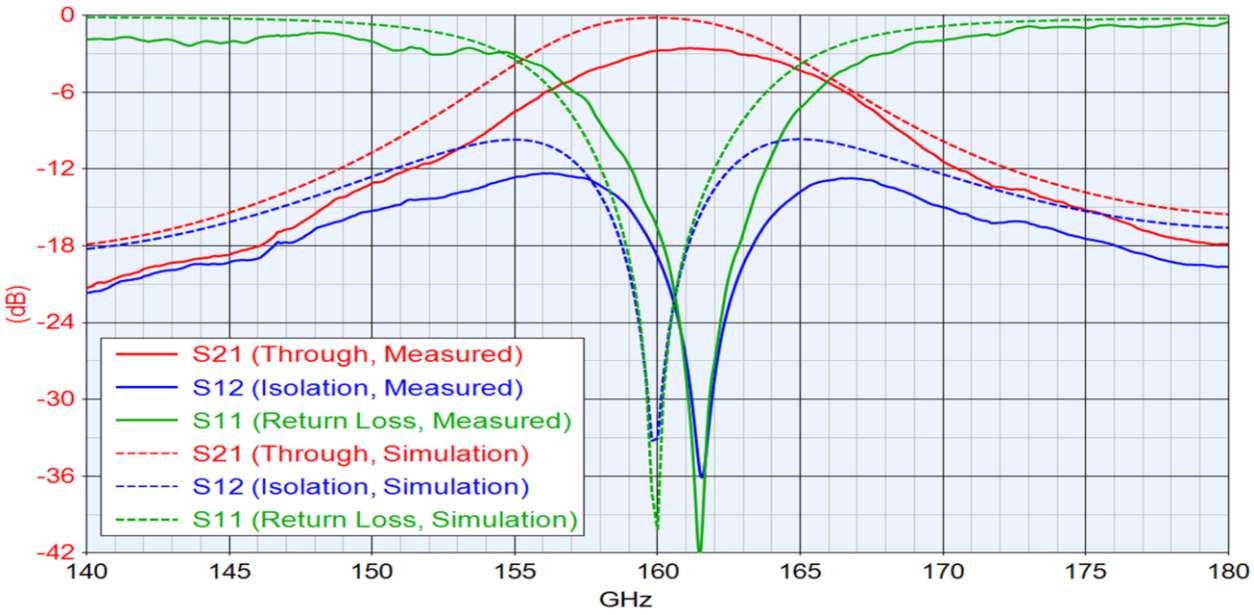
Below we present an overview of the current state of circulator technology at Micro Harmonics. Our near term goal is to develop a line of circulators operating in sub-bands from 50 GHz to over 140 GHz with significantly improved performance over the current state-of-the-art. Our long term vision is to develop components operating up to 500 GHz. These components will find immediate use in a broad range of commercial and scientific systems. Please contact us to discuss how we can apply our capabilities to your requirements.

Circulator Development

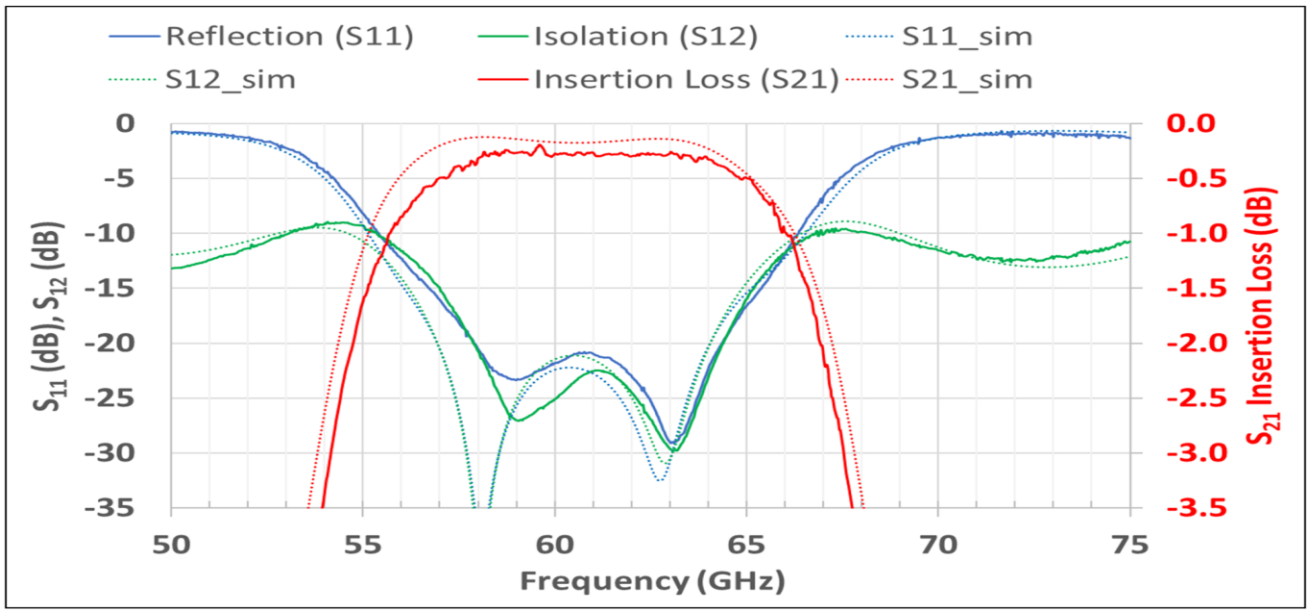
Introduction - Y-junction circulators are useful for directing signal flow in a wide variety of millimeter-wave transmit and receive systems. At the heart of the device is a ferrite core located at the junction of three waveguides. The magnetically biased ferrite is non-reciprocal which gives rise to the unique circulator behavior. Most of the commercially available components are based on designs that are more than forty years old and there has been little effort at modernization. Using modern electromagnetic simulation tools, we are able to design high-frequency circulators that exhibit significantly improved bandwidth making them useful for many transmit/receive systems such as millimeter-wave radar systems.

WR-5.1 Circulator - Micro Harmonics started developing millimeter-wave ferrite devices in 2012. We were convinced that the performance of the commercial isolators and circulators could be greatly enhanced through the use of modern electromagnetic simulation tools that we had been using for the development of state-of-the art millimeter-wave and terahertz varactor and varistor frequency multipliers. Our initial prototype circulator was designed to operate at 160 GHz in WR-5. The measured test data and the simulation data are shown in the graph to the right. The data are in good agreement with only a 1.5 GHz shift in the center frequency. This result affirmed our ability to accurately simulate and build these ferrite components.



The measured insertion loss (solid red curve) is higher than the simulated data (dashed red curve) because the simulations did not include any waveguide losses. The bandwidth is about 2% of the center frequency when defined as the band over which the isolation and input return loss are both greater than 20 dB. At 161 GHz the isolation is greater than 36 dB and the input return loss is greater than 40 dB. The bandwidth at this frequency is close to the best reported on the commercial market.

WR-15 Circulator - The WR-5.1 circulator employed a triangular ferrite core. These were difficult to machine and subject to chipping on the vertices. We decided to change to a cylindrical ferrite core and to put more emphasis on broadband design. The WR-15 circulator was our first attempt with the new topology. It employs no dielectric matching elements. There are only three parts; a waveguide block, a cylindrical ferrite core and a neodymium magnet for bias. All of the impedance matching and mode controlling elements are machined into the waveguide block. This makes the performance highly repeatable from one assembly to the next. Alignment of the ferrite in the block is trivial as there are machined features to ensure proper alignment.



The graph shows good agreement between the measured and simulated data for the WR-15 circulator. The insertion loss is about 0.3 dB across the 58-64 GHz band. The 20 dB bandwidth (the bandwidth over which the isolation is greater than 20 dB) is 6 GHz from 58-64 GHz. This is slightly less than the 7 GHz bandwidth predicted in the simulations. The discrepancy arises from some initial miscalculations in the ferrite material parameters. At this point, to achieve the full 7 GHz bandwidth requires a slight redesign of the waveguide block. Competitor products in WR-15 typically are rated at 1-2 GHz bandwidth, so this result is about a 200% increase in bandwidth compared to the previous state-of-the-art.

Circulators at Higher Frequencies - We have extended this work to circulators in WR-12, WR-10 and WR-8. Please see our circulator product pages for more information.