Cryogenic-Capable Isolators Improve the Performance of Millimeter-Wave Systems by Lowering Noise Levels

Isolators

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NASA-ready technology provides design engineers a new option for lowering received noise in MMW applications

Silence is golden when it comes to filtering out unwanted reflected noise, especially in extremely high frequency, millimeter wave (MMW) applications. While recent improvements in isolator designs are solving many of these problems, one critical challenge remains: finding isolators that operate optimally under cryogenic conditions.

For manufacturers of ultra-high frequency wireless applications such as 5G and 6G communications, stand-off security scanning, and military defense products, the issue of MMW and cryogenics is relatively new. In fact, some system designers may still be unaware that an isolator built to operate at room temperatures will fail to operate optimally when temperatures are reduced to cryogenic levels.

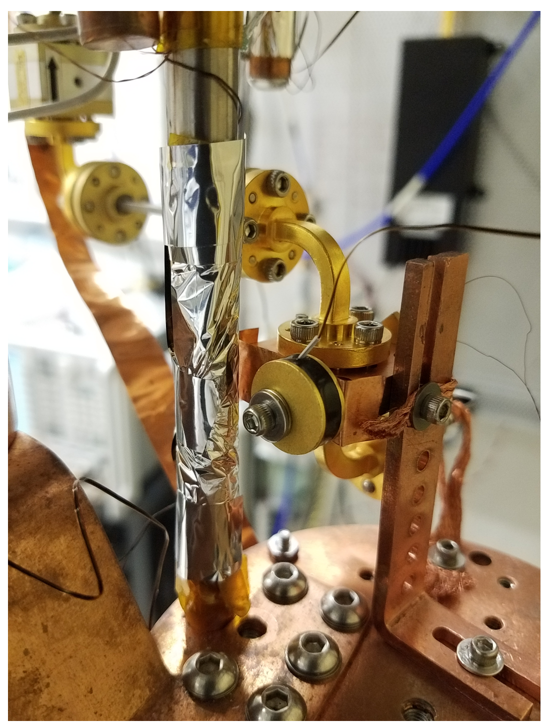


FIG: Cryogenic millimeter-wave measurement setup

“That happened to us,” says Alexander Anferov, a graduate research assistant in the Schuster Lab at the University of Chicago. “We tried using regular isolators from one vendor. We cooled them down and assumed they would work, but they weren’t behaving right.”

Anferov, a recent Caltech graduate, looked to NASA and its Jet Propulsion Laboratory just outside of Los Angeles for a solution.

"It turned out they had just commissioned a grant for a company to design isolators specifically for cryogenics," says Anferov. "After talking with them it became obvious from shared experiences that we were actually causing the problem in our setup by utilizing isolators that could not stand up to extremely cold conditions."

Due to the fact that there is no industry standard, MMW manufacturers often, though unintentionally, make components out of metals that when cooled to cryogenic levels start superconducting. "That completely changes the device properties for the worse," adds Anferov. "The real issue is that the results are unpredictable. Surprise resonances and new leakage paths can crop up, and power that used to be absorbed can be reflected instead."

A Universal Challenge

Antenna designers are very familiar with the constant battle of standing waves. Without control, these unwanted waves reflect back into the transmitter to attenuate power output while raising unwanted noise input. Especially in the MMW bands – which cover the frequencies between 30 GHz to 500 GHz – the reduction of transmitted signal strength jeopardizes the battle; almost literally in military applications.

To reduce the voltage standing wave ratio (VSWR) and help increase the signal-to-noise (S/N) ratio, microwave engineers typically rely on isolators (aka Faraday rotation isolators). These discrete components allow electromagnetic signals to pass in one direction but absorb them in the opposite direction, thus reducing noise.

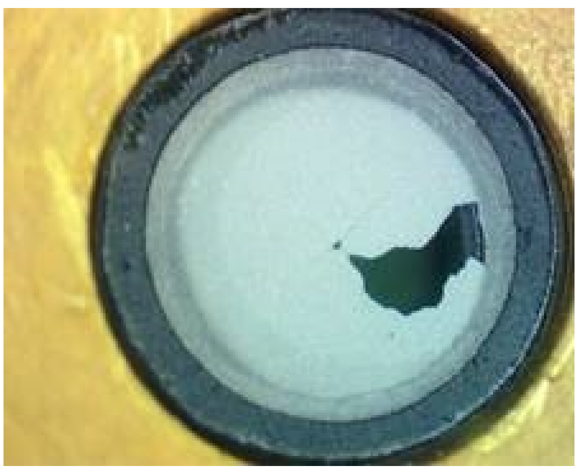


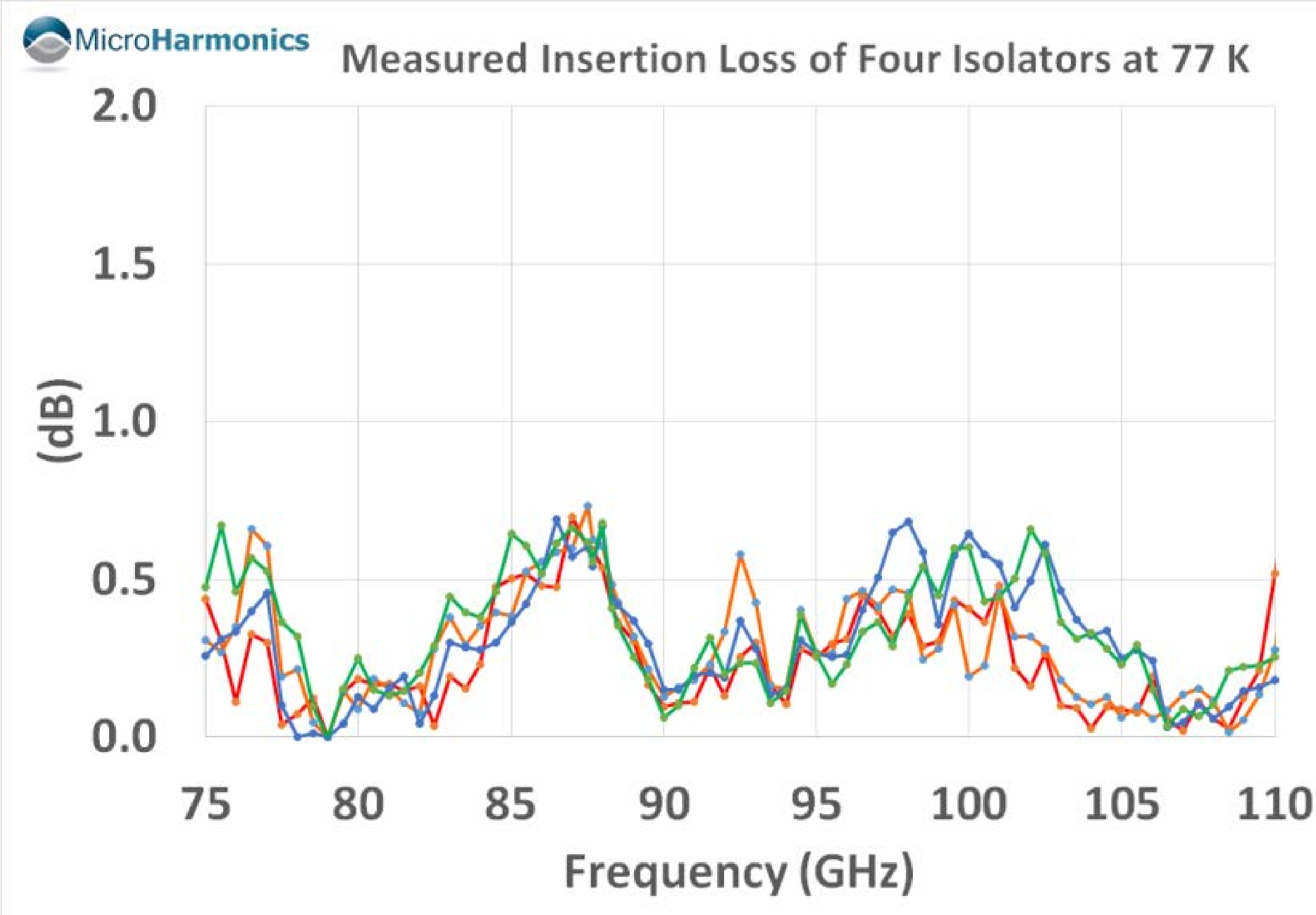
FIG: Damage from repeated thermal cycling

However, Dana Wheeler, CEO of Massachusetts-based Plymouth Rock Technologies explains how standard isolators often become problematic with next-gen electronics that require components that must withstand more extreme environments.

"We received an SBIR grant from the Navy to decrease the size of the large satcom antenna systems on aircraft carriers in order to put them higher up onto the ship's superstructures because the jet-blast from the new fighter planes was damaging the radomes," began Wheeler. "The challenge was to lower the weight and size, without losing any performance."

Plymouth Rock Technologies comprises a team of scientists and engineers formed to develop the technology required to meet the challenges in security screening and threat detection. Wheeler explained that for any antenna system, if you shrink the size of the antenna aperture, gain (G) drops by a logarithmic amount, which is in contrast to the goal. But if you can lower the noise temperature (T), then you can get back the gain that was lost.

"Our solution was to cryogenically cool the low noise amplifier," concludes Wheeler. "We can get down to less than 100 Kelvins with commercially available cryo-coolers," he continues. "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."



Headquartered in Virginia, Micro Harmonics specializes in design solutions for components used in MMW products. Under a NASA contract awarded in 2015, the company successfully developed an advanced line of isolators for 50 GHz to 330 GHz applications. That successful project led NASA to award the company a subsequent grant to address the issue of isolators at cryogenic temperatures.

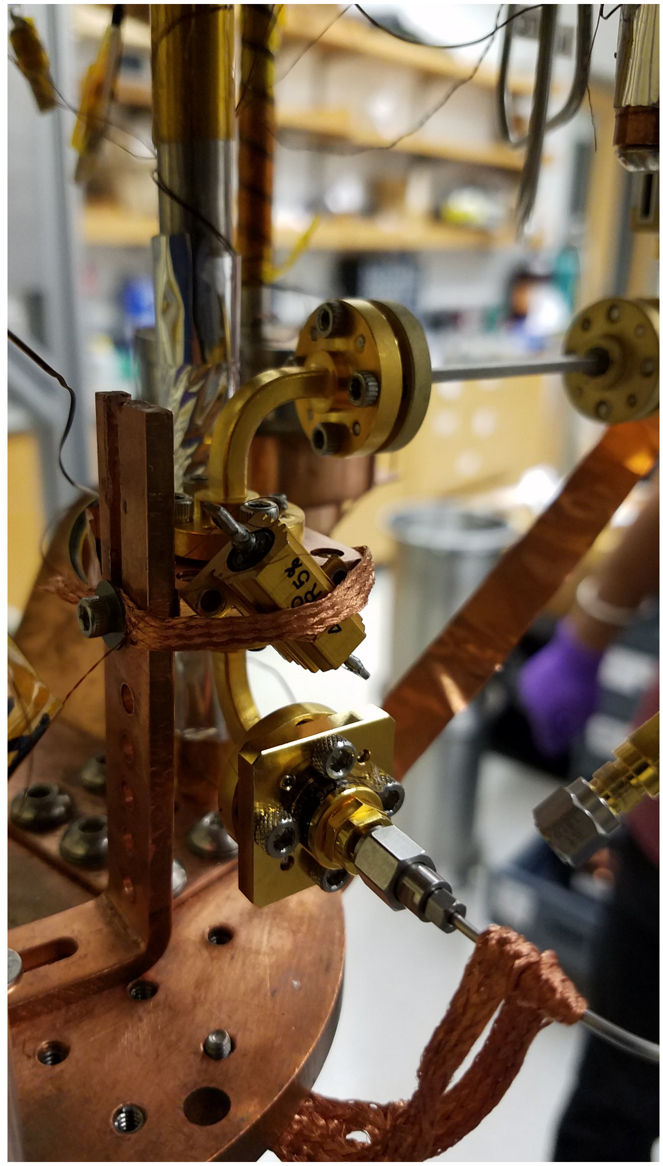
“Low-noise integrated circuit amplifiers work because of the nature of a Schottky diode or a FET transistor, in that as it gets cooler, it has lower noise,” says Wheeler. “However, cryogenic low noise amplifiers are not cheap. With ferrite isolators you get more bang for the buck: a better gain over noise figure at room temperatures, and even more so at cryogenic temps.”

There are numerous material issues that must be addressed to ensure that an isolator is able to withstand the rigors of thermal cycling. The substantial temperature dependence of the ferrite magnetization is also a challenge. Ferrite magnetization follows a modified Bloch law, increasing by more than 20% when cooled from room temperature down to 4 K. As the temperature decreases there is less thermal energy and it is easier to align magnetic dipoles in the ferrite.

The design used by Micro Harmonics compensates for the change. It also uses magnetic armatures designed to achieve a focused, uniform bias field in the ferrite. This strong magnetic saturation allows the shortest possible length of ferrite – hence small footprint – while achieving a low insertion loss of less than 1 dB at 75-110 GHz and only 2 dB at 220-330 GHz.

Proven Results in Research and Practice
While manufacturers are now realizing the benefits of isolators for cryo’ applications, on the research side, Anferov and his team at the University of Chicago are on a mission to see just how low they can go.

“Our lab does experiments at 1 Kelvin, and there are components that can function at temperatures close to absolute zero,” says Anferov. “However, at the extremely high frequencies demanded by today’s applications, it takes a specialized ferrite isolator to perform consistently under such extremes. A ferrite that won’t over-rotate the field and create unwanted issues.”



It is essential for any MMW application that each isolator is tested over the full frequency band on a vector network analyzer to ensure compliance. This includes reliability testing (Belcore) and cryogenic cycling tests.

Comprehensive VNA test data should back up every component since there are often signatures in the data that can be missed. “Knowing that isolators would now perform in the MMW bands at single-digit Kelvin temperature was good news for us because that was one less component we had to worry about,” says Anferov.

For Wheeler’s mil-spec work, the cryogenic isolators will help ensure the reliability of Plymouth Rock’s technology and products.

“In harsh environments the contaminates on the radome of the antenna can really add to the system noise figure due to reflections (VSWR),” says Wheeler. “By integrating a cryogenic isolator in front of your low noise receiver you will realize a reduction in the noise and increase the gain ratio.”

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