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Calculation of the Booster proton cavity using the Superfish Program

J. Zhang

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Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

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CALCULATION OF THE BOOSTER PROTON CAVITY USING THE "SUPERFISH" PROGRAM

AD

Booster Technical Note

No. 109

JIAN ZHANG

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ACCELERATOR DEVELOPMENT DEPARTMENT

Brookhaven National Laboratory

Upton, N.Y. 11973

CALCULATION OF THE BOOSTER PROTON CAVITY USING THE "SUPERFISH" PROGRAM

Jian Zhang

INTRODUCTION

For the AGS Booster Project, two RF acceleration stations are needed for the proton. For each station, a four half-wave coaxial line with monogap filled with ferrites to allow for permeability tuning, has been adopted for the RF cavities. It has been chosen to operate at a peak voltage of 22.5KV, in each half-wave cavity, for accelerating proton, and a tunable frequency range of 2.4-4.1MHz is required. Presented here are some results and design features, for this cavity, calculated by using a "SUPERFISH"[1] program developed by Los Alamos National Laboratory (LANL).

FERRITE TYPE

The choice of ferrite for such purpose depends fundamentally upon the power losses and heat dissipation allowed. The losses increase very rapidly with the magnetic flux density and working frequency. A commercially available candidate for lower loss ferrite meeting the requirements of the Booster cavity is the Philips type 4M2. It has been used in the CERN PS Booster and Rutherford SNS accelerators. A test cavity based on a ferrite-loaded resonator, consisting of ferrite toroids with 50cm O.D., 25cm I.D. and 2.5cm thickness, has been built for the measurements on RF characteristics. The power losses are measured as a function of magnet flux over whole frequency range. The curves of μQ product is obtained for comparison with that provided by the Philips company (Figure 1). According to data measured, the number of ferrite rings in each half-wave cavity is evaluated to be at least 30 to satisfactorily run at highest frequency of 4.1MHz, the peak voltage of 22.5KV and within the limit of power losses of 0.30W/cm^3. In this calculation, we assumed no cooling. In the actual design, there are cooling provided for the ferrite; therefore, fewer ferrite ring is possible. Main dimensions of this cavity are shown in Figure 2.

CALCULATION METHOD

In the past, simple formulas were utilized for the design of cavity with ferrites. Recently, a series of programs, named "SUPERFISH", have been developed for this purpose. It is a special program that can solve the MAXWELL's equation in two-dimension, by calculating properties of cavity resonator exhibiting an axial circular symmetry and the cut-off modes of uniform straight waveguides.

Because the oscillating frequency of cavity with ferrites is lower than the bare program produces, certain modification should be done when this program is used for the Booster cavity. Some special regions can be reset for program changes when used and a variety of new constants such as the permeabilities, permittivities and required accelerating voltage were put into the program for satisfying the needs of design.

The output file of the program contains a list of the parameters used for solution, a list of material properties for each region, and an iteration history. Many formulas were used in the program to calculate auxiliary properties such as average accelerating field, stored energy, power losses, etc.

Again, all these calculations do not contain the power losses on the ferrites and beam loading effect. Therefore, extra losses should be taken into account.

In order to eliminate the random error caused in the measurements, a sixth order polynomial obtained by fitting the measured data was used in the calculation.

For comparison, five parameter tables calculated with different numbers of ferrite rings in a half-wave cavity are listed in the end of this report.

SOME RESULTS

(1) From the calculation, if the power losses of ferrite is limited to below $0.30 W/cm^3$, at least 30 rings are needed in a half-wave cavity. Fewer rings are possible if cooling is provided.

(2) When the dielectric constant of the ferrite is swept from 1 to 30 gradually, a small variation of the frequency develops, which is less than 2%.

(3) The cooling plate existing around the ferrites do not affect the main parameters except the tolerable heat dissipation. (Figure 3.)

(4) The electric field distribution is influenced by the shape of the accelerating electrodes, obviously within the region nearby the

electrode edge. To avoid the voltage breakdown the smooth arc shapes in these edges are preferred (Figure 4).

(5) The capacitance of the gap capacitor can be selected between 400-1000 (pf) for different requirements. The amount of capacitance does not affect the shunt impedance but the quality factor of the cavity is certainly modified. Larger capacitance gives larger quality factor.

(6) On the basis of data provided by the Philips Company, the maximum biasing current is about 2500A, if the biasing coil has one turn.

(7) The possible uncertainties of the calculation are mainly from the data provided by the measurement and the Philips Co. The results obtained should be reliable for the prototype design.

ACKNOWLEDGMENT

I would like to thank M. Goldman, F. Khiari, A. Ratti, and A. McNerney for their helpful discussions.

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2. U. Bigliani et al., IEEE Trans. Nul Sci, NS-18,233 (1971)
3. J. M. Baillod et al., IEEE Trans. Nul Sci, NS-30,3499 (1983)

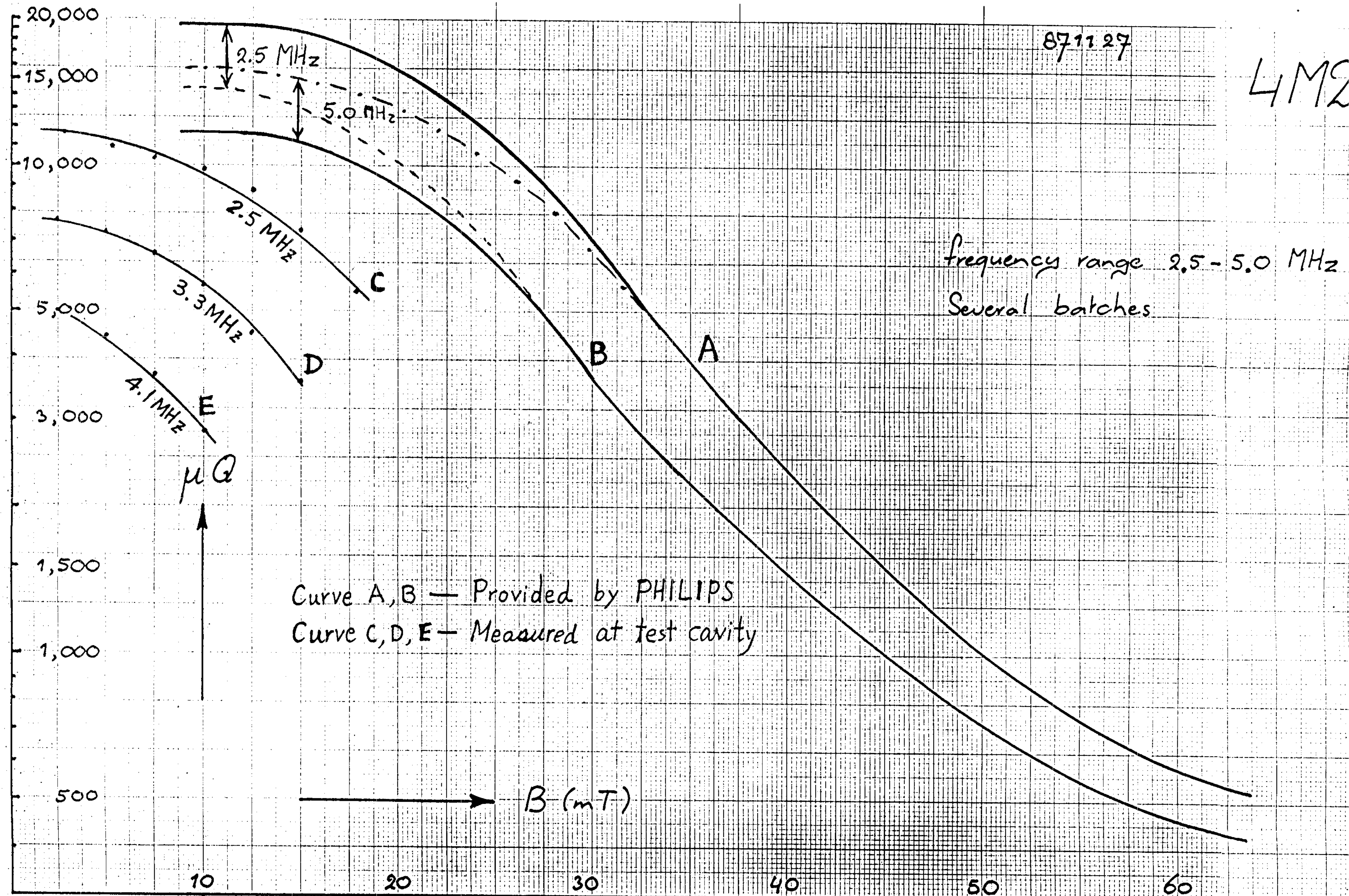

Fig.1 Some curves about uQ vs. Bm

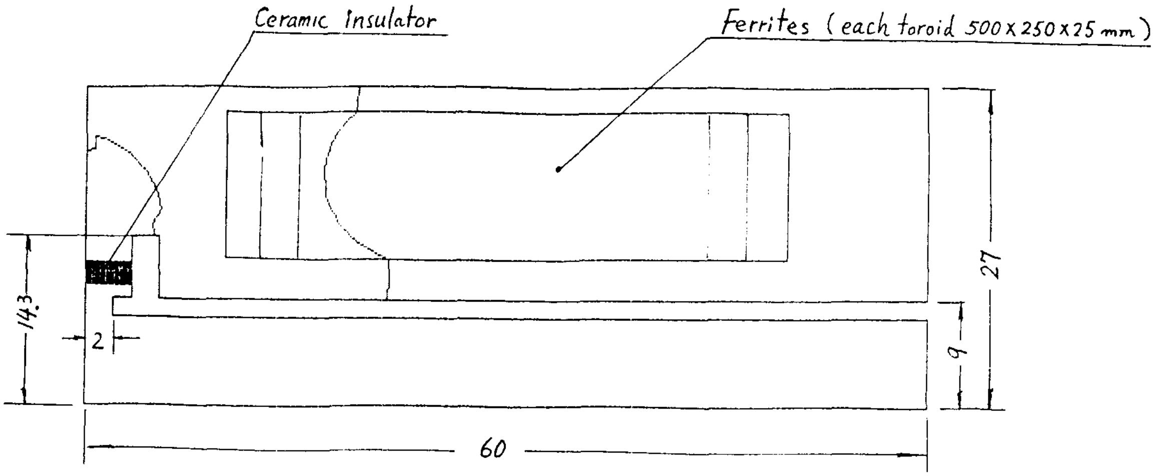

Fig.2 Main dimension of a quarter of cavity

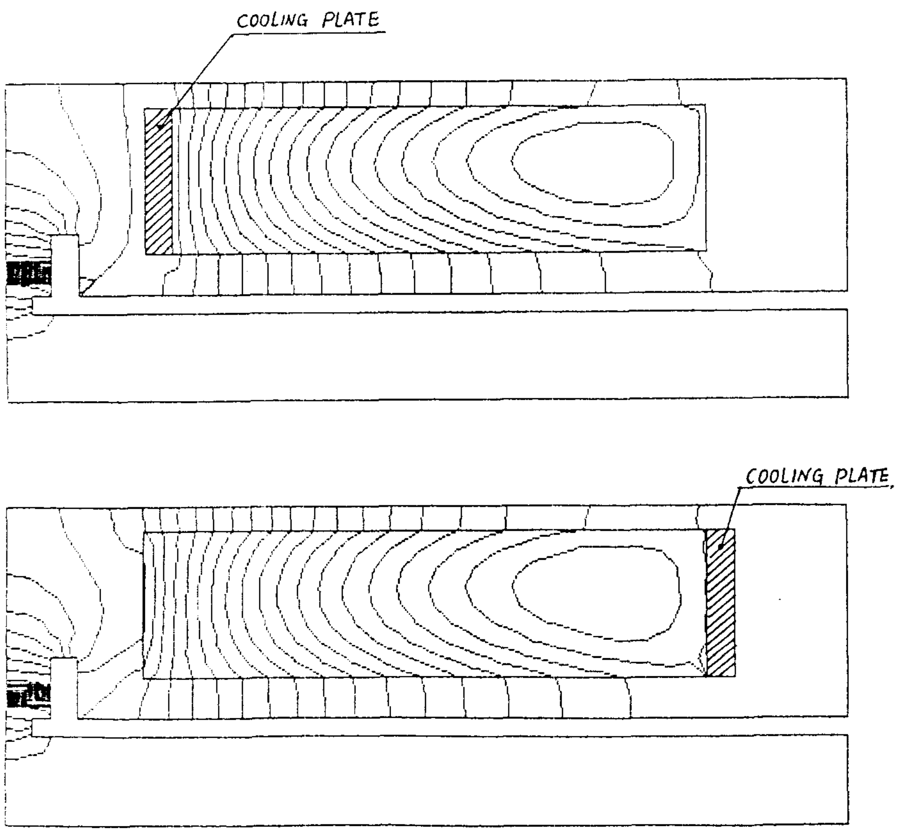

Fig.3 Position of the cooling plate in ferrites

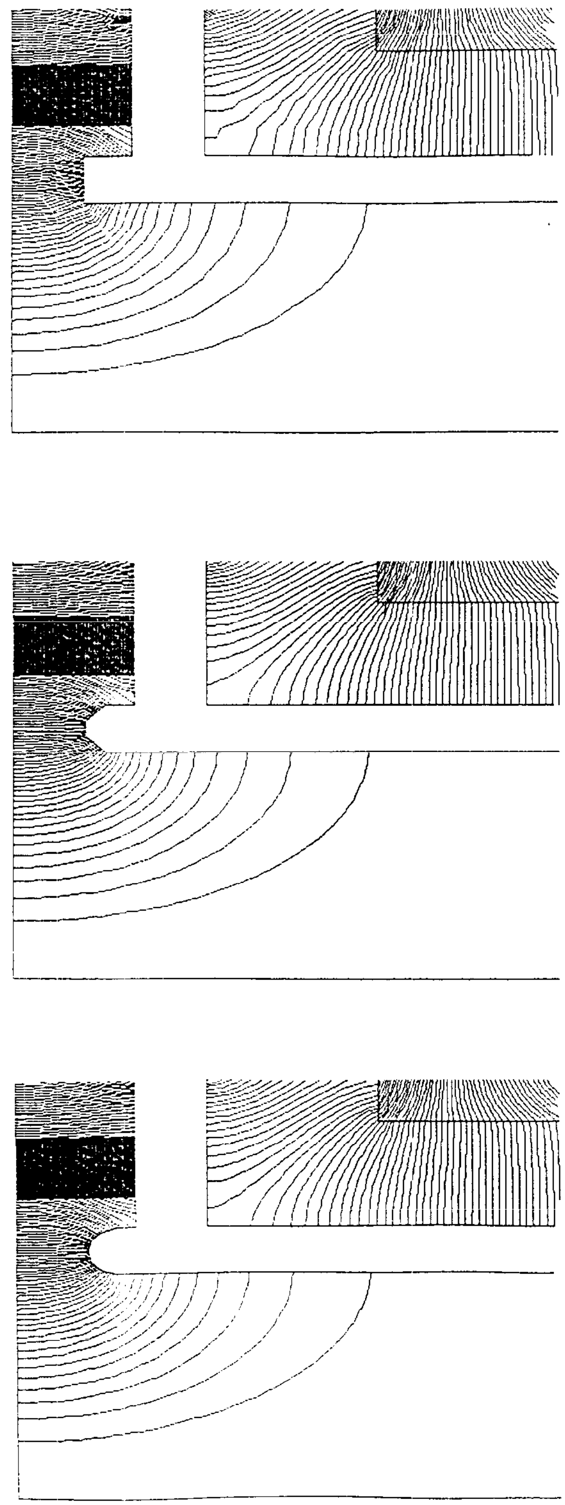

Fig.4 Electric field distribution with different shapes of accelerating electrode

NF	CG (PF)	UR	F0 (MHz)	H0 (A/M)	A1 (A)	BB (mT)	UQ (W/cm3)	PF (KW)	Q0	Z0 (KOHM/M)	Q1	Z1 (KOHM/M)	Q2	Z2 (KOMH/M)
14.0	300.0	130.0	2.42	67.00	1.13	16.39	0.23	23.43	56.63	18.00	14.60	4.64	9.76	3.10
14.0	300.0	94.0	2.84	81.40	196.24	14.40	0.28	28.80	54.05	14.64	16.17	4.38	11.02	2.99
14.0	300.0	73.0	3.21	92.15	329.25	12.66	0.28	28.53	61.75	14.78	18.35	4.39	12.50	2.99
14.0	300.0	58.0	3.59	103.10	433.38	11.25	0.25	26.04	75.65	16.19	21.07	4.51	14.23	3.04
14.0	300.0	43.0	4.10	119.20	543.09	9.65	0.39	40.69	55.28	10.36	20.80	3.90	14.69	2.75
14.0	400.0	102.0	2.39	88.86	149.33	17.06	0.25	25.69	66.23	16.42	18.26	4.53	12.32	3.05
14.0	400.0	70.0	2.88	106.90	349.49	14.08	0.27	28.31	72.24	14.89	21.36	4.40	14.53	3.00
14.0	400.0	51.0	3.36	124.70	484.03	11.97	0.26	27.16	87.84	15.51	25.22	4.46	17.10	3.02
14.0	400.0	43.0	3.76	139.50	543.09	11.29	0.31	31.81	83.99	13.24	26.93	4.25	18.53	2.92
14.0	400.0	33.0	4.14	153.00	561.79	9.50	0.40	41.55	70.77	10.14	26.99	3.87	19.11	2.74
14.0	500.0	88.0	2.32	105.80	232.64	17.52	0.23	23.95	84.61	17.60	22.17	4.61	14.86	3.09
14.0	500.0	60.0	2.80	127.60	419.16	14.41	0.27	27.56	88.75	15.29	25.75	4.44	17.48	3.01
14.0	500.0	43.0	3.29	149.90	543.09	12.13	0.26	26.75	107.20	15.74	30.47	4.47	20.63	3.03
14.0	500.0	32.0	3.79	172.70	584.49	10.40	0.25	26.27	125.69	16.02	35.28	4.50	23.84	3.04
14.0	500.0	27.0	4.11	187.00	785.65	9.50	0.37	38.56	92.83	10.92	33.80	3.97	23.74	2.79
14.0	600.0	73.0	2.34	126.10	329.25	17.32	0.23	23.88	101.34	17.65	26.51	4.62	17.76	3.09
14.0	600.0	50.0	2.81	151.70	491.38	14.27	0.26	27.13	107.21	15.53	30.77	4.46	20.86	3.02
14.0	600.0	35.0	3.34	180.10	606.32	11.86	0.25	25.88	133.05	16.25	36.95	4.51	24.94	3.05
14.0	600.0	26.0	3.84	207.30	843.41	10.14	0.24	24.52	161.53	17.14	43.16	4.58	29.00	3.08
14.0	600.0	20.0	4.34	234.30	1312.67	8.82	0.39	40.53	110.49	10.37	41.54	3.90	29.34	2.75
14.0	700.0	63.0	2.34	145.70	398.04	17.27	0.23	23.61	118.35	17.84	30.71	4.63	20.56	3.10
14.0	700.0	42.0	2.84	177.30	550.82	14.01	0.26	26.68	127.42	15.78	36.15	4.48	24.47	3.03
14.0	700.0	30.0	3.34	208.30	647.43	11.76	0.24	25.22	158.04	16.67	43.10	4.55	29.03	3.06
14.0	700.0	22.0	3.86	241.00	1132.86	9.98	0.24	24.81	185.53	16.91	50.07	4.56	33.68	3.07
14.0	700.0	17.0	4.35	271.40	1626.22	8.68	0.36	37.04	139.89	11.33	49.72	4.03	34.78	2.82
14.0	800.0	54.0	2.36	167.30	462.15	17.00	0.23	23.95	133.94	17.58	35.13	4.61	23.55	3.09
14.0	800.0	37.0	2.83	200.70	590.21	13.97	0.25	26.18	146.85	16.06	41.13	4.50	27.79	3.04
14.0	800.0	26.0	3.35	237.40	843.41	11.62	0.24	24.54	184.93	17.11	49.48	4.58	33.25	3.08
14.0	800.0	19.0	3.88	274.70	1411.34	9.82	0.24	24.89	210.50	16.83	57.01	4.56	38.36	3.07
14.0	800.0	15.0	4.32	305.90	1670.97	8.63	0.33	34.47	169.39	12.16	57.51	4.13	39.93	2.87
14.0	900.0	48.0	2.36	187.30	505.16	16.92	0.23	23.70	151.51	17.75	39.45	4.62	26.42	3.10
14.0	900.0	32.0	2.87	227.60	584.49	13.71	0.25	25.79	168.86	16.29	46.82	4.52	31.60	3.05
14.0	900.0	23.0	3.36	265.90	1051.72	11.51	0.23	23.92	212.27	17.53	55.80	4.61	37.41	3.09
14.0	900.0	17.0	3.86	305.70	1626.22	9.78	0.23	23.62	246.42	17.70	64.31	4.62	43.09	3.09
14.0	900.0	13.0	4.35	344.90	2043.19	8.44	0.32	33.25	197.59	12.58	65.60	4.18	45.39	2.89
14.0	1000.0	43.0	2.37	207.70	543.09	16.81	0.23	23.49	169.57	17.90	43.89	4.63	29.37	3.10
14.0	1000.0	29.0	2.86	250.80	687.66	13.69	0.25	25.34	189.38	16.56	51.88	4.54	34.96	3.06
14.0	1000.0	20.0	3.40	298.40	1312.67	11.23	0.22	23.14	245.93	18.08	63.18	4.64	42.25	3.11
14.0	1000.0	15.0	3.88	340.30	1670.97	9.61	0.23	23.80	271.84	17.53	71.46	4.61	47.91	3.09
14.0	1000.0	13.0	4.14	362.00	2043.19	8.86	0.29	30.23	228.33	13.81	71.15	4.30	48.77	2.95

NF--Number of ferrites in a half-wave cavity
CG--Capacitance of gap capacitor
UR--Relative permeability of ferrite
F0--Frequency of fundmental oscillation
H0--Magnet field on the outer wall of cavity
A1--Ferrite biasing current
BB--Magnetic flux density
UQ--Power losses in unit volume

PF--Power losses in whole ferrites
Q0--Qulity of cavity without beam loading
Z0--Shunt impedence without beam loading
Q1,Z1--Qulity and shunt impedence with beam loading of 3A average current
Q2,Z2--Qulity and shunt impedence with beam loading of 5A average current

NF	CG (PF)	UR	F0 (MHz)	H0 (A/M)	A1 (A)	BB (mT)	UQ (W/cm3)	PF (KW)	Q0	Z0 (KOHM/M)	Q1	Z1 (KOHM/M)	Q2	Z2 (KOMH/M)
15.0	300.0	128.0	2.35	67.00	11.68	16.14	0.19	21.23	60.94	19.86	14.59	4.75	9.68	3.15
15.0	300.0	88.0	2.83	81.44	232.64	13.49	0.23	25.02	62.23	16.86	16.83	4.56	11.33	3.07
15.0	300.0	64.0	3.31	95.20	391.06	11.47	0.22	24.39	74.61	17.29	19.81	4.59	13.30	3.08
15.0	300.0	49.0	3.77	108.40	497.73	10.00	0.22	24.67	83.96	17.08	22.49	4.58	15.12	3.07
15.0	300.0	40.0	4.16	119.00	566.43	8.96	0.32	35.35	64.66	11.92	22.24	4.10	15.47	2.85
15.0	400.0	95.0	2.39	89.00	190.26	15.91	0.20	21.80	78.19	19.34	19.10	4.72	12.70	3.14
15.0	400.0	66.0	2.86	106.50	377.19	13.23	0.22	24.51	83.15	17.20	22.17	4.58	14.89	3.08
15.0	400.0	48.0	3.34	124.40	505.16	11.24	0.21	23.63	100.71	17.83	26.14	4.63	17.50	3.10
15.0	400.0	36.0	3.84	143.00	598.24	9.69	0.22	24.19	112.99	17.41	29.85	4.60	20.03	3.09
15.0	400.0	30.0	4.19	156.00	647.43	8.81	0.31	34.48	86.50	12.21	29.28	4.13	20.32	2.87
15.0	500.0	83.0	2.31	105.40	264.00	16.46	0.19	20.91	96.49	20.16	22.84	4.77	15.14	3.16
15.0	500.0	56.0	2.80	127.70	447.71	13.46	0.22	23.95	102.13	17.59	26.77	4.61	17.94	3.09
15.0	500.0	40.0	3.30	150.50	566.43	11.33	0.21	23.30	123.56	18.07	31.76	4.64	21.24	3.11
15.0	500.0	30.0	3.78	172.60	647.43	9.74	0.21	23.58	139.93	17.84	36.31	4.63	24.31	3.10
15.0	500.0	25.0	4.13	188.00	906.98	8.84	0.29	31.64	113.76	13.30	36.37	4.25	25.02	2.93
15.0	600.0	68.0	2.34	126.40	363.42	16.17	0.19	20.93	115.73	20.13	27.42	4.77	18.18	3.16
15.0	600.0	46.0	2.83	152.90	520.19	13.24	0.21	23.58	124.14	17.86	32.19	4.63	21.55	3.10
15.0	600.0	33.0	3.32	179.50	561.79	11.15	0.20	22.58	151.97	18.63	38.18	4.68	25.47	3.12
15.0	600.0	25.0	3.79	204.80	906.98	9.63	0.21	23.07	169.56	18.21	43.33	4.65	28.95	3.11
15.0	600.0	19.0	4.30	232.50	1411.34	8.31	0.28	31.00	143.19	13.55	45.20	4.28	31.04	2.94
15.0	700.0	58.0	2.35	146.80	433.38	16.02	0.19	20.66	136.12	20.38	31.94	4.78	21.15	3.17
15.0	700.0	39.0	2.85	178.00	574.31	13.06	0.21	23.19	146.88	18.14	37.63	4.65	25.16	3.11
15.0	700.0	28.0	3.34	208.60	733.73	10.99	0.20	22.01	181.16	19.09	44.69	4.71	29.75	3.13
15.0	700.0	21.0	3.82	238.90	1219.84	9.44	0.20	22.26	204.70	18.84	51.00	4.69	33.98	3.13
15.0	700.0	16.0	4.34	271.00	1521.27	8.16	0.27	29.28	176.47	14.32	53.62	4.35	36.62	2.97
15.0	800.0	51.0	2.35	166.50	484.03	15.98	0.18	20.40	156.25	20.63	36.33	4.80	24.04	3.17
15.0	800.0	34.0	2.86	202.50	544.92	12.96	0.21	22.79	169.95	18.45	43.01	4.67	28.71	3.12
15.0	800.0	24.0	3.37	239.00	976.43	10.79	0.19	21.38	213.24	19.61	51.53	4.74	34.22	3.15
15.0	800.0	18.0	3.86	273.30	1515.86	9.26	0.20	22.58	230.62	18.54	58.14	4.67	38.80	3.12
15.0	800.0	14.0	4.32	306.70	1844.94	8.08	0.25	27.55	211.87	15.19	61.78	4.43	41.96	3.01
15.0	900.0	45.0	2.36	187.10	527.77	15.84	0.18	20.18	177.39	20.84	40.93	4.81	27.05	3.18
15.0	900.0	30.0	2.87	227.40	647.43	12.84	0.20	22.40	193.94	18.74	48.50	4.69	32.33	3.12
15.0	900.0	21.0	3.39	269.10	1219.84	10.63	0.19	20.85	245.94	20.08	58.37	4.77	38.70	3.16
15.0	900.0	16.0	3.85	305.20	1521.27	9.19	0.20	21.90	264.83	19.07	65.37	4.71	43.52	3.13
15.0	900.0	12.0	4.38	347.50	2265.72	7.85	0.22	24.75	266.32	16.84	72.09	4.56	48.51	3.07
15.0	1000.0	40.0	2.37	208.30	566.43	15.68	0.18	20.04	198.85	20.97	45.66	4.81	30.17	3.18
15.0	1000.0	27.0	2.87	251.40	785.65	12.77	0.20	22.03	217.92	19.04	53.85	4.71	35.85	3.13
15.0	1000.0	19.0	3.38	296.50	1411.34	10.60	0.18	20.41	276.28	20.48	64.61	4.79	42.77	3.17
15.0	1000.0	14.0	3.89	341.00	1844.94	8.98	0.20	22.28	290.37	18.70	72.73	4.68	48.50	3.12
15.0	1000.0	11.0	4.33	379.80	2512.52	7.86	0.22	24.17	297.41	17.20	79.27	4.58	53.24	3.08

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F0--Frequency of fundmental oscillation
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A1--Ferrite biasing current
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UQ--Power losses in unit volume
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Q1,Z1--Qulity and shunt impedence with beam loading of 3A average current
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NF	CG (PF)	UR	F0 (MHz)	H0 (A/M)	A1 (A)	BB (mT)	UQ (W/cm3)	PF (KW)	Q0	Z0 (KOHM/M)	Q1	Z1 (KOHM/M)	Q2	Z2 (KOMH/M)
16.0	300.0	120.0	2.35	67.85	54.01	15.32	0.16	18.88	68.49	22.34	14.97	4.88	9.84	3.21
16.0	300.0	83.0	2.82	81.39	264.00	12.71	0.19	21.93	70.71	19.23	17.35	4.72	11.54	3.14
16.0	300.0	60.0	3.31	95.44	419.16	10.78	0.18	21.47	84.69	19.63	20.45	4.74	13.58	3.15
16.0	300.0	48.0	3.69	106.40	505.16	9.61	0.18	21.43	94.54	19.66	22.81	4.74	15.14	3.15
16.0	300.0	37.0	4.18	120.70	590.21	8.40	0.26	30.23	76.07	13.94	23.55	4.32	16.13	2.96
16.0	400.0	89.0	2.39	89.28	226.48	14.95	0.16	18.87	90.33	22.34	19.74	4.88	12.98	3.21
16.0	400.0	66.0	2.77	103.40	377.19	12.84	0.18	21.40	92.25	19.70	22.22	4.74	14.75	3.15
16.0	400.0	48.0	3.24	120.80	505.16	10.91	0.18	21.02	109.68	20.04	26.07	4.76	17.29	3.16
16.0	400.0	38.0	3.63	135.30	582.24	9.68	0.17	20.36	126.72	20.68	29.41	4.80	19.45	3.17
16.0	400.0	29.0	4.13	154.10	687.66	8.41	0.24	28.41	103.61	14.85	30.69	4.40	20.89	2.99
16.0	500.0	71.0	2.41	110.40	342.71	14.75	0.16	18.74	112.54	22.49	24.48	4.89	16.09	3.21
16.0	500.0	49.0	2.89	132.30	497.73	12.20	0.18	20.92	120.62	20.13	28.58	4.77	18.94	3.16
16.0	500.0	35.0	3.41	155.80	606.32	10.26	0.17	20.41	145.71	20.61	33.90	4.80	22.43	3.17
16.0	500.0	28.0	3.79	173.40	733.73	9.14	0.18	21.69	152.45	19.39	37.16	4.73	24.70	3.14
16.0	500.0	23.0	4.16	190.40	1051.72	8.24	0.23	27.31	132.94	15.40	38.38	4.45	26.03	3.02
16.0	600.0	59.0	2.43	131.50	426.25	14.60	0.16	18.57	135.23	22.67	29.22	4.90	19.19	3.22
16.0	600.0	43.0	2.83	153.40	543.09	12.41	0.18	20.68	141.66	20.36	33.28	4.78	22.04	3.17
16.0	600.0	31.0	3.32	179.60	613.04	10.48	0.17	19.96	171.59	21.06	39.27	4.82	25.94	3.18
16.0	600.0	24.0	3.75	203.00	976.43	9.17	0.17	20.58	187.92	20.40	44.07	4.78	29.18	3.17
16.0	600.0	19.0	4.18	226.60	1411.34	8.10	0.22	26.06	165.62	16.11	46.29	4.50	31.27	3.04
16.0	700.0	55.0	2.34	146.20	454.91	15.13	0.15	17.63	158.53	23.88	32.88	4.95	21.51	3.24
16.0	700.0	37.0	2.83	177.30	590.21	12.34	0.17	20.33	166.49	20.69	38.63	4.80	25.55	3.17
16.0	700.0	26.0	3.35	209.90	843.41	10.27	0.17	19.49	205.28	21.54	46.18	4.84	30.44	3.19
16.0	700.0	20.0	3.80	237.80	1312.67	8.95	0.18	20.83	217.25	20.12	51.48	4.77	34.12	3.16
16.0	700.0	16.0	4.21	263.70	1521.27	7.94	0.21	24.70	203.06	16.96	54.68	4.57	36.77	3.07
16.0	800.0	48.0	2.34	166.40	505.16	15.03	0.15	17.45	182.13	24.10	37.51	4.96	24.52	3.25
16.0	800.0	32.0	2.85	202.40	584.49	12.19	0.17	19.94	193.67	21.06	44.31	4.82	29.27	3.18
16.0	800.0	23.0	3.37	236.90	1051.72	10.25	0.17	19.59	232.36	21.41	52.51	4.84	34.64	3.19
16.0	800.0	18.0	3.74	265.90	1515.86	9.01	0.17	19.59	257.93	21.36	58.40	4.83	38.53	3.19
16.0	800.0	14.0	4.20	298.60	1844.94	7.87	0.20	23.64	239.76	17.68	62.62	4.62	41.96	3.09
16.0	900.0	42.0	2.36	187.70	550.82	14.84	0.15	17.34	206.50	24.24	42.33	4.97	27.67	3.25
16.0	900.0	28.0	2.87	228.20	733.73	12.02	0.17	19.60	221.80	21.41	50.12	4.84	33.06	3.19
16.0	900.0	21.0	3.29	261.50	1219.84	10.33	0.16	18.77	264.79	22.30	57.97	4.88	38.12	3.21
16.0	900.0	16.0	3.74	296.90	1521.27	8.94	0.16	19.05	295.34	21.91	65.55	4.86	43.16	3.20
16.0	900.0	13.0	4.11	326.50	2043.19	7.99	0.20	23.05	268.35	18.10	68.88	4.65	46.05	3.11
16.0	1000.0	35.0	2.45	215.60	606.32	14.20	0.15	17.90	229.63	23.45	48.31	4.93	31.65	3.23
16.0	1000.0	24.0	2.94	258.20	976.43	11.66	0.16	19.13	256.77	21.90	57.02	4.86	37.55	3.20
16.0	1000.0	18.0	3.36	295.60	1515.86	10.01	0.16	18.27	306.74	22.85	65.88	4.91	43.24	3.22
16.0	1000.0	14.0	3.78	331.90	1844.94	8.74	0.16	19.10	328.55	21.79	73.22	4.86	48.23	3.20
16.0	1000.0	11.0	4.20	370.10	2512.52	7.66	0.18	21.37	325.78	19.43	79.28	4.73	52.70	3.14

NF--Number of ferrites in a half-wave cavity
CG--Capacitance of gap capacitor
UR--Relative permeability of ferrite
F0--Frequency of fundmental oscillation
H0--Magnet field on the outer wall of cavity
A1--Ferrite biasing current
BB--Magnetic flux density
UQ--Power losses in unit volume

PF--Power losses in whole ferrites
Q0--Qulity of cavity without beam loading
Z0--Shunt impedence without beam loading
Q1,Z1--Qulity and shunt impedence with beam loading of 3A average current
Q2,Z2--Qulity and shunt impedence with beam loading of 5A average current

NF	CG (PF)	UR	F0 (MHz)	H0 (A/M)	A1 (A)	BB (mT)	UQ (W/cm3)	PF (KW)	Q0	Z0 (KOHM/M)	Q1	Z1 (KOHM/M)	Q2	Z2 (KOMH/M)
17.0	300.0	113.0	2.35	67.93	88.14	14.45	0.13	16.53	78.36	25.50	15.42	5.02	10.05	3.27
17.0	300.0	78.0	2.82	81.58	296.20	11.97	0.16	19.43	80.07	21.70	17.90	4.85	11.80	3.20
17.0	300.0	57.0	3.29	95.17	440.53	10.21	0.15	19.25	94.25	21.89	20.93	4.86	13.78	3.20
17.0	300.0	43.0	3.78	109.20	543.09	8.84	0.17	20.84	99.89	20.22	23.59	4.77	15.63	3.16
17.0	300.0	35.0	4.18	120.70	606.32	7.95	0.20	25.54	90.06	16.50	24.75	4.53	16.68	3.06
17.0	400.0	92.0	2.29	85.35	208.28	14.78	0.13	15.66	104.09	26.91	19.62	5.07	12.73	3.29
17.0	400.0	67.0	2.67	99.78	370.29	12.58	0.15	18.80	101.36	22.41	22.10	4.89	14.53	3.21
17.0	400.0	48.0	3.15	117.50	505.16	10.61	0.15	18.84	119.02	22.35	26.01	4.88	17.10	3.21
17.0	400.0	35.0	3.67	137.00	606.32	9.02	0.15	18.92	138.11	22.25	30.29	4.88	19.92	3.21
17.0	400.0	27.0	4.16	155.20	785.65	7.89	0.20	24.43	121.17	17.22	32.26	4.59	21.66	3.08
17.0	500.0	67.0	2.41	110.40	370.29	13.92	0.13	16.67	126.54	25.27	25.09	5.01	16.35	3.27
17.0	500.0	49.0	2.81	128.70	497.73	11.87	0.15	18.69	131.55	22.53	28.57	4.89	18.77	3.21
17.0	500.0	38.0	3.18	145.60	582.24	10.41	0.15	18.42	150.91	22.84	32.42	4.91	21.28	3.22
17.0	500.0	28.0	3.69	168.70	733.73	8.89	0.15	18.69	172.25	22.50	37.45	4.89	24.61	3.21
17.0	500.0	22.0	4.14	189.30	1132.86	7.84	0.19	23.52	153.52	17.87	39.78	4.63	26.63	3.10
17.0	600.0	56.0	2.42	131.10	447.71	13.82	0.13	16.52	151.68	25.49	29.87	5.02	19.46	3.27
17.0	600.0	41.0	2.82	152.60	558.60	11.77	0.15	18.35	158.98	22.94	34.04	4.91	22.34	3.22
17.0	600.0	29.0	3.33	180.40	687.66	9.84	0.14	17.97	191.64	23.39	40.41	4.93	26.48	3.23
17.0	600.0	22.0	3.80	205.90	1132.86	8.52	0.16	19.75	198.70	21.25	45.16	4.83	29.80	3.19
17.0	600.0	18.0	4.18	226.30	1515.86	7.67	0.18	22.44	192.21	18.70	48.15	4.68	32.11	3.12
17.0	700.0	52.0	2.33	146.00	476.71	14.29	0.12	15.46	180.13	27.23	33.63	5.08	21.81	3.30
17.0	700.0	35.0	2.83	177.10	606.32	11.66	0.14	18.06	186.70	23.28	39.52	4.93	25.90	3.23
17.0	700.0	26.0	3.26	204.30	843.41	10.00	0.14	17.65	220.07	23.78	45.80	4.95	29.97	3.24
17.0	700.0	20.0	3.70	231.40	1312.67	8.71	0.14	18.00	244.02	23.28	51.65	4.93	33.86	3.23
17.0	700.0	16.0	4.10	256.60	1521.27	7.73	0.17	21.78	224.59	19.32	54.90	4.72	36.51	3.14
17.0	800.0	45.0	2.35	166.90	527.77	14.13	0.12	15.46	206.10	27.19	38.52	5.08	24.98	3.30
17.0	800.0	30.0	2.86	203.10	647.43	11.47	0.14	17.73	218.53	23.69	45.62	4.95	29.87	3.24
17.0	800.0	22.0	3.32	235.50	1132.86	9.75	0.14	17.27	259.51	24.26	53.17	4.97	34.75	3.25
17.0	800.0	17.0	3.74	266.00	1626.22	8.51	0.15	18.21	277.43	22.96	59.35	4.91	38.94	3.22
17.0	800.0	13.0	4.24	301.00	2043.19	7.36	0.17	21.00	271.92	19.88	65.04	4.76	43.15	3.15
17.0	900.0	40.0	2.35	186.80	566.43	14.06	0.12	15.30	233.12	27.45	43.23	5.09	28.02	3.30
17.0	900.0	27.0	2.84	225.90	785.65	11.48	0.14	17.47	246.48	24.01	50.90	4.96	33.29	3.24
17.0	900.0	20.0	3.28	260.50	1312.67	9.80	0.14	16.96	291.91	24.65	59.04	4.99	38.54	3.25
17.0	900.0	16.0	3.64	289.30	1521.27	8.71	0.13	16.76	327.29	24.89	65.68	5.00	42.85	3.26
17.0	900.0	12.0	4.16	330.30	2265.72	7.46	0.17	20.77	301.07	20.06	71.53	4.77	47.42	3.16
17.0	1000.0	36.0	2.35	206.80	598.24	14.01	0.12	15.17	259.85	27.67	47.88	5.10	31.02	3.30
17.0	1000.0	24.0	2.86	251.20	976.43	11.35	0.14	17.16	278.54	24.41	56.79	4.98	37.10	3.25
17.0	1000.0	18.0	3.28	287.90	1515.86	9.75	0.13	16.66	327.59	25.05	65.41	5.00	42.66	3.26
17.0	1000.0	14.0	3.68	323.60	1844.94	8.53	0.13	16.80	363.82	24.75	73.35	4.99	47.87	3.26
17.0	1000.0	11.0	4.11	361.20	2512.52	7.48	0.16	20.23	336.95	20.53	78.63	4.79	52.04	3.17

NF--Number of ferrites in a half-wave cavity
CG--Capacitance of gap capacitor
UR--Relative permeability of ferrite
F0--Frequency of fundmental oscillation
H0--Magnet field on the outer wall of cavity
A1--Ferrite biasing current
BB--Magnetic flux density
UQ--Power losses in unit volume

PF--Power losses in whole ferrites
Q0--Qulity of cavity without beam loading
Z0--Shunt impedence without beam loading
Q1,Z1--Qulity and shunt impedence with beam loading of 3A average current
Q2,Z2--Qulity and shunt impedence with beam loading of 5A average current

NF	CG (PF)	UR	F0 (MHz)	H0 (A/M)	A1 (A)	BB (mT)	UQ (W/cm3)	PF (KW)	Q0	Z0 (KOHM/M)	Q1	Z1 (KOHM/M)	Q2	Z2 (KOMH/M)
18.0	300.0	107.0	2.35	68.02	121.04	13.70	0.11	14.85	87.10	28.39	15.71	5.12	10.16	3.31
18.0	300.0	74.0	2.82	81.62	322.57	11.37	0.13	17.40	89.17	24.23	18.29	4.97	11.95	3.25
18.0	300.0	54.0	3.29	95.29	462.15	9.68	0.13	17.47	103.71	24.13	21.34	4.96	13.95	3.25
18.0	300.0	41.0	3.76	109.00	558.60	8.41	0.15	19.31	107.32	21.82	23.90	4.86	15.74	3.20
18.0	300.0	33.0	4.18	121.20	561.79	7.53	0.17	22.38	102.88	18.82	25.65	4.69	17.09	3.13
18.0	400.0	87.0	2.28	85.49	238.85	14.00	0.10	13.90	117.41	30.32	20.07	5.18	12.92	3.34
18.0	400.0	59.0	2.77	103.50	426.25	11.49	0.13	17.04	115.96	24.73	23.40	4.99	15.27	3.26
18.0	400.0	45.0	3.16	118.20	527.77	10.01	0.13	17.04	132.36	24.72	26.72	4.99	17.44	3.26
18.0	400.0	34.0	3.62	135.50	544.92	8.67	0.13	17.11	150.99	24.60	30.59	4.98	19.97	3.25
18.0	400.0	26.0	4.12	154.20	843.41	7.54	0.16	21.78	135.01	19.32	33.00	4.72	21.94	3.14
18.0	500.0	63.0	2.42	110.90	398.04	13.15	0.12	15.31	138.36	27.51	25.61	5.09	16.60	3.30
18.0	500.0	44.0	2.88	132.20	535.40	10.95	0.13	16.74	150.75	25.14	30.01	5.01	19.57	3.26
18.0	500.0	34.0	3.27	149.80	544.92	9.58	0.13	16.71	171.15	25.18	34.04	5.01	22.19	3.26
18.0	500.0	27.0	3.66	167.50	785.65	8.51	0.13	17.09	186.90	24.59	37.87	4.98	24.73	3.25
18.0	500.0	21.0	4.12	188.90	1219.84	7.46	0.16	21.49	167.60	19.56	40.59	4.74	26.97	3.15
18.0	600.0	53.0	2.42	131.20	469.41	13.09	0.11	15.11	165.97	27.86	30.41	5.10	19.69	3.31
18.0	600.0	36.0	2.92	158.50	598.24	10.74	0.12	16.45	183.99	25.57	36.14	5.02	23.53	3.27
18.0	600.0	28.0	3.30	179.00	733.73	9.43	0.12	16.46	207.36	25.52	40.80	5.02	26.57	3.27
18.0	600.0	22.0	3.70	200.90	1132.86	8.32	0.13	17.41	219.87	24.10	45.28	4.96	29.61	3.25
18.0	600.0	17.0	4.19	227.10	1626.22	7.27	0.16	20.67	209.19	20.29	49.27	4.78	32.64	3.16
18.0	700.0	49.0	2.34	146.50	497.73	13.51	0.11	14.06	199.12	29.92	34.41	5.17	22.18	3.33
18.0	700.0	33.0	2.83	177.70	561.79	11.04	0.12	16.27	208.49	25.83	40.61	5.03	26.43	3.27
18.0	700.0	23.0	3.37	211.30	1051.72	9.15	0.12	16.19	248.76	25.91	48.35	5.04	31.46	3.28
18.0	700.0	18.0	3.79	237.40	1515.86	8.04	0.14	18.04	250.37	23.21	53.12	4.92	34.82	3.23
18.0	700.0	15.0	4.13	258.70	1670.97	7.30	0.15	20.22	243.21	20.70	56.41	4.80	37.31	3.17
18.0	800.0	42.0	2.37	168.20	550.82	13.29	0.11	14.31	224.90	29.38	39.45	5.15	25.45	3.33
18.0	800.0	29.0	2.83	201.30	687.66	10.99	0.12	16.01	240.19	26.22	46.23	5.05	30.05	3.28
18.0	800.0	22.0	3.23	229.90	1132.86	9.52	0.12	15.85	276.37	26.43	52.86	5.05	34.34	3.28
18.0	800.0	17.0	3.76	267.30	1626.22	8.55	0.15	19.91	255.60	21.01	58.59	4.82	38.70	3.18
18.0	800.0	13.0	4.14	294.40	2043.19	7.20	0.15	19.59	285.31	21.30	64.72	4.83	42.70	3.19
18.0	900.0	38.0	2.35	186.70	582.24	13.35	0.11	13.97	255.44	30.06	43.97	5.17	28.33	3.33
18.0	900.0	27.0	2.77	220.30	785.65	11.19	0.12	15.82	265.79	26.51	50.70	5.06	32.94	3.29
18.0	900.0	19.0	3.28	260.60	1411.34	9.32	0.12	15.62	317.37	26.76	60.09	5.07	39.01	3.29
18.0	900.0	14.0	3.78	300.70	1844.94	7.92	0.13	17.28	330.20	24.12	67.94	4.96	44.42	3.25
18.0	900.0	12.0	4.06	322.90	2265.72	7.29	0.12	15.78	386.74	26.31	74.24	5.05	48.25	3.28
18.0	1000.0	34.0	2.36	207.20	544.92	13.26	0.11	13.93	283.95	30.11	48.82	5.18	31.45	3.33
18.0	1000.0	23.0	2.84	250.20	1051.72	10.83	0.12	15.56	306.19	26.89	57.75	5.07	37.48	3.29
18.0	1000.0	17.0	3.28	288.70	1626.22	9.24	0.12	15.34	357.34	27.19	66.79	5.08	43.31	3.30
18.0	1000.0	13.0	3.72	327.20	2043.19	8.00	0.12	16.32	379.46	25.47	74.77	5.02	48.70	3.27
18.0	1000.0	10.0	4.20	369.00	2783.59	6.94	0.14	18.17	383.01	22.80	82.40	4.91	54.10	3.22

NF--Number of ferrites in a half-wave cavity
CG--Capacitance of gap capacitor
UR--Relative permeability of ferrite
F0--Frequency of fundmental oscillation
H0--Magnet field on the outer wall of cavity
A1--Ferrite biasing current
BB--Magnetic flux density
UQ--Power losses in unit volume

PF--Power losses in whole ferrites
Q0--Qulity of cavity without beam loading
Z0--Shunt impedence without beam loading
Q1,Z1--Qulity and shunt impedence with beam loading of 3A average current
Q2,Z2--Qulity and shunt impedence with beam loading of 5A average current

APPENDIX: FORMULAS FOR CALCULATION OF BOOSTER CAVITY
IN CYLINDRICAL COORDINATES

1. AVERAGE ACCELERATING FIELD (From 'SUPERFISH' program)

$$E_0 = \frac{1}{L}\int_{-L/2}^{L/2} E_z(z, r=0)\, dz$$

Ez--Electric field strength in z axis
L---Length of cavity in half-wave

2. STORED ENERGY (From 'SF' program)

$$U = \frac{\varepsilon}{2} \frac{\int [H_\theta(z,r)]^2 r\,dr\,dz}{\int r\,dr\,dz}$$

ε --Dielectric constant
H_θ--Component of the magnetic field

3. POWER LOSSES

$$P = P_w + P_s + P_f + P_b$$

Pw,Ps--Power loss on walls and stems,which are given by 'SF' program

Pf= $Vol \cdot \mu Q(F, B_m)$ --Power losses on ferrites

Vol--Volume of whole ferrites
Bm --Maximum megnet flux density in ferrite
F --Oscillating frequency given by 'SF'
Pb=Ib•Eo --Power loss of average beam current

4. SHUNT IMPEDANCE

$$Z_S = E_0^2 L / P$$

5. QUAILTY FACTOR

$$Q = 2\pi F\, U / P$$