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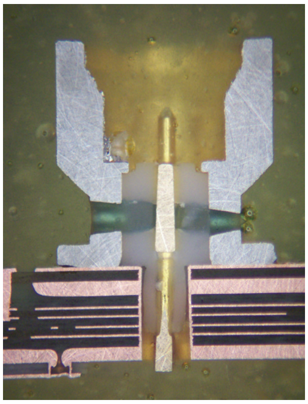
Millimeter-Wave Technology Prepares For A Wealth Of Applications

Fiber-optic-like data rates, micro-antennas, and high-resolution imagers are just the tip of the iceberg when it comes to millimeter-wave technology's capabilities.

MILLIMETER-WAVE TECHNOLOGIES WILL soon touch virtually every industry. Until recently, the semiconductor and machining capabilities of manufacturers were too inaccurate or cost prohibitive to enable millimeter-wave device production for all but specialized applications. Now, advances in semiconductor technology, testing techniques, and micromachining are beginning to bring millimeter-wave solutions to a wide range of applications.



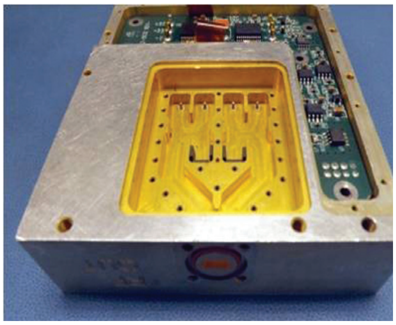
1. A frequency-modulated-continuous-wave (FMCW) millimeter-wave imager can be used safely to produce high-resolution security scans.

The growth of the global millimeter-wave technology market in terms of revenue is expected to reach $1.1 billion in 2018 at a CAGR of 59.10%. Millimeter-wave product volumes are estimated to grow from roughly 11,800 units to more than 360,000 units in 2018. Alongside this growth, the demand for high-data-rate technologies for wireless backhaul is driving innovation in the unlicensed 57-to-64-GHz frequency band.

For decades, millimeter-wave technology has been implemented in many military, aerospace, meteorology, and satellite applications. Mono-pulsed radar systems and weather radiometers were very common. Another example of applied millimeter-wave technology is the imaging of objects in space with large radar installations that pick up millimeter-wave radiation. Discrete satellite-to-satellite communications also is enabled by highly directional millimeter-wave signals. More recently, homeland security has been using millimeter-wave imagers for security screeners *(Fig. 1)*. Because millimeter-wave energy is non-ionizing and depletes rapidly in the environment, the technology can be safely used to image metallic and non-metallic objects on people.

The rapid atmospheric attenuation of millimeter-wave signals also can benefit high-speed wireless-technology links by limiting interference between transceivers. The dimensions of millimeter waves lead to very directional and high-gain antennas. Such antennas, in turn, translate into lower levels of interference and higher data rates *(Fig. 2)*. These millimeter-wave properties have nurtured the development of a variety of short- to mid-range high-speed data-link technologies *(Fig. 3)*. Development is being focused on applications for these high-speed data links, such as pico-cell wireless, wireless backhaul, chip-to-chip communication, and higher-performing RF electronics.

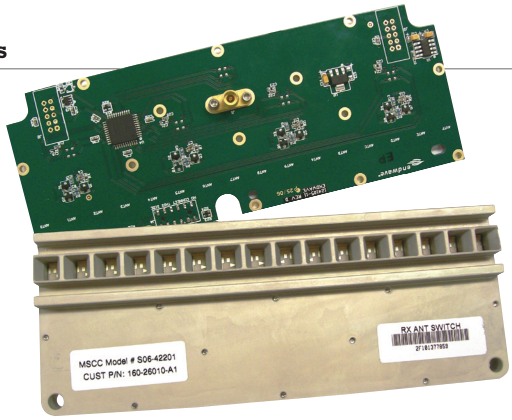
The increased interest in these data links also has been driven by the limited licensing issues in the unlicensed 60-GHz band as well as the lightly licensed frequencies from 71 to 76 GHz and 81 to 86 GHz. These frequency bands require a very minimal cost per license or no license at all, depending upon where the links are in the world. There are, however, constraints in transmit power in accordance with the Maximum Permissible Exposure (MPE) limits. Technical complexities also arise when



2. As a product of atmospheric absorption and millimeter-wave dimensions, antennas for millimeter-wave transmission can benefit from extraordinarily narrow beam widths.

maintaining stable output power at millimeter-wave frequencies.

Because these technologies have a wealth of bandwidth options in which to operate their links, fully duplex data rates beyond the common 1.25 Gbps are possible. Less spectral clutter also enables the use of modulation schemes, such as direct digital modulation, which lead to lower communication-electronics costs. This is detailed in the Shannon-Hartley theorem in the equation:



3. The very small dimensions of millimeter-wave devices allow for direct orthogonal mounting on PCB substrates. Copper patterns are used to create controlled impedance paths across the laminate and through the board.

$$C = B \log (1 + S/N)$$

where C is the channel capacity in bits per seconds, B is the bandwidth in hertz, S is the average received signal power over the bandwidth in watts, and N is the average noise figure over the bandwidth in watts.

It is evident in the equation that even with lower signal power, the lack of interference noise and the ability to use a very wide bandwidth can offer a very-high-capacity channel link. The atmospheric absorption does limit these devices to a range of a few hundred to a few thousand meters when used in a directional manner. The very narrow transmission beam also requires that the alignment between the two transceivers is accurate.

4. Millimeter-wave wireless links are a potential solution to enable fiber-optic-like speeds in highly congested areas or in environments where routing fiber might not be feasible.

For this reason, companies like HXI provide gun-sight mounts on their HDTV-link systems. These links have an aggregate throughput of 2.97 Gbps with a two-channel unit and an operating range from 20 to 300 m. In the telecommunications arena, more carriers are employing Long-Term-Evolution (LTE) networks to meet the data demand for mobile broadband.

Small-cell solutions also are increasingly being adopted to service the higher-demand areas that are not being fully served by larger macrocells. Offering these services in congested areas, either in-building or externally, is often prohibitively expensive to implement with fiber-optic cabling. And, it is impossible to service the growing capacity demands with slower-speed passive cabling. Using fiber-optic-speed millimeter-wave solutions is a proposed method for offering wireless backhaul in these difficult-to-service areas with minimal cost compared to other solutions. The available bandwidth also may eventually allow data rates as high as 40 Gbps.

Another advantage of millimeter-wave devices is the relative size of the antennas and the device components. These compact components can be very light and portable, which opens doors to more environments in which millimeter-wave devices could be used. On the other hand, the wavelength dimensions of these signals require very precise tolerances on small components *(Fig. 4)*.

The skin effect causes these higher-frequency waves to travel at the surface of the conductors, making surface finish and plating serious concerns. Small imprecisions in machining also lead to very low yields and higher costs. A solution to these problems has been to develop semiconductor-based millimeter-wave systems and other micro-fabrication techniques.

Another growing trend has been to implement on-chip antennas with self-testing electronics to cut down on expensive millimeter-wave test. Companies like IBM and United Monolithic Semiconductors have implemented processes with tool support for enabling millimeter-wave design as well as digital integration. Testing systems like digital-signal processing, internal noise sources, and loop-back sensing methods can all enable a self-testing device. IBM's 9HP process uses silicon-germanium (SiGe) BiCMOS for this integration. Other semiconductors used for millimeter-wave electronics are implemented in gallium arsenide (GaAs), indium phosphide (InP), and gallium nitride (GaN).

When working with semiconductor components, difficulties often arise when interfacing to the external electronics or antenna. Companies like Nuvotronics have developed highly refined micro-fabrication methods to create complete millimeter-wave structures in a monolithic process. Nuvotronics claims that its PolyStrata manufacturing technology can be used to make 3D transmission lines with advanced routing while enabling other features with 3D stacking. In addition to being able to create an effective millimeter-wave interface, millimeter-wave surface-mount-technology (SMT) components and other monolithic microwave integrated circuits (MMICs) can be included in the 3D design.

With these advanced fabrication techniques, millimeter-wave devices could soon be found in many commercial and industry environments. With the potential for integrated, ultra-high-speed data connections and low transmission power, this technology also could enable the Internet of Things and Big Data revolutions. mw