A Growing Number of Applications Boosts mm-Wave Technology

Sensors, radar, focused power and personal communications are highlights of a growing list of applications at millimeterwave frequencies. The valuable functions represented by these applications are causing excitement in the engineering and business offices of companies involved in mm-wave components, assemblies and test equipment. As development continues and costs come down, mm-waves will become a well-used portion of the electromagnetic spectrum.

First, a review, beginning with advantages of working with short wavelengths. The biggest advantages are the related characteristics of size and resolution. Size is an advantage in that physically resonant structures (waveguide, cavities, antennas, etc.) are small. The assemblies, enclosures and antenna arrays of mm-wave systems can be both high performance and miniature with few performance compromises. High resolution follows from the short wavelengths. For the same beamwidth, a 110 GHz mm-wave antenna will be 1/10 the size of an X-band antenna. Also, if a radar or sensor system can resolve distances to, say, 1/4 wavelength, that resolution is 1 mm at 77 GHz.

Disadvantages are also related to size. While physical structures are manageable, circuits are very difficult, since interconnections can easily be an appreciable fraction of a wavelength. Distributed techniques must be used even in the smallest integrated circuits, and since large devices cannot be readily fabricated, multiple devices in parallel are required. Techniques to deal with these challenges are being developed by engineers around the world, to make mm-waves available for promising new applications.

Radar and Imaging

The term *radar* means detection and distance measurement. The inherent high resolution and small antenna size have made precision radar a natural first application area for mm-waves. Evolution of advanced radar from X-band to 24 GHz, to 77 GHz, then to 100 GHz or 220 GHz has meant that sub-millimeter distance resolution is possible. Radar can now be used for applications at short distances. The well-publicized “smart cruise control” or anti-collision radar has a range from the vehicle to the roadway, or to other nearby vehicles. Military, public safety and emergency personnel may use in-building radar. Short-range mm-wave radar is also used for ground penetration, such as mine detection. One of the earliest applications was precision approach landing systems, although this has largely been supplanted by precision GPS navigation.

Radar-like applications are abundant in manufacturing process control. Position measurement and control is an obvious use where the level of precision does not require laser ranging. Less obvious are flow measurement of fluids or slurries carrying solid materials and safety systems that detect personnel or undesired objects. As a non-optical system, mm-wave radar can be used with optically opaque media such as pipes or plenums, or dust and smoke. An application already in use is level sensing in large tanks, such as those found at petroleum refineries and distribution sites.

Imaging is an extension of radar that is possible at mm-waves because of the high resolution. Using interferometry and holographic techniques, mm-wave imaging can provide X-ray type investigation without the ionizing properties. Note, however, that mm-waves are much more energetic than lower frequency radio energy and require precautions similar to high power microwaves and laser lightwaves.

Imaging applications range from scanning baggage for security to ground-penetrating imaging at archeological sites. When used with multi-frequency or ultrawideband (UWB) techniques, the resolution approaches optical quality. Holographic techniques can use the reconstructed wavefront to view and analyze the image from multiple observation points simultaneously.

Although classic radar scanning is used at mm-waves, there is greater interest in passive techniques. There are two types of passive mm-wave imaging: general illumination with a mm-wave source, and use of thermally-generated energy from the object. Both use similar radiometric detectors as a mm-wave “camera.” With an illumination source—sometimes multiple frequencies or a noise-like frequency spread—the quality of the image is greatly enhanced due to the higher energy level observed by the detectors.

Such mm-wave imaging systems can easily detect a weapon concealed under clothing, even ceramic weapons that do not alert typical metal detectors. They can also detect the presence of persons through non-metallic walls, such as the sides of some truck boxes.

Other current or developing applications for imaging include cloud imaging for weather research, high-resolution artificial vision for autonomous vehicles and robots, and aerial terrain mapping with penetration through rain forest canopy vegetation.

High Data Rate Communications

Another significant application for mm-waves is very high data rate links and personal area networking. High frequencies support wide bandwidth modulation much more easily than lower frequencies, and data rates in the gigabit range can be achieved at mm-wave frequencies. Propagation challenges are greater at mm-waves, but are not a significant problem for point-to-point and short-range systems.

For point-to-point data communications, mm-waves offer an alternative to fiber optics for short-distance links, without the environmental limitations of laser links (rain, snow, fog and haze). With 500 Mbps to 1 Gbps data rates, these links should be commercially viable products.

In the 60 GHz unlicensed band, commercial activities include development of high definition multimedia home networking systems. The poor wall penetration of mm-waves requires a terminal (wireless transceiver) to be located in each room, but this also allows frequency re-use, or different data streams at each terminal. The attraction of wireless routing of all data and entertainment programming in a home is clear—complete portability of HDTV equipment, audio systems, telephone and Internet. The short-range propagation characteristics also provide a degree of security against intrusion into the system, and the high data rate has plenty of headroom for robust encryption schemes.

As the bandwidth requirements for communications and entertainment continue to increase, mm-wave distribution systems appear to have the necessary performance, and strong efforts are underway to make the technology affordable to consumers.

Sensor Technology

It can be argued that radar and imaging are subsets of sensors, but common use of the term has come to mean applications outside of those specific applications. Field disturbance monitors and motion detectors were the earliest microwave sensors, and refined versions are using the higher resolution of mm-waves.

Black-body energy emissions allow mm-waves to be used for thermal measurement and living organism detection that has commonly been done by infrared detectors. The advantage of mm-waves is that resolution can be achieved electronically through antenna arrays, rather than by mechanical or optical means, as needed for infrared sensors.

Low-precision versions of radar and imaging applications may be more accurately described as sensors—flow detection rather than measurement, or collision avoidance warning rather than distance measurement.

Other Applications

Focused power was mentioned at the beginning of this report, but is mostly an interesting research item at this time. There are medical applications for localized heating, but they are not presently mm-wave systems. Microwave “stun-guns” and high-energy weapons are being investigated, but again, most work involves frequencies below about 20 GHz.

There is promise for coupling power across spaces that must be isolated for environmental or mechanical reasons. Closely-spaced high-gain (narrow beam-width) antennas can transfer energy with high efficiency, and the potential for longer distance transmission is being explored, as well.

Overall, the future is bright for mm-waves. The performance capabilities that come with short wavelengths enable many new applications, only a few of which have been covered here.

From May 2006 *High Frequency Electronics*