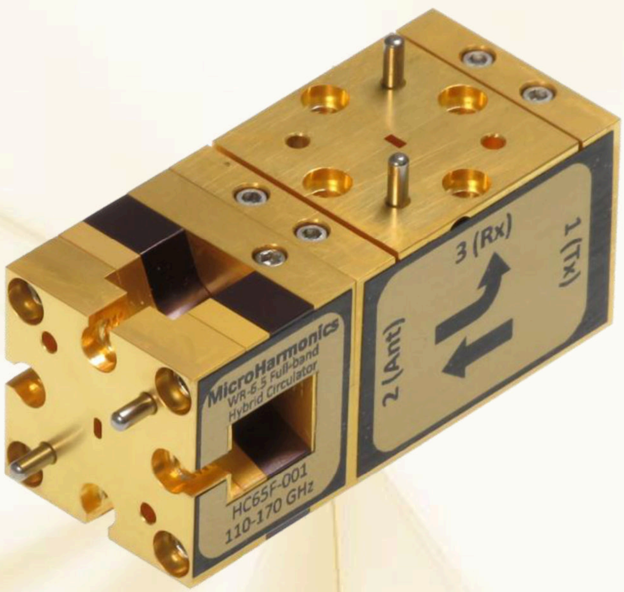
Micro Harmonics

mm-Wave Ferrite Components
25-400 GHz

New! D Band 110-170 GHz Hybrid Circulator



Micro Harmonics Corporation
20 S Roanoke St, Ste 202
Fincastle, VA 24090

Ph: 1+ 540.473.9983
Fax: 1+ 844.449.1561
microharmonics.com

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Introduction

Micro Harmonics specializes in the design and manufacture of advanced ferrite components including Faraday rotation isolators, hybrid circulators, voltage variable attenuators, cryogenic isolators, and Y-junction circulators. Our products cover every standard waveguide band from WR-28 (26-40 GHz) through WR-2.8 (260-400 GHz).

Why Choose Micro Harmonics Products?

Our products exhibit state-of-the-art performance in terms of low-insertion loss, broad-bandwidth, and the highest frequency coverage in the industry. We employ unique diamond heatsinks for improved power handling and reliability. Our patented hybrid circulators offer unprecedented bandwidths at mm-wave frequencies. Our compact variable attenuators have a 35 dB dynamic range.

Every component is fully tested on a vector network analyzer to ensure compliance. All parts are thoroughly examined for dimensional tolerance. We do reliability testing (Belcore) and cryogenic cycling tests. We use nylon thread lockers to ensure that our components stay assembled in the field.

Our products are designed and manufactured in the United States. Many of our components were developed under NASA SBIR grants. Because of language in the congressional SBIR authorization, these products can be sole sourced for government acquisitions.

Many companies are engineering our components into their systems and seeing improvements in system performance. Their systems are getting smaller and better. Join the growing number of engineers and scientists across the globe who are using our components to unlock the full potential of their mm-wave and terahertz systems.

- **Lowest insertion loss**
- **Comprehensive test data**
- **Highest power rating**
- **25 GHz to 400 GHz**
- **Cryogenic options**
- **Extended bandwidth**
- **Resist stray magnetic fields**
- **Lightweight gold-plated aluminum**
- **Compact size**
- **Anti-cocking waveguide flanges**

Guarantee

No two mm-wave components have the same exact frequency response. Unique signatures arise from small misalignments and variations in the internal parts. The differences can be substantial. Max, Min, and typical specs are helpful, but what you need to see are the actual test data for the components you are buying. Micro Harmonics tests every component across the full waveguide band on a vector network analyzer. We supply the test data to the customer at no additional cost. Don’t settle for anything less.

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MicroHarmonics
Superior mm-Wave Components

Faraday Rotation Isolators

Micro Harmonics offers a complete line of Faraday rotation isolators covering 25-400 GHz in every standard waveguide band from WR-28 through WR-2.8. These isolators exhibit state-of-the-art performance in terms of low-insertion loss, broad-bandwidth, low port reflections, and the highest frequency coverage in the industry. They are the most advanced isolators on the market today.

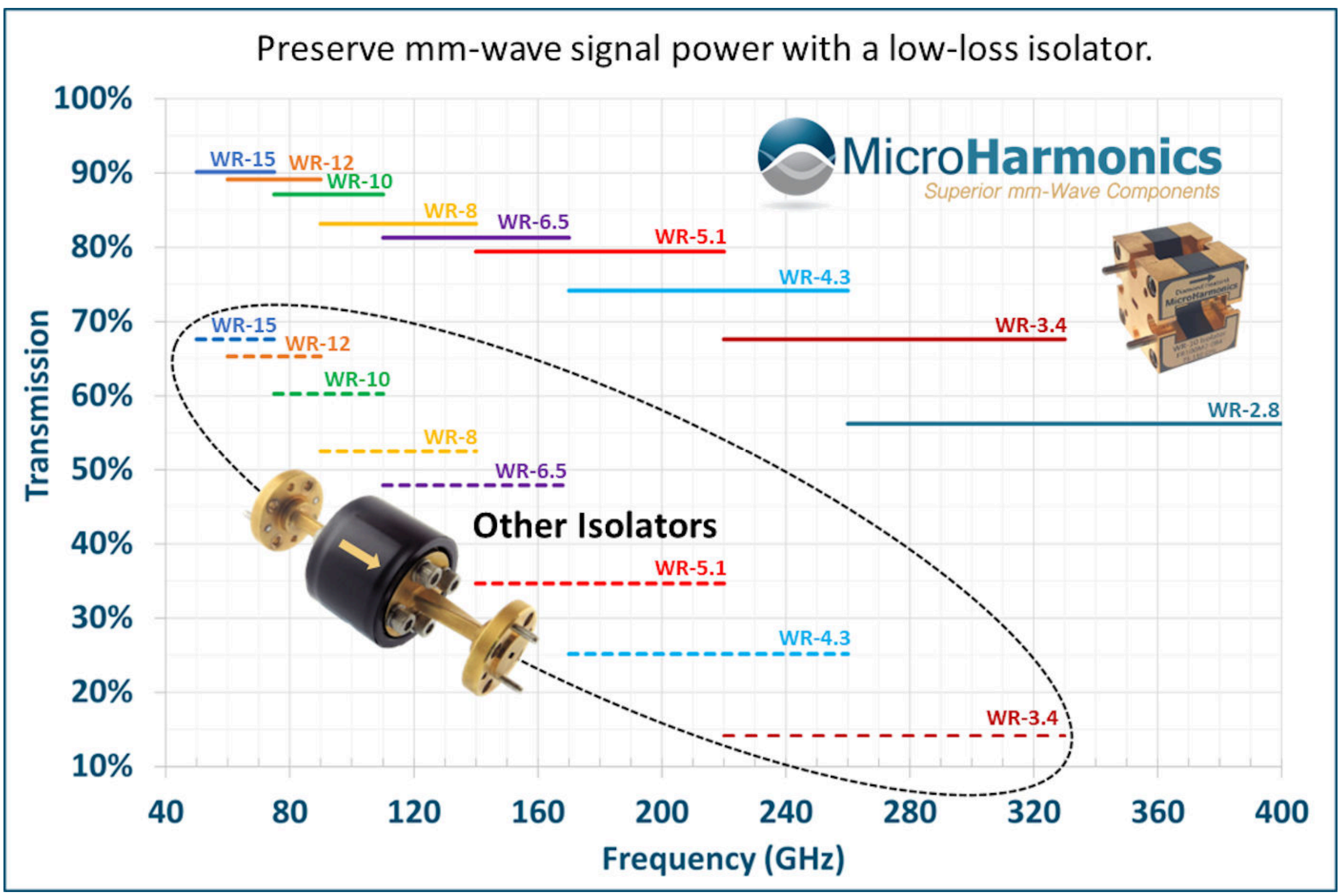
"The compact size, extremely low insertion loss, and the wide bandwidth have allowed us to use isolators in a wider variety of our systems than was previously possible and have led to significant improvements in key system performance metrics such as source power and sensitivity."

Jeffrey Hesler, Ph.D.
CTO, Virginia Diodes

"They had an isolator with the single most important parameter I needed, low insertion loss. They were ultimately able to select one with just 1.2 dB loss at 240 GHz, which is pretty phenomenal."

Curt Dunnam, Director of Operations
ACERT National Biomedical Center at Cornell

The graph below shows the insertion loss of our isolators as compared to other vendors. The insertion loss of our WR-3.4 isolator is only 2 dB! Don't waste valuable mm-wave signal power by using an isolator with high insertion loss. Join the many companies who are using our isolators in their systems and seeing tangible improvements in system performance.



Faraday Rotation Isolators

Model	Flange (EIA)	Band (GHz)	Insertion Loss (dB, typ)	Isolation (dB, typ)	Max Power† (W)
FR280	WR-28	26 - 40	0.5	25	5.0
FR188	WR-19	40 - 60	0.7	25	4.3
FR148	WR-15	50 - 75	0.7	25	3.8
FR122	WR-12	60 - 90	0.8	25	3.5
FR100	WR-10	75 - 110	0.8	25	2.9
FR090	WR-9	82 - 122	1.0	24	2.7
FR080	WR-8	90 - 140	1.0	25	2.4
FR065	WR-6.5	110 - 170	1.3	24	1.9
FR051	WR-5.1	140 - 220	1.5	23	1.3
FR043	WR-4.3	170 - 260	1.7	22	1.0
FR034	WR-3.4	220 - 330	2.3	22	0.6
FR028	WR-2.8	260 - 400	3.8	22	0.4

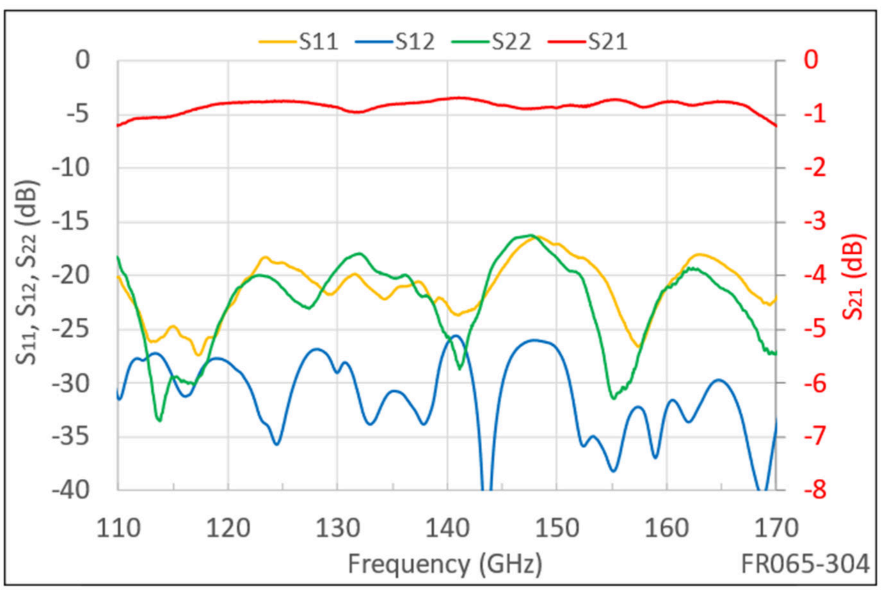
† See pages 6-8.

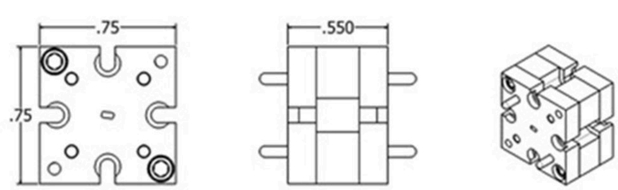
Isolator webpage

A typical specification sheet is shown below. Every component is thoroughly RF tested and the data for each individual component is shared with the customer. Our isolators employ a unique diamond heatsink for improved power handling and reliability. Our isolators are resistant to stray magnetic fields. We use anti-cocking waveguide flanges. All our products are fully guaranteed. We design and manufacture all our products in the United States.

Model: FR065

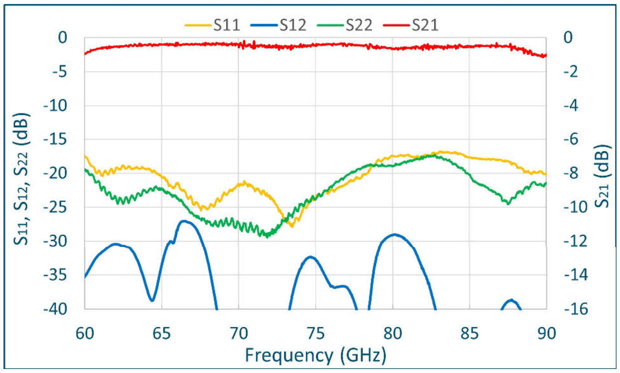
Specifications	
Flange	WR-6.5 UG-387/UM
Frequency (GHz)	110-170
Insertion Loss (dB, avg)	0.9
Insertion Loss (dB, max)	1.8
Isolation (dB, typ min)	23
Input RL (dB, typ min)	16
Output RL (dB, typ min)	17
VSWR (typ max)	1.35:1
Maximum Power (W)	1.9
Diamond Heatsink	Yes



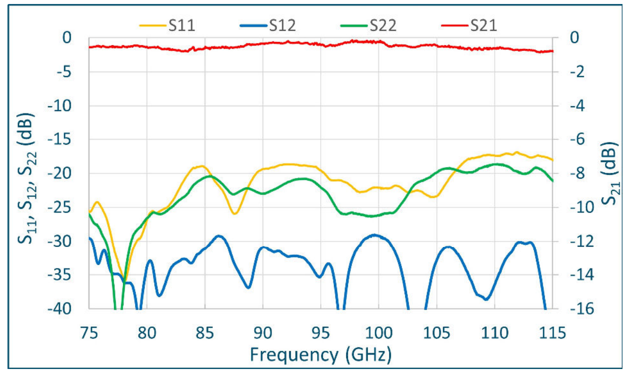


Faraday Rotation Isolators – Sample Test Data

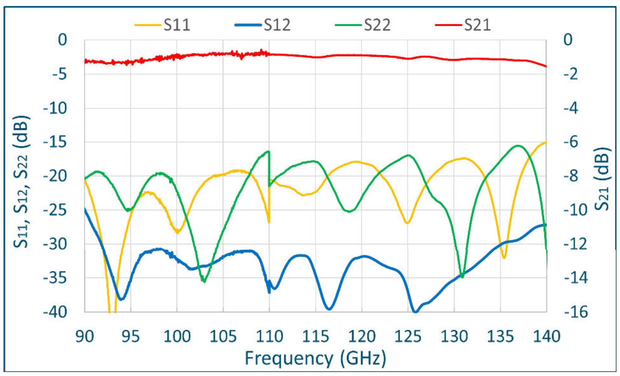
FR122: 60-90 GHz



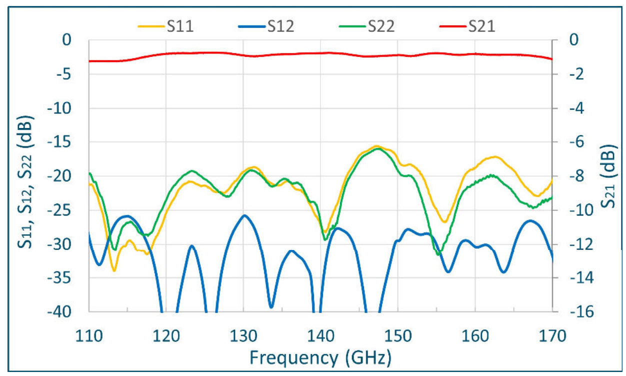
FR100: 75-110 GHz



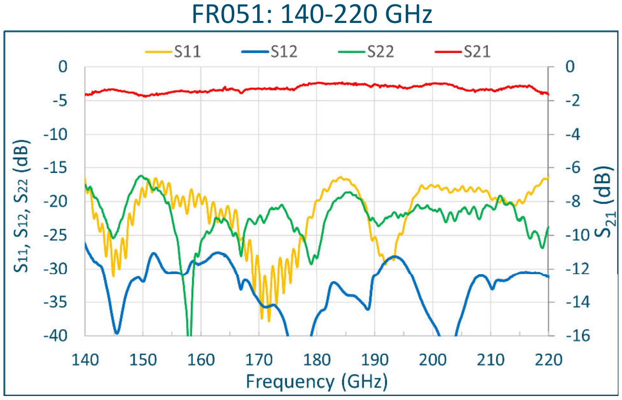
FR080: 90-140 GHz



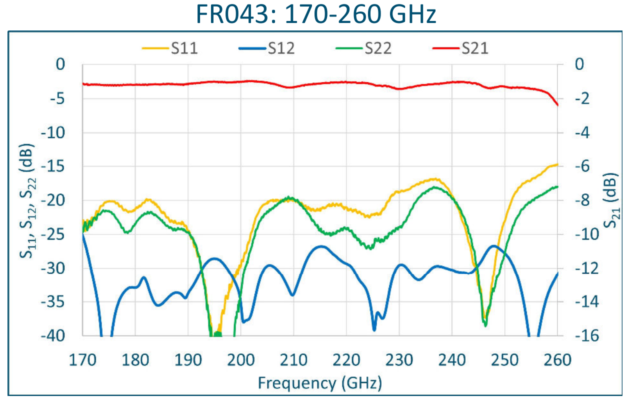
FR065: 110-170 GHz



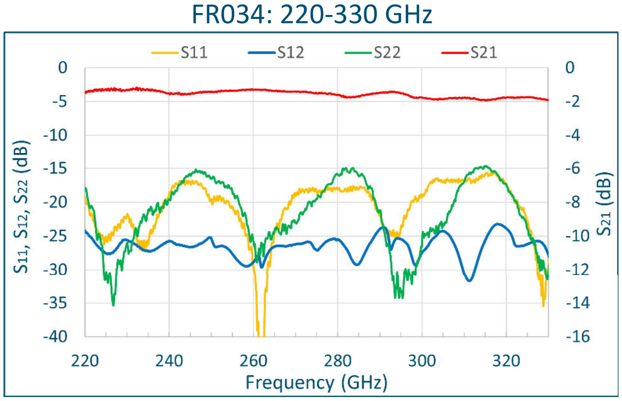
FR051: 140-220 GHz



FR043: 170-260 GHz



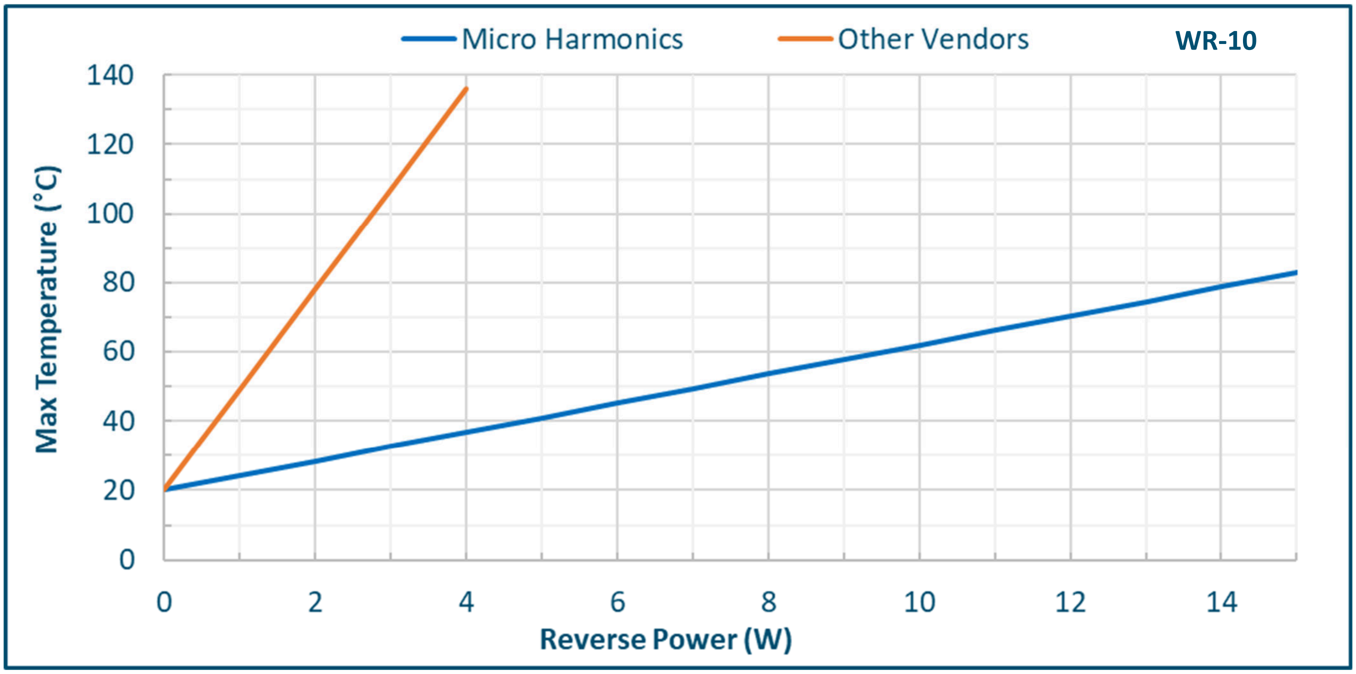
FR034: 220-330 GHz



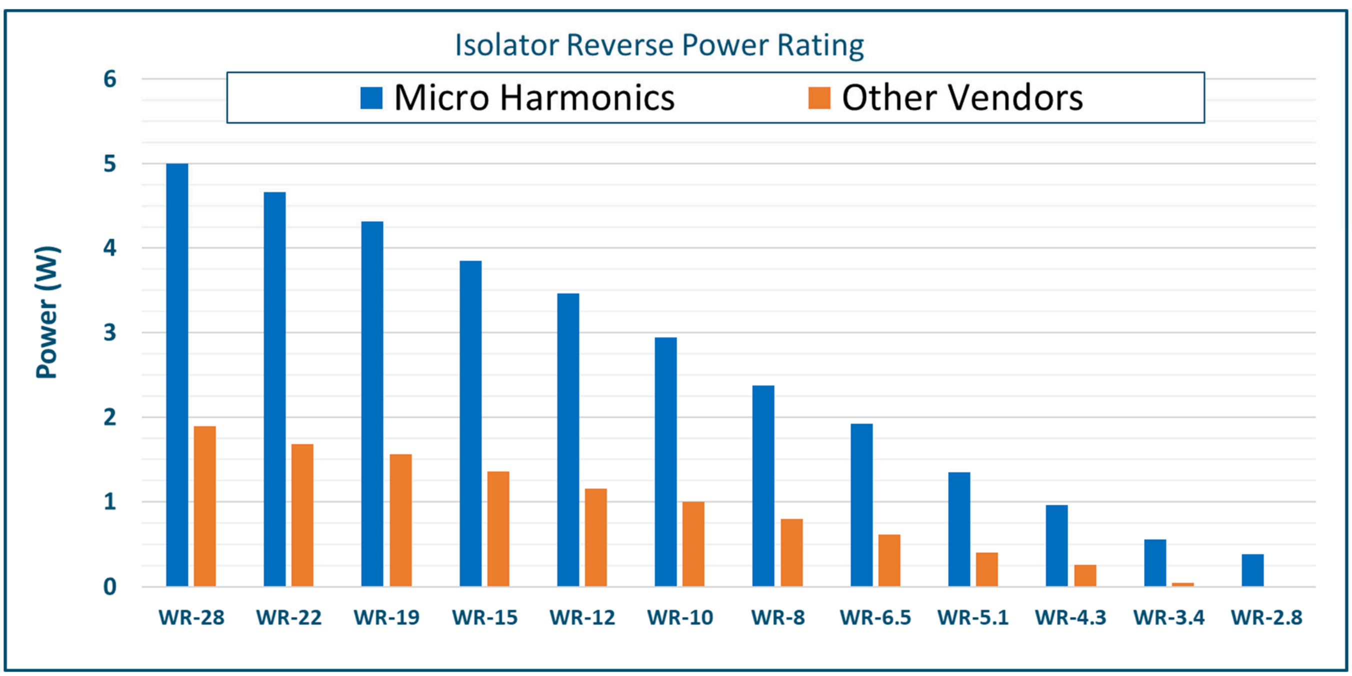
"We had a WR-3.4 isolator from Micro Harmonics on the shelf. We plugged it in and got fantastic results. High isolation was extremely important... We were also starved for power because our transmitter was weak, and we were really pleased with the low insertion loss the isolator provided which allowed us to get the maximum signal to noise."

James Greenberg, Ph.D.
Research Scientist/Program Manager
IMRA

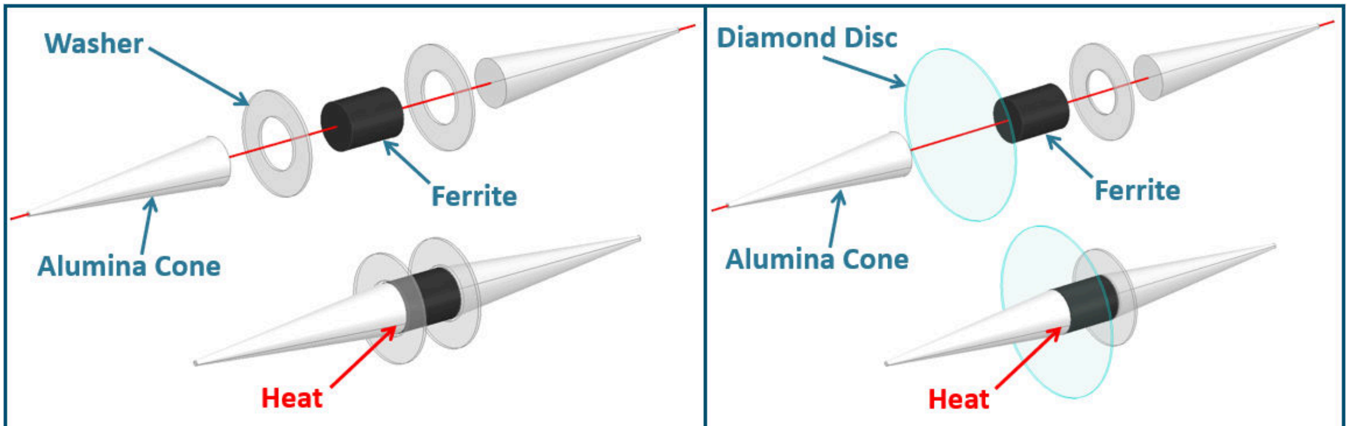
Isolator Power Ratings - In a Faraday rotation isolator, reverse power is absorbed in a resistive layer and converted to heat energy. In the legacy isolators sold by other vendors, the resistive layer can get hot because it is thermally isolated. But Micro Harmonics isolators employ a diamond disc that provides an excellent path to conduct heat from the resistive layer to the metal block. Data from our thermal simulations of WR-10 isolators are shown in the graph below. Simulations indicate a max temperature of 50°C in the legacy isolators at the rated power level of 1 W. A Micro Harmonics WR-10 isolator reaches 50°C when absorbing 7 W. See "Diamond Heatsink Technology" on pages 7-8 for more information.



The graph below shows the maximum reverse power ratings of our isolators and the average of other vendors. The MHC power ratings are conservative to ensure low temperatures and long life.



Diamond Heatsink Technology - Our isolators employ a unique diamond support disc that allows them to handle greater reverse power levels and operate at lower temperatures. At the heart of a Faraday rotation isolator are a pair of alumina cones and a ferrite rod. The cones are used to couple signals from the waveguides to the ferrite. The cones are bisected by a resistive layer along their central axis. In most commercial Faraday rotation isolators, the ferrite and cones are suspended by a pair of washer-shaped supports as shown in the left-side sketch below. The support material is typically BOPET, Styrene, a resin, or some other material with a low dielectric constant and low loss at mm-wave frequencies. These materials are generally in the class of thermal insulators and thus the cones and ferrite are thermally isolated from the metal block.

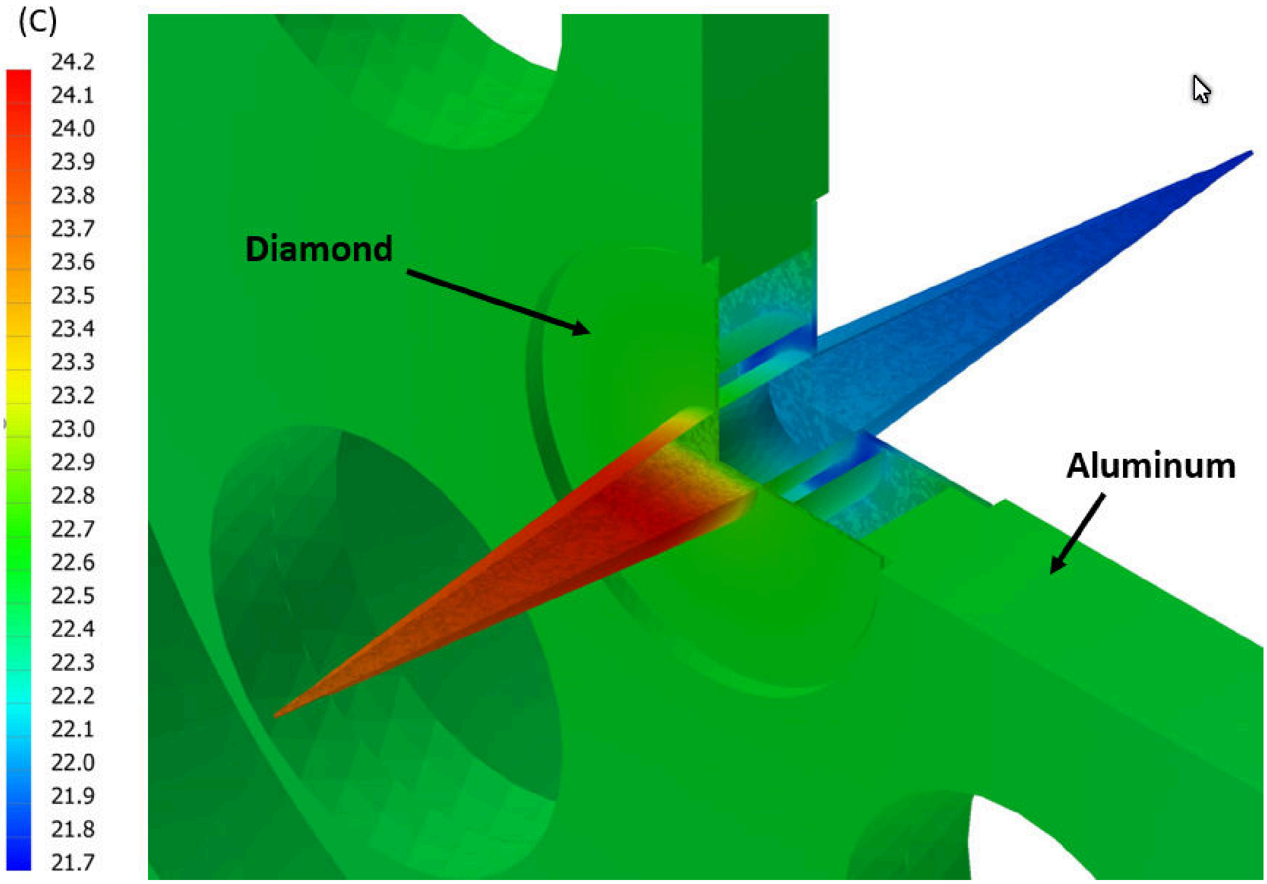


(a) Legacy isolator with thermally insulating supports. (b) Micro Harmonics isolator with diamond disc.

Signals entering the output port of the isolator pass through the ferrite rod and are absorbed in the resistive layer bisecting the input side alumina cone. The absorbed power is converted to heat energy. Very little of this heat energy can be channeled away by thermal conduction through the washer-shaped supports, rather it must be dissipated through a radiative process or by means of convection through the surrounding air. The resistive layers are thus subject to high heat levels and even damage if too much reverse power is incident on the device. Historically this was not an issue as there was very little power available at these frequencies. But as higher power sources are becoming available there is a renewed interest in the power ratings of these devices.

At Micro Harmonics we have replaced the input support washer with a uniform high-grade optical CVD diamond disc. The diamond disc does not have a hole at the center. Diamond is the ultimate thermal conductor approaching 2200 W/m·K, more than five times higher than copper. The diamond disc is sandwiched between the base of the input cone and the ferrite rod and is in intimate contact over the entire area of the cone base. This is the optimal location for the diamond disc since it is the region subject to the highest heat levels. The diamond disc is attached to the metal waveguide block over its periphery and provides an excellent conduit to channel heat away from the resistive layer. The thermal conduction path is clearly superior and thus our isolators operate at much lower temperatures.

The top graphic on the facing page shows the result of a thermal simulation of our WR-10 isolator. The resistive layer in the left side cone is treated as a heat source equivalent to the power absorbed from a 1 W RF signal. The maximum temperature is 24°C in the left side cone. No thermal gradient appears across the diamond disc. The high thermal conductivity of the diamond disc effectively ties the cone base to the aluminum block temperature. A 7 W RF source gives a max temperature of 50°C in our WR-10 model.



Micro Harmonics isolator power ratings webpage.

Thermal simulations indicate a maximum reverse power rating of 7 W for our WR-10 isolators. But we have taken a conservative approach and set the maximum reverse power rating at 2.9 W. When a Micro Harmonics WR-10 isolator absorbs a 2.9 W signal travelling in the reverse direction, the maximum temperature should not exceed 10°C above the ambient waveguide block temperature. In contrast, the simulations indicate a max temperature of 80°C above ambient for a legacy isolator absorbing 2.9 W.

The QR code to the left will take you to our power rating webpage where we provide a more in-depth look at our thermal models and how we use them to establish power ratings for our isolators.

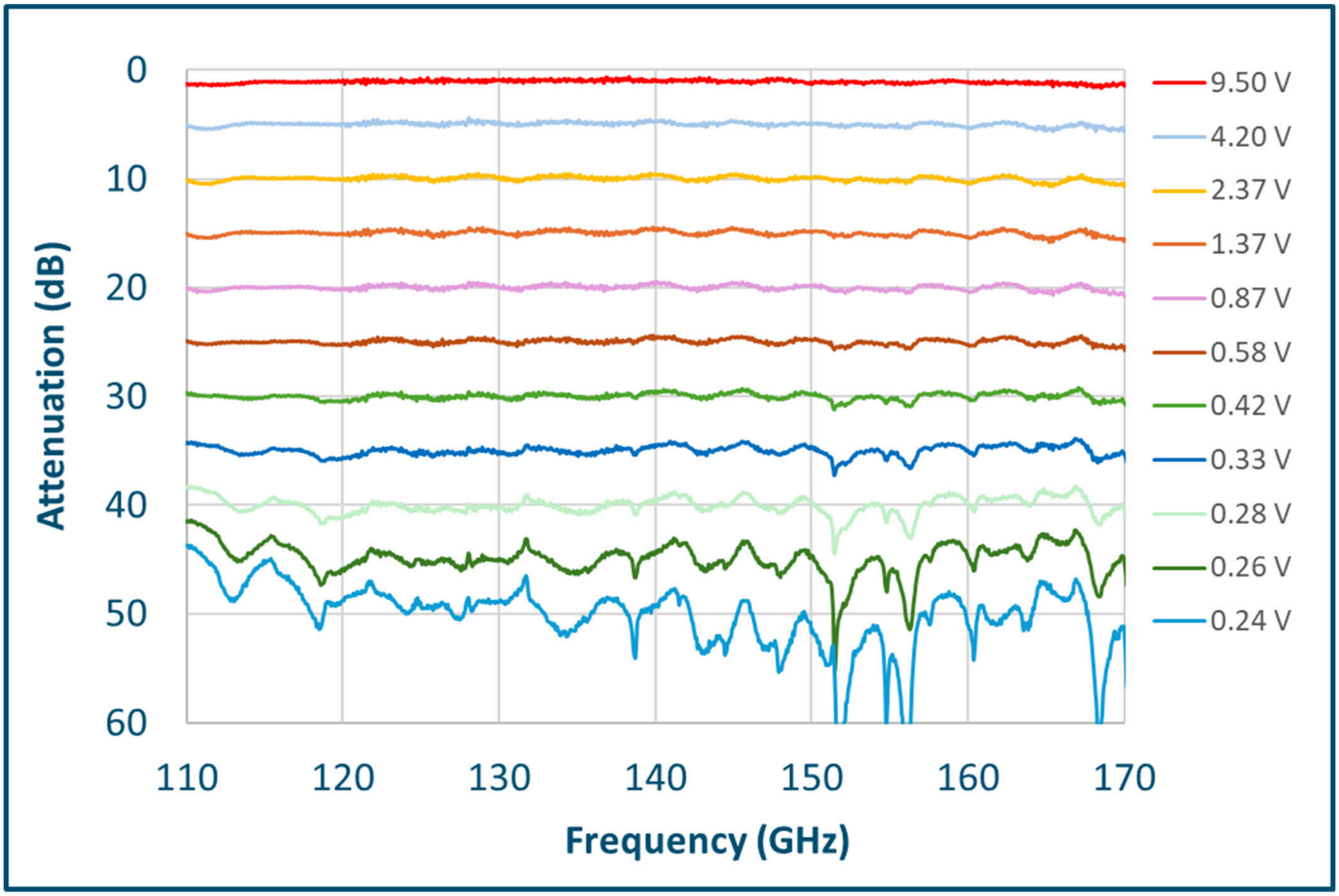
Micro Harmonics Isolators are Insensitive to Stray Magnetic Fields

Have you seen the label on the legacy isolator that warns you to keep it away from magnetic fields? You will not find that label on a Micro Harmonics isolator because our isolators are highly resistant to external magnetic fields. The legacy isolators use a highly tuned magnetic field that is easily perturbed by even a small external magnetic field. This causes under- or over-rotation of the signal and severe performance degradation. Micro Harmonics isolators use a highly saturated magnetic bias field which makes them insensitive to stray magnetic fields. The phenomenon is explained in more detail in an article published in the April 2021 edition of the Microwave Journal.

Microwave Journal article on stray magnetic fields.

Voltage Variable Attenuators

Our attenuators use Faraday rotation in a ferrite rod to rotate an RF signal into a fixed resistive vane. The attenuation level is set using a simple DC voltage in the range from 0 - 9.5 V. They are configured so that maximum attenuation is achieved at 0 V bias. Models are currently available at WR-10 and WR-6.5 with additional models planned for every band from WR-15 through WR-3.4. Measured data from our D-band WR-6.5 attenuator is shown below. The dynamic range is more than 35 dB. The WR-6.5 attenuator has a power rating of 1.5 W. Our attenuator has a flatter response, higher return loss, higher power handling, higher dynamic range, and higher frequency coverage than a PIN attenuator.

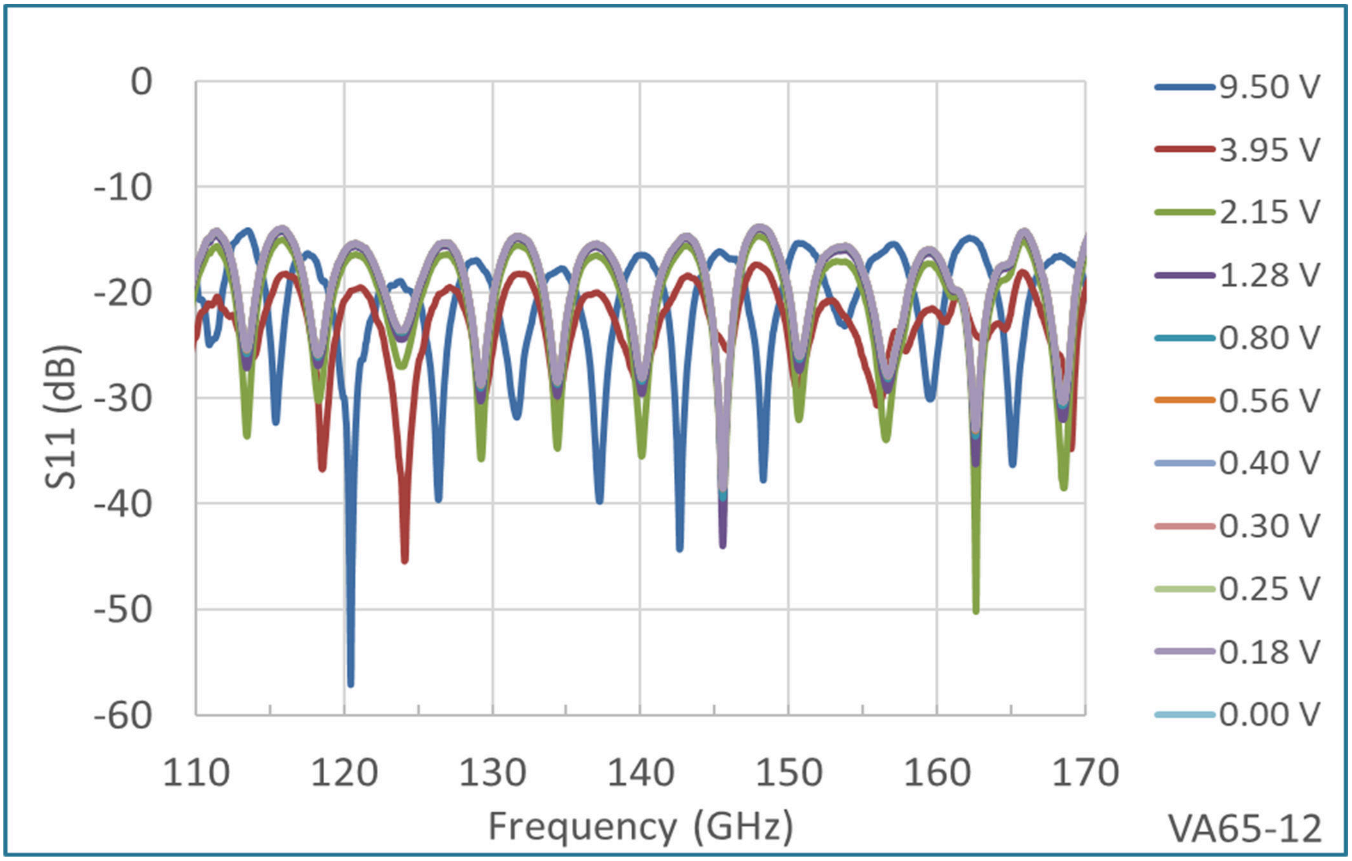


WR-6.5 attenuator

Our WR-6.5 attenuator is shown to the left. The attenuator is lightweight and compact with the main body measuring (0.75 x 0.75 x 1.2 inch) (19 x 19 x 30 mm). The small size makes the attenuator very easy to fit into millimeter-wave systems. A DC control voltage is applied through an SMP (M) connector.

Attenuator page

An important advantage of the ferrite attenuator is the relatively low port reflections. The graph below shows measured reflections on Port 1 at the various attenuation levels of the WR-6.5 attenuator. The reflections are less than -14 dB across the band for every attenuation level. This compares favorably to the port reflections found on PIN attenuators which can approach -5 dB.



Our ferrite attenuator is compact, lightweight, and has no moving parts. The technology is passive and insensitive to ESD damage. CVD diamond discs are used to channel heat away from the ferrite rods and resistive vanes which enables our ferrite attenuators to handle significantly higher power levels than PIN attenuators. The table below shows a comparison of insertion loss, return loss (port reflections), and maximum power for both our ferrite attenuators and the PIN attenuators offered by other vendors. The comparison is shown for the mm-wave bands from WR-10 through WR-3.4.

Comparison of PIN Diode Attenuators and Ferrite Attenuators.

Band		Frequency Range (GHz)			Insertion Loss (dB)			Return Loss (dB)			Max Power (W)	
		PIN	Ferrite		PIN	Ferrite		PIN	Ferrite		PIN	Ferrite
WR-3.4			**220-330**			**2.7**			**14**			**0.4**
WR-4.3			**170-260**			**2.5**			**14**			**0.7**
WR-5.1			**140-220**			**2.3**			**14**			**1.0**
WR-6.5		110-145	**110-170**		5	**2.0**		6	**14**		0.006	**1.5**
WR-8		90-140	90-140		4	**1.8**		6	**14**		0.006	**1.8**
WR-10		75-110	75-110		4	**1.5**		6	**14**		0.100	**2.3**

Note: Green numbers indicate a substantial advantage for the ferrite attenuator.

MicroHarmonics
Superior mm-Wave Components

Hybrid Circulators

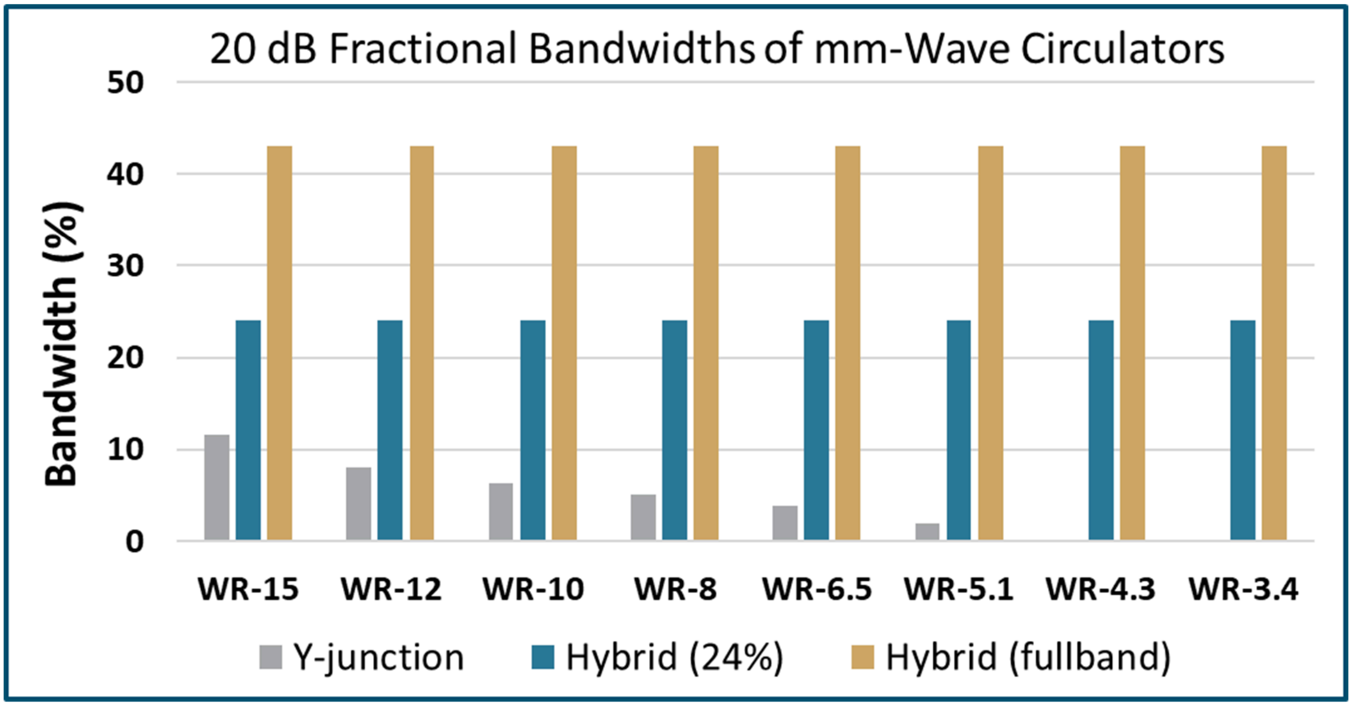
Micro Harmonics markets two types of broadband mm-wave hybrid circulators. One type has a 24% fractional bandwidth and is available in every standard waveguide band from WR-15 through WR-3.4 as indicated in the table below. The second type is designed to cover full rectangular waveguide bands having fractional bandwidths in excess of 40%. The first prototype of the full band model was recently tested in the WR-6.5 band. Additional full band models are planned for development in every band from WR-15 to WR-3.4.

Hybrid circulators

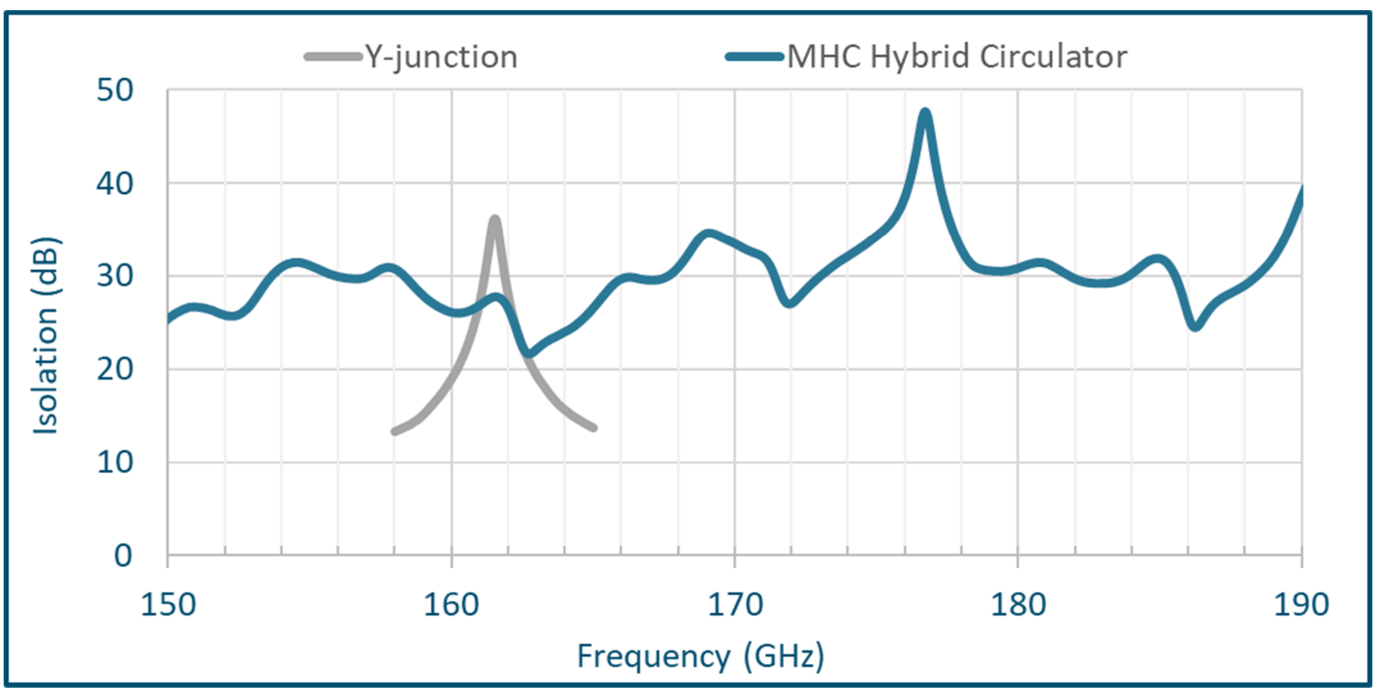
Flange (EIA)		Model Name (24%)	Frequency (GHz)		Model Name (40%)	Frequency (GHz)
WR-15		**HC148**	**54 - 68**		**HC148F**	**50 – 75**
WR-12		**HC122**	**70 - 86**		**HC122F**	**60 – 90**
WR-10		**HC100**	**85 - 104**		**HC100F**	**75 – 110**
WR-8		**HC080**	**107 - 133**		**HC080F**	**90 – 140**
WR-6.5		**HC065**	**118 - 150**		**HC065F**	**110 - 170**
WR-5.1		**HC051**	**150 - 190**		**HC051F**	**140 - 220**
WR-4.3		**HC043**	**196 - 250**		**HC043F**	**170 - 260**
WR-3.4		**HC034**	**258 - 330**		**HC034F**	**220 - 330**
Blue: Models currently available.				**Gold: Models under development.**		

Historically, the Y-junction has been the most common type of circulator at mm-wave frequencies. A Y-junction comprises a ferrite core located at the convergence of three waveguides. At the higher mm-wave frequencies, the Y-junction has a narrow bandwidth and is difficult to tune. The theory of operation and architecture of the hybrid circulator are very different from the Y-junction. The hybrid circulator comprises a Faraday rotator and an orthomode transducer (OMT). Since both the Faraday rotator and OMT are inherently broadband, the hybrid circulator is also broadband. A comprehensive technical description is given by D. W. Porterfield, "Broadband Millimeter-Wave Hybrid Circulators," *IEEE Trans. Microw. Theory Techn.*, vol. 71, no. 8, pp. 3501-3507, Aug. 2023. The hybrid circulator technology is patent pending. Please visit our website for more information.

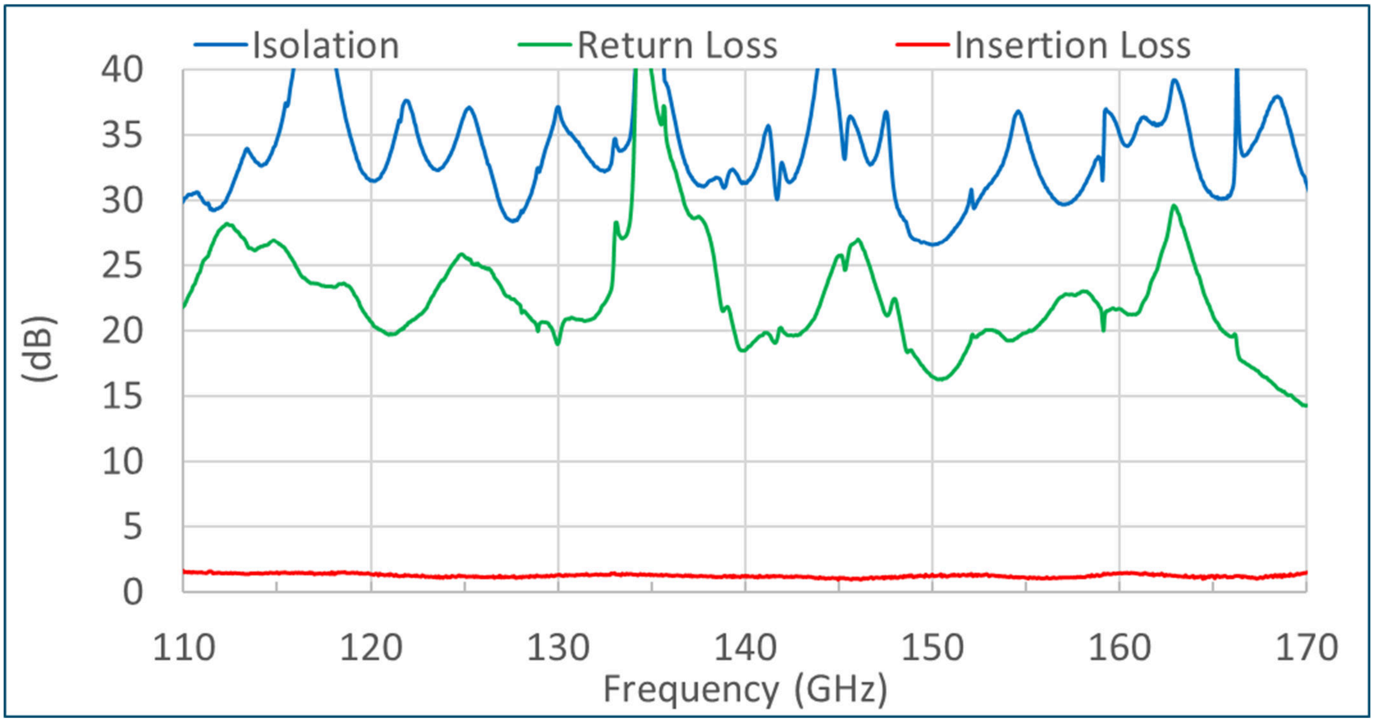
The bar chart below shows fractional bandwidths for the hybrid circulators and Y-junction circulators. The bandwidth of the Y-junction circulator steadily drops as the frequency increases, approaching only 2% at 160 GHz. We define the 20 dB bandwidth as the band over which the isolation between circulator ports is more than 20 dB.

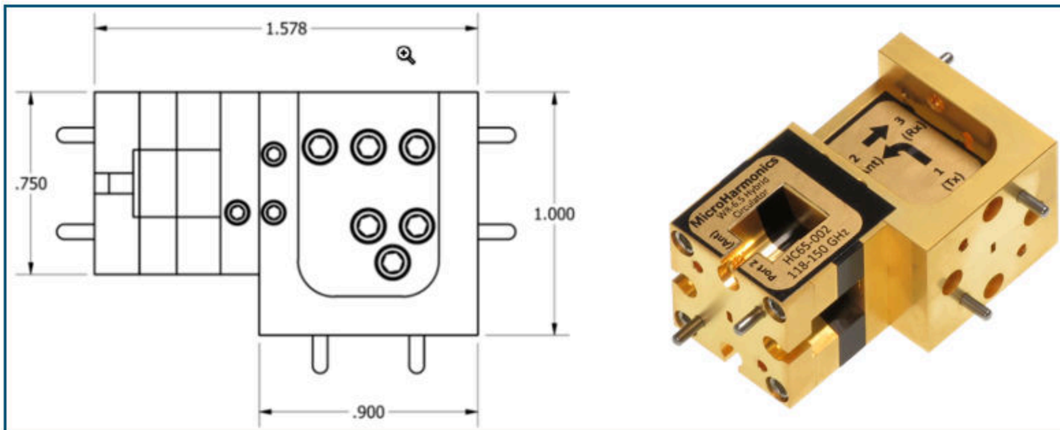


Sample test data from one of our WR-5.1 hybrid circulators are shown in the lower graph along with test data from a Y-junction circulator for comparison. This hybrid model is designed for 24% bandwidth. The insertion loss of our WR-5.1 hybrid circulator is less than 2.2 dB.

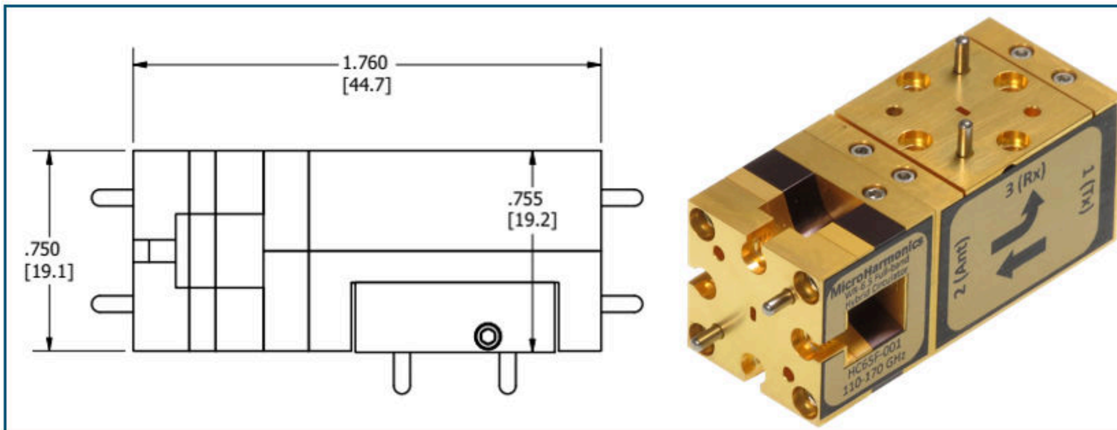


Measured data for the full band WR-6.5 hybrid circulator are shown in the graph below. Isolation is greater than 20 dB. Return loss is greater than 15 dB. Insertion loss is less than 1.5 dB across most of the band. This level of performance has never been achieved before in a D band circulator.





HC065
WR-6.5
(24%)



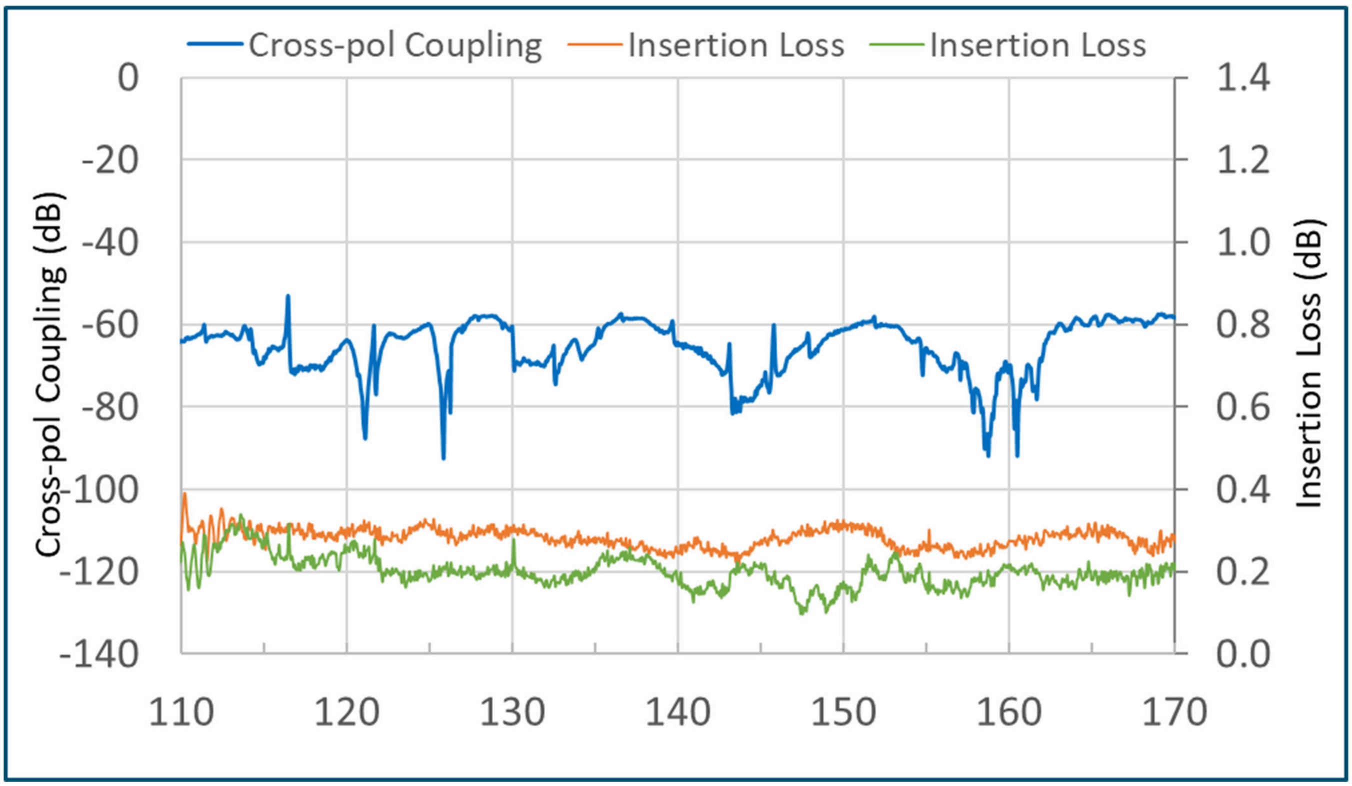
HC065F
WR-6.5
(> 40%)

MicroHarmonics
Superior mm-Wave Components

Orthomode Transducers

Our orthomode transducers (OMTs) cover full waveguide bands. The common mode waveguide is square. Over the next three years we will develop these OMTs in every standard waveguide band from WR-15 to WR-3.4.

The graph shows measured data from our WR-6.5 OMT. The orange and green traces show insertion loss at less than 0.4 dB across the band. The blue trace shows cross-polarization coupling at -60 dB between the single mode ports and the opposite polarity in the common mode port.



Y-junction Circulators

At Micro Harmonics, the Y-junction circulator is being replaced by the broad band hybrid circulator (see pages 11-13). But for narrow bandwidth applications, we continue to offer a line of Y-junction circulators covering sub-bands within the WR-15, WR-12, WR-10, and WR-8 bands (50-140 GHz). These circulators exhibit state-of-the-art performance in terms of high isolation, low-insertion loss, and low port reflections. Check our website for stock models. Special order designs optimized for specific sub-bands are considered on a case-by-case basis.

Y-junction circulators

Cryogenic Isolators

It is a common misconception that isolators designed to work at room temperature will work reasonably well at cryogenic temperatures. The problem is that the ferrite materials have a strong temperature dependence that impacts the signal rotation. This can cause significant over-rotation of the signal and severely degrade performance at cryogenic temperatures.

"We tried using regular isolators from one vendor. We cooled them down and assumed they would work, but they weren't behaving right."

Alexander Anferov, GRA
Shuster Lab, University of Chicago

"We can get down to less than 100 Kelvins with commercially available cryo-coolers…Our biggest challenge was finding an isolator that could perform at those temps. Fortunately for us, a company called Micro Harmonics had just designed some specifically for NASA."

Dana Wheeler, President
Aerowave, Inc.

At Micro Harmonics we have developed a line of isolators designed for optimal performance at cryogenic temperatures. The ferrite is biased in magnetic saturation for minimal insertion loss, and the length of the ferrite rod is optimized to achieve the desired rotation at cryogenic temperatures.

Sophisticated models are constructed to simulate the thermal stress levels throughout the isolator as it is cooled. Materials are chosen that reduce thermal stress. Reliability is verified through repeated thermal cycling in a liquid nitrogen bath. Our isolators are built to withstand the rigors of repeated cryogenic cycling.

Our cryogenic isolators are routinely tested at 25 K in our cryostat. We use a resistive thin film for isolation that is not in the class of super conductors. The performance has been independently verified down to 1 K by researchers at the University of Chicago and at the Smithsonian Astrophysical Observatory.

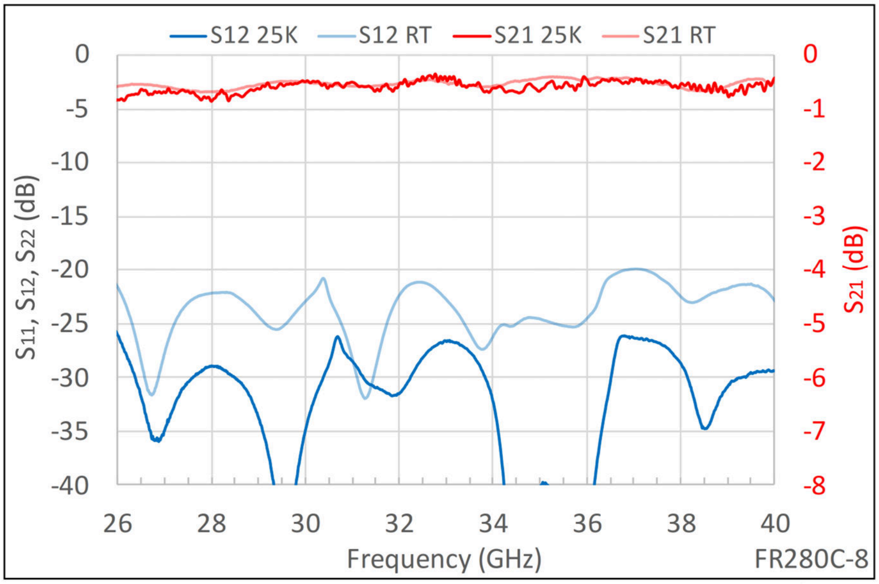
Eight models of the cryogenic isolator are now available as indicated in the Table below. These models cover most frequencies from 26 GHz to 220 GHz. Models at WR-4.3 and WR-3.4 will be added pending customer demand.

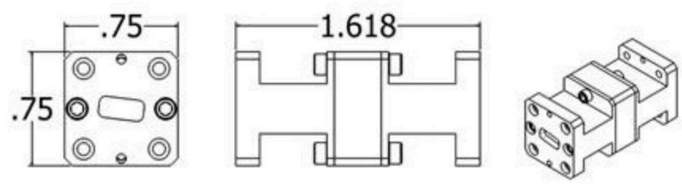
Cryogenic Isolators

Model	Flange	Band (GHz)	Insertion Loss (dB, typ @ 25 K)	Isolation (dB, typ @ 25 K)
FR280C	WR-28	26 - 40	0.5	25
FR148C	WR-15	50 - 75	0.5	28
FR122C	WR-12	60 - 90	0.7	25
FR100C	WR-10	75 - 110	0.5	30
FR090C	WR-9	82 - 122	0.5	30
FR080C	WR-8	90 - 140	0.7	27
FR065C	WR-6.5	110 - 170	0.9	23
FR051C	WR-5.1	140 - 220	1.2	23

Model: FR280C

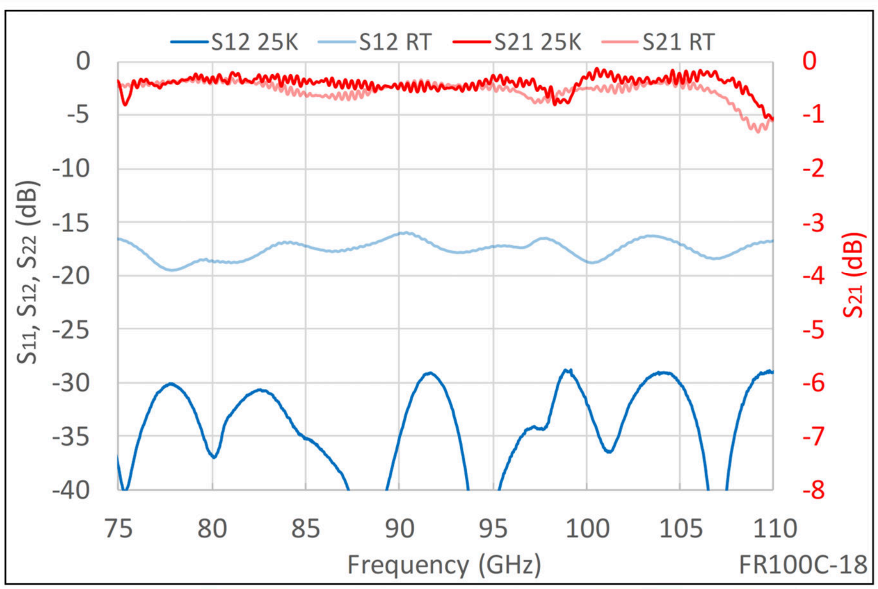
Specifications	
Flange	WR-28 UG 599/U
Frequency (GHz)	26.5-40
Insertion Loss (dB, avg)	
@ 25K	0.6
@ Room Temperature	0.5
Isolation (dB, typ min)	
@ 25K	24
@ Room Temperature	19
Input RL (dB, typ min)	17
Output RL (dB, typ min)	17
VSWR (typ max)	1.35:1
Maximum Power (W)	1.2

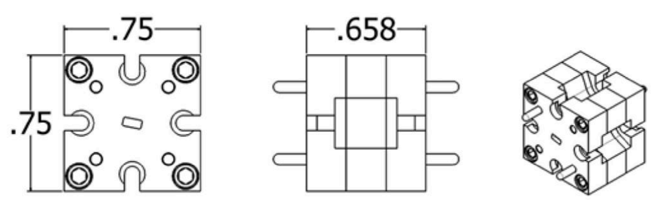




Model: FR100C

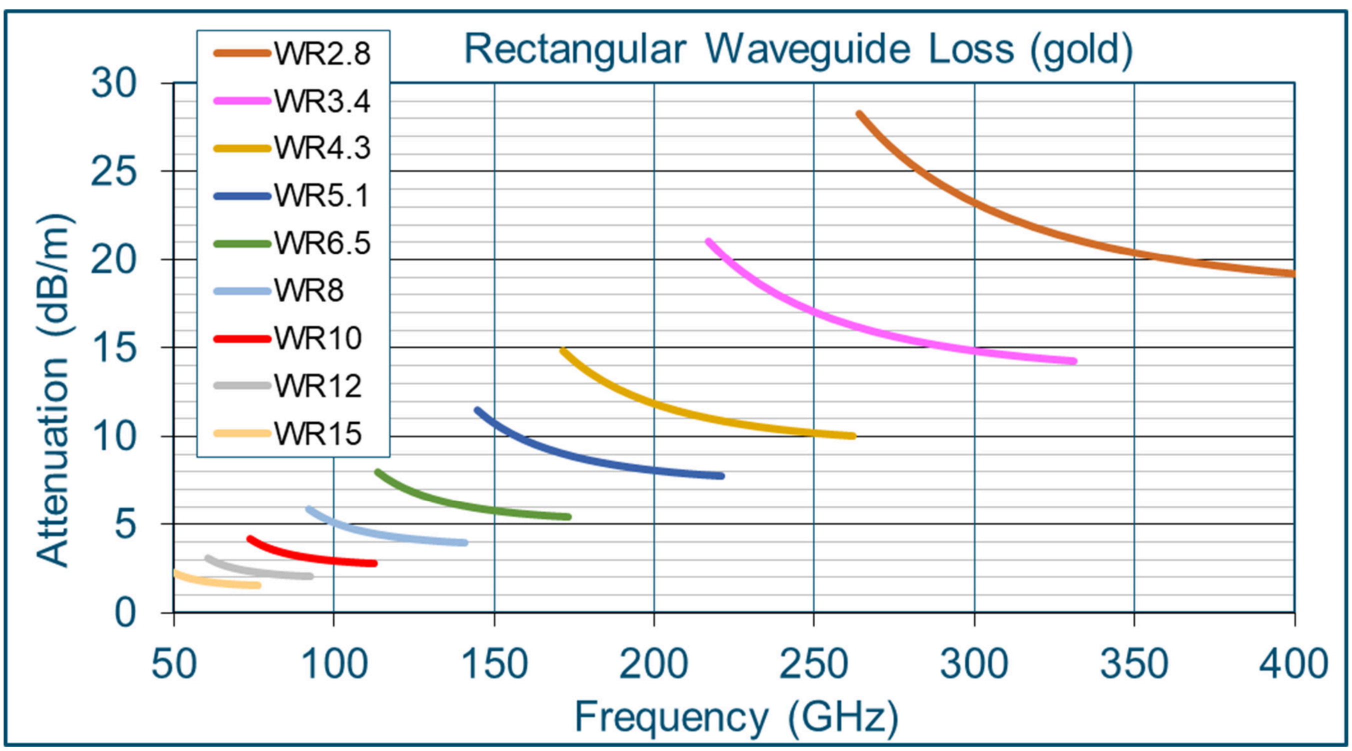
Specifications	
Flange	WR-10 UG387/UM
Frequency (GHz)	75-110
Insertion Loss (dB, avg)	
@ 25K	0.5
@ Room Temperature	0.6
Isolation (dB, typ min)	
@ 25K	24
@ Room Temperature	17
Input RL (dB, typ min)	18
Output RL (dB, typ min)	18
VSWR (typ max)	1.3:1
Maximum Power (W)	1.0



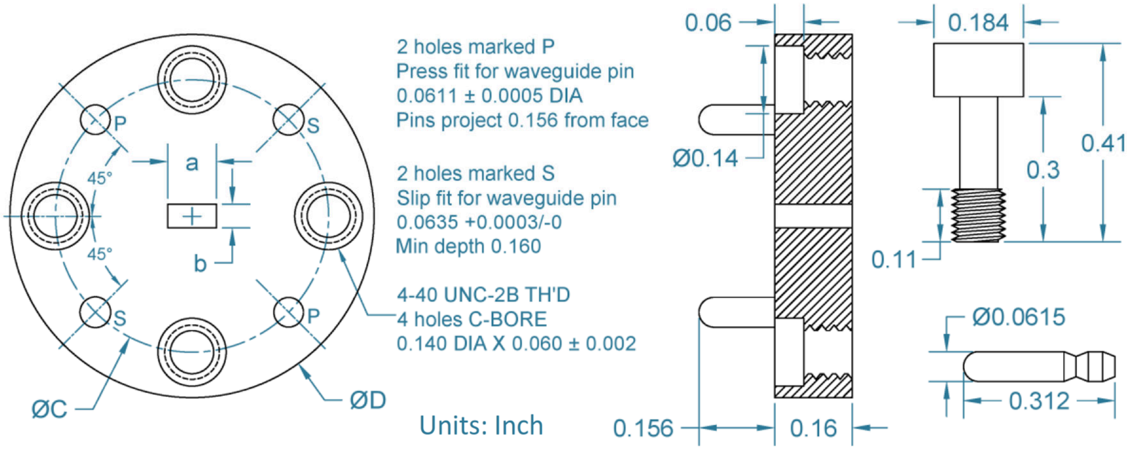


Insertion Loss –vs- Transmission Conversion Table

IL (dB)	T (%)	IL (dB)	T (%)	IL (dB)	T (%)	IL (dB)	T (%)	IL (dB)	T (%)	IL (dB)	T (%)
0.0	100.00	2.0	63.10	4.0	39.81	6.0	25.12	8.0	15.85	10.0	10.00
0.1	97.72	2.1	61.66	4.1	38.90	6.1	24.55	8.1	15.49	10.1	9.77
0.2	95.50	2.2	60.26	4.2	38.02	6.2	23.99	8.2	15.14	10.2	9.55
0.3	93.33	2.3	58.88	4.3	37.15	6.3	23.44	8.3	14.79	10.3	9.33
0.4	91.20	2.4	57.54	4.4	36.31	6.4	22.91	8.4	14.45	10.4	9.12
0.5	89.13	2.5	56.23	4.5	35.48	6.5	22.39	8.5	14.13	10.5	8.91
0.6	87.10	2.6	54.95	4.6	34.67	6.6	21.88	8.6	13.80	10.6	8.71
0.7	85.11	2.7	53.70	4.7	33.88	6.7	21.38	8.7	13.49	10.7	8.51
0.8	83.18	2.8	52.48	4.8	33.11	6.8	20.89	8.8	13.18	10.8	8.32
0.9	81.28	2.9	51.29	4.9	32.36	6.9	20.42	8.9	12.88	10.9	8.13
1.0	79.43	3.0	50.12	5.0	31.62	7.0	19.95	9.0	12.59		
1.1	77.62	3.1	48.98	5.1	30.90	7.1	19.50	9.1	12.30	0	100
1.2	75.86	3.2	47.86	5.2	30.20	7.2	19.05	9.2	12.02	10	10
1.3	74.13	3.3	46.77	5.3	29.51	7.3	18.62	9.3	11.75	20	1
1.4	72.44	3.4	45.71	5.4	28.84	7.4	18.20	9.4	11.48	30	0.1
1.5	70.79	3.5	44.67	5.5	28.18	7.5	17.78	9.5	11.22	40	0.01
1.6	69.18	3.6	43.65	5.6	27.54	7.6	17.38	9.6	10.96	50	0.001
1.7	67.61	3.7	42.66	5.7	26.92	7.7	16.98	9.7	10.72	60	0.0001
1.8	66.07	3.8	41.69	5.8	26.30	7.8	16.60	9.8	10.47	70	0.00001
1.9	64.57	3.9	40.74	5.9	25.70	7.9	16.22	9.9	10.23	80	0.000001

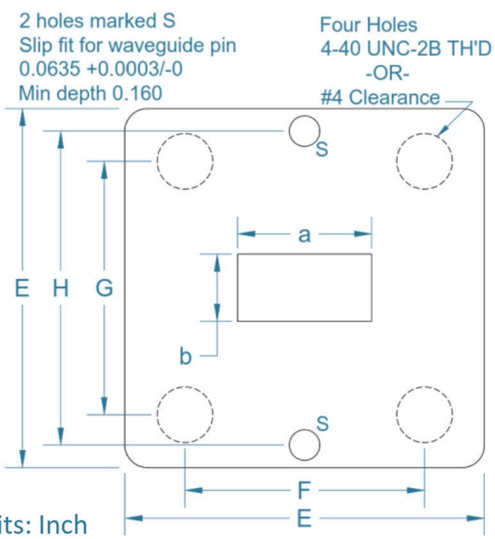


Anti-Cocking Round Waveguide Flanges



WR-	22	19	15	12	10	8	6.5	5.1	4.3	3.4	2.8
GHz	33 50	40 60	50 75	60 90	75 110	90 140	110 170	140 220	170 260	220 330	260 400
a	.224	.188	.148	.122	.100	.080	.065	.051	.043	.034	.028
b	.122	.094	.074	.061	.050	.040	.0325	.0255	.0215	.017	.014
ϕC	.9375		.5625								
ϕD	1.125		.750								

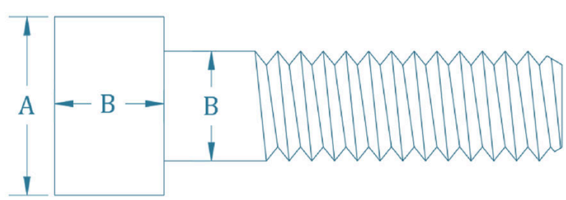
Square Waveguide Flanges



Units: Inch

WR	a	b	E	F	G	H
42	.420	.170	.875	.640	.670	.7500
28	.280	.140				
22	.224	.122	.750	.500	.530	.6562
19	.188	.094				

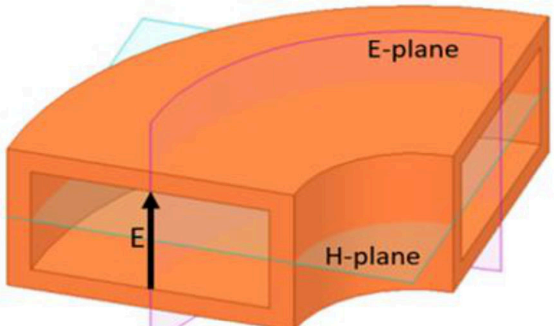
Cap-Head Screws



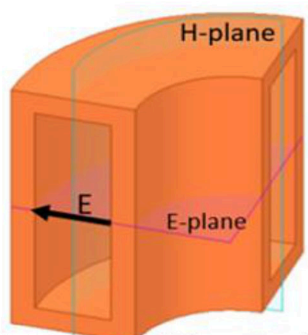
Size	Thread /inch	Head Dia. A	Body Dia. B	Tap Drill	Counter bore (inch)	Clearance Hole Close/Free
#0	80	.096	.060	3/64	1/8	.0635/.070
#1	72	.118	.073	#53	5/32	.076/.081
#2	56	.140	.086	#50	3/16	.089/.096
#4	40	.183	.112	#43	7/32	.116/.1285
#6	32	.226	.138	#36	9/32	.114/.1495
#8	32	.270	.164	#29	5/16	.1695/.177
#10	24	.312	.190	#25	3/8	.196/.201
1/4	20	.375	.250	#7	7/16	.257/.266

Rectangular Waveguide Chart

EIA WR- (##)	RCSC WG- (##)	IEEE WM- (####)	Band	Internal Dimension (mil)	Standard Frequency (GHz)	fc TE10 (GHz)	fc TE20 (GHz)	UG- (###/#)
42	20		K	420 x 170	17.5 - 26.5	14.1	28.2	
34	21			340 x 170	22.0 - 33.0	17.4	34.8	
28	22		Ka	280 x 140	26.5 - 40.0	21.1	42.2	599/U
22	23		Q	224 x 112	33.0 - 50.5	26.3	52.6	383/U
19	24		U	188 x 94	40.0 - 60.0	31.4	62.8	383/UM
15	25		V	148 x 74	50.5 - 75.0	39.9	79.8	385/U
12	26		E	122 x 61	60 - 90	48.4	96.8	387/U
10	27	2540	W	100 x 50	75 - 110	59	118	387/UM
8	28	2032	F	80 x 40	90 - 140	73.8	147.6	387/UM
6.5	29	1651	D	65 x 32.5	110 - 170	90.8	181.6	387/UM
5.1	30	1295	G	51 x 25.5	140 - 220	116	232	387/UM
4.3	31	1092	Y	43 x 21.5	170 - 260	137	274	387/UM
3.4	32	864	J	34 x 17	220 - 330	174	348	387/UM
2.8		710		28 x 14	260 - 400	211	422	387/UM
2.2		570		22 x 11	325 - 500	268	536	387/UM
1.9		470		19 x 9.5	400 - 600	311	622	387/UM
1.5		380		15 x 7.5	500 - 750	393	786	387/UM
1.2		310		12 x 6	600 - 900	492	984	387/UM
1.0		250		10 x 5	750 - 1100	590	1180	n/a
0.8		200		8 x 4	900 - 1400	738	1476	n/a
0.65		164		6.5 x 3.25	1100 - 1700	908	1816	n/a
0.51		130		5.1 x 2.55	1400 - 2200	1157	2314	n/a



H-Plane Bend



E-Plane Bend

VSWR/|Γ|/RL

VSWR	|Γ|	RL (dB)
1.065	0.0316	30
1.074	0.0355	29
1.083	0.0398	28
1.094	0.0447	27
1.1	0.0476	26.444
1.106	0.0501	26
1.119	0.0562	25
1.135	0.0631	24
1.152	0.0708	23
1.173	0.0794	22
1.196	0.0891	21
1.2	0.0909	20.828
1.222	0.1	20
1.253	0.1122	19
1.288	0.1259	18
1.3	0.1304	17.692
1.329	0.1413	17
1.377	0.1585	16
1.4	0.1667	15.563
1.433	0.1778	15
1.499	0.1995	14
1.5	0.2	13.979
1.577	0.2239	13
1.6	0.2308	12.736
1.671	0.2512	12
1.7	0.2593	11.725
1.785	0.2818	11
1.8	0.2857	10.881
1.9	0.3103	10.163
1.925	0.3162	10

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

$$RL = -20\log|\Gamma|$$

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MicroHarmonics
Superior mm-Wave Components

Micro Harmonics Corporation
20 S Roanoke St, Ste 202
Fincastle, VA 24090 USA
sales@mhc1.com
Ph: 1+ 540.473.9983
www.microharmonics.com