ALS IMPEDANCE AND BEAM STABILITY

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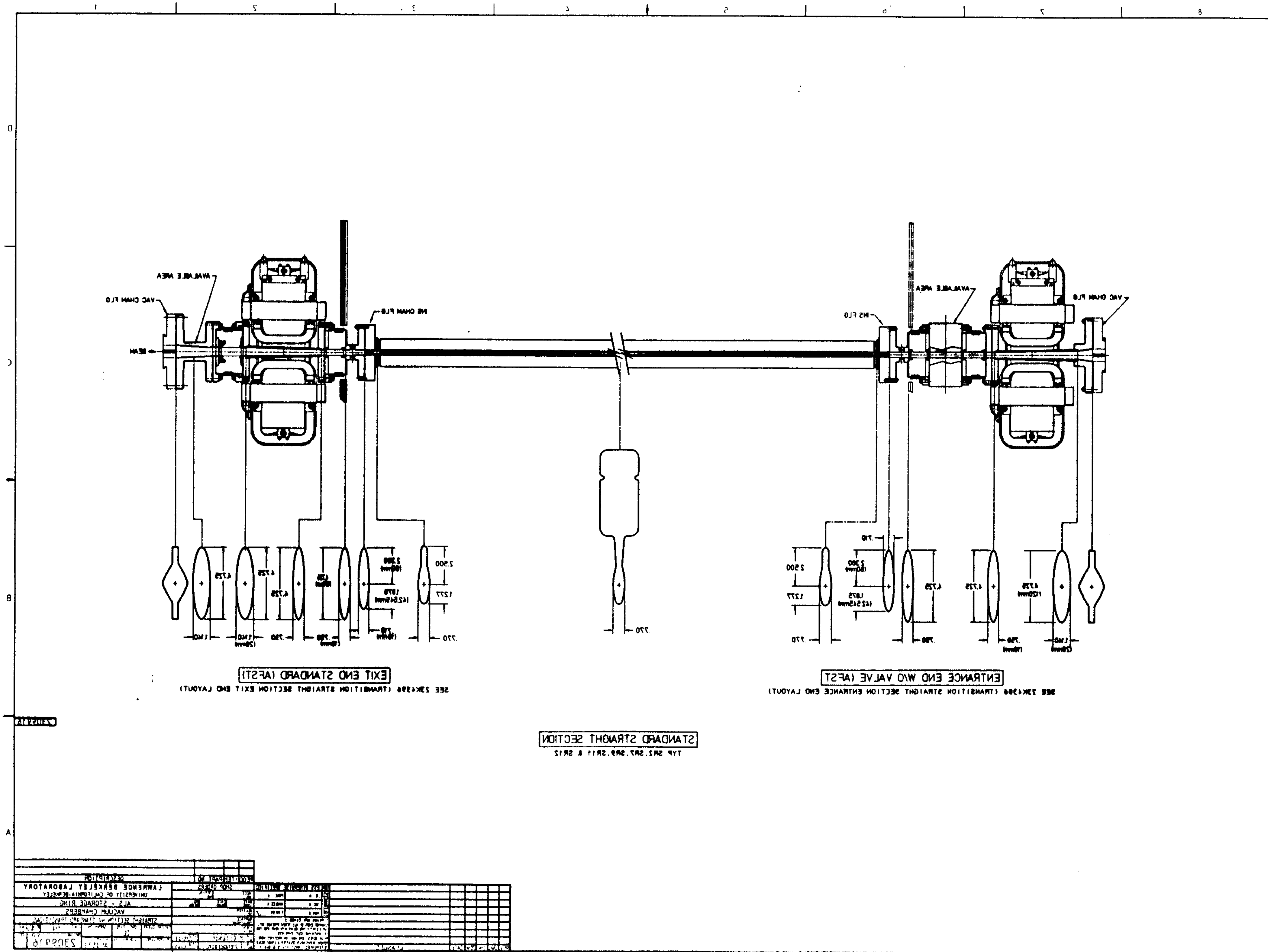
Impedance budget

- Antechamber for synchrotron radiation absorbers and pumping
- 2 RF cavities
- 48 bellows units
- 2 transverse coupled-bunch feedback kickers
- 4 longitudinal coupled-bunch feedback kickers
- DCCT (current transformer)
- 96 sets of 4 beam position monitors
- 24 tapers

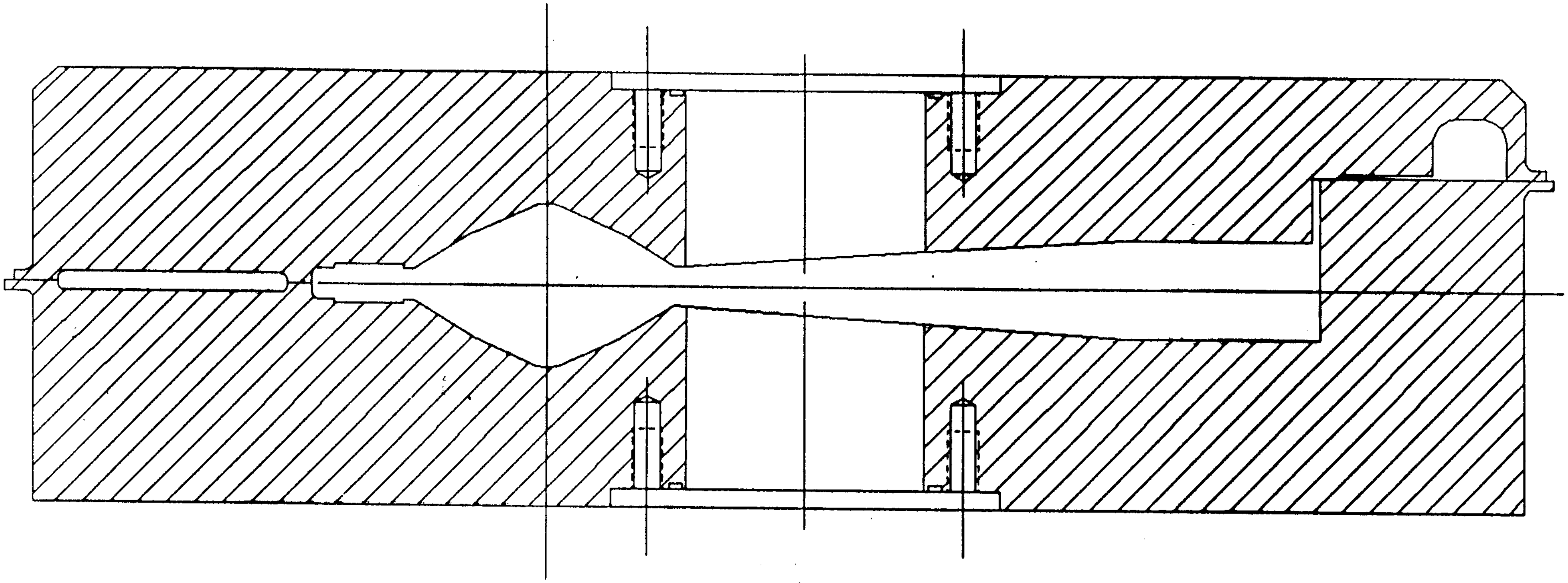
Impedance determination

- Most ALS components measured
  - ◇ Coaxial wire technique
  - ◇ Traveling-wave technique
- Computation
  - ◇ URMEL
  - ◇ ABCI
  - ◇ MAFIA



VAC CHAM FLG
AVAILABLE AREA
BEAM
INS CHAM FLG
INS FLG
EXIT END STANDARD (AFST)
SEE 23K4396 (TRANSITION STRAIGHT SECTION EXIT END LAYOUT)
ENTRANCE END W/O VALVE (AFST)
SEE 23K4386 (TRANSITION STRAIGHT SECTION ENTRANCE END LAYOUT)
STANDARD STRAIGHT SECTION
TYP SR2, SR7, SR9, SR11 & SR12
4.725
2.500
1.277
.770
.750
1.140
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA-BERKELEY
ALS - STORAGE RING
VACUUM CHAMBERS
DESCRIPTION
SHOP ORDERS
23Q9916

ALS ARCS CROSS-SECTION



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average, corresponding to $Z/n \approx 0.0015\Omega$, (10Ω @ 10GHz).

Conclusions

Both methods are capable of measuring very small impedances above the beam pipe cutoff; the wire method has the advantage that one seamless measurement can be made for all frequencies while the waveguide mode method works only above cutoff but can be used in situations where it is impractical to use a wire.

The test resonator shows that either method should be able to detect objects of the order of $Z/n=0.00075\Omega$, ($Z \approx 5\Omega$@10GHz). Under laboratory conditions it is possible to improve repeatability to a point where objects as small as $Z/n=0.00015\Omega$, ($Z=1\Omega$ @10GHz) can be resolved.

The broadband skin effect wall loss of the beam chamber is estimated to be approximately $Z/n=0.0015\Omega$, ($Z=10\Omega$ @ 10GHz) from the waveguide mode insertion loss experiment.

The wire and traveling wave methods show that the increase in beam impedance due to the antechamber is $Z/n<0.001\Omega$ and $<0.0005\Omega$, ($Z<6.7\Omega$ and $<3.3\Omega$) respectively. There is very little coupling to the antechamber even above the slot TM cutoff frequency of 15GHz.

The total impedance budget for the ALS is $Z/n<2\Omega$. For twelve chambers and an allowance of 10% for beam chamber losses this makes the maximum tolerable impedance $<0.017\Omega$ (Z/n).

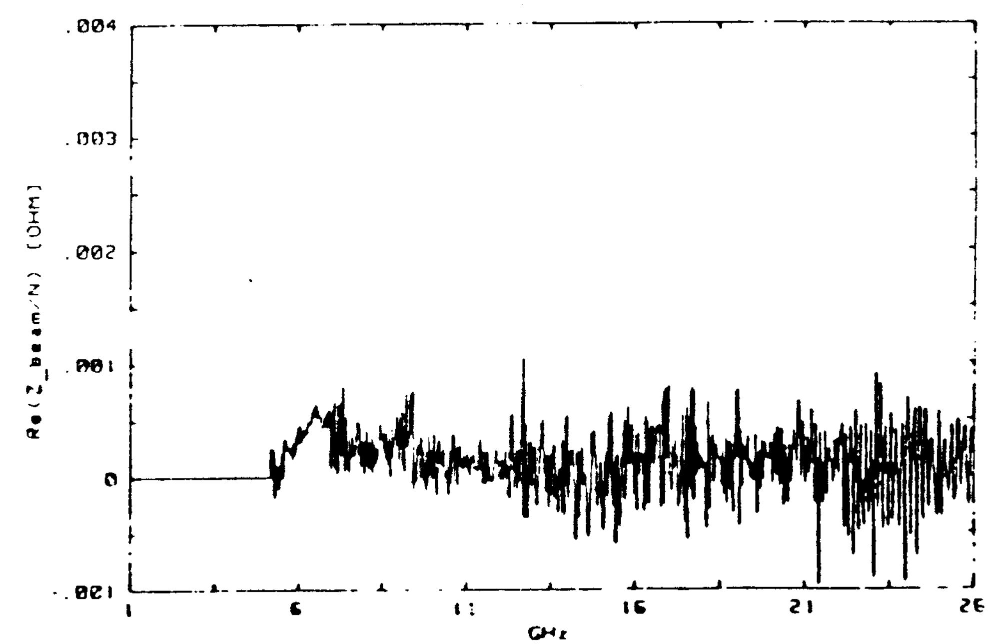


Fig.5 Impedance due to antechamber, wireless method

Rimmer / Goldberg / Jacobs / Lambertson / Voelker
LBL - 29231

[1] M. Sanc
Stored Bean

[2] F. Casper
Using a Synt
Vol. NS-32, r
Measuremen
Impedance a
Facility BP2

[3] G. R. Lam
ments Above

Feedback kickers

- Measured impedance
- Q=1 broad-band model
    - ◇ $f_{resonant}$ at cut-off = 3 GHz

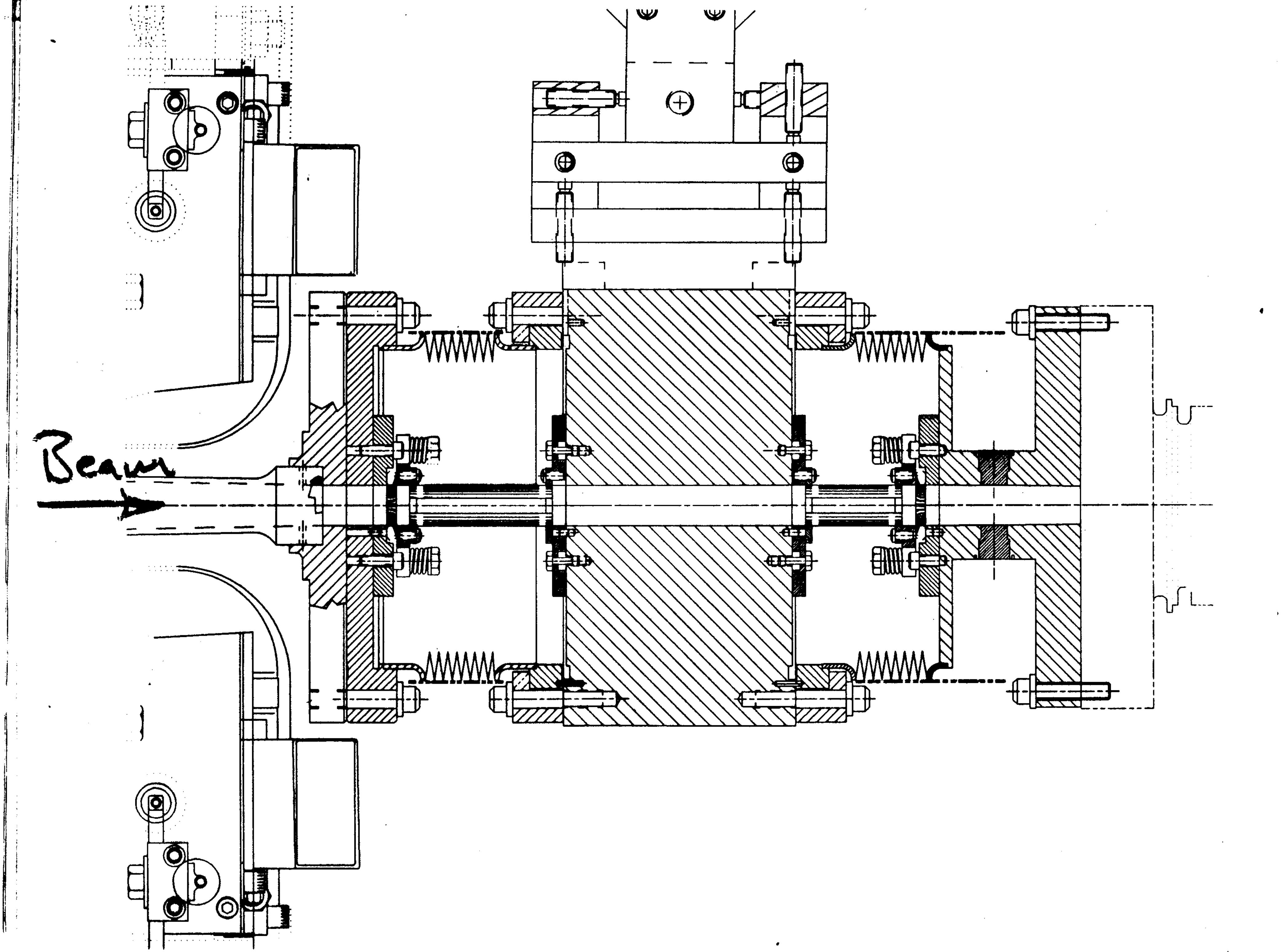
- Transverse
    - ◇ k = 0.66 V/pC @ R = 70 Ω

- Longitudinal
    - ◇ k = 0.44 V/pC @ R = 47 Ω

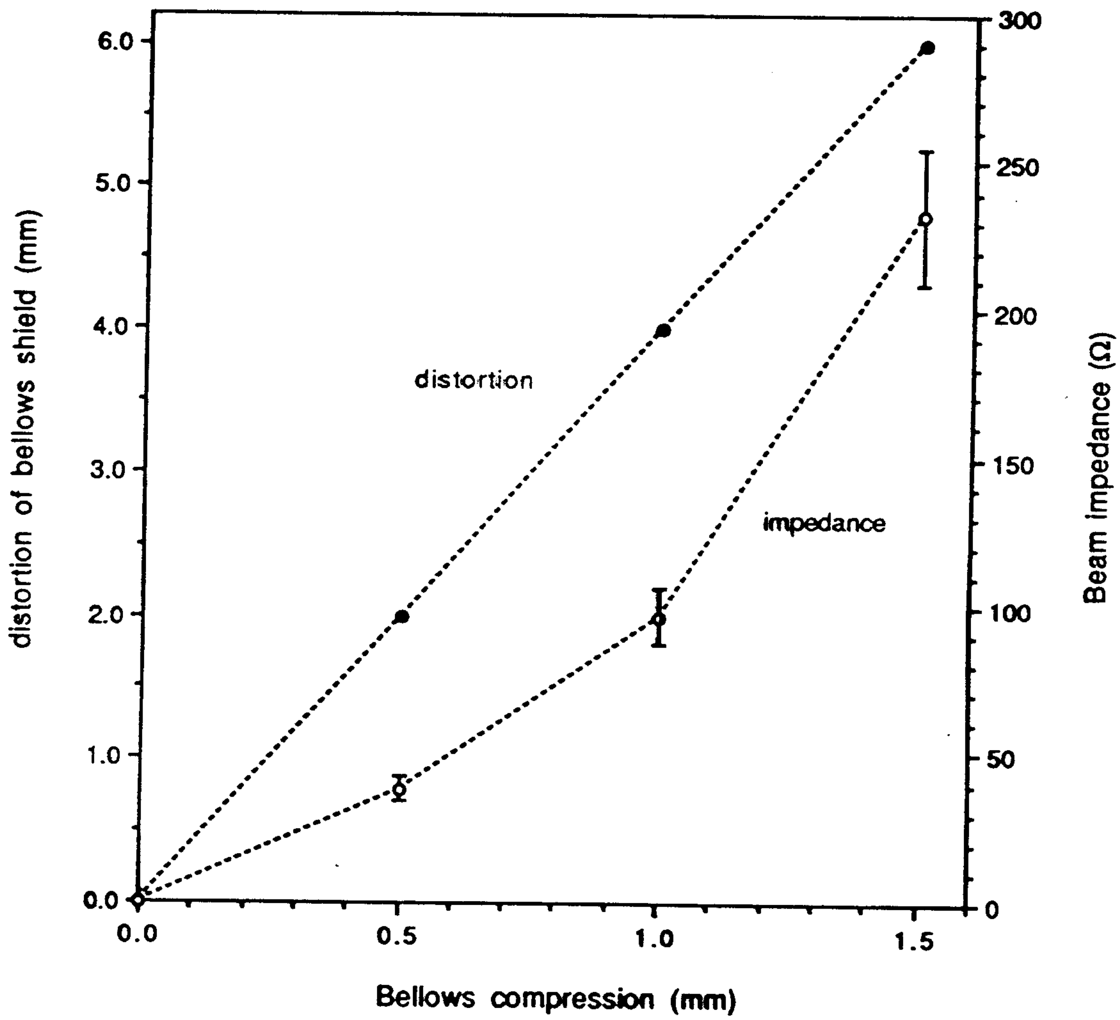
Bellows units

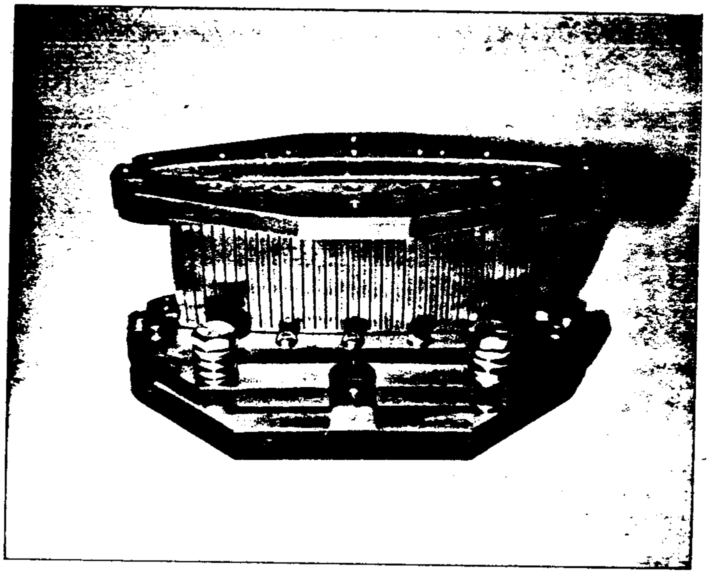
- Several weak resonances
  - ◇ 1.4 GHz - 23 GHz
  - ◇ 1 - 3 Ω
  - ◇ Q ≈ < 10

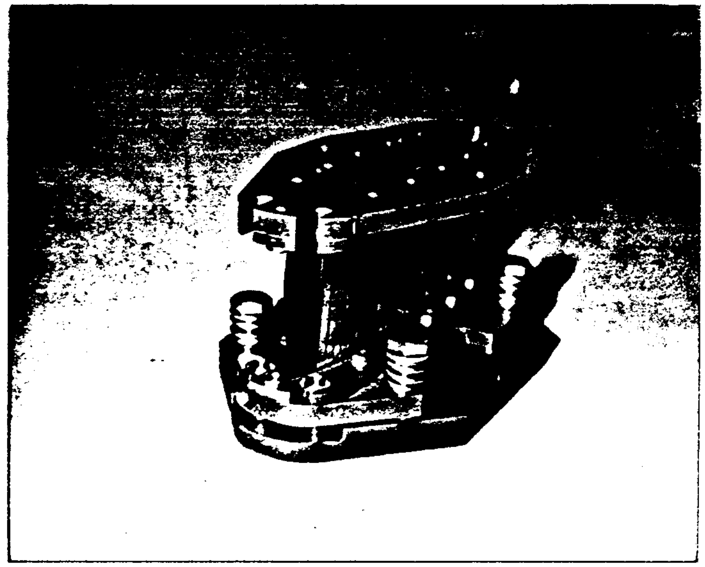
- Trapped mode at cut-off
  - ◇ 8.3 GHz, R ≈ 250 Ω, Q ≈ 1200
  - ◇ May cause beam heating
  - ◇ Flexband damaged April 1995

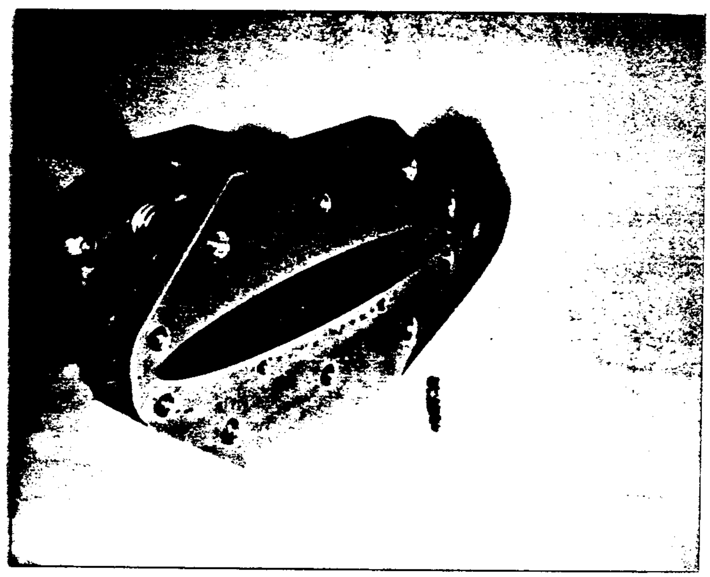

Beam

Approximate impedance of short bellows shield



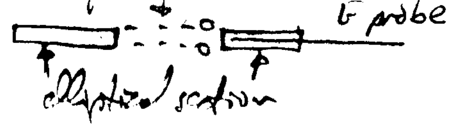


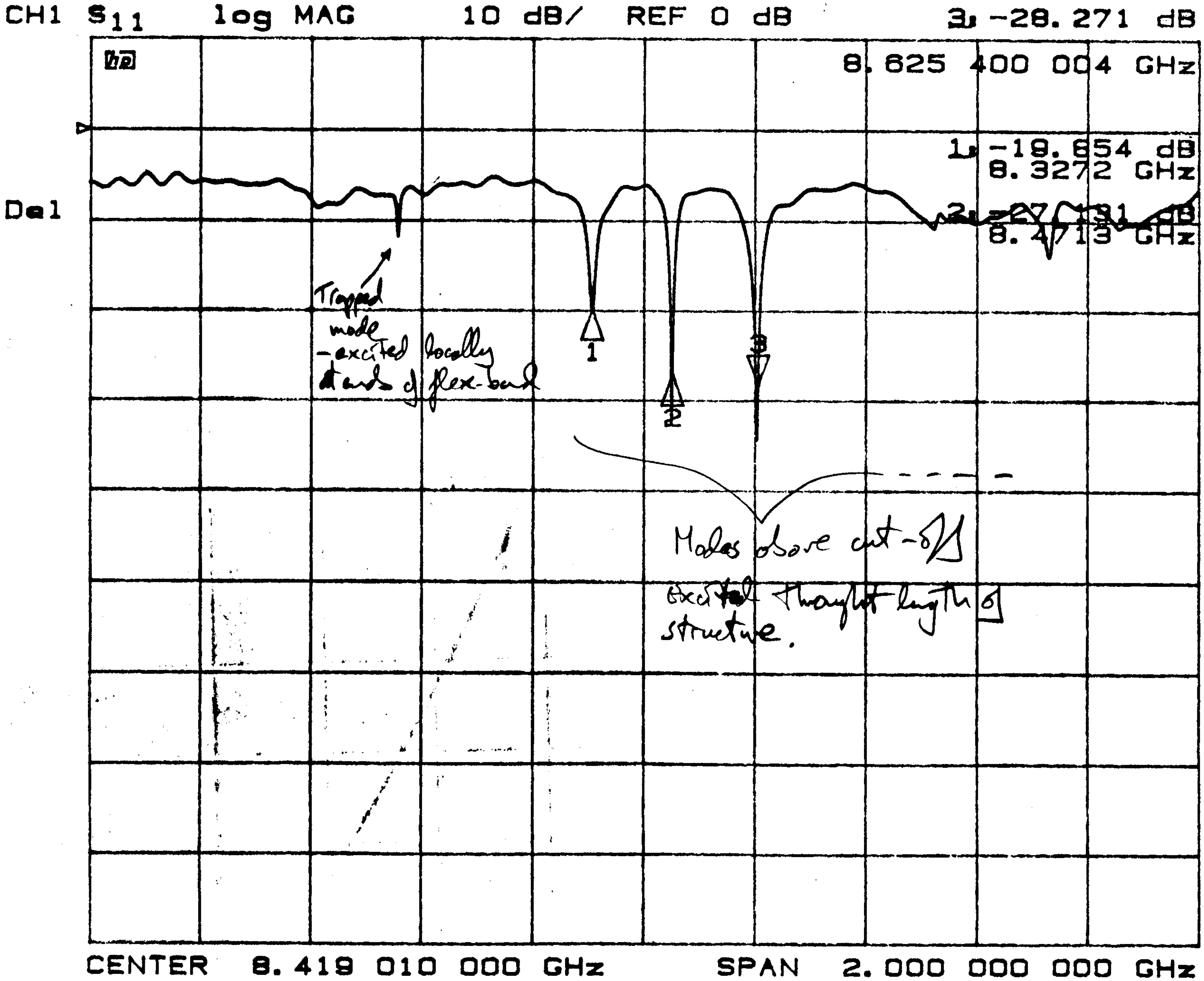




120 x 18 mm axes

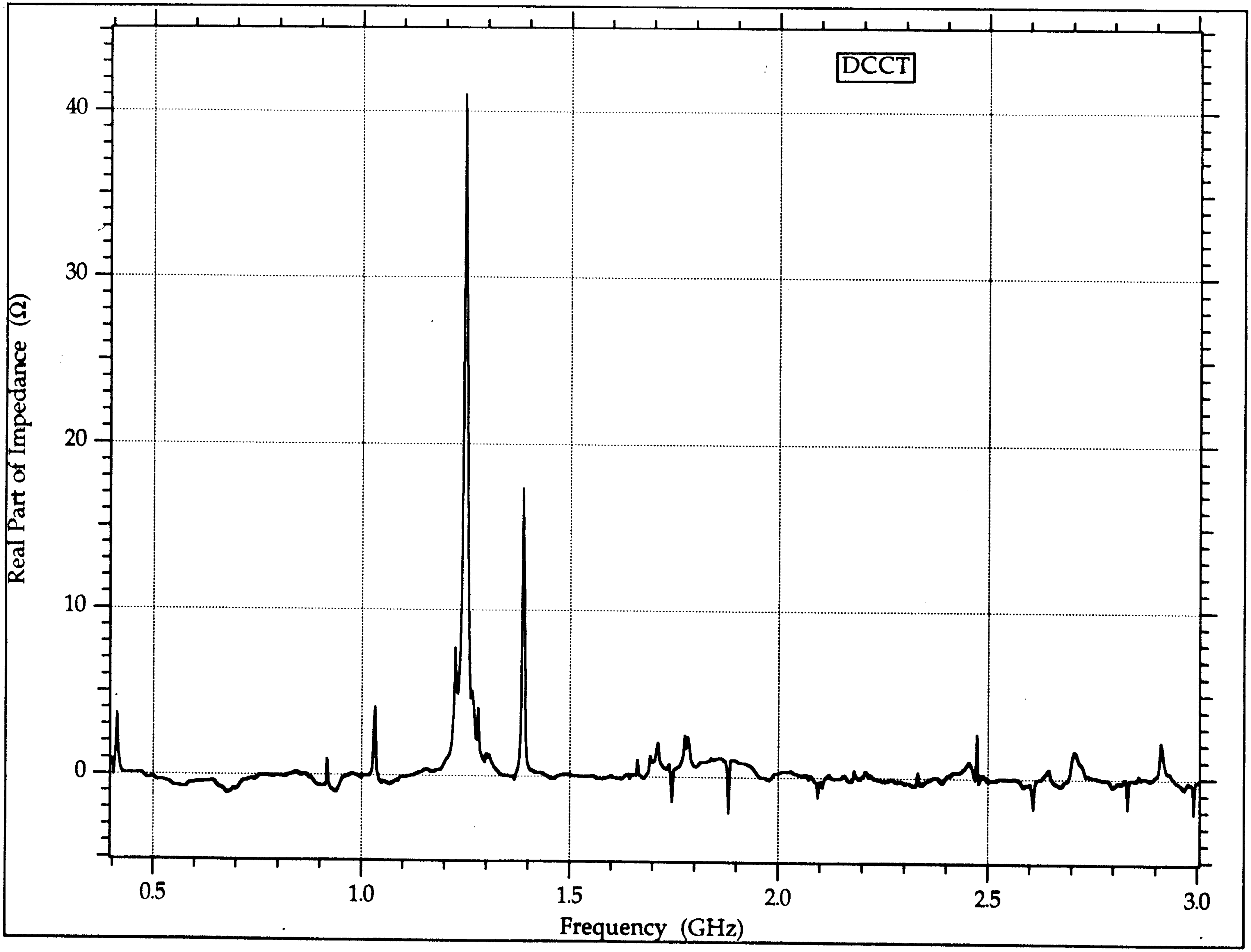
11/22/95 ALS flex-band





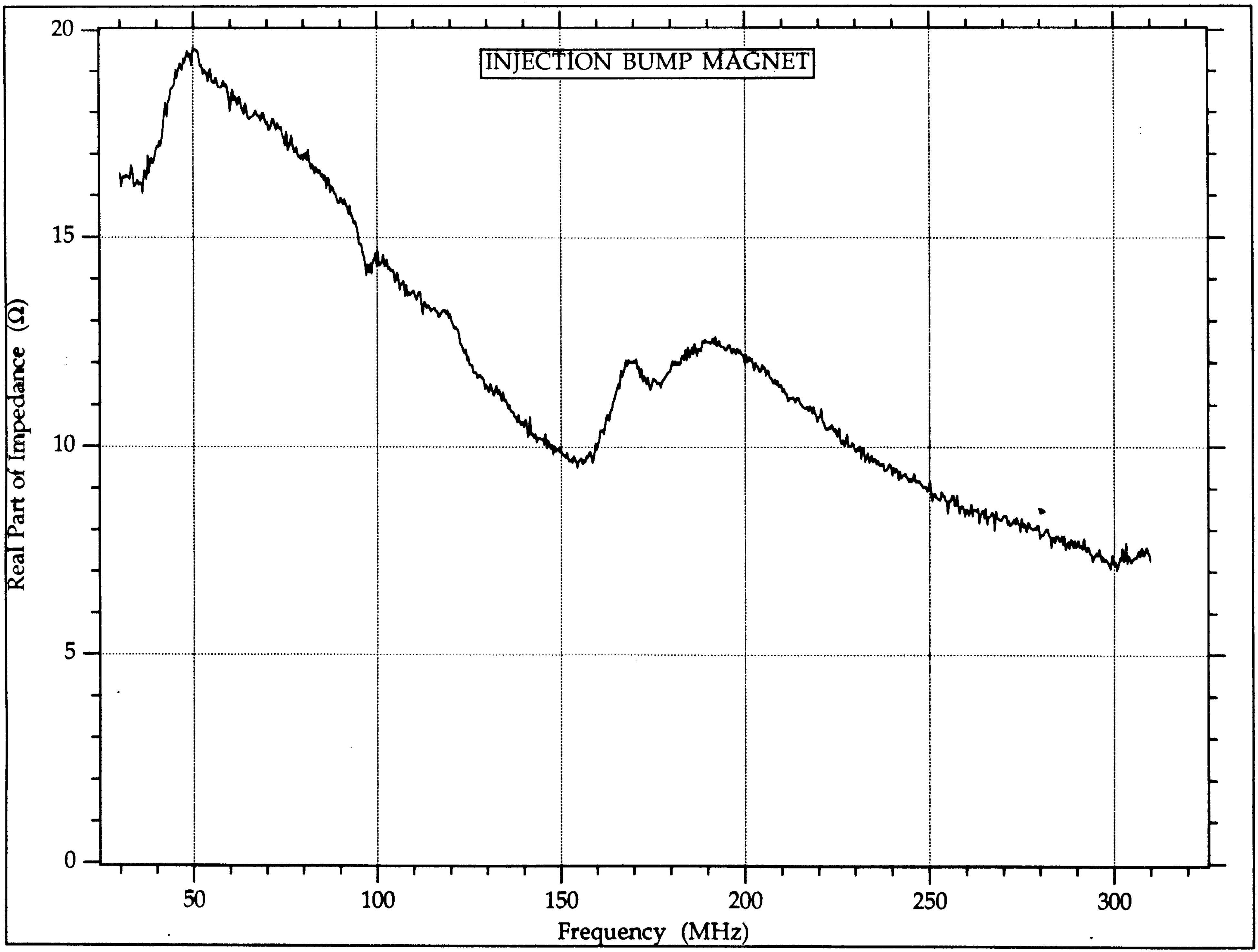
DCCT

- **Two resonances**
  - ◇ **1.23 GHz, R = 40 Ω, Q = 1000**
  - ◇ **1.38 GHz, R = 18 Ω, Q = 500**


DCCT
Real Part of Impedance (Ω)
Frequency (GHz)
0
10
20
30
40
0.5
1.0
1.5
2.0
2.5
3.0

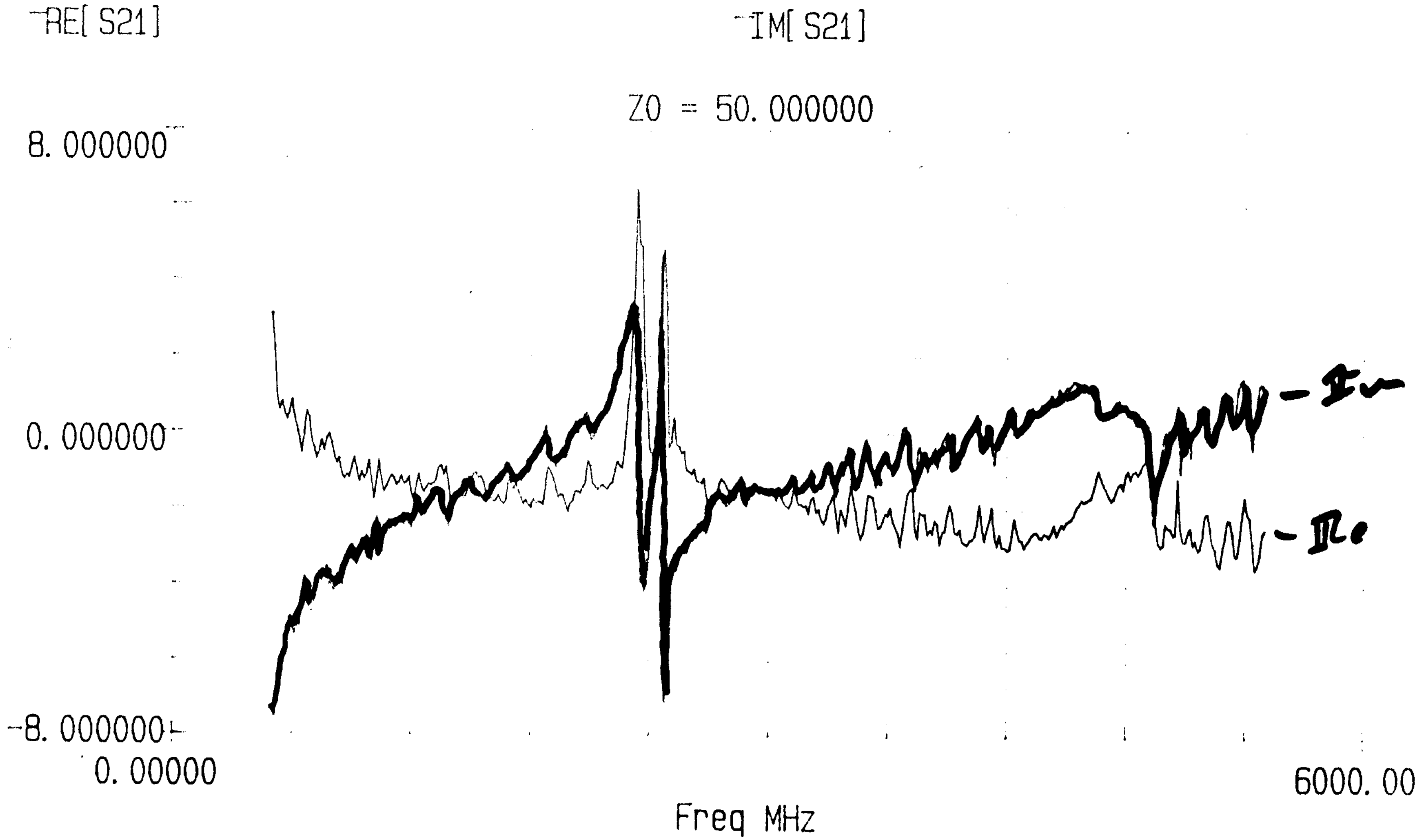
Injection kickers

- **Low-frequency resonances**
  - ◇ **50 MHz, R = 20 Ω, Q ≈ 1**
  - ◇ **190 MHz, R = 12 Ω, Q ≈ 1**


INJECTION BUMP MAGNET
Real Part of Impedance (Ω)
Frequency (MHz)
20
15
10
5
0
50
100
150
200
250
300

Injection straight “cages”

- **Resonances develop as cage is displaced**
  - ◇ **For 4.5 mm displacement**
  - ◇ **2.34 GHz, $R = 6\ \Omega$, $Q = 50$**
  - ◇ **2.47 GHz, $R = 5\ \Omega$, $Q = 60$**



ANACAT (TM)
Tue Jul 28 12:29:27 1992

alscage (racetrack)
4.5mm displaced
cage2.ref/cage2.obj

Beam Position Monitors

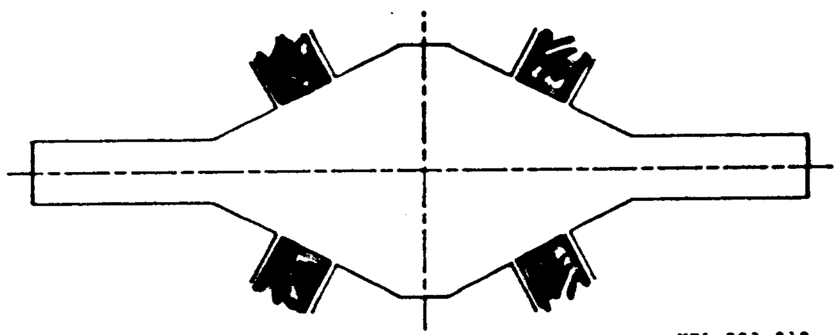
- **Two resonances**
  - ◇ **3.3 GHz, R = 130 Ω, Q = 17**
  - ◇ **16.2 GHz, R = 63 Ω, Q = 470**

Introduction

It is desired that the position-monitoring electrodes, as designed for the Advanced Light Source (ALS), present an acceptably low impedance to the electron beam in order to avoid exciting coupled-bunch instabilities or heating of the electrodes from induced currents. These concerns require that resonant responses of any one of the 400 assumed identical electrodes have peak beam impedances that are less than 2.5 ohm within the frequency range from 0.5-to-20 GHz.

Description of electrodes

Each pickup is a coaxial structure as sketched in Fig. (1) having a 7.6 mm diameter exposed surface flush with the wall of the beam tube and connected to a 50 ohm cable. Further details of the electrode are found in reference [1]. Measurements with a wire excited at 500 MHz have shown the coupling impedance of a single button to the beam to be $Z_p = 0.05$ ohm as a pickup driving a $R_o = 50$ ohm load. At low frequency the button has capacitance $C = 20$ pF.



XBL 893-818

Fig. 1 Schematic cross-section of ALS beam chamber with four button electrodes.

Method

For measuring the beam impedance, we chose to avoid the complexities of the wire method extended to 20 GHz, which is well above the beam-tube cutoff frequency of 5 GHz. Instead, we measured the impedance Z_e presented at the face of a single button and from that calculated the beam impedance.

*This work was supported by the Director, Office of Energy Research, Office of High Energy ... Division, U.S. Dept. of Energy, under Contract No. DE-AC03-76SF00098.

Jacob + Lambertson
LBL-25955

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Fig. 2 Model of the

One way to ass
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0B network analyzer (NWA)
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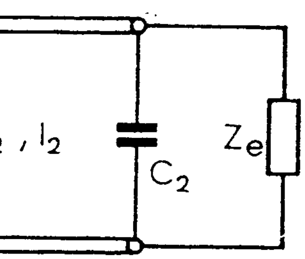

XBL 893-821

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Results

The measurements covered the range 0.1-to-20 GHz which is well below the cutoff frequency of the first higher order mode excited in the coaxial test fixture. For a higher resolution the frequency range has been subdivided into four intervals. As a typical result Figs. (6) and (7) show the button impedance in two of these intervals. In the range 0.1-to-5 GHz (Fig. (6)) there is only one resonance at 3.3 GHz. Its unloaded Q is approximately 17. The peak button impedance is 130 ohm. With eqs. (3) and (4) this gives a beam impedance of 0.06 ohm for a single button. A resonance with a higher Q factor can be seen in Fig. (7) which shows the upper frequency range. At 16.2 GHz the button resonates with a Q of 470 and a peak impedance of 63 ohm. This corresponds to a beam impedance of 0.7 ohm.

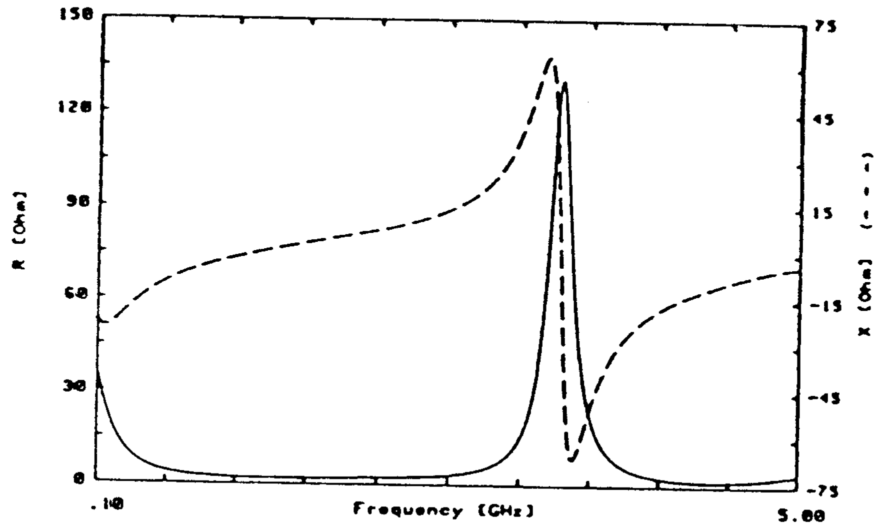

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Fig. 6 Real and imaginary parts of the measured button impedance in the frequency range 0.1-to-5 GHz.

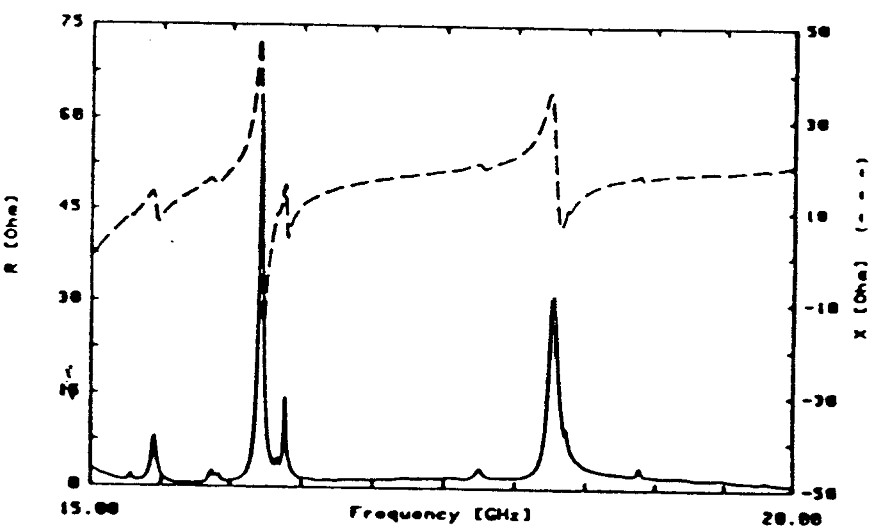

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Fig. 7 Real and imaginary parts of the measured button impedance in the frequency range 15-to-20 GHz.

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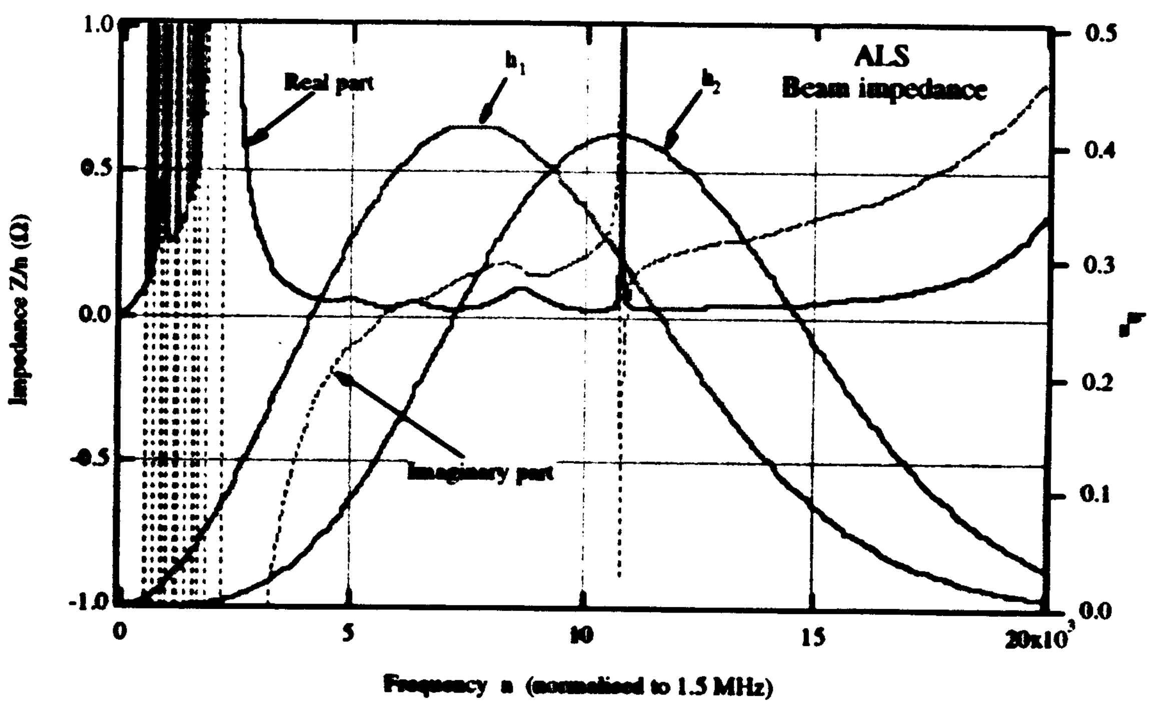
Jacob + Lambertson
LBL-25955

Impedance model

- **Use measured or computed resonant impedance of components as input**

- **$|Z/n|_{effective}$**

$$\left|\frac{Z_{\parallel}}{n}\right|_{effective} = \frac{\int \left|\frac{Z_{\parallel}}{n}\right| h_m^2 \, dn}{\int h_m^2 \, dn} \quad \text{and} \quad h_m(y) = \frac{1}{\Gamma\left(m + \frac{1}{2}\right)} y^{2m} e^{-y^2}$$

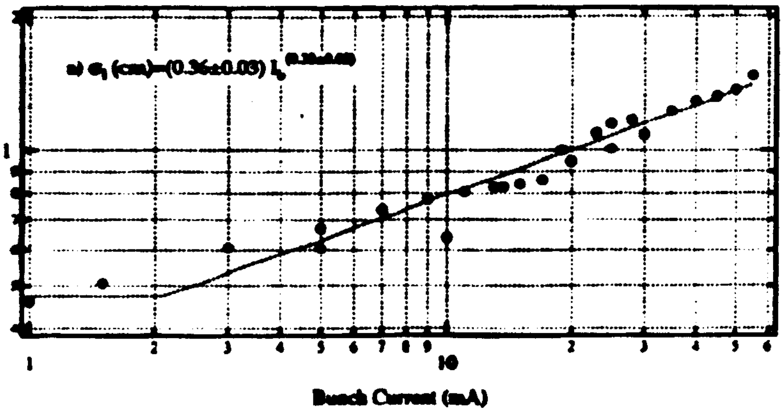


Predicted $|Z/n|_{effective}$ = 0.25 Ω

Bunch lengthening: [J. Byrd]

- **Microwave instability threshold peak current**

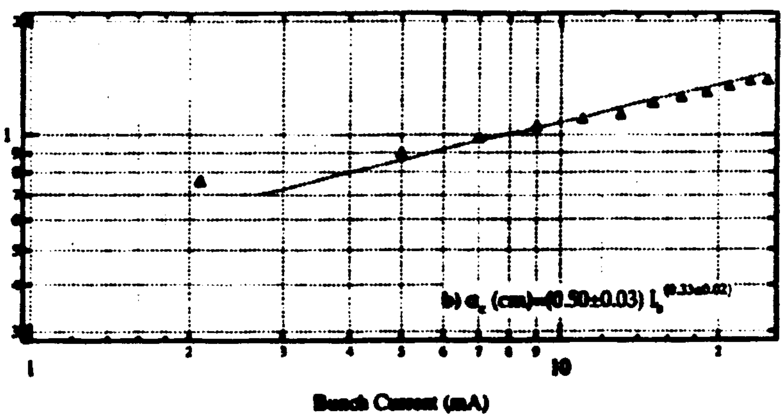
$$I_p = \frac{2\pi |\eta| \left(\frac{E}{e}\right) (\beta \sigma_p)^2}{\left|\frac{Z_\parallel}{n}\right|_{effective}}$$



- **Predict threshold 100 A peak, 1.75 mA average**

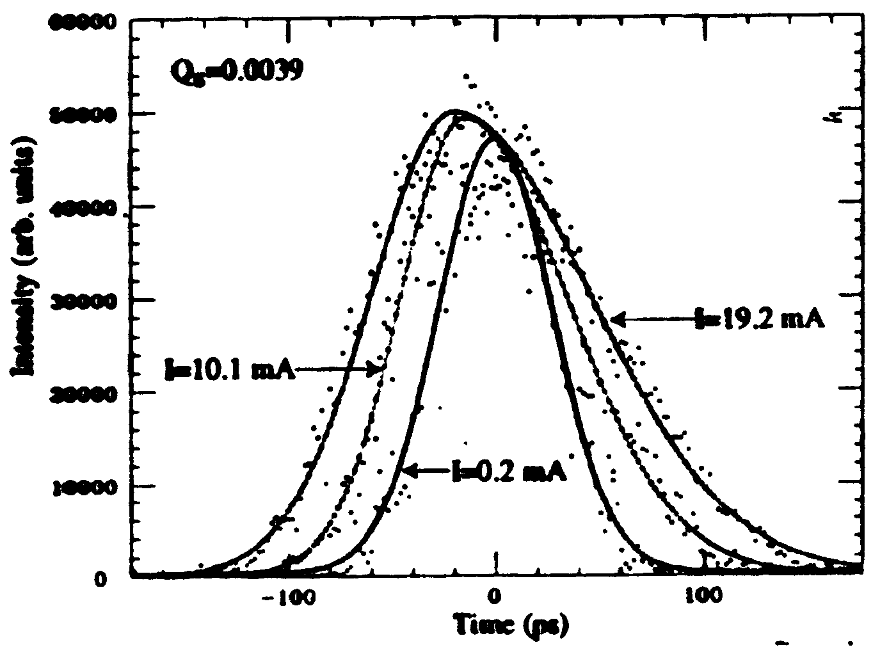
- **Bunch length above threshold**

$$\sigma_l^3 = \frac{\alpha R^3}{2\pi \left(\frac{E}{e}\right) Q_s^2} \left|\frac{Z_\parallel}{n}\right|_{effective} I_b$$



- **Measured threshold 2 mA**

- **Measured $|Z/n|_{effective}$ 0.22 Ω**



Betatron tune shift: [J. Byrd]

- **Relate transverse impedance to longitudinal**

Attachment 5

$$Z_{\perp,\,effective} = \left|\frac{Z_{\parallel}}{n}\right|_{effective}\left(\frac{2R}{b^2}\right)$$

Letter dated February 11, 1999 from Timothy Vitkus to Rod Cummings with the enclosed "Proposed Verification Survey Plan for the Hot Cell Facility, General Atomics, San Diego, California"

- **Then $Z_{y,\,effective} \approx 157\ k\Omega/m$, $Z_{x,\,effective} \approx 40\ k\Omega/m$**

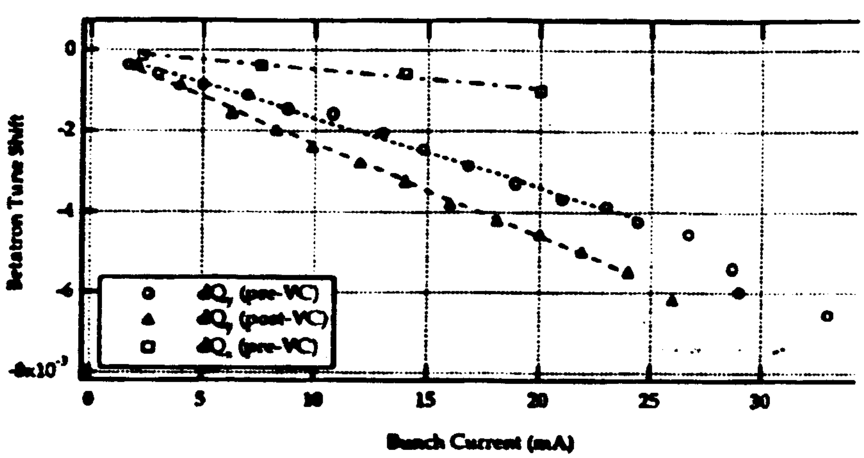
- **Measure betatron tune shift as a function of current**

$$\frac{dQ_{\perp}}{dI} = \frac{R}{4\sqrt{\pi}\,\frac{E}{e}\,\sigma_l}\,\beta_{\perp}\,Z_{\perp,\,effective}$$

- **Measured tune shift**

$$\frac{dQ_y}{dI} = -2.3 \times 10^{-4}\ /mA$$

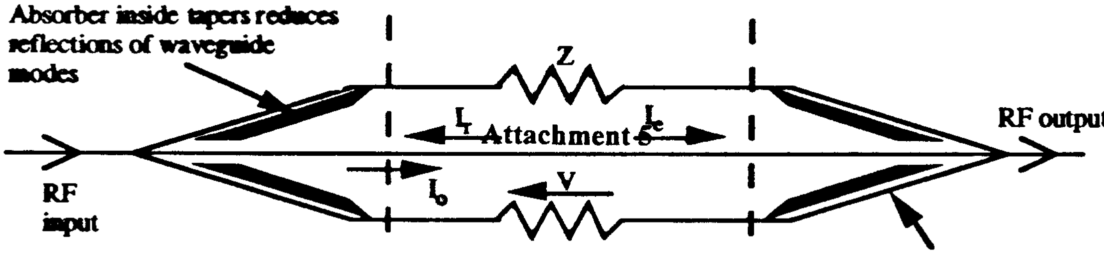
$$\frac{dQ_x}{dI} = -4.9 \times 10^{-5}\ /mA$$



- **$Z_{y,\,effective} = 155\ k\Omega/m$**

- **$Z_{x,\,effective} = 58\ k\Omega/m$**

Frequency domain



Letter dated February 11, 1999 from Timothy Vitkus to Rod Cummings with the enclosed "Proposed Verification Survey Plan for the Hot Cell Facility, General Atomics, San Diego, California"

Coaxial wire impedance measurement

Current I_0 is applied upstream of the impedance to be determined, Z. The coaxial wire forms a line of characteristic impedance R with the vacuum chamber. A voltage V is generated at the impedance, inducing currents V/2R traveling equally upstream and downstream. For a localized impedance (small in extent compared to the wavelength of the applied current), the current that excites the voltage V in the impedance is

$$I_e = I_o - I_r$$

The perturbation in wire current is

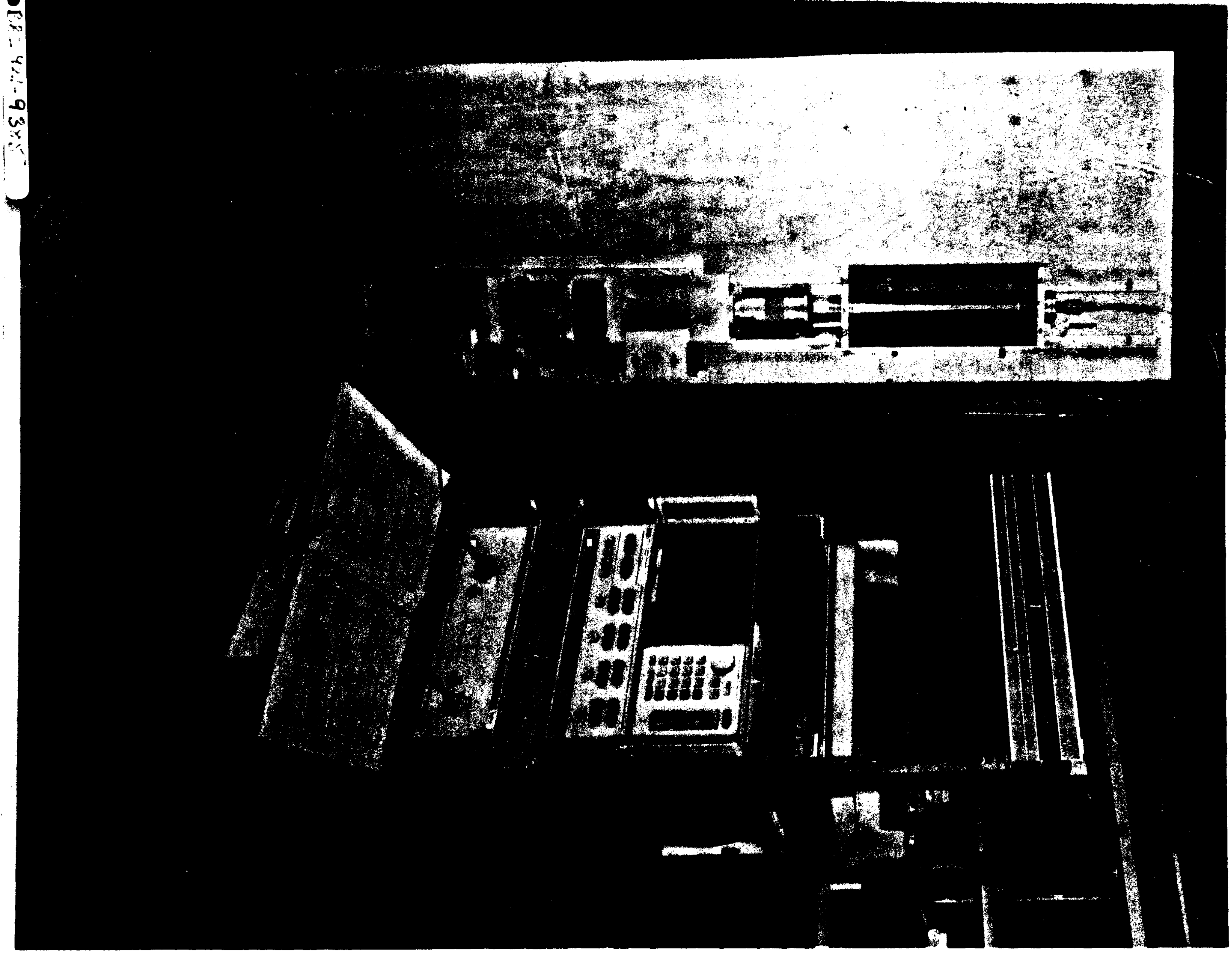
$$\Delta I = I_o - I_e = \frac{V}{2R} = \frac{I_e Z}{2R}$$

and

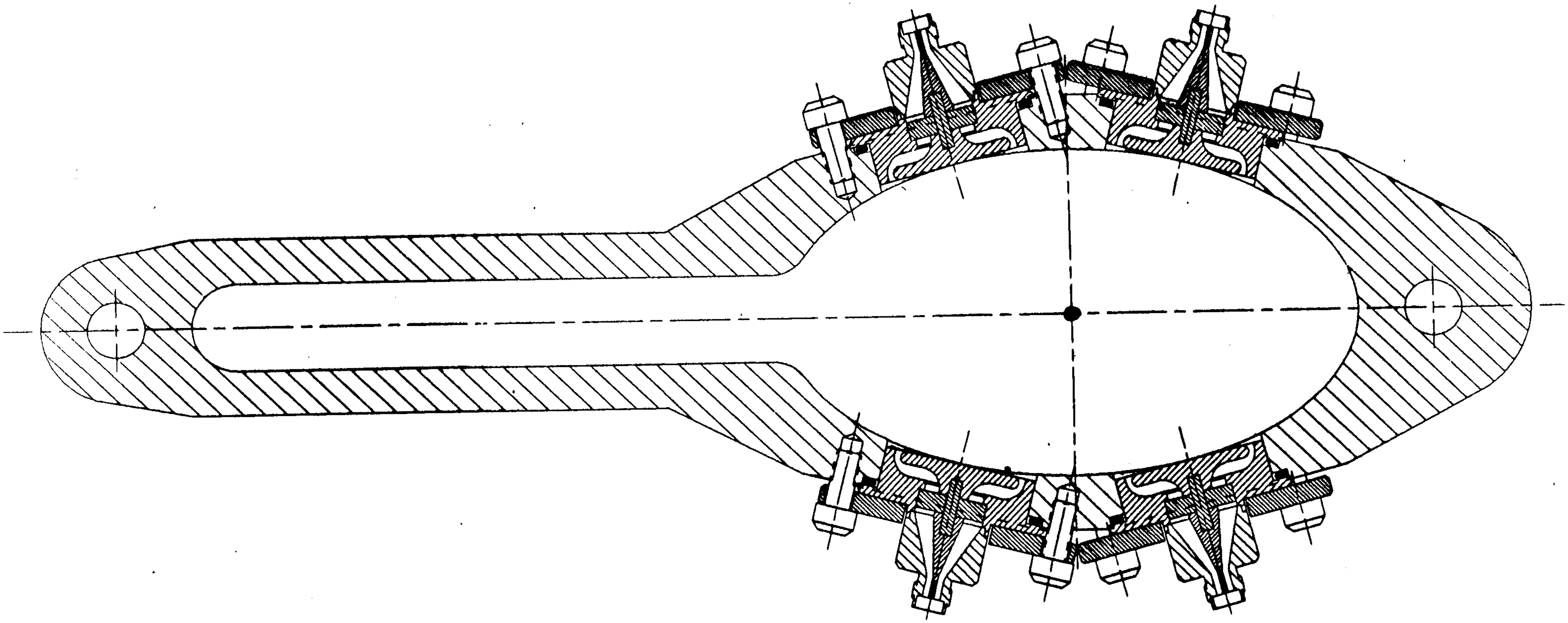
$$Z = \frac{2R(I_o - I_e)}{I_e} = 2R\left(\frac{I_o}{I_e} - 1\right)$$

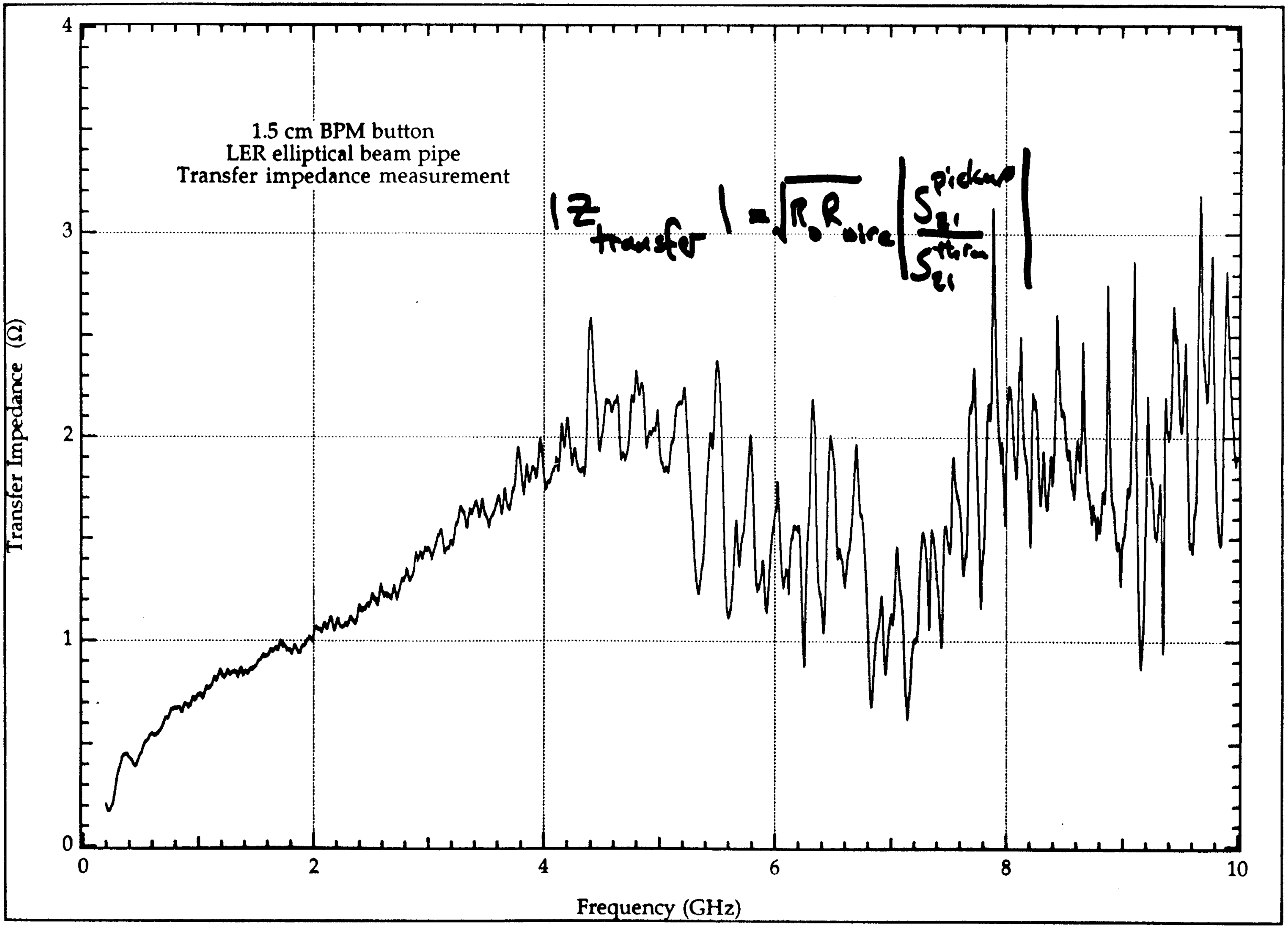
S_{21} measurements without the impedance Z (reference measurement) and with the impedance Z (object measurement) give

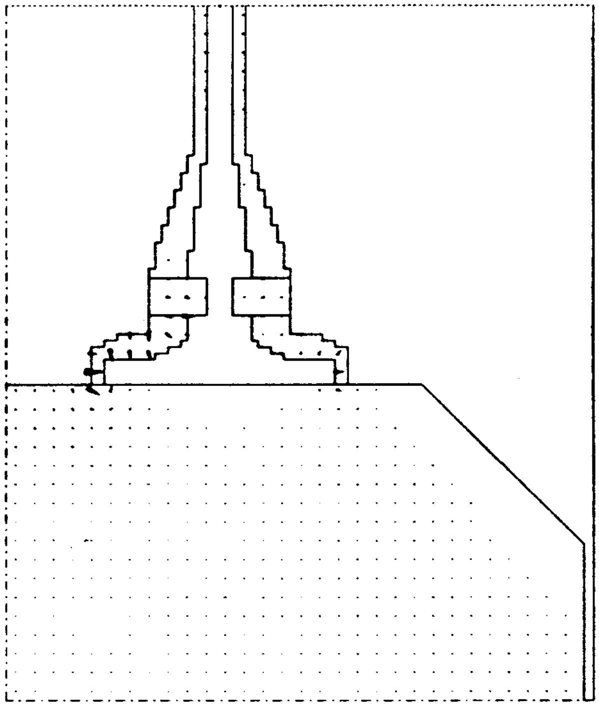
$$Z = 2\,R\left(\frac{S_{21}^{\text{reference}}}{S_{21}^{\text{object}}} - 1\right)$$



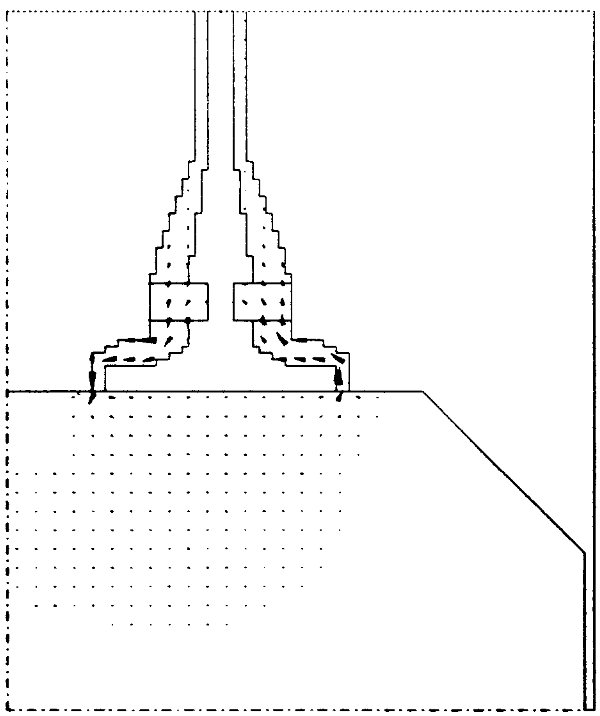
- LER beam position monitor buttons




1.5 cm BPM button
LER elliptical beam pipe
Transfer impedance measurement
Transfer Impedance (Ω)
Frequency (GHz)
0
1
2
3
4
0
2
4
6
8
10



(a)



(b)

Figure 7: (a) Electric field; (b) magnetic field distribution at the button of the 2-cm BPM at the center plane of the BPM along the vacuum chamber.

Fig. K2 : Ktype BPM Impedance spectrum

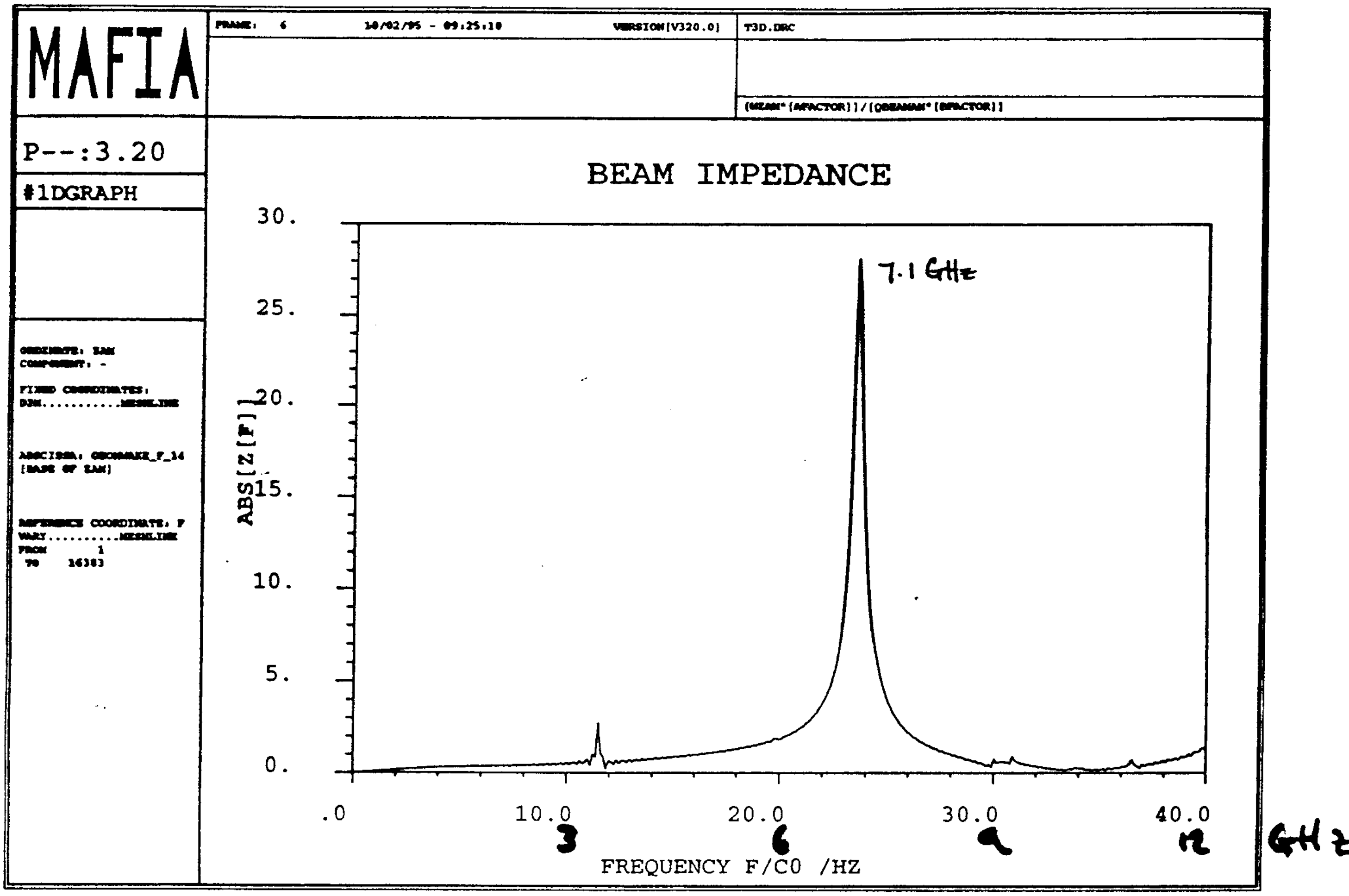
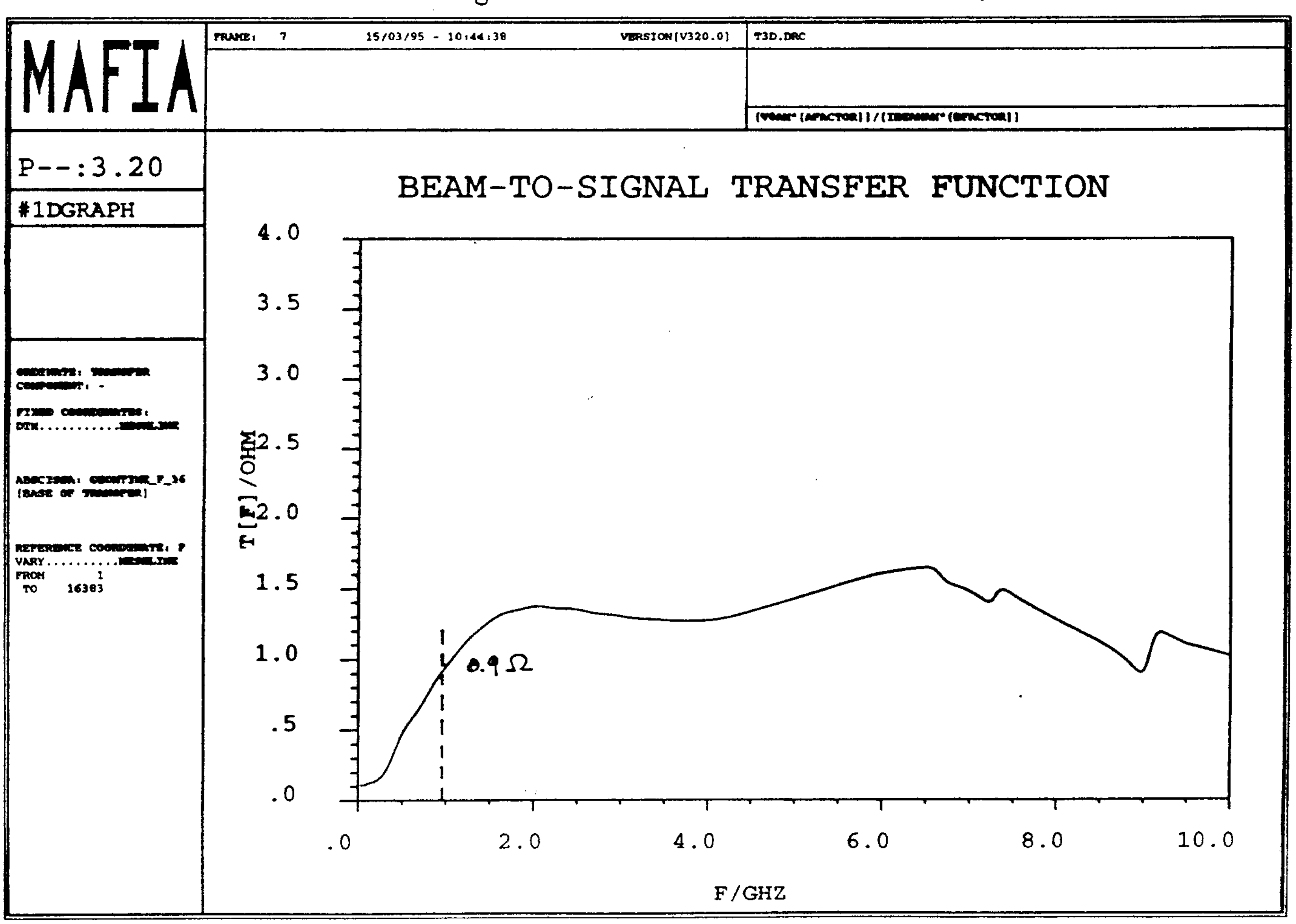
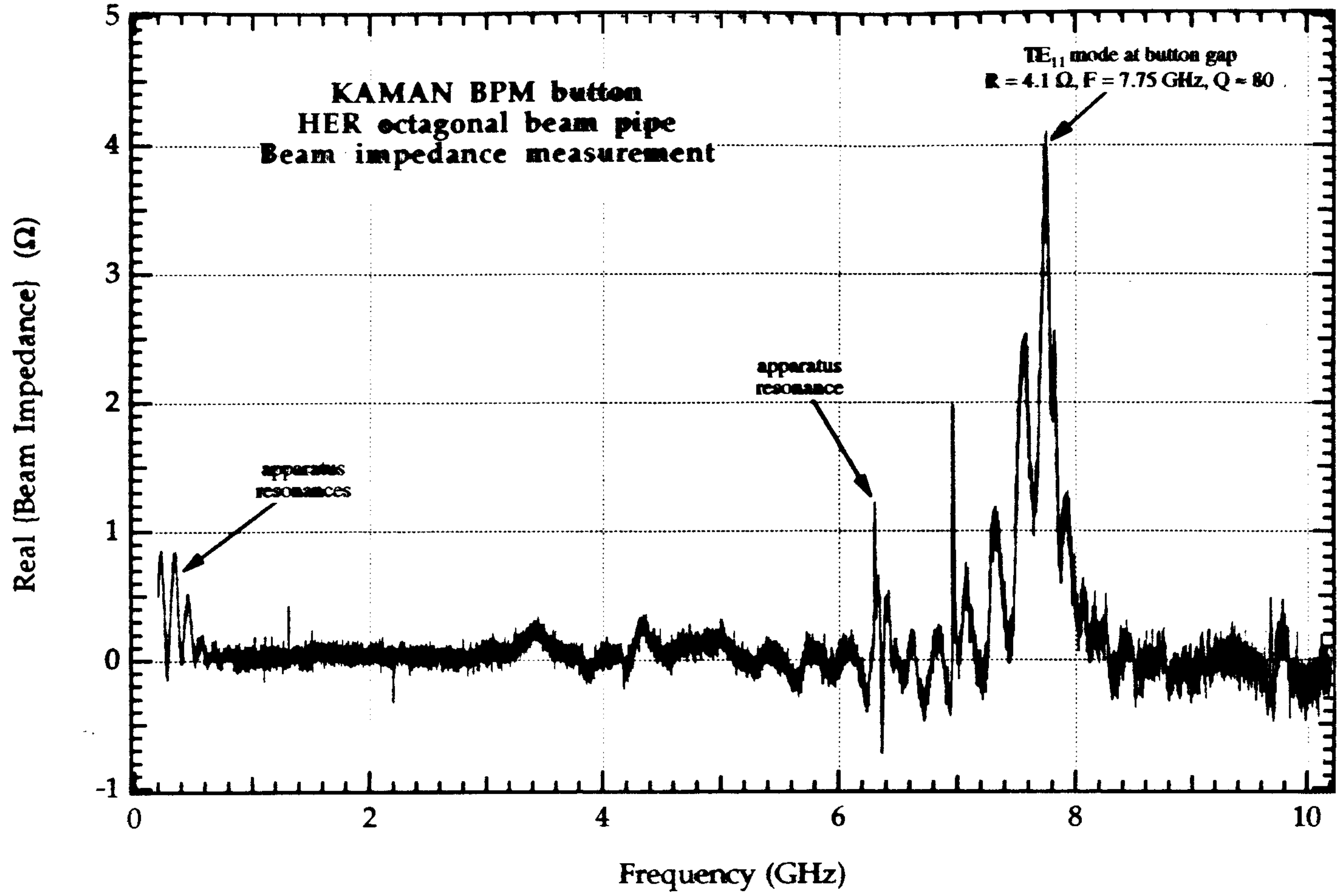
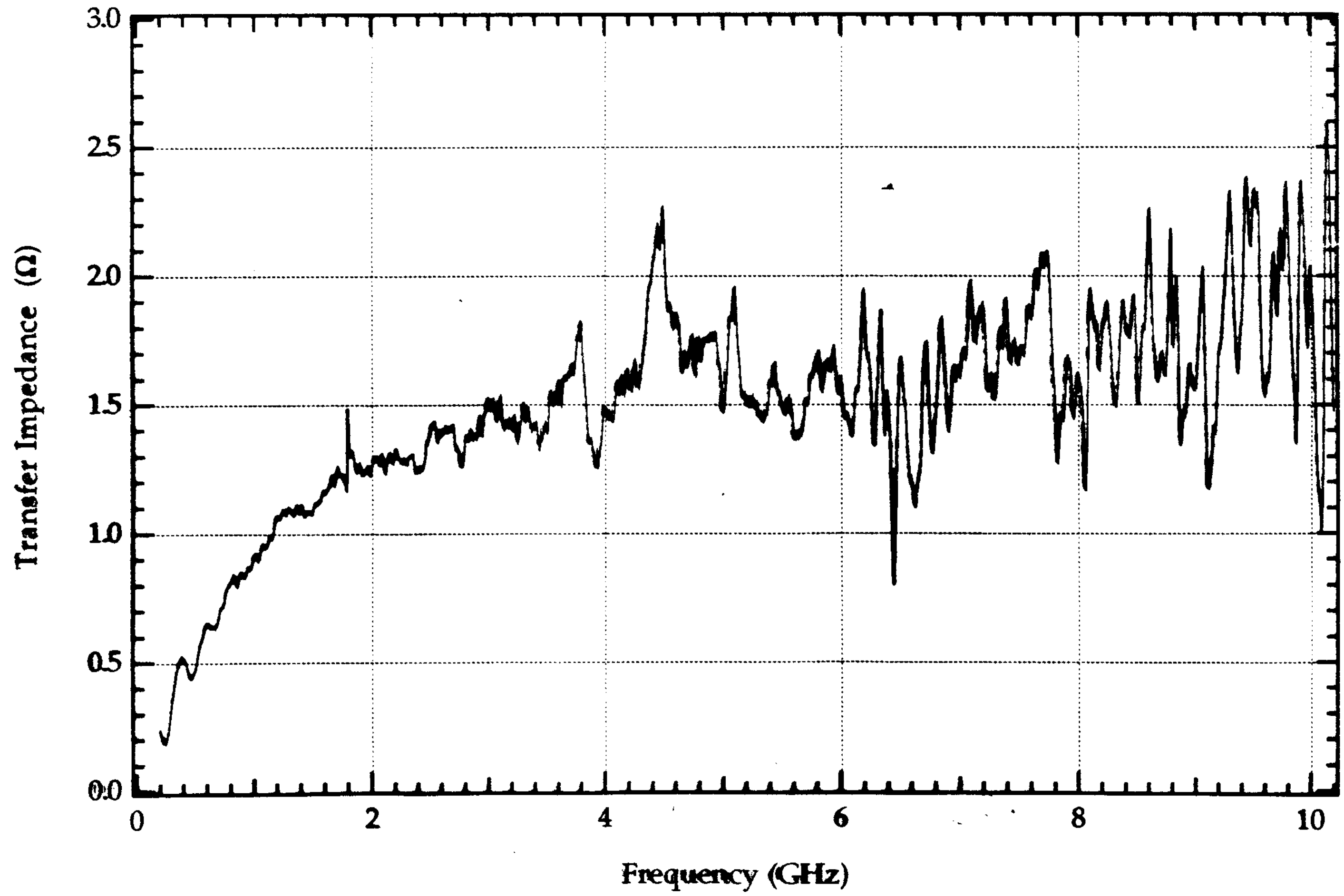
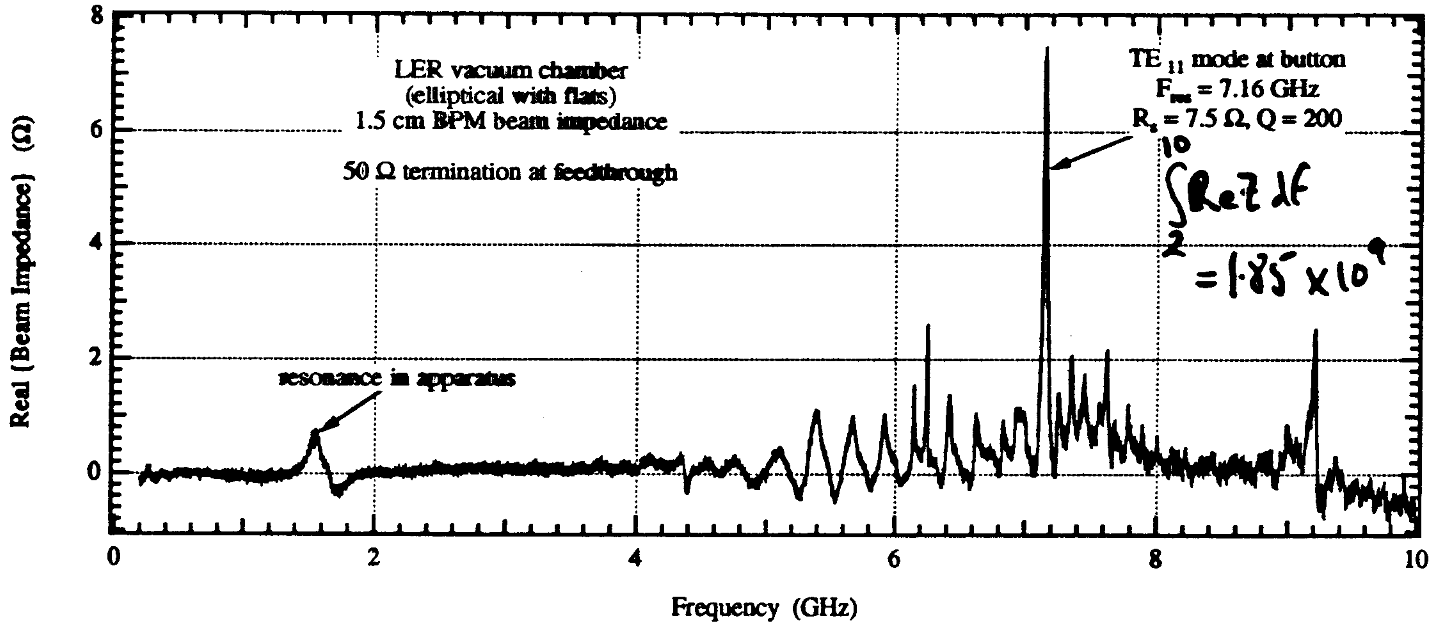


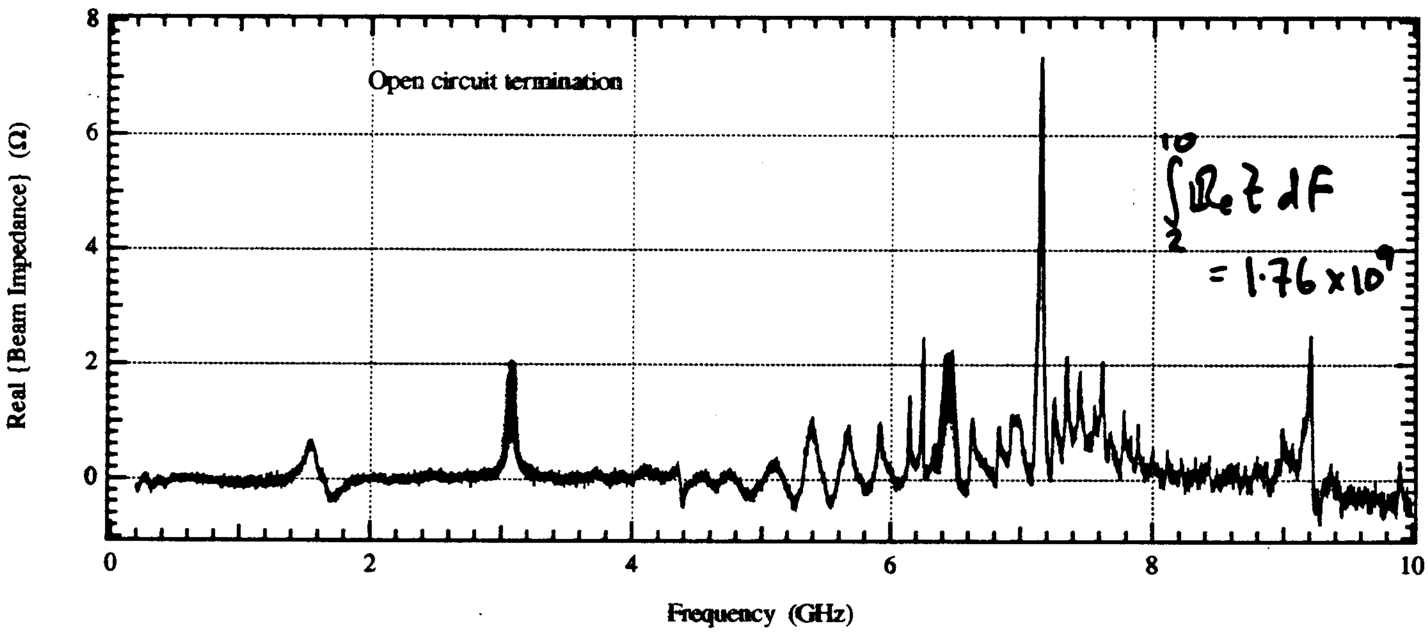
Fig. K3 : Ktype BPM Transfer Impedance spectrum

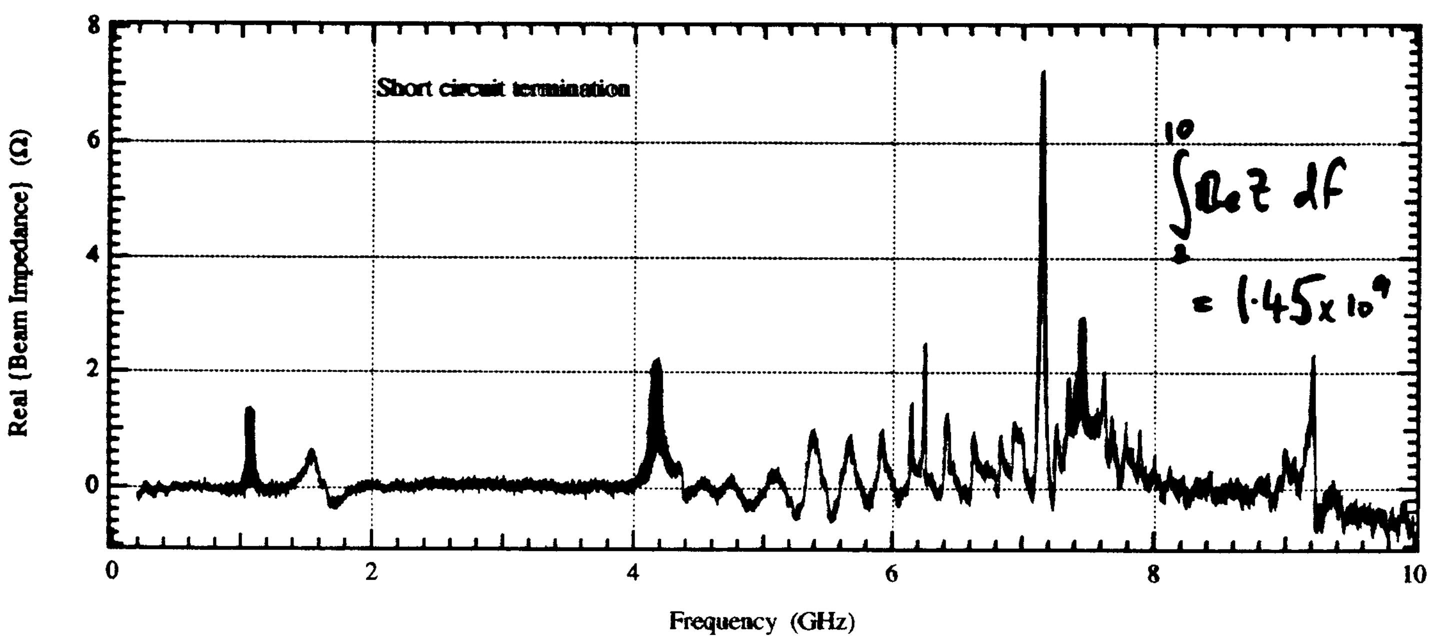



KAMAN BPM button
HER octagonal beam pipe
Beam impedance measurement
TE11 mode at button gap
R = 4.1 Ω, F = 7.75 GHz, Q ≈ 80
apparatus resonance
apparatus resonances
Real {Beam Impedance} (Ω)
Frequency (GHz)
5
4
3
2
1
0
-1
0
2
4
6
8
10


Transfer Impedance (Ω)
Frequency (GHz)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
2
4
6
8
10


LER vacuum chamber
(elliptical with flats)
1.5 cm BPM beam impedance
50 Ω termination at feedthrough
TE 11 mode at button
F res = 7.16 GHz
R s = 7.5 Ω, Q = 200
resonance in apparatus
∫ 2 10 Re Z dF = 1.85 x 10^9
Real {Beam Impedance} (Ω)
Frequency (GHz)
0
2
4
6
8
10


Open circuit termination
∫ 2 10 Re Z dF = 1.76 x 10^9
Real {Beam Impedance} (Ω)
Frequency (GHz)
0
2
4
6
8
10


Short circuit termination
∫ 2 10 Re Z dF = 1.45 x 10^9
Real {Beam Impedance} (Ω)
Frequency (GHz)
0
2
4
6
8
10