5G mmWave

The Challenge of mmWave Isolator Design

mmWave spectrum promises much. But it is not without challenges, particularly in component design.

By David Rizzo

As 5G becomes more and more mainstream new challenges arise, especially in the millimeter wave (mmWave) spectrum, that changes the status quo of typical design metrics. One of the major issue design engineers face, as they try to utilize the higher frequencies of the mmWave spectrum, is with isolators.

This part of the RF spectrum is critical for the future of wireless technologies like autonomous vehicles, the Internet of Things, 5G and onto 6G, as well as a host of other products. There simply is not enough room at the lower frequencies to handle the bandwidth required of next-gen wireless products, but moving into the higher, millimeter wave spectrum means dealing with a major issue – that of standing waves.

At lower frequencies, isolators are used to solve this problem, but as you move up the spectrum traditional isolators kill the signal, frustrating engineers who then have to try and tune out the problem manually.

It does not 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 IoT, the sky is the limit for utilizing the higher ends of the electromagnetic (EM) spectrum.

Meeting this demand requires products capable of capitalizing on the mmWave bands which presently cover the frequencies between 30 GHz to 500 GHz. However, these higher frequencies present a significant problem that design engineers must address – 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 in one direction but absorbs them in the opposite direction. However, traditional isolators fall short at the higher frequencies required for next-generation 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 mmWave 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, and a large advance from what was previously available,” says Jeffrey Hesler, Ph.D., CTO of Virginia Diodes, Inc.

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

By understanding these advancements in each of the five properties of isolator functionality, designers can better harness isolators to improve their mmWave products.

High Isolation

Isolation is a measure of how much of the signal traveling in the reverse direction passes back through the isolator. Because isolators are intended to prevent, or minimize, this from happening, the higher the isolation, the better. “The issue that mmWave system designers face is impedance mismatches and the resulting reflections between components,” states David Porterfield, Founder, and CEO of Micro Harmonics Corporation (MHC).

“In mmWave systems, the distance between components is often more than a wavelength, putting reflected signals out of phase,” continues 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 degrees 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 degree.

“The only way to confirm such precision is to fully characterize each isolator on a vector network analyzer,” says Porterfield. “This validates total compliance, as opposed to just spot-checking at a couple of frequencies in the band, continues Porterfield.”

Low Insertion Loss

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 lower microwave bands. However, at the higher mmWave frequencies the loss becomes increasingly problematic. For instance, in the WR-10 band (75-110 GHz) the insertion loss can exceed 3 dB, meaning half of the signal power is lost. In the WR-5.1 band (140 -220 GHz) the loss climbs to more than 5 dB. Because of high losses, traditional isolators are often precluded for use in mmWave systems.

“A designer’s main fear is that the isolator will significantly degrade the strength of the final output,” continues Porterfield. “It can be frustrating for engineers to try and tune the standing waves out of each system, usually with limited success. Many of the alternate methods used are narrow band in nature, so that the solution may work well only over an insufficiently narrow band of frequencies.”

Faraday rotation isolators operate by using ferrite discs to rotate the signal. However, the traditional method to manufacturer 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.

Porterfield points out a two-fold problem with this workaround. First, there is more of the lossy ferrite in the signal path, and second, the ferrite loss parameter increases at lower magnetization levels.

To minimize loss, it is essential that the ferrite length be reduced as much as possible. The design developed for NASA saturates the ferrite with a strong magnetic bias field, which allows for the shortest possible length of ferrite to achieve the ideal 45 degrees of rotation. This lowers the insertion loss to less than 1 dB at 75-110 GHz and only 2 dB at 220-330 GHz.

“The extension of isolator technology above 220 GHz is an impressive technical feat, and a key technology that enables the delivery of accurate measurements with higher sensitivity than we were previously able to achieve,” notes VDI’s Hesler.

Low Port Reflection

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 mmWave 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.

High Power Rating

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 little power available at mmWave frequencies. However, 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 2200 W/m•K (watts per meter-Kelvin), more than five times higher than copper. Diamond effectively channels heat from the resistive layer in the isolator to the metal waveguide block, and thus lowers operating temperatures for improved reliability.

Small Footprint

Minimizing the size and weight of mmWave components is especially important in today's wireless applications. "A standard traditional-style isolator in the WR-10 band is about 3 inches long, with a cylindrical section in the center that's about 1.3 inches in diameter," observes Porterfield. "But the newest design shapes are rectangular and can be as small as 0.75 inches per side and 0.45 inches thick." The same technology used to reduce insertion loss – utilizing the shortest possible length of ferrite – also partially accounts for the reduction in footprint.

Summary

In addition to the five critical characteristics, other properties of modern isolators improve their utility at mmWave frequencies. Wide bandwidth for instance. Standard waveguide bands typically extend to 40 percent on either side of the center frequency. Newer, high-performing isolators operate over extended bandwidths exceeding 50 percent from the center frequency, giving designers greater freedom to build more bandwidth into their systems.

Going forward, as technologies advance, isolators will be able to operate in cryogenic conditions. This is a significant achievement because a traditional isolator designed for room-temperature operation will perform poorly when cooled. Such advances, and others, will greatly aid the design of these extremely high frequencies and bring them into the realm of 5G.

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