Dôme

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MODIFICATION OF COUPLERS

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1. INTRODUCTION

The radio-frequency cavities of the SPS[1] have undergone modifications in length (as well as in number). Another change has been made to these cavities, namely the addition of dipole antennae, in order to damp their 460.6 MHz deflecting mode[2]. These changes in the RF cavities necessitate modification of the input and the output couplers so that the cavities with their 50 Ohm terminating loads maintain the VSWR seen by the amplifier to a value lower than 1.5 in the operating frequency range of 199.5 MHz to 200.4 MHz.

2. EXPERIMENT AND RESULT

The modification of the couplers was carried out empirically in order to arrive at the best matching. This was achieved by varying the length and the diameter of the inner conductors L3 and L8 of the couplers (see Figs. 1 and 2). Varying the lengths of L3 and L8 would simultaneously change L2 and L9, respectively. The matching is obtained in two steps. Firstly, the output coupler is adjusted to match the 50 Ohm terminating load to the cavity; the impedance locus, as seen from the input line of the cavity in the frequency range from 199.5 to 200.4 MHz, is shrunk to a minimum. Secondly, by adjusting the input coupler this impedance locus is shifted and re-located near to the centre of the Smith Chart for minimum VSWR. The mechanism of this matching technique is outlined in Appendix 1.

A convenient place for the measurement of these impedance loci is in BA3, at the input of the coaxial feeder line going down to the cavities. The lengths of the rigid feeder lines from BA3 to the input coupler of each cavity are different and therefore different compensating cables (RG 213/U) of twice the feeder line length must be inserted in the reference channel in order to measure the reflection coefficient at the input of each cavity.

A cable drum has been prepared for this purpose. Table 1 shows the present configuration of the four cavities, the dimensions of the modified inner conductors of the input and the output couplers, and the measured air length of the feeder lines 1 to 4 from BA3 to the respective input couplers.

Figures 3 to 6 show the measurements of input impedance of the cavities with and without compensating cable. The impedance loci of the respective 500 kW terminating loads of the cavities are shown in figures 7 to 10. The dipole antenna is described in Appendix 2.

3. CONCLUSION

The modified couplers with the cavities and the terminating loads, provide a matching to the amplifiers with a VSWR less than 1.3 in the worst case for the frequency range of 199.5 to 200.4 MHz. If other changes to the RF cavities are made in the future, the couplers, both input and output, must undergo similar modification.

ACKNOWLEDGEMENTS

The author would like to thank C. Zettler for his constant guidance in the measurements of the couplers and the dipoles, and G. Dôme for many useful discussions. The author would also like to thank G. Rochepeau for the measurement data of the loads.

REFERENCES

1. G. Dôme, The SPS acceleration system travelling wave drift-tube structure for the CERN SPS, CERN-SPS/ARF/77-11.

2. C. Zettler, private communication.

APPENDIX 1

Input and output couplers (computation)

The input and the output couplers provide a match between the cavity and the power amplifier at one end, and between the cavity and the terminating load at the other end. The central conductors of the couplers end up in two coupling loops connected to the pedestals of the first and the last drift tube assemblies of the cavity. This is shown in Fig. 2. The impedance is ideally a match and hence the coupling loop and the cavity may be replaced by a 50 Ohm (characteristic impedance) line with the same length and the same dispersion (i.e. same group velocity). The dispersion of the cavity can be approximated as follows:

The phase deviation $\Delta\phi$ in radians, per unit cell (in the operating mode)

$$\Delta\phi = \frac{2\pi\ell}{vg}\,\Delta f$$

where

ℓ = cell length

vg = group velocity

Δf = total frequency variation in the operating range

The total phase shift in degrees for N cells

$$\phi = N \times \left[90 + 4.746(f_0 - f)\right]$$

when

N = total number of cells

f_0 = transition frequency = 200.222 MHz, where phase shift per cell is 90°

f = frequency in the range of 199.5 to 200.4 MHz

vg/c = 0.0946

c = 3×10^{8} m/sec .

ℓ = 374 mm

Since the 50 ohm feeder line from the power amplifier splits into two identical sections in the input coupler and similarly for the output couplers, the schematic of Fig. 2 simplifies to Fig. 11. This is an approximate equivalent circuit and the section L7 is a short-circuited stub. The input impedance of this system, consisting of 50 ohms load, output coupler, cavity (represented by 44 cells) and input coupler, can be computed rather easily and the input impedance is $Z_{IN}/2$. The input coupler, Section L8-D8, is first arbitrarily fixed and the locus of the input impedance in the frequency range from 199.5 to 200.4 MHz for a given L3-D3 in the output coupler is obtained. The optimum value of L3 and D3 are found when the locus shrinks to a minimum; this is shown in Fig. 12. With these values of L3 (200 mm) and D3 (94 mm) the input coupler, Section L8-D8, can now be modified in such a way that the input impedance locus is shifted and re-located at the centre of the Smith Chart to give overall minimum VSWR. Typical loci are shown in Fig. 13. The optimum values of L8 and D8 are 200 mm and 94 mm, respectively.

In reality, the cavity is not absolutely uniform in cross-section throughout its length and there is a finite power loss in the cavity. Therefore, the input and the output couplers are not identical.

APPENDIX 2

The dipoles

The purpose of installing dipoles at both ends of the RF cavity is to damp the 460.6 MHz deflecting mode which causes beam instability in the SPS. Since the main couplers are not intended to couple to the higher modes, they hardly provide any damping for them.

The commonly-known technique of inserting resonant probes through the top holes of the cavity may be, and has already been applied; but a large number of probes (say 20) must be installed per cavity in order to damp the unwanted mode significantly. (Since the cavity is very high Q and maximum RF power fed is 500 kW), the dipoles must be designed in such a way that they couple out a minimum of power at the fundamental frequency (199.5 to 200.4 MHz) and a maximum of power at 460 MHz.

The dipoles are installed near the couplers, two at each end, in order to preserve the symmetry of the cavity with respect to its central horizontal plane. As shown in Fig. 14, the voltages induced on the two dipole arms at the fundamental frequency are of the same phase and magnitude, and therefore the current in the terminating load of the dipole is zero. However, at 460 MHz, the induced voltages are out of phase and they produce a net current in the dipole-load.

The dipole and the impedance matching balun are an integral part and matching the dipole to 50 ohms is achieved by changing the inner conductor (diameter d_i) of the balun. The length ℓ of the dipole differs from free space $\lambda/2$ since the cavity inner cylindrical surface and the end plate modify strongly the electrical length. The dimensions ℓ, ℓ_{st} and d_i are obtained from low-level measurements with the dipole mounted in a cavity section (11 cells only). An inox cover plate is mounted on the other end of the cavity. The dipole is optimized by making Q_L (obtained by reflection measurement) a minimum as shown in Figure 15. The final dimensions in mm are:-

$$\ell = 250, \qquad \ell_{st} = 160, \qquad d_i = 19.5$$

Measurement at 200 MHz with 400 kW input power to the cavity 3 without any beam shows that the power coupled into the dipole is of the order of 3 Watts. The effectiveness of the dipoles at 460.6 MHz can be found from the measurement of Q_0, unloaded Q of the cavity and Q_L, Q of the cavity when dipoles are installed; this is shown in Table 2.

Table 1

Present configuration of couplers and cavities

CAVITY	1	2	3	4
Number of sections	4	4	5	4
Number of dipoles	4	4	4	4
Input coupler L8 mm D8 mm	 185 100	 255 97	 190 100	 230 98
Output coupler L3 mm D3 mm	 245 95	 190 100	 230 98	 265 97
Length (m) of feeder line from BA3 to cavity	99	114.7	149	184
500 KW terminating load	Inner conductor first version unmarked	CERN load 3a final version	CERN load 5a	CERN load 4a

Note: Cavity 1 is the first cavity along the beam line.

Table 2

Measurement of the 3rd cavity

Frequency MHz	Q	Comments
459.342	19139	No dipoles
459.266	1300	1 dipole
459.208	1180	2 dipoles
459.220	891	4 dipoles
460.445	24234	No dipoles
460.491	1968	1 dipole
460.249	1354	2 dipoles
460.243	975	4 dipoles
461.427	27142	No dipoles
461.433	27000	1 dipole
461.425	1285	2 dipole
461.420	973	4 dipoles

Note: Q measurement with 4 dipoles is rather difficult, since the 3 dB points are no longer well-defined.

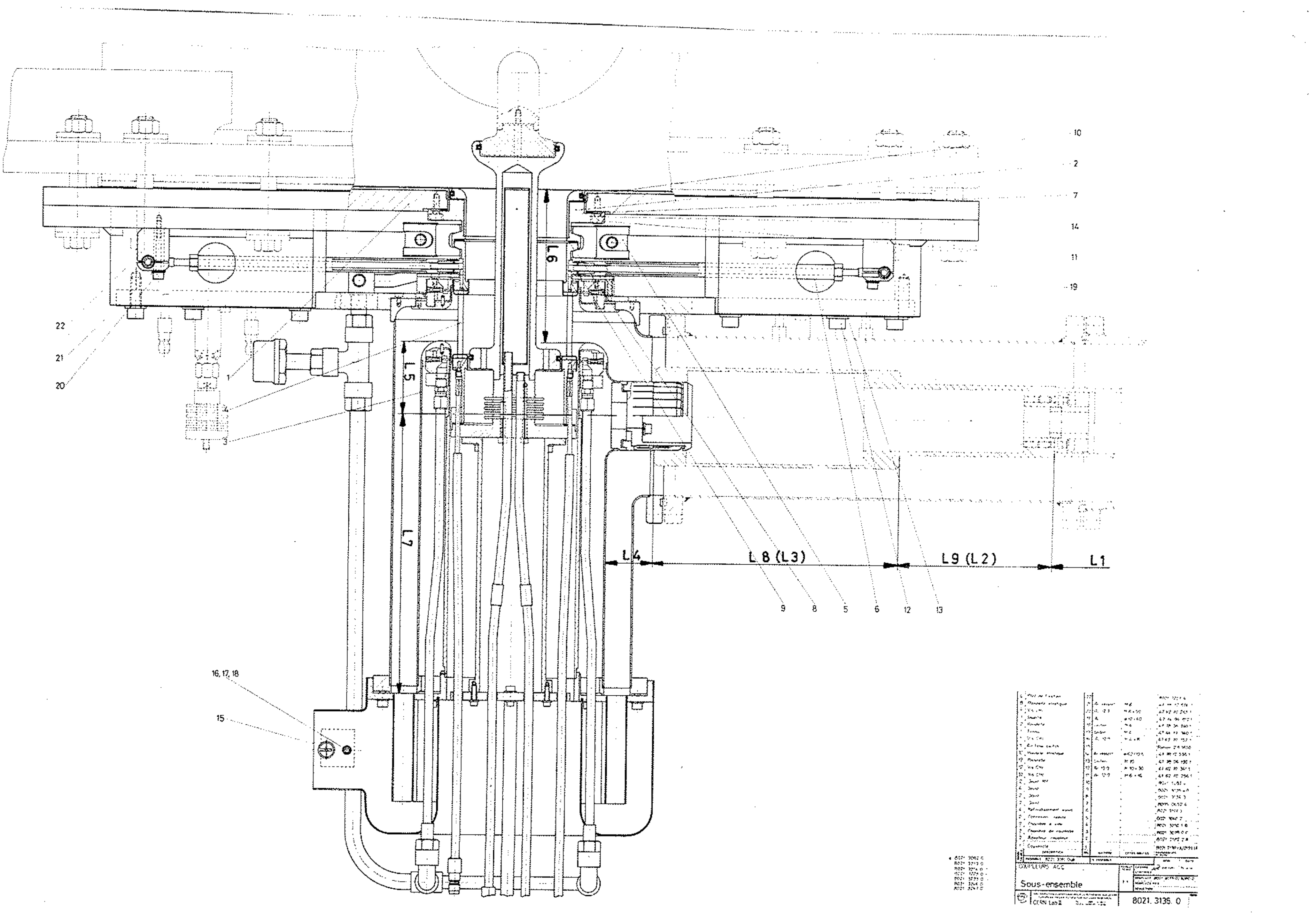


Figure 1 - Cross-sectional view of coupler

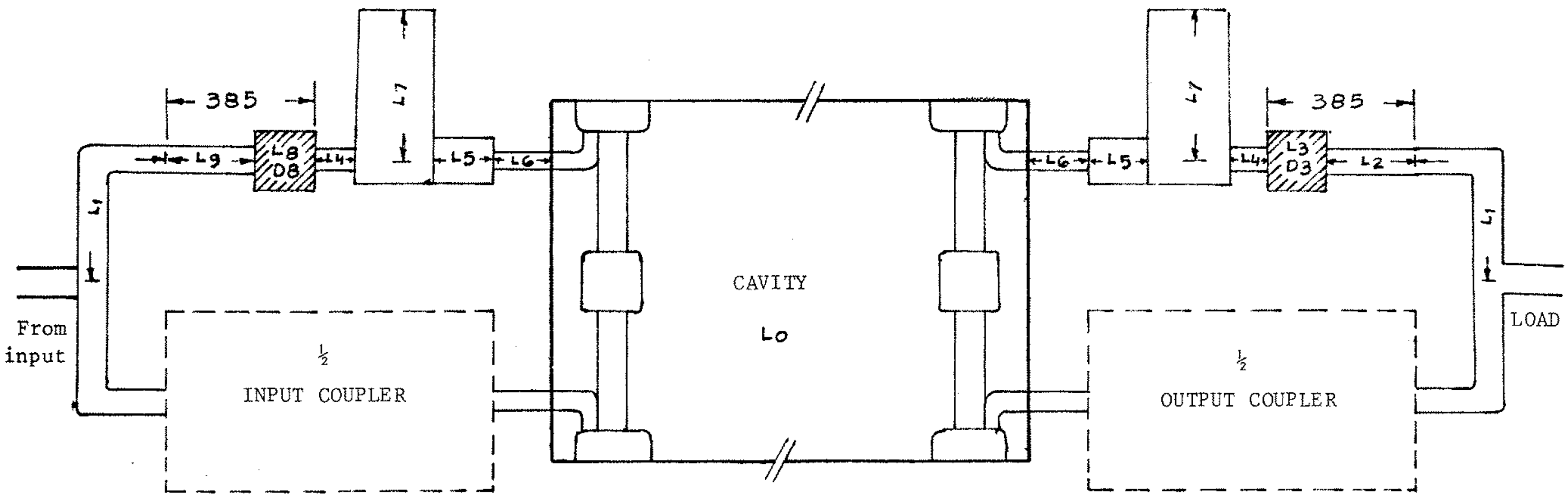


Figure 2 - Schematic of input and output couplers

Figure 3 - Input impedance of Cavity I with compensating cable

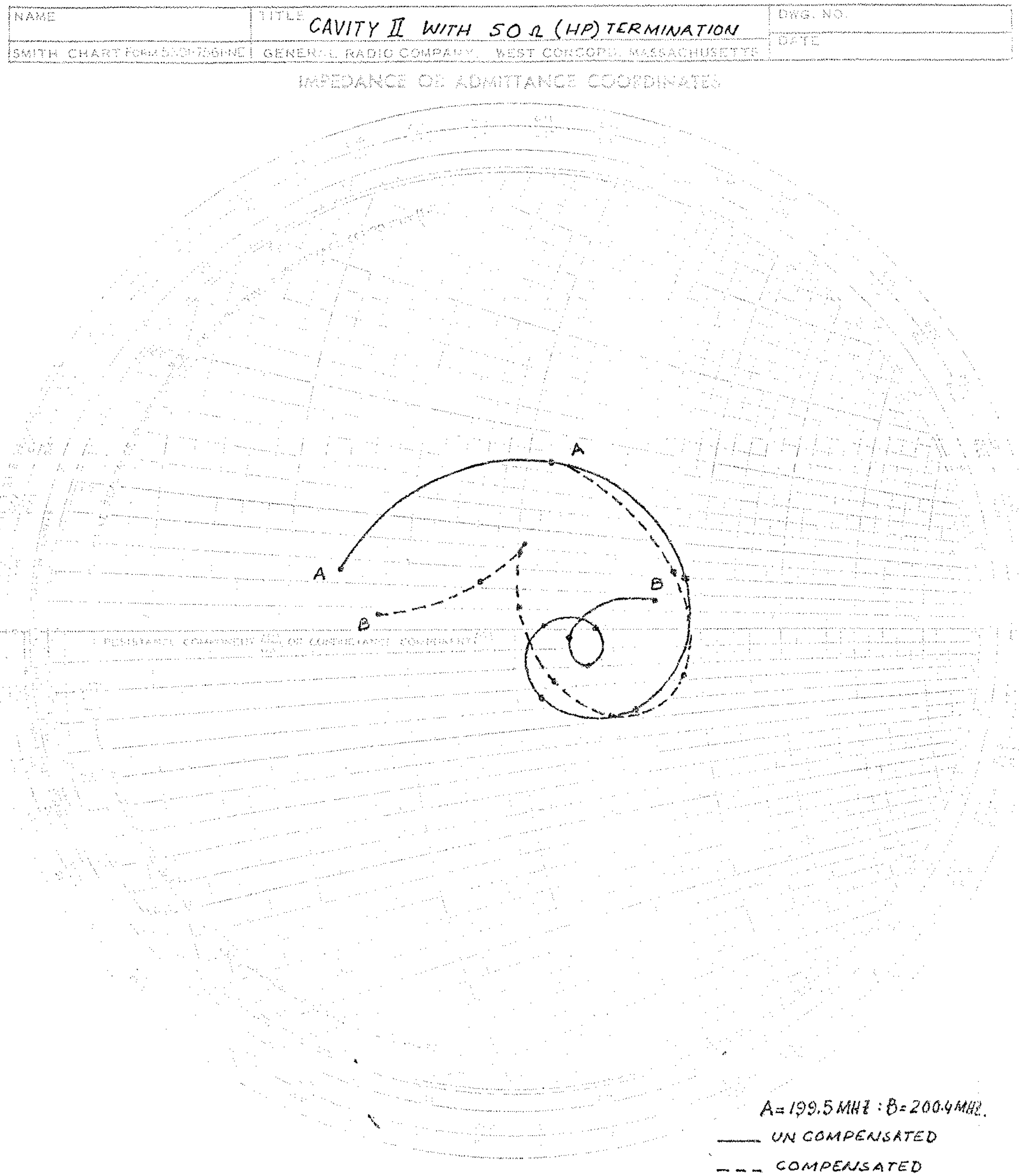


Figure 4 - Input impedance of cavity II with and without compensating cable

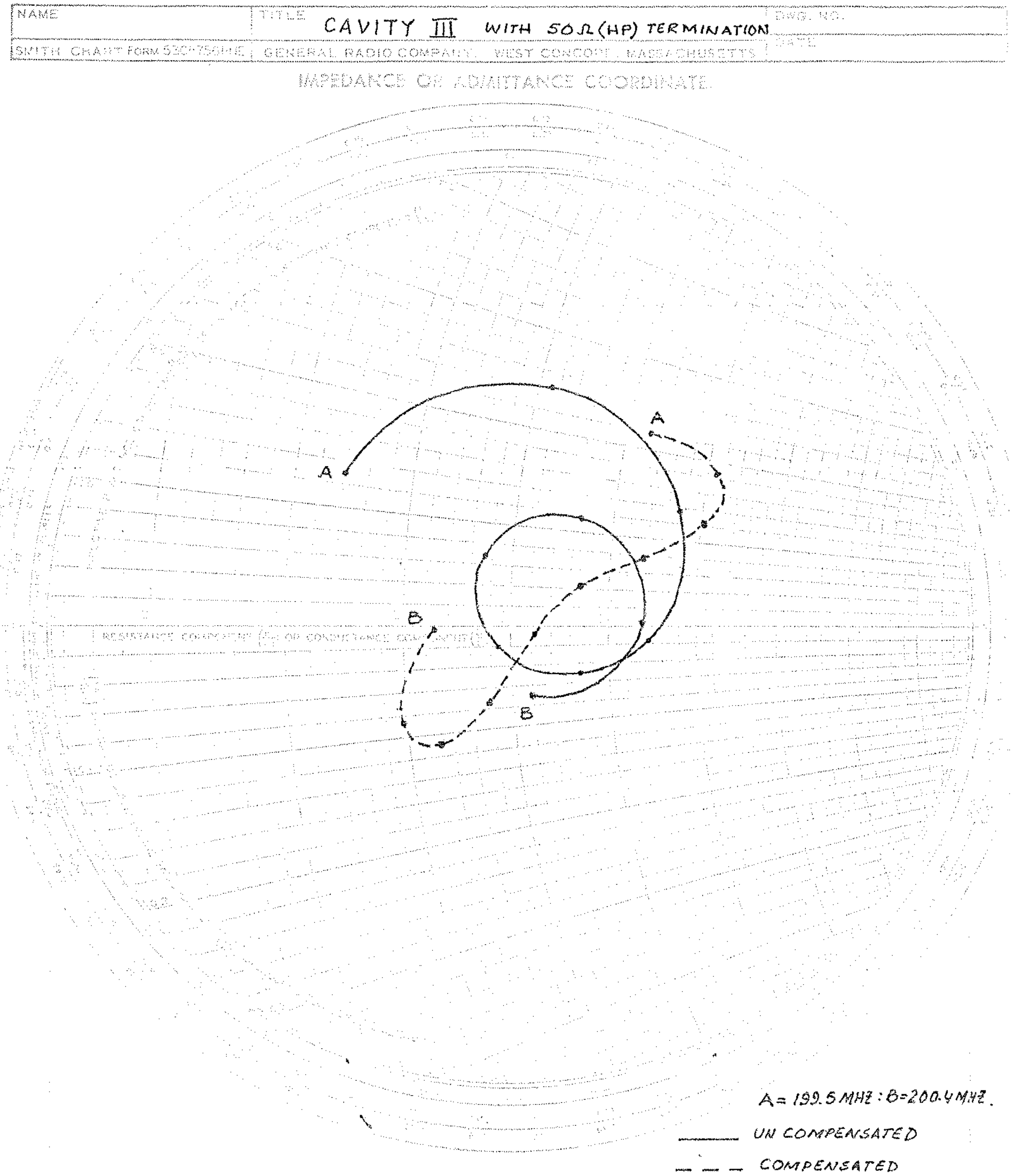


Figure 5 - Input impedance of Cavity III with and without compensating cable

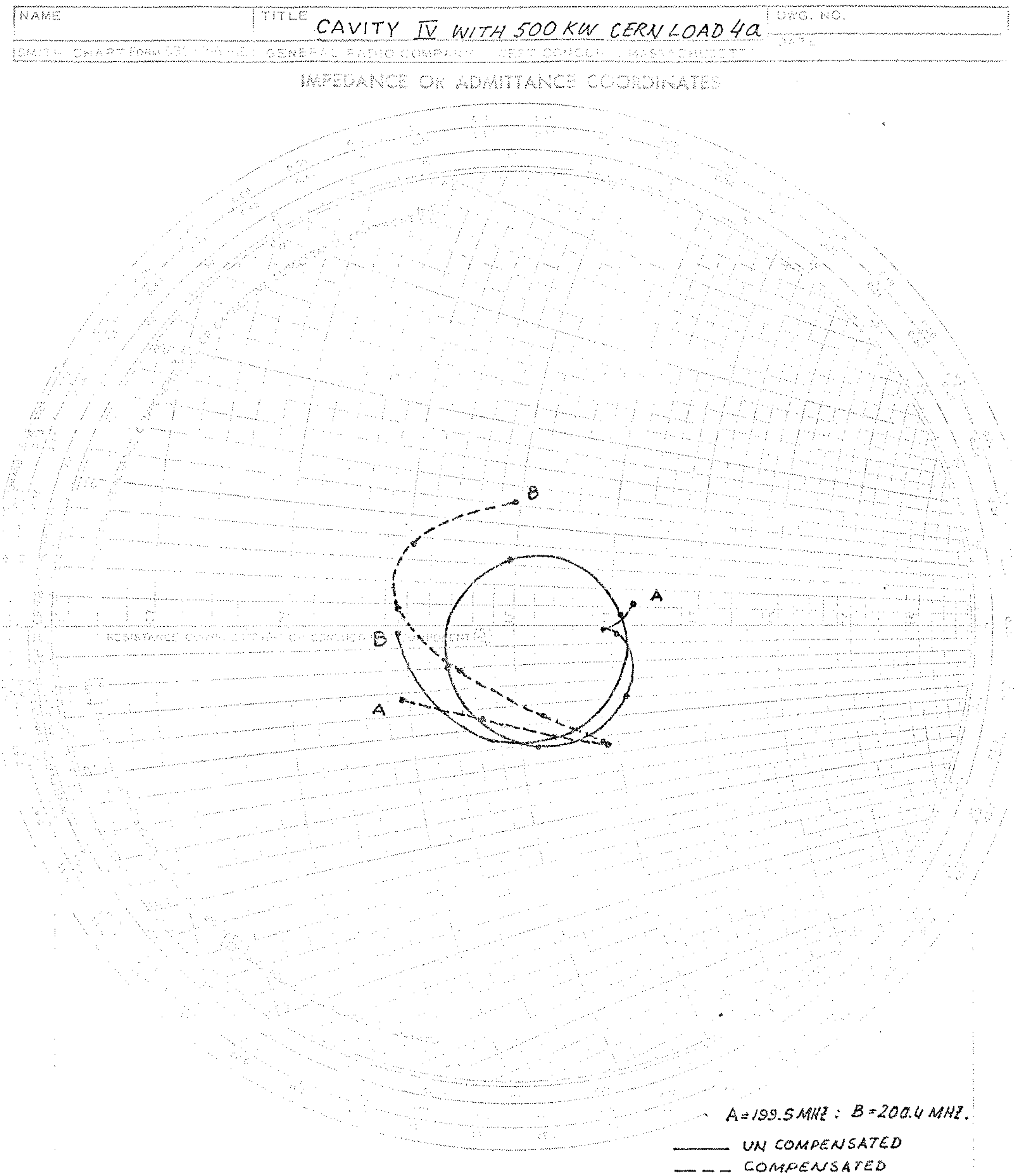


Figure 6 - Input impedance of cavity IV with and without compensating cable

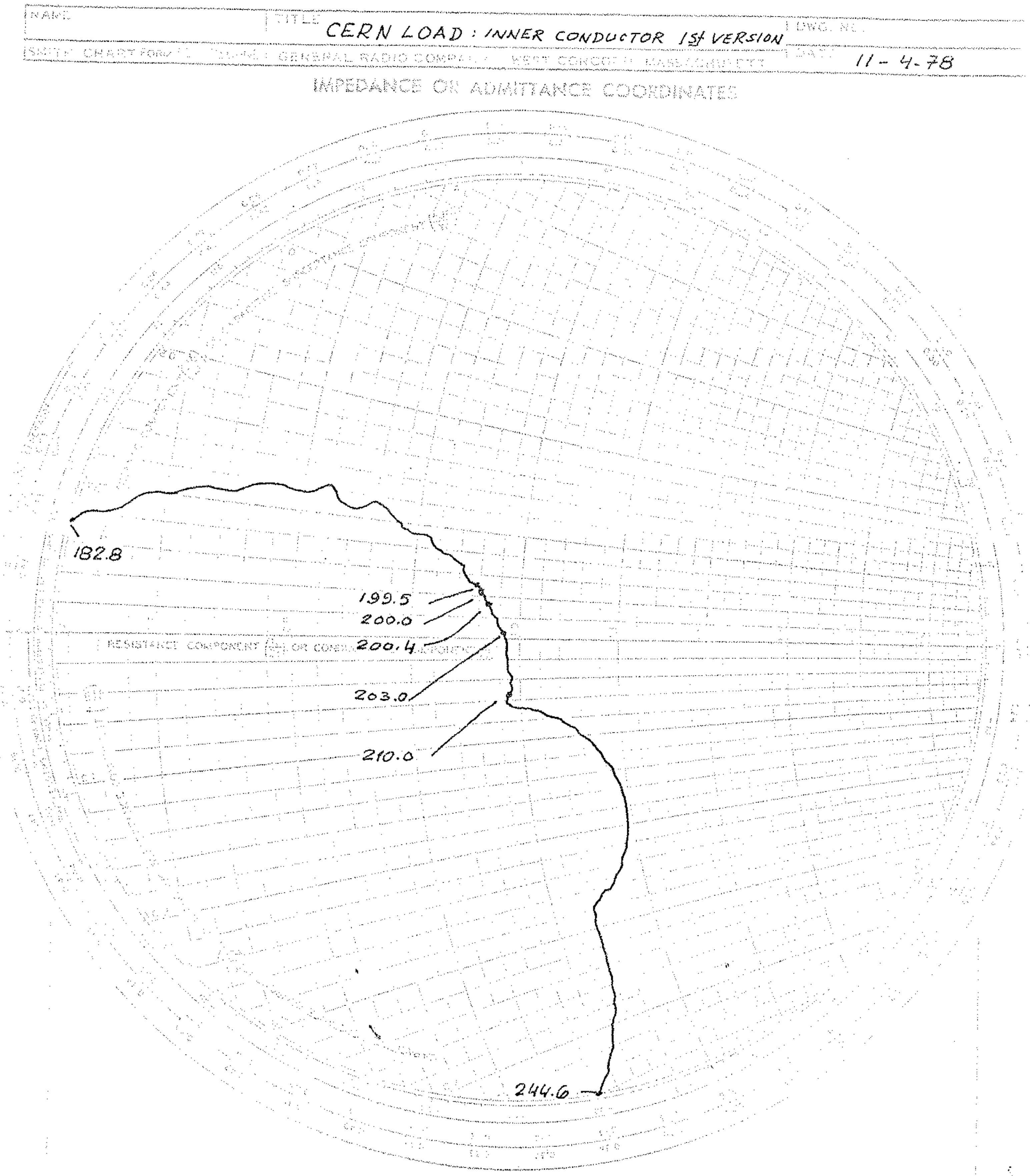


Figure 7 - Cavity I

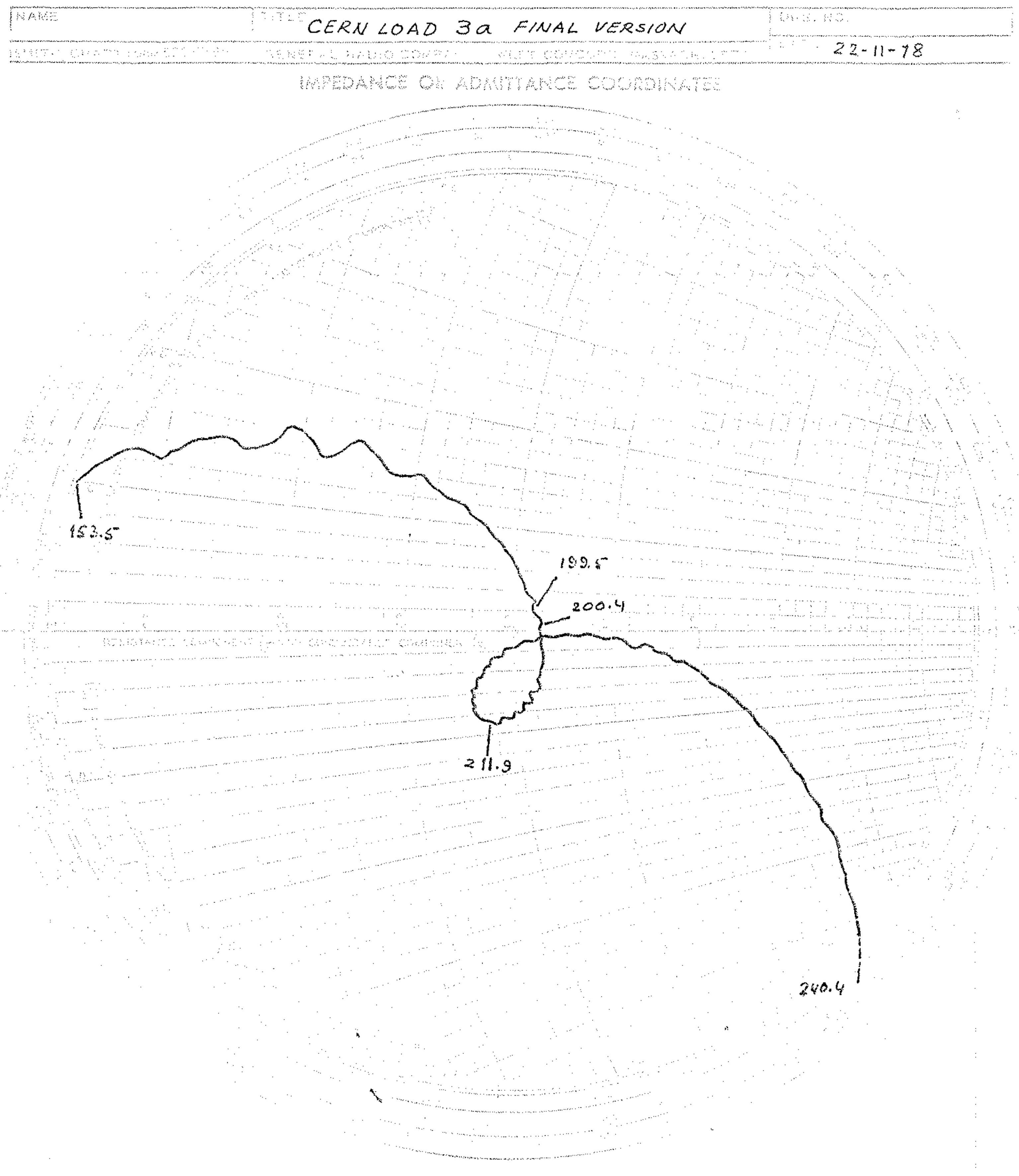


Figure 8 - Cavity II

NAME	TITLE CERN LOAD 5a	DWG. NO.
SMITH CHART FORM 530-756PNE	GENERAL RADIO COMPANY, WEST CONCORD, MASSACHUSETTS	DATE 15-2-79

IMPEDANCE OR ADMITTANCE COORDINATES

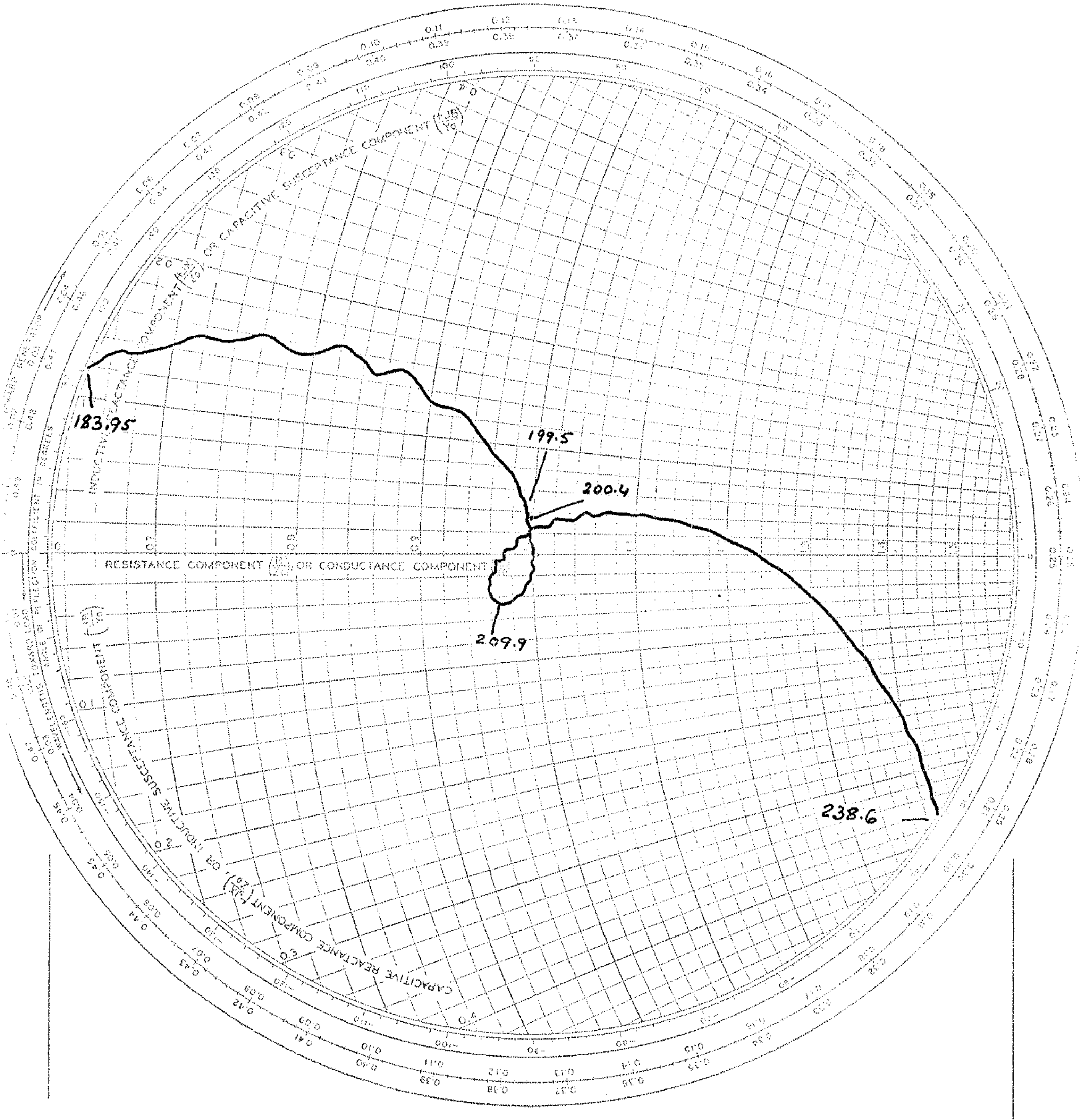


Figure 9 - Cavity III

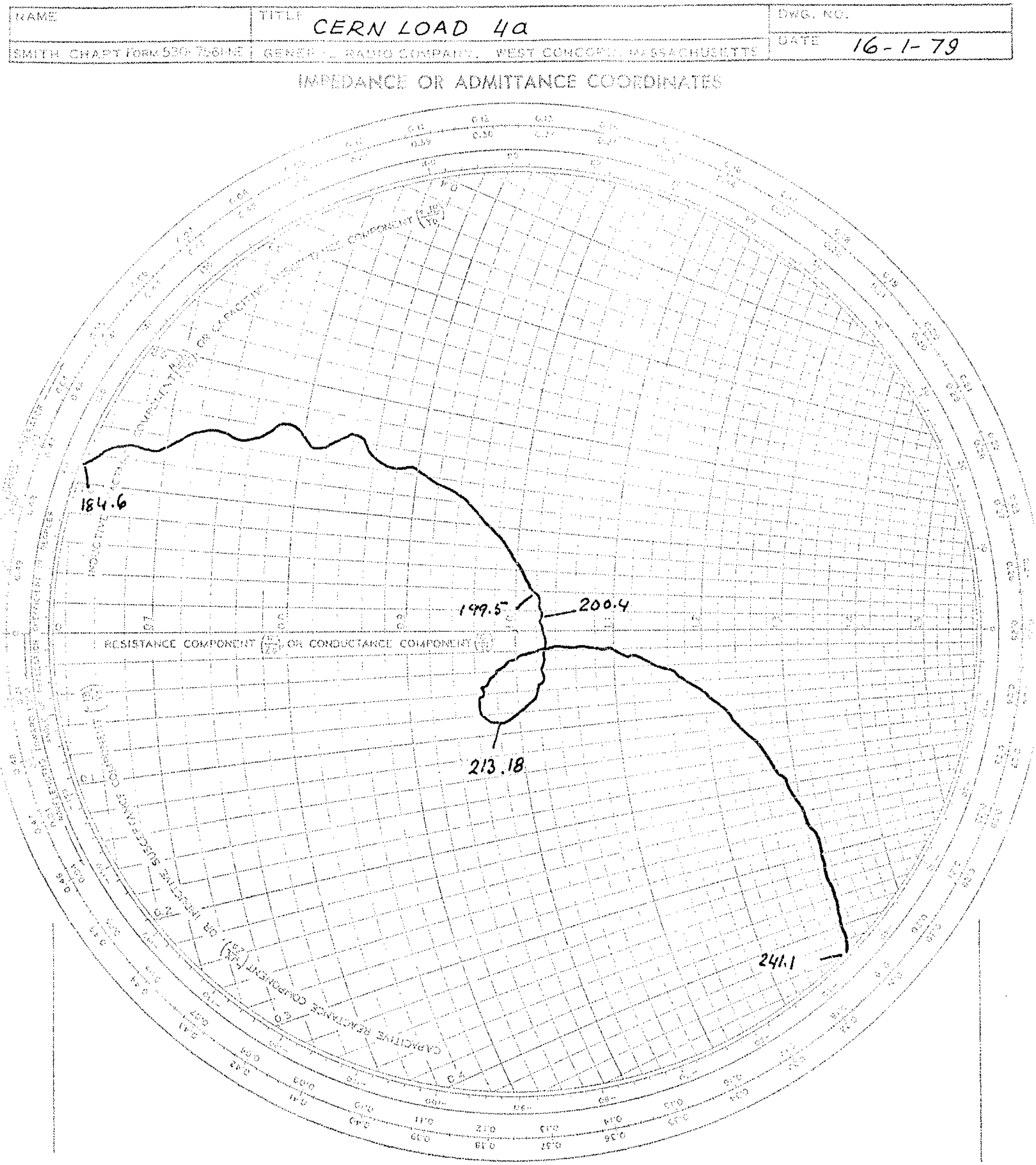
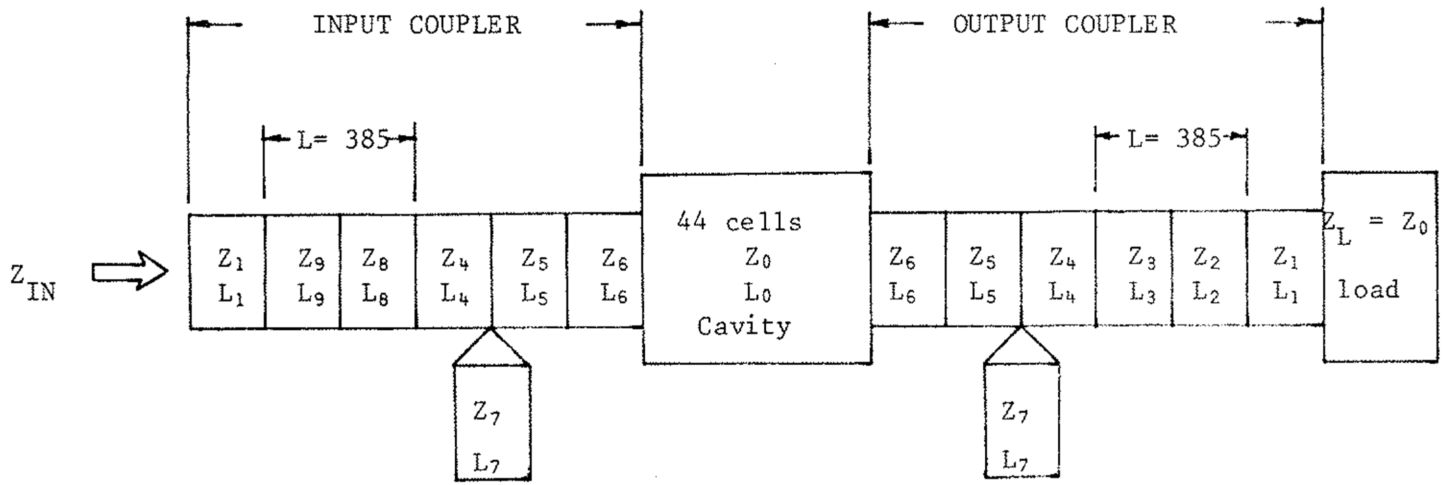


Figure 10 - Cavity IV



i	L_i (mm)	D_{I_i} (mm)	D_{o_i} (mm)	$Z_i/Z_0 = 1.2\ \ell n(D_{o_i}/D_{I_i})$
0	44x374	-	-	1.0
1	375	68	152	0.965
2	385-L_3	68	152	0.965
3	-	-	152	-
4	45	66	152	1.0
5	70	180	229	0.289
6	146	40	96	1.0
7	270	180	229	0.289
8	-	-	152	-
9	385-L_8	68	152	0.965

D_{I_i} and D_{o_i} are inner and outer diameters of the sections respectively

Figure 11 - Equivalent circuit of Input and Output couplers

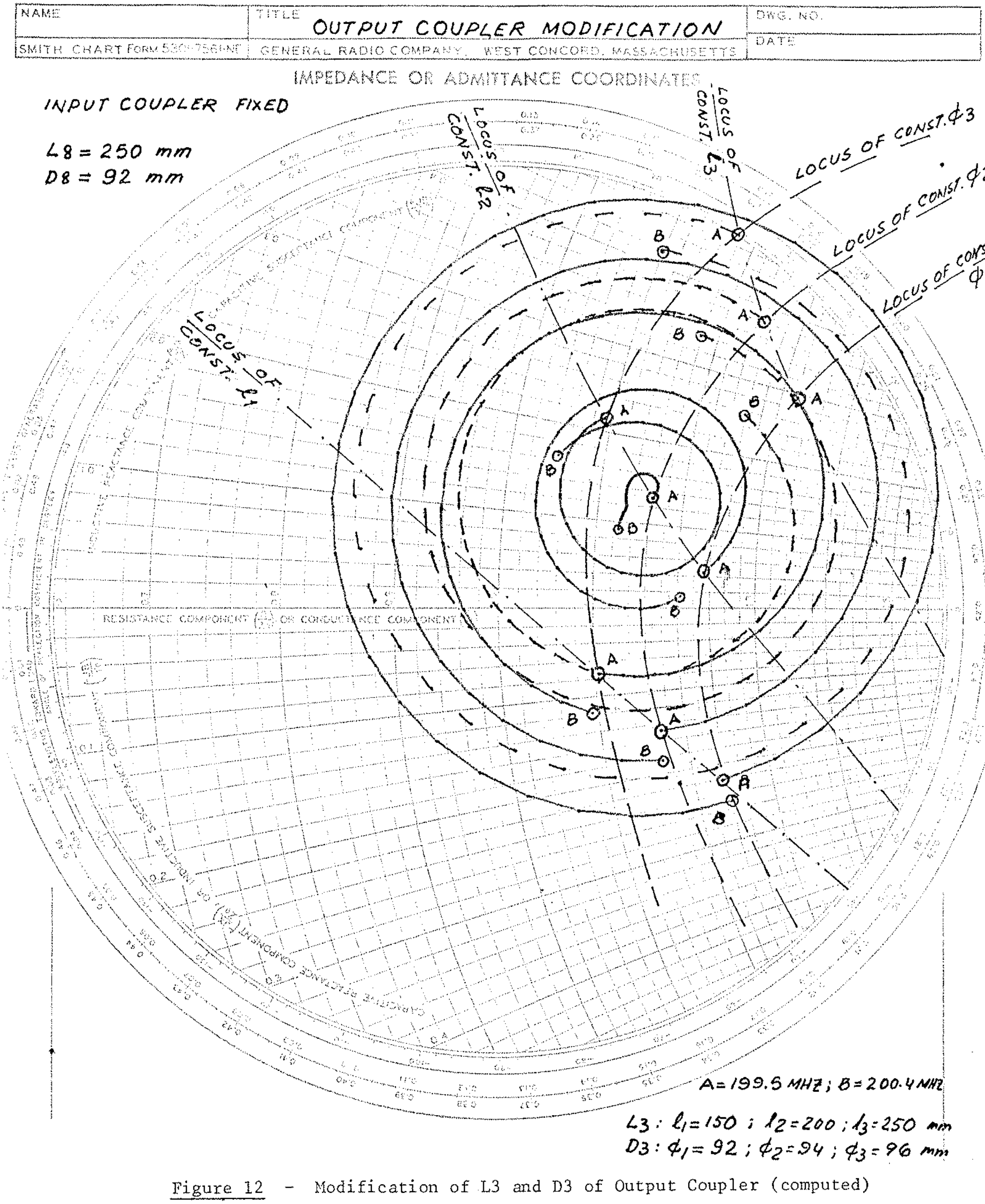


Figure 12 - Modification of L3 and D3 of Output Coupler (computed)

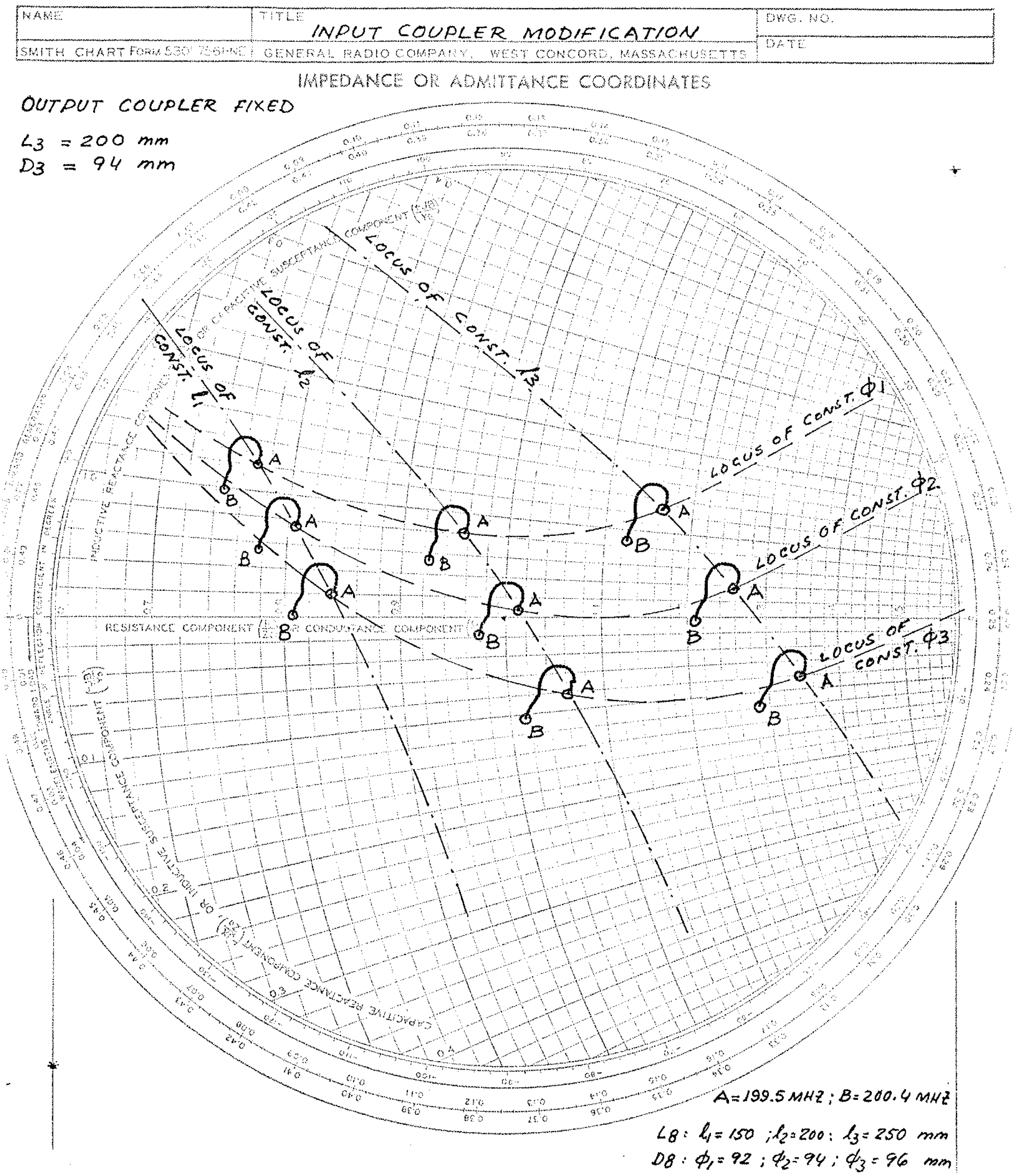
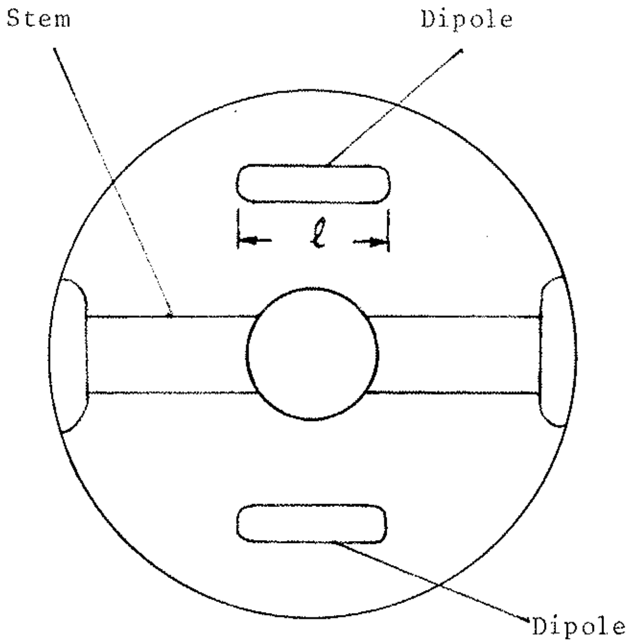
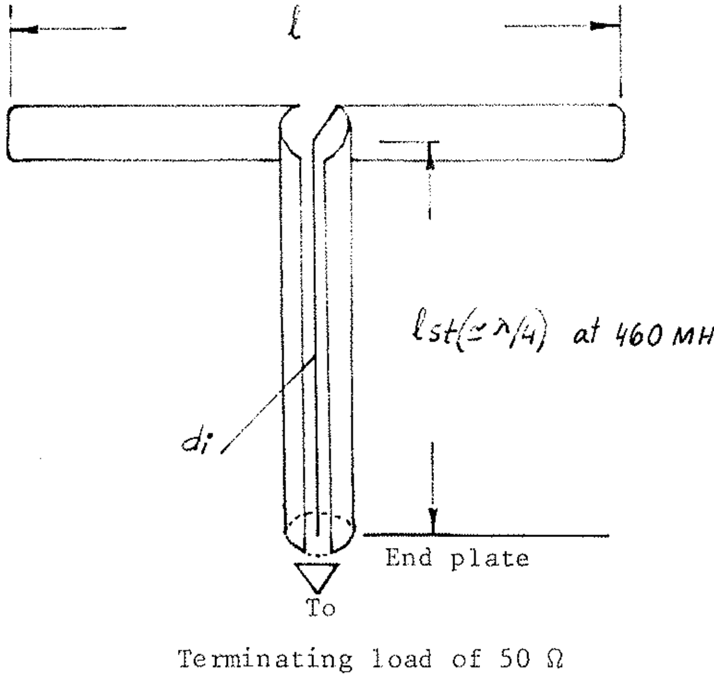


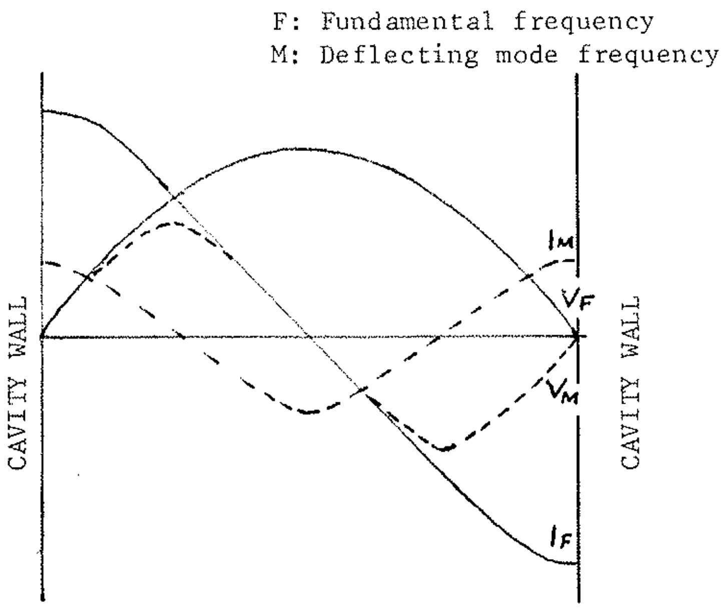
Figure 13 - Modification of L8 and D8 of Input Coupler (computed)



Cavity with dipoles



Dipole schematic
(top view)



Voltage and current distribution
on the stem

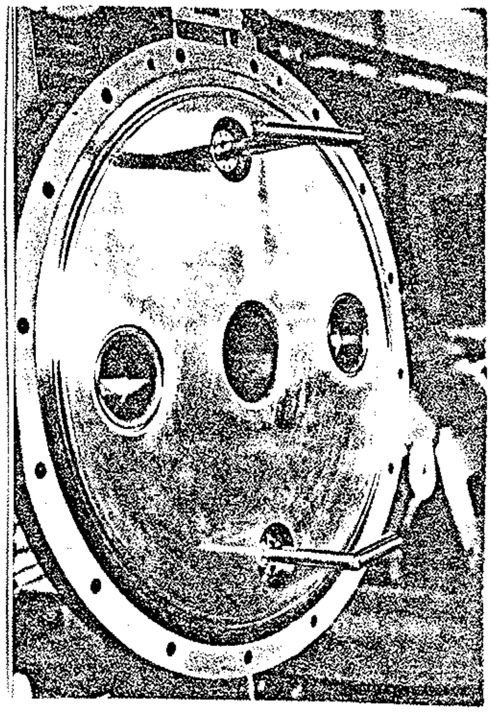


Figure 14 - Schematic of dipoles in the cavity

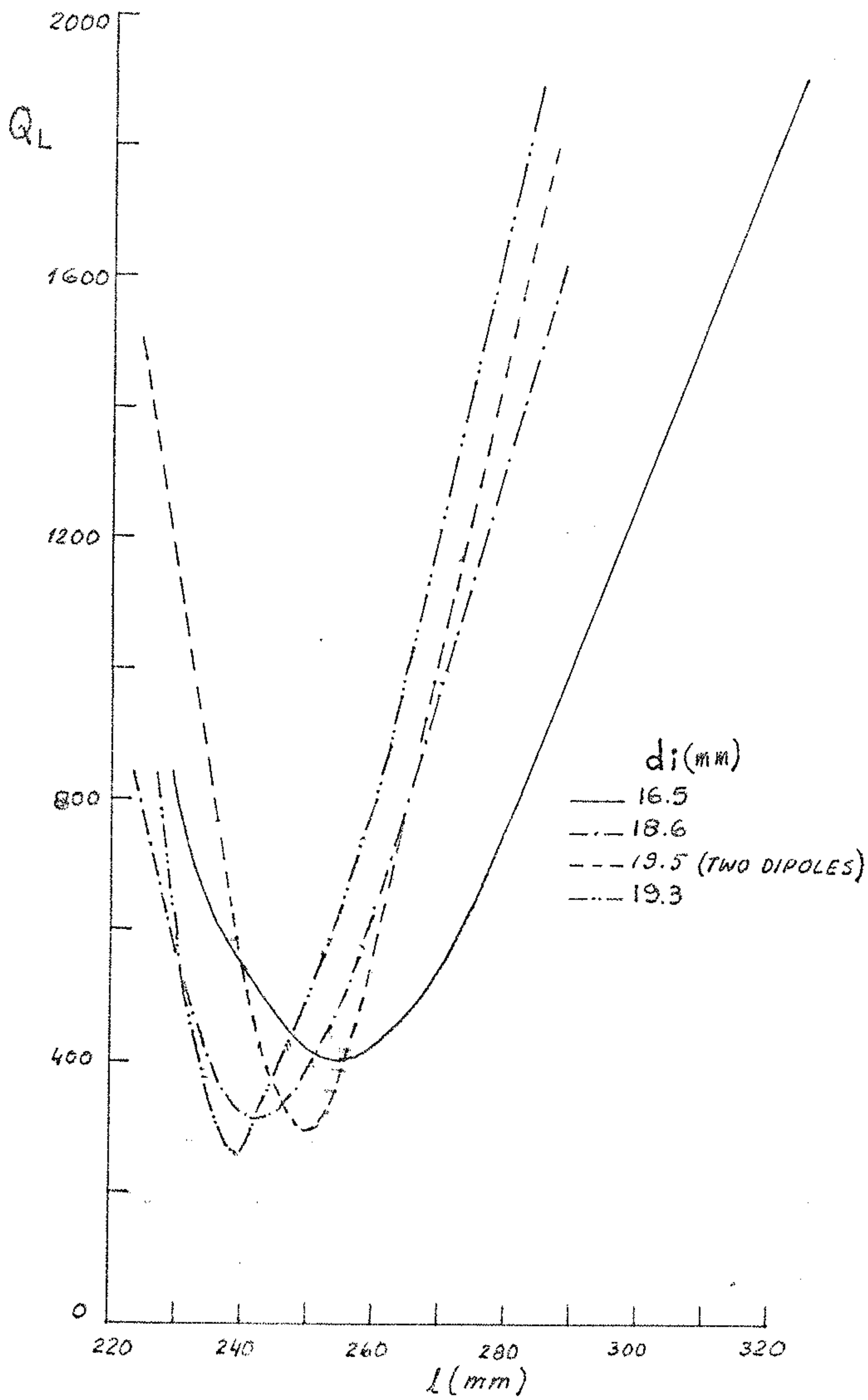


Figure 15 - Dipole parameters against Q_L