Design of 118 MHz Twelfth Harmonic Cavity of APS PAR

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I. Introduction

Two radio frequency (RF) cavities are needed in the Positron Accumulator Ring (PAR) of the Advanced Photon Source. One is for the first harmonic frequency at 9.8 MHz, and the other is for the twelfth harmonic frequency at 118 MHz. This note reports on the design of the 118 MHz RF cavity. Computer models are used to find the mode frequencies, impedances, Q-factors, and field distributions in the cavity.

The computer codes MAFIA [1], URMEL, and URMEL-T [2] are useful tools which model and simulate the resonance characteristics of a cavity. These codes employ the finite difference method to solve Maxwell's equations. MAFIA is a three-dimensional problem solver and uses square patches to approximate the inner surface of a cavity. URMEL and URMEL-T are two-dimensional problem solvers and use rectangular and triangular meshes, respectively. URMEL-T and MAFIA can handle problems with arbitrary dielectric materials located inside the boundary.

The cavity employs a circularly cylindrical ceramic window to limit the vacuum to the beam pipe. The ceramic window used in the modeling will have a wall thickness of $0.9cm$. This wall thickness is not negligible in determining the resonant frequencies of the cavity. In the following, results of two- and three-dimensional modeling of the cavities using the URMEL-T and MAFIA codes are reported.

II. Design Constraints

The cavity parameters used in the design of the twelfth harmonic PAR cavity are shown in Table 1 [3]. The twelfth harmonic cavity employs a $\lambda/2$ reentrant coaxial structure and is symmetrical with respect to the equatorial plane. The accelerating gap is placed at the center of the cavity. The length of the cavity has $0.9m$ limit. The cavity gap voltage is specified to $30KV$. The accelerating gap is vacuum sealed with a ceramic window to minimize the vacuum volume and multipactoring effects.

Using commercially available ceramic windows can save cost and time in cavity manufacturing. A commercially available circularly cylindrical window such as the model 807B3006- 09-W of Ceramaseal is a possible choice. This ceramic part has

2

an inner cylinder diameter of 6″ and a length of 4.5″. A circular stainless steel ring with a diameter of 6″ is brazed to each end of the ceramic tube. In computer simulations $\epsilon_r = 9.0$ is used for modeling the ceramic window.

In the following, results of computer modeling and design of the PAR cavity are presented. Physical dimensions and dielectric properties of the ceramic window described above are used in all models. The beam pipe is chosen to have a 6″ diameter to match the ceramic window for easier fabrication. The 6″ diameter beam pipe has cutoff frequencies of $1.5GHz$ and $1.16GHz$ for the TM_{01} and TE_{11} modes, respectively.

III. Simulations and Results

For the twelfth harmonic frequency cavity, both URMEL-T and MAFIA codes are used for comparison; the two-dimensional model with URMEL-T and the three-dimensional model with MAFIA. Both codes were used to find the first 15 modes of each type of boundary condition. The cavity is symmetrical with respect to the equatorial plane. The right half of the cavity is used in URMEL-T with each type of azimuthal variation; for monopole and dipole. A quarter of the half cavity is used for 3-D MAFIA with eight combinations of boundary conditions. Modes are listed in tables for each model in order of ascending frequency.

URMEL-T result

The cross-sectional view of the cavity is shown in Figure 1. The internal dimensions of the cavity are $0.80m$ in length and $0.70m$ in diameter. The meshes generated by the code are shown in Figure 2. Since there is a symmetry about the equatorial plane of the cavity, a half cavity is modeled. The code input data for this cavity is shown in Table 2. Different boundary conditions at the cavity mid-plane allow computation of the symmetric and anti-symmetric modes. That is, the plane of symmetry is replaced by either an electric wall or a magnetic wall in order to find all modes. At the left end of the cavity, an electric wall defines the anti-symmetric modes and a magnetic wall defines the symmetric modes. The longitudinal and the transverse impedances are found for each mode. R/Q is the longitudinal R/Q. For

3

dipole modes the transverse R/Q,

$$(R/Q)_t = \frac{(R/Q)}{(k * R_o)^{2m}},$$

is computed. Here m is the mode number and k is the wavenumber at each mode frequency. The impedances are found on axis ($R_o = 0.0$) for monopole modes and at the beam pipe radius ($R_o = 0.076m$) for modes of higher order than monopole. For monopole modes the code calculates the longitudinal impedance using the line integral of the longitudinal component of E^{peak} on the beam axis divided by twice the dissipated power. The first 25 modes found by URMEL-T for the cavity are listed in order of frequency in Table 3. For the fundamental mode, computed Q and shunt impedance R_s are 32,331 and 3.313, respectively.

The ratio of the outer to inner conductor radii, r_o/r_i, is chosen to be 2.3 ($Z_o = 50\Omega$). In order to increase the resistance to corona discharge, the end of the center conductors are rounded. For the fundamental mode, the square of the axial component of the gap electric field $|E_z(z)|^2$ at $r = 0.0$ is shown in Figure 3.

MAFIA result

Using rotational symmetry and the symmetry about the cavity midplane, a quarter of a half cavity was modeled with MAFIA. With this model the codes must be run for eight different cases with different boundary conditions in the three planes of symmetry: a plane of symmetry in each rectangular coordinate and a plane in either an electric wall or a magnetic wall. Figure 4 shows a three-dimensional view of the model of the cavity. Cavity dimensions used in the code input are identical to the dimensions used in the URMEL-T case. Table 4 shows the results of the MAFIA simulations for the first 20 monopole modes. Boundary conditions for the symmetric and anti-symmetric modes are as follows: $H^{tan}|_{x=0} = 0, H^{tan}|_{y=0} = 0, H^{tan}|_{z=0} = 0$ for symmetric modes, $H^{tan}|_{x=0} = 0, H^{tan}|_{y=0} = 0, E^{tan}|_{z=0} = 0$ for anti-symmetric modes. 72,111 mesh points were used in this model. Conductivity of copper is used for the computation of Q-factors. The monopole modes found by URMEL-T have been identified in the MAFIA result. Comparing the results of MAFIA and URMEL-T, MAFIA gives slightly lower frequencies and lower Q-

4

factors for most modes. Figures 5 through 9 show the electric field distribution of the first 5 monopole modes.

IV. Discussion and Conclusion

The URMEL-T code finds the modes with longitudinal or radial electric field component. Thus, the transverse electric monopole modes TE_{0mn} are not found. These fields have no impedance for a beam on the cavity axis, but have a transverse impedance for off-axis beams. The URMEL-T code does not give absolute location of the modes in azimuth in the cavity. The impedances are given as maxima and on the beam axis. With MAFIA, modes of higher frequency were not found as this would require a considerable increase in cpu time. The cavity design satisfies the dimensional limits shown in Table 1. The computed Q and R/Q at the fundamental mode frequencies are all greater than the values specified in Table 1.

References

[1] U. Laustroer et al, URMEL and URMEL-T User's Guide, DESY M-87-03.

[2] The MAFIA Collaboration, MAFIA User's Guide, LA-UR-90-1307.

[3] Advanced Photon Source Design Handbook - RF Section.

Table 1. PAR cavity parameters

f (MHz)	117.309
V (kV)	30
Type	$\lambda/2$
Length (m)	0.9
Z_0 (Ω)	50
Power (kW)	0.222
R_S (kΩ)	2020
Q	25,300
τ [= $2Q/\omega$] (μS)	68

Table 2. URMEL-T code input data for the 118MHz cavity

```
$FILE LPLO=T ITEST=0 LXY=F $END
PAR 12TH HARMONIC CAVITY
$BOUN $END
#MATDEF
3 (8.5,0.0) (1.0,0.0) 0
999
$MESH NPMAX=12000 MAT0=1 $END
#MATDIS
0 0
0.000 0.000
0.350 0.000
0.350 0.400
0.150 0.400
0.150 0.095
-1 0.040
0.110 0.055
0.087 0.055
-1 0.002
0.085 0.057
0.085 0.070
0.076 0.070
0.076 0.400
0.000 0.400
0.000 0.000
8888 8888
3 3
0.076 0.000
0.085 0.000
0.085 0.070
0.076 0.070
0.076 0.000
8888 8888
9999 9999
$MODE MROT=0 NMODE=15 FUP=1800 $END
$PLOT LCAVUS=T LMECI=T LMECU=T LMESH=T LFLE=T LFLH=T $END

$PRIN LER=F LEFI=F LEZ=T LHR=F LHFI=F LHZ=F $END
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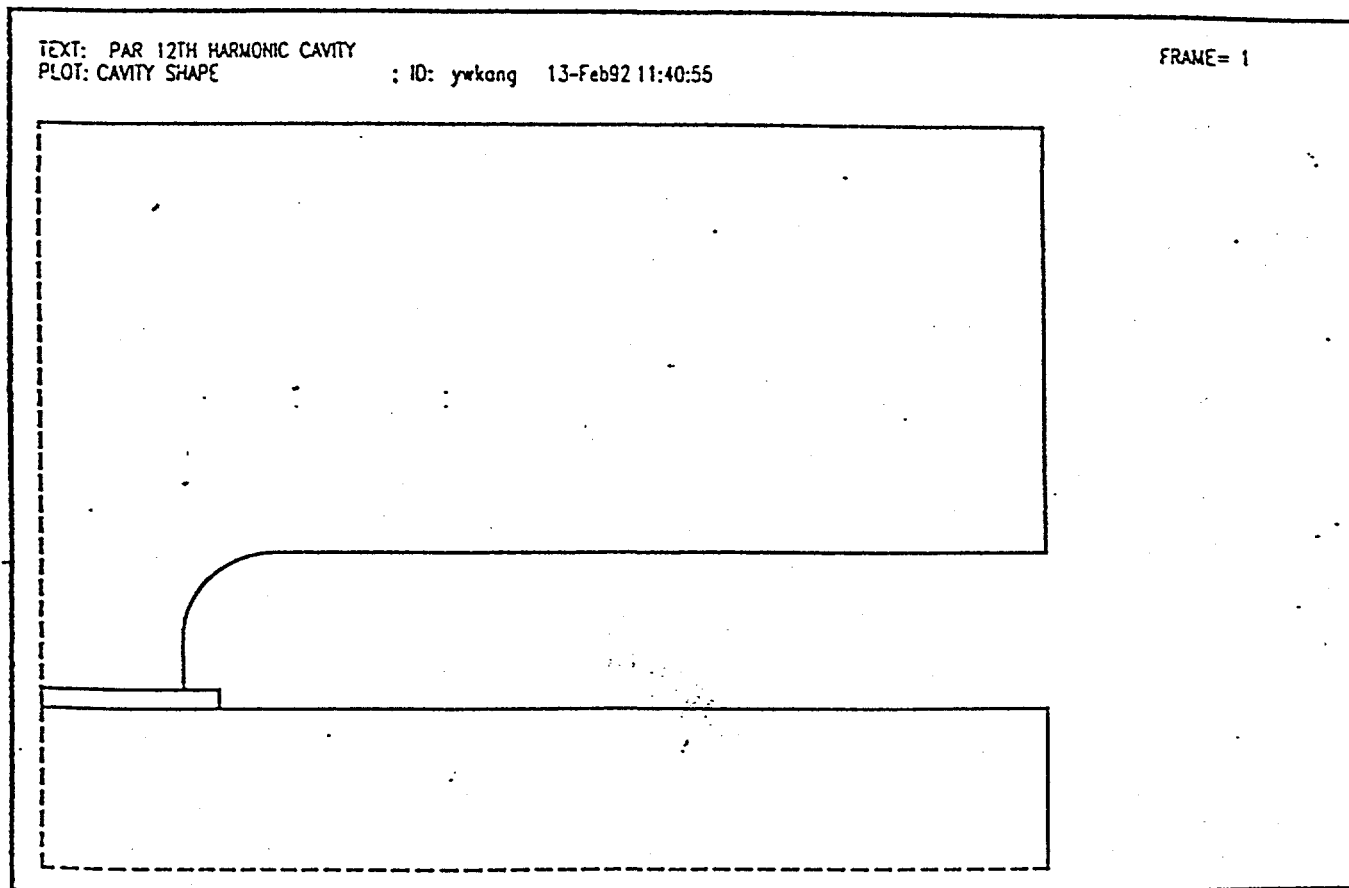
Figure 1. 2-D shape defined for the 118MHz cavity

TEXT: PSR 12TH HARMONIC CAVITY
PLOT: MESH
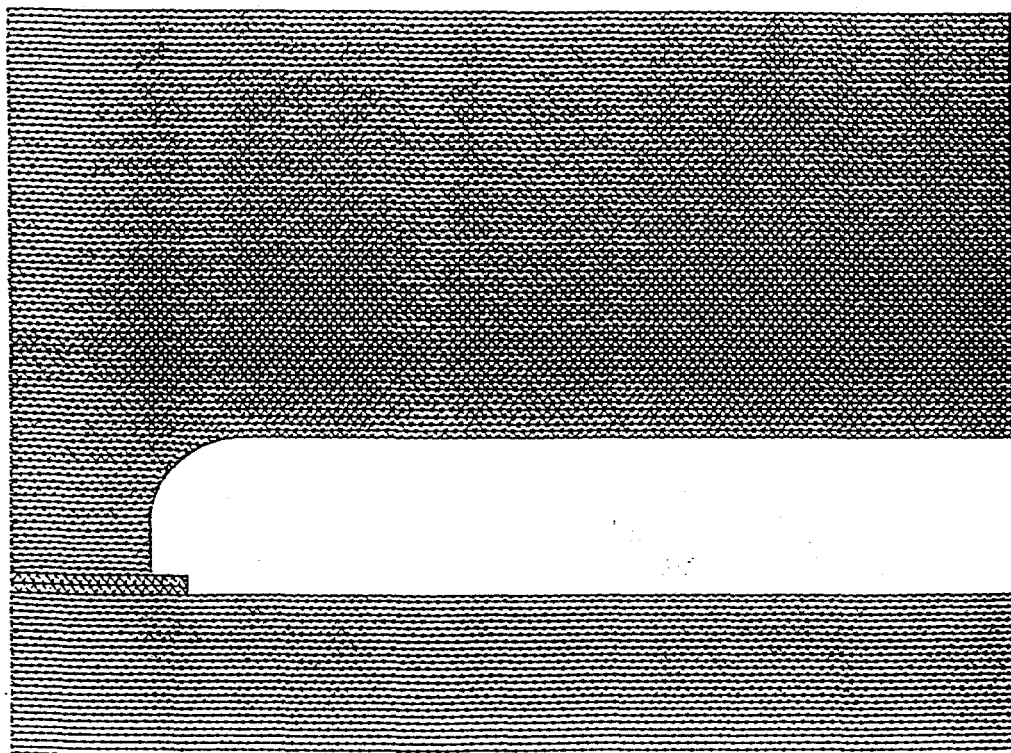: IO: ywkong   13-Feb92 12:46:55   FRAME= 2

Figure 2. Triangular meshes used in URMEL-T for the 118MHz cavity

9

Table 3. Computed modes with URMEL-T for the 118MHz cavity. TM0-monopole modes, TM1-dipole modes, EE-end plates are electric wall (symmetric modes), ME-plane of symmetry at $z = 0$ is magnetic wall and the end plate is electric wall (anti-symmetric modes). Voltages integrated at $R_o = 0.0m$ off axis for monopole modes and at $R_o = 0.076m$ off axis for dipole modes.

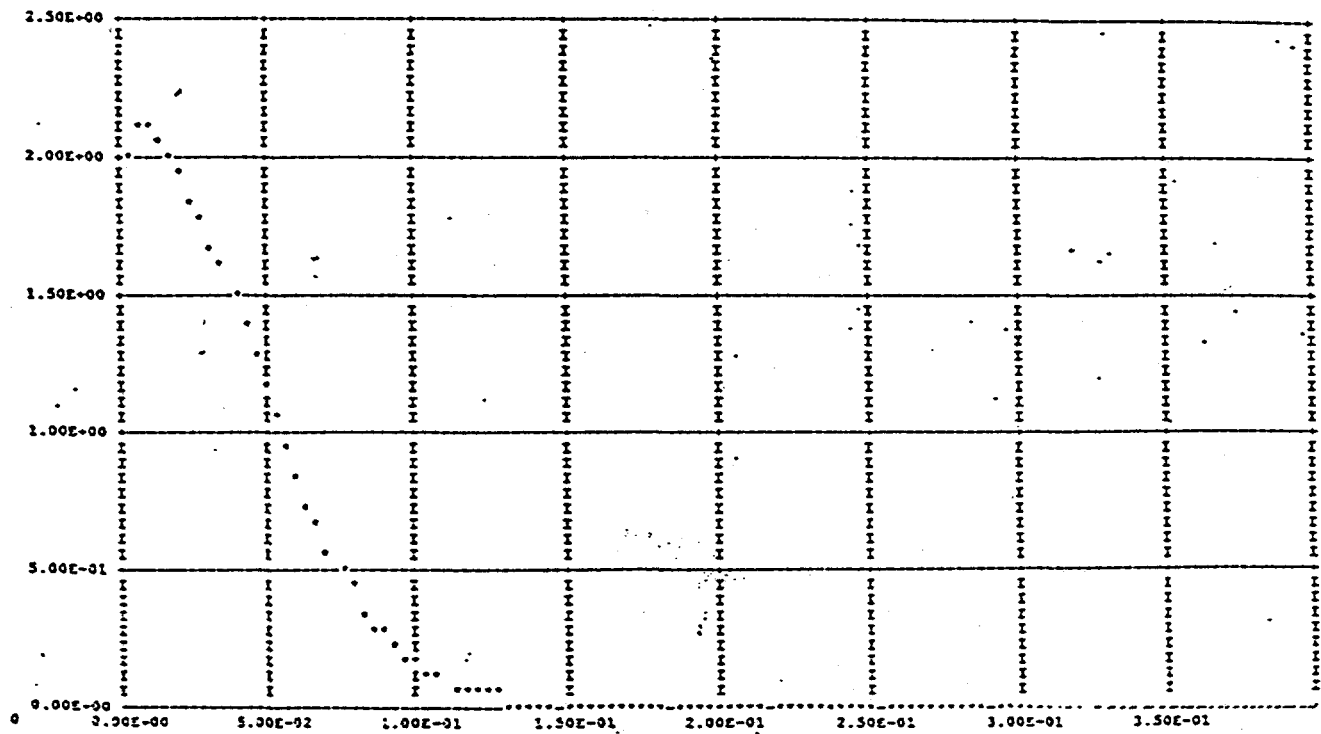| MODE TYPE	FREQUENCY (MHz)	R/Q@R_o (Ω)	$\frac{(R/Q)}{(K*R_o)^{2M}}$ (Ω)	Q	R_s (MΩ)
TM0-EE- 1	118.229	102.460		24493	3.313
TM0-ME- 1	193.095	0.004		26145	
1-ME- 1	276.384	0.006	0.031	39950	
1-EE- 1	353.864	19.247	60.581	43281	0.995
TM0-EE- 2	403.822	10.707		45612	0.715
1-EE- 2	502.910	26.648	41.527	52341	1.677
TM0-ME- 2	575.248	0.014		46946	0.001
1-ME- 2	606.503	0.011	0.012	51304	0.001
TM0-EE- 3	719.249	7.895		53952	0.481
TM0-EE- 4	748.976	0.241		44811	0.014
TM0-ME- 3	767.353	0.002		33323	
1-EE- 3	771.545	1.955	1.294	41962	0.097
1-EE- 4	782.828	8.496	5.465	58834	0.693
1-ME- 3	787.995	0.077	0.049	41382	0.004
1-ME- 4	796.269	0.101	0.062	37339	0.004
TM0-EE- 5	805.933	1.970		37693	0.097
1-EE- 5	848.121	9.586	5.253	43066	0.523
1-EE- 6	883.133	0.162	0.082	47768	0.008
1-ME- 5	894.882	3.501	1.723	34960	0.123
TM0-ME- 4	932.183			41552	
1-ME- 6	952.382	0.029	0.013	44834	0.002
TM0-ME- 5	956.203	0.064		53765	0.005
1-ME- 7	961.308	0.296	0.126	59979	0.021
1-ME- 8	980.532	0.114	0.047	53131	0.008
TM0-EE- 6	1003.88	1.743		44702	0.099

Figure 3. $|E_z(z)|^2$ at radius $R = 0.0$ for the fundamental mode of the $118MHz$ cavity
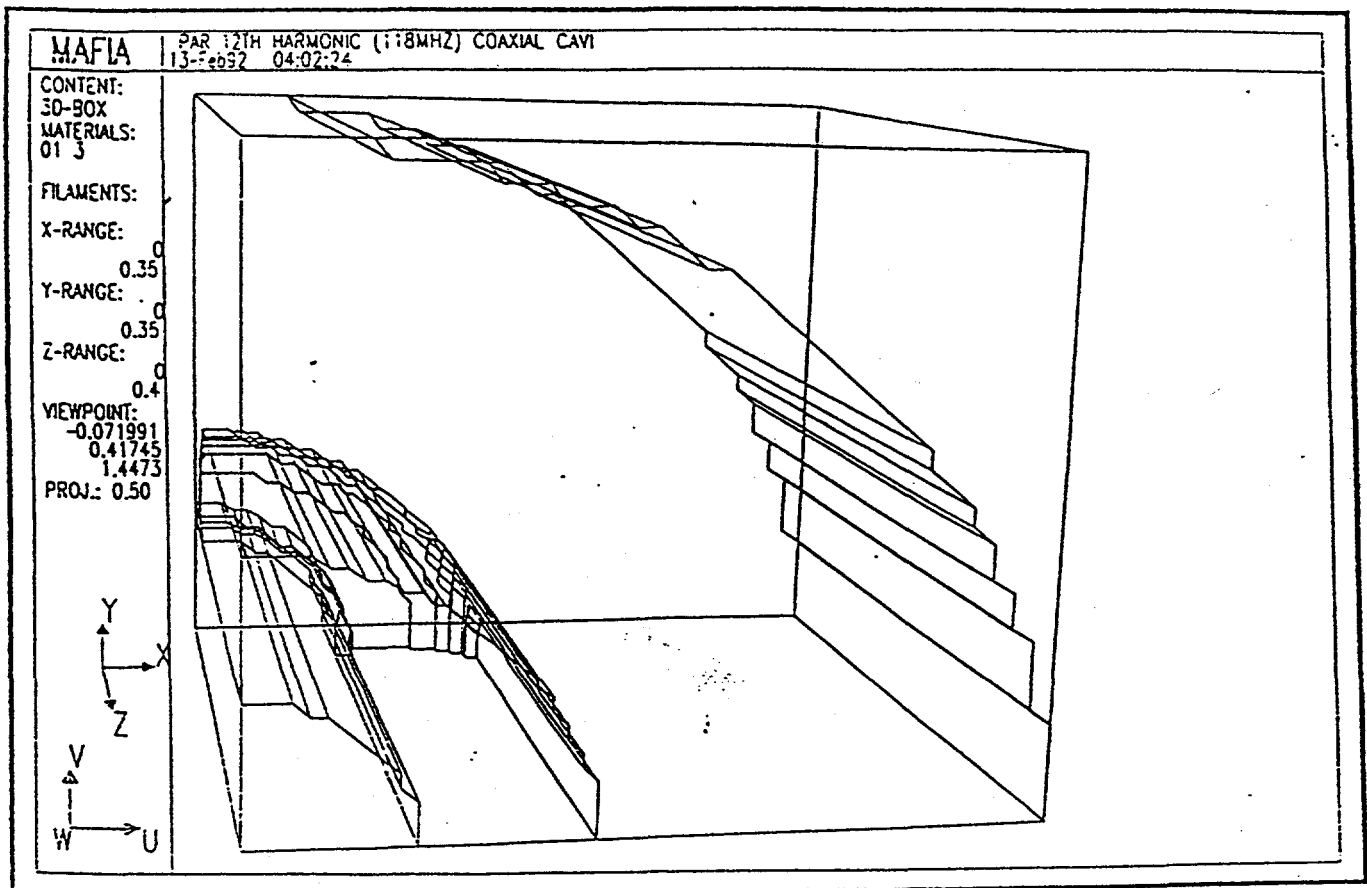
Figure 4. 3-D shape defined for the 118MHz cavity
A quarter of a half cavity is modeled

Table 4. Computed monopole modes with MAFIA for the 118MHz cavity. TM0-monopole modes, EEE-three planes of symmetry in $x, y, z-$ cooredinates are all electric walls (symmetric modes), EEM-electric walls for x, and $y-$ symmetry, and magnetic wall for $z-$ symmetry (anti-symmetric modes).

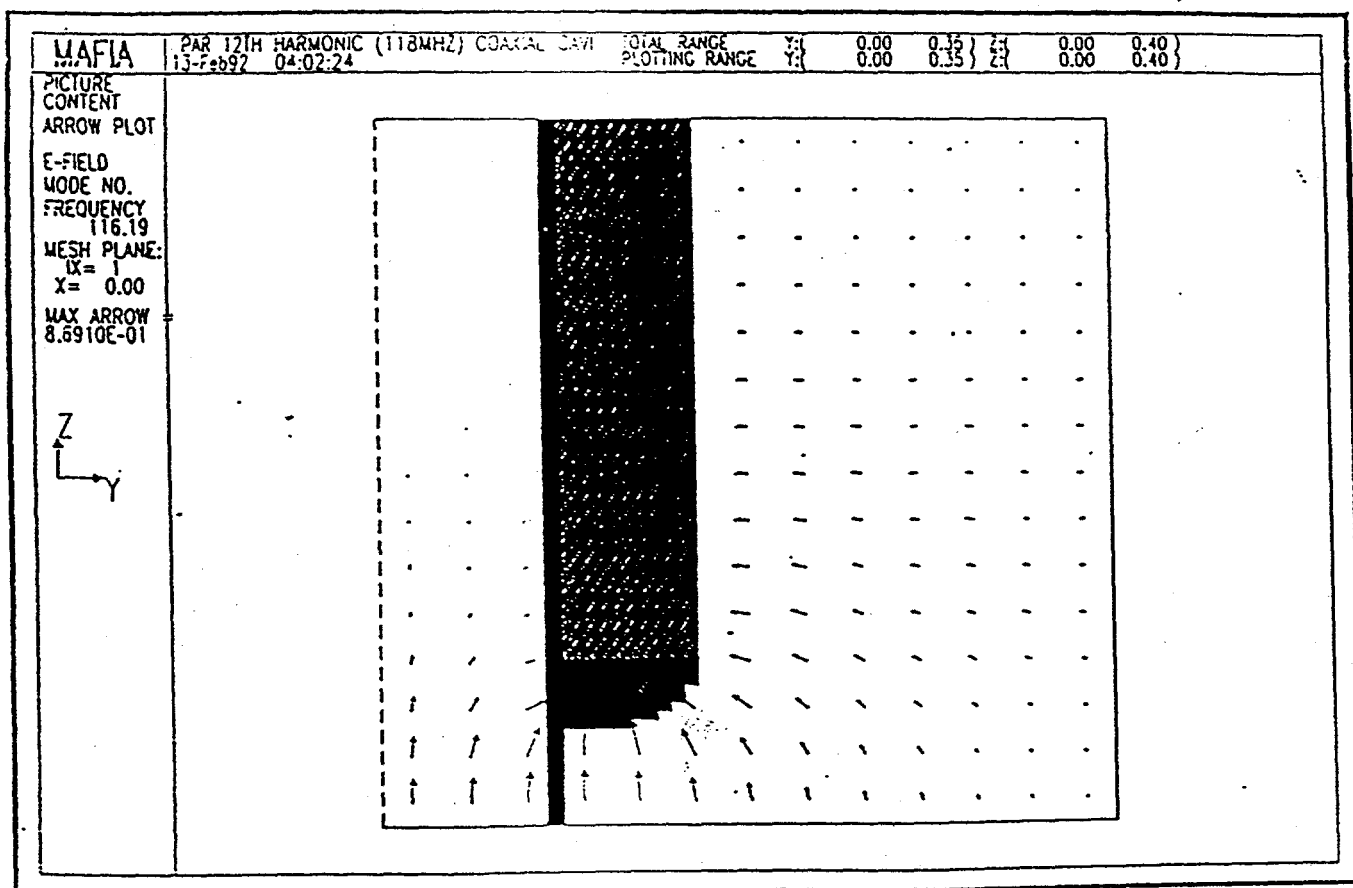| MODE TYPE	FREQUENCY (MHz)	TOTAL ENERGY (pJoule)	LOSSES (μW)	Q
TM0-EEE- 1	116.186	5.122E-03	1.603E-04	2.332E+04
TM0-EEM- 1	192.813	1.247E-02	5.229E-04	2.889E+04
TM0-EEE- 2	401.961	2.060E-02	1.579E-03	3.293E+04
TM0-EEM- 2	429.965	1.316E-02	6.484E-04	5.483E+04
TM0-EEE- 3	520.028	1.667E-02	1.156E-03	4.714E+04
TM0-EEM- 3	574.491	2.183E-02	1.534E-03	5.137E+04
TM0-EEM- 4	686.745	1.955E-02	1.316E-03	6.410E+04
TM0-EEE- 4	711.538	4.046E-03	4.818E-04	3.754E+04
TM0-EEE- 5	714.605	1.329E-02	1.666E-03	3.582E+04
TM0-EEM- 5	734.653	8.630E-03	1.356E-09	2.938E+10
TM0-EEM- 6	740.334	3.141E-02	2.526E-03	5.784E+04
TM0-EEE- 6	749.552	3.053E-02	3.568E-03	4.029E+04
TM0-EEM- 7	771.460	3.507E-02	4.563E-03	3.726E+04
TM0-EEE- 7	805.815	3.304E-02	2.935E-03	5.700E+04
TM0-EEE- 8	807.336	3.902E-02	5.919E-03	3.344E+04
TM0-EEM- 8	840.571	8.498E-03	3.677E-11	1.221E+12
TM0-EEE- 9	842.123	1.655E-02	1.897E-04	4.616E+05
TM0-EEE-10	843.062	2.114E-02	2.123E-03	5.277E+04
TM0-EEM- 9	864.520	1.883E-02	2.041E-03	5.014E+04
TM0-EEM-10	895.209	9.930E-03	1.049E-03	5.327E+04

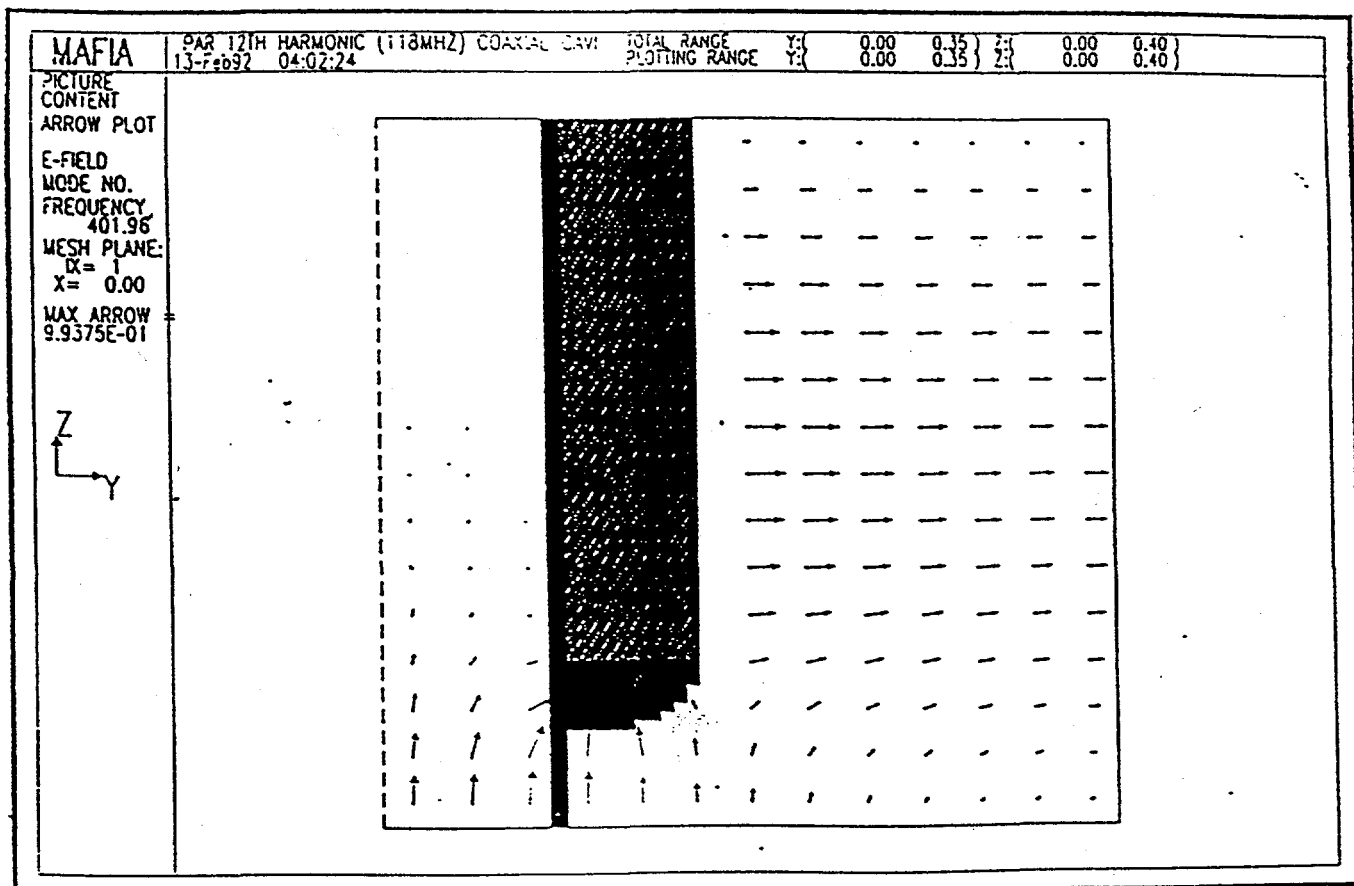Figure 5. Electric field plot for the fundamental mode
of the 118MHz cavity

Figure 6. Electric field plot of the 118MHz cavity
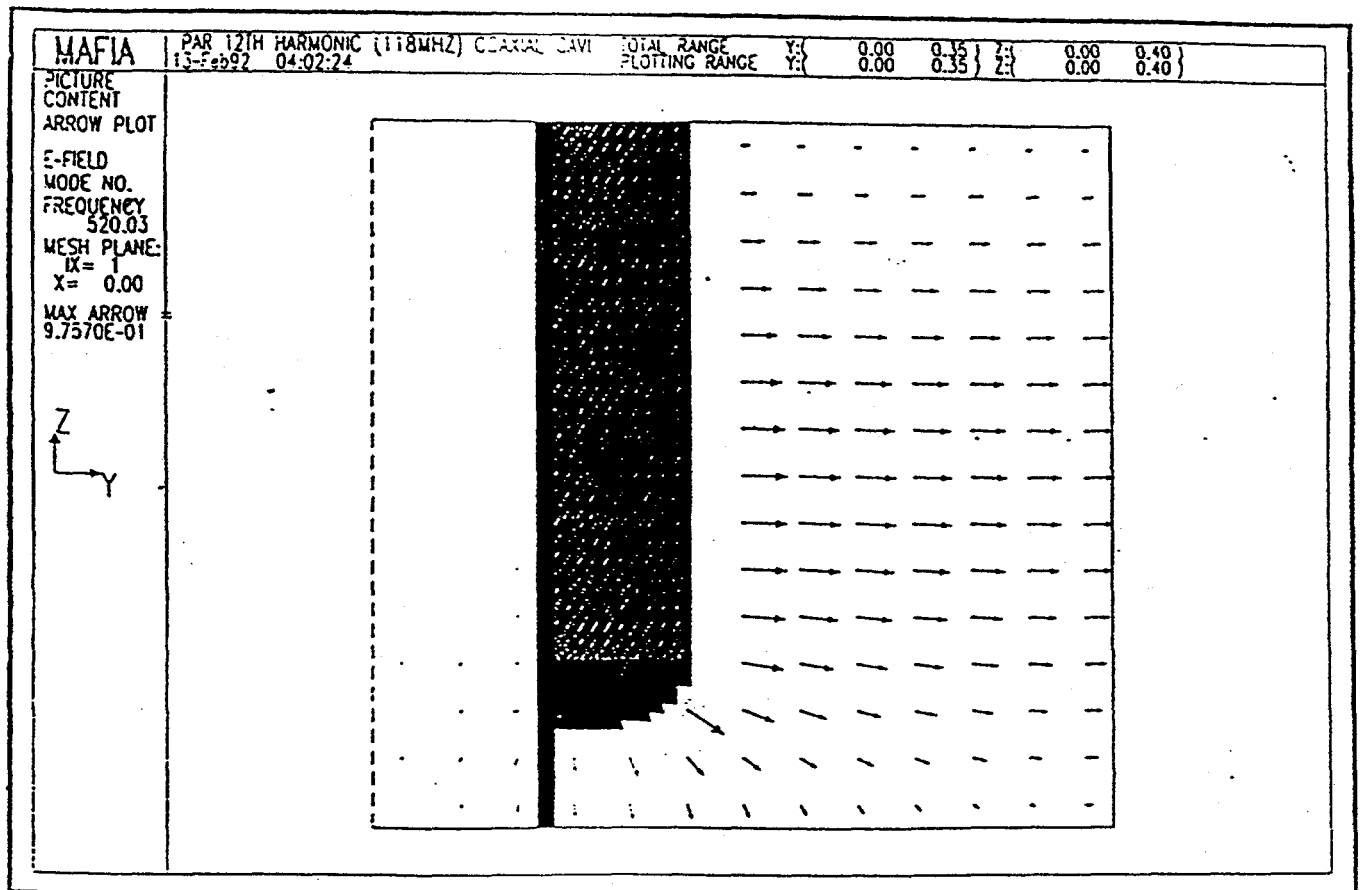for the mode at 401.96MHz

Figure 7. Electric field plot of the 118MHz cavity
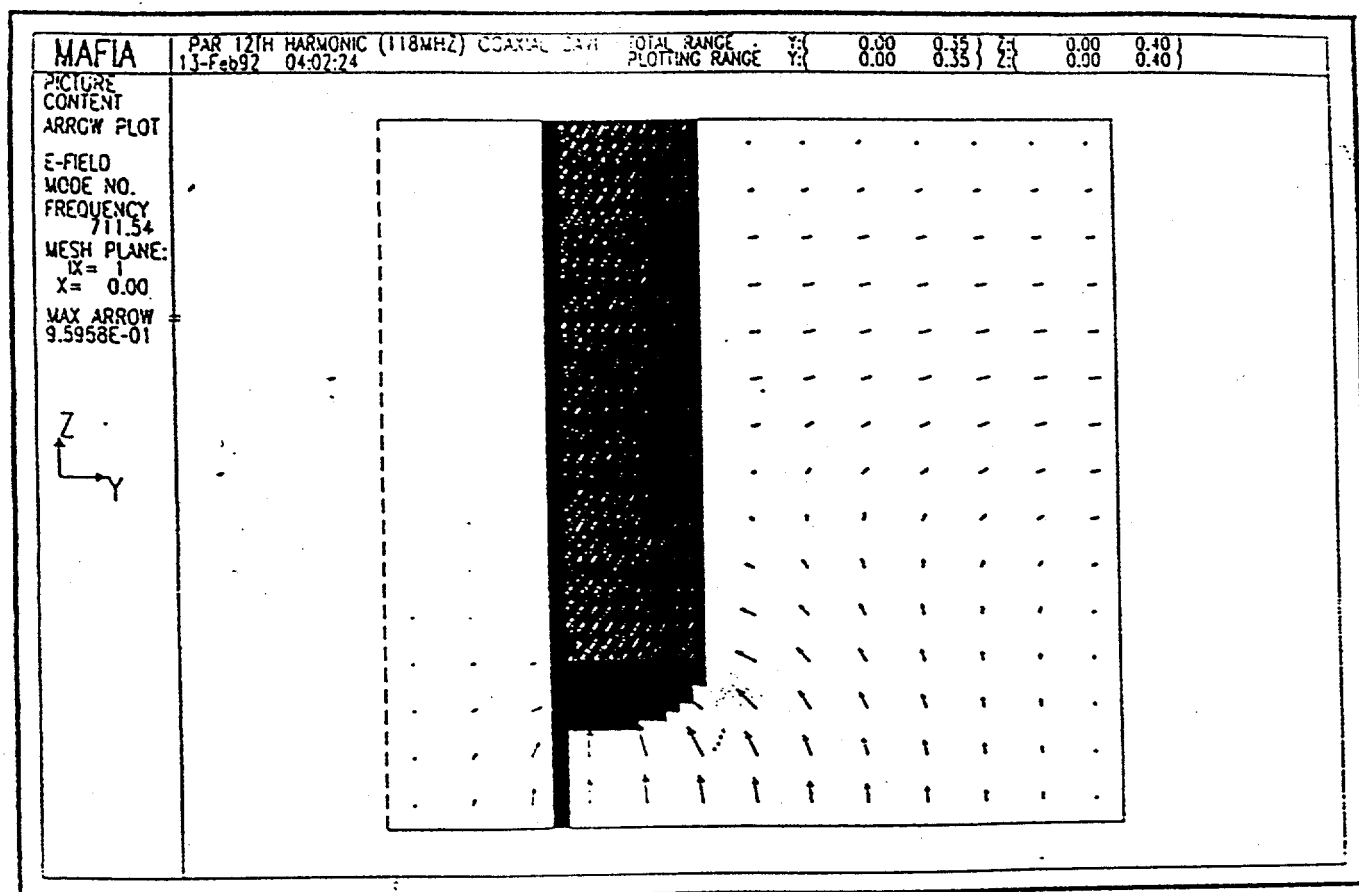for the mode at 520.03MHz

Figure 8. Electric field plot of the 118MHz cavity
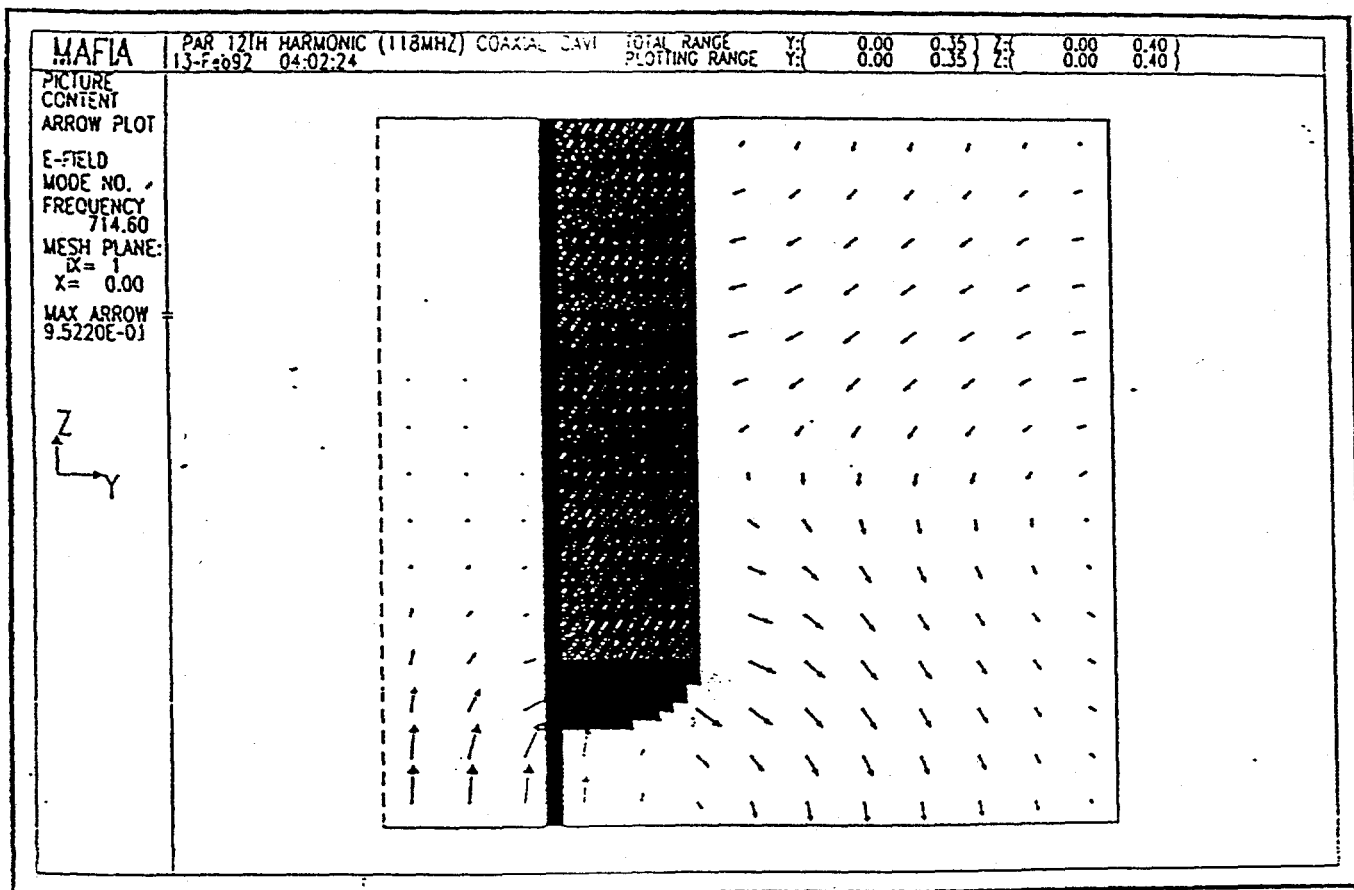for the mode at 711.54MHz

Figure 9. Electric field plot of the 118MHz cavity
for the mode at 714.62MHz