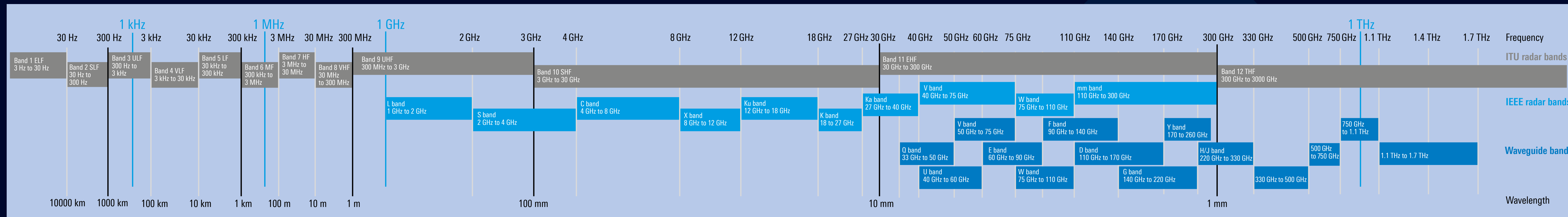
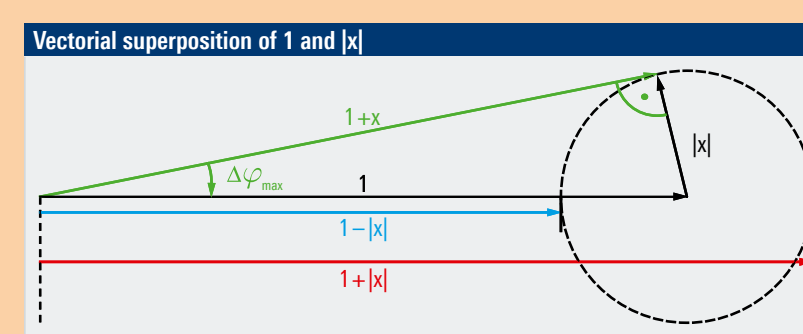


MICROWAVES AND BEYOND



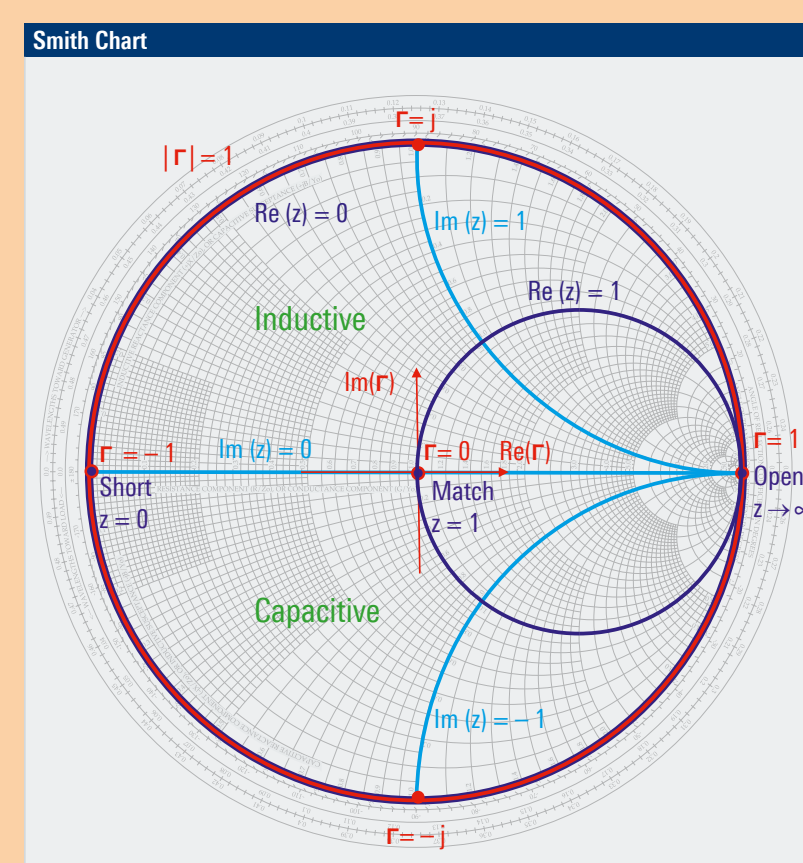
MISMATCH REFERENCE AND ESTIMATE OF MEASUREMENT UNCERTAINTY

Return loss	Reflection coefficient	Standing wave ratio	Impedances in a 50 Ω system
RL in dB	Γ	VSWR	Z _L (real) or Z _L (j)
0	1.0000	∞	0.0 or ∞
1	0.8913	1.2391	23.9 or 89.5
2	0.7943	1.3724	13.7 or 43.2
3	0.7079	1.5488	8.5 or 29.2
4	0.6310	1.7611	5.7 or 21.0
5	0.5623	2.0000	4.0 or 15.0
6	0.5012	2.2794	3.0 or 11.0
7	0.4467	2.6031	2.2 or 8.0
8	0.3981	2.9843	1.7 or 6.0
9	0.3548	3.4229	1.3 or 4.5
10	0.3162	3.9212	1.0 or 3.0
11	0.2818	4.4668	0.8 or 2.5
12	0.2512	5.0794	0.7 or 2.2
13	0.2239	5.7688	0.6 or 1.9
14	0.1995	6.5436	0.5 or 1.6
15	0.1778	7.4125	0.4 or 1.3
16	0.1585	8.3913	0.4 or 1.2
17	0.1413	9.4969	0.3 or 1.0
18	0.1259	10.7590	0.3 or 0.9
19	0.1122	12.1875	0.3 or 0.8
20	0.1000	13.7870	0.3 or 0.7
21	0.0891	15.5488	0.2 or 0.6
22	0.0794	17.4969	0.2 or 0.5
23	0.0708	19.6590	0.2 or 0.5
24	0.0631	22.0629	0.2 or 0.4
25	0.0562	24.7500	0.2 or 0.4
26	0.0501	27.7643	0.2 or 0.3
27	0.0447	31.1125	0.2 or 0.3
28	0.0398	34.9212	0.2 or 0.3
29	0.0355	39.2125	0.2 or 0.2
30	0.0316	44.0000	0.2 or 0.2
31	0.0282	49.3308	0.2 or 0.2
32	0.0251	55.2500	0.2 or 0.2
33	0.0224	61.8590	0.2 or 0.2
34	0.0200	69.1875	0.2 or 0.2
35	0.0178	77.2812	0.2 or 0.2
36	0.0158	86.1875	0.2 or 0.2
37	0.0141	96.0000	0.2 or 0.2
38	0.0126	106.8590	0.2 or 0.2
39	0.0112	118.8125	0.2 or 0.2
40	0.0100	131.9212	0.2 or 0.2
41	0.0089	146.2500	0.2 or 0.2
42	0.0079	161.8590	0.2 or 0.2
43	0.0071	178.7500	0.2 or 0.2
44	0.0063	197.0000	0.2 or 0.2
45	0.0056	216.7500	0.2 or 0.2
46	0.0050	238.1250	0.2 or 0.2
47	0.0045	261.2500	0.2 or 0.2
48	0.0040	287.1875	0.2 or 0.2
49	0.0035	315.0000	0.2 or 0.2
50	0.0032	344.7500	0.2 or 0.2



Measurement uncertainty: $20 \log(1 - |x|)$ dB

Phase deviation maximum: $\Delta\phi_{max} = \arcsin(x)$



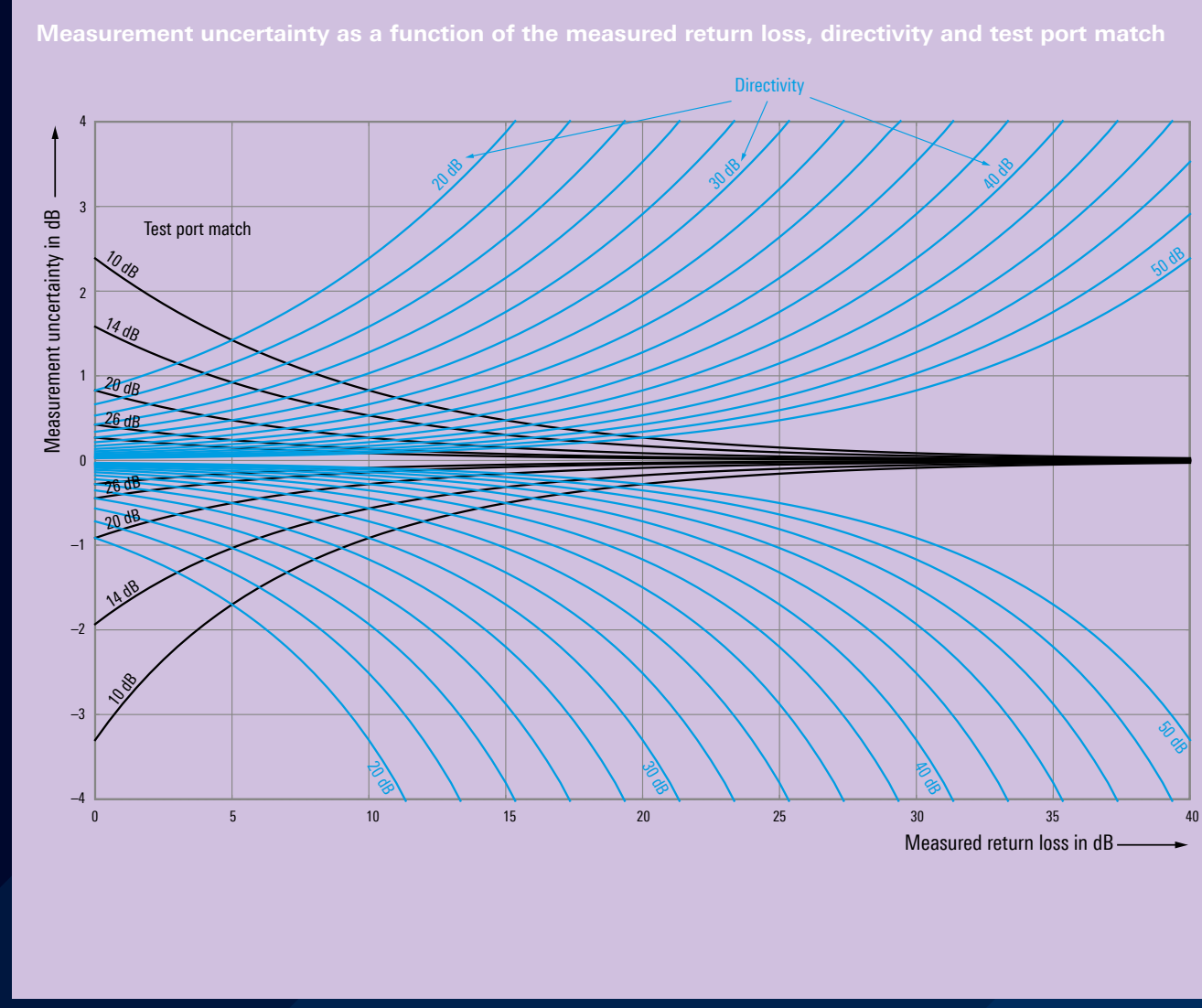
Return loss: $|r| = 10^{-\frac{RL}{20}}$ RL/dB = $-20 \log |r|$

Reflection coefficient: $VSWR = \frac{1+|r|}{1-|r|}$ $|r| = \frac{VSWR-1}{VSWR+1}$

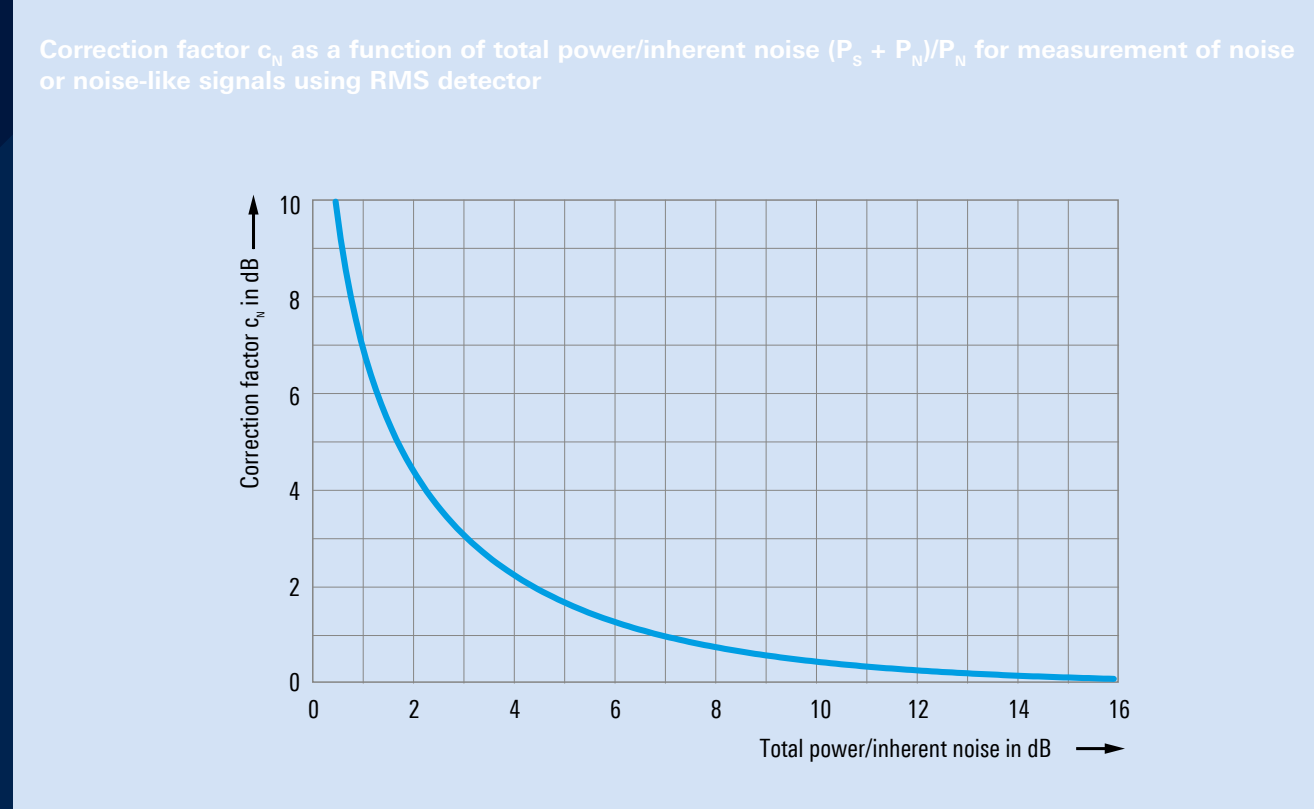
$Z_L = Z_0 \frac{1+\Gamma}{1-\Gamma}$ $\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}$

Signal to error ratio	Measurement uncertainty
x in dB	Δφ _{max} in °
0	90.0
1	83.0
2	76.6
3	70.7
4	65.3
5	60.3
6	55.7
7	51.5
8	47.6
9	44.0
10	40.7
11	37.7
12	35.0
13	32.5
14	30.2
15	28.1
16	26.2
17	24.4
18	22.8
19	21.3
20	20.0
21	18.8
22	17.7
23	16.7
24	15.8
25	15.0
26	14.2
27	13.5
28	12.8
29	12.2
30	11.6
31	11.0
32	10.5
33	10.0
34	9.5
35	9.1
36	8.6
37	8.2
38	7.8
39	7.4
40	7.0
41	6.7
42	6.4
43	6.1
44	5.8
45	5.6
46	5.3
47	5.1
48	4.9
49	4.7
50	4.5

DIRECTIVITY AND UNCERTAINTY



CORRECTION FACTOR FOR S/N



SIGNAL LEVEL CONVERSIONS

dBm	dBμV	dBV	W	V _{RMS}	V _{pp}
50	157	37	100.00 mW	70.71 V	200.00 V
40	147	27	10.00 mW	22.36 V	63.25 V
30	137	17	1.00 mW	7.07 V	20.00 V
20	127	7	0.10 W	2.24 V	6.32 V
10	117	-3	0.010 mW	0.7071 mV	2.00 V
9	116	-4	7.94 mW	630.21 mV	1.78 V
8	115	-5	6.31 mW	561.87 mV	1.58 V
7	114	-6	5.01 mW	500.58 mV	1.42 V
6	113	-7	3.98 mW	446.15 mV	1.26 V
5	112	-8	3.16 mW	397.64 mV	1.12 V
4	111	-9	2.51 mW	354.39 mV	1.00 V
3	110	-10	2.00 mW	315.85 mV	0.89 V
2	109	-11	1.58 mW	281.50 mV	0.80 V
1	108	-12	1.26 mW	250.89 mV	0.71 V
0	107	-13	1.00 mW	223.61 mV	0.63 V
-1	106	-14	794.33 μW	199.29 mV	563.68 mV
-2	105	-15	630.96 μW	177.62 mV	502.38 mV
-3	104	-16	501.19 μW	158.30 mV	447.74 mV
-4	103	-17	398.11 μW	141.09 mV	398.05 mV
-5	102	-18	316.23 μW	125.74 mV	355.66 mV
-6	101	-19	251.19 μW	112.07 mV	316.88 mV
-7	100	-20	199.53 μW	99.88 mV	282.51 mV
-8	99	-21	158.49 μW	89.02 mV	251.79 mV
-9	98	-22	125.89 μW	79.34 mV	224.40 mV
-10	97	-23	100.00 μW	70.71 mV	200.00 mV
-20	87	-33	10.00 μW	22.36 mV	63.25 mV
-30	77	-43	1.00 μW	7.07 mV	20.00 mV
-40	67	-53	0.10 μW	2.24 mV	6.32 mV
-50	57	-63	0.01 μW	0.71 mV	2.00 mV
-60	47	-73	0.001 μW	223.61 μV	632.46 μV
-70	37	-83	0.0001 μW	70.71 μV	200.00 μV
-80	27	-93	0.00001 μW	22.36 μV	63.25 μV
-90	17	-103	0.000001 μW	7.07 μV	20.00 μV
-100	7	-113	0.10 pW	2.24 μV	6.32 μV
-110	-3	-123	0.01 pW	0.71 μV	2.00 μV
-120	-13	-133	0.001 pW	0.22 μV	0.63 μV

Formulas for signal level conversion

Conversion mW ↔ dBm
 $y / mW = 10^{\frac{x}{10}}$
 $x / dBm = 10 \times \log(y / mW)$

Conversion dBμV ↔ dBV
 $y / dBμV = x / dBV + 120$
 $x / dBV = y / dBμV - 120$

Conversion V_{pp} ↔ V_{RMS}
 $V_{pp} = 2\sqrt{2} \times V_{RMS}$

Conversion W ↔ V_{RMS}
 $z / V = \sqrt{(y / W) \times 50 \Omega}$
 $y / W = \frac{(z / V)^2}{50 \Omega}$

Conversion dBV ↔ V_{RMS}
 $x / dBV = 20 \times \log(z / V)$
 $z / V = 10^{\frac{x}{20}}$

Conversion dBm ↔ dBμV
 $y / dBμV = x / dBm + 107$
 $x / dBm = y / dBμV - 107$

WAVEGUIDE STANDARDS

Operating frequency in GHz	Cutoff frequency in GHz	Waveguide band	Waveguide designations	Inner dimensions waveguide opening				
in GHz	in GHz		IEEE 1785.1-2012	in mm				
1.12 to 1.70	0.908	L (part)	WR650	WG6	R14	185.10 × 82.550	6.5000 × 3.2500	
1.45 to 2.20	1.157		WR910	WG7	R18	225.54 × 84.710	5.1000 × 2.5500	
1.70 to 2.60	1.372		WR430	WG6	R22	109.22 × 54.610	4.3000 × 2.1500	
2.20 to 3.30	1.736	S (part)	WR340	WG9A	R26	98.390 × 43.180	3.4000 × 1.7000	
2.80 to 3.95	2.078	S (part)	WR284	WG10	R32	72.136 × 34.036	2.8400 × 1.3400	
3.30 to 4.90	2.577	C (part)	WR229	WG11A	R40	58.166 × 29.083	2.2900 × 1.1450	
3.85 to 5.85	3.152	C (part)	WR187	WG12	R48	47.549 × 22.149	1.8720 × 0.8720	
4.80 to 7.05	3.712	C (part)	WR159	WG13	R58	40.386 × 20.193	1.5900 × 0.7950	
5.85 to 8.2	4.301	C (part)	WR137	WG14	R70	34.849 × 15.799	1.3720 × 0.6220	
7.05 to 10.0	5.260		WR112	WG15	R84	28.499 × 12.624	1.1220 × 0.4970	
8.2 to 12.4	6.557	X	WR90	WG16	R100	22.860 × 10.160	0.9000 × 0.4000	
10 to 15	7.869		WR75	WG17	R120	19.050 × 9.525	0.7500 × 0.3750	
12.4 to 18	9.485	Ku	WR62	WG18	R140	15.799 × 7.899	0.6220 × 0.3110	
15 to 22	11.572		WR51	WG19	R180	12.954 × 6.477	0.5100 × 0.2550	
18 to 26.5	14.051	K	WR42	WG20	R220	10.668 × 4.318	0.4200 × 0.1700	
22 to 33	17.357		WR34	WG21	R260	8.636 × 4.318	0.3400 × 0.1700	
26.5 to 40	21.077	Ka	WR28	WG22	R320	7.112 × 3.556	0.2800 × 0.1400	
33 to 50	26.346	Q	WR22	WG23	R400	5.690 × 2.845	0.2240 × 0.1120	
40 to 60	31.391	U	WR19	WG24	R500	4.775 × 2.388	0.1880 × 0.0940	
50 to 75	38.875	V	WR15	WG25	R620	3.759 × 1.880	0.1480 × 0.0740	
60 to 90	48.373	E	WR12	WG26	R740	3.099 × 1.549	0.1220 × 0.0610	
75 to 110	59.014	W	WM-2540	WR10	WG27	R900	2.540 × 1.270	0.1000 × 0.0500
90 to 140	73.768	F	WM-2032	WR8	WG28	R1.2K	2.032 × 1.016	0.0800 × 0.0400
110 to 170	90.791	D	WM-1651	WG29	WR1.4K	1.651 × 0.826	0.0650 × 0.0325	
140 to 220	115.75	G	WM-1295	WR5	WG30	R1.8K	1.295 × 0.648	0.0510 × 0.0255
170 to 260	137.27	Y	WM-1092	WR4	WG31	R2.2K	1.092 × 0.546	0.0430 × 0.0215
220 to 325								
220 to 330	173.49	H/J	WM-864	WR3	WG32	R2.6K	0.864 × 0.432	0.0340 × 0.0170
325 to 500	268.16							
330 to 500	262.58		WM-570	WR2.2**			0.559 × 0.279	0.0220 × 0.0110
500 to 750	334.46		WM-380			RAK	0.570 × 0.285	0.0224 × 0.0112
750 to 1100	599.58		WM-250			RAK	0.250 × 0.125	0.0098 × 0.0049
1100 to 1700	914.00		WM-164			R1.4K	0.164 × 0.082	0.0065 × 0.0032

RF CONNECTOR TYPES

Connector type	Frequency range	Mechanically compatible with
BNC	DC to 3 GHz	-
7/16 ^h	DC to 8.5 GHz	-
PC7 ⁿ	DC to 18 GHz	-
N ^e	DC to 18 GHz	-
SMA ^h	DC to 18 GHz	PC 3.5 (3.5 mm), 2.92 mm (K)
PC 3.5	DC to 34 GHz	SMA, K
2.92 mm (K)	DC to 40 GHz	SMA, PC 3.5 (3.5 mm)
2.4 mm	DC to 40 GHz	SMA, PC 3.5 (3.5 mm)
1.85 mm (V)	DC to 67 GHz	2.4 mm
1.35 mm (E)	DC to 90 GHz	-
1.00 mm (W)	DC to 110 GHz	-

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