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14. ABSTRACT
This final report includes a copy of the electronic Magic User's Manual. The Manual illustrates the basic concepts of EM-PIC and introduces the concepts necessary for application to a variety of VEC and PLASMA processes. In addition, it contains numerous examples illustrating the techniques for matching laboratory and engineering measurements to equivalent simulation modeling measurements. There are several seminar presentations (PPT documents plus input files) designed to introduce specific engineering and vacuum electronic concepts in a comprehensive and intuitive fashion. These presentations summarize many of the research activities with specific examples that we have been involved in during the period of performance. They provide a record of the sophisticated techniques developed for obtaining quantitative and predictive results from simulations that are equivalent to laboratory measurements. Finally, a copy of the low power 35 GHZ, klystron amplifier template developed in collaboration with SLAC is included. The report provides a step-by-step approach to evaluation of the klystron design as well as providing the opportunity to modify this design and compare the results.

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Simulation of a 35 GHz Klystron Using a Magic2D Template

The following document describes the steps involved in tuning a 6 cavity 35 GHz klystron. The initial design for this template was developed at SLAC (Caryotakis, Scheitrum, Sphren, and Song). Modifications have been made at MRC. The bulk of the klystron template has been buried in an internal MAGIC file. The remainder of the template consists of the controls (type of simulation) and the tuning parameters. It is recommended to the user that the control file be used to annotate the results of each simulation. Since the tuning procedure is iterative, it will be instructive as well as essential to record the sequence of changes within the control file, (or within a sequence of modified files. Each set of changes potentially impacts the performance of each of the following simulations, so good record keeping is critical.

The magic input file for the klystron template is "F3506.m2d". This file includes the user modifiable input and tuning parameters. Once these are set the file calls the internal coded klystron template embedded in MAGIC2D. This document indicates the procedure and order in which the various tuning parameters should be used.

At the beginning of the file are the current design parameters for the Frequencies, Qe, Qo, and R/Q for the input cavity, the intermediate cavities, and the output cavity.

The file is setup so that you serially run a series of Steps beginning with Cavity1 (the input cavity) thru Cavity6 (the output cavity.

The cavity tuning procedure for Cavities 1 through 5 is the following.

1. Run one of the Steps, Step 1 thru 5.
2. Obtain the frequency.
3. Adjust the tuners to increase/decrease the frequency.
    a. The tuner parameters are tune_left and tune_right.
    b. If frequency is high, decrease values of tune_left and tune_right. Rerun.
    c. If frequency is low increase values of tune_left and tune_right. Rerun.
    d. If frequency is good, then frequency tuning is complete.
4. Check $Q_{effective}$ and R/Q. Remember that you are measuring and tuning to $Q_{effective}$, not to Q_e or Q_0.
    a. If the measured Q is greater/less than the desired value of Q than adjust the loading conductance. Adjust the conductance, sigma, by the following factor. Sigma (desired) = Sigma (used) * Q (measured) / Q (desired).
    b. Rerun and verify Q.

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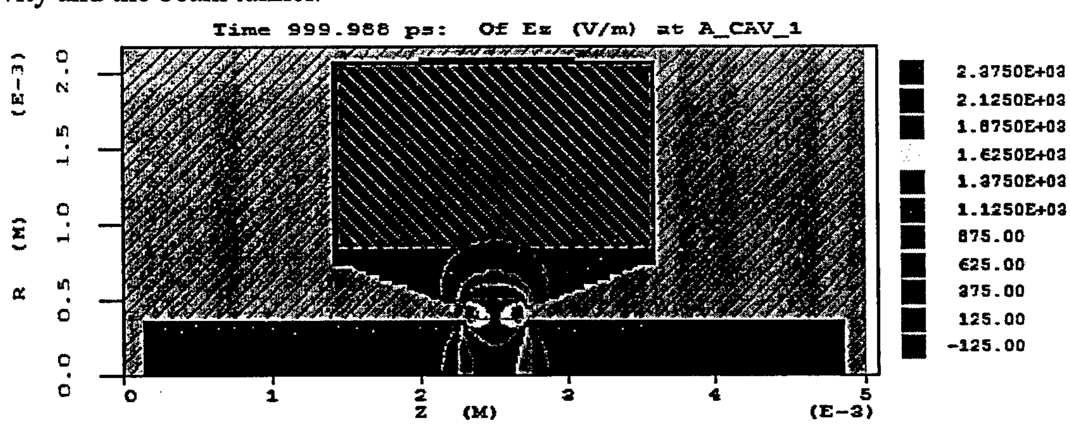
Example Step 1: Tuning the Frequency and Q of Cavity 1

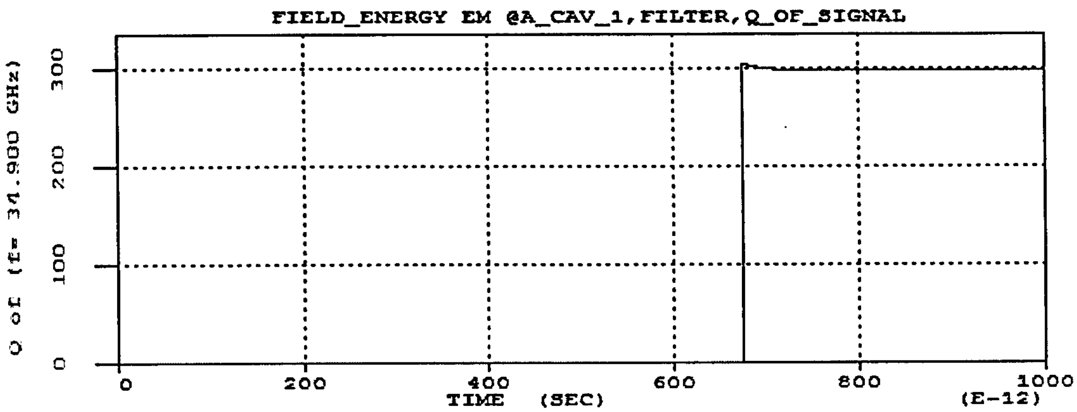
Selecting Step1 allows you to tune Cavity1. The section of the file for this Step looks like the following:

```
!*****************************************************************************
!==> Step1, Cavity1,  Can Use either Magic2d_Sng or Magic2d_Dbl
!    Cold test and tune cavity 1.
!*****************************************************************************
Comment " === Tuning for Input Cavity ======================================" ;

IF (ISTEP.eq.1) THEN ;
   I_Run_Type         = 1;   ! 0 = Hot test
   Cold_Test_Cavity   = 1  ;
ENDIF ;

! Cavity 1, tuning parameters.

Parameter_GHZ  Desired_f1 = f1;       ! Desired Frequency for Cavity 1
Tune_Left_1= 13 ;                     ! Use tuners to adjust the frequency,
Tune_Right_1= 12;                     ! Change by about +/-1, to give about
                                        +/- 6.5 MHz frequency change.

PARAMETER QT1   = 1/(1/QE1 +1/Qo1 ) ;  ! Desired Q effective (of Qo and Qe)
Parameter Sigma_1 = 0.32114E-01;       ! Change this value to adjust the Q.

! Record results here.
Parameter_GHZ  CF_1 = 34.982 GHZ ;     ! Frequency
Parameter      CQ_1 = 298 ;            ! Q effective (of Qo and Qe)
Parameter      CROQ_1 = 127            ! R over Q as measured on Axis.
```

When you run Step1 you should see a figure like the following. This illustrates the E_z field in the cavity and the beam tunnel.

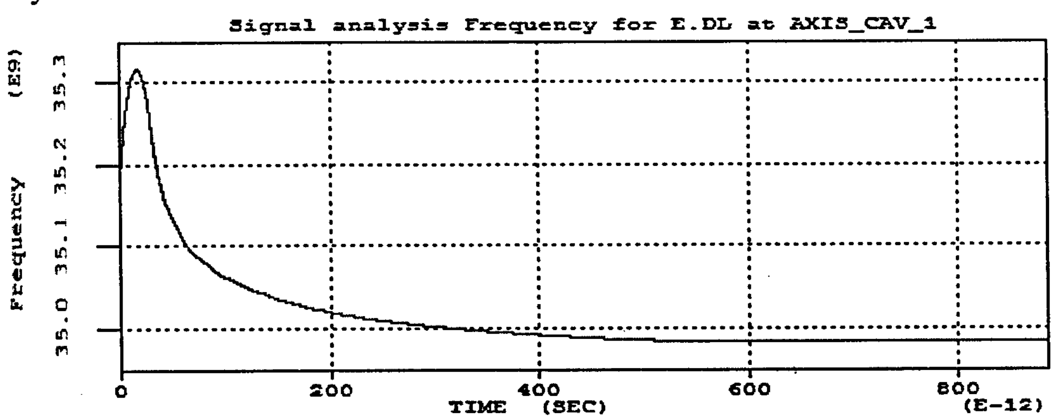


The figure of interest will give you the Q of the cavity. It will look like the following.
(Please note, that are multiple measurements of Q, but they should all give the same value within a percent or so.



Using the mouse, you can the precise value of Q as 298. Record this value in the control file as CQ_1 = 298. (See above listing.) We measure Q by directly looking the energy in the cavity and the rate at which it is decreasing in time. Thus we use $Q = -2\pi f\, W(t)/(dW(t)/dt)$. In the above measurement of Q, we start with total energy in the simulation, evaluate the derivative, and we know the frequency.

The next figure of interest, will look like the following. Use the mouse, click on the curve in the flat region. Record the value of the frequency, CF_1 = 34.982 GHZ. This is the resonance value of the cavity.

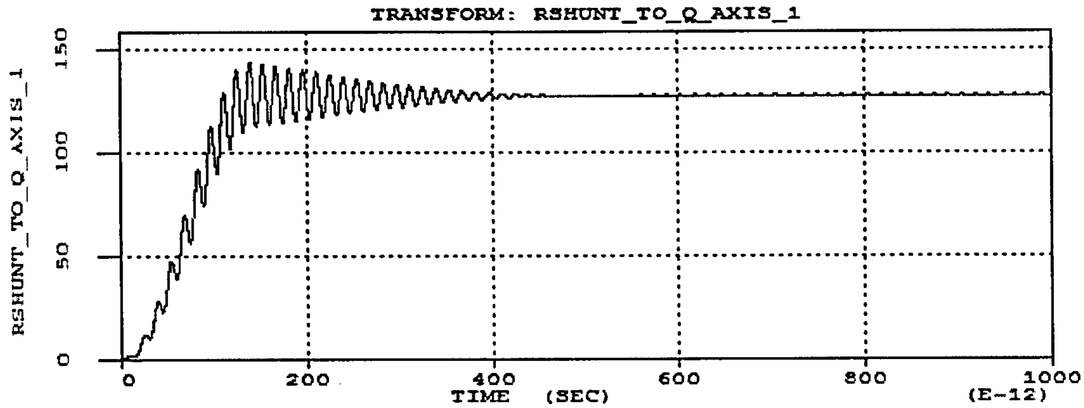


The next figure of interest will look like the following this a measurement of the R/Q on axis. (Incidentally, we also have such a measurement at the cavity gap radius.) Record the value of R/Q, as CROQ_1 = 127. To obtain R/Q we use MAGIC to measure the

$\langle V_{axis}^2\rangle(t)$, the integral of the Ez(z,r=0), averaged over 1 RF period, and to measure $\langle W_E\rangle(t)$, the electric field energy in the cavity, averaged over 1 RF period. Then the ratio of these measurements gives us a measure of R/Q, as follows.

$$\langle R/Q\rangle(t) = \langle V_{axis}^2\rangle(t), / (2\pi f \langle W_E\rangle(t)).$$

Initially we are driving the cavity, so this value must be obtained after the drive is terminated the cavity has relaxed to its natural resonant frequency.



The same procedures hold for Cavities 1 through 5. These are the single gap cavities.

Run Steps: 1 through 5 and record results and parameter updates in control file.

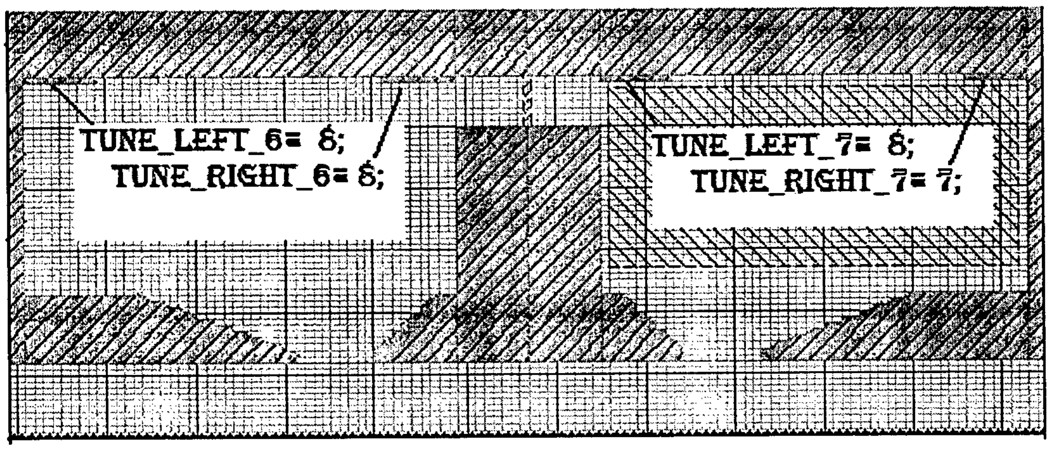
Eample Step 6: Tuning the Frequency of the Output Cavity

In Step=6, we tune the Frequency of the output cavity. Unlike cavities 1 through 5, we use the eigenmode solver to get a good estimate of the frequency. This cavity, which has two gaps, can oscillate at two frequencies, the 0-mode (tune to 35.00 GHz) and the π-mode (which is about 0.5 GHz below the 0-mode frequency). The proximity of these two modes, make it difficult to tune by exciting the cavity with a drive signal, since any drive envelope will have some contamination of the undesired component. It is preferable to use the MAGIC2D_DBL in obtaining this solution, as we can make direct measurements of R/Q from the eigenmode solution, provided the fields have only weak contamination.

```
!***************************************************************************
!==> Step6, Output Cavity,  Use Magic2d_Dbl
!    Cold test and tune Output cavity.
!    This output cavity is set for 0-mode, not the pi-mode.
!    Output Cavities, USe double precision Eigenmode to tune these cavities.
!    Get R/Q FROM EIGENMODE, Integrate |Ez| along axis.
!    Then R/Q = (|E|.dl)^2/4pi/f/1joule_from eigen soln.
!***************************************************************************

    IF (ISTEP.eq.6) THEN ;
       I_Run_Type          = 2 ;
       Cold_Test_Cavity    = OutputCAvity ;
       I_Cold_Type     = 2   ;
    ENDIF ;

    Parameter_GHZ  Eigenmode_fOut_0     = Fout_0   ;
    Tune_Left_6=  8;
    Tune_Right_6= 8;
    Tune_Left_7=  8;
```

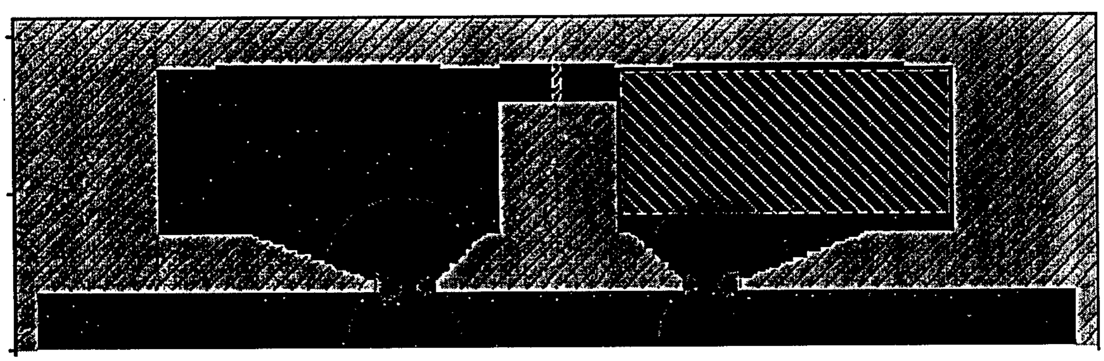
```
Tune_Right_7= 7;

! Record Results.
Parameter_GHZ CF_7_0 = 34.998 GHZ;   ! adjusted after eigenmode.
```

Notice that this cavity has 4 tuning elements. These correspond to shims in each side of the dual cavity output structure. By adjusting the number of cells in each shim element, the frequency can be fine tuned to within 6MHz.

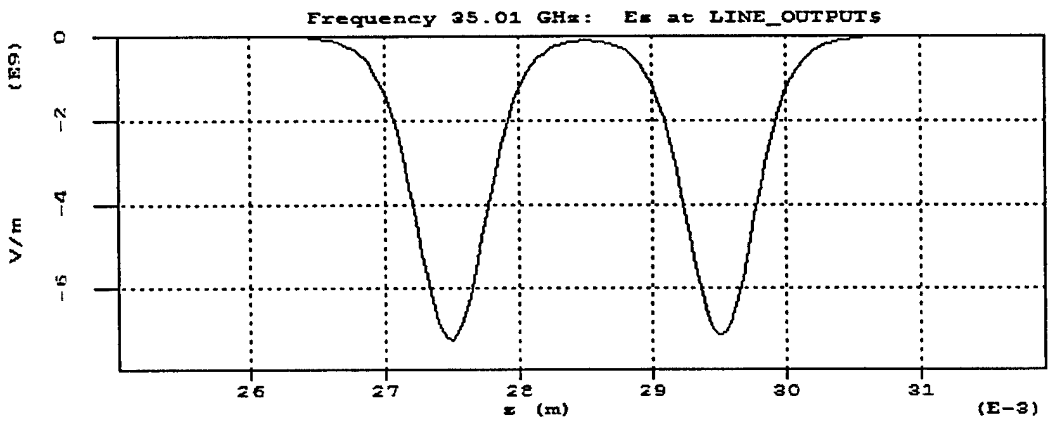


The first figure of interest in running Example Step 6 is the contour plot of the Ez field. By visual inspection, we see that it is indeed the 0-mode. The frequency to the 5th decimal can be found at the end of the log file or the sum file. Record this value, `CF_7_0 = 34.998 GHZ`.

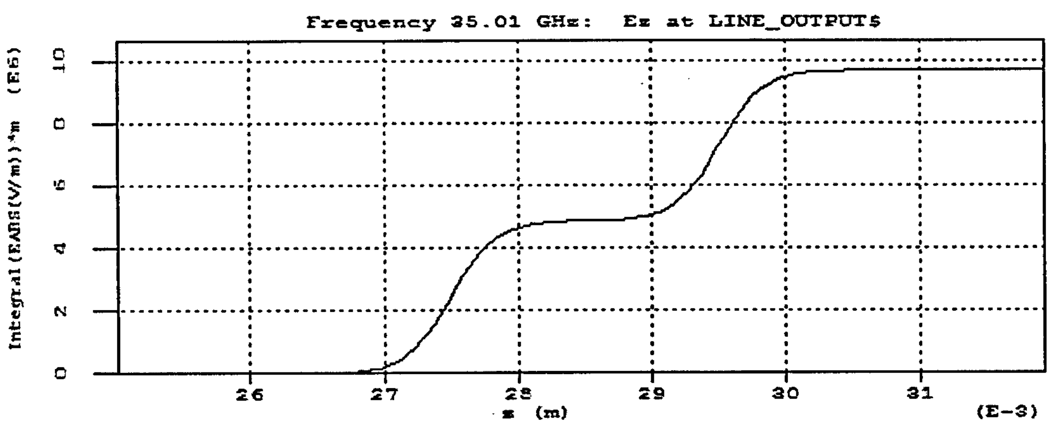
Frequency 35.00 GHz: Of Ez (V/m) at AREA_OUTPUT



Another figure of interest is the Range plot of the Ez field on Axis. By visual inspection we see that this has a nice clean profile.



The next figure is the integral of the |Ez| along the axis.



Obtain the final integrated peak of V_{axis} = 9.706e6. From this number we can obtain an estimate of R/Q, using the following expression.

$$R/Q = |V_{axis}|^2 / (4\pi f W_E) = |9.706e6|^2 / (4\pi\ 35.\text{GHz}\ \ 1\text{Joule}) = 214.$$

Note, that the eigenmode solution is normalized to W_E= 1Joule.

After the simulation is complete, examine the file "f3506.sum". Provided the eigenmode solver converged there will a section that looks like the following.

```
! ########################################################
! ######## Eigenmode Report #############################
! ########################################################
! ###
! ### Searching for a frequency in the range:
! ### ... 3.37E+10 (3.50E+10) 3.63E+10
! ### >>>> THE EIGENMODE FREQUENCY IS:  3.50054E+10 Hz
! ### ... with error:  0.0001 %
! ###
! ########################################################
! ########################################################
! ########################################################
```

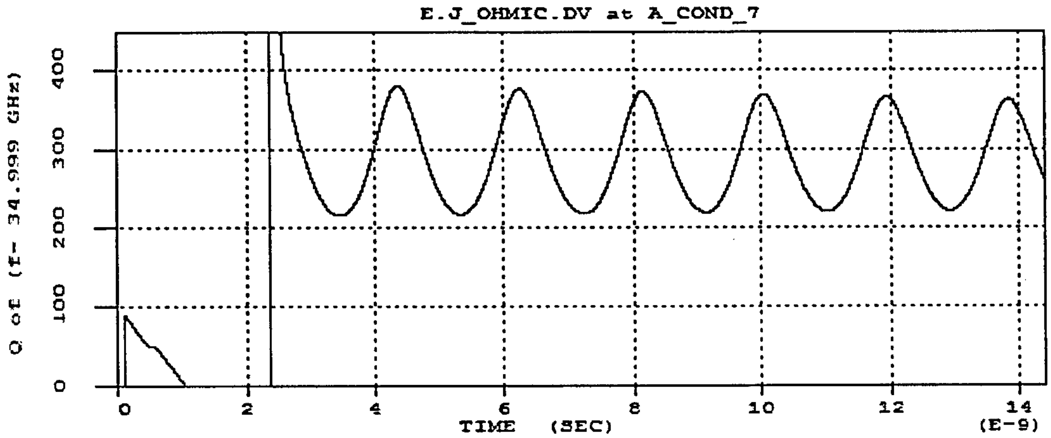
Examine this section and record the resultant frequency. If necessary, make adjustments to the tuners for the output cavity. Repeat until satisfied with the frequency.

Example Step 7: Tuning the Q of the Output Cavity.

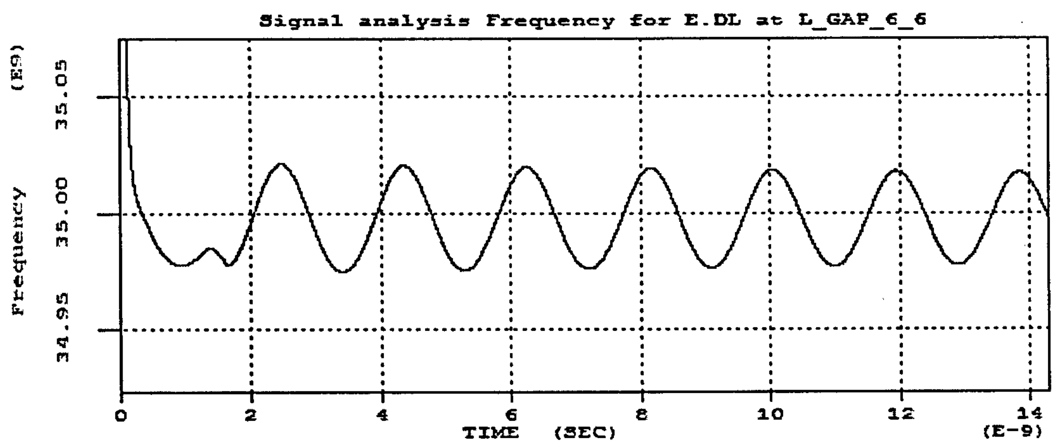
In Step 7, we use a current driver to introduce the RF into the output cavity at the frequency of the 0-mode, much as we did for the single gap cavities, (1 through 5). However, because there are two modes close to this frequency, we are not able to excite a pure mode. None the less, we can use measurements similar to those used in the single cavity tuning Steps. . The section of the file for this Step looks like the following:

```
!*****************************************************************************
!==> Step7, Output Cavity, Tune Q.
!    Cold test and tune Output cavity.
!    This output cavity is set for 0-mode, not the pi-mode.
!    Measure/Tune Q and R/Q
!*****************************************************************************

     IF (ISTEP.eq.7) THEN ;
        I_Run_Type         = Cold_Test ;
        Cold_Test_Cavity   = OutputCAvity ;
        I_Cold_Type    = 2   ;
     ENDIF ;

     PARAMETER QT6 = 1/(1/QE6 +1/Qo6) ;        ! Effective Q of output cavity.
     Parameter Sigma_'OutputCavity'    = 0.0 ;
     Parameter Sigma_'MaxCavities'     = 0.5940E-01 ;

     ! Record Results.
     Parameter      Q_7 = 298 ;
     Parameter      CROQ_7_RingDOWN = 211 ;
     Parameter      CROQ_7_Eigen    = 214 ;
```

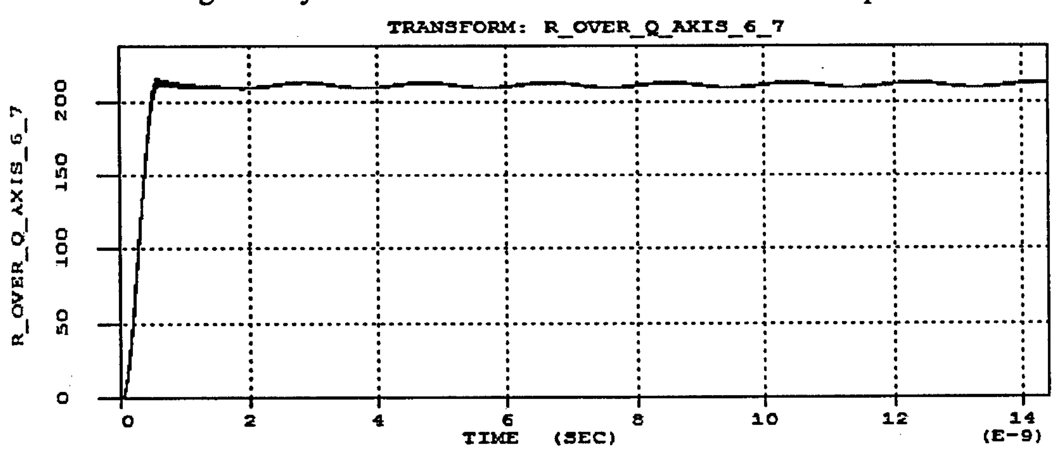
The first figure of interest is the measurement for Q. It will resemble the following figure. Notice the ripple in the measurement. Our best estimate for Q is the center value between the extremes (218 minimum to 372 maximum), thus we get Q = 295. There are additional measurements that give similar figures. Verify that all indicate the same central value for Q. If this value is to far from the desired $Q_{effective}$, than adjust the conductance, sigma value.



The next figure of interest is the frequency versus time analysis. Note that the frequency wobbles from 34.977 to 35.018 GHz, with center frequency at 34.997 GHz. Verify that this is consistent with the eigenmode frequency.



The next figure of interest gives us an estimate of the R/Q_{axis}. Obtain the value (in this Step we have a value of 211. Again very close to the value of 214 obtained from Step 6.



Example Step 8: Estimate Mfactors from the Input Cavity.

In Step 8, we solve cavity 1 with eigenmode. The eigenmode frequency should be nearly identical to that obtained with excitation cold test of Step1. What we want from this simulation is a measure of the Mfactor. The definition we use is that

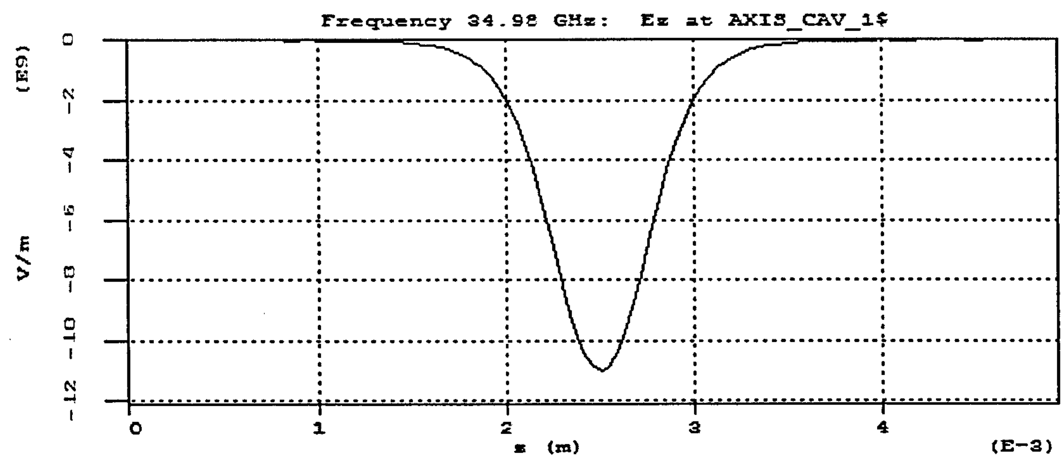
$$M = M_n / M_d$$

Where

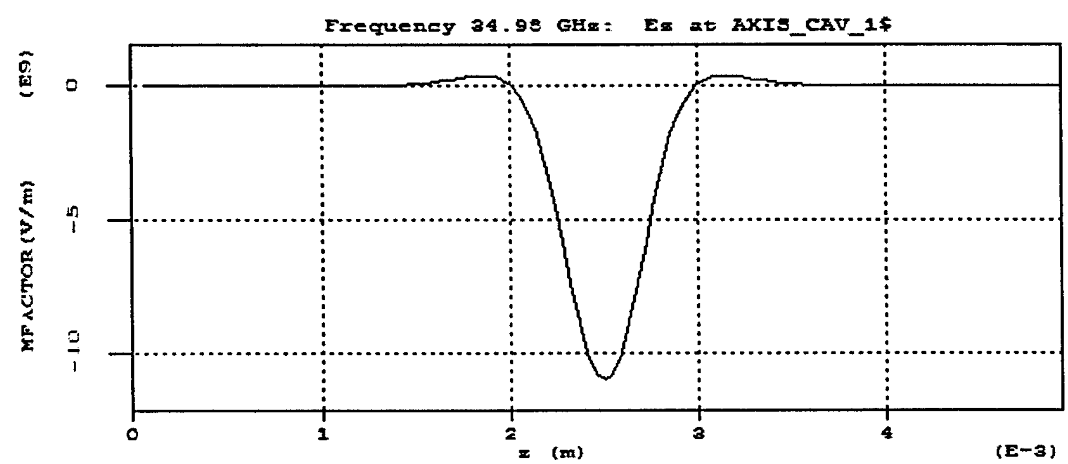
$$M_n (r) = \int |Ez(z,r) \cos [2\pi f_1(z-z_{centergap})/v_{beam}] \, dz$$

$$M_d (r) = \int |Ez(z,r)| \, dz$$

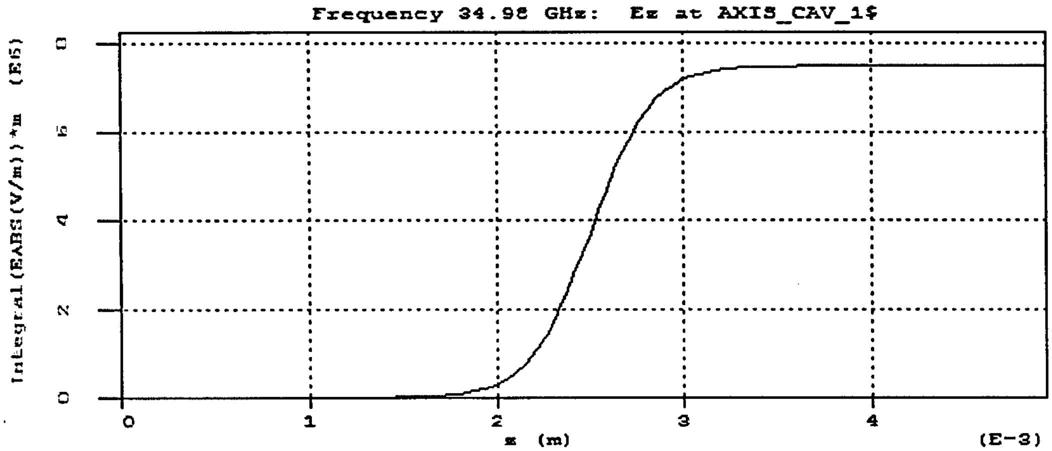
Using Magic we obtain the following plot of Ez(z,r=0).



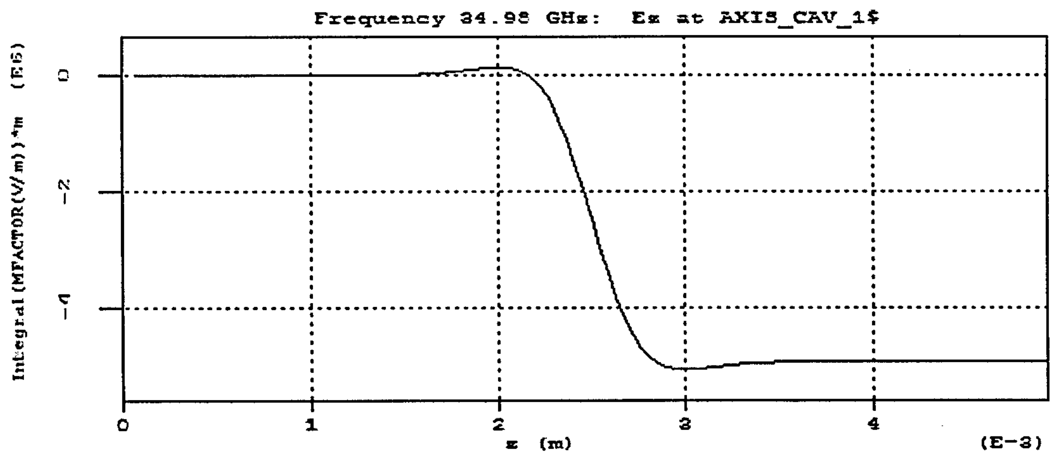
and the following figure gives the profile of Ez(z,r=0) cos $[2\pi f_1(z-z_{centergap})/v_{beam}]$.



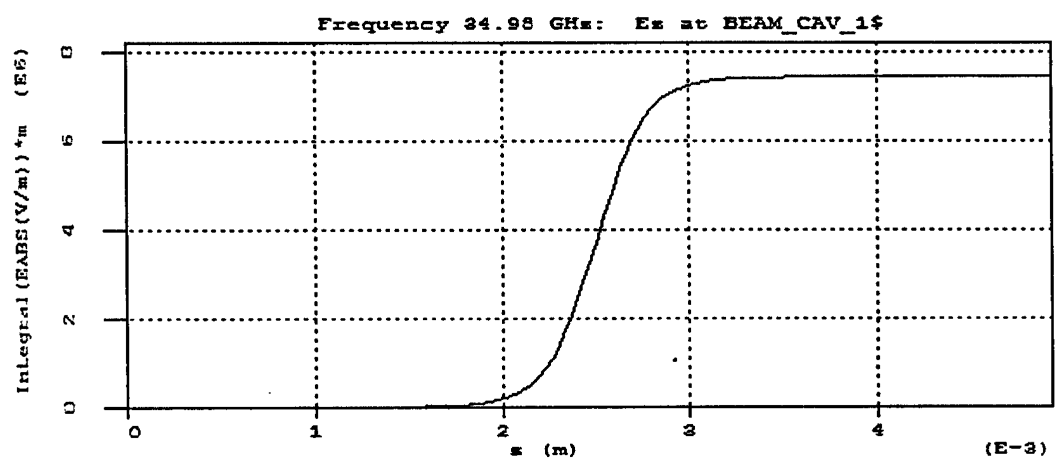
Using the integrate option in MAGIC we obtain the running integrals of these profiles.
The maximum value of M_d (r=0) = $\int|Ez(z,r)| \, dz$ = 7.485E6 is obtained from the following figure.



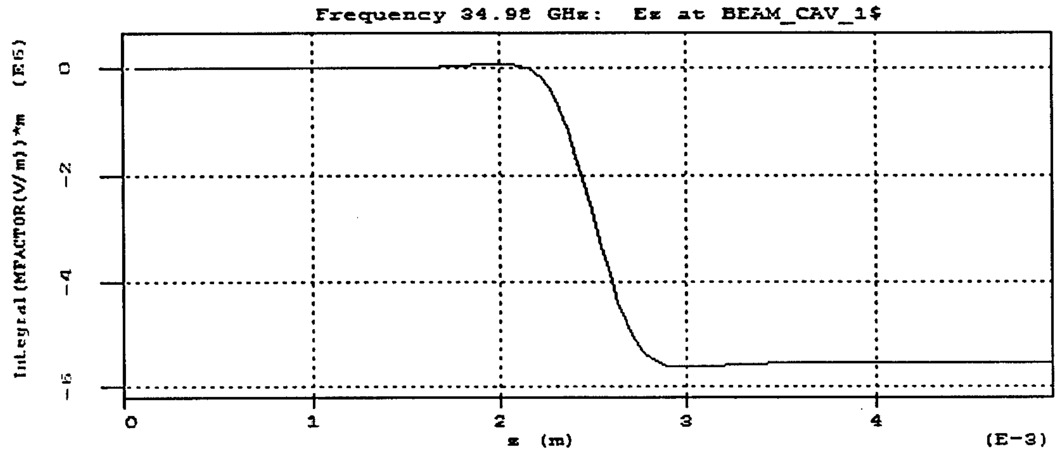
The maximum value of $M_n\,(r=0) = \int \int Ez(z,r) \cos\,[2\pi f_1(z-z_{centergap})/v_{beam}]\,dz = 4.945E6$ is obtained from the following figure.



Taking the ration we obtain the on-axis M factor = 0.662. Record this value.
We also obtain the same type of figures at the beam radius. 7.435e6



Integral value is 5.537e6.



Taking the ration we obtain the on-axis M factor = 0.745. Record this value.

Example Step 9: Estimate Qbeam from Short hot test with the Input Cavity only.

It is important to find a good value for Qbeam. This allows us to properly set the desired input power.

```
!*******************************************************************************
!==> Step9.  Short Hot test. Obtain beam loading in first cavity.
!*******************************************************************************

     IF (ISTEP.eq.9) THEN ;
        I_Run_Type        = 0;
        Freq = CF_1 ;
        t_sim   = 5.0nanosec;
        ExitCavity    = 1 ;
     ENDIF ;

     ! This number determined from hot test. Insert proper value here.
     Parameter Qb1 = 1206 ; ! Beam loading Q.
     PARAMETER QTb1 = 1/(1/QE1 +1/Qo1 + 1/Qb1) ;
```

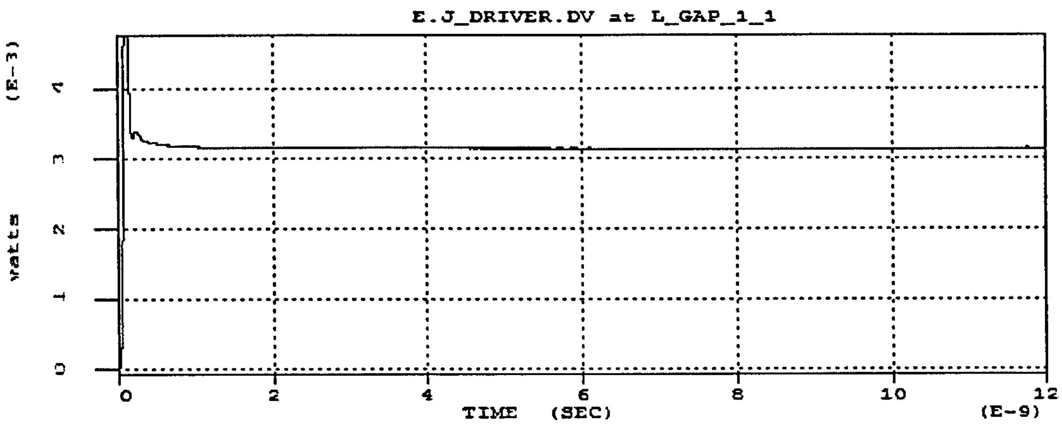
We measure the cavity1 gap Voltage and the power loss in the empirical load in cavity1. We measure Qtotal by evaluating the following expression.

$$\text{Qtotal} = \langle V^2 \rangle / P_{gap} / (R/Q)$$

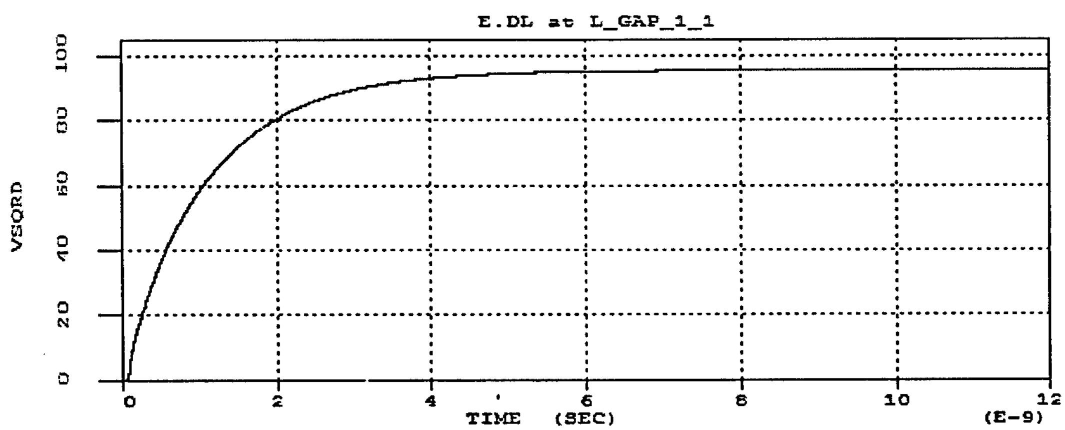
We measure $\langle V^2 \rangle$ and P_{gap} using Magic. We know the R/Q from the first cavity.
Once we have Qtotal, we can back out Qbeam.

$$1/\text{Qtotal} = 1/\text{Qbeam} + 1/\text{Qo} + 1/\text{Qe}.$$

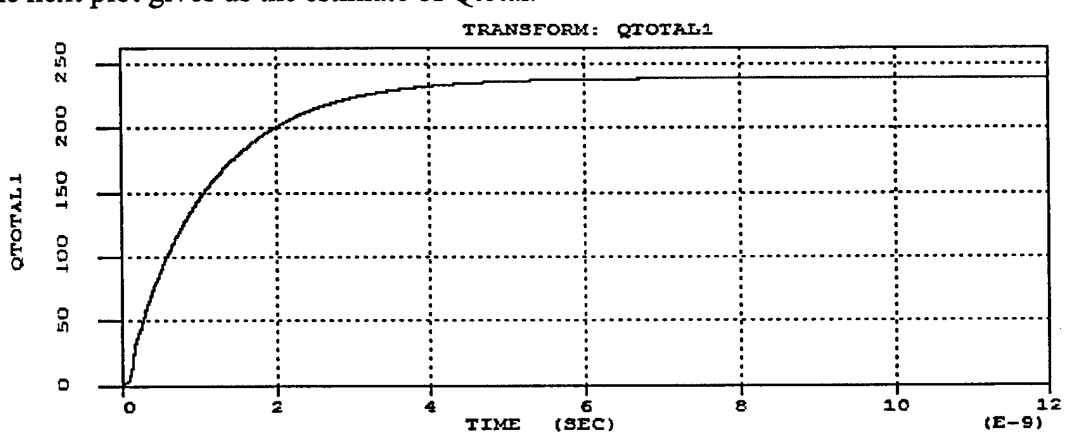
The first plot of interest is the measurement of P_{gap}.



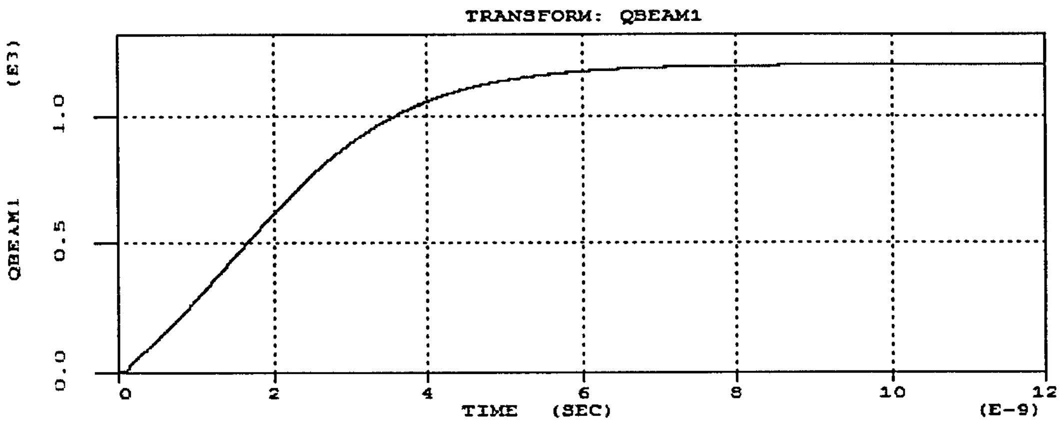
The next plot of interest in this section is the measurement of <V^2>.



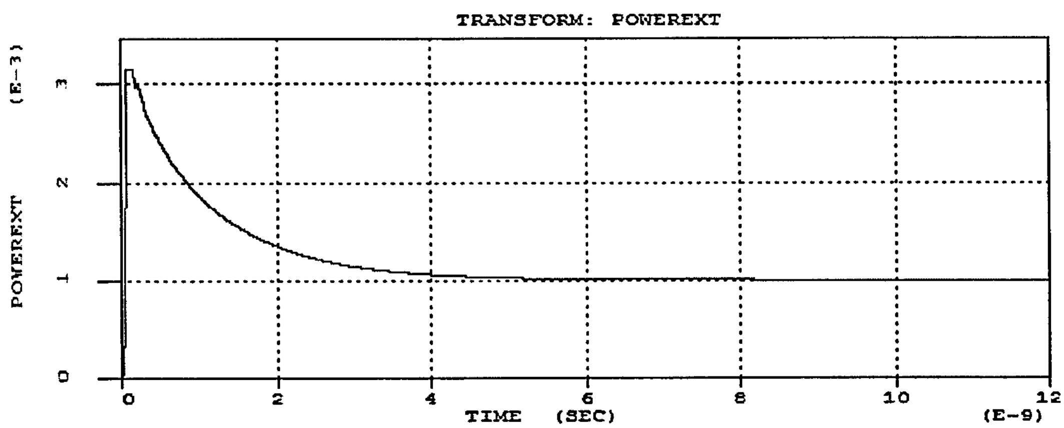
The next plot gives us the estimate of Qtotal.



The next plot gives us the estimate of Qbeam.



The input power is given by the following figure.



Example Step 10: Run Frequency and Power Sets.

We use the following expression to estimate the necessary current for the desired input power. We first get the drive power required from the following expression.

$$P_{Drive} = Pr_{Desired} /(1 - Q_{tb1}/Q_{e1})$$

Since we the driver is actually a current source we need to relate the applied current to the applied power. We note that the power can be written at the applied current times the gap voltage. We estimate the gap voltage from the following expression.

$$V_{gap} = I_{gap}\, Q\, (R/Q)\; 1/[1+i2Q(f-f_1)/f]\; M_{factor}$$

Define a phase factor, ϕ, with the following expression:

$$\phi = |\, 1/[1+i2Q(f-f_1)/f]\, |$$

Then we finally use the following expression to set the applied current.

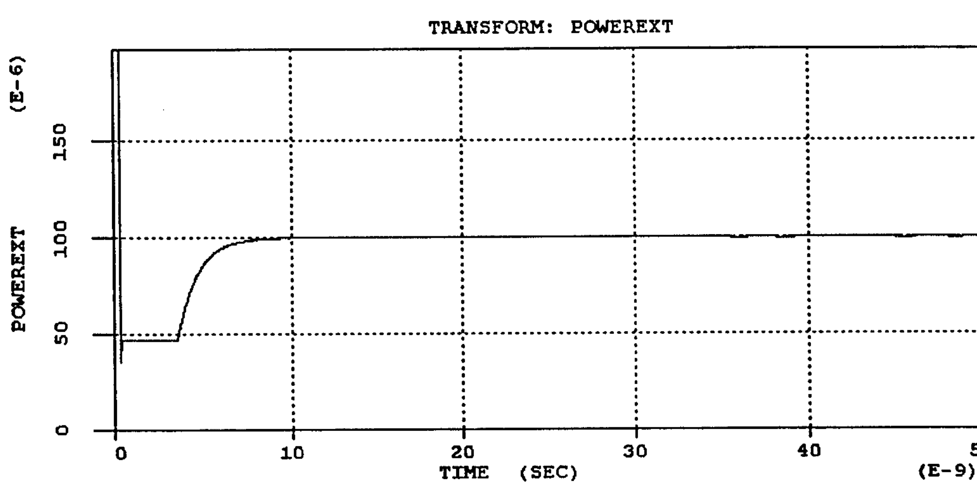
$$I_{drive} = (2\, P_{drive} / (Q_{tb1}\, (R/Q)_1\, \phi\, M_{factor})$$

The only user inputs for Step10 are the frequency and the desired input power.
For this design the range of frequencies recommended is 34.8 GHz to 35.2 GHz, and the recommend input power is 0.1 milliwatt to 100 milliwatt.

```
!************************************************************************
!==> Case10.  Hot tests. Select frequency and input power.
!************************************************************************

     IF (IStep.eq.10) THEN ;
        I_Run_Type         = 0;
        t_sim  = 50.0nanosec;
        Header Remarks "Hot Test " ;

        ! Select Drive Frequency and Input Power for Hot tests.
        parameter_ghz              Freq = 35.000 GHz;
        Parameter     Desired_PowerIn  = 1_milliwatts;

        ! These are the nominal operating parameters.
        Parameter_KiloVolt  V_beam     = 14.0kV ;
        Parameter_Amp       A_beam     = 0.5A ;
        Parameter_Gauss     Bz         = 0.80tesla;
     ENDIF ;
```

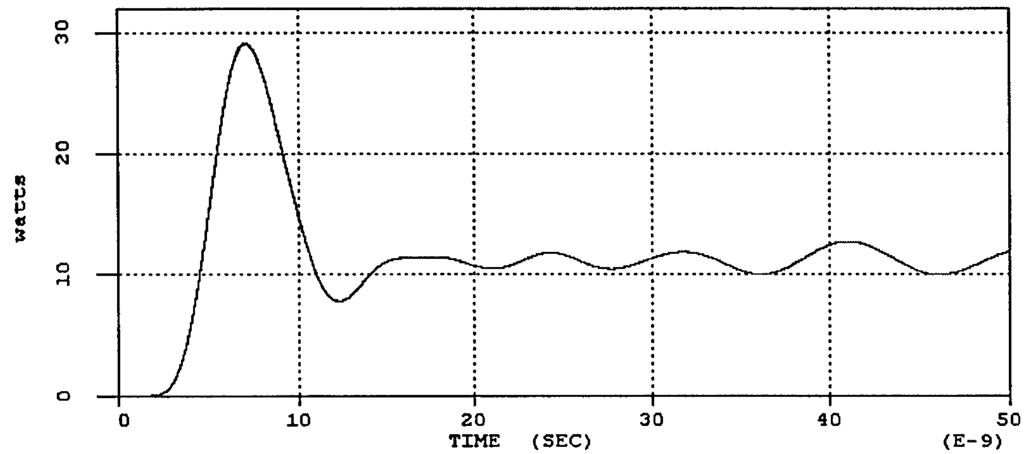
The following figures illustrate the type of output available for each hot test simulation.
The simulation below was at 35 Ghz with an input power of 0.1 milliWatt.

Input power: 0.1 mWatt



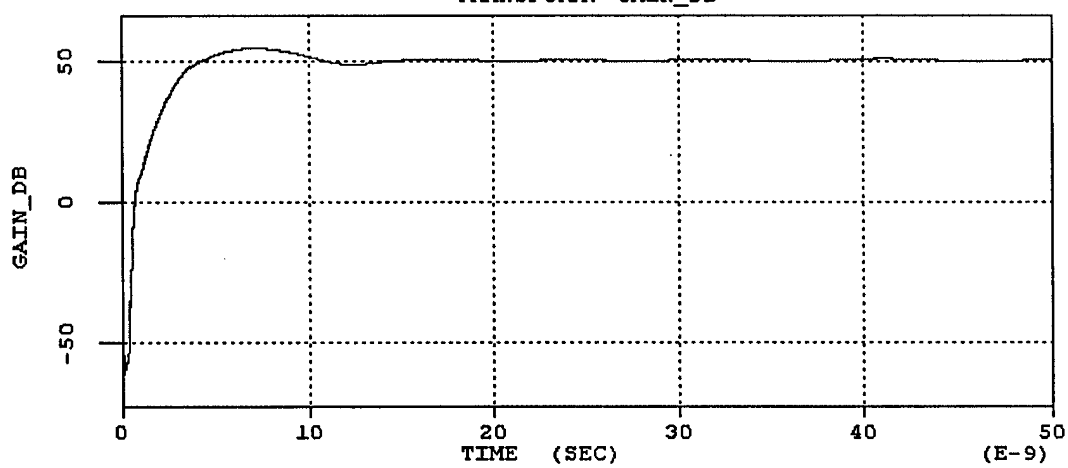
Power in output cavity.

E.J_OHMIC.DV at A_COND_7



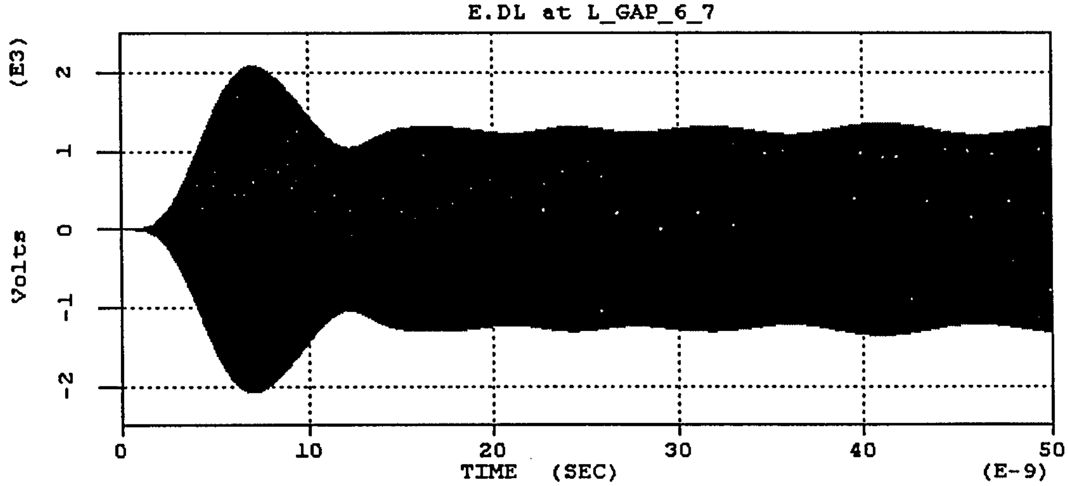
Gain. 50 dB

TRANSFORM: GAIN_DB

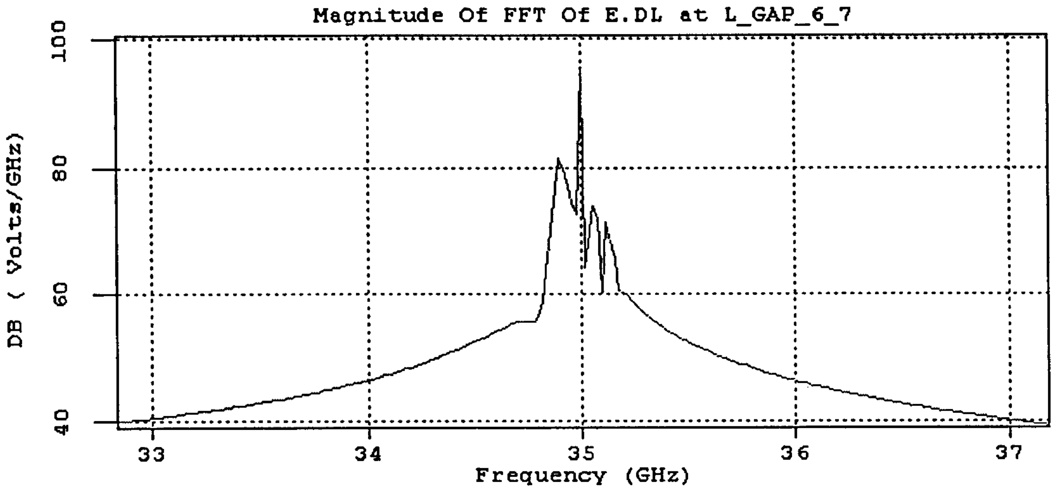


Voltage in output cavity. 1.26kV

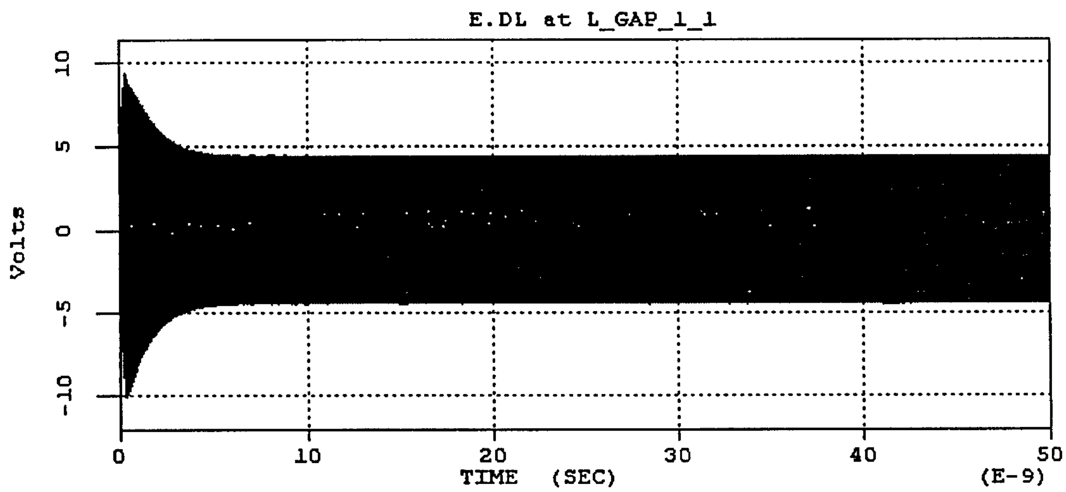
E.DL at L_GAP_6_7



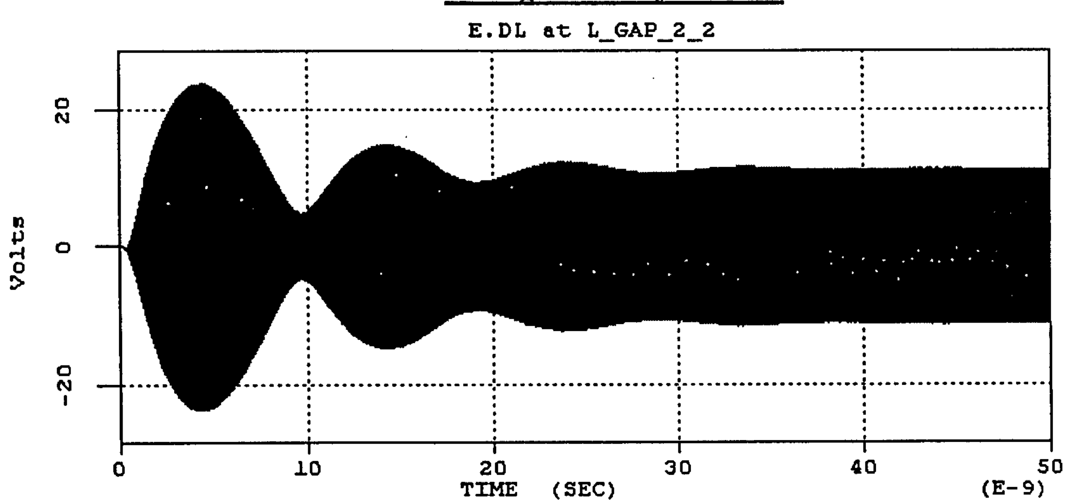
FFT of Voltage in output cavity. 1.26kV



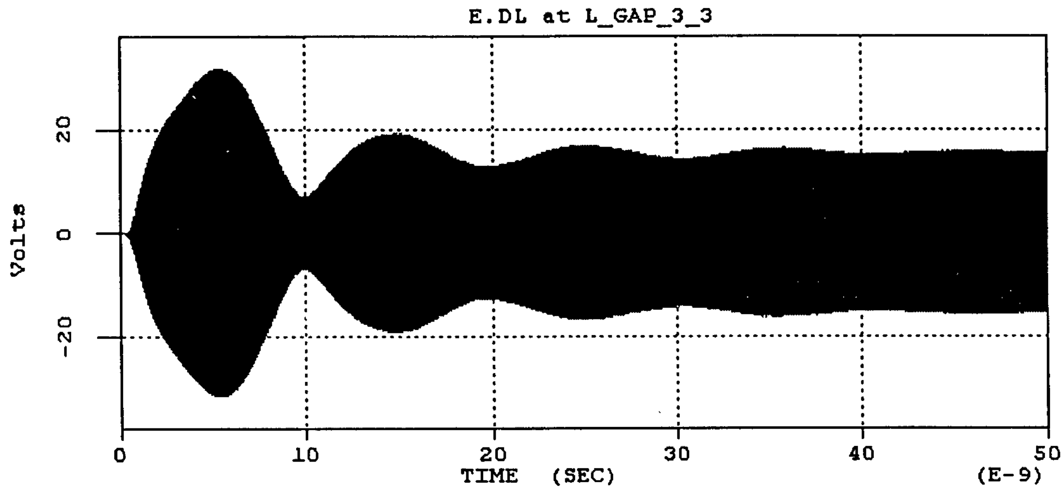
Voltage in input cavity. 4.4 V



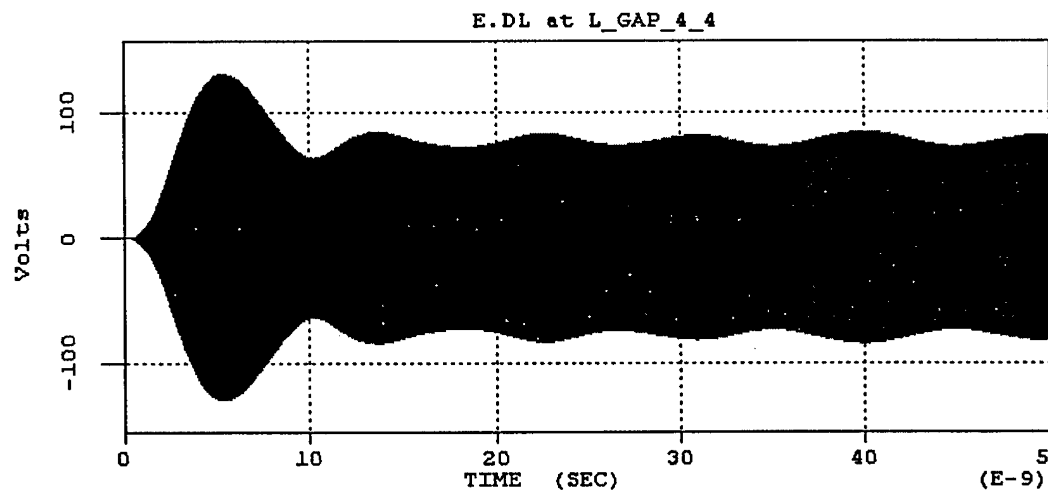
Voltage in cavity 2: 10.44



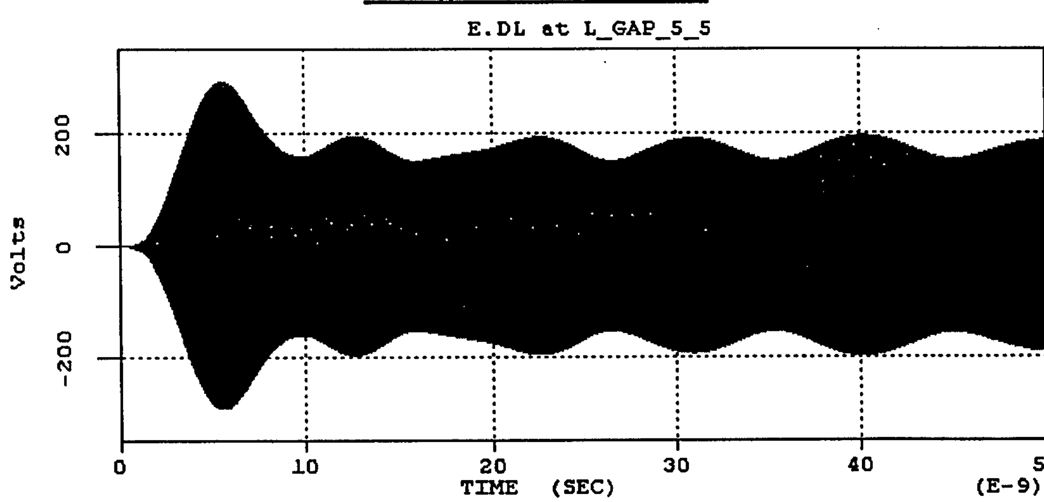
Voltage in cavity 3: 15.39

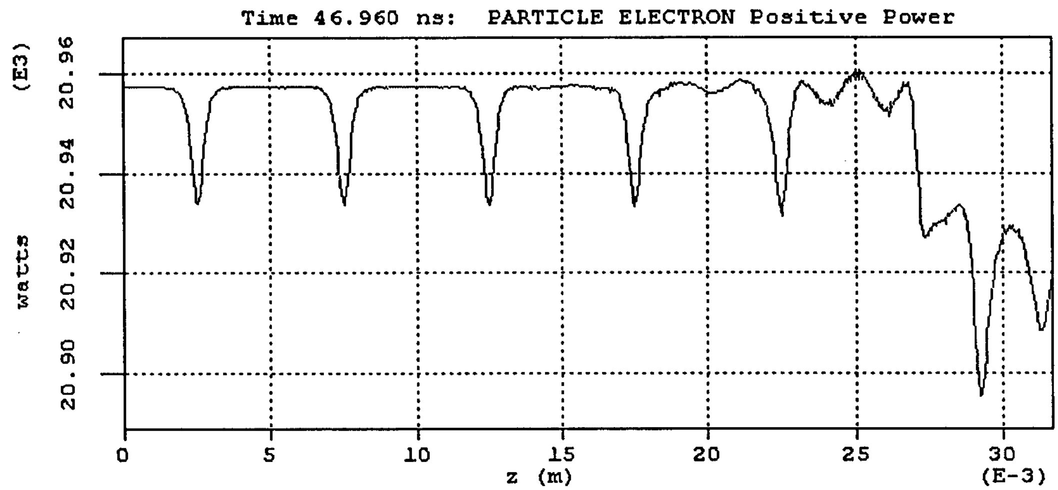


Voltage in cavity 4: 77.5



Voltage in cavity 5: 173.5





Other data is also avialable. This set represents the most interesting data.

APPENDIX: Input file listing
F3506.m2d

```
! ***********************************************************************
! F3607.m2d  - Base File Name for 35 GHz, 7 Cavity klystron.
! ***********************************************************************
! Cavity 1: Input Cavity.
! Cavity 2-5: Intermediate Cavities.
! Cavity 6&7: Dual Output Cavity
! Cold test runs of individual cavities. Excite using antenna driver at
! the target cavity frequency. Adjust by adding/removing conductor cells
! from the the tuning strips. Resolution is approximately 6.5Mhz/cell.
! Adding/removing cells  shifts frequency up/down as the inductance
! changes.

Comment " Specify output cavity. ";

        Integer  OutputCavity, ExitCavity, ColdTestCavity ;
        OutputCavity = 6 ;
        MaxCavities  = OutputCavity+1 ;
        ExitCavity   = MaxCavities ;
        ColdTestCavity = 1;

Comment " The desired Cavity Design frequencies.";

PARAMETER_GHZ   ftube     = 35.0GHz;     ! operating mode of the output
PARAMETER_GHZ   f1        = 34.98 GHz;
PARAMETER_GHZ   f2        = 34.90 GHz;   ! "
PARAMETER_GHZ   f3        = 35.09 GHz;   ! "
PARAMETER_GHZ   f4        = 35.09 GHz;   ! "
PARAMETER_GHZ   f5        = 35.17 GHz;   ! "
PARAMETER_GHZ   f6        = 35.00 GHz;   ! "
PARAMETER_GHZ   fOut_0    = 34.999 GHz;  ! Use Eigenmode Dbl prec.
PARAMETER_GHZ   fOut_PI   = 34.4564GHz;  ! Use Eigenmode Dbl prec.

Comment " Nominal operating parameters." ;

        parameter_ghz            Freq = 35.000 GHz;
        Parameter    Desired_PowerIn  = 1_milliwatts;
        Parameter_KiloVolt  V_beam    = 14.0kV ;
        Parameter_Amp       A_beam    = 0.5A ;
        Parameter_Gauss     Bz        = 0.80tesla;
        Parametert          t_sim     = 40.0nanosec;

Comment " The desired Cavity Qs and R/Q.";

Parameter QE1 = 350 ;  Parameter Qo1 = 2000 ;  Parameter RoverQ1 = 128 ;
Parameter QE2 = 1E9 ;  Parameter QO2 = 2000 ;  Parameter RoverQ2 = 128 ;
Parameter QE3 = 1E9 ;  Parameter QO3 = 2000 ;  Parameter RoverQ3 = 128 ;
Parameter QE4 = 1E9 ;  Parameter QO4 = 2000 ;  Parameter RoverQ4 = 128 ;
Parameter QE5 = 1E9 ;  Parameter QO5 = 2000 ;  Parameter RoverQ5 = 128 ;
Parameter QE6 = 350 ;  Parameter QO6 = 2000 ;  Parameter RoverQ6 = 128 ;
```

```
Comment " Design Gap to Gap spacing. "

PARAMETER_MM    dZ_gap2gap_0_1      = 5.0 mm;
PARAMETER_MM    dZ_gap2gap_1_2      = 5.0 mm;
PARAMETER_MM    dZ_gap2gap_2_3      = 5.0 mm;
PARAMETER_MM    dZ_gap2gap_3_4      = 5.0 mm;
PARAMETER_MM    dZ_gap2gap_4_5      = 5.0 mm;
PARAMETER_MM    dZ_gap2gap_5_6      = 4.7 mm;
PARAMETER_MM    dZ_gap2gap_6_7      = 2.0 mm;
PARAMETER_MM    dZ_gap2gap_7_8      = 5.0 mm;

! Parameter definitions. Do NOT change these.

On              = 1;
Off             = 0;
Hot_Test        = 0;
Cold_Test       = 1;
EigenMode_Test  = 2;
I_Cav_Cndctnc   = on ;! Use cavity loss in all cavities if present.
I_Run_Type      = 0;  ! 0 = Hot test
                      ! 1 = Antenna Driven cold test
                      ! 2 = Eigenmode cold test
I_Cold_Type    = 2  ; ! 1 = 1by1 (applies to all cavities and cells)
                      ! 2 = 2by2 (applies only to output structure)
                      ! 3 = 2by2 pulse
! Cold test cavity, or first cell if I_Cold_Type = 2.
Cold_Test_Cavity = OutputCAvity  ;

! Header Definition.

         HEADER AUTHOR "Liqun Song" ;
         HEADER DEVICE "35GHz Klystron";
         HEADER ORGANIZATION "SLAC";
         GRAPHICS PAUSEon;
         graphics pause ;

! Run Controls and Global Parameters *******************
! Select simulation cases here.

IStep=1 ;   ! Magic2d_Sng: Cold test, Tune cavity 1.
IStep=2 ;   ! Magic2d_Sng: Cold test, Tune cavity 2.
IStep=3 ;   ! Magic2d_Sng: Cold test, Tune cavity 3.
IStep=4 ;   ! Magic2d_Sng: Cold test, Tune cavity 4.
IStep=5 ;   ! Magic2d_Sng: Cold test, Tune cavity 5.
IStep=6 ;   ! Magic2d_Dbl: Eigenmode test, Tune cavity 6 Frequency.
IStep=7 ;   ! Magic2d_Sng: Cold test, Tune cavity 6, Tune Q.
IStep=8 ;   ! Magic2d_Dbl: Eigenmode cavity 1. Measure M factors.
IStep=9 ;   ! Magic2d_Sng: Hot test of cavity 1, obtain Beam loading Q.
IStep=10;   ! Magic2d_Sng: Run Hot tests at desired frequency and
            !              input power.

! *** Select case here.
ISTEP = 1 ;
```

```
!**************************************************************************
! Cavity Tuning Procedure, for Input and Intermediate Cavities.
! Procedure, run Case and obtain frequency.
! If frequency lo, increase values of tune_left and tune_right.
! If frequency hi, decrease values of tune_left and tune_right.
! IF frequency good. Check Qeffective and R/Q.
! Remember that you are measuring and tuning to Q effective
! IF Q (measured) is greater/less than Q (desired),
! then alter value of sigma.
! Adjust sigma as follows:
! Sigma (desired) = Sigma (used) * Q (measured) / Q (desired).
!**************************************************************************
!==> Case1, Cavity1,  Can Use either Magic2d_Sng or Magic2d_Dbl
!     Cold test and tune cavity 1.
!**************************************************************************

IF (IStep.eq.1) THEN ;
        I_Run_Type         = 1;  ! 0 = Hot test
        Cold_Test_Cavity  = 1  ;
        ExitCavity    = 1 ;
        Header Remarks "Tuning Input Cavity" ;
ENDIF ;

! Cavity 1, tuning parameters.

Parameter_GHZ  Desired_f1 = f1;  ! Desired Frequency for Cavity 1
Tune_Left_1= 13 ;                ! Use tuners to adjust the frequency,
Tune_Right_1= 12;                ! Change by about +/-1, to give
                                 ! about +/1 6.5 MHz frequency change.

PARAMETER QT1  = 1/(1/QE1 +1/Qo1 ) ;  ! Desired Q effective (of Qo and Qe)
Parameter Sigma_1 = 0.32114E-01;      ! Change this value to adjust the Q.

! Record results here.
Parameter_GHZ  CF_1 = 34.982 GHZ ;    ! Frequency
Parameter      CQ_1 = 298 ;           ! Q effective (of Qo and Qe)
Parameter      CROQ_1 = 127           ! R over Q as measured on Axis.

!**************************************************************************
!==> Case2, Cavity2,  Can Use either Magic2d_Sng or Magic2d_Dbl
!     Cold test and tune cavity 2.
!**************************************************************************

IF (IStep.eq.2) THEN ;
    I_Run_Type         = 1;
    Cold_Test_Cavity  = 2 ;
    ExitCavity    = 2 ;
    Header Remarks "Tuning Intermediate Cavity 2" ;
ENDIF ;

Parameter_GHZ  Desired_f2 = f2;   ! Desired Frequency for Cavity 2
Tune_Left_2= 6 ;                  ! Use tuners to adjust the frequency,
Tune_Right_2= 6 ;                 ! Change by about +/-1, to give
                                  ! about +/1 6.5 MHz frequency change.

PARAMETER QT2 = 1/(1/QE2 +1/Qo2) ;       ! Desired Q effective (of Qo and Qe)
Parameter Sigma_2 = 0.47441E-02;         ! Change this value to adjust the Q

! Record results here.
Parameter_GHZ CF_2 = 34.898 GHZ ;
Parameter     CQ_2 = 2000;
Parameter     CROQ_2 = 127 ;
```

```
!*****************************************************************************
!==> Case3, Cavity3,  Can Use either Magic2d_Sng or Magic2d_Dbl
!    Cold test and tune cavity 3.
!*****************************************************************************

IF (IStep.eq.3) THEN ;
   I_Run_Type         = 1;
   Cold_Test_Cavity  = 3 ;
   ExitCavity    = 3 ;
   Header Remarks "Tuning Intermediate Cavity 3" ;
ENDIF ;

Parameter_GHZ  Desired_f3    = f3;   ! Desired Frequency for Cavity
Tune_Left_3= 21 ;                    ! Use tuners to adjust the frequency,
Tune_Right_3= 21;                    ! Change by about +/-1, to give
                                     ! about +/1 6.5 MHz frequency change.

PARAMETER QT3 = 1/(1/QE3 +1/Qo3) ;  ! Desired Q effective (of Qo and Qe)Parameter Sigma_3
= 0.48437E-02;              ! Change this value to adjust the Q.

! Record results here.
Parameter_GHZ CF_3 = 35.091 GHZ ;
Parameter     CQ_3 = 2000;
Parameter     CROQ_3 = 127 ;

!*****************************************************************************
!==> Case4, Cavity4,  Can Use either Magic2d_Sng or Magic2d_Dbl
!    Cold test and tune cavity 4.
!*****************************************************************************

IF (IStep.eq.4) THEN ;
   I_Run_Type         = 1;
   Cold_Test_Cavity  = 4 ;
   ExitCavity    = 4 ;
   Header Remarks "Tuning Intermediate Cavity 4" ;
ENDIF ;

Parameter_GHZ  Desired_f4     = f4;  ! Desired Frequency for Cavity
Tune_Left_4 = 21 ;                   ! Use tuners to adjust the frequency,
Tune_Right_4= 21;                    ! Change by about +/-1, to give
                                     ! about +/1 6.5 MHz frequency change.

PARAMETER QT4 = 1/(1/QE4 +1/Qo4) ;       ! Desired Q effective (of Qo and Qe)
Parameter Sigma_4 = 0.48437E-02;         ! Change this value to adjust the Q.

! Record results here.
Parameter_GHZ CF_4 = 35.091 GHZ ;
Parameter     CQ_4 = 2000;
Parameter     CROQ_4 = 127 ;

!*****************************************************************************
!==> Case5, Cavity5,  Can Use either Magic2d_Sng or Magic2d_Dbl
!    Cold test and tune cavity 5.
!*****************************************************************************

IF (IStep.eq.5) THEN ;
     I_Run_Type         = 1;
     Cold_Test_Cavity  = 5 ;
     ExitCavity    = 5 ;
     Header Remarks "Tuning Intermediate Cavity 5" ;
ENDIF ;

Parameter_GHZ  Desired_f5  = f5;   ! Desired Frequency for Cavity
```

```
Tune_Left_5= 2 ;                        ! Use tuners to adjust the frequency,
Tune_Right_5= 3;                        ! Change by about +/-1, to give
                                        ! about +/1 6.5 MHz frequency change.

PARAMETER QT5 = 1/(1/QE5 +1/Qo5) ;         ! Desired Q effective (of Qo and Qe)
Parameter Sigma_5 = 0.48861E-02;           ! Change this value to adjust the Q.

! Record Results.
Parameter_GHZ CF_5 = 35.168 GHZ ;
Parameter      CQ_5 = 1996;
Parameter      CROQ_5 = 127 ;

!*******************************************************************************
!==> Case6, Output Cavity,  Use Magic2d_Dbl
!     Cold test and tune Output cavity.
!     This output cavity is set for 0-mode, not the pi-mode.
!     Output Cavities, USe double precision Eigenmode to tune these cavities.
!     Get R/Q FROM EIGENMODE, Integrate |Ez| along axis.
!     Then R/Q = (|E|.dl)^2/4pi/f/1joule_from eigen soln.
!*******************************************************************************

IF (IStep.eq.6) THEN ;
   I_Run_Type          = 2 ;
   Cold_Test_Cavity   = OutputCAvity ;
   I_Cold_Type    = 2   ;
   Header Remarks "Frequency Tuning Output Cavity " ;
ENDIF ;

Parameter_GHZ  Eigenmode_fOut_0     = Fout_0   ;
Tune_Left_6=  8;
Tune_Right_6= 8;
Tune_Left_7=  8;
Tune_Right_7= 7;

! Record Results.
Parameter_GHZ CF_7_0 = 35.0054 GHZ;   ! adjusted after eigenmode.

!*******************************************************************************
!==> Case7, Output Cavity.
!     Cold test and tune Output cavity.
!     This output cavity is set for 0-mode, not the pi-mode.
!     Measure/Tune Q and R/Q
!*******************************************************************************

IF (IStep.eq.7) THEN ;
    I_Run_Type          = Cold_Test ;
    Cold_Test_Cavity   = OutputCAvity ;
    I_Cold_Type    = 2   ;
    Header Remarks "Tuning Q/Load of Output Cavity " ;
ENDIF ;

PARAMETER QT6 = 1/(1/QE6 +1/Qo6) ;                ! Effective Q of output cavity.
Parameter Sigma_'OutputCavity'   = 0.0 ;
Parameter Sigma_'MaxCavities'    = 0.5940E-01 ;

! Record Results.
Parameter      Q_7 = 298 ;
Parameter      CROQ_7_RingDOWN = 211 ;
Parameter      CROQ_7_Eigen    = 214 ;

!*******************************************************************************
!==> Case8, Cavity1,  Can Use either Magic2d_Sng or Magic2d_Dbl
!     Eigenmode test and tune cavity 1.
```

```
!***********************************************************************
IF (IStep.eq.8) THEN ;
        I_Run_Type         = 2;
        Cold_Test_Cavity   = 1  ;
        Freq = CF_1 ;
        ExitCavity    = 1 ;
        Header Remarks "Cavity1, obtain Beam Mfactors " ;
ENDIF ;

Parameter_KiloVolt  V_beam    = 14.0kV ;

! Record Results.
Parameter  Axial_M_factor = 0.662 ; ! these are obtained from range integrals,
                                    ! AND eigenmode OF CAVITY1.
Parameter  BeamR_M_factor = 0.745 ;

!***********************************************************************
!==> Case9.  Short Hot test. Obtain beam loading in first cavity.
!***********************************************************************
     IF (IStep.eq.9) THEN ;
        I_Run_Type         = 0;
        Freq = CF_1 ;
        t_sim  = 12.0nanosec;
        ExitCavity    = 1 ;
        Header Remarks "Cavity1, obtain Beam Loading Q " ;

        ! Select Drive Frequency and Input Power for Hot tests.
        parameter_ghz            Freq = 35.000 GHz;
        Parameter     Desired_PowerIn  = 1_milliwatts;
        Parameter_KiloVolt  V_beam     = 14.0kV ;
        Parameter_Amp       A_beam     = 0.5A ;
        Parameter_Gauss     Bz         = 0.80tesla;
    ENDIF ;

     ! This number determined from hot test.
     ! Record proper value here.
     Parameter Qb1 = 1206 ; ! Beam loading Q.
     PARAMETER QTb1 = 1/(1/QE1 +1/Qo1 + 1/Qb1) ;

!***********************************************************************
!==> Case10.  Hot tests. Select frequency and input power.
!***********************************************************************

 IF (IStep.eq.10) THEN ;
    I_Run_Type         = 0;
    t_sim  = 50.0nanosec;
    Header Remarks "Hot Test " ;

    ! Select Drive Frequency and Input Power for Hot tests.
    parameter_ghz            Freq = 35.000 GHz;
    Parameter     Desired_PowerIn  = 1_milliwatts;
    Parameter_KiloVolt  V_beam     = 14.0kV ;
    Parameter_Amp       A_beam     = 0.5A ;
    Parameter_Gauss     Bz         = 0.80tesla;
 ENDIF ;

!***********************************************************************
!***********************************************************************
! Start internal template.

TEMPLATE KLYSTRON ;
Stop ;
```