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A COMMEMORATION OF DESCHAMPS' AND SICHAK'S "MICROSTRIP MICROWAVE ANTENNAS": 50 YEARS OF DEVELOPMENT, DIVERGENCE, AND NEW DIRECTIONS

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Abstract: Fifty years ago, the Third Symposium on the USAF Antenna Research and Development Program was held at Robert Allerton Park. During this symposium, Deschamps and Sichak, working for the Federal Telecommunications Laboratory, presented their work entitled "Microstrip Microwave Antennas." Here we commemorate this now declassified work, often cited as the "first microstrip antenna paper," by reflecting upon it in light of the significant advances in microstrip antenna theory and design that have sprung from the pages of the Symposia proceedings since. We conclude with a discussion of the future of microstrip antennas and related structures.

1. Introduction

October 1953: The Armistice agreement formally ending the Korean War has been signed in July, with the DMZ established and manned with U.S. Marines in September. The Brooklyn Dodgers and the New York Yankees have played the World Series, with the Yankees taking it in six games. And, of course, the Symposium at Robert Allerton Park is taking place.

Certainly the impact of each of these events can never be directly measured or compared. However, one can certainly argue that the paper written by Deschamps and Sichak [1] fostered the beginnings of a new discipline within the antenna community that has had significant and long-lasting effects on countless aspects of communication, exploration, and defense. We commemorate the fiftieth anniversary of this work by reflecting upon the emergence of the microstrip microwave antenna and subsequent papers of import that have been presented at Robert Allerton House over the years. The paper [1] is reprinted here as an appendix for further reference and enjoyment. This work concludes with a brief discussion of the future direction of microstrip antennas and related structures.

2. "Microstrip Microwave Antennas": A Review

Engineers familiar with references to the subject paper [1] may wonder how the name W. Sichak has now become attached to it. In the 1953 Symposium proceedings program, the paper is indeed listed as being by a sole author – Georges Deschamps – and has been referenced as such in a number of highly cited publications [e.g., 2, 3]. However, the annotated copy of the proceedings housed in the Electromagnetics Laboratory at the University of Illinois lists W. Sichak as a co-author on the paper. William Sichak, later named an IRE Fellow, worked at Federal Telecommunication Laboratories with Georges Deschamps and no doubt contributed to the paper, but evidently not in time to have his name on the program or paper officially. Here we correct this oversight, as Deschamps must have done during his presentation.

In [1], the authors detail the development of a high resolution X-band antenna with a shaped vertical pattern and a horizontal beamwidth of less than one degree. Having decided upon a long linear array with a cylindrical reflector to achieve the operational goals, the authors weighed the benefits of using a sectoral lens, a slot array, or an array composed of waveguide-fed horns as a feed mechanism. Given the bulk of such a waveguide system with 300 radiating elements, the authors developed a microstrip feeding system. This is the "microstrip" to which the title refers. Indeed, when one reads the paper, one is struck by the fact that there is, in fact, no microstrip antenna included as we would recognize it today.

What does follow in the rest of the paper is a description of the complete system with measured results. The paper describes the critical issues for each system component – the waveguide-to-microstrip (or stripline) transition, the bends and junctions in the power dividers, and finally, the radiating elements. The radiating elements are either horns created by three-dimensional extensions of the microstrip or lenses.

The microstrip patch we recognize today did not become widely known for another 17 years, through the work of Byron [4], Munson [5, 6], and Howell [7, 8]. However, what the Deschamps and Sichak paper did do was to foster new ways of thinking about complete antenna structures and the subsequent performance benefits and reductions in size, weight, and cost that could be realized through the use of microstrip or stripline transmission lines. The following sections detail some of the important papers presented through the history of this Symposium that owe, at least in part, their origins to the work of Deschamps and Sichak.

3. "Microstrip Phased Array Antennas" – Munson, 1972

In a paper presented at the Twenty-Second Annual Symposium of the USAF Research and Development Program in 1972, Bob Munson described the first embodiment of the microstrip antenna that quickly captured the attention of the antenna community and grew in popularity and usefulness [5]. The microstrip radiators that Munson used were either metallic strips wrapped around missiles for telemetry systems or flat elements. These antennas differed from a standard "patch" design in that they were several wavelengths long and up to a half wavelength wide with multiple feed points located along the length. Rules of thumb for their design are included along with measured results for a flat version of a wrap-around antenna. Bandwidth was always an issue: Munson states "Several methods are currently being explored...to increase the bandwidth of microstrip antennas [5]." In the same paper, he also mentioned work on arrays of individual microstrip (patch) elements that would use pin diodes for phase shifting. This phased array concept proposed by Munson in the Symposium and later reiterated in a more extensive 1974 *IEEE Transactions on Antennas and Propagation* article [6] is still the baseline configuration for phased arrays today.

Munson's publication in the Symposium Proceedings predates by a few months that of the classical paper by J. Q. Howell at the 1972 International Symposium of the Antennas and Propagation Group of the IEEE in December of 1972 [7]. The latter conference paper and its associated journal article published in 1975 [8] are frequently referenced as the original work on microstrip patches. However, Howell credits Munson with the idea in the reference section of his paper, but only as a private communication. In 1981, Munson returned to Allerton to describe "Advances in Microstrip Antenna Technology." Unfortunately, no printed version of his paper was preserved in the Proceedings.

4. Contributions of John Kerr, 1977-1978

For many years, John Kerr, US Army Electronics Command, Ft Monmouth, NJ, participated in the antenna symposia at Allerton Park. In the 1970's, microstrip antenna technology was advancing at a rapid pace through a combination of simple models (e.g., the cavity model [9]) and empirical development by engineers whose talents were honed before computer simulations contributed significantly to antenna innovation. At the 1977 and 1978 Symposia, John Kerr presented three papers [10]-[12] that employed and elucidated key properties of microstrip antennas that subsequently have been exploited in a variety of ways. In this section, we recap Kerr's papers and then trace their influence on further developments.

4.1 Summary of Kerr's Papers, 1977-1978

Kerr's 1977 paper [10] introduced the concept of controlling the resonant frequency of a rectangular microstrip patch antenna by removing a portion of the metal in the center of the patch. According to the paper, this discovery came as result of the need to add an inexpensive L-band feed to an existing 4-foot reflector operating at X-band with a shepherd's hook feed. A simple microstrip patch antenna would provide adequate illumination of the reflector, but the X-band shepherd's hook feed could not radiate through the somewhat larger L-band patch and its ground plane. Kerr's solution was to remove the central portion of the patch, the dielectric and the ground plane clearing a pathway for the X-band feed to radiate through the patch while locating both at the reflector's focus, Fig. 1. The dual-frequency reflector problem was solved, and the robustness of microstrip patch antennas to (severe) configuration changes was demonstrated. Kerr noted that removing the one-inch-square region lowered the resonant frequency of the patch from 1370 MHz to 1250 MHz, making the patch electrically smaller at its operating frequency. Three years later, Mink presented a theory that explained Kerr's observations and extended the notion to include ring antennas [13].

Kerr's first paper at the 1978 symposium [11] was a short note that suggested a simple means to add reactance to the usual resonance of a patch antenna and thereby to tune its operating frequency. This result is similar to the well-known techniques for tuning microwave cavities with a lumped reactance, but Kerr employed a length of printed microstrip line, which was easily implemented when the antenna was fabricated, Fig. 2. He showed that a good impedance match is obtained with short-circuit or open-circuit terminations located various distances from the patch, Fig. 3. Kerr noted that the antenna's radiation pattern might limit its useful bandwidth even if its impedance remains acceptable.

His second paper at the 1978 symposium [12] relies on the phenomenon reported in his 1977 paper, but Kerr cleverly employed the change of resonant frequency caused by removal of metalization to create the conditions necessary for circular polarization from a patch with only a single feed port. Kerr observed that creating a narrow slot in the metalization of the patch had little effect on the antenna's performance if the long axis of the slot was parallel to the dominant currents flowing on the patch, but it significantly lowers the resonant frequency if the slot axis is perpendicular to the current flow. This led to a new variation of the slightly off-square patch to produce circular polarization, Fig 4. Unlike the 1977 paper, Kerr removed metal only from the patch, leaving the ground plane and dielectric intact. He created another version of the antenna that utilizes a perfectly square (or circular) patch and a polarizing slot placed diagonally to the dominant current flow, Fig. 5. The spin linear radiation pattern in Fig. 6 shows that the conditions for circular polarization are fulfilled very well. Two other variations of his circularly polarized antenna are shown in Fig. 7.

4.2. Post-Tuned Patch Antennas for Frequency Agility and Polarization Diversity

Jones et al. presented a paper at the 1977 symposium [14] that described the use of vias in a radial transmission line to tune the operating frequency of an edge-slot antenna mounted on a cylindrical body. After hearing presentations by Kerr about the tuning phenomenon, they recognized that microwave varactors or switching diodes could be used with the via-post technique employed in their edge-slot antennas to produce tunable patch antennas, Fig. 8. As is well known, shorting posts along the centerline of a microstrip patch have no effect on the dominant mode of the patch antenna because the voltage is zero there. However, shorting posts located elsewhere can add inductive reactance that raises the operating frequency of the antenna.

John Kerr's discovery again provided inspiration, and the antenna was modified by removal of metalization, thus lowering the basic operating frequency. Tuning posts can then be employed to adjust the operating frequency to any desired value within a 1.4:1 frequency range that is approximately centered at the operating frequency of the standard patch antenna, Fig. 9. The example in Fig. 9 maintains good impedance match and stable radiation patterns over the tuning range indicated. Unfortunately, the inductive loading causes the antenna to be electrically larger than the untuned version.

By selectively locating posts that affect one polarization of a square patch while being located at voltage nulls of the orthogonal polarization, the effects of Kerr's polarizing slot can be replicated. Overall, although the post-tuned antenna is slightly larger than Kerr's slot-tuned antenna operating at the same frequency, it can produce similar effects, including polarization diversity, Fig. 10. Furthermore, it is easier to implement switching vias than to change the metalization pattern of the patch. Thus, the work of Kerr and of Jones et al., stimulated development of an alternative configuration that incorporates the benefits of both.

4.3 Multimode Patch Antennas with Slots and Posts

Considering the cavity model for the microstrip patch antenna [9], it is apparent that the antenna can support different resonant modes at different frequencies. Square and circular patches typically support two orthogonally polarized modes at the frequency of the dominant resonance, but rectangular patches typically support only a single mode with a particular polarization at any specified frequency. By properly selecting the dimensions, post locations and feed point, the post-tuned antenna can support two copolarized modes simultaneously. The combination of these two modes creates an asymmetric beam that may be useful to enhance the gain in a preferred direction, Fig. 11. A feed on the opposite side of the antenna will produce a beam tilted in the opposite direction, and the difference of these two beams could provide a tracking signal as in sequential lobing or monopulse systems. Changing the post configuration allows the same patch also to operate in linear polarization at one or more frequencies.

4.4 Piggyback Patch Antennas

The use of a parasitic patch antenna stacked above a driven antenna is a common means to increase the bandwidth of microstrip antennas. An alternative stacked configuration, sometimes referred to as a piggyback antenna, has been demonstrated [17]. The piggyback antenna is two essentially independent antennas sharing a common aperture. The upper patch covers part of the central region of the larger lower patch, Fig. 12. As observed by Kerr [10], an object attached to the central region of the patch has little impact on its basic operation. Thus, the metalization of the upper patch has little impact on the lower patch. The feed for the upper patch, on the other hand, is connected to the ground plane and to the lower patch forming a tuning post within the lower antenna, which raises the operating frequency as described above. Any combination of half-wavelength and quarter-wavelength antennas can be stacked in the piggyback configuration, and the antennas may be polarized in the same or different directions. Furthermore, additional tuning posts may be included in the antennas or metal may be removed from the patches to alter their characteristics. Kerr's 1977 paper [10] includes a dual-frequency X- and L-band antenna that is coplanar. He removed a portion of the metal from the central region of the L-band patch and then used this vacant region for the X-band patch.

5. "Theory and Experiment on Microstrip Antennas" – Lo et al., 1978

This paper [9] was presented at the Antenna Applications Symposium in 1978, six years after the original Allerton paper by Munson [5] that described microstrip antennas on missiles and flat surfaces. In the intervening years Munson and most other authors had few design guidelines and inadequate theoretical tools to predict element and array performance, so they used transmission line theory for computing patch element size and either a two slot model or a patch current model to estimate radiation patterns. However, it was becoming apparent that much more sophisticated modeling would soon be necessary in order to take advantage of the great versatility of this new antenna. This became even more clear during the 1978 symposium when Kerr [11, 12] presented two papers wherein small changes to basic microstrip patch antennas are incorporated to provide a variable resonant frequency by terminating the patch in an impedance loaded line [11], or by making asymmetric cuts in the patch to produce circular polarization [12]. Although Howell [8] mentioned the similarity between a microstrip patch and a cavity bounded on top and bottom by electric walls and on the sides by magnetic walls, it remained for Y. T. Lo and his student collaborators to develop a theory based upon this idea.

The paper by Lo et al. [9] introduced the cavity method that became the first theoretical solution to include the electromagnetics of the microstrip antenna. The cavity model assumed the patch antenna to have magnetic walls along the edges, and electric walls above and below. The internal fields could then be determined by cavity theory, including probe or other sources. Radiating fields are evaluated via integrals over the current carrying surfaces and aperture fields. This paper and the journal articles that followed it, developed a theoretical basis that was used to explain not only the behavior of the basic patch elements, but also the loading effects of various probes and stubs for frequency tuning and the shape changes that resulted in circularly polarized radiation. Much of this later work is summarized in a book chapter by William Richards [19]. Prof. Lo and his colleagues extended their cavity model theory for microstrip patch antennas to annular sector and circular sector shapes in the 1981 Proceedings [20]. The cavity model is still one of the most widely used theoretical models of the microstrip antenna in existence, as evidenced by its use in major popular texts [2] and reference books [3].

An interesting sidelight to this paper is that although the cavity model was used successfully for many years, the seeds of change were already planted at the same 1978 meeting. James P. (Pat) Montgomery [21] outlined a "full wave" method for an infinite two-dimensional array of microstrip patches. Full wave methods have since shown the ability to handle thicker dielectrics and shape variations as well as to provide more accurate analysis of mutual coupling, but none of this was to be available until many years after Lo's introduction of the cavity model.

6. Microstrip Antenna Impedance Bandwidth Improvements

One limiting factor in the performance of microstrip patch antennas is the narrow impedance bandwidth. As evidenced even in Munson's first paper [5], this has always been an issue. In a 1983 Symposium paper [22], Dean Paschen showed how filter theory could be used to expand the impedance bandwidth of microstrip antennas up to 35%. Lo and his group attacked the problem of extending the bandwidth of circularly polarized radiation from a patch antenna at the 1984 Symposium [23]. They applied the cavity model theory [9] to a patch with thick substrate and achieved good results in spite of the fact that the theory is only justifiable for antennas on very thin substrates. Bandwidth enhancement through double-tuned patch elements was demonstrated in a 1986 paper by Tanner and Mayes [24]. At the same Symposium, Paschen presented several examples of broadband patch antennas where the matching elements were included in the antenna structure [25]. Gonzalo et al. [26] presented use of photonic crystal structures in microstrip antenna substrates in 1999, showing increased bandwidth as well as a decrease in surface-wave related pattern effects.

7. Microstrip Antenna Feeds

A packaging problem for arrays of large numbers of patch elements was solved by Schaubert and Pozar in two papers given in 1985 [27] and 1986 [28] that employed aperture coupling between the patch elements and the feed network. More recently in 1994, Herscovici et al. [29] developed a new feed network for microstrip that ameliorates parallel-plate modes excited in stripline feed configurations for microstrip antennas. This method solves the problem by using two different dielectric substrates on either side of the stripline center strip in the vicinity of the feed. This material mismatch retards the formation of a strong parallel-plate mode in the stripline, leading to a more efficient coupling of energy to the antenna.

8. Future Directions

As the years of the Symposia Proceedings attest, the number of approaches to implementing microstrip antennas and related structures for a variety of interesting and useful applications continues to grow. Certainly, new feed methods, new kinds of slotted and loaded designs, and new kinds of substrates are expanding the capabilities of single elements as well as arrays. Ironically, another way that the microstrip antenna is being re-invented is in the third dimension – in ways much like that first described by Deschamps and Sichak in 1953. Recent Symposia papers [e.g., 30, 31] detail developments that lift the radiating element off of the plane using now-practical microelectromechanical fabrication methods, providing dramatic improvements in impedance bandwidth.

9. Conclusions

The Antenna Symposia at Allerton Park have provided a rich and varied resource on cutting-edge antenna techniques and technologies. Deschamps' and Sichak's paper is but one example of many that have provided attendees with "something to chew on." We look forward to many more years of this unique and valuable scientific event.

10. Acknowledgments

Thanks to the Fall 2002 graduate class of ECE 477, Advanced Antenna Theory, at the University of Illinois who inspired this paper. JTB.

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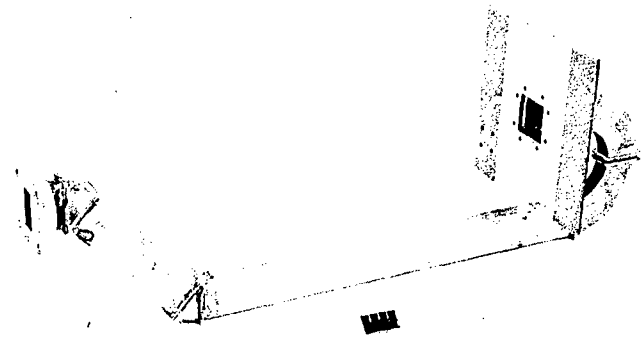


Figure 1. Kerr's L-band patch antenna with hole for X-band feed horn. From [10].

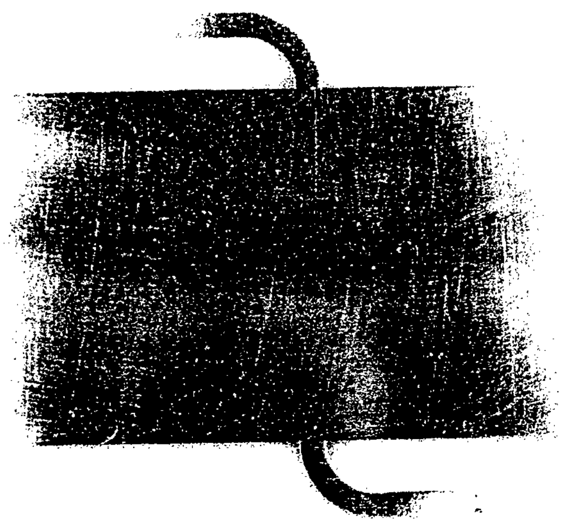


Figure 2. Terminated microstrip antenna demonstrating frequency tuning by reactive loading of the patch. From [11].

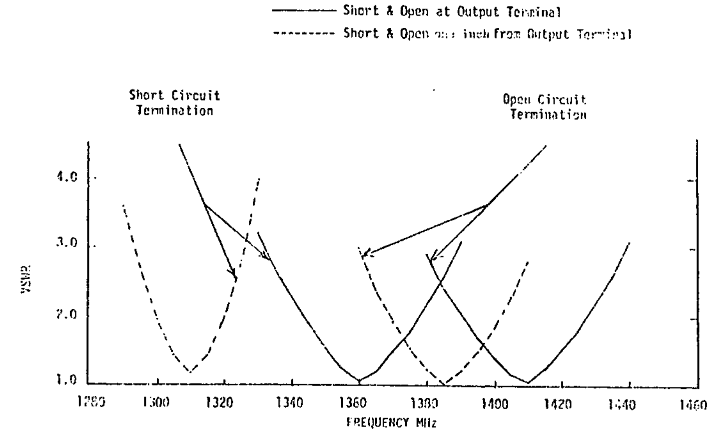


Figure 3. Kerr's results for frequency tuning by open-circuit and short-circuit loads at two locations. From [11].

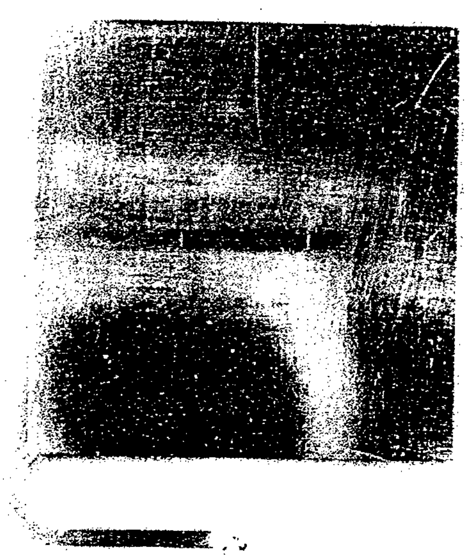


Figure 4. Corner-fed square patch antenna with horizontal slot to lower vertically polarized resonance slightly, resulting in circularly polarized antenna. From Kerr [12].

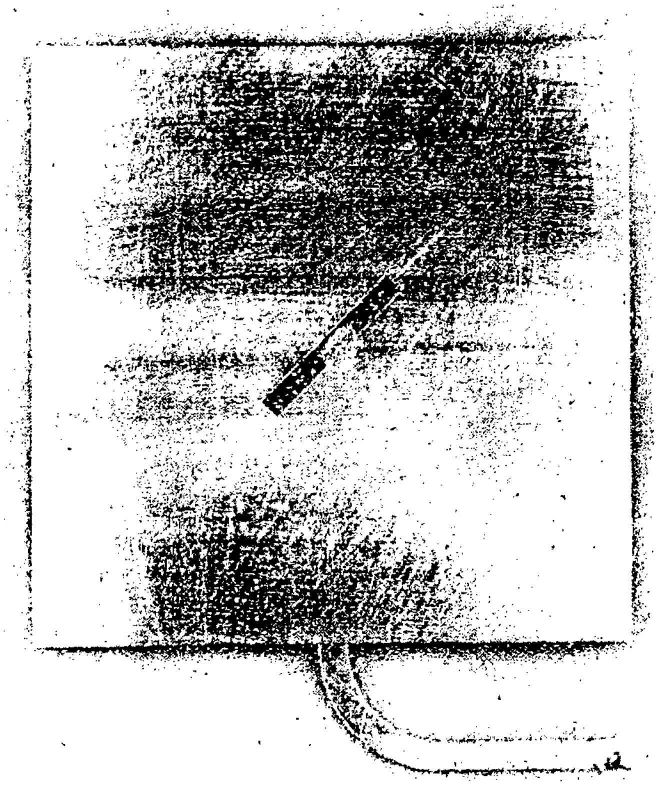


Figure 5. Edge-fed square patch with diagonal slot to create circularly polarized antenna. From [12].

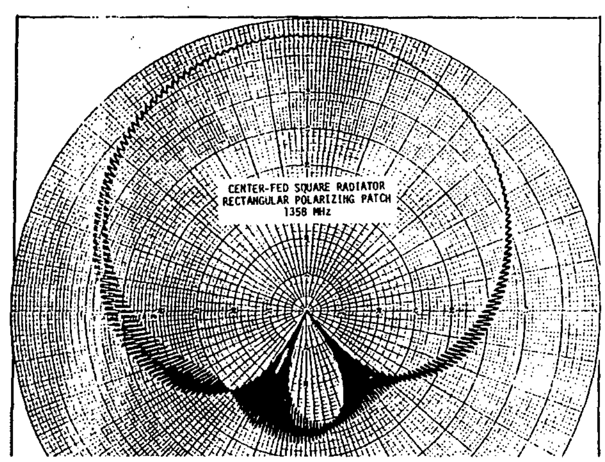
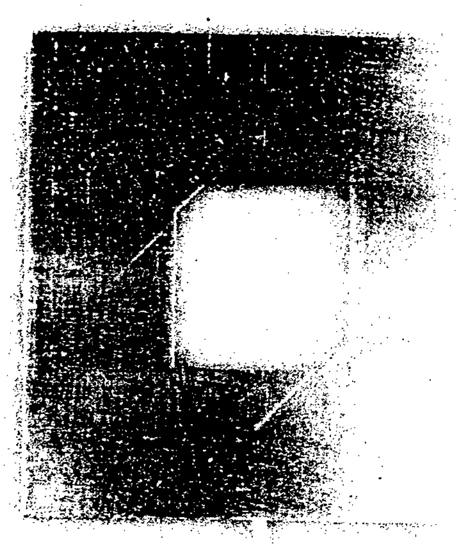


Figure 6. Radiation pattern of antenna in Figure 5. The large back radiation and low axial ratio in horizontal plane suggest that the ground plane was rather small. From [12].



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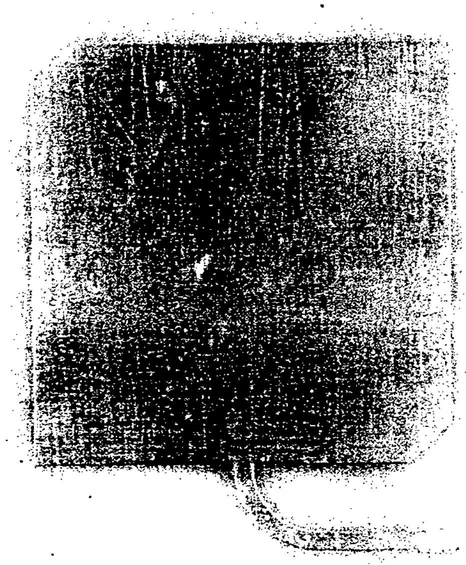
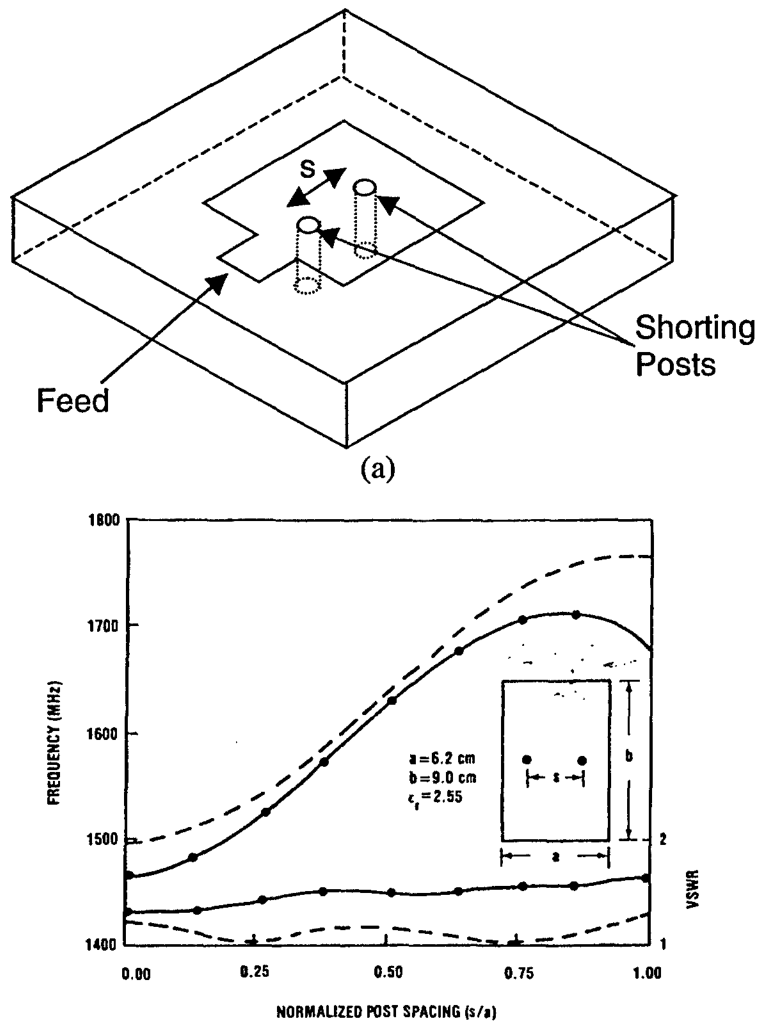


(b)

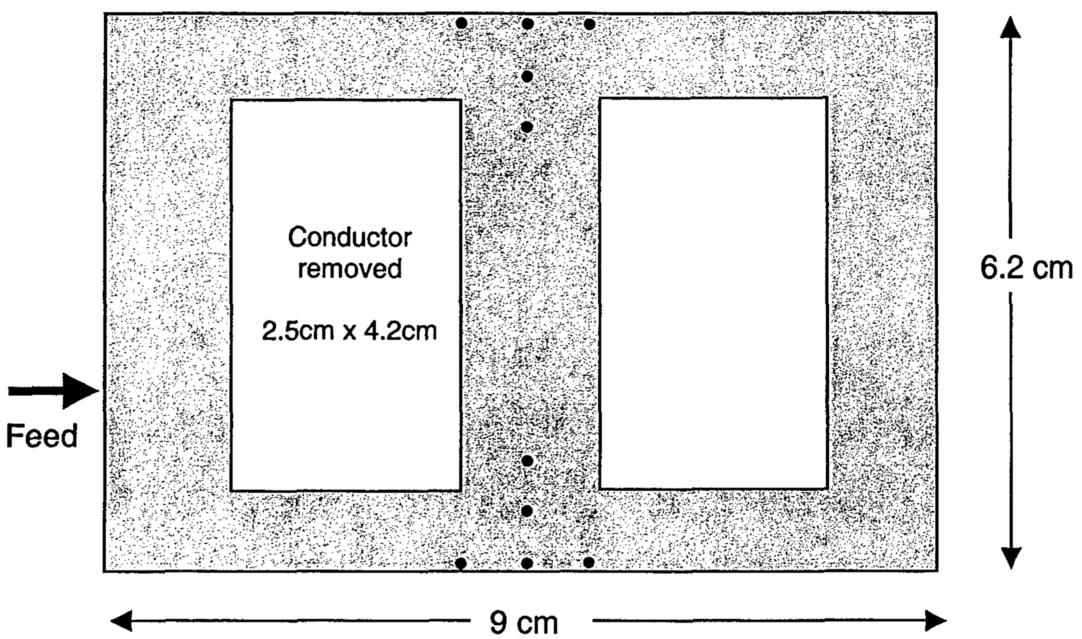
Figure 7. Two patches produce circular polarization. (a) Square patch with square central hole that has opposite corners clipped. (b) Square patch with opposite corners clipped. From [12].



(a)

(b)

Figure 8. Post-tuned microstrip patch antenna inspired by work in [10], [11] and [14]. (a) Antenna with pair of posts separated by distance *s*. (b) Frequency tuning and VSWR of post-tuned antenna, from [15].



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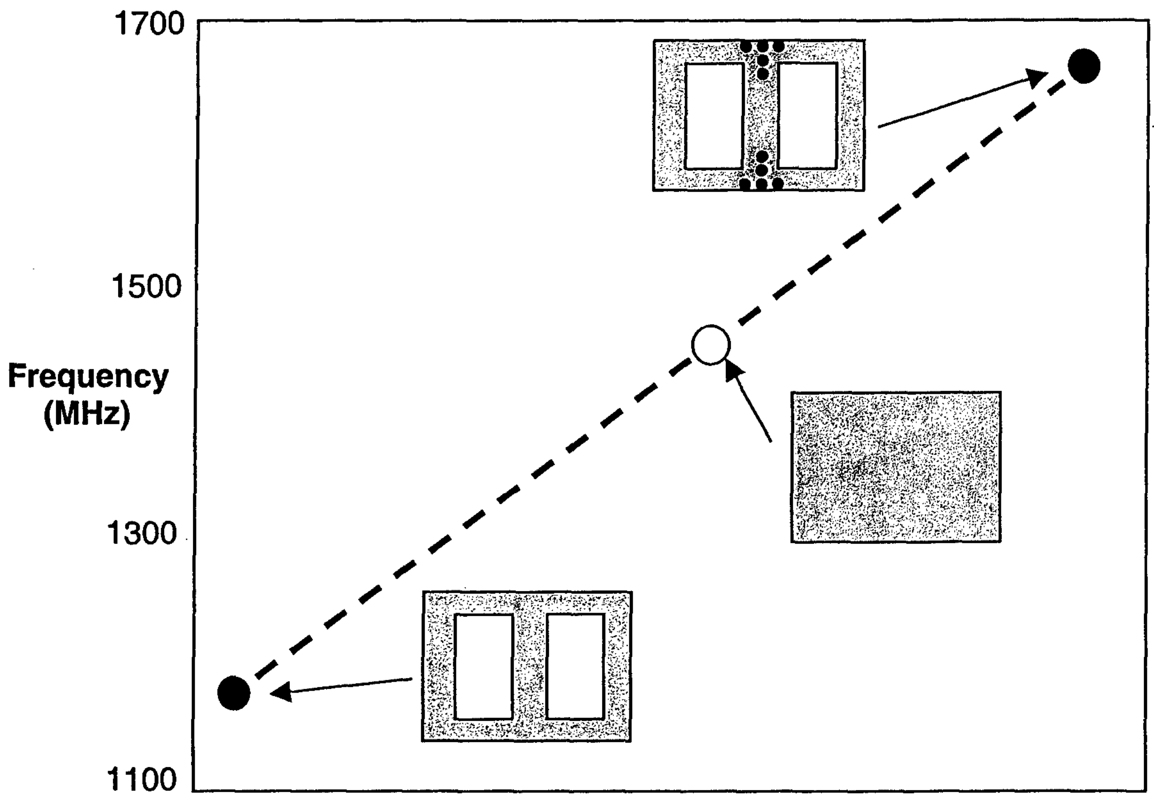

(b)

Fgiure 9. (a) Patch antenna with metalization removed to lower basic operating frequency and posts added to then raise it. (b) Typical tuning range of patch antenna. Standard patch antenna of same size operates at 1465 MHz. After [16].

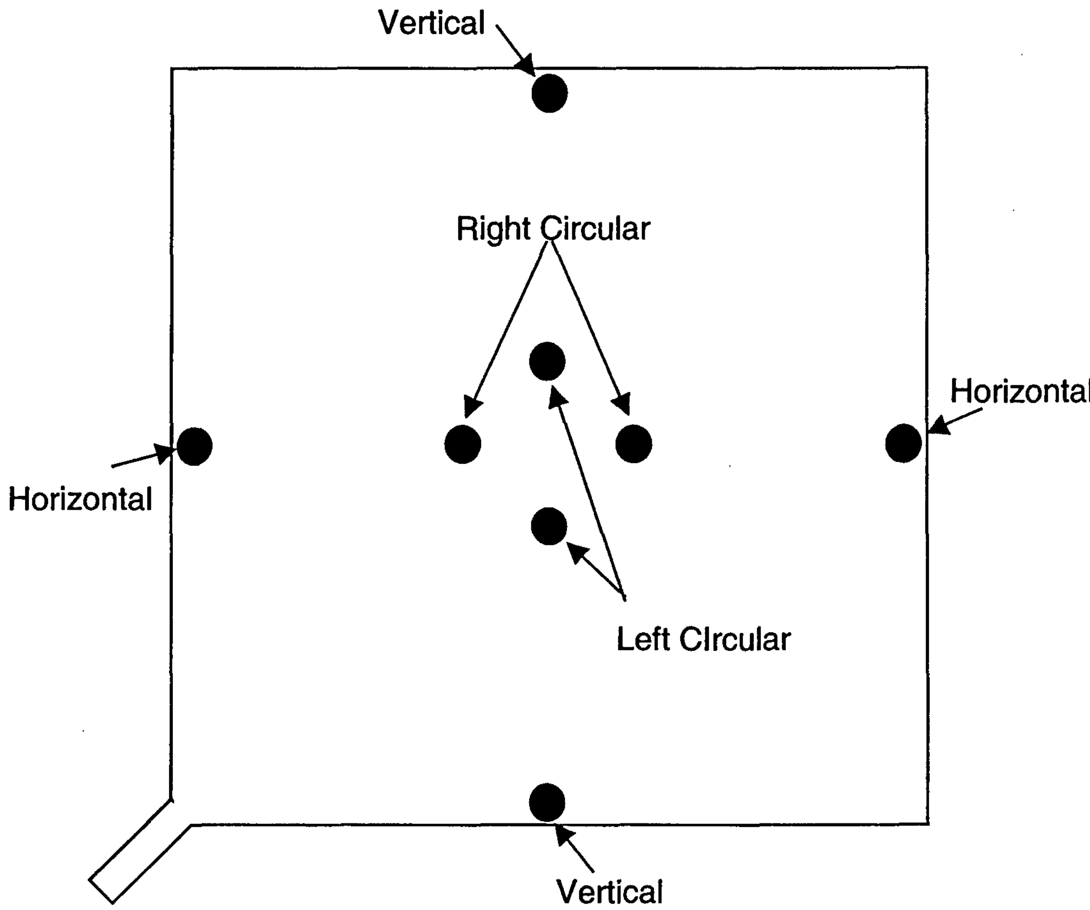

Figure 10. Switchable shorting posts provide polarization diversity of a corner-fed patch antenna. After [15].

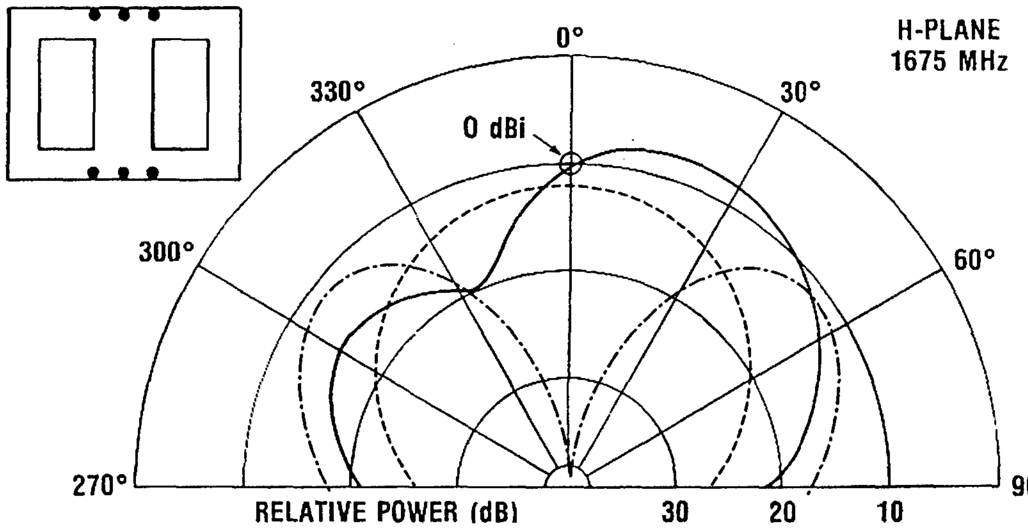

Figure 11. Combining holes in metalization and posts can force two modes of the patch to share a common resonant frequency. The patterns of the individual modes are indicated by the dashed lines sketched onto the plot. The solid curve is the measured radiation pattern of the 6.2-cm x 9-cm antenna at 1675 MHz. From [16].

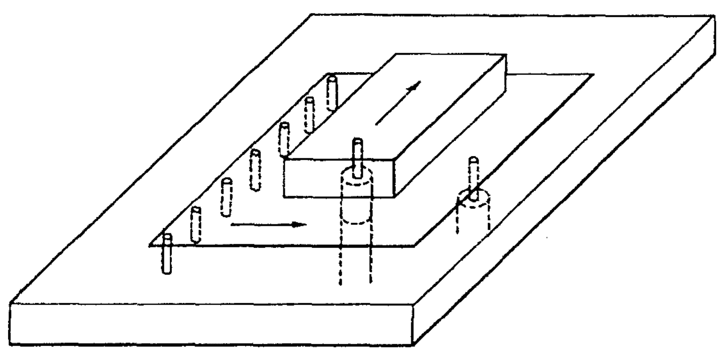

Figure 12. Example of piggyback antennas. The lower antenna is a quarter-wavelength horizontally polarized element and the upper element is a half-wavelength vertically polarized element. From [18].

APPENDIX

G. Deschamps and W. Sichak, "Microstrip Microwave Antennas," *Proceedings of the Third Symposium on the USAF Antenna Research and Development Program*, October 18-22, 1953.

UNCLASSIFIED

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ADB 283180

THE THIRD SYMPOSIUM
ON
THE USAF ANTENNA RESEARCH
AND
DEVELOPMENT PROGRAM

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20 Jan 1965 from E. M. Turner

Doris M. Richards

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8 Mar 04

ROBERT ALLERTON PARK
(University of Illinois)
Monticello, Illinois
18, 19, 20, 21, 22, October 1953

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ESC 04-0289

[redacted]

MICROSTRIP MICROWAVE ANTENNA

By Georges Deschamps and W. Sichak
Federal Telecommunication Laboratories

Contract AF33(038)-13289

INTRODUCTION

The problem was to obtain a high resolution, X-band antenna with shaped vertical-pattern and a horizontal beamwidth of less than one degree. The usual solution of using a long linear array feeding a cylindrical reflector was adopted and it remained to design the linear array, which in the present case was to be 300 wavelength long.

Methods for obtaining such an array are: 1) The pillbox or sectoral lens, 2) The end fed slot array, 3) The linear array where all elements are fed through equal lengths of waveguide. With the second solution the pattern varies with frequency and the design is complicated by mutual effects between slots. The first and third solutions avoid this difficulty and are essentially similar; in (1) the power distribution is done continuously by spreading of the wave and bending by refraction or reflection, in (2) it occurs at the junctions along the feed system.

The third solution with standard waveguides makes a rather bulky system. In the present case since about 300 radiating element spaced one wavelength apart had to be fed, 255 or 511 two-way power dividers would be needed. The recent development at FTL of the microstrip removed this objection and it was decided to investigate a solution based on this transmission medium.

[redacted]

The microstrip is a variant of "wire above ground" transmission line, adapted to microwaves. The conductor can be a strip printed on a dielectric sheet backed by a conducting plane (Fig. 1). In spite of the composite nature of its crossection this waveguide acts substantially as if it was supporting a TEM mode. For instance the dispersion is negligible and it is possible to define a characteristic impedance 1/Cv (C = capacity per unit length, v = phase velocity). This impedance is a function of the strip width and distance to the ground plane and accounts well for the properties of the junction between two strips of different characteristics.

The advantages of a feed system using microstrips rather than conventional waveguides would be:

1. Less volume and much less weight

2. Less fabrication cost - possibility of exact photographic reproduction of even critical adjustments

3. Possibility of shaping or stacking

The same advantages would obtain with the dielectric covered microstrip and with the sandwich line[1] (Fig. 1).

In a first model of microstrip feed the line was made of copper foil fastened to polystyrene sheets with polyethylene scotch tape. The antenna worked substantially as expected but had a rather poor pattern. This was attributed to radiation from the junctions and it was decided to make a more systematic study of the elements of the systems:

---

1. R. M. Barrett, "Etched Sheets Serve as Microwave Components," <u>ELECTRONICS</u>, June, 1952.

the line itself, bends, power dividing junctions, transducer from waveguide to microstrip and radiating elements. It was also decided to make a comparison with similar systems constructed with the sandwich line.

Microstrip

The strip width and dielectric thickness were varied and the wavelength and attenuation constant measured. A relatively low-loss dielectric was found: a Teflon Fiberglass laminate backed by copper.

A compromise choice of dimensions: width 1/8", thickness 1/8", was used in the finished antenna. Losses in this case were about 0.6 db per foot.

Waveguide to Microstrip Transducer

The initial transition must be made between a standard rectangular waveguide and the microstrip. This was achieved by a tapered ridge connecting the upper side of the waveguide to the strip while the lower side is soldered to the ground plane (Fig. 2). Insertion loss of less than 1/4 db was obtained without difficulty.

Bends

Circular bends of various curvature and mitered bends of various cuts were tried. Circular bends of appropriate radii appear to give less radiation loss (1/2 db) and negligible mismatch. The minimum acceptable radius is a function of strip width.

Short Circuit and Matched Load

For measurement purposes a good reflecting load and an absorbing load are useful. The reflecting load can take the form of a resonant obstacle, ring or V, placed above the strip (Figure 3). Reflection coefficients of 0.9 were obtained. A matched load producing a standing wave ratio of 1.02 and a loss of more than 30 decibels can be made of a tapered resistive card (400 ohms per square) placed also on top of the strip (Figure 4).

The measurements were made by moving the reflective obstacle in back of the element to be evaluated (junction or line) according to methods which were developed in an early part of this contract.

Power Dividing Junctions

This is the main component of the system. The first configuration (Figure 5a) based on the idea of matching characteristic impedance, showed too much radiation because of abrupt changes (which would not matter in closed waveguides). The most satisfactory solution used a smooth splitting of the upper strip into circular bends of sufficient radius. The tangents at A - A (Figure 5b) must be carefully matched.

Data were taken on symmetrical two-way and three-way power dividers and on two-way assymmetrical power dividers. With the sandwich line the power split was studied as a function of the width of the two conductors, in order to make an array with non uniform distribution.

Radiating Elements

The microstrip can be transformed smoothly into a horn or a parallel plate region by widening progressively the strip (Figure 6).

For the sandwich line the same thing can be done after stopping abruptly the upper plate (Figure 7a). Alternatively the two plates can merge into the floor and ceiling of the horn while a 180-degree phase difference is introduced between the fields above and below the central strip by stopping the dielectric (Figure 7b). This latter transition gave a better E-plane pattern.

Dipole arrangements could also be used (Figure 8). In one of the experimental arrays the radiating elements were small lenses (aperture 8λ).

Arrays and Patterns

A number of experimental arrays have been constructed having relatively small apertures (32 elements). These could be used as building blocks for the larger array. The lines feeding these blocks being relatively long it could be advantageous to use there ordinary waveguides.

The first array was a 32 element microstrip antenna designed with two-way power splitters for uniform illumination. Figure 8 shows the layout before etching of the feed system and Figure 9 a perspective view. The H plane pattern is shown on Figure 10 and the average input impedance of the feed when reflection at the radiating element has been taken out (Figure 11) is shown on Figure 12.

In a second array (Figure 13) four lenses are fed with microstrip. The pattern (Figure 14) is cleaner but scanning would not be possible. The average input impedance is shown on Figure 15.

The third array, Figure 16, was fed with a sandwich line system. Radiation at the junctions ceases to be a problem and the bends can be more sharply curved making the overall system less deep. The strip conductor, however, must be the same distance from the two plates and this seems critical. More care has to be exercised in making the line. The transition to the horn, figure 7b was found to be more satisfactory than 7a.

A fourth array with sandwich line feed was built with a cosine tapered amplitude distribution (end element 12 db below central elements). Junctions with unequal power division as shown in Figure 5c were used.

The patterns in the H and E planes are shown respectively in Figures 17 and 18.

More details can be found in FTL Final Engineering Report, Research on Bombing-Radar Antenna Problems, Contract AF33(038)-13289.

Conclusions:

A choice between microstrip (easier to fabricate) and sandwich line (less radiation) cannot be made yet. More data are still needed on the components, specially the power dividing junctions and the transducers to the radiating elements. It would also be important to find a still better dielectric since the losses in the feed system are a definite limitation to the size of the array (Figure 19).

In spite of this and of the fact that a complete array has not been demonstrated, printed waveguides of the microstrip or sandwich type have obvious advantages over ordinary waveguide and show promising possibilities for the problem considered.

[redacted] UNCLASSIFIED
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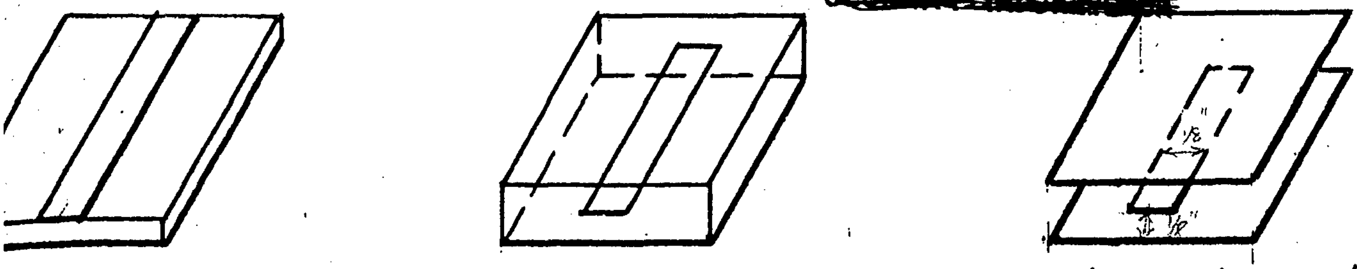
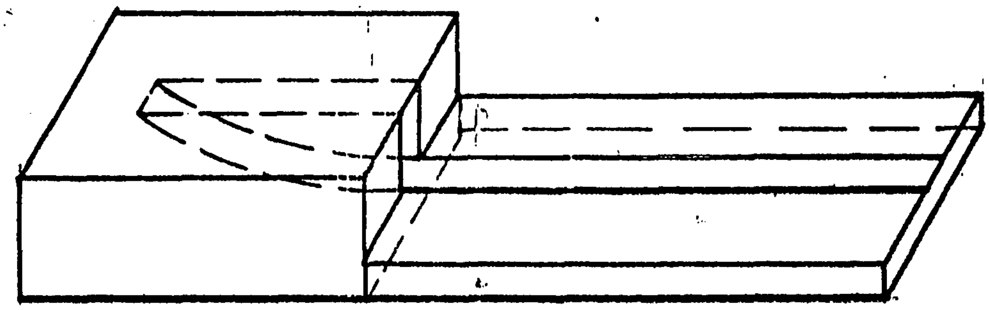
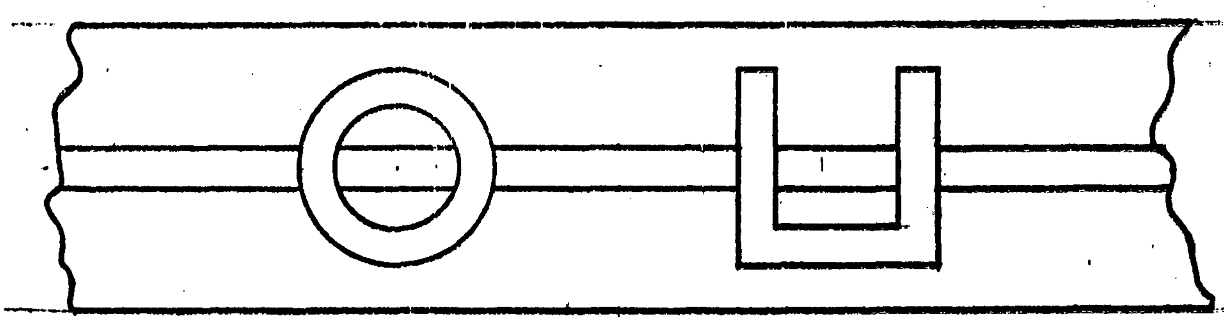


ICROSTRIP DIELECTRIC COVERED MICROSTRIP SANDWICH LINE

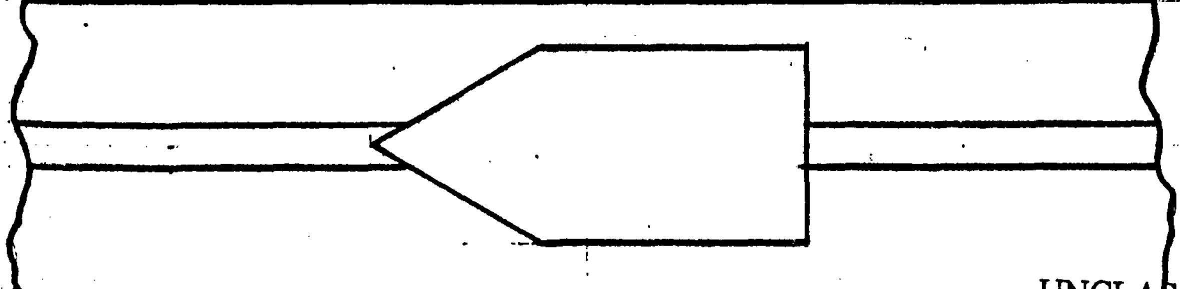
FIG. 1



WAVEGUIDE TO MICROSTRIP TRANSDUCER
FIG. 2



REFLECTIVE OBSTACLES
FIG. 3



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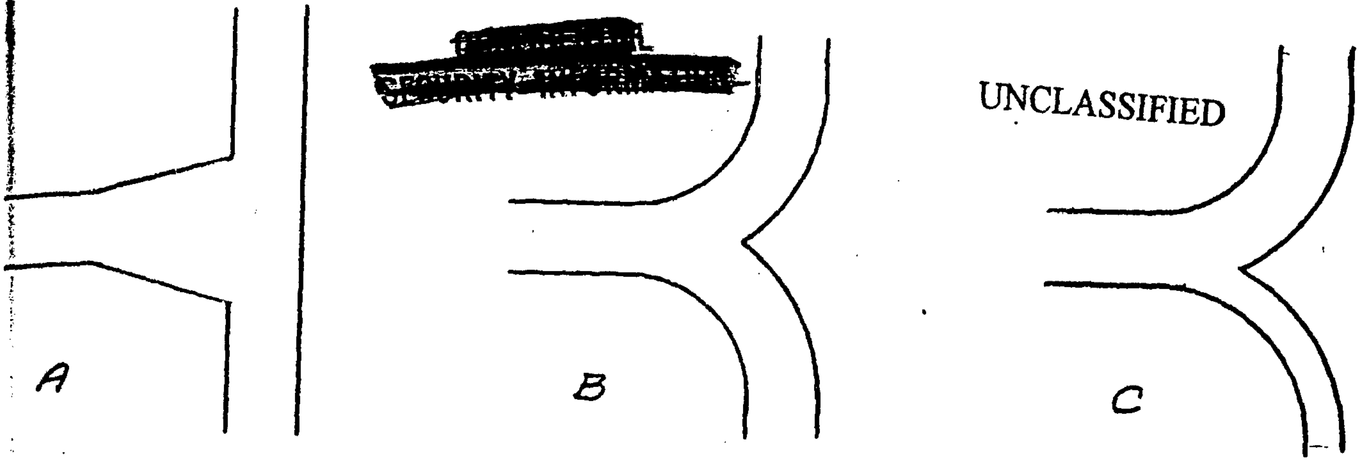
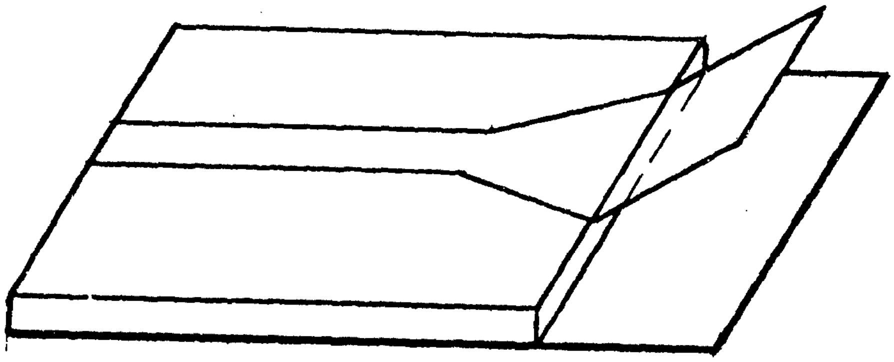
MATCHED LOAD [redacted]
FIG. 4

[redacted]

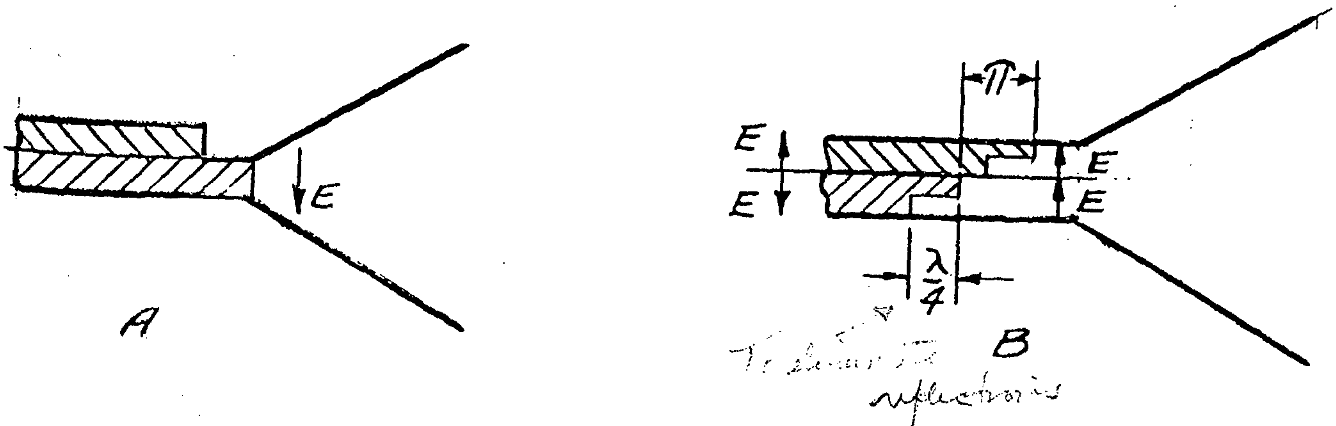
UNCLASSIFIED



POWER DIVIDING JUNCTIONS
FIG. 5



MICROSTRIP TO HORN TRANSITION
FIG. 6



SANDWICH-LINE TO HORN TRANSITIONS
FIG. 7

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[redacted]

RX-412326-1

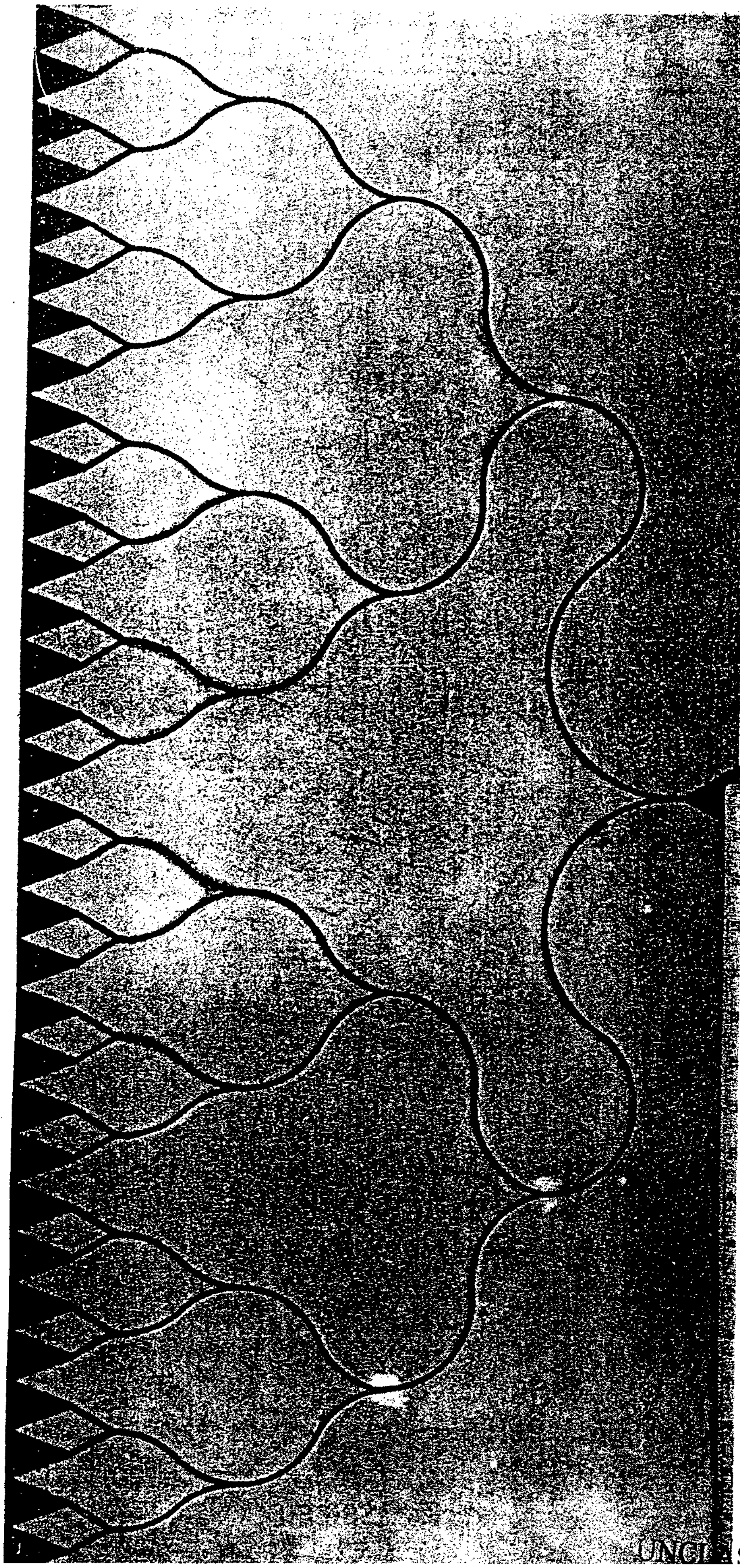

FIGURE 8

[redacted]

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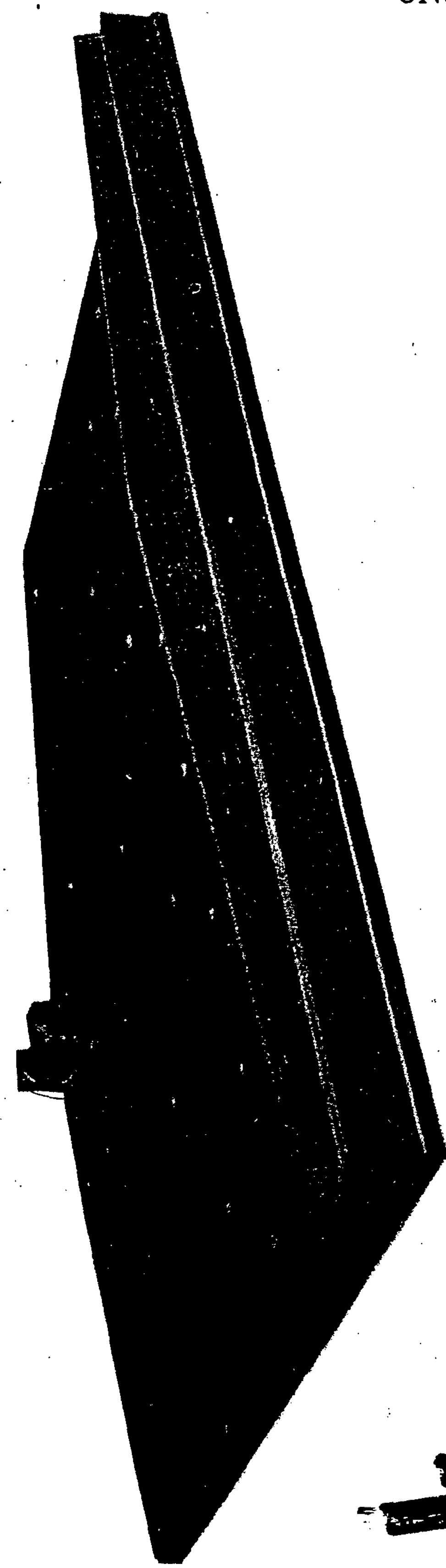

FIGURE 9

UNCLASSIFIED

[redacted]

UNCLASSIFIED [redacted]

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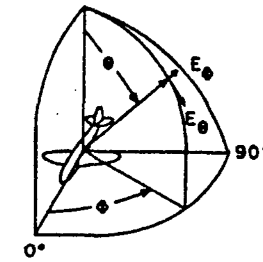
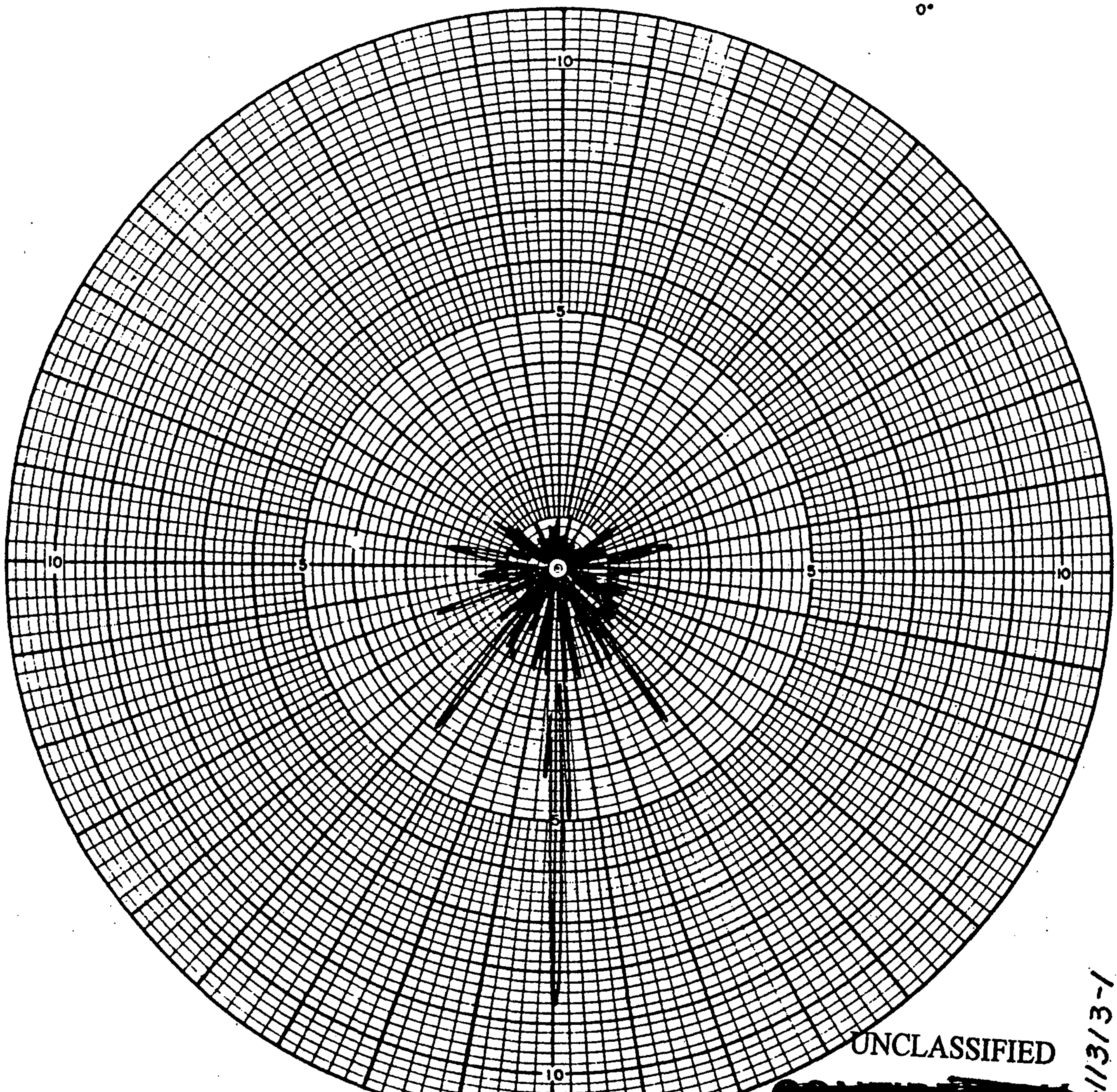




UNCLASSIFIED [redacted]

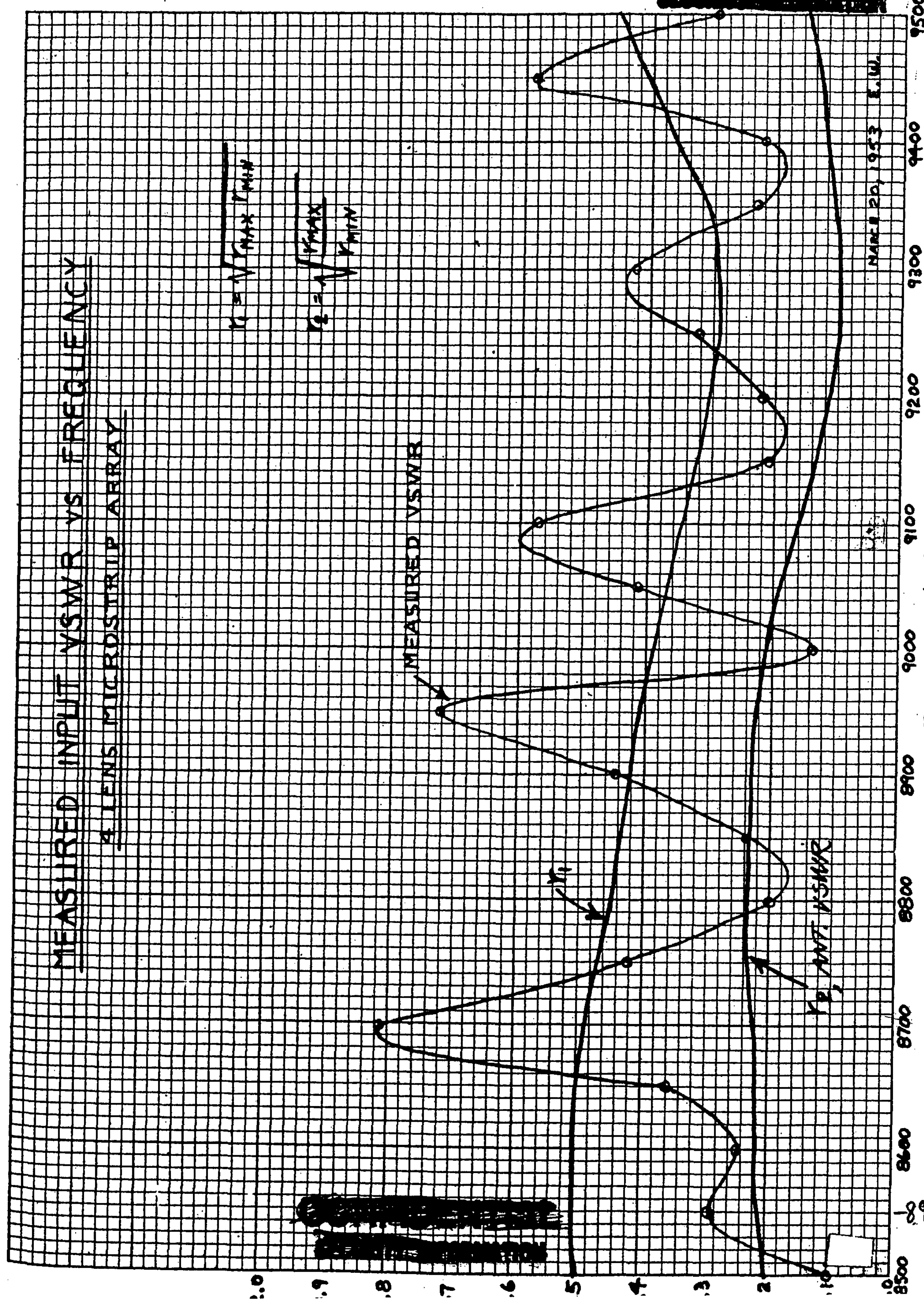
RX-411313-1

DATE: 1-13-53
OBSERVERS: 1 DJL
2 WE, RM
PLANE TYPE:
SCALE FACTOR: 1:1
MODEL FREQUENCY: 9000 MCS.

FIG. 10

PATTERN: θ= 90° ϕ= VARIABLE
POLARIZATION E_θ ✓ E_ϕ OTHER
CURVE PLOTTED IN: VOLTAGE ✓ POWER DB
ANTENNA TYPE: ETCHED MICROSTRIP ARRAY
ANTENNA LOCATION:
DISTANCE FROM ILLUMINATING SOURCE: 60 FT.

[redacted]



[redacted]

FREQUENCY - MC

FIG. 11

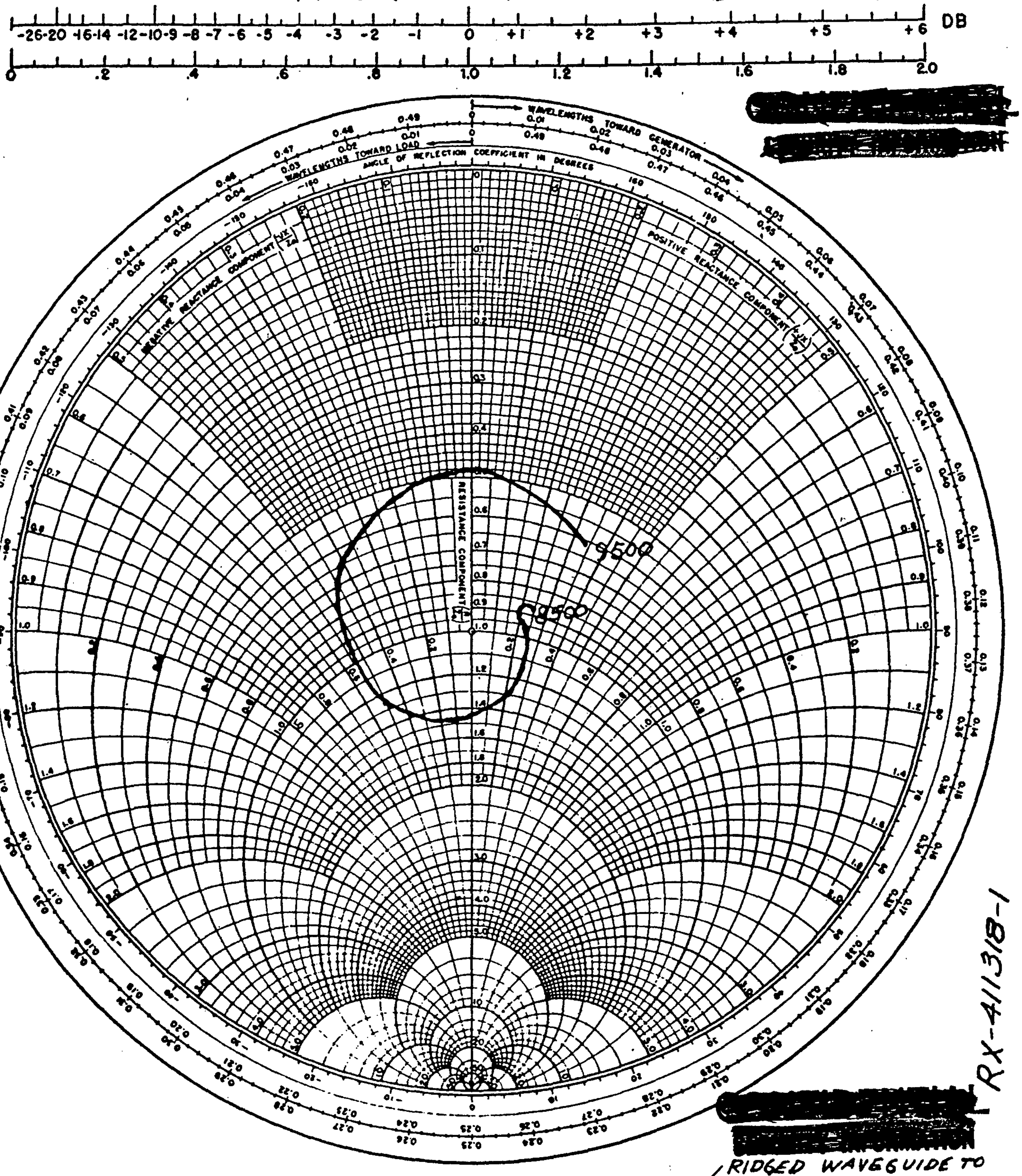
MARCH 20, 1953 E.W.

RX-41597-1B

AVERAGED INPUT IMPEDANCE VS FREQUENCY
ETCHED MICROSTRIP 32 ELEMENT ARRAY ANTENNA
MEASURED AT FACE OF FLANGE ON INPUT.

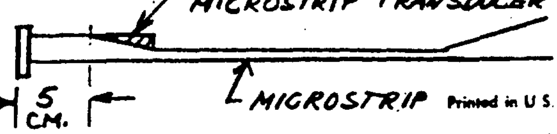
THE EMELOID CO., INC.
HILLSIDE 5, N. J.
JANUARY 1948

[redacted]



[redacted]

RX-411318-1



1-28-53 DJL

Philip H. Smith "Transmission Line Calculator" Electronics Jan 1939 and Jan 1944

Printed in U.S.A.

FIG. 12

[redacted]

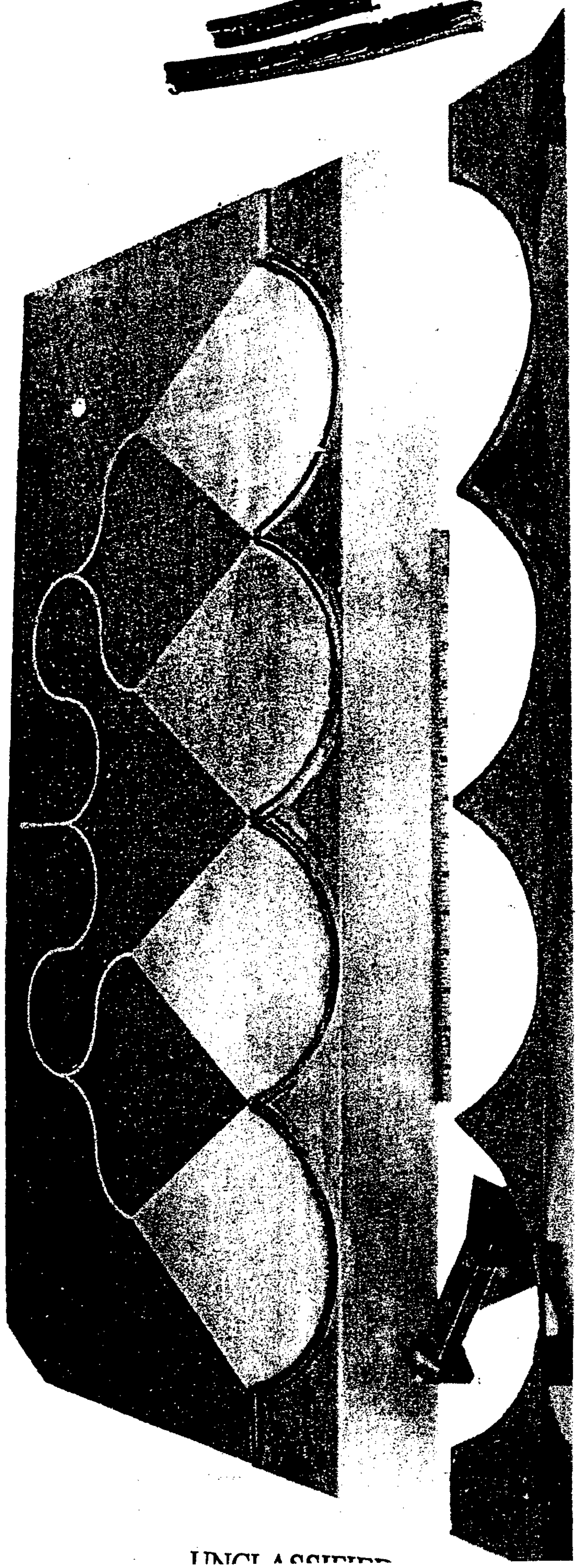


FIGURE 13

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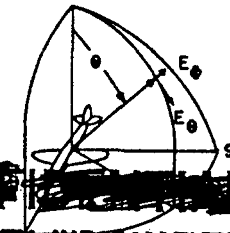
FEDERAL TELECOMMUNICATION LABORATORIES, INC.



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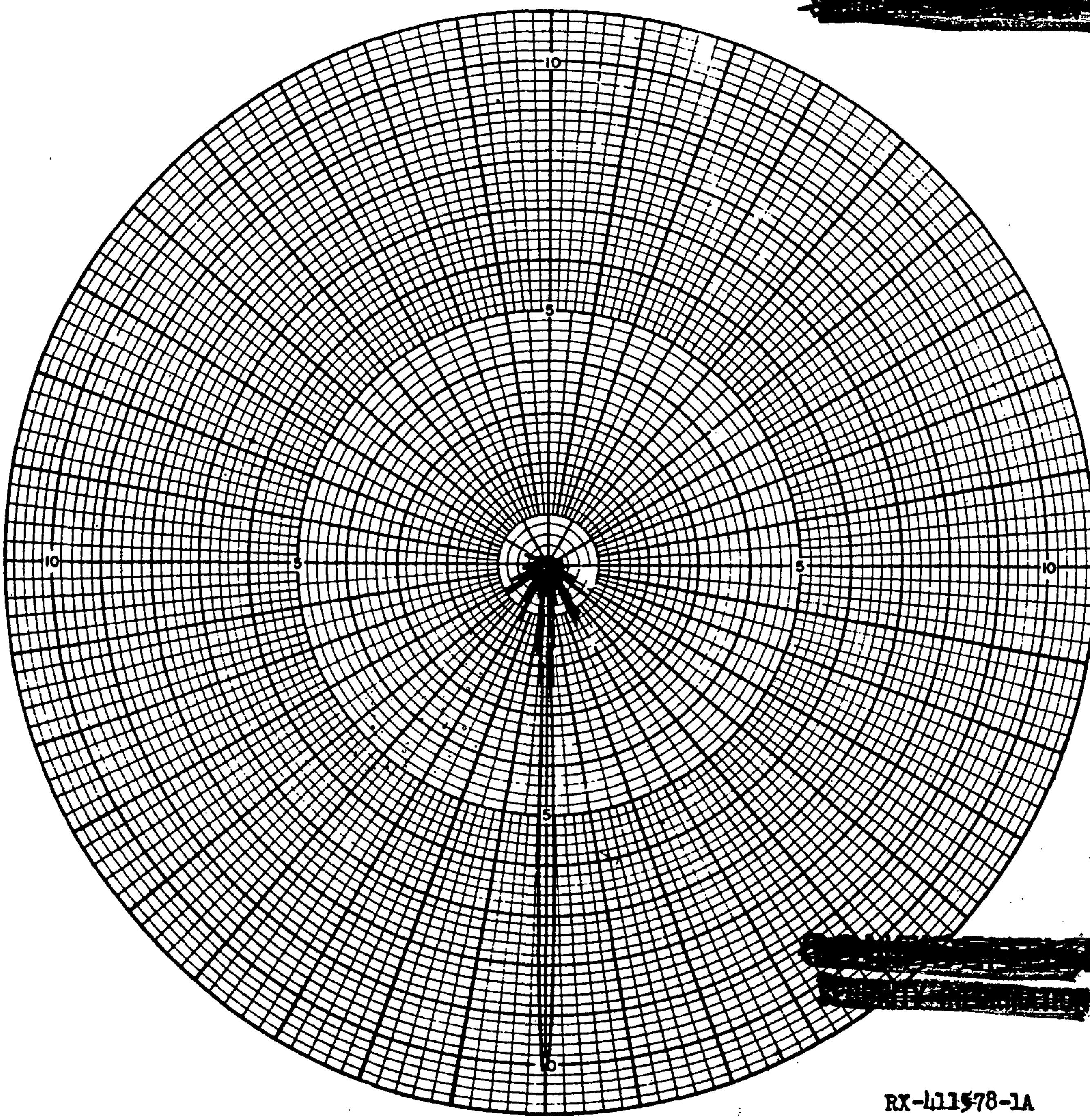


[redacted]

RX-411578-1A

DATE: 3-10-53
OBSERVERS: 1. EW
2. RM, WE
PLANE TYPE: None
SCALE FACTOR: Full Scale

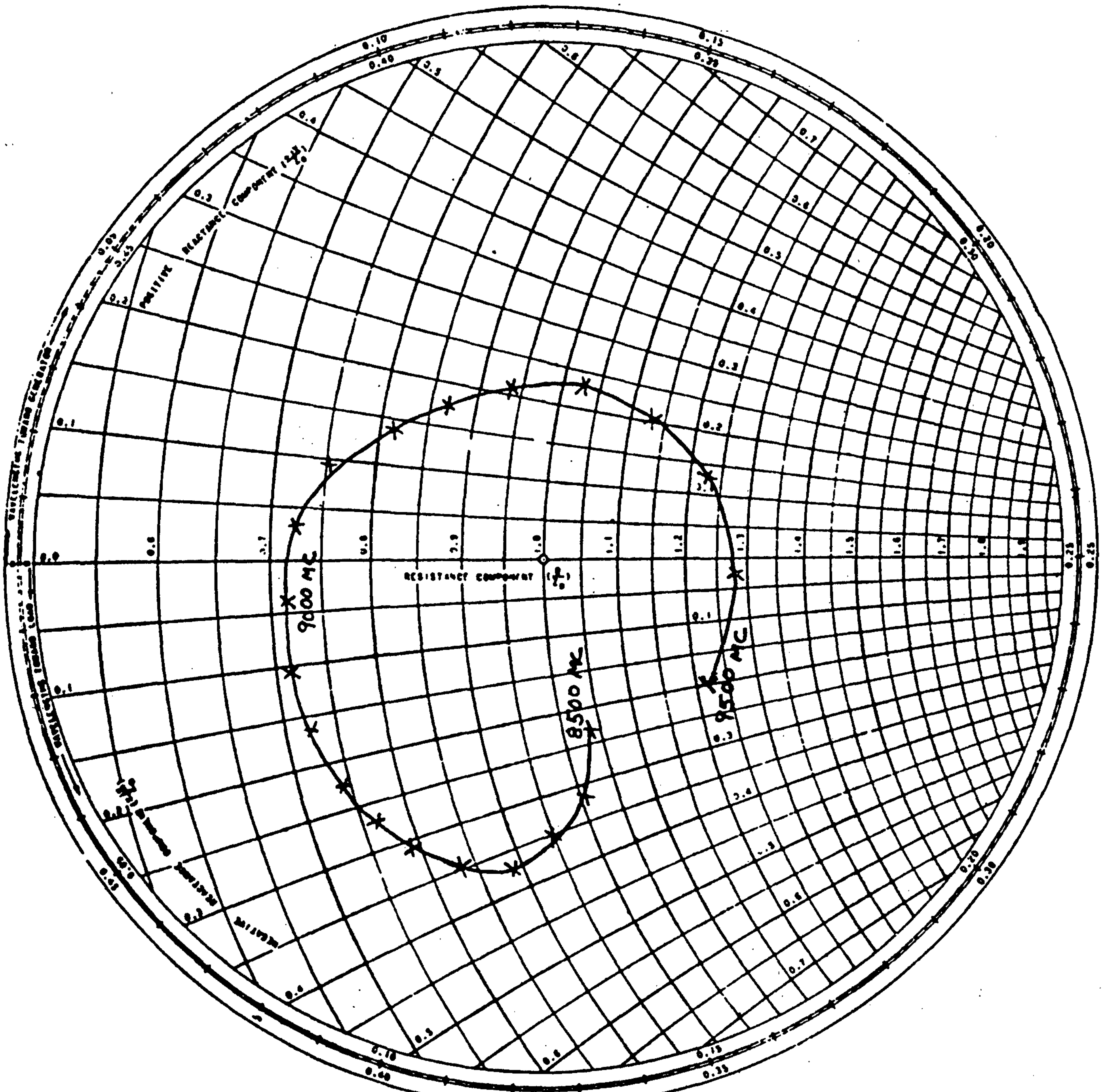
PATTERN: θ: 90° φ: Variable
POLARIZATION E_θ ✓ E_ϕ OTHER
CURVE PLOTTED IN: VOLTAGE ✓ POWER DB
ANTENNA TYPE: 4 lens microstrip array
ANTENNA LOCATION:

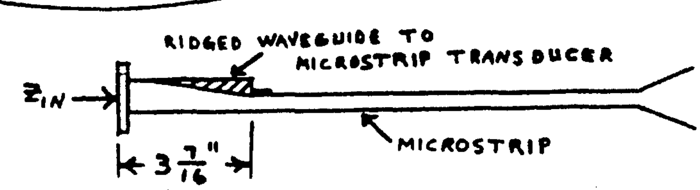
 [redacted]

AVERAGED INPUT IMPEDANCE VS FREQUENCY - [redacted]

ETCHED MICROSTRIP 4 LENS ARRAY ANTENNA.

MEASURED AT FACE OF FLANGE ON INPUT.





MARCH 17-1953 F.W.

RX- 411595-1A

[redacted]

FIG. 15

[redacted]

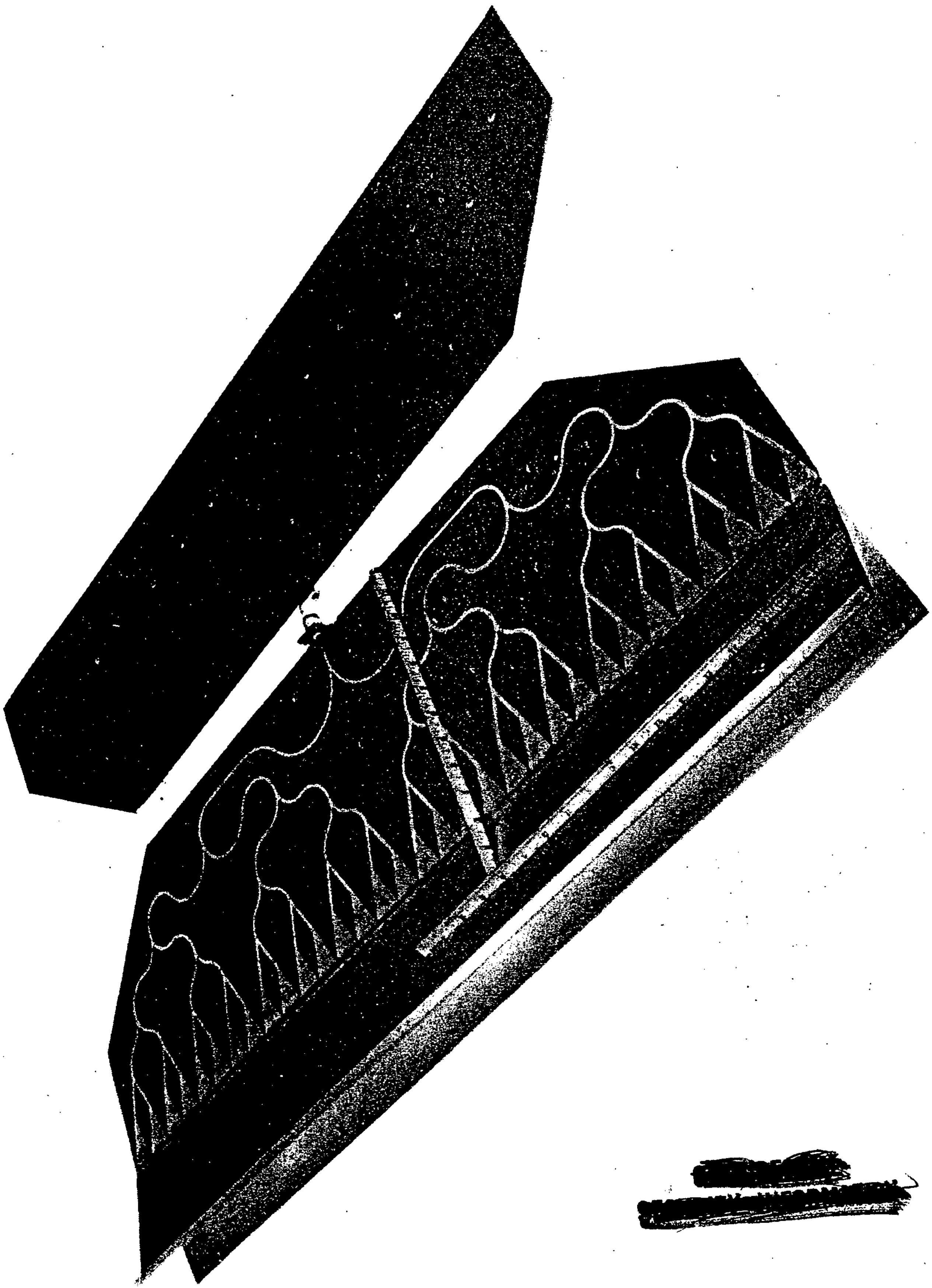


FIGURE 16

[redacted]

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[redacted]

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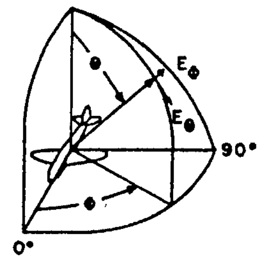
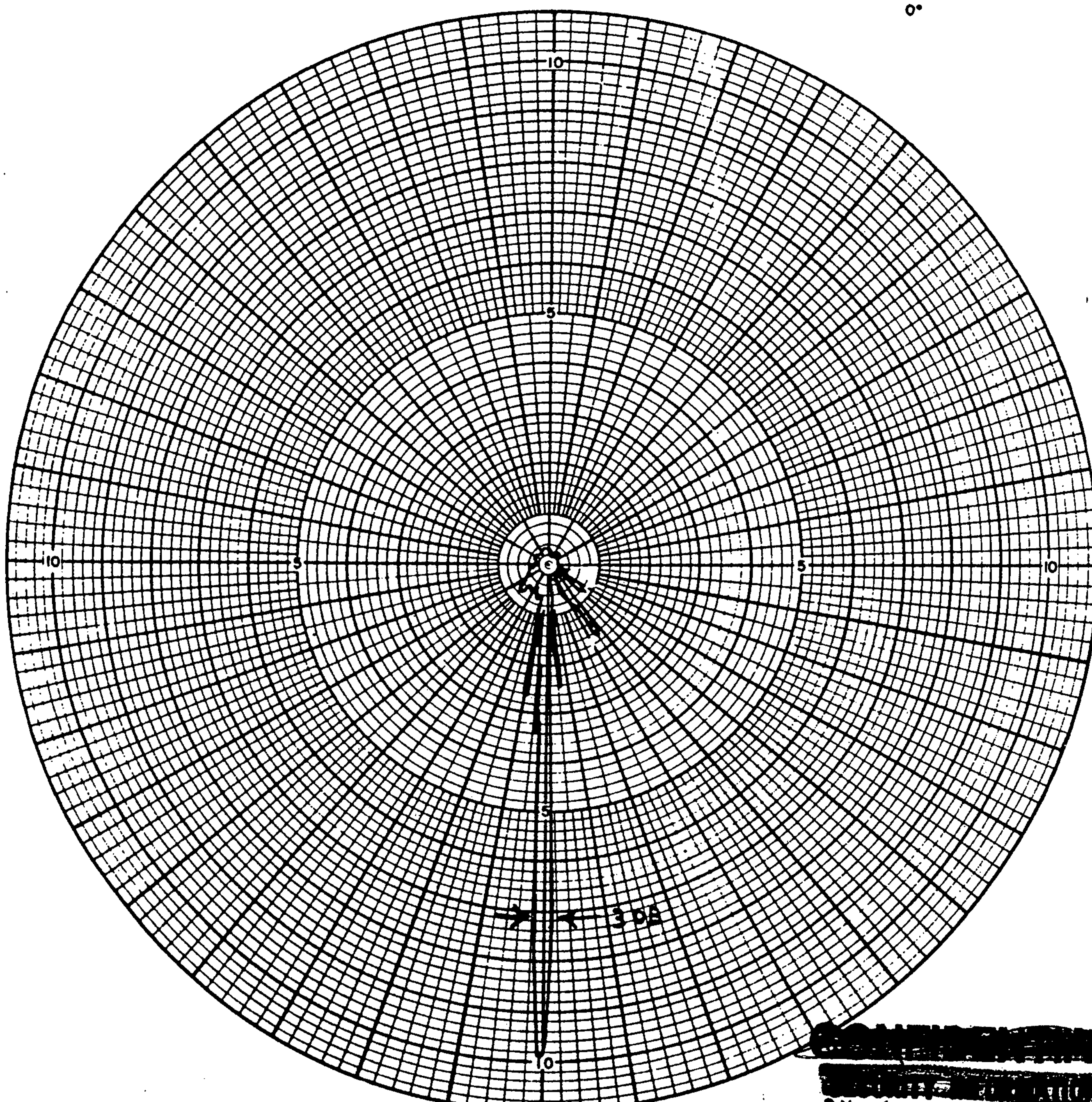




[redacted]

RX-411799-1A

DATE: APRIL 20, 1953
OBSERVERS: 1. E.W.
2.
PLANE TYPE:
SCALE FACTOR:

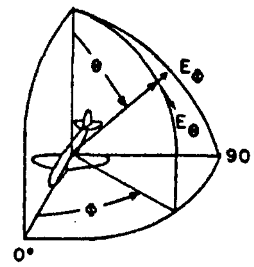
PATTERN: θ= 90° φ= VARIABLE
POLARIZATION E_θ ✓ E_ϕ OTHER
CURVE PLOTTED IN: VOLTAGE POWER ✓ DB
ANTENNA TYPE: 32 ELEMENT, COSINE POWER DISTRIBUTION, MICROSTRIP SANDWICH, BALANCED FEED

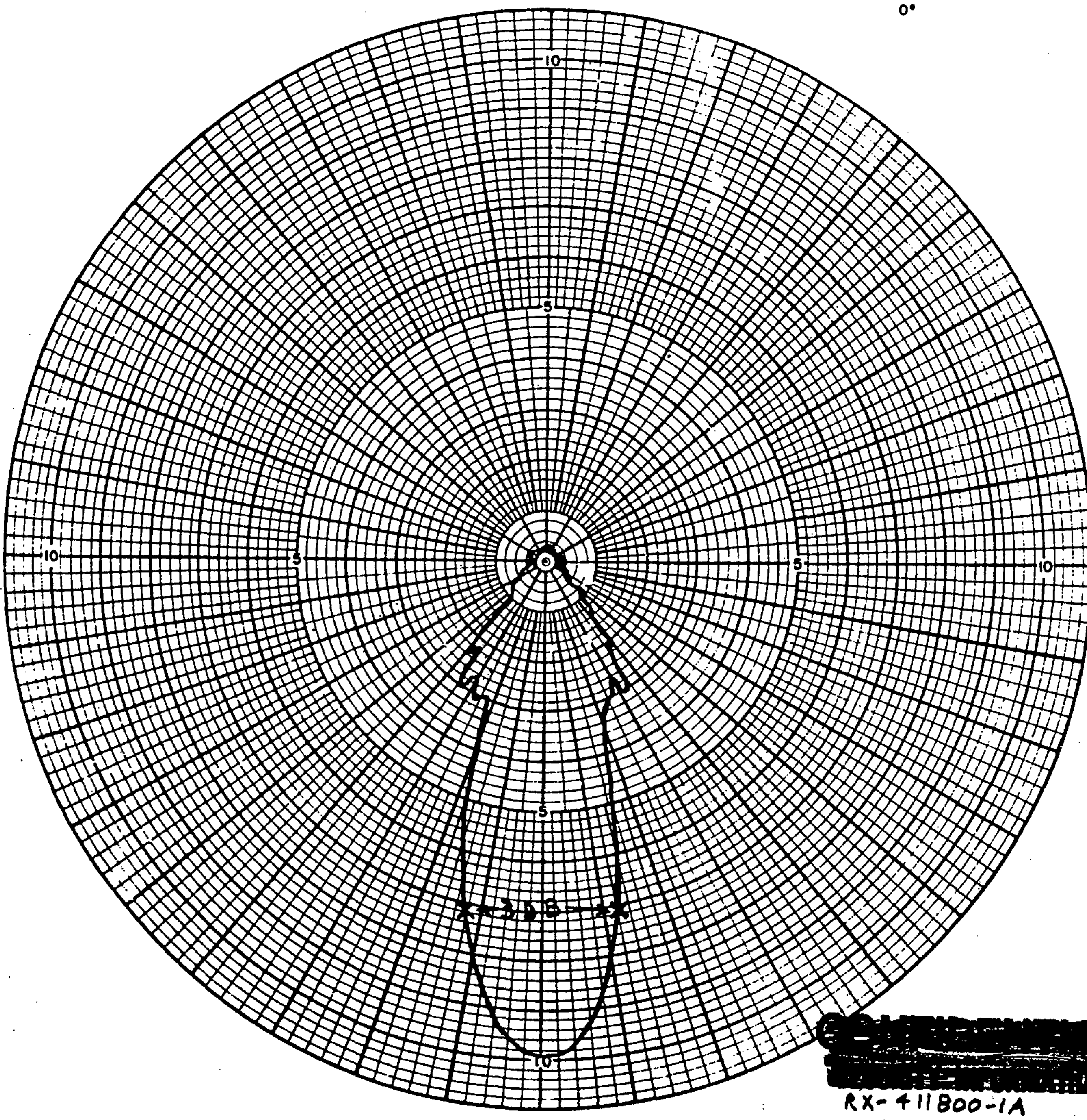
UNCLASSIFIED

UNCLASSIFIED

[redacted]

FEDERAL TELECOMMUNICATION LABORATORIES, INC.





[redacted]

RX-411800-1A

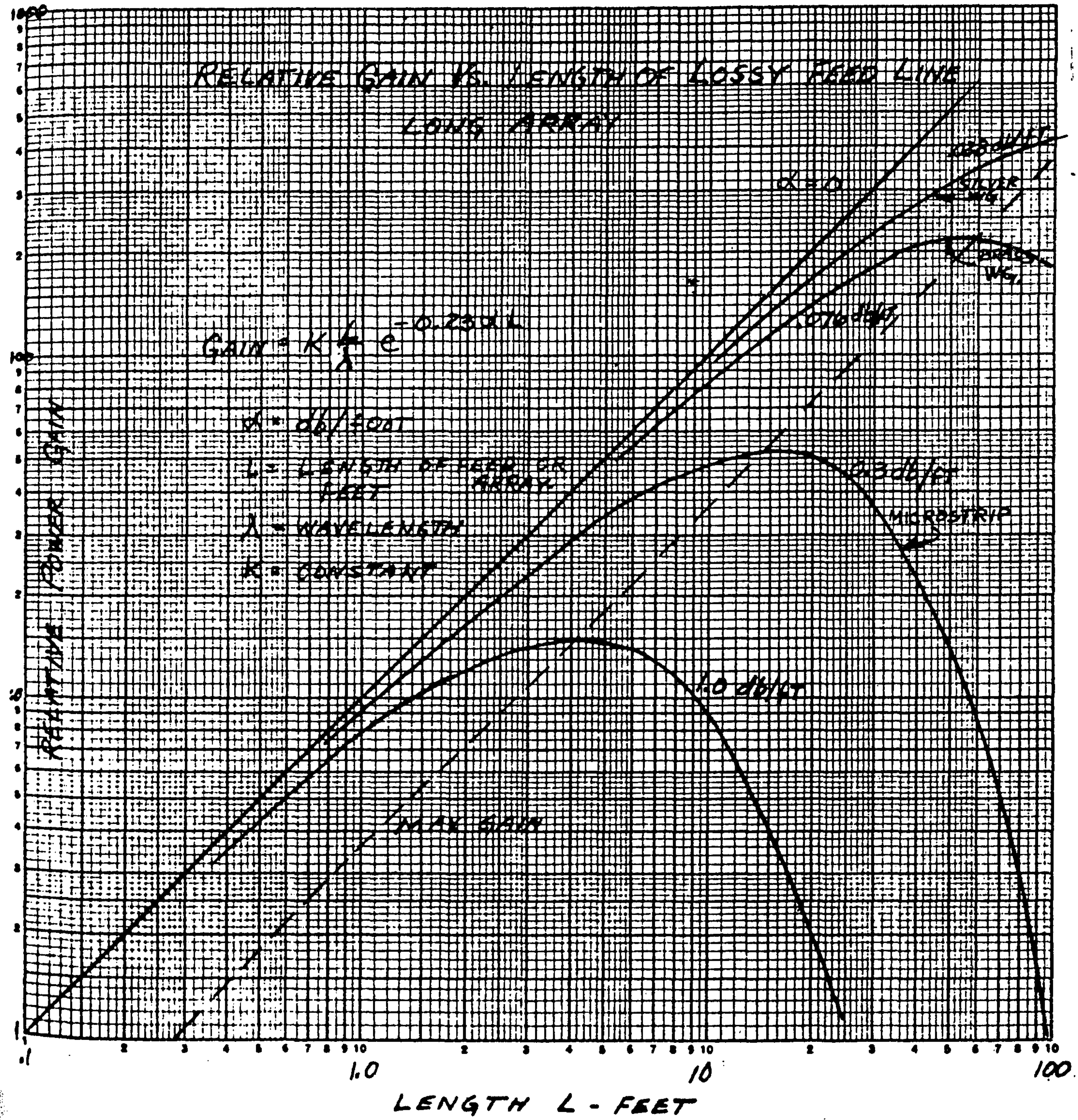
DATE: APRIL 20, 1953
OBSERVERS: 1. E.W.
2.
PLANE TYPE:
SCALE FACTOR:
MODE: ...

UNCLASSIFIED

FIG. 18

PATTERN: θ = VARIABLE φ = 0°
POLARIZATION E$_\theta$ ✓ E$_\phi$ OTHER
CURVE PLOTTED IN: VOLTAGE POWER ✓ DB
ANTENNA TYPE: 32 ELEMENT, COSINE POWER DISTRIBUTION, MICROSTRIP SANDWICH, BALANCED FEED
[redacted]: TO HORN.

[redacted]



1-26-53 WS/DSL

[redacted]

FIG. 1[illegible]