Passive Millimeter-Wave Imaging for Security

By Dr. Tom Williams, Millivision Technologies

100 GHz LNAs and detectors and attention to engineering details make frame-rate whole body passive millimeter-wave imaging a reality today.

Millivision Technologies of South Deerfield, Mass., has been working with millimeter-wave scanning technology for the last two decades. Its forte is passive scanning of humans for security applications, and through continuing development of new products it has refined and extended its capability to provide the ultimate in safe, private, effective and affordable security.

How It Works

Unlike X-Ray systems with their ionizing radiation, and active Microwave systems which bathe the subject in RF, passive millimeter-wave (PMMW) imaging systems read the natural thermal energy in environment, much like an infrared camera. Unfortunately, infrared wavelengths are too short to pass through clothing, so we choose a longer wavelength of 3 millimeters (specifically 80 to 100 GHz) to detect and image thermal energy in the environment (see Fig. 1). Heat coming off

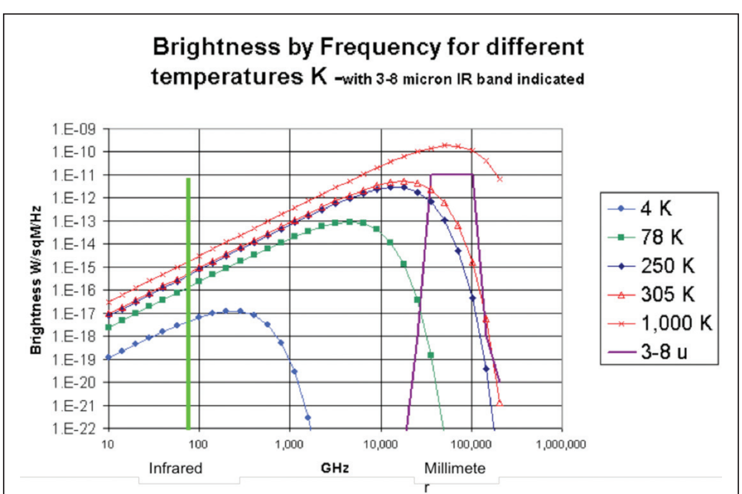

Figure 1 • Power is proportional to temperature. At infrared, where humans sense heat and conventional heat cameras operate the short waves do not penetrate clothing. At millimeter wavelengths (the green vertical line) clothing is nearly transparent.

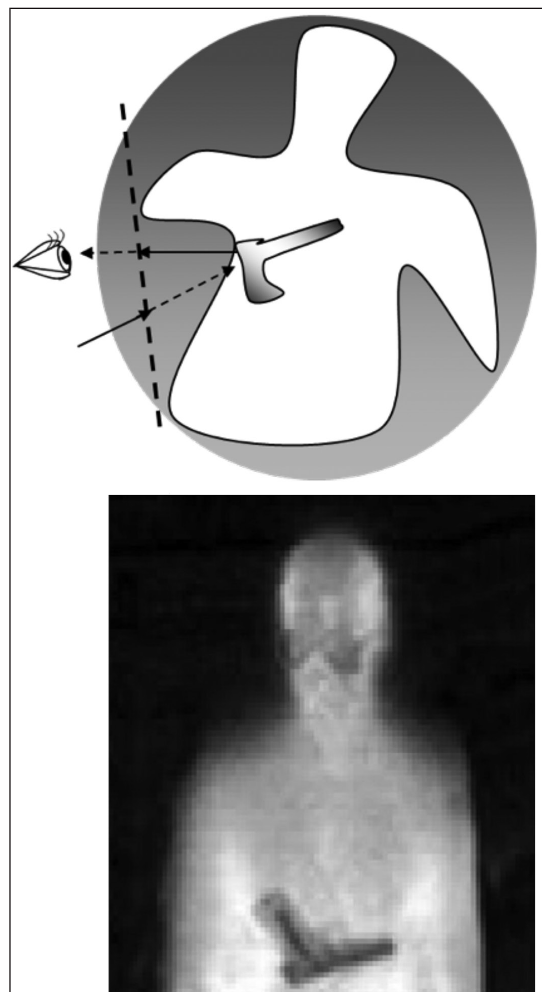

Figure 2 • The difference between the apparent temperature of the contraband object (which is reflecting the cool environment) and the warmer human creates contrast (which is only slightly reduced by intervening clothing).

the body is interrupted by occluding objects which have a temperature of their own, or reflect other temperatures in the environment, giving rise to contrast in the scene (see Fig. 2).

Because the wavelength we use (at W-Band) is so much longer than infrared, larger optics are needed and even then, spatial resolution is limited compared to typical optical systems. Also, because the total power levels at W-Band are so low, very sensitive receivers are needed to amplify the signal before detection and processing into an image.

The Challenges in Achieving Good Sensitivity

All remote temperature sensors are called "radiometers." They achieve sensitivity through a combination of low noise electronics (especially the front end), wide bandwidth prior to detection, and as long an integration time as possible. ΔT is the minimum discernible temperature difference that can be detected, which is the same as the R.M.S. value of the signal expressed in Kelvin. Lower numbers describe better sensitivity. The simple equation

$$\Delta T = T_{sys} / \sqrt{(\beta \tau)}$$

relates those factors (where T_{sys} is the total system temperature or noise figure expressed in Kelvin, β is the bandwidth in Hz and τ is the effective sample time in seconds) to the ΔT performance summary value. The goal in scanning humans for concealed objects is in the range of 1 Kelvin or lower.

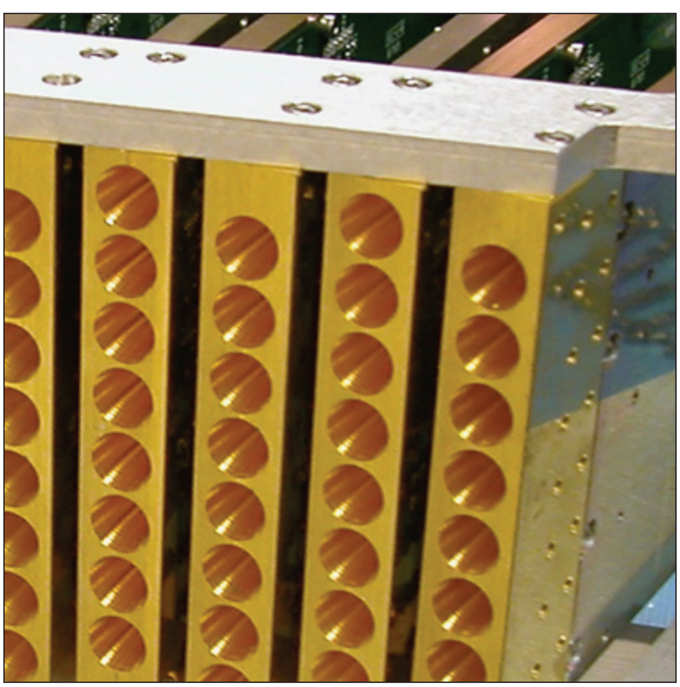

Figure 3 • In this photo we see some of the feed horns of an array of channels which sit at the focal plane of the optics.

To form images, some number of channels is used to scan the scene in some amount of time. It is most efficiently scanned when the size of a pixel is the same as ½ the diameter of the half-power beamwidth in the scene (in order to achieve Nyquist sampling of the scene). So, the speed of sampling is related to the resolution, the scan area and the imaging speed (frame rate).

An example follows, not directly from our systems, but illustrative for a reasonable PMMW imager for security. Consider a need to scan a person with 33 mm resolution cells, and assume the area to scan is 1 meter by 2 meters. There are 30 x 60 cells or 1800, and for Nyquist sampling we need four times that many (twice as many in X and in Y), or 7200 samples. Let's assume we need motion and would like to form complete images at 10 Hz, or 0.1 seconds per frame. Therefore we need 72,000 samples per second in some combination of dwell time and channels.

With a desire to keep the number of channels low, perhaps 60, then 72,000 samples per second/60 channels yields 1/1200 of a second dwell time on average, or 0.8 milliseconds. Let's assume we have channels with a T_{sys} of 1600 Kelvin (T_{sys} is $T_{receiver}$ e.g. 500K plus T_{scene} of 300K equals 800K plus optics losses e.g. 3 dB or x2 = 1600K). Let's assume we have a bandwidth of 20 GHz and we know that our integration time is 0.8 milliseconds. This yields a ΔT of 0.4 Kelvin. In a practical system there would be other losses attributable to gain fluctuation or reference switching, raising this to about 0.8 Kelvin. And so, this would be a good design point to achieve the goal of under 1 Kelvin ΔT.

Implementation

Millivision's implementations of its PMMW scanners rely on a scalable architecture of modular components. The sensed signal, once focused on an array of feed horns at the focal plane, is amplified, detected, the weak detected signal amplified further and digitized all on one printed circuit board. Eight such channels of high sensitivity processing are built into one circuit board, and those boards are stacked as appropriate to form a focal plane for the application (see Fig. 3).

Technical challenges which have been overcome in order to commercially replicate this product include the facts that: the total power received in one channel is on the order of -70 dBm across the W Waveguide Bandwidth; in-circuit noise figures as low as 4 dB are needed to achieve sufficient sensitivity; and operation at W-Band requires special attention to precise fabrication. Furthermore, optics loss, beam efficiency, and circuit noise levels must be state-of-the art to achieve a quality image.

Figure 4 • The Millivision Passive Millimeter-Wave whole body scanner is self-contained, with imager, power, control and automatic threat recognition.

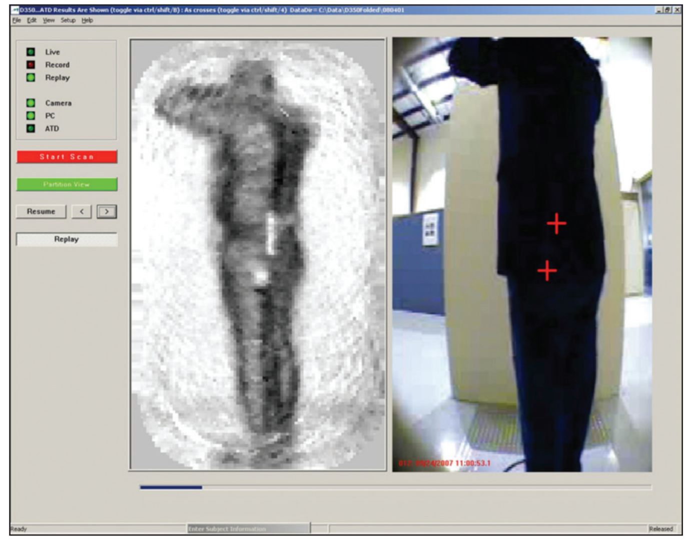

Figure • 5 A photo from the operator console interface. A live real-time image shows the subject. Normally, the operator does not see the millimeter-wave image as seen on the left (here the contrast is reversed to improve visual detection). The automatic threat recognition software places markers on the video image as seen on the right, eliminating any need to view the subject.

PMMW Whole Body Imaging is the Answer to the Future of Security Problems

The effectiveness of PMMW for security scanning is pretty much the same as with any kind of security scanning. What does effective scanning mean? The answer is different across security applications. Screening people who are boarding flights (for explosives and weapons) is quite different from screening people entering through customs (who might be smuggling). Screening people visiting a prison (for weapons, drugs, cellphones) is quite different from employees leaving work (who might be secreting electronic items of value). And, in each case the level of detection required and the cost for failure is different. In general, no single screening device or method is foolproof and when high levels of performance are required, multiple methods are brought together in a comprehensive system (see Fig. 4).

In the case of PMMW, the good resolution, high sensitivity systems that Millivision produces not only meet effectiveness goals, but also employ the only technology which is unquestionably safe for the person being scanned (and the system operators). When people will be subjected to scans on a regular basis, this safety becomes a critical to acceptance.

Another important factor to consider when screening is the dignity of the subject during the search. Invasive technologies, especially those which reveal anatomical details, are unacceptable to the public in general. They may also be unacceptable in a variety of situations where employees are being scanned. To this end, automatic detection of concealed threats, so called “ATR” (automatic threat recognition) software has been developed for most of the existing security scanning systems. Millivision has a very advanced form of this software which uses techniques that mimic the way that humans find objects. With this tool, customers can process a large number of people quickly and still alert when suspicious objects are found. One distinct advantage of imaging systems over metal detectors is that the specific body location of the detected object is indicated to security personnel, speeding the clearing process (see Fig. 5).

Software and Improvements

Although better electronics will always improve image quality, one primary way to do so is through image processing. Various noise reduction techniques (smoothing, non-linear filtering) have some positive effect, but in general, most such attempts also sacrifice what little resolution there is in the image. The converse is also true. Attempts to improve resolution tend to increase noise. Once images are as good as they can be, through proper modeling of the sensing process and effective reconstruction, the next area of improvement is ATR.

Simple histogram techniques, and even some sophisticated ones have some success but also often fail in a variety of real situations. When we view these images we might report that we are simply looking for and finding “the thing on the body has a different brightness.”

However, the actual values do not support such a simplified description. Much like any image understanding task, a quality result comes from a clear understanding of the sensor, the target, and the "clutter." In this case the clutter is the human, which can take on a wide range of thermal qualities. Millivision is continuing to develop advanced imaging-understanding technologies to mimic the performance of humans at this threat recognition task.

In summary, state-of-the-art 100 GHz LNAs and detectors and attention to engineering details make frame-rate whole body passive millimeter-wave imaging a commercially available reality today. Coupled with real-time ATR, these systems are the safest scanners in existence, and preserve dignity and privacy.

Further Reading:

http://www.millivision.com/

http://www.stores.org/STORES%20Magazine%20February%202012/shape-things

About the Author:

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