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New Advanced Circulators Overcome mmWave Design Challenges

Greater isolation and bandwidth enable telecom providers and radar technology designers to fully capitalise on the mmWave spectrum

As telecommunications providers race to deliver on the promise of 5G, research and design projects are already looking towards 6G and beyond. The promise of ultra-fast broadband speeds – potentially as much as 10Gbit/s – can catapult cellular technology into new markets like smart cities, connected vehicles, defence, and the rapidly expanding IoT.

However, a major hurdle awaits the impending move up the millimeter wave (mmWave) spectrum; that being a lack of acceptable mmWave components. This threatens to not only delay the rollout of the high-band portion of the 5G spectrum (46GHz to 86GHz), but jeopardises the deployment of a number of systems needing to operate at the terahertz regime (100GHz – 10THz).

“It is an enormous technical challenge we are facing,” says Fred Daneshgaran, a California State University, Los Angeles, professor who specialises in RF design, telecommunications and quantum communications. As such, Daneshgaran is frequently brought in as lead technician on

some of the most cutting-edge RF military and telecom projects.

“The only way to support the billions of users at higher data rates is to keep utilising higher and higher frequency bands. So, components are going to have to catch up to those higher frequencies within the mmWave regime and then into the terahertz as well,” explains Daneshgaran. “The problem is, however, as you go up the spectrum it gets harder and harder to build critical components like circulators that can operate at those frequencies.”



Micro Harmonics Circulators

Moving on up

The higher-end of the 5G spectrum (26GHz to 86GHz) will provide much of the leap forward in data speeds, capacity, quality and reduced latency. However, at such frequencies the design of transmit/receive components becomes critical. Without advancements, the deployment of systems capable of operating even higher on the spectrum – within the terahertz regime (100GHz – 10THz) where 6G and 7G will operate – are also in jeopardy.

Recognising that national security could be affected, in late 2020 the Department of Defence in the US 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 330GHz and beyond.

“One component that is especially critical to telecom infrastructure is the circulator,” Daneshgaran explains. “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 one, goes out port two, and any signal coming in port two, goes out to port three.

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 120GHz stopped Daneshgaran's team in its tracks.

"Theoretically, you can design one, then simulate its performance, and it will be fine. However, actually making them is more of an art than a science," explains Daneshgaran. "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," says Daneshgaran.

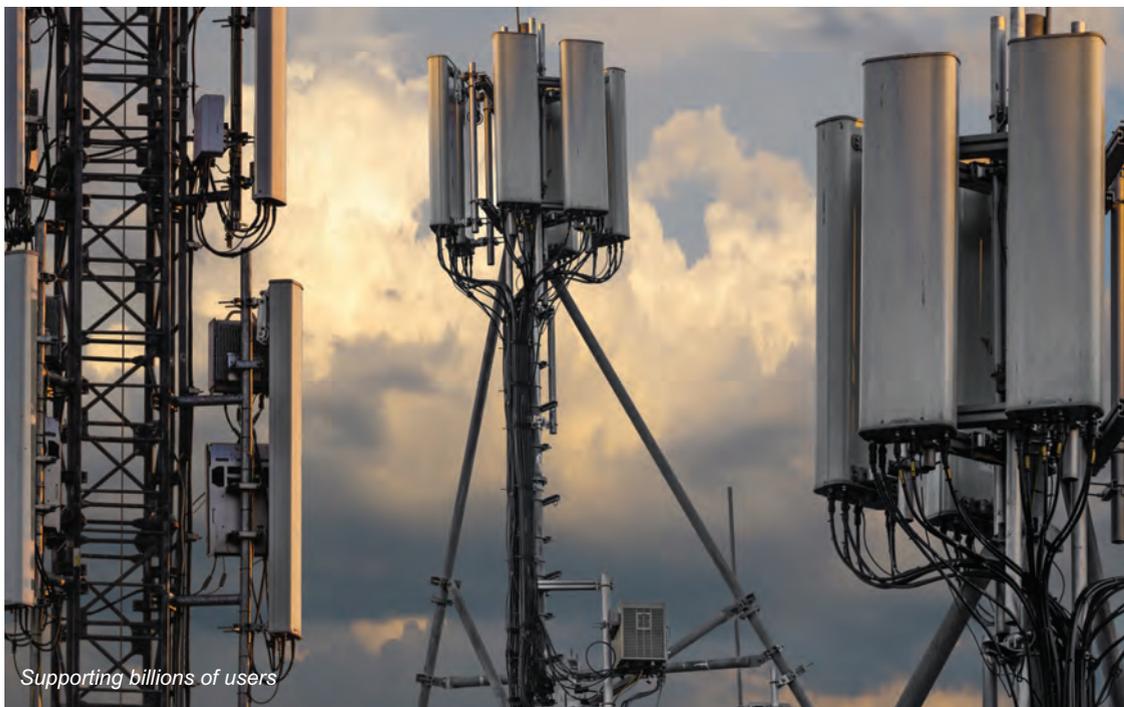
As an alternative, Daneshgaran had also designed the system to incorporate a orthomode transducer (OMT), but admits he would have only implemented that as a last resort.

An OMT can be used in place of a circulator, but you have to adjust polarization. With a circulator the polarization on the transmit and receive can be the same. However, an OMT would only work if the transmit and receive polarizations are different.

"We could have built the rig with an OMT, but it just didn't fit the kind of measurements we wanted to do," explains Daneshgaran. "We would have had to sort of spatially control the orientation and no one wants to go through all that if they don't have to. It would have been just a huge headache."

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

Headquartered in Virginia, Micro Harmonics Corporation specialises in research and design solutions for components used in numerous mmWave applications. The company has been awarded more than a half dozen Phase I and Phase II SBIR (Small Business Innovation Research) contracts with NASA. These include the development of an advanced line of Faraday rotation isolators in bands from WR-15 through WR-3.4 (50GHz to



330GHz) as well as critical ongoing improvements for its wide-band circulators.

"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," explains 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 adds. So, you want as much isolation as possible."

"The Micro Harmonics circulators demonstrated some pretty awesome isolations," continues Daneshgaran. "At the frequency we operated on, we realised

almost 30dB 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," says Daneshgaran. "This is because your data rate is directly proportional to the amount of bandwidth you have around your carrier frequency."

Daneshgaran goes 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 favour 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 30dB isolation we seek for our application," notes Daneshgaran. "If we were willing to accept something like 20dB of port isolation, we could have four or more 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," concludes Daneshgaran. "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."



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