THEORY OF DIELECTRIC-FILLED EDGE-SLOT ANTENNAS

Final Report

Period Covered: 1 June 1977 to 31 May 1979

by

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June 1979

Prepared for

U.S. Army Research Office

P.O. Box 12211

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Work performed under grant No. DAAG29-77-G-0152

15418-1-F = RL-2282

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I. Introduction

This is the final report summarizing the work done from 1 June 1977 to 31 May 1979, under Grant No. DAAG29-77-G-0152, entitled "A Theoretical Study of Dielectric-Filled Edge-Slot Antennas."

The Harry Diamond Laboratories (HDL) has developed a number of dielectric-Filled Edge-Slot (DFES) antennas [1] which are very simple to fabricate, can be conformally mounted on conducting bodies of revolution, and appear to have considerable potential for application to various systems. The work done at HDL was mostly experimental, leading to an empirical design of such antennas. The present study originated from the need for a theory for the DFES antennas so that their performance may be better understood and their design carried out more efficiently.

The purpose of the present study was to develop a theory for the input behavior of DFES antennas, thereby explaining the experimental results obtained at HDL, and allowing the extension of those results to arbitrary combinations of the various parameters of the antenna.

II. Technical Approach and Accomplishments

2.1 Basic DFES Antenna

Most of the first year was spent on the development of a theory for the basic DFES antenna which consists of a circular dielectric (Teflon) substrate mounted between the two halves of a perfectly conducting cylinder of infinite length. The antenna was excited symmetrically at its center with the help of a coaxial stub. For analysis, the antenna was modelled by a radial waveguide excited at its center with a coaxial stub, and terminated by an equivalent admittance (or impedance) uniformly distributed along the edge-slot.

The symmetry of the system indicated that only E-type radial modes [2] would exist within the radial waveguide region. From a modal analysis of the region, a dominant mode equivalent non-uniform transmission line circuit was obtained for the antenna. The notion of outward radial impedance at a certain radial distance (ρ) from the exciting stub was then introduced, and an expression derived for the impedance at $\rho = \ell$, for arbitrary ℓ, in terms of the impedance at any other distance $\rho > \ell$. We were then able to express the radial impedance at the feed end in terms of the terminating impedance provided by the radiating slot. The radial impedance at the feed end was assumed to be the load presented by the DFES antenna to the input coaxial line, from which the input reflection coefficient could be obtained as a function of frequency provided the terminating impedance was known.

The terminating impedance appropriate for the radiating slot was obtained as follows. At first, a rigorous integral expression for the impedance of a circumferential slot on an infinite cylinder was obtained. However, due to the excessive computational costs of the repeated numerical integrations involved in this expression, it was not considered to be efficient. A more convenient expression for the desired terminating impedance was developed by using the known results [3] for the impedance of a flanged parallel-plate waveguide radiating into a half-space.

From a numerical computation it was found that the magnitude of the input reflection coefficient has very sharp minima at certain frequencies called the operating frequencies. At these frequencies, the reflection coefficient has a magnitude of the order of 0.2 or less, but the value increases rapidly to 0.9 or more as the frequency is varied. Hence, the frequencies at which the basic

DFES antenna has a reasonably good radiation efficiency are within relatively narrow bands about the operating frequencies. A simple but accurate expression for the nth operating frequency was developed which showed that it is inversely proportional to the radius of the antenna and to the refractive index of the dielectric used. All numerical results were in excellent agreement with the experimental results obtained from HDL. This established the validity of the theoretical model and the equivalent circuit developed for the antenna.

2.2 DFES Antennas With Tuning Posts

Part of the first, and all of the second year's efforts were devoted to DFES antennas with off-axis arrangements of passive metallic posts used as tuning devices. These axially oriented posts are typically distributed among several radial elements, each of which consists of a radial section of uniformly distributed posts of equal radii. The several elements are equi-spaced angularly so that the arrangement of posts may also be considered as a radial region containing a number of equi-spaced rings around the exciting post, each ring containing an equal number of uniformly distributed posts.

Each ring of posts would produce a discontinuity in the equivalent transmission line, mentioned earlier, at the position corresponding to the location of the ring. The main task therefore consisted of the determination of the equivalent impedance produced by each ring of posts. The equivalent transmission line was then periodically loaded with an equivalent impedance at the position corresponding to the location of each ring, and thereafter, the input reflection coefficient was determined as before.

The simplest case, basic to our analysis, was the case of only one passive post in an infinitely extended radial line. In that structure it was assumed that the exciting stub would produce only an outgoing dominant mode, and that the induced currents in the passive post would be such that they would produce an infinite sum of E-type modes, centered at the passive post, in such a way that the total tangential electric field would vanish at the surface of the passive post. When the infinite sum, which represents the field produced by the passive post, was expressed in a cylindrical coordinate system centered at the exciting stub, it turned out that only the dominant mode terms are important, as was checked by computations using typical values of the various parameters. These dominant mode terms include waves propagating in the direction of increasing radius, for radial coordinates larger than the radial coordinate of the post, and waves propagating in the directions of both increasing and decreasing radius, for radial coordinates smaller than the radial coordinate of the passive post.

From this analysis, we deduced an expression for the equivalent shunt admittance of the one-post ring discontinuity, and used it in the equivalent circuit for the dominant mode in the finite DFES antenna. In order to generalize this theory to the case of more than one post, we notice that only the zeroth order induced current in the post enters in the field expressions, when only the dominant mode is taken into account. Hence, in the case of several passive posts, we consider that each one of them carries an induced zeroth order current along its axis, and add together the dominant mode field contributions due to each one of those induced currents in each region of the radial line. This allows us to determine the equivalent shunt admittance of each ring of posts, and use the results in the equivalent circuit for the dominant mode in the finite DFES antenna, whereupon we can compute the input impedance and the reflection coefficient at the feed.

The expression for the terminal admittance of the antenna is the same as used for the basic DFES antenna, and so is the expression to transfer the impedance from the radial coordinate of each ring discontinuity to the radial coordinate of the next ring discontinuity. This method yielded very good results for the cases of 2 equal elements with any number of posts, and of one ring with an arbitrary number of equispaced posts. For more general cases of several elements and several rings, the method breaks down when the total number of posts exceeds some value dependent on the radius of the antenna, and when the innermost ring of posts is placed too close to the exciting stub (e.g., the theory provides good results for an antenna of radius 10.15 cm using up to 25 - 30 tuning posts).

3. Conclusions

A theory has been developed for the performance of a DFES antenna mounted on a conducting cylinder. It explains accurately the experimental results, furnished by HDL, for basic, two-element, and single ring DFES antennas, containing an arbitrary number of tuning posts. For such antennas, detailed computations have been carried out for arbitrary variations of the relevant parameters of the DFES antenna. These results will clearly be of help in the future design of this type of antenna allowing a choice of parameters to be made beforehand in order to achieve a desired frequency response.

For DFES antennas having more than two elements or one ring, the theory breaks down when the total number of tuning posts used exceeds some value dependent on the radius of the antenna and when the innermost ring of posts is placed too close to the exciting post. For such antennas, more thorough analysis is needed, involving higher order modes and terms which have been neglected in the present theory.

4. Reports, Etc.

The following literature resulted from the work accomplished under this grant:

(i) D.L. Sengupta and L.F. Martins-Camelo, "Input Reflection Coefficient of a Basic Dielectric-Filled Edge-Slot Antenna," The University of Michigan Radiation Laboratory Technical Memorandum, 015418-500-M, October 1977 (35 pages).

(ii) D.L. Sengupta, L.F. Martins-Camelo, H.S. Jones, and D.H. Schaubert, "Input Reflection Coefficient of a Basic Dielectric-Filled Edge-Slot Antenna," 1978 International Symposium Digest, Antennas and Propagation, IEEE, pp. 276-279.

(iii) D.L. Sengupta and L.F. Martins-Camelo, "Theory of Dielectric-Filled Edge-Slot Antennas," The University of Michigan Radiation Laboratory Technical Memorandum, 015418-501-M, September 1978 (50 pages).

(iv) D.L. Sengupta, L.F. Martins-Carelo, H.S. Jones, and D.H. Schaubert, "Theory of the Input Behavior of a Dielectric-Filled Edge-Slot Antenna," 1979 International Symposium Digest, Antennas and Propagation, Vol. 1, IEEE, pp. 138-141.

(v) One technical report and one technical paper (for journal publication) are in preparation, and will be ready during the continuation period of the present work.

5. Recommendation for Future Work

The immediate generalization of the results presented here will require a consideration of the higher order modes in the radial waveguide. This will considerably complicate the present theory, but is a necessary step to obtain satisfactory results for a DFES antenna with an arbitrary number of passive posts. Due to the high complexity of the mathematics involved, an alternative path will also be tried, which consists in replacing, in our model, elements with a few posts by a thin metallic screen starting at the position of the innermost post of the element and ending at the position of the outermost post of the element. This should provide an accurate simulation of the behavior of a general DFES antenna.

Another aspect which deserves more attention is the radiation pattern of the antenna. The study of the fields in the outside region requires the shape of the body to be well defined, and several representative and geometrically simple shapes will be considered. In the equatorial plane, however, the pattern should be relatively independent of the body shape, provided it is a body of revolution, and primarily a function of the fields inside the radial waveguide, i.e., of the number and disposition of the passive posts. Higher order modes in the guide will obviously be needed.

These problems will be investigated during the coming period of continuation of the present work.

6. References

[1] D.H. Schaubert, H.S. Jones, Jr., and F. Leggin, "Conformal Dielectric-Filled Edge-Slot Antennas for Bodies of Revolution," HDL-TR-1837, Harry Diamond Laboratories, Adelphi, MD 20783, September 1977.

[2] C.G. Montgomery, R.H. Dicke, and E.M. Purcell, "Principles of Microwave Circuits," McGraw-Hill Book Co., Inc., New York, NY, Chapter 8, 1948.

[3] N. Marcuvitz, "Waveguide Handbook," McGraw-Hill Book Co., Inc., New York, NY, pp. 180-184, 1961.

7. Administration

The present project provided support for the following scientific personnel:

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