TECHNICAL REPORT ECOM-2675

FERRITE CABLE CHOKES

BY

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MARCH 1966

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Institute for Exploratory Research

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U. S. ARMY ELECTRONICS COMMAND
FORT MONMOUTH, NEW JERSEY

ABSTRACT

This technical report describes a theoretical and experimental investigation of factors affecting the performance of toroidal inductors with ferrite cores and windings of coaxial cable. Design procedures are developed and described for toroidal cable chokes which provide a specified minimum amount of rf isolation over a band of frequencies. It is shown how one may maximize the width of the frequency band for a given rf isolation impedance. In fact it is shown that the entire band, from 2 to 30 Mc, may be covered by a set of only three individual cable chokes, providing an rf isolation of better than 5,000 ohms.

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FERRITE CABLE CHOKES

INTRODUCTION

The employment of ferrites in HF and VHF antennas[1] is being extensively explored as part of the current research effort[2] undertaken by personnel of the Institute for Exploratory Research Division C. In particular, one requirement is the wideband rf-isolation of an antenna from its feed system and transmitting equipment. That is, it is necessary to suppress the flow of rf antenna currents on the outer conductor of the coaxial feed cable. The presence of such currents affects unpredictably the readings of measuring equipment at the driving end of the feed cable. These currents also radiate electromagnetic energy, thus altering the overall radiation characteristics of the antenna. In addition, these currents cause additional losses in the antenna and thereby decrease antenna efficiency.

These currents can be suppressed to a large extent by the proper design of rf cable chokes placed between the antenna and the driven end of the coaxial feed cable. The purpose of these chokes is to provide a high rf impedance over a broad frequency band between opposite ends of the braided outer conductor of the coaxial cable with which the choke is wound.

I. PERFORMANCE FACTORS

The purpose of the investigation described in this section was to design cable chokes covering the HF frequency range in a small number of bands and providing a minimum of 5,000 ohms of rf isolation. As a result of this initial investigation those factors which affect the performance of toroidal cable chokes are established.

As illustrated in Figure 1, the isolation is to appear between terminals a and a' of an inductor which consists of a toroidal ferrite core wound with N turns of RG-188 miniature coaxial cable. The equivalent circuit of Figure 2 was chosen to interpret the measured performance of the choke. It will be shown that this circuit describes the electrical performance of the choke with sufficient accuracy. The capacitance C includes the capacitance of the container in addition to the capacitance between turns of the winding. The conductance G includes the conductor loss and the frequency-dependent electric and magnetic losses in the ferrite. The choke susceptance can be measured as a function of frequency. L and C may then be evaluated from the data using a graphical method described by Czerwinski.[3]

During the initial phase of this investigation, the 2- to 20- Mc frequency range was covered in five "bands" with a ferrite cable choke for each band. Each choke was designed to be self-resonant at a frequency f_o near the center of each band when mounted inside a container. The objective was to make each choke wideband.

In designing each choke, the following steps were taken: 1) the self-capacity of the container was measured: 2) the equivalent capacitance between turns of the choke was estimated on the basis of past experience: 3) the inductance required to resonate the contained choke at a given frequency f_0 was then computed: and 4) the number of turns necessary to produce the calculated inductance was calculated from the relation between the inductance and the dimensions of a toroid:

$$N^2 = \frac{L}{.0046\ \mu\ H\ \log_{10}\frac{OD}{ID}} \qquad (1)$$

where L = inductance in μh

μ = initial permeability

H = height of toroid in cm

OD = outside diameter of toroid

ID = inside diameter of toroid .

After winding the toroid it was placed in the container. The admittance was then measured in a band of frequencies on either side of the self-resonant frequency. The magnitude of the admittance was plotted versus frequency.

As an example, Figure 3 shows the data for a nine turn cable choke. The "bandwidtn" indicated is the frequency range for which the absolute value of the admittance is smaller than 0.2 millimhos. This definition of bandwidth is used throughout. It is arbitrary, of course, but adequate for comparison purposes. The exact values of L, C, and f_0 for the nine turn choke were determined from the measured data as shown in Figure 4. Figure 5 is a composite arrangement of the individual characteristics of each cable choke designed for each of the five frequency bands.

The following pertinent facts were noted:

1. Use of "H" ferrite (General Ceramics) resulted in a conductance higher than considered tolerable. The conductance for a nine turn "H" ferrite toroid was between .2 and .3 millimhos, in the 3-Mc wide band, from 5 to 8 Mc.

2. The ferrite designated 4373 (General Ceramics) resulted in too high a conductance in the TC1-06 cup core arrangement. Part of the problem was that no more than six turns of RG-188 coaxial cable could be conveniently wound on the cup. The conductance for six turns varied between .4 and .5 millimhos, in the 4-Mc wide band, from 8 to 12 Mc.

3. It was found that the conductance exceeded the limit of .2 millimhos when the height of the toroid was decreased to approximately the thickness (difference between outside and inside radii) of the toroid. The results of this investigation suggest keeping the height at least four or five times the thickness of the toroid.

4. Whenever a many-turn toroid was rewound with only a few turns, the conductance increased greatly. This phenomenon cannot be explained solely on the grounds, for example, that the self-resonant frequency changed, because of the great increase in conductance. Two 4373 ferrite chokes, one wound with nine turns and the other with five turns exhibited a difference of a factor of three in conductance when the chokes were compared at the self-resonant frequency of each of them.

5. Because of this phenomenon the 4373 ferrite was not found useful above 5 Mc since the conductance exceeded the limit considered tolerable.

The dependence of conductance upon the number of turns and height of the toroid can be explained by considering the equivalent circuit of Figure 6. The resistance R_s represents both the conductor losses and magnetic losses in the ferrite. The inductance L_s represents the hypothetical inductance of the choke in the absence of capacitance: the resistance R_p represents the electric losses in the ferrite. This modified equivalent circuit is a more accurate description of the electrical properties of the choke than that of Figure 2.

The inductance L is theoretically related to the parameters of Figure 6 by the following expression:

$$L = \frac{R_s^2 + \omega^2 L_s^2}{\omega^2 L_s} . \qquad (2)$$

As long as the quality factor $Q = \omega L_s / R_s$ is sufficiently large, this expression reduces to $L = L_s$. The capacitance C measured between the terminals a and a' shown in Figure 2, is exactly the C of Figure 6.

The measured conductance G, pictorially represented in Figure 2, is related to the parameters of the equivalent circuit of Figure 6 by:

$$G = \frac{1}{R_p} + \frac{R_s}{R_s^2 + \omega^2 L_s^2} . \qquad (3)$$

Assuming that one operates in the frequency range where the magnetic losses predominate and that the quality factor Q is sufficiently large, the expression for G simplifies to:

$$G \approx \frac{R_s}{\omega^2 L^2} \quad (4)$$

The resistance R_s can be considered the sum of two components; R'_s which represents conductor losses, and R''_s which represents magnetic losses.

The conductor losses are given by:

$$R'_s = A \frac{(2H+OD-ID) N \sqrt{f}}{d} \quad (5)$$

where d is the O.D. of the braided outer conductor and A is a constant factor. The magnetic losses may be expressed as

$$R''_s = \omega L \tan \delta_m \quad (6)$$

where δ_m is the magnetic loss tangent. Substituting into (4) expressions for R'_s, R''_s, and L from (5), (6), and (1) respectively, one writes

$$G = A \frac{2H+OD-ID}{f^{3/2} N^3 H^2 \mu^2 d \log^2 \frac{OD}{ID}} + B \frac{\tan \delta_m}{f N^2 H \mu \log \frac{OD}{ID}} . \quad (7)$$

This equation indicates the strong dependence of G upon both N and H. If either the number of turns or height of the toroid is decreased, the conductance will correspondingly increase. This explains the observed increase of G with a decrease in height, and the very rapid increase of G with a reduction of the number of turns. Thus, one may conclude that the equivalent circuit of Figure 2 suffices to describe the actual susceptance by ascribing frequency-independent values to L and C. However, in order to explain the variation of G, one must refer to the equivalent circuit of Figure 6 and (7).

II. PARAMETRIC VARIATION

An experimental investigation was undertaken to determine the manner in which the inductance and self-capacitance of a ferrite cable choke varied as a function of the number of turns when the winding consisted of RG-196 coaxial cable and different winding geometries were employed. The theory, measurement, and employment of these inductors have been considered in the preceding section.

The measured inductance, normalized to the square of the number of turns, plotted as a function of the number of turns is shown in Figure 7.

The first and last turns were kept apart. The loop consisting of the two leads connected to the measuring equipment was counted as a turn.

If all turns were linked magnetically 100%, all of the experimental points would have the same ordinate, corresponding to a constant ratio of L/N^2. In the presence of stray magnetic flux, the equation of the curve joining the measured values is a constant plus a term which is inversely proportional to N, assuming that the stray flux is proportional to N. The curve of this nature which best fits the experimental points has been drawn in Fig. 7 as a solid line. Its equation is given by:

$$\frac{L}{N^2} = 0.21 + \frac{0.18}{N} . \tag{8}$$

The first constant term corresponds to an initial permeability of 79. It is possible that this unexpectedly low value is due to a frequency dependence of the permeability. The value of permeability derived from this curve is probably closer to the actual permeability of the ferrite than any value derived from a single measurement. The second term of (8) represents the stray inductance. It gives a value of 3.6 μ h for twenty turns. The proportionality factor of 0.18 corresponds to a magnetic coupling factor between turns of

$$K = 1 - \frac{0.85}{N} . \tag{9}$$

Each choke was measured under two conditions: 1) Adjacent turns were uniformly spaced around the entire circumference of the toroid: and 2) the first and last turns were separated considerably more than adjacent turns. The difference in measured inductance between the two conditions was within the limits of experimental error.

The measured self-capacitance, plotted as a function of the number of turns, is shown in Figure 8. It remains fairly constant from two to ten turns. For more than ten turns it generally increases at a fairly rapid rate. There is a marked decrease in self-capacitance for the separated condition above nine turns.

Another opportunity to modify the geometry of the winding lies in padding the toroid, that is, by adding foam spacers on the outside of the toroid in order to wind the coaxial cable a finite distance away from the ferrite. Brueckmann has shown that a maximum of the ratio L/C will be obtained if one pads the toroid in accordance with the formula

$$\frac{OD}{ID} = \left[\frac{od}{id}\right]^{\frac{1}{2}\left(\frac{\kappa}{\kappa-1} - \frac{1}{\mu_r - 1}\right)} \tag{10}$$

where

od = diameter of winding on outside

id = diameter of winding on inside

OD = outside diameter of ferrite

ID = inside diameter of ferrite

κ = relative dielectric constant

μ_r = relative initial permeability.

This formula is based on the assumption that the electric displacement in air is negligible compared to the displacement in the ferrite. A sixteen turn ferrite toroid was padded in accordance with (10). An increase in inductance is noted as one observes the primed experimental point in Figure 7. As illustrated in Figure 8 the padded sixteen turn choke exhibited more than a 40% reduction in self-capacitance for both the evenly spaced and the separated conditions. The L/C ratio for each condition doubled upon padding the toroid according to (10). The results given show that the inductance follows the formula of (1) fairly well, especially for large N. Padding the toroid results in a small increase in L. The self-capacitance tends to increase with number of turns when N is moderately large but is rather unpredictable for a few number of turns. Separation of the first and last turns and padding are shown to be effective techniques for reducing the capacitance.

Utilizing a measurement technique based on the formula $Q = f_0/BW$ and which employs magnetic coupling to the generator and the measurement of the 3 db-bandwidth by a voltmeter across the inductor, the quality factor was measured as a function of the number of turns. As can be seen in Figure 9, all the measured Q-values lie between 50 and 120. The quality factor was not measured below fourteen turns because of a coupling problem caused by too low a self-capacitance.

The self-resonant frequency was computed from measured data and is plotted in Figure 10 as a function of the number of turns. It is approximately inversely proportional to N. The choke exhibited higher self-resonant frequencies for the winding geometry with first and last turns separated because of the lower self-capacitance. Chokes for the purpose of isolation with less than thirteen turns are not useful since losses become too high at frequencies above 20 Mc.

An unsuccessful attempt was made to verify the value of stray inductance predicted by (8) for a twenty-turn choke by winding a brass toroid of identical dimensions with 20 turns of RG-196 coaxial cable and measuring the inductance between opposite ends of the braided outer conductor with the outer conductor shorted to the brass body at one end. This simulates a conducting wire over ground with a short circuit at the terminal end. The theoretical inductance for such a transmission line is given by

$$L_1 = 0.2\ell \cosh^{-1}\left(\frac{2D}{d}\right) \text{ in } \mu h \tag{11}$$

where

ℓ = total length of winding

D = distance from center of conducting wire to "ground."

The value computed from (11) was .53 μh: the measured value was .3 μh. Both these values are very low in comparison to a value of 3.6 μh expected from (8). It is concluded that much of the stray inductance is due to fields which couple into the ferrite. The brass toroid, being a good conductor, effectively eliminates these fields thereby decreasing the value of stray inductance.

III. ADMITTANCE BANDWIDTH

It is the purpose of this section to present a method for quickly and accurately determining the frequency band, throughout which the admittance of a ferrite cable choke is below a prescribed value, in the case where the conductance is negligible compared to the maximum acceptable susceptance B_o. This assumption regarding the conductance is valid, for example, for a Q-1 toroidal ferrite choke wound with more than six to eight turns of RG-196 coaxial cable with $B_o \geq .2$ millimhos. In ignoring the conductance the equivalent circuit of Fig. 2 reduces to an inductor of inductance L shunted by a capacitor of capacitance C. The frequency limits for which $B = \pm B_o$ can be determined by solving the equation for the susceptance of the circuit for the frequency f:

$$f_{2,1} = \frac{\pm B_o}{4\pi C}\left[1 \pm \sqrt{1 + \frac{4C}{B_o^2 L}}\right]. \tag{12}$$

The plus signs apply to the upper frequency limit f_2 where $B = +B_o$, and the minus signs to the lower frequency limit f_1 where $B = -B_o$. The bandwidth may be computed from the equation

$$BW = f_2 - f_1 = \frac{B_o}{2\pi C}. \tag{13}$$

Therefore the bandwidth is directly proportional to the maximum allowable susceptance and is inversely proportional to the self-capacitance of the coil.

Figure 11 is a graph of measured capacitance versus the inverse of the frequency squared for a ferrite toroid wound with sixteen turns of RG-196 miniature coaxial cable padded for a maximum L/C ratio. Arbitrarily setting $B_0 = 2 \times 10^{-4}$ mhos and substituting for L and C from the graph into (12) one obtains $f_2 = 25.6$ Mc and $f_1 = 8.8$ Mc. Therefore the admittance bandwidth of the choke is 16.8 Mc. Throughout this frequency band the susceptance, and therefore the absolute value of the admittance, will be below two tenths of a millimho. One may, in addition to (13) compute the ratio f_2/f_1. In the above example it is 2.9 which means that the bandwidth of the choke is nearly three to one.

Figure 12 illustrates the change in bandwidth and in the frequency limits for the choke as additional self-capacitance is added, e.g. by placing the choke within a container which by itself exhibits a finite self-capacitance. Note that the lower frequency limit decreases slightly with increasing capacitance while the upper frequency limit decreases rapidly with additional capacitance. If one wishes to design a choke with a specified tolerance that allows for additional stray capacitance, then the effective bandwidth should be calculated by computing f_2 with the stray capacitance included and f_1 without the additional self-capacitance.

IV. CONTAINER DESIGN

The first section described the employment of ferrite cable chokes in antenna isolation units. These inductors by themselves provide high isolation of the antenna from ground at rf frequencies, i.e. small values of conductance and susceptance between the input and output ends of the outer conductor of the coaxial transmission line that feeds the antenna. In order to avoid degrading this isolation while protecting the walls of the inductor against weather, etc., by enclosing it in a container, it is useful to make the container of non-conducting material. Another consideration bearing on the design of the container is that the capacitance between the input and output terminals, apart from the self-capacitance of the inductor, should be as low as possible in value while ensuring that it is well defined. A high capacitance will narrow the usable frequency range and may increase the susceptance beyond the desired limit. Hence, if it is unavoidable for mechanical reasons to make the mounting plates for the terminal connectors of conducting material, they should be as small as practical, and be as far apart as possible without making the unit appreciably longer than the choke. An isolation unit has been designed with these considerations in mind.

This isolator unit is shown in Figure 13. The cylindrical body is made of fiberglass tubing. The sidewall thickness was doubled at either end by bonding smaller tubes to the inside of the main cylindrical tube with epoxy resin. This arrangement provides sufficient wall thickness to hold nylon screws which fasten the mounting plates to both ends of the cylindrical body. The design of these plates is shown in Figures 14 and

15. The top mounting plate was designed for use with the center-fed dipole Antenna AS-1729( )/VRC. The bottom plate was designed to be mounted in the center of a 15-foot ground plane. Notice in this connection that the unit would mount above the ground plane instead of below, as shown in Figure 1. The isolation would then be provided between the ground plane and the top connecting plate. Figure 16 shows the design of mounting plates to be used when the isolation unit is not required to be an integral part of the antenna system. A photograph of the experimental isolation unit is shown in Figure 17. Figure 18 shows the component parts of the isolation unit including the main cylindrical body, mounting plates, and a ferrite toroid wound with nine turns of RG-188 coaxial cable. Figure 19 and 20 provide a comparison of the experimental unit with the standard unit MX-6707( )/VRC used with Antenna AS-1729( )/VRC. These photographs are for comparison purposes only and are not meant to imply the replacement of the standard unit by the experimental one.

The capacitance of the unit with the choke removed was measured as 3.3 picofarads at F = 10 Mc for the configuration of Figure 16. When the aluminum mounting plates were replaced by plates made of Lexan the unit capacitance was measured as 1.0 picofarad.

V. WIDEBAND ISOLATION COVERAGE

The insights gained during the investigation of particular aspects of the performance of HF toroidal cable chokes with ferrite cores, as described in the preceding pages, have been combined successfully in arriving at a final design which provides high isolation from 2 to 30 Mc by the use of a set of only three individually designed chokes.

A self-resonant frequency was determined for each choke by estimating the desired band of frequencies to be covered by each choke and setting f_0 near the center of each band. The self-capacitance of the winding was then estimated on the basis of past experience, taking into account the fact that each choke would be padded for maximum L/C ratio and would later be placed in a container. The number of turns was then computed from (1) after calculating the required inductance from the known f_0 and C. Two of the three toroids were then padded by foam spacers according to (10). It was found advantageous to pad the toroid on the outside of the ferrite core since padding it on the inside caused the turns of coaxial cable to be placed closer together thereby tending to increase the self-capacitance and negating the objective for padding. Next the toroids were wound with the estimated number of turns of RG-196 coaxial cable leaving a moderate separation between the first and last turns. Next the admittance of each choke was measured on a bridge and then the data was plotted as in Figure 11, for example, and L and C were then accurately determined. The frequency limits of the chokes were then calculated from (12) setting B_0 equal to 0.2 millimhos. The band edges were then shifted by adding or subtracting turns, with a subsequent remeasurement of admittance, until the proper band was covered by each choke so that the entire HF band from 2 to 30 Mc was covered. Next the chokes were imbedded in foam in order to secure the windings in place; finally molded containers of Lucite were formed for each choke for protection.

A photograph of each of the chokes prior to being imbedded in foam is given in Figure 21. **Figure 22 gives the complete set of design parameters and measured characteristics for each choke.**

SUMMARY

This investigation has been conducted with the objective of providing a high rf impedance between two discrete points on the outer conductor of miniature coaxial transmission lines. Systematic design procedures have been developed and are described in Section I for toroidal cable chokes that provide this isolation over a band of frequencies. The observed variation in conductance has been explained by theory. Section II relates an exhaustive experimental investigation to determine the variation of inductance, capacitance, self-resonant frequency and quality factor with the number of turns. A method for decreasing capacitance and a technique for increasing the L/C ratio were presented. Finally, the factors affecting stray inductance have been considered. Section III presents simple formulas for admittance bandwidth calculations that are applicable when the conductance is negligible compared to the maximum allowable susceptance. The detrimental effects of additional capacitance upon bandwidth were graphically portrayed. Section IV documents the design of an insulating container suitable for mounting the cable chokes. Variations in design aimed at specific applications were described. Finally, Section V presented the design for a set of only three individual cable chokes which provide better than 5,000 ohms of rf isolation from 2 to 30 Mc. Note that the isolation requirement has only been met by providing a specified amount of rf isolation over a specific frequency range with a minimum number of cable chokes. But the requirement may be to provide as much isolation as possible over a specific frequency band by a single choke. Regardless of the isolation requirement the amount of rf isolation actually required will depend upon the application.

It is concluded that toroidal ferrite cores can be wound with miniature coaxial cable to successfully solve wide or narrow band isolation problems in the HF range. Futhermore it is expected that isolation requirements in the lower VHF range, from 30 to 80 Mc, will also be met with such ferrite cable chokes.

RECOMMENDATIONS

It is recommended that in designing toroidal cable chokes for isolation applications in the HF band of frequencies one should 1) wind them with RG-196 coaxial cable if power handling capability is not a restriction 2) pad the toroid for maximum L/C ratio as outlined in Section II, 3) wind the toroids with enough turns so that the conductance is negligible and the design procedures of Section III may be utilized, and 4) design a container with very low container capacity and dielectric loss. Note that all of these suggestions will result in either a broadening of the admittance bandwidth, thereby enabling one to cover a broader range of frequencies with fewer individual chokes, or provide a larger rf impedance over the same frequency band.

ACKNOWLEDGEMENT

The author thanks Dr. Helmut Brueckmann and Mr. W. P. Czerwinski for their help and encouragement in the study of the characteristics of ferrite cable chokes.

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3. W. Czerwinski, "Obtaining Equivalent Circuits of Inductors Graphically," Electronics, Vol. 33, No. 35, August 26, 1960, p. 70.

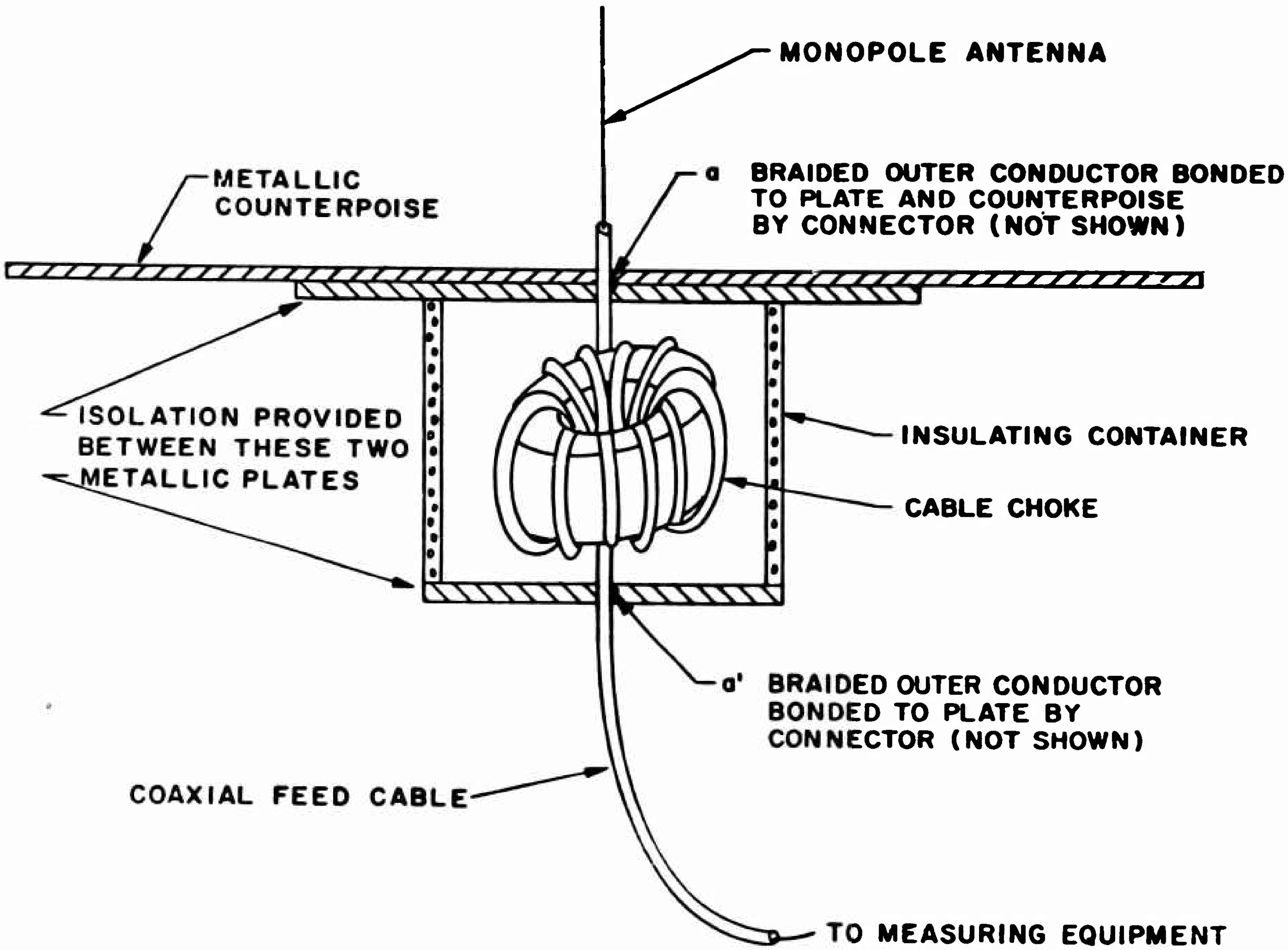


FIG.- I EMPLOYMENT OF ISOLATION UNIT

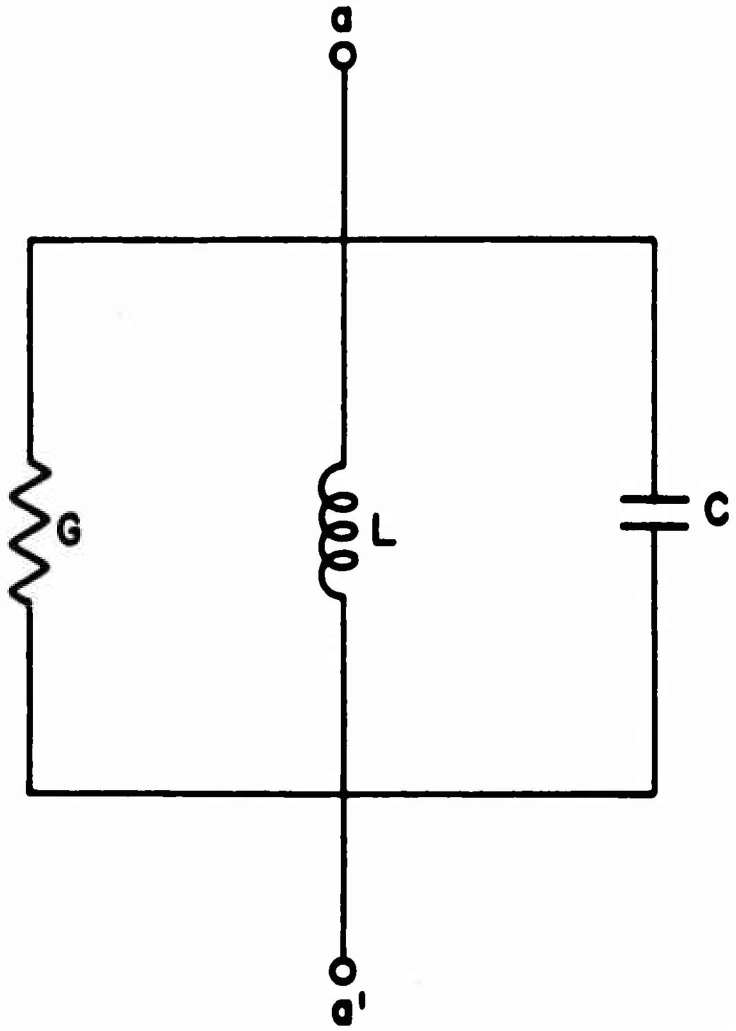


FIG. 2- EQUIVALENT CIRCUIT OF
ISOLATION UNIT

⊙ CAPACITANCE IN PICOFARADS
△ CONDUCTANCE IN MILLIMHOS
⊡ $\sqrt{G^2 + \omega^2 C'^2}$ IN MILLIMHOS

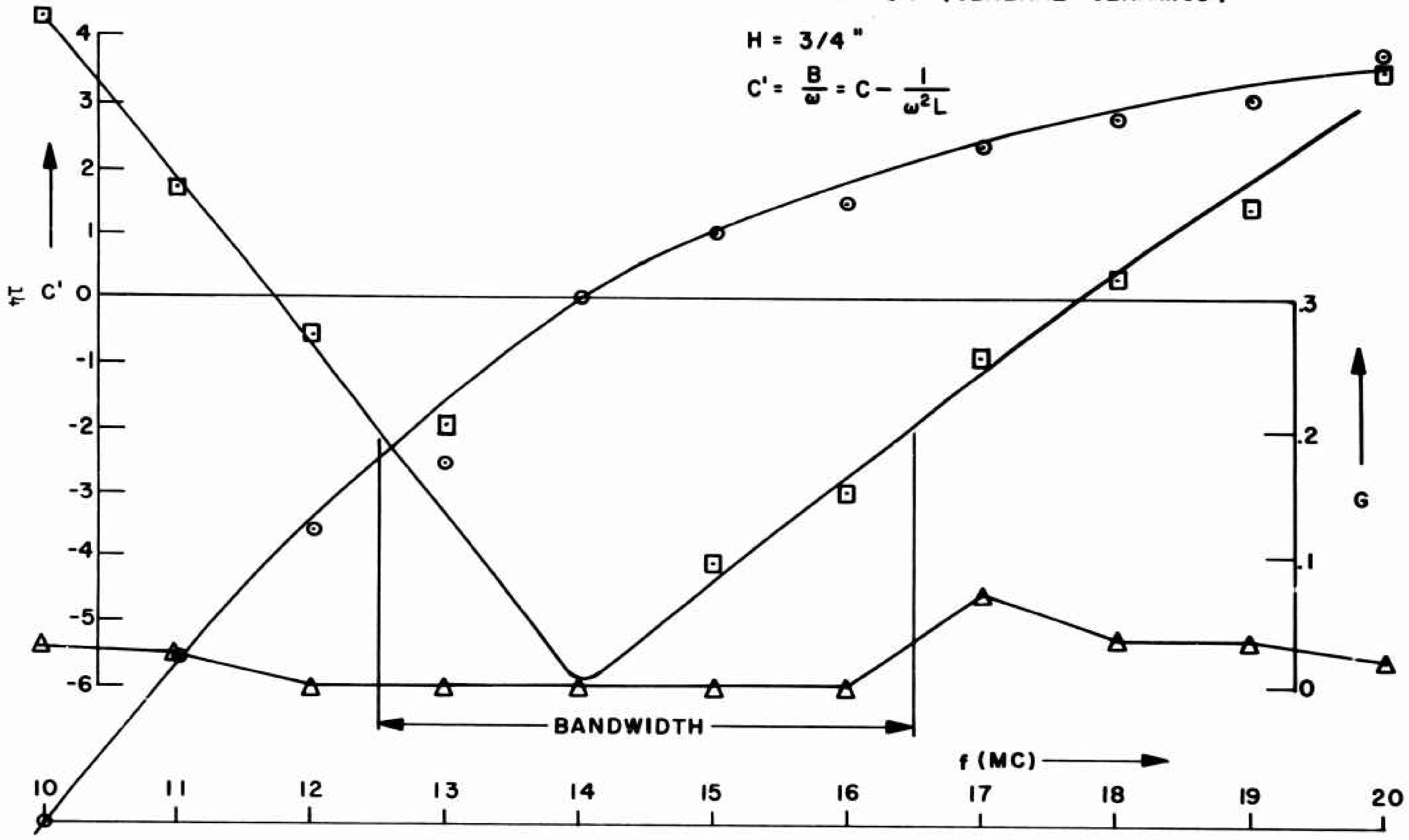


FIG. 3 - ADMITTANCE DATA FOR A NINE TURN CABLE CHOKE.

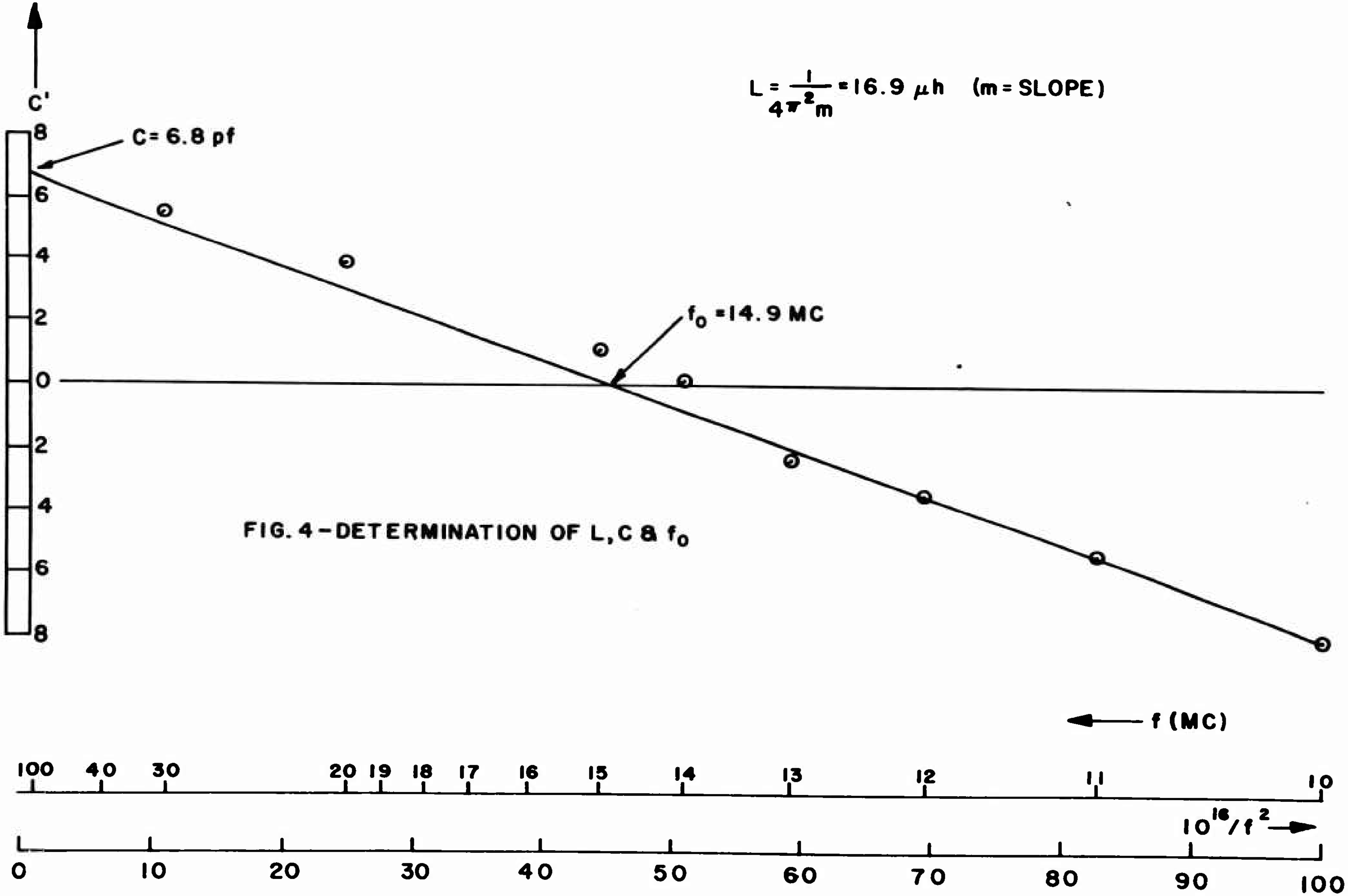


FIG. 4 - DETERMINATION OF L, C & f_0

TOROIDAL INDUCTOR CHARACTERISTICS

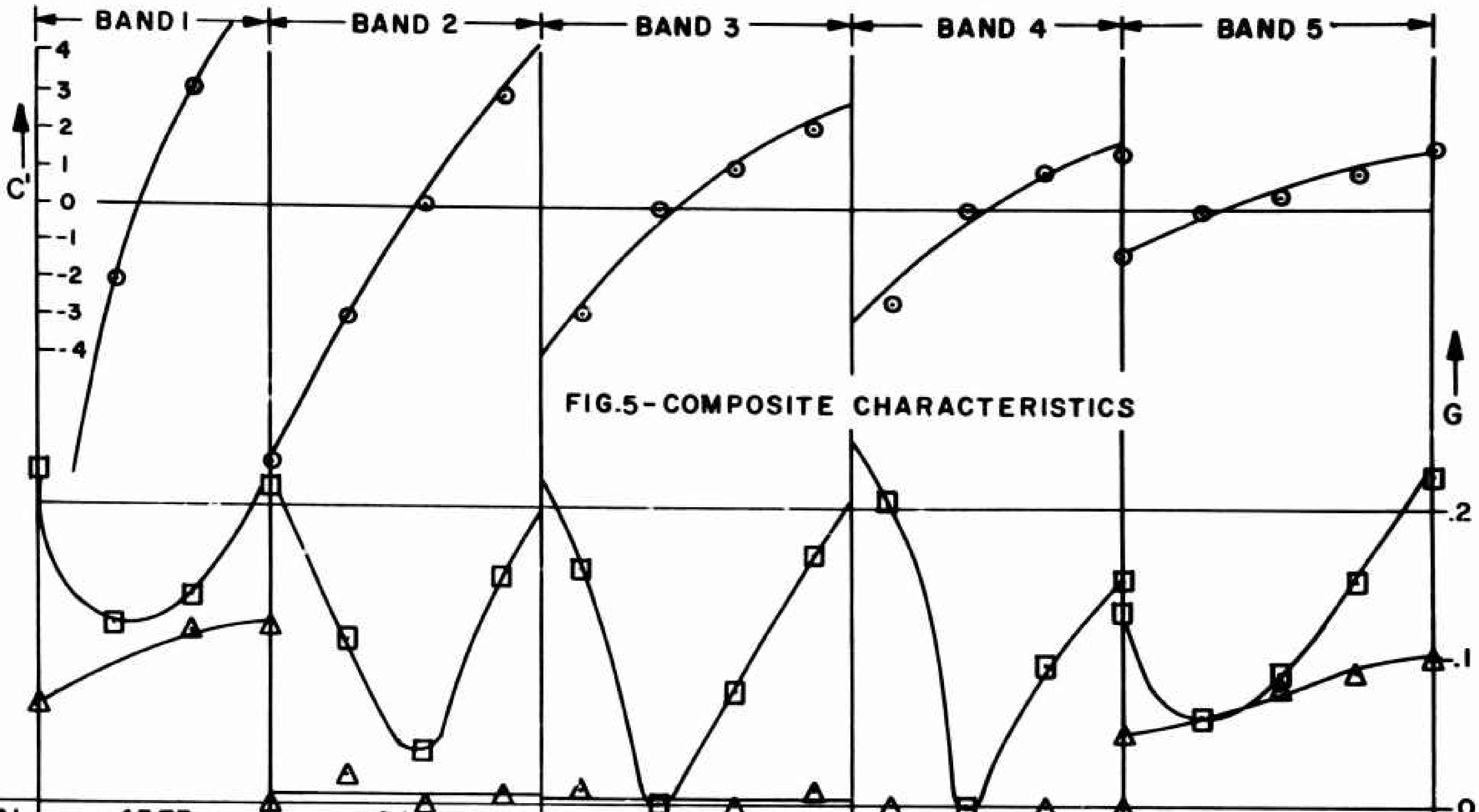


FIG.5-COMPOSITE CHARACTERISTICS

MATERIAL	4373	Q1	Q1	Q1	Q1
TURNS	9	14	10	9	7
Fo MC	3.26	6.84	10.6	14.9	17.5
L uh	235	56.4	31.4	16.9	13
C pf	10.1	9.6	7.2	6.8	6.4
H "	1	1	1	.75	.75

□ $\sqrt{G^2+\omega^2C^2}$ m℧ ⊙ C' pf C (Q1) ≈ .36 pf/TURN Q1: OD = 1.25" ID = .75"

△ G m℧ UNIT C = 3.8 pf WIRE = RG 188 COAX 4373: OD = .875" ID = .525"

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

F (MC) →

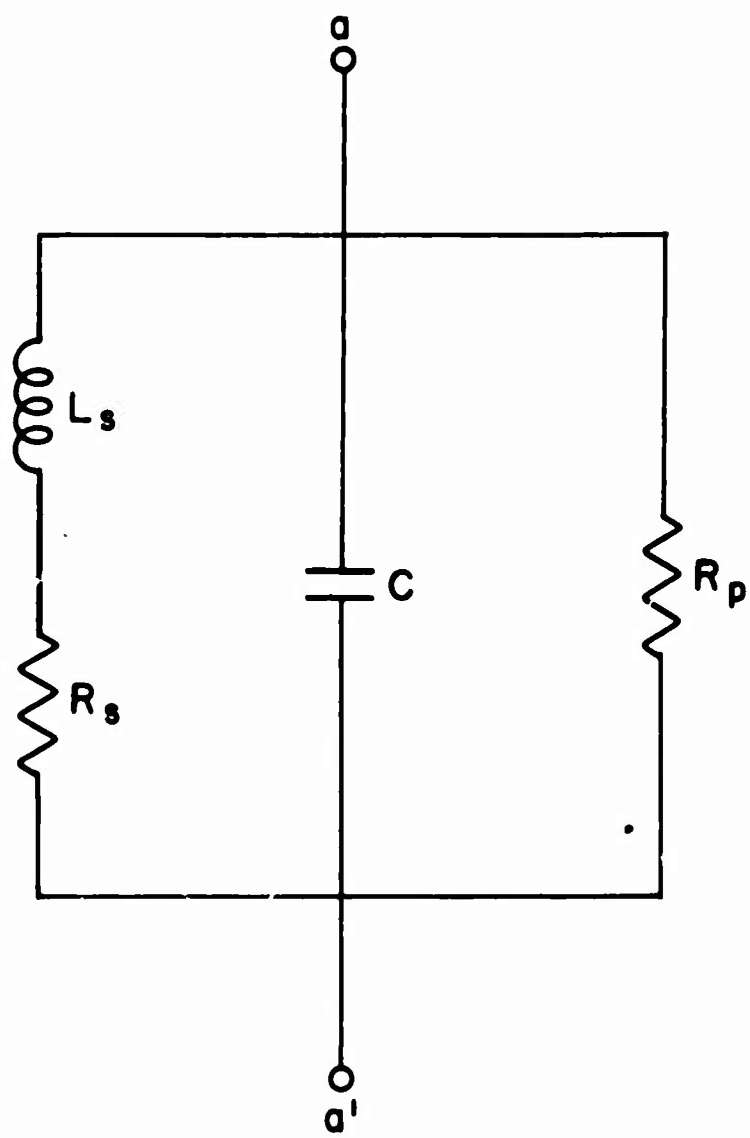


FIG. 6 - MODIFIED EQUIVALENT CIRCUIT

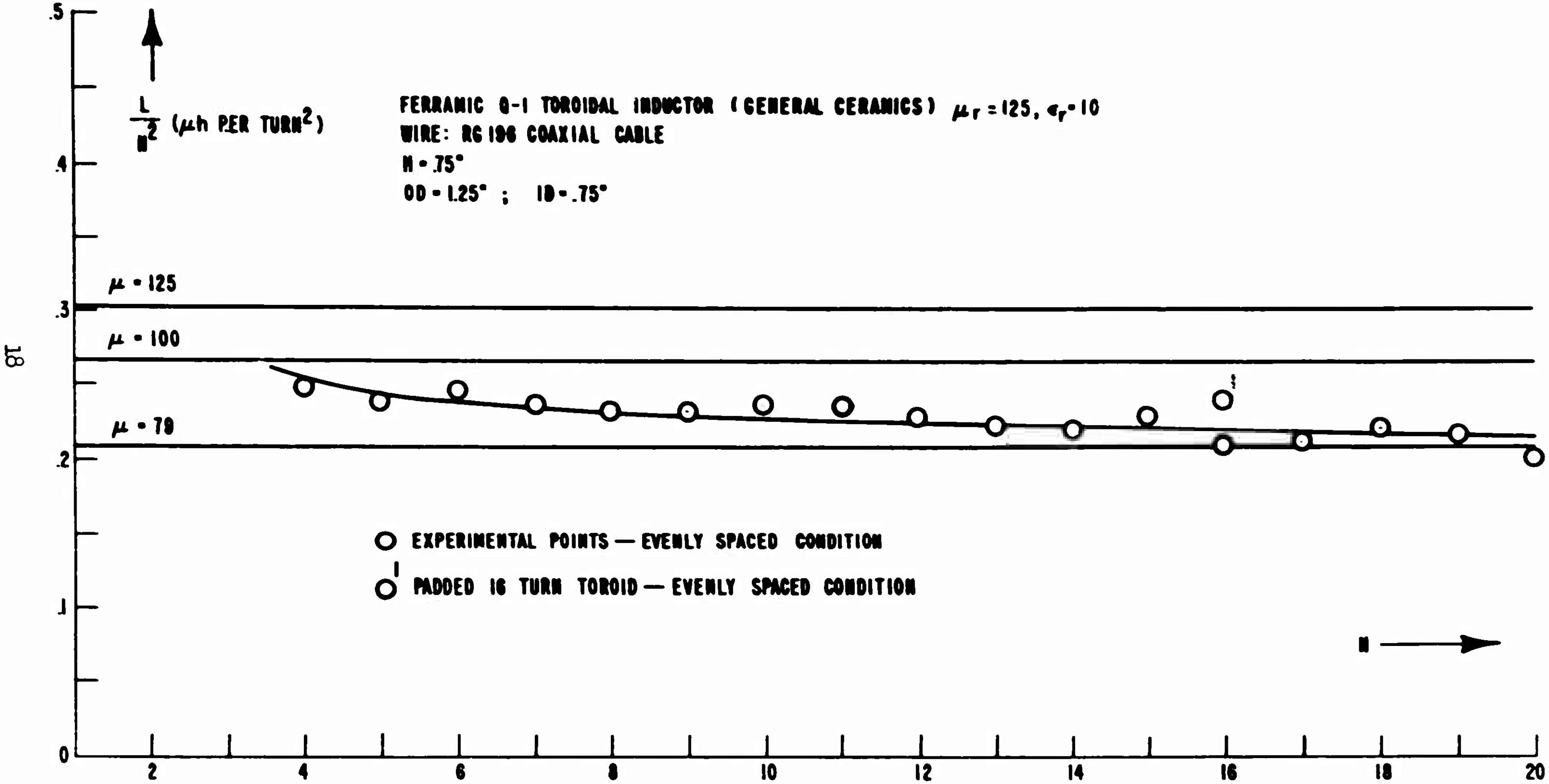


FIG. 7 - INDUCTANCE VERSUS NUMBER OF TURNS

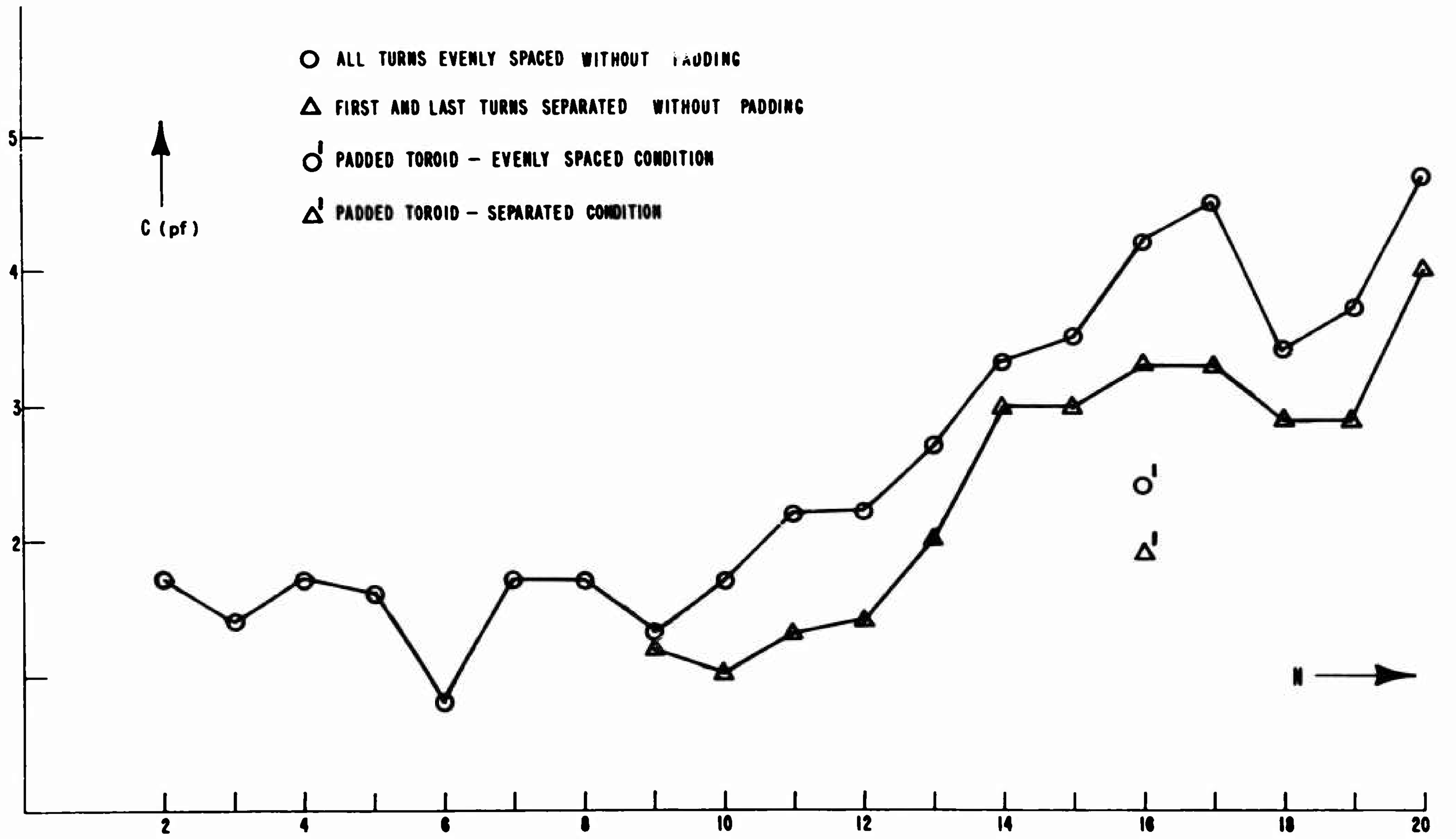


FIG. 8 - SELF CAPACITY VERSUS NUMBER OF TURNS

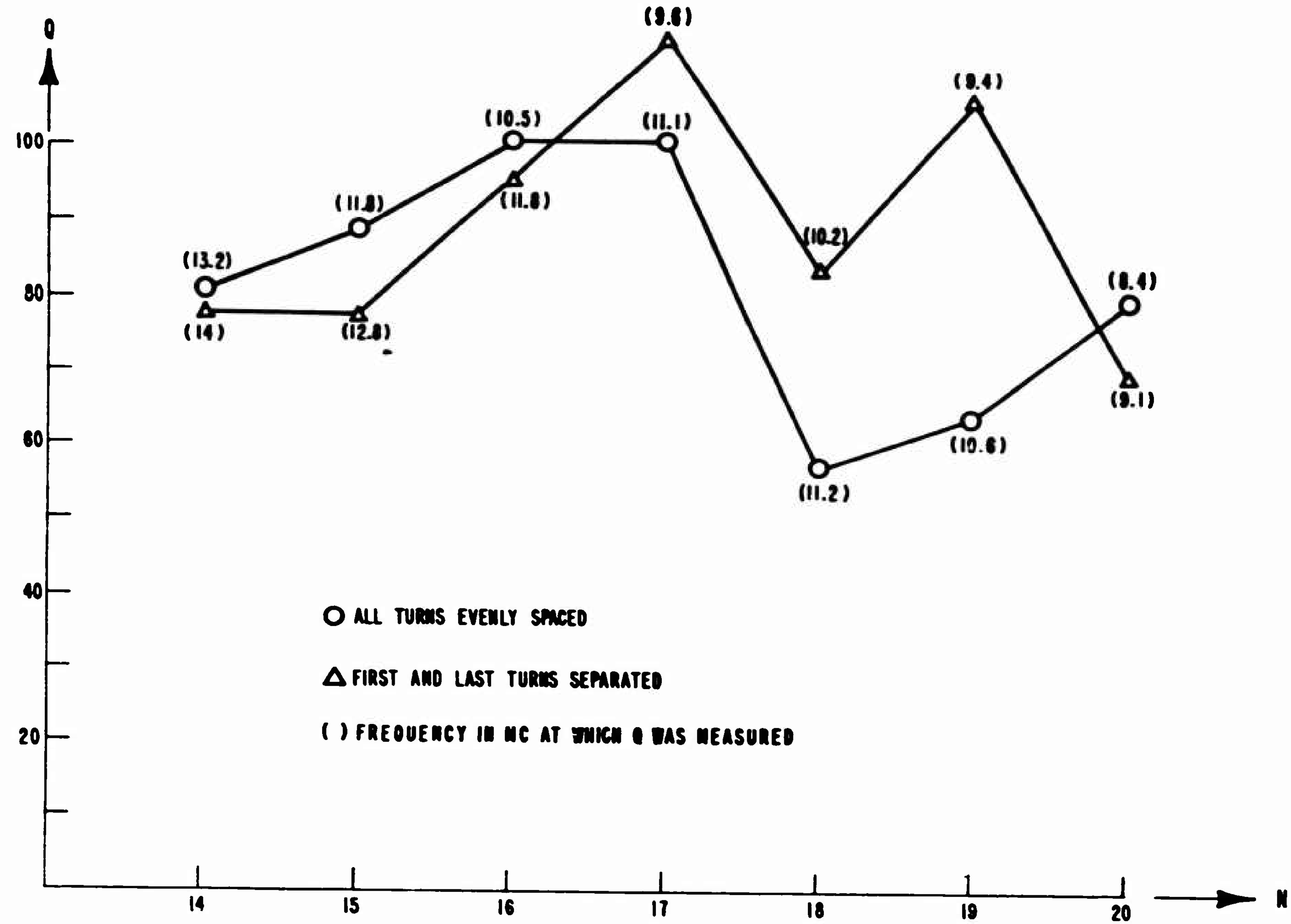


FIG. 9 - QUALITY FACTOR VERSUS NUMBER OF TURNS

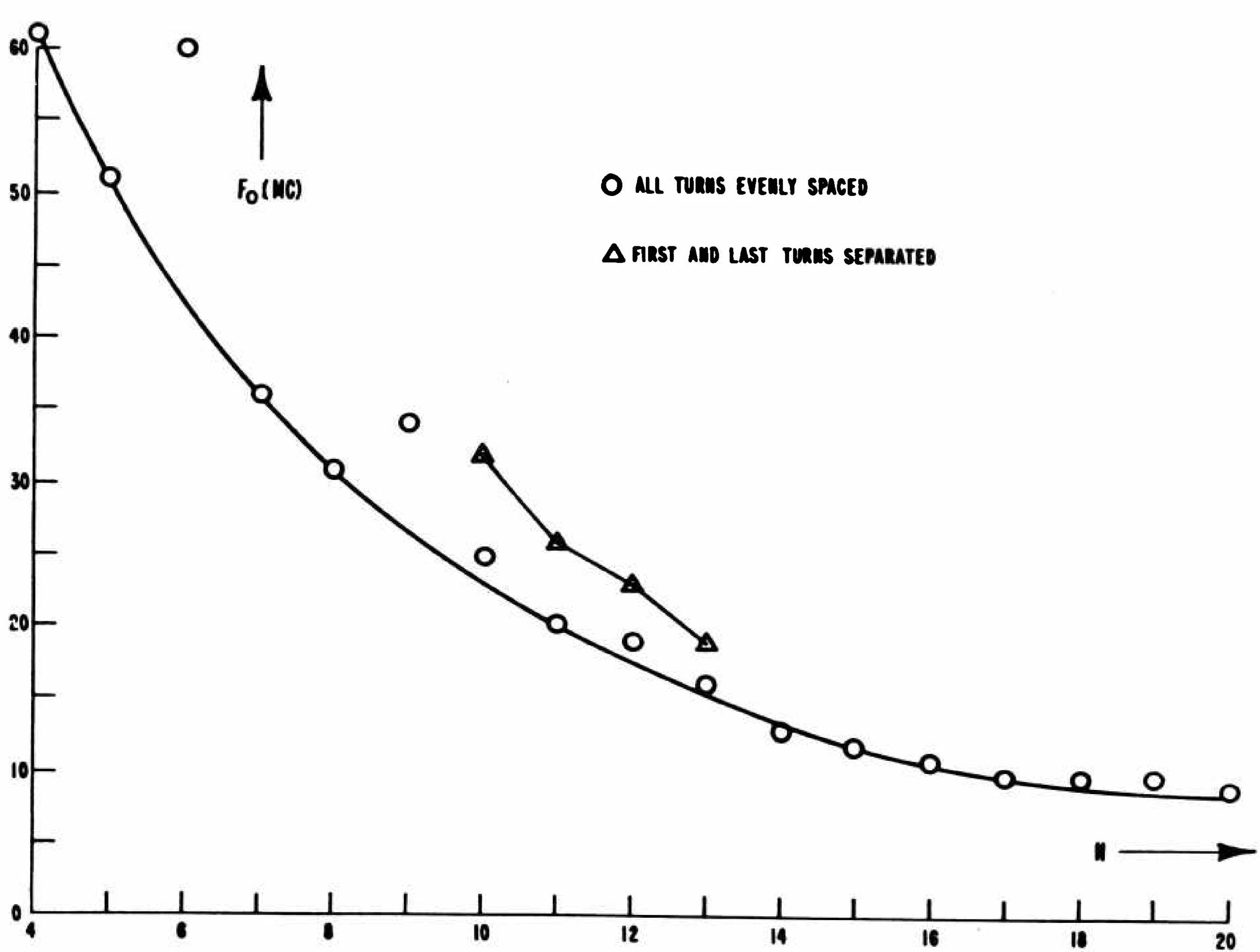


FIG. 10 - SELF RESONANT FREQUENCY VERSUS NUMBER OF TURNS

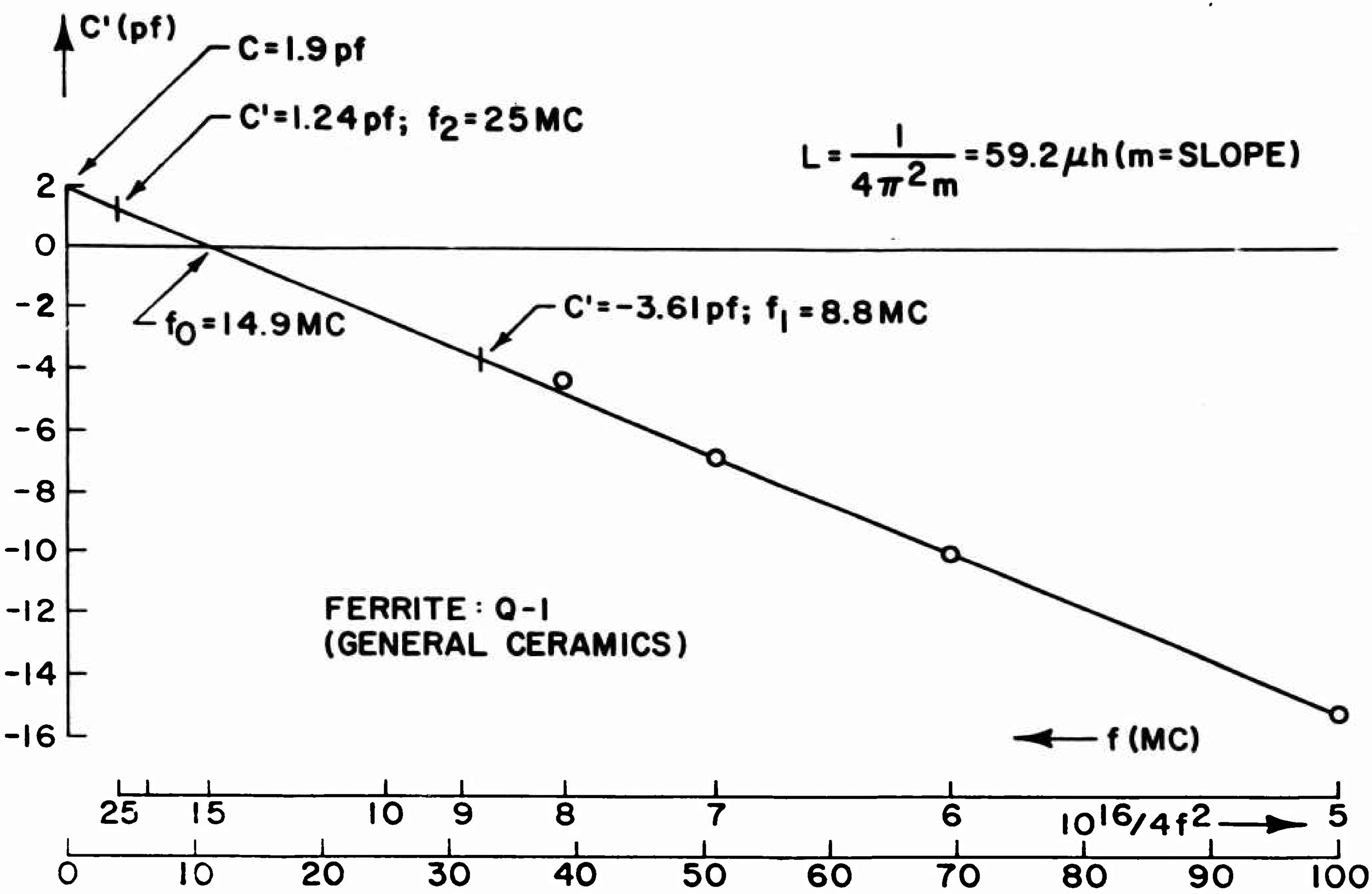


FIG. 11 - BANDWIDTH OF A SIXTEEN TURN CHOKE

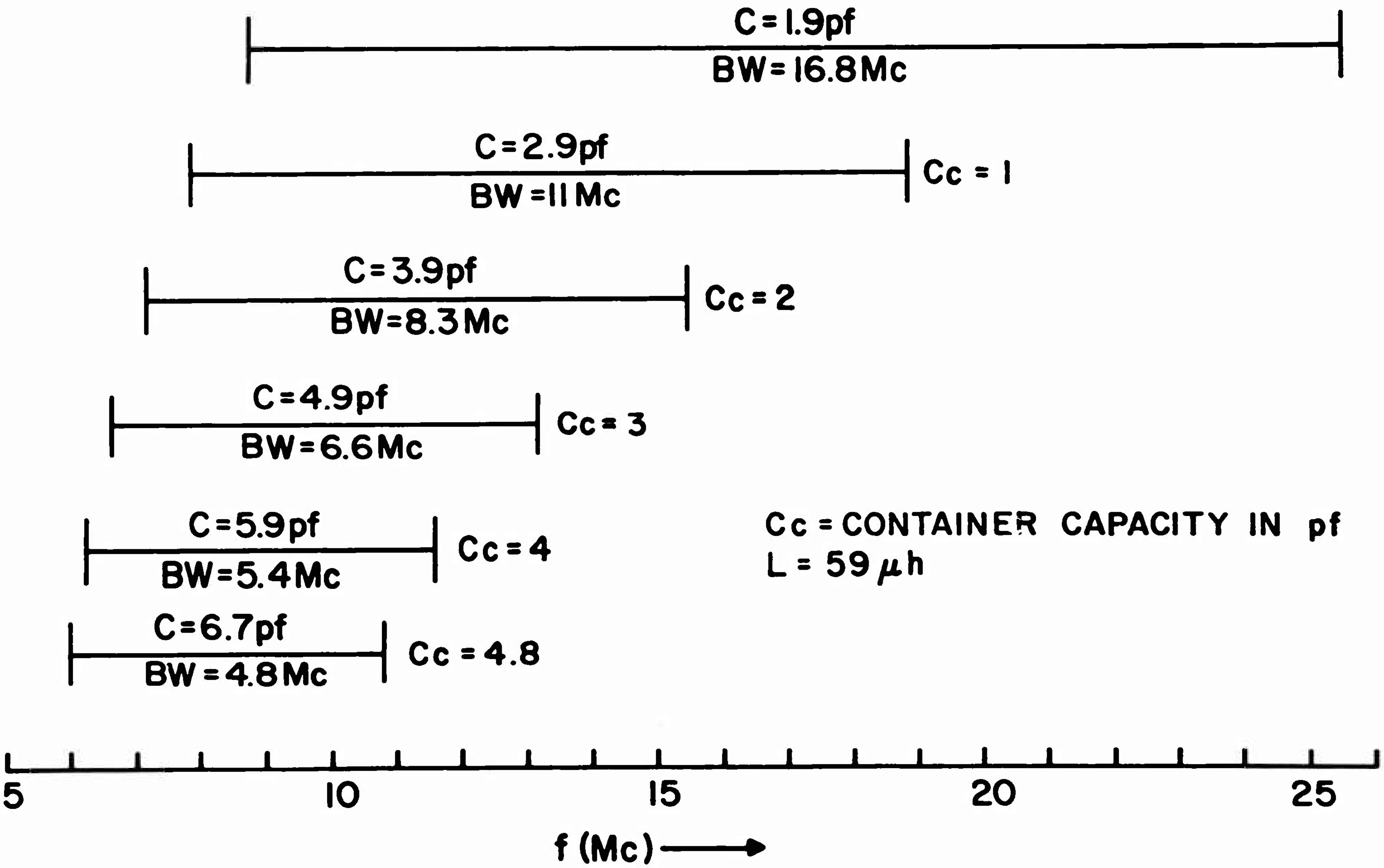


FIG. 12- BANDWIDTH VERSUS CAPACITANCE FOR A 16 TURN CHOKE

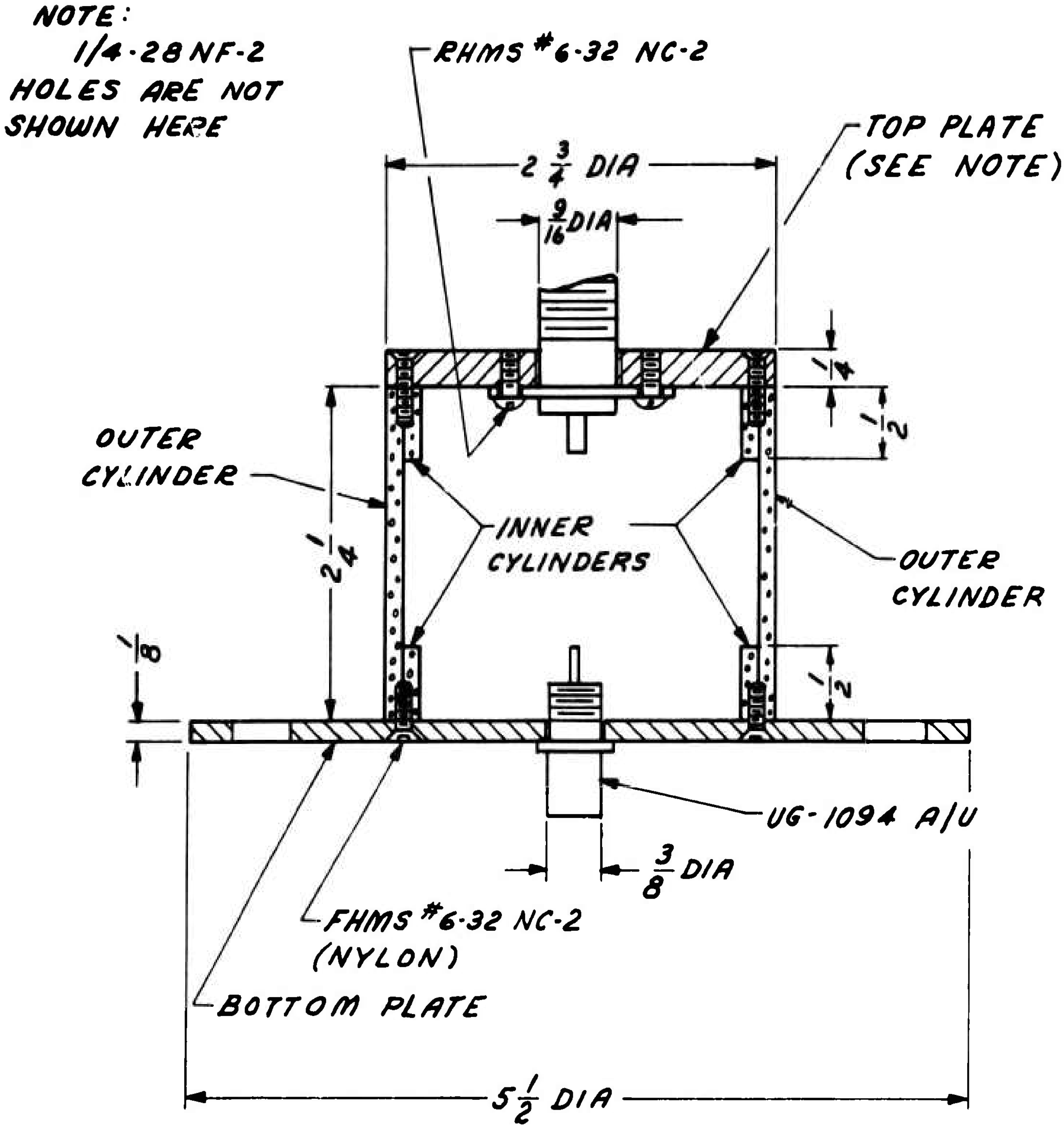


FIG. 13 CONTAINER DESIGN

SCALE 1/1

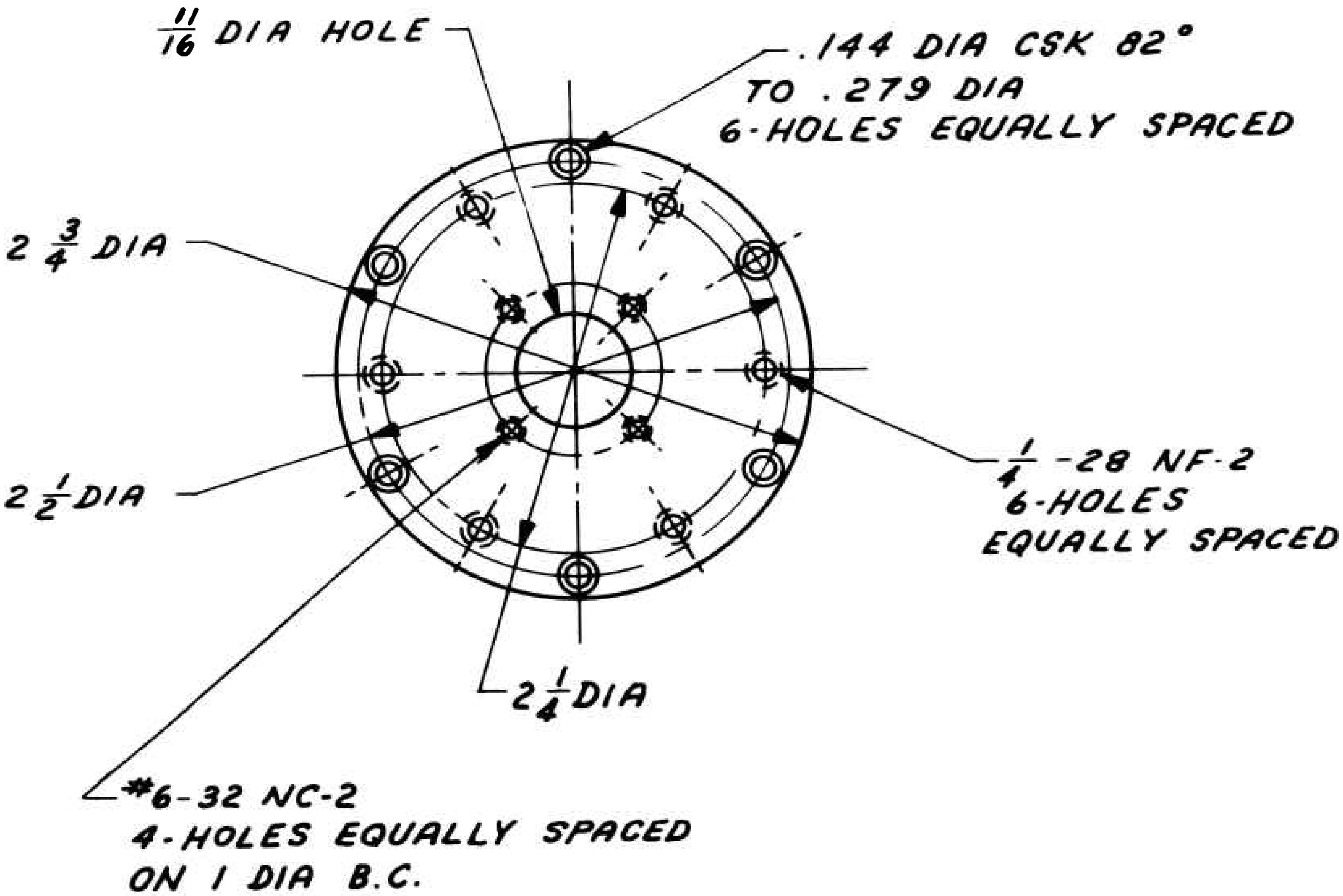


FIG. 14 DESIGN OF TOP MOUNTING PLATE

SCALE 1/1

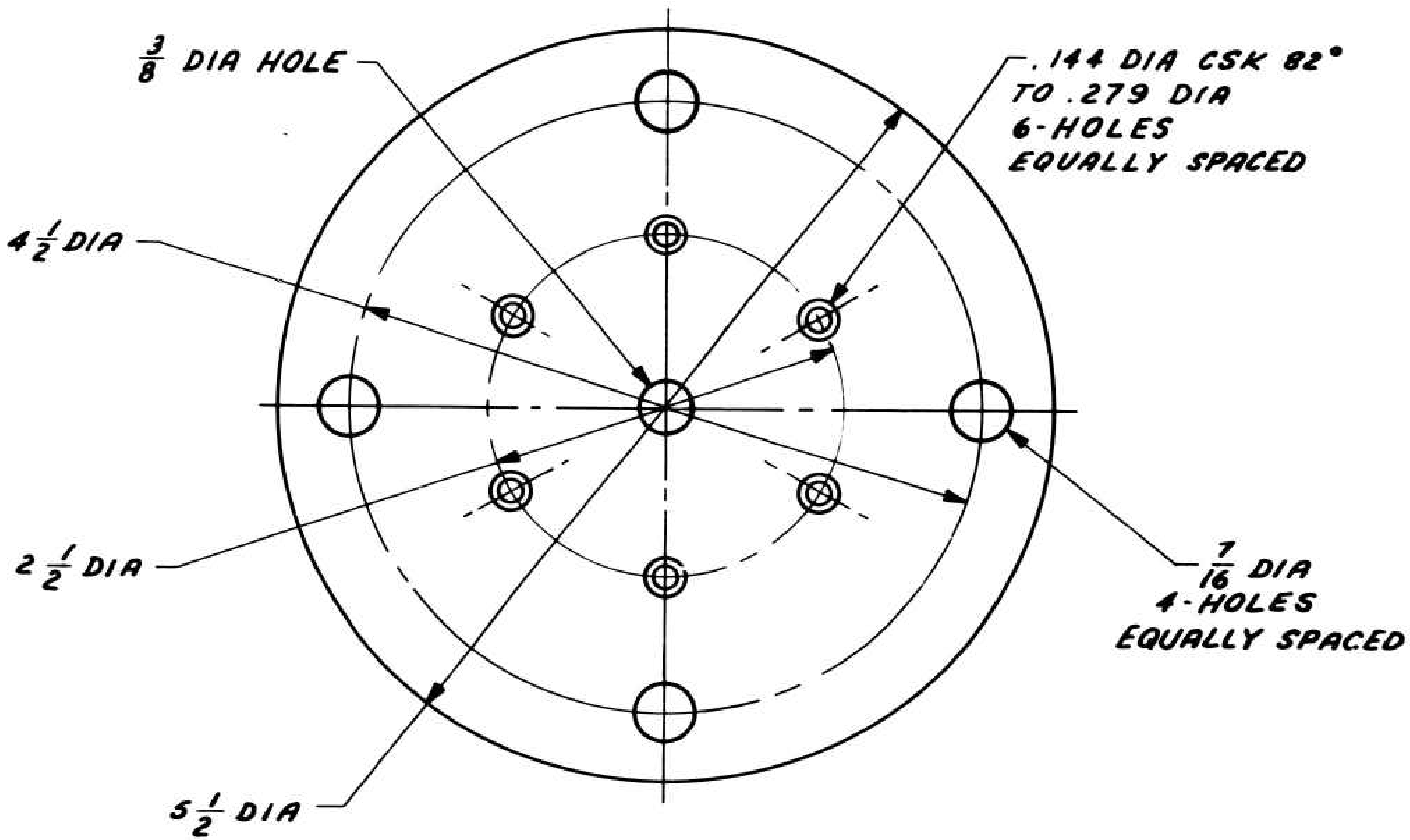


FIG. 15 DESIGN OF BOTTOM MOUNTING PLATE

SCALE 1/1

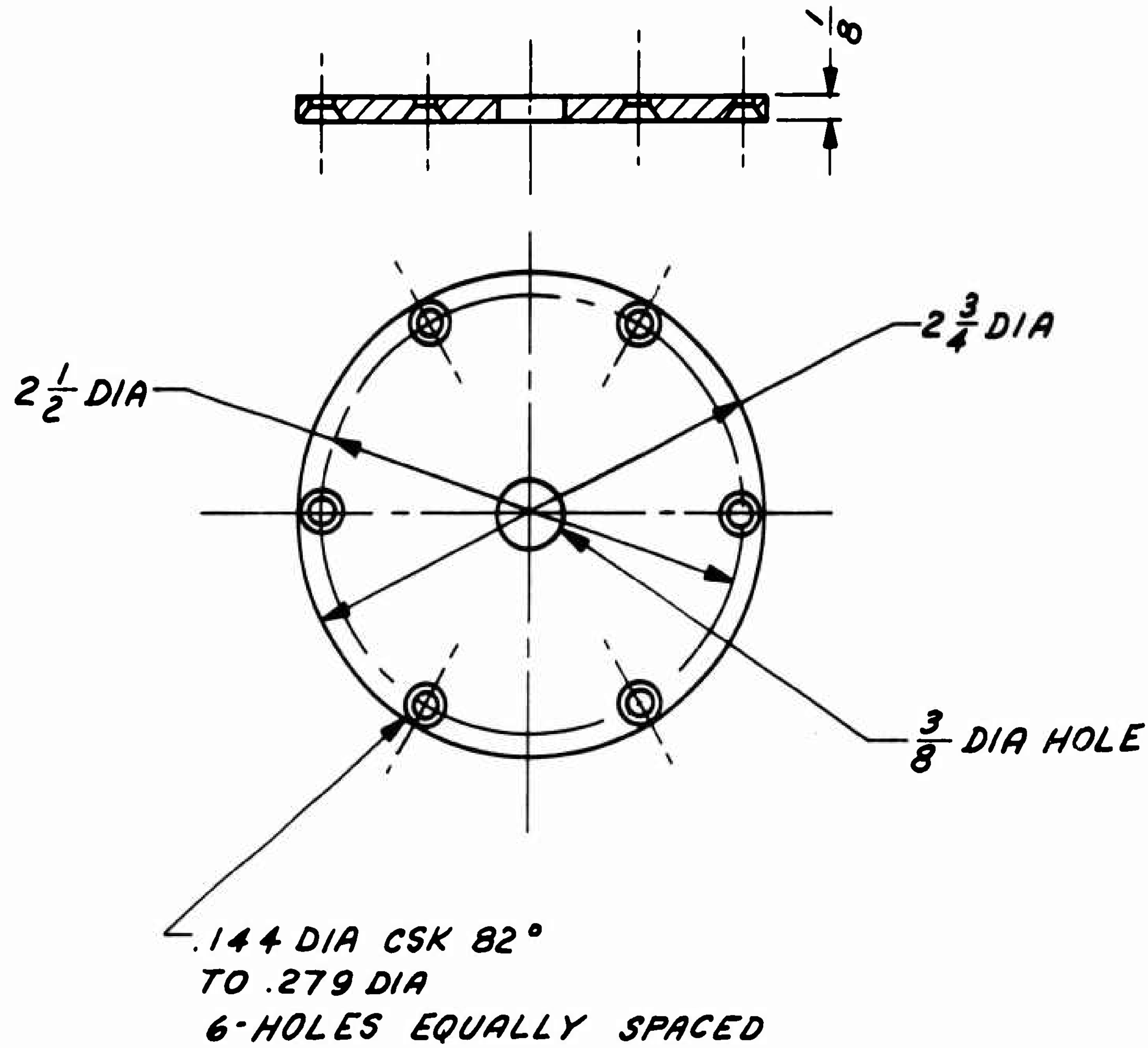


FIG. 16 MOUNTING PLATES FOR NON ANTENNA USE.

SCALE 1/1

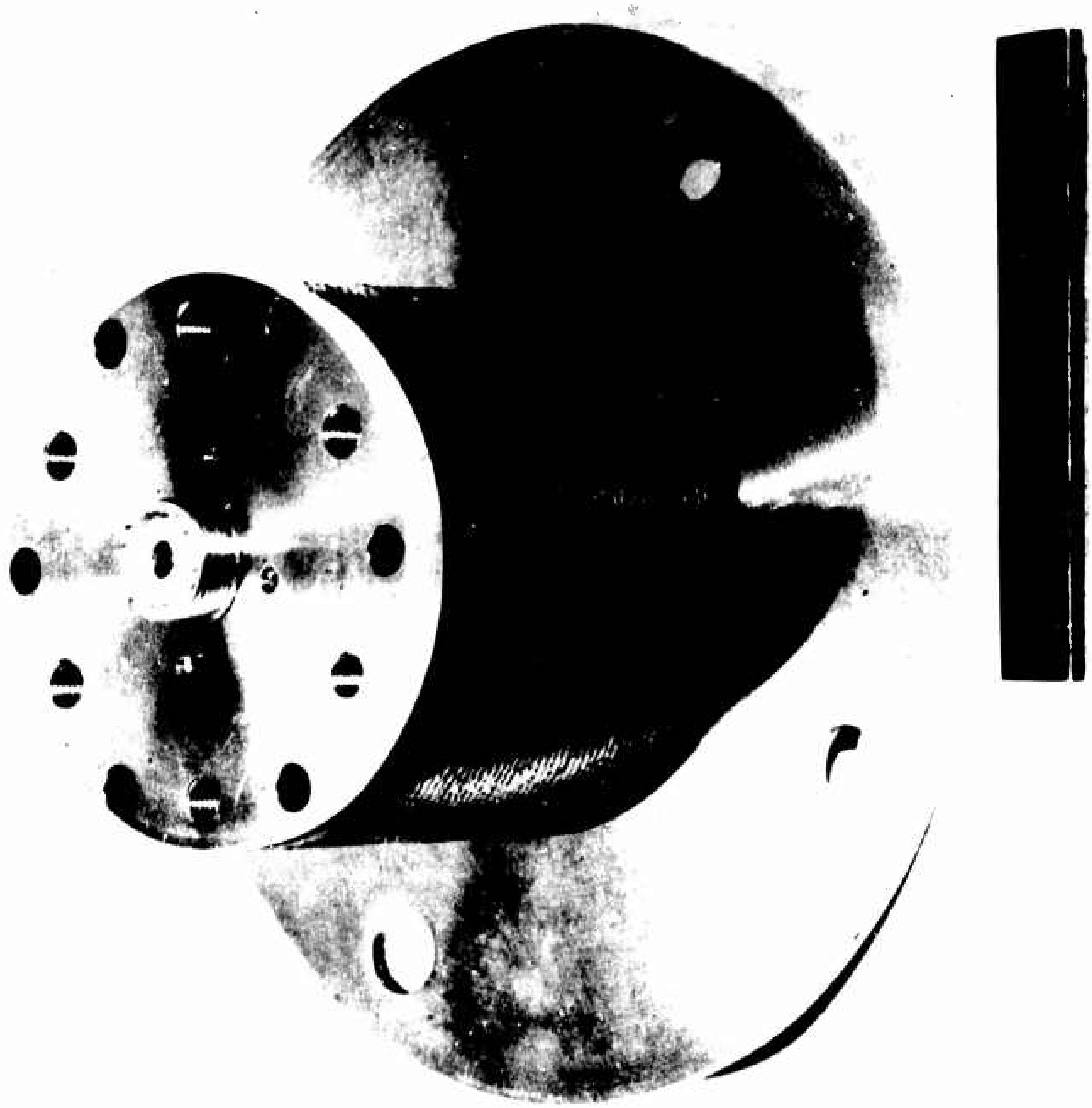


FIG. 17 - ISOLATION UNIT

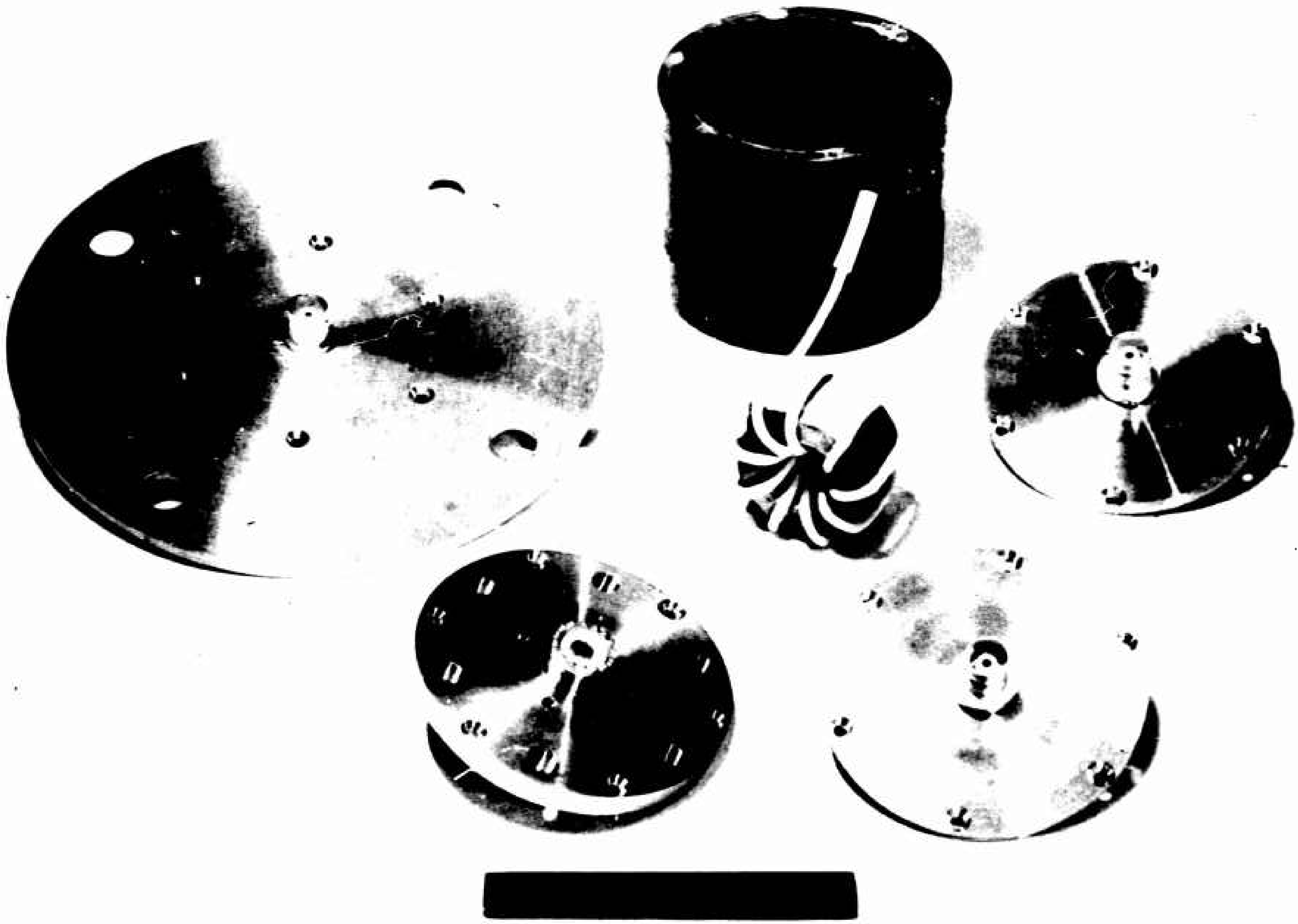


FIG. 18 - COMPONENT PARTS

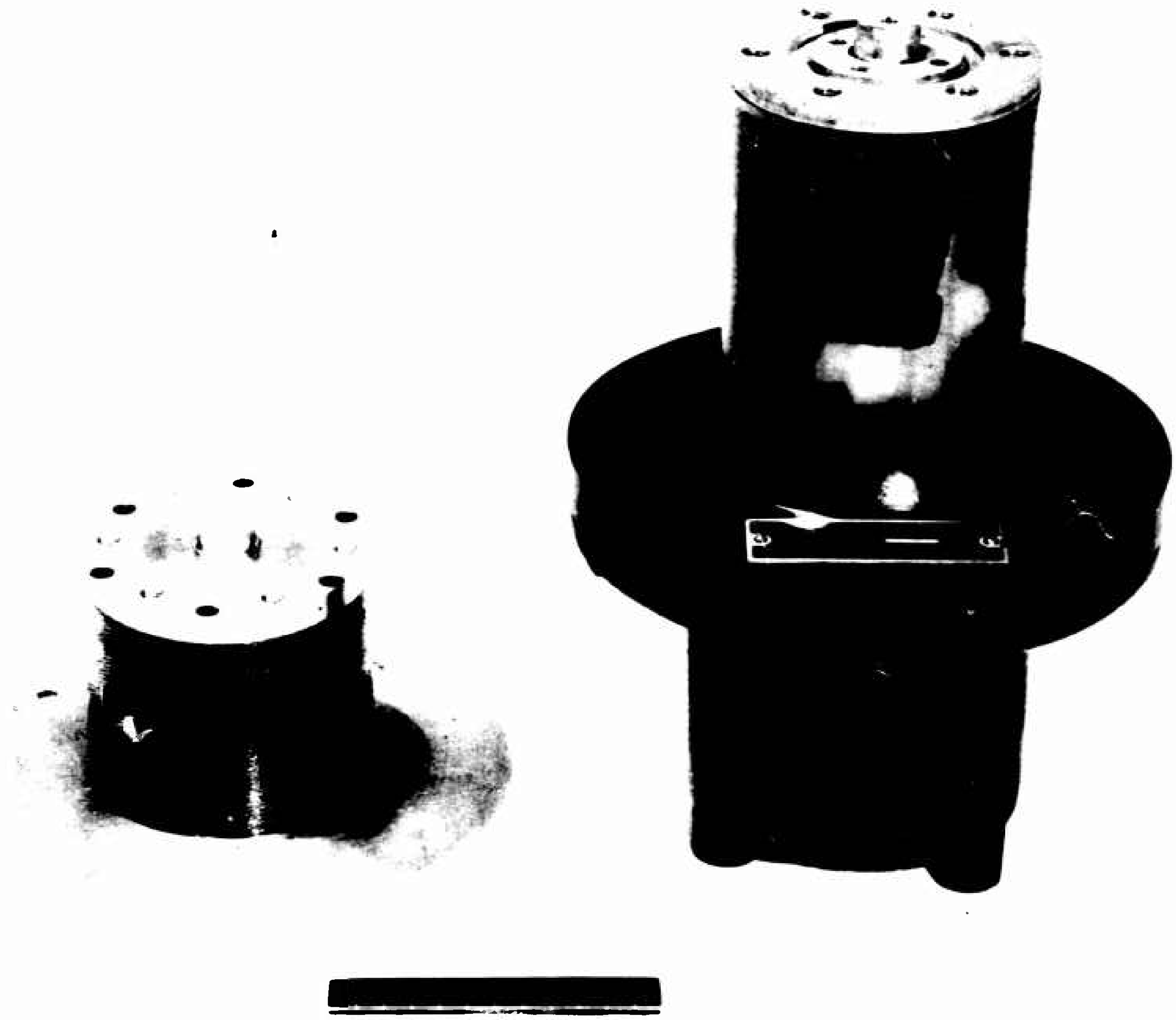


FIG.19 - FRONT VIEW OF ISOLATION UNITS

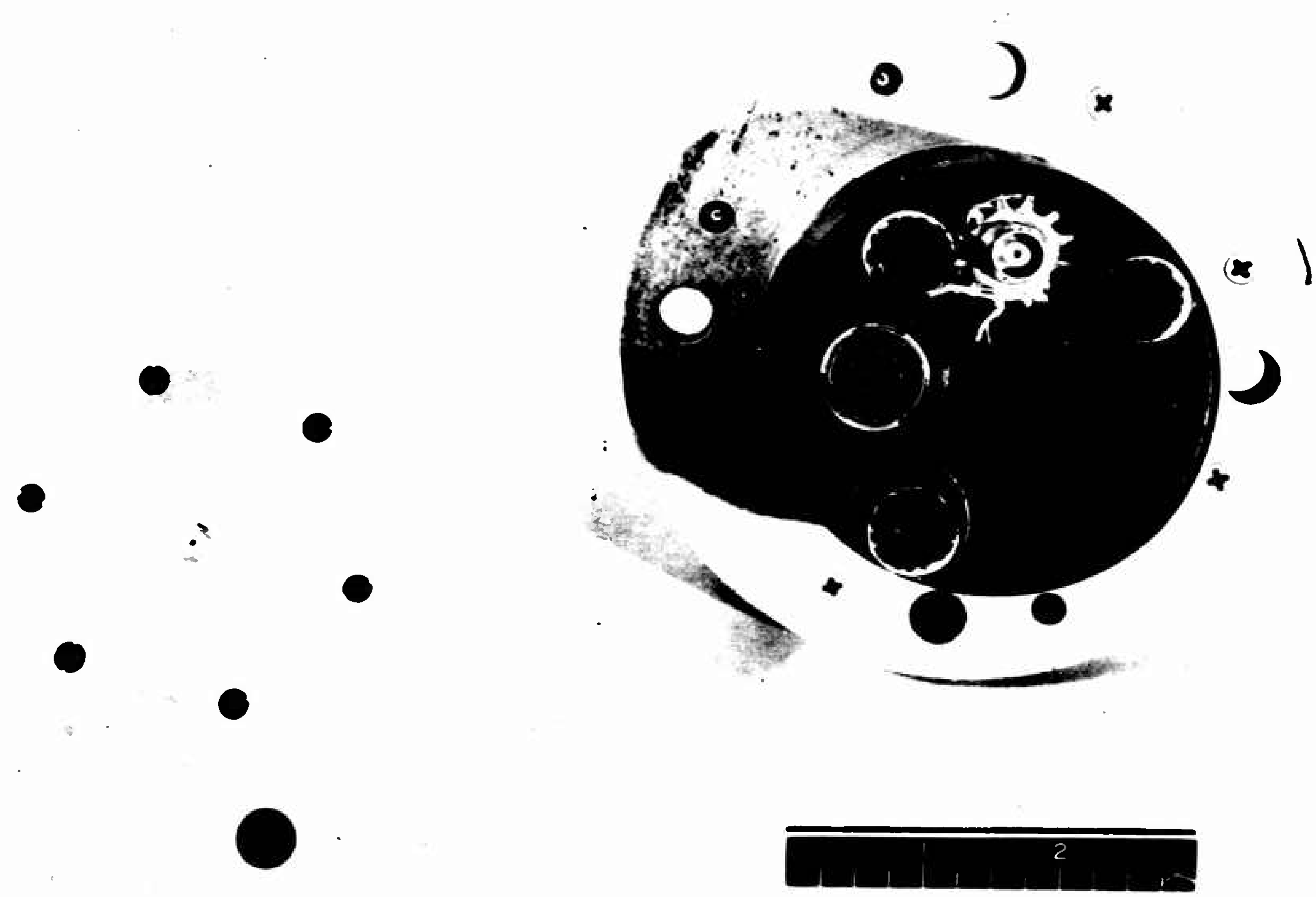


FIG. 20 - BOTTOM VIEW OF ISOLATION UNITS

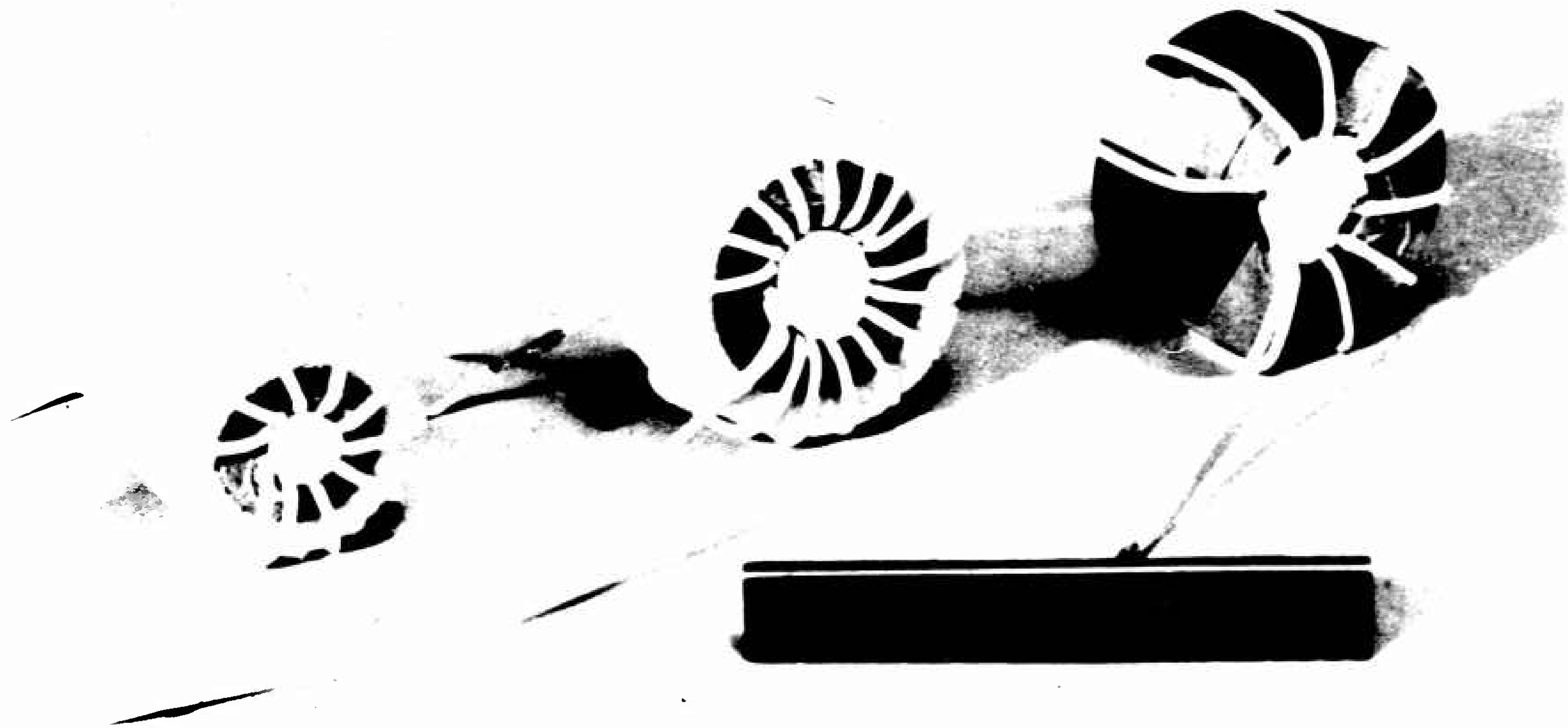


FIG. 21 - WIDEBAND CABLE CHOKES

	BAND 1	BAND 2	BAND 3
RANGE (Mc)	2 - 8	8 - 20	20 - 30
FERRITE [1]	4373	Q - 1	Q - 2
N	9	17	10
L (μh)	271	63.1	14.8
C[2] (pf)	5.5	2.5	2.9
f_0 (Mc)	4.1	12.8	24
f_1 (Mc)	2.2	7.9	19.5
f_2 (Mc)	8.5	20.6	30.5
BW (Mc)	6.3	12.7	11
f_2/f_1	3.9	2.6	1.6
H (in)	1.	.75	.75
OD (in)	.875	1.25	1.875
ID (in)	.525	.75	.80
od (in)	1.37	1.86	1.895
id (in)	.491	.67	.78

NOTES:

1. MANUFACTURED BY GENERAL CERAMICS.
2. INCLUDES MEASURED CONTAINER CAPACITY OF 1/2 PICOFARAD.

FIG. 22- WIDEBAND CHOKE CHARACTERISTICS

APPENDIX

BRIDGE MEASUREMENT ACCURACY

The accuracy of admittance bridge measurements of self-capacitance on the Wayne-Kerr Model B801 is of concern especially when measuring very low values of self-capacitance, e.g. of the order of 1/2 to 1 picofarad. Thus it becomes important to analyze in a general theoretical way, and experimentally, the effect of the copper straps which lead from the measuring terminals of the bridge to the device being measured. The effect of these straps is to cause the initial balance of the bridge to be inaccurate and/or to cause more or less self-capacitance* to be present when making the reading than when the device is disconnected from both terminals of the bridge.

Consider the measuring set-up photographed in Figure A1 and illustrated by Figure A2. Point A is the "hot" terminal. A short copper strap is connected to it. Point D is the ground terminal. A long copper strap is connected to it. This "ground" strap is fastened to the container connector at point C. It also serves to hold the container in place. The bridge is initially balanced with the strap at point A disconnected from the container connector at point B. Then the strap is connected and a bridge reading is accomplished.

Note that there exists a finite capacitance C_A between the strap at point A, and point B, when the bridge is being initially balanced. It is non-existent when the bridge reading is being made. Its effect is to raise the initial balance level of capacitance: therefore causing the bridge reading to be in error on the low side. The capacitance C_o is the capacitance which is to be measured and consists of the capacitance through the container material plus the capacitance through the air space between the two connectors. Of course the major contribution to C_o is through the material of the container. Note that one is not measuring exactly the capacitance solely between the two connectors but rather between the connector at point B and the connector at C plus the ground strap. The ground strap effectively increases the surface area of the connector at C in addition to complicating its configuration somewhat. However, it has been shown experimentally that this effect of the ground strap is small so long as the copper strap is not too wide. The second effect of the ground strap is to cause a finite value of inductance to exist between points D and C. It has been shown experimentally that this effect can be made negligible by making the ground strap wide enough. Note that it is impossible to 'tune out' the effect of this inductance in the initial balance of the bridge.

---

* This term refers here to self-capacitance which could not be accounted for by the initial balance of the admittance bridge.

The capacitance C_B is a spurious capacitance which exists between the hot strap and ground. Its effect can be made negligible through the initial balance of the bridge so long as the position of the strap at point A is not altered radically before and after it is connected to point B. The strap at point A is in closest proximity to the ground when it is disconnected from point A because the local surface area in the plane of terminals A and D is all at ground potential. Therefore a slightly lower self capacitance than actually exists will be measured.

In order to understand more accurately the effects of the ground strap inductance and the capacitance C_A, consider the approximate equivalent circuit of Figure A3. For the moment ignore the inductance L and consider the effect of C_A on the bridge reading of C_o. The bridge dial then reads

$$C_o - \Delta C_B - \frac{C_A\ C_o}{C_A + C_o} . \tag{1}$$

Therefore the copper strap at point A must be far enough away from point B to make C_A very small: yet it must not be so far away that a significant change in C_B is introduced. It is evident from (1) that the best initial position of the hot strap is that position in which the highest self-capacitance is measured.

Now for the purpose of analyzing the inductive effect of the ground strap let us ignore for the moment C_A. Therefore the bridge dial reads

$$\frac{C_o}{1 - \omega^2 L\ C_o} - \Delta C_B . \tag{2}$$

Hence it is evident from (2) that the finite inductance of the ground strap tends to cause an error on the high side. In addition the reading becomes frequency dependent. Therefore, it becomes imperative to make the ground strap wide enough so that the inductance is negligible, but it must not be made so wide that the capacitance C_o itself is increased while the measurement is being made.

By way of experiment, five different size ground straps were used to measure the self-capacitance of the container shown in Figure 1: beginning with a ground strap 1/4" wide up to one which was one inch wide. The three ground straps in between the thinnest and widest ones all resulted in a measured 1.0 picofarad. The thinnest ground strap and widest ground strap both produced very slight increases in measured self-capacitance, of the order of 5μ. These measurements which were performed at a frequency of 10 Mc, showed that the inductance of the thinnest strap was becoming slightly influential in raising the true self-capacitance of the container and that the larger surface area of the widest strap was beginning to cause C_0 to increase slightly above its actual value with both straps disconnected. In order to experimentally verify (1) the bridge was initially balanced in a separate measurement with the "hot" strap at a very small acute angle with respect to the plane of terminals A and D. A decrease in measured self-capacitance of an estimated 1/10 picofarad was measured. This decrease was solely a change in C_B since the initial placement of the strap was such that it was a much greater distance away from point B, causing C_A to be negligible.

This information has provided an insight into the problem of how copper straps influence bridge measurements. It has been determined how one may avoid inaccuracies in measurement by adjusting the size and position of the straps properly. Any bridge measurements which take into account the foregoing considerations should be accurate to within an estimated 1/10 picofarad for measurements made in the HF band of frequencies.

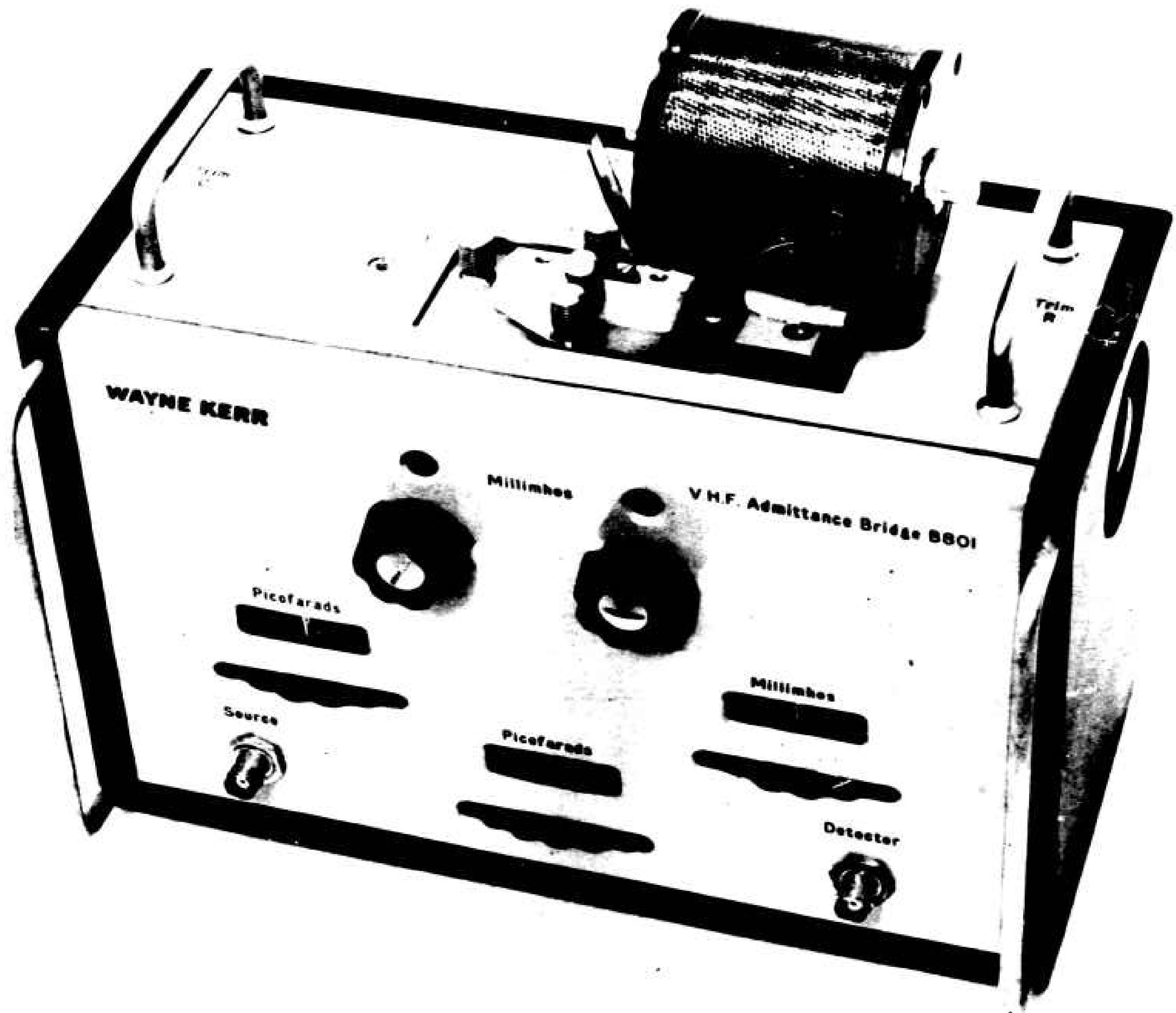
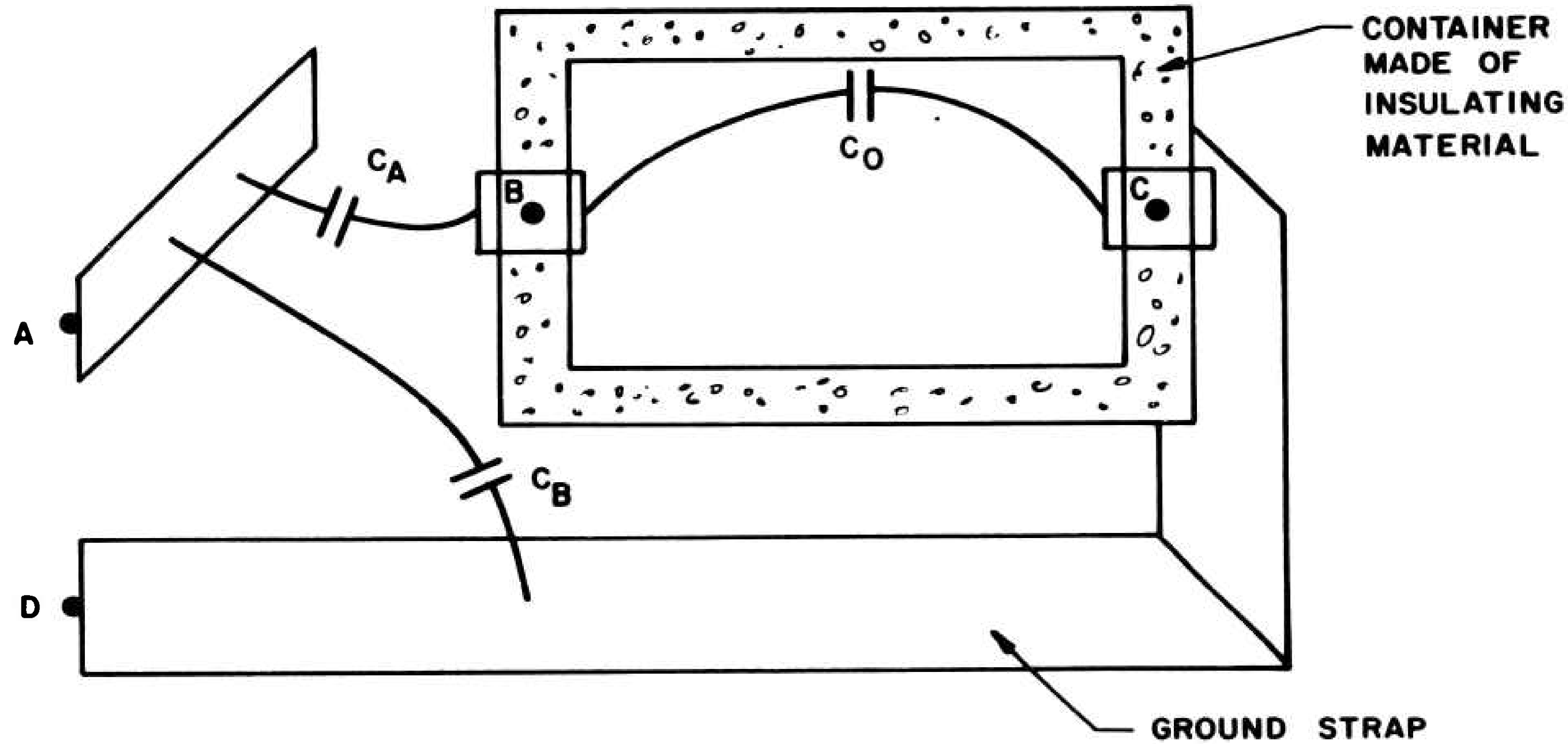


FIG. A1 - CONTAINER & STRAP ARRANGEMENT

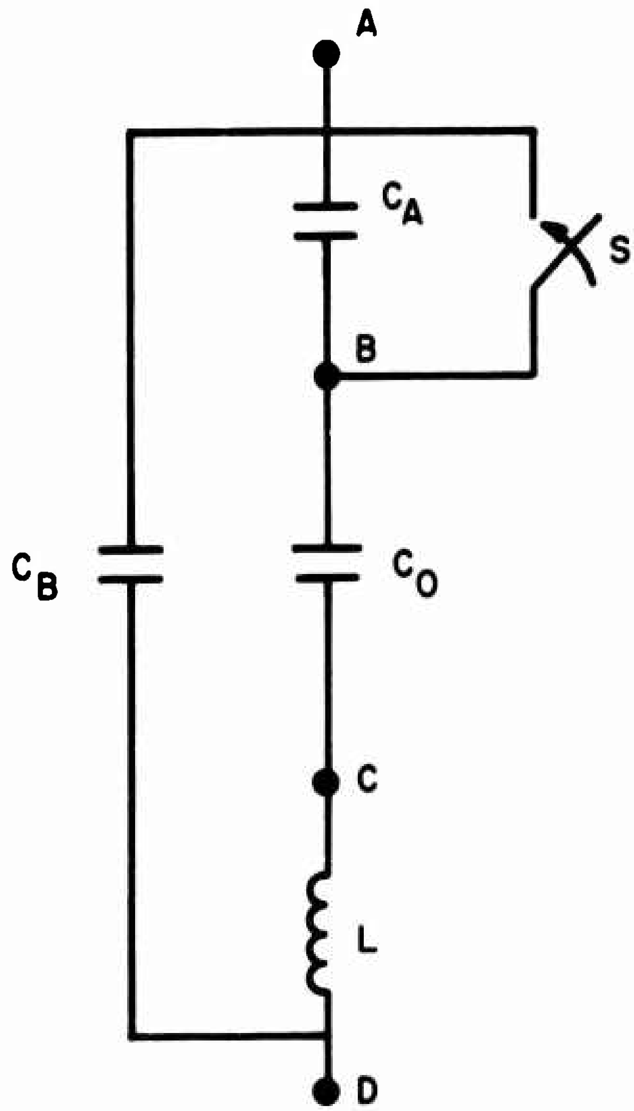


B,C - COAXIAL CONNECTORS

A - HOT TERMINAL OF BRIDGE

D - GROUND TERMINAL OF BRIDGE

FIG. A2- BRIDGE MEASUREMENT SET-UP



S - CLOSED FOR BRIDGE READING

FIG. A3 - APPROXIMATE EQUIVALENT CIRCUIT

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13. ABSTRACT

This technical report describes a theoretical and experimental investigation of factors affecting the performance of toroidal inductors with ferrite cores and windings of coaxial cable. Design procedures are developed and described for toroidal cable chokes which provide a specified minimum amount of rf isolation over a band of frequencies. It is shown how one may maximize the width of the frequency band for a given rf isolation impedance. In fact it is shown that the entire band, from 2 to 30 Mc, may be covered by a set of only three individual cable chokes, providing an rf isolation of better than 5,000 ohms.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Cable Choke						
Inductor						
Ferrite toroid						
Miniature Coaxial Cable						
RF Isolation						
Wideband						
Self-capacitance of a Cable Choke						
Inductance of a toroidal choke						
Number of Turns						
Admittance Bandwidth of a Choke						
Padding the toroid						
Separation of First and Last Turns						
Insulating Container						

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