Micro Harmonics

mm-Wave Ferrite Components

25-400 GHz

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

Ph: 540.473.9983
Sales@mhc1.com
MicroHarmonics.com

June 2023

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 isolators to unlock the full potential of their MMW 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 MMW 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.

Table of Contents

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.

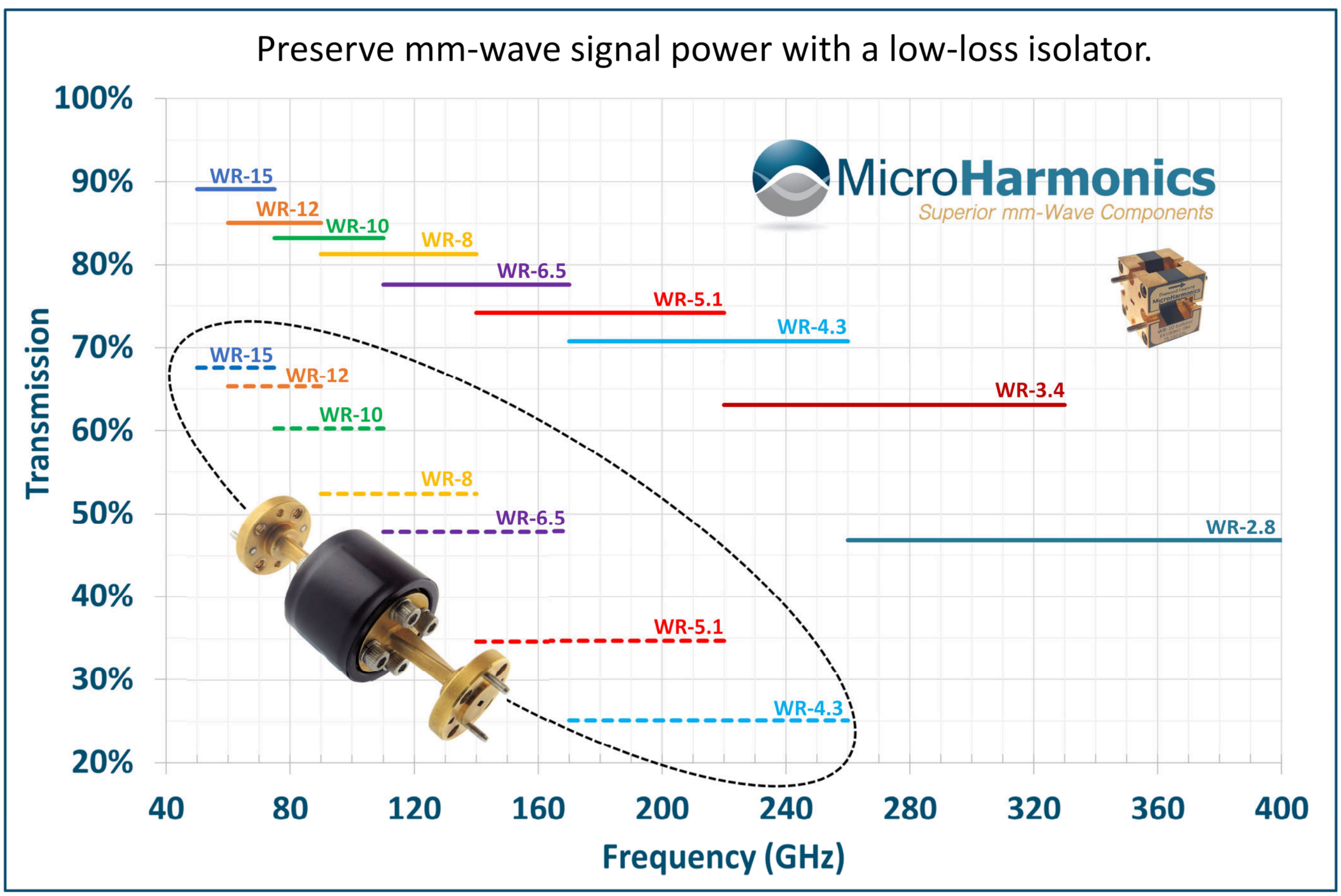
"The compact size, extremely low insertion loss, and the wide bandwidth have allowed us to use isolators in a wider variety of our systems than was previously possible and have led to significant improvements in key system performance metrics such as source power and sensitivity."

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	4.0
FR188*	WR-19	40 - 60	0.7	25	3.4
FR148M2*	WR-15	50 - 75	0.7	25	3.0
FR122M2*	WR-12	60 - 90	0.8	25	2.7
FR100M2*	WR-10	75 - 110	0.8	25	2.3
FR90	WR-9	82 - 122	1.0	24	2.1
FR80M2*	WR-8	90 - 140	1.0	25	1.8
FR65M2*	WR-6.5	110 - 170	1.3	24	1.5
FR51M2*	WR-5.1	140 - 220	1.5	23	1.0
FR43	WR-4.3	170 - 260	1.7	22	0.7
FR34M2*	WR-3.4	220 - 330	2.3	22	0.4
FR28*	WR-2.8	260 - 400	3.8	22	0.3

† See pages 6-8.

* These models have interior access to waveguide flange screws.

Isolator webpage

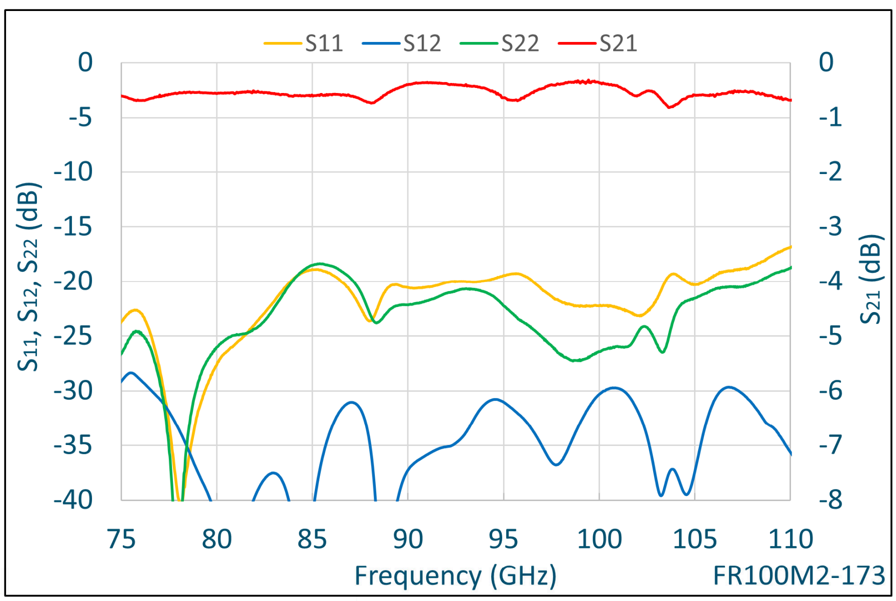
A typical specification sheet is shown below. Every component is thoroughly RF tested and the data for each individual component is shared with the customer. Our isolators employ a unique diamond heatsink for improved power handling and reliability. Our isolators are resistant to stray magnetic fields.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

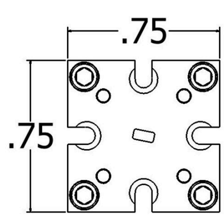
FR100M2

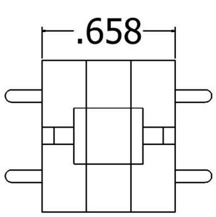
WR-10 waveguide isolator

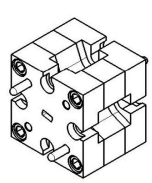
Specifications	
Flange	WR-10
Frequency (GHz)	75-110
Insertion Loss (dB, typ)	0.8
Insertion Loss (dB, max)	1.8
Isolation (dB, typ)	25
Input Return Loss (dB, typ)	20
Output Return Loss (dB, typ)	22
VSWR (max)	1.4:1
Maximum Power (W)	2.3
Diamond Heatsink	Yes

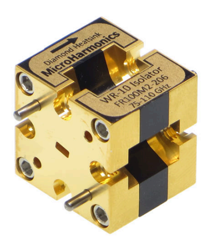
Every isolator is tested on a vector network analyzer to ensure conformity and the test data is provided.





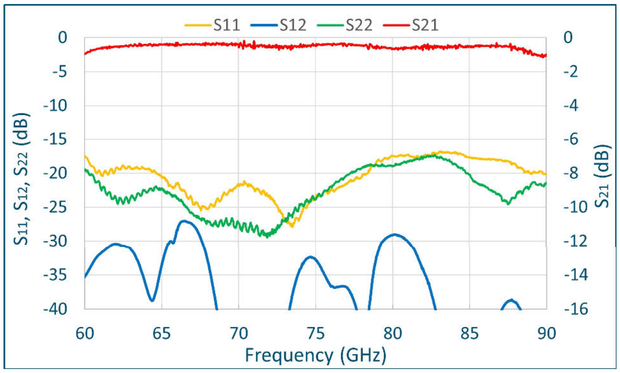




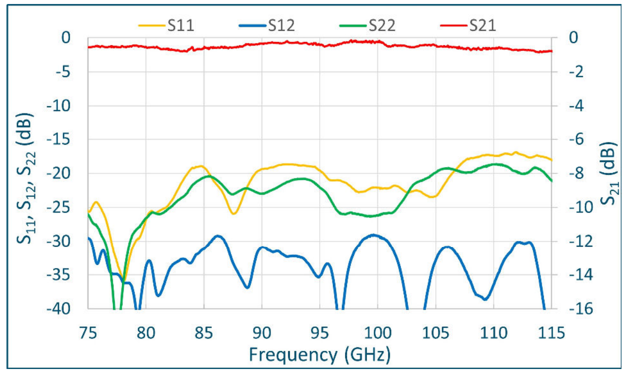


Faraday Rotation Isolators – Sample Test Data

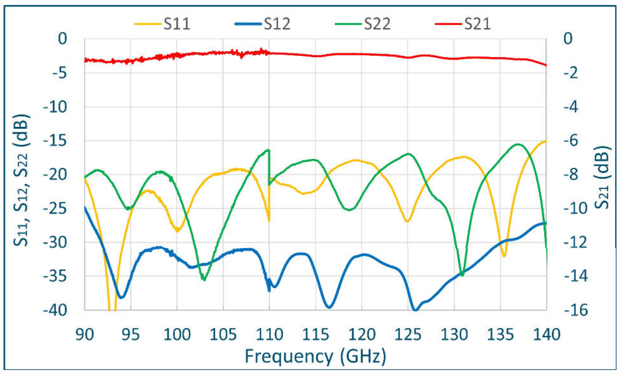
FR122: 60-90 GHz



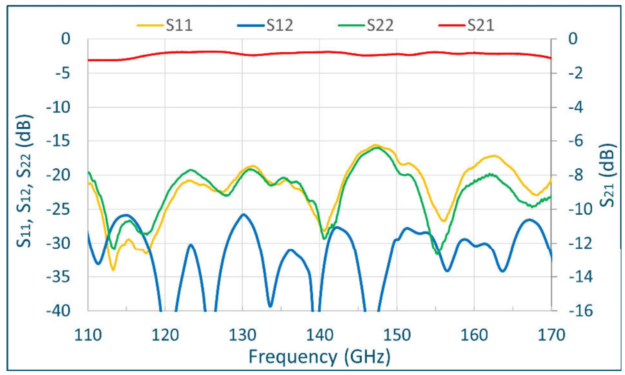
FR100M2: 75-110 GHz



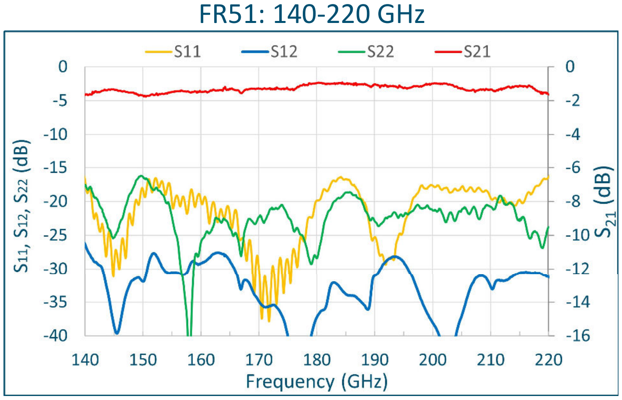
FR80: 90-140 GHz



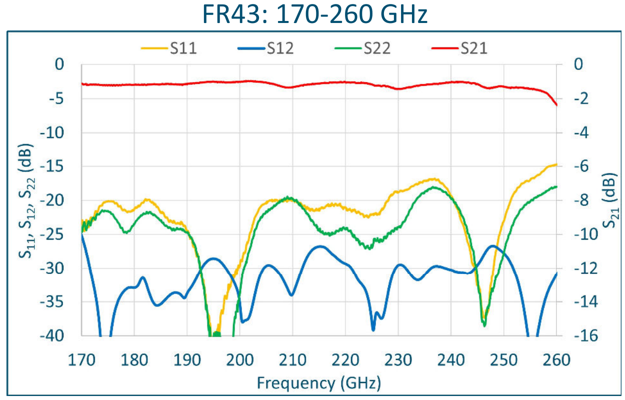
FR65: 110-170 GHz



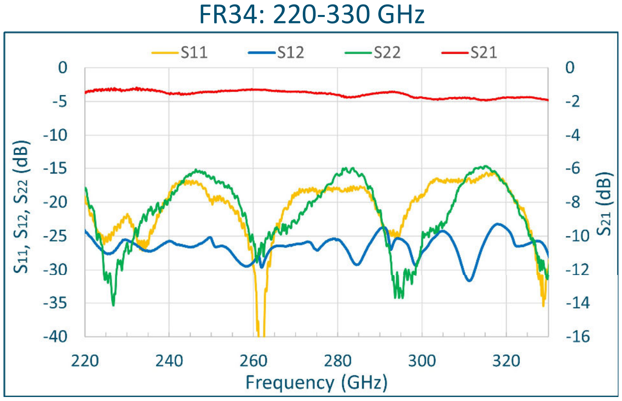
FR51: 140-220 GHz



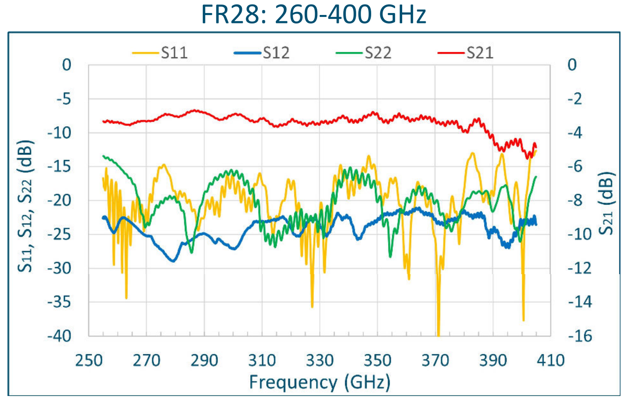
FR43: 170-260 GHz



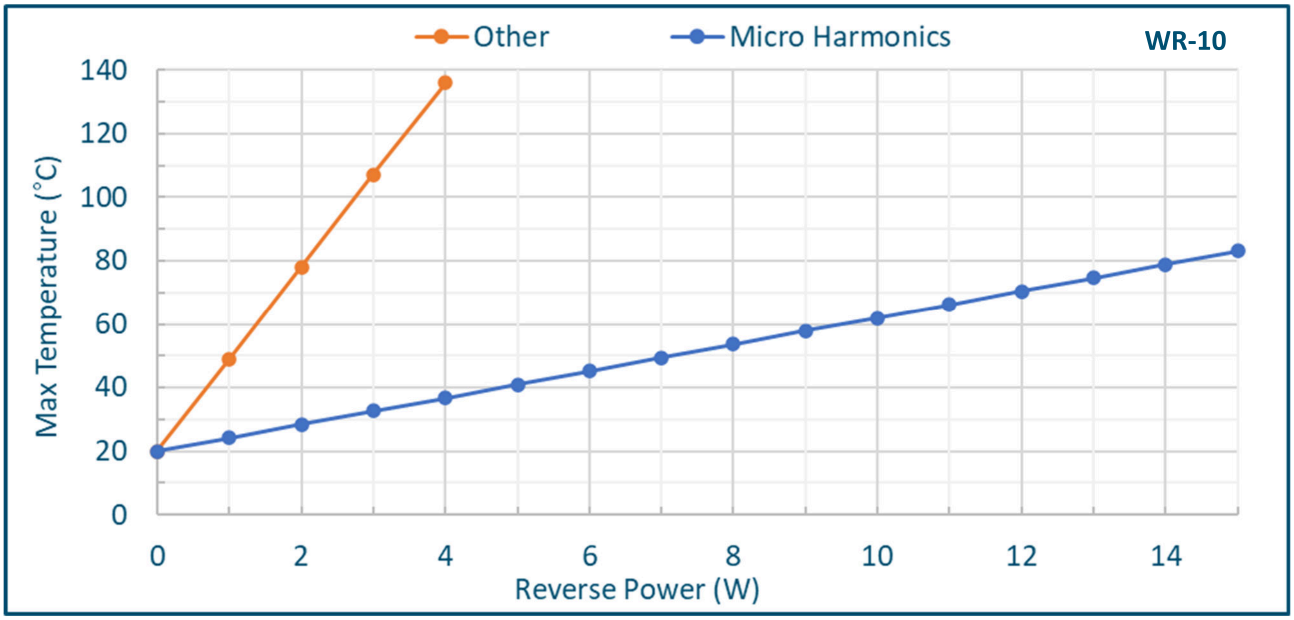
FR34: 220-330 GHz



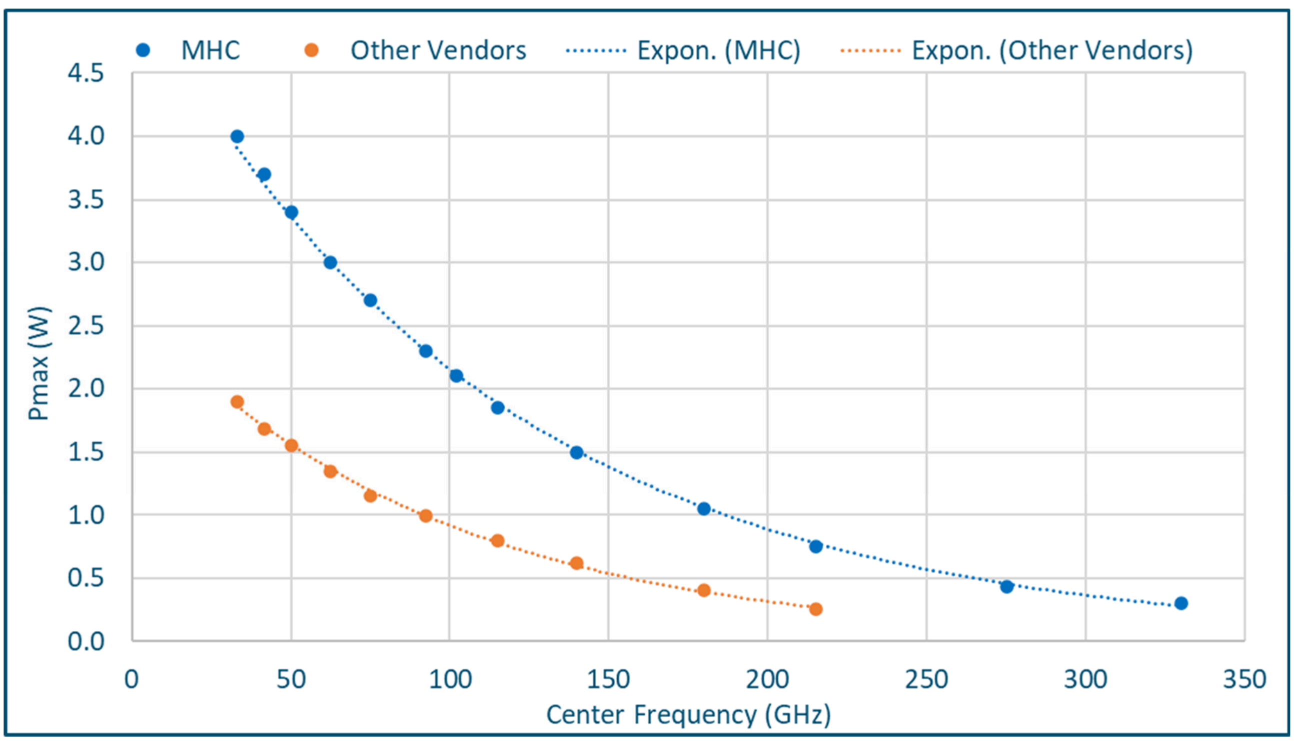
FR28: 260-400 GHz



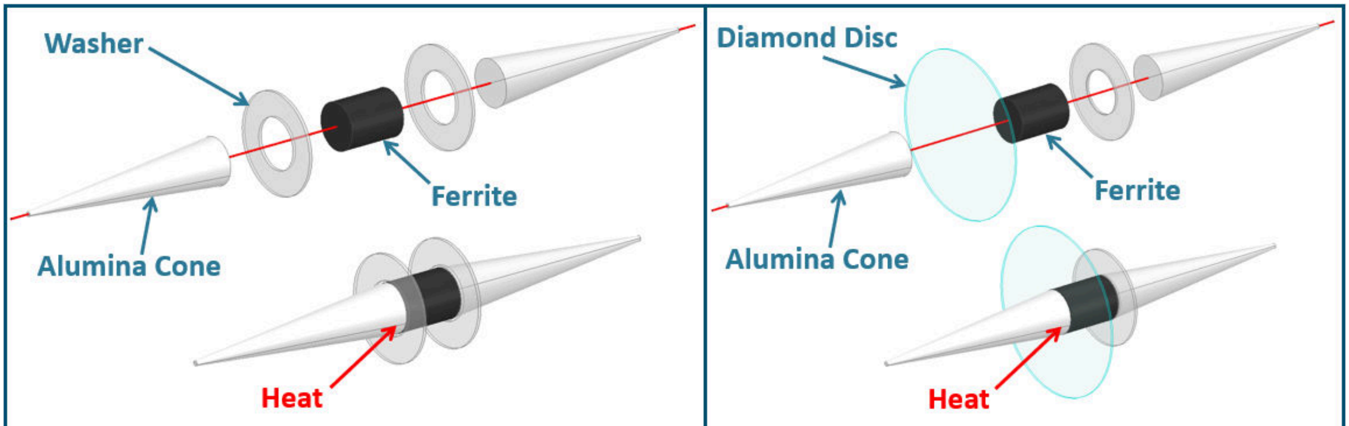
Isolator Power Ratings - In a Faraday rotation isolator, reverse power is absorbed in a resistive layer and converted to heat energy. In the legacy isolators sold by other vendors, the resistive layer can get hot because it is thermally isolated. But Micro Harmonics isolators employ a diamond disc that 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. The simulations indicate a max temperature of 50°C in the legacy isolators at the rated power level of 1 W. A Micro Harmonics isolator reaches 50°C when absorbing 7 W. See "Diamond Heatsink Technology" on pages 7-8 for more info.



The graph below shows the maximum reverse power ratings of our isolators (MHC) 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.

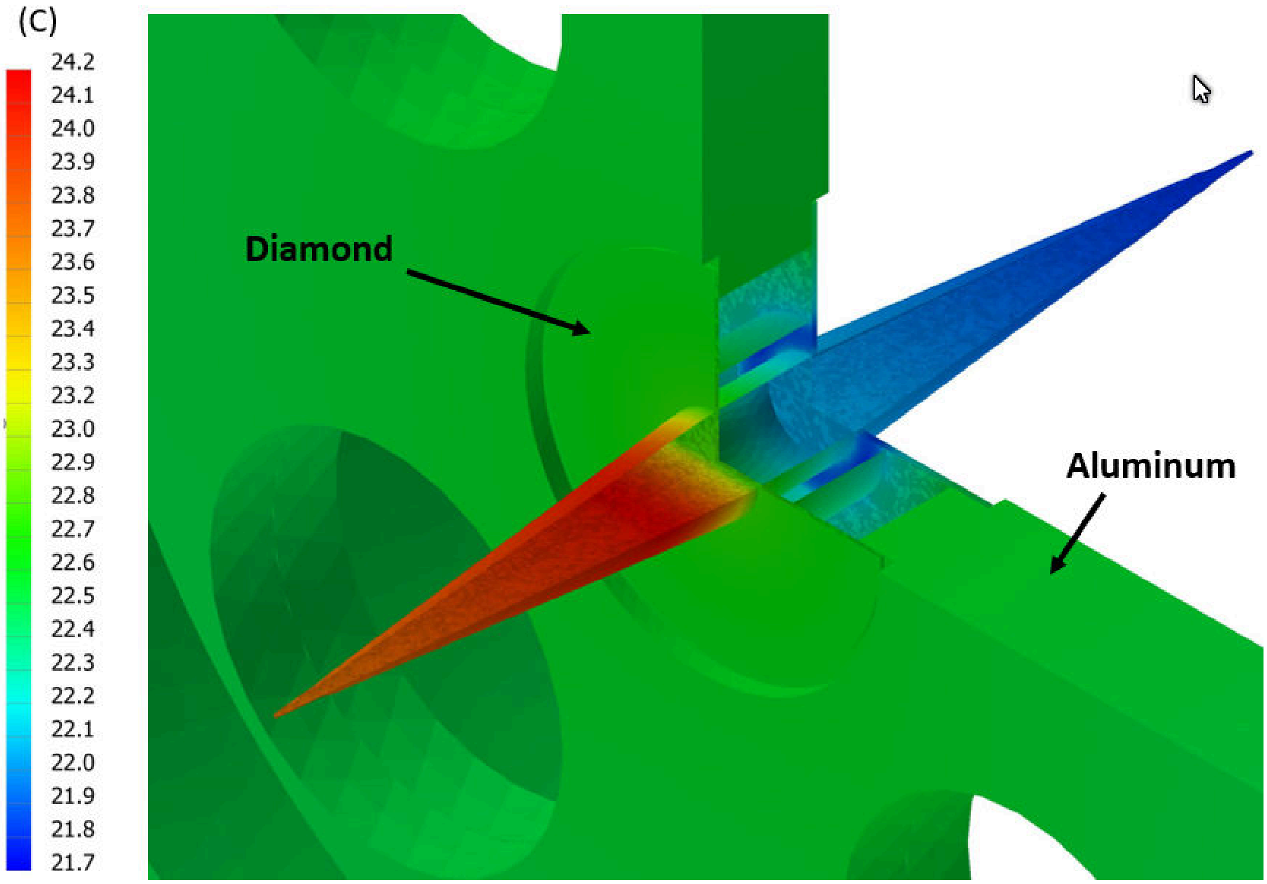


(a) Legacy isolator with thermally insulating supports. (b) Micro Harmonics isolator with diamond disc.

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.



Our 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 2.3 W. When a Micro Harmonics WR-10 isolator absorbs a 2.3 W signal travelling in the reverse direction, the maximum temperature should not exceed 8°C above the ambient waveguide block temperature. In contrast, the simulations indicate a max temperature near 90°C for a legacy isolator (at 2.3 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 isolator power ratings webpage.

Micro Harmonics Isolators are Insensitive to Stray Magnetic Fields

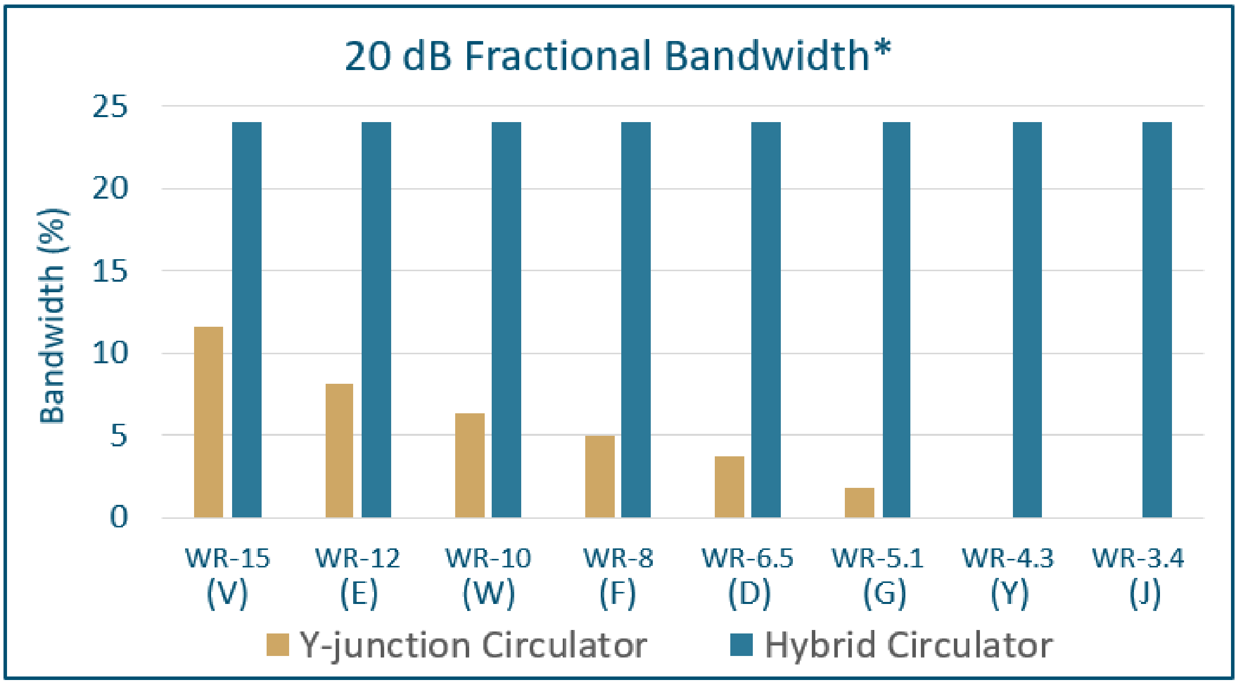
Have you seen the label on the legacy isolator that warns you to keep it away from magnetic fields? You will not find that label on a Micro Harmonics isolator because our isolators are highly resistant to external magnetic fields. The legacy isolators use a highly tuned magnetic field that is easily 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.

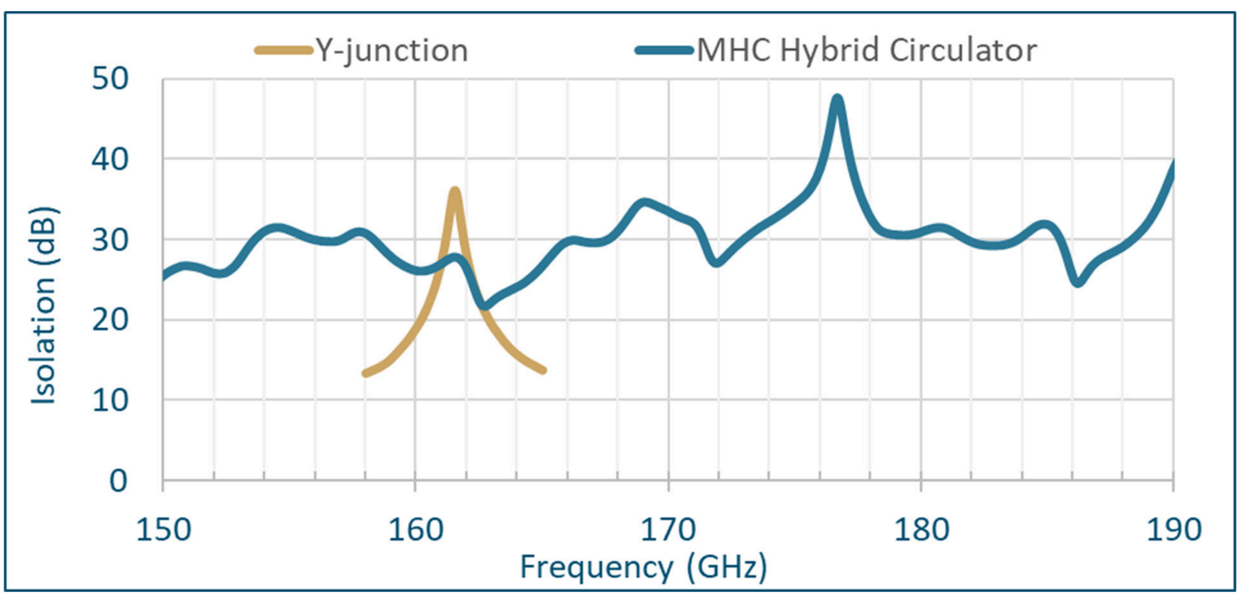
Microwave Journal article on stray magnetic fields.

Hybrid Circulators

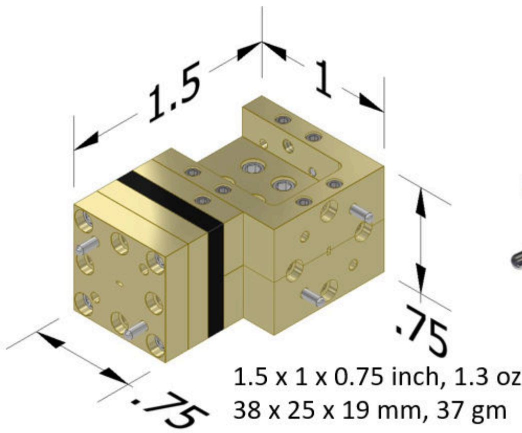
Micro Harmonics has developed a new mm-wave hybrid circulator technology that has a 20 dB fractional bandwidth* of 24% in every waveguide band from WR-15 through WR-3.4. In contrast, the bandwidth of a Y-junction circulator degrades rapidly at the higher mm-wave bands. Test data from our WR-5.1 hybrid circulator are shown in the lower graph along with test data from a Y-junction circulator for comparison. The insertion loss (not shown) of our WR-5.1 hybrid circulator is less than 2.2 dB.

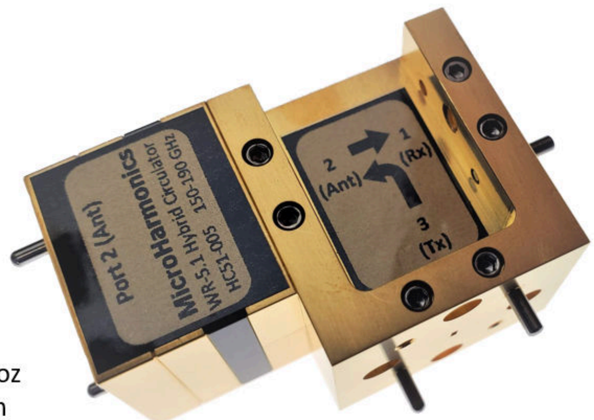
**20 dB bandwidth - The band over which the isolation between circulator ports is more than 20 dB.*





The theory of operation for the hybrid circulator is very different than the Y-junction. In the hybrid, the circulator function is achieved in a unique way that circumvents the bandwidth limitations found in the Y-junction. Hybrid circulator development is currently limited to frequencies below 400 GHz due to practical limitations imposed by the fabrication process. A photograph and dimensional sketch of a WR-5.1 hybrid circulator prototype are shown below. A more comprehensive technical description is given in the following paper: D. W. Porterfield, "Broadband Millimeter-Wave Hybrid Circulators," in *IEEE Trans. Microw. Theory Tech.*, doi: 10.1109/TMTT.2023.3239886.





Hybrid circulators

A WR-5.1 circulator with a 24% fractional bandwidth is a remarkable result. In fact, this would have to be considered an enabling technology. But the good news gets even better. In theory, the hybrid circulator can be designed to cover full rectangular waveguide bands with fractional bandwidths exceeding 40%. This requires a change in the geometry that is both more complicated and more costly to machine. Therefore, the immediate development efforts will continue to be in 24% fractional bands.

Micro Harmonics has worked with NASA to develop a line of hybrid circulators in additional 24% bands as indicated in the table below. Please visit our website for more information.

Model Name	EIA Flange	Frequency (GHz)
HC148	WR-15	54 - 68
HC122	WR-12	70 - 86
HC100	WR-10	85 - 104
HC80	WR-8	107 - 133
HC65	WR-6.5	118 - 150
HC51	WR-5.1	150 - 190
HC43	WR-4.3	196 - 250
HC34	WR-3.4	258 - 330

The hybrid circulator technology is patent pending.

Voltage Variable Attenuators

Voltage variable attenuators (VVA) find wide application in many microwave and millimeter-wave systems. At frequencies above 50 GHz, most VVA's are either based on PIN diodes or resistive vanes with motor driven mechanical actuators. Both technologies cover full rectangular waveguide bands (40% fractional bandwidths). PIN attenuators are available up to the WR-10 band (75-110 GHz) with 20 dB dynamic range, 3 dB insertion loss, and 100 mW power ratings. Perhaps the primary appeal of the PIN attenuators is fast switching speeds near 100 ns. On the downside, they are sensitive to ESD damage and in some cases may generate low level noise and harmonic content.

Electronically tunable resistive vane attenuators are large, heavy, and slow compared to PIN devices. But they have a much flatter frequency response and significantly higher dynamic range. The resistive vane attenuators are useful in lab environments but are unsuitable for many fielded systems. They employ calibrated control circuits and motor driven actuators to precisely position a resistive vane within a waveguide. They are available up to the WR-2.2 band 330-500 GHz. In the WR-10 band they have 3 dB insertion loss, 60 dB dynamic range, two second switching speed, and 2 W maximum power rating.

Micro Harmonics is developing a third technology that uses a Faraday rotator to rotate the RF signal polarity into a fixed resistive layer embedded in a ceramic cone. This is similar to the resistive vane technology but eliminates the mechanical motion of the vane. The new Faraday Rotation Attenuators (FRA) have some unique characteristics that make them attractive options for mm-wave applications.

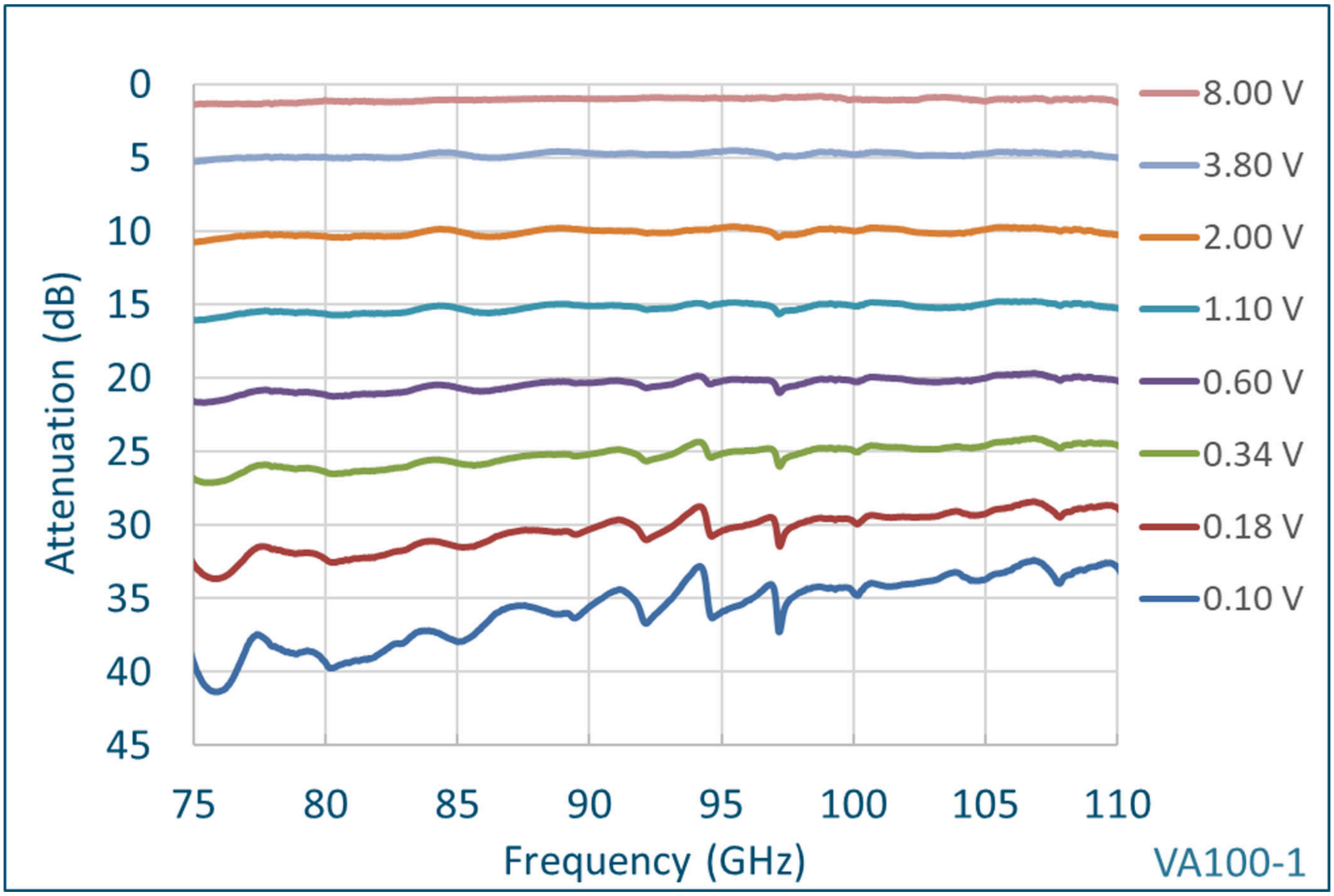
The FRA technology is passive which makes it insensitive to ESD damage. FRAs have characteristics such as flat response and high dynamic range that are much better than the PIN attenuators but not quite as good as the resistive vane devices. There are no moving parts in the FRA. The dynamic range of the MHC WR-10 FRA is 35 dB. However, a dynamic range up to 50 dB may be possible through refinements to the design. The FRA is lightweight and compact like the PIN attenuator. The FRA can be scaled to at least 330 GHz, well above the 110 GHz limit for commercially available PIN attenuators.

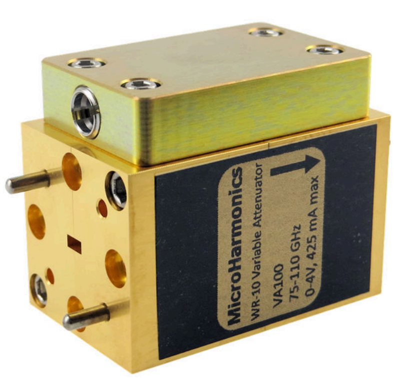
CVD diamond discs are used in the FRAs to channel heat away from the ferrite rods. The CW power rating for the WR-10 FRA is more than 2 W which is comparable to some resistive vane attenuators and significantly higher than the 100 mW rating for the PIN attenuators. Measured port reflections for the FRA are typically less than -17 dB. This compares favorably to the -10 dB level reflections in the PIN diode attenuators. The FRA switching speed is 10 ms. This is about two orders of magnitude faster than the resistive vane and five orders of magnitude slower than the PIN devices. And finally, the insertion loss of the WR-10 FRA is 1 dB which is less than the 3 dB insertion loss of the PIN diode and resistive vane attenuators.

The new attenuator is now available from Micro Harmonics in the WR-10 band (75-110 GHz). A WR-6.5 model covering 110-170 GHz will become available in August 2023. Models in other bands will follow. Please check our website periodically for updates.

Voltage Variable Attenuators

Our attenuator is configured so that maximum attenuation is achieved at 0 V bias. Measured data from our WR-10 attenuator is shown below. The dynamic range is more than 35 dB. The attenuator uses diamond heatsink technology and has a power rating in WR-10 of 2.3 W CW. Switching speed is 10 ms. PIN diode attenuators are faster, but our attenuator has a flatter response, higher power handling, and higher dynamic range. And it does not produce any intermodulation distortion products (none that we have been able to detect).





WR-10 attenuator

Our WR-10 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

MicroHarmonics
Superior mm-Wave Components

Cryogenic Faraday Rotation 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, CEO
Plymouth Rock Technologies

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 of our cryogenic isolators has been verified down to 1 K.

Cryogenic models are now available in bands from WR-15 through WR-5.1. A model at WR-28 (FR280C) has also been released. Models at WR-4.3 and WR-3.4 will be added pending customer demand.

Cryogenic Isolators

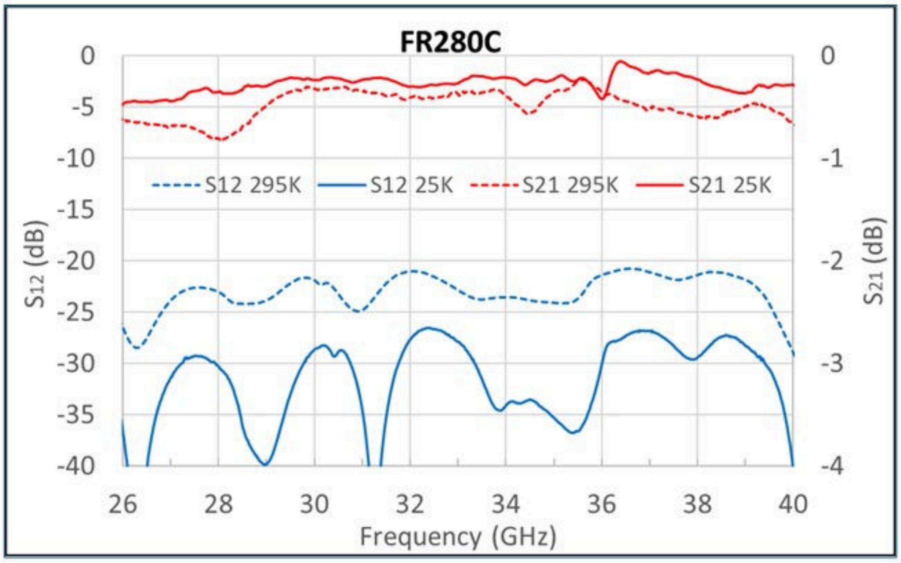
Model	Flange	Band (GHz)	Insertion Loss (dB, typ @ 25 K)	Isolation (dB, typ @ 25 K)
FR280C	WR-28	26 - 40	0.5	25
FR148C	WR-15	50 - 75	0.5	28
FR122C	WR-12	60 - 90	0.7	25
FR100C	WR-10	75 - 110	0.5	30
FR90C	WR-9	82 - 122	0.5	30
FR80C	WR-8	90 - 140	0.7	27
FR65C	WR-6.5	110 - 170	0.9	23
FR51C	WR-5.1	140 - 220	1.2	23

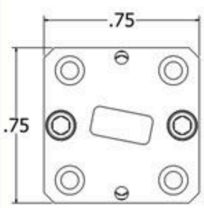
Cryogenic Faraday Rotation Isolators

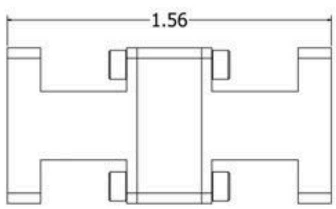
Model: FR280C

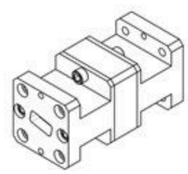
Specifications	
Flange	WR-28
Frequency (GHz)	26-40
Insertion Loss (dB, typ, 300K)	0.5
Insertion Loss (dB, typ, 77K)	0.4
Isolation (dB, typ, 300K)	20
Isolation (dB, typ, 77K)	28
Input Return Loss (dB, typ)	20
Output Return Loss (dB, typ)	20
VSWR (max)	1.4:1
Maximum Power (W)	1.7
Diamond Heatsink	No

Every isolator is tested on a vector network analyzer to ensure conformity.







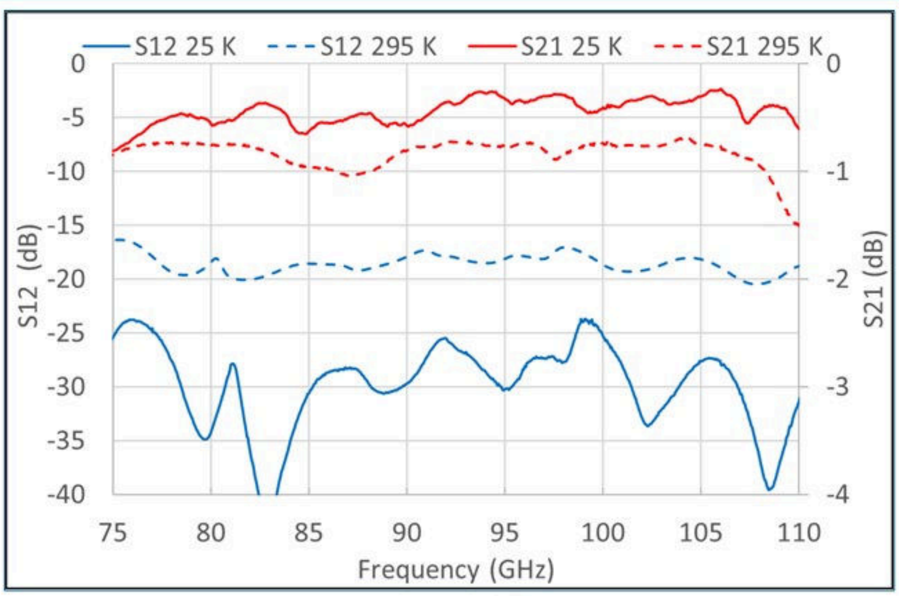


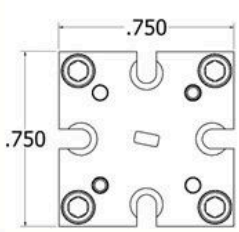
April 2022

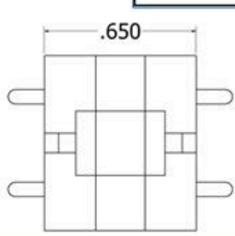
Model: FR100CM2

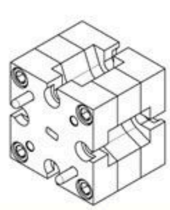
Specifications	
Flange	WR-10
Frequency (GHz)	75-110
Insertion Loss (dB, typ, 300K)	0.9
Insertion Loss (dB, typ, 77 K)	0.4
Isolation (dB, typ, 300 K)	19
Isolation (dB, typ, 77 K)	26
Input Return Loss (dB, typ)	20
Output Return Loss (dB, typ)	20
VSWR (max)	1.4:1
Maximum Power (W)	1.0
Diamond Heatsink	No

Every isolator is tested on a vector network analyzer to ensure conformity.









May 2021

MicroHarmonics
Superior mm-Wave Components

Y-junction Circulators

Micro Harmonics offers a line of millimeter-wave Y-junction circulators in the WR-15, WR-12, WR-10, and WR-8 bands covering the spectrum from 50-140 GHz. These circulators exhibit state-of-the-art performance in terms of low-insertion loss, broad-bandwidth, and low port reflections.

Our Y-junction circulators do not employ complicated dielectric matching elements. Rather, the impedance matching circuitry is implemented through precision CNC machined features in the waveguide block which are highly repeatable and tightly controlled. The machined structures also make it easy to align the ferrite cores with some precision and obtain a high degree of uniformity between the three circulator ports.

Y-junction circulators

Model	Flange (EIA)	20 dB Band* (GHz)	Insertion Loss (dB, max)	Isolation (dB, min)
YC148-61	WR-15	58 – 64	0.4	20
YC148-68	WR-15	65 – 71	0.5	20
YC122-73	WR-12	71 – 76	0.5	20
YC122-78	WR-12	75 – 81	0.5	20
YC122-83	WR-12	81 – 86	0.6	20
YC100-86	WR-10	83 – 89	0.6	20
YC100-93	WR-10	90 – 95	0.7	20
YC100-95	WR-10	92 – 98	0.7	20
YC100-97	WR-10	94 – 100	0.7	20
YC100-105	WR-10	102 – 108	0.7	20
YC80-110	WR-8	107 – 113	1.1	20
YC80-118	WR-8	115 – 120	1.1	20
YC80-127	WR-8	125 – 129	1.1	20

*The band over which the isolation is greater than 20 dB.

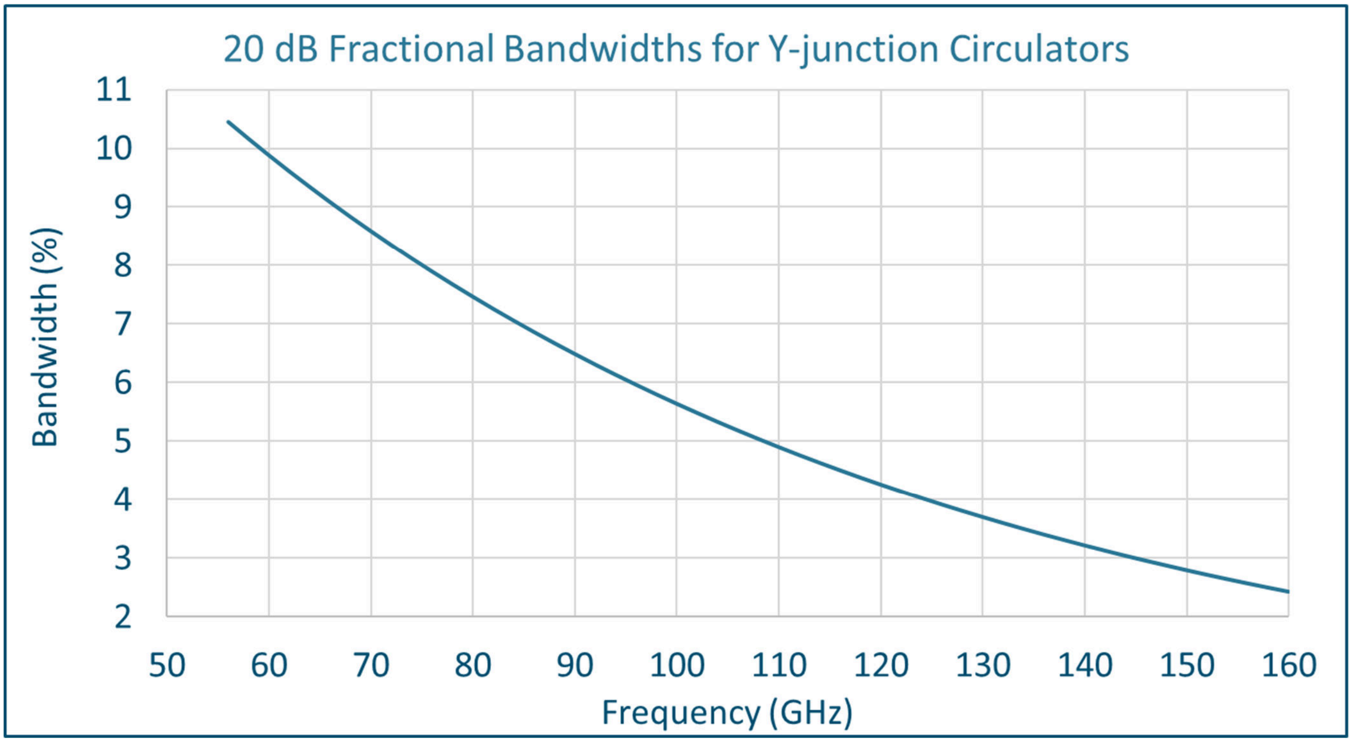
Our initial offerings are targeted to bands where there is widespread interest in the millimeter wave community. Over time we will continue to add products tuned to other sub-bands within the 50-140 GHz window in response to customer requests. Designs above 140 GHz will be considered on a case-by-case basis.

Please do not hesitate to contact us to discuss how we can apply our capabilities to your requirements. We typically do not charge a design fee (NRE) to develop a circulator tuned to a specific sub-band. Our primary concern is to identify bands of interest and provide components to serve the broader community.

"We couldn't find anybody that was capable of producing circulators in the frequency band we required, much less with the high isolation and wide bandwidth we wanted… Micro Harmonics fine-tuned the design to meet the performance characteristics we needed within a very precise band."

Dr. Fred Daneshgaran, Professor, Chairman
California State University, Los Angeles

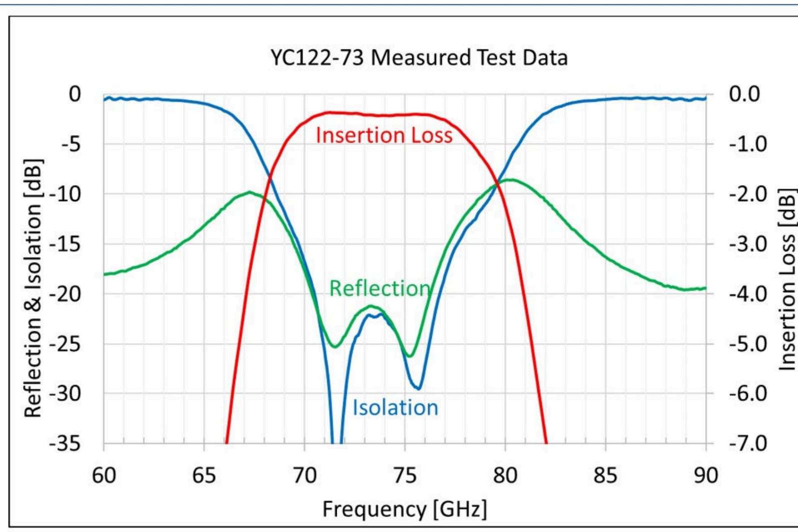
We define the bandwidth as the band over which a circulator has more than 20 dB isolation. The graph below gives an estimate for the 20 dB bandwidth that can be achieved at a given center frequency. For example, a circulator designed with a center frequency of 110 GHz has a fractional bandwidth near 5%. The isolation would be greater than 20 dB across the band 107.3-112.7 GHz.

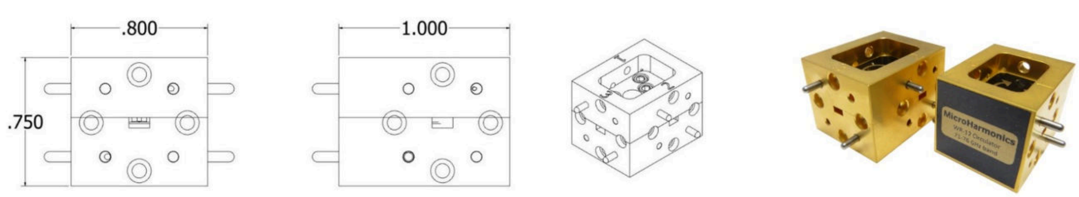


A typical Y-junction circulator specification sheet is shown below. The circulators can also be tuned for higher isolation over more narrow bandwidths. The three flanges are equidistant from the Y-junction.

Model: YC122-73

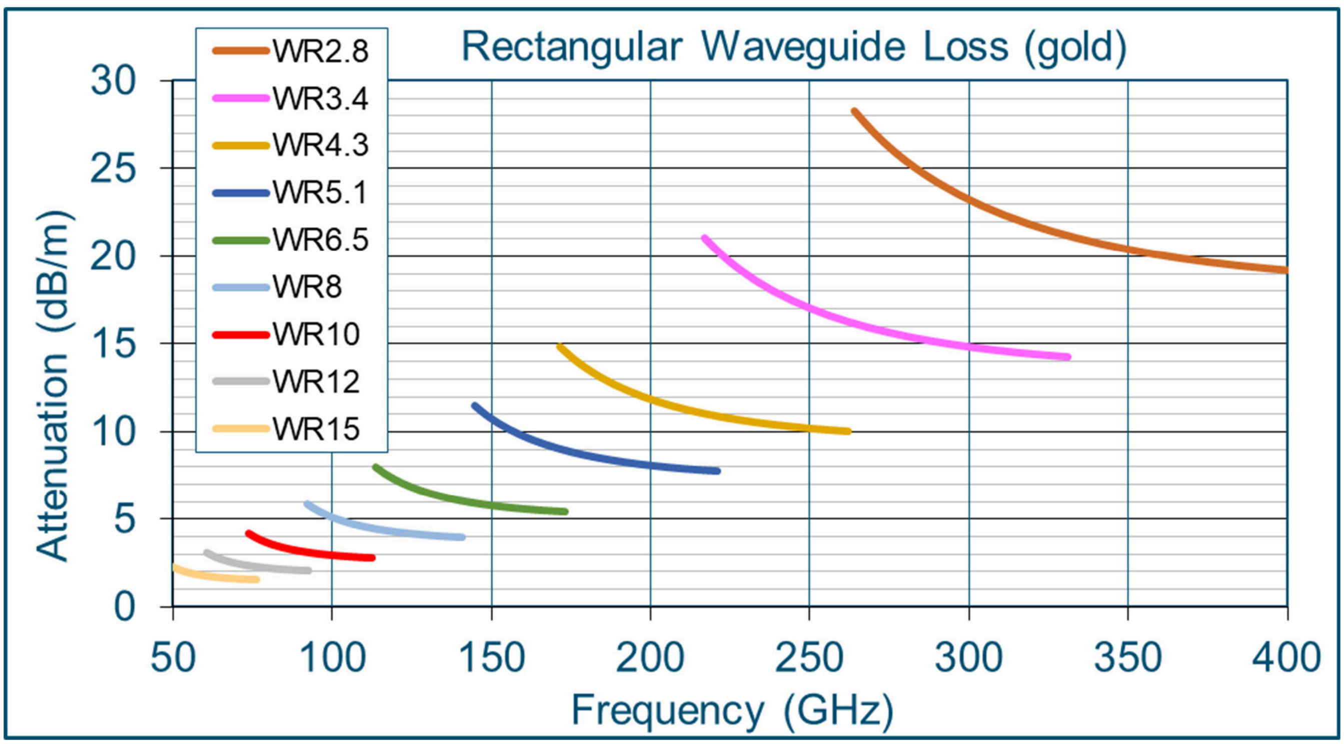
Specifications	
Flange	WR-12
Frequency (GHz)	71-76
Insertion Loss (dB, typ)	0.4
Insertion Loss (dB, max)	0.6
Isolation (dB, min)	20
VSWR (max)	1.3:1



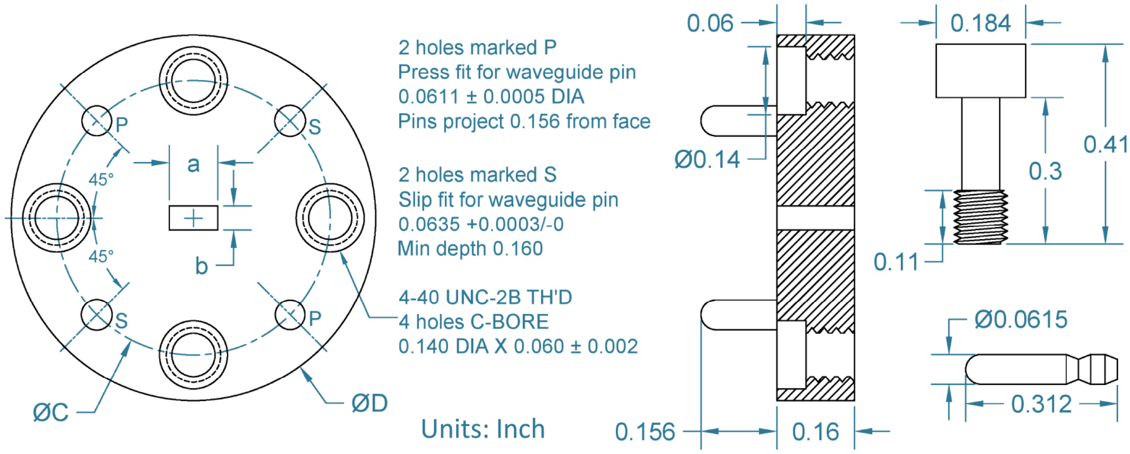


Insertion Loss -vs- Transmission Conversion Table

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	3.01	50.00	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

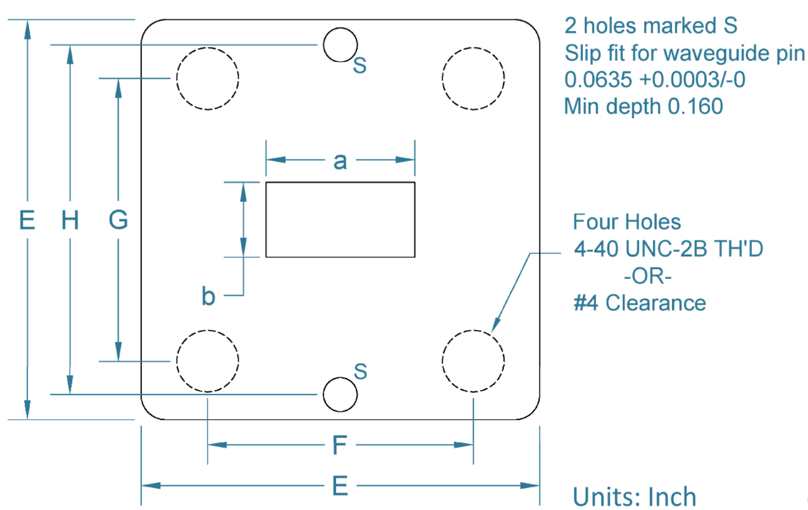


Anti-Cocking Round Waveguide Flanges



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



MHC Website

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

MicroHarmonics
Superior mm-Wave Components

Micro Harmonics Corporation
20 S Roanoke St, Ste 202
Fincastle, VA 24090
sales@mhc1.com
Ph: 540.473.9983
MicroHarmonics.com

Rectangular Waveguide Chart

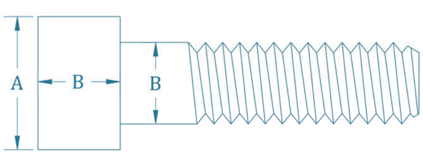
EIA WR- (##)	RCSC WG- (##)	IEEE WM- (####)	Band	Internal Dimension (mil)	Standard Frequency (GHz)	fc TE10 (GHz)	fc TE20 (GHz)	UG- (###/#)
42	20		K	420 x 170	17.5 - 26.5	14.1	28.2	
34	21			340 x 170	22.0 - 33.0	17.4	34.8	
28	22		Ka	280 x 140	26.5 - 40.0	21.1	42.2	599/U
22	23		Q	224 x 112	33.0 - 50.5	26.3	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

VSWR/|Γ|/RL Conversion

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

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

$$\mathrm{RL} = -20\log|\Gamma|$$



Cap-Head Screws

Size	Threads /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

MicroHarmonics
Superior mm-Wave Components

Micro Harmonics Corporation
20 S Roanoke St, Ste 202
Fincastle, VA 24090
sales@mhc1.com
Ph: 540.473.9983
MicroHarmonics.com