Advances in MMW Isolator Design Launch Manufacturers into Stratospheric Operating Frequencies

By Dr. Dave Rizzo

It doesn't take a crystal ball to know where the future of wireless is heading. With inexhaustible demand driven by 5G, 6G and beyond, ultra-high definition video, autonomous driving cars, security applications and the Internet of Things (IoT), the sky's the limit for utilizing the higher ends of the electromagnetic spectrum.

Meeting this demand requires products capable of capitalizing on the millimeter wave (MMW) bands that cover frequencies between 30 and 500 GHz. However, these higher frequencies present a significant problem that design engineers must address — that of standing waves. Without control, these unwanted waves can attenuate power output, distort the digital information on the carrier and, in extreme cases, damage internal components.

To counteract the problem of standing waves at lower microwave frequencies, engineers rely on Faraday rotation isolators — more commonly referred to simply as isolators. At their very basic level, an isolator is a two-port, input-and-output component that allows EM signals to pass on in a direction, but absorbs them in the opposite direction. Traditional isolators fall short at the higher frequencies required for next-gen wireless applications.

A big part of the problem is that the first isolators were designed more than a half century ago, with very few modifications, since the original concept. With recent advancements, however, companies at the cutting edge of MMW technologies are gaining the ability to launch products that operate optimally at stratospheric frequencies.

"The new series of waveguide isolators have been a key enabling technology for VDI, a large advance from what was previously available," says Jeffrey Hesler, Ph.D., CTO of Virginia Diodes, Inc.

VDI is a Virginia-based manufacturer of state-of-the-art test and measurement equipment, such as vector network analyzer, spectrum analyzer and signal generator extension modules, for MMW and THz applications.

"The issue that MMW system designers face is impedance mismatches and the resulting reflections between components," says David Porterfield, founder and CEO of Micro Harmonics Corporation (MHC). Headquartered in Virginia, MHC specializes in design solutions for components used in MMW products.

Under a two-phased NASA contract awarded in 2015, the company successfully developed an advanced line of isolators for WR-15 through WR-3.4 (50 to 330 GHz) applications. "In MMW systems, the distance between components is often more than a wavelength, putting reflected signals out of phase," says Porterfield.

"The out-of-phase reflected signal can perturb the operating point of the upstream component. As you sweep frequencies, the phase changes and you get nulls, dips and degraded performance. However, when you insert an isolator between components, the reflected signal gets absorbed and the problem goes away.

The highest possible isolation occurs when the reverse wave is rotated exactly 45° into the plane of the isolator's resistive layer. Isolation can degrade by as much as 10 dB when the signal rotation is off by just 1°.

While isolation is the namesake of these components, the suppression of the reverse wave cannot come at the expense of attenuating the forward, input signal. Insertion loss is a measure of how much loss a signal incurs as it passes through the isolator in the forward direction.

For traditional-style isolators, insertion loss is low in the microwave bands, but at MMW frequencies the loss becomes increasingly problematic. For instance, in the WR-10 band (75 to 110 GHz) the insertion loss can exceed 3 dB, meaning half of the signal power is lost.

In the WR-5.1 band (140 to 220 GHz) the loss climbs to more than 5 dB. Because of high losses, traditional isolators are often precluded for use in MMW systems.

Faraday rotation isolators operate by using ferrite discs to rotate the signal. However, the traditional method to manufacture them has been to use ferrites that are substantially longer than the minimum required length and then tune the magnetic bias field to achieve optimal performance. This delivers good isolation, but at a much higher insertion loss.

A good isolator must also have low port reflections. Voltage Standing Wave Ratio (VSWR) is a measure of the reflections at the input and output ports. A good range at MMW frequencies is 1.5:1 or less, 1:1 equals no reflection.

The importance of low port reflections is often overlooked. An isolator with high port reflections creates an alternate set of standing waves. The adjacent components are still adversely impacted by out-of-phase signals reflected back into their ports. High isolation and low insertion loss are of little value if the port reflections are large.

Power in the reverse traveling signal is absorbed in the isolator, resulting in heat. The more heat it can handle, the higher the power rating. Historically, high heat was not an issue, as there was very little power available at MMW frequencies. As higher power sources become available, the importance of power ratings increases.

To handle the problem of high heat loads, some newer isolators are already incorporating diamond heat sinks into their design. Diamond is the ultimate thermal conductor, approaching 2,200 W/m-K, more than five times higher than copper. Diamond effectively channels heat from the resistive layer in the isolator to the metal waveguide block, thus lowering operating temperatures for improved reliability.

Finally, minimizing the size and weight of MMW components is especially important in today's wireless applications. "A standard traditional-style isolator in the WR10 band is about 3 in. (7.6 cm) in diameter," says Porterfield. "But, the newest design shapes are rectangular and can be as small as 0.75 in. (2 cm) per side and 0.45 in. (1.1 cm) thick."

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