as a short circuit and as a centering device. The slugs and two 0.113-inch diameter drive rods in both waveguide models are made of polystyrene. In the X-band model the slugs are 0.675 inch long, three-quarters wavelength at 9,380 mc, and in the K-band model 0.475 inch long, five-quarters wavelength at 23,000 mc, in order to improve their rigidity and stability within the guide. The two thumb screws shown in Fig. 3 are tightened on the drive rods to anchor the slugs in position once they have been properly adjusted. In the waveguides a single drive rod was sufficient for mechanical control of each transformer slug. With each waveguide termination it was found that a match could be obtained to a vswr of 1.01 (reflection coefficient <0.005).

IV. Conclusion

This instrument is capable of covering wide frequency ranges. The coaxial termination will provide a match to a vswr of 1.004 with two pair of slugs over the entire uhf range. Similarly waveguide models will provide matches to 1.01 over their particular frequency ranges. Not only can these terminations provide a match, but they may also be adjusted to given values of vswr of the order of one to ten when for various reasons such a vswr is desired.

The outstanding features of this termination are its simplicity of construction and ease of tuning. There are no critical dimensions and the essential requirements are three dielectric slugs (one lossy) to fit loosely within a transmission line and the rods by which they may be moved. It takes but a short time to reduce the vswr to less than 1.01. The vswr could be reduced still further if closer tolerances and more refined components were used, such as a gearing arrangement to adjust the position of the slugs, with a sacrifice, of course, of some of the simplicity of construction.

A UHF Surface-Wave Transmission Line*

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Summary—**A description is given of a surface-wave transmission-line unit developed to meet a requirement for an efficient, easy to install and maintain antenna feed line.**

Introduction

SINGLE-CONDUCTOR surface-wave transmission lines[1,2] are particularly advantageous as antenna feeds in the uhf range. In this frequency range the loss of flexible coaxial lines is usually too high, and rigid coaxial lines and waveguides are costly and difficult to install. Although there is a certain radiation loss inherently connected with the launching of surface waves, this loss is very small, if the launchers are properly designed. The efficiency of a surface transmission line is much greater than that of a coaxial line, assuming the diameter of the surface-wave conductor is comparable to that of the center conductor of the coaxial line. A surface-wave line is easily installed since it can be stretched directly between the antenna and the transmitter or receiver.

Since the field is on the outside of the conductor, the performance of a surface-wave transmission line is, to a certain extent, affected by weather conditions. It has been found that rain causes an appreciable increase of the transmission loss at the higher frequencies of the uhf band, if many drops form along the conductor. In the case of an antenna feed where the line is inclined from the ground, drops will not form and the effect of rain is negligible. Ice, if formed in thick layers, increases the transmission loss considerably, but the formation of ice can be prevented by heating the line electrically.

The surface-wave line assembly to be described was developed for operation in the frequency range from 1,700 to 2,400 mc. The electrical requirements were insertion loss for 150-foot line length, less than 3 db, and a standing-wave ratio not exceeding 1.5. Other requirements were ruggedness, simple installation and maintenance, and electric heating to prevent ice formation on the line.

Description

The conductor used for the surface-wave line is a number 10 (0.102-inch diameter) soft-drawn copper wire covered with an extruded layer of pigmented polyethylene of 0.014-inch thickness. The theoretical loss of this conductor, assuming a power factor of 5×10^{-4} for the dielectric, ranges from 0.7 db/100 feet at 1,700 mc to 0.95 db/100 feet at 2,400 mc. The phase velocity of the surface wave is about 1.2 per cent below the free-space velocity; the 90-per cent power radius of the field around the conductor at the center of the frequency range is about 4 inches.

Fig. 1 shows a cross-section view of a line termination or "launcher." The coaxial end section, I, together with the horn section, II, can be considered a tapered coaxial line in which the coaxial-wave mode is gradually converted into the surface-wave mode, or vice versa. The center conductor (1) is tapered down until it matches the diameter of the wire. The outer conductor (2) flares

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[1] G. Goubau, "Surface waves and their application to transmission line," *Jour. Appl. Phy.*, vol. 21, pp. 1119–1128; November, 1950.

[2] G. Goubau, "Single-conductor surface wave transmission lines," Proc. I.R.E., vol. 39, pp. 619–624; June, 1951.

out until it has little effect on the field as the surface wave is developed. The wire is connected to the center conductor by means of a specially designed wire fastener made of stainless steel. A cross-section drawing of this fastener is shown separately in Fig. 1. The connection is made in the following manner: The wire, after removing the insulation over a length of about 3 inches, is fed through the end (12) of this wire fastener at an angle of about 30 degrees to the axis of the fastener. Then the end of the wire is bent to form a hook and forced into the hole (13) and the slot (14). This method of fastening the wire has proven very satisfactory as it provides a smooth transition from the center conductor (1) to the wire. The holding strength of this connection is greater than the breaking strength of the wire. The collar (15) on the fastener compensates for the small electrical discontinuity at the junction (12) between wire and fastener.

The feed into section I is located at a quarter-wave distance from the shorted end. The coupling is made by a quarter-wave coaxial-line section, the inner conductor (3) of which is threaded into the center conductor (1); the outer conductor (4) is also the inner conductor of the coaxial feed section, III, shown separately in Fig. 1, which terminates in a standard LN-type connector (5). This coupling arrangement provides for uniform coupling over the frequency range and rejects low-frequency signals which may be received by the line acting as long wire antenna.

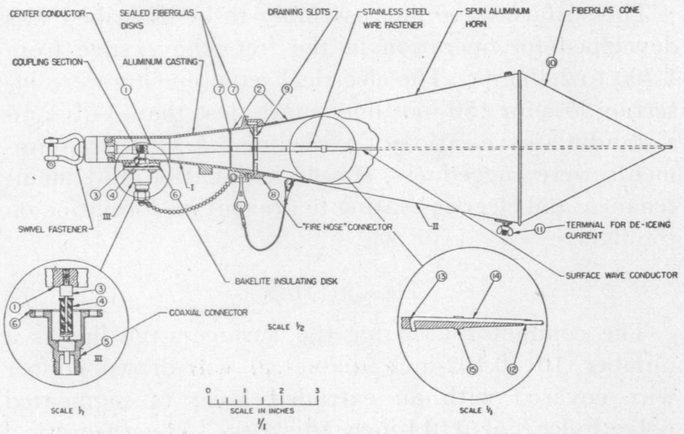

Fig. 1—Cross-section drawing of a launching unit.

The feed section, III, is insulated from section I by a bakelite disk (6). In this manner the current required for de-icing the line is entirely isolated from the equipment connected to the line assembly. Section I is sealed to prevent entry of water. The sealing is accomplished by two fiberglas disks (7) cemented in place. They are spaced about one quarter wavelength to compensate for reflection.

The horn section, II, is joined to the end section I by means of a "fire-hose" type connector (8). This connector has draining slots (9) on its circumference to avoid the collection of water in the horn. The opening of the horn is covered by a fiberglas cone (10) to prevent snow and insects from entering. The horn section contains a heating wire (not shown in the figure) for melting the snow which might collect on the outside of the fiberlas cone. One end of this heating wire is connected to the terminal (11), the other end to the metal horn.

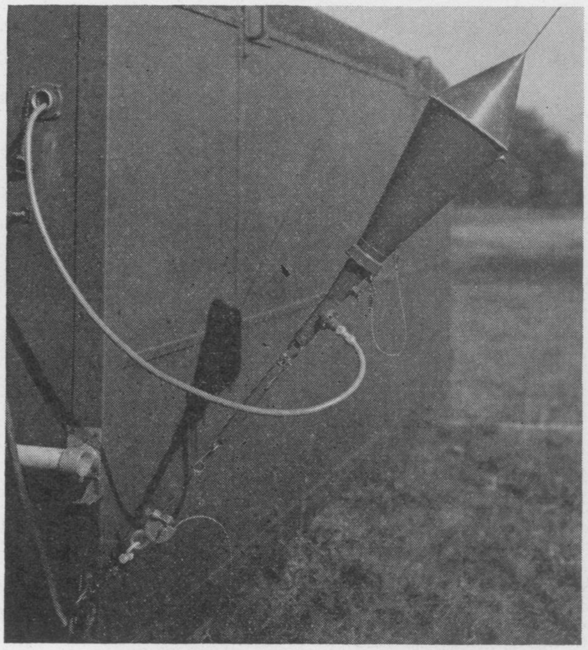

Fig. 2—View showing one launching unit of the test-model line assembly.

The de-icing current enters at the terminal (11), passes through the heating wire, the metal horn, the outer and inner conductor of section I, the surface-wave line, and returns through the other line termination. Measurements in a cold chamber indicated that a heating power of 2 watts per foot of the line is more than adequate to prevent ice formation.

The line assembly is supported at both ends by swivel fasteners and kept under a constant tension of about 100 pounds by a spring assembly. Fig. 2 shows a launching unit of the installed line.

PERFORMANCE DATA

The insertion loss and the standing-wave ratio were measured for a line 130 feet in length. The results are shown in Fig. 3. Within the required operating range of 1,700 to 2,400 mc, the insertion loss measured between 2.1 and 2.4 db. The calculated loss, which takes into account the loss of the dielectric coated wire and the launching loss, is 0.5 db less than the measured value, but this discrepancy can be accounted for. It is known from measurement that the fiberglas cones contribute about 0.1 db each to the loss. There is also some additional loss in the launching units caused particularly by the two fiberglas disks and the wire fastener, which was not plated in the test model.

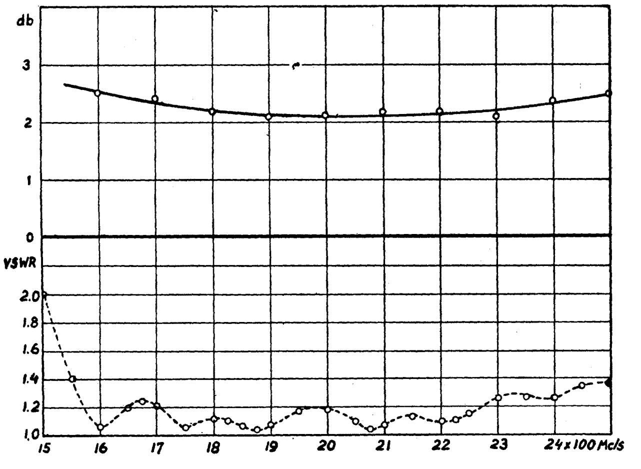

Fig. 3—Upper curve shows insertion loss of a 130-foot line assembly. Lower curve is a plot of voltage standing-wave ratio maxima.

The plot of the standing-wave ratio in Fig. 3 represents the maxima of this ratio with the line terminated in a 50-ohm load. Since some reflection occurs at the terminating launching unit, the standing-wave ratio has many maxima and minima within the frequency band. The standing-wave ratio is below 1.3 over the required band.

ACKNOWLEDGMENT

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Gain of Electromagnetic Horns*

E. H. BRAUN†

Summary—Recent experimental evidence indicates that the measured gain of pyramidal electromagnetic horns may be considerably in error if the measurements are carried out at short distances, and the aperture to aperture separation between horns is used in the gain formula $G=(4\pi R/\lambda)\sqrt{P_R/P_T}$.

Further experimental verification of this effect has been obtained and a theory developed which is in good quantitative agreement with present experimental data and demonstrates the physical reasons why the previous "far field" criterion of $2D^2/\lambda$ is invalid.

Curves are presented from which the error in gain measured at any distance may be obtained and applied as a correction.

INTRODUCTION

RECENT EXPERIMENTS[1] have indicated that considerable error may be incurred in measuring the gain of electromagnetic horns at short distances if the aperture to aperture distance between the horns is used in the gain formula

$$G = \frac{4\pi R}{\lambda}\sqrt{\frac{P_R}{P_T}}. \tag{1}$$

Previously, an aperture to aperture separation (R) of about $2D^2/\lambda$ ($D=$ larger horn dimension) was considered adequate, but the above experiments indicate that an error of the order of 1 db may occur at this distance, and that the true Fraunhofer gain may not be realized even at distances several times $2D^2/\lambda$.

The present work provides a theoretical explanation of the failure of the $2D^2/\lambda$ criterion, together with further experimental data in good quantitative agreement with the theory. The theory replaces the $2D^2/\lambda$ criterion with a new criterion, and in addition makes it possible to calculate the error incurred when this criterion is not satisfied.

THEORY

Two assumptions are implicit in the gain formula: (a) The power arriving at the receiving aperture varies as $1/R^2$; (b) the wave striking the receiving horn is sensibly plane, so that the effective cross section of the receiving horn is $(\lambda^2/4\pi)G_\infty$, where G_∞ is the true Fraunhofer gain.

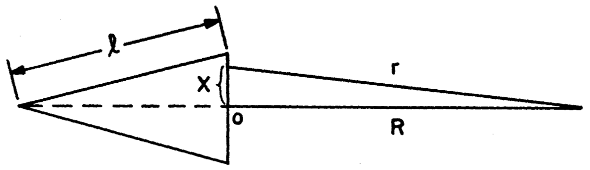

Fig. 1—Physical dimensions for computing the phase errors.

Actually, neither of these conditions is necessarily satisfied until the separation between the horn apertures is considerably greater than $2D^2/\lambda$. To show this qualitatively it should first be noted that the relative phases of contributions from different points in the aperture depend on the intrinsic phasing of the aperture and on the space phasing in exactly the same way; both are quadratic errors. Considering a sectoral horn for simplicity (Fig. 1), the intrinsic phase error can be shown[2] to be $-k(x^2/2l)$. The space phase error is $-k(r-R)=-k(\sqrt{R^2+x^2}-R)\cong -k(x^2/2R)$. The effect

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* Decimal classification: R165×R265.2. Original manuscript received by the Institute September 29, 1952.

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[1] W. C. Jakes, Jr., "Gain of electromagnetic horns," PROC. I.R.E., vol. 39, pp. 160–162; February, 1951.

[2] S. A. Schelkunoff, "Electromagnetic Waves," D. Van Nostrand Book Co., New York, N. Y., p. 361, ff.; 1943.