Direct IR Diagnostics of Antenna Aperture Distributions

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ABSTRACT

A thermal imaging technique has been developed to measure electromagnetic (EM) fields. This technique is applied in this paper to measure the EM fields radiated by large phased array antennas. This thermal technique is based on infrared (IR) measurements of the heating patterns produced in a thin, lossy detector screen made from a carbon loaded polyimide film placed near the antenna in the plane over which the field is to be measured. The temperature rise in the screen material (over the ambient background temperature of the screen) is related to the intensity of the field incident on the screen. An experimental calibration table was developed at NIST/Boulder to convert the temperature rise into equivalent field strength at any point on the screen by irradiating the screen with a plane wave of known intensity. This thermal imaging technique has the advantages of simplicity, speed, and portability over existing hard-wired probe methods and produces a 2D picture (a pseudo-color image) of the field. In general, these images can be used for field diagnostics of the antenna (near-field or far-field patterns) and/or to evaluate the aperture excitation of the array. The aperture distribution can be compared to a standard “test pattern” to determine the operational state of each individual element of the array, which controls the radiation pattern of the antenna. Phase shifters and/or attenuators which produce incorrect element magnitudes or phase shifts can be identified with this technique.

Keywords: Phased arrays, aperture distributions, field diagnostics, infrared, thermograms

1. INTRODUCTION

A thermal technique has been developed to determine the radiation properties of phased array radar antennas. The magnitude and the phase of the individual radiating elements of an array can be measured with this technique. This information can be used for diagnostic or calibration purposes to determine the electrical state and condition of the phase shifters and attenuators controlling the radiation pattern of the array.
2. THEORY - IR Thermal Measurement Technique

The thermal technique is based on IR thermographic/holographic images of the heating patterns produced in a thin, planar, lossy IR detector screen placed near the antenna in the plane over which the EM field is to be measured. Carbon loaded foams or polyimide films are used to measure electric field intensities; ferrite loaded epoxies are used to measure magnetic field intensities. Due to the electric and/or magnetic losses in the screen material, the screen absorbs EM energy and heats in proportion to the intensity of the field incident on the screen. The loss mechanisms that cause heating of the screen are due to conduction, polarization, and magnetization effects in the screen material. The absorbed heat energy is converted, in part, to EM radiation, which is emitted as “blackbody” radiation. A sensitive IR thermal camera is used to measure the intensity of the blackbody radiation, which can be used to determine the temperature of the screen. The screen temperature is then used to determine the intensity of the field incident on the screen.

3. APPLICATION – Large Phased Array Antennas

One important application of this thermal technique is to the testing of phased array antennas. From a measurement of the near-field pattern of the antenna (in the Fresnel Zone), the far-field antenna pattern (in the Fraunhofer Zone) and the distribution of the field (magnitude and phase) in the aperture (source) plane can be determined. Alternately, the magnitude of the aperture field can be measured directly in the aperture plane of the antenna. This technique is implemented in the measurements to follow.

A F16 Fire Control Radar (FCR) phased array antenna was used to test the feasibility of the thermal technique. The initial experimental work on the array was performed in the anechoic chamber at AFRL/RRS (Rome Laboratory). The antenna was removed from the aircraft, mounted on a dielectric platform, and placed on a styrofoam platform in the chamber. This antenna is a 2D planar phased array with an elliptical footprint, with 548 slot elements arranged in 24 rows, as shown in Figure 1.

![Figure 1: Close-up view of an F16/FCR phased array X-Band radar antenna mounted on a wooden platform for off-plane testing in an anechoic chamber at AFRL/RRS (Rome Laboratory).](image-url)
In a typical test, the antenna was driven with a CW signal within its operating band of 8-12 GHz (X-Band). The frequency was stepped over the operating range to determine the aperture excitation and the radiation pattern as a function of frequency. The IR detection screen was placed near the antenna in two orthogonal planes. First, the screen was placed in the vertical plane of the antenna (axial E-Plane, centered on the aperture), as shown in figure 2a. Then, the screen was rotated 90 degrees into the horizontal axial plane (H-Plane). Later, the screen was placed in a transverse plane of the antenna (in the near field, parallel to the aperture), as shown in figure 2b.

3.1 Axial Measurements (Near-Field to Far-Field Transitions)

Thermal measurements were made of the electric field distributions in the axial plane. E-plane and H-plane cuts were made. The temperature profiles in these axial planes show the transition of the electric field from the near field to the far field.

The measured IR thermogram of the axial field temperature distribution in the vertical E-plane near mid-band is shown in figure 3a. The measured IR thermogram of the transverse field temperature distribution in the horizontal H-plane near mid-band is shown in figure 3b. Notice that the E-plane beam is split into two search beam lobes at this frequency.
The measured temperature profiles captured in the IR thermograms were digitized and stored in the memory of the IR camera. The thermal data were then converted into equivalent electric field intensity profiles, using a calibrated color temperature table based on the thermal and electrical parameters of the screen material. For example, the conductivity of the screen used to take the above thermograms was 1500 Ohms/Square.

Two dimensional contour plots and three dimensional relief maps of the intensity of the electric fields were then produced to aid in the visualization of the magnitude of the resultant electric field distributions.

A 2D contour plot of the digitized axial field intensity distribution in the vertical E-plane near mid-band is shown in figure 4a. A 2D contour plot of the digitized axial field intensity distribution in the horizontal H-plane near mid-band is shown in figure 4b. Similarly, a 3D relief map of the digitized axial field intensity distribution in the vertical E-plane near mid-band is shown in figure 5a. A 3D relief map of the digitized axial field intensity distribution in the horizontal H-plane near mid-band is shown in figure 5b.

3.2 Transverse Measurements

Thermal measurements were then made of the electric field distributions in the transverse plane. Near-field and aperture-plane cuts were made.

3.2.1 Near-Field Cut

The thermogram of the near-field temperature pattern for the F16/FCR phased array antenna, at mid-band (10 GHz), is shown in Figure 6a, where only the thermogram taken at 406 mm from the aperture is shown. The 2D contour plot and the 3D relief map of the electric field intensity pattern are shown in Figures 6b and 6c. The aperture excitations of the elements of the array interfere constructively and
destructively with each other to develop into the near-field patterns shown in Figures 6b-c. The main beam and the first sidelobe are visible in the thermograms.

Figure 4a: 2D contour plot of the magnitude of the electric field intensity distribution in the axial E-Plane (vertical plane) near mid-band of the F16/FCR phased array antenna.

Figure 4b: 2D contour plot of the magnitude of the electric field intensity distribution in the axial H-Plane (horizontal plane) near mid-band of the F16/FCR phased array antenna.

Figure 5a: 3D relief map of the magnitude of the electric field intensity distribution in the axial E-Plane (vertical plane) near mid-band of the F16/FCR phased array antenna.

Figure 5b: 3D relief map of the magnitude of the electric field intensity distribution in the axial H-Plane (horizontal plane) near mid-band of the F16/FCR phased array antenna.
3.2.2 Aperture-Plane Cut

The thermograms of the aperture-plane temperature pattern for the F16/FCR phased array antenna were taken with a regular 20º lens to view the entire aperture source region and with a close-up 5º lens (of the 4th quadrant) to look at the details of the individual radiating elements of the array.

Thermograms of the aperture temperature distributions, at mid-band (10 GHz), are shown in Figures 7a and 8a (regular lens and telephoto lens, respectively). The 2D contour plots of the electric field intensity patterns are shown in Figures 7b and 8b. The corresponding 3D relief maps of the electric field intensity patterns are shown in Figures 7c and 8c.
Note that the intensity distribution of the excitation (from an open-ended waveguide) of each element of the array is clearly visible in the thermograms.
4. CONCLUSION

It was shown that the IR thermal technique could be used to determine the magnitude of the individual radiating elements of a phased array antenna by directly measuring the aperture-plane temperature pattern. This information can be used to identify faulty elements in the array. This thermal technique has the advantages over conventional hard-wire probe techniques of being simpler to use, easier to apply, and, in some circumstances, more accurate.