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Diagnostic Array for Characterizing Narrow-Band High-Power Microwave Sources

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Accurate characterization of radiated antenna patterns is critical to successfully developing high-power microwave (HPM) sources. Accurately measuring the intense fields and radiation patterns of these dynamic sources is a difficult task. This paper details the design and operation of a 31-element, time-resolved diagnostic array that has been used in the development of various HPM sources.

KEYWORDS: Antenna, Array, Diagnostic, HPM

1. Introduction

Source development and characterization is an essential step in fielding high-power microwave (HPM) systems. Characterization of a system's radiated pattern can not only validate the antenna design but also potentially give insights into the operation of the source itself. However, due to the high-power nature of the source, pattern measurements can be difficult. Shot-to-shot repeatability of the source output complicates single-point mapping techniques. Even worse, breakdown of the antenna feed or antenna elements during the pulse can mean that there is a dynamically changing pattern during a single pulse.

These complications have been addressed by building a 31-element receiving array, with the time history of the received power being measured at each location. Postprocessing of the recorded data then yields a wealth of information describing the antenna and source performance.

In Sec. 2 of this paper, the overall system layout is described. Hardware, data acquisition, and processing algorithms are discussed. The sensor elements are required to operate in extremely high power densities and are a critical component of this system. In Sec. 3, the design and calibration techniques for these sensors are reviewed. Finally, in Sec. 4, an example of source characterization by the array is presented, where various figures of merit

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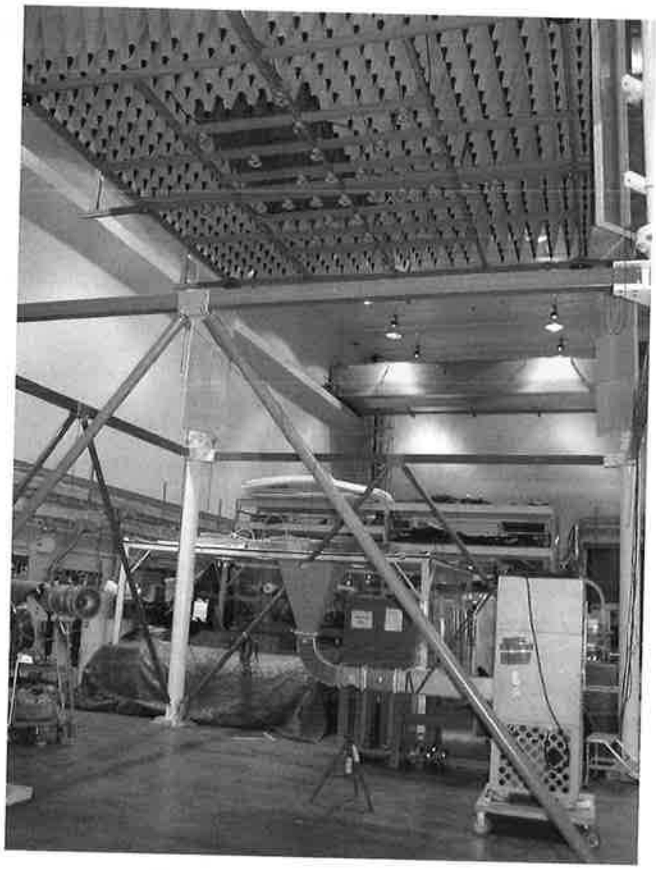

Fig. 1. Perspective view of array.

(i.e., power, effective radiated power, pulse width, energy, beam widths, etc.) and pattern profiles are calculated and plotted.

2. System Description

Figures 1 and 2 show views of the diagnostic array. It consists of a 31-element array suspended 5.5 m above the floor. Positions of the array elements are adjustable to optimize characterization of anticipated patterns. The radio frequency (RF) envelopes are detected from each sensor, thus providing simultaneous pattern amplitude information at 31 separate spatial locations. The system is currently configured to monitor L-band antenna patterns.

Figure 3 illustrates the system layout. The source antenna radiates RF up to the array. The sensors sample the pattern at 31 different locations. Signals from the individual sensors are detected using microwave crystals and are routed to digitizers located in a shielded rack on the back side of the array. The recorded data are then ported via fiber-optic cable back to the data acquisition computer.

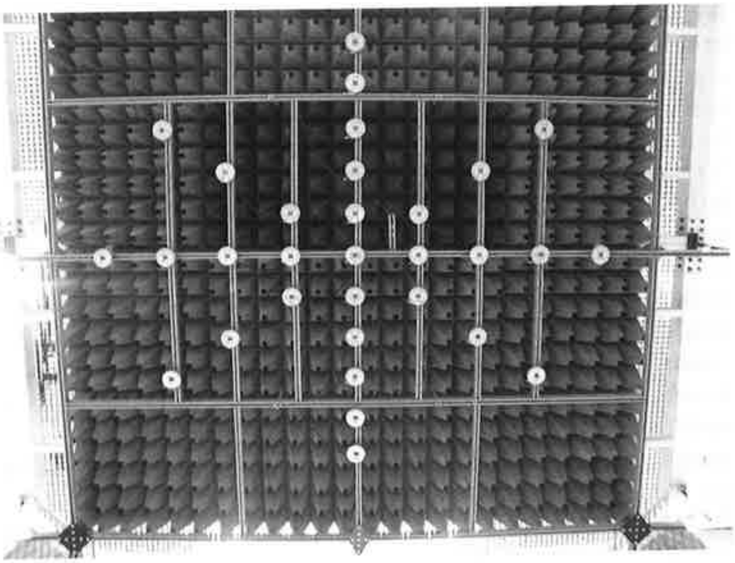

Fig. 2. Vertical view of sensor layout.

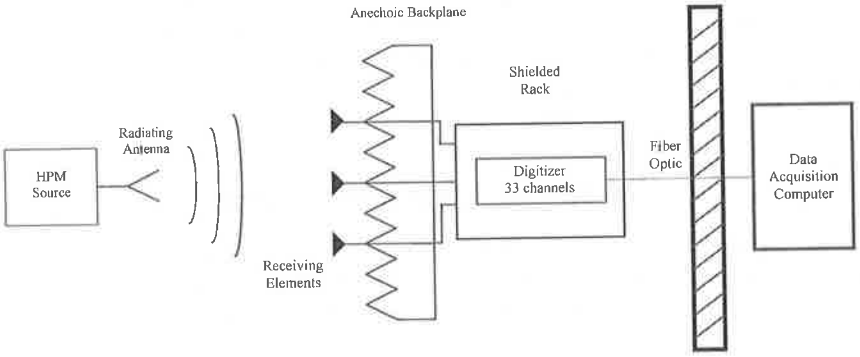

Fig. 3. System block diagram.

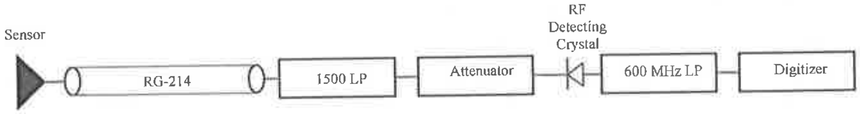

Fig. 4. Sensor line diagram.

Details of an individual sensor line are shown in Fig. 4. The receiving sensor (detailed in Sec. 3) captures the RF signal, which is run over cable to the shielded rack located behind the anechoic back plane. A low-pass filter is used to filter out potential harmonic content. Fixed attenuators are used to reduce the signal amplitude as needed down to approximately a 10-dBm level. Crystals (Wiltron model 75N50B) are then used to detect the RF envelope. This detected signal is then recorded by the digitizer. The digitizers (Acqiris model 270, 1 Gsample/s) record the time history for each sensor. The signal from the center element is split, one leg being detected for amplitude information and the other leg mixed with a local oscillator to provide frequency information. Local memory allows the digitizers to record a burst of multiple ($\approx$10) shots. After the burst, data are ported back to the data acquisition computer for storage and analysis.

DAAAC (Data Acquisition, Archival, Analysis, and Instrument Control from Voss Scientific) is the primary software package used in controlling the digitizers and acquiring the data. The package allows for remote instrument control, full signal path documentation, database archival, and automated data analysis. It handles the logistics of accounting for various attenuations, frequency-dependent losses, and appropriate calibrations allowing for quick quantitative review of the data.

DAAAC stores the 31 power density waveforms in its database. IDL (data visualization and analysis software from ITT) is then used to postprocess these data and extract various figures of merit from the data.

At each time step, a surface is fitted to the power densities, $S_i(x,y,t)$, at the 31 spatial points. The power density is integrated over this surface to get the total power radiated, $P_{\text{rad}}(t)$, at each time step. The effective radiated power (ERP) is also calculated for each time step as $\text{ERP}(t) = \max_{x,y} S(t)*4\pi R^2$.

With these time-resolved data now available, $P_{\text{rad}}(t)$ is integrated over time to get the total radiated energy, E. The effective pulse width is calculated as $E/\max(P_{\text{rad}})$. Looking at energy densities is often useful in judging an "average" radiation pattern. Integration of $S_i(x,y,t)$ over time gives the energy density at each of the 31 points. IDL then fits a surface to these points to get an average radiation pattern. Cuts of this pattern in the x and y directions then yield E and H plane patterns and their beam widths.

3. Sensor Characterization

The probe used in diagnosing HPM radiation patterns is a critical element of the array design. The probe needs to be insensitive enough to avoid cable/connector breakdown issues in high power densities, yet still have a large enough effective area to be accurately calibrated.

Consider the case in which the probe is exposed to a 10-kW/cm^2 fluence. To avoid breakdown ($<$1,500 V on 50 Ω cable, i.e., $<$22.5 kW), the effective area of the sensor should be $<$2 cm^2. One convenient way to get this small area is to use below-cutoff waveguide to coax transitions.[1] For this array, WR284 (S-band) waveguide-to-coax adaptors are used in measuring L-band patterns (see Fig. 5).

The cutoff waveguide is used to attenuate the signal levels with the fields evanescing into the guide as $e^{-\alpha z}$, where $\alpha = k_c^*[1 - (f/f_c)^2]^{1/2}$ with k_c and f_c the cutoff wave number and frequency, respectively.[2]

The probes are calibrated in an anechoic chamber using standard antenna techniques. A network analyzer is used to measure the transmission loss between two standard-gain L-band horns. The probe is then substituted for one of the horns, and its gain is measured relative to the standard-gain horn.

Figure 6 shows a typical effective area vs. frequency for these probes. Note the strong dependence on frequency. It is therefore important to use the appropriate calibration for the frequency being used. Also, a low-pass filter should be used to avoid harmonic content from influencing the probe's response.

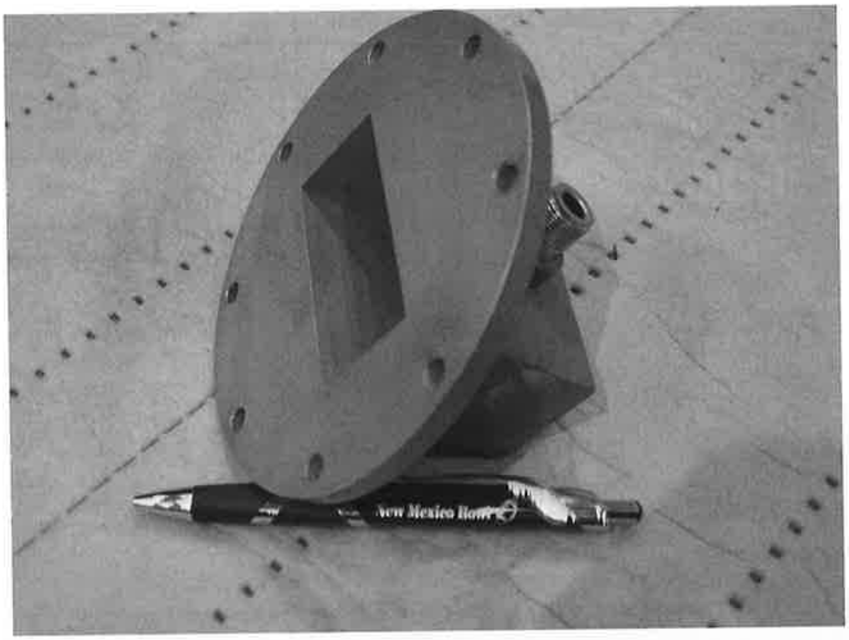

Fig. 5. Array element: WR284 waveguide to coax adaptor.

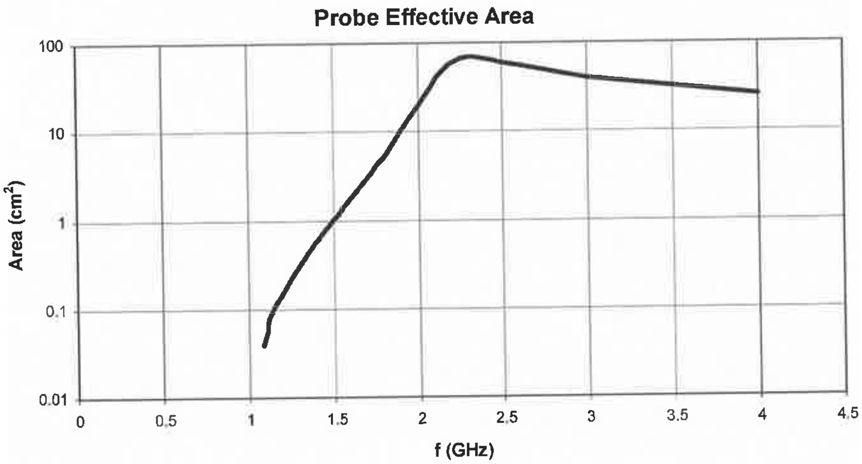

Fig. 6. Probe calibration curve.

Figure 7 shows the probe receiving pattern. As expected, the small effective area (low gain) leads to broad beam widths.

4. Source Characterization Example

As an example of the array operation, a surrogate source (500 kW, 1,250 MHz, 4 μs magnetron feeding a standard-gain horn) is used to illuminate the array. The DAAAC software is used to collect the data and apply calibration to the waveforms. IDL then compiles

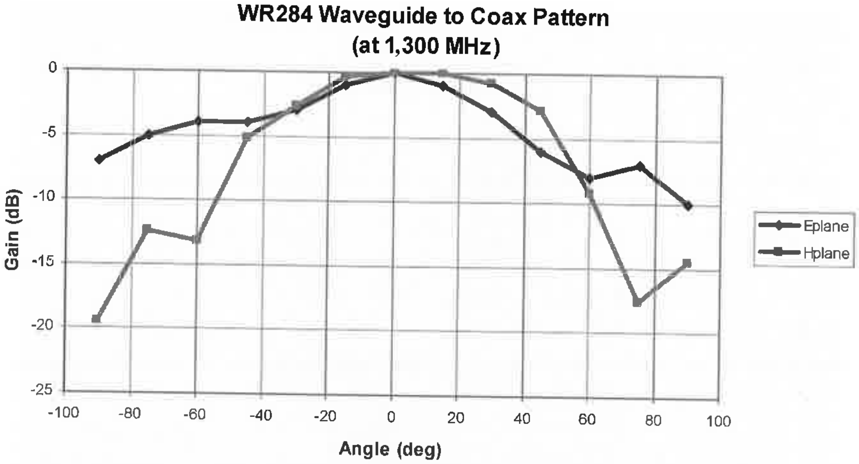

Fig. 7. Probe E and H plane patterns.

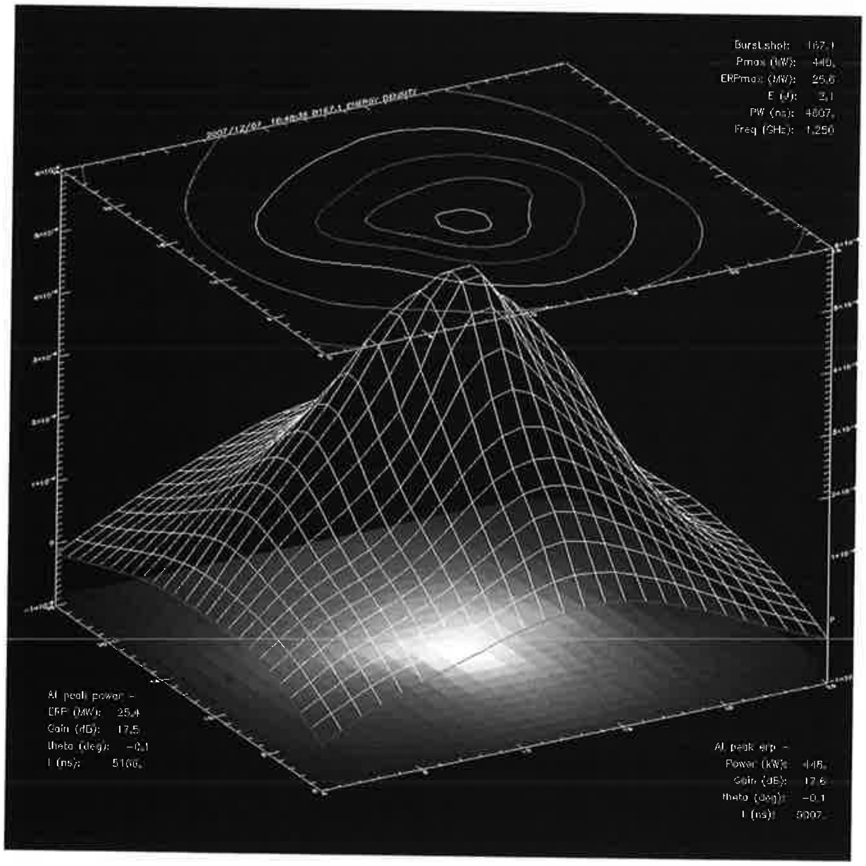

Fig. 8. Characterization summary plot.

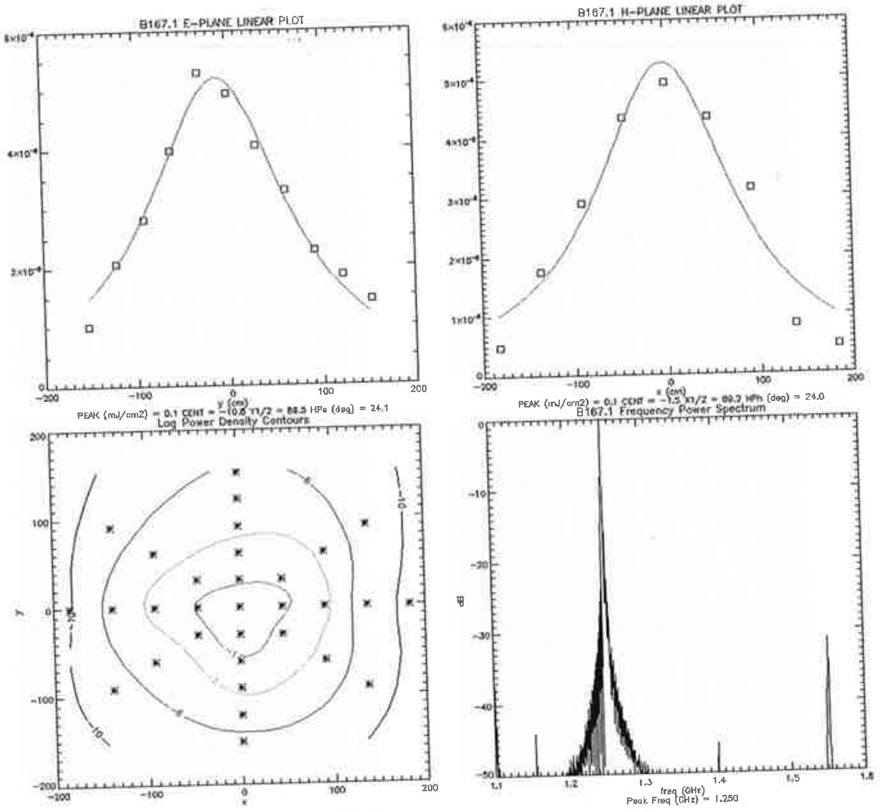

Fig. 9. E and H plane patterns.

the data from all the sensors in order to calculate pattern information. The following figures show the processed data.

For well-behaved pulses, looking at the energy density received at each sensor can give a quick look at the "average" pattern. Figure 8 is a summary window that shows a surface plot of the energy density. The total received power, calculated ERP, pulse width, gain, and pointing angle are also displayed for quick reference.

Figure 9 again uses energy densities to look at the E and H plane patterns. Beam widths and pointing angles are derived from these data. Also displayed are a contour plot of the pattern and the spectrum derived from the heterodyne data channel.

The time history of a radiated pulse can sometimes lead to insights such as breakdown occurring in the antenna feed or radiating aperture. For visualizing how the pattern evolves with time, a routine was written that plots the pattern (surface and contours) for each time step. The routine then plays these "frames" in sequence to form a movie showing the time history of the pattern. Figure 10 shows four frames of the well-behaved magnetron pulse. The top right-hand quadrant of each frame shows a time history of the total power received by the array. A marker on this waveform changes frame to frame, providing a time reference for each frame. This type of data visualization can provide very useful insights into dynamic processes occurring during a pulse.

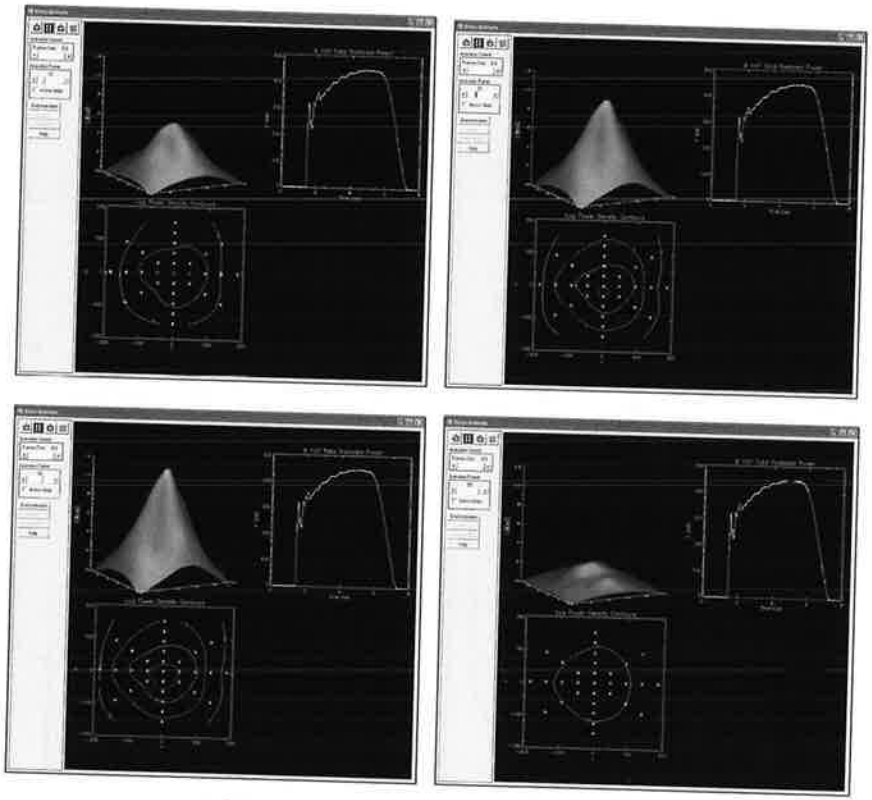

Fig. 10. Frames from a pattern movie.

5. Conclusions

This paper has described the design and operation of a 31-element, time-resolved diagnostic array used in various HPM source developments. Out-of-band waveguide sensors are successfully used in very high-power-density environments to sample the pattern over a spatial grid. Recorded time histories of the individual sensors are then processed to provide a wealth of information on the radiated pattern and source performance. The flexibility and near-real-time, shot-to-shot analysis of patterns has been extremely useful in the successful development and diagnosis of many HPM sources.

6. Acknowledgments

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Dr. Dale Coleman received his B.S. in physics and M.S.E.E. and Ph.D. in electrical engineering from Texas Tech University in 1977, 1980, and 1983, respectively. Dr. Coleman joined Sandia National Laboratory in 1983 and began research in linacs and HPM sources. From 1990 to 1993 he was with the Super Conducting Super Collider, working on synchrotron RF systems. He rejoined Sandia in 1993. His interests include high-current-induction linacs, RF accelerators, high-power microwave sources, antenna design, and RF propagation.

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