

RF System Design Considerations

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U.S. Department of Energy

USDOE Office of Science (SC)

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RF SYSTEM DESIGN CONSIDERATIONS

For

RHIC

M. Puglisi

(BNL, January 27, 1984)

RF SYSTEM DESIGN CONSIDERATIONS

2) - ENERGY STORAGE IN THE CAVITY

BECAUSE OF THE RADIAL CONSTRAINTS WE CONSIDER ONLY FORESHORTENED COAXIAL CAVITIES.

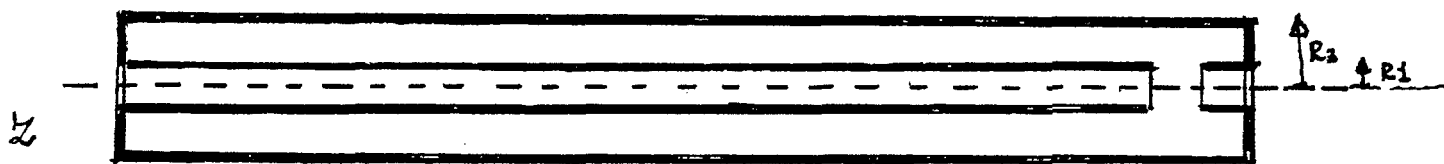
Let L AND Z_0 BE THE INDUCTANCE PER METER AND THE CHARACTERISTIC IMPEDANCE OF THE LINE. (HENRY/METER; OHMS).

WE CAN WRITE :

$$L = \frac{\mu_0}{2\pi} \ln \frac{R_2}{R_1} = \sqrt{\epsilon_0 \mu_0} \frac{1}{2\pi} \sqrt{\frac{\mu_0}{\epsilon_0}} \ln \frac{R_2}{R_1} = \frac{Z_0}{c} \quad (1)$$

WHERE $c = 2.9979 \times 10^8$ IS THE SPEED OF LIGHT

ASSUME THAT WE CONSIDER A SIMPLE $\lambda/4$ COAX. CAVITY



IF THE GAP CAPACITY IS NEGLIGIBLE WE HAVE :

$$I(z) = \frac{V_0}{Z_0} \cos \beta z \quad (2)$$

WHERE λ IS THE RESONANT WAVELENGTH.

AND: -

$$\left\{ \begin{array}{l} V_0 = \text{GAP VOLTAGE} \quad [\text{VOLT}] \\ \omega = \text{RADIAN FREQUENCY} \quad [\text{RAD/SEC}] \\ \beta = \frac{2\pi}{\lambda} = \frac{2\pi}{cT} = \frac{\omega}{c} \quad [\text{RAD/METER}] \end{array} \right.$$

AT RESONANCE THE STORED ENERGY IS AS FOLLOWS:

$$E_s = \frac{1}{2} L \int_0^{\lambda/4} I^2(z) dz = \frac{1}{2} \frac{Z_0}{c} \left(\frac{V_0}{Z_0} \right)^2 \int_0^{\lambda/4} \cos^2 \beta z dz$$

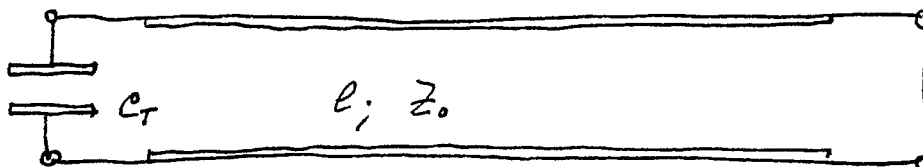
INTEGRATING WE OBTAIN:

$$E_s = \frac{1}{16} \frac{V_0^2}{Z_0 c} = \frac{1}{16} \frac{V_0^2}{c Z_0} \quad (3)$$

THE STORED ENERGY INCREASES WITH THE WAVELENGTH.

THE SITUATION DOES NOT CHANGE VERY MUCH IN THE CASE OF A COAX. CAVITY WITH A CAPACITIVE LOAD ON THE GAP.

ACCORDING TO THE "NORMAL" SCHEME AS SKETCHED IN THE FIGURE WE HAVE.



$$\left\{ \begin{array}{l} I(z) = -j \frac{V_0}{Z_0 \sin \beta l} \cos \beta z \\ C_T = \frac{1}{\omega Z_0 \tan \frac{\omega l}{c}} = \text{TUNING CAPACITOR} \end{array} \right. \quad (4)$$

THE STORED ENERGY IS NOW:

$$E_S = \frac{V_0}{2} \frac{1}{C Z_0 \sin^2 \beta l} \int_0^l \cos^2 \beta z \, dz$$

INTEGRATING WE OBTAIN:

$$E_S = \frac{1}{16} \frac{V_0^2}{C Z_0} \chi \frac{2\beta l + \sin 2\beta l}{\pi \sin \beta l} \quad (5)$$

THE PREVIOUS EQ. CAN BE WRITTEN AS FOLLOWS

$$E_S = E_s(l/4) * \chi$$

WHERE χ (THE LOADING FORM FACTOR) IS GIVEN IN THE FOLLOWING TABLE. (βl IN DEGREES).

FOR $\beta l = 50^\circ$ WE HAVE $\chi = 1.256$ AND

FOR $\beta l = 90^\circ$ $\chi = 1.0$ AS EXPECTED

EL. LENGTH (DEG). χ

0.1000E+02	0.7295E+01
0.1100E+02	0.6632E+01
0.1200E+02	0.6080E+01
0.1300E+02	0.5612E+01
0.1400E+02	0.5211E+01
0.1500E+02	0.4864E+01
0.1600E+02	0.4560E+01
0.1700E+02	0.4292E+01
0.1800E+02	0.4054E+01
0.1900E+02	0.3841E+01
0.2000E+02	0.3649E+01
0.2100E+02	0.3475E+01
0.2200E+02	0.3318E+01
0.2300E+02	0.3174E+01
0.2400E+02	0.3042E+01
0.2500E+02	0.2920E+01
0.2600E+02	0.2809E+01
0.2700E+02	0.2705E+01
0.2800E+02	0.2609E+01
0.2900E+02	0.2519E+01
0.3000E+02	0.2436E+01
0.3100E+02	0.2358E+01
0.3200E+02	0.2285E+01
0.3300E+02	0.2216E+01
0.3400E+02	0.2152E+01
0.3500E+02	0.2091E+01
0.3600E+02	0.2034E+01
0.3700E+02	0.1980E+01
0.3800E+02	0.1929E+01
0.3900E+02	0.1880E+01
0.4000E+02	0.1834E+01
0.4100E+02	0.1791E+01
0.4200E+02	0.1749E+01
0.4300E+02	0.1710E+01
0.4400E+02	0.1672E+01
0.4500E+02	0.1637E+01
0.4600E+02	0.1603E+01
0.4700E+02	0.1570E+01
0.4800E+02	0.1539E+01
0.4900E+02	0.1509E+01
0.5000E+02	0.1481E+01
0.5100E+02	0.1454E+01
0.5200E+02	0.1428E+01
0.5300E+02	0.1403E+01
0.5400E+02	0.1379E+01
0.5500E+02	0.1356E+01
0.5600E+02	0.1335E+01
0.5700E+02	0.1314E+01
0.5800E+02	0.1294E+01
0.5900E+02	0.1275E+01
0.6000E+02	0.1256E+01
0.6100E+02	0.1239E+01
0.6200E+02	0.1222E+01
0.6300E+02	0.1206E+01
0.6400E+02	0.1191E+01
0.6500E+02	0.1176E+01
0.6600E+02	0.1162E+01

EL. LENGTH (DEG). χ

0.6700E+02	0.1149E+01
0.6800E+02	0.1136E+01
0.6900E+02	0.1124E+01
0.7000E+02	0.1113E+01
0.7100E+02	0.1102E+01
0.7200E+02	0.1091E+01
0.7300E+02	0.1082E+01
0.7400E+02	0.1072E+01
0.7500E+02	0.1064E+01
0.7600E+02	0.1056E+01
0.7700E+02	0.1048E+01
0.7800E+02	0.1041E+01
0.7900E+02	0.1035E+01
0.8000E+02	0.1029E+01
0.8100E+02	0.1023E+01
0.8200E+02	0.1019E+01
0.8300E+02	0.1014E+01
0.8400E+02	0.1011E+01
0.8500E+02	0.1007E+01
0.8600E+02	0.1005E+01
0.8700E+02	0.1003E+01
0.8800E+02	0.1001E+01
0.8900E+02	0.1000E+01
0.9000E+02	0.1000E+01

```

OPEN(UNIT=7,STATUS='NEW')
P2=4.*ATAN(1.)
DO 10 I=10,90
F=P2/100.
ARG=F*I
F1=2*ARG
F2=SIN(F1)
F3=(SIN(ARG))*2.
FW=(F1+F2)/(P2*F3)
FF=FW*P2
A=I+0.00001
WRITE(7,20) A,FW,FF
FORMAT(5X,3E20.4)
CONTINUE
CLOSE(UNIT=7,STATUS='SAVE')
STOP
END

```

20

10

\$

 $\chi \equiv FW$

b) POWER LOSSES (GENERAL CONSIDERATIONS)..

FOR THE UNLOADED COAX. CAVITY ($l = \lambda/4$)

THE LOSSES ARE AS FOLLOWS.*

$$\begin{aligned}
 W &= \frac{1}{2} R_s \left(\frac{V_0}{Z_0} \right)^2 \left(\frac{1}{2\pi R_1} + \frac{1}{2\pi R_2} \right) \int_0^{\lambda/4} I^2(z) dz = \\
 &= \frac{1}{2} \frac{V_0^2}{Z_0} \frac{R_s}{Z_0} * \frac{1}{16\pi} \left(\frac{\lambda}{R_1} + \frac{\lambda}{R_2} \right) \quad (6)
 \end{aligned}$$

WHERE $R_s = \sqrt{\pi \omega \nu / \sigma}$ $[\Omega]$ (7)

IS THE WELL KNOWN SURFACE RESISTANCE OF THE CAVITY WALLS.

(CU: $R_s = 2.61 \times 10^{-7} \sqrt{\nu}$; AL: $R_s = 3.3 \times 10^{-7} \sqrt{\nu}$)

TAKING INTO ACCOUNT THAT THE SURFACE

RESISTANCE IS PROPORTIONAL TO $1/\sqrt{\nu}$

IT FOLLOWS THAT THE LOSSES INCREASE

WITH SQUARE ROOT OF THE WAVELENGTH.

* THE LOSSES ON THE SHORT CIRCUITED END ARE IGNORED FOR THIS PRELIMINARY EVALUATION..

c) - THE CAVITY INNER RADIUS R_1

WE CONSIDER THE POWER DISSIPATION AS APPEARS IN FORMULA (6) HAVING IN MIND THAT R_3 IS DICTATED BY THE GEOMETRY OF THE MACHINE WHILE λ AND V_0 ARE ALREADY SPECIFIED BY BEAM DYNAMICS CONSIDERATIONS. THIS MEANS THAT THE LOSSES COULD BE MINIMIZED BY CHOOSING THE RATIO $\alpha = R_3/R_1$ PROPERLY.

IN FACT (6) CAN BE REWRITTEN AS FOLLOWS:

$$W = \frac{1 + \alpha}{\ln^2 \alpha} * K \quad (8)$$

WHERE K IS A CONSTANT. ($Z_0 = 60 * \ln \alpha$)

THE FUNCTION $y = \frac{1 + \alpha}{\ln^2 \alpha}$ (9)

IS TABULATED BELOW:

α	y	α	y	α	y
1.1	231.17	1.9	7.039	3.	3.314
1.2	66.18	2.0	6.244	4.	2.601
1.3	33.41	2.1	5.631	5.	2.31
1.4	21.19	2.2	5.147	6.	2.18
1.5	15.20	2.3	4.756	7.	2.11
1.6	11.76	2.4	4.436	8.	2.08
1.7	9.58	2.5	4.16	9.	2.071339
1.8	8.10	2.6	3.94	10.	2.074729

AND IT IS SEEN THAT A VERY BROAD MINIMUM OCCURS AT $\alpha = 9.18632$ WHERE $\gamma = 2.071122$.

IN OUR CASE THE BORE TUBE RADIUS IS EQUAL TO 3 CM, CONSEQUENTLY, THE INNER ELECTRODE OF THE CAVITY CANNOT BE SMALLER THAN 4 CM.

THE OUTER RADIUS OF THE CAVITY SHOULD BE NOT LARGER THAN 21 CM AND WE HAVE

$\alpha = 21/4 = 5.25$, $\gamma = 2.2729$ WHICH IS NOT VERY FAR FROM THE MINIMUM.

MOREOVER WE COULD CHOOSE $\beta\alpha = 1.047$ (WHICH MEANS AN ELECTRICAL LENGTH OF THE CAVITY EQUAL TO 60°) AND THE CAVITY MECHANICAL LENGTH l WOULD BE:

$$l = \frac{49.965}{\nu} \quad (10)$$

WHERE THE FREQUENCY ν IS IN MEGAHERTZ. ONE FINDS FROM THE ABOVE FORMULA FOR $25 \leq \nu \leq 55$ MHz THAT $0.90 \leq l \leq 1.99$ METERS.

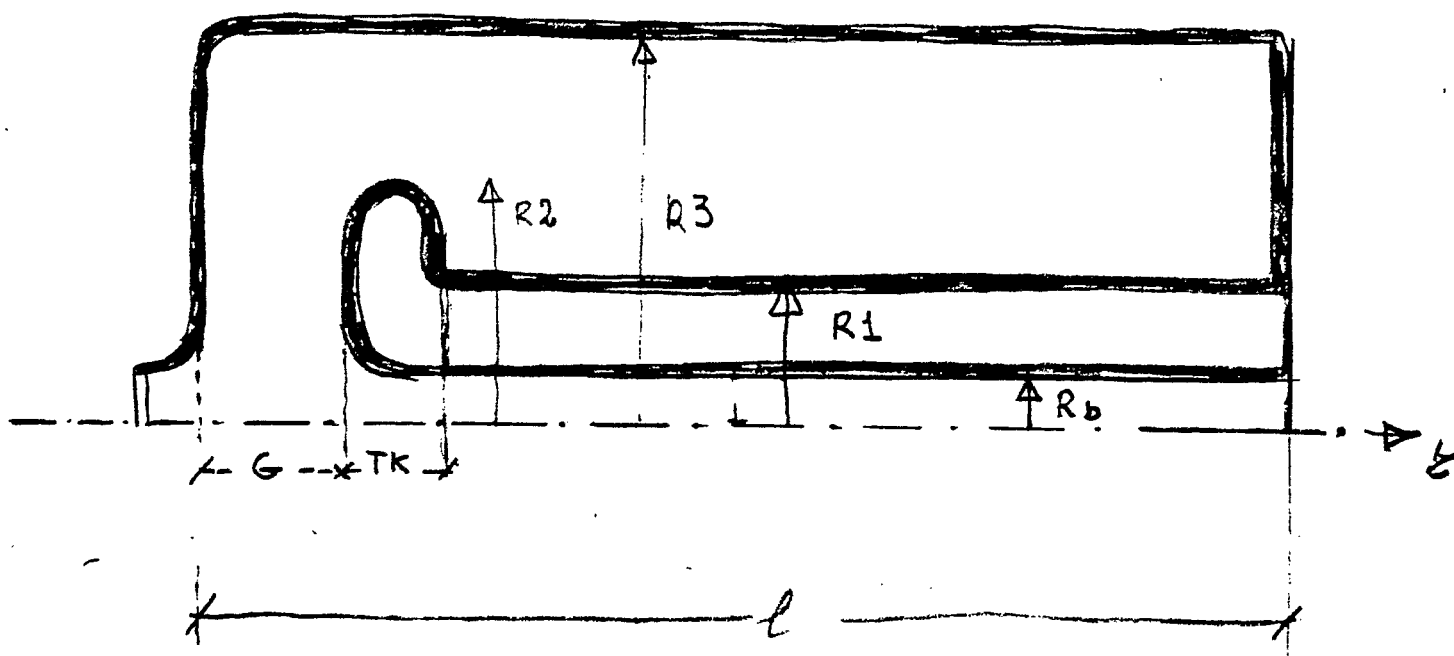
IF THE CAVITY LENGTH SHOULD BE NEAR TO ~ 2 METERS THEN R/l SHOULD BE, AT LEAST, EQUAL TO 5 CM; THE RATIO α BECOMES EQUAL TO 4.2

and $y = 2.52$ IS STILL AN ACCEPTABLE VALUE. ⁷

MANY OTHER FACTORS SHOULD BE TAKEN INTO ACCOUNT BEFORE DECIDING UPON THE FINAL SHAPE OF THE CAVITY BUT IT IS CLEAR FROM (9) THAT VALUES OF α SMALLER THAN 4 ARE NOT ADVISABLE.

d) - OPTIONS FOR THE ACC. CAVITIES -

THE BASIC SECTION OF THE ACC. CAVITY IS GIVEN IN FOLLOWING SKETCH:



WHERE, AS MENTIONED ABOVE, R_3 CANNOT BE LARGER THAN 21 cm and R_b CANNOT BE SMALLER THAN 3 cm.

d1) - WORKING FREQ 50 MHz . . HIGH CHARACT. IMPEDANCE.

ACCORDING TO THE PREVIOUS CALCULATIONS

WE MINIMIZE THE LOSSES BY REDUCING R_1 .

BECAUSE FOR $\nu = 50 \text{ MHz}$ $\lambda/4 = 1.5 \text{ METERS}$

(9)

THE INNER ELECTRODE SHOULD NOT BE LONGER THAN
 1.3 METER. ASSUMING $R_1 = 4$ THE INNER ELECTRODE
 CAN BE CANTILEVERED AT THE SHORTED END
 AND WE HAVE:

$$\left\{ \begin{array}{l} l = 1.30 \quad ; \quad \text{GAP} = 0.04 \\ R_3 = 0.21 \quad \quad \text{TK} = 0.02 \\ R_2 = 0.08 \\ R_1 = 0.04 \end{array} \right.$$

THE RESULTS OF A SUPERFISH ANALYSIS ARE
 GIVEN ON PAGES 10 - 11 - 12.

FOR THE S.F. VOLTAGE OF 100 KV THE CALCULATED POWER IS
 3.887 KW WHICH IMPLIES A SHUNT IMPEDANCE R_{sh}
 EQUAL TO:

$$R_{sh} = \frac{(100.000)^2}{2 \times 3.887 \text{ E}3} = 1.286 \text{ M}\Omega$$

FOR 200 KV, THAT IS STILL TOLERABLE WITH A
 4 CM GAP WE HAVE:

$$W = \frac{(200.000)^2}{2 \times R_{sh}} = 15.522 \text{ kW}$$

RUG HIGH Z0

*2 2 *21 1 0 1 1 *9 1.0000
*36 16 *37 1 SKIP

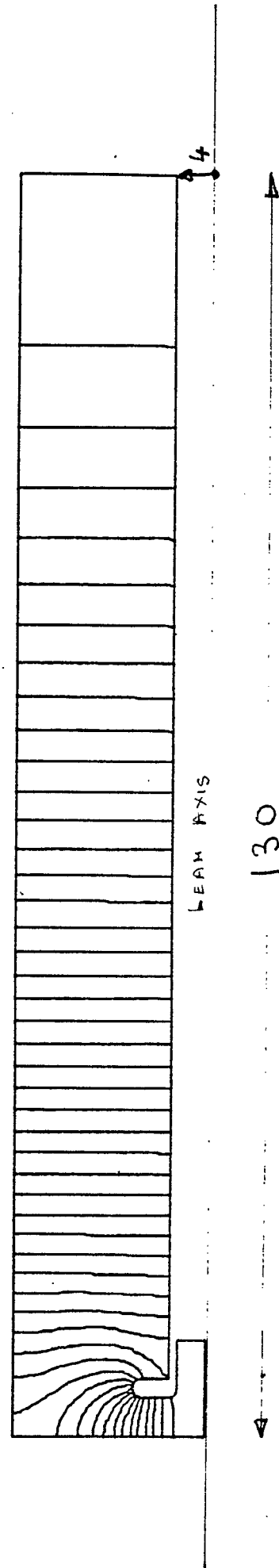
1	1	1	0	13	1
13	1	1	0	17	1
17	1	0	1	17	0
17	0	-1	0	13	0
13	0	-1	0	11	0
11	0	-1	0	9	10
9	10	0	1	9	17
9	17	1	1	13	17
13	17	0	-1	13	10
13	10	1	0	137	10
137	10	0	1	137	17
137	17	0	1	137	33
137	33	-1	0	13	33
13	33	-1	0	1	33
1	33	0	-1	1	17
1	17	0	-1	1	1

F = 50.037 Hz

1 1 0.0000 0.0000 0 1 REGION

1	1	0.0000	0.0000
13	1	6.0000	0.0000
17	1	10.0000	0.0000
17	0	10.0000	3.0000
13	0	6.0000	3.0000
11	0	5.0000	3.0000
10	0	4.5000	3.1340
9	9	4.1340	3.5000
9	10	4.0000	4.0000
9	17	4.0000	7.0000
10	10	4.1910	7.5878
11	10	4.6910	7.9511
12	10	5.3090	7.9511
13	10	5.8090	7.5878
13	17	6.0000	7.0000
13	10	6.0000	4.0000
137	10	130.0000	4.0000
137	17	130.0000	7.0000
137	33	130.0000	21.0000
13	33	6.0000	21.0000
1	33	0.0000	21.0000
1	17	0.0000	7.0000
1	1	0.0000	0.0000

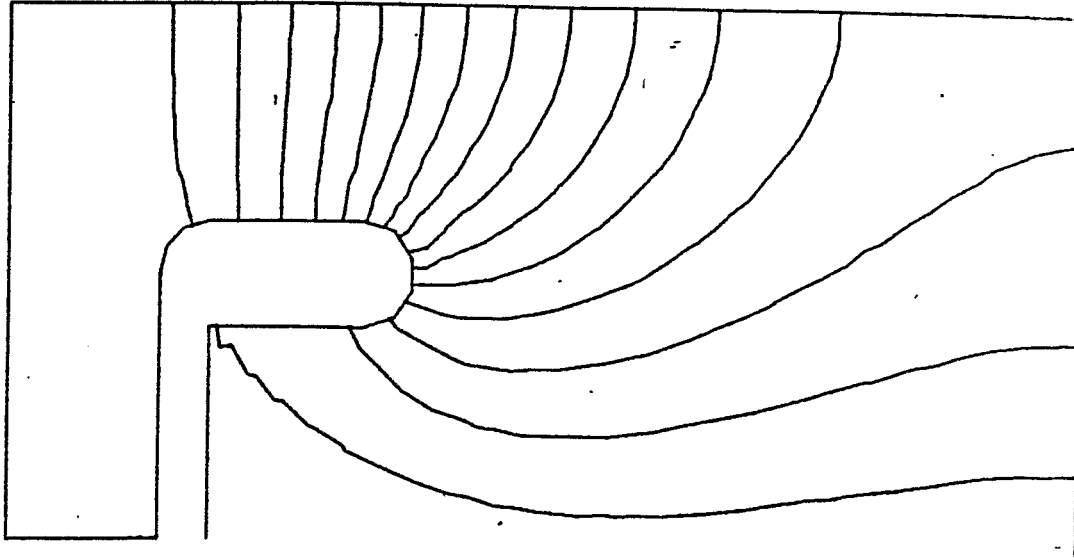
2 1 1.0 0.00 0 -1 REGION
137 33 130.0000 21.00 COUN



XRUG HIGH Z0

\$REG NREG=1,DX=0.5,XMAX=140.,YMAX=22.,
 XREG1=6.0,YREG1=7.0,NPOINT=12\$
 \$PO X=0.0,Y=0.0\$
 \$PO X=10.0,Y=0.0\$
 \$PO X=10.0,Y=3.0\$
 \$PO X=5.0,Y=3.0\$
 \$PO NT=2,X0=5.0,Y0=4.0,R=1.0,THETA=-180.0\$
 \$PO X=4.0,Y=7.0\$
 \$PO NT=2,X0=5.0,Y0=7.0,R=1.0,THETA=0.0\$
 \$PO X=6.0,Y=4.0\$
 \$PO X=130.,Y=4.0\$
 \$PO X=130.,Y=21.0\$
 \$PO X=0.0,Y=21.0\$
 \$PO X=0.0,Y=0.0\$

\$



```

F
00100  XRUG HIGH Z0
00200  $REG NREG=1,DX=0.5,XMAX=140.,YMAX=22.,
00300  XREG1=6.0,YREG1=7.0,NPOINT=12$
00400  $PO X=0.0,Y=0.0$
00500  $PO X=10.0,Y=0.0$
00600  $PO X=10.0,Y=3.0$
00700  $PO X=5.0,Y=3.0$
00800  $PO NT=2,X0=5.0,Y0=4.0,R=1.0,THETA=-180.0$
00900  $PO X=4.0,Y=7.0$
01000  $PO NT=2,X0=5.0,Y0=7.0,R=1.0,THETA=0.0$
01100  $PO X=6.0,Y=4.0$
01200  $PO X=130.,Y=4.0$
01300  $PO X=130.,Y=21.0$
01400  $PO X=0.0,Y=21.0$
01500  $PO X=0.0,Y=0.0$
*EBT

```

$$F = 50.057 \text{ MHz}$$

SUPERFISH OUTPUT SUMMARY 15:21:41 17-JAN-8

PROBLEM NAME =RUG HIGH Z0

CAVITY LENGTH = 20.000 CM CAVITY DIAMETER = 42.000 CM

D.T. GAP = 20.000 CM STEM RADIUS = 1.000 CM

FREQUENCY (STARTING VALUE = 50.057) = 50.057 MHZ

BETA = 0.0000 PROTON ENERGY = 0.000 MEV

NORMALIZATION FACTOR (E0=1 MV/M) ASCALE = 3015.0

STORED ENERGY (MESH PROBLEM ONLY) = 0.1380 JOULES

POWER DISSIPATION (MESH PROBLEM ONLY) = 3887.29 WATTS

T, TP, TPP, S, SP, SPP = 0.000 0.000 0.000 0.000 0.000 0.000

Q = 11165 SHUNT IMPEDANCE = 25.72 MOHM/M

PRODUCT Z*T**2 ZTT = 0.00 MOHM/M

MAGNETIC FIELD ON OUTER WALL = 800 AMP/M

MAXIMUM ELECTRIC FIELD ON BOUNDARY = 4.800 MV/M

ISEG	ZBEG (CM)	RBEG (CM)	ZEND (CM)	REND (CM)	EMAX (MV/M)	POWER (W)		D-FREQ (DELZ)	D-FREQ (DELR)
3	10.000	0.000	10.000	3.000	0.0436	1.48E-06	WALL	0.0000	0.0000
4	10.000	3.000	6.000	3.000	0.2107	1.25E-04	WALL	0.0000	0.0001
5	6.000	3.000	5.000	3.000	0.7743	5.74E-04	WALL	0.0000	0.0006
6	5.000	3.000	4.000	4.000	3.2963	1.61E-02	WALL	0.0151	0.0090
7	4.000	4.000	4.000	7.000	3.8047	3.99E-01	WALL	0.0888	0.0000
8	4.000	7.000	6.000	7.000	4.8079	2.84E+00	WALL	0.0000	0.1387
9	6.000	7.000	6.000	4.000	2.0499	7.62E+00	WALL	0.0095	0.0000
10	6.000	4.000	130.000	4.000	1.4356	3.02E+03	WALL	0.0000	-0.1434
11	130.000	4.000	130.000	7.000	0.6479	9.14E+01	WALL	-0.0097	0.0000
12	130.000	7.000	130.000	21.000	0.2530	1.79E+02	WALL	-0.0219	0.0000
13	130.000	21.000	6.000	21.000	0.2816	5.75E+02	WALL	0.0000	-0.0248
14	6.000	21.000	0.000	21.000	0.1968	3.13E+00	WALL	0.0000	0.0006
15	0.000	21.000	0.000	7.000	1.9148	6.68E+00	WALL	0.0491	0.0000
16	0.000	7.000	0.000	0.000	2.3523	3.54E-01	WALL	0.0633	0.0000

DUMP NUMBER 1 HAS BEEN WRITTEN.
\$

THE STORED ENERGY E_s , FROM SF, IS EQUAL TO 0.138 JOULES - (FOR 200 KV E_s BECOMES EQUAL TO 0.552 JOULES)

FROM EQ (5) WE OBTAIN: (AS A CHECK) -

$$E_s = \frac{1}{16} * \frac{(2E_s)^2}{2.9979E8 * 99.49} * 6 * \chi = 0.5029\chi$$

IN THIS CASE THE ELECTRICAL LENGTH IS EQUAL TO $1.30 - (0.04 + 0.02) = 1.24$ m.

$$\beta l = 2\pi \frac{l}{\lambda} = 74.4^\circ ; \chi = 1.07 . \text{ CONSEQUENTLY}$$

$$E_s = 0.5029 * 1.07 = 0.538$$

IN A VERY GOOD AGREEMENT WITH THE S.F. CALCULATIONS.

WE COULD REASONABLY ASSUME TO WASTE 20 KW PER CAVITY ; THE ACTUAL SHUNT IMPEDANCE

BECOMES :

$$R_{sh} = \frac{(2E_s)^2}{2 * 2E4} = 1 \text{ M}\Omega$$

d 2) WORKING FREQ. 50 MHz. LOW CHARACT. IMPEDANCE.

INCREASING THE INNER RADIUS R_i TO 6 cm

WE OBTAIN THE FOLLOWING CAVITY.

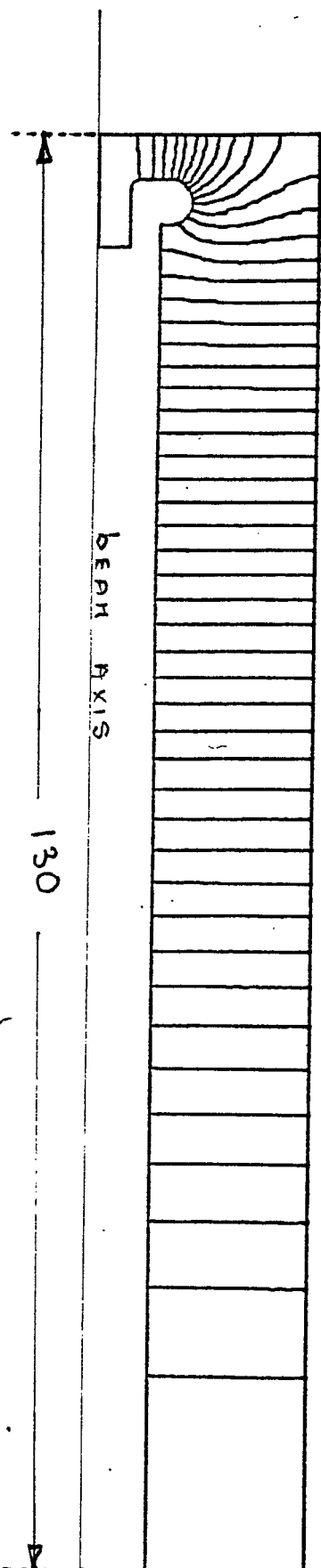
$$\left\{ \begin{array}{l} \beta = 1.30 \quad \text{GAP} = 0.04 \quad \text{TK} = 0.04 \\ R_3 = 0.21 \\ R_2 = 0.09 \end{array} \right.$$

THE RESONANT FREQUENCY IS 50.957 KHz AND FOR 200 ~~MHz~~ $\sqrt{\text{V}}$ THE REQUESTED POWER IS EQUAL TO 18.860 KW - (THE SHUNT IMPEDANCE IS NOW EQUAL TO 1.060 $\text{K}\Omega$) - THE STORED ENERGY IS INCREASED TO 0.692 JOULES.

ON PAGES 15-16-17-18 THE MOST IMPORTANT S.F. RESULTS ARE GIVEN -

ON PAGE 17 THE AXIAL GRADIENT IS LISTED BECAUSE THE REPRESENTATION USED BY S.F. (IN CYLINDRICAL COORDINATES) COULD BE MISUNDERSTOOD.

WE SEE THAT THIS CAVITY DOES NOT SHOW ANY PECULIAR MERIT IN FRONT OF THE PREVIOUS ONE - WE PAY THE PRICE OF INCREASING THE INNER TUBE RADIUS.



RUG HIGH Z0

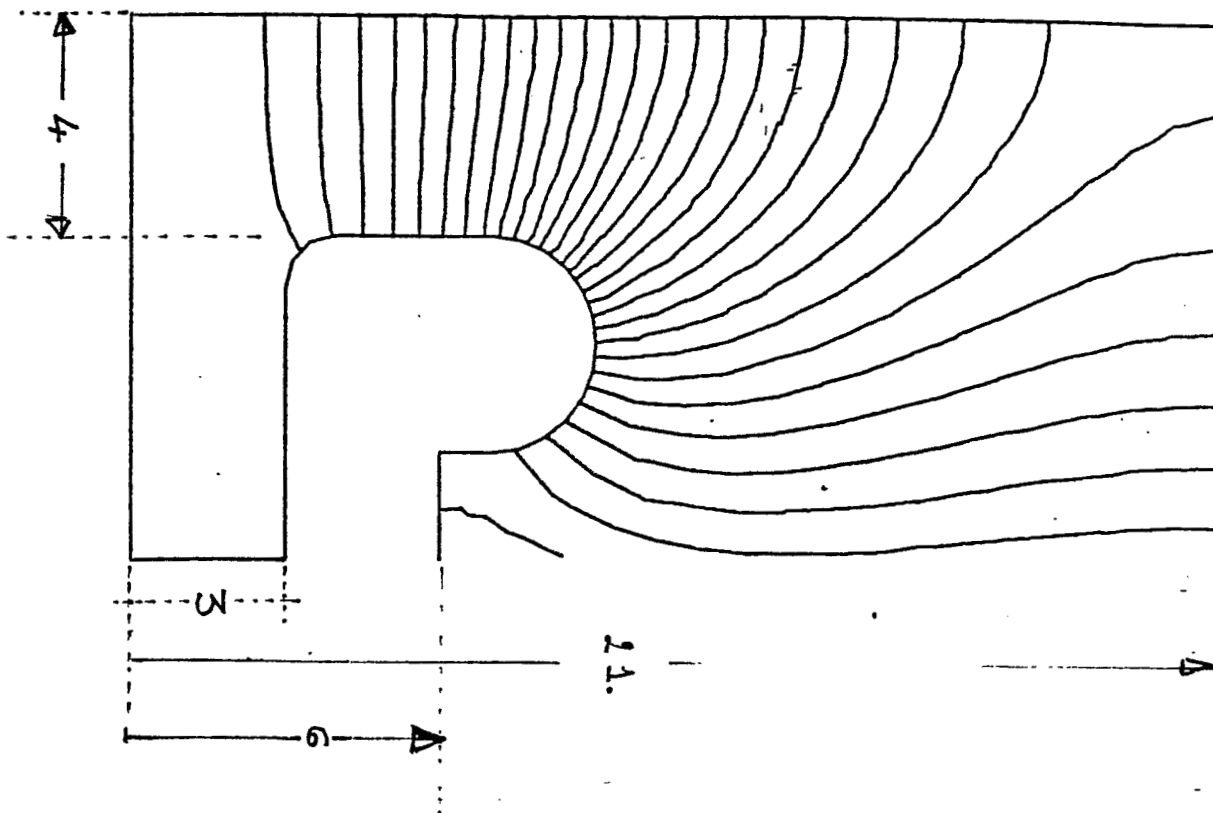
*2 2 *21 1 0 1 1 *9 1.0000

*35 16 *37 1 SKIP

1	1	1	0	17	1
17	1	1	0	19	1
19	1	0	1	19	7
19	7	0	1	17	8
17	8	-1	0	11	8
11	8	-1	0	9	10
9	10	0	1	9	17
9	17	0	1	17	17
17	17	0	-1	17	14
17	14	1	0	139	15
139	15	0	1	139	19
139	19	0	1	139	34
139	34	-1	0	17	34
17	34	-1	0	1	34
1	34	0	-1	1	19
1	19	0	-1	1	1
1	1	0.0000	0.0000	0	1 REGION
1	1	0.0000	0.0000		
17	1	0.0000	0.0000		
19	1	10.0000	0.0000		
19	7	10.0000	3.0000		
19	8	9.3333	3.0000		
17	8	0.0000	3.0000		
11	8	5.0000	3.0000		
10	8	4.5000	3.1340		
9	9	4.1340	3.5000		
9	10	4.0000	4.0000		
9	17	4.0000	7.0000		
9	18	4.0681	7.5176		
9	19	4.2679	8.0000		
10	19	4.5858	8.4142		
11	20	5.0000	8.7321		
12	20	5.4824	8.9319		
13	20	6.0000	9.0000		
14	20	6.5176	8.9319		
15	20	7.0000	8.7321		
16	20	7.4142	8.4142		
16	19	7.7321	8.0000		
17	18	7.9319	7.5176		
17	17	8.0000	7.0000		
17	14	8.0000	6.0000		
139	14	129.0000	6.0000		
139	15	130.0000	6.0000		
139	19	130.0000	8.0000		
139	34	130.0000	21.0000		
17	34	8.0000	21.0000		
1	34	0.0000	21.0000		
1	19	0.0000	8.0000		
1	1	0.0000	0.0000		COUN
2	1	1.00	0.00	0	-1 REGION
139	34	130.0000	21.0000		COUN

\$

F = 50.957 MHz



EDIT/SOS RUG.;1

Input assumed unsequenced

F = 50.957 KHz

Edit: ..DRA1:[VACUUMØ]RUG;1

*P

00100

XRUG HIGH ZØ

00200

\$REG NREG=1,DX=0.5,XMAX=140.,YMAX=22.,

00300

XREG1=8.0,YREG1=8.0,NPOINT=12\$

00400

\$PO X=0.0,Y=0.0\$

00500

\$PO X=10.0,Y=0.0\$

00600

\$PO X=10.0,Y=3.0\$

00700

\$PO X=5.,Y=3.0\$

00800

\$PO NT=2,XØ=5.,YØ=4.0,R=1.0,THETA=-180.0\$

00900

\$PO X=4.,Y=7.0\$

01000

\$PO NT=2,XØ=6.,YØ=7.,R=2.0,THETA=0.0\$

01100

\$PO X=8.0,Y=6.0\$

01200

\$PO X=130.,Y=6.0\$

01300

\$PO X=130.,Y=21.0\$

01400

\$PO X=0.0,Y=21.0\$

01500

\$PO X=0.0,Y=0.0\$

*

ELECTRIC FIELD ALONG THE L = 1 R = 0.000

F = 50.957 MHz

K	Z(CM)	EZ(V/M)
1	0.0000	
2	0.5000	2.1864E+06
3	1.0000	2.1672E+06
4	1.5000	2.1264E+06
5	2.0000	2.0600E+06
6	2.5000	1.9624E+06
7	3.0000	1.8281E+06
8	3.5000	1.6539E+06
9	4.0000	1.4425E+06
10	4.5000	1.2051E+06
11	5.0000	9.6101E+05
12	5.5000	7.3207E+05
13	6.0000	5.3509E+05
14	6.5000	3.7762E+05
15	7.0000	2.5859E+05
16	7.5000	1.7183E+05
17	8.0000	1.0926E+05
18	9.0000	6.6354E+04
19	10.0000	4.4990E+04

```

$BUG HIGH Z0
$REG NREG=1,DX=0.5,XMAX=140.,
XREG1=0.0,YREG1=0.0,NPOINT=12
$PO X=0.0,Y=0.0$
$PO X=10.0,Y=0.0$
$PO X=10.0,Y=3.0$
$PO X=5.0,Y=3.0$
$PO NT=2,X0=5.0,Y0=4.0,R=1.0,T
$PO X=4.0,Y=7.0$
$PO NT=2,X0=6.0,Y0=7.0,R=2.0,TH
$PO X=8.0,Y=6.0$
$PO X=130.0,Y=6.0$
$PO X=130.0,Y=21.0$
$PO X=0.0,Y=21.0$
$PO X=0.0,Y=0.0$

```

\$

INTEGRAL ALONG THE L = 1 R = 0.000

INTEGRAL E(Z)*DZ = 1.0000E+05 (VOLTS)

STORED ENERGY = 1.732E-01 (JOULES)

SUPERFISH OUTPUT SUMMARY

21:18:20 19-JAN-8

PROBLEM NAME =RUG HIGH Z0

CAVITY LENGTH = 20.000 CM CAVITY DIAMETER = 42.000 CM

D.T. GAP = 20.000 CM STEM RADIUS = 1.000 CM

FREQUENCY (STARTING VALUE = 48.000) = 50.957 MHZ

BETA = 0.0000 PROTON ENERGY = 0.000 MEV

NORMALIZATION FACTOR (E0=1 MV/M) ASCALE = 3921.1

STORED ENERGY (MESH PROBLEM ONLY) = 0.1732 JOULES

POWER DISSIPATION (MESH PROBLEM ONLY) = 4715.01 WATTS

T, TP, TPP, S, SP, SPP = 0.000 0.000 0.000 0.000 0.000 0.000

Q = 11762 SHUNT IMPEDANCE = .21.21 MOHM/M

PRODUCT Z*T**2 ZTT = 0.00 MOHM/M

MAGNETIC FIELD ON OUTER WALL = 1040 AMP/M

MAXIMUM ELECTRIC FIELD ON BOUNDARY = 4.165 MV/M

ISEG	ZBEG (CM)	RBEG (CM)	ZEND (CM)	REND (CM)	EMAX (MV/M)	POWER (W)		D-FREQ (DELZ)	D-FREQ (DELR)
3	10.000	0.000	10.000	3.000	0.0450	1.64E-06	WALL	0.0000	0.0000
4	10.000	3.000	8.000	3.000	0.0412	5.82E-06	WALL	0.0000	0.0000
5	8.000	3.000	5.000	3.000	0.7597	6.97E-04	WALL	0.0000	0.0005
6	5.000	3.000	4.000	4.000	3.2160	1.62E-02	WALL	0.0117	0.0070
7	4.000	4.000	4.000	7.000	3.2477	3.78E-01	WALL	0.0587	0.0000
8	4.000	7.000	8.000	7.000	4.1654	9.27E+00	WALL	0.0000	0.1412
9	8.000	7.000	8.000	6.000	0.7625	3.44E+00	WALL	0.0003	0.0000
10	8.000	6.000	130.000	6.000	1.2562	3.37E+03	WALL	0.0000	-0.1234
11	130.000	6.000	130.000	9.000	0.3942	8.02E+01	WALL	-0.0074	0.0000
12	130.000	8.000	130.000	21.000	0.2076	2.69E+02	WALL	-0.0266	0.0000
13	130.000	21.000	8.000	21.000	0.3713	9.63E+02	WALL	0.0000	-0.0320
14	8.000	21.000	0.000	21.000	0.3177	6.13E+00	WALL	0.0000	0.0024
15	0.000	21.000	0.000	8.000	1.8434	8.41E+00	WALL	0.0422	0.0000
16	0.000	8.000	0.000	0.000	2.3629	6.25E-01	WALL	0.0661	0.0000

DUMP NUMBER 1 HAS BEEN WRITTEN.

\$

d 3) - 27 MHz RESONANT CAVITY.

IN THIS CASE THE WAVELENGTH IS EQUAL TO 11.1M.
AND AN INNER RADIUS OF 6 CM IS ALMOST
MANDATORY FOR A REASONABLE STIFFNESS
OF THE INNER ELECTRODE.

ACCORDINGLY WITH EQ (5) and (6)
DOWN THE STORED ENERGY AND THE POWER
WASTED SHOULD INCREASE.

THE SIZES COULD BE AS FOLLOWS:

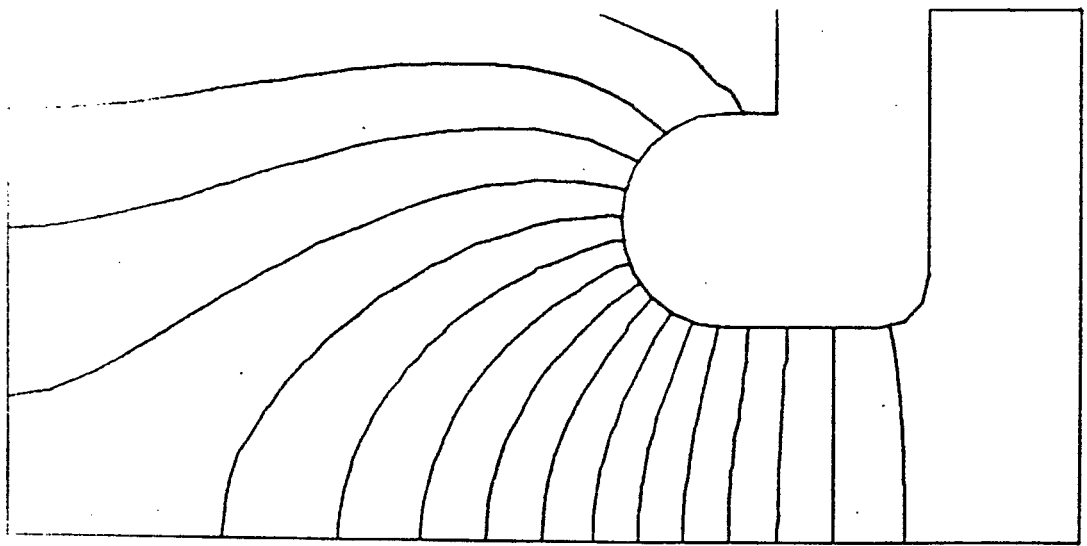
$$\left\{ \begin{array}{l} l = 2.50 \\ R_3 = 21 \\ R_2 = 0.09 \\ R_1 = 0.06 \end{array} \right. \quad \text{GAP} = 0.04 \quad \text{TK} = 0.04$$

ON PAGES 20 - 21 - 22 ARE SHOWN THE MOST
SIGNIFICANT S.F. RESULTS.

XRUG HIGH Z0

```
$REG NREG=1,DX=0.5,XMAX=250.,YMAX=22.,  
XREG1=8.0,YREG1=8.0,NPOINT=12$  
$PO X=0.0,Y=0.0$  
$PO X=10.0,Y=0.0$  
$PO X=10.0,Y=3.0$  
$PO X=5.,Y=3.0$  
$PO NT=2,X0=5.,Y0=4.0,R=1.0,THETA=-180.0$  
$PO X=4.,Y=7.0$  
$PO NT=2,X0=6.,Y0=7.,R=2.0,THETA=0.0$  
$PO X=8.0,Y=6.0$  
$PO X=250.0,Y=6.0$  
$PO X=250.0,Y=21.0$  
$PO X=0.0,Y=21.0$  
$PO X=0.0,Y=0.0$
```

28.082 MHz



TAPE 73. DAT 1

F = 28.083 MHz

RUG HIGH Z0

*2 2 *21 1 0 1 1 *9 1.0000

*36 16 *37 1 SKIP

1	1	1	0	17	1
17	1	1	0	19	1
19	1	0	1	19	7
19	7	0	1	17	8
17	8	-1	0	11	8
11	8	-1	0	9	10
9	10	0	1	9	17
9	17	0	1	17	17
17	17	0	-1	17	14
17	14	1	0	259	15
259	15	0	1	259	19
259	19	0	1	259	34
259	34	-1	0	17	34
17	34	-1	0	1	34
1	34	0	-1	1	19
1	19	0	-1	1	1

1 1 0.0000 0.0000 0 1 REGION

1	1	0.0000	0.0000
1	1	0.0000	0.0000
17	1	8.0000	0.0000
19	1	10.0000	0.0000
19	7	10.0000	3.0000
19	8	9.3333	3.0000
17	8	8.0000	3.0000
11	8	5.0000	3.0000
10	8	4.5000	3.1340
9	9	4.1340	3.5000
9	10	4.0000	4.0000
9	17	4.0000	7.0000
9	18	4.0681	7.5176
9	19	4.2679	8.0000
10	19	4.5858	8.4142
11	20	5.0000	8.7321
12	20	5.4824	8.9319
13	20	6.0000	9.0000
14	20	6.5176	8.9319
15	20	7.0000	8.7321
16	20	7.4142	8.4142
16	19	7.7321	8.0000
17	18	7.9319	7.5176
17	17	8.0000	7.0000
17	14	8.0000	6.0000
259	14	249.0037	6.0000
259	15	250.0000	6.0000
259	19	250.0000	8.0000
259	34	250.0000	21.0000
17	34	8.0000	21.0000
1	34	0.0000	21.0000
1	19	0.0000	8.0000
1	1	0.0000	0.0000

COUN --

2 1 1.0 0.0 0 -1 REGION
259 15 250.0 6.0 COUN

\$

\$

PROBLEM NAME =RUG HIGH Z0

CAVITY LENGTH = 20.000 CM CAVITY DIAMETER = 42.000 CM
 D.T. GAP = 20.000 CM STEM RADIUS = 1.000 CM
 FREQUENCY (STARTING VALUE = 27.000) = 28.033 MHZ
 BETA = 0.0000 PROTON ENERGY = 0.000 MEV
 NORMALIZATION FACTOR (E0=1 MV/M) RSCALE = 13519.4
 STORED ENERGY (MESH PROBLEM ONLY) = 0.3069 JOULES
 POWER DISSIPATION (MESH PROBLEM ONLY) = 5974.29 WATTS
 T,TP,TPP,S,SP,SPP = 0.000 0.000 0.000 0.000 0.000 0.000
 Q = 9048 SHUNT IMPEDANCE = 16.74 MOHM/M
 PRODUCT Z*T**2 ZTT = 0.00 MOHM/M
 MAGNETIC FIELD ON OUTER WALL = 1025 AMP/M
 MAXIMUM ELECTRIC FIELD ON BOUNDARY = 4.179 MV/M

ISEG	ZBEG (CM)	RBEG (CM)	ZEND (CM)	REND (CM)	EMAX (MV/M)	POWER (W)		D-FREQ (DELZ)	D-FREQ (DELR)
3	10.000	0.000	10.000	3.000	0.0450	3.69E-07	WALL	0.0000	0.0000
4	10.000	3.000	8.000	3.000	0.0412	1.31E-06	WALL	0.0000	0.0000
5	8.000	3.000	5.000	3.000	0.7598	1.56E-04	WALL	0.0000	0.0002
6	5.000	3.000	4.000	4.000	3.2169	3.63E-03	WALL	0.0036	0.0022
7	4.000	4.000	4.000	7.000	3.2517	8.49E-02	WALL	0.0183	0.0000
8	4.000	7.000	8.000	7.000	4.1790	2.09E+00	WALL	0.0000	0.0444
9	8.000	7.000	8.000	6.000	0.7685	7.77E-01	WALL	0.0002	0.0000
10	8.000	6.000	250.000	6.000	1.3087	4.45E+03	WALL	0.0000	-0.0387
11	250.000	6.000	250.000	8.000	0.7104	5.77E+01	WALL	-0.0018	0.0000
12	250.000	8.000	250.000	21.000	0.3745	1.94E+02	WALL	-0.0078	0.0000
13	250.000	21.000	8.000	21.000	0.3823	1.27E+03	WALL	0.0000	-0.0100
14	8.000	21.000	0.000	21.000	0.3225	1.38E+00	WALL	0.0000	0.0009
15	0.000	21.000	0.000	8.000	1.8446	1.89E+00	WALL	0.0133	0.0000
16	0.000	8.000	0.000	0.000	2.3637	1.41E-01	WALL	0.0206	0.0000

DUMP NUMBER 1 HAS BEEN WRITTEN.

\$

THE FREQUENCY IS EQUAL TO 28.033 MHz
AND THE SHUNT IMPEDANCE IS EQUAL TO
0.836 $\mu\Omega$. (AS EXPECTED).

THIS MEANS THAT FOR 200 KV WE NEED,
AL LEAST, 23.9 KW AND \sim 32 KW SHOULD BE SAFE.

IT SHOULD BE NOTED THAT INCREASING THE
WAVELENGTH THE COST OF THE CAVITY INCREASES
MORE OR LESS LINEARLY WITH THE WAVELENGTH
SINCE THE RADIUS R_3 IS CONSTANT.

ON THE OTHER HAND COULD BE NOT CONVENIENT
TO LOAD THE CAVITY WITH A LARGER CAPACITOR
BECAUSE IN THIS CASE THE LENGTH DECREASES
BUT THE FACTOR χ INCREASES LEADING TO
A LARGER WASTE OF ENERGY.

NEVERTHELESS, THE LONGITUDINAL SPACE
OCCUPIED BY THE CAVITIES INCREASES WITH
INCREASES WITH INCREASING THE WAVELENGTH
WHICH MAY BE IMPORTANT.

E) - THE POWER AMPLIFIERS

SOME PRIVATE COMMUNICATIONS* SUGGEST THAT A SUITABLE POWER GENERATOR ($25 \div 55 \text{ MHz}$; 10% BW, REASONABLE LINEARITY IN AMPLITUDE AND PHASE, 1 VOLT PEAK DRIVING VOLTAGE ON 60Ω ; 60Ω COAX OUTPUT) WOULD COST ABOUT 4.5\$ PER WATT. ASSUMING AN OVER ALL EFFICIENCY $\sim 50\%$ THE GENERATOR FOR THE FIRST OPTION WOULD COST ABOUT 0.9 M\$. (THAT CORRESPONDS TO 5 AMPLIFIERS EACH CONNECTED WITH A SINGLE CAVITY; GROUNDED GRID STRUCTURE 4×3500)

FOR THE THIRD OPTION (27 MHz) THE COST OF THE GENERATOR SHOULD BE CLOSE TO 1.4 M\$.

IT IS IMPORTANT TO RECOGNISE THAT A CAREFULL ANALYSIS OF THE BEAM LOADING COULD DEMAND AN INCREASE OF THE INSTALLED POWER WHICH WOULD INCREASE THE AMPLIFIER COST.

* CONTINENTAL ELECTRONICS
 P.O. BOX 270879 DALLAS 75227
 ROSS FAULKNER (214) 3817161.

F) - FREQUENCY MODULATION.

THE FREQUENCY CHANGES BY ABOUT 5×10^{-3} , OF WHICH THE LARGER PART OCCURS IN THE FIRST FEW SECONDS.

THIS SUGGESTS THAT A MECHANICAL SOLUTION SHOULD BE FEASIBLE.

A MOVING DIAPHRAGM PLACED IN FRONT OF THE CAVITY DISC WOULD DO THE JOB. A DISPLACEMENT ABOUT 2 mm. OF THE WALL IN FRONT OF THE INTERNAL DISC IS ENOUGH

IF THE CAPACITIVE LOADING IS INCREASED (WHICH MEANS USING A SHORTER CAVITY) THIS MOTION COULD BE REDUCED. AN OLEODYNAMIC SERVO SYSTEM (ACCURATE TO ABOUT 10^{-2}) IS ENOUGH AND A VERY SIMPLE SLOW FEEDBACK PHASE LOOP WOULD COMPENSATE FOR ERRORS OF THE SERVO.

G) - SOME BEAM LOADING CONSIDERATIONS..

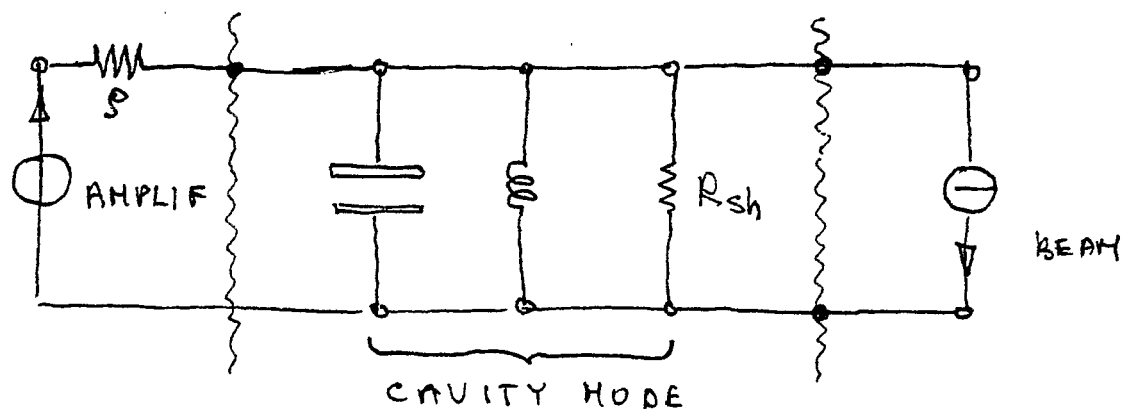
THE TOTAL CHARGE PER BUNCH IS EQUAL TO
 $1.39 \text{ E-}8$ COULOMB (FOR GOLD)

THE CAVITY GAP CAPACITANCE IN OPTION ONE
 IS VERY NEAR TO $\sim 9.8 \text{ E-}12 \text{ F. (S.F.)}$ THIS
 MEANS THAT FOR A δ SHAPED BUNCH THE
 INDUCED VOLTAGE WOULD BE $V_g = 1.418 \text{ KV.}$

THIS IS A VERY REASONABLE VALUE. THE
 BEAM HARMONICS ARE EQUAL: $|I_m| = 0.123 \text{ A.}$

WITH ONE $\text{M}\Omega$ CAVITY SHUNT IMPEDANCE
 THE INDUCED VOLTAGE IS NEARLY ABOUT 100 KV
 WHICH IS HALF OF THE VOLTAGE DUE
 TO THE AMPLIFIER. (THE BEAM LOADING IS TO BE CONSIDERED).

IT SHOULD BE VERY IMPORTANT TO TRY
 TO DESIGN A RELATIVELY LOW OUTPUT IMPEDANCE
 AMPLIFIER IN ORDER TO REDUCE THE BEAM
 INDUCED VOLTAGE AND TO RENDER THE
 CAVITY VOLTAGE CONTROL MORE EASY.



FROM THE ABOVE FIGURE IT IS EVIDENT THAT, AT RESONANCE, THE AMPLIFIER SEES THE VERY HIGH CAVITY SHUNT IMPEDANCE WHILE THE BEAM SEES THE CAVITY SHUNT IMPEDANCE IN PARALLEL WITH THE AMPLIFIER'S EQUIVALENT OUTPUT IMPEDANCE. A TRIDDE WOULD BE MORE ADVISABLE THAN A TETRODE FOR THE FINAL AMPLIFIER -.

H) - ALTERNATIVE PROPOSAL

GENERAL STATEMENT: THE CAVITIES CAN BE MADE IN AIR --

FOR EACH GAP A TOTAL VOLTAGE OF 20 KV IS STILL POSSIBLE. THEN WE NEED 50 CAVITIES -. THE LENGTH OF EACH CAVITY CAN BE REDUCED TO 0.75 M AND THE TOTAL AZIMUTHAL LENGTH CAN BE REDUCED TO 37 ÷ 40 METER. (50 KHz OPTION) -

THE γ FACTOR BECOMES EQUAL TO 1.63 AND THE TOTAL SHUNT IMPEDANCE PER CAVITY COULD BE IN THE RANGE OF ~ 0.8 Ω . THE TOTAL POWER REQUESTED SHOULD BE AROUND ~ 400 W₂₄₅. FOR 50 CAVITIES $W_T = \sim 20$ KW. THE INSTALLED POWER FOR THE RF SYSTEM SHOULD BE EQUAL TO 50 KW. WE NOTE THAT WITH THIS SYSTEM EACH CAVITY COULD BE HEAVILY LOADED BY ITS OWN TRIODE SITTING ON THE CAVITY. THE TOTAL IMPEDANCE OFFERED TO THE BEAM

COULD BE GREATLY REDUCED WITH
A SIGNIFICANT SIMPLIFICATION OF
THE BEAM LOADING PROBLEM.

THE 25 MHz OPTION CAN BE ALSO
CONSIDERED.

IN THE LIMITING CASE OF A CAVITY
80 CM LONG! THE SF CALCULATIONS
INDICATE THAT A POWER OF ~ 700 WATT
IS REQUIRED FOR 20 kV AT THE GAP.
THE INSTALLED POWER FOR THE RF
SYSTEM SHOULD BE CLOSE TO 80 KW.

OBVIOUSLY A CAVITY MORE LONG DEMANDS FOR LESS POWER.

REMARKS

- EACH CAVITY IS VERY CHEAP.
- NO MULTIFACTOR AND CONDITIONING PROBLEMS.
- THE SAL GIORDANO TECHNIQUE FOR MODE SUPPRESSION,
EASILY APPLICABLE
- REDUCTION OF THE RF GENERATOR COST.
- MINIMIZATION OF THE BEAM LOADING PROBLEM.



ACKNOWLEDGEMENTS

THE AUTHOR IS HAPPY TO THANK J. CLAUS
FOR READING AND CORRECTING THE MANUSCRIPT.