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National Laboratory

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## RF System Design Considerations

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**Brookhaven National Laboratory**

**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.

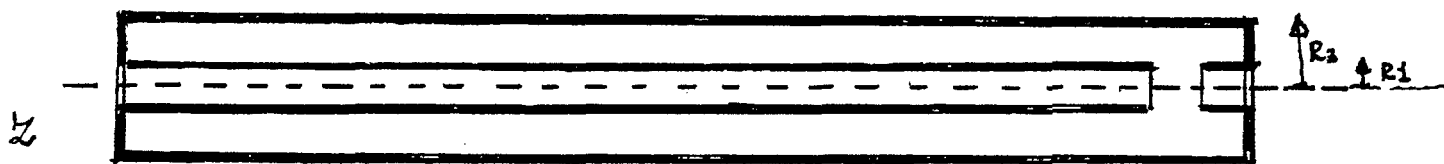
Let  $L$  AND  $Z_0$  BE THE INDUCTANCE PER METER AND THE CHARACTERISTIC IMPEDANCE OF THE LINE. (HENRY/METER; OHMS).

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  $\lambda$  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:

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

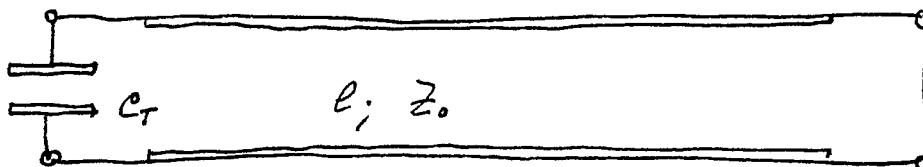
INTEGRATING WE OBTAIN:

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

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  $\chi$  (THE LOADING FORM FACTOR) IS GIVEN IN THE FOLLOWING TABLE. ( $\beta l$  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).  $\chi$ 

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).  $\chi$ 

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.\*

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

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  $\lambda$  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:

$\alpha$	$y$	$\alpha$	$y$	$\alpha$	$y$
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  $60^\circ$ ) AND THE CAVITY MECHANICAL LENGTH  $l$  WOULD BE:

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

WHERE THE FREQUENCY  $\nu$  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.

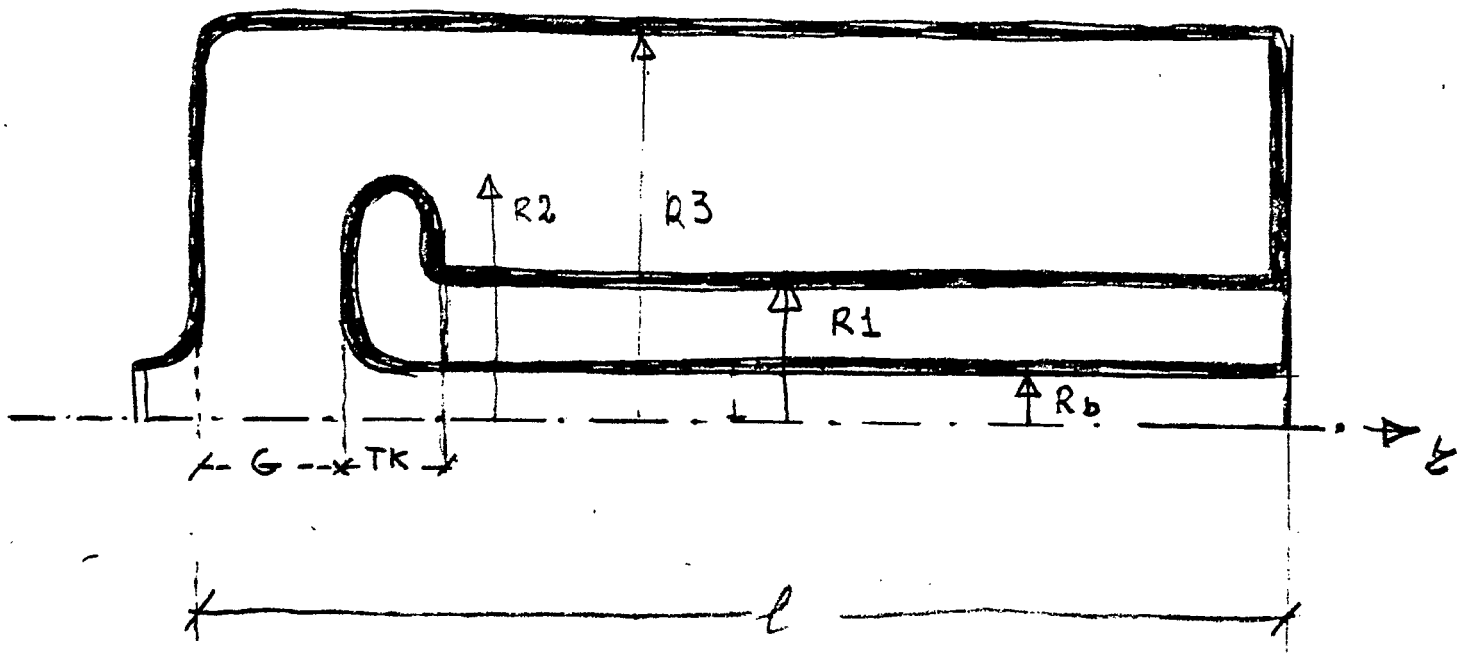
IF THE CAVITY LENGTH SHOULD BE NEAR TO  $\sim 2$  METERS THEN  $R/l$  SHOULD BE, AT LEAST, EQUAL TO 5 CM; THE RATIO  $\alpha$  BECOMES EQUAL TO 4.2

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  $\alpha$  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  $50 \text{ MHz}$  . . 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:

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

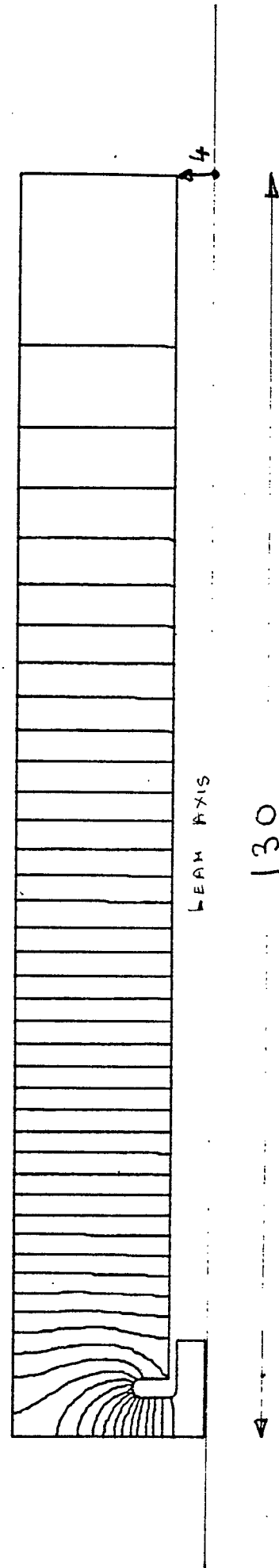
RUG HIGH Z0

\*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	8
17	8	-1	0	13	8
13	8	-1	0	11	8
11	8	-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

$F = 50.037 \text{ Hz}$

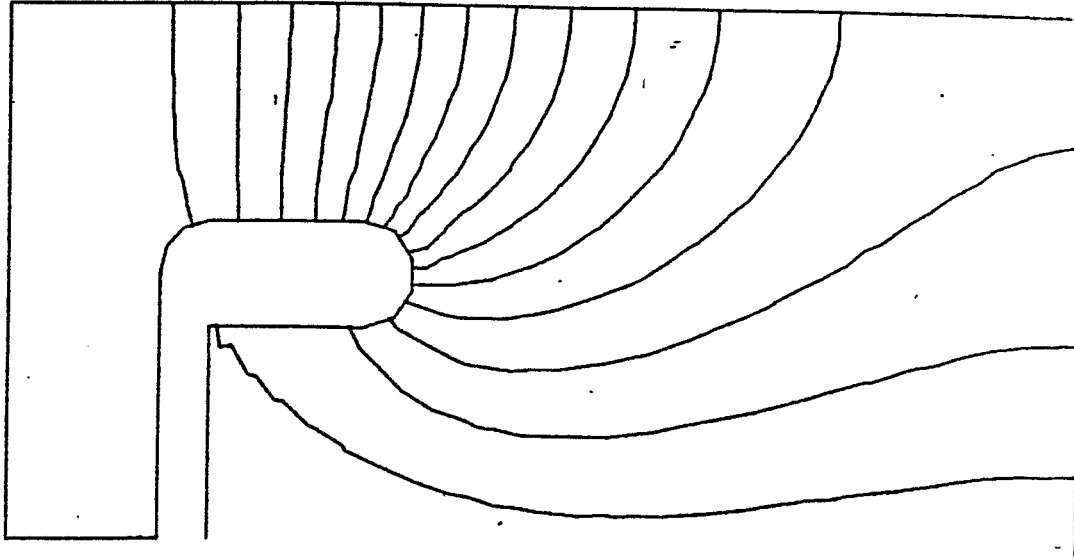
1	1	0.0000	0.0000	0	1	REGION
1	1	0.0000	0.0000			
13	1	6.0000	0.0000			
17	1	10.0000	0.0000			
17	8	10.0000	3.0000			
13	8	6.0000	3.0000			
11	8	5.0000	3.0000			
10	8	4.5000	3.1340			
9	9	4.1340	3.5000			
9	10	4.0000	4.0000			
9	17	4.0000	7.0000			
10	18	4.1910	7.5878			
11	18	4.6910	7.9511			
12	18	5.3090	7.9511			
13	18	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	COUN		
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.

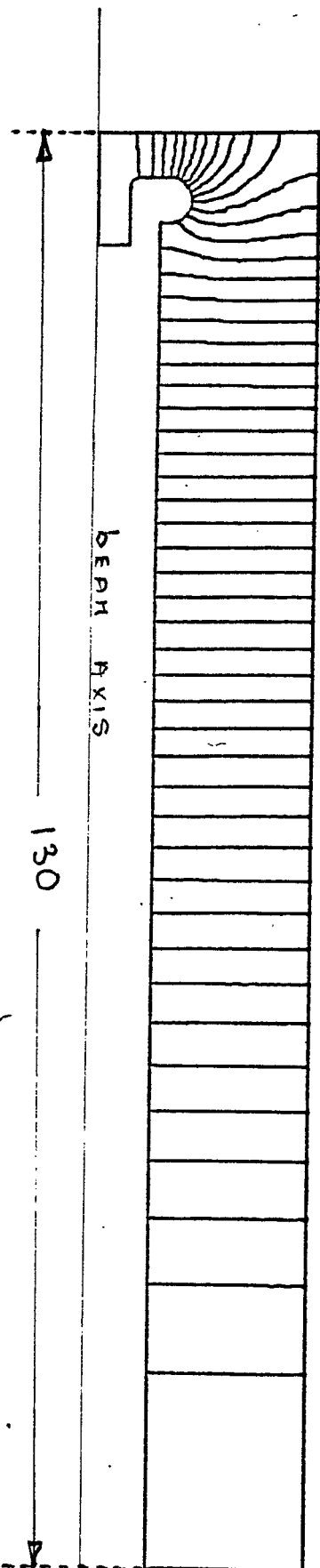
$$\left\{ \begin{array}{l} \beta = 1.30 \quad \text{GAP} = 0.04 \quad \text{TK} = 0.04 \\ R3 = 0.21 \\ R2 = 0.09 \end{array} \right.$$

THE RESONANT FREQUENCY IS 50.957 KHz AND FOR 200 ~~MHz~~  $\sqrt{V}$  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

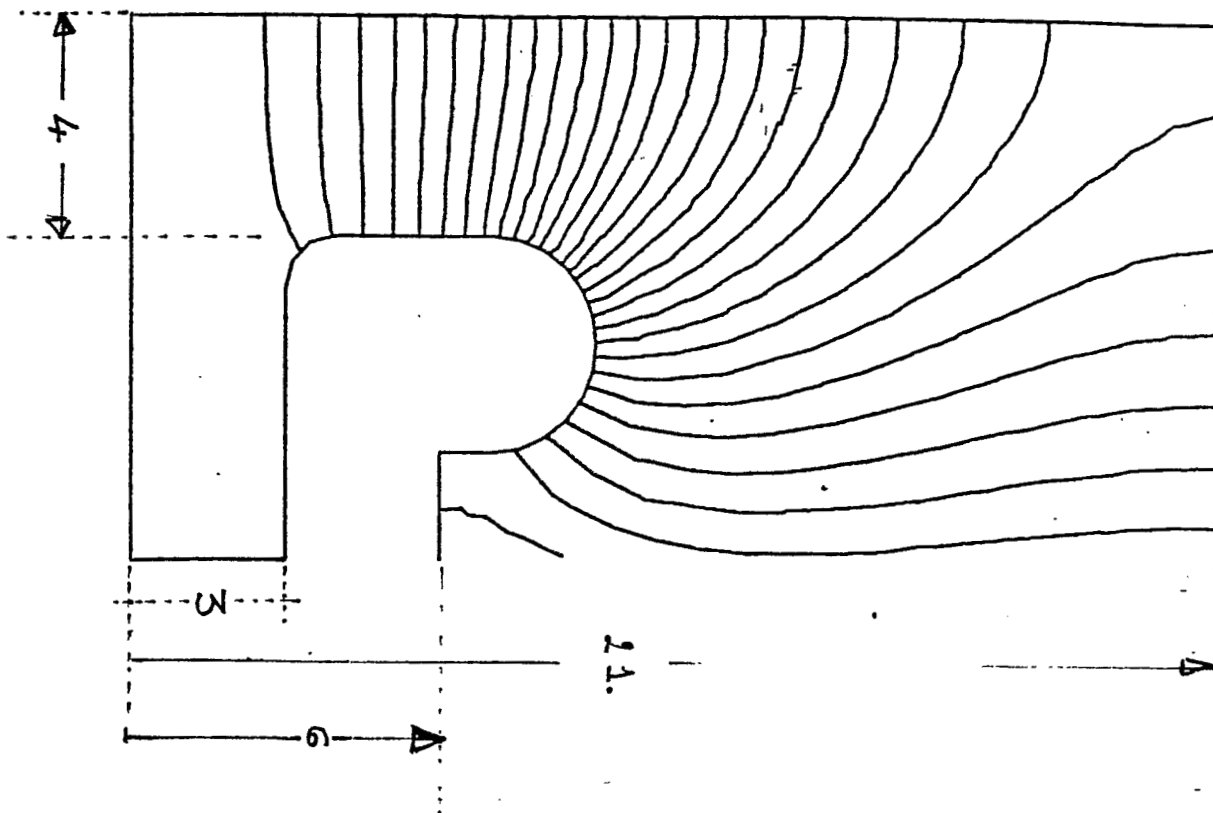
\*2 2 \*21 1 0 1 1 \*9 1.0000

\*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:

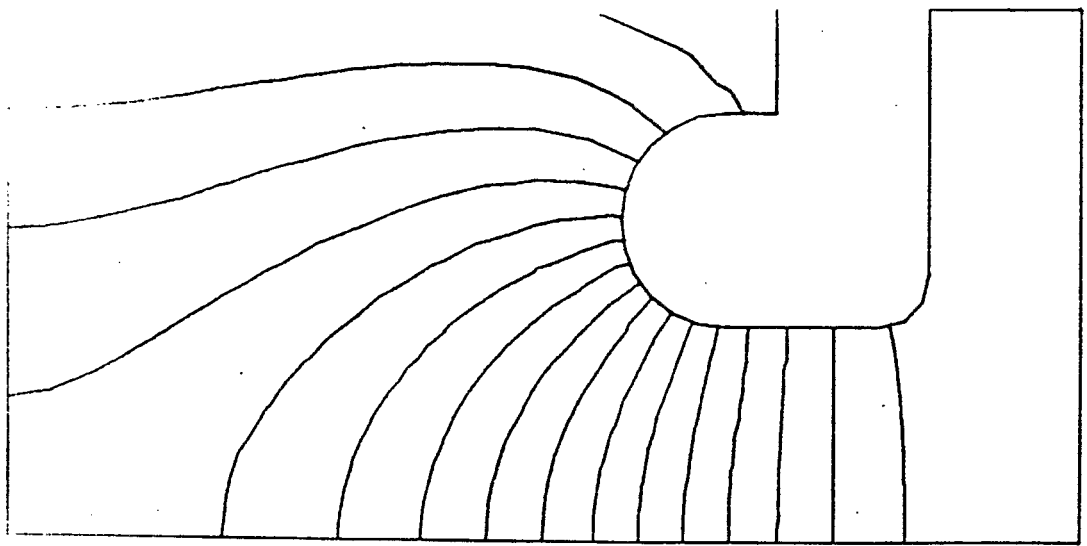
$$\left\{ \begin{array}{l} l = 2.50 \\ R_3 = 21 \\ R_2 = 0.09 \\ R_1 = 0.06 \end{array} \right. \quad \text{GAP} = 0.04 \quad \text{TK} = 0.04$$

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  $\chi$  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  $60 \Omega$ ;  $60 \Omega$  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  $4 \times 3500$  )

FOR THE THIRD OPTION ( $27 \text{ MHz}$ ) 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  $5 \times 10^{-3}$ , 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..

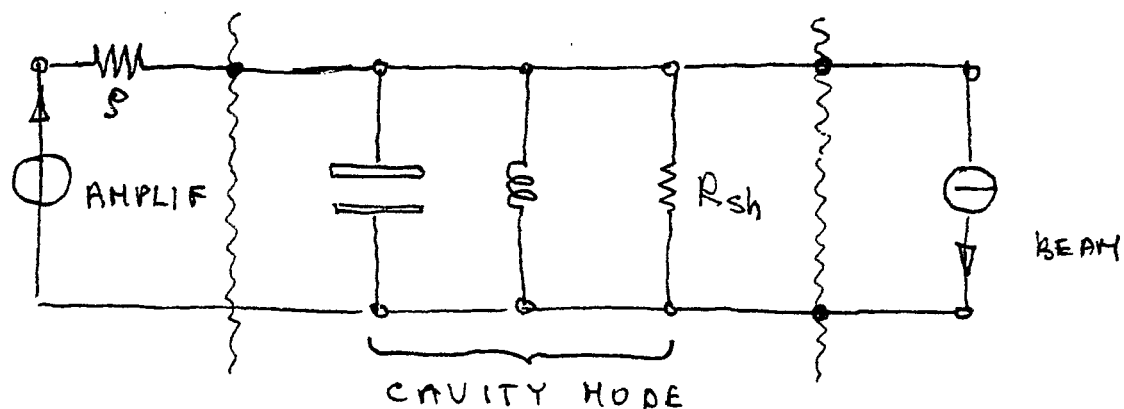
THE TOTAL CHARGE PER BUNCH IS EQUAL TO  
 $1.39 \text{ E-}8$  COULOMB (FOR GOLD)

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  $\delta$  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  $100 \text{ KV}$   
 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  $\gamma$  FACTOR BECOMES EQUAL TO 1.63 AND THE TOTAL SHUNT IMPEDANCE PER CAVITY COULD BE IN THE RANGE OF ~ 0.8  $\Omega$ . THE TOTAL POWER REQUESTED SHOULD BE AROUND ~ 400 W<sub>245</sub>. 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  $\sim 700$  WATT  
IS REQUIRED FOR  $20 \text{ kV}$  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.