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SCTM-88-53-54

AN ANALYSIS OF A 217 MC CAVITY ANTENNA MOUNTED IN THE TAILPLATE OF THE MK-6 WEAPON TO BE USED FOR TELEMETRY PURPOSES

Edmond S. Gillespie

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ABSTRACT

The radiation pattern of the cavity antenna when mounted in the tailplate of the MK-6 weapon was found to be greatly affected by the fins and case of the MK-6. Proper orientation of the antenna with respect to the fins will alleviate this condition somewhat; however, in general, the cavity antenna is not recommended for use on the MK-6 weapon.

Case No. 520.2

August 6, 1953

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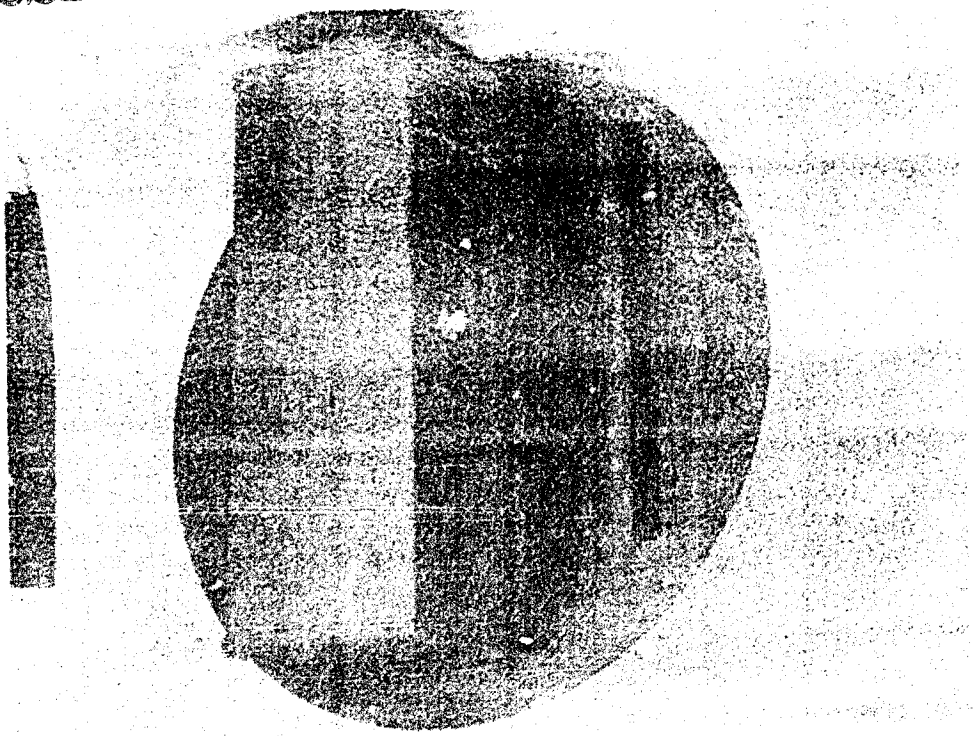
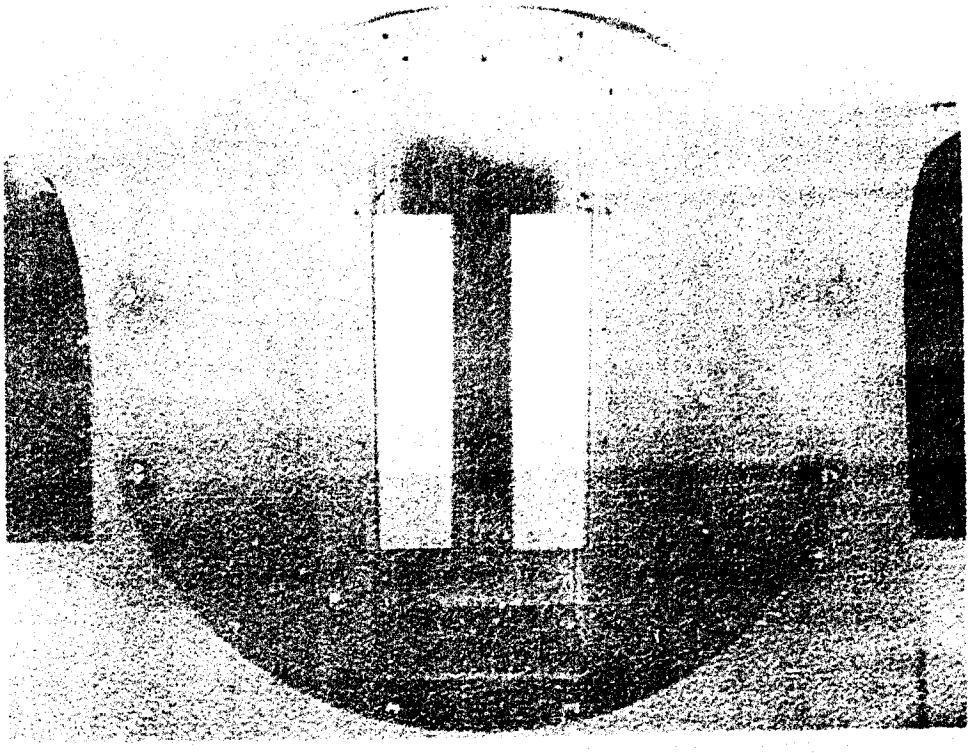


Rear View



Front View

Fig. 1 -- 217 McCavity Antenna

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AN ANALYSIS OF A 217 MC CAVITY ANTENNA MOUNTED IN THE TAILPLATE OF THE MK-6 WEAPON TO BE USED FOR TELEMETRY PURPOSES

Introduction

It has been suggested on several occasions that standard, ready-made antennas be adopted to be used on various weapons and aircraft for telemetry purposes. This is desirous in that these antennas are available, efficient radiators, and in general are well designed. However, the fallacy of this line of reasoning lies in the fact that when these antennas are mounted on a body of finite and often irregular dimensions, such as missiles, aircraft, etc., the generated radiation pattern is determined less by the antenna than by the carrying vehicle. This is not meant to imply that such an antenna cannot be used, but does suggest that a careful study be made to determine its feasibility. Thus, when considering the 217 MC cavity antenna to be used mounted in the tailplate of the Mk-6 weapon, (See Fig. 15) the effect of the finite dimensions of the carrying vehicle on the radiation pattern must be determined.

Theoretical Discussion

The cavity antenna as shown in Fig. 1 is in essence a dumbbell slot radiator backed by a cavity and will be treated as such in this report. If this antenna is mounted in an infinite and perfectly conducting ground plane, the radiation pattern will be as shown in Fig. 2. Note that in the E plane, i.e., plane of polarization, the beam width is 180° and in the H plane, i.e., normal to plane of polarization, the pattern approximates 1/2 the E plane pattern of a dipole having the same dimensions and configuration as the slot.[1] As the ground plane is reduced to finite dimensions in the H plane, the effect upon the radiation pattern is not very great. This is because the E vector is tangential to the ground screen in this plane and approaches zero at low angles to the ground screen even for the case of the infinite ground screen. In the E plane, however, as the ground screen is reduced to finite dimensions, the pattern will be greatly altered because of the abrupt discontinuity of the normal component at the edges of the screen. It can be visualized as reflected waves at the edges of the ground screen interfering with the direct wave from the slot. The resultant radiation pattern is one whose beam width is something less than 180° and has an undulating characteristic, as the pattern suggested in Fig. 3. A method of calculating these maximums and minimums and the angles at which they appear has

[1] H. G. Booker, "Slot Aerials and Their Relation to Complementary Wire Aerials," J.I.E.E. 93, Part III A, No. 4, London, 1946.

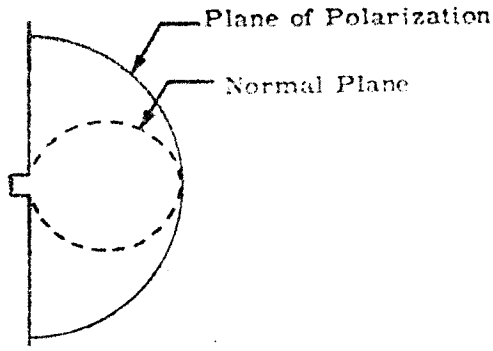

Fig. 2 -- Radiation pattern of the cavity antenna mounted in an infinite ground plane.

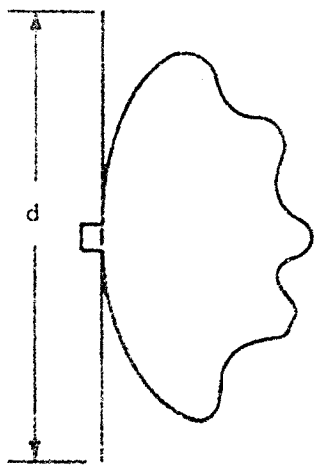

Fig. 3 -- Suggested radiation pattern in the plane of polarization of the cavity antenna mounted in a finite ground plane.

been presented by A. Dorne and D. Lazarus.[2] This is done by assuming that the far field pattern is the result of interference from three sources (See Fig. 4), one at the slot of strength $E \sin \omega t$ and two at the edges of the ground plane of strength $KE \sin(\omega t - \phi)$, where K is an amplitude constant much less than unity and ϕ is the phase difference. Both K and ϕ are functions of d and will remain constant for any given value of d.

Thus the relative field at point P is given by

$$E = \sin \omega t + K \sin(\omega t - \phi - \beta d \sin \theta) + K \sin(\omega t - \phi + \beta d \sin \theta)$$

where

$$\beta = 2\pi/\lambda.$$

By trigonometric expansion,

$$E = \sin \omega t + 2K \sin(\omega t - \phi) \cos(\beta d \sin \theta) =$$

$$\sin \omega t + 2K \sin \omega t \cos(\beta d \sin \theta) \cos \phi - 2K \cos \omega t \cos(\beta d \sin \theta) \sin \phi.$$

Setting $z = \beta d \sin \theta$

$$E = \sin \omega t (1 + 2K \cos \phi \cos z) - \cos \omega t (2K \sin \phi \cos z)$$

And the modulus of E is

$$/E/ = \sqrt{(1 + 2K \cos \phi \cos z)^2 + (2K \sin \phi \cos z)^2}$$

Squaring and neglecting K^2 terms, since $K \ll 1$,

$$/E/ = \sqrt{1 + 4K \cos \phi \cos z} \qquad (1)$$

To determine maximum and minimum values of /E/, the derivative of the square of equation (1) is taken and equated to zero.

$$\frac{d/E/^2}{dz} = 0 = -4K \sin z \cos \phi \qquad (2)$$

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[2] "Very High Frequency Techniques," Vol. 1, Chap. 7, Sec. 7-3.

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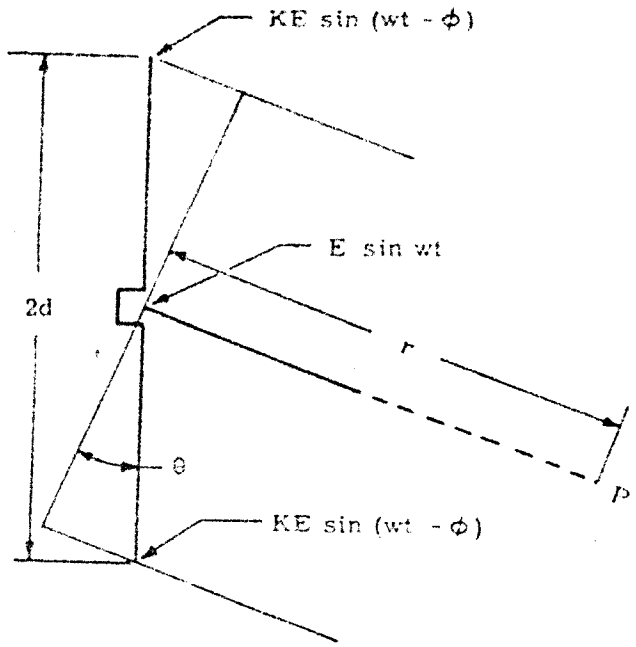

Fig. 4 -- Ground plane with cavity and image radiators (2d is width of ground screen in E plane)

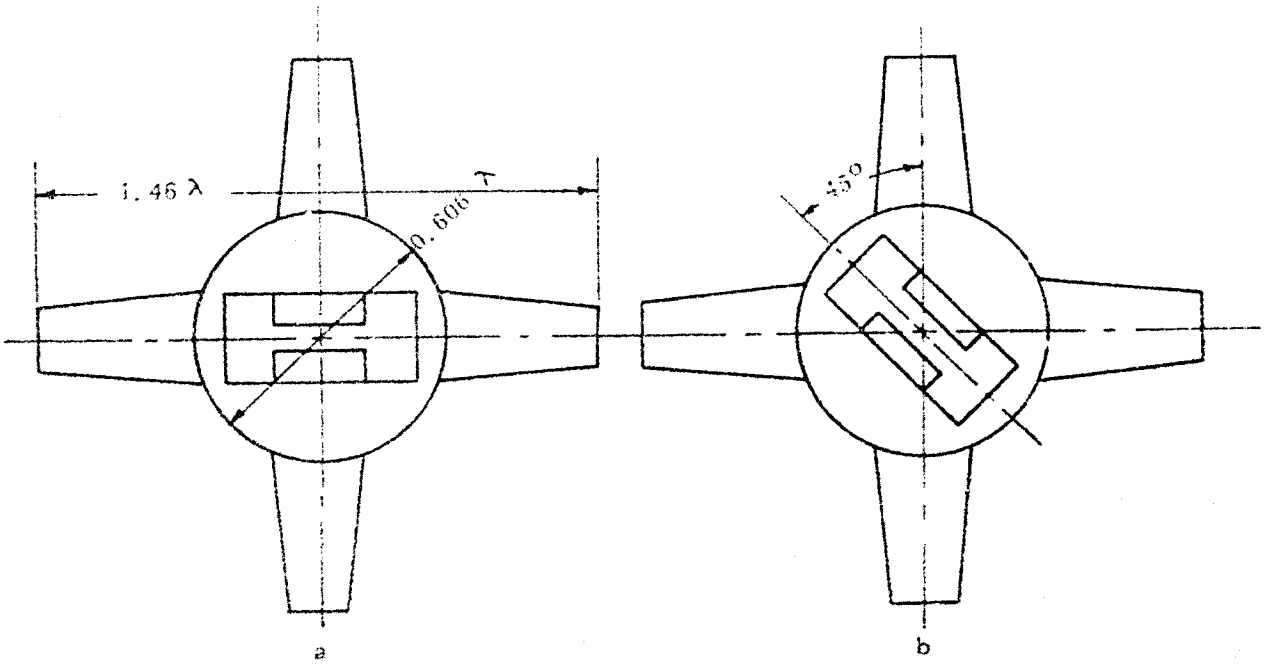

Fig. 5 -- Cavity antenna mounted in a flat ground plane whose dimensions & configuration is same as rear view of the Mk-6.

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If $\cos \phi \neq 0$, $\sin z = 0$ satisfies equation (2).

$\sin z = 0$ when $z = \beta d \sin \theta = n\pi$, where n is an integer.

Then

$\sin \theta = n\pi/\beta d = n\lambda/2d$.

Substituting these values in equation (1),

$/E/ = \sqrt{1 \pm K \cos \phi}$ and is positive for n even and negative for n odd.

Thus the positions of these maximums and minimums are determined only by the width of the ground plane. The sign of $\cos \phi$ determines whether or not it is a maximum or minimum. Also it is obvious that as the ground screen is increased in size more maximums and minimums will occur and at the same time the value of the amplitude constant K will decrease in value, causing the undulations to decrease in magnitude. In the limiting case, an infinite ground plane, the pattern will be circular with no undulation. (See Fig. 2).

Now, applying the above to the case of the cavity antenna mounted in the tail plate of the Mk-6 weapon, let us assume a flat ground plane with a configuration like that of the profile of the rear view of the Mk-6. (See Fig. 5). In the actual situation, i.e., cavity mounted on the Mk-6 weapon, the effective "ground screen" is obviously not known and can only be determined experimentally. This hypothetical case we are considering will at least give an indication of what actually exists. Also, the antenna can be oriented to any position with respect to the fins. However, we will only consider the limiting cases, i.e., E and H planes are the planes of the fins (See Fig. 5a) and E and H planes 45° to the planes of the fins. (See Fig. 5b).

Case No. 1. E and H Planes of Cavity in the Planes of the Fins.

$d = 1.46\lambda/2$ at 217 mc.

$2d = 1.46\lambda$ at 217 mc.

$\phi = (1.46/2)\, 2\pi$ radians. Thus $\cos \phi$ is negative.

$\lambda = 54.4''$ at 217 mc.

Maximums and minimums occur when

$\sin \theta = n\lambda/2d = n(54.4'')/(1.46)\,(54.4'') = n/1.46$

Let $n = 1$

$\sin \theta = 1/1.46 = 0.685$

$\theta = 43.2^\circ$

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Substituting into Equation (1)

$$/E/ = \sqrt{1 - 4K \cos \phi}$$

But $\cos \phi$ is negative. Therefore there is a maximum at

$$\theta = 43.2^{\circ}$$

Case No. 2. E and H Planes of Cavity 45° to Planes of Fins.

$d = 0.606\lambda/2$ at 217 mc.

$2d = 0.606\lambda$ at 217 mc.

$\phi = (0.606/2)\, 2\pi$ radians. Thus $\cos \phi$ is positive.

$\lambda = 54.4''$ at 217 mc.

Maximums and minimums occur when

$$\sin \theta = n\lambda/2d = n(54.4'')/(0.606)\ (54.4'') = n/0.606$$

Obviously no maximums or minimums occur.

Comparison of Experimental and Calculated Data

The experimental data are given in Figs. 6-13. Note that the data were taken using a full scale mock-up of the tail section and a 1/13.8 scale model. Also, the patterns are plotted in power linear units. The following is a comparison of E plane patterns taken experimentally with those calculated (See Figs. 6-9)

WIDTH OF GROUND PLANE		CALCULATED DATA		MEASURED DATA	
		MAX.	MIN.	MAX.	MIN.
Case 1	1.46	43.2°	None*	35°	None*
Case 2	0.606	None*	None*	None*	None

*In fact, there necessarily would be a minimum at $\theta = 0^{\circ}$ if there is a maximum at 43.2°; likewise, there would be a maximum at $\theta = 0^{\circ}$ for case 2.

The correlation of the calculated and measured data is quite good. The discrepancy of angle in Case 1 occurs because the antennas on the full scale mock-up and the model are recessed corresponding to the actual situation; whereas, the calculated data assumed a flat ground plane. Thus, the actual dimensions of the 'ground screen' are not known as this recession would in effect change its width. The 35° angle indicates a wider ground screen in the E plane. Also, in Case 2

where the E plane of the cavity was oriented 45° to the fins, the measured patterns showed a half-power beam width of 122° (See Fig. 7); whereas, the beam width of the cavity mounted in a flat ground plane with a diameter equal to the diameter of the tailplate is only 90° (See Fig. 10). This again indicates an effective ground screen wider than the tailplate of the Mk-6. Further investigation revealed that when the cavity antenna is mounted flush with the rear of the Mk-6 and oriented 45° to the plane of the fins, the E plane pattern again exhibits an undulating characteristic with maximum signal strength in a direction $\theta = 37°$ (See Fig. 12). Thus if the cavity is mounted flush with the rear of the Mk-6, the E plane pattern is approximately the same despite the cavity's orientation with respect to the fins. This widening of the effective ground screen in the E plane is obviously caused by the case of the Mk-6 weapon. The effects of the case are counteracted somewhat by recessing the cavity.

Examining the measured H plane patterns, we find that in Case 1 the half-power beam width is an apparent 72° but the maximum power in this plane is approximately 2 db down because of the E plane pattern, thus giving an effective half-power beam width of only 34° (See Figs. 6-8). In Case 2 the H plane pattern has a half-power beam width of 103°, also, the maximum power is the same for both the E and H planes (at $\theta = 0°$) (See Figs. 7-9).

Explanation of Results

Obviously, the cavity antenna is intended to be used where an accompanying aircraft will be the receiving station. Also, because the Mk-6 rolls, a circularly polarized receiving antenna is required. If the receiving aircraft is able to maintain a position to rear of and on the axis of the Mk-6 during its flight, a reasonably stable signal will be available at the receiving antenna on the airplane. However, if the cavity is oriented so that its E and H planes are in the planes of the fins, approximately 2 db of directive power gain will be lost, also, as the receiving aircraft moves away from the axis of the Mk-6 in any direction, the signal strength becomes quite roll sensitive, i.e., an alternate maximum and minimum signal at each 90° of roll. This is accentuated because of the maximum directive gain at 35° in the E plane. (See Fig. 6). If the cavity is oriented so that its E and H planes are 45° to the planes of the fins and is recessed as described above, maximum directive gain will be obtained along the axis of the Mk-6 in both the E and H planes, and as the receiving station is deviated away from the axis of the Mk-6 again roll sensibility will be detected but not pronounced for small deviations. (See Fig. 7). Thus, if the cavity antenna is to be used, it should be oriented so that its E and H planes are 45° to the planes of the fins.

Now suppose it was required that the receiving plane had to maintain a slant range distance of 60,000 feet from the point of detonation and the plane in question cannot exceed the altitude of 30,000 feet. (See Fig. 14). Note

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also that for this example, the Mk-6 is dropped from an altitude of 40,000 feet. Because of the nature of the Mk-6 trajectory and the fact that the radiation of the cavity will be to the rear (See Fig. 7) it is advisable to locate the receiving station to the rear of the mother plane. It can be either moving away from it or normal to its path. We will disregard the pattern of the receiving antenna. At the time of release, the axis of the Mk-6 is horizontal as indicated by Fig. 14. At this time the receiving aircraft is in a direction 17° from the axis of the Mk-6; referring to the radiation pattern, Fig. 7, in this direction the power is approximately maximum. As the Mk-6 falls along its trajectory the signal will decrease until the time of detonation, at which time the receiving plane will be in a direction 50° from the axis of the Mk-6. This corresponds to a decrease in power to approximately 3 db from the maximum. Note that when operating in this region of the pattern any small changes in the geometry of the situation will produce large changes in signal strength. For example, if the Mk-6 just before detonation had a yaw or pitch with an angular displacement of 20°, the power deviation at the receiving antenna would be approximately 10 db plus any variation because of roll. Another possibility is that the receiving equipment may not operate at altitudes approaching 30,000 feet. Suppose the receiving aircraft had an altitude of 20,000 feet; obviously the situation would be much worse.

Conclusions

If the cavity can be used for a specific application, it should be mounted so that its E plane is oriented 45° to the plane of the fins. However, in general, because of the physical limitations imposed upon it, the receiving aircraft cannot operate in a desirable portion of the cavity's radiation pattern. Also the receiving antenna requirements would be quite stringent. For these reasons the cavity antenna is not recommended for use on the Mk-6 weapon.

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Case No. 520.2
August 6, 1953

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MODEL NUMBER MK-6	PROJECT
MODEL SCALE 1/13.6	CLASSIFICATION
MODEL FREQUENCY 3000 MC	ANTENNA TYPE Cavity
REMARKS E plane in the plane of the fins	ANTENNA LOCATION tailplate (processed)
	FULL SCALE FREQUENCY 217 MC

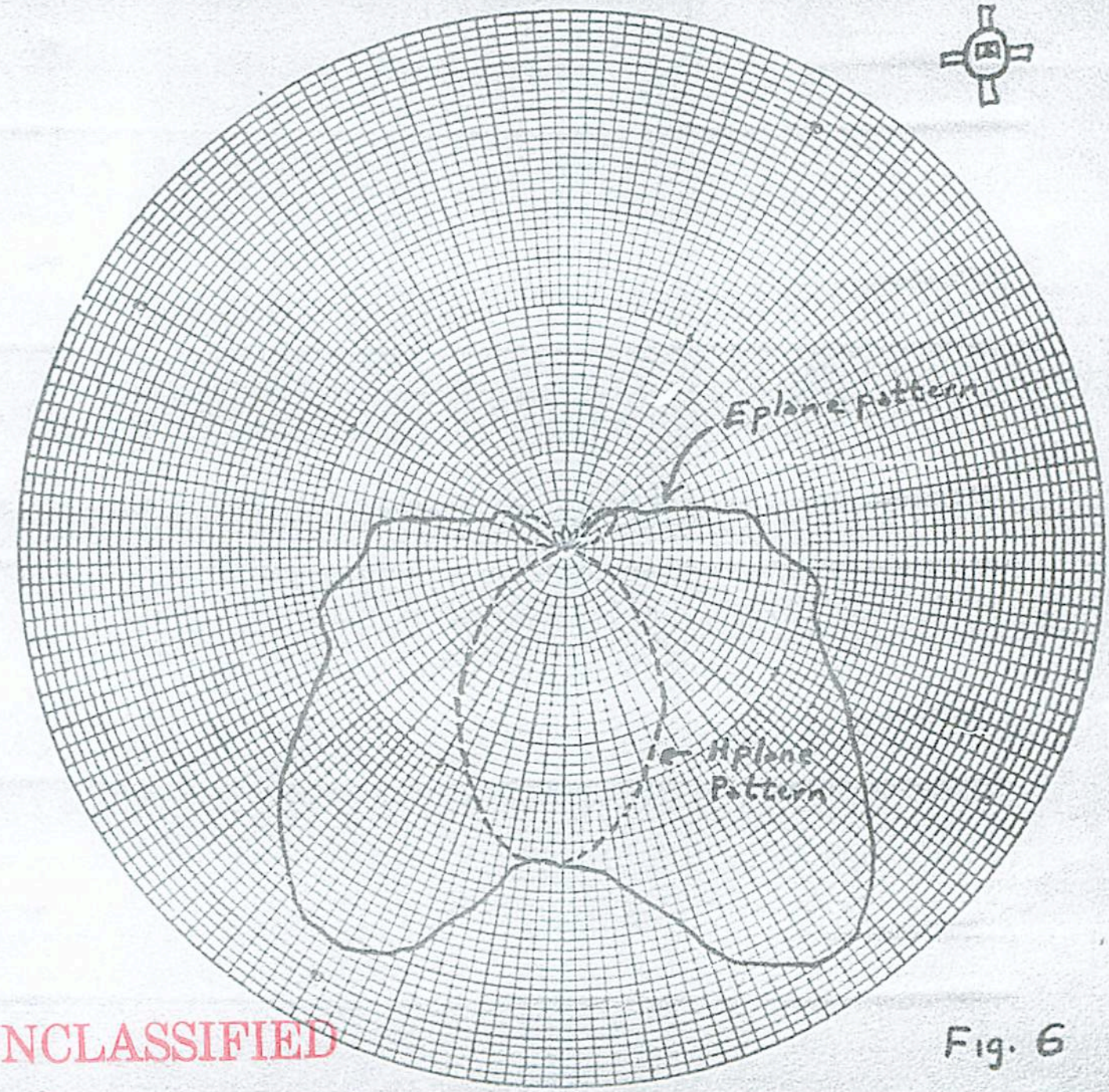

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Fig. 6

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REMARKS	ELEVATION ANGLE
	POLARIZATION Both Shown
OPERATOR Smith DATE	REMARKS
APPROVED ESM DATE	CURVE PLOTTED IN: VOLTAGE ( ), POWER (✓), DECIBELS ( )

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MODEL NUMBER MK-6	PROJECT
MODEL SCALE 1/13.8	CLASSIFICATION
MODEL FREQUENCY 3000MC	ANTENNA TYPE Cavity
REMARKS E plane 45° to plane of fins	ANTENNA LOCATION tailplate (Recessed)
	FULL SCALE FREQUENCY 217Mc

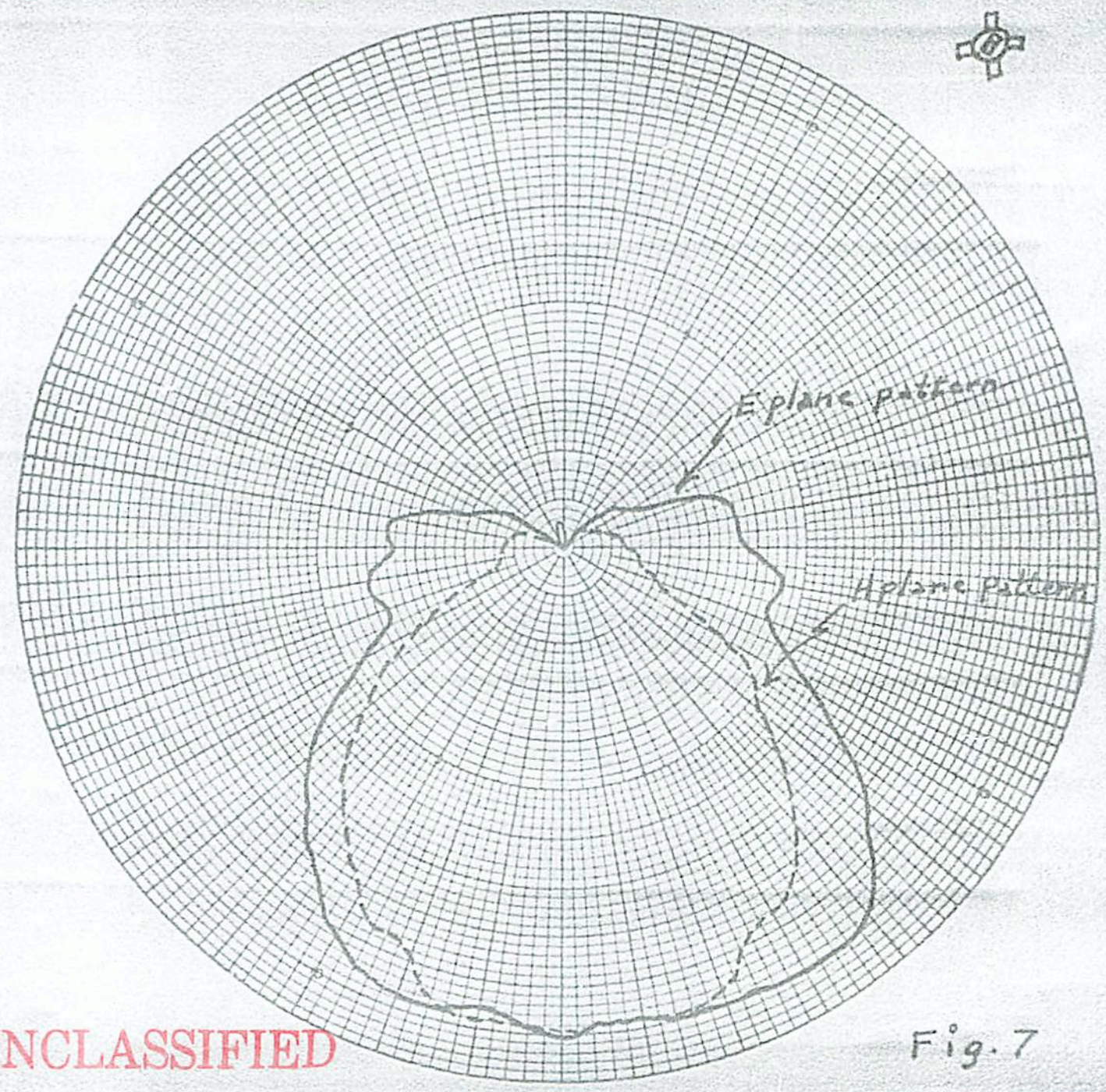

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Fig. 7

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REMARKS	ELEVATION ANGLE
	POLARIZATION Both Shown
OPERATOR Smith DATE	REMARKS
APPROVED EEG DATE	CURVE PLOTTED IN: VOLTAGE ( ), POWER (X), DECIBELS ( )

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MODEL NUMBER Mock-up of the MK-6 tail	PROJECT
MODEL SCALE Full	CLASSIFICATION
MODEL FREQUENCY 217 MC	ANTENNA TYPE Cavity
REMARKS E plane in the plane of the fins	ANTENNA LOCATION tail plate
	FULL SCALE FREQUENCY 217

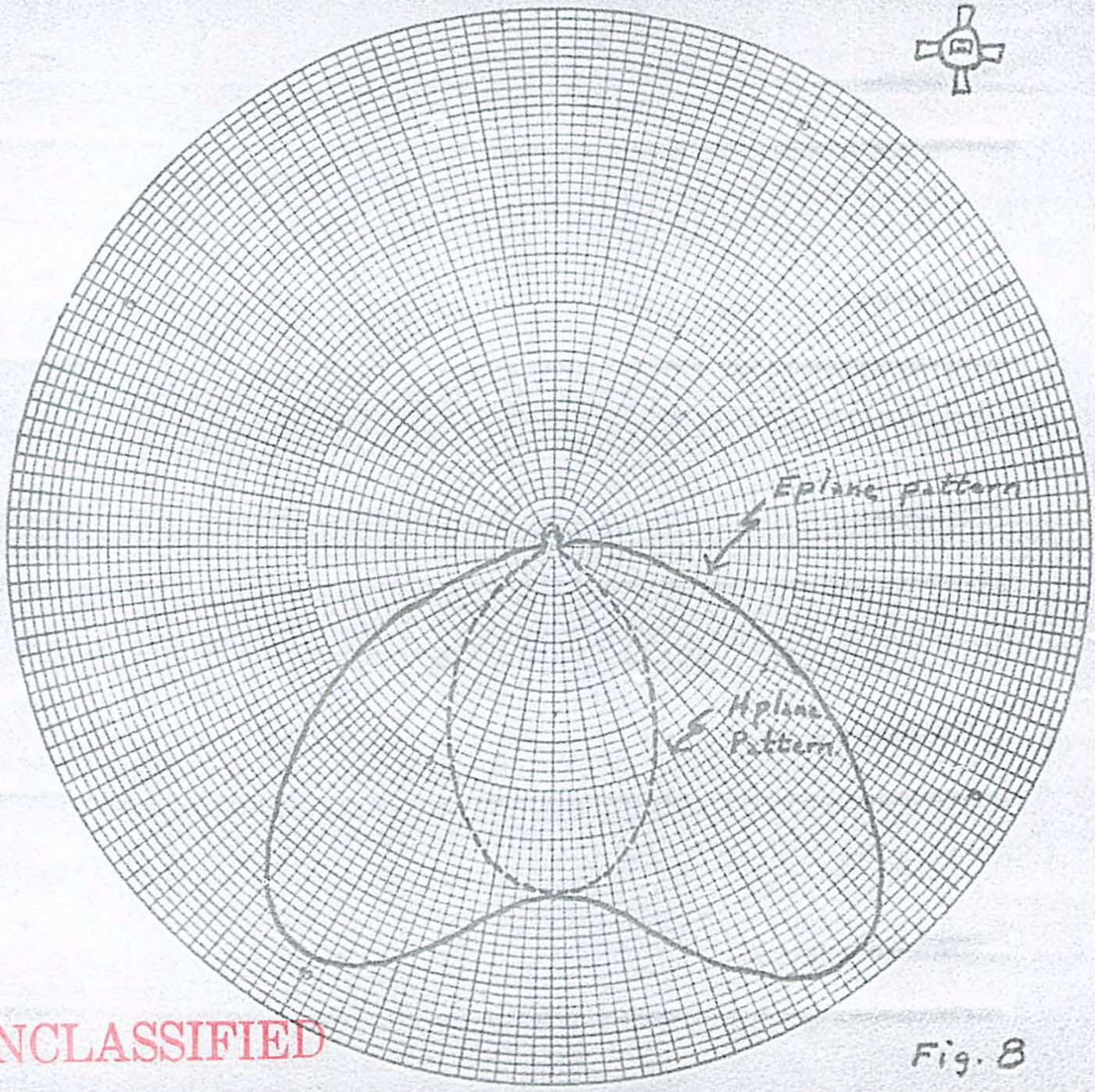

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Fig. 8

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REMARKS	ELEVATION ANGLE
	POLARIZATION Both Shown
OPERATOR Smith DATE	REMARKS
APPROVED EAM. DATE	CURVE PLOTTED IN: VOLTAGE ( ), POWER (X), DECIBELS ( )

MODEL NUMBER Mock-up of MK-6 tail
MODEL ~~SCALE~~ Freq 217MC
MODEL FREQUENCY Full Scale
REMARKS E plane 45° to plane of the fins.

PROJECT
CLASSIFICATION
ANTENNA TYPE Cavity
ANTENNA LOCATION tailplate
FULL SCALE FREQUENCY 217 M.C.

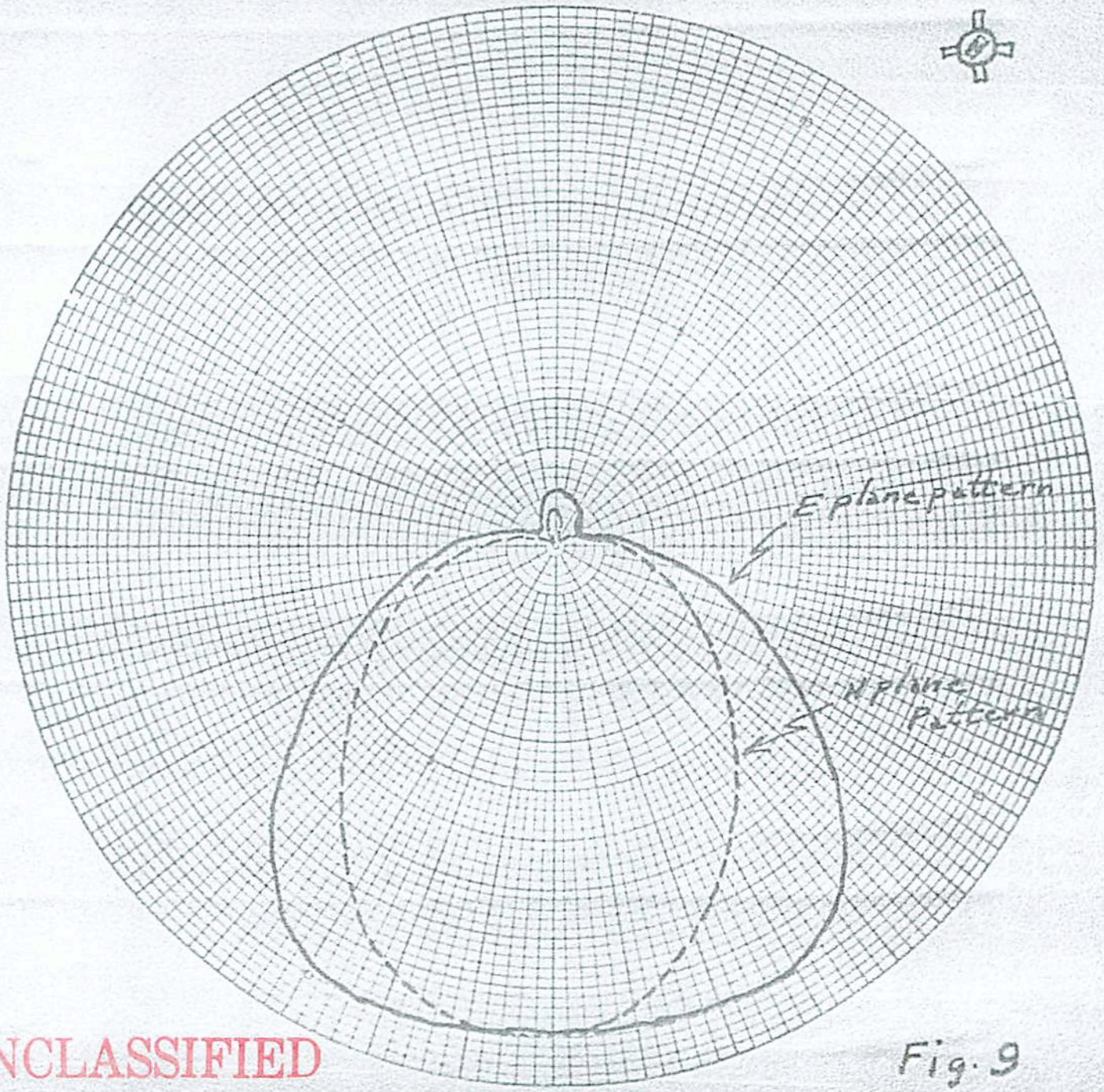

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Fig. 9

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REMARKS
OPERATOR Smith DATE
APPROVED E.B.Y. DATE

ELEVATION ANGLE
POLARIZATION Both shown
REMARKS
CURVE PLOTTED IN: VOLTAGE ( ), POWER (X), DECIBELS ( )

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MODEL NUMBER Cavity Antenna	PROJECT
MODEL SCALE 1/13.8	CLASSIFICATION
MODEL FREQUENCY 3000 MC	ANTENNA TYPE
REMARKS Using the tailplate as A ground plane	ANTENNA LOCATION
	FULL SCALE FREQUENCY 217 MC

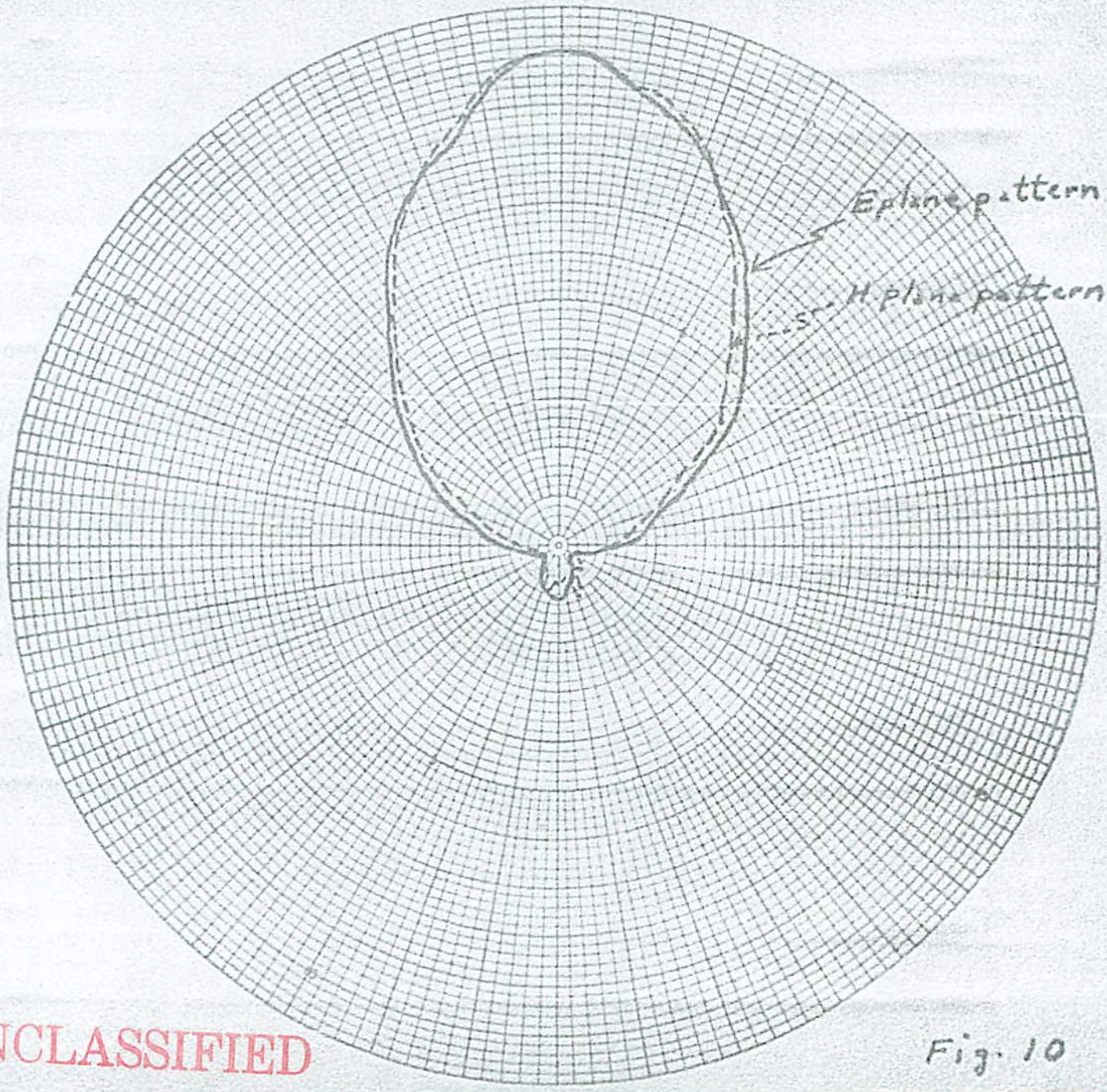

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Fig. 10

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REMARKS	ELEVATION ANGLE
	POLARIZATION Both Shown
OPERATOR Smith DATE	REMARKS
APPROVED E.B.J. DATE	CURVE PLOTTED IN VOLTAGE ( ), POWER (✓), DECIBELS ( )

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MODEL NUMBER MK-6
MODEL SCALE 1/13.8
MODEL FREQUENCY 3000 MC
REMARKS E plane in plane of the fins.

PROJECT
CLASSIFICATION
ANTENNA TYPE Cavity
ANTENNA LOCATION tailplate (Flush)
FULL SCALE FREQUENCY

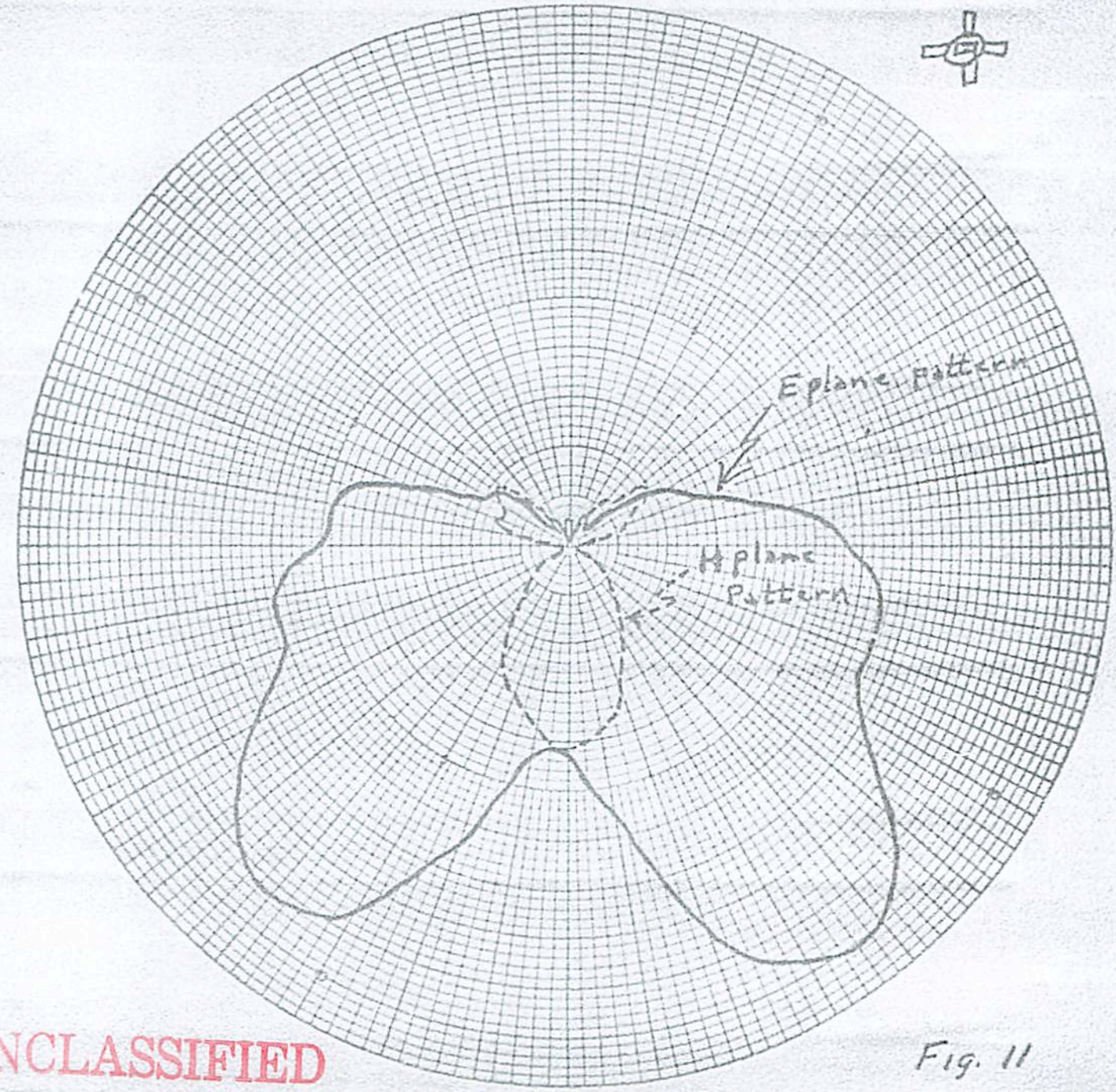

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Fig. 11

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REMARKS
OPERATOR Smith DATE
APPROVED E. S. G. DATE

ELEVATION ANGLE
POLARIZATION Both Shown
REMARKS
CURVE PLOTTED IN: VOLTAGE ( ), POWER (X), DECIBELS ( )

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MODEL NUMBER MK-6	PROJECT
MODEL SCALE 1/17.8	CLASSIFICATION
MODEL FREQUENCY 3000 MC	ANTENNA TYPE Cavity
REMARKS E plane 45° to plane of fins.	ANTENNA LOCATION Tailplate (Flush)
	FULL SCALE FREQUENCY 217 MC.

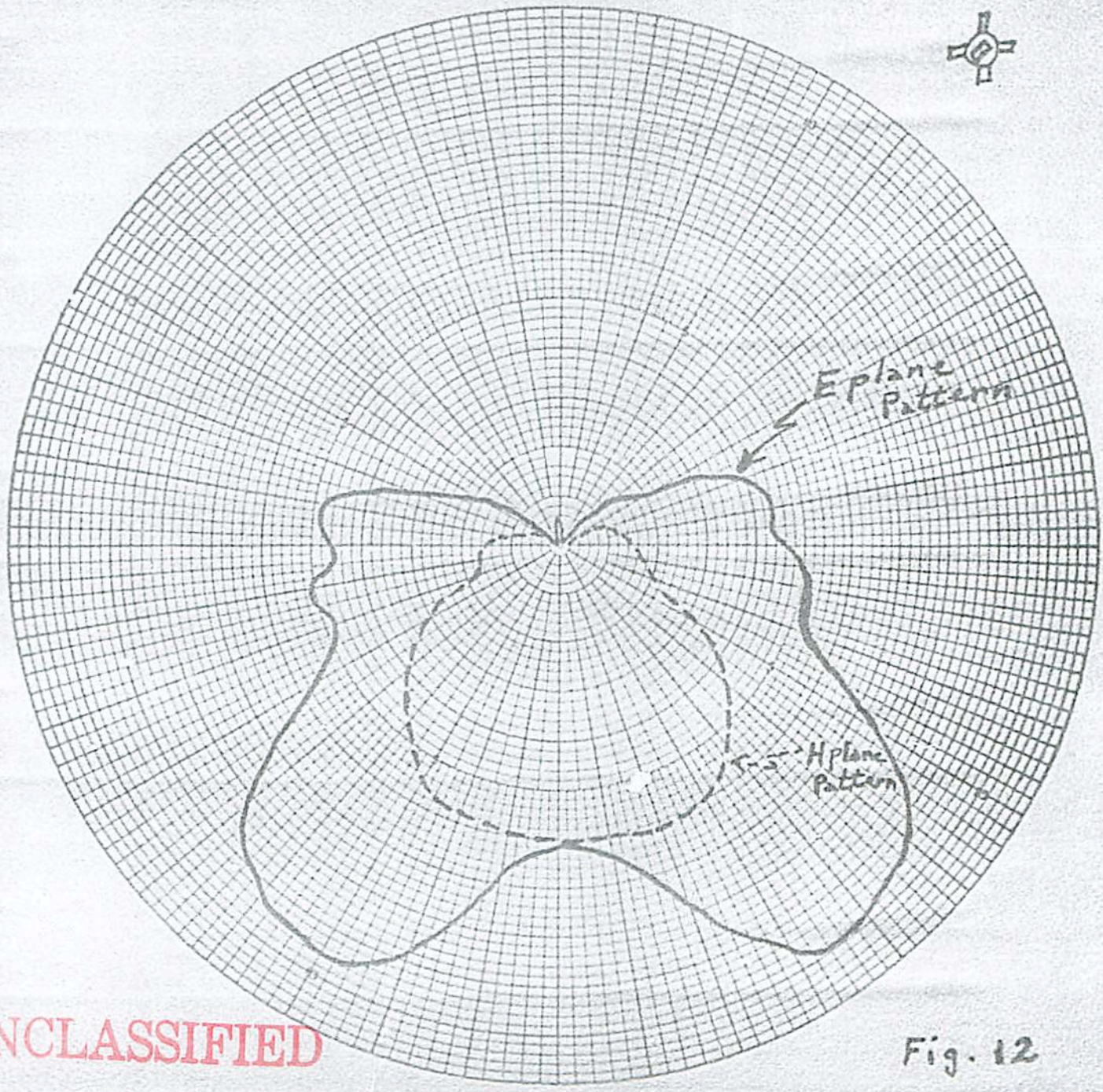

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Fig. 12

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REMARKS	ELEVATION ANGLE
	POLARIZATION Both Shown
OPERATOR Smith DATE	REMARKS
APPROVED E.S.S. DATE	CURVE PLOTTED IN: VOLTAGE ( ) POWER (X) DECIBELS ( )

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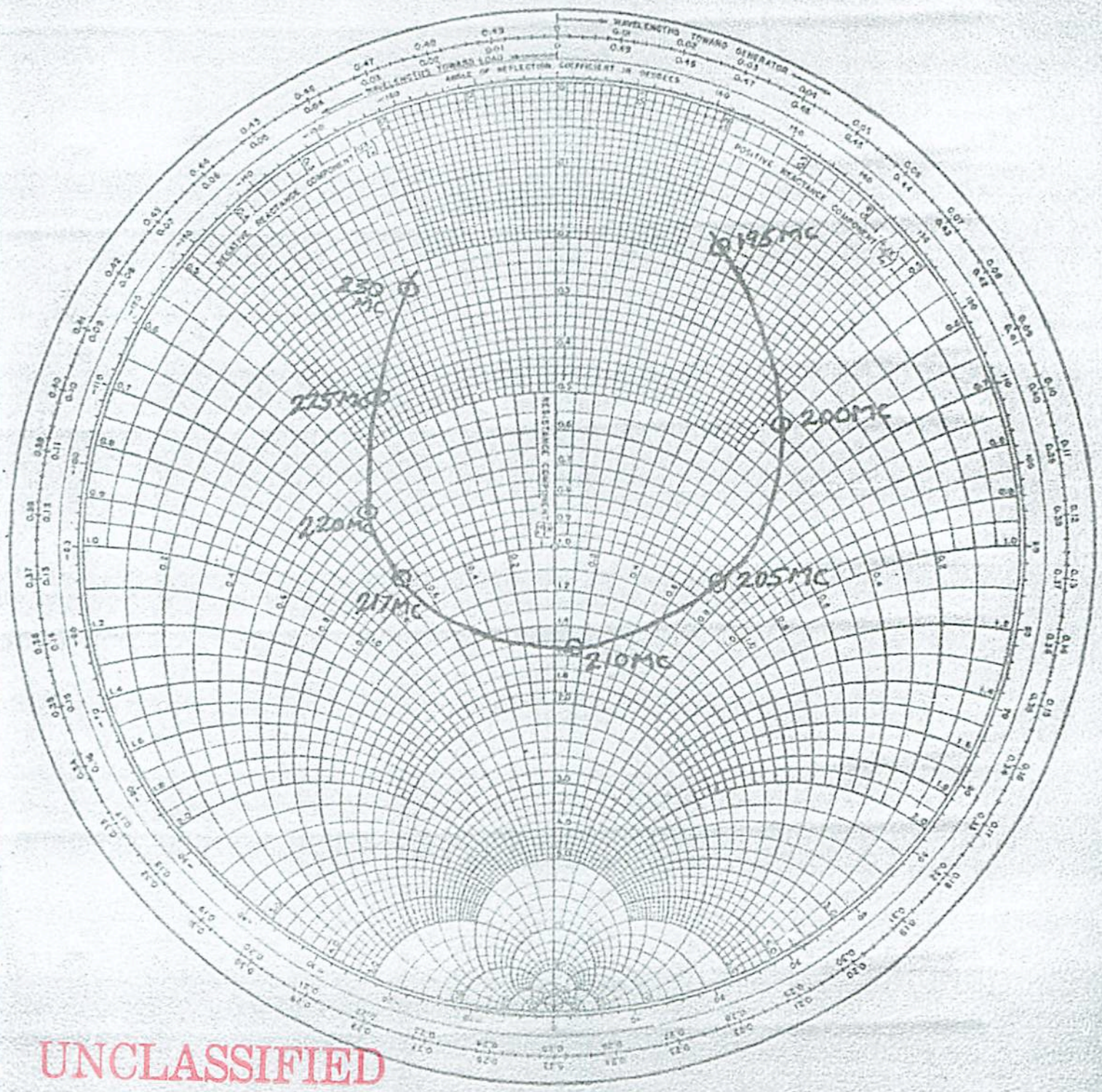

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Fig. 13 Impedance curve of the cavity antenna mounted in the tailplate of the MK-6 weapon.

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

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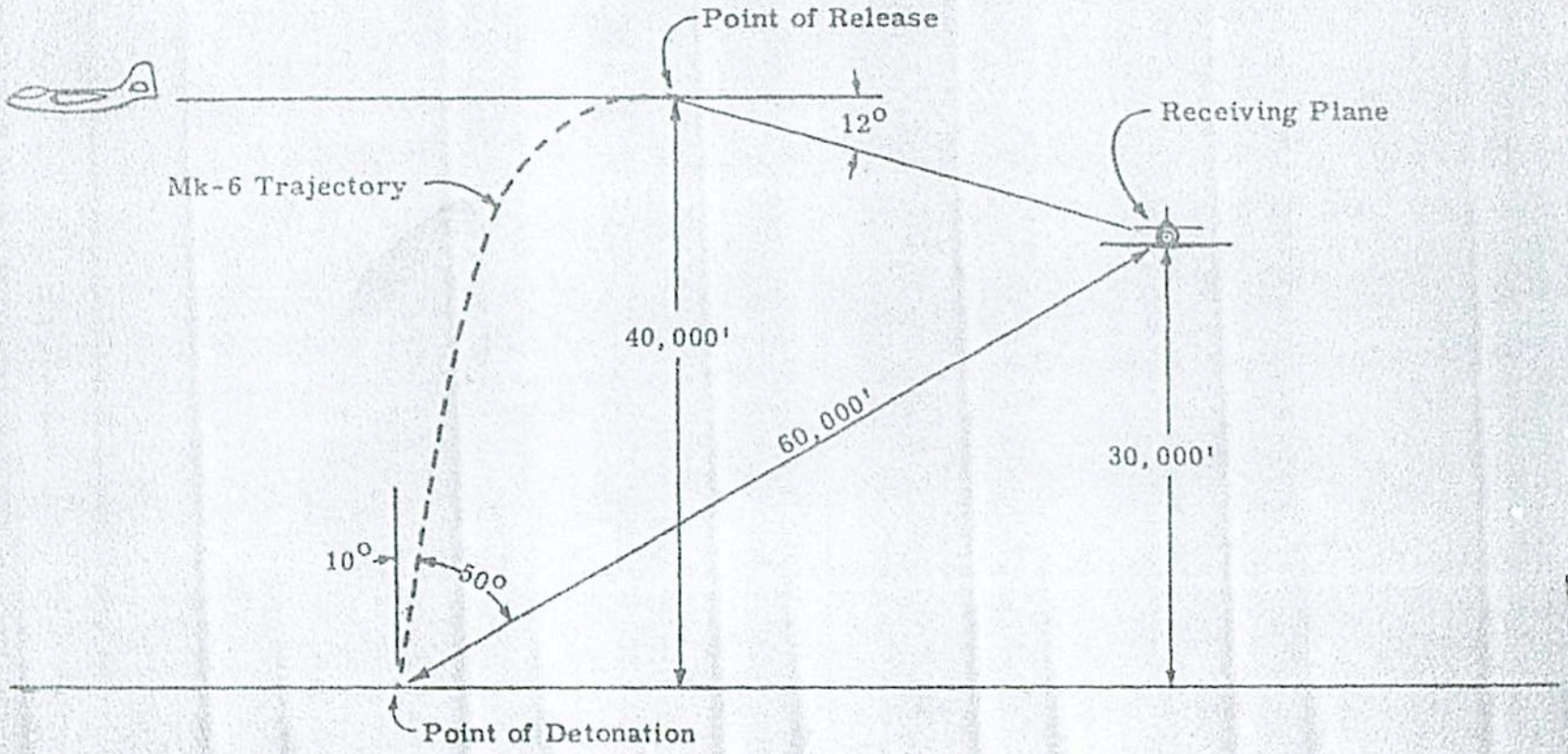

Fig. 14 -- Possible flight pattern for telemetering the Mk-6 Weapon, when the cavity antenna is used as a transmitting antenna.

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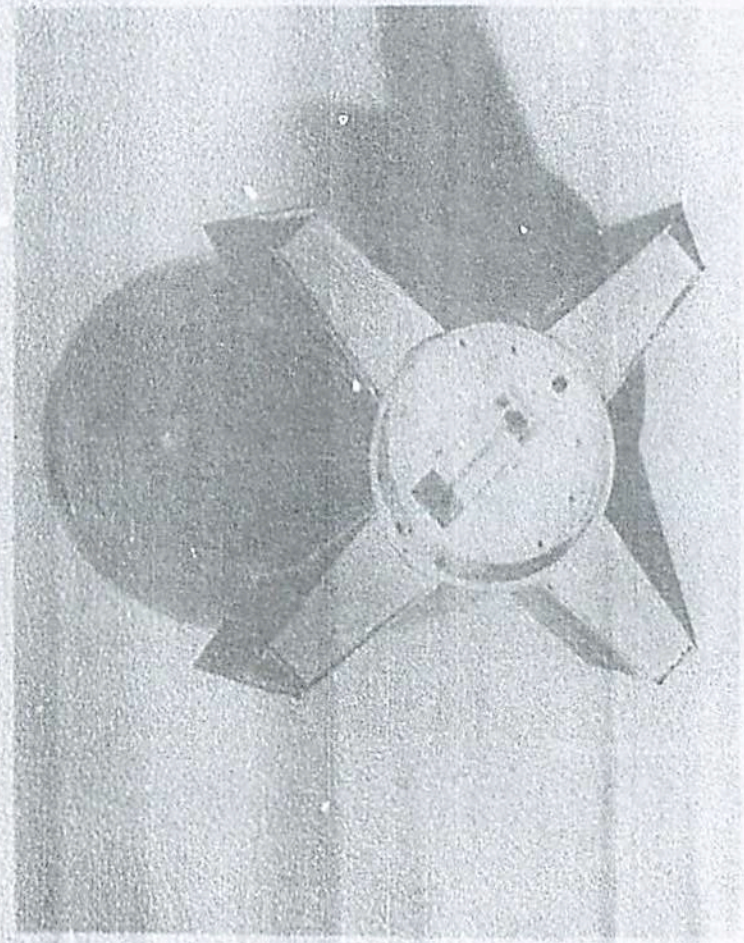
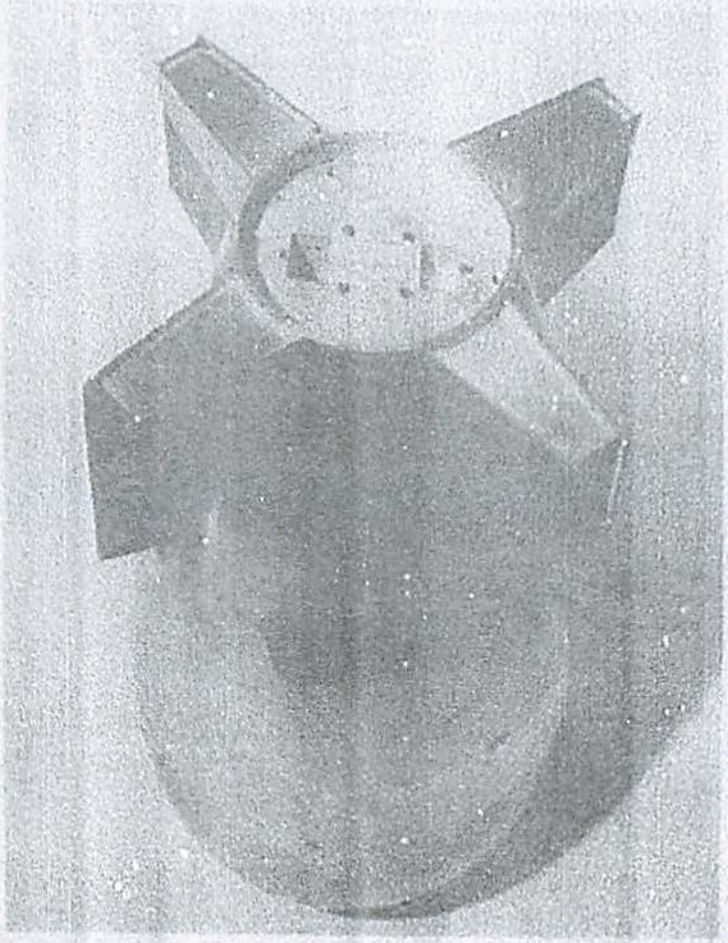


E and H Planes in the Planes of the Fins



E and H Planes of Cavity 45° to Planes of the Fins

Fig. 15 -- 1/13.8 Scale Model of Mk-6 With Cavity Antenna Mounted in the Tailplate

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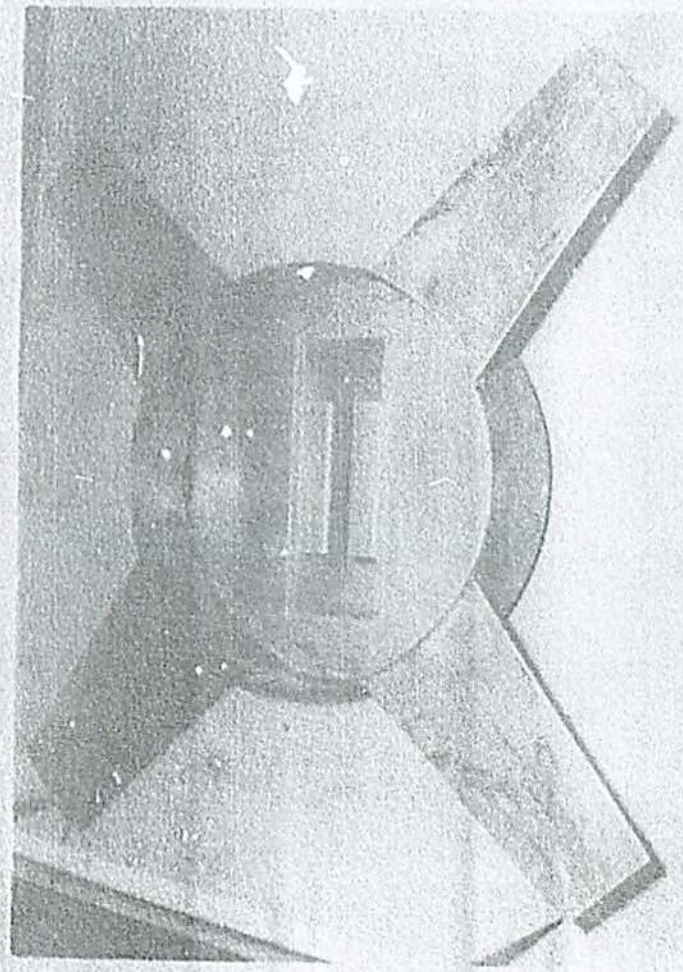
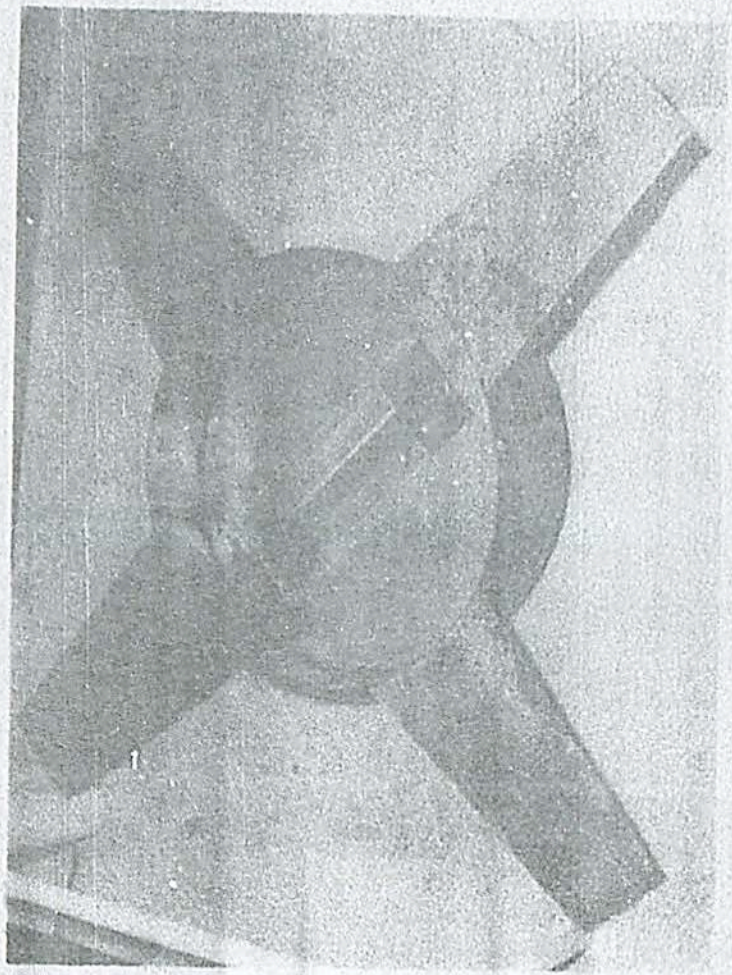


E and H Planes in the Planes of the Fins



E and H Planes of Cavity 45° to Planes of the Fins

Fig. 16 -- Full Scale Mock-up of Mk-6 Tailplate

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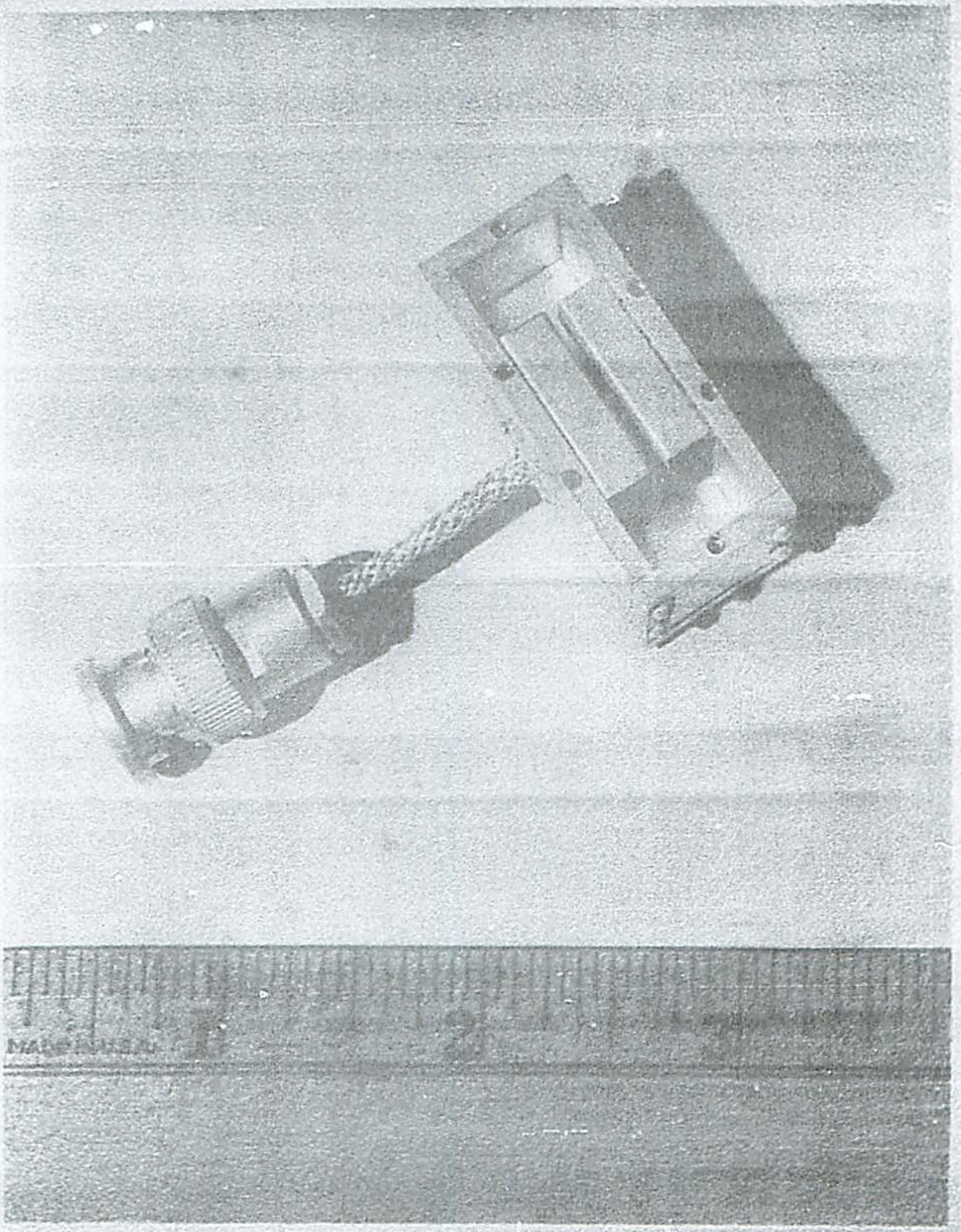

Fig. 17 -- 1/13.8 Scale Model of the 217 Mc. Cavity Antenna

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