STRIPLINE RADIATORS

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Summary

Progress on the use of strip conductors as microwave antennas indicates that the technique is flexible and economical. Broadside curtains can be fabricated with sufficient accuracy. Several types of balanced Stripline feed have been considered, and twists have been successfully built. A variety of baluns have been evaluated and used to feed colinear Franklin arrays through binary splits.

Whereas in these structures the design is such as to minimize the field within the supporting dielectric, we have deliberately directed the field into the dielectric in various applications of surface waves. By etching configurations on the foil face of the dielectric, the surface index of refraction or surface reactance is controlled.

Introduction

The possibility of employing etching techniques for the construction of microwave circuits has been demonstrated exhaustively during the work at this Laboratory during the past several years and has been discussed by the previous speakers. I would like now to present a progress report on a different side of the problem, namely that of using etching techniques for the construction of microwave antennas.

The basic difference between Stripline antennas and known types lies in the method of construction which permits the use of antennas that would otherwise be impractical if not impossible. Because of the flexibility of the construction methods employed, new approaches and modifications to otherwise known principles can be found.

This discussion will be divided into two parts. The first deals with the construction of microwave arrays consisting of a large number of resonant elements. The second part of the discussion deals with the use of etching techniques as a means of controlling the propagation of surface waves on dielectric sheets. The ultimate purpose of the latter work is the construction of surface metal lenses. Other types of surface wave antennas may also be studied.

Broadside Curtains

The reason why curtains of dipoles have not been employed in the microwave regions is that the number of dipoles or resonant elements in an antenna of practical size becomes so large that the problem of constructing it and maintaining the necessary tolerances becomes unmanageable. However, if etching techniques are employed, a successful design can be reproduced with high accuracy. We believe this accuracy to be sufficient to make antenna arrays satisfactory up to X-band. Some types of printable broadside arrays are shown in Fig. 1.

To start the discussion, let me ask you to visualize a conventional Franklin antenna consisting of vertical half-wave dipoles in a colinear arrangement and separated by coils which essentially rotate the phase of the current by 180 degrees without radiating or with a minimum of spurious radiation. The Stripline equivalent of this antenna would consist of half-wave elements in a colinear array separated by a folded piece of line a half wavelength long, as in Fig. 2. Arrays of this kind could be made by placing an etched dielectric sheet a quarter wavelength away from a reflector and end feeding the elements as shown in Fig. 3. This type of array looked attractive as the one on which to start work because it does not imply the use of balanced feed lines. On the other hand, since the ground plane is finite, the beam tilts with frequency change as shown in Fig. 4 and, therefore, the practical use of such an antenna is limited. It is useful, however, in order to study the characteristics of Stripline arrays. The tilt effect in the array and consideration of other possible arrays indicates the necessity of constructing balanced feeds.

Balanced Lines

Striplines, as we have employed them up to now, are essentially unbalanced and, to the best of our knowledge, no substantial work has been conducted on two-strip balanced line. Several types of such line are possible. The first would use two strips face-to-face on either side of a thin dielectric strip. The second type would also use two strips on either side of the dielectric sheet but would offset one from the other so they would no longer be face to face. The third type would use four strips, two on one side and two on the other side of the strip. The two strips facing each other would be of the same potential and the line would become equivalent to a conventional two-conductor line with part of the space between the two conductors filled with dielectric. The first type is the least desirable because of the strong field inside the dielectric. Dielectric losses can be serious and the velocity of propagation substantially less than the velocity of light. The other two types reduce the field inside the dielectric and therefore reduce the losses and bring the velocity closer to that of the waves in air. These three types of balanced line differ in another important respect. In the first two, it is possible to apply "twists" by just printing the radiating elements on one or the other side of the sheet. If the thickness of the sheet corresponds to a small percentage of the wavelength, the characteristics of the array are not changed by the fact that the two sets of radiating elements do not lie on the same plane. The third type of balanced feed, on the other hand, requires breaks in the strips to permit twisting.

Twists

Twists are required because radiating elements are usually located at a distance of a half wavelength in free space, and to obtain broadside radiation, the polarities of adjacent radiating elements must be reversed. These twists would not be actually necessary if the velocity of propagation of the wave along the feed were between 50 and 70 percent of the velocity of light. In this case radiating elements could be separated by 0.5 to 0.7 of a free space wavelength and still be fed in the proper phase (because the length of the feed between two radiators would correspond to a 360 degree phase shift). This method of avoiding the twist of balanced feeds is attractive because of its simplicity but is likely to be costly in terms of losses.

It is obvious, of course, that if the dielectric can slow down the velocity of propagation by such large amounts it will also contribute a proportionally large amount of losses. For the time being, therefore, we intend to attempt to use twists especially because preliminary results obtained on these structures have been quite satisfactory. The velocity of propagation of waves in a balanced line made with two strips etched on the two sides of the dielectric sheet but offset one from the other have indicated velocities of the order of 92 to 94 percent of the free space velocity. Results on the discontinuity introduced by uncompensated twists indicate this to correspond to an SWR on the order of 2.

Baluns

To successfully employ balanced feeds but at the same time resort to conventional Stripline technique for power splitting and phasing features, it is necessary to construct baluns. Several types of baluns can be designed which are inspired by the coaxial counterparts. Some of them, however, do not meet the basic requirement that we set for ourselves; that is, to maintain as much as possible the Stripline structures on a single plane so as to reduce production costs. It is possible to make compound types of Stripline with multiple ground planes to simulate most, if not all, coaxial baluns. However, since broadside arrays are intrinsically narrow band (because of impedance and not because of pattern characteristics), broadband baluns are not really necessary. Some types which had been considered are shown in Fig. 5. Having convinced ourselves that broadside arrays are practical when constructed with etching techniques, we are now proceeding with the construction of actual arrays. A center-fed colinear Franklin array energized by a balanced feed line is shown in Fig. 6 and the radiation pattern in the plane of the array is shown in Fig. 7. An example of a complete center-fed 40-element Franklin array is shown in Fig. 8.

Power Dividers

We have not mentioned yet an important feature of this type of array which makes the construction of Stripline arrays appear in principle more flexible than the construction of conventional curtains at lower frequency. I am referring to the fact that the impedance of each radiating element or feed can be easily changed by changing the width of the strip. Furthermore, it is possible to use power dividers so as to carefully control the power distribution along the arrays. One is not restricted to a number of splits equal to an exponent of 2. As a matter of fact, since it is perfectly possible in Stripline to divide by 3; that is, to feed three lines in parallel from one line any number of separate feeds properly controlled in amplitude and phase can be obtained. For applications, which are different from those of antennas, we have made binary power splits of one line into eight outputs with phase and amplitude error within a few degrees and few percent respectively. The phase is easily adjusted by introducing variable phase shifters to act as verniers for each channel. These phase shifters are exceedingly easy to build in Stripline and are, of course, much less complicated than in two-wire lines.

In summary thus far, the types of broadside arrays on which we are working consist of a conventional Stripline feed with binary or ternary splits. To the output of the power divider we attach baluns which then connect to strip two-wire lines feeding curtains as broadside half-wave radiating elements. Before concluding this part of the talk I should mention that end-fire arrays are also possible and may be easier to build than broadside arrays.

Surface Wave Investigation

It is well known that a metal plate covered with a dielectric sheet can support surface waves. These surface waves can be either of the TE or TM mode. In the TE mode, the electric vector is parallel to the plane of the dielectric-coated metal sheet whereas in the TM mode the electric vector is perpendicular to the plane. Surface waves in such structures are explained by considering the propagating wave as the resultant of multiple reflections of a conventional wave bouncing back and forth between the metal and the air-dielectric boundary as indicated in Fig. 9. When the trapped wave is reflected from the air-dielectric boundary it produces in the air an evanescent field which is the equivalent of the total reflection wave phenomenon in optics. The parallelism between surface waves and totally reflected waves has been pointed out before but is being stressed here again because it is a very helpful concept in understanding surface wave phenomena.

The main reason for investigating surface waves is that we expect that, by etching metal strips on the surface of the dielectric, we can change the surface index of refraction in such a manner as to curve, focus or, in general, modify and control the type of pattern radiated by the surface wave. Different methods will need to be applied for changing the index of refraction of the two different polarizations mentioned above.

TE Mode Surface Waves

We started our investigation with the TE mode. The TE surface wave cannot propagate unless the dielectric sheet thickness exceeds a minimum value. Fig. 10 shows the surface waveguide and the lathe compound rest used in the investigation of this mode. The waveguide is 2 inches wide and 20 inches long; the dielectric used is polystyrene with a thickness of 0.457 inches. The feed used to launch this wave stimulates the field distribution in air of the desired surface wave.

Since the field in air of a surface wave decays exponentially (the rate of decay depending theoretically on frequency, dielectric constant and size of the guide) with distance from the waveguide surface, it was decided to employ as a launcher a waveguide beyond cut-off with a slot in the narrow side. Fig. 11 shows details of such a launcher in which the variable plunger serves to adjust the rate of decay in the waveguide to that of the desired surface wave. Although this feed is not efficient because of the high mismatch to the generator, the purity of the generated surface wave mode is excellent.

Figs. 12 and 13 show the variation of the electric field intensity in a plane transverse to the waveguide surface and as a function of distance from the surface respectively. Measured and calculated guide wavelengths differed by about + 4.5 percent, the measurement technique in this particular case being accurate to ±2 percent.

Control of Surface Reactance

The next step was to find means for controlling the surface reactance. The simplest scheme that we could think of was that of using thin metal strips all parallel to each other and placed crosswise on the surface of the dielectric; that is, perpendicular to the direction of propagation. Instead of computing the effect of this type of loading on the surface wave velocity, we decided to measure the wave inside a waveguide by simulating experimentally conditions to which the strips are subjected when placed as loading elements on the dielectric surface of the surface waveguide. These conditions are (1) that the electric field have a tangential component which is zero at the surface metal ground plane and at the dielectric-strip-air interface and (2) that the electric field decay exponentially away from that surface. The conditions are all satisfied at the junction of a waveguide terminated in another waveguide beyond cut off. These conditions can be easily simulated in practice by filling a waveguide with dielectric and terminating it in another similar waveguide but not filled with dielectric and operating at a frequency at which the air filled guide is below cut-off and the dielectric filled guide is above cut-off.

The experimental setup for making these measurements is shown in Fig. 14. As is visible from the photograph, the metal strips are parallel to the electric field in the guide and are at a boundary that provides exactly the same conditions as the strips would be subjected to as loading elements on the surface waveguide. By noting the position of the voltage minimum first with a shorting plate behind the strips and then with the cut-off waveguide behind the strips, the shift of the null may be used to compute the surface reactance. The reactance was measured for various strip widths and spacings.

We found, and our results were later confirmed theoretically by Dr. A. A. Oliner of Brooklyn Polytechnic Institute, that the amount of control possible was small. In other words, the impracticability of making strips thin enough to cover wide limits of surface reactance excludes, for the TE mode at least for the time being, such simple loading methods as parallel strips across the waveguide surface. On the other hand, we found, as expected, that resonant elements could be used effectively to change the surface reactance. The metal loading results for the TE mode were somewhat disappointing because we hoped that the amount of control over surface reactance with the use of continuous metal strips would have been great enough to permit the construction of broadband lens elements. Fig. 15 shows results obtained in the waveguide with resonant-element loading in which the metal constitutes 50 percent of the window area if there is no gap. Fig. 16 shows two field plots, one for a 6-inch wide guide and the other for a 2-inch wide guide. It appears from these results and other field plots for the 6-inch guide that interfering modes were present preventing the system from propagating a pure surface wave.

When we tried loading with widely spaced thin strips of the nonresonant type, we found that either the amount of control was slight or the waveguide radiated. Fig. 17 shows the radiation pattern of such a loaded surface waveguide which can be compared to the operation of a leaky waveguide.

TM Mode Surface Waves

Before proceeding to the construction of antennas using resonant metal strips as a method of velocity control, we decided to explore the behavior of the TM mode. This mode is the one normally employed in the study of surface waves. Instead of using a horn, the wave was launched by means of the inner conductor of a coaxial line that passed through the dielectric and protuded by 1/8 inch above the surface. Early results indicate that beyond three wavelengths the field is free of feed effects. We are conducting surface loading experiments on this mode similar to the ones described for the TE mode. Decay curves taken on this type of mode indicate reasonably close correspondence between theory and experiment. Attenuation of more than 25 db from the surface wave has been obtained. The measured guide wavelength (average value) checked with the theoretically computed value to better than 0.2% although the spread was of the order of ±1.4 percent.

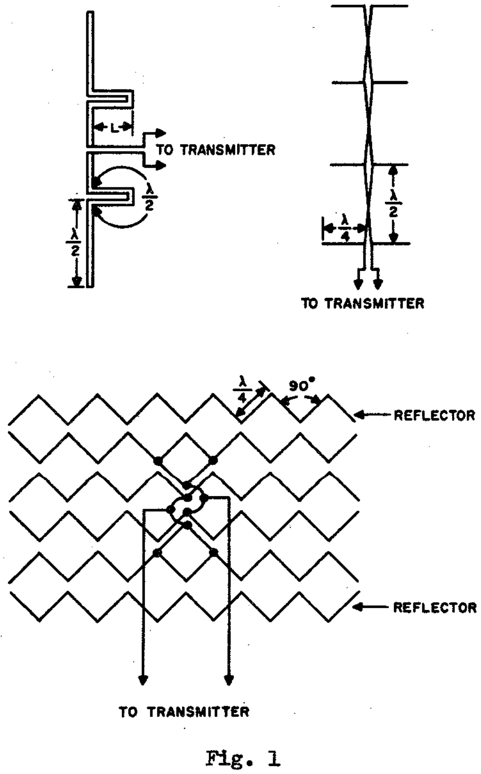


Fig. 1

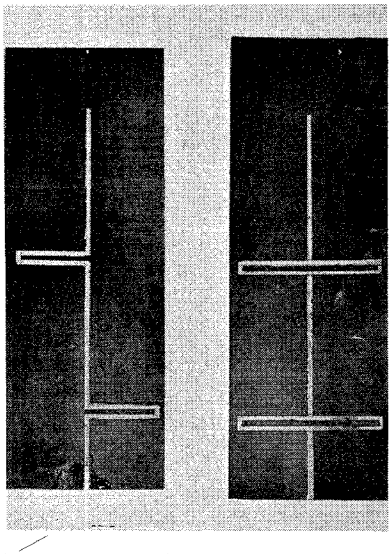


Fig. 2

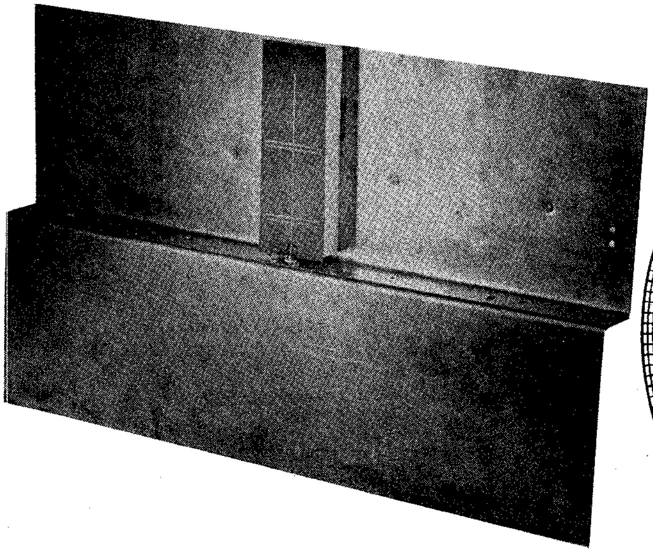


Fig. 3

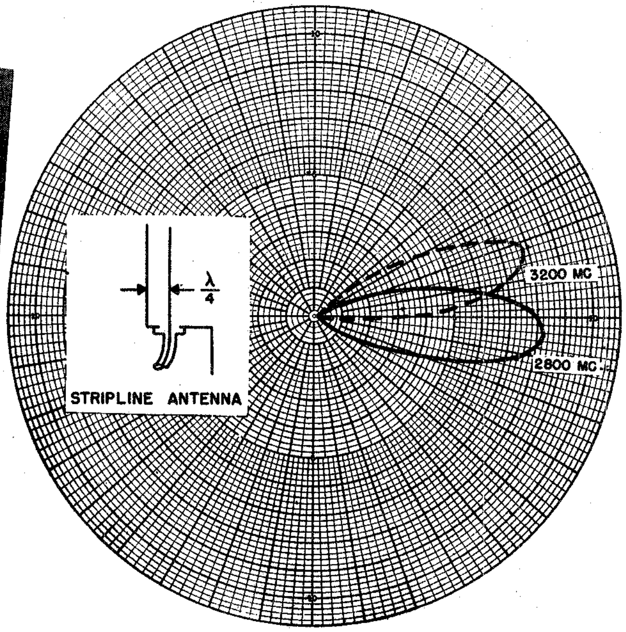


Fig. 4

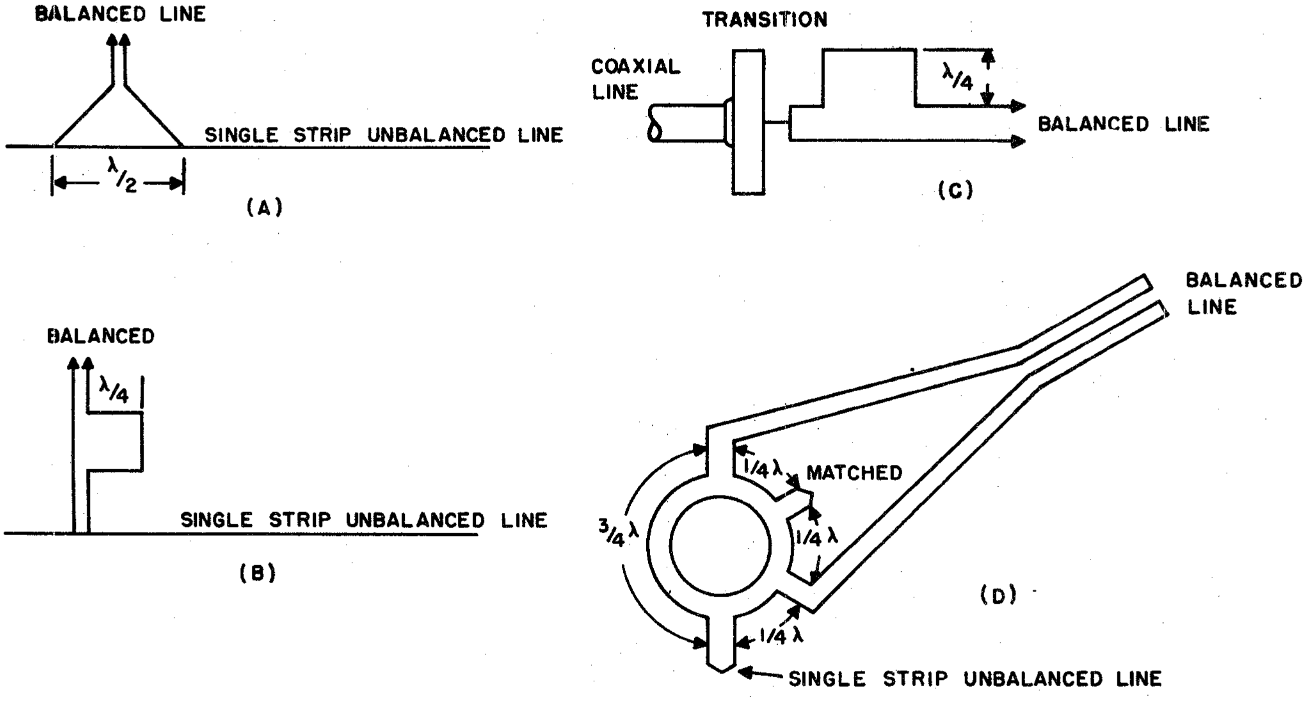


Fig. 5

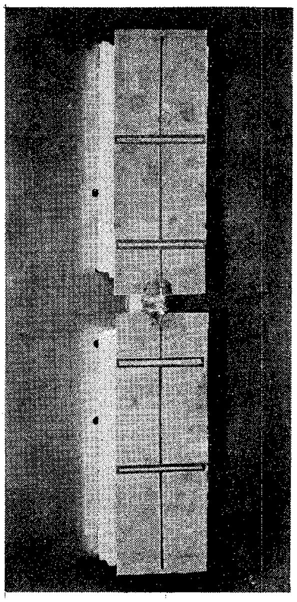


Fig. 6

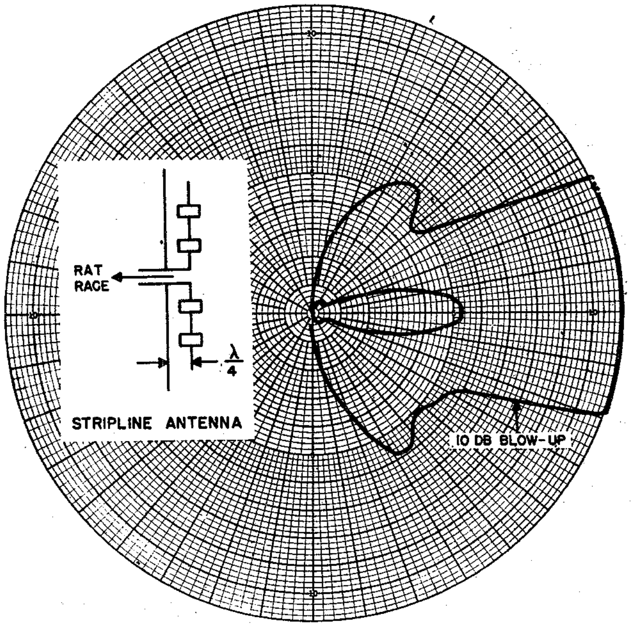


Fig. 7

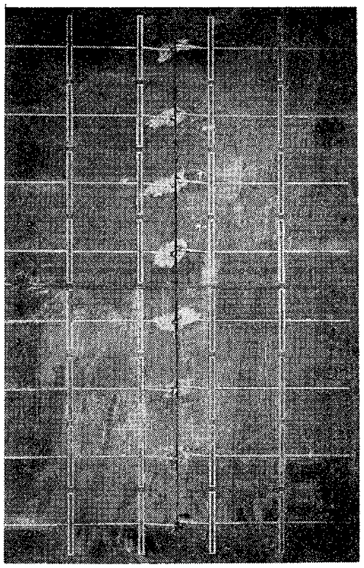


Fig. 8

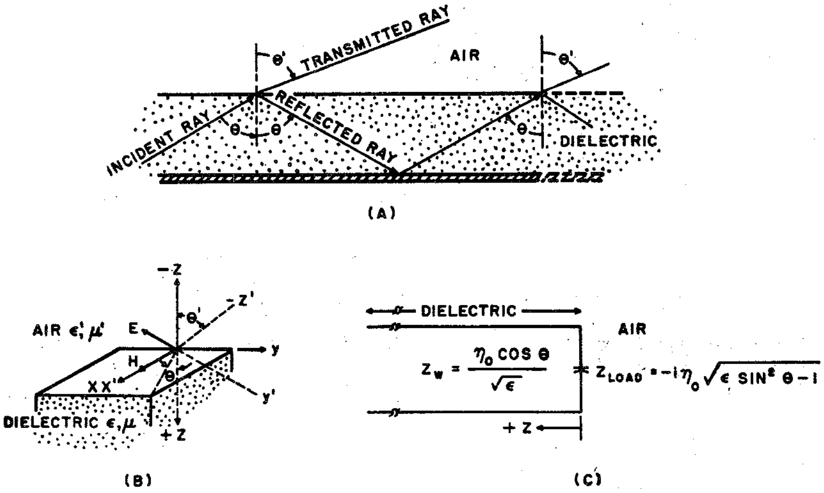


Fig. 9

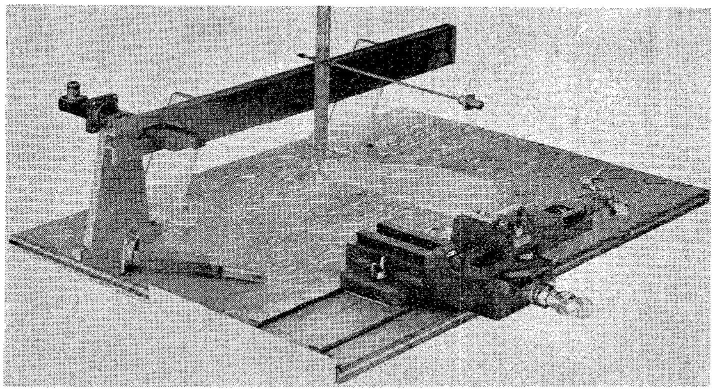


Fig. 10

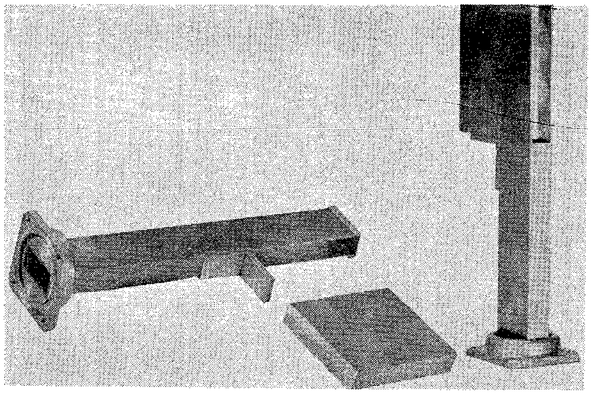


Fig. 11

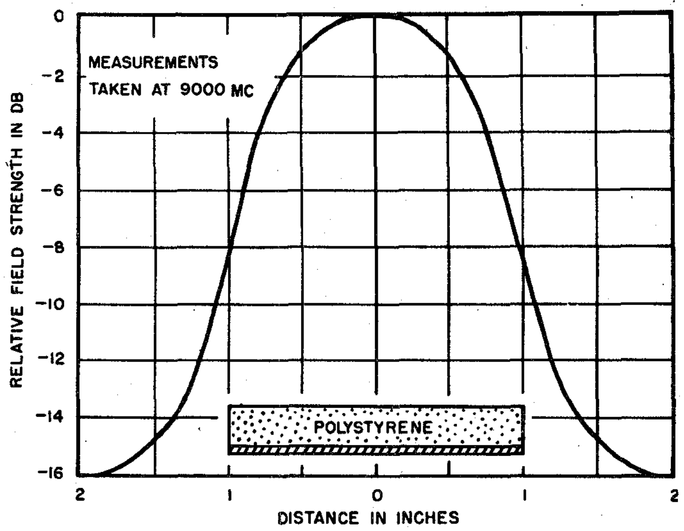


Fig. 12

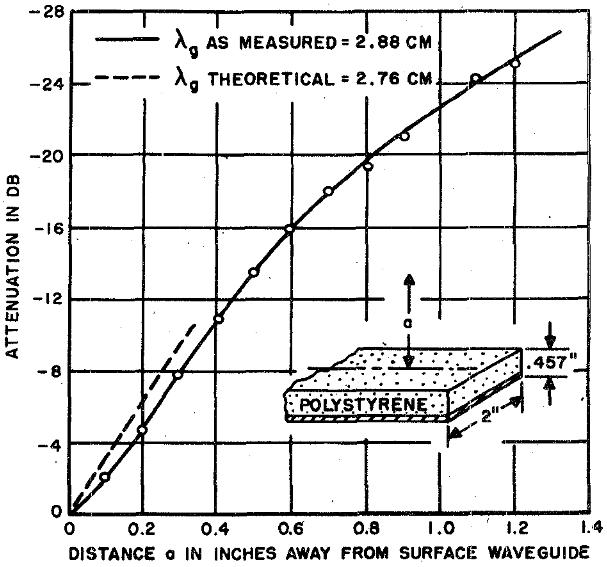


Fig. 13

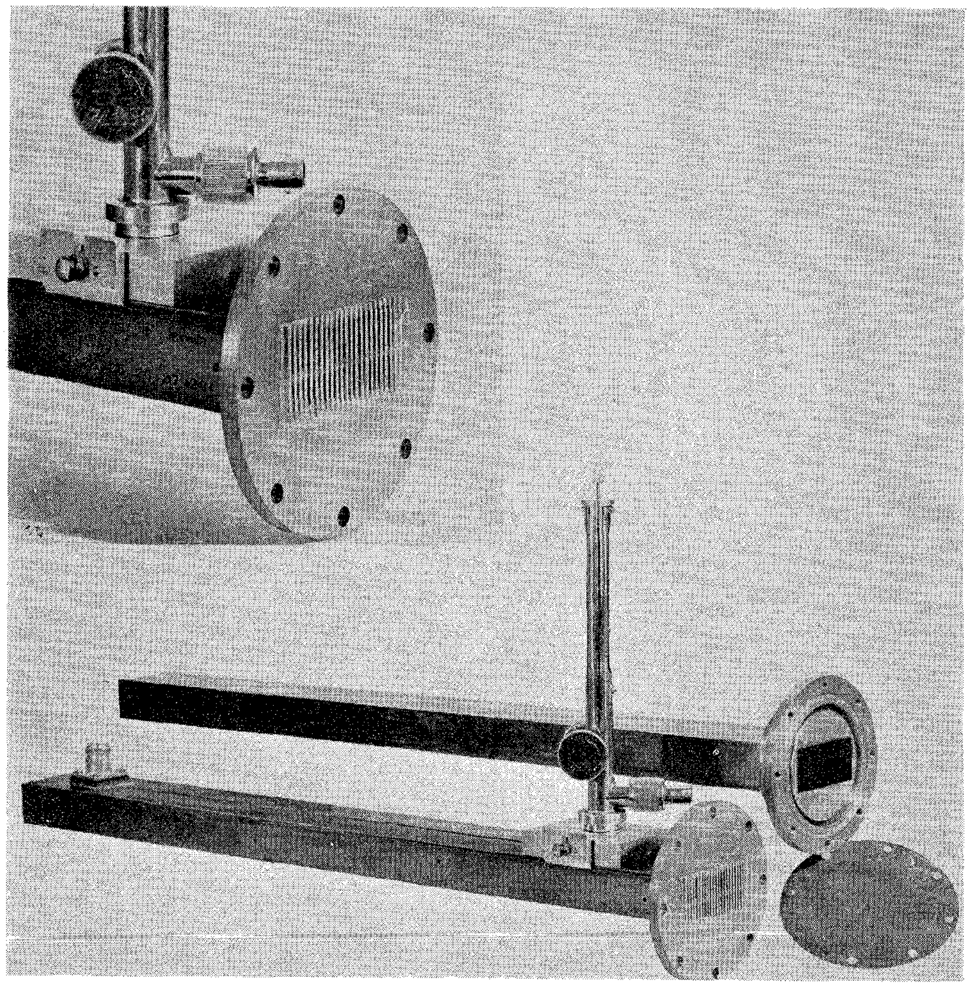


Fig. 14

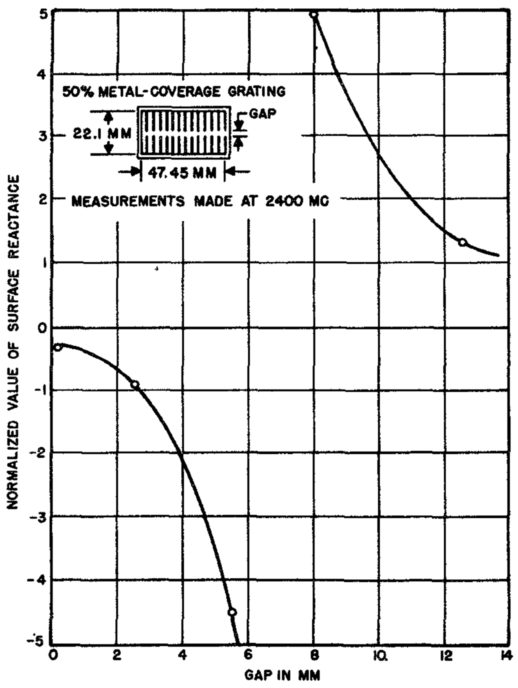
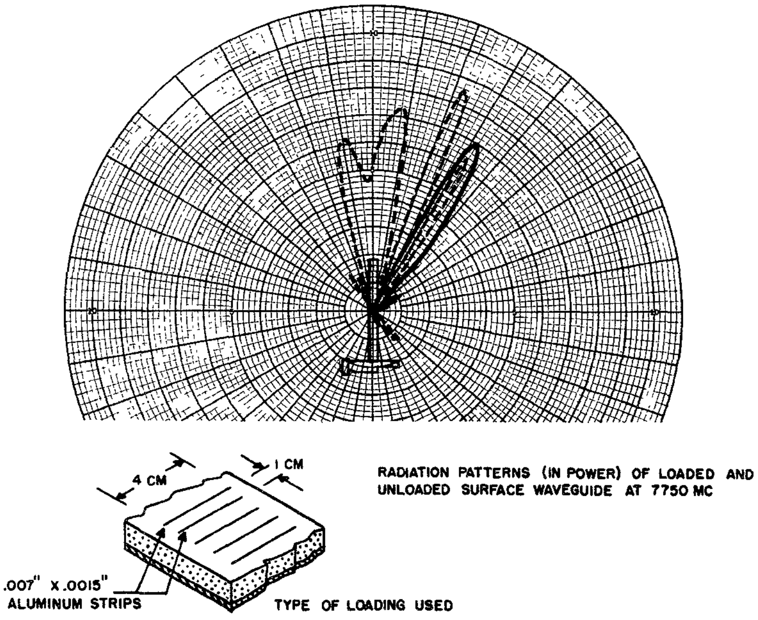


Fig. 15



RADIATION PATTERNS (IN POWER) OF LOADED AND UNLOADED SURFACE WAVEGUIDE AT 7750 MC

Fig. 17

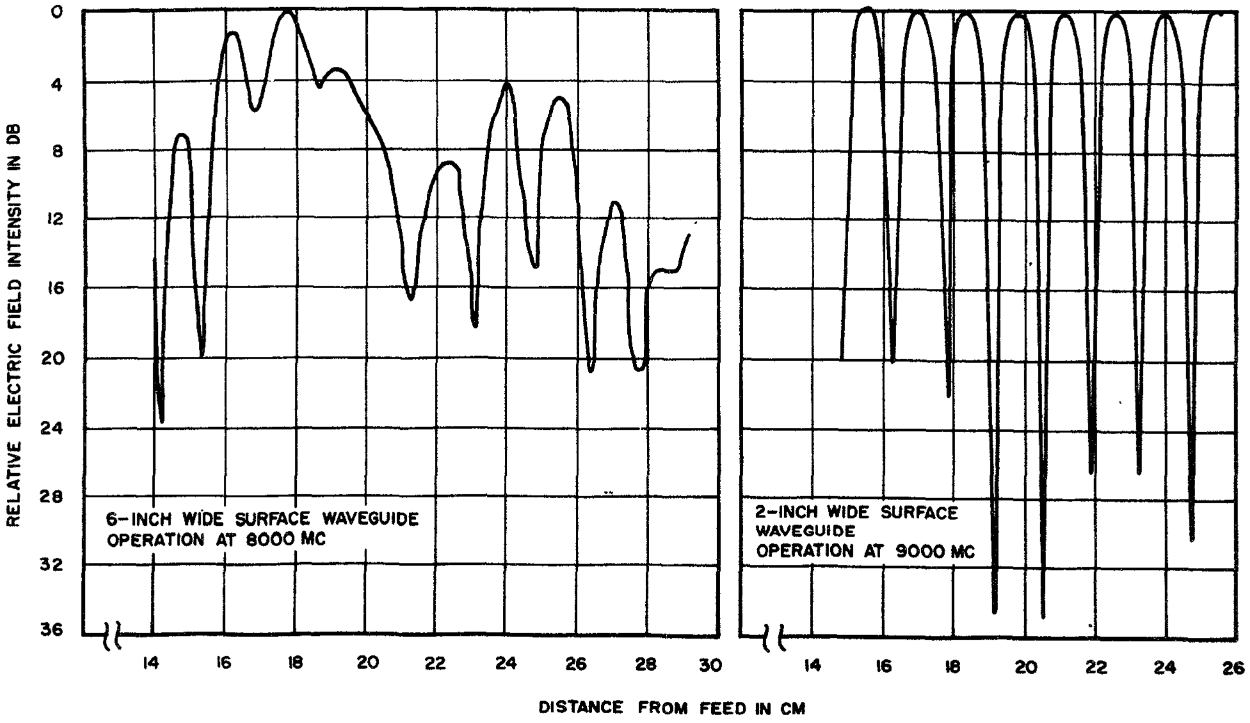


Fig. 16