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THE UNIVERSITY OF MICHIGAN

COLLEGE OF ENGINEERING

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

Radiation Laboratory

TRANSIENT RADIATION FROM ANTENNAS

Technical Report (1 September 1970 - 31 August 1971)

By

Chen-To Tai

Grant GK-22898

September 1971

Prepared for:

National Science Foundation
Attn: John M. Ide, Division Director
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Washington, DC 20550

Ann Arbor, Michigan

Summary

For the period 1 September 1970 to 1 September 1971, most of the research under NSF Grant GK-22898 has been devoted to the following problems.

(1) The transmission and the reception of a transient field involving a cylindrical antenna.

(2) The transmission of transient field by a biconical antenna.

(3) Re-examination of Kirchhoff's theory and Huygen's principle.

Discussion of Research

The research resulted from the first problem was presented at the URSI Spring Meeting in Washington (April, 1971). A summary of this talk is attached to this report.

The research on the biconical antenna is still in progress. What we intend to do is to apply the Fourier transform to the exact expressions for the fields and the impedance of a small-angle biconical antenna. The main task involved is the numerical evaluation of the Fourier transform of the sine and cosine integral functions.

Since there is no closed-form solutions for these transforms, it appears that we have to evaluate them with the aid of a digital computer. It is hoped that with the aid of the fast Fourier transform technique the problem can be resolved.

The problem which deals with Kirchhoff's theory is not only of historical interest but also of practical importance. Ever since Stratton and Chu presented their formulation in 1937, a great many engineers and scientists have adopted their formula as the basic tool in formulating scattering and diffracting problems. A much superior formulation due to Franz (1948) was neglected by many workers in this country. A Communication has recently been addressed to the Transactions of Antennas and Propagation giving a critical review of this

topic. A copy of this Communication is included in this report. It is hoped that this work will put Franz' formula in a prominent place as it should be.

Publications

(1) A paper entitled "Transient Properties of an Antenna in the Transmit and Receive Modes" was presented by Professor Chen-To Tai and Mr. Harold E. Foster at the URSI Spring Meeting in Washington on April 7-10.

(2) A paper entitled "Kirchhoff's Theory: Scalar, Vector or Dyadic?" by Professor Chen-To Tai has been accepted for publication by the Transactions of Antennas and Propagation.

Personnel

NSF Grant GK-22898 was awarded to the University of Michigan, Radiation Laboratory. The Project Director is Professor Chen-To Tai. Mr. Harold E. Foster, a graduate student under Professor Tai's supervision, is working on a thesis supported by this Grant.

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Radiation Laboratory

TRANSIENT RADIATION FROM ANTENNAS AND ITS RECEPTION

Final Report (1 September 1970 - 31 August 1972)

By

Professor Chen-To Tai

August 1972

Grant GK-22898

Prepared for:

National Science Foundation
Washington, D.C. 20550

Ann Arbor, Michigan

THE UNIVERSITY OF MICHIGAN

FINAL REPORT

Summary

From the period 1 September 1970 to 31 August 1972 most of the research under NSF Grant GK-22898 was devoted to the following problems.

1) Transient radiation from resistively loaded cylindrical and from thin biconical antennas,
2) The basic structure of Maxwell's theory.

The transient radiated field of a resistively loaded cylindrical antenna excited by a finite step function has been determined by combining the transmission line theory with the induced EMF method. For biconical antennas we have used the sinusoidal current distribution on a thin biconical antenna to investigate the radiation field. However, the exact input impedance function has been used in the formulation so that the input current remains finite for all frequencies of excitation.

The basic structure of Maxwell's theory has been reviewed in an invited paper for the Proceedings of IEEE. The integral form of Faraday's law was studies in detail both from the conventional point of view and from the relativistic point of view.

Discussion of Research

The approach which we have taken to investigate the transient radiation of a resistively loaded cylindrical antenna is based on two steps. The approximate current distribution on the antenna is determined by considering a resistively loaded transmission line with a characteristic impedance numerically equal to the average characteristic impedance of a cylindrical antenna, namely, $Z_A = 120\,(\ell n \frac{2\ell}{a} - 1)$ ohms, where ℓ and a denote respectively the half-length and the radius of a cylindrical antenna. It is known from the theory of cylindrical antennas that the current distribution so determined is a good approximate solu-

tion as far as the computation of the radiation field is concerned. For an unloaded antenna, the sinusoidal current distribution fails to predict accurately the input impedance of a cylindrical antenna near anti-resonance. Such a difficulty does not exist for a resistively loaded antenna, because the input value of the approximate current distribution so determined remains finite for all frequencies.

To determine the input impedance of such an antenna we apply the method of induced EMF. The method can be applied either to a discretely loaded antenna or to a continuously loaded antenna. Thus, for a discretely loaded antenna we found that the input impedance can be expressed in the following form

$$Z_i = \sum_{n=1}^{N} 2R_n \left|\frac{I_n}{I_i}\right|^2 + \sum_{n=1}^{N}\sum_{m=1}^{N} Z_{nm} \frac{I_n I_m}{|I_i|^2}$$

where I_n denotes the current at a site of a discrete resistance. Z_{nm} represents an intersection coefficient which can be evaluated in closed form in terms of the sine and cosine integral functions. This formulation is believed to be new. Much of the numerical computation based on this formulation has not been completed yet.

For thin biconical antennas we use a sinusoidal current distribution to calculate the radiation field. The current is assumed to be of the form

$$I(z) = \frac{V_i \sin k(\ell - z)}{Z_c \left[Z_o Y_t \sin k\ell - j \cos k\ell\right]}$$

where Y_t denotes the equivalent terminal admittance of a thin biconical antenna with characteristic impedance Z_c as defined by Schelkunoff [1] and given by

$$Y_t = G_t + jB_t$$

where $$G_t = \frac{\eta}{4\pi Z_c^2}\left[2\,\mathrm{cin}\,2k\ell + \sin 2k\ell\,(\mathrm{Si}\,4k\ell - 2\,\mathrm{Si}\,2k\ell) + \cos 2k\ell\,(2\,\mathrm{cin}\,k\ell - \mathrm{cin}\,4k\ell)\right],$$

$$B_t = \frac{\eta}{4\pi Z_c^2}\left[2\,\mathrm{Si}\,2k\ell + \sin 2k\ell\,(\ell n\,4 - \mathrm{cin}\,4k\ell) - \cos 2k\ell\,\mathrm{Si}\,4k\ell\right],$$

$$\eta = 120\,\pi\,\Omega\ ,$$

and k is the wave number.

It can be shown that the current I(z) described by (1) is, indeed, the leading current on the antenna. By applying the method of Fourier analysis, we can determine the transient radiation field of thin biconical antennas excited by a finite step input voltage. The numerical work pertaining to this problem is near completion. Preliminary calculation shows that the result is comparable to that obtained by Palciauskas and Beam [2] based on Hallen's integral equation method.as applied to a cylindrical antenna. The previous two problems constitute the main research work done by Mr. Harold E. Foster as his Ph.D. dissertation at the University of Michigan under the supervision of the principal investigator.

Another basic problem which we have studied under this grant deals with the presentation of Maxwell's theory, particularly, the derivation and the implication of the integral form of Faraday's law. The work contains a review of Maxwell's original theory in modern notation, a discussion of its implications, the relativistic foundation of the theory, and finally, the ambiguities as found in many well known text books. The paper will appear shortly (August, 1972). A copy of the original manuscript is attached here.

THE UNIVERSITY OF MICHIGAN

FINAL REPORT

Publications and Presentation of Papers

1) "Transient Properties of an antenna in the Transmit and Receiver Modes," URSI Spring Meeting, Washington, D.C. (April 1971) by H.E. Foster and C-T. Tai.

2) "Processes of Transient Radiation and Reception," 1971 International Symposium on Antennas and Propagation, Japan, September 1-3, 1971, by H.E. Foster and C-T. Tai. (This paper was read at the meeting by another speaker because both Foster and Tai were unable to attend that symposium).

3) "On the Presentation of Maxwell's Theory," by C-T. Tai, to appear in the August issue of the Proceedings of IEEE as an invited paper.

Personnel

NSF Grant 22898 was awarded to the University of Michigan and administered in the Radiation Laboratory, which is under the direction of Professor R.E. Hiatt. The principal investigator of the Grant has been Professor C-T. Tai, who was assisted by Mr. H.E. Foster and Mr. Y-P. Liu, graduate students in the Department of Electrical and Computer Engineering. Mr. Foster has worked under this Grant during the last two years. He is expected to complete his thesis work within the next six months. Mr. Liu has started his thesis work recently. His research will be in the area of transient radiation.

References

[1] S.A. Schelkunoff: Electromagnetic Waves, p. 453, D. Van Nostrand Company, New York (1943).

[2] R.J. Palciauskas and R.E. Beam, "Transient Fields of Thin Cylindrical Antennas," IEEE Trans. Ant. and Prop., March 1970, pp. 276-278.