AFCRL-64-374

INVESTIGATION OF APPLIED PROBLEMS IN ELECTROMAGNETIC RADIATION

by

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Contract Number AF19(604)-8057
Project 4600
Task 460002

Final Report

April 2, 1964

PREPARED FOR

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

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ABSTRACT

Topics in electromagnetic theory which have been covered in five scientific reports under the contract are propagation in multilayered media, improved feeds for aperture antennas, techniques for the analysis of radiation from bounded wave fronts, and efficient launching of surface waves. This report gives the abstracts and summaries of the five scientific reports plus supplementary pertinent information.

I. PROPAGATION OF ELECTROMAGNETIC WAVES IN MULTILAYER MEDIA (SR-1)

The work performed in this area has been described in Scientific Report No. 1, entitled "Modes in Lossy Stratified Media with Application to Underground Propagation of Radio Waves," by M. Viggh, with the following abstract:

"The problem considered is that of determining the complex propagation constant of a plane wave on a flat layer of lossy dielectric with a loss-tangent, less than one, and of uniform thickness, surrounded on both sides by identical layers having a loss-tangent greater than one and of thickness much greater than the skin depth. A formula is given, relating this propagation constant to the path loss between two antennas provided their excitation efficiencies are known. As an example, curves showing attenuation and wavelength are given for the following properties of the layers:

Middle layer: $\sigma = 10^{-6}(\text{ohm meter})^{-1}$, $\epsilon_r = 10$, $\mu_r = 1$

Surrounding layers: $\sigma = 10^{-2}(\text{ohm meter})^{-1}$, $\epsilon_r = 10$, $\mu_r = 1$

Frequencies between 1kc and 10 mc/s are covered, as well as values on thickness of the middle layers ranging from 10 meters to 200 meters.

The computations were performed under the direction of Mr. John Nihen."

In the abstract, as well as in the report itself, some errors have been found, and a list of errors is included. (See Appendix II).

II. WIDE FLARE FEED (SR-2)

In this report the basic theory of a new type of feed for an aperture antenna is described. The characteristics of this feed which distinguish it from a conventional or diffraction limited feed are shown in Table 1 and Figure 1. The feed can be either conical, sectoral, or even elliptical in cross-section.

FIGURE 1

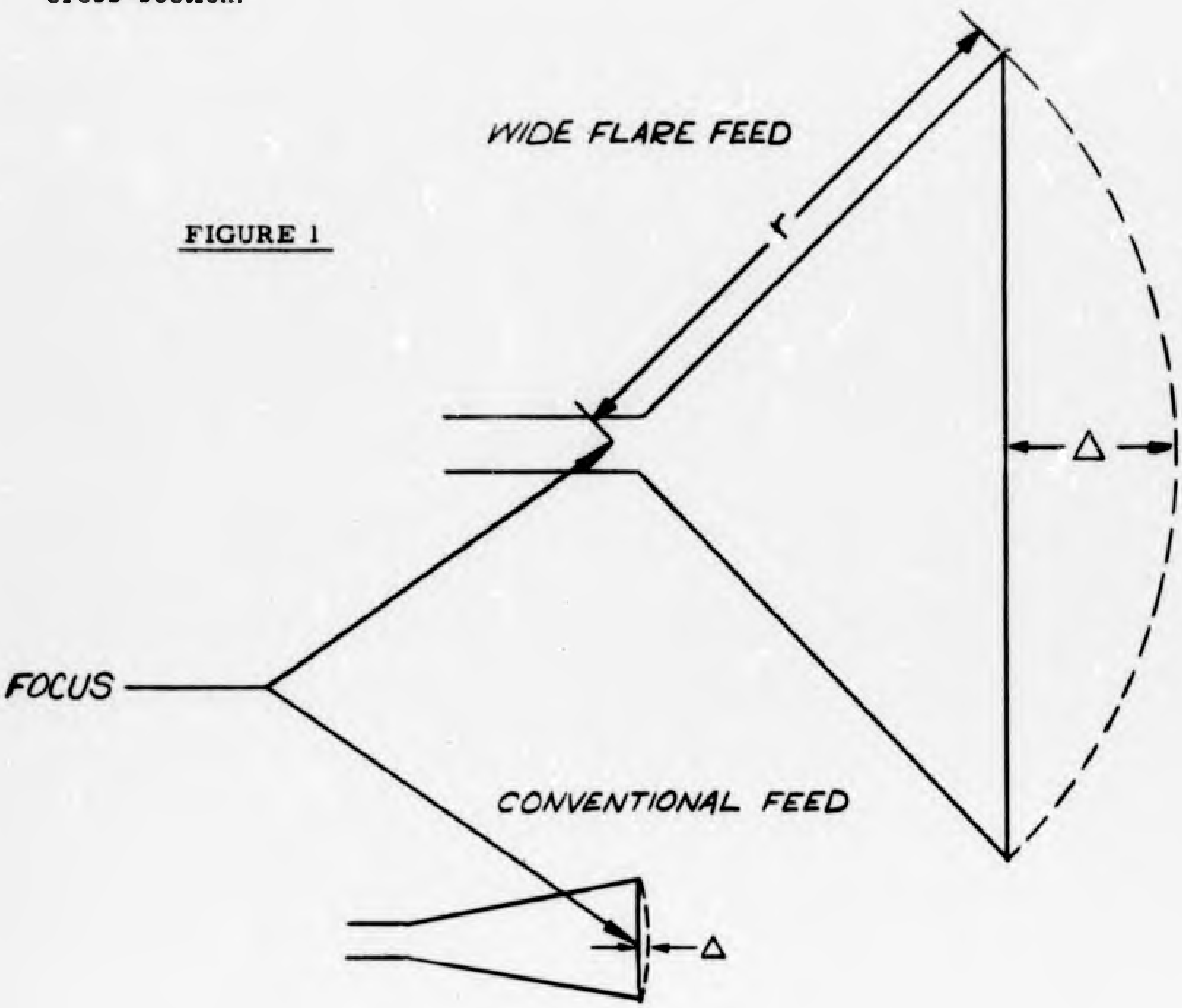

TABLE 1

COMPARISON SUMMARY, WIDE FLARE FEED AND CONVENTIONAL FEED

	Wide Flare Feed	Conventional Feed
(1) Phase front in aperture	Spherical, $\Delta > \lambda/2$	"Flat," $\Delta < \lambda/2$
(2) Phase center	In throat at vertex of cone.	In or near aperture
(3) Spillover (% energy which does not strike reflector)	Inversely proportional to flare length - less than conventional feed for same aperture taper.	Typically: 20% for 10db taper 10% for 20db taper
(4) Beamwidth	At flare angle: E plane 6-9db depending on θ_0, independent of λ, r_0, H plane 13-25db depending on θ_0 and slightly on r_0/λ.	Proportional to λ: 10db BW $\simeq 2\lambda/d$ 20db BW $\simeq 4\lambda/d$
(5) Aperture diameter d	$d = 2r_0 \sin\theta_0 >> \lambda$	$.5 < d < 1.5\lambda$
(6) Aperture efficiency	Larger than conventional feed with same reflector aperture.	

In an initial approach to predicting the behavior of such a feed, it is assumed that the aperture has a spherical wave front traveling thru it emanating from a phase center at the throat and bounded by the feed flare structure. Two different theories are used to predict the resulting far field patterns including especially radiation into the shadow zone. The results agree well with each other and with measured values on several feeds.

It is shown in this report that the spillover (percentage of energy not striking the secondary aperture) decreases directly with flare length r/λ. It is also shown that for the same slant length and aperture size, spillover of wide flare feeds whether pyramidal or conical in cross-section is about the same.

The actual fields in the aperture of the conical cross-section case are then determined assuming only dominant mode excitation in the conical waveguide. From the agreement between the theoretical and measured values it was concluded that the several methods of exciting the conical flare region produced substantially only dominant mode excitation. Pure dominant mode excitation of the feed when used with an appropriate reflector produces an antenna which has reasonable high gain and low noise temperature. According to both theory and measurements described in this report aperture efficiencies of 50-60% can be obtained with total spillover of about 1 or 2%. This implies a high gain antenna with maximum excess noise temperature, looking at a cold, sourceless sky of less than $7^{O}K$.

There are two drawbacks to pure dominant mode excitation. One is that the primary E plane beamwidth is 20-40% wider than the primary H plane beamwidth, making an optimum choice of the spillover and gain tradeoff poorer in either or both cases. This problem can be alleviated by the use of transverse fins on the surface of the conical flare, or by an elliptical shaped cross-section flare. The second and more significant problem arises from the fact that the primary illumination taper in the E plane is slight, generally 2-4db, and therefore spurious sources appear at the intersections of the E plane and the feed aperture which can be described by diffraction rays having only 10 to 14db less strength than the principal ray from the feed phase center. These spurious sources produce high sidelobes in the E plane (15 to 17db) and some decrease in gain.

A number of attempts were made to eliminate these sources by exciting (a) symmetric higher order mode (s) which would produce in the E plane a taper similar to that of the H plane, namely, nearly a cosine taper with nulls at the edges. Attempts reported in SR-2 were not particularly successful. A fully successful technique embodied the Scalar feed, is described however, in SR-5.

The effects of aperture blocking of a wide flare feed were also investigated and it was determined that for secondary apertures greater than about 70λ the advantages of a wide flare feed would outweigh the pattern deterioration due to blocking. In SR-5 it is shown that the Scalar feed suitably modified can show this advantage with apertures as small as 30λ.

It is shown (p. 73, SR-5) that in very low noise applications, the low spillover of a wide flare feed can cause an increase of system sensitivity of up to 5db as compared to conventional feeds.

III. FRESNEL ZONE THEORY (SR-3)

In this report the fundamental formulas of geometrical optics are rederived from the Huygens-Kirchoff formula in such a way that a number of more or less new results useful for microwave antenna design become apparent. In particular the presence of diffracting edges which bound a wave front are accounted for both mathematically and by a simple physical picture based on the use of Fresnel zones. Simple formulas are given for the maximum gain as measured at a given observation point that can be obtained by (a) stopping down or (b) focussing any source which can be represented by a finite (i.e. bounded) wave front. Such sources include, for example, the common (and generally accurate) approximation for the aperture field produced by a lens or reflector regardless of the contour of the lens or reflector, regardless of whether the observation point is in the near or far field, and regardless of whether the aperture is perfectly focussed to the observation point (or any other point) or in fact regardless of whether the aperture field has any of a wide variety of phase and amplitude distortions.

The behavior of the field in the twilight and dark zones with respect to such a source is determined semi-quantitatively from elementary considerations.

This theory had been previously applied by the author to the improved design of line source feeds for spherical reflectors and to the design of high aperture efficiency, low noise feeds. In this report two more applications are considered in detail. The first gives simple estimates of the gain of a spherical reflector antenna fed by any feed with a point phase center, for various locations of the phase center and for various feed amplitude tapers. A general formula for the optimum amplitude taper for a point phase center feed to maximize the gain of an imperfect focussing device (of which the spherical reflector is an example) is also given in this report. The improvement in gain of the optimum over actual feeds is described.

The use of a wide flare feed to improve the gain of a spherical reflector is investigated. Unless modes can be excited in the horn which give more of an inverse amplitude taper to the spherical phase front of the feed aperture, the wide flare feed will offer only a slight improvement in gain over conventional feeds, optimally focussed.

The second example is the focussing of spillover energy. Formulas are given for the focussing of that part of the energy beamed toward a lens or reflector which "spills over" behind the diffraction object (such as a Cassegrain subdish). With this formula the optimum size of a Cassegrain subdish, for example, can be derived. The subdish should be as small as possible to minimize blocking, but if too small the edge taper is excessive and excessive spillover results which increases sidelobes and often lowers gain. Knowing the optimum edge taper, fixes the optimum subdish size in view of previously known relationships for the minimum blocking condition. The result may be called the "minimum blocking and spillover" condition.

IV. EFFICIENT SURFACE-WAVE LAUNCHER (SR-4)

The work in this area has been reported in Scientific Report No. 4 entitled "Efficient Flush-mounted Surface-wave Launcher" by M. Viggh. The abstract reads as follows:

"Various methods for launching surface waves are reviewed, and the basic design principles are outlined for different kinds of launchers.

The case of a slot in a dielectric-clad groundplane is analyzed in detail, and experiments supporting the calculated results are reported. A way of combining several slots for good launching efficiency is derived and a five slot launcher designed after this principle is described. Results from measurements of radiation patterns and efficiency are reported; as well as from measurements of radiation patterns from discontinuities on a surface-waveguide excited by this launcher in combination with a cylindrical parabolic reflector

In particular, a launching efficiency of over 80 percent was achieved with five slots, as compared to about 48 percent with one slot. Radiation patterns due to abrupt changes in dielectric thickness were measured and compared with theoretical results for a corresponding change in surface reactance. The agreement was good at least within the main lobe."

The main significance of this work seems to be that the feasibility of using the design principle has been proved, and that design formulas have been worked out. For laboratory experiments, especially when studying modulated or discontinuous surface-wave structures, this type of launcher should be very useful.

For example, the structure analyzed by Felsen in [1] has to our knowledge never been experimentally investigated, despite its apparently good properties as an antenna. A launcher with very low radiation is required for such an investigation, if conclusive results are to be reached as to the validity of the analysis, and the described launcher should be very suitable for this purpose. Many similar experiments where low feed radiation is imperative for good results could be brought up.

Practical antenna application for this type of launcher requires some engineering work on the power division network, and in the case of more slots than five, parasitic excitation of the side slots ought to be possible. For low noise applications, where bandwidth is not a major concern, the launcher should have definite advantages over most other existing launching devices.

V. THE SCALAR FEED (SR-5)

A type of wide flare feed called the "Scalar Feed," which produces low spillover, high aperture efficiency and broad bandwidth was described. This feed operates with no loss of its high performance characteristics over a full waveguide band (and more) and takes full waveguide power. It has low VSWR, supports linear, circular, or dual polarization, and has inherently low cross-polarization. Many primary and secondary performance characteristics are described, which verify the high gain, low sidelobe, and low noise temperature features.

As a tracking feed it can be used with multimode inputs, either the TE_{11} and TM_{01} mode circular guide type or the two or four horn monopulse type. The feed operates well in the former system but has unsolved problems in monopulse operation involving controlled mode excitation at the throat.

APPENDIX I

A1. FLUSH MOUNTED SURFACE-WAVE STRUCTURE

One of the main advantages with surface-wave antennas is their low-silhouette properties that make these antennas suitable for installation in aircraft, missiles and other vehicles where good aerodynamic properties are at a premium. This has been recognized for many years, but so far very few surface-wave antennas have come to use. There are a multitude of reasons for this. One obvious reason is the difficulties encountered in analyzing surface-wave structures where the properties vary along the antenna, the only apparent possibility to achieve more sophisticated patterns than pure endfire. Experimental work on such structures has also been hampered by lack of efficient launching devices, a problem that is treated in next section of this report.

Another very important problem in surface-wave antenna design is to find guiding structures that can be accepted by the vehicle designer. Most "classical" structures (dielectric slabs on a ground plane, corrugated surfaces, Yagis, etc.) seem to have drawbacks of a practical nature. This fact points towards the necessity for finding other guiding structures more acceptable from the designer's point of view. Such structures can be expected to be more difficult to analyze electrically than the classical ones, that undoubtedly were selected for studies primarily because of their relative simplicity in this respect.

To warrant a further investigation, a surface-wave structure should:

1) be easy to manufacture.

2) be capable of flushmounting.

3) not noticeably affect the strength properties of the surface in which it is integrated.

4) be suitable for variation of properties along the structure.

One structure that seems to meet all these specifications has been treated by Hougardy.[2] It was decided to look into a linear version of Hougardy's arrangement, shown in Figure A1. This structure will support a surface-wave, provided the slot spacing $S << \lambda_0$, and the width of the channel below the ground-plane $a < \lambda_0/2$. The fields in the channel will decay exponentially away from the slots, and a "bottom" conductor can be introduced fairly close to the slots without too much effect on the velocity of the guided wave. The whole structure could be made less than $\lambda_0/2$ thick, and since only simple slots have to be cut in the groundplane, conditions 1-3 above are satisfied. Condition 4 can also be met, since at least three possibilities for changing the phase-velocity along the structure are at hand. Slot length, channel width and depth all affect the phase-velocity, and the introduction of dielectrics or other slow-wave structures in the channel offer additional variation potential.

The dependence of the phase-velocity on these parameters has to be determined, and a good launcher has to be designed in order to convert the structure in Figure A1 to a practical antenna. Both these problems were attacked, but with limited success.

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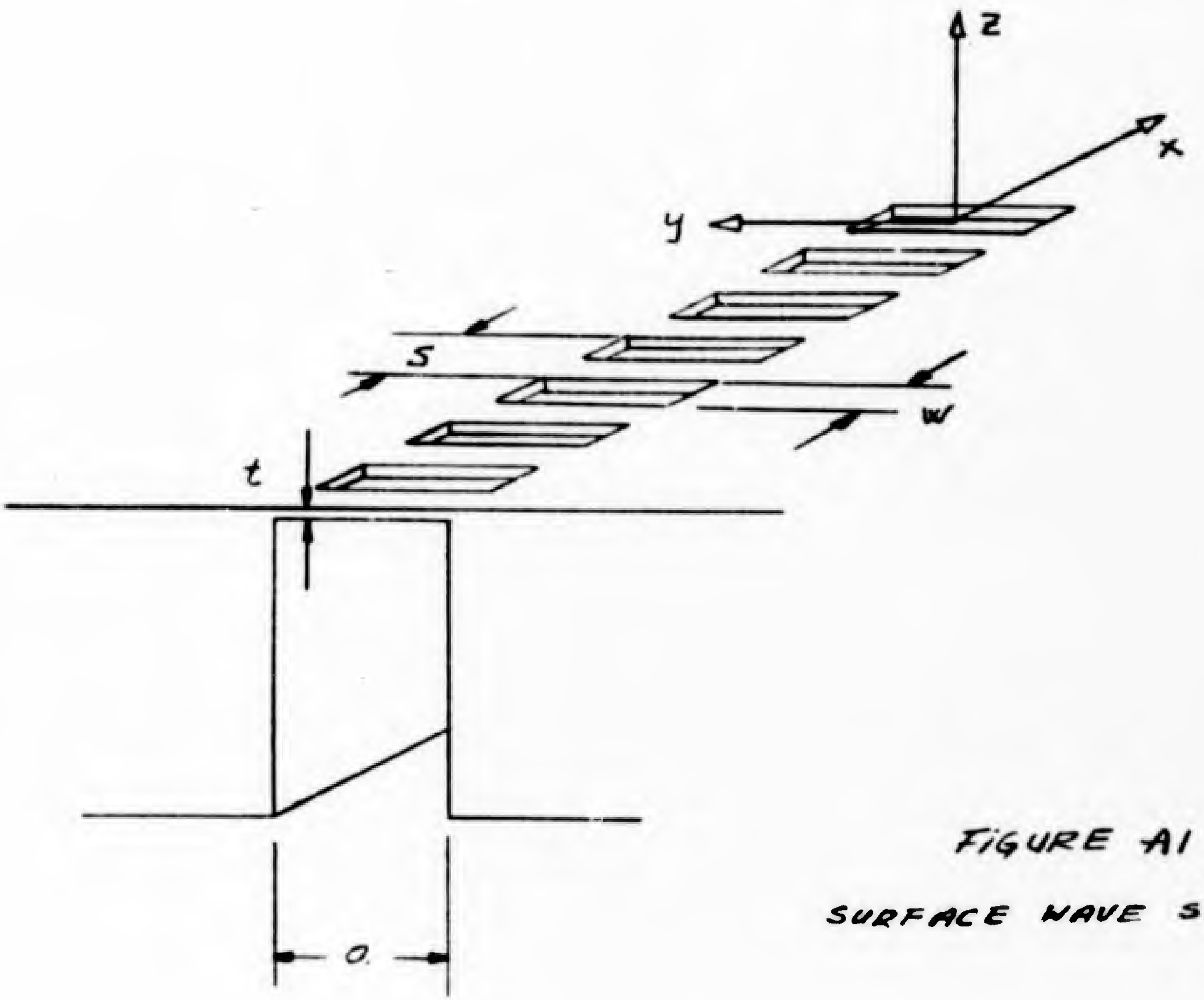

FIGURE A1

SURFACE WAVE STRUCTURE

A2. PHASE VELOCITY

The theoretical method for determining the phase velocity used by Hougardy can be used also for the linear version. The main difference is that a Fourier integral rather than a Fourier series has to be used to express the field above the ground plane. This is done as follows:

We assume that the channel is infinitely deep (Fig. A1), and that the ground plane has zero thickness (t = 0). In each slot we assume that the E-field has only an x-component, and H only a y-component. The propagation constant for the propagating mode is assumed to be β (real), and with this assumption the x-component of the E-field in the plane $z = 0$ can be expressed in the way conventional for periodic structures:

(A1)
$$E_x(x, y, 0) = \sum_{n=-\infty}^{+\infty} A_n \cdot f(y) e^{-j\beta_n x}$$

where $\beta_n = \beta + \frac{2\pi n}{s}$, and $f(y)$ expresses the y-variation of E_x in the slot ($f(y) = 0$ on the ground-plane). For A_n we have:

(A2)
$$A_n = \frac{1}{s} \int_{-w/2}^{+w/2} E_0 \cdot e^{j\beta_n \xi} d\xi = \frac{E_0 w}{s} \cdot \frac{\sin \beta_n \frac{w}{2}}{\beta_n \frac{w}{2}} .$$

$f(y)$ can be expressed as:

(A3)
$$f(y) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} e^{-j\beta_y y} \left[\int_{-a/2}^{a/2} f(\eta) e^{j\beta_y \eta} d\eta \right] d\beta_y .$$

For $z > 0$, E_x is then given by:

(A4)
$$E_x'(x, y, z) = \sum_{-\infty}^{+\infty} \frac{1}{2\pi} \int_{-\infty}^{+\infty} e^{-j\beta_y y - a_n z} F(\beta_y) d\beta_y \cdot e^{-j\beta_n x}$$

where

(A5)
$$a_n = \sqrt{\beta_n^2 + \beta_y^2 - \beta_0^2}$$

$\beta_0 = \frac{2\pi}{\lambda_0}$, λ_0 being the free space wavelength

and

(A6)
$$F(\beta_y) = \int_{-\infty}^{+\infty} f(\eta) e^{j\beta_y \eta} d\eta .$$

From the symmetry of the structure it follows that the fields can be expressed by one vector potential having only a y-component and we have:

(A7)
$$\overline{E} = \nabla \times \overline{P}; \quad j\omega\mu_0 \overline{H} = - \nabla \times \nabla \times \overline{P}.$$

From (A7) we obtain

$$E_x = -\frac{\partial}{\partial z}P_y; \quad j\omega\mu_0 H_y = \left(\frac{\partial^2}{\partial z^2} + \frac{\partial^2}{\partial x^2}\right)P_y .$$

Performing the necessary integrations and differentiations under the integral sign of (A4) gives for $z > 0$:

$$\text{(A8)} \qquad j\omega\mu_0 H_y' = \sum_{n=-\infty}^{+\infty} A_n \frac{1}{2\pi} \int_{-\infty}^{+\infty} \frac{a_n^2 - \beta_n^2}{a_n} F(\beta_y) e^{-a_n z - j(\beta_y y + \beta_n x)} d\beta_y .$$

(A5) gives $a_n^2 - \beta_n^2 = \beta_y^2 - \beta_0^2$, which can be inserted in (A8).

For the channel, $f(y)$ is expressed as a Fourier sum, as follows:

$$\text{(A9)} \qquad f(y) = \sum_{m=1}^{\infty} \frac{1}{a} \int_{-a/2}^{+a/2} f(\eta)\cos\frac{m\pi\eta}{a} d\eta \cdot \cos\frac{m\pi y}{a}$$

or with a shorter notation:

$$\text{(A9a)} \qquad f(y) = \sum_{m=1}^{\infty} B_m \cos\frac{m\pi y}{a} .$$

Following the same procedure as before, we get:

$$\text{(A10)} \qquad j\omega\mu_0 H_y'' = \sum_{n=-\infty}^{+\infty} A_n e^{-j\beta_n x} \sum_{m=1}^{\infty} B_m \cos\frac{m\pi y}{a} \frac{\beta_0^2 - (\frac{\pi m}{a})^2}{a_{m,n}} e^{a_{m,n} z}$$

where

$$a_{m,n} = \sqrt{\beta_n^{\,2} + \left(\frac{\pi m}{a}\right)^2 - \beta_0^{\,2}} \;.$$

The H-field must be continuous at $z = 0$, and the equation $H_y'(z = 0) - H_y''(z = 0) = 0$ gives us an expression for β. Following Hougardy, this expression can be transformed to a variational form, and β can be evaluated numerically for a certain $f(y)$. If this assumed $f(y)$ is close to the correct function, the β-value obtained is close to the actual β, since our expression is stationary in β for small variations in $f(y)$. For the case when the slots extend over the whole width of the channel, and $f(y) = \cos(\frac{\pi}{a}y)$, the equation for β is:

$$\text{(A11)} \quad \sum_{n=-\infty}^{+\infty} \frac{4\sin^2\beta_n\frac{w}{2}}{\beta_n^{\,2}} \; \frac{E_0}{s}\left[\frac{1}{2\pi}\int_{-\infty}^{+\infty} \frac{\beta_0^{\,2}-\beta_y^{\,2}}{\sqrt{\beta_n^{\,2}+\beta_y^{\,2}-\beta_0^{\,2}}} \cdot \frac{4\pi}{a^2} \, \frac{\cos^2(\beta_y\frac{a}{2})}{\left[(\frac{\pi}{a})^2-\beta_y^{\,2}\right]^2} \, d\beta_y \right.$$

$$\left. + \frac{a}{4} \, \frac{\beta_0^{\,2}-(\frac{\pi}{a})^2}{\sqrt{\beta_n^{\,2}+(\frac{\pi}{a})^2-\beta_0^{\,2}}}\right] = 0 \;.$$

The evaluation of (A11) is not too cumbersome, since the magnitude of the terms decrease rapidly for increasing n. Some calculations were performed for values of the various parameters corresponding to those used in the experiments described below. Consistently too large β-values were obtained from these calculations, which also was observed by Hougardy.

The conclusion is that this theory is inadequate, and before describing our experiments a short discussion of one of the possible reasons for this will be undertaken.

A comparison between (A3) and (A8) shows that the y-dependence of the H_y-field in one slot is: (apart from a constant factor)

(A12)
$$g(y) = \sum_{-\infty}^{+\infty} A_n \int_{-\infty}^{+\infty} \frac{\beta_y^2 - \beta_0^2}{\sqrt{\beta_n^2 + \beta_y^2 - \beta_0^2}} \cdot F(\beta_y) e^{-j\beta_y y} \, d\beta_y \, .$$

For the trial-function used in the variational expression we obtain:

(A13)
$$F(\beta_y) = \frac{2\pi}{a} \frac{\cos \beta_y \frac{\pi}{a}}{(\frac{\pi}{a})^2 - \beta_y^2} \, .$$

The integral (A12) turns out to diverge, when $y \rightarrow \pm a/2$, if (A13) is inserted. To show this, we can perform the integration for $|\beta_y| > \beta_1$, where $\beta_1 >> \beta_n, \frac{\pi}{a}$. We get after some transformations:

(A14)
$$\int_{-\infty}^{-\beta_1} + \int_{\beta_1}^{\infty} = \frac{2\pi}{a} \left[C_i \left[\beta_1 (\tfrac{a}{2} - y) \right] + C_i \left[\beta_1 (\tfrac{a}{2} + y) \right] \right] .$$

The C_i function has a logarithmic singularity when the argument is zero, and since the integrand is bounded for $-\beta_1 < \beta_y < +\beta_1$, this means that (A12) has logarithmic singularities for $y = \pm a/2$.

This behavior does not make the theory invalid, but it shows that the trial function used is not very likely to be close to the real conditions in the slot.

Another evidence of the shortcomings of the theory is obtained from the measured values of β. These were obtained from the resonator shown in Figure A2. The cavity was used as a transmission cavity, with one coupling loop in each end. By making measurements for several different lengths of the cavity, it was determined that the coupling loops had no detuning effect, and the results are shown in Figure A3. The wavelength is normalized to the channel width a, and the reactance X is defined by:

$$\beta = \beta_0 \sqrt{1 + X^2} \quad . \tag{A15}$$

It is obvious that the groundplane thickness t has a profound effect on X, which indicates that any theoretical method for determining X has to take t into account. This means a more sophisticated approach than that described above, and since experimental methods are available for obtaining X it was deemed unnecessary to continue the theoretical work.

A3. LAUNCHING METHODS

A launcher for the considered structure should not violate any of the conditions set up for the structure itself. This means first of all that the launching arrangement has to be located in the channel under the groundplane.

A directional coupler approach seems most attractive, and the main problem is to select a suitable waveguide as a feeding line.

The first condition that has to be fulfilled in a 100 percent transfer coupler is that the propagation constants of the two lines have to be equal or nearly equal before the coupling is introduced. [3] The feeding line can be

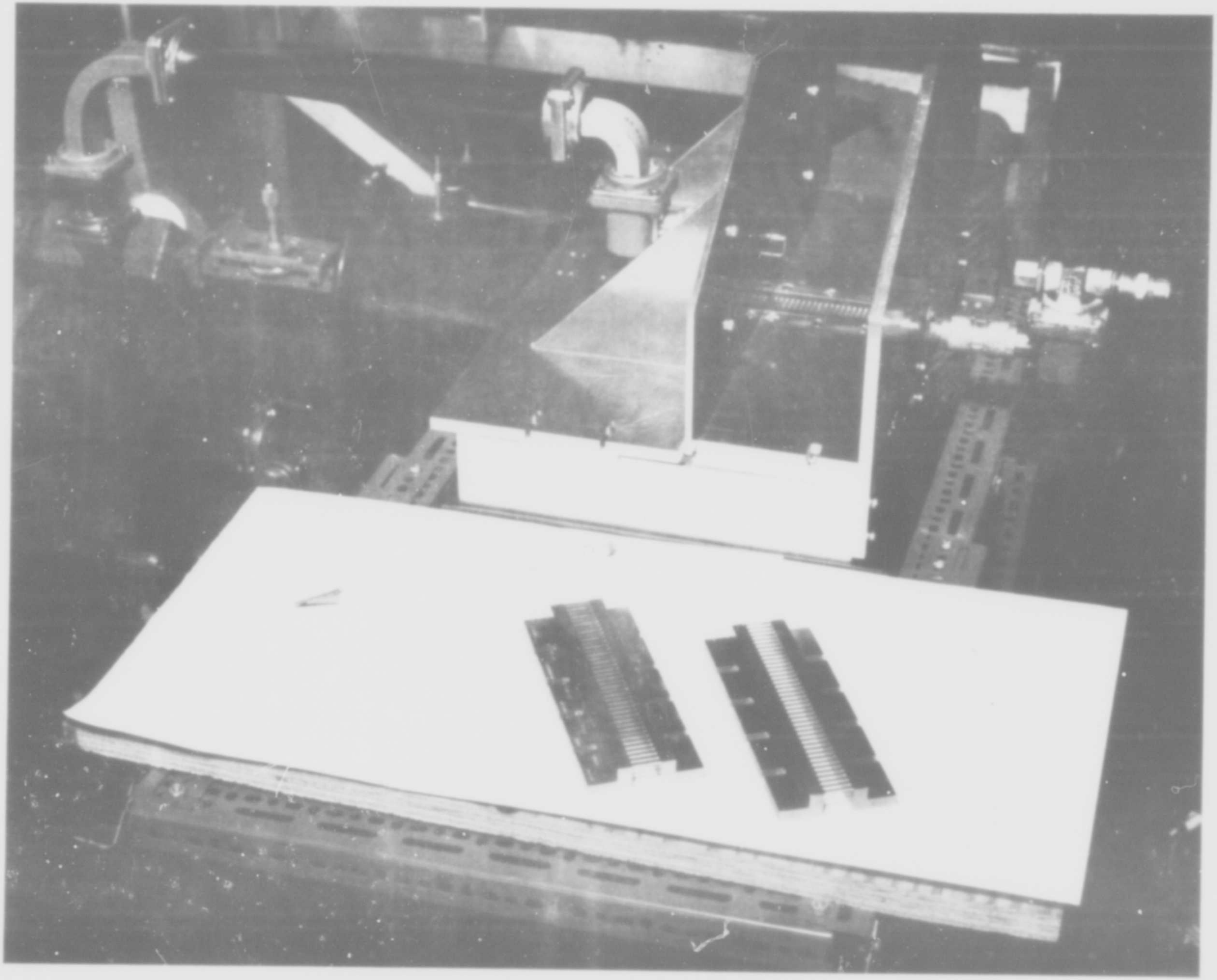

FIGURE A2 - SURFACE WAVE RESONATOR

Note the coupling loop in one of the end walls, and the two inserts with different slot configurations shown in the foreground.

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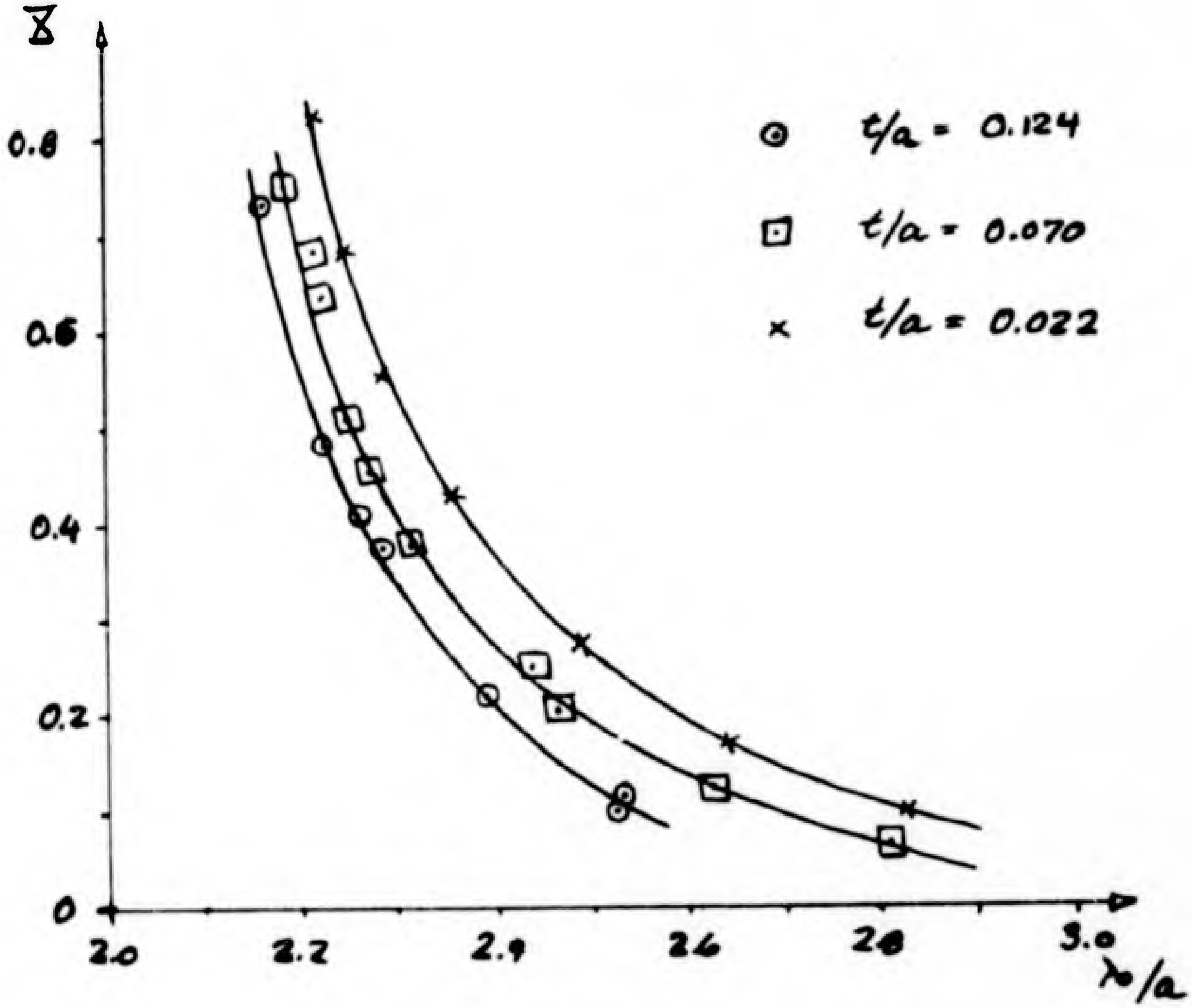

FIGURE A3

$\bar{X}$ AS FUNCTION OF λ_0/a FOR VARIOUS t/a

either a TEM structure or a tube waveguide, loaded with dielectric or other delaying media. The basic relationships between phase-velocity v and free space velocity c versus frequency for these two types of transmission lines are shown in Figure A4, as well as for our surface-wave structure.

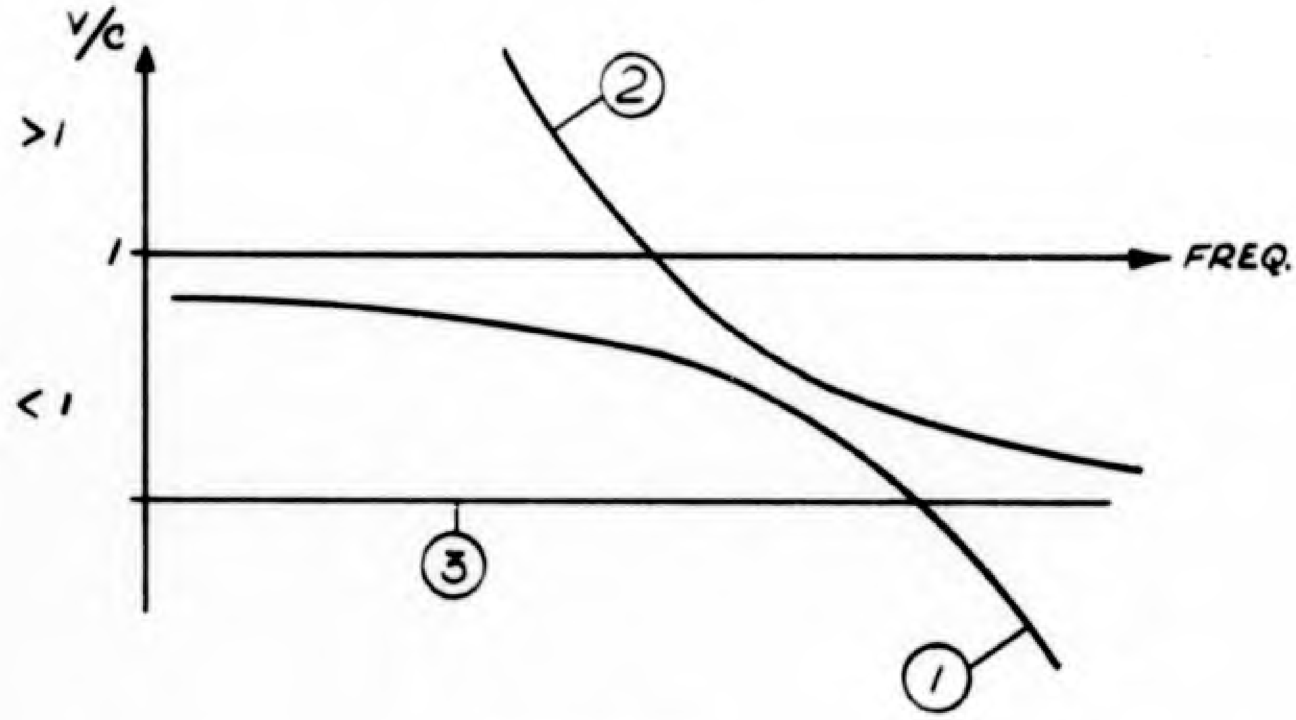

FIGURE A4

v/c as Function of Frequency for:

(1) Surface-wave structure
(2) Tube waveguide with loading (i.e. dielectric)
(3) TEM-guide with loading (i.e. dielectric)

Curves (2) and (1) can be brought very close over a band of frequencies by appropriate loading, but curve (3) can only intersect curve (1) in one point. This rules out TEM-structures, and our efforts were concentrated on tube guides.

Next, one has to design a feeding guide that together with the surface-wave structure can propagate the proper combination of modes (even and odd) with power balance between the two lines. [4] The correct combination of coupling and length of coupling region must also be determined.

The major problem in our case was that the mode on the surface-wave structure is incompletely known, and an analysis comparable to that in [4] is very difficult to carry out. The alternative is an experimental approach and for this we needed a simple feeding arrangement, in which changes could be easily made. Our choice was a dielectric slab-line in the channel (H-guide)[5] as shown in Figure A5. To match the phase-velocities presented no problem, and the coupling is easily changed by moving the slab relative to the slots. The power balance can also be changed by selecting different dielectric materials, but a closer look at this problem reveals a still simpler possibility. The power transported above the ground plane is - for constant slot-field - a function of X. Within the region where the phase-velocities are nearly equal, X will vary considerably, and a mere change of frequency may be enough to find the proper power distribution in an experiment.

The scheme outlined above was tried, and the coupling was changed for a certain length of the coupler with the hope of finding the correct values of the parameters by repeating this for different frequencies. The criteria on a good result would be a low input VSWR combined with surface-wave fields above the slots that increase along the coupler in the manner described by theory. [3] Arrangements were made for measurement of both these properties, and a

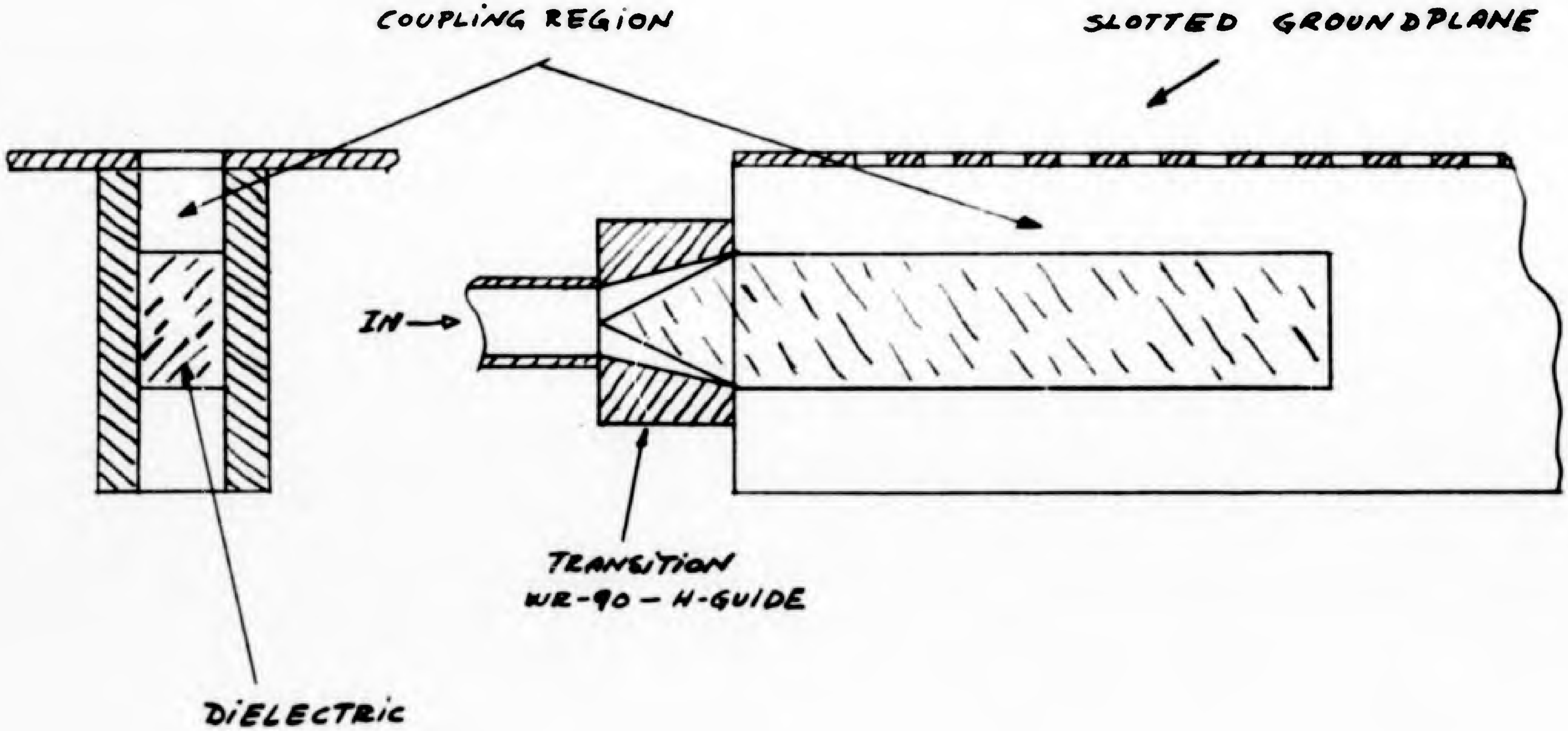

FIGURE A5

LAUNCHING ARRANGEMENT
(NOT TO SCALE)

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thoroughly planned experimental program was begun. A startling effect was immediately noticed: the VSWR at the input was below 1.5 for a wide range of coupling.

Near 100 percent coupling could definitely not take place for all these values of coupling degree; and at the termination of the dielectric energy could not propagate in the channel, since $a < \lambda_0/2$, but should be reflected back towards the input. The remaining possibility is that most of the energy is lost by radiation through the slots. The field above the slots was measured with a probe (Figure A6) and a standing-wave pattern was obtained in the coupling region with 5-10db difference between maxima and minima, and a periodicity of a half wavelength. Beyond the coupling region, some surface-wave was set up, but with low efficiency. Tuning elements introduced at the end of the dielectric slab only changed the details of the standing-wave pattern, so waves reflected from this point could not be the cause of the fluctuations. Had this been the case, and the coupler in other respects behaved as expected, the low input VSWR would still have remained unexplained.

All these facts taken together definitely told us that something else but the anticipated coupling process takes place in the structure. A closer look at the fields of the two transmission lines reveals that whereas E_x and H_y of both lines gave the same type of reactive field impedance in the z-direction, and thus can be coupled properly, this may not be enough. The H-guide field also contains another pair of components, E_y and H_x, with the same ratio as E_x, H_y. The field on the surface-wave structure does have an H_x-component,

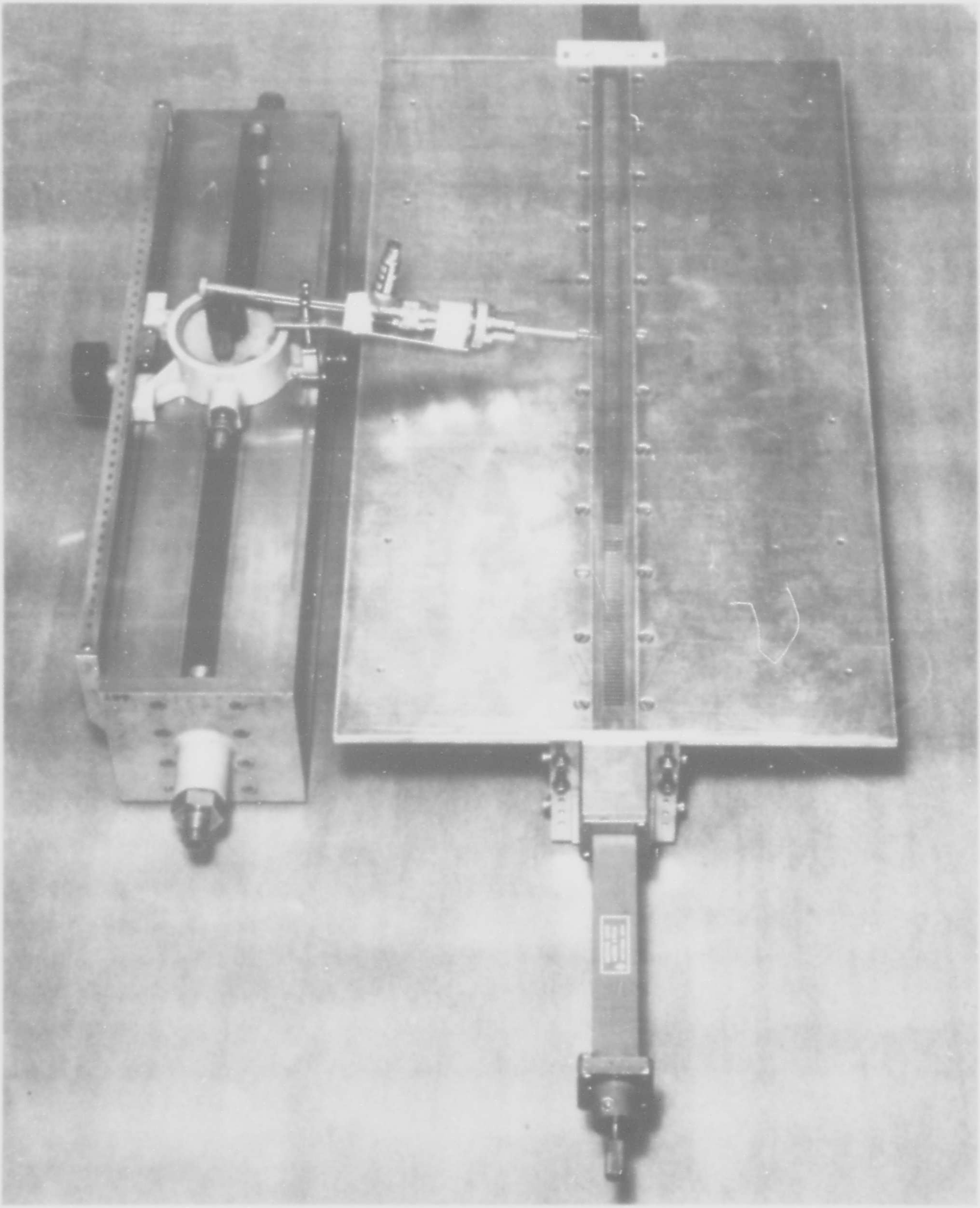

FIGURE A6

but $E_y = 0$. This in effect makes the two modes incompatible, and directional coupling is not feasible. This does not mean, however, that a suitable feeding waveguide cannot be designed for the surface-wave structure under consideration. On the other hand, it is apparent that also this phase of the investigation requires extensive work. The mechanical advantages thus are compensated by severe difficulties in all phases of the electrical design work.

APPENDIX II

Errata in:

"MODES IN LOSSY STRATIFIED MEDIA
WITH APPLICATION TO UNDERGROUND
PROPAGATION OF RADIO WAVES"

by
Mats E. Viggh

Scientific Report Number 1
Contract Number AF19(604)-8057

The abstract should read as referenced on p. 1 of this report:

1) p. 1, line 12, the last word should be "assuming."

2) p. 14, line 3 should read "In the limit, when $\sigma_1 \to \infty$, and $\sigma_2 \to 0$, . ."

3) p. 19, line 3 from bottom, "B_0" should be changed to "β_0."

4) p. 22, line 3 from bottom should begin "$\sigma_2 = \ldots$"

5) p. 25, line 2, "fro" should read "for."

6) p. A8, in Eq. (A15) as well as in the line next below, "ζ_{02}" should read "ζ_{20}."

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