ACTIVE DENIAL ARRAY

By Randy Woods and Matthew Ketner

Active Denial Technology (ADT)—which encompasses the use of millimeter waves as a directed-energy, nonlethal, counterpersonnel weapon—has the potential to provide an important new escalation-of-force capability to U.S. operating forces. ADT projects a focused beam of 95-GHz millimeter waves to induce an intolerable heating sensation on an adversary's skin, repelling the individual with minimal risk of injury. More than a decade of research has established the biological and behavioral effects of ADT for large spot size systems, such as Active Denial System 1 (Figure 1). While the effects of this large spot size system have been successfully established, the technology that produces those effects has the potential to progress in a number of ways, particularly with the development of smaller, lighter, and lower-cost systems.

One research effort focuses on the development of smaller, lighter, and lower cost ADT demonstrators that produce commensurate "ADS-effects," with effective spot size and power densities on target. In support of this effort, the Joint Non-Lethal Weapons Program (JNLWP) sponsored the Naval Surface Warfare Center, Dahlgren Division (NSWCDD) to develop a "smart target system," which measures the millimeter-wave beam using fast-response, 95-GHz diode detectors. NSWCDD subsequently developed and tested the W-Band Beam Diagnostic Array to characterize the system's beam with a temporal resolution of 30 Hz and a high spatial resolution of 1 inch.

The current method of measuring the 95-GHz beam is to use carbon-loaded Teflon (CLT) to produce an average power beam image. This method works as the CLT is exposed to the system's beam. The material heats, over a period of seconds, proportional to the magnitude of the radio frequency (RF) field, resulting in an image as shown in Figure 2. After the exposure, the specific heat capacity of the CLT can be used with the temperature increase in the CLT to provide an indication of the total energy deposited in the material. This method produces a good representation of the average RF field; however, any peak variations in the beam are averaged out.

To allow for high temporal-resolution measurements of the 95-GHz beam, a high-density, 95-GHz diode-detector array was commissioned by the Joint Non-Lethal Weapons Directorate (JNLWD), and was designed and built by NSWCDD, with support from Millitech, Inc. The array consists of a center 11 × 11 matrix (shown in Figure 3) with four removable arms that can be attached (shown in Figure 4), resulting in a measurement area of approximately 1 × 1 m.

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Figure 1. Active Denial System 1

Each element's profile consists of the individual horn antenna from the array, an attenuator, a detector, and a SubMiniature version A (SMA) connection to the digitizer circuitry. This configuration allows for the power received from the antenna to be attenuated and converted to a direct current (DC) output capable of being measured by an analog-to-digital converter. The machined antenna elements provide a uniform effective area for each element, allowing field strength (W/cm^2) to be converted into power received (W or dBm). The aperture antennas also provide an impedance match between free space and the waveguide system. A cross-sectional view of the array element is shown in Figure 5, followed by a signal flow diagram shown in Figure 6.

The basic principle of operation behind the array is that the derivative of the diode detector's power vs. output voltage curve is very repeatable between detector elements. Therefore, when the detector elements arrived at NSWCDD, each detector element was paired with a variable

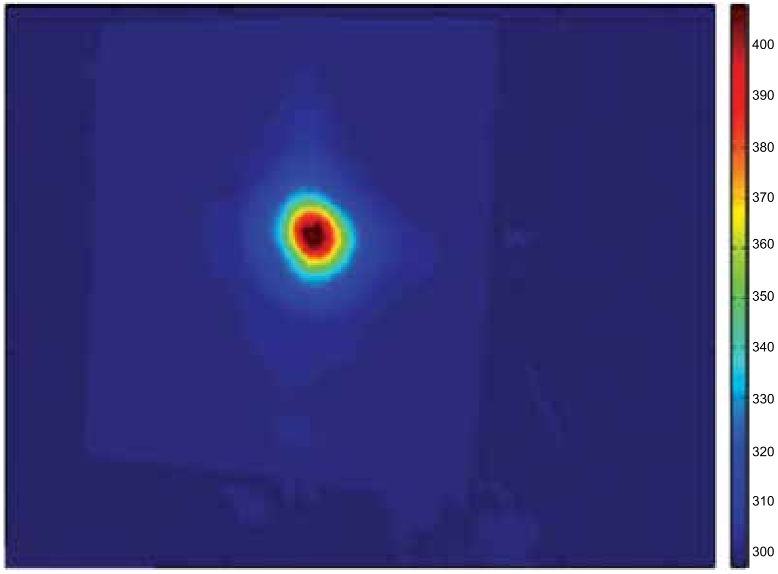


Figure 2. CLT Representation of Small, 95-GHz Spot

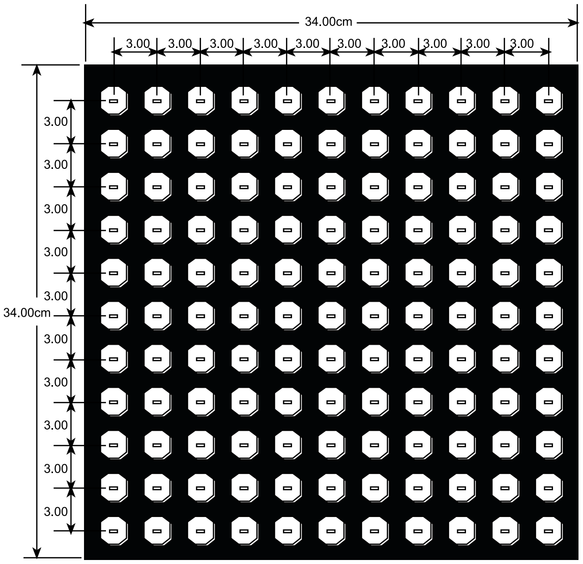


Figure 3. Main Array Face

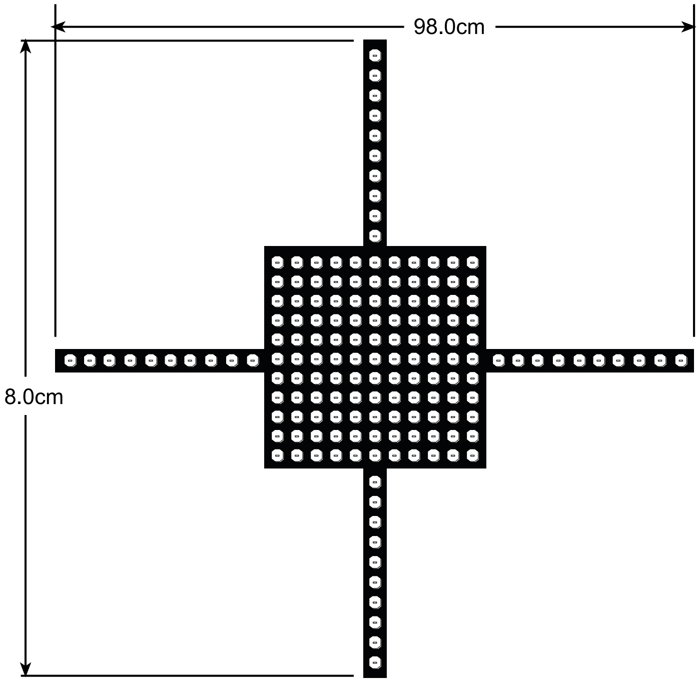


Figure 4. Full W-Band Array

attenuator and calibrated as a single unit. The calibration was accomplished by inserting a known input power of +5 dBm into the input of the attenuator and setting the DC output voltage at a predetermined millivolt (mV) output. This allowed the detector's individual offset voltages to be removed and caused the detectors to behave in a repeatable manner. The attenuator is able to be adjusted by varying the depth that the aluminum nickel card is inserted into the section of waveguide.

The final section of the electrical system converts the DC voltage output from the detectors to a digital signal to send back to the operator station. For this, it was determined that a 16-bit digitizer would be required to enable measuring the microvolts output by the detectors on the low end of their range, while still allowing the digitizer to measure the full output voltage of 1.8 V for high-input powers. Also, due to the proximity of the operator to the array and overall system flexibility, it was determined that Ethernet communications would provide a sufficient means of reading the system data.

To display the data to the operator, a two-dimensional array is populated and displayed for the user (shown in Figure 7). This allows values to be

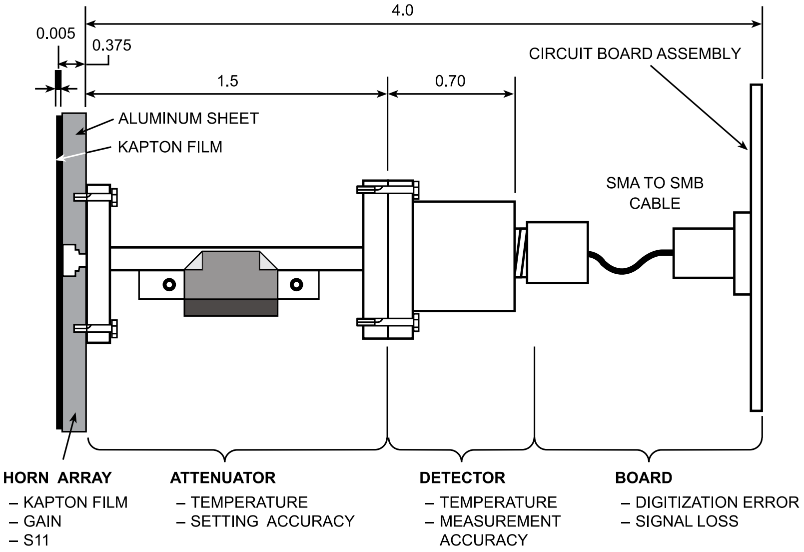


Figure 5. Cross-Sectional View of Array Element

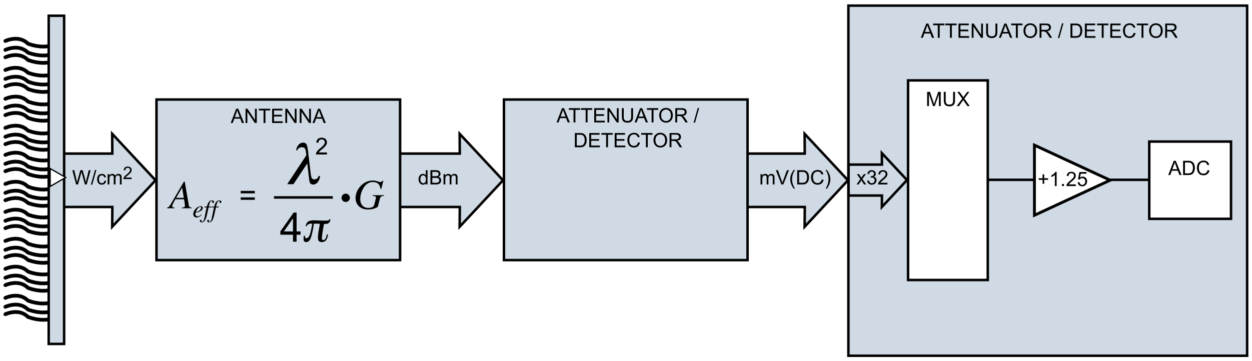
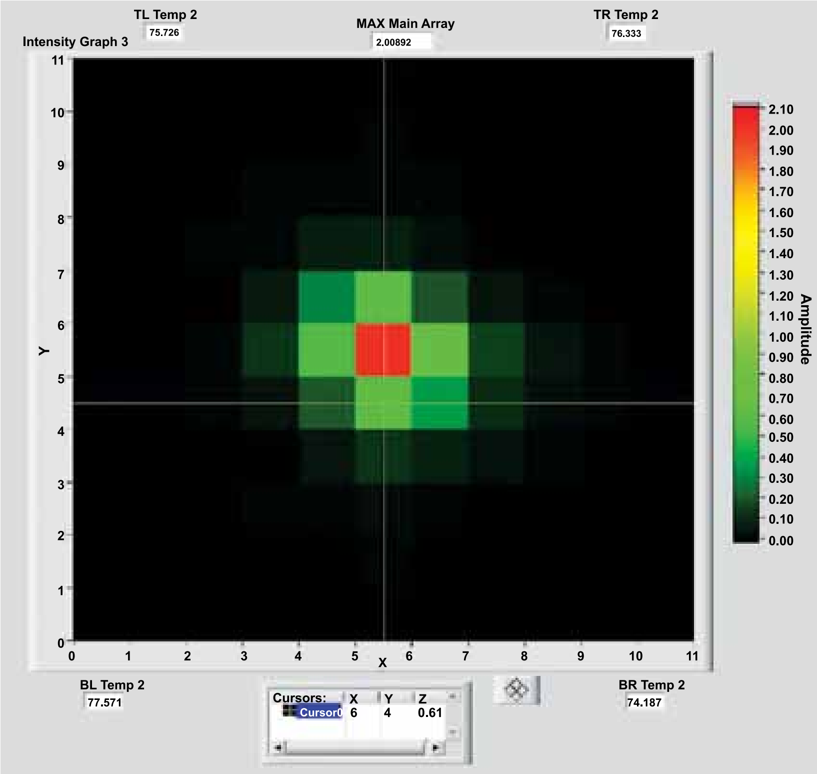


Figure 6. Signal Flow Diagram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MAX Main Array: 2.00892

TR Temp 2: 76.333

BL Temp 2: 77.571

BR Temp 2: 74.187

Cursors:	X	Y	Z
Cursor0	6	4	0.61

Figure 7. Array's Operator Interface Showing a Small Spot Source

read directly from the display corresponding to the watts per centimeter squared (W/cm^2) present at the array face. Data also is recorded so that it can be viewed later in a player application, such as a video file, or it can be viewed in a spreadsheet application, frame by frame. The data shown in Figure 7 is representative of small-source testing performed recently and very clearly shows the beam profile.

CONCLUSION

NSWCDD engineers successfully met the W-band array's design goals of providing a high temporal-resolution image of 95-GHz beams. The system has been tested against two active denial systems, providing good agreement with the currently accepted methods, as well as valuable information regarding the system's beam characteristics. These accomplishments will allow future system development to take advantage of this better understanding to possibly reduce system size and increase the effective range. A better understanding of the 95-GHz beam helps to facilitate future ADT development for this much-needed, nonlethal escalation-of-force capability for U.S. warfighters, homeland defenders, and law enforcement personnel.