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RADIO AND ELECTRICAL ENGINEERING DIVISION

THE DESIGN OF PRACTICAL HIGH POWER SLOTTED WAVE GUIDE ARRAYS

OTTAWA

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THE DESIGN OF PRACTICAL HIGH POWER SLOTTED WAVE GUIDE ARRAYS.

by

D.R. HAY

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ABSTRACT

Design information for the resonant dimensions of 3/8-inch shunt dumbbell slots is given. It is expected that such 3/8-inch slots are sufficient for safe operation of a five-megawatt, S-band wave guide array, thirteen feet in length.

Climatic tests indicate the necessity of water-repellent wave guide slot coverings, and broad-banding in an array. Measurements on a thirteen-foot, non-resonant, S-band wave guide array of forty-five 3/8-inch shunt, dumbbell slots, covered with vinylite and glyptal, show that it should operate satisfactorily under climatic extremes. The array described here has a band width greater than eight per cent.

A suitable adhesive, 3M-EC826, has been found for bonding vinylite sheet to clean brass wave guide.

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THE DESIGN OF PRACTICAL HIGH POWER SLOTTED WAVE-GUIDE ARRAYS

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I Introduction

A high-power, slotted wave-guide array must not only resist breakdown due to arcing, but must also operate satisfactorily under extremes of climate.

The maximum power capacity of a wave-guide array is limited by the operating breakdown potential in the wave guide. For 3 by 1.5-inch, rectangular S-band guide, 8.5 megawatts appears to be the power breakdown point, but a safe operating maximum is considerably less than this.

A thirteen-foot S-band array of forty-five shunt slots, with a 4:1 power taper illumination, requires that a single slot handle a maximum of four per cent of the total power. It has been found that slots one-quarter inch in width do not break down until the power transfer exceeds 150 kilowatts (7). Breakdown measurements made at the National Research Council on 3/8-inch slots have not led to conclusive results, but it is expected that they will operate satisfactorily when transferring 200 kilowatts. This permits a total power of five megawatts; here, the wave-guide power safety factor is probably greater than that of the slots.

Experience has shown that dumbbell slots (Fig.1) are more easily machined in wave guide than are rectangular slots. The chief difference in the characteristics of the two types is the shorter resonant length of the dumbbell slot (7).

Some of the climatic extremes which may be encountered in practice are summarized below:

Ambient temperatures up to 55°C, with extremes as high as 71°C
Relative humidity up to saturation
Heavy rain and snow
Fungus and bacterial growth
Temperatures as low as -40°C
Ice formation
Insect attacks
Dust

Although changes in humidity of the air have little observable effect on the breakdown potential of an air gap (3), the presence of ice or water in the wave-guide slots will reduce their power handling capacity. Four square inches of water condensed on the inside walls of an S-band wave guide result in a ten per cent attenuation of power transfer; the presence of a dessicator (e.g. silica gel) in a closed guide is of little value because of the slow diffusion rate of moisture through air (6). The necessity of a weatherproof slot covering in a practical array is apparent.

The slot covering to be used must be satisfactory not only physically, but from an electrical point of view, under the climatic conditions listed above. Many types of coverings have been tested:

Polythene and teflon possess excellent electrical characteristics; a useful bonding adhesive is still under consideration.

Glass inserts in the wave-guide slots are invaluable in pressurized guide, but considerable developmental work remains to be done on them.

A moulded perspex cover for the wave-guide array is very satisfactory even in heavy rain, but is easily damaged in handling(4).

Mica slot covers are very brittle; they require high temperature bonding to wave-guide(4).

A single layer of Scotch acetate fibre tape with a varnish waterproof covering possesses suitable electrical characteristics, but has a maximum life of about two months in damp climates(4).

Recently sheet vinylite (.009" in thickness) has been tested at the National Research Council as a weatherproof slot covering. It is bonded easily to clean brass wave guide by applying a layer of 3M-EC826 adhesive (Minnesota Mining and Manufacturing Co.) to the wave guide and vinylite patch, and smoothing the latter in place. The vinylite may be coated with glyptol lacquer for further waterproofing.

Some difference of opinion exists on the relative merits of lacquer or varnish as a waterproofing material. In general, varnishes harden in containers in tropical climates and become unserviceable; lacquers are rapid drying, but may be restored for use readily.

II. Design Data for 3/8-inch Shunt Dumbbell Slots

To design an array of 3/8-inch shunt waveguide slots at S-band, measurements over the bands 9.8 cm to 10.2 cm and 10.5 cm to 10.9 cm were made on single 3/8-inch dumbbell slots, at the National Research Council both with, and without the vinylite slot covering in place. The resonant lengths and slot offsets (Fig.1) are plotted in Figs. 2,3,4 and 5; the graphs have been idealized somewhat.

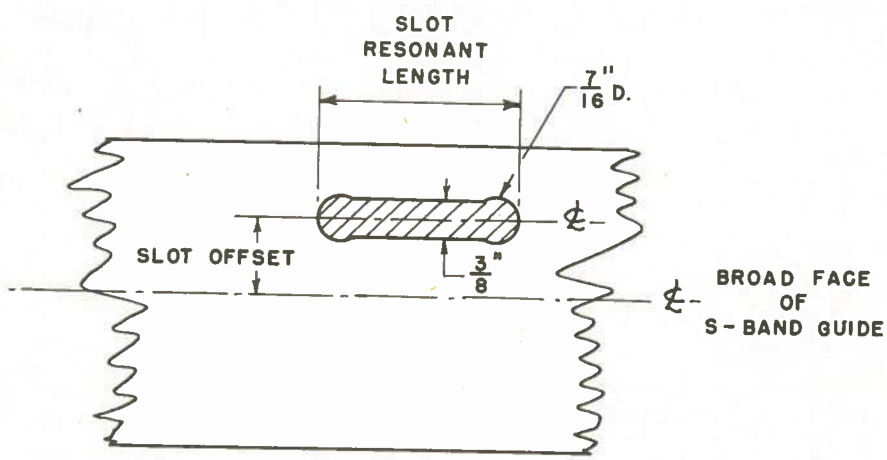

Fig. 1

A set of slot susceptance curves is given in Fig. 10; for small slot offsets, the change in susceptance of the slots with offset is negligible. For this reason, the slot resonant length may be held constant for slot offsets below the values plotted. The slot resonant conductances for these corresponding small offsets may be approximated by extrapolating the empirical curves to zero conductance at zero offset.

III. Climatic Tests on the Vinylite Slot Covering

To determine the physical and electrical properties of the vinylite slot covering, with and without glyptal waterproofing, under various climatic conditions, pairs of 3 by 1.5-inch brass wave-guide shunt-slotted sections were prepared as shown in Fig.6. The 3/8-inch slots were covered as they would be in a practical array. One end of the sections was closed by a shorting plate; the other was left open for admittance measurements. The open end was sealed by polythene during the intervals of exposure.

Four weather tests were performed:

(a) A pair of test sections was placed in a tropicalization chamber, where the temperature varied between 42°C and 48°C in cycles, with the humidity approaching saturation. For one day each week, the temperature was decreased to 20°C and the condensed moisture was allowed to remain on the slot coverings. During the 75 days of exposure, periodic admittance measurements were made at room temperature on the test sections, shortly after removal from the chamber.

(b) A second pair of test sections was kept in a low-temperature chamber at -40°C for 76 days. Periodic admittance measurements were made at a temperature of -18°C. Wavelengths at this low temperature were measured on a wavemeter specially calibrated from careful standing wave measurements.

(c) A third pair of test sections was subjected to a fine heated spray of 20 per cent sodium chloride in water, for 38 days.

(d) A fourth pair of test sections was innoculated with aspergillus niger fungus and maintained under favourable conditions of growth for ten weeks. In tropical climates this type of fungus is the one most likely to attack the vinylite slot covering and glyptal layer.

The visible results of the above tests are shown in Figs. 7, 8 and 9. No change was apparent on the coverings in the low-temperature chamber.

IV. Results of the Climatic Tests on the Covered Slot Characteristics

1. No appreciable changes occurred in the electrical characteristics of the covered slots after the first few days of exposure.

2. The presence of the glyptal layer on vinylite had little effect on the electrical properties of vinylite.

3. Although exposure to tropical temperatures, moisture and salt spray caused pitting of the surface of the glyptal layer, it still retained its waterproofing ability after $2\frac{1}{2}$ months.

4. It has been found that a layer of ice .05 inches thick reduces microwave power transmission by about 13 per cent[2]; and when this thickness of ice was in contact with the slot covering, the slot susceptance was almost doubled. The result in a non-resonant wave-guide slot array is a change in the illumination pattern and an increased mismatch at the input end of the array. Under this condition, the amount of power delivered to the wave-guide termination may become sufficiently great to overheat the termination.

   In a resonant array operating at an off-resonance frequency, standing waves within the feeder guide increase in amplitude with distance from the feed position because of the cumulative effect of slot susceptance; a layer of ice or water on the slot coverings of this type of array may cause power breakdown within the guide.

   Although little consideration has been given to methods of de-icing wave-guide arrays up to the present time, it is felt that a water-repellent layer of glyptal on the slot covering is a partial solution to the problem.

5. Only slight traces of aspergillus niger were visible on the surface of the vinylite slot covering after ten weeks' exposure, but no visible growth appeared on the covering with the glyptal surface. (A profuse growth would be expected on a suitable culture after six days under similar conditions.) A glyptal surface reduces the possibility of changes in slot susceptance caused by colonies of fungus, whose bodies contain a considerable amount of moisture.

6. Tropical conditions increase the resonant length of a slot covered by vinylite, while low temperatures decrease the resonant length. In each case, the change in resonant wavelength is less than one per cent. The result is a change of approximately ten per cent in the slot conductance at the design wavelength, or effectively, off-frequency performance of the slot. Bell has pointed out[5] that in a thirteen-foot non-resonant S-band array of forty-five shunt

slots, a ten per cent change in slot conductance increases the voltage standing-wave ratio at the feed end by only one per cent. The decrease in power transfer down the feed guide is negligible.

A corresponding change in the covered slots of a resonant array is more serious because of the narrow band width of the array. A comparison of the band widths of similar resonant and non-resonant arrays is given in the following section.

7. Although vinylite, without a glyptal coating, expanded and sagged into the slot under tropical conditions, little difference appeared in the electrical characteristics from those of the vinylite with glyptal, which remained taut. The sagging slot cover may allow moisture to collect in the region of the slot, with the results explained above.

8. At low temperatures, the vinylite slot covering bonded on the wave guide showed no indication of cracking due to contraction.

9. None of the weather tests resulted in any appreciable decrease in the bonding strength of the 3M-EC826 adhesive, and aspergillus niger fungus showed no inclination to grow on it. At the end of the ten-week tests, no signs of permanent deterioration were apparent in the vinylite covering and its bonding adhesive. It is expected that this type of wave-guide slot covering with glyptal would be serviceable over a considerably longer period; this shows a definite superiority over varnished Scotch acetate fibre tape, whose maximum life under the same conditions is about two months.

In general, these tests show the necessity of a durable, water-repellent slot covering like vinylite with glyptal. In addition, an acceptable wave-guide array must operate satisfactorily over a band width of at least two per cent.

V. A Practical Broad-Band Wave-Guide Array

Measurements have been made on a thirteen-foot, S-band non-resonant wave-guide array of forty-five shunt dumbbell slots, each 3/8-inch in width, as shown in Fig. 11. This array has a power taper distribution of 3:1. Some of the vinylite slot covers have been removed in the photograph to show the slot spacing.

The expected broad-band behaviour of this array is based upon the following facts:

(a) The Q of a resonant slot decreases as the slot width increases. The conductance of 3/8-inch slots will change less with frequency than that of 3/16-inch slots.

(b) The Q of a resonant slot increases as the slot offset increases. From the definition of the Q of a slot, it may be shown that the Q is proportional to the slope of the susceptance curves at resonance in Fig.10. A long array like this requires slot conductances of the order of .01, so that small slot offsets are employed.

Voltage standing-wave ratios at the feed point of the array over the band 9.7 cm to 11.0 cm are plotted in Fig.12. An approximate analysis of non-resonant arrays (5) shows that the input match is better for increasingly small slot admittance and slot spacing other than $\lambda/2$. The increase in the standing-wave ratio as the wavelength exceeds 11.0 cm results when the slot spacing approaches $\lambda/2$.

As the wavelength decreases, the slot spacing becomes increasingly greater than $\lambda/2$. Typical of non-resonant arrays is the increase in side-lobe amplitude and the decrease in the principal lobe amplitude with increase in non-resonant slot spacing. Figs. 18a, b, c, d show that the array performance for wavelengths below 10.2 cm is not desirable for most applications.

The central beam structure of the field pattern of this array is illustrated in Figs.13 - 17, for $\lambda = 10.5$ to 10.9 cm. Even at wavelengths of 9.8 cm and 11.2 cm (Figs.19a, b) slight corrections in the resonant dimensions of the wave-guide slots would produce half-voltage beam widths (θ) little different from 2°, and secondary lobes of amplitude less than 20%.

The band width of an array is determined by the tolerable amplitude of the secondary lobes and the standing-wave ratios at the feed point. The following table compares the band widths of three S-band wave-guide arrays constructed at the National Research Council.

	13' resonant array of 50 - 3/16" dumb-bell shunt slots (4:1 power taper)	13' non-resonant array of 45 - 3/16" dumbbell shunt slots (4:1 power taper)	13' non-resonant array of 45 - 3/8" dumbbell shunt slots (3:1 power taper)
VSWR at feed point	Less than 1.15 over band width of 0.3%	Less than 1.10 over band width of 4%	Less than 1.15 over band width greater than 13%.
Secondary Lobes	Less than 20% over band width of 1%	Less than 20% over band width of 4%	Less than 20% over band width greater than 8% (for corrected design)

The field pattern of the thirteen-foot array of 3/8-inch shunt slots has an appreciable back lobe (twenty per cent) as shown in Fig.20. For some applications this is undesirable, and a horn flare along the top and bottom of the front face of the array may be necessary.

-oOo-

Acknowledgment

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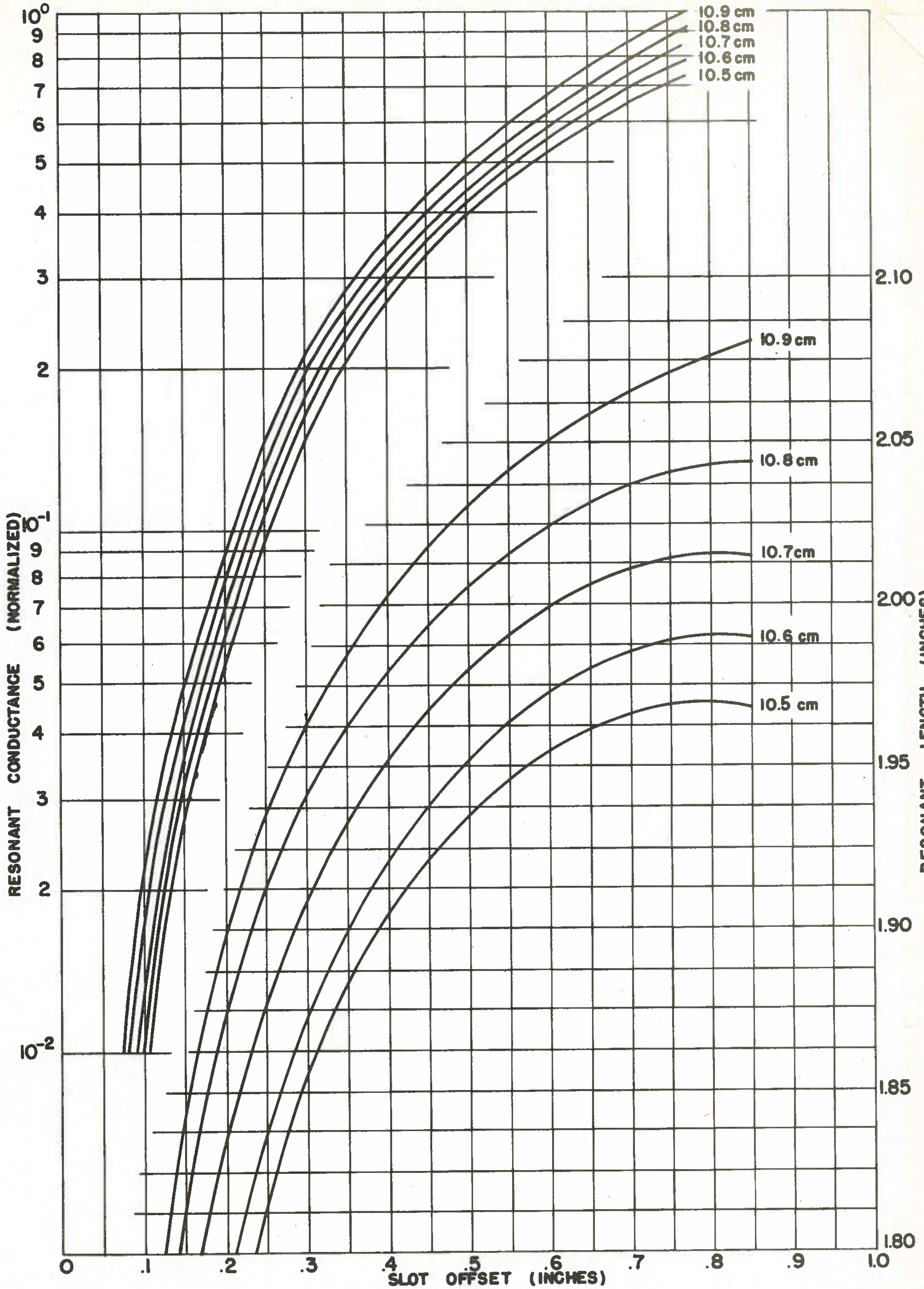


FIG. 2

DESIGN CURVES FOR ARRAY OF 3/8" DUMBELL SLOTS COVERED WITH VINYLITE AND GLYPTAL

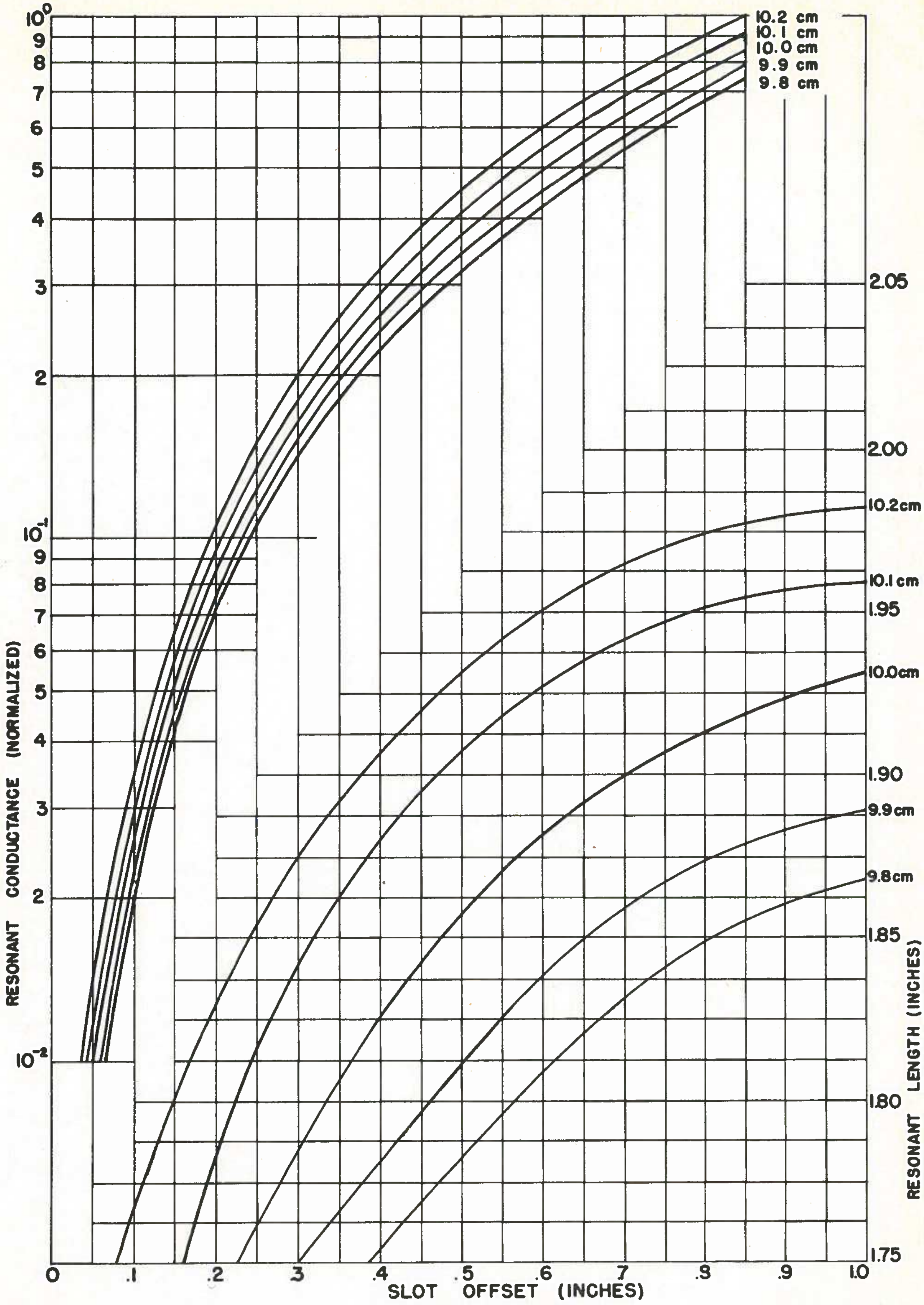


FIG. 3

DESIGN CURVES FOR ARRAY OF 3/8" DUMBELL SLOTS COVERED WITH VINYLITE AND GLYPTAL

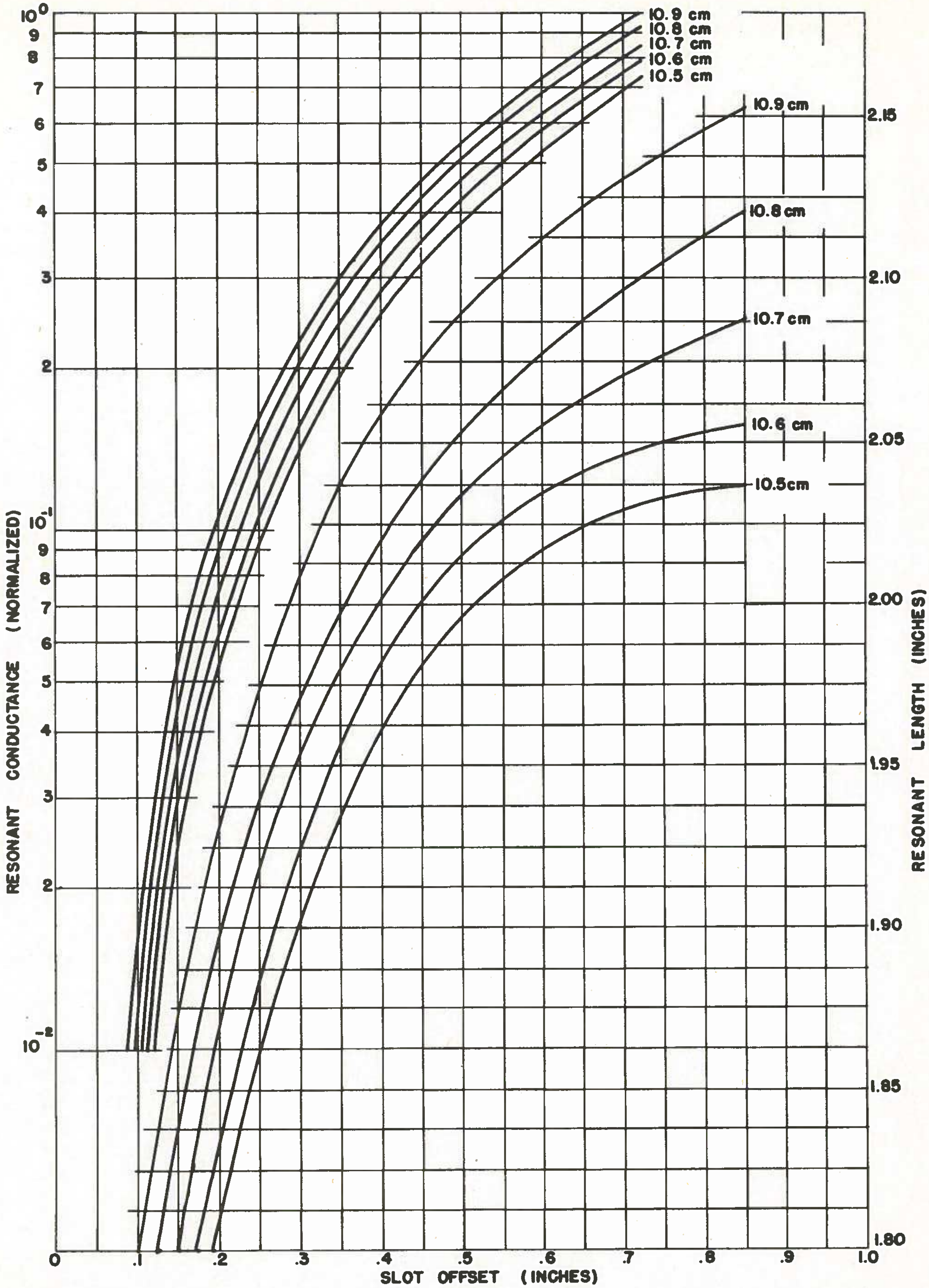


FIG. 4

DESIGN CURVES FOR ARRAY OF 3/8" DUMBELL SLOTS UNCOVERED

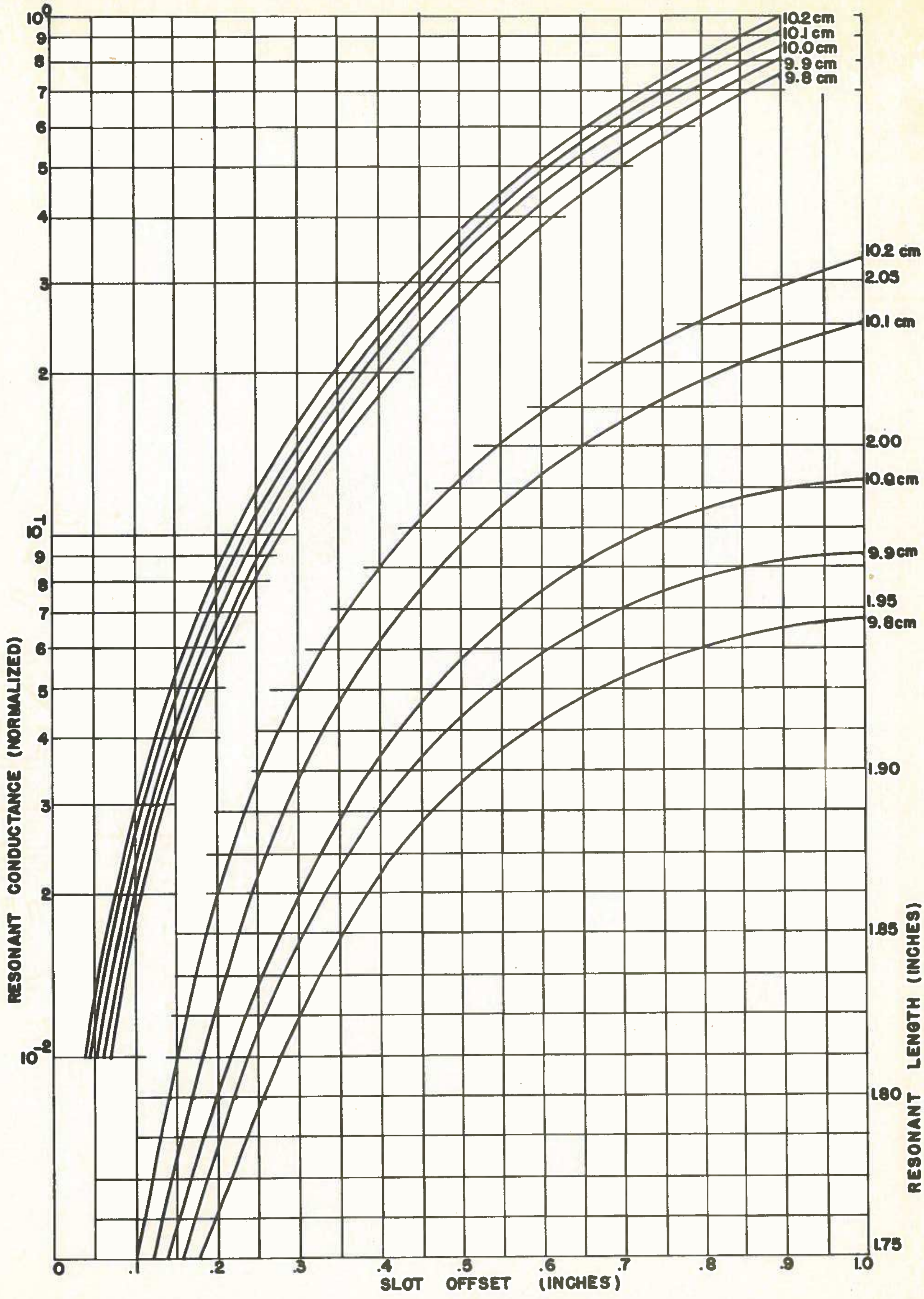


FIG. 5

DESIGN CURVES FOR ARRAY OF 3/8" DUMBELL SLOTS UNCOVERED

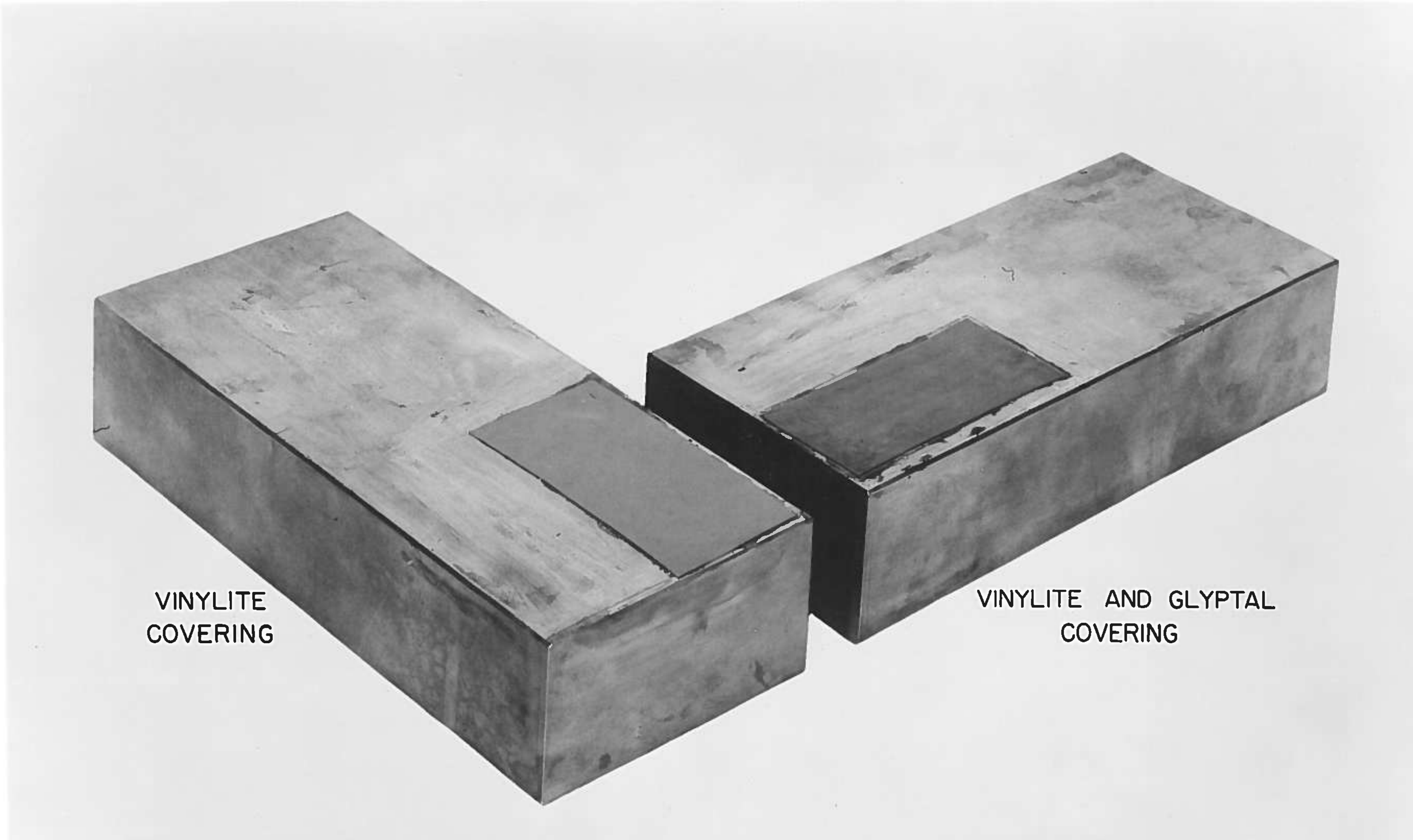


FIG. 6

WAVE GUIDE SLOT COVERINGS BEFORE TESTS

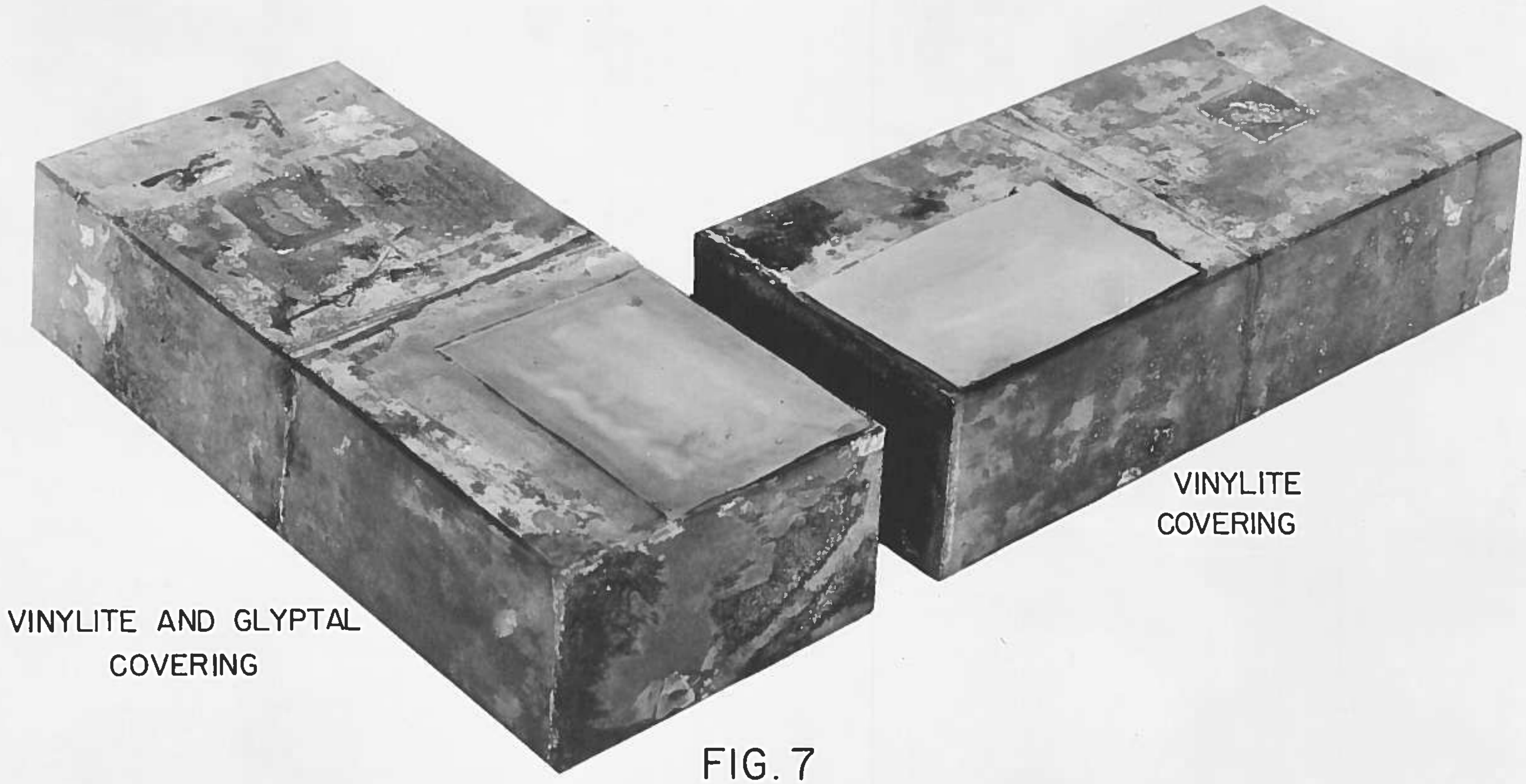


FIG. 7

WAVE GUIDE SLOT COVERINGS
AFTER 75 DAYS IN TROPICAL CHAMBER

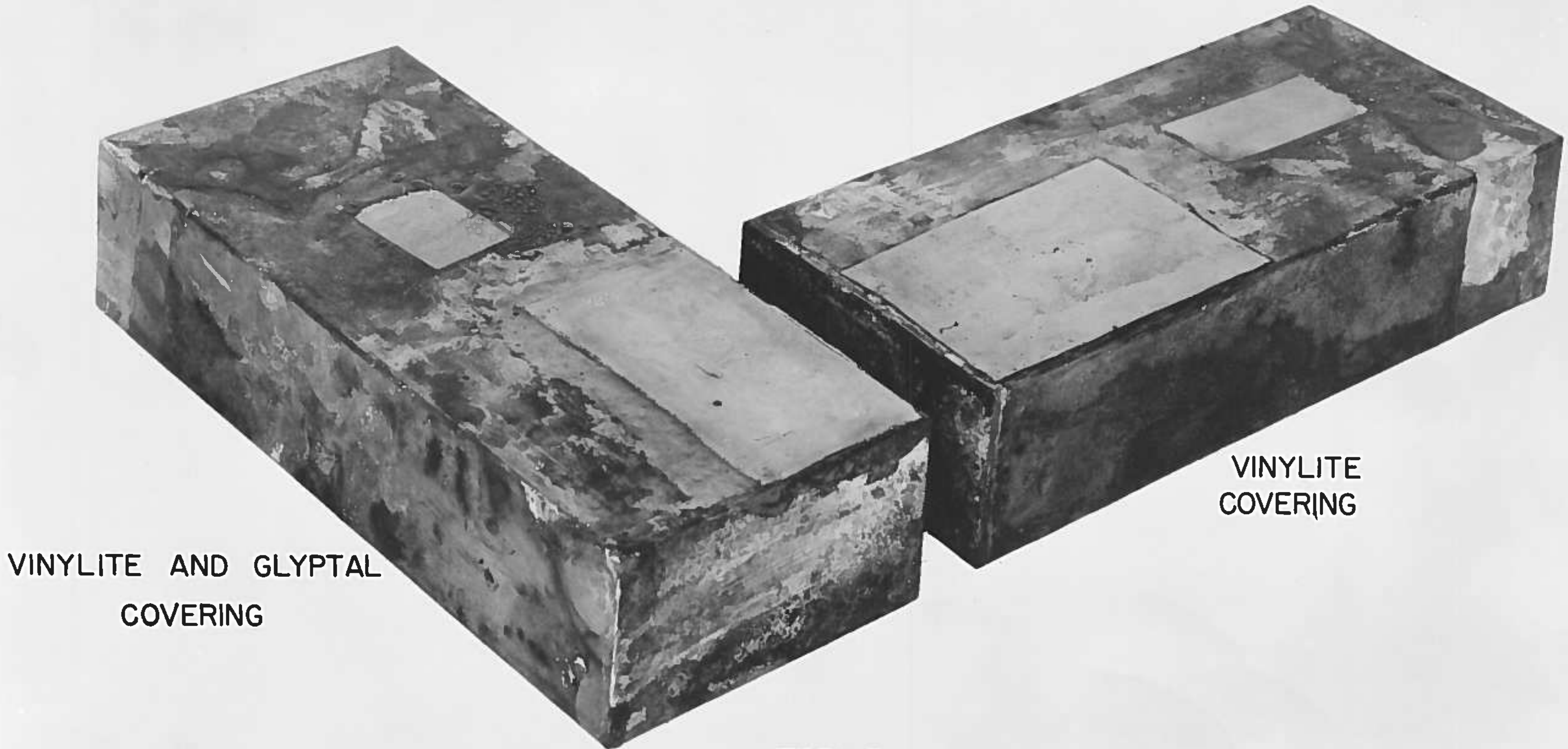


FIG. 8
WAVE GUIDE SLOT COVERINGS
AFTER 10 WEEKS' EXPOSURE TO FUNGUS GROWTH

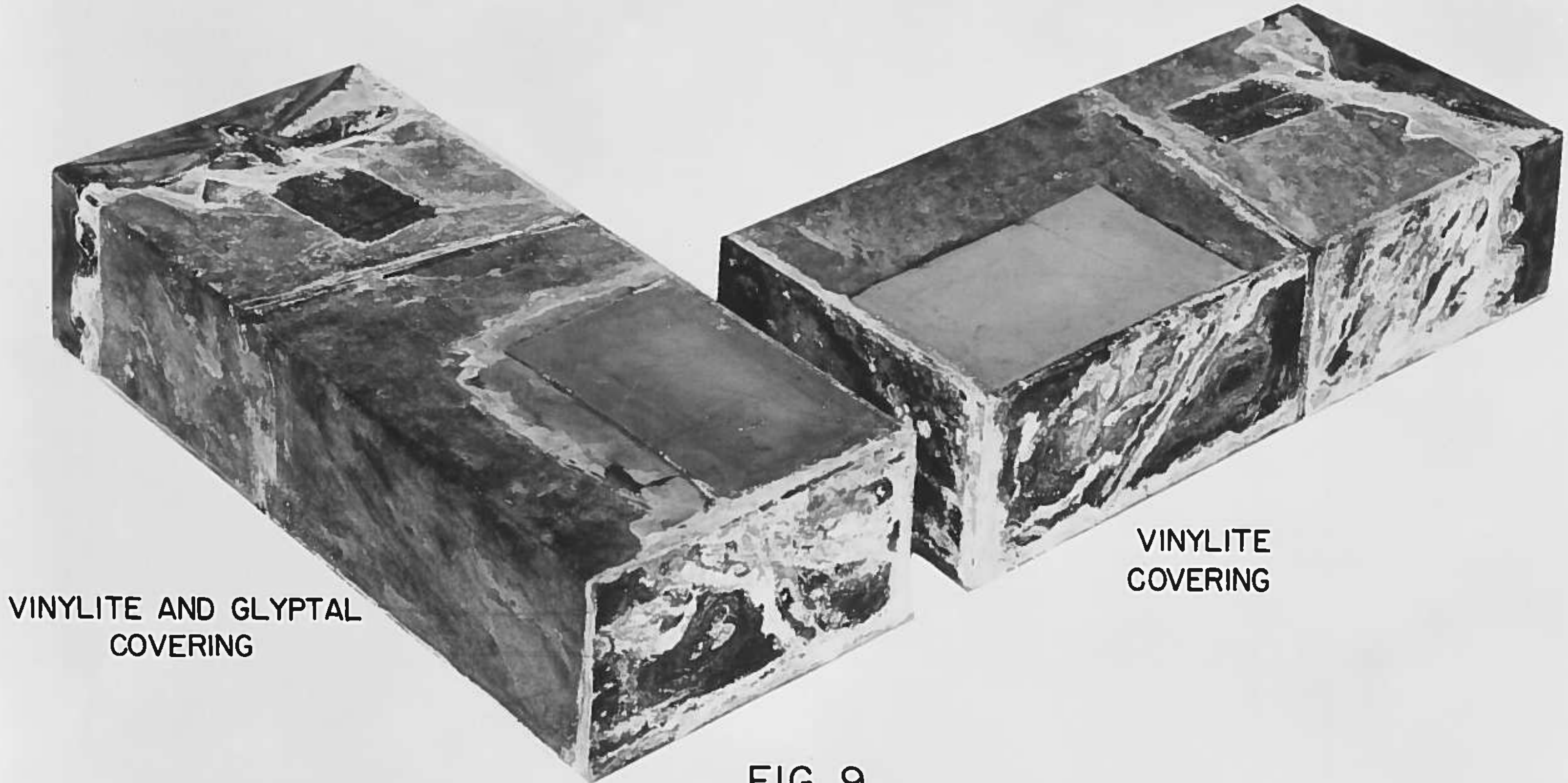


FIG. 9

WAVE GUIDE SLOT COVERINGS
AFTER 38 DAYS IN SALT SPRAY CHAMBER

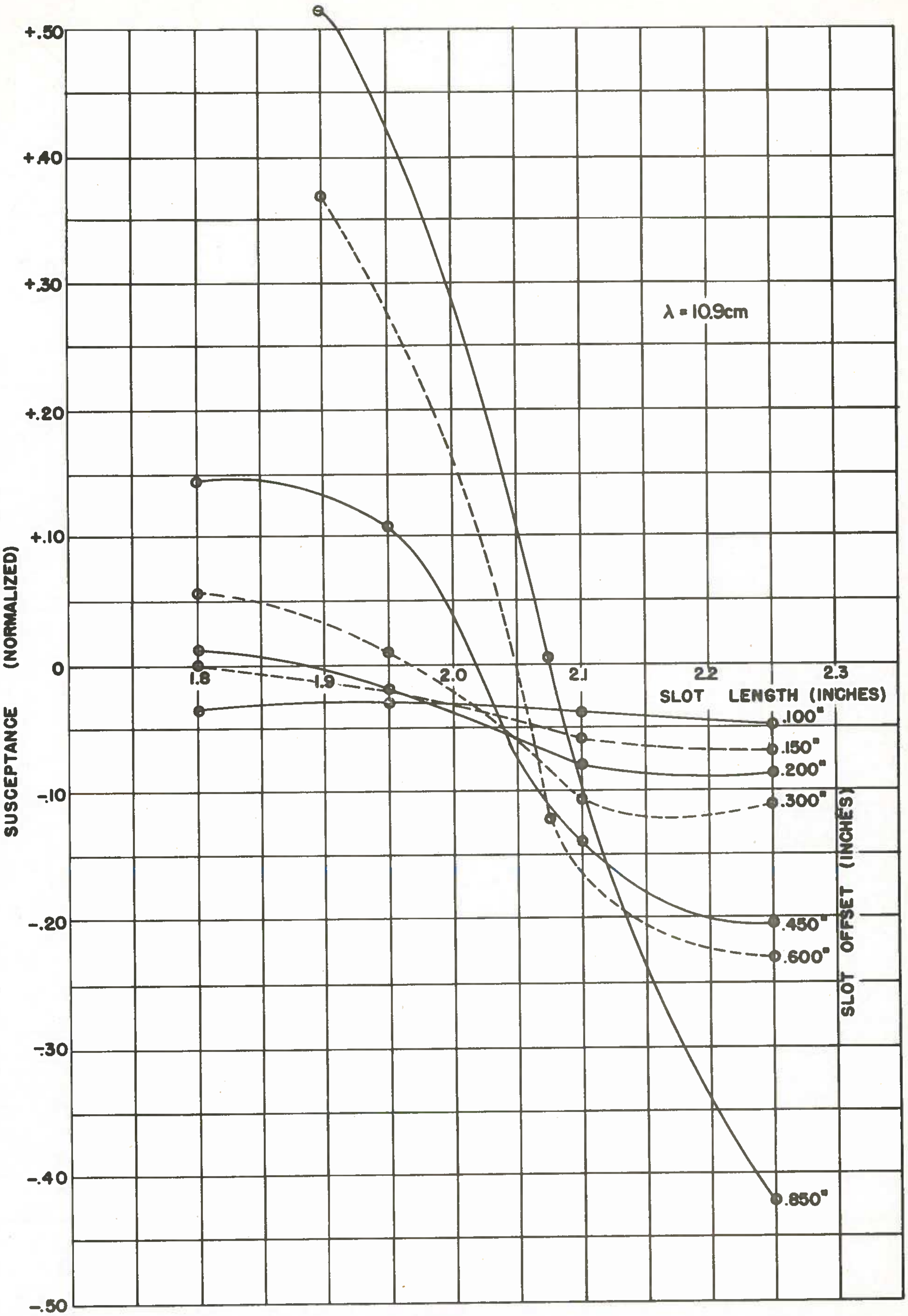


FIG. 10

TYPICAL SET OF SUSCEPTANCE CURVES FOR 3/8" WAVEGUIDE SLOTS

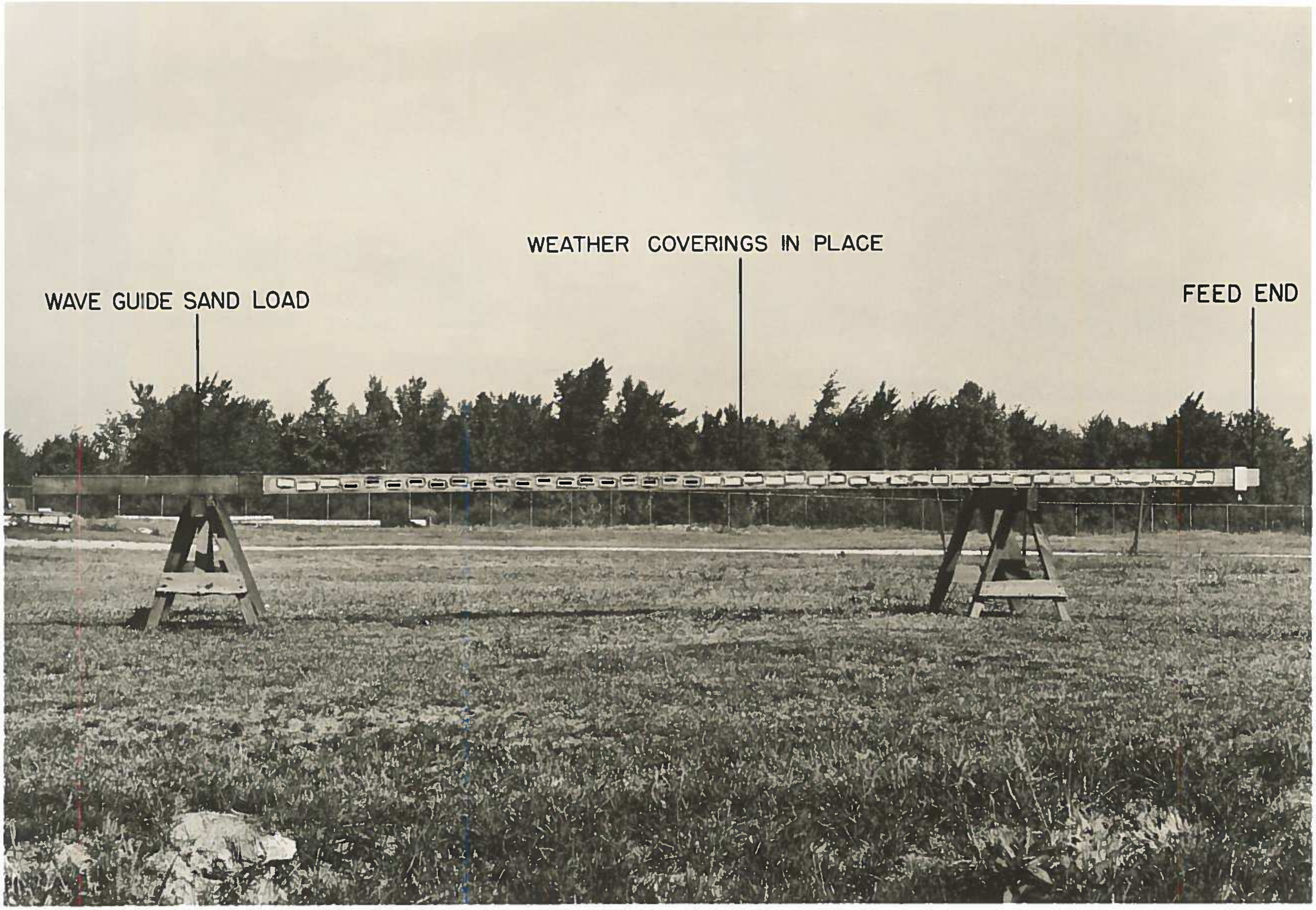


FIG. II

NON-RESONANT WAVE GUIDE ARRAY OF $\frac{3}{8}$-INCH DUMBBELL SLOTS

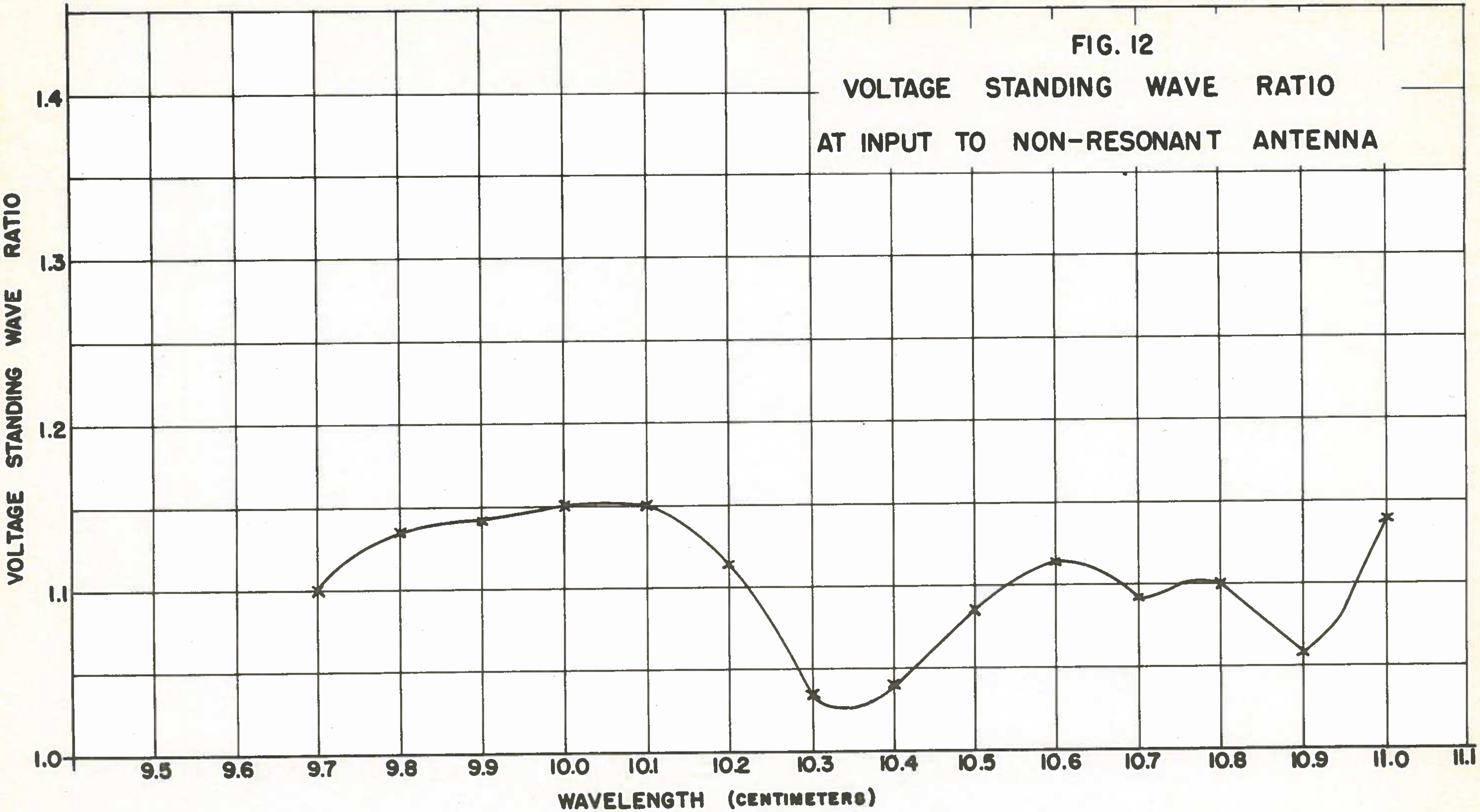
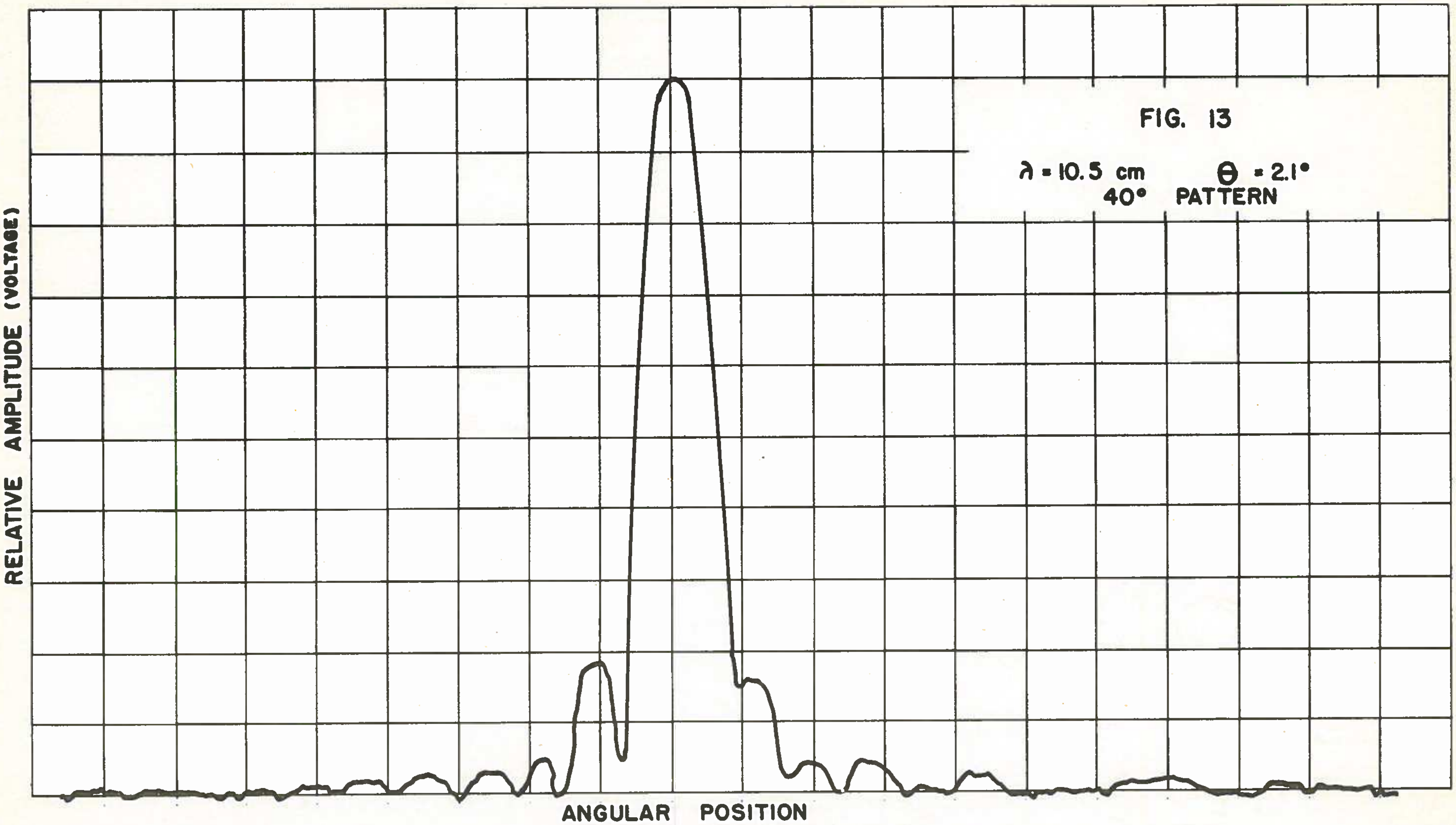
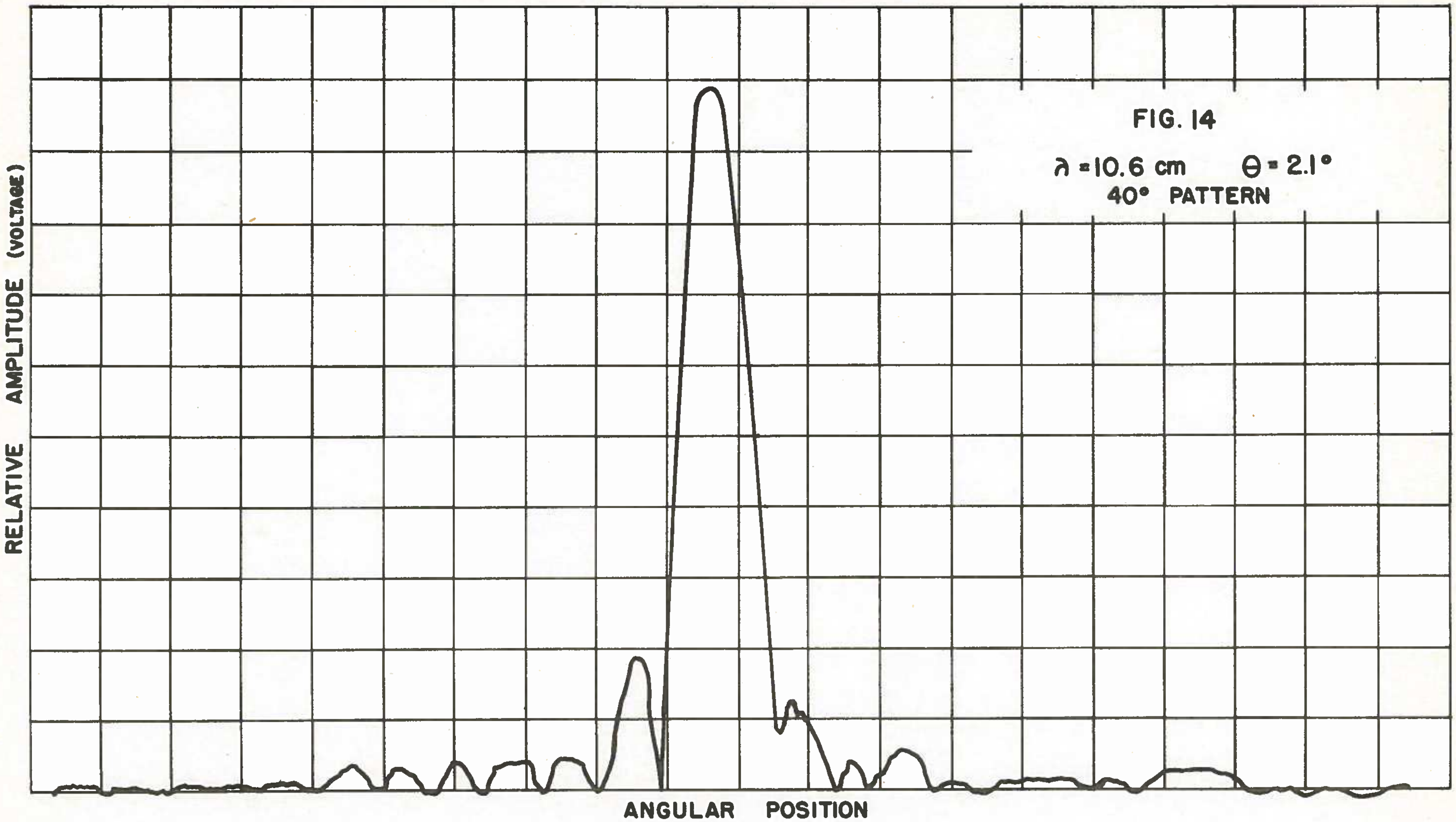


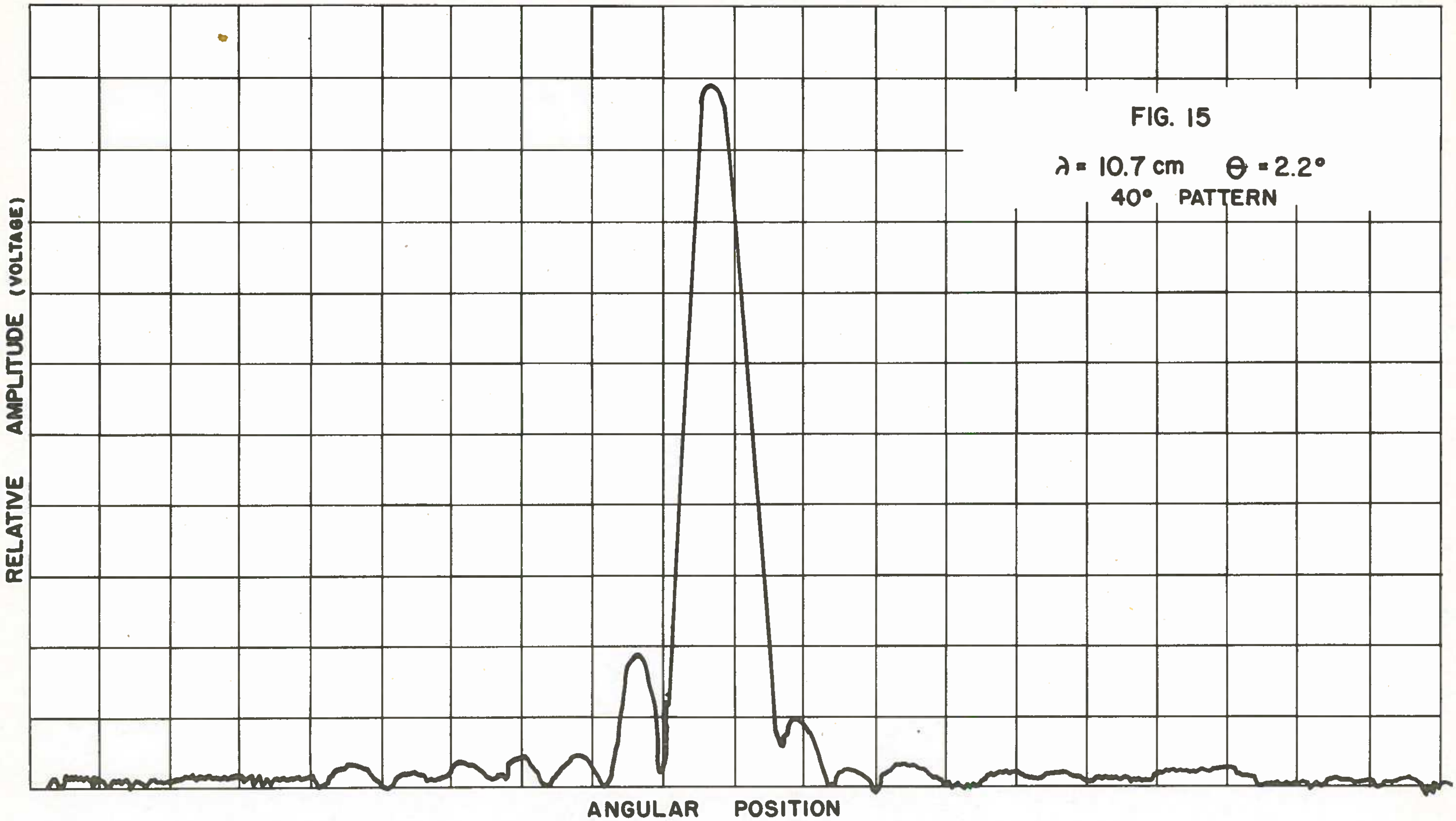
FIG. 12
VOLTAGE STANDING WAVE RATIO
AT INPUT TO NON-RESONANT ANTENNA
VOLTAGE STANDING WAVE RATIO
1.4
1.3
1.2
1.1
1.0
9.5
9.6
9.7
9.8
9.9
10.0
10.1
10.2
10.3
10.4
10.5
10.6
10.7
10.8
10.9
11.0
11.1
WAVELENGTH (CENTIMETERS)



DISTANT AMPLITUDE PATTERN OF NON-RESONANT ARRAY



DISTANT AMPLITUDE PATTERN OF NON-RESONANT ARRAY



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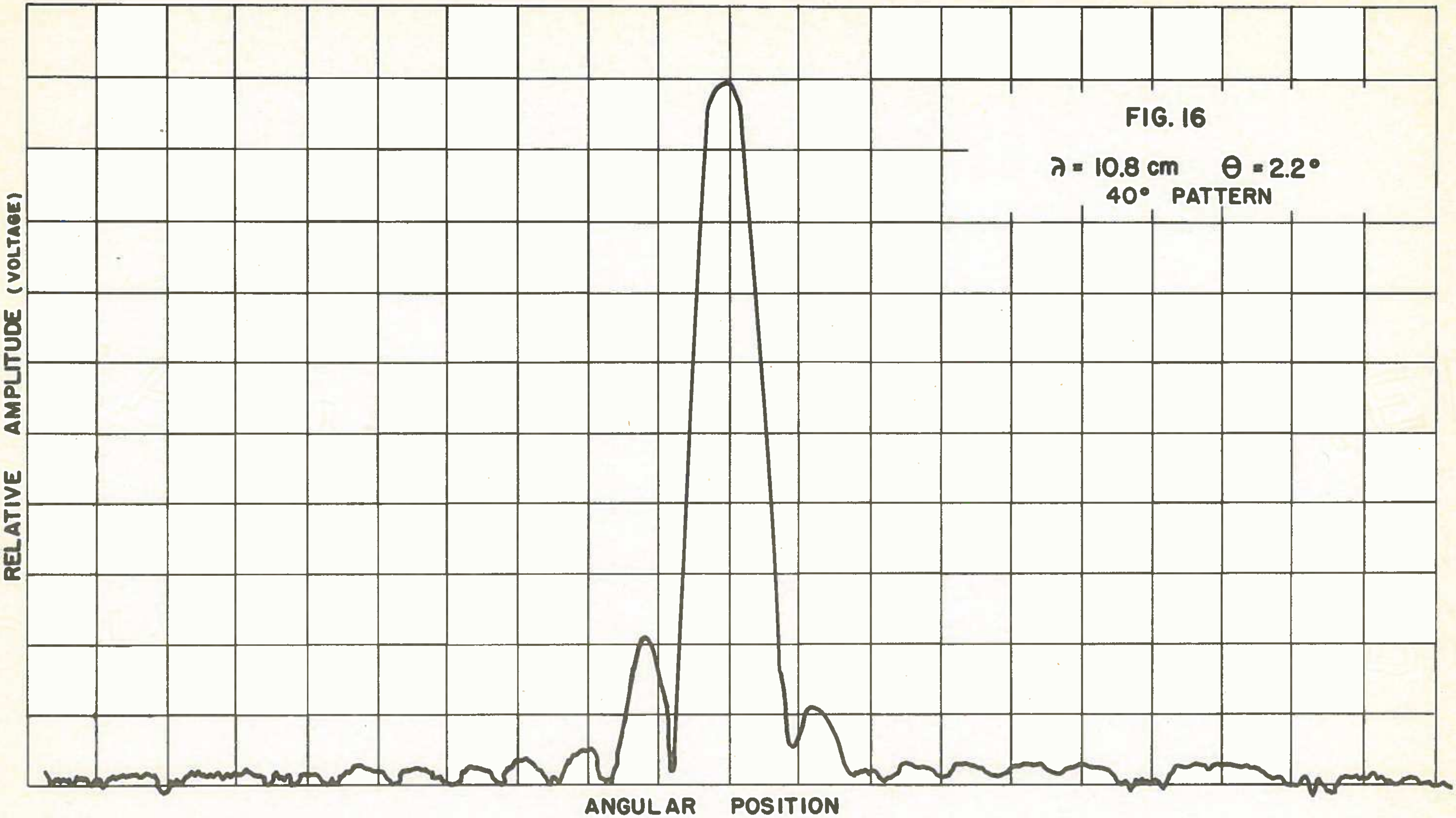

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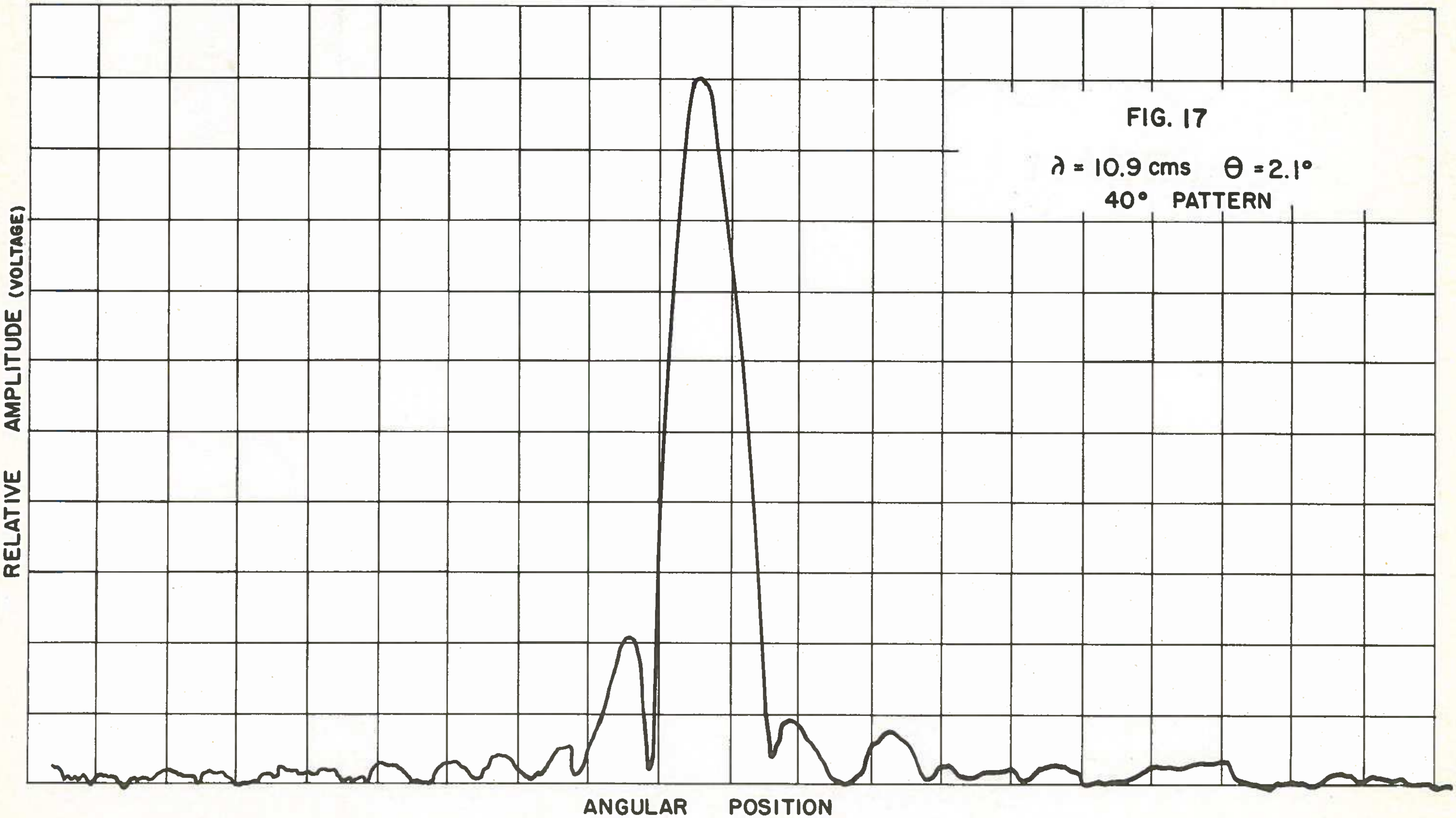

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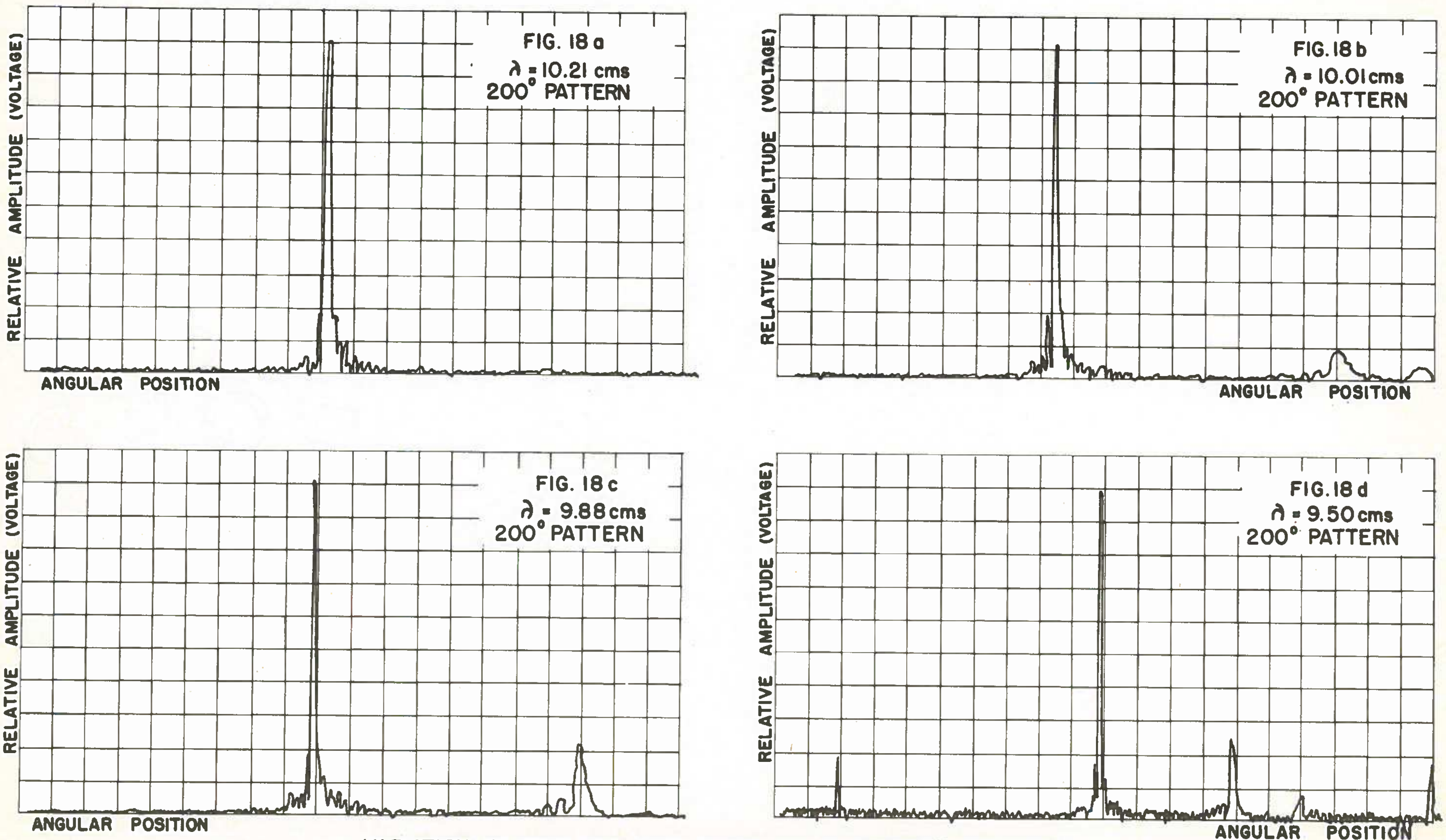
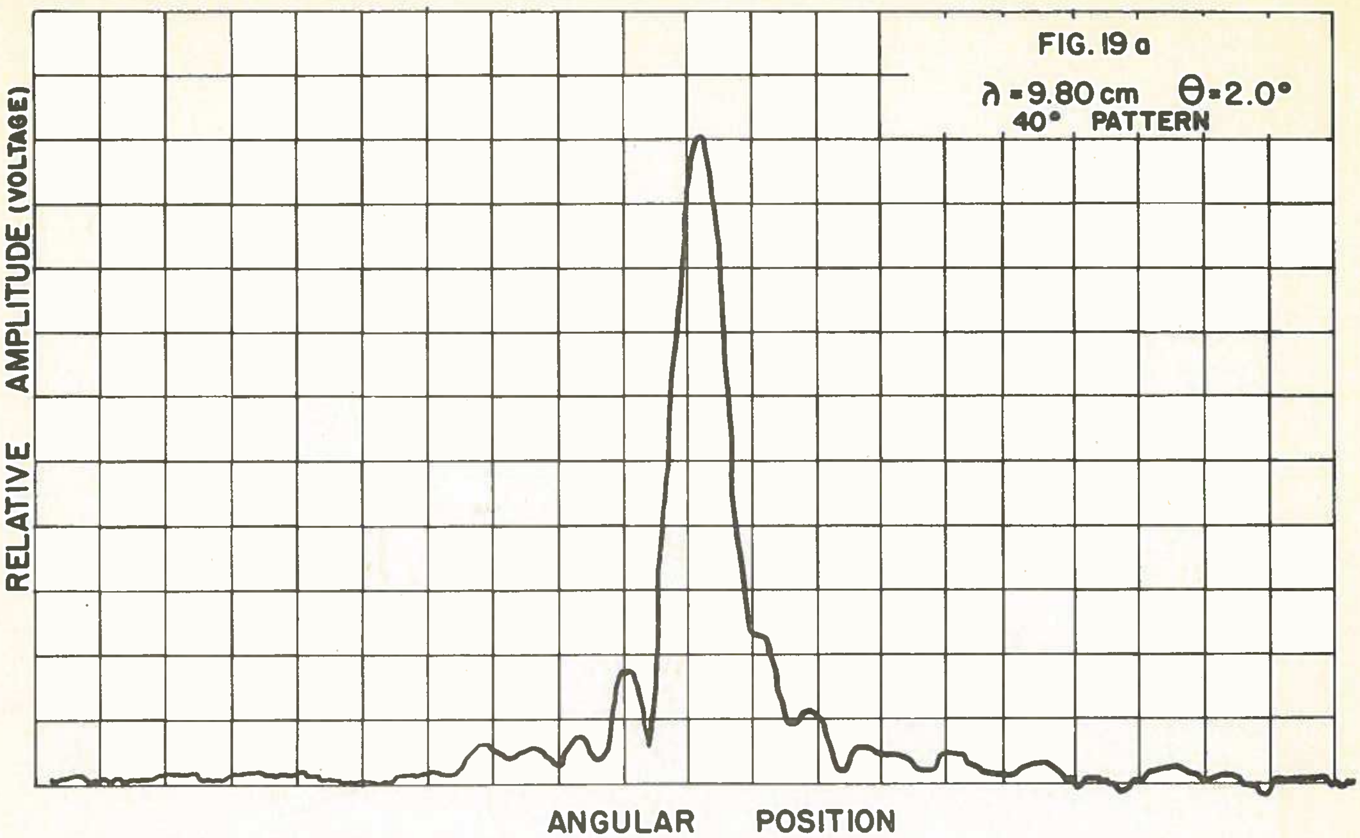
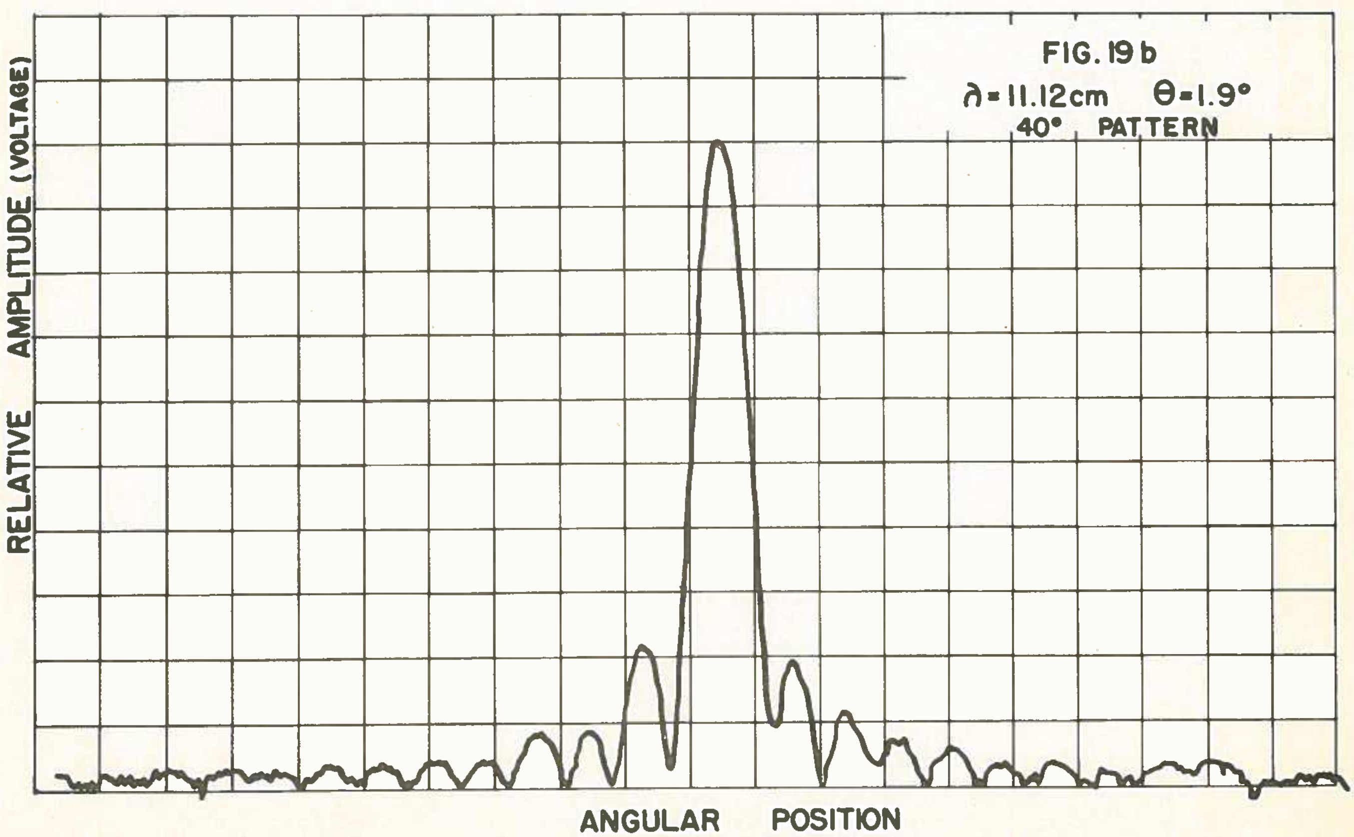


VARIATION IN SIDELOBE AMPLITUDE OF NON-RESONANT ARRAY





BROAD BAND PERFORMANCE OF NON-RESONANT ARRAY

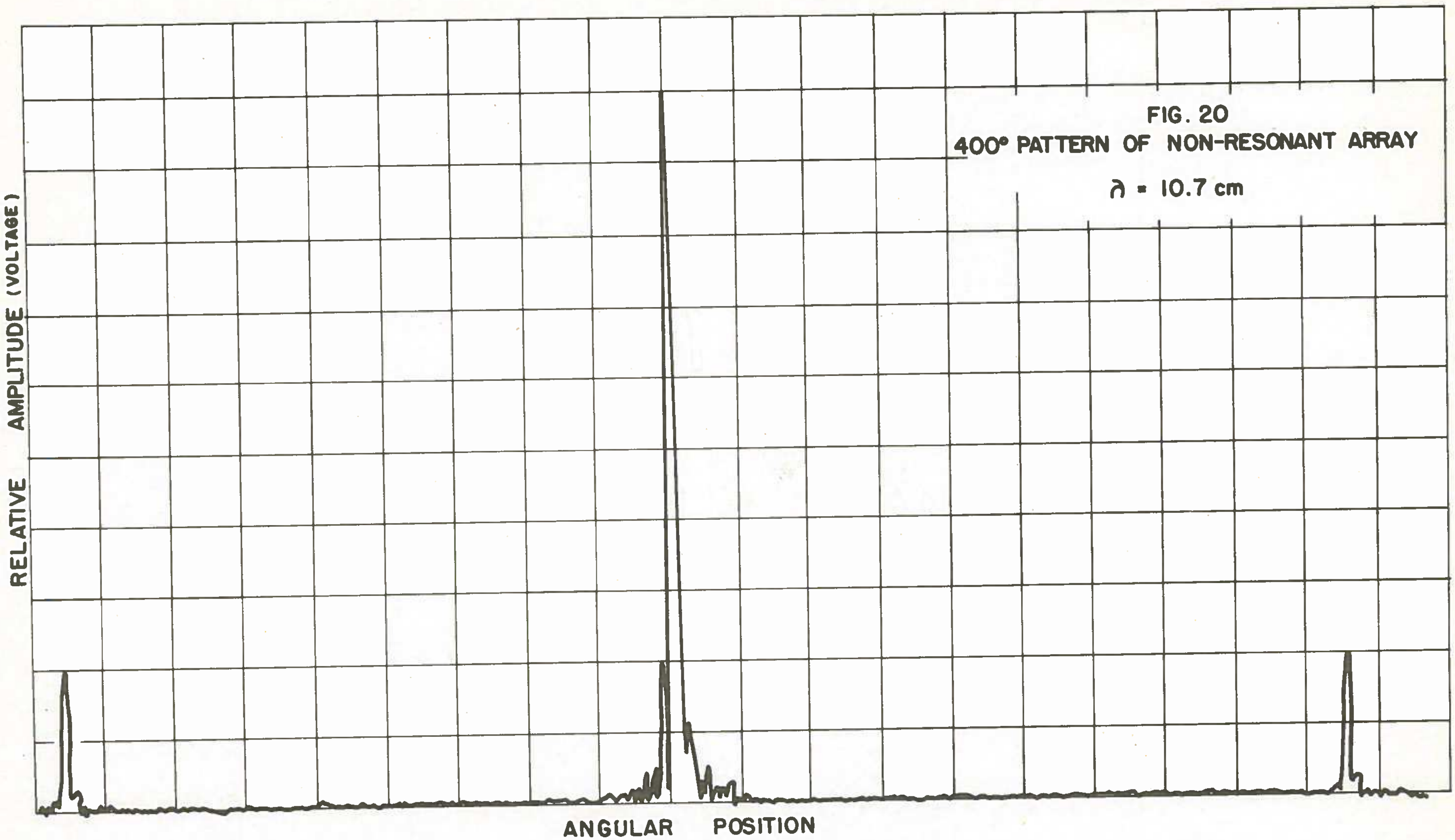


FIG. 20
400° PATTERN OF NON-RESONANT ARRAY
λ = 10.7 cm