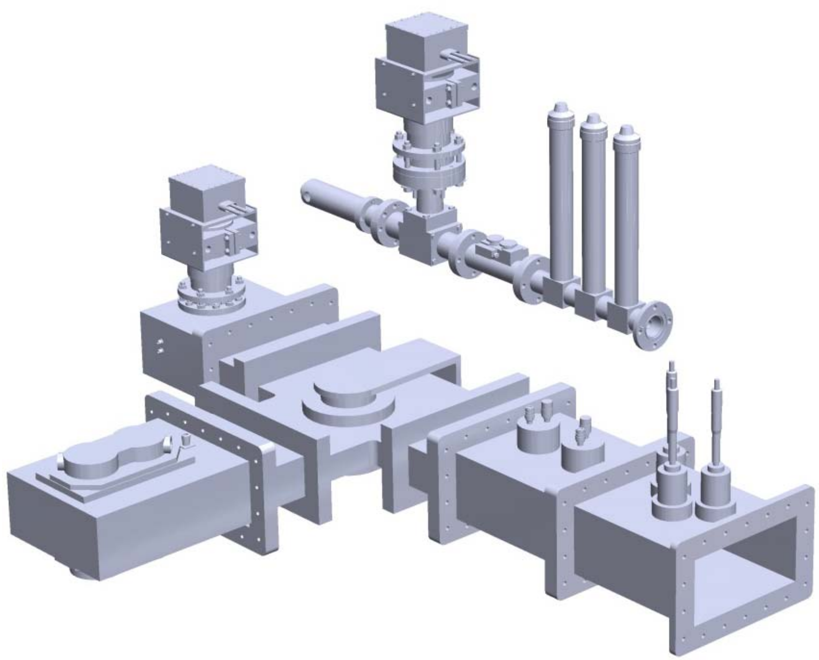
Waveguide or Coax?

Practical Considerations for Microwave Heating Applications



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New Orleans, LA

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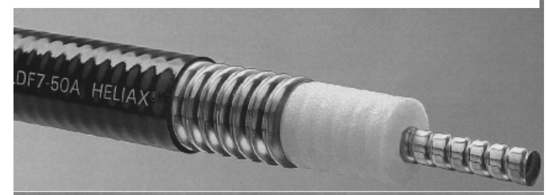
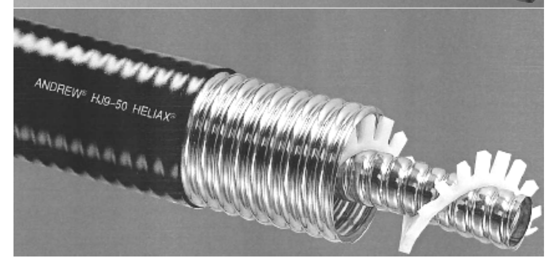
Presentation Overview

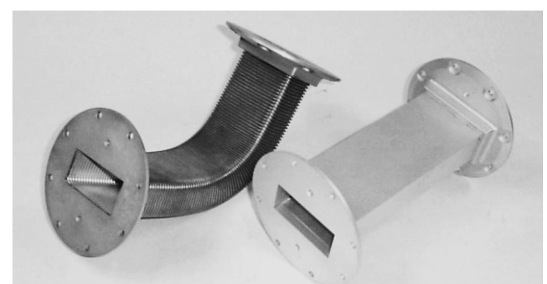
- Types and Sizes for High Power
- Selection Criteria
- System Components
- Application Considerations

Transmission Line Types

- Flexible coaxial cable
  - Two concentric conductors
  - Solid dielectric
- Semi-flexible coax
  - Two concentric conductors
  - Air or foam dielectric
- Rigid coax
  - Two concentric conductors
  - Air dielectric
- Waveguide
  - Single hollow conductor
  - Rectangular or circular
  - Rigid or flexible
  - Air dielectric







Available Sizes

- Standards developed by Electronic Industries Association (EIA) and adopted worldwide under various designations
- Rectangular waveguide

Inside Dimensions (inches)	Frequency Band	Official Designations IEC	RCSC (UK)	EIA (US)
1.59 x .795	C	R58	WG13	WR159
2.84 x 1.34	S	R32	WG10	WR284
3.40 x 1.70	S	R26	WG9A	WR340
4.30 x 2.15	S	R22	WG8	WR430
9.75 x 4.875	L		WG4	WR975

- Rigid coax

Nom. OD of Outer Condr.	Zo (ohms)	Maximum Freq. (MHz)	Vel. of Prop (Percent)	Nom. OD of Inner (Inches)	Nom ID of Outer (Inches)
7/8"	50	6000	99.8	.341	.785
1-5/8"	50	3000	99.8	.664	1.527
3-1/8"	50	1588	99.8	1.315	3.027
4-1/16"	50	1197	99.8	1.711	3.935
6-1/8"	50	788	99.8	2.600	5.981
6-1/8"	75	900	99.7	1.711	5.981
8-3/16"	75	709	99.7	2.293	8.000
9-3/16"	50	530	99.7	3.910	9.000
9-3/16"	75	600	99.7	2.580	9.000

- Semi-flexible coax and flexible coaxial cable
  - Products vary by manufacturer in similar sizes as rigid

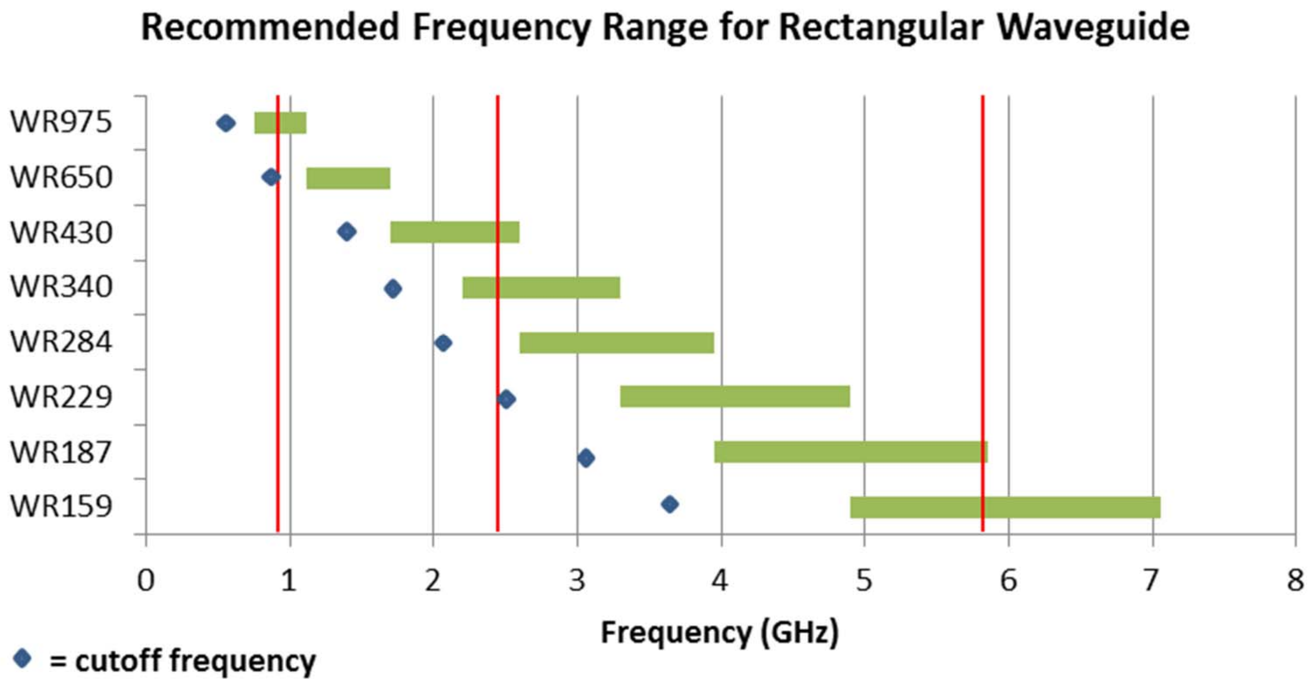
Selection Criteria

- Frequency
  - Upper and lower limit for rectangular waveguide
  - Upper limit for coax
- Attenuation
  - Larger size for lower attenuation
- Power
  - Peak vs. average
  - Larger size for higher power
  - Varies by component type
  - Must be derated for VSWR (load impedance mismatch)
- Other factors
  - Size and weight
  - Cost

Frequency – Rectangular Waveguide

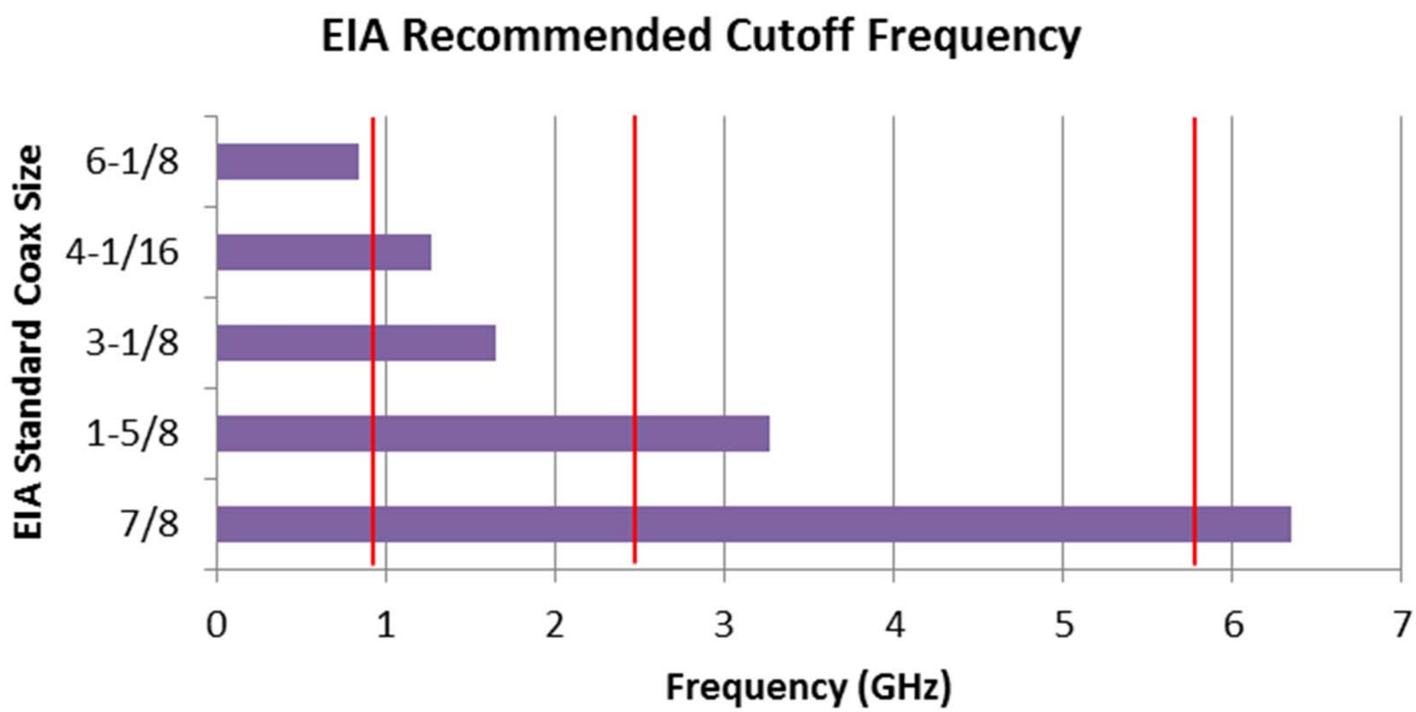
- Lower limit for lowest order mode (TE_{10}) cutoff
- Upper limit for cutoff of undesirable higher order modes

$$(f_c)_{mn} = \frac{1}{2\pi\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2}$$



Frequency – Coax

- No lower limit for desired fundamental (TEM) mode
- Upper limit for cutoff of higher order (TE_{11}) mode
  - Approximation based on mean circumference of conductors equal to wavelength (EIA standard)

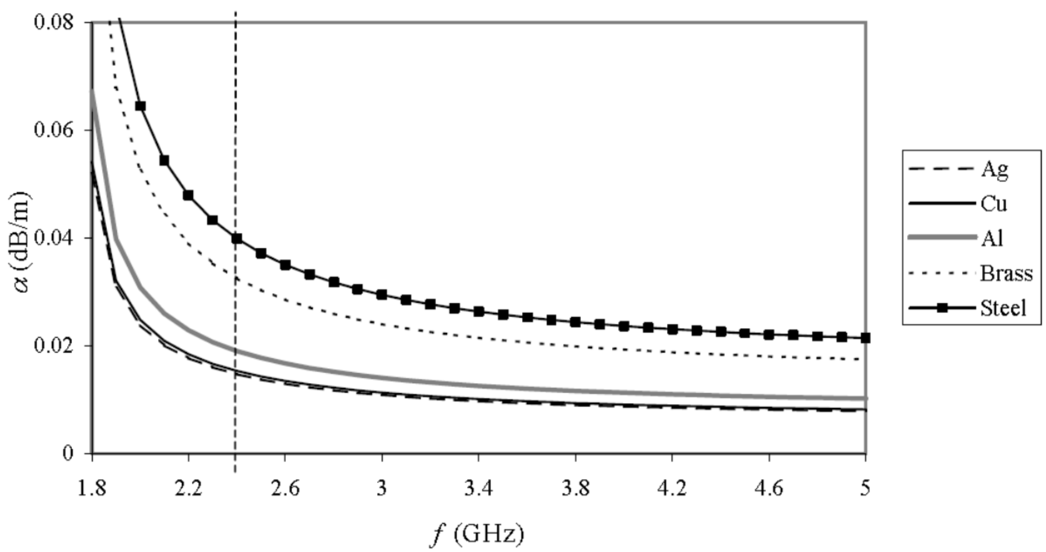


Attenuation – Waveguide

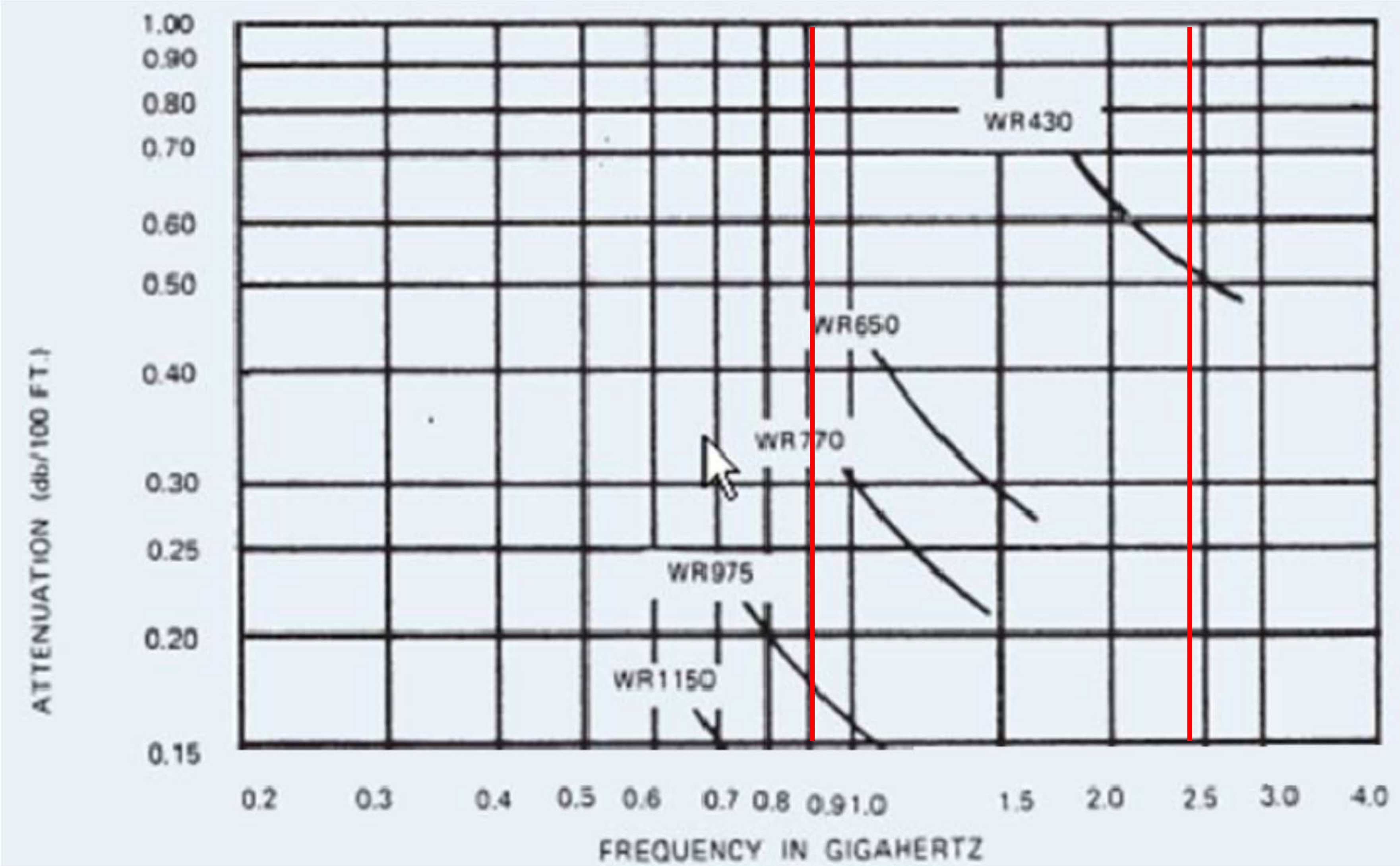
- Attenuation constant

$$\alpha = \frac{R_s}{Z_c b} \cdot \frac{1 + 2\frac{b}{a}\left(\frac{f_c}{f}\right)^2}{\sqrt{1 - \left(\frac{f_c}{f}\right)^2}}$$

- Effect of materials on surface resistance (example: WR340)



Attenuation – Waveguide

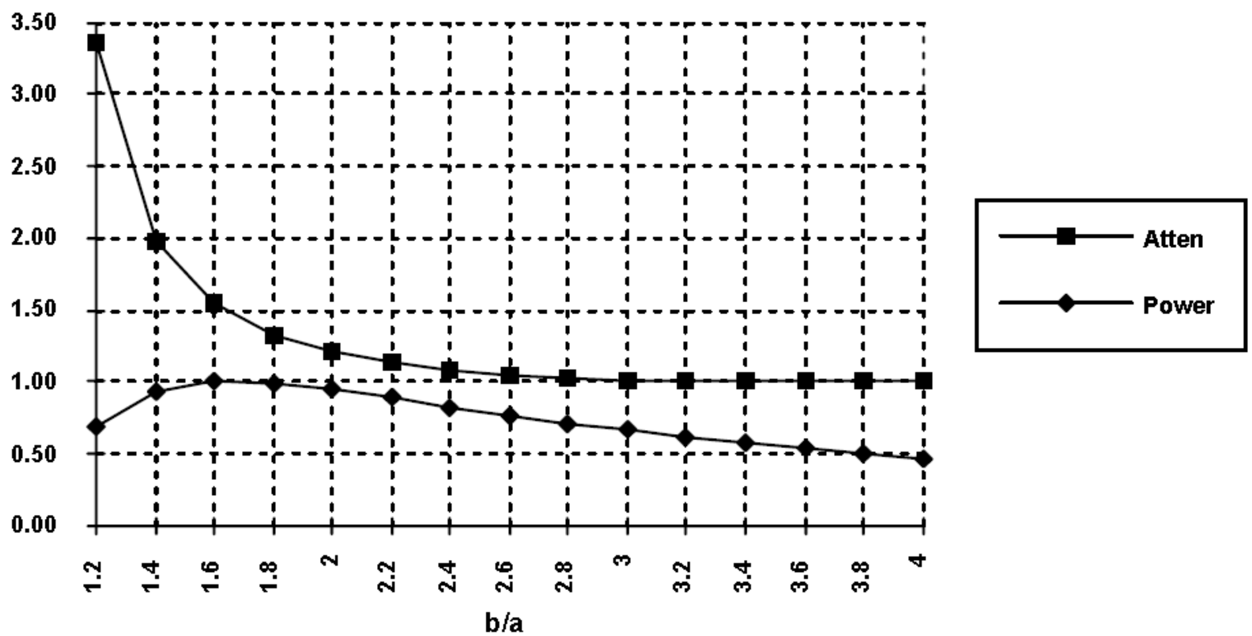


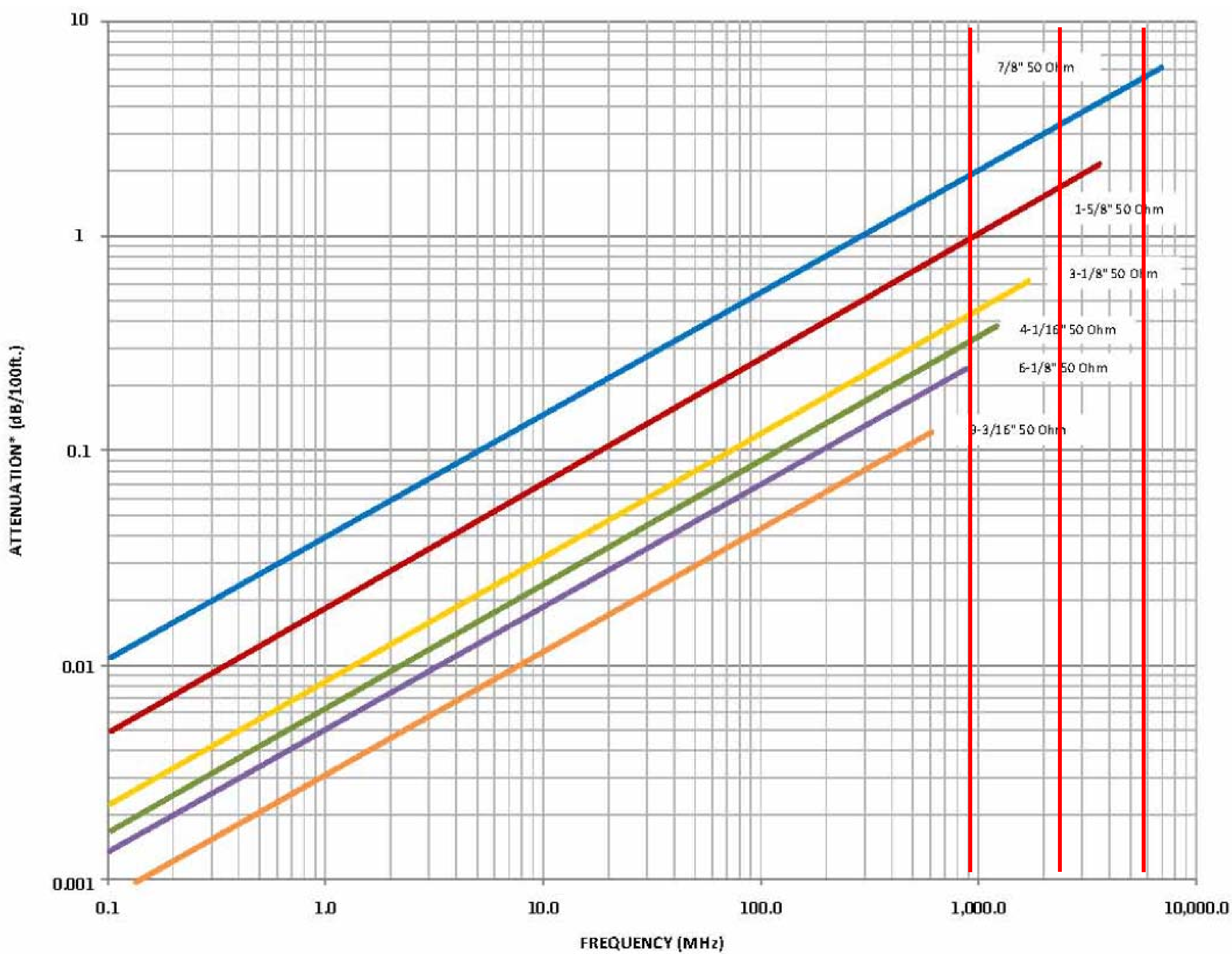
Attenuation – Coax

- Attenuation constant

$$\alpha = \frac{0.433}{Z_0}\left(\frac{1}{D}+\frac{1}{d}\right)\sqrt{f}$$

- Optimal D/d = 3.59, Z_0 = 77 Ohms

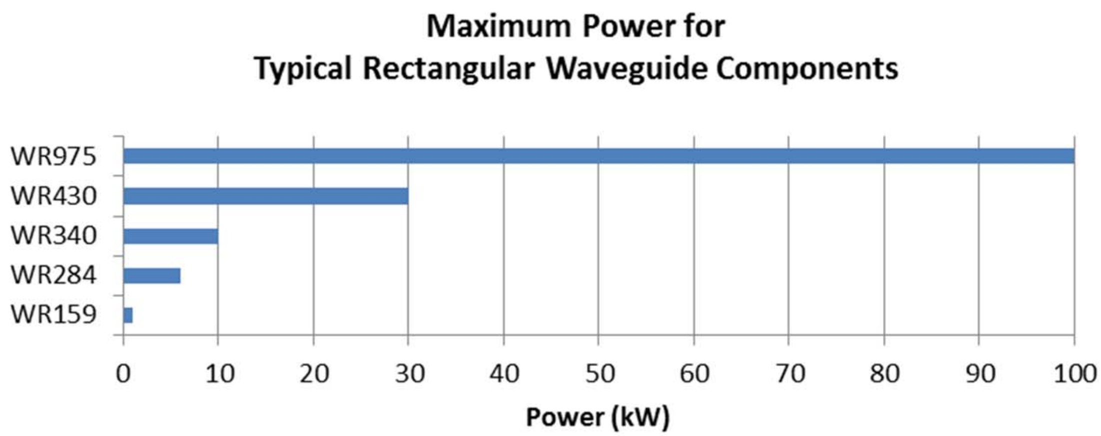




7/8" 50 Ohm
1-5/8" 50 Ohm
3-1/8" 50 Ohm
4-1/16" 50 Ohm
6-1/8" 50 Ohm
9-3/16" 50 Ohm
ATTENUATION* (dB/100ft.)
10
1
0.1
0.01
0.001
0.1
1.0
10.0
100.0
1,000.0
10,000.0
FREQUENCY (MHz)

Power – Rectangular Waveguide

- Peak and average power ratings are much higher than maximum power output from microwave generator
- Components rated for microwave generator maximum output
- Example: WR430 aluminum waveguide rated for 18 MW peak, 95 kW average while 2.45 GHz microwave generator maximum output is 30 kW



- Derating for VSWR applies to theoretical power limits only
  - Does not apply to most component ratings
  - Applicable to tuners and coaxial adapters based on design

Power – Coax

- Peak power determined by e-field at which discharge occurs

$$E_{max} = \frac{0.278}{d}\sqrt{\frac{P}{\ln\frac{D}{d}}}$$

  - E_{max} is lowest when D/d = 1.65, 30 Ohms
  - Much higher than microwave generator maximum output

- Average power based on maximum operating temperature of dielectric support for center conductor.

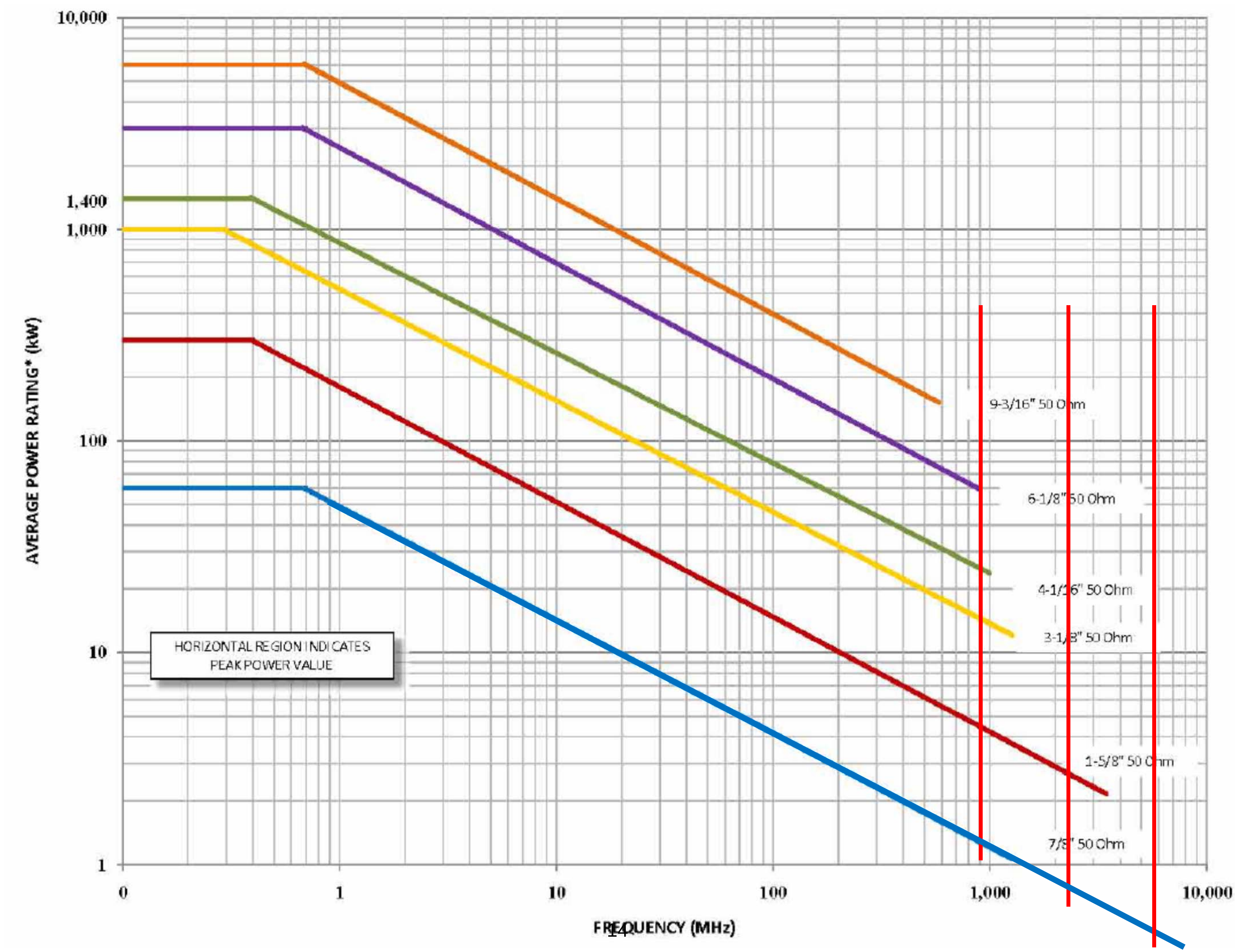
$$P_{ave} = \frac{16380 \cdot \sigma \cdot D}{\alpha \cdot M_{\alpha}}$$

$\sigma = heat\ emissivity\ coefficient\ of\ outer\ conductor$

$M_{\alpha} = attenuation\ correction\ factor\ for\ temperature$

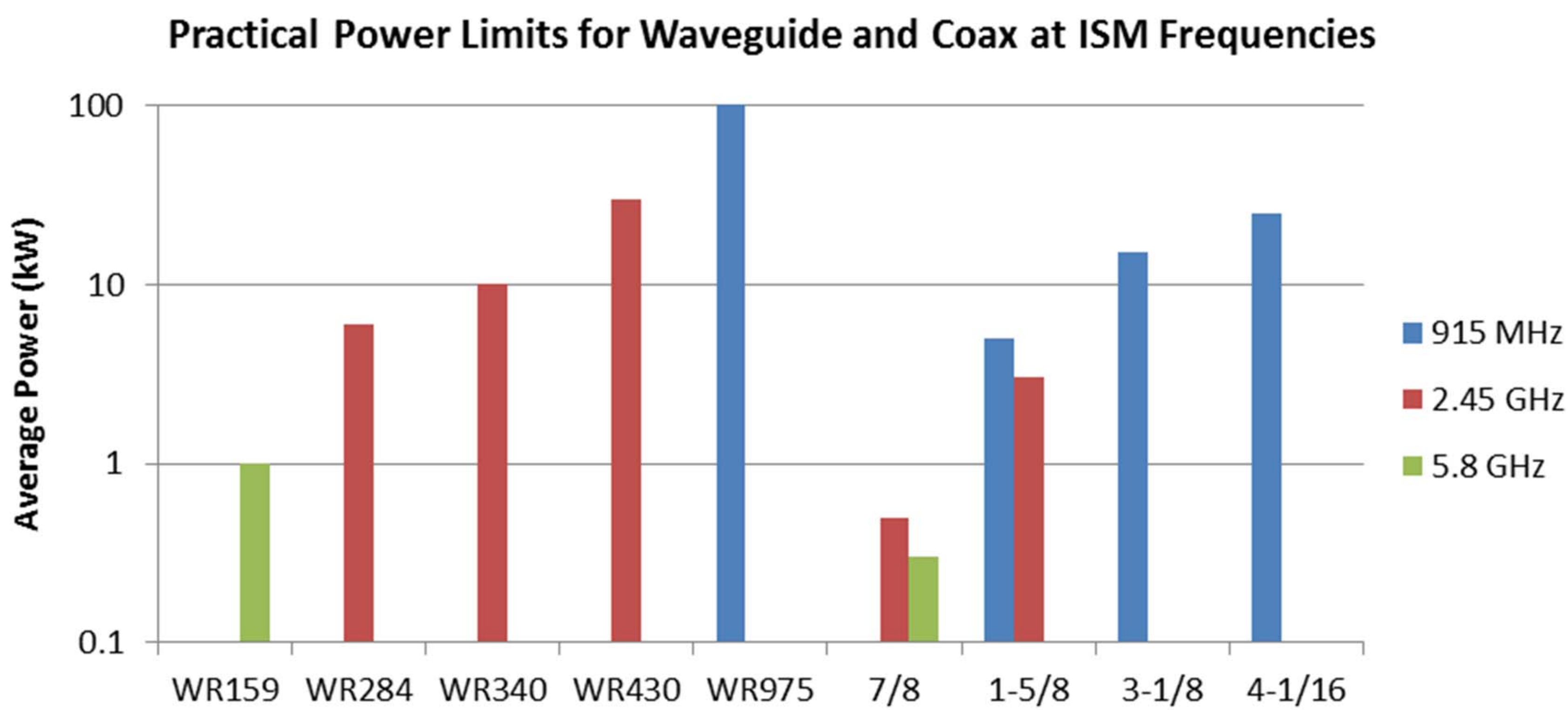
- Derating factor

$$DF = \frac{VSWR^2 + 1}{2 \cdot VSWR}$$


10,000
1,400
1,000
100
10
1
0
1
10
100
1,000
10,000
AVERAGE POWER RATING* (kW)
FREQUENCY (MHz)
HORIZONTAL REGION INDICATES
PEAK POWER VALUE
9-3/16" 50 Ohm
6-1/8" 50 Ohm
4-1/16" 50 Ohm
3-1/8" 50 Ohm
1-5/8" 50 Ohm
7/8" 50 Ohm

Power limit comparison

- Based on the lower of conductor or component maximum power



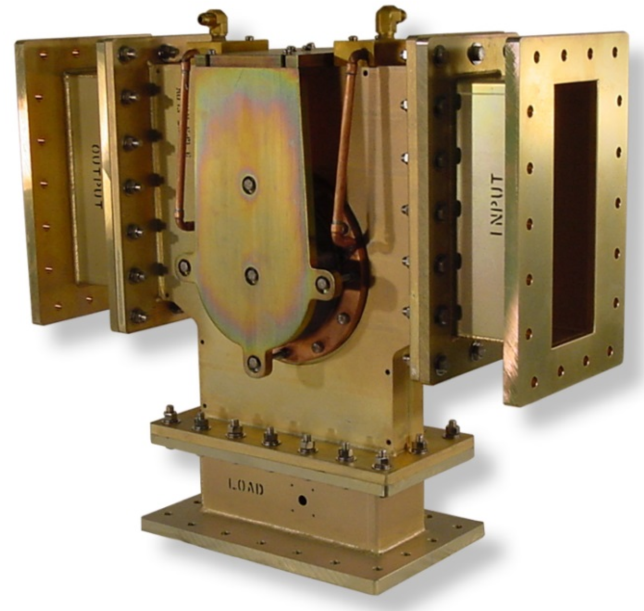
Other selection factors

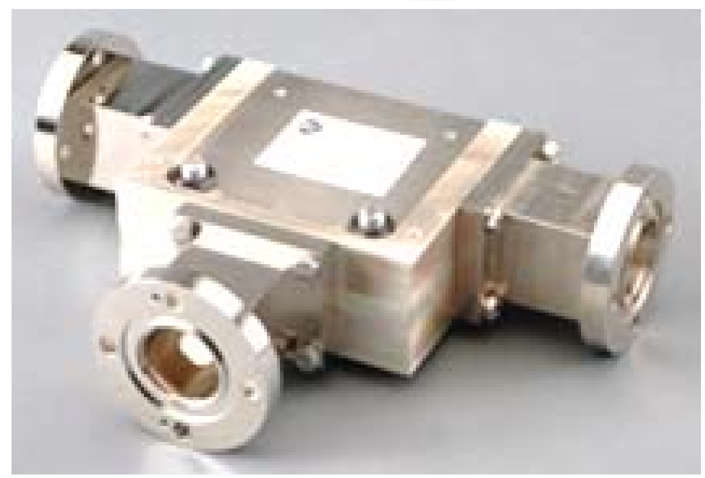
(ignoring other factors)

- Size and weight
  - 5.8 GHz: waveguide is favored
  - 2.45 GHz: roughly equal
  - 915 MHz: coax is favored
- Cost
  - 5.8 GHz and 2.45 GHz: roughly equal
  - 915 MHz: Coax is favored
- Component availability
  - Waveguide is heavily favored at all ISM frequencies

Component Availability

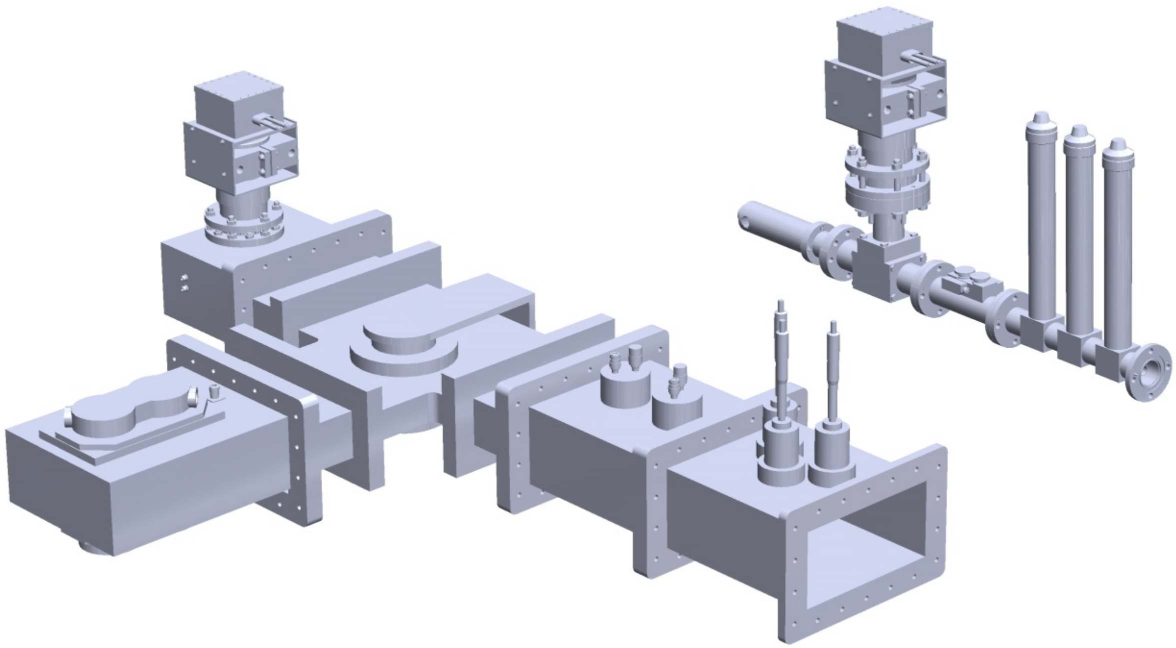
- ♦ Waveguide
  - All types and sizes readily available from multiple manufacturers at ISM frequencies for all generator power levels
- ♦ Coax
  - Most commercially available components are designed for wifi, telecom and defense applications
  - Designed for broadband operation and/or limited in power
  - Very few rated for high power at ISM frequencies





Application Considerations

- Power and VSWR – Is the process static or dynamic?
- Size and weight –Available real estate on the system?



- Applicator coupling – Waveguide or coax feed?
- System configuration – Long runs at high power or short runs at low power?

Waveguide or Coax?

No longer an easy choice...for microwave.

(was it ever?)

Thank you!