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An earth mat for the cathode ray direction finder antenna

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AN EARTH MAT
FOR THE CATHODE RAY DIRECTION FINDER ANTENNA

BY

H. L. ARMSTRONG AND J. R. WALLER

OTTAWA

OCTOBER, 1949

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AN EARTH MAT

FOR THE CATHODE RAY DIRECTION FINDER ANTENNA

by

H.L. Armstrong and J.R. Waller*

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Text - 4
Figures - 7

* On loan from the Defence Research Board.

ABSTRACT

The form of the earth mat used is that described by R.L. Smith-Rose and W. Ross in J.I.E.E., Part III, vol. 94, March, 1947. A method is described of measuring the impedance of radial wires at the edge of the mat, and thus of chosing suitable combinations of lengths to offer a low impedance over a wide band.

AN EARTH MAT

FOR THE CATHODE RAY DIRECTION FINDER ANTENNA

INTRODUCTION

The Adcock antenna used with the high-frequency cathode-ray direction finder (CRDF) depends on the presence of a uniform, low-impedance ground plane for successful operation. The ideal would be an infinite conducting plane at the surface of the earth on which to mount the antenna array. When attempts are made to use the natural soil as the ground plane, several faults at once appear. The most obvious one is that the ground-return impedances of the masts themselves are not equal. That is, for a uniform vertically polarized field, unequal currents will flow in the masts. This will occur if the soil is not uniform around the array. The presence of connecting cables in, or on, the earth will also affect this balance. Changes of weather, such as drought or freeze-up, will make it much more critical. When the incident field is horizontally polarized the masts should pick up no signal, but again the presence of cables lying in the ground will induce unequal charges on the masts, and hence produce undesirable pickup. The relative amount of unwanted pickup depends on the conductivity of the soil and on the depth to which the cables are buried in it. There is a practical limit to the depth, and in some cases it is not at all feasible to excavate. In soil of poor conductivity, where it is necessary to go to great depths to secure sufficient attenuation of the incident wave, one usually finds that troubles due to non-uniformity and changing conductivity due to weather are important. Thus, it would seem desirable to attempt to approximate the ideal of an infinite conducting plane by introducing an earth mat of limited size, such as is described by R.L. Smith-Rose and W. Ross.[1]

The mat is circular in shape and consists of wire mesh in which the wire spacing is less then $\frac{\lambda}{10}$. The spacing ordinarily used is about two feet. The diameter of the mat is generally made as large as possible, consistent with practical considerations. It should be several times the antenna mast spacing (5 to 10 times), and preferably several wavelengths in diameter. When the lowest frequency is about three megacycles, one wavelength is about 325 feet. Practical considerations generally restrict the size to less than this. The edges of the mat must be "grounded" somehow, either by the use of ground rods or by the use of resonant radial wires. When the length of a radial wire is one-quarter wavelength, it behaves, with its image, as a quarter-wave open-circuited line, presenting a low impedance at the edge of the mat. When the radial is lying on the ground it is naturally subject to considerable loss (depending on ground constants at the time), and the value of the impedance presented at the quarter-wave point will rise above the free space value, but, at the same time, the "bandwidth" will be increased, so that it will be effective over a much broader band of frequencies.

To cover the very large bandwidth required by the direction-finding equipment, several different lengths of radials are used to provide quarter-wave points well spaced in the band. As many radials are used as possible in order to help lower the impedance at the edge of the mat to ground. The total number of radials employed is limited by their relative spacing, which must be great enough so that the mutual impedance between them does not interfere to any large extent with their electrical properties. With a mat of diameter 100 feet, Ross[1] found that the mutual impedance effects were almost negligible using a total of 108 radials.

EXPERIMENTAL RESULTS

Experiments were carried out on various lengths of radial, measured from the edge of a mat 200 feet in diameter. The mesh itself was galvanized wire with a 6-inch spacing. The soil conductivity had been measured some time previously and was found to be about 5×10^{-14} e.m.u.

An r-f impedance bridge was used to measure the impedances of a number of lengths of #14 gauge copper wire radials lying on the ground. Fig. 1 shows the equivalent circuit of the measuring setup. Z_B is the impedance measured by the bridge, Z_R the impedance between the radial and the electrical ground plane, Z_M the impedance between the mat and the electrical ground plane, and Z_S the stray shunt impedance between the near end of the radial and the mat.

Z_B will then be equal to $\dfrac{Z_S (Z_R + Z_M)}{Z_R + Z_S + Z_M}$,

and if the stray shunt impedance is very high, we can write

$$Z_B \simeq Z_R + Z_M.$$

Fig. 2 shows the plotted curves for resistance and reactance of a 40-foot radial with respect to the mat. It is believed that the drop toward capacitive reactance at the high frequencies was due mainly to the presence of Z_S. Fig. 3

shows similar curves for an 80-foot radial. Fig. 4 shows a comparison of resistance as calculated for an 80- and a 40-foot radial in parallel, with that measured for the combination. The comparison reveals little mutual effect on the resistance, and also shows that the impedance Z_M of the mat itself is low compared with that of one or two radials. Similarly, Fig. 5 shows a comparison of measured and calculated reactances for the same combination.

Since the low end of the frequency range in which we are interested is about 2.5 megacycles, the longest radial was chosen to give zero reactance at that point. Its reactance would also be zero at 5 megacycles. Two other lengths were chosen to give reactance zeros evenly spaced between 2.5 and 5 megacycles, at 3.4 and 4.2 megacycles. From Figs. 2 and 3 the velocity of propagation can be deduced and lengths selected to correspond to the three chosen frequencies of resonance 2.5, 3.4, and 4.2 megacycles. These lengths are approximately 70 52, and 42 feet. Fig. 6 shows plotted curves of resistance and reactance for these three lengths in parallel, with respect to the edge of the mat.

It was felt that because of the levelling-off of the reactance curves for radials several wavelengths in length, it might be profitable to make one of them much longer than the other two lengths. A length of 160 feet, having reactance zeros at 2.2 and 3.3 megacycles, was combined with a 70-foot and a 40-foot radial having zeros at 2.5 Mc., 5 Mc., and 3.7 Mc. The measured values of resistance and reactance are shown in Fig. 6 (insets). There is little to choose between the two sets of radials as far as impedance is concerned. The shorter lengths are, of course, more practical.

CONCLUSIONS

For the case under consideration, the radials of length 70-feet, 52-feet and 42-feet provide a fairly uniform impedance characteristic. Thirty-six of each length were attached to the mat to provide a low-impedance termination at its edges. Because of the levelling-off of both reactance and resistance curves at high frequencies, it is only necessary to pay particular attention to the characteristics at the low-frequency end of the band. It was found that the mutual impedance effects were negligible in this experiment where adjacent radials were 3 1/3° apart on a 200-foot diameter. It is quite possible that a larger number of radials could have been used on this mat, thus further improving the termination at the edges. Fig. 7 shows the final earth mat design.

It should be noted here that as the mat itself contributes to the measured impedance, this method of choosing radials will not apply in the case of a very small mat which has a high impedance to ground.

REFERENCES

1. R.L. Smith-Rose and W. Ross, The Use of Earth Mats to Reduce the Polarization Error of U-type Adcock Direction-Finders, J.I.E.E., Part III, vol. 94, March, 1947.

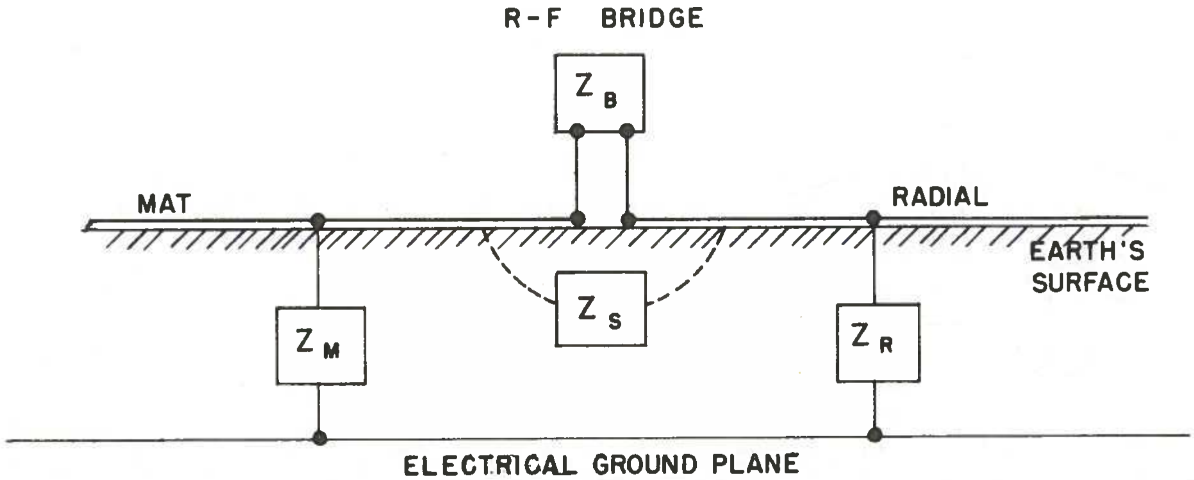
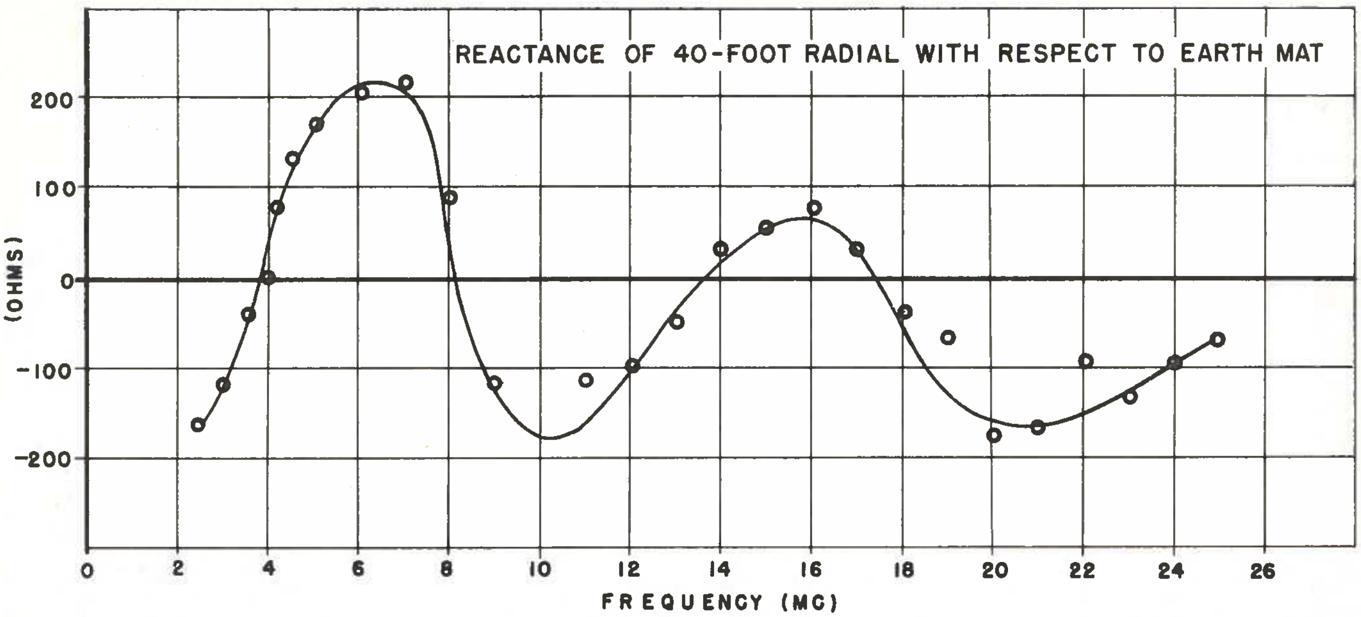


FIG. I

EQUIVALENT CIRCUIT FOR RADIAL IMPEDANCE MEASUREMENT


REACTANCE OF 40-FOOT RADIAL WITH RESPECT TO EARTH MAT
200
100
0
-100
-200
(OHMS)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
FREQUENCY (MC)

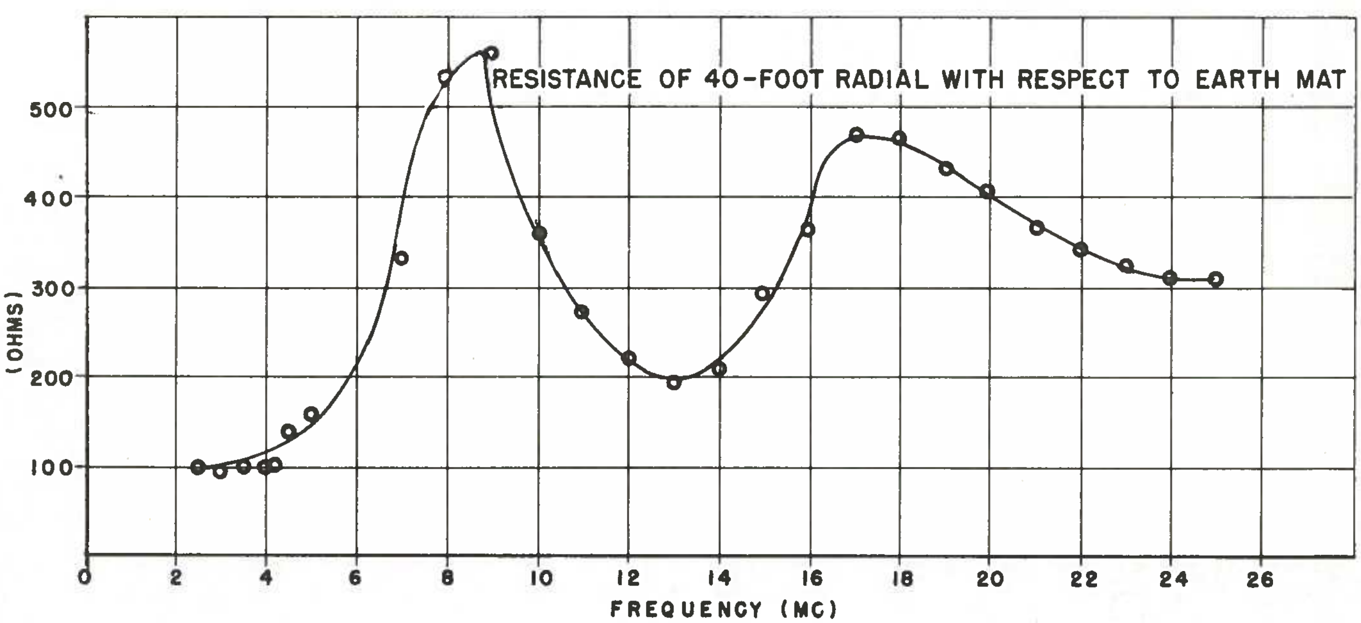

RESISTANCE OF 40-FOOT RADIAL WITH RESPECT TO EARTH MAT
500
400
300
200
100
(OHMS)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
FREQUENCY (MC)

FIG. 2

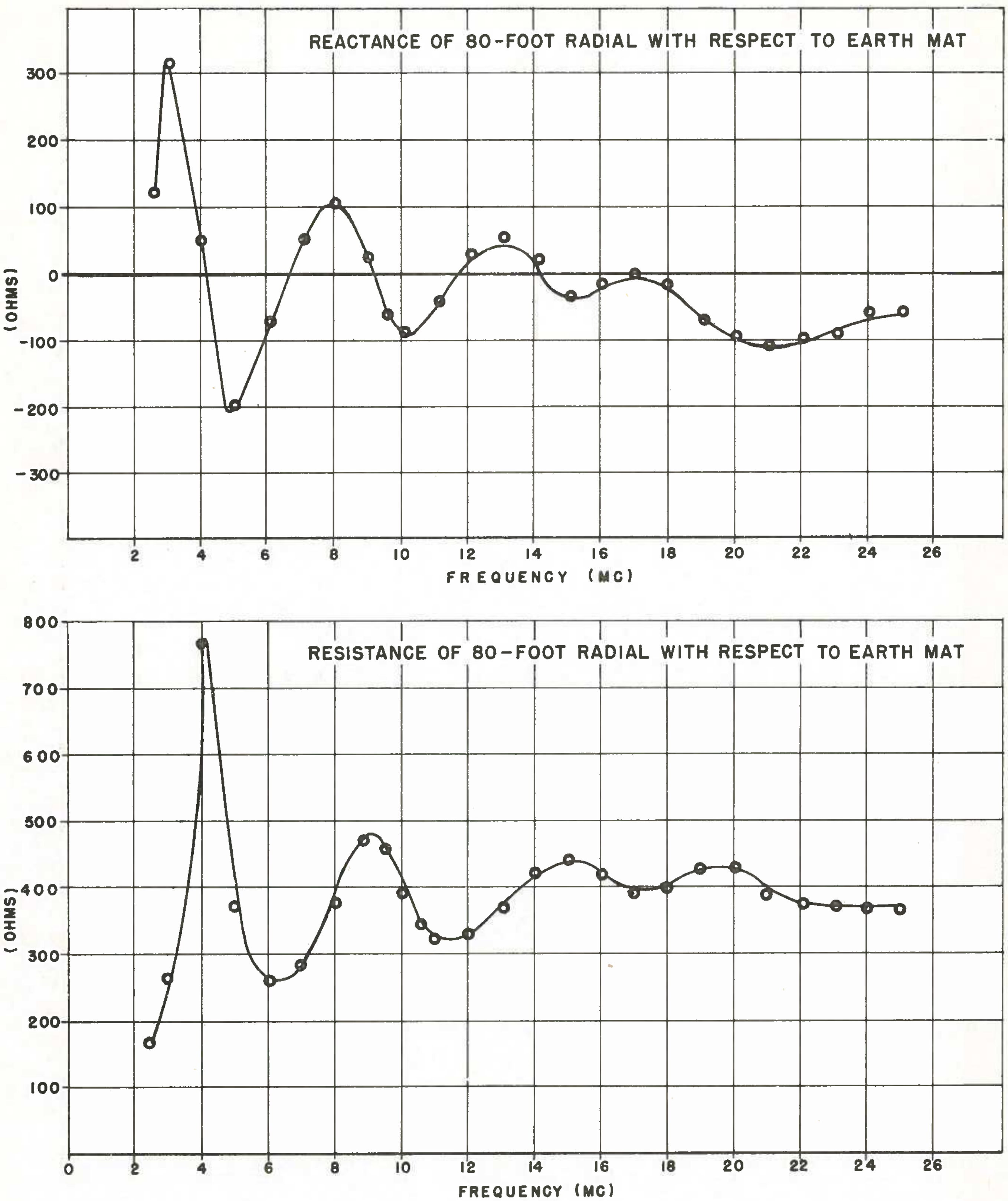

REACTANCE OF 80-FOOT RADIAL WITH RESPECT TO EARTH MAT
300
200
100
0
-100
-200
-300
(OHMS)
2
4
6
8
10
12
14
16
18
20
22
24
26
FREQUENCY (MC)
RESISTANCE OF 80-FOOT RADIAL WITH RESPECT TO EARTH MAT
800
700
600
500
400
300
200
100
(OHMS)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
FREQUENCY (MC)

FIG. 3

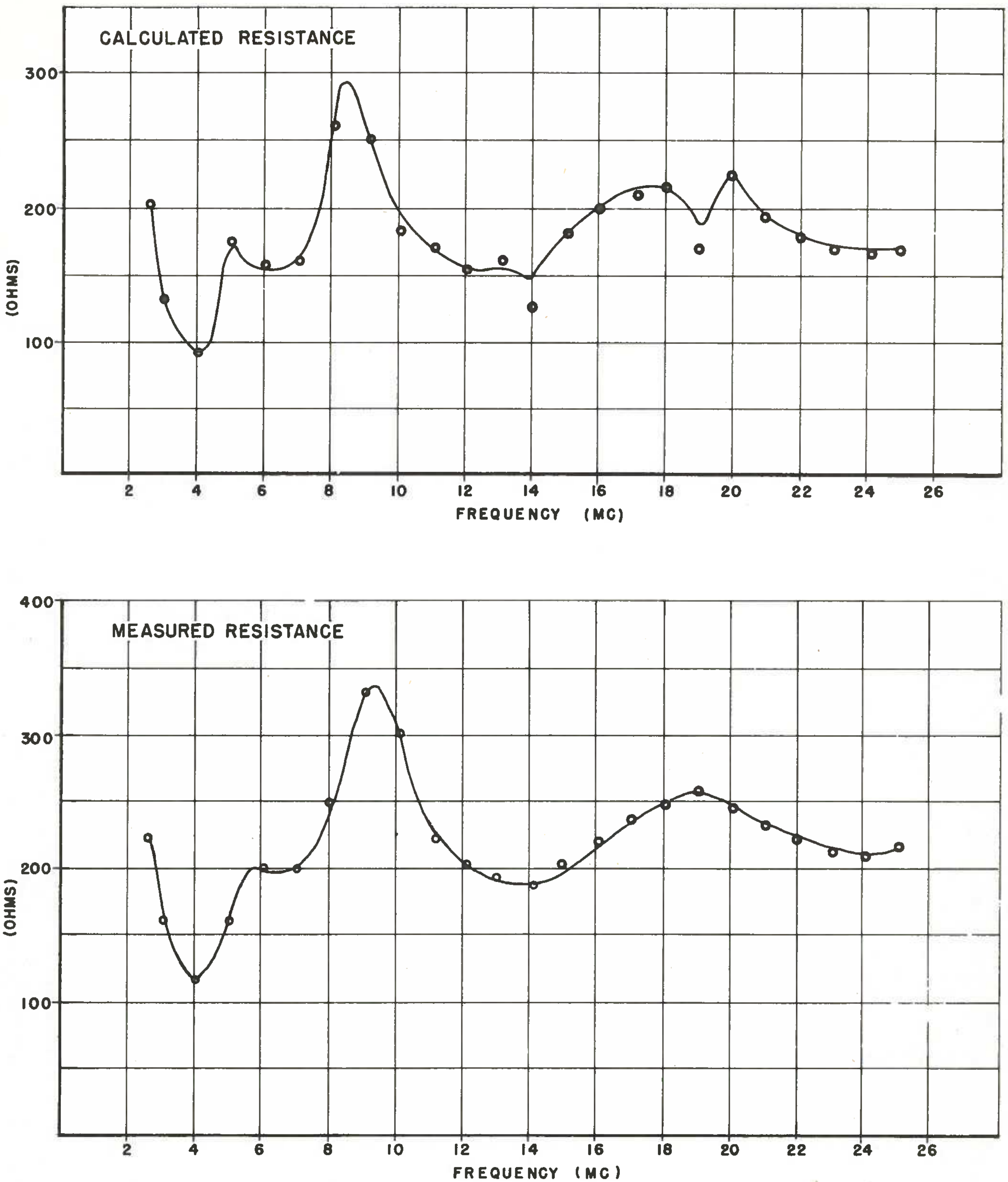


FIG. 4

COMPARISON OF CALCULATED AND MEASURED RESISTANCES OF AN 80-FOOT AND A 40-FOOT RADIAL IN PARALLEL

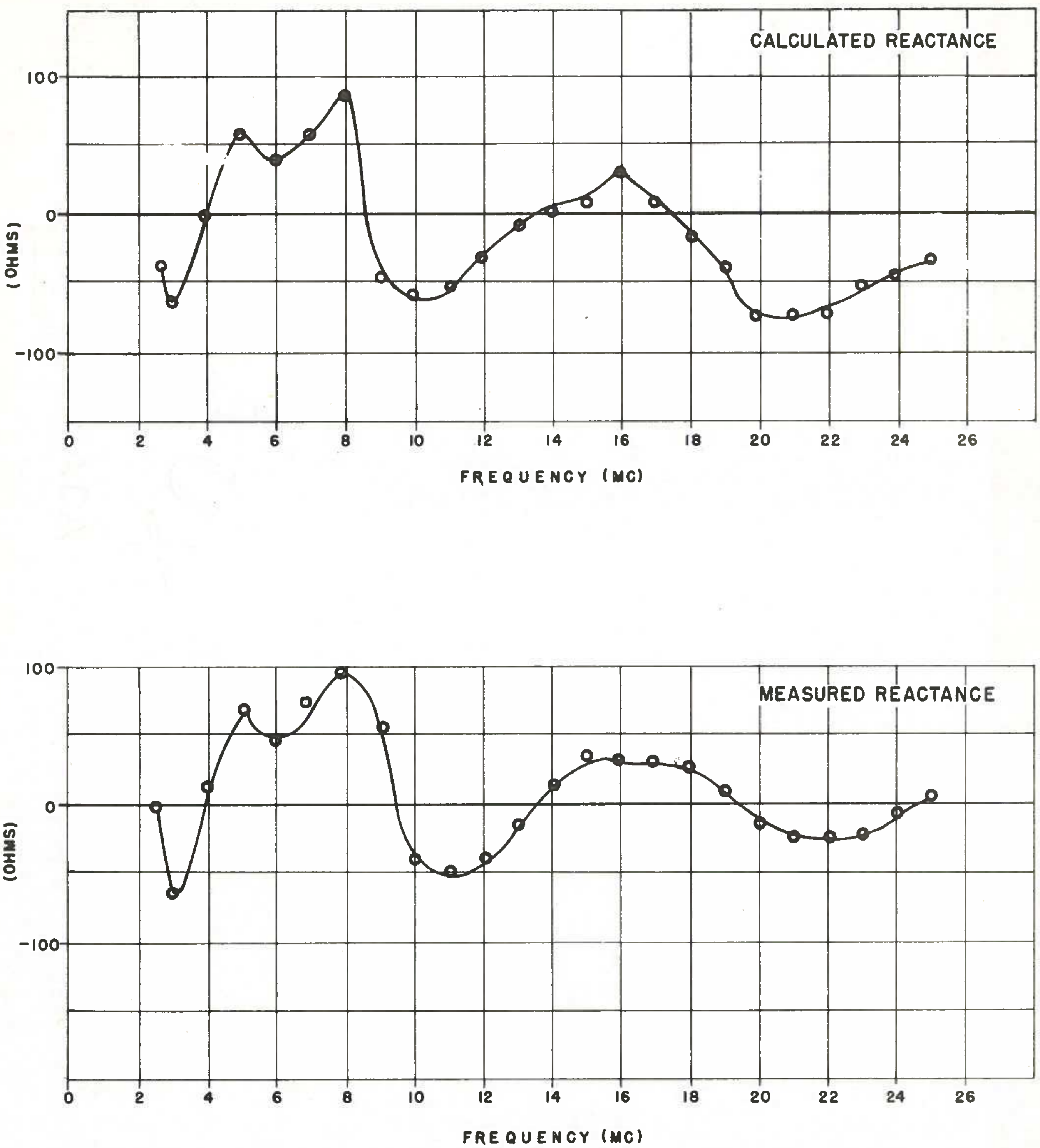
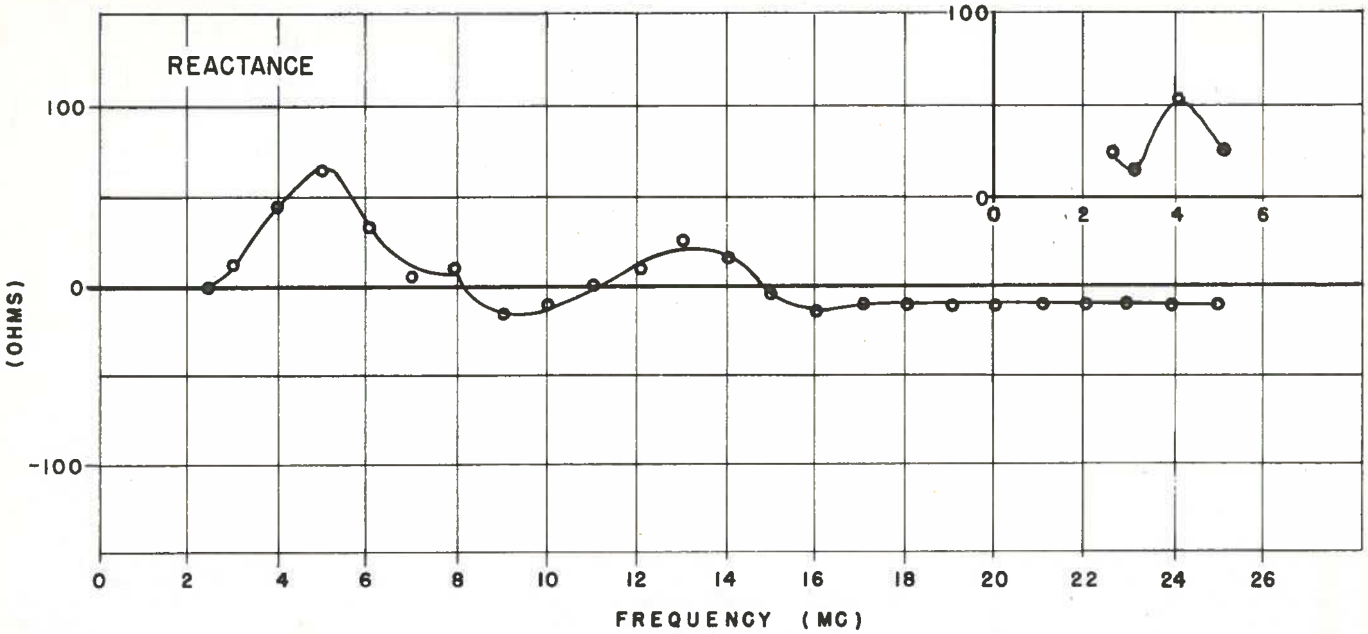


FIG. 5

COMPARISON OF CALCULATED AND MEASURED REACTANCES
OF AN 80-FOOT AND A 40-FOOT RADIAL IN PARALLEL



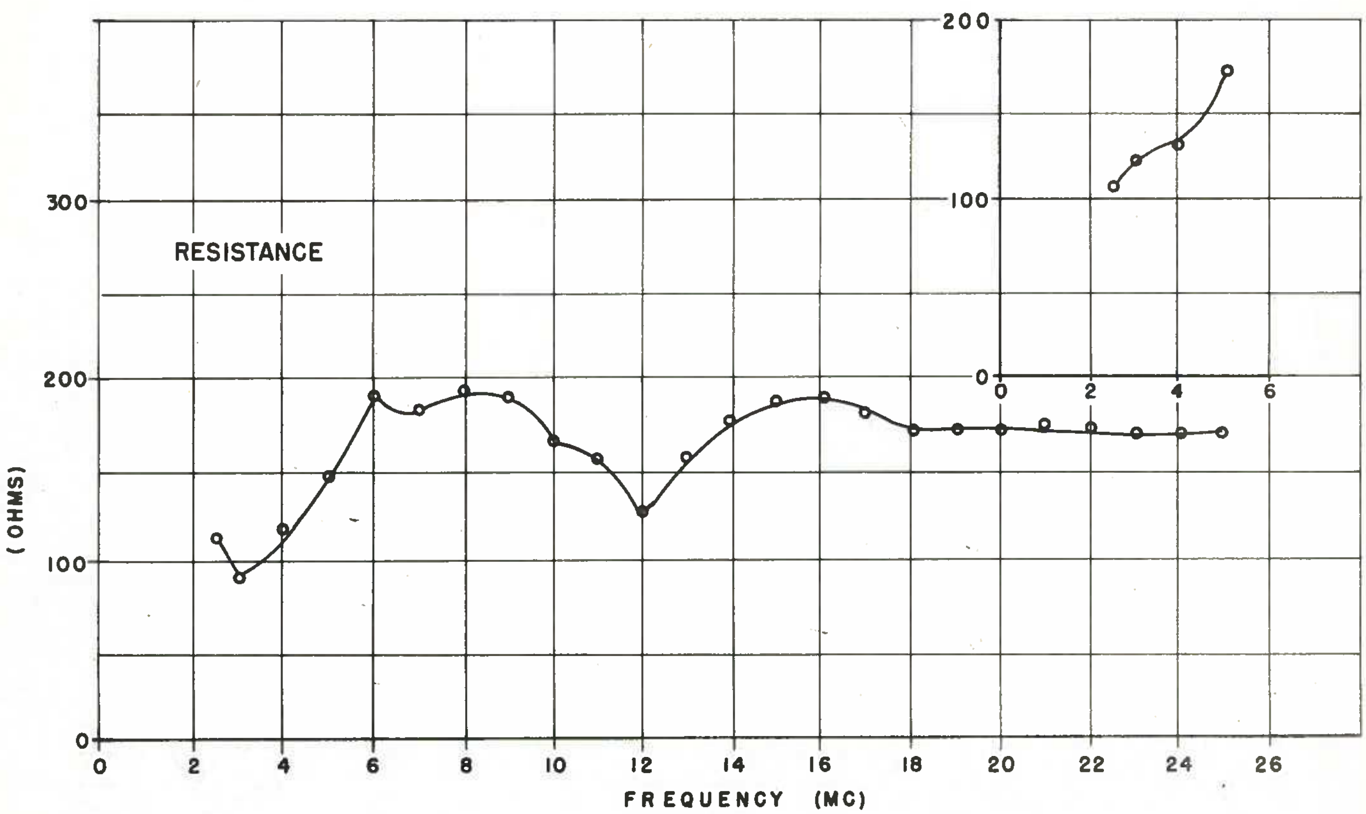


FIG. 6

MEASURED RESISTANCE AND REACTANCE

OF THREE PARALLELED RADIALS 42, 52 AND 70 FEET IN LENGTH

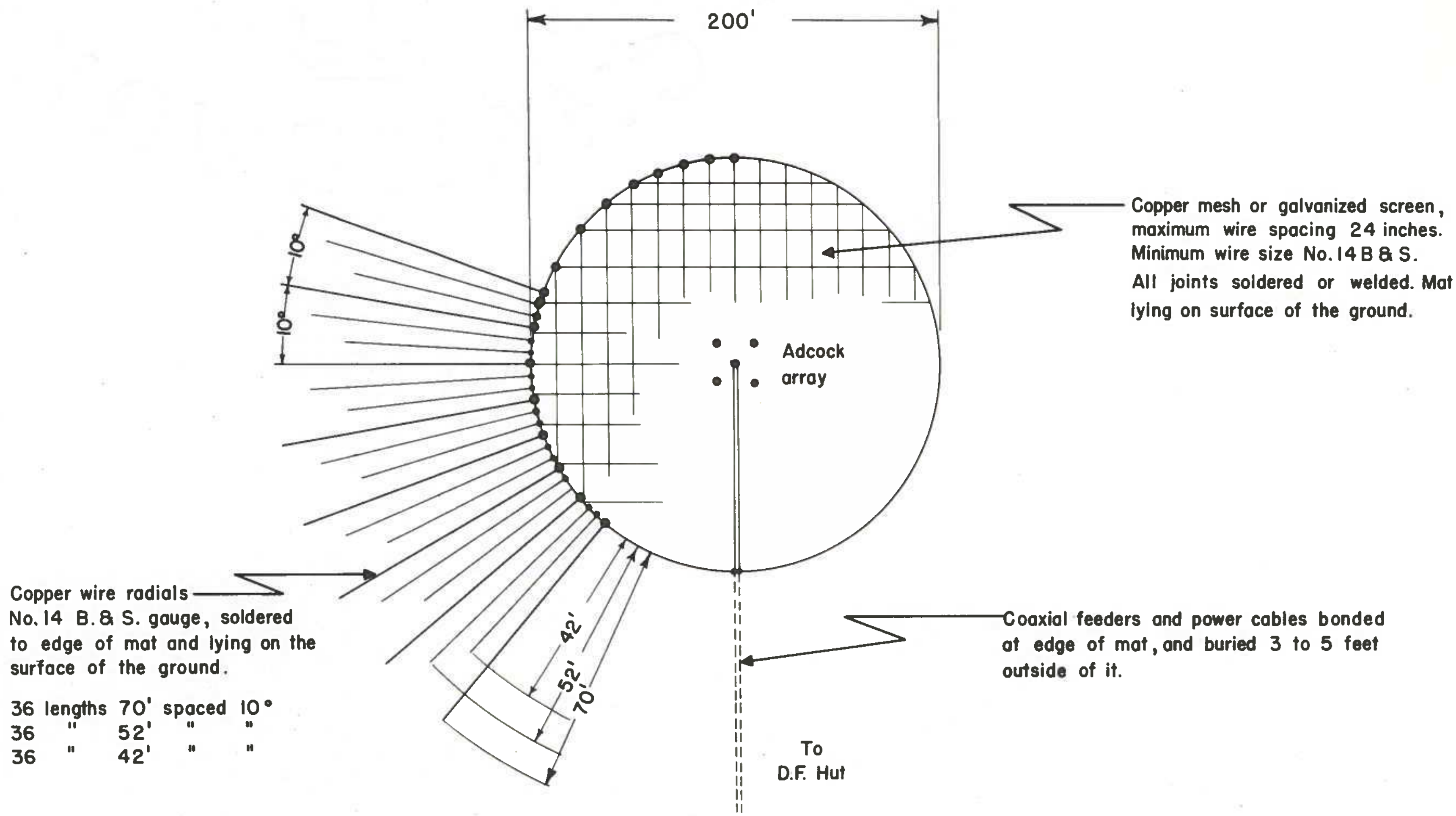


FIGURE 7
DIMENSIONS OF ROSS-TYPE EARTH MAT FOR C.R.D.F.

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