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ELECTROMAGNETIC RADIATION FROM QUASI-PERIODIC STRUCTURES

Richard B. Kieburtz

College of Engineering
State University of New York at Stony Brook
Stony Brook, L.I., New York

Contract No. AF19(628)-4144

Project No. 4600
Task No. 460004

FINAL REPORT

Period Covered 1 June 1964 through 31 May 1967

19 July 1967

Contract Monitor: H. W. Ehrenspeck
Microwave Physics Laboratory

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Prepared
for

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
BEDFORD, MASSACHUSETTS 01730

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Abstract

The results of theoretical and experimental research on log-periodic dipole arrays and their periodic prototypes is summarized. A perturbational method for the analysis of boundary value problems with log-periodic boundary conditions is also discussed.

The principal results of these studies have been a better understanding of radiation phenomena from periodic and log-periodic traveling wave structures and the evaluation of some principles which may lead to the design of frequency-independent log-periodic antennas realizing significantly greater directivity gain than is presently possible.

Objectives: The objectives of the research supported by this contract are to develop methods of analysis for, and to study the properties of radiating structures which can be generated from periodic structures by a spatially variable scaling function. The log-periodic antennas are memebers of this class of structures which are of particular interest.

I. Summary of Research Carried Out During the Contract Period

The topics which are explored during the tenure of this contract included:

a) a theoretical study of a log-periodic (L-P) corrugated plane,

b) the use of spatial dispersion relations in the analysis and synthesis of log-periodic antennas,

c) a phase-integral (WKB) approximation for the dispersion relation of an L-P structure,

d) application of coupled-mode theory to obtain the dispersion relation of an L-P structure from that of its periodic prototype structure

e) possible methods of increasing the directivity of L-P dipole antennas, including multi-mode operation,

f) an experimental and theoretical study of capacitive coupling of dipole elements to the feeding transmission time,

g) an experimental study of the consequences of glide-symmetric excitation of a transmission-line coupled dipole array,

h) experimental and theoretical studies of periodic dipole arrays having parasitic elements, and their application to L-P antennas. The results of many of these studies have been included in scientific reports submitted under this contract. Some of the research begun on this contract is being continued under Contract No. F 1962867C0056 and has not yet been reported on. A brief summary of some of the research is given in the following paragraphs.

A. Log Periodic Corrugated Plane

In order to better understand the possibilities for treatment of quasi-periodic structures as boundary value problems, the task of analysis of the modes of propagation along an L-P corrugated plane was undertaken. By employing a spatial coordinate transformation equivalent to loading the structure with a nonuniform dielectric, it becomes possible to convert the L-P boundary conditions to periodic ones and to adapt a function theoretic technique used with periodic structures. The method is only approximate, however, as the coordinate transformation distorts the differential operation of the wave equation in such a way that a perturbational treatment is necessary. The results of this work, which was partially supported under this contract, are to appear in the SIAM Journal, and reprints of the paper will be distributed as Scientific Report No. 4, subsequent to publication.

B. Use of Spatial Dispersion Relations in the Analysis and Synthesis of L-P Antennas.

The dispersion curves of a log-periodic structure also give the spatial distribution of phase and attenuation of a traveling wave mode along the structure, because of the fundamental scaling relation which relates adjacent elements along its length. Thus, from the dispersion curves, one can determine the length of the active region of an L-P antenna, and the phase velocity of the wave on the structure as it passes through the active region. These are important parameters, directly related to the width of the principal lobe of the radiation pattern of such a structure. The use of dispersion relations to infer the reasons for directivity limitations of L-P antennas has been reported in Scientific Report No. 2.

C. Phase-Integral Approximation for the Fields on L-P Structures.

A natural idea to try to infer the dispersion curves of L-P structures from those of their periodic prototypes is to employ a phase-integral or WKB approximation. A study of the validity of the approximation when applied to radiating L-P structures was made and reported in Scientific Report No. 1. The general conclusion was that although the phase-integral approximation appears to hold in regions of the dispersion curve in which there are no resonances of the radiating elements, it fails to hold in the vicinity of such resonances. Since the resonances regions happen to be the ones of greatest interest in applications to L-P antennas, the phase-integral approximation is not as useful as it had originally appeared to be.

D. Coupled-Mode Theory for Aperiodic Structures

In order to obtain theoretically the dispersion curve of an L-P array driven from a uniform transmission line, a coupled-mode approach was developed. This theory assumes that the effect of L-P boundary conditions will be to couple the dominant modes of the periodic prototype structure. Appreciable coupling occurs only between modes having propagation constants which are nearly equal. Favorable conditions for such coupling occur near the resonances of radiating elements. For the case of dipole arrays excited from a uniform transmission line, the coupling coefficients can be evaluated in terms of the iterative impedances of a unit all of the periodic prototype structure. The results obtained explain many of the observed characteristics of L-P dipole antennas. The coupled-mode theory for aperiodic structures and theoretical results of this method have been presented in Scientific Report No. 2.

Direct experimental confirmation of the theory has recently been attempted by measuring the spatial distribution of the voltage along the feeding transmission line of a dipole antenna. The accuracy with which the spatial dispersion relation can be obtained from such measurements is severely limited by unavoidable ambiguities. However, the results do show qualitiative agreement with the theory.

E. Directivity Improvement of L-P Antennas

From the studies of spatial dispersion curves of L-P dipole arrays, it is found that the length of the active region of such antennas is far too short (typically of the order of 0.15λ) to permit realization of appreciable directivity gain. Changes which can be made in the geometric parameters of the array, such as elements length-to-spacing, apex angle, or scaling parameter, have little influence on the length of the active region. To obtain appreciable directivity from an L-P dipole antenna, it is necessary either to increase the active length to 0.5λ or greater, or to employ more than one active region simultaneously on the antenna. Either of these schemes necessitates a large reduction of the coupling of the dipoles to the feeding transmission line. In multi-mode operation, part of the incident energy would be allowed to pass the first active region, in which the half-wavelength dipole resonance occurs, to be radiated from a second active region in which the dipoles exhibit a higher mode resonance. Experimental work on this concept will be continued under Contract No. F 1962867C0056.

F. Capacitive Coupling of Dipole Elements

Various possible schemes for controlling the degree of coupling of the radiating dipoles to the feeding transmission line have been explored. The most promising appears to be the use of capacitive coupling, whereby the dipoles are connected to the transmission line by means of a pi-network of capacitors as shown in Fig. 1. This network is easily implemented in practice. One such implementation is furnished by the sandwich construction shown in Fig. 2. The advantages of this type of capacitive coupling are

1) No undesired resonances are introduced by the coupling network.

2) The degree of coupling can be fixed at any desired amount from zero to direct coupling.

3) The characteristic impedance of the transmission line is not affected when the dipoles present an open-circuit impedance.

A periodic dipole array using capacitive coupling has been built and tested. The dispersion curve was found to agree closely with that predicted theoretically.

G. Dipole Arrays with Glide-Symmetric Excitation

An experimental study has been carried out of a periodic dipole array driven from an unbalanced, coaxial feed line with glide-symmetric excitation. A diagram of the structure appears in Fig. 3. The model was constructed to confirm the self-balun effect often attributed to structures having glide-symmetry. An interesting and unexpected phenomenon was observed, however. Instead of measuring a single propagation constant at each frequency, the structure exhibited two distinct propagation constants over some frequency bands. This was attributed to the fact that on a dipole array driven from an unsymmetric coaxial line, unlike one driven from a symmetric two-wire line, the balanced and unbalanced modes of propagation are not independent but are coupled. Thus, both modes are observed simultaneously at frequencies at which both can propagate.

H. Periodic and L-P Dipole Arrays containing Parasitic Elements

In another approach to the problem of increasing directivity gain of L-P antennas, dipole arrays having parasitic elements interspersed between the driven elements have been investigated. The use of parasitic elements reduces coupling to the radiating dipole array by reducing by a factor of 1/2, 1/3 or 1/4 the fraction of elements which are directly excited. The results of this study show that this reduction in the coupling should enable the length of the active region to be significantly increased, while still radiating virtually all of the incident energy from the principal active region.

The theoretical dispersion curves of periodic prototype structures with parasitic elements have been experimentally confirmed. These results are presented in Scientific Report No. 3.

II. Technical Conclusions Relation to the Future Development of Log-Periodic Antennas

Although not all of the research undertaken during the contract period has yet been completed, it is possible at this time to draw some conclusions pertaining to the future development of frequency-independent L-P antennas. It appears that the limitation on the directivity gain of L-P antennas which has heretofore been found in practice is not a fundamental limitation. However, higher gain antennas will require more sophisticated design and construction techniques, and somewhat greater overall length.

Several methods of controlling the coupling to the radiating elements of L-P dipole arrays have been found. These include the use of capacitive coupling networks, and the use of parasitic elements interspersed between driven elements. The freedom to vary the element coupling affords the designer some degree of control over the field distribution in the active region of an L-P antenna, and therefore may enable a limited amount of pattern synthesis to be performed while retaining the frequency-independent character of these antennas. The implementation of this principle to produce a high-gain frequency-independent antenna is the object of further research.

<u>Reports and Publications</u>

R. B. Kieburtz, A phase-integral approximation for the current distribution along a log-periodic antenna, <u>IEEE Trans. on Antennas and Propagation,</u> vol. AP-13, pp. 813-814, Sept., 1965; also Scientific Report No. 1 on AF 19(628)-4144, College of Engineering Technical Report No. 37 March, 1965, State University of New York at Stony Brook.

R. B. Kieburtz, Analysis and synthesis of aperture fields of log-periodic antennas, to appear in the <u>proceedings of the 1965 URSI Symposium on Electromagnetic Waves</u>, Pergamon Press, 1967; also Scientific Report No. 2 on AF 19(628)-4144, College of Engineering Technical Report No. 51, August 1965, State University of New York at Stony Brook.

R. B. Kieburtz and David F-D Sun, Dispersion relation of periodic and log-periodic dipole arrays with parasitic elements, Scientific Report No. 3 on AF 19(628)-4144, College of Engineering Technical Report No. 92, June 1967, State University of New York at Stony Brook.

D. Varon, R. B. Kieburtz and B. R-S Cheo, A perturbational analysis of a log-periodic structure, to appear in the <u>SIAM Journal on Applied Mathematics,</u> also as Scientific Report No. 4 on AF 19(628)-4144, College of Engineering Technical Report No. 94, July, 1967, State University of New York at Stony Brook.

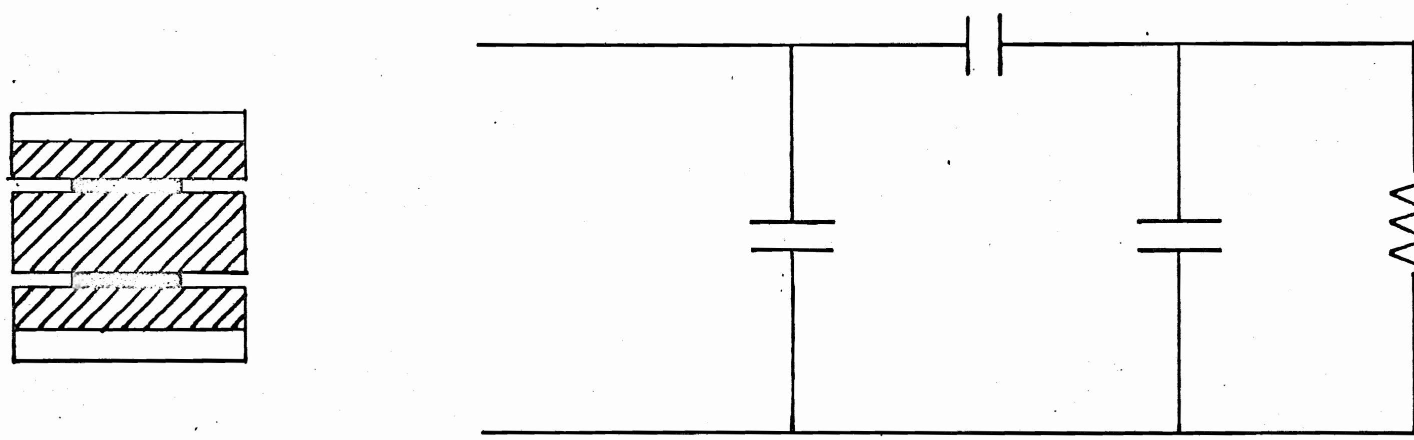

FIG. I EQUIVALENT CIRCUIT OF CAPACITIVELY COUPLED DIPOLES IN TRANSMISSION LINE

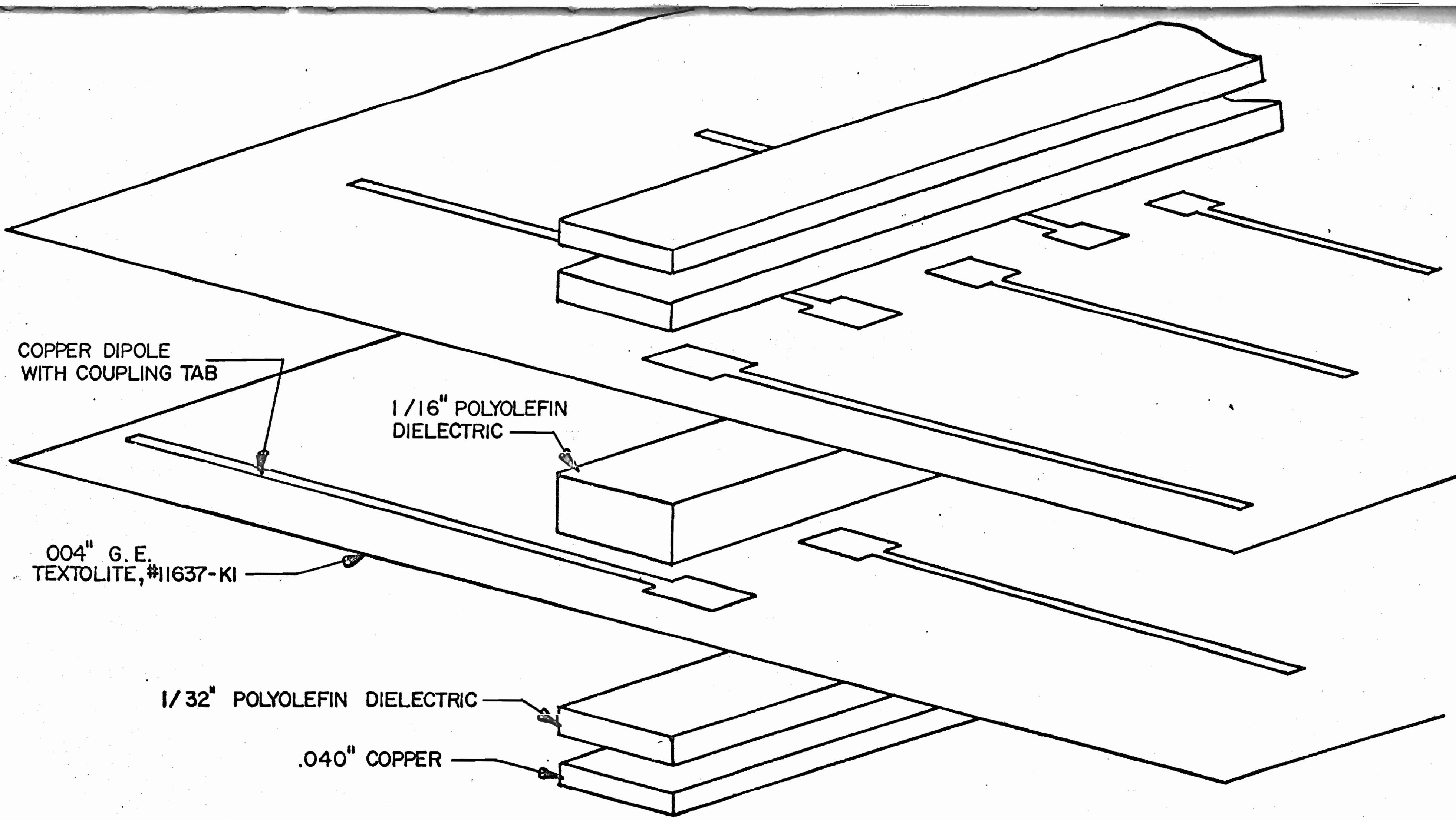

FIG. 2 EXPLODED VIEW OF PHOTO-ETCHED LOG-PERIODIC DIPOLE ARRAY

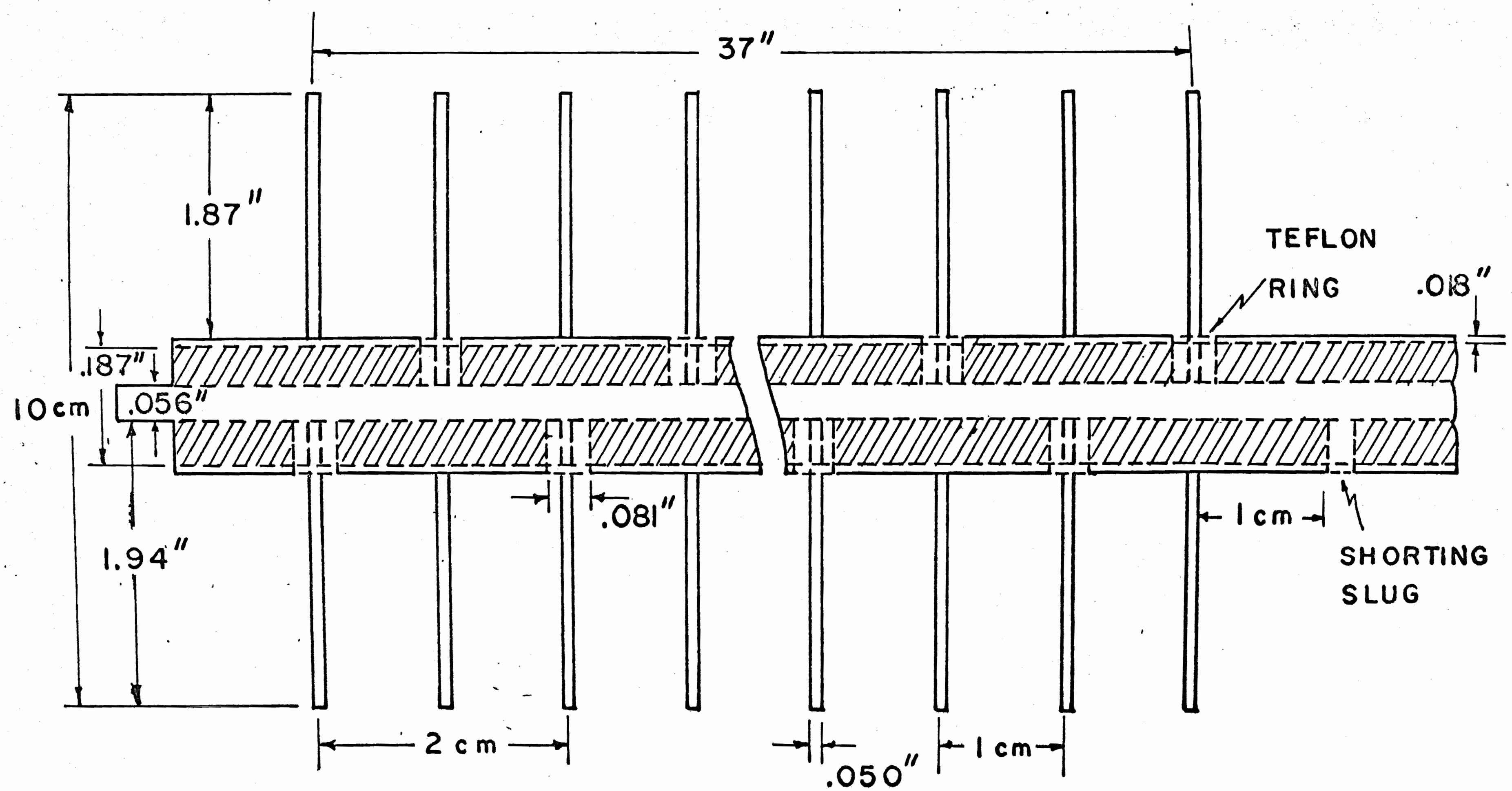

FIG. 3 COAXIALLY DRIVEN DIPOLE ARRAY

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