INFRARED DETECTION OF SURFACE CHARGE AND CURRENT DISTRIBUTIONS

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Abstract

A technique has been devised using infrared detection of I^2R heating of conducting materials to determine the surface charge and current distributions on various objects. The measurement process is explained and comparisons between experimentally determined and actual charge and current distributions are presented.

Introduction

Knowledge of the charge and current distributions is essential in many applications of antenna design, electromagnetic scattering, and electromagnetic compatability. Although it is possible to measure these quantities directly on a given object using electrically small probes[1], it is an extremely slow, tedious, and expensive process. To avoid this, computer analysis of structures has become increasingly important.[2,3] These models require assumptions concerning geometry, wire size, boundary conditions, and the like. In all such investigations, model verification has become important.[4,5] Thus a technique yielding real-time measurement of charge and current magnitude distributions has obvious advantages.

La Varre and Burton have shown[6] that surface currents on radiating and scattering structures can, under certain conditions, generate sufficient heat to be detectable by infrared measurements with equipment such as an AGA Thermovision 680 system.

Factors Affecting IR Detection

The detectability of I^2R heating by surface currents is a function of the threshold temperature gradient of the measuring equipment, the conductivity and emissivity of the surface under investigation, and the microwave power levels present.

A temperature gradient of 0.2° can be detected by the Thermovision system. If a scattering or radiating structure has sufficient currents to cause a 2°C temperature difference, ten isotherms may be selected in various colors and displayed to indicate the temperature distributions.

The surface under consideration must be sufficiently conductive to allow representative charge and current distributions to form. However, the surface must not be so conductive that either no significant I^2R heating is produced, or any generated heat is quickly dissipated by the thermal conductivity of the material. Electrical and thermal conductivity go virtually hand-in-hand in electrically conductive materials.

The spectral emissivity (the ratio of the emittance of a body in a specified portion of the spectrum to that of an ideal radiator) must also be high enough to allow good Thermovision detection of the surface. In general, black colored objects have the high emissivity sought.

Sufficient power levels to cause the surfaces to produce images corresponding to the charge and current distributions on good conductors, but within the government allowed maximum human continuous exposure level (10mw/cm^2) were used in all experiments.

Experimental Procedure

To determine the charge distributions on a radiating antenna, a sheet of resistive paper was placed between the radiator and the detector. A dielectric material was used as a backing for the paper to give the required stiffness. As the electric fields produced converge on the charge concentrations on the radiator, currents are produced on the resistive paper parallel to the lines of force. Thus, the current magnitude produced near large charge concentrations is higher, producing greater heating of the paper. Detecting these temperature levels yields the relative values of the charge distributions on the radiator. Application of the continuity equation allows current magnitude determination.

Radiating Structures

3λ/4 Monopole over Conducting Ground Plane (Fig. 1)

For a basis for the discussion of points of interest and to show the relationship between the Thermovision display and the known charge and current distributions, a monopole of height $h=3\lambda/4$ was driven with a sinusoidal source at its base. Points A and B ($h=\lambda/2$ and $h=\lambda/4$) are points of interest corresponding to easily accessible points of charge minimum/current maximum and charge maximum/current minimum. Cross arms of length $\lambda/4$ will be attached at these points.

Crossed Dipoles

The crossed dipole (Figures 2 and 3) is of interest to gain insight into structures such as aircraft with the same general shape. Burton, King, and Blejer[4,5] have shown the solutions to be functions of the various critical lengths and the boundary conditions imposed by the location of the cross arms on the monopole. Figure 2 shows the monopole above with the arms attached at point A (the charge minimum/ current maximum). The significant current in the cross arms results from the resonant combination of the lower vertical member and one of the cross arms. The charge distribution is derived from the continuity equation. Note also the agreement of the Thermovision image of the charge distribution.

Figure 3 is the monopole with the arms attached at point B (the charge maximum/current minimum). The resonant length of the lower portion of the monopole plus the cross arms causes a significant different in the response in this case compared to the monopole.

Scattering Structures

Laboratory Set Up

Figure 4 shows the laboratory set up for the scattering experiments. It consists of a $\lambda/4$ monopole in front of a 60° corner reflector, all on a large aluminum ground plane. Although the same technique used in the radiator measurements can be used to determine the charge distributions, a coating on the scattering surface was used to enhance direct Thermovision measurement of the current distributions.

Flat Plate

A flat plate with a resistive paper surface of length $\lambda/2$ on each side was oriented as shown in Figure 4. The Thermovision response of the irradiated plate is shown in Figure 5. Figure 6 is a horizontal profile of the temperature distribution $\lambda/10$ above the ground plane. Note the increase current magnitude on the plate's lateral edges.

Aircraft Model

A plastic model airplane that has been coated with carbon paint is shown in Figures 7 and 8. The incident microwave signal of Figure 7 is 1.5 times the frequency of Figure 8. Although structures such as this have significantly greater resonance complexity, these figures show the intuitively pleasing change in the temperature distribution associated with surface currents that one expects with a change in frequency.

Summary

Infrared detection has been shown to be capable of yielding a real-time analysis of the current and charge distributions on various surfaces. This process is ideally suited to the analysis of complex structures where a theoretical solution is difficult, time consuming, or even impossible. Although other methods of visual imaging of charge and current distributions have been proposed[7], the Thermovision technique requires little surface and no imaging preparation. Without the requirement of object cooling or any obvious restrictions in frequency, this technique offers interesting opportunities for future measurements on a variety of surfaces.

REFERENCES

1. H. Whiteside, "Electromagnetic Field Probes", Technical Report No. 377, Cruft Laboratory, Harvard University, Cambridge, Mass., 25 Oct. 1962.

2. C. M. Butler, "Currents Induced on a Pair of Skew Crossed Wires", IEEE Trans. Antennas Propagat., Vol. AP-20,pp. 731-736, Nov. 1972.

3. H. H. Chao and B. J. Strait, "Radiation and Scattering by a Configuration of Bent Wires with Junctions", IEEE Trans. Antennas Propagat. (Commun), Vol. AP-19, pp. 701-702, Sept. 1971.

4. R. W. Burton and R. W. P. King, "Measured Currents and Charges on Thin Crossed Antennas in a Plane-Wave Field", IEEE Trans. Antennas Propagation , Vol. AP-23, No. 5, pp. 657-64, Sept. 1975.

5. R. W. Burton, R. W. P. King, D. Blejer, "Surface Currents and Charges on a Thick Conducting Tube in an E-Polarized Plane-Wave Field II". Measurements, "Radio Science, Vol. 11, No. 8,9, pp. 701-11, Aug-Sept 1976.

6. C. A. La Varre and R. W. Burton, "Thermographic Imaging of Electromagnetic Fields", Thesis Report No. NPS-52 AN 75121, Naval Postgraduate School, Monterey, Ca., Dec. 1975.

7. Keigo Iizuka, "A Method for Photographing Microwave with a Polaroid Film", Division of Engineering and Applied Physics, Harvard University, Cambridge, Ma., Technical Report. No. 558, p.3, March 1968.

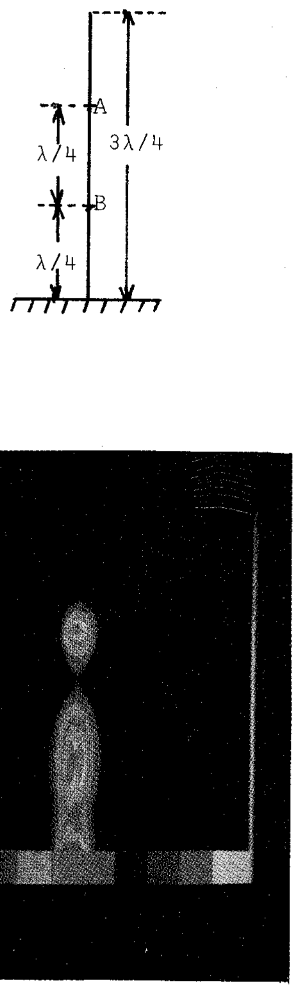
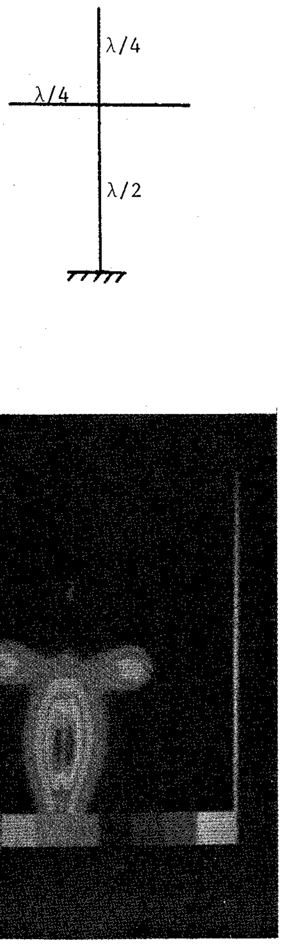


Fig 1(a)-Driven monopole of height $3\lambda/4$
(b)-Thermovision response of 1(a)



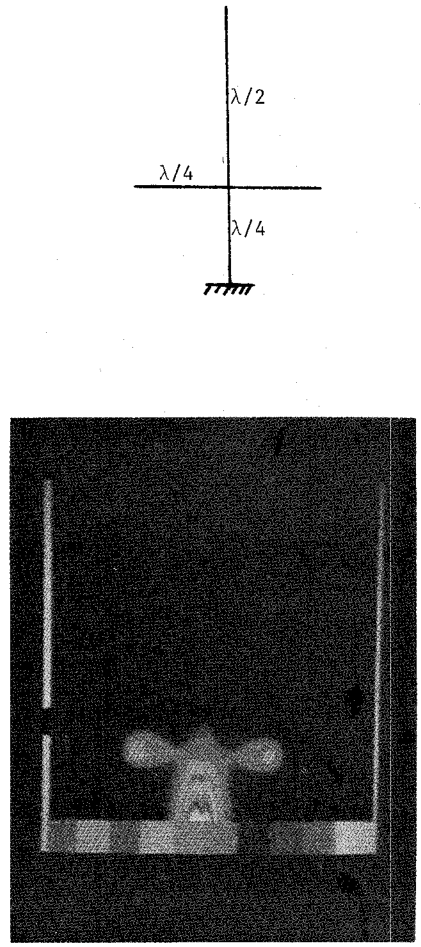


Fig 2(a)-Driven crossed dipole with arms at $h=\lambda/2$
(b)-Thermovision response of 2(a)

Fig 3(a)-Driven crossed dipole with arms at $h=\lambda/4$
(b)-Thermovision response of 3(a)

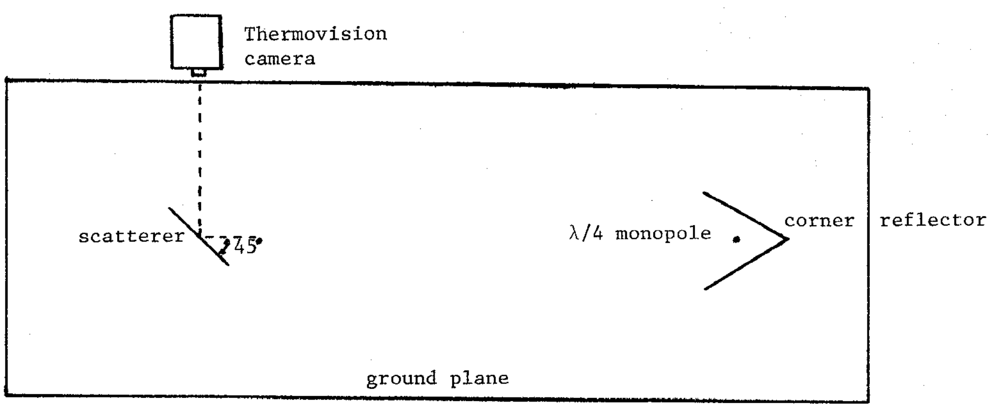


Fig 4-Laboratory set up for scattering experiments

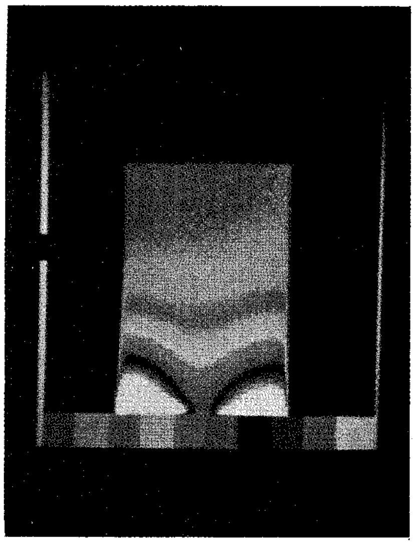


Fig 5-Thermovision response of flat plate

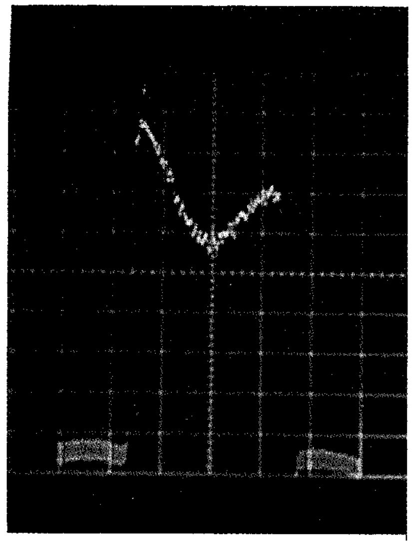


Fig 6-Temperature profile of flat plate at h=λ/10

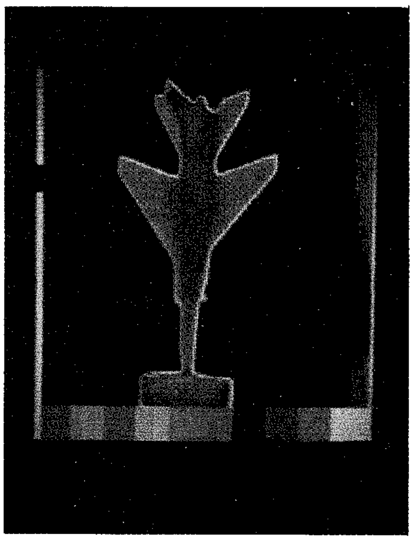


Fig 7-Thermovision response of carbon painted airplane model (low frequency)

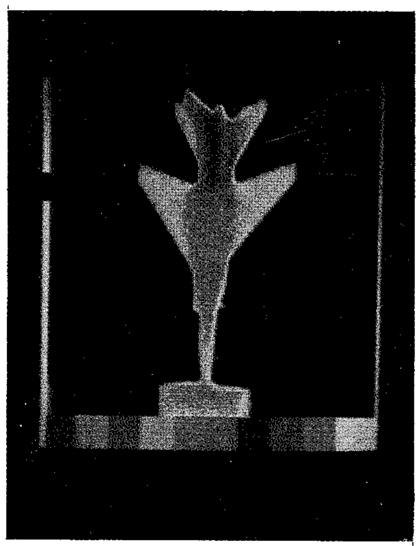


Fig 8-Thermovision response of carbon painted airplane model (high frequency)