650 MHz 5-cell beta 1.0 cavity optimization

Technical Note TD-10-020

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Abstract

A brief overview of the 650 MHz 5-cell beta 1.0 cavity optimization process provided. Design limitations are discussed. Longitudinal and transverse higher order modes are studied. Results of multipacting simulation are presented.

INTRODUCTION

The new facility to be built in Fermilab - ProjectX consits of two parts: continues wave mode part and pulsed 3 to 8 GeV 1.3 GHz linac (fig.1). There is a suggestion (Valeri Lebedev) to use this pulsed linac in future for recirculator for muon collider. 650 MHz frequency is more preferable for this case, so new types of cavities are needed for these purposes. In this report results of 650 MHz 5-cell beta 1.0 cavity optimization are presented.

In this report process of cavity optimization is described and main results are discussed.

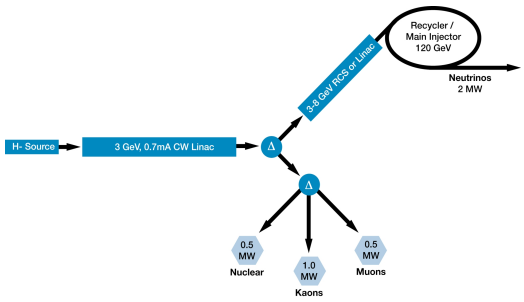


Figure 1: ProjectX concept

UNDERSTANDING OF THE OPTIMIZATION PROCESS

Designing of a cavity is a complex problem that should be solved in the respect of main limitations, e.g., flatness of the field in the cavity, field emission, mechanical stability, surface processing.

One of the significant limitation that should be taken into account is a field nonuniformity which is proportional to $\frac{\Delta f}{f} \cdot N^{3/2} \cdot k^{-1}$. Where $\frac{\Delta f}{f}$ – average relative error of cell frequency, N – number of cells in the cavity and k is a coupling coefficient which can be calculated as $\frac{2(f_\pi - f_0)}{f_\pi + f_0}$ (where f_π is a frequency of fundamental mode and f_0 is a frequency of the zero mode). The coupling coefficient should be optimized to maintain the field flatness in the whole cavity. Also it determines the iris radius of the cell.

The values of surface fields should not be too large to prevent the high-field Q-slope effect appearance, that is sharp drop in quality factor in excess of the threshold value of the magnetic field.

Other limitations connected with technological process of the cavity's development do not let to make field enhancement factors smaller, for example by reducing a wall-slope of the cell.

So the process of optimization means searching the cell's shape with parameters which will lead to the minimization both of the magnetic and electric field enhancement factors ($FEF_E = \frac{E_{peak}}{E_{acc}}$, $FEF_H = \frac{H_{peak}}{E_{acc}}$, where E_{acc} is the accelerating electric field, H_{peak} and E_{peak} are peak values of the surface fields), in the respect of main limitations to provide a higher gradient.

CELL GEOMETRY

The shape of the half-cell is described by two elleptical arcs (equatorial arc and iris arc) and a straight segment which connects them (Fig.2). The length of the half-inner cell is selected as $L = \frac{1}{4} \cdot \beta \cdot \lambda$, where λ is a wave-length of the

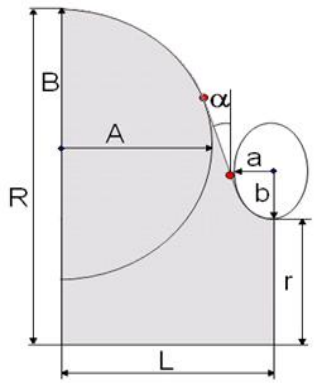


Figure 2: Geometrical parameters of a cell

fundamental mode.

CAVITY DESIGN PROCESS

Designing of the RF cavity can be divided into the three steps:

- Regular (middle) cell optimization.
  Varying geometrical parameters to get as small as possible magnetic field enhancement factor when electric field enhancement factor is approximately equal to 2.
- End cell optimization.
  Field enhancement factors for the end cell should not be greater than such are for the regular cell. The frequency spectrum of the end-cell should be close to regular cell's one. If this condition is not satisfied trapping of higher order modes can occur. Also geometric parameters of end and inner cells should coincide in the places of their connection.
- Complete 5-cell cavity optimization
  The complete 5-cell cavity is designed using parameters of inner and end cells. Field in the cavity should not be locked in the inner cells.

2D code Superslans and TunedCell programm for calculations were used.

Aperture 110 mm for cells was chosen. This value of aperture seems reasonable both from beam dynamics' and from the electrodynamics' points of view.

RESULTS

Inner-cell

Geometric parameters for the inner cell are presented in the table 1.

R	199.786 mm
r	55 mm
A	92.5 mm
B	84 mm
a	20 mm
b	28 mm
L	115.378 mm

Table 1: Optimized inner cell geometric parameters

End-cell

The optimized cavity is not symmetric so in the table 2 parameters for both left and right end-cells are presented.

	Left	Right
R	199.786 mm	199.786 mm
r	55 mm	55 mm
A	72.5 mm	85 mm
B	70 mm	60 mm
a	18 mm	15 mm
b	28 mm	50 mm
L	97.053 mm	114.868 mm

Table 2: Optimized end cell geometric parameters

Complete 5 cell cavity

The rf parameters for 5 cell cavity are summarized in the table 3.

Parameter	Magnitude	Units
Coupling coefficient	0.867	%
R/Q	700	Ohm
E_{peak}/E_{acc}	1.97	
H_{peak}/E_{acc}	3.65	mT/(MV/m)
G	268	Ohm
Wall angle	4.5	degree
Beam pipe dia	110	mm
Active length	1135	mm

Table 3: RF parameters for fundamental mode

The dispersion curve for first monopole pass band is show on the figure 4. The relative separation of the fundamental mode with its neighbor is 0.09 %. Dispersion curves for other monopole and dipole modes' pass bands are shown at the end of report. Only frequencies before critical are presented (critical frequency for monopole modes is ν_{crit} =2089 MHz and ν_{crit} =1599 MHz for dipole modes).

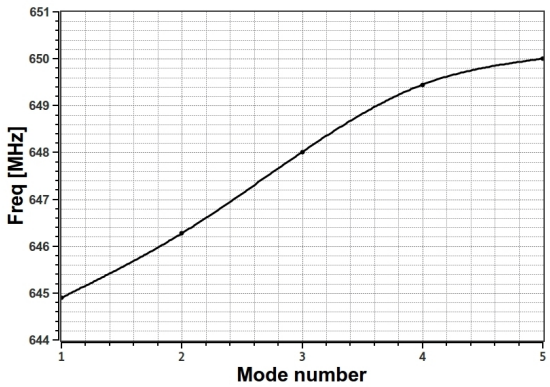


Figure 3: Frequencies of operating pass-band

Study of higher order modes for 5 cell cavity

Studying of the Higher Order Modes (HOM) is very important for beam dynamics. The cavity has been studied for longitudinal and traverse higher order mode. The distribution of effective impedance of longitudinal and traverse HOM is shown on the figures 5, 6.

Distribution of the fields along the length of the cavity both in monopole and dipole cases is shown on the figures Monopole mode 1-30 and Dipole mode 1-30 at the end of this report.

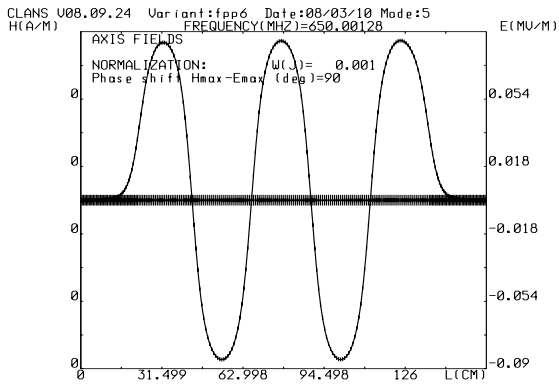


Figure 4: Electric field distribution for the fundamental mode

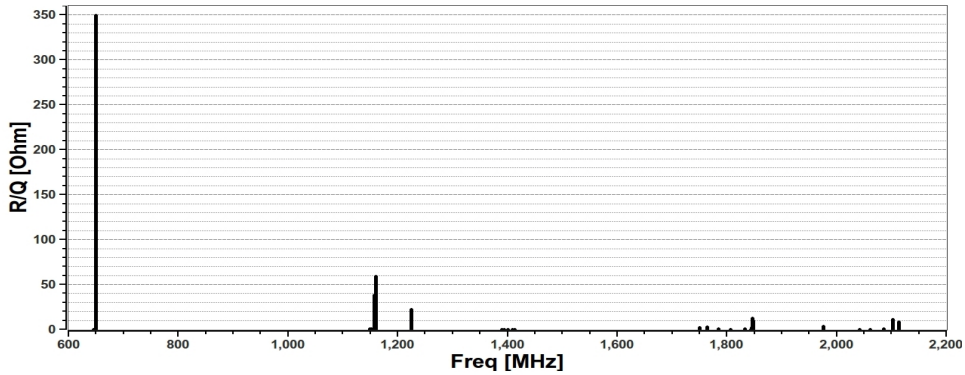


Figure 5: Distribution of longitudinal HOM

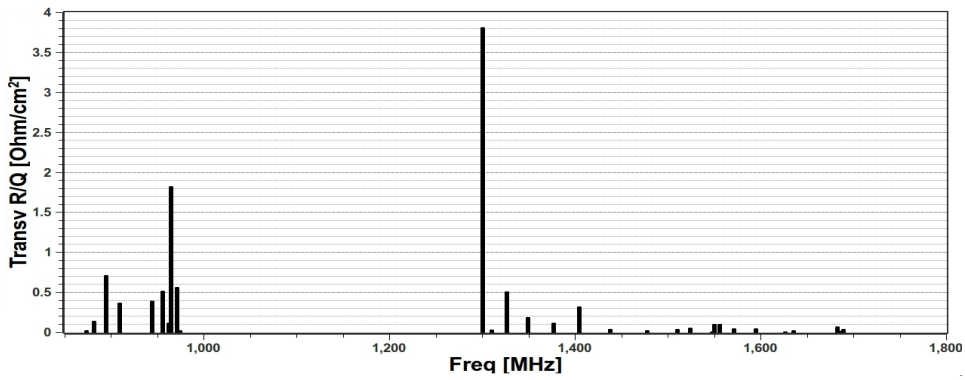


Figure 6: Distribution of transverse HOM

According to the study of HOM it can be concluded that no trapped modes in the designed cavity are presented.

Multipacting simulation

Multipaction simulation has been held. Multipac 2.1 program for Matlab was used.

Multipacting is the process when an electron spontaneously emitted from the surface of an rf structure causes an exponential increase of secondary emitted electrons, so called electron avalanche. The number of secondary electrons depends o the impact energy of the first (impacting) electron and the wall material characteristics at the location of the impact.

There are two conditions for multipacting:

- An electron emitted from the cavity wall is driven by the electromagnetic field and returns back after an integer number of rf cycles to the same point of the cavity wall
- The impacting electron produces more than one secondary electron

Multipacting simulation was held for all three types of cells, i.e. inner-cell and two end-cells. All the results of the simulation are provided at the end of the report. According to the results of this simulation, peak values of the impact energy are lower than 30 eV. We assume (according to the secondary yield for a niobium curve fig.7) that for multipacting to occur impact energy of 50 eV is needed. This allows to conclude that there is no multipacting in the proposed cavity.

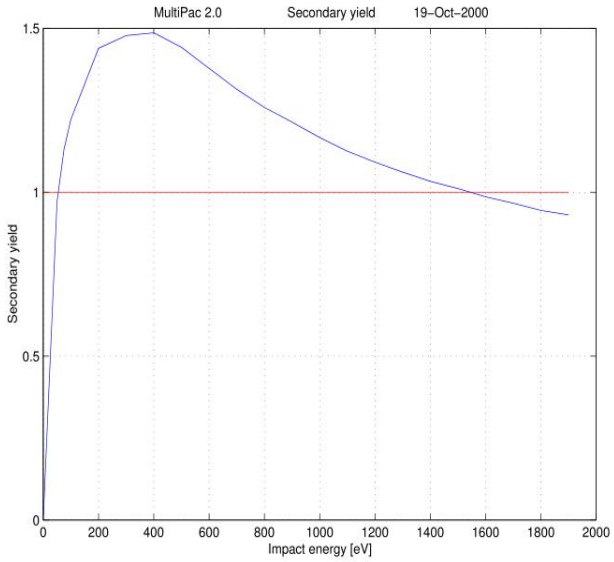


Figure 7: Secondary yield for niobium

CONCLUSION

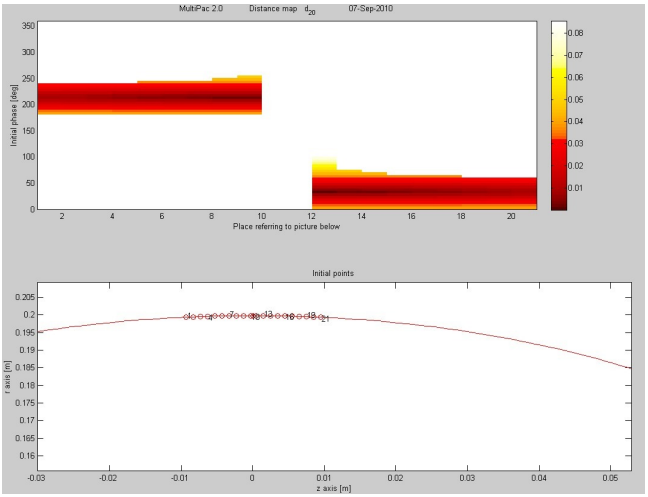
The 5 cell 650 MHz beta 1.0 cavity was proposed. Among the advantages of this type of cavity worth to emphasize the next ones:

- Low possibility of trapped higher order modes.
- Low magnetic and electric field enhancement factors which allows to increase gradient of the cavity.

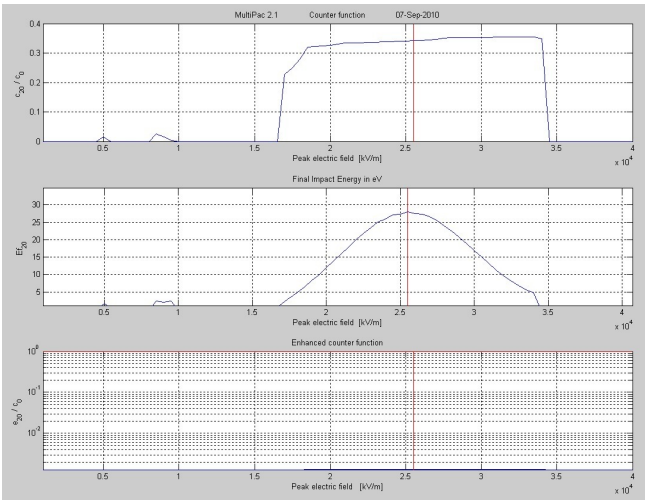
The cavity also has been studied for higher order modes among which no trapped modes were found.

Multipaction simulation has been held. No multipacting in the designed cavity.

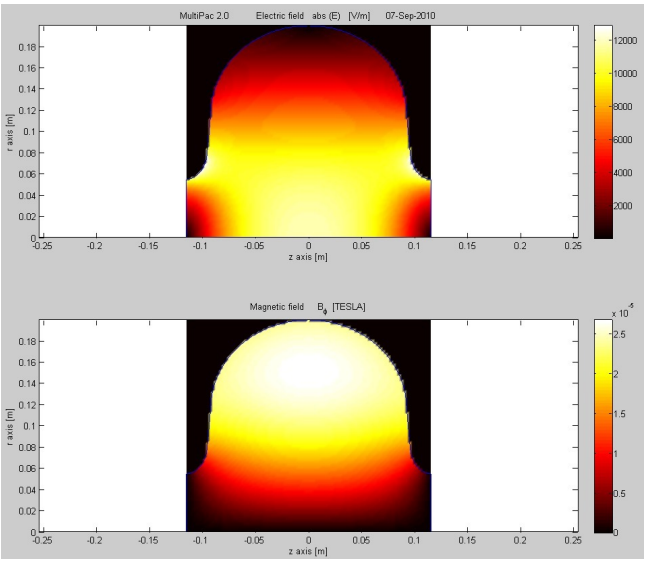
Multipacting simulation results for inner-cell.



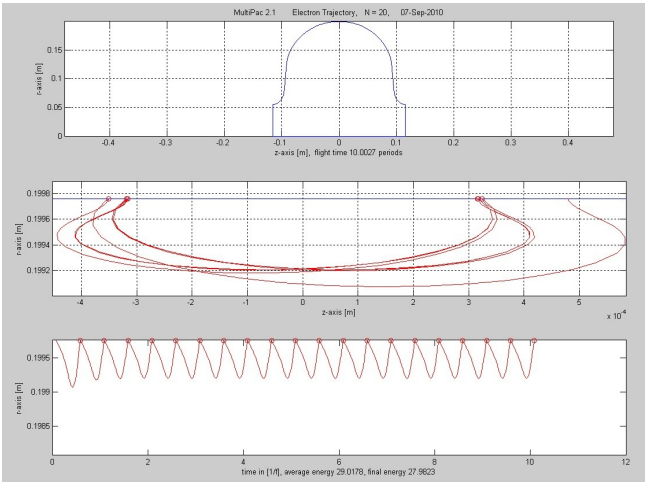
Distance function



Average impact energy of the last impact

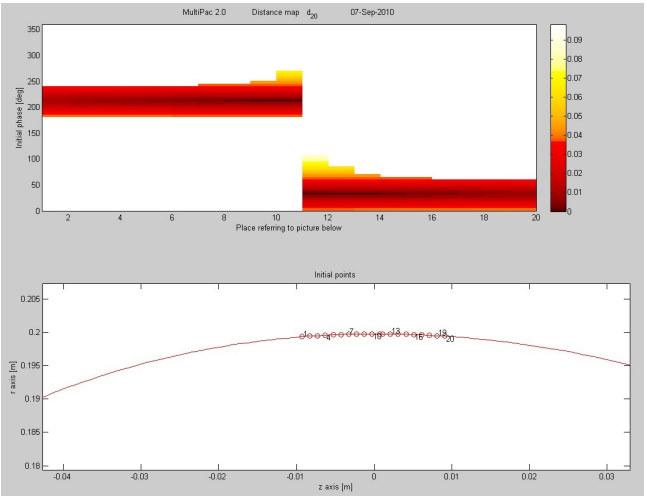


Magnetic and electric fields distribution

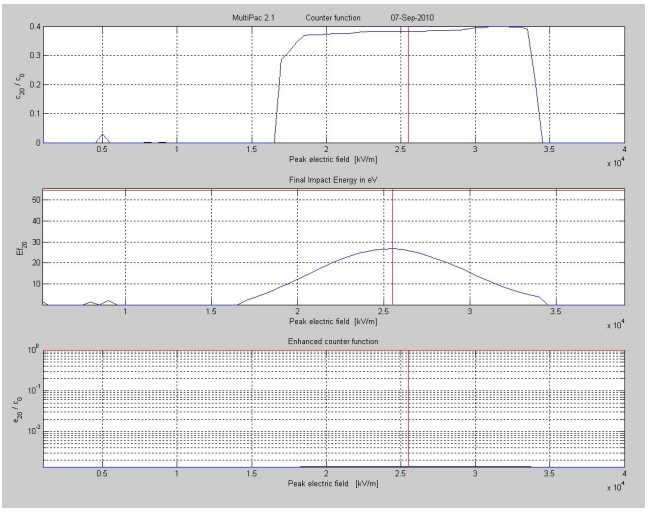


Electrons' trajectories

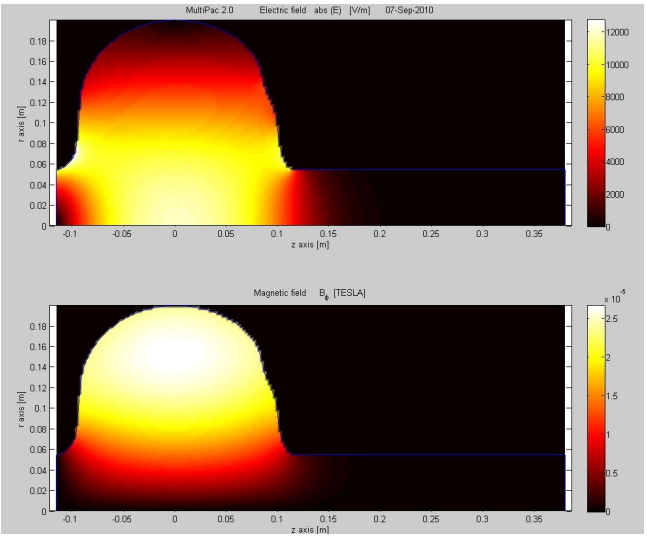
Multipacting simulation results for right end-cell.



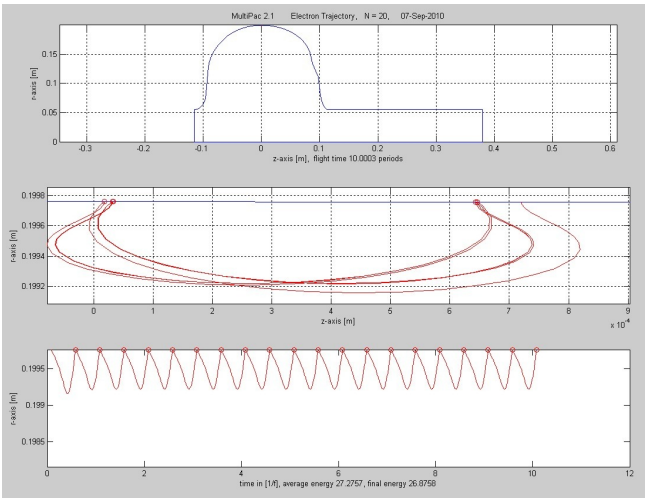
Distance function



Average impact energy of the last impact

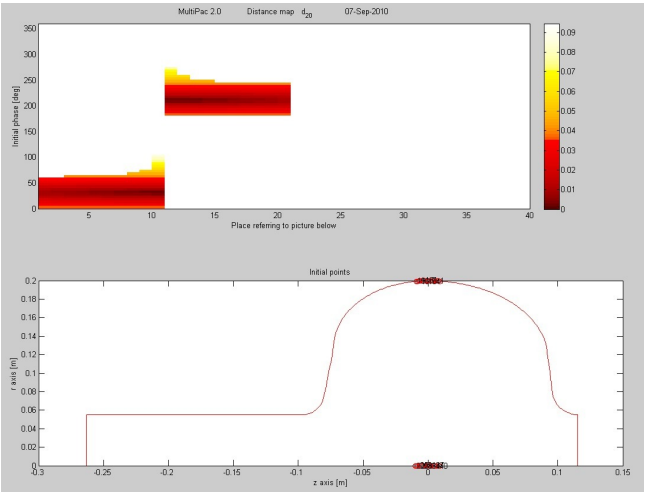


Magnetic and electric fields distribution

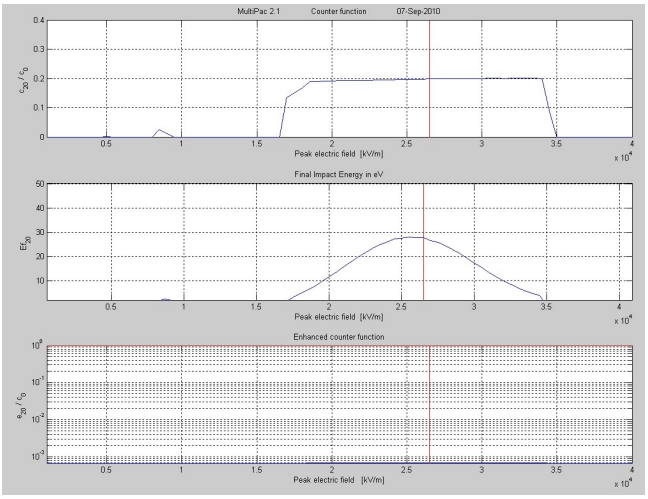


Electrons' trajectories

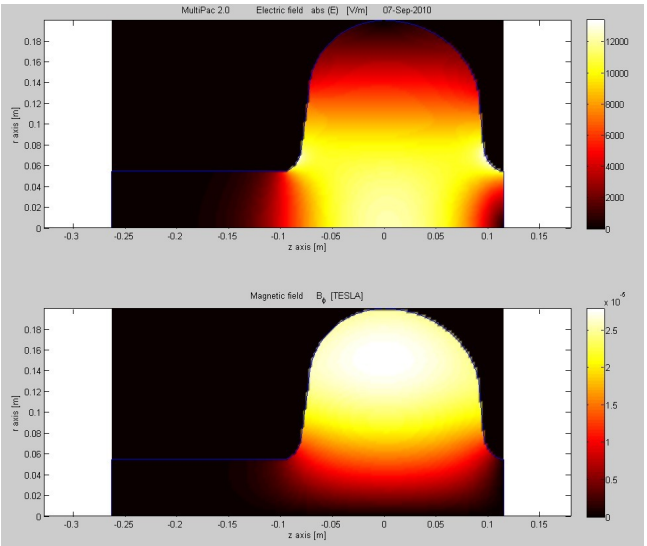
Multipacting simulation results for left end-cell.



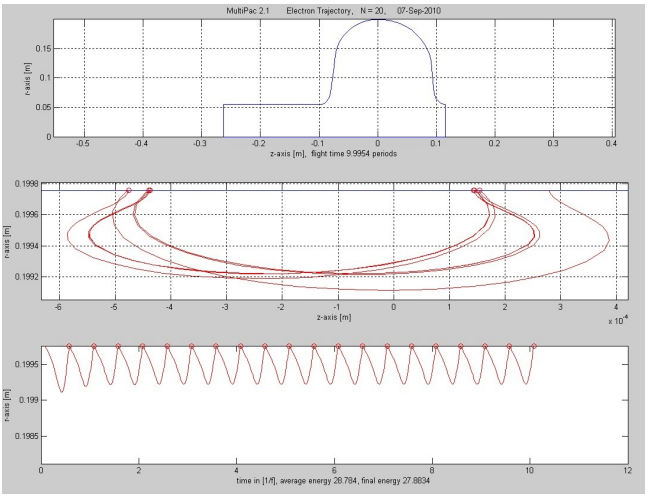
Distance function



Average impact energy of the last impact

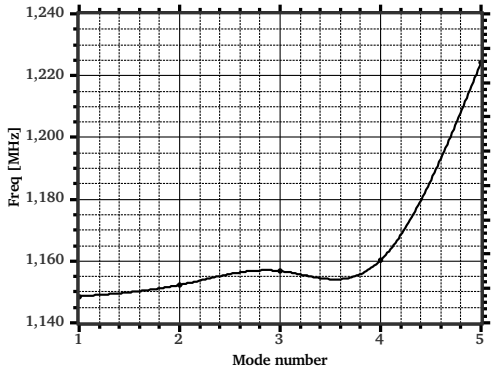


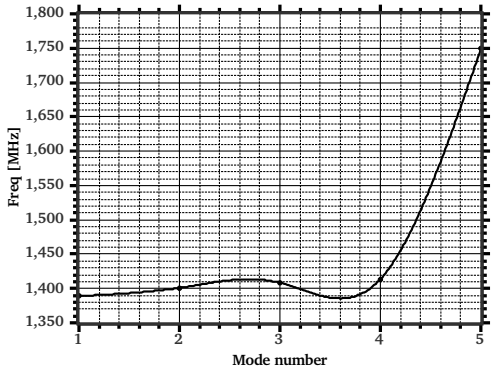
Magnetic and electric fields distribution

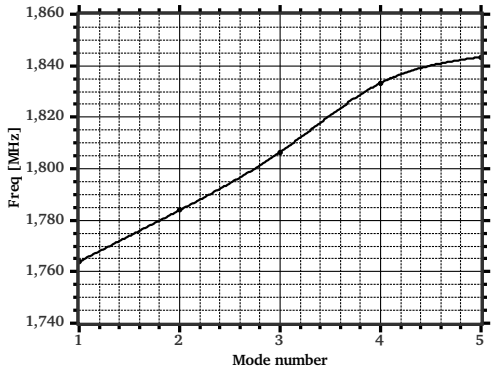


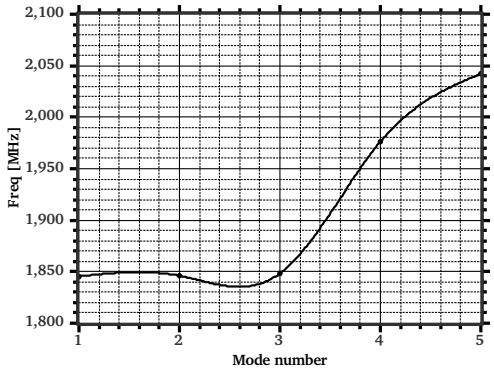
Electrons' trajectories

Pass bands for monopole modes below cut-off frequency.

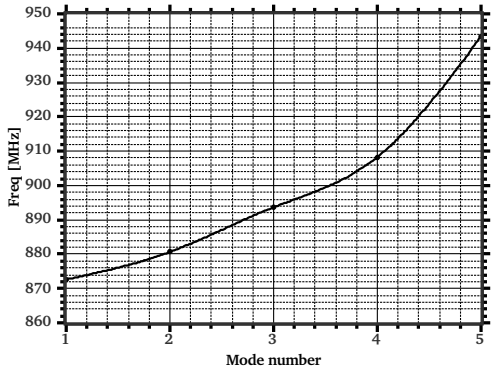


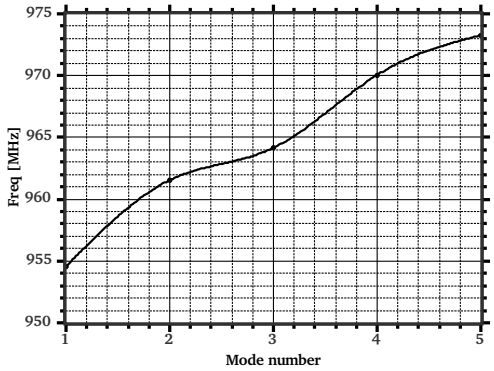


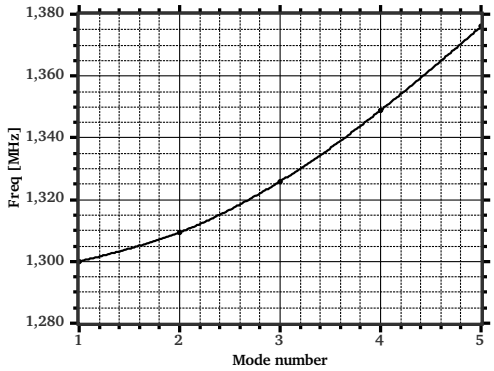


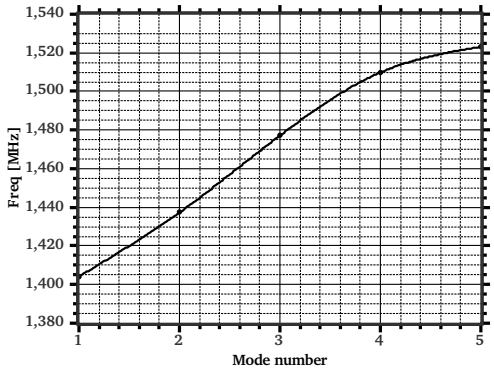


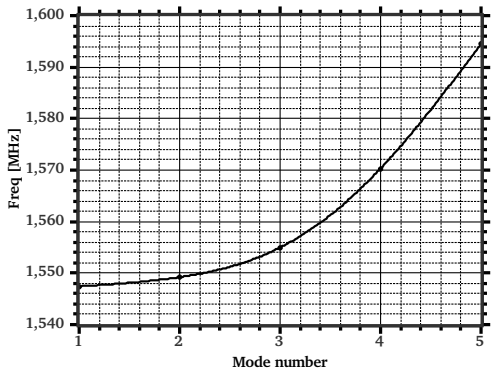
Pass bands for dipole modes below cut-off frequency.











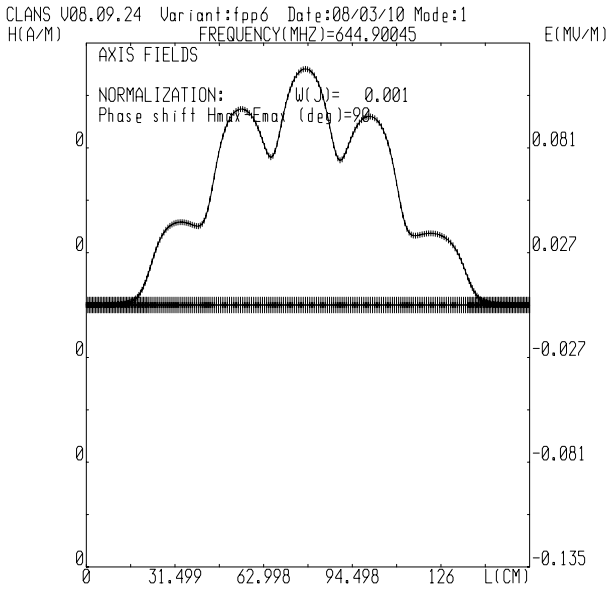


Fig. Monopole mode 1

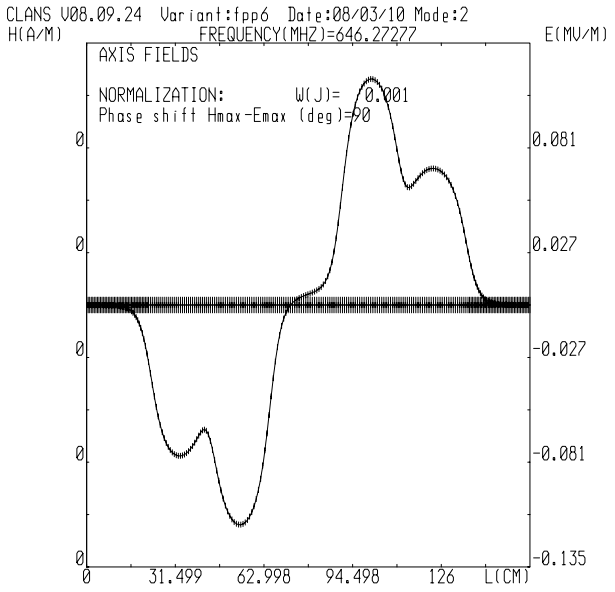


Fig. Monopole mode 2

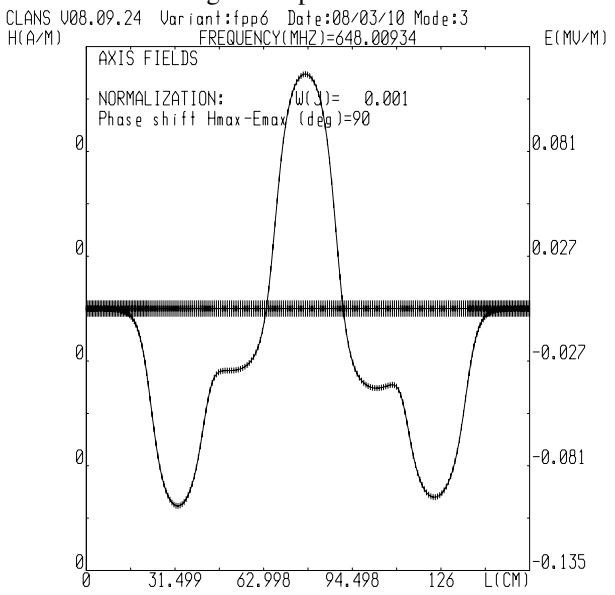


Fig. Monopole mode 3

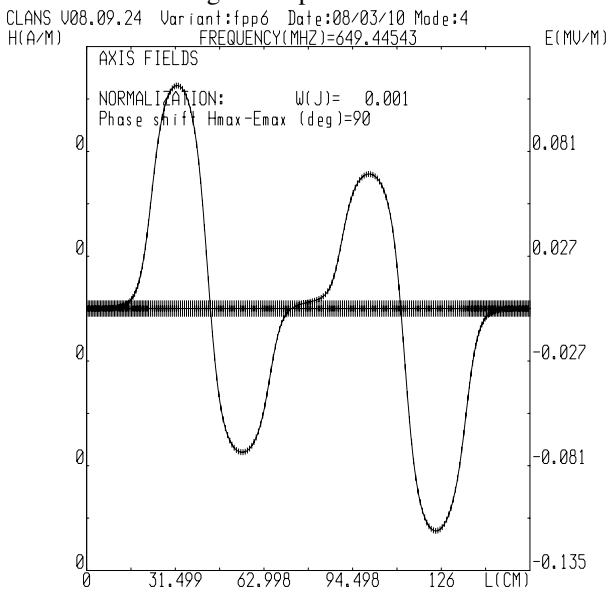


Fig. Monopole mode 4

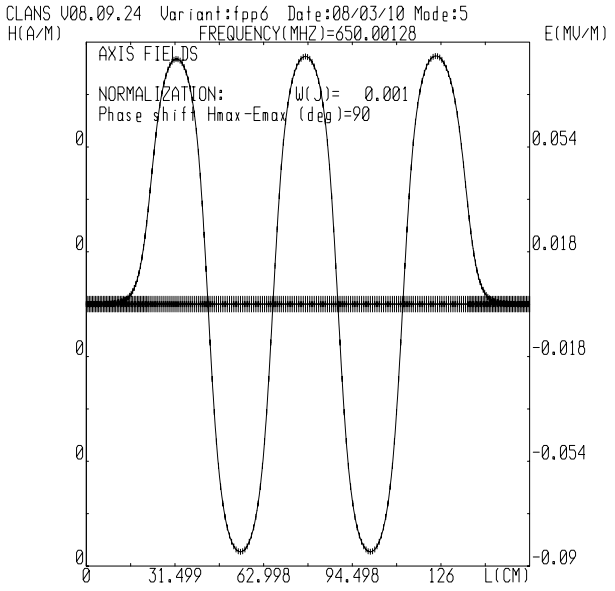


Fig. Monopole mode 5

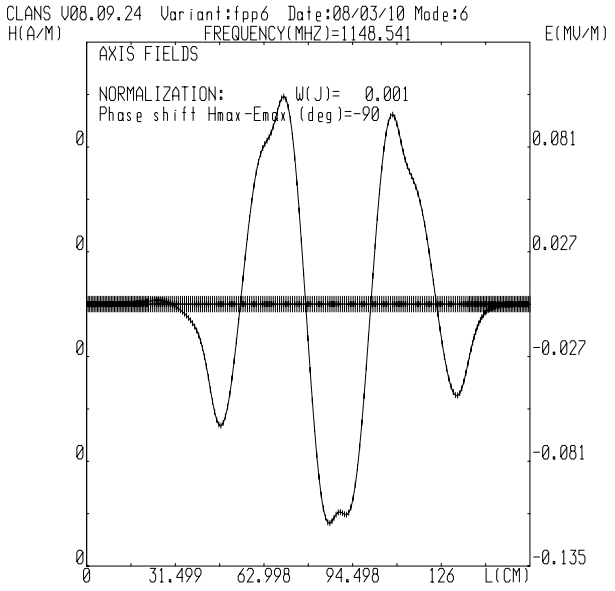


Fig. Monopole mode 6

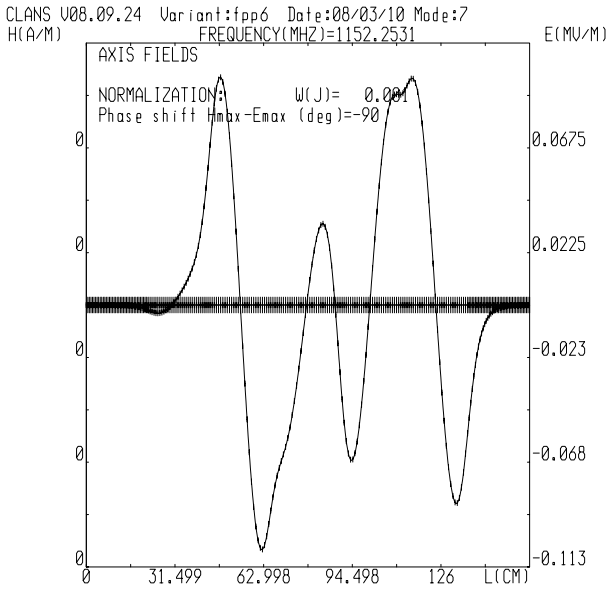


Fig. Monopole mode 7

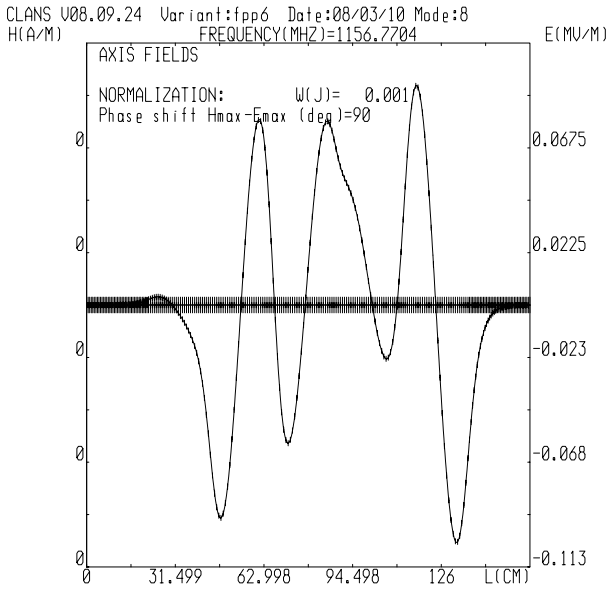


Fig. Monopole mode 8

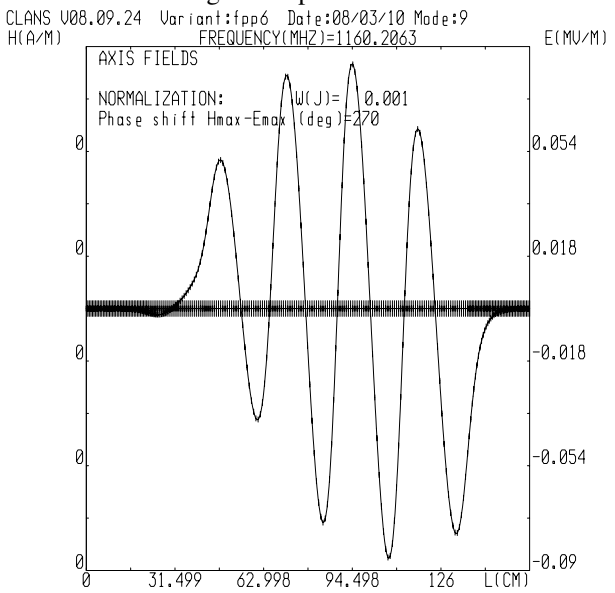


Fig. Monopole mode 9

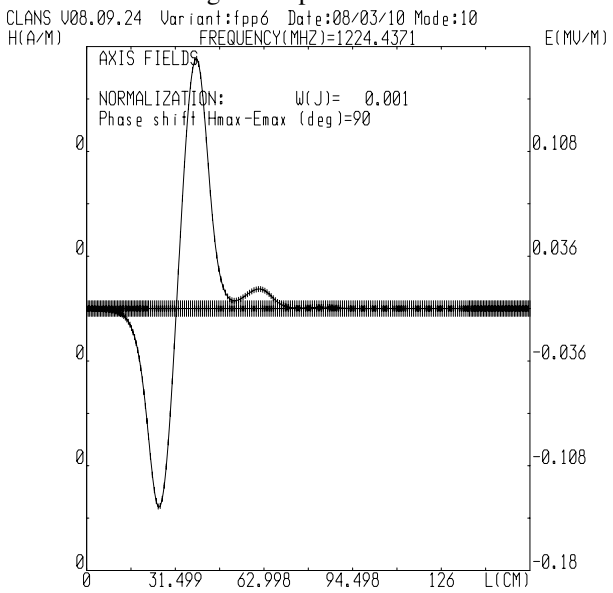


Fig. Monopole mode 10

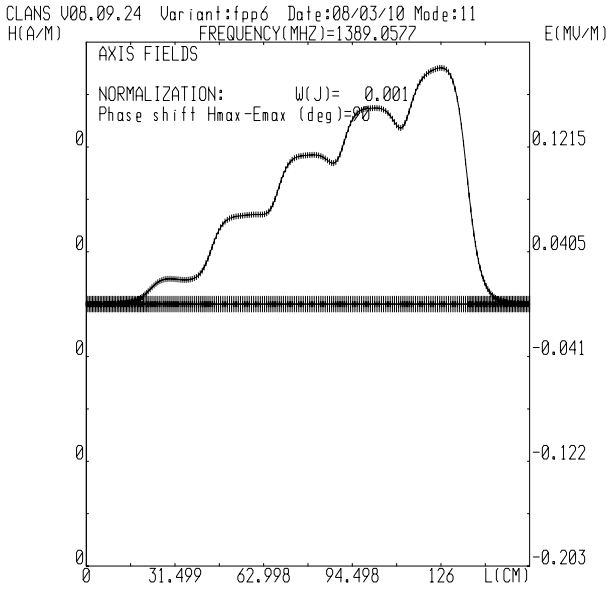


Fig. Monopole mode 11

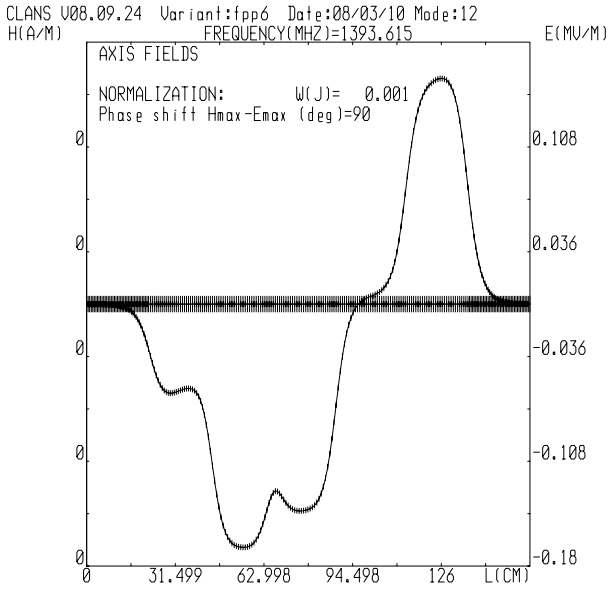


Fig. Monopole mode 12

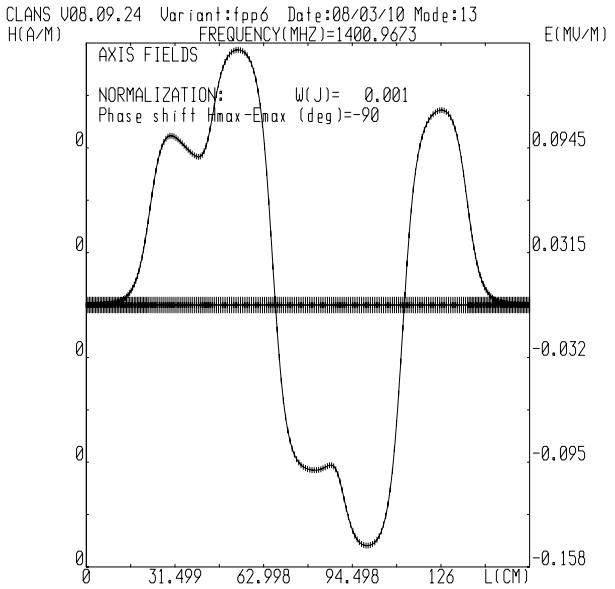


Fig. Monopole mode 13

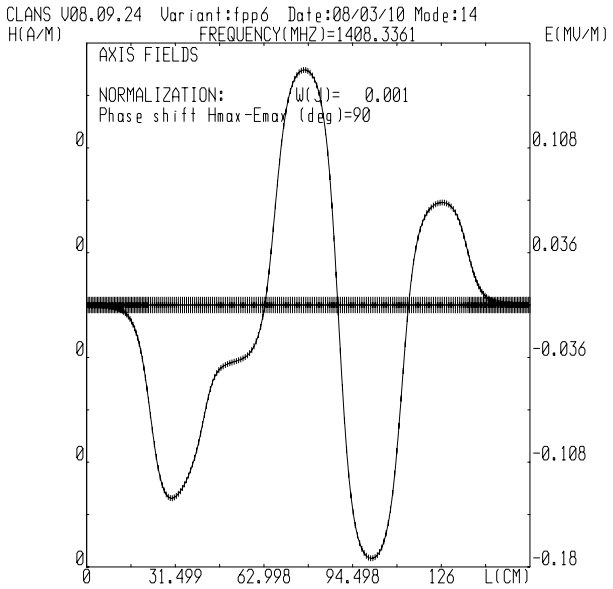


Fig. Monopole mode 14

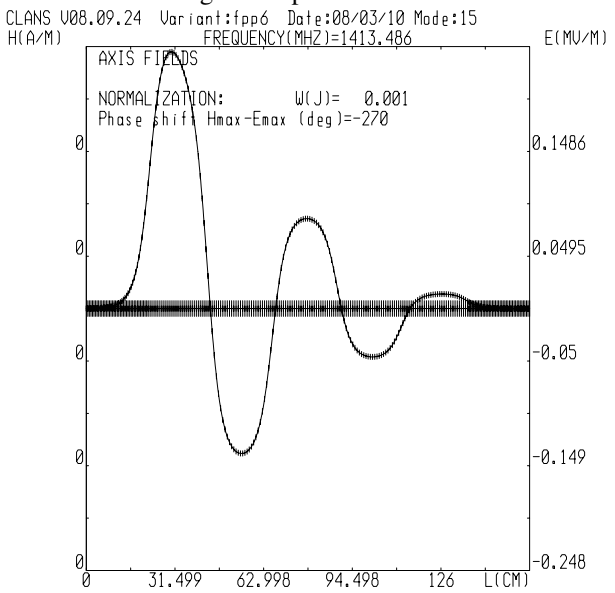


Fig. Monopole mode 15

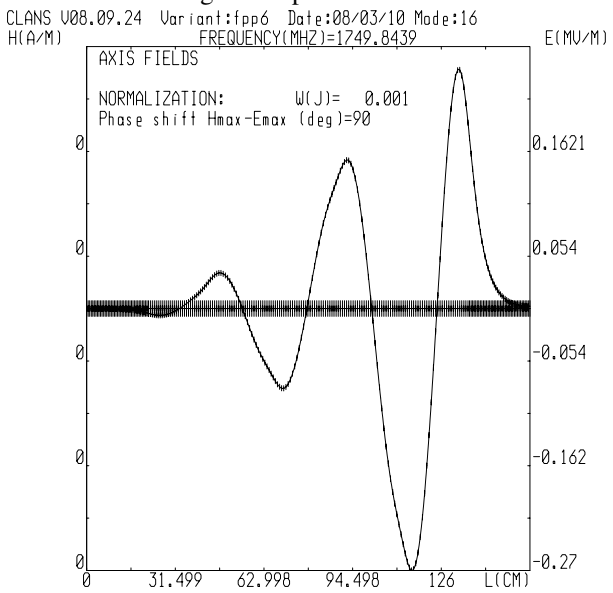


Fig. Monopole mode 16

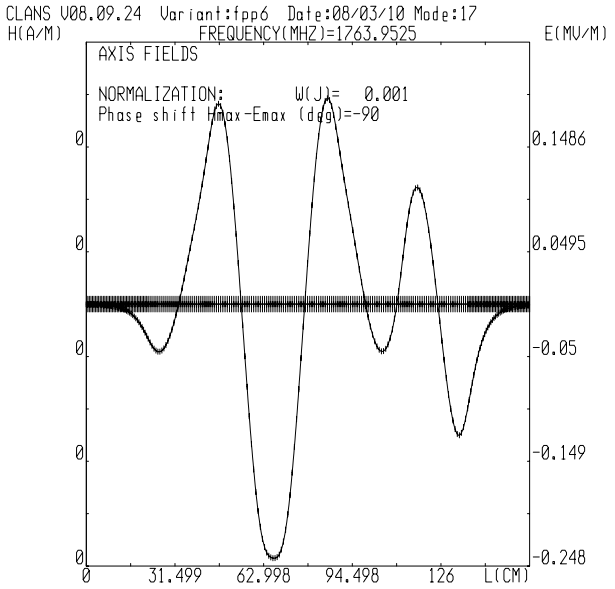


Fig. Monopole mode 17

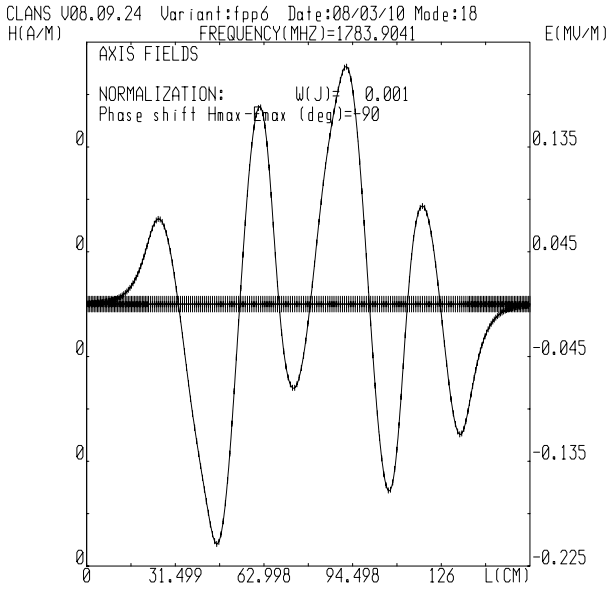


Fig. Monopole mode 18

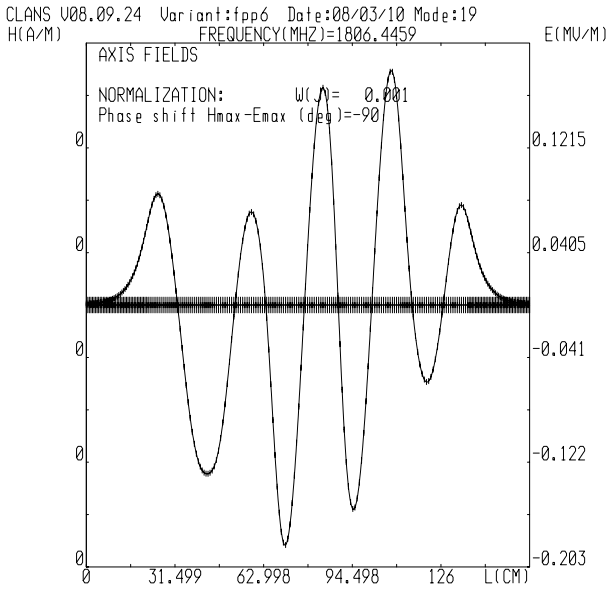


Fig. Monopole mode 19

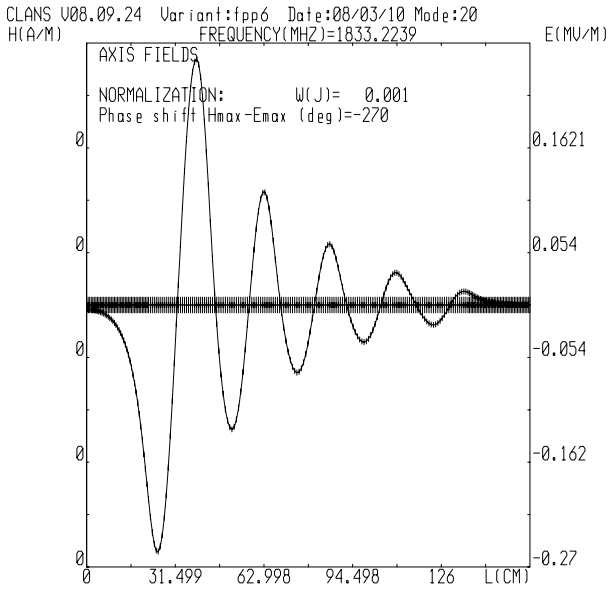


Fig. Monopole mode 20

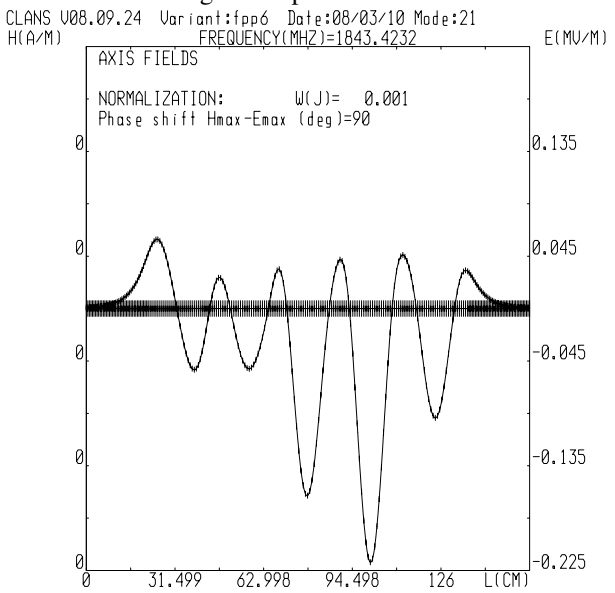


Fig. Monopole mode 21

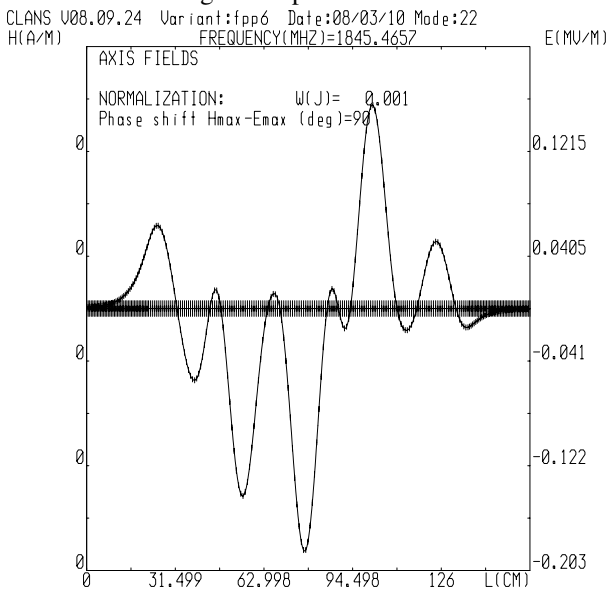
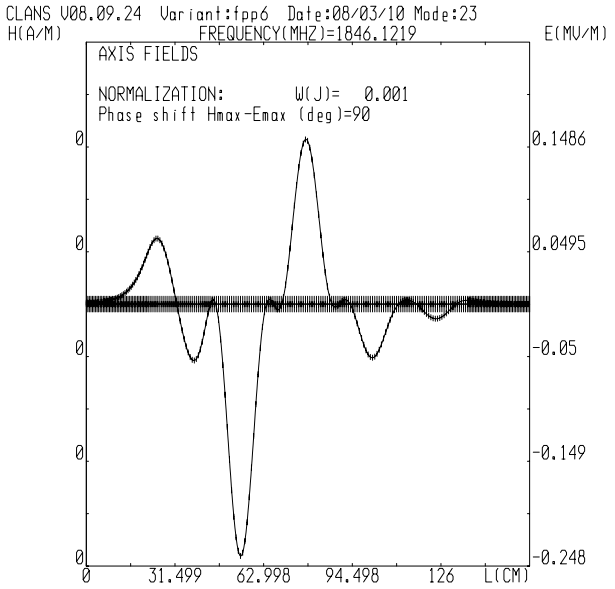


Fig. Monopole mode 22



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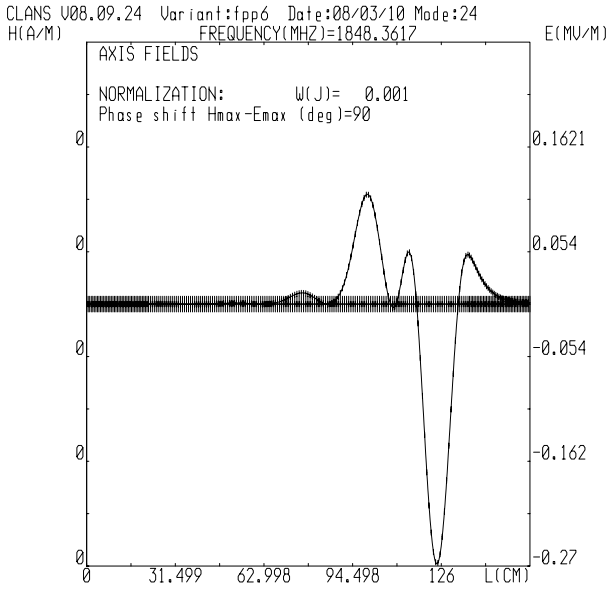

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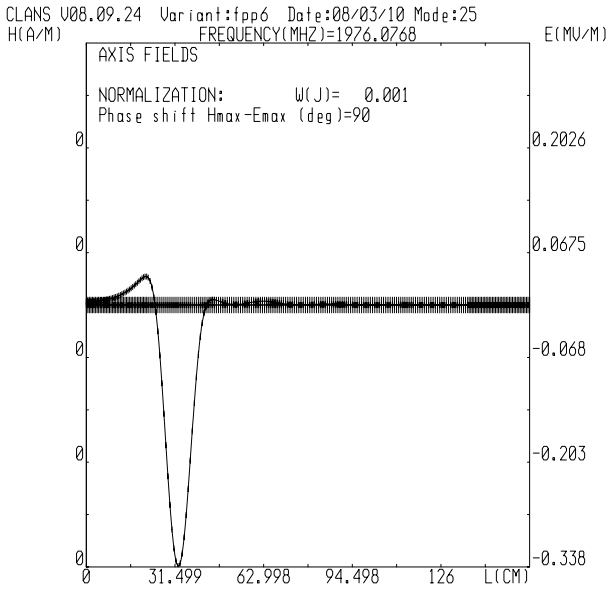


Fig. Monopole mode 25

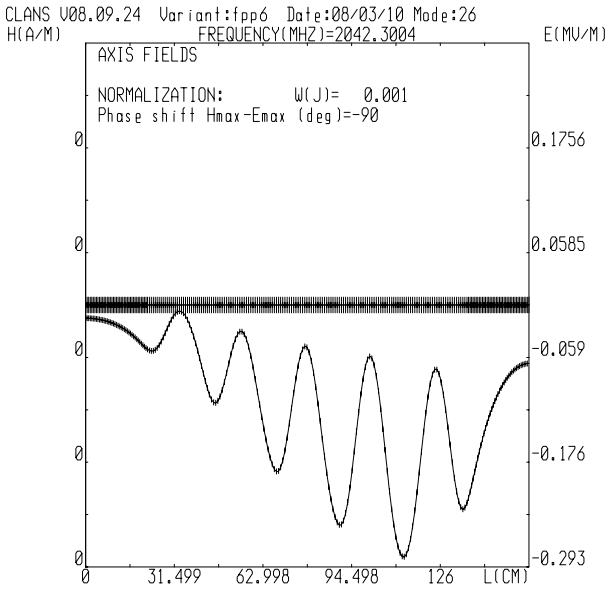


Fig. Monopole mode 26

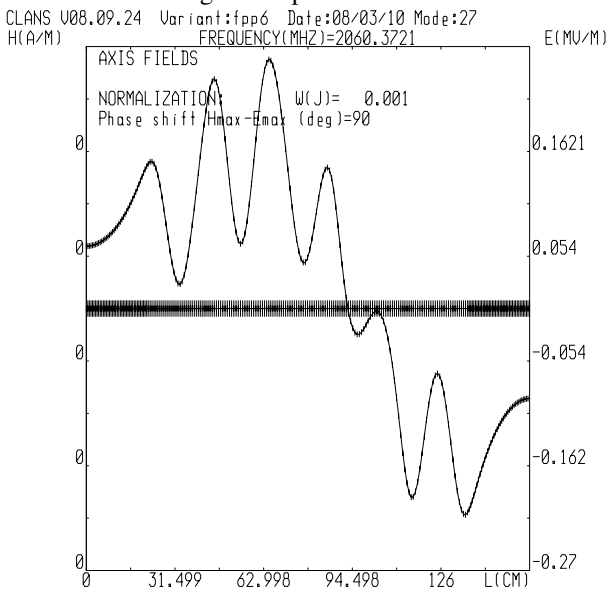


Fig. Monopole mode 27

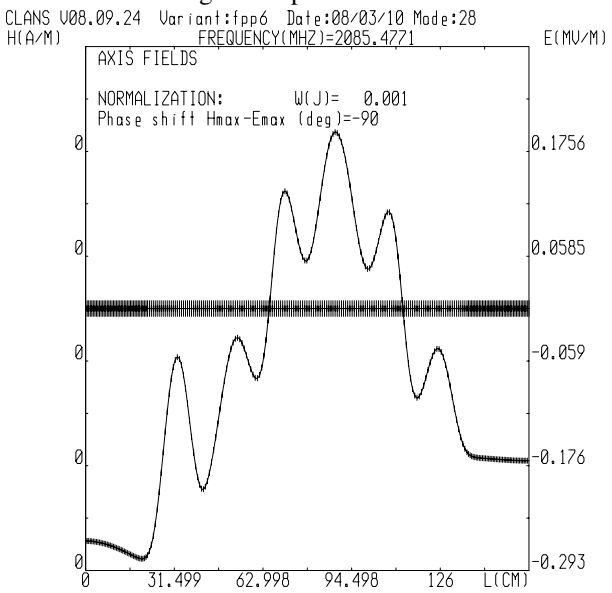


Fig. Monopole mode 28

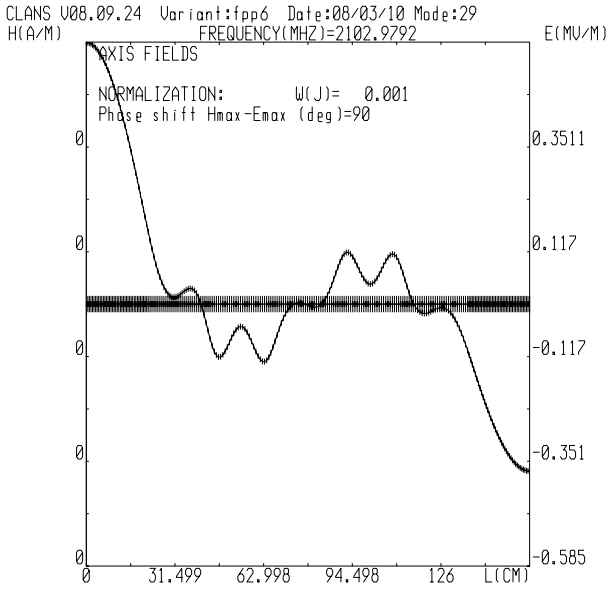


Fig. Monopole mode 29

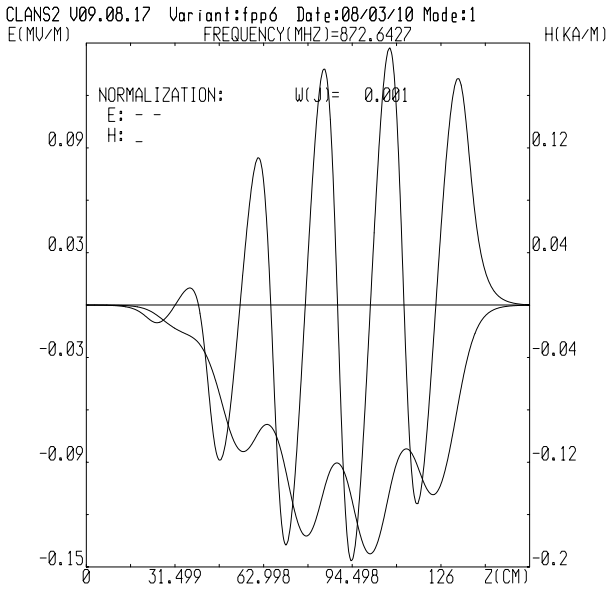


Fig. Dipole mode 1

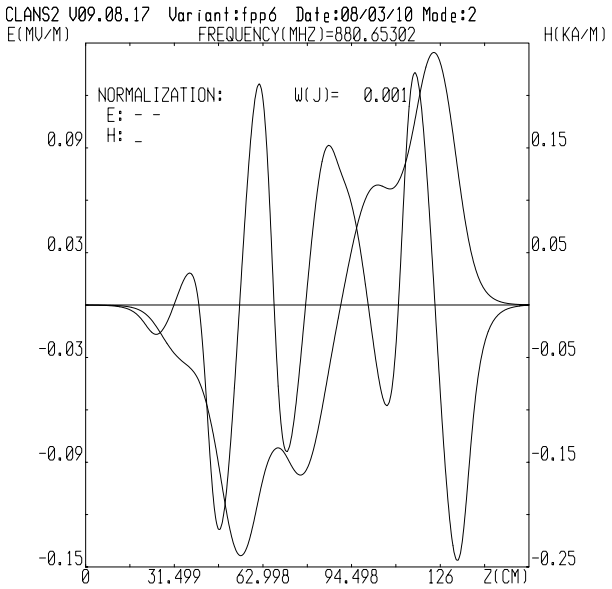
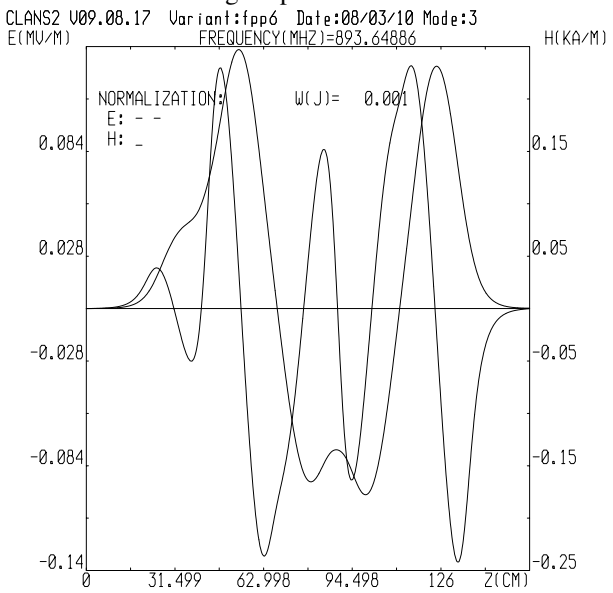


Fig. Dipole mode 2



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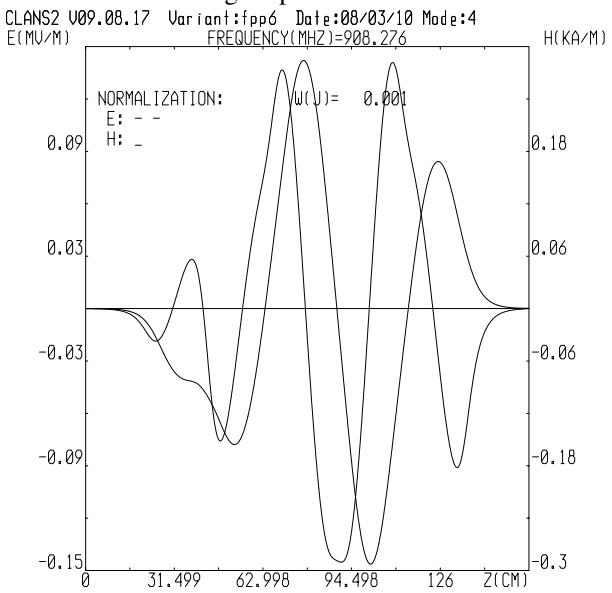


Fig. Dipole mode 4

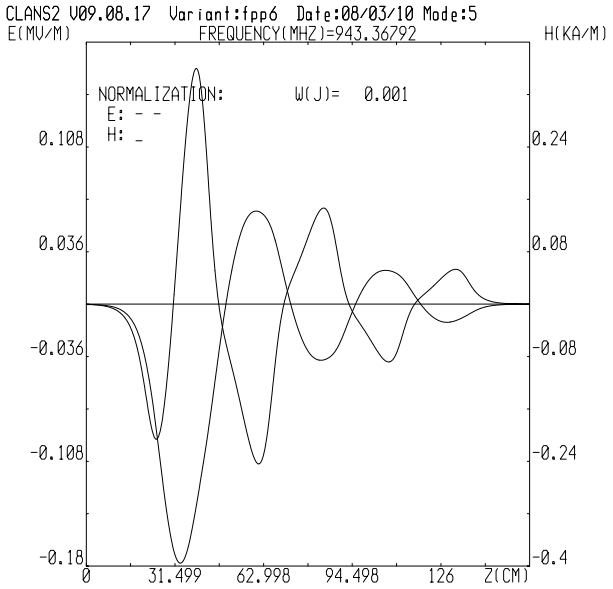
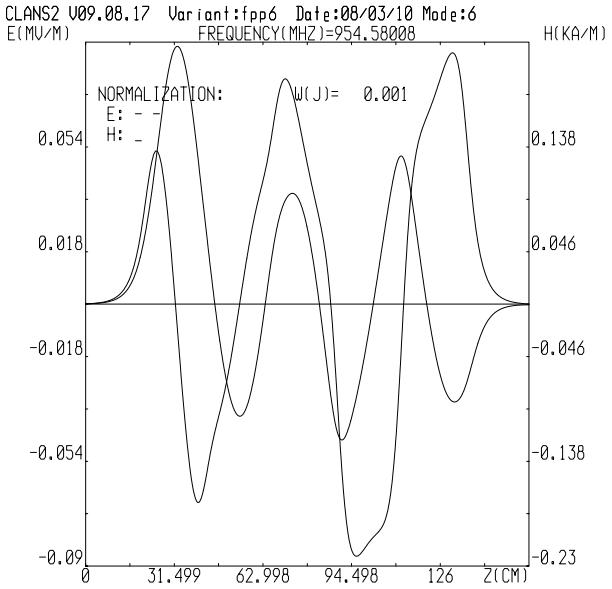


Fig. Dipole mode 5



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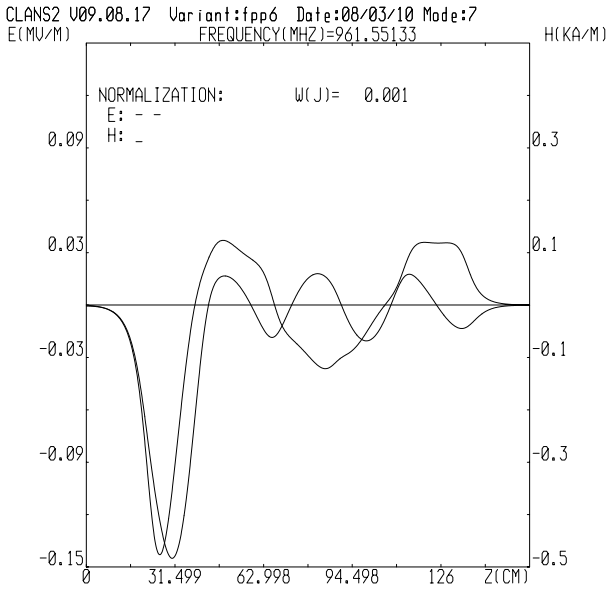

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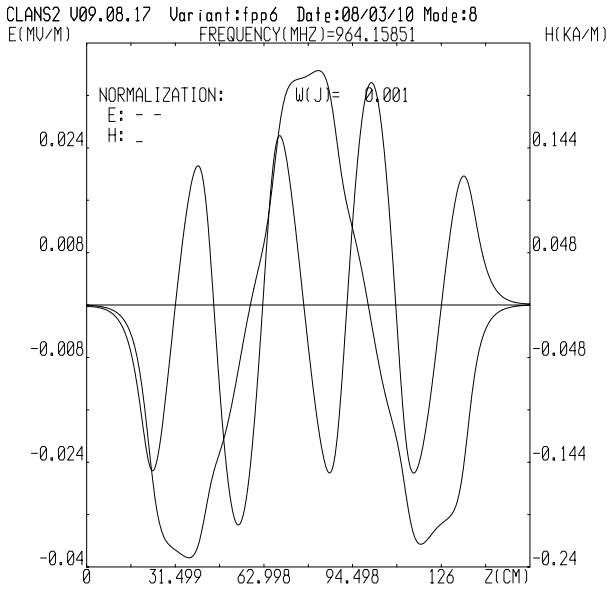

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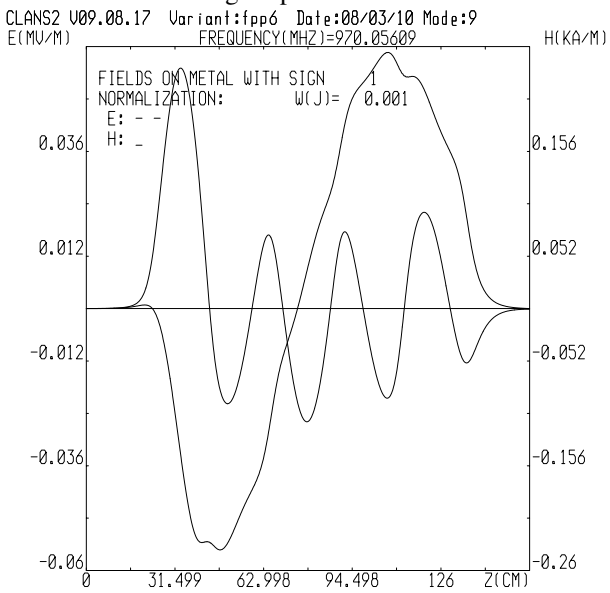


Fig. Dipole mode 9

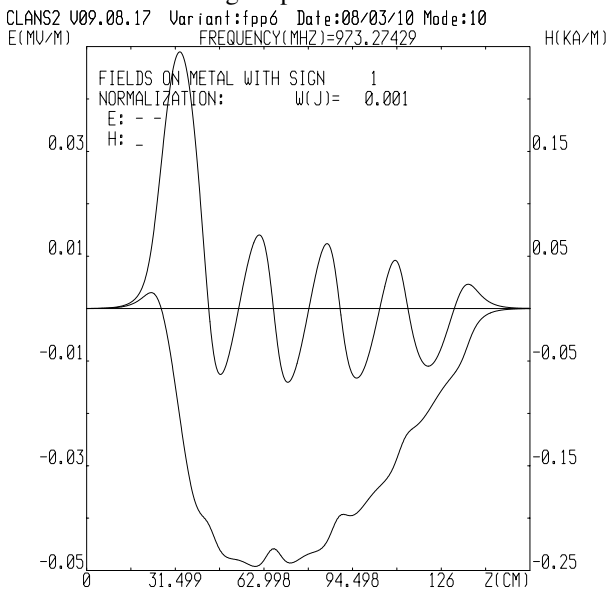
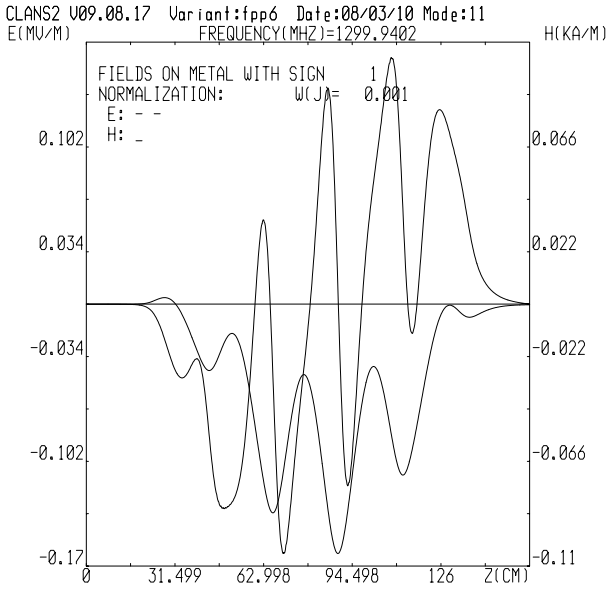


Fig. Dipole mode 10



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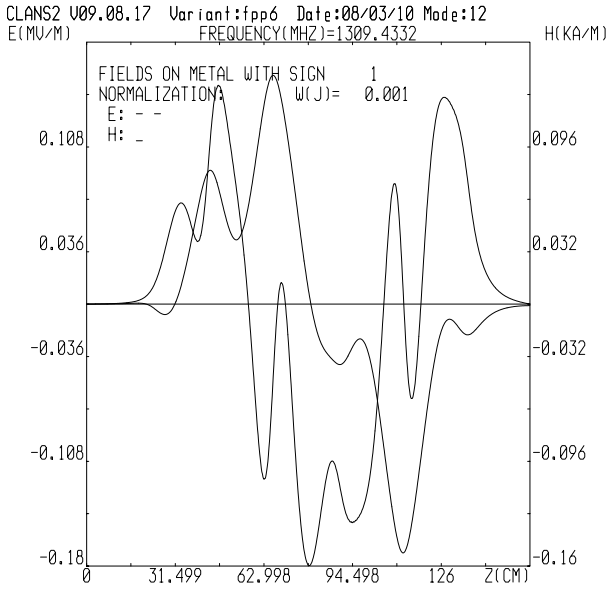


Fig. Dipole mode 12

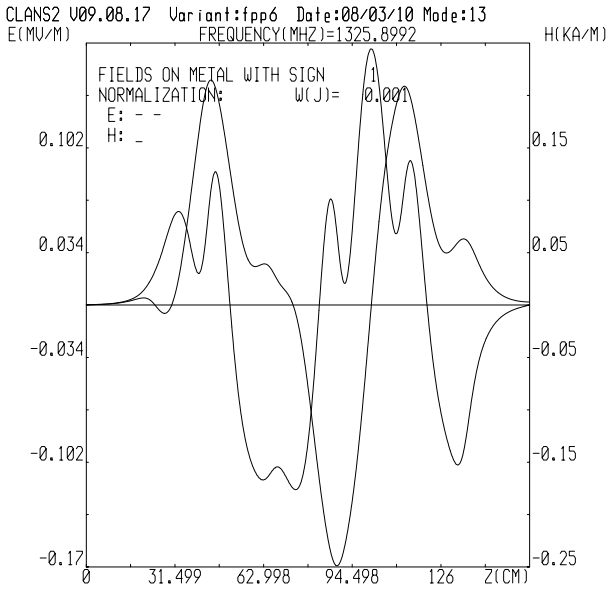
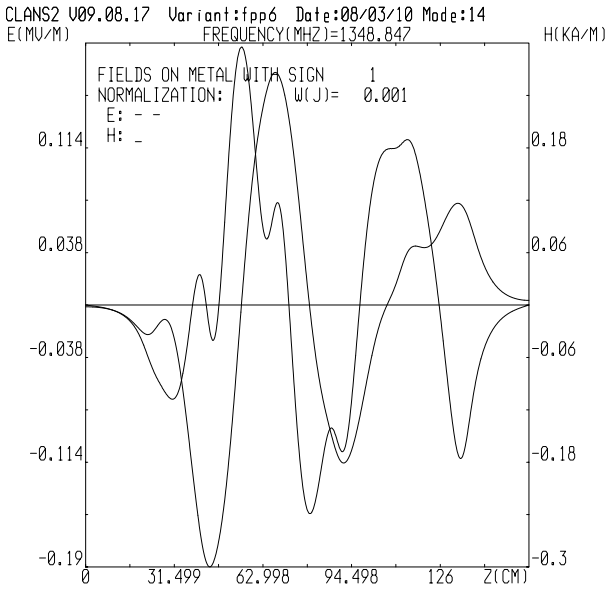


Fig. Dipole mode 13



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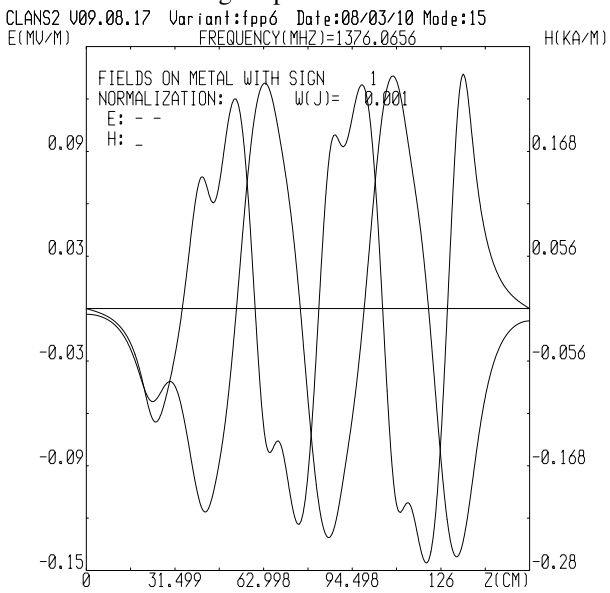

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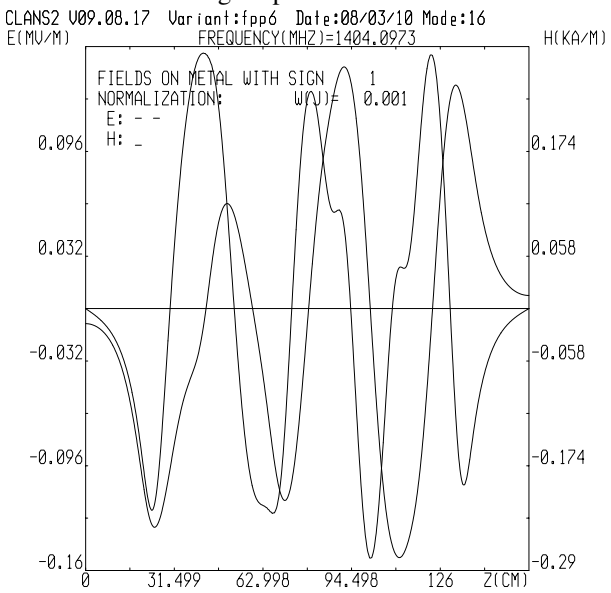


Fig. Dipole mode 16

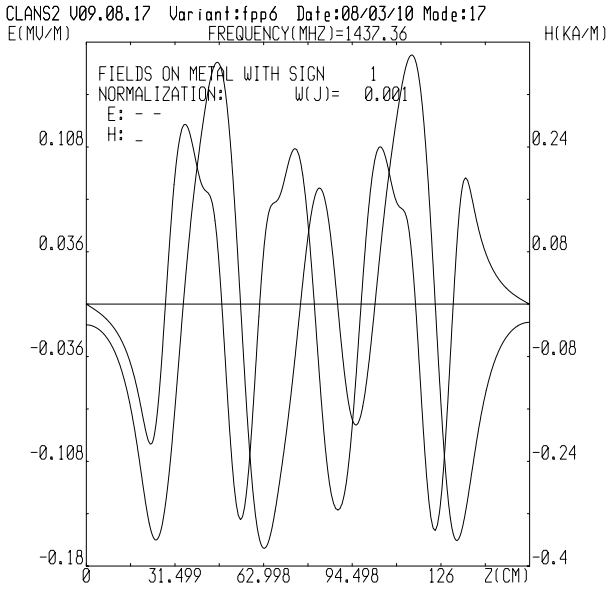


Fig. Dipole mode 17

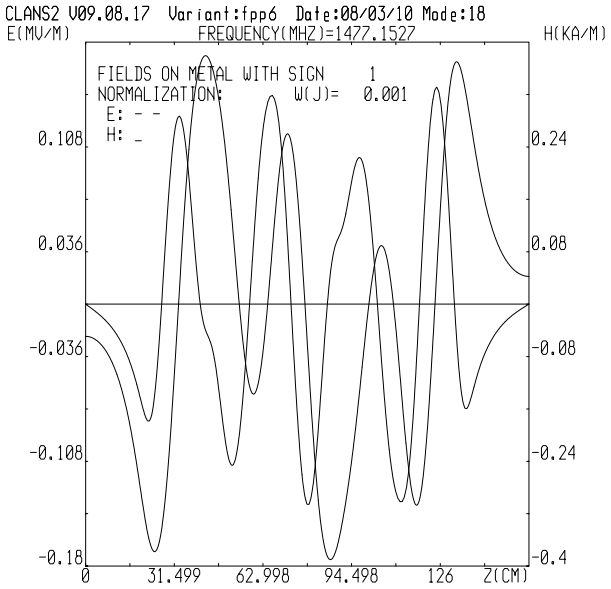
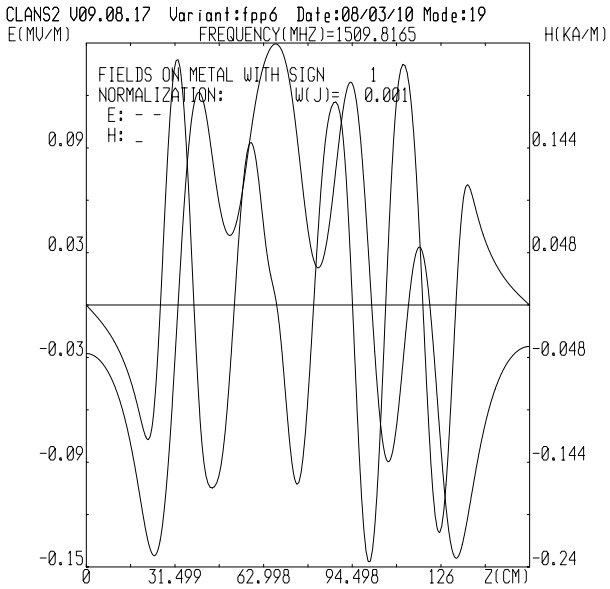


Fig. Dipole mode 18



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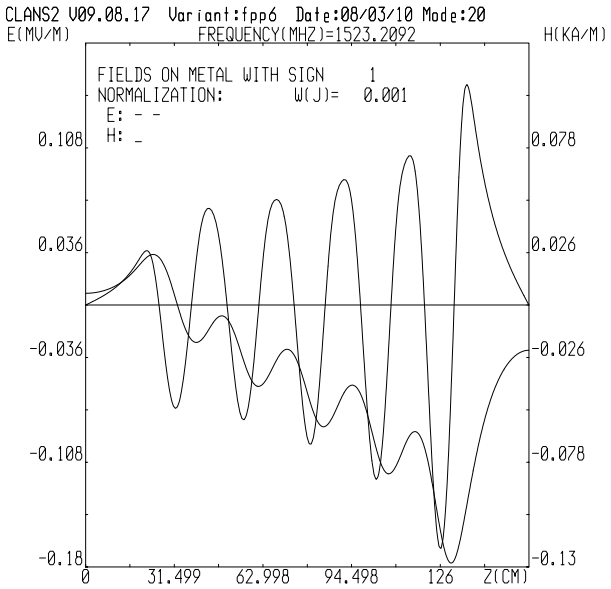


Fig. Dipole mode 20

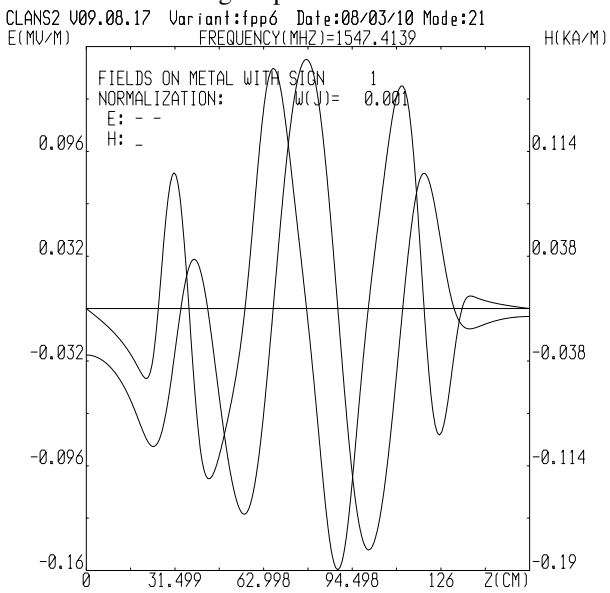


Fig. Dipole mode 21

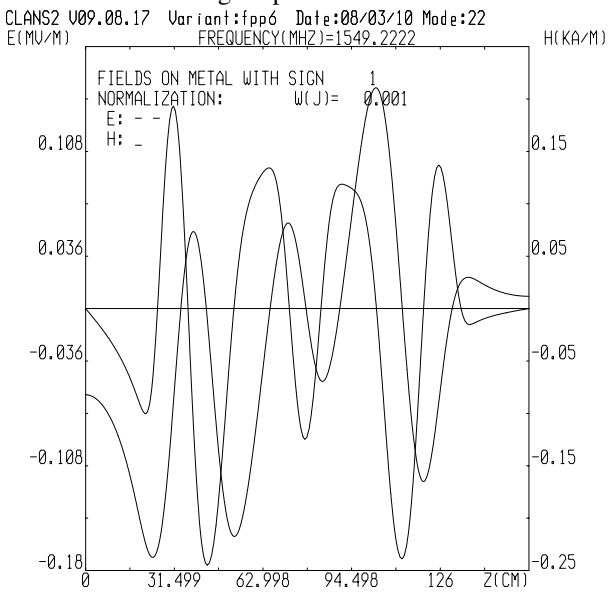


Fig. Dipole mode 22

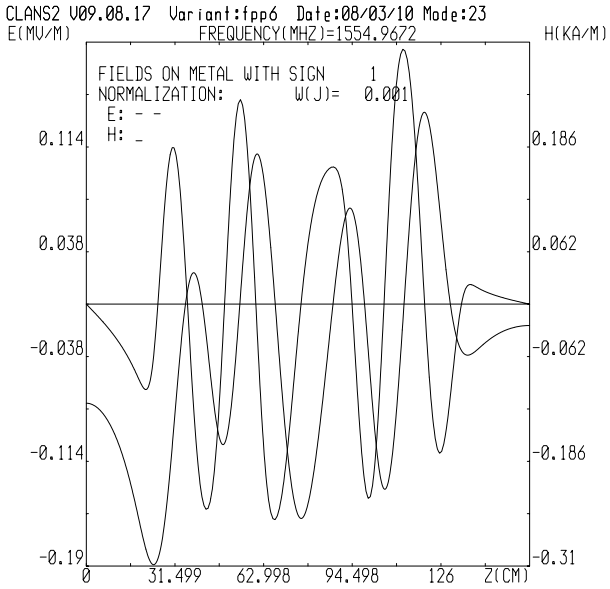


Fig. Dipole mode 23

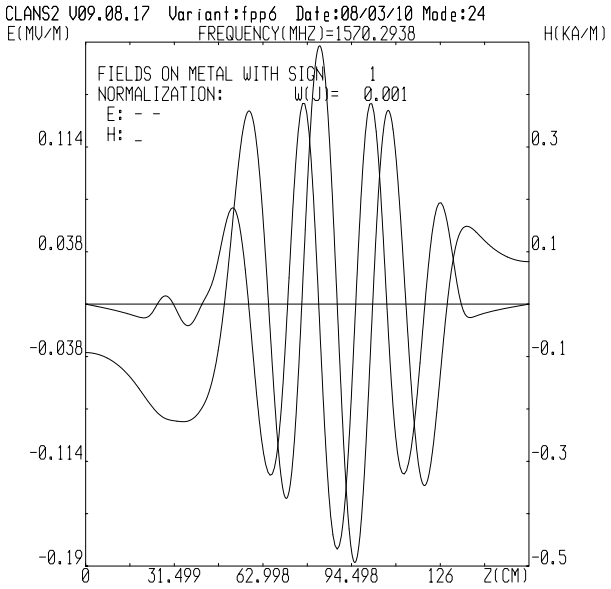


Fig. Dipole mode 24

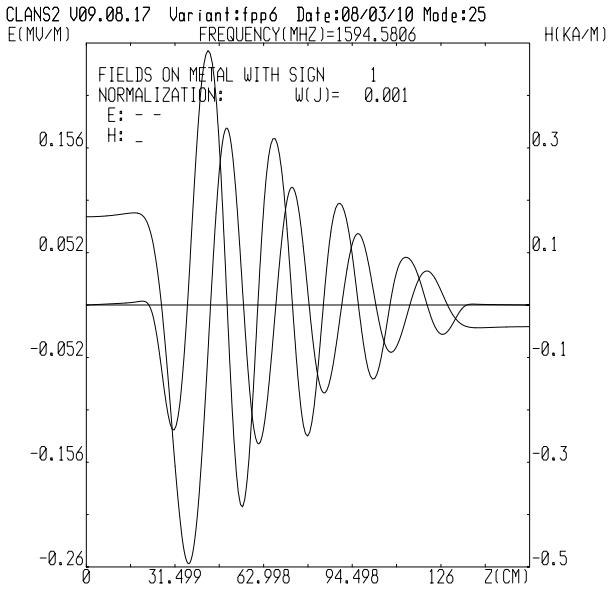


Fig. Dipole mode 25

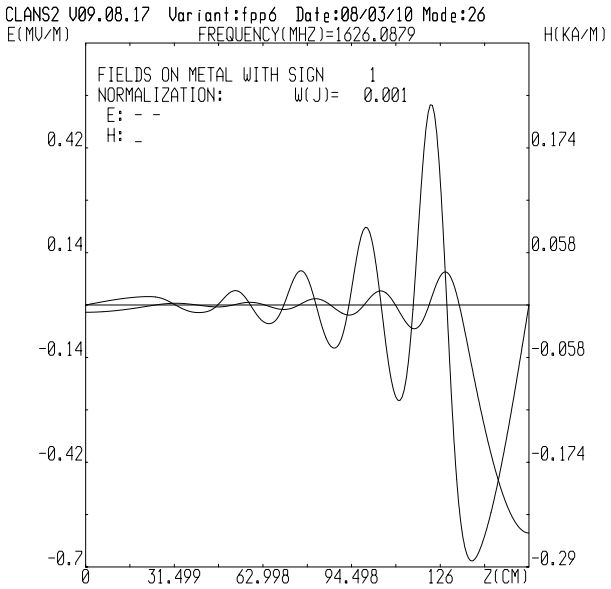
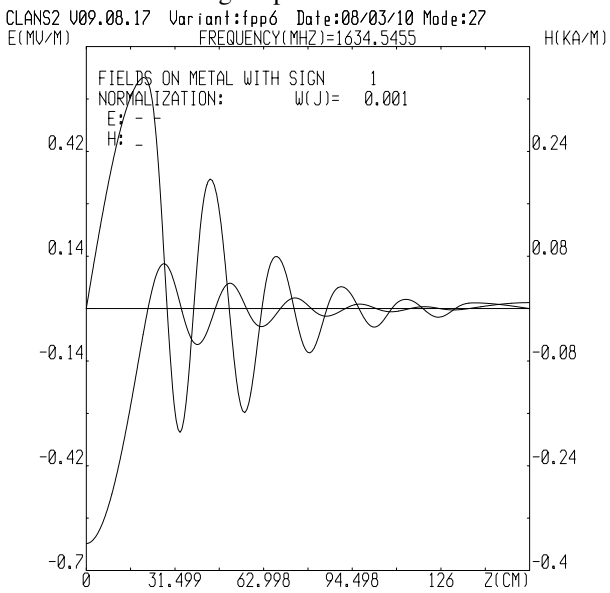


Fig. Dipole mode 26



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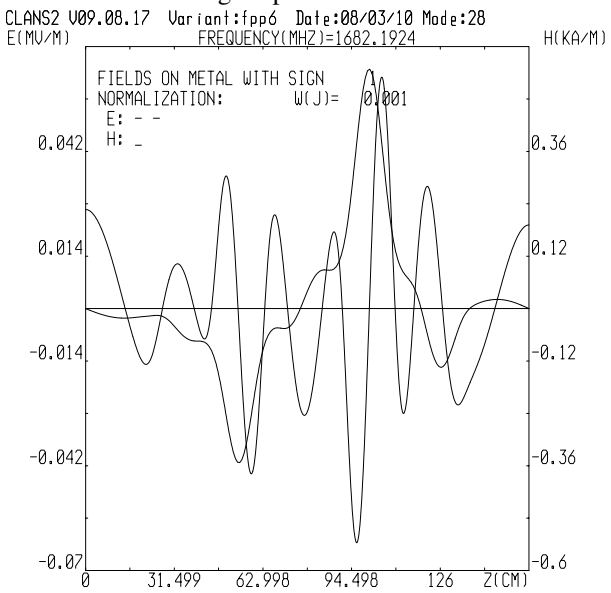

Fig. Dipole mode 28

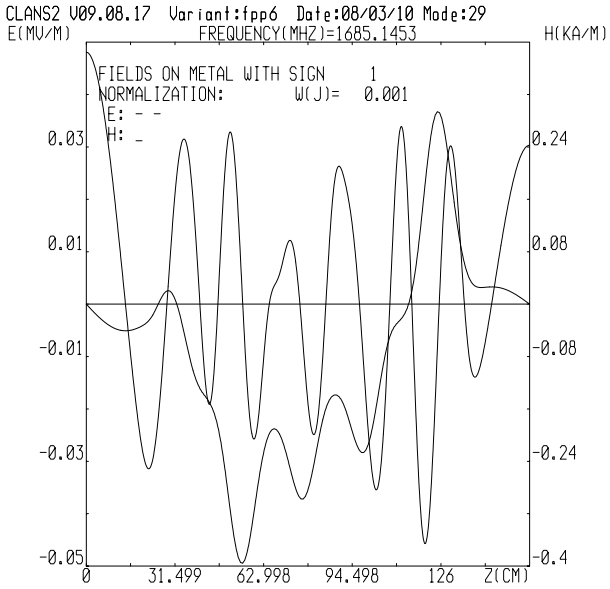

Fig. Dipole mode 29

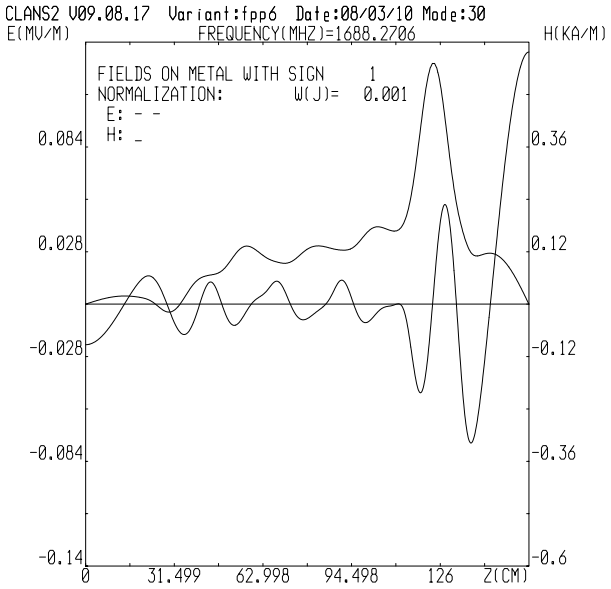

Fig. Dipole mode 30