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LONGITUDINAL COUPLING IMPEDANCES
AT INSULATED PS VACUUM CHAMBER FLANGES

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Introduction

The longitudinal coupling impedance, Zn, is a measure of the voltages generated by a sinusoidally modulated beam current at the n^{th} harmonic of the revolution frequency, and enters into calculations of the stability of coasting and bunched beams. The threshold impedances for the start of an instability vary over several orders of magnitude, depending on the mode of oscillation considered and the parameters of the beam. A desirable value for the PS beam at high energy and intensity might be as low as 5 Ω, while estimates of less than 60 Ω have been made for the actual machine.[1)] One of the contributing factors to the impedance, especially at low harmonic numbers, is the impedance created at the insulated vacuum chamber gaps by the capacity shunting the gap and the circuit in parallel with it outside of the vacuum chamber. While such gaps have received attention before [2)], and have been of concern at the Booster, their impedance has been probably under estimated because of oversimplification of the external circuit. Measurements of the gap impedance[*] in a number of locations at the PS suggest a value of about 100 Ω at every gap at the resonant frequency of the most common circuit, and a total impedance of several kilohms for the machine.

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1) A. Sørenssen, What sort of coupling impedances are tolerable in the future CPS ? CERN/MPS/DL 70-1

2) E.D. Courant, Effect of insulation between vacuum chamber sections on resistive instabilities, BNL/AADD-136, April, 1967

* By an informal group including E. Brouzet, A. Faltens, L. Henny, W. Kubischta, D. Möhl, F. Sacherer, H. Umstätter, after similar measurements were begun at the Booster by G. Nassibian and F. Sacherer.

Simplified Description of the Problem

The impedance at a gap is that due to the parallel combination of the gap capacity and the external circuit. This external circuit may be quite complicated, and is generally unknown, but involves such paths as the outside of the beam vacuum chamber, connections from the beam line to building "earth", connections through apparatus in the beam line, etc., which effectively shunt the gap capacitors with inductances. The essential features of the circuit are illustrated by an approximately equivalent parallel resonant circuit, Fig. 1, and the element values may be found by measurement.

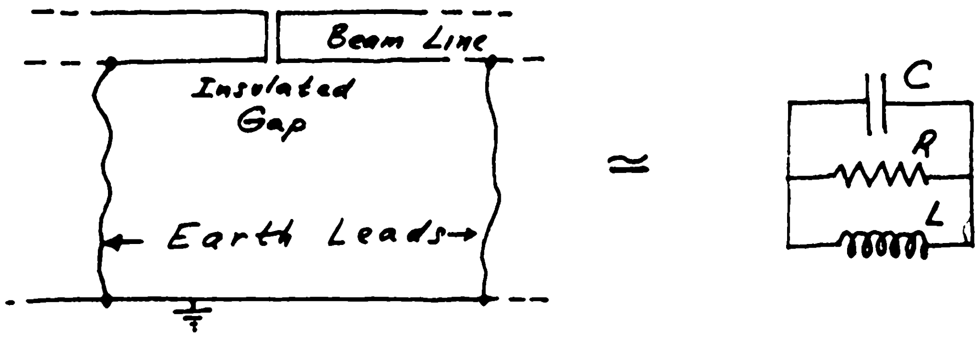

Figure 1. Equivalent circuit for a section of beam line.

Neglecting for the moment the coupling of one section to the others, the (low frequency) inductance, L, is formed by the beam line and earth leads, the capacitor, C, is essentially a lumped capacitor at the gap, formed by the thin insulating ceramic and the flange 'electrodes', and the resistor is an equivalent element which represents all loss mechanisms in the circuit, such as conductor resistance, eddy current and hysteresis losses in the portion of the beam line going through magnets, radiation, etc.
The most common element values obtained from measurements are in the range of $L = 10 \mu Hy$, $C = 1$ nFd, $R = 100\ \Omega$, with $Q \sim 1$ and f resonant ~ 1.6 MHz, and apply to the upstream flanges in the straight section. For the simple circuit shown, the impedance seen by the beam at the gap is equal to the measured impedance.

The measured impedance curves only approximate a simple single resonance as described here because the coupling to adjoining sections is not entirely negligible, because the losses are expected to be frequency dependent, and because the measuring instrument itself perturbed the circuit. An overlay of the measured values for a few of the most common type of impedances is shown in Fig. 2. Some of the major circuit variations are shown in Fig. 3. As there are a number of different types of sections in the PS, and a great variety of apparatus within them, the resonant frequencies do not coincide and therefore the mutual impedances between the sections should have a relatively minor effect on the resonances. The impedances of uncoupled circuits may be added in series, whereas for coupled circuits involving several gaps the electrical mode of oscillation and the excitation of the mode by the beam have to be determined before an impedance may be computed. Considering the different sections as similar but uncoupled circuits thus simplifies the problem and allows an estimate of the total machine impedance to be made by adding the impedances. Adding the magnitudes of the impedances of the $\sim$80 similar sections gives a broad peak of about 7 K Ω at the third harmonic.

The second most common circuit involves the downstream flanges which often are short circuited but which usually, for reasons to be ennumerated later, are left open. The capacity at these flanges is about 9 nFd, and thus the resonant frequency would be about 3 times lower, for comparable external circuits, than at the upstream flanges, and somewhat below the range of the measurements, as shown in Fig. 4. In this range the flange impedances are resistive-capacitive, and as there are about 69 non-shorted flanges of the downstream type, their total impedance may be estimated as $\frac{-j\ 2.4\ K\ \Omega}{n}$ for the first few harmonics, for n > 1, which is considerably smaller in magnitude than the contribution from the upstream flanges. For n = 1 the impedance is largely resistive. The total impedance, considering both types of flanges can thus be estimated as about 2 K Ω resistive for the first mode, increasing to about 7 K Ω resistive for the third mode. $\frac{|Z_n|}{n}$ thus is close to 2 K Ω for the first four harmonics.

Description of the PS Flange Insulations and Earthing

The initial intent apparently was to prevent the flow of induced currents in the beam line from the main field, and to provide a one point earth connection for every piece of apparatus with a low impedance capacitive path for the beam image currents across the necessary interruptions in the conducting vacuum chamber. The physical realization of these circuits takes a number of different forms, as detailed below:

a) In principle the stainless steel vacuum chamber in each of the 100 magnet units is insulated from the magnet itself and from the vacuum chamber of the following straight section by a flange with 0.2 - 0.3 mm ceramic insulation of (typically 10 M Ω [3]) on the upstream end of the straight section.

b) Each vacuum chamber in the magnet is connected at its downstream end only to the grounded magnet. Each magnet for its part has a rigid copper ground connection 3 mm x 25 mm of more than a meter length at its downstream end, except for the 20 magnets which precede long straight sections (superperiod) and which are grounded at their upstream end. Finally groups of 25 magnets have a common earth i.e. 4 earths in the PS [4]. The RF-cavities are earthed independently. At the beam revolution frequency and its first few harmonics all these ground connections are inductances with skin effect losses and radiation resistance (the beam exciting them as antennas).

c) At the downstream end of each straight section there is another vacuum flange with thin aluminium oxide insulation and high capacity but this flange was in 31 cases short circuited or bypassed in order to connect the vacuum chamber in the straight section to the grounded vacuum chamber in the following magnet [3].

d) If the vacuum chamber in the straight section has a good ground connection from the installed equipment (9 RF-cavities, kickers, 3 IBS, wide band p.u. etc.) then the downstream flange is not bypassed. This good ground connection applied to 54 straight sections.

e) Special cases are the 3 non-metallized ceramic chambers of the bumpers S.S. 40, 43, 44 which also interrupt the vacuum chamber and resonate at higher frequencies. There are also upstream flanges which don't insulate. So we may assume that there are a few less than 100, say 90 ceramic upstream flanges and 69 aluminium oxide (downstream) flanges open.

Proposed Modification of the Circuits

The impedance at the gaps may be reduced by about a factor of 100 by an external low impedance shunt across the gap capacity. The gap capacity itself should not be changed as it is an integral part of the vacuum chamber system and a good high-frequency element. If the DC grounding of the system should remain the same, then a large capacity should be included in series in the shunt: e.g. 1 μFd. At high frequencies the impedance of this capacitor should be negligible, so the main element of concern is the inductance, L, of the leads of this element and of the conductors completing the circuit across any gap. This inductance should be minimized. Minimizing this inductance raises the resonant frequency and lowers the characteristic impedance, $Z = \sqrt{\frac{L}{C}}$, of the circuit, both of which are desirable here. After the minimum L has been determined, a damping resistor of value $R = \sqrt{\frac{L}{C}}$ should be added in series if Z versus frequency is to be minimized and a value

$$R = \frac{\sqrt{\frac{L}{C}}}{\sqrt{n}} = \sqrt{2\pi\, f_{rev}}\;\; L^{3/4}\;\; C^{-1/4}$$

if $\frac{|Zn|}{n}$ versus frequency is to be minimized.

References

1. A. Sørenssen, What sort of coupling impedances are tolerable in the future PS ? CERN/MPS/DL 70-1

2. E.D. Courant, Effect of insulation between vacuum chamber sections on resistive instabilities, BNL/AADD-136, April 1967

3. H. Dubler and A. Burlet, Relevé des valeurs d'isolation des chambres à vide du PS, 11-13 fév. 74. Private communication.

4. "Earthing system of the PS area". Drawing number CERN PS 26-135-1c (20 Oct. 1958) Also private communication from A. Burlet and R. Gouiran.

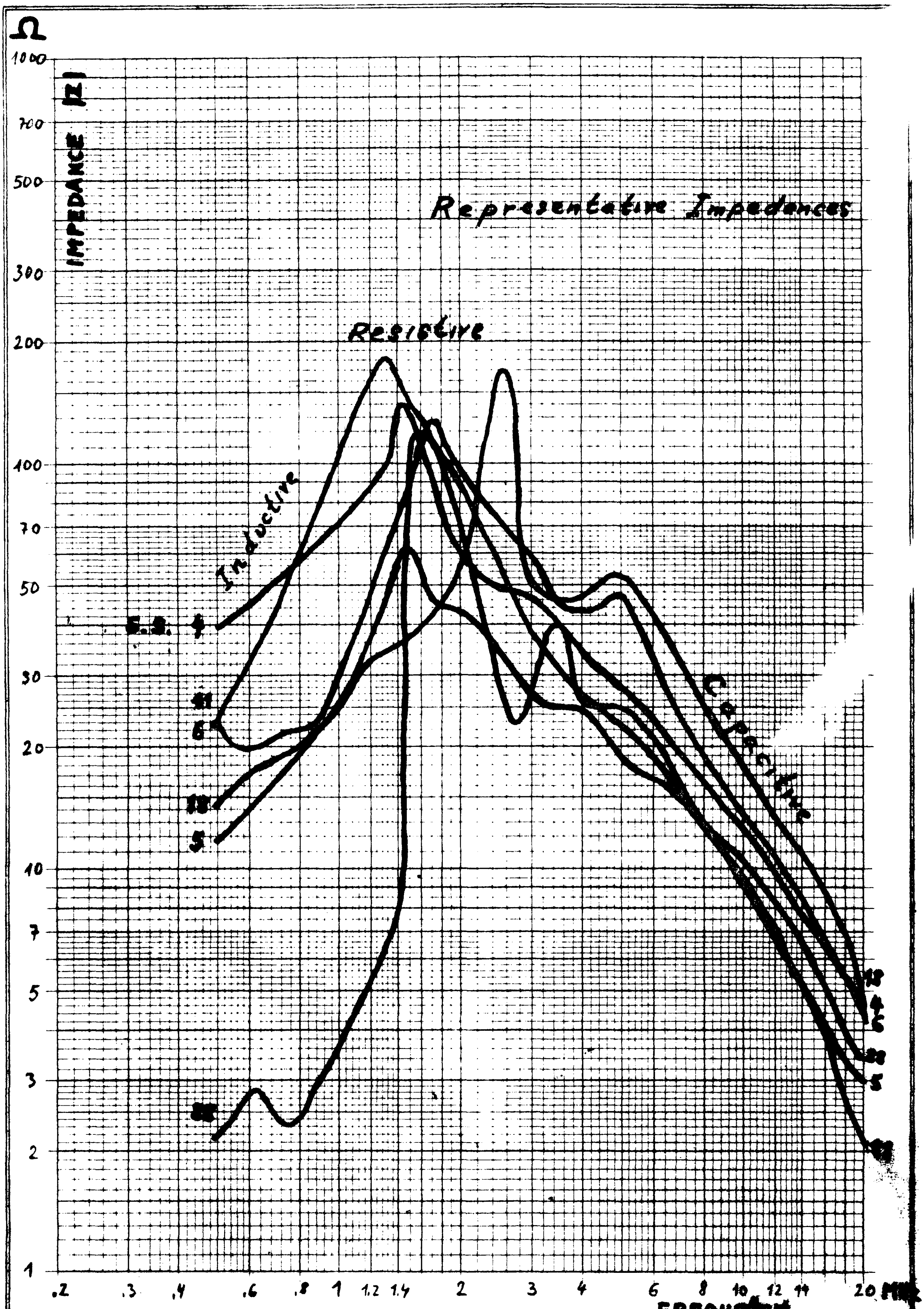

FIG.2. Ceramic insulated flanges, upstream. C≈1nF

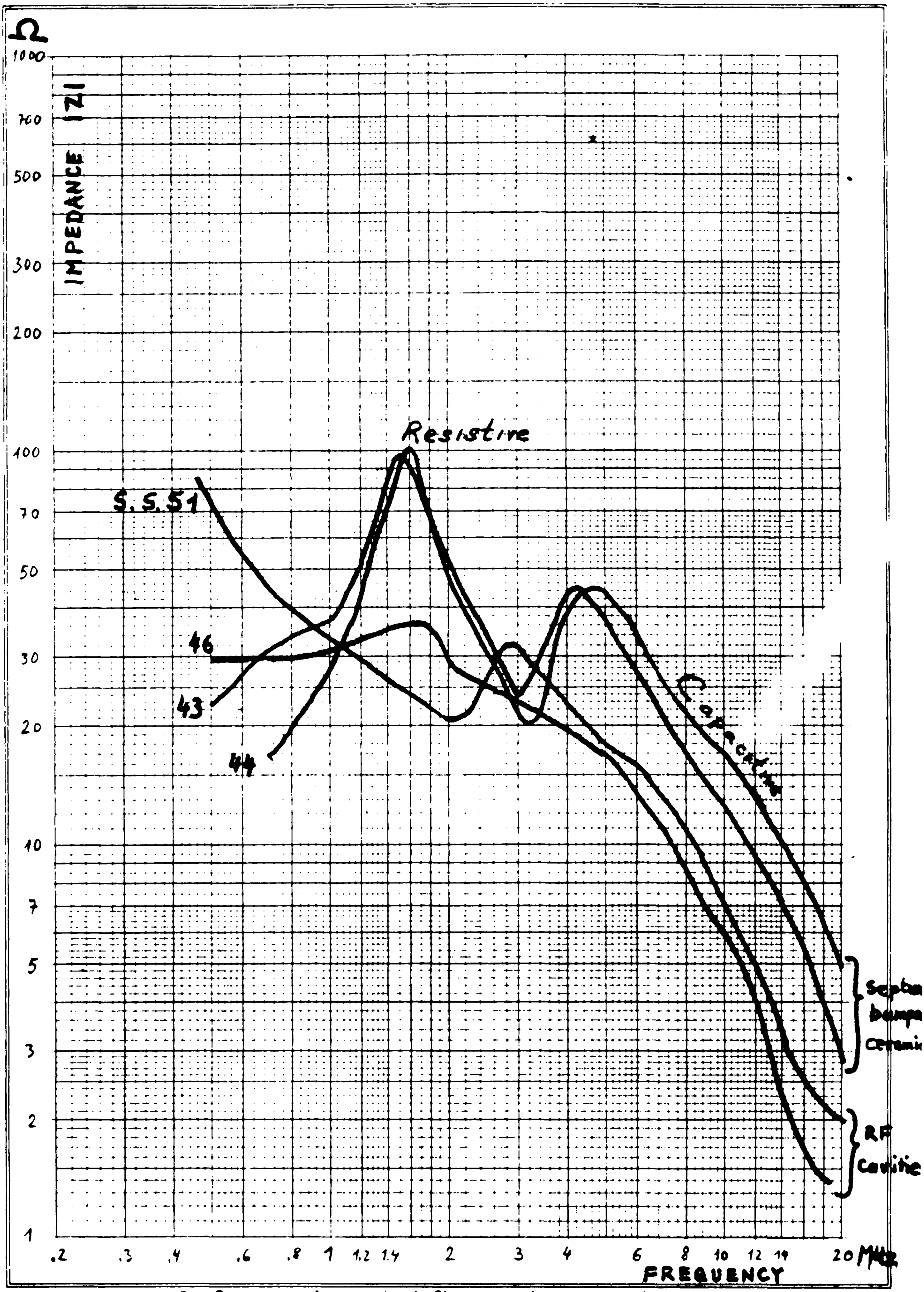

FIG. 3. Ceramic insulated flanges (upstream)
near septum bumpers and RF-cavities

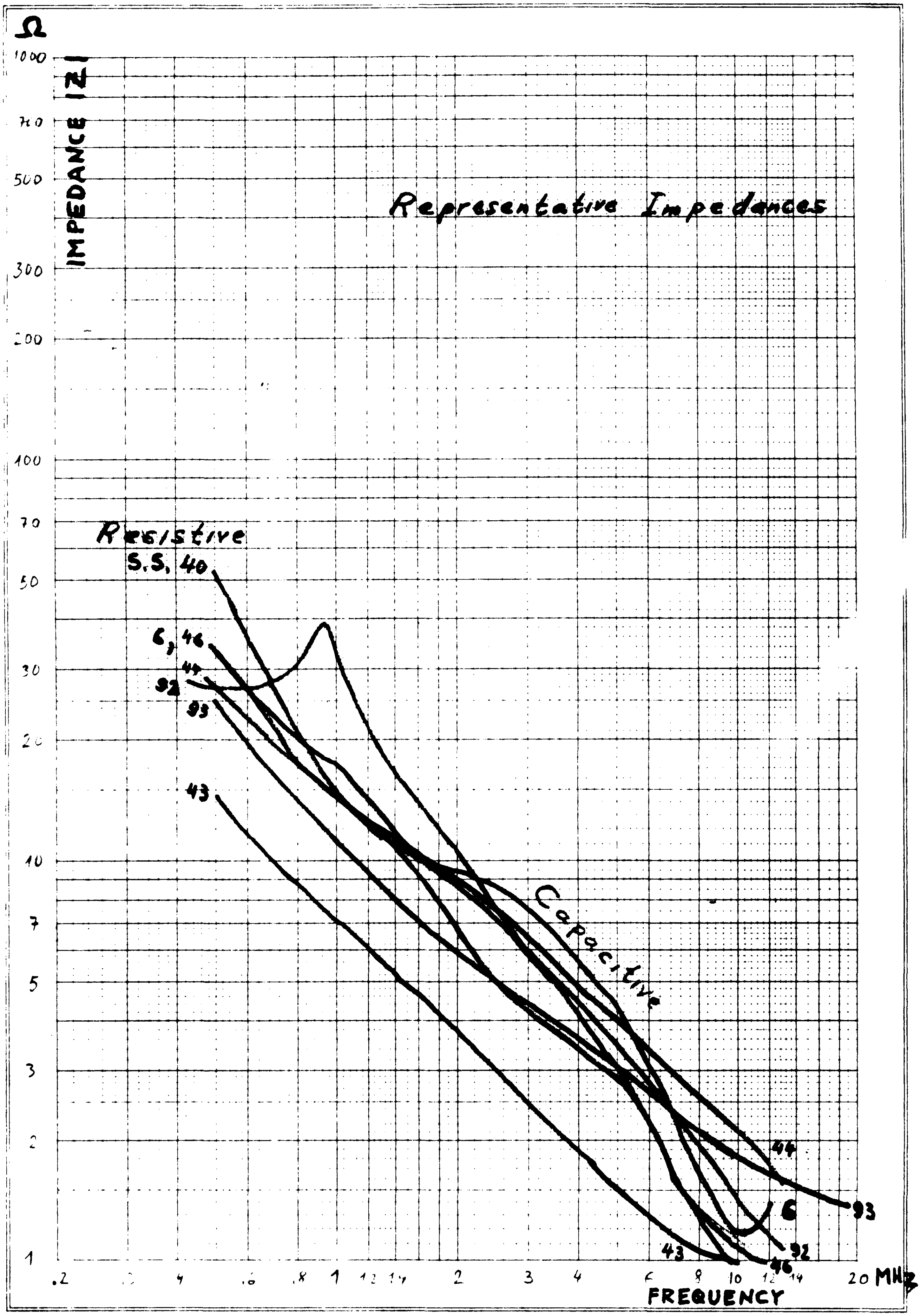

FIG.4. Aluminum oxide insulated flanges, downstream. C≈9 nF