PS/RF/Note 94-14 (Min.)
23.2.1994

Minutes of the 1st meeting of the Specification Committee for the supply, forging, and machining of mechanical pieces for the PS/RF 40 MHz (LHC) prototype cavity. (PE-2232/LHC/PS)

Monday, 21 February, 1994

present: J. Conciencia/FI, R. Garoby/PS, E. Jensen/PS, H.-P. Kindermann/SL, S. Milner/MT, F. Pedersen/PS, A. Poncet/MT, M. Van Rooij/AT

F. Pedersen opened the meeting mentioning the new CERN guidelines (CERN/FC/ 3662, CERN/ 2006) which recommend a market survey (= preliminary inquiry) for projects of above CHF 200'000. He mentioned the importance of this bunching cavity for tests of critical RF issues in the SPS. Due to the primary task of the PS to supply many different types of beams, he stressed the essential importance of the mechanical short circuit constructed and presently being built by S. Milner.

Schedule:	I / 95	assembly
	II,III / 95	lab testing
	IV / 95	installation in PS ring
	II / 96	Test beam → SPS

E. Jensen presented the technical choices which lead to the actual design of the cavity. Copies of the transparencies are attached.

Discussion:

H. P. Kindermann corrected an obvious error: the skin depth in Cu at 40 MHz is approx. 10 μm. He recommended to make the Cu plating not thicker than a few skin depths. A. Poncet mentioned the experiences which have been made with heat treatment of LHC cavities. S. Milner mentions the intermediate Ni layer (between inox and Cu) which should not be problematic.

A. Poncet questions the necessity of forging and asks whether the cavity could be made of plate material. The calculations of J. Genest show that this is not well possible, even though he did not account for a possible supporting rib structure in his calculations. Such a rib would be inconvenient (welding!), but S. Milner recommends to have a fall back solution in case no company could forge our pieces.

R. Garoby asks whether the results of the present market survey could give valuable information also for this fall back solution. S. Milner affirms.

We discussed the recent proposal by P. Bourquin to use (thicker) Cu instead of steel; A. Poncet: this would be difficult. Cooling is not a serious problem with this cavity, since the average power loss is only in the order of 200 W.

F. Pedersen asks whether a pure functional specification should be meaningful. General agreement when A. Poncet negates this.

The total weight of the cavity would be around 5 tons.

R. Garoby mentions the possible (later) 80 MHz version of this cavity which will have to be operated in CW. Replacing just the inner part by forged Cu (for better heat conductivity) would alleviate the cooling problem.

The discussion then addressed the different types of inox: 304 L, 304 LN, 316L, 316LN (N for nitrogen). CERN specifications exist for 304L and 316LN only. A. Poncet suggests to use the CERN specifications, but let the company eventually propose alternatives if necessary. E. Jensen will have to make sure whether 304L is acceptable from its magnetic property (permeability).

The market survey contains two technical documents: a specification and a questionnaire. S. Milner proposes some modifications to these documents to make clear,

1) that the dimensions after forging are not the final dimensions (but + 10 mm),
2) that the dimensions after the rough machining are not the final dimensions (but + 3 mm),
3) that the point "final machining" should be added between c) and d) of the technical specifications,
4) that we should at first ask for forging only, or at least make clear that we are willing to split the task (forging and rough machining and baking, fine machining, welding).

S. Milner gives additional addresses of potential companies to J. Conciencia.

M. Van Rooij recommends that the drawings should be more detailed.

It was discussed then whether price information should be asked for in the preliminary inquiry. J. Conciencia informs us that this is not usually done but could be added as an optional question in the technical part (not to pre select companies, but to value our technical approach).

The modifications to the technical part of the market survey will be done a.s.a.p., in order for the inquiry to be sent out to in week 8.

Erk Jensen

Technical choices

E.J. 21/2/94

What do we need? Y.A.C. ("yet another cavity")

40 MHz, (protons, PS, 26 GeV, $h = 84$)
3…300 kV, bunching ($\phi = 180°$), 10 ms

"standard" (use as much experiences & hardware as possible)

BUT:

- Heavy beam loading $I_{beam} \approx 2A$
  requires fast tuning $\frac{\Delta f}{f} \approx 1\%$
  RF feedback
  low impedance helps
- Other PS cycles (where cavity should be "invisible")
  movable short circuit
  RF feedback
- Geometrical constraints PS short section, $l < 1m$
  capacitive loading

How to choose SHAPE & MATERIAL

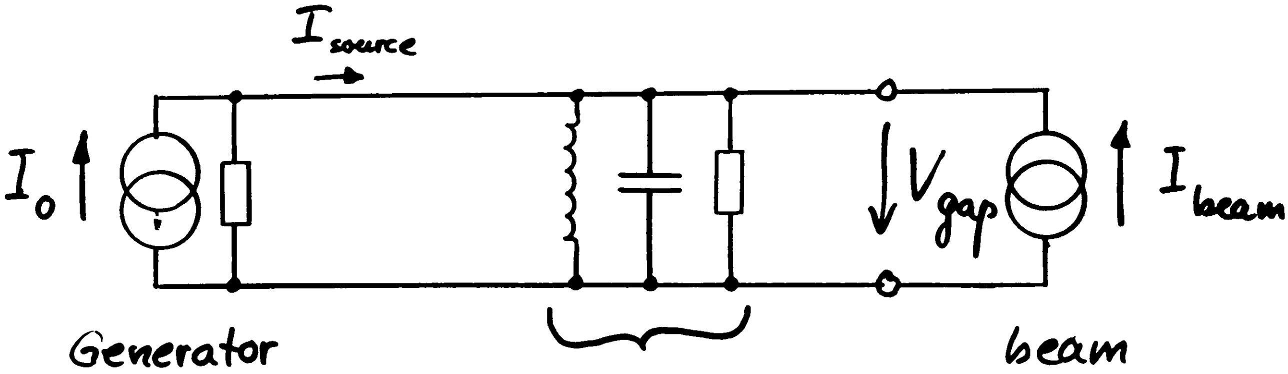
To be considered:

RF breakdown, multipactor
Mode composition & HOM damping
Temperature variations & deformation
Mechanical stability & deformation
Vacuum requirements,
Construction & machining aspects
Practical considerations

E.J. 21/2/94

40 MHz cavity, principle

cavity

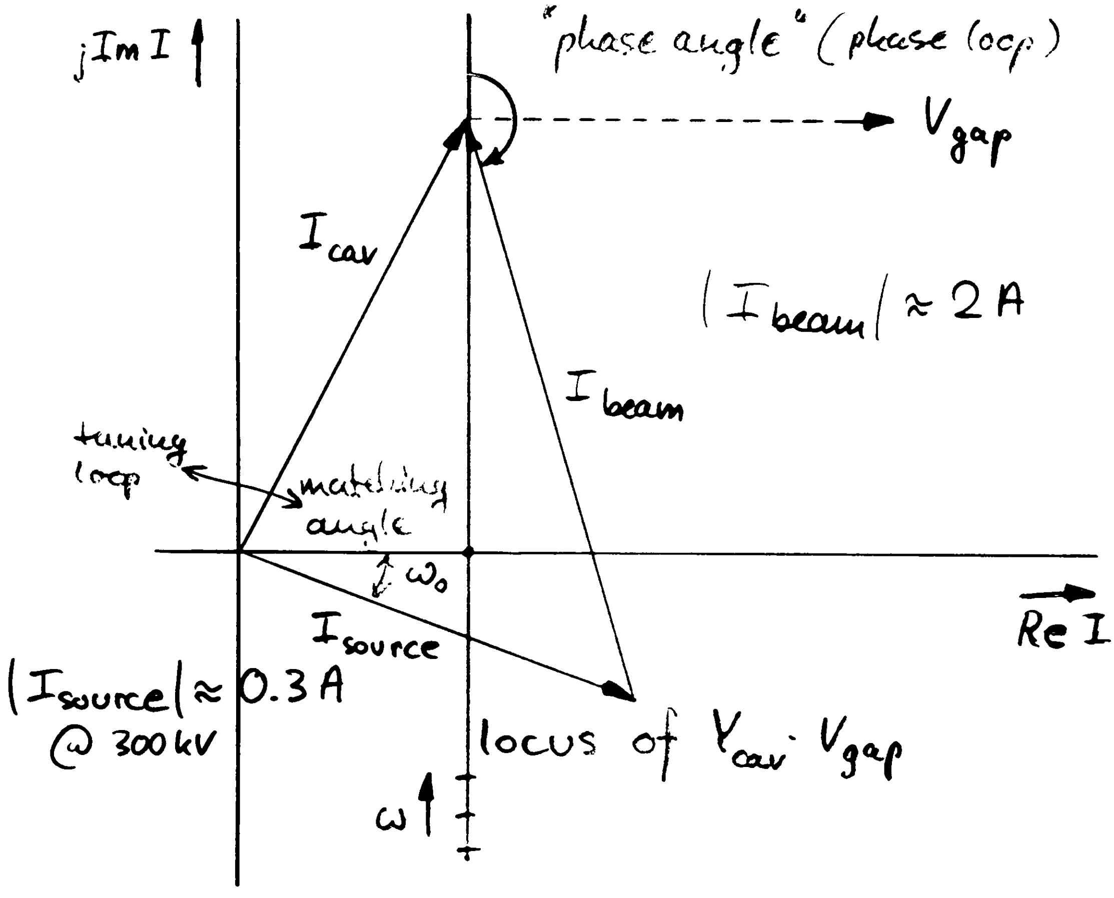


$$Y_{cav}(\omega_0, R_{sh}, Q)$$

$$Y_{cav} = \frac{1}{R_{sh}} + j\frac{1}{(R_{sh}/Q)}\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)$$

with detuning $\Delta \equiv \frac{\omega - \omega_0}{\omega_0}$, $\Delta \ll 1$:

$$Y_{cav} \approx \frac{1}{R_{sh}} + j\frac{2\Delta}{(R_{sh}/Q)}$$



E.J. 21/02/94

Evolution of the shap_ of the LHC/PS prototype cavity 40 MHz

Date	nominal frequency	gap	outer diameter			Q	(R/Q)/Ohm
Nov-92	66.8 MHz			2 approaches:			
				1) R. Hohbach: modified 114 MHz cavity		33400	115.0
				capacitive loading			
				2) W.Pirkl: halved SPS cavity (G. Rogner/MT)		27300	98.0
				required also capacitive loading		24000	83.0
Feb-93	40 MHz			decision on 25 ns bunch spacing taken			
				symmetrical approach:			
		10 cm	1.84 m		a)	27200	65.0
		6 cm	1.60 m		b)	32500	57.0
				but how and where to put the mechanical S.C.?			
Jul-93				asymmetric approach			
		10 cm	2.20 m		c)	33400	45.6
				beginning of design of the machanical S.C. (S. Milner/MT)			
				inner diameter 820 mm (!)	d)	31500	31.5
				shorter stroke for S.C. => shortest possible gap			
				breakdown voltage calculations			
Aug-93				beginning of mechanical studies (W.Fritschi/MT)			
		5 cm	1.80 m		e)	28200	28.3
				reducing inner diameter	f)	27800	32.0
					g)	28900	35.4
				inner diameter 580 mm	h)	28800	36.7
Sep-93				multipactor calculations, discussion E. Haebel/SL => Ti layer!			
				mechanical stress and deformation calculations (J. Genest (MT)			
				=> reduce outer diameter			
				Material decision			
				fit form of shell to standard "decimal" vessel-heads			
			1.60 m		i)	25900	37.7
					k)	26400	35.8
				trial with "flat end"	l)	26800	37.5
16-Dec-93				actual form	m)	26300	32.8
Jan-94				vacuum requirements discussion (A. Burlet, C. Burnside, M. van Rooij/AT)			
				higher order mode (HOM) calculations			

Fig 1 PS proposal
(R. Hohbach)

R/Q = 115.4 Ω
Q = 33'417
Rp = 3.85 MΩ

→ P = 46.75 kW for Û = 600 kV

Proposal
R. Hohbach
1990
66.8 MHz

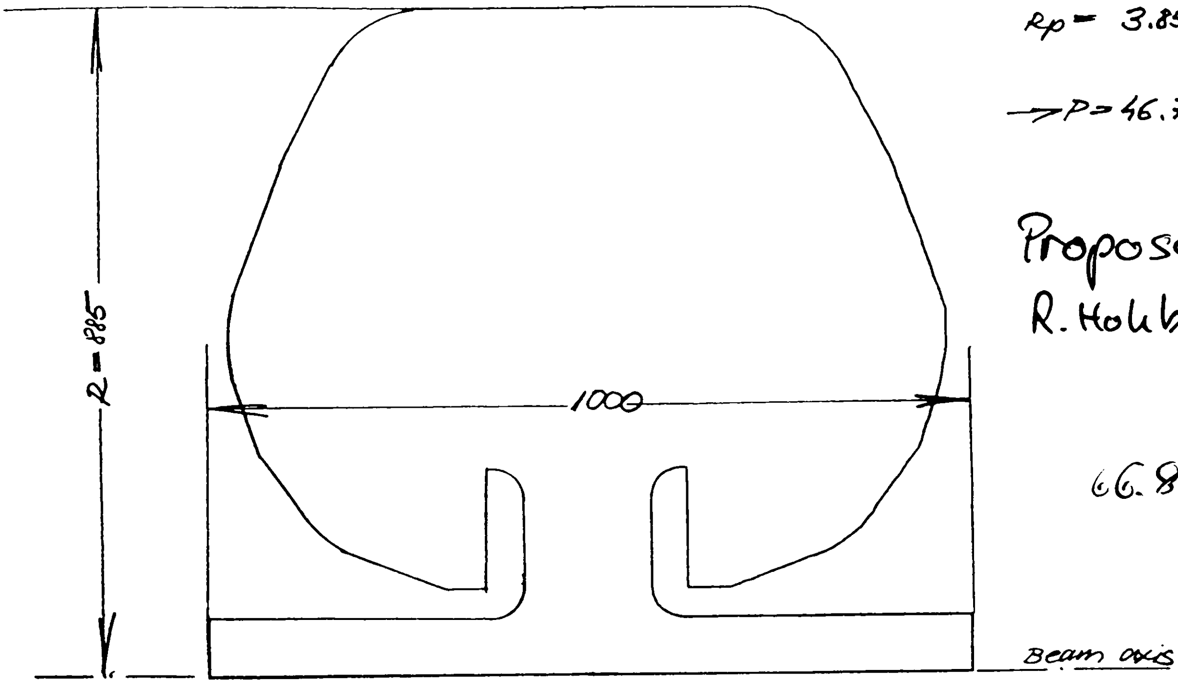


Fig 2 SPS proposal
(G. Rogner)

R/Q = 195.14 Ω
Q = 28'676
Rp = 5.596 MΩ
→ P = 89.35 kW (Û = 1 MV)

SPS – design, G. Rogner

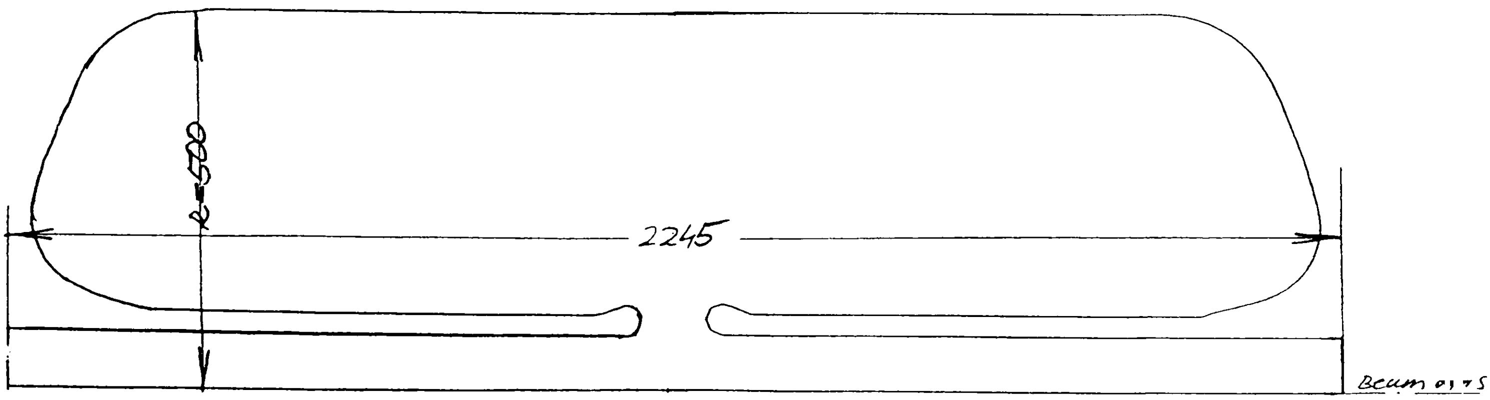


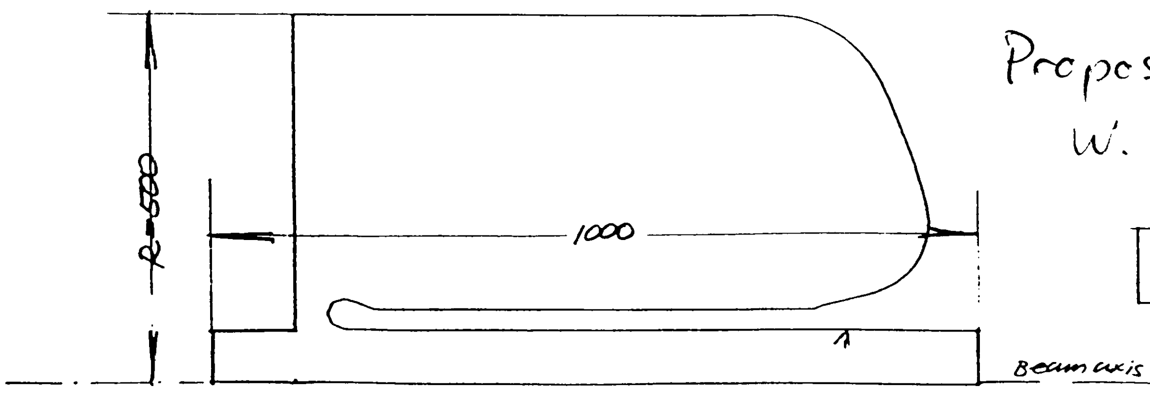
Fig 3 Common design
(clone of SPS for PS)

R/Q = 98 Ω
Q = 27'257
Rp = 2.67 MΩ

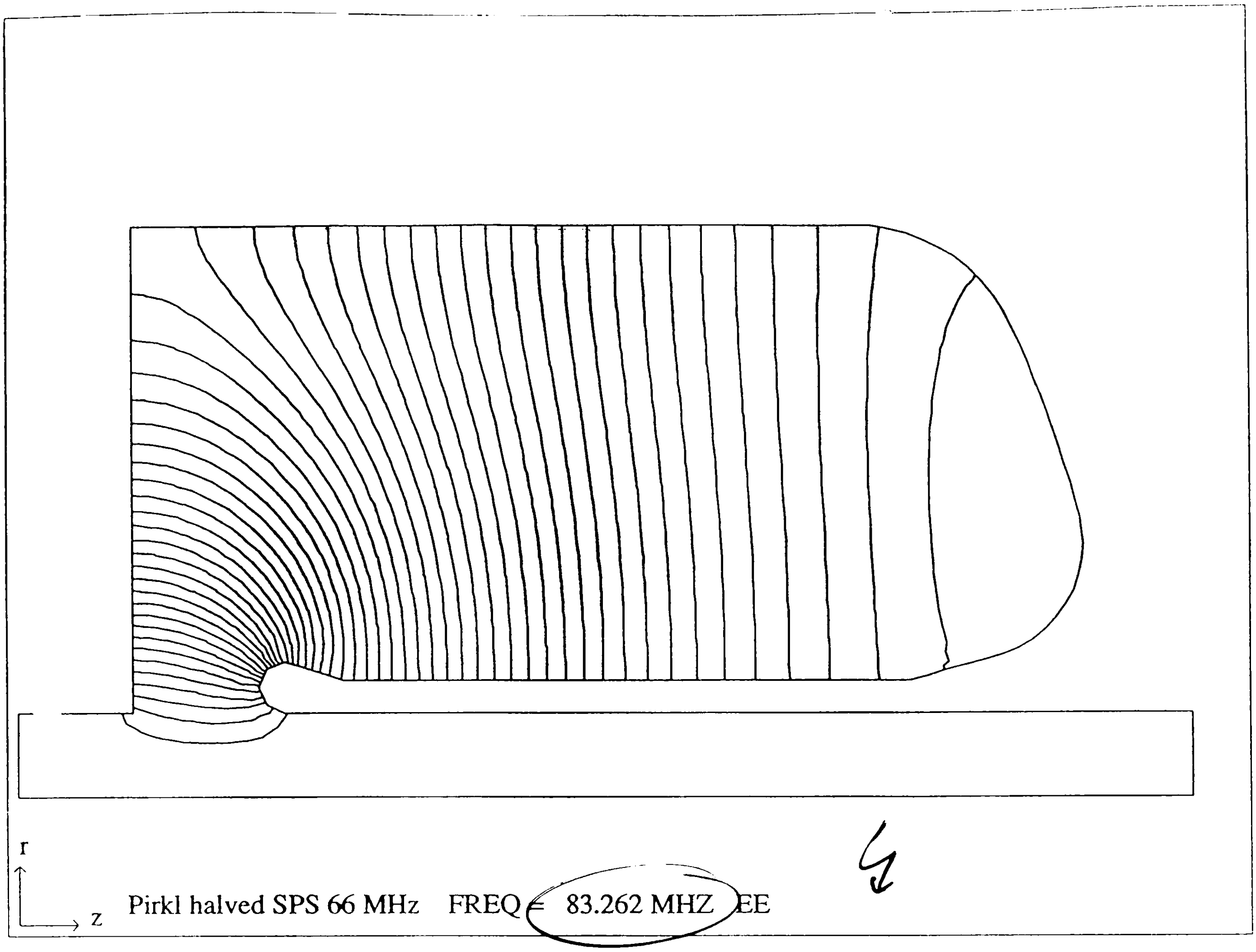
→ P = 67.4 kW (Û = 600 kV)

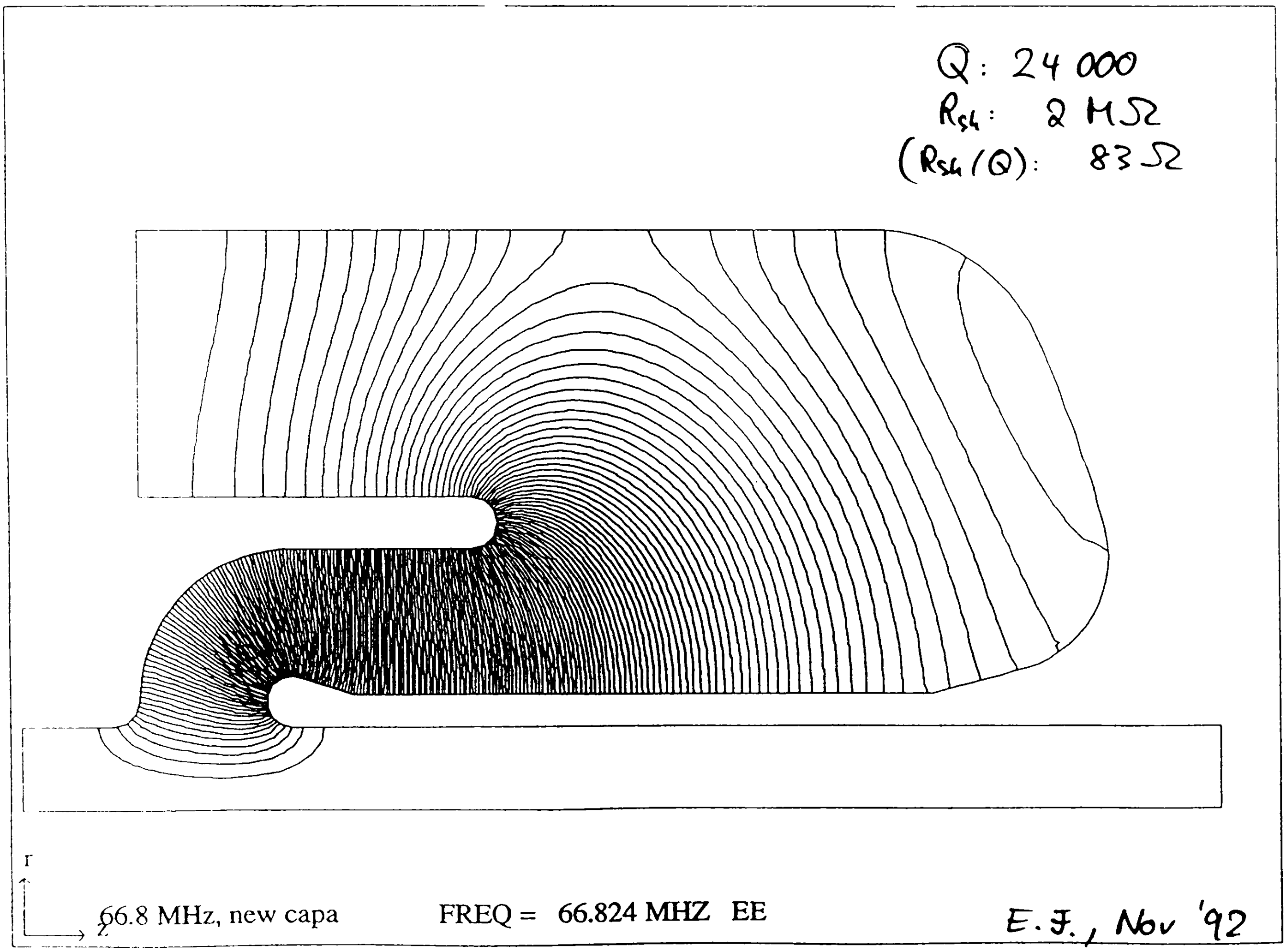
Proposal
W. Pirkl, Feb. 1992

M ~ 1/10

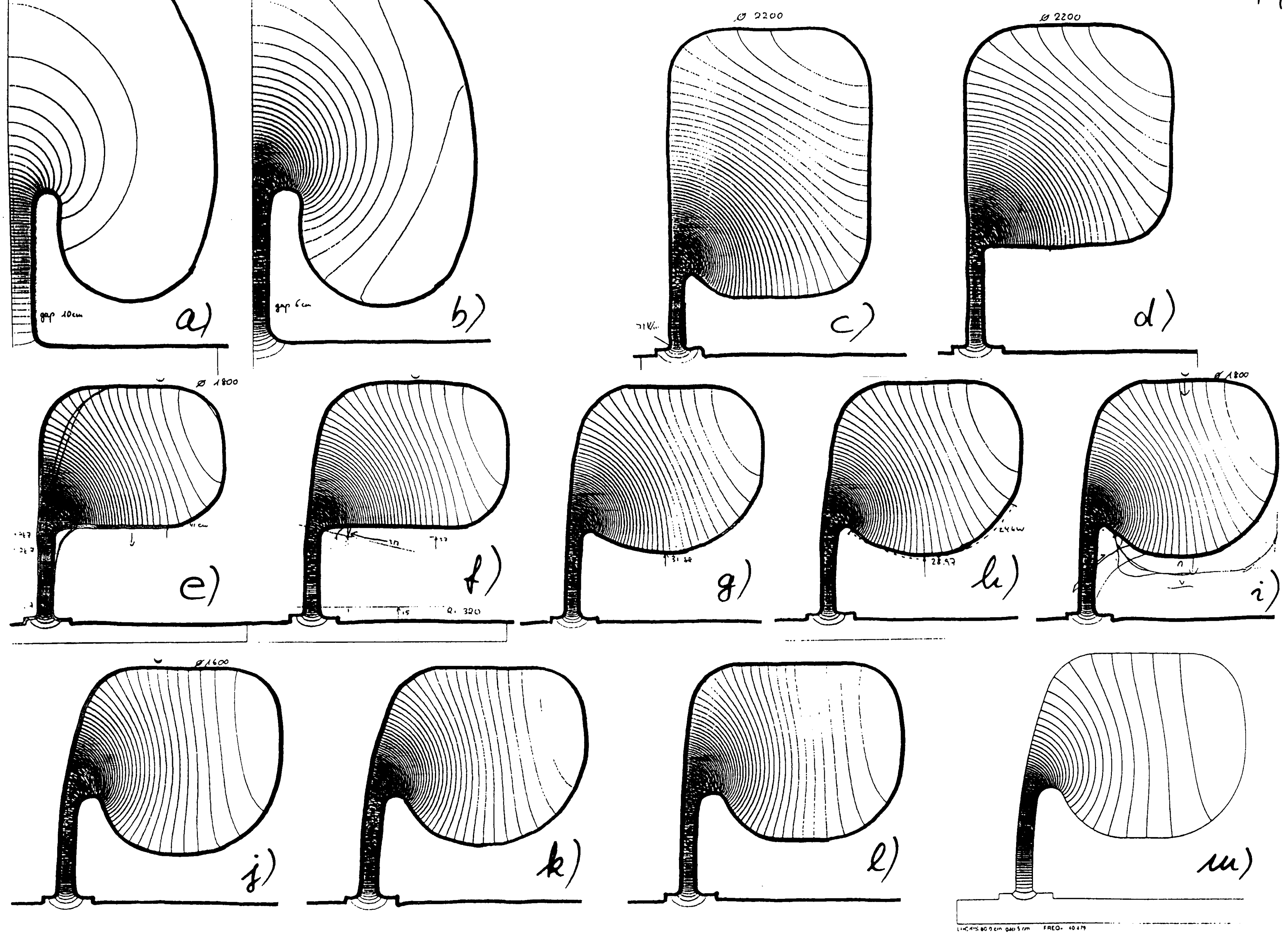


144 möglich, SPS 150

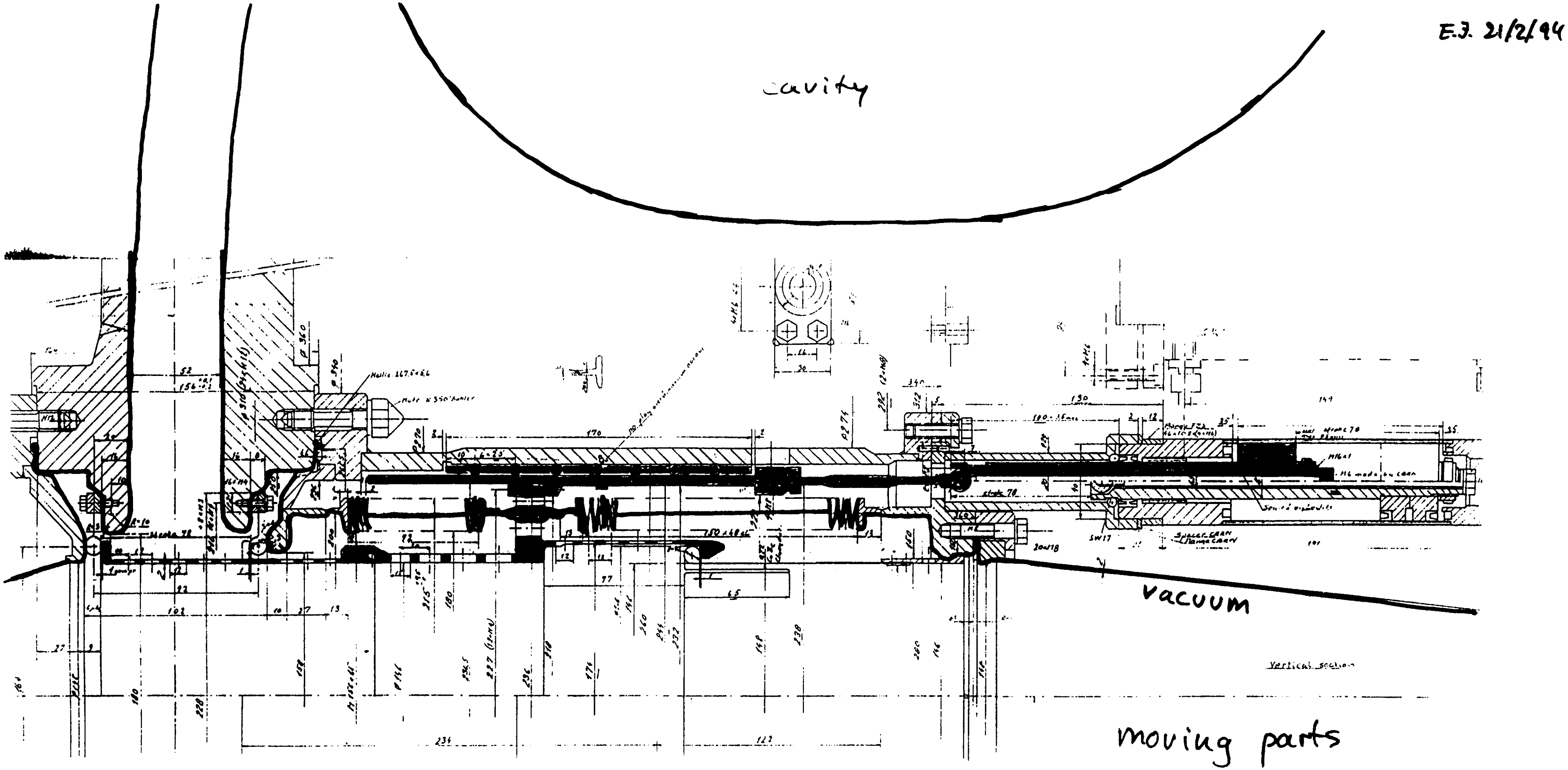

r
z
Pirkl halved SPS 66 MHz FREQ = 83.262 MHZ EE


Q: 24 000
Rsh: 2 MΩ
(Rsh/Q): 83 Ω
r
z
66.8 MHz, new capa FREQ = 66.824 MHZ EE
E.J., Nov '92

E. J. 21/2/94

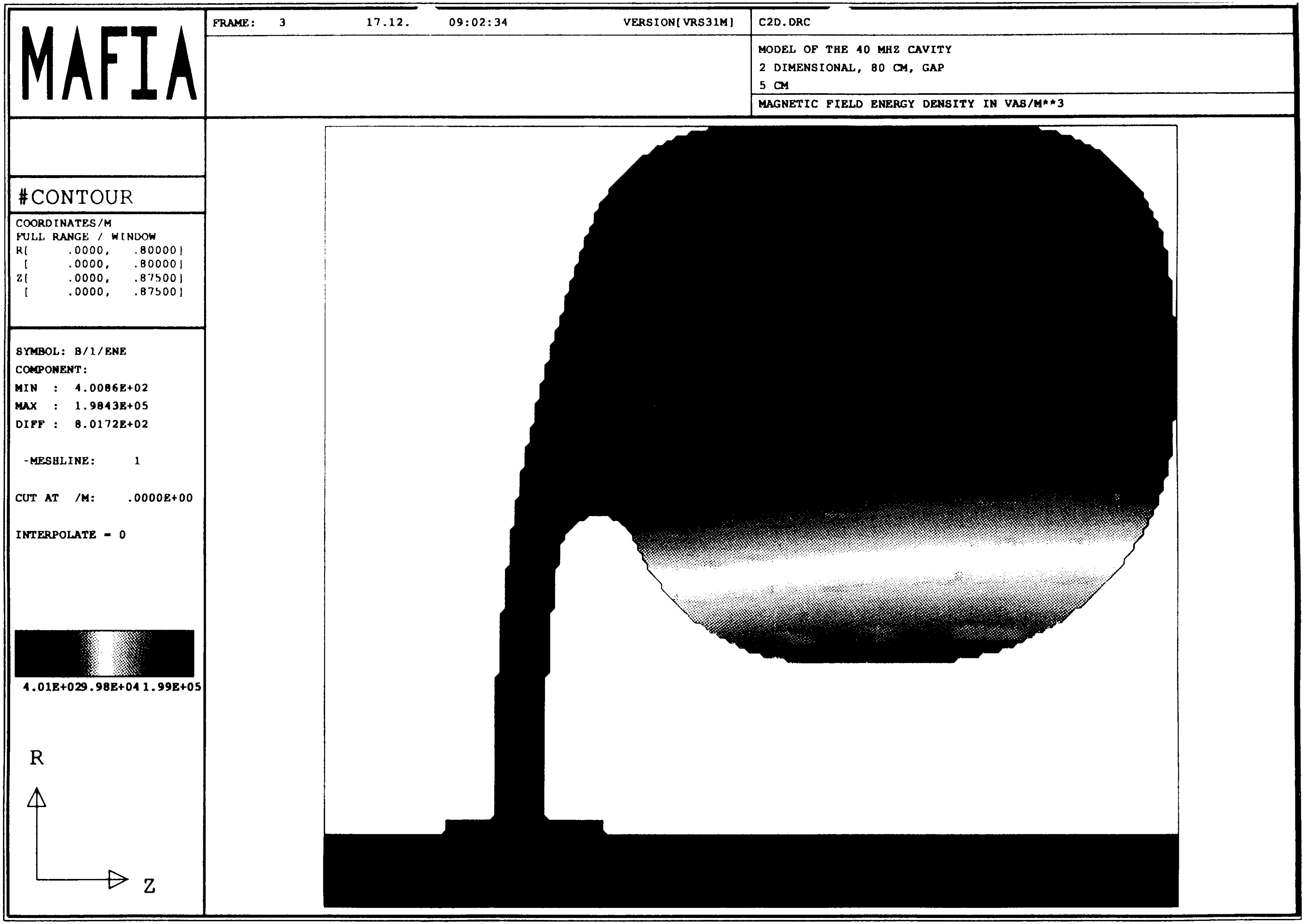

gap 10cm
a)
gap 6cm
b)
Ø 2200
c)
Ø 2200
d)
Ø 1800
e)
f)
R. 320
g)
h)
Ø 1800
i)
Ø 1600
j)
k)
l)
m)

E.J. 21/2/94



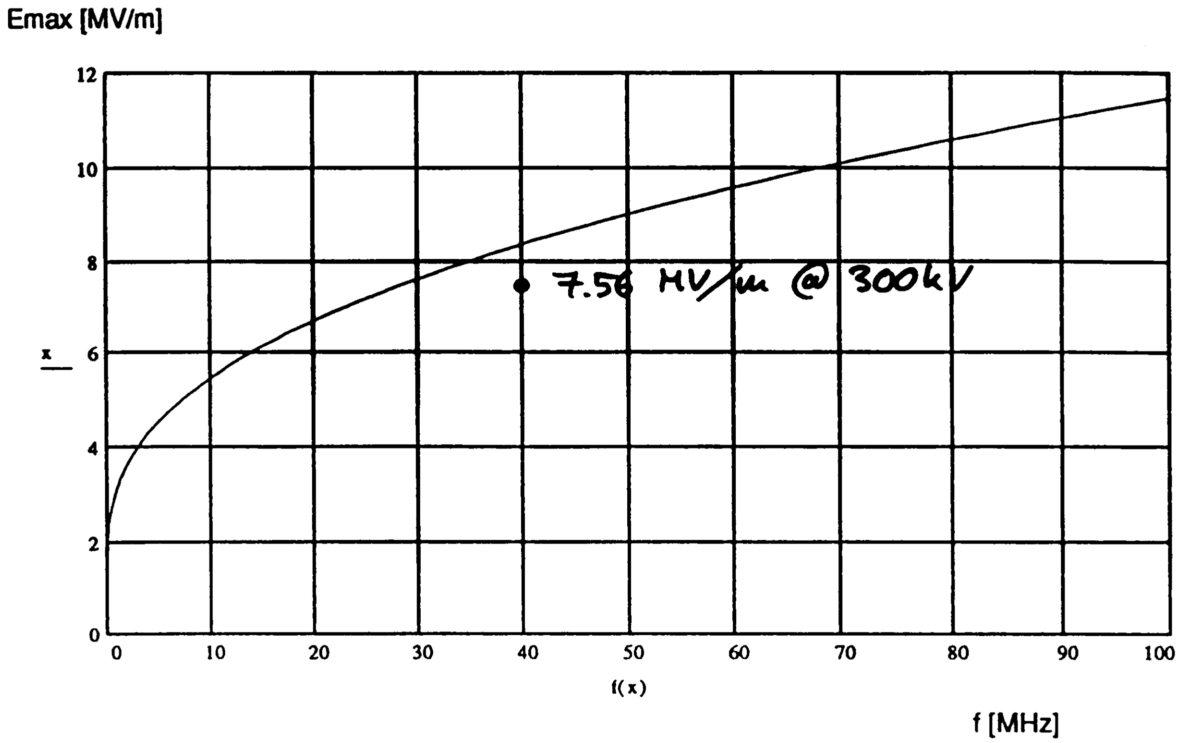
Mechanical short circuit

(S. Milner/MT)


MAFIA
FRAME: 3 17.12. 09:02:34 VERSION[VRS31M]
C2D.DRC
MODEL OF THE 40 MHZ CAVITY
2 DIMENSIONAL, 80 CM, GAP
5 CM
MAGNETIC FIELD ENERGY DENSITY IN VAS/M**3
#CONTOUR
COORDINATES/M
FULL RANGE / WINDOW
R[.0000, .80000]
[.0000, .80000]
Z[.0000, .87500]
[.0000, .87500]
SYMBOL: B/1/ENE
COMPONENT:
MIN : 4.0086E+02
MAX : 1.9843E+05
DIFF : 8.0172E+02
-MESHLINE: 1
CUT AT /M: .0000E+00
INTERPOLATE = 0
4.01E+02 9.98E+04 1.99E+05
R
Z

Kilpatrick limit for RF breakdown

$$x := 0.1, 0.2 .. 12 \quad f(x) := 1.6 \cdot x^2 \cdot \exp\left(-\frac{8.5}{x}\right)$$



The Kilpatrick limit is a very conservative one.
Electric fields well beyond this limit have been reportet.
The presented formula is taken from "W. Peter et al.: Criteria for Vacuum Breakdown in RF Cavities", IEEE Transactions of Nuclear Science, Vol. NS-30#4, Aug. 1983, where experimental fields of 40 MV/m at 20 MHz were reported.

MAFIA

FRAME: 5 17.12.: 09:02:34 VERSION[VRS31M] C2D.DRC

MODEL OF THE 40 MHZ CAVITY
2 DIMENSIONAL, 80 CM, GAP
5 CM

ELECTRIC FIELD ENERGY DENSITY IN VAS/M**3

#CONTOUR

COORDINATES/M
FULL RANGE / WINDOW
R[.0000, .80000]
[.0000, .80000]
Z[.0000, .87500]
[.0000, .87500]

SYMBOL: E/1/ENE
COMPONENT:
MIN : 4.6075E+03
MAX : 2.2807E+06
DIFF : 9.2150E+03

-MESHLINE: 1

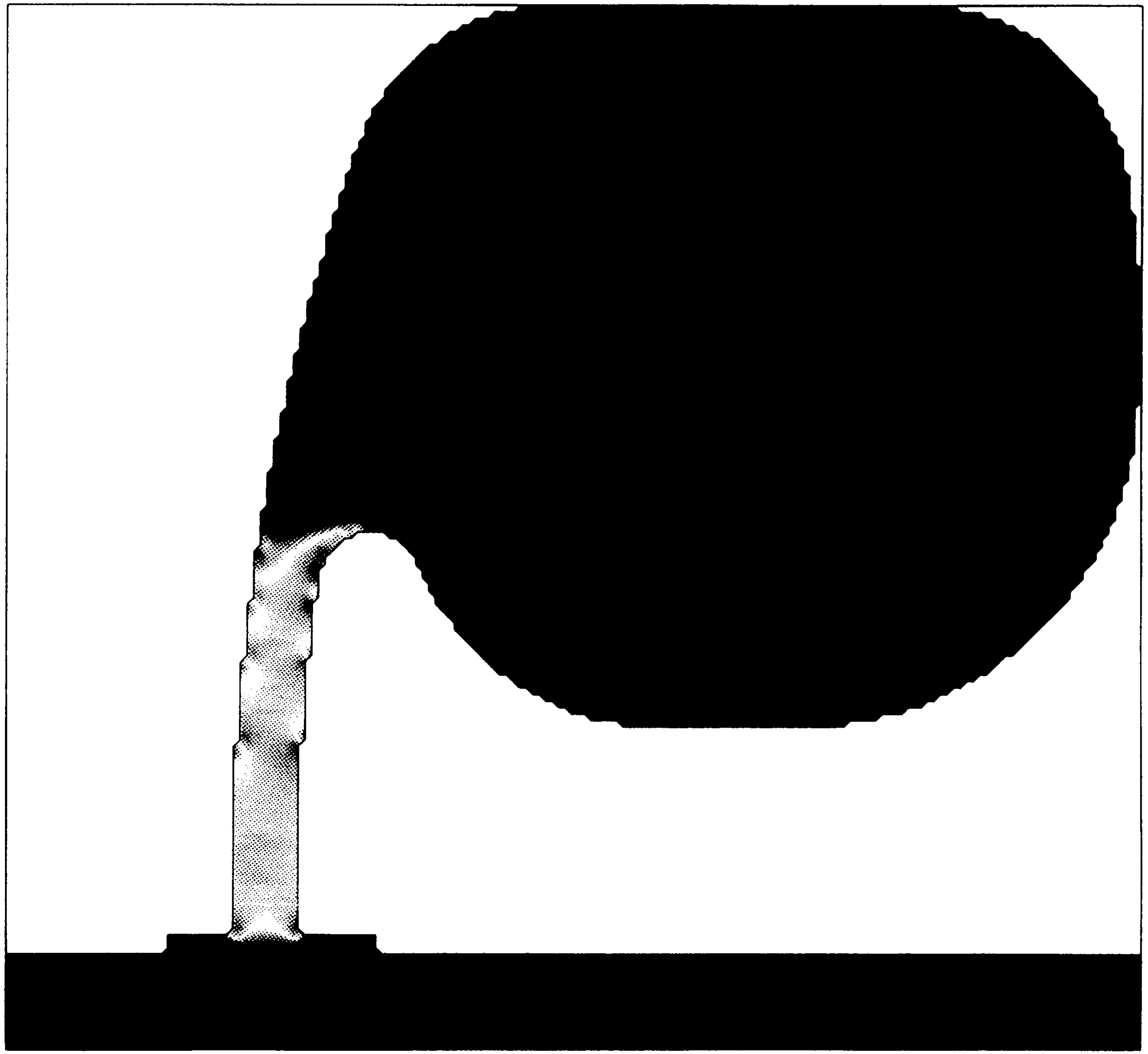
CUT AT /M: .0000E+00

INTERPOLATE = 0

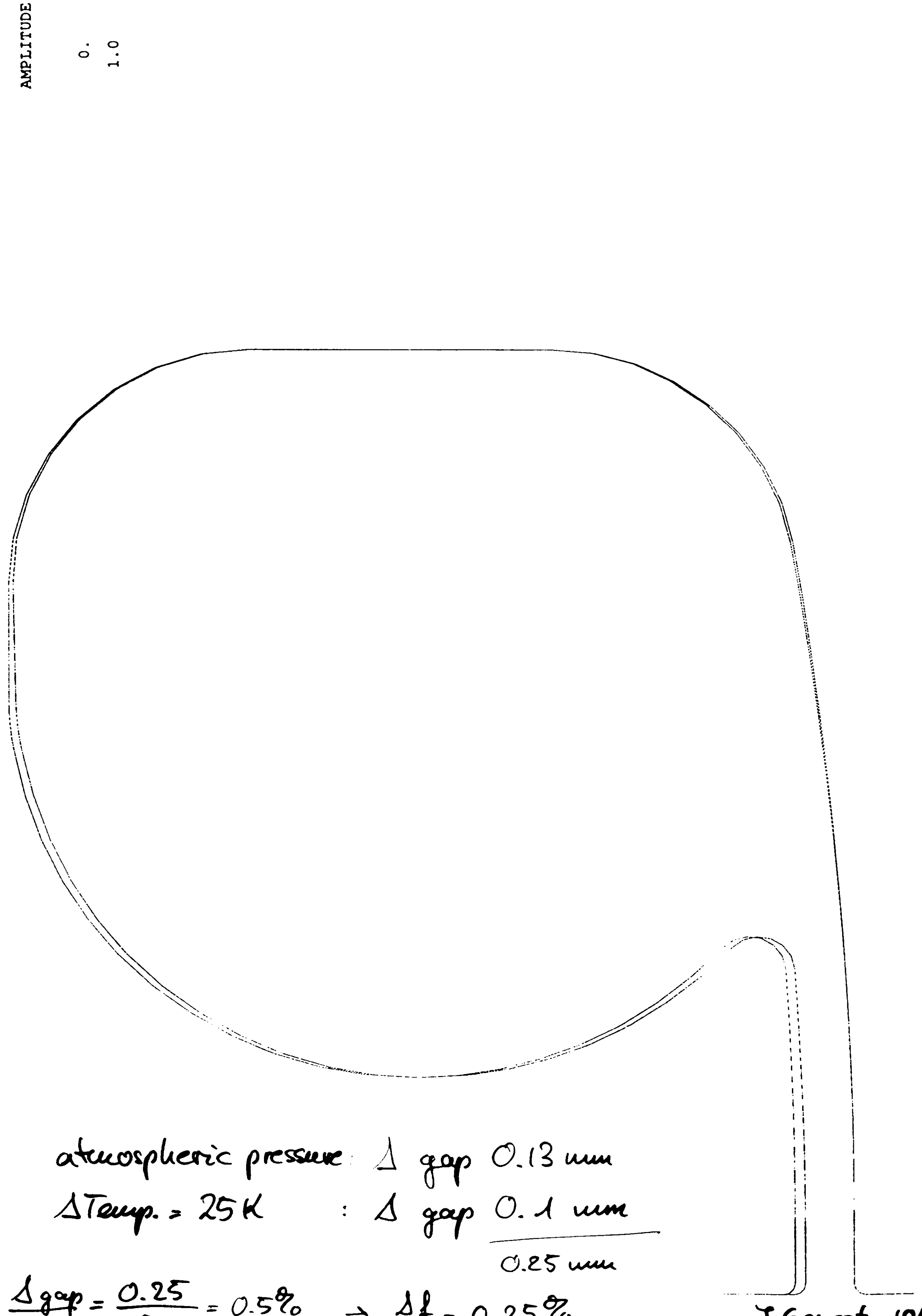
4.61E+03 1.15E+06 2.29E+06

R

Z



E.S. 21.2.94



atmospheric pressure : Δ gap 0.13 mm

ΔTemp. = 25 K : Δ gap 0.1 mm

0.25 mm

$\frac{\Delta gap}{gap} = \frac{0.25}{50} = 0.5\%$ $\Rightarrow$ $\frac{\Delta f}{f} = 0.25\%$

J. Genest 10/93

Distribution of power losses

EJ, 16.2.94

@ 300 kV gap

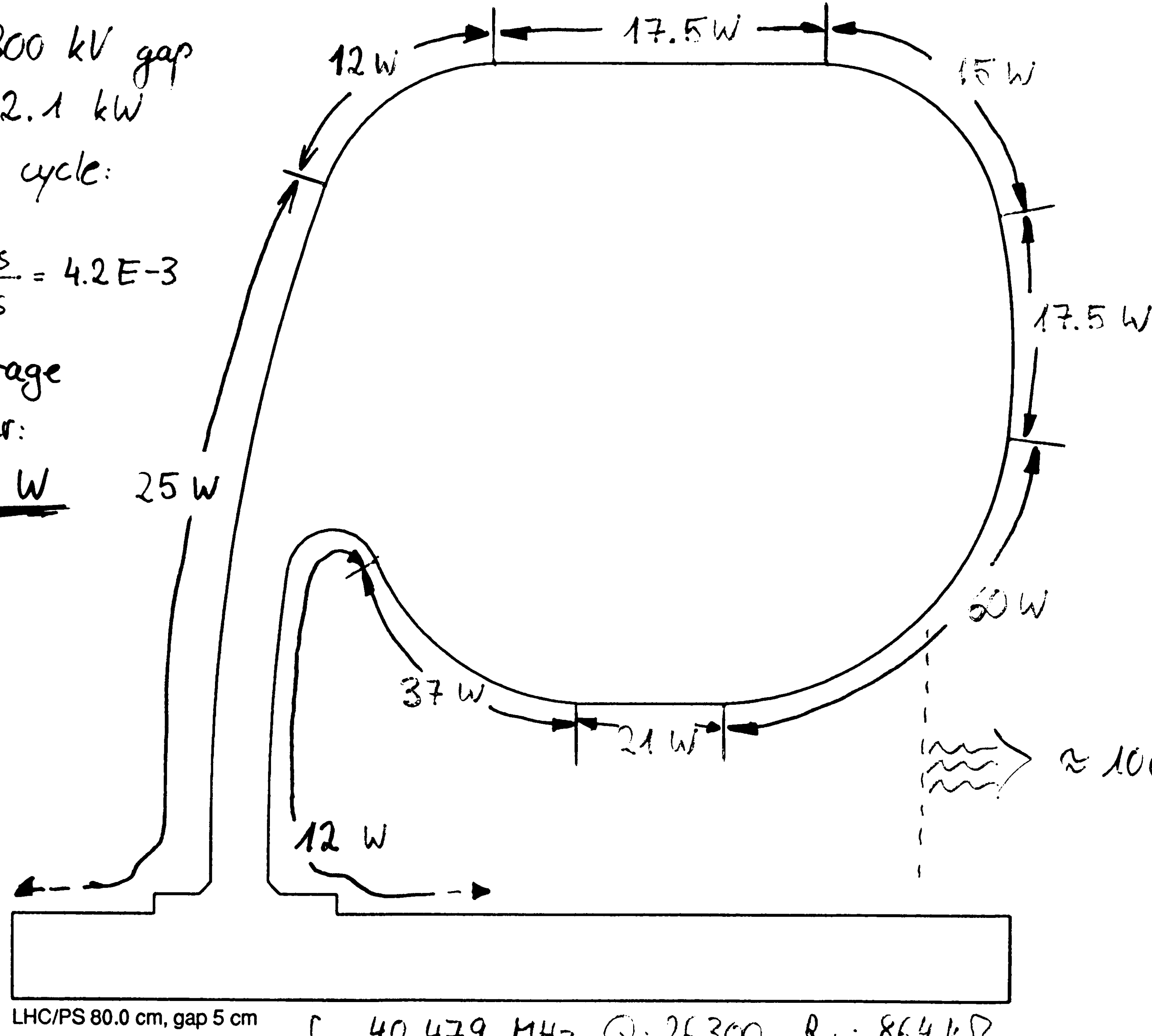
P: 52.1 kW

duty cycle:

$\frac{10\,ms}{2.4\,s} = 4.2E-3$

Average Power:

217 W



f 40.479 MHz, Q: 26300, R_{sh}: 864 kΩ

Higher order mode distribution

E.J. 21/02/94

40 MHz cavity (MAFIA)

f/MHz	Rsh/Ohm	Q	R/Q		
40.21	814300	25048	32.51	1	1
265.57	64100	40580	1.58	6.60	0.0787
294.67	1800	50443	0.04	7.33	0.0022
394.66	198700	20565	9.67	9.81	0.2440
452.00	12200	48986	0.25	11.24	0.0150

40 MHz cavity (Superfish)

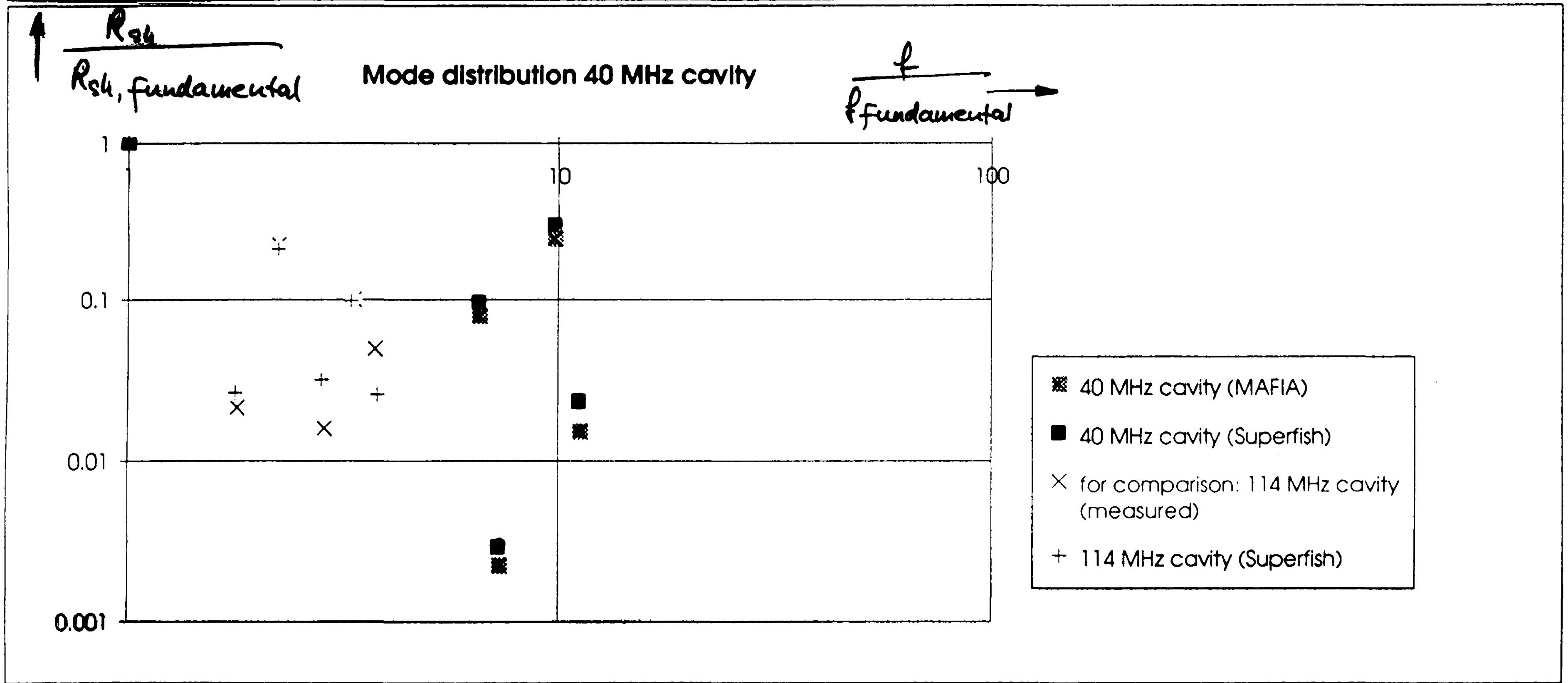
f/MHz	Rsh/Ohm	Q	R/Q		
40.48	863900	26337	32.80	1	1
266.00	83025	43170	1.92	6.57	0.0961
295.00	2480	52423	0.05	7.29	0.0029
397.05	260415	21623	12.04	9.81	0.3014
453.11	19840	51600	0.38	11.19	0.0230

for comparison: 114 MHz cavity (measured)

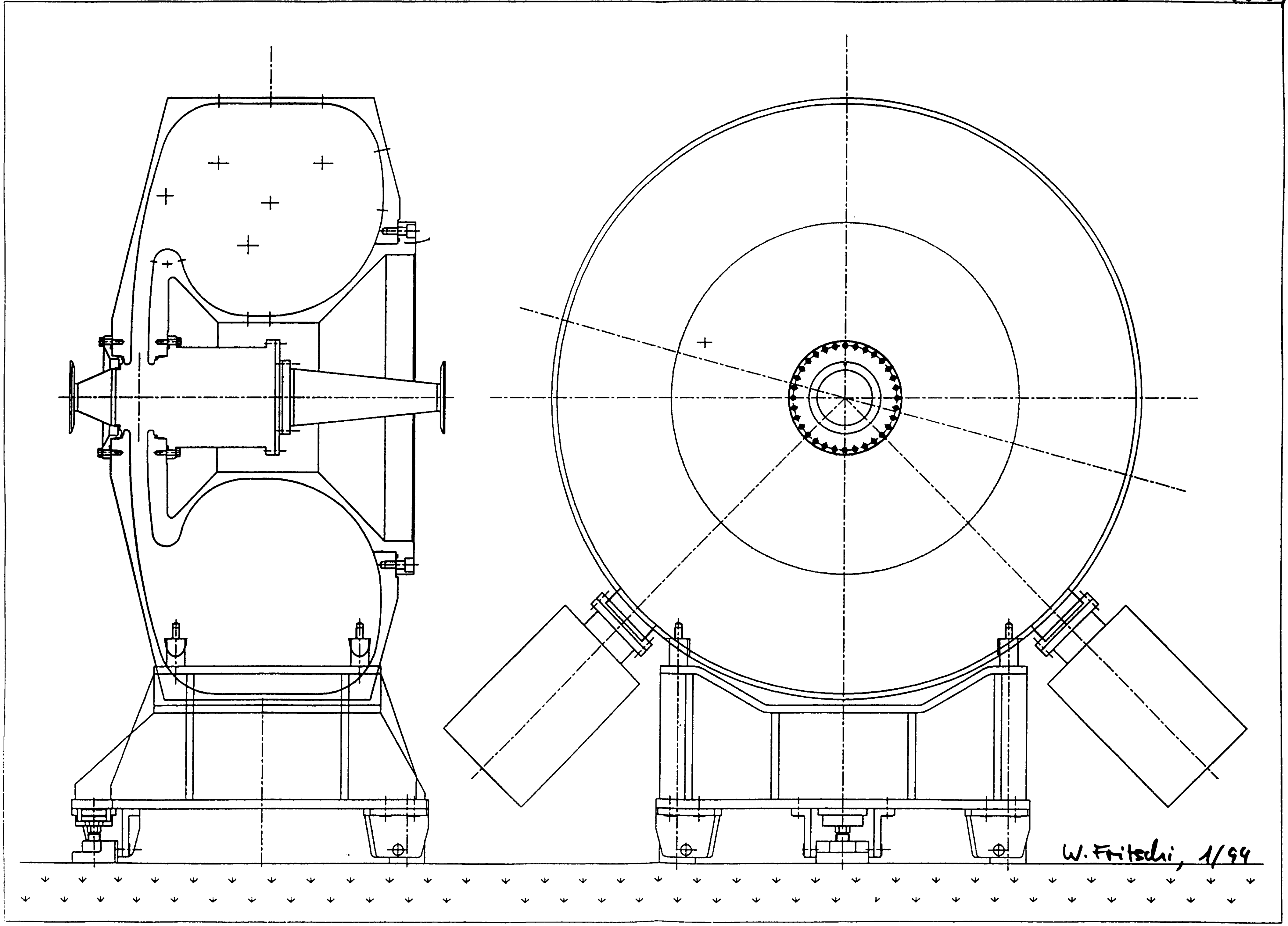
f/MHz	[illegible]	Q	R/Q		
[illegible]	[illegible]	55556	180.00	1	1
[illegible]	[illegible]	47000	4.50	1.80	0.0211
[illegible]	[illegible]	50000	45.00	2.25	0.2250
[illegible]	[illegible]	45000	3.50	2.88	0.0157
[illegible]	[illegible]	80000	12.50	3.38	0.1000
[illegible]	[illegible]	70000	7.00	3.78	0.0490

114 MHz cavity (Superfish)

f/MHz	Rsh/Ohm	Q	R/Q		
115.00	12250000	70000	175.00	1	1
204.80	320000	64000	5.00	1.78	0.0261
258.20	2590000	70000	37.00	2.25	0.2114
325.20	384000	64000	6.00	2.83	0.0313
382.00	1210000	110000	11.00	3.32	0.0988
430.00	265000	85000	3.00	3.82	0.0255

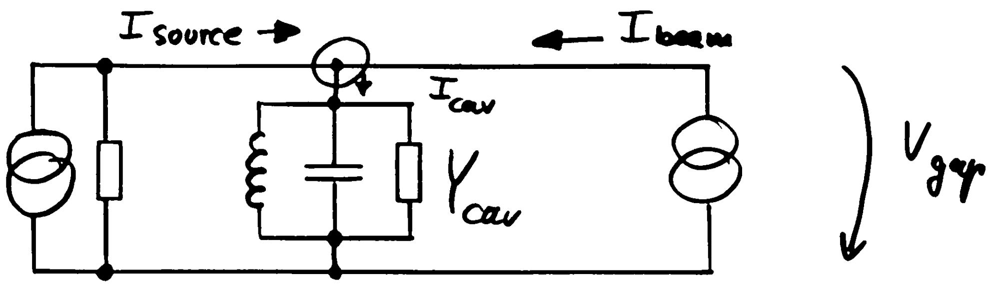


EJ 21/2/94



Fast tuning

PS, protons, 26 GeV: $\quad 84 \cdot f_{rev} = 40.055\ \text{MHz}$



$$I_{cav} = I_{source} + I_{beam} = Y_{cav} \cdot V_{gap} = \left(\frac{1}{R_{sh}} + j \frac{2\Delta}{(R/Q)} \right) \cdot V_{gap}$$

1) pure bunching, no acceleration
requires stationary bucket, phase angle 180°
⇒ I_{beam} purely imaginary

2) matching the source:
⇒ I_{source} purely real

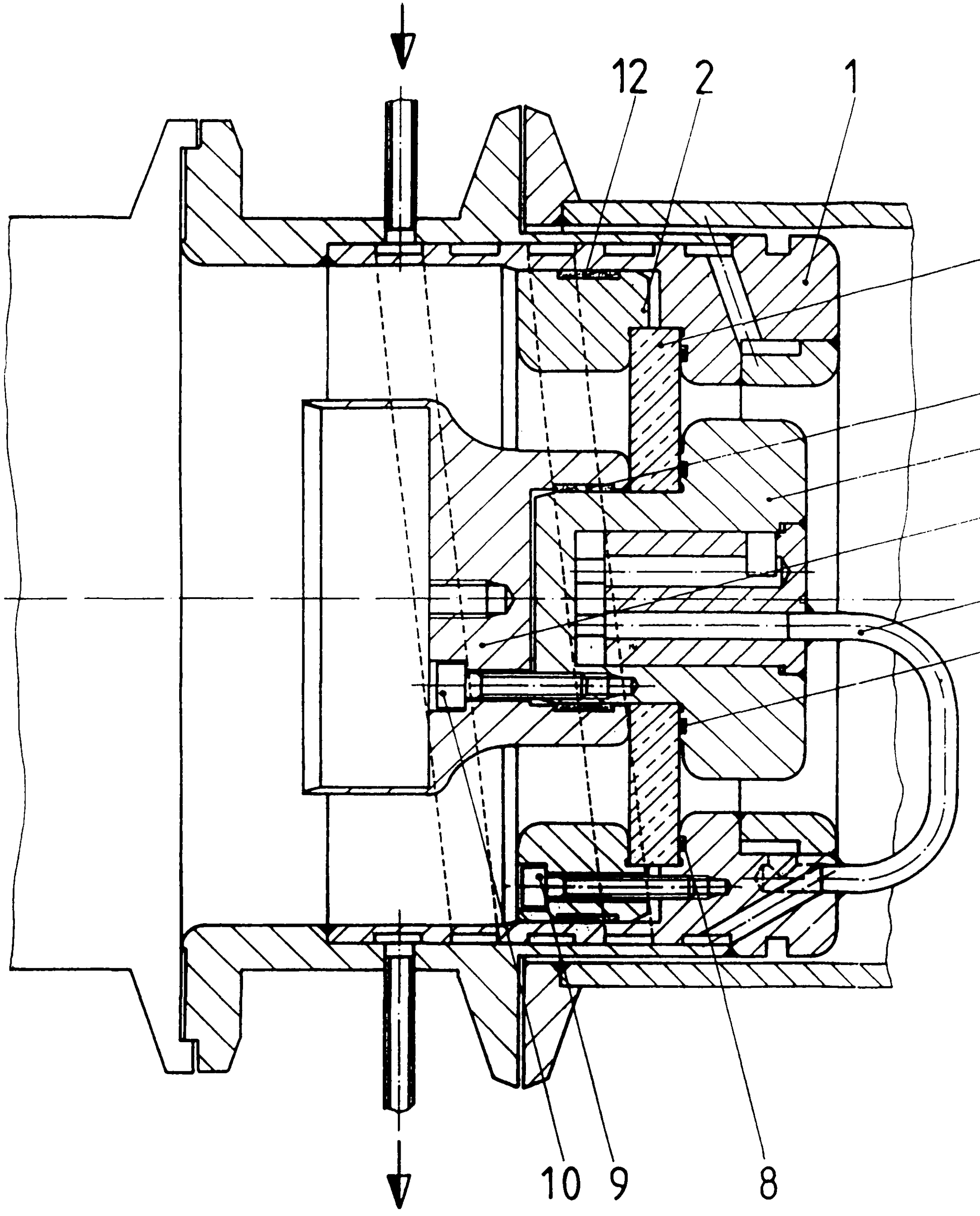
$$I_{source} = \frac{V_{gap}}{R_{sh}} \quad ; \quad I_{beam} = j \frac{V_{gap}\, 2\Delta}{R/Q}$$

$$\boxed{\Delta = \frac{|I_{beam}|\,(R/Q)}{2\, V_{gap}}}$$

for $I_{beam} = 2\,A$, $(R/Q) = 30\,\Omega$:

at 3 kV: $\Delta = 0.01$ tune cavity to 39.65 MHz
at 300 kV: $\Delta = 1E{-}4$ 40.05 MHz

1% fast tuning range!



QUANT.	DESCRIPTION	POS.	MATIERE	OBSERVATIONS
1	Contact à lamelles	12	Cu	Multi - Contact type: LA
1	Contact à lamelles	11	Cu	Multi-Contact type: LA
8	Vis tête cyl. 6pc. M6x25	10	Ac. Inox	SCEM: 47.62.71.260.7
20	Vis tête cyl. 6p.c. M5x30	9	Ac. Inox	SCEM: 47.62.71.211.6
1	Joint ϕ103/107	8	AL.	HELICOFLEX Type: HNV 100
1	Joint ϕ53/57	7	AL.	HELICOFLEX Type: HNV 100
2	Loop for RF Window	6	Ac. Inox	PS.2C.15.531.4
1	Ceramic discs	5	Al_2O_3	PS.2C.15.530.4
1	Center Conductor	4	Ac. Inox	PS.2C.15.535.3
1	Inner Conductor	3	Cuivre	PS.2C.15.533.3
1	Retaining ring	2	Ac. Inox	PS.2C.15.534.3
1	Outer shell	1	Ac. Inox	PS.2C.15.537.2

ENSEMBLE / ASSEMBLY: PS. LEP 114 MHz RF Window.
S. ENS./S. ASSY.

RF Window

Version II

ECHELLE SCALE		NOM	DATE
1:1	DESSINE	BTB . MJ	28.10.91.
	CONTROLE		
	VU		
	REMPLACE		

ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
GENEVE

PS 2C 15 532 3 — INDICE

INDICE	DATE	NOM	ZONE	MODIFICATION

DESSIN, RUGOSITE, TOLERANCES SELON NORMES ISO
DRAWINGS, RUGOSITY, TOLERANCES ACCORDING TO ISO STANDARDS

TOLERANCES GENERALES: USINAGE GROSSIER / ROUGH MACHINING ±0.2 ±0.5 ±0.8 ±1.2 ±2 ±3; MECANO SOUDURE / WELDED STRUCTURE ±0.5 ±1 ±2 ±3 ±5 ±7