RL 252
2/10/64

APPLICATION OF SURFACE FIELD MEASUREMENTS TO RADAR CROSS SECTION STUDIES

T. B. A. Senior
Radiation Laboratory, The University of Michigan
Ann Arbor, Michigan

Introduction

When an electromagnetic wave is incident upon a body, a surface distribution of fields or currents is set up which then radiates to produce the scattered field. In some senses, therefore, the surface field is more fundamental than the scattered field; the latter is given in terms of the former by an integral which is relatively simple in the far zone, and consequently, for a given direction of incidence the complete (monostatic and bistatic) field can be derived from the surface field by quadratures. On the other hand, the reverse procedure is not quite so straightforward.

The surface field is the natural product of most integral equation methods for the solution of diffraction problems, and since it is usually more sensitive to minor shape (and material) perturbations than is the scattered field, it provides a stringent check on those approximate techniques which are our only way of treating all but the simplest shapes of body. In addition, however, it has considerable practical importance in itself, even when the ultimate objective is the determination of the scattered field. Many of today's problems in the radar cross section area are concerned with the reduction or enhancement of the field at large distances by modifications to the shape and/or material of the scattering object, and in cases where the field is not dominated by specular reflections, a detailed knowledge of the surface field and of how it is excited is an almost essential prerequisite to any scientific attempt at cross section control. It is certainly essential if near-optimum results are to be achieved.

During the last two years the Radiation Laboratory has given increased attention to the study of surface fields on selected shapes by extensions of the more standard theoretical methods involving physical optics, creeping waves, etc. and by direct measurement of the currents using probes. The latter approach has proved extremely valuable in these investigations, and is already filling a vital role in improving our theoretical tools for the prediction of scattering patterns. With its aid it is a relatively simple matter to discover the direct effect of minor modifications to the shape of a body, and it is expected to prove even more important in later applications to absorbing coatings. It may therefore be appropriate to describe the experimental facility as it exists at the moment, and mention some of the measurements which have been made.

Historical Survey

The use of probes to determine the fields excited on the surface of a conducting object is by no means new. As early as 1938 it was employed by Pippel and Baerner[1] to measure the currents induced by radio antennas on an aircraft structure, and similar work was carried out by Granger and Altman[2] and Granger and Morita[3] soon after World War II. Since 1948 it has been widely exploited by the Cruft Laboratory of Harvard University and many of the improvements in probe design originated there. Reynolds[4] and Dunn[5] studied different forms of detection probes and measured the fields on flat conducting plates, and the latter author also considered the effect of elliptical polarization on loop systems. An extensive analysis of loop antennas was later published by King[6] and still more recently Whiteside[7] has examined the response of different types of probe to electromagnetic fields. The information provided by this last author is probably sufficient to design and construct any probe necessary for a surface field measurement.

One of the most difficult problems with a probe technique is to avoid stray pick-up in the wires leading from the probe to the detector, and if these wires are kept short the possibility of reflections from the associated equipment is introduced. An attractive way of avoiding both these problems is to use a ground plane and to cut a slot in the body along the trajectory to be followed by the probe. The latter is now below the surface and the lead wires can be taken from the inside of the body through the ground plane to the detector hidden underneath. This method was used by Morita[8] to study linear antenna elements and a slight variation upon it was employed by Ribblet[9] in his work on the 'infinite' circular cylinder and the parabolic reflector. Another application of the ground plane system was by Wetzel and Brick[10], whose measurements of the surface field on the shadow portion of an elliptic cylinder confirmed the accuracy of the creeping wave approximation, but for two dimensional objects the parallel plate system becomes appropriate, and this was employed by Row[11] and, later, by Plonsey[12].

The obvious disadvantages of all these systems are the necessary restrictions on shape of body, direction of incidence and polarization, and none of them are consistent with a routine type of measurement which would assist in the analysis of scattering from 'practical' (and almost inevitably complex) shapes. One of the few attempts to measure surface fields directly was the limited investigation of flat plates at glancing incidence by Hey and Senior[13]. In some respects the present Radiation Laboratory work is a natural outgrowth of this, and perhaps the major accomplishment is the demonstration that surface fields on three dimensional objects can be measured under reasonably wide circumstances, and with a sufficient degree of accuracy to be of help in studies of scattering phenomena.

Experimental Facility

The facility is housed in a room 13 1/2 ft wide and 100 ft long but the entire operation is confined to a region 25 ft in length. The model to be measured is mounted on a styrofoam pedestal just in front of a shaped absorbing screen composed of high performance absorbing materials, and shielding the traversing mechanism for the probe.

The choice of frequencies has been influenced by two factors: the desire to measure models whose dimensions are comparable or larger than a wavelength, and the necessity of having probes very small in comparison with the wavelength if they are not to disturb the field unduly. The first of these forces one to the higher frequencies if the models are to be of reasonable physical dimensions and this in turn reduces the size of the probe. Ultimately the limit is provided by the difficulties of construction and handling of probes only a few mm in dimension, as well as by the accuracy of positioning, and all of our measurements so far have been carried out at L- and S-band frequencies. It is hoped to add a C-band capability at a later date.

The type of probe depends in part on the field component to be measured. A variety of different types have been investigated including a diode loop, two diodes forming a balanced dipole, and a simple shielded loop. This last has proved convenient for most of our measurements, and several versions have been constructed differing only in size. The latest has a loop 3 mm in outside diameter, which is probably somewhat smaller than the optimum for S-band. This is connected to a piece of rigid coaxial line (Coaxitube, manufactured by the Precision Tube Company) of outer diameter 0.03 in., with inner conductor of diameter 0.01 in. and glass wrap insulation. Because of the relatively high loss in a line of such small dimensions, only a 6 in. length is used and this is attached to a 12 in. length of larger (0.085 in.) diameter Coaxitube. These constitute the support mechanism for the probe. They are maintained in a vertical position perpendicular to the incident field polarization, and coupled at the upper end to a horizontal coaxial line which is coated to reduce surface wave effects. This last rests on a styrofoam beam and passes over the center of the absorbing screen to a vertical tower mounted on the probe positioner. The general arrangement can be seen from Fig. 1.

The mechanism for positioning the probe consists of two coupled horizontal motion lead-screw carriages operating at right angles to one another, and an associated elevating device. The coverage in the horizontal plane is 15 cm by 36 cm, and the latter dimension therefore represents the maximum length of model that can be traversed without repositioning on the pedestal. With this system the probe can be located within 0.2 mm of its intended position in a horizontal plane, but since the vertical alignment is not quite as accurate due to mechanical oscillations, the probe is usually placed in physical contact with the model. To ensure that no conduction currents will flow in this situation, a bead of epoxy resin is placed at the gap in the loop and filed down on the lower surface to leave a film a few mils in thickness.

The illumination is from a standard gain horn, and to cut down room reflections attributable to the side lobes, an absorbing tunnel 24 in. in length has been attached to the horn aperture. The distance to the center of the model is about 3.5 m, which is not sufficient to provide uniform excitation over the full length of some of the models that have been studied, and for the sphere discussed in the next section the incident field taper is theoretically 0.7 db and has been measured as such. The effect can be seen in the data, but to increase the range would decrease still further the level of the signal fed to the receiver. At S-band this is already 80 db below a milliwatt. The transmitted power is here some 300 milliwatts, produced by a klystron tube modulated at 1 Kc. The receiver was constructed in the Laboratory from low noise components and has an overall noise level 100 db below a milliwatt. A block diagram of the S-band equipment is shown in Fig. 2.

Data

In the year that this equipment has been in operation a variety of models has been investigated, and included amongst these are (i) thin wires of up to 3λ in length at end-on and near end-on incidence, (ii) flat plates at glancing incidence, (iii) thin cylinders for over 30 different lengths L spanning the range $0.36\lambda < L < 1.86\lambda$ and for all angles of incidence, but with concentration on broadside aspects, (iv) the same cylinders as in (iii) but with a cavity-backed slot at the center to produce a sequence of reactive loadings, (v) spheres and (vi) cone-spheres at nose-on incidence. It is obviously impossible to do more than give typical results here, and attention will be confined to amplitude[+] data.

The work on the thin cylinders referred to in (iii) and (iv) above is described in detail by Chen and Liepa[14]. The cylinder was constructed so that one basic model was sufficient to embrace the full range of lengths by the insertion of extension pieces and rounded end-pairs of different sizes. The radius was 0.183 in. and all measurements were carried out at a frequency 1.088 Gc. Three samples of the data for broadside incidence on the unloaded cylinder are given in Fig. 3. The upper curve is for the first resonant length, $L = 0.426\lambda$, and the peak value of the current here has been used as the reference level for the amplitudes in the lower curves, in which $L = 0.887\lambda$ and 1.303λ.

Some data for a sphere taken at a frequency of 3.066 Gc is presented in Fig. 4. The probe trajectory is in the equatorial plane containing the incident electric vector, so that in the shadow the field is predominantly the major creeping wave component, and the central point on the rear of the sphere is

---

[+] A phase measurement system is still in its trial stages.

the left-hand end of the horizontal scale. Also shown is the curve computed from the exact Mie series representation of the surface field, and it should be noted that this has been superimposed using the measured value of the incident field in the plane of the support rather than on a 'best fit' basis. The curves are everywhere within 1 db of one another, and the agreement becomes even better if the systematic discrepancy attributable to the incident field taper is subtracted.

Corresponding data for a cone-sphere with vertex angle 30° is shown in Fig. 5. The radius of the spherical cap is identical to that of the sphere used for Fig. 4, and direct comparison of the results now shows the enhancement of the creeping wave component previously deduced[15] from measurements of the nose-on cross section. Its magnitude is such as to remove most of the discrepancy between theory and experiment for the nose-on cross section of a cone-sphere (see, for example, Blore[16]), and its origin has been determined. A detailed treatment of cone-sphere scattering, including measured data for both the far and surface fields, will be published shortly.

Acknowledgement

The author is grateful to Mr. V. V. Liepa for the construction and operation of the Facility described in this paper.

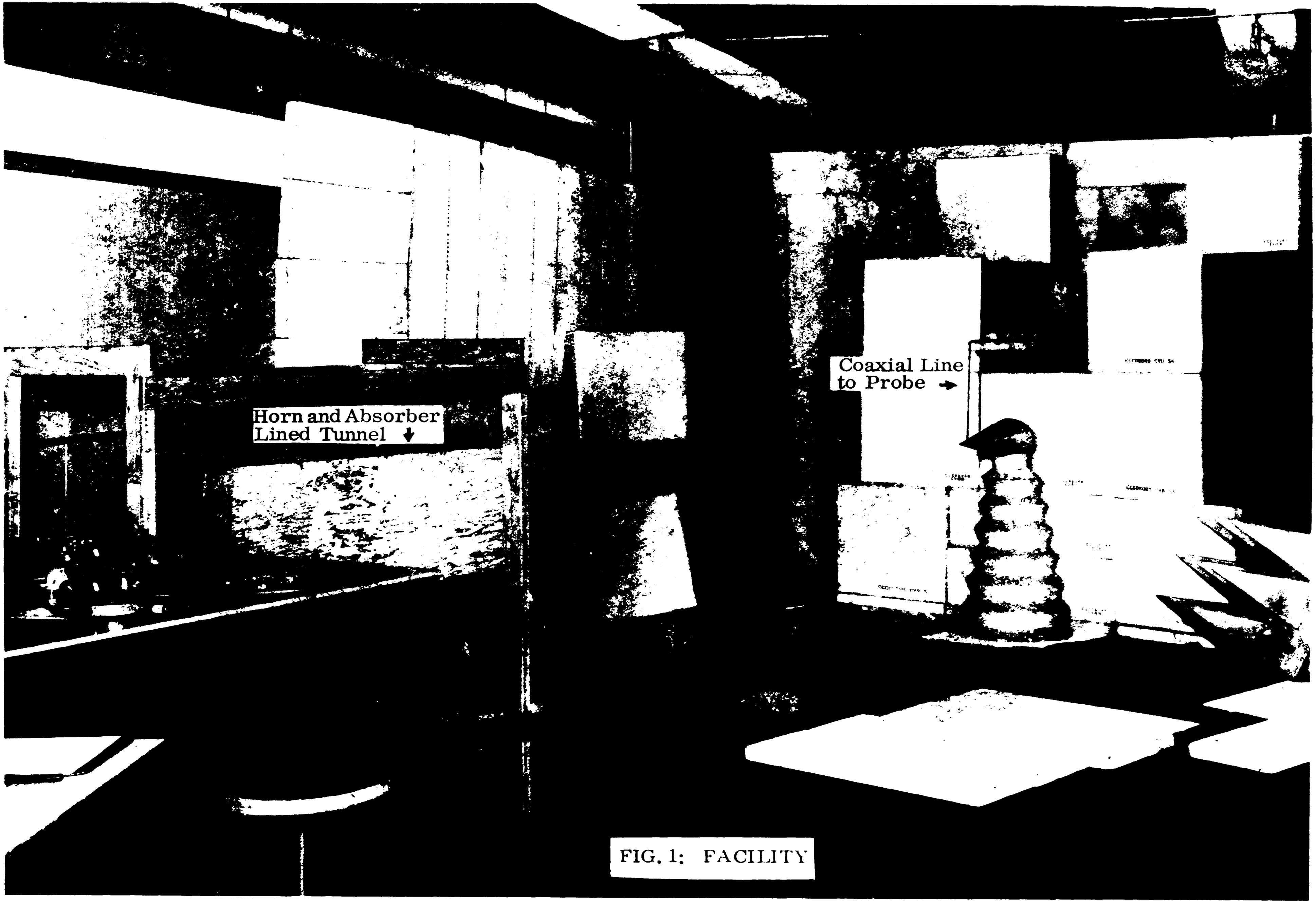

FIG. 1: FACILITY

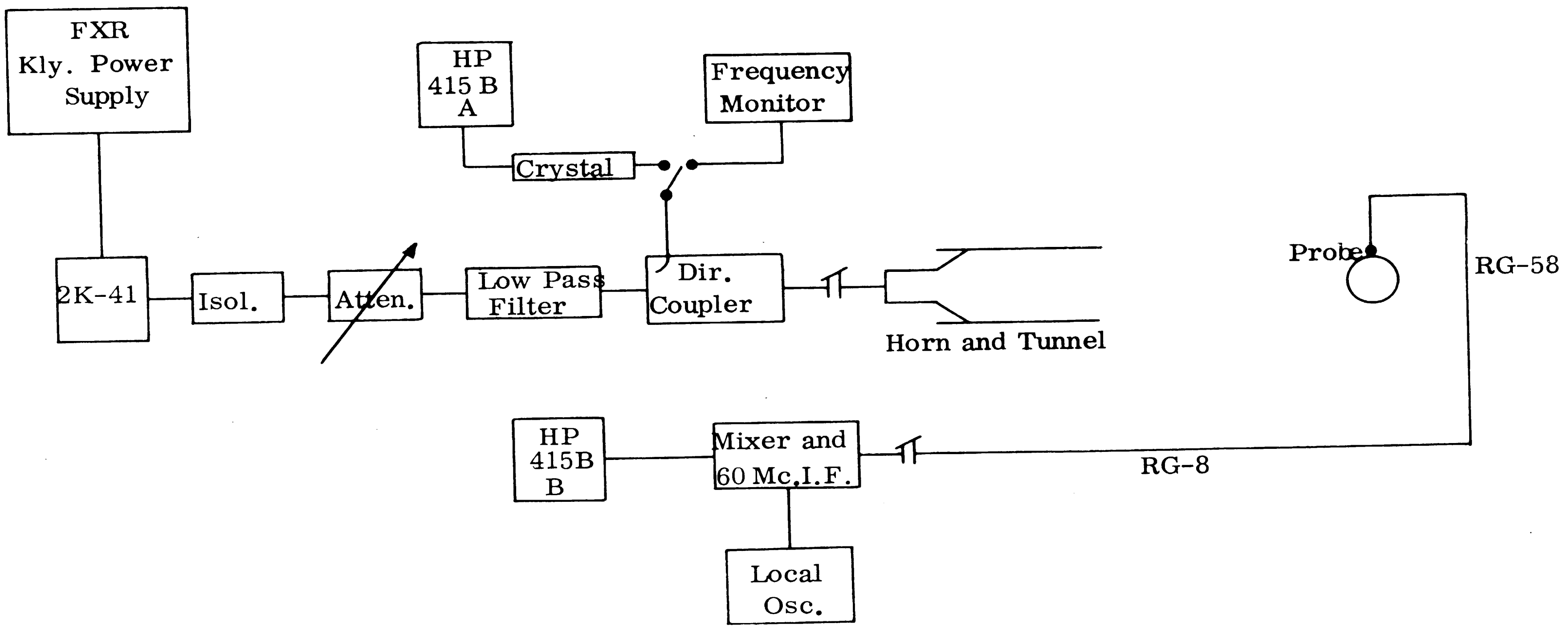

FIG. 2: BLOCK DIAGRAM OF THE S-BAND EQUIPMENT

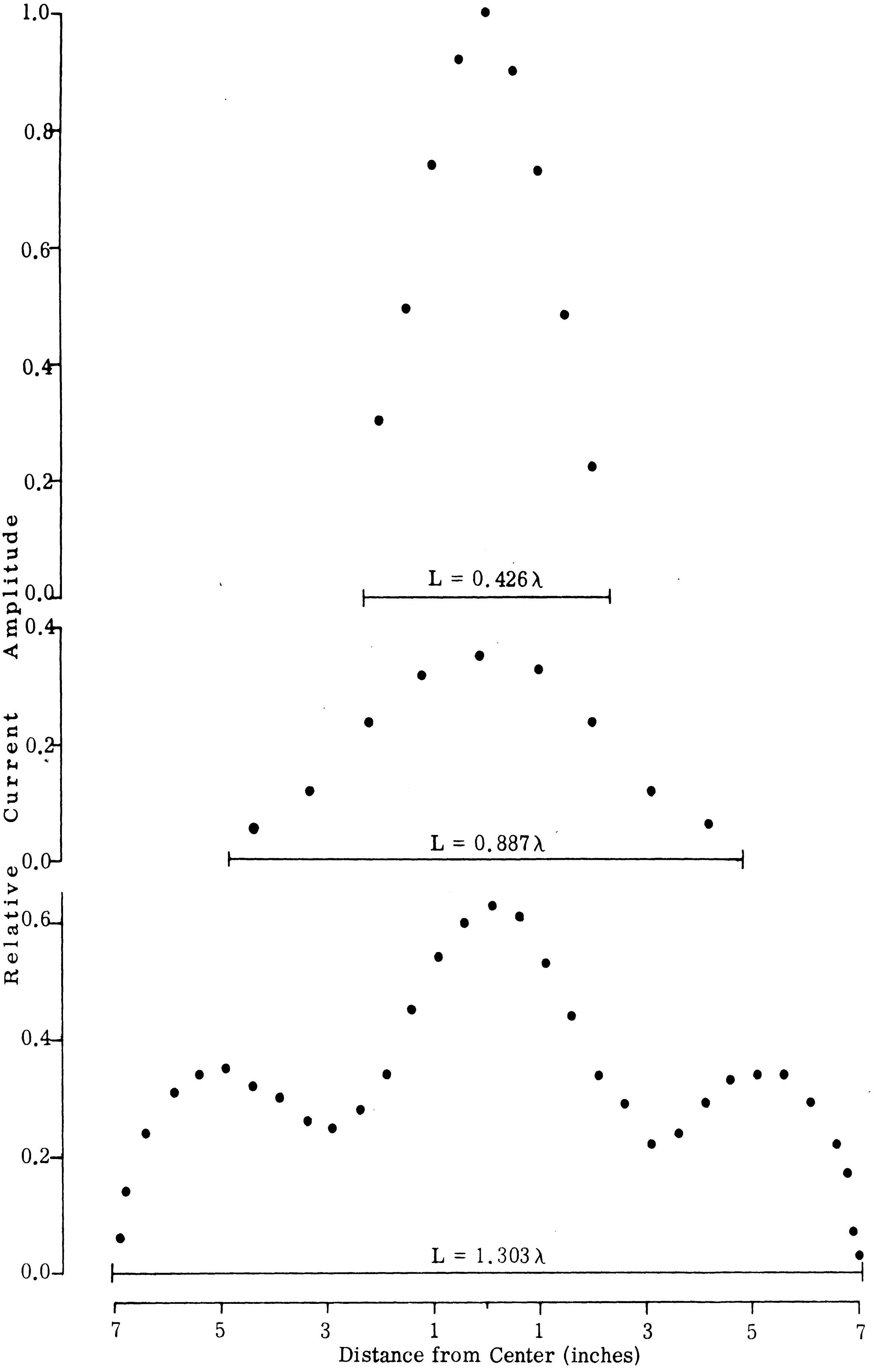

FIG. 3: MEASURED CURRENT AMPLITUDES FOR THIN CYLINDERS

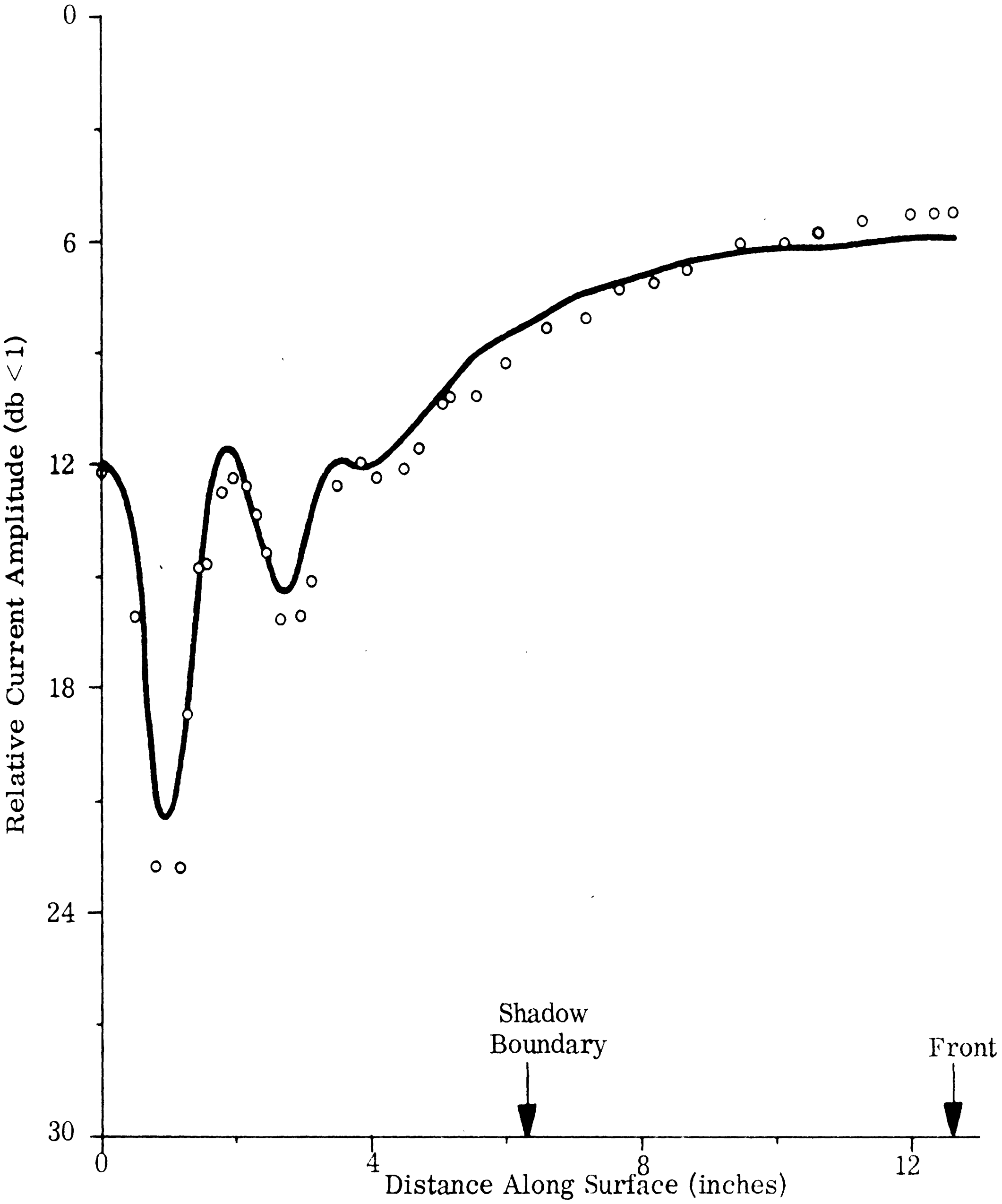

FIG. 4: MEASURED (o o o) AND THEORETICAL (——) CURRENT AMPLITUDES FOR SPHERE

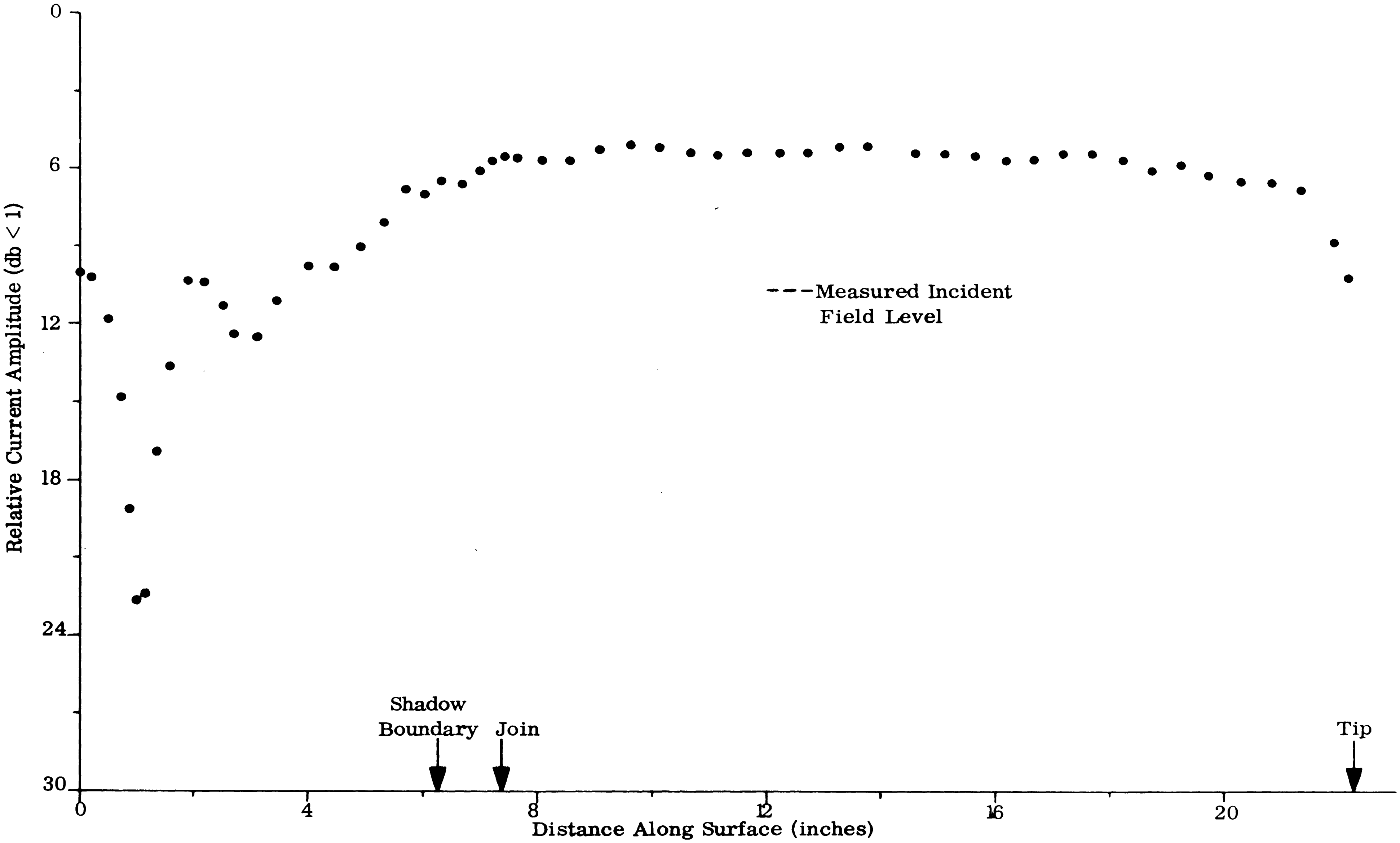

FIG. 5: MEASURED CURRENT AMPLITUDE FOR CONE-SPHERE

References

1 Pippel, K. and H. Baerner (1938)"Strom-und Spannungs-Verteilung auf Hoch-frequent Schwingender Flugzengen, " Forschungsberich No. 915, Flugfunk-Forschunginstitute, Germany; USAF Translation No. 511.

2 Granger, J. V. N. and N. G. Altman (1949) "Full-Scale Aircraft Antenna Measurements," Harvard University Cruft Laboratory Report No. TR-63.

3 Granger, J. V. N. and T. Morita (1951), Proc. IRE, 39, p. 932

4 Reynolds, D. K. (1948) "Surface-Current and Charge Measurements on Flat Flat Metal Sheets", Harvard University Cruft Laboratory Report No. TR-53.

5 Dunn, B. C., Jr. (1949) " On Response of Loops to the Electromagnetic Field, " Harvard University Cruft Laboratory Report No. TR-73.

6 King, R. W. P. (1957)"The Loop Antenna as a Probe in Arbitrary Electromagnetic Fields, "Harvard University Cruft Laboratory Report No. TR-262.

7 Whiteside, H. (1962) "Electromagnetic Field Probes, " Harvard University Cruft Laboratory Report No. TR-377.

8 Morita, T. (1950), Proc. IRE, 38, p. 898.

9 Ribblet, H. J. (1952) "Geometric-Optical Currents, " Microwave Development Laboratories Final Report on Contract AF19(122)-167.

10 Wetzel, L. and D. B. Brick (1955)"An Experimental Investigation of High Frequency Current Distributions on Conducting Cylinders, " Harvard University Cruft Laboratory Report SR-4.

11 Row, R. V. (1953), J. Appl. Phys., 24, p. 1448.

12 Plonsey, R. (1962). Trans. IRE-PGMTT, MTT-10, p. 214.

13 Hey, J. S. and T. B. A. Senior (1958). Proc. Phys. Soc., 72, p. 981.

14 Chen, K-M and V. V. Liepa (1964), "The Minimization of the Back Scattering of a Cylinder by a Central Loading, " to be published in the Trans. IEEE-PTGAP.

15 Senior, T. B. A. (1963) "Cross Sections of Nose Cones, " The University of Michigan Radiation Laboratory Report No. 5212-1-F. CONFIDENTIAL

16 Blore, W. E. (1963), Proc. IEEE, 51, 1. 1263.