Test & Measurement

Overcoming mmWave Design Challenges with Next-Gen Circulators

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The rollout of 5G was always intended to be incremental; beginning at the sub-6-GHz range and then over time expanding into the mmWave range at 24.25 GHz and above. It is at this higher end of the 5G spectrum (24.25 GHz to 86 GHz) that the massive leap forward in data speeds, capacity, quality, and reduced latency will catapult cellular technology into new markets.

However, the rollout into mmWave frequencies is facing a dilemma, which may halt much-anticipated technological breakthroughs, such as smart cities, autonomous vehicles, and the IoT. It will also have far-reaching implications for military and defense.

"It is an enormous technical challenge we are facing," said Fred Daneshgaran, a California State University, Los Angeles, professor who specializes in RF design, telecommunications, and quantum communications.

"The problem is, as you go up the spectrum, it gets harder and harder to build critical components like circulators that can operate at those frequencies," he explained. "The only way to support the billions of users at higher data rates is to keep utilizing higher- and higher-frequency bands, so components are going to have to catch up."

Without advancements, the deployment of systems capable of operating even higher on the spectrum — within the terahertz regime (100 GHz to 10 THz), where 6G and 7G will operate — are also in jeopardy.

Critical to telecom infrastructure

In late 2020, the U.S. Department of Defense detected that national security would also be affected if the problem with mmWave components is not properly addressed. It quickly announced $600 million in awards for 5G experimentation and testing. Given this impetus, microwave components such as antennas, waveguides, isolators, and circulators are now being developed that are capable of broadband operation at mmWave frequencies up to 330 GHz and beyond.

"One component that is especially critical to telecom infrastructure is the circulator," Daneshgaran said. "Antenna systems capable of both transmitting and receiving a signal are typically expensive because they are reciprocal devices. To keep the signals separated, you have to put something like a circulator at the front end; otherwise, you'd need two different antennas."

Basically, a circulator is a three-port device in which power entering any port is transmitted to the next port in rotation. Hence, any signal that goes into Port 1 goes out Port 2, and any signal coming in Port 2 goes out to Port 3.

This issue of duplexing at mmWave frequencies is not only problematic for telecom applications but also for radar technology, which relies on circulators to separate the signal on the transmission path from the signal on the receiving side.

Overcoming performance challenges

In a recent effort to design and build an R&D system for a major commercial contractor, the lack of a circulator capable of operating at 120 GHz stopped Daneshgaran's team in its tracks.

"Theoretically, you can design one, then simulate its performance, and it will be fine," he said. "However, actually making them is more of an art than a science. It is just very hard to build circulators at the mmWave range.

"At first, 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," he added.

In a continued search for a circulator with the necessary attributes, Daneshgaran and his team learned of Micro Harmonics, which had developed a circulator for mmWave systems while working with NASA on a number of SBIR projects.

Micro Harmonics Corporation specializes in components for mmWave applications and successfully developed an advanced line of circulators operating from 25 GHz up to 150 GHz.

"Micro Harmonics fine-tuned the design to meet the performance characteristics we needed within the very precise band we were going to be operating on," said Daneshgaran.

Whether it's for high-speed data transmission and reception or for target detection, isolation is a key parameter.

"If the circulator doesn't have good port-to-port isolation, you get self-interference — meaning the signal I'm trying to transmit is interfering with the signal I'm trying to receive," he added. "So you want as much isolation as possible.

"The Micro Harmonics circulators demonstrated some pretty awesome isolations," said Daneshgaran. "At the frequency we operated on, we realized almost 30 dB of port-to-port isolation, which is a lot. Typically, it is very hard to even get above 20."

A circulator must also offer a wide bandwidth, a major challenge at mmWave frequencies.

"For telecoms, the more bandwidth you have, the more data you can support," said Daneshgaran. "This is because your data rate is directly proportional to the amount of bandwidth you have around your carrier frequency."

Daneshgaran went on to explain that in a radar application, wide bandwidth is important because it involves continuous frequency sweeps. The larger the bandwidth, the easier it is to discern a target in a given sweep.

In Micro Harmonics' case, increased bandwidth for its circulators is achieved by abandoning complicated dielectric impedance-matching elements in favor of a mechanical engineering solution. This makes the performance highly repeatable from one assembly to the next.

"With these circulators, we are getting a clean couple of gigahertz, if not more, of bandwidth within the characteristic limits of 30-dB isolation we seek for our application," said Daneshgaran. "If we were willing to accept something like 20 dB of port isolation, we could have 4-plus gigahertz of bandwidth, which is very significant.

"Because of the initial delays in finding workable mmWave components, we really needed to jump in and make several measurements that we had fallen behind on," Daneshgaran concluded. "With the implementation of advanced circulators, our machine has been running continuously ever since we set it up, and we could not be more pleased with the results."