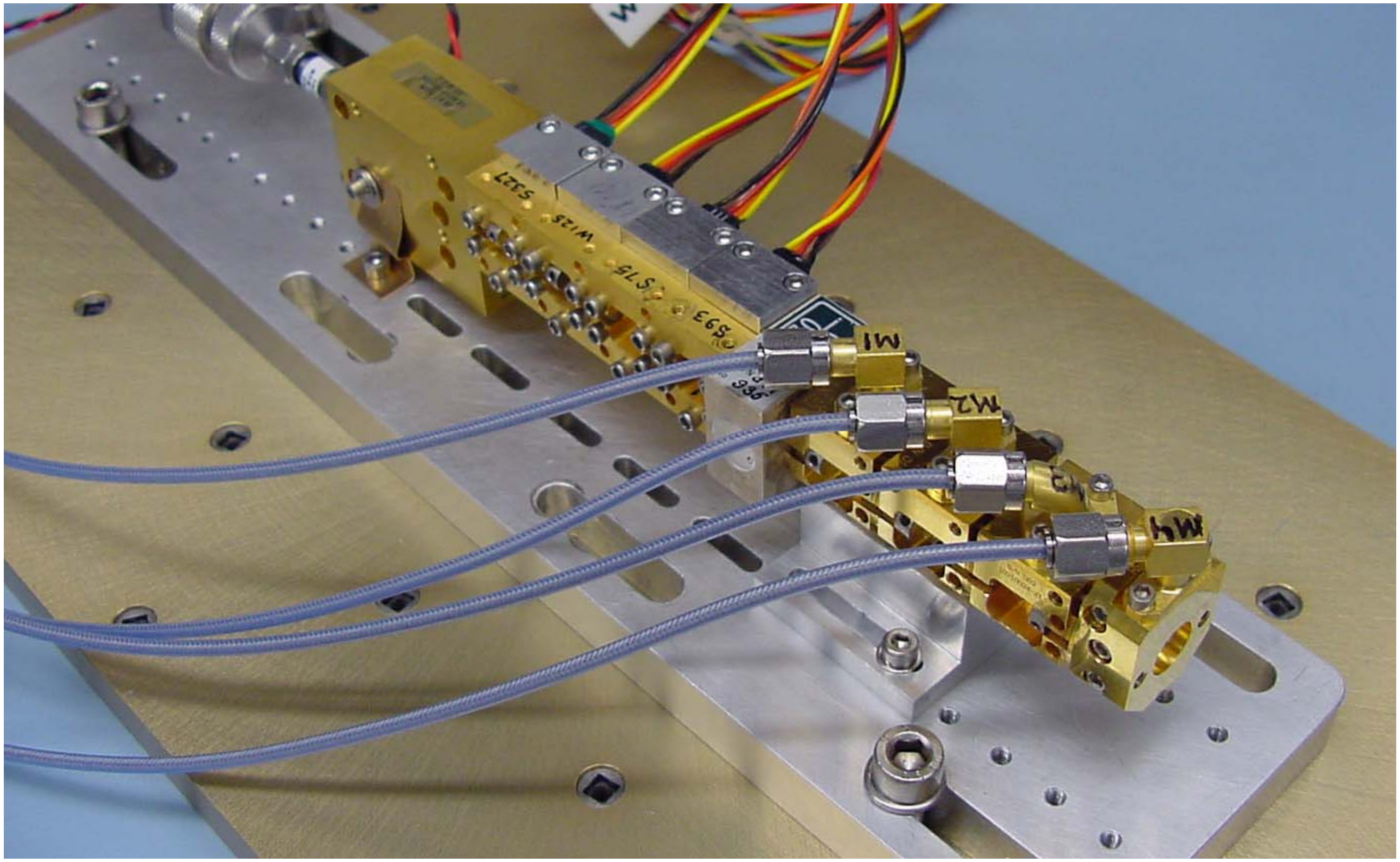
700 GHz model in work

Quasioptics

- Currently the only “standard” above 1 THz
- Can have very low loss
- Not ideal for all applications
  - Alignment
  - Mode matching
  - Sensitive to vibration and thermal drift
  - Bulky
  - Long path lengths (absorption)

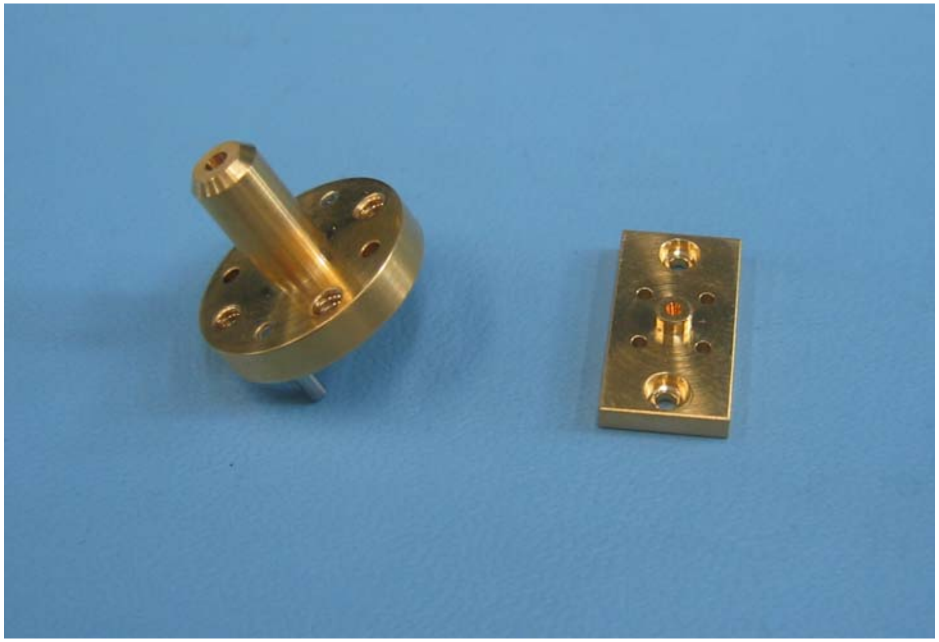
➔ Quasioptics don’t replace waveguides

Sources



JPL 1.5 THz Frequency Multiplier Chain

Passive Components



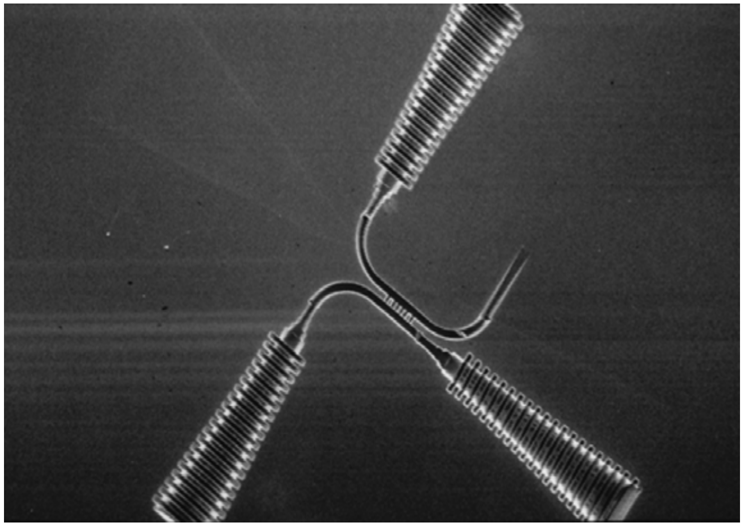
Corrugated feed-horns up to 1.47 THz,

Conical and dual-mode up to 2 THz

(Radiometer Physics GmbH, Germany)

Future Prospects

- Fabrication technologies advancing
- Device technologies advancing
- Medical imaging interest
- Military & homeland security interest
- Earth science & astrophysics interest



5 THz horns and coupler
(C. Walker / U. Arizona)

Why new standards?

- Industry standards end at 325 GHz (WR-3)
- No compatibility among hardware
  - Flanges don't mate
  - Waveguide sizes incompatible
  - Tolerances too loose
- High frequencies make transitions impractical
- Lab infrastructure is building fast

➔ **Now is the time to develop new standards to enable interchangeable hardware**

A Well-Stocked Lab

- Network analyzers
- Spectrum analyzers
- Sources
- Horns
- Frequency multipliers
- Upconverters
- Downconverters
- Mixers
- Harmonic mixers

- Amplifiers
- Filters
- Power meters
- Directional couplers
- Hybrid couplers
- Isolators
- Loads
- Wafer probes
- Solid-state lasers

Rectangular Waveguide Sizes

“WR” Standard

Band	Frequency	WR	Cut Off	Dim
F	90-140	08	73.84	0.080
D	110-170	06	90.84	0.065
G	140-220	05	115.75	0.051
	170-260	04	137.52	0.043
	220-325	03	173.28	0.034

Extend "WR" Standard?

- Doesn't extend beyond 325 GHz
- No guidance to extend to higher frequency
- No guidance for in-between sizes
- No guidance for preferred sizes
- Defined in inches
- Waveguide name, band name, & size all different
- Oddball sizes and cutoff frequencies
- Military standards carry extra baggage

➔ **No, we can do better!**

ISO 497 Preferred Metric Sizes

- Widely used global industry standard
- Logarithmic scale
- “dB millimeters” (2, 1, 0.5, & 0.25 dB spacing)
- First, second, third, and fourth choices
- Infinitely extendable
- Repeats every decade
- ISO 497 should be applied to waveguides even without a dedicated standard
- Recommend applying to long dimension

ISO 497 Preferred Metric Sizes

<table>
<tr><th>1st Choice</th><th>2nd Choice</th><th>3rd Choice</th></tr>
<tr><td rowspan="2">1</td><td rowspan="3">1.25</td><td rowspan="2">1.1</td></tr>
<tr></tr>
<tr><td rowspan="2">1.6</td><td>1.4</td></tr>
<tr><td rowspan="2">2</td><td>1.8</td></tr>
<tr><td rowspan="2">2.5</td><td>2.2</td></tr>
<tr><td rowspan="2">3.2</td><td>2.8</td></tr>
<tr><td rowspan="2">4</td><td>3.6</td></tr>
<tr><td rowspan="2">5</td><td>4.5</td></tr>
<tr><td rowspan="2">6.3</td><td>5.6</td></tr>
<tr><td rowspan="3">8</td><td>7.1</td></tr>
<tr><td rowspan="2">10</td><td rowspan="2">9</td></tr>
<tr></tr>
</table>

Does this work with waveguides?

- Based on broadest, most-accepted industry standards
  - SI, ISO 3, ISO 17, ISO 497
- Convenient spacing (logarithmic scale)
- Sizes and cutoff frequencies repeat every decade
- Sizes and cutoff frequencies mostly round numbers
- Decision tree with range of coarse and fine spacings
- Nomenclature:
  - "500 µm waveguide" and "500 µm waveguide band"
  - Name is also TE20 cutoff wavelength
  - Avoids arbitrary letter names (E, F, G, D band)

First and Second Choices

a (µm)	b (µm)	Fc (GHz)	Fmin	Fmax
1000	**500**	**150**	**180**	**290**
800	400	187	230	360
630	**315**	**238**	**290**	**450**
500	250	300	360	570
400	**200**	**375**	**450**	**720**
320	160	468	570	900
250	**125**	**600**	**720**	**1150**
200	100	750	900	1450
160	**80**	**937**	**1150**	**1800**
125	62.5	1200	1450	2300
100	**50**	**1500**	**1800**	**2900**

Recommendations

- ISO 497 ideally suited to rectangular waveguide
- Formalize the new standard A.S.A.P.
- Long dimension from ISO 497 R' series
- Nominal bands ≈ 1.2 – 1.9 TE10 cutoff
- Specify tolerances
- Make automatically extendible

Waveguide Flanges

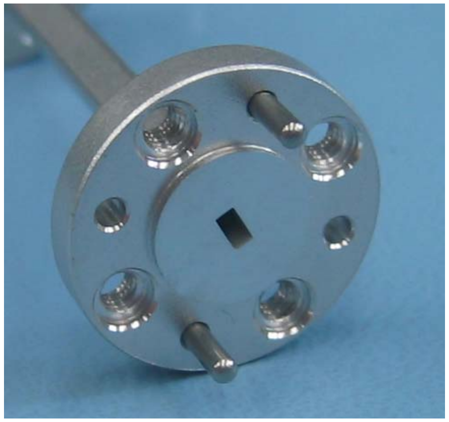
UG-387 Flanges

Advantages:

- Prevent cross-guiding
- Common, simple, inexpensive

Disadvantages:

- Large / bulky
- Poor repeatability
- High skill / labor intensive
- Tolerances limit to ~ 100 GHz



TRG-714 Flanges

Advantages:

- Prevent cross-guiding
- Toolless mating / easy to use
- More compact than UG-387

Disadvantages:

- Poor repeatability
- Inspection impossible
- Poor performance above ~ 100 GHz
- More difficult to fabricate than UG-387

Desired Flange Properties

- Repeatable, guaranteed RF performance
- Guaranteed to always mate (tolerances)
- Prevent cross-guiding
- Compact / short insertion length
- Fast and easy to use
- Toolless mating
- Robust – not damaged by reasonable handling
- Inexpensive to manufacture
- Compatible with E and H plane split blocks
- Specified in millimeters with metric threads
- Gendered?

Gendered Flanges?

- Insertable gender-changers not acceptable
- Genderless useful for many components
- Gender would be useful for directional devices like amplifiers, isolators, etc.
- Consider reconfigurable system to change gender without impacting waveguide / RF performance

➔ Select gender with removable rings?

A Flange Standard Should...

- Include drawing of flange
- Include table of tolerances based on waveguide size
- In-spec. waveguides must always mate
- Tolerances should guarantee in-band performance
- Be extendible to smaller guide sizes
- Be defined in SI units with metric threads

Conclusions

- Incompatible hardware is a waste of time & money
- Formalize standard for waveguide sizes **now**
- Flange standard may require R&D
- Use opportunity wisely
- Focus on long-term benefit
- Big cost savings

Use the new standards!

References

- ISO 3
- ISO 17
- ISO 497
- Mil-DTL-3922/67 revision C
- Mil-DTL-85/3 revision B
- A.R. Kerr, E. Wollack, and N. Horner, “Waveguide flanges for ALMA instruments,” ALMA memo 278, November 1999.
- A.R. Kerr, L. Kozul, and A.A. Marshall, “Recommendations for flat and anti-cocking waveguide flanges,” ALMA memo 444, January 2003.
- G. Chattopadhyay, E. Schlecht, J. Ward, J. Gill, H. Javadi, F. Maiwald, and I. Mehdi, “An all solid-state broadband frequency multiplier chain at 1500 GHz,” IEEE Trans. Microwave Theory and Tech., vol. 52, no. 5, pp. 1538-1547, May 2004.

1st Choice Cutoff Frequencies

a (µm)	b (µm)	fc (GHz)	2*fc (GHz)
1000	500	150	300
630	315	238	476
400	200	375	750
250	125	600	1200
160	80	937	1874
100	50	1500	3000