BNL-101824-2014-TECH

AD/RHIC/RD/42;BNL-101824-2013-IR

Conceptual Design of Ferrite Turners for the RHIC 26 MHz Accelerating Cavity

J. Rose

August 1992

Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC)

DISCLAIMER

AD/RHIC/RD-42

RHIC PROJECT

Brookhaven National Laboratory

Conceptual Design of Ferrite Tuners for the RHIC 26 MHz Accelerating Cavity

James Rose

August 1992

Conceptual Design of Ferrite Tuners for the RHIC 26 MHz Accelerating Cavity

James Rose
RHIC rf Group
Brookhaven National Laboratory

Introduction:

The preliminary design of a ferrite tuner has been completed, with the goal of providing enough information to obtain budgetary estimates of cost from vendors. The design is based on three tuners connected in parallel to the 26 MHz POP cavity to achieve greater than 260 kHz of tuning.

Requirements:

The frequency tuning required for compensating the change in ion velocity in the RHIC synchrotron is driven by accelerating gold ions from an energy of $\gamma=12.2$ to $\gamma=108.4$. Given the ring circumference of 3833.852 meters, the rotation frequency is given by:

$$f_{rot}=\frac{\sqrt{1-\frac{1}{\gamma^2}}*c}{C}$$

The accelerating frequency is $342*f_{rot}$, resulting in 26.6537 MHz at injection, and 26.7426 MHz at top energy. The Δf required is thus 89 kHz. Protons at injection ($\gamma=30.9$) and top energy ($\gamma=268.2$) leads to frequencies of 26.73 and 26.7435 MHz respectively.

The detuning required for compensating beam loading is driven by protons at injection, and is calculated as:

$$\Delta f=\frac{-I_{fourier}*\cos\psi_s}{V_{cav}*2}*\frac{R}{Q}*f_{rf}$$

The average beam current is 71 mA, the rf voltage at injection is 12kV for protons, and the R/Q is 69 resulting in a $\Delta f=-10.9$ kHz. Allowing for future upgrades which consider a threefold increase in particles per bunch and a doubling in the number of bunches, this corresponds to -66 kHz. Gold ions, with an average of 56 milliamps and cavity voltage of 220 kV requires a detuning of less than -500 Hz, even with a sixfold increase in average beam current this remains less than -3 kHz.

The total rf tuning required is thus from the lowest frequency with gold ions just after injection ($f_{rf}=26.651$ MHz) to the highest frequency with protons at top energy, zero current ($f_{rf}=26.744$ MHz), or 93 kHz. Expressed as a percentage of the fundamental this is 0.093/26.7=0.0035 or 0.35%. Allowing for cavity frequency errors, temperature compensation etc., this has been increased to a 1 % tuning range.

Cavity Laboratory Scale Model

A scale model was constructed at a scale of 5.4:1, as shown in figure 1. The model has a nominal resonant frequency of 144 MHz. Modeling the tuners as ferrite loaded transmission lines the equivalent series impedance for different tuner lengths as a function of permeability was calculated. These results are plotted in Figure 2.

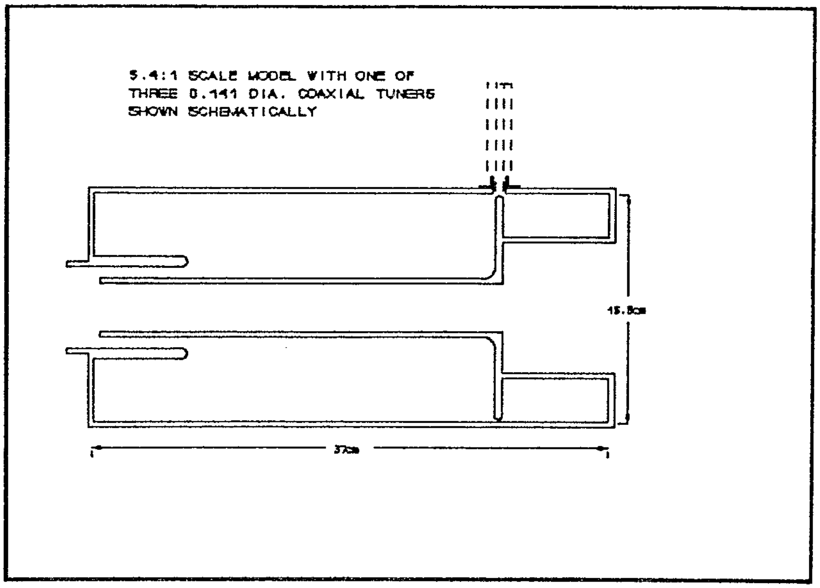


Figure 1 144 MHz Scale Model (37 cm long) with one of the three coax tuner locations shown.

Representative tuner impedances were mimicked by shorted lengths of 0.141 diameter coaxial line (hardline). Total frequency shift of the cavity as a function of the input impedance of a single tuner is plotted in Figure 3. The graph is projected to the Y-axis intercept to the frequency obtained by shorting the tuner disk with a strip of sliding contacts, and this first step between the disk shorted position and the frequency of the cavity with BNC connector shorts at the tuner ports is attributed to the stray inductance of the connection. This stray inductance is in series with the tuner inductance and lowers their effectiveness. The tuner disk itself is the result of trying to

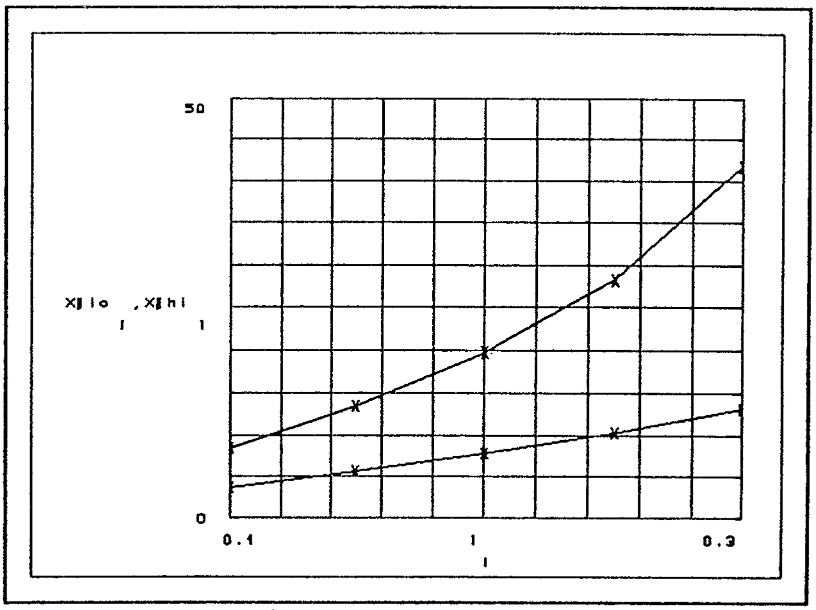


Figure 2 Plot of Calculated Input Reactance (Ohms) vs. Length (m) of Ferrite Filled Coax (ratio $r_2/r_1=2.3$) for Permeablity $\mu_r=1.2$, $\mu_r=3.2$

minimize the stray inductance this presents to the tuner. In parallel with the lab prototype, an lumped element equivalent circuit (PSPICE) model was developed and baselined to the laboratory measurements. PSPICE modeled the cavity as a series of transmission lines with the tuner disk discontinuity represented as a T-network. The PSPICE model is shown in Figure 4. SUPERFISH was used to check the overall validity of the pspice model by comparing the frequency shift resulting from a change in time delay of the shorted transmission line in the pspice model (Z4 and l4 in Figure 4) to an equivalent shift in the shorting plane location in the Superfish model. The stray inductance which had to be included in the pspice model to normalize the results to the laboratory model agrees well with that projected by shorting the tuner disk (Figure 3). With agreement between the 144 MHz laboratory data and pspice model, the pspice model was scaled to 26.7 MHz, and the design of the full size ferrite tuner begun.

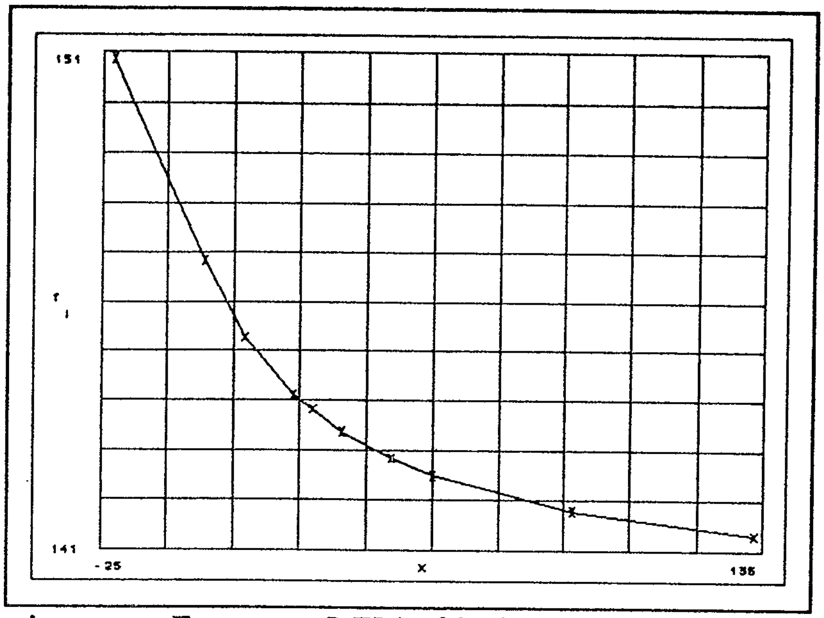


Figure 3 Frequency (MHz) of Scale Model With 3 Tuners vs. Input Reactance (Ohms) of a Single Tuner

<u>Tuner Design:</u>

An analytical model (appendix A1) was used to calculate coaxial line impedance and time delay as a function of inner and outer conductor radii and ferrite permeability and permitivity. The calculated values were then input into a PSPICE model to obtain the resonant frequency, input voltage and current at the tuner node. These were then put back into the analytical model to obtain total ferrite power dissipation and by narrowing the volume integral to specific "hot spots" peak power density locations quantified. This approach works for true coaxial line geometries completely filled with ferrite, but is unable to model inhomogeneous coaxial line (air/ferrite combinations) or geometries which are not coaxial. Rather than develop radial line transmission line formalism[1], SUPERFISH was used to model axially symmetric ferrite loaded lines. The input voltage was determined using SHY, and the input current determined from the values of the H-field from SFO1. The ratio of voltage to current defines an equivalent impedance at the plane of the input. In order to provide a self consistent input for Pspice, an

equivalent terminal impedance was calculated for a lossless transmission line using the expression $Z_{in}=Z_o*\tan(\beta l)$, where Z_o was calculated for a ferrite filled line and the expression solved for βl.
The resulting impedance and time delay were then used by PSPICE to determine frequency. A representative input file is given in the appendix. This was repeated for relative permeability constants $\mu_r=1.2$ and $\mu_r=3.2$, with the difference in calculated resonant frequencies noted.

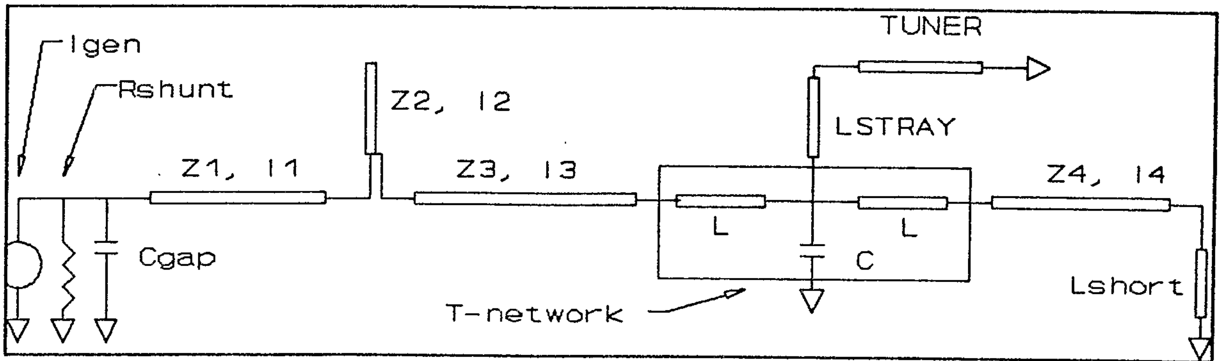


Figure 4 Pspice Model Schematic: Z#, l# Refer to the Impedance and Electrical Length of the Transimission Lines Used in the Model

This process converged on the two designs shown in figures 5, and 6. Both designs utilize the ferrite in thin (1 cm thick) tiles attached to water cooled plates to maximize the heat transfer out of the ferrite.
The first approach uses a series of radial lines with the ferrite attached to annular rings for heat transfer to the outer (cooled) conductor.

The second approach uses a folded transmission line to increase the radius of the coaxial line at the shorted (high field) end to decrease the energy density. With this approach the energy density at the shorted end can be made equal to the energy density at the end of the inner coaxial line by adjusting their respective lengths. In this manner the power loss may be more evenly distributed, and ferrite volume minimized. The optimum would be a tapered line keeping the energy density constant, but this was judged to be impractical to both the tuner and bias magnet fabrication.

After preliminary mechanical design considerations, a variation of the first approach was taken. The cooling plates were attached instead to the inner conductor which allows easier fabrication and places the cooling water closer to the peak power dissipation in the ferrite. The final tuner SUPERFISH plot is shown in Figure 7, with a isometric cutaway view in Figure 8. The tuner characteristics are provided in Table I, for relative permeability's 1.2 and 3.

For the final power analysis the magnetic field as a function of radius for a radial section of the tuner was obtained from SUPERFISH. The coefficients of a third order polynomial were determined by a least squares fit to the SUPERFISH data. This polynomial was then integrated to find the stored energy in the ferrite with the following expression:

$$W=\frac{\mu}{\pi*4}*\int_0^l\left(\int_0^{2\pi}\left(\int_{r_1}^{r_2}H_r^2 dr\right)d\Phi\right)dl$$

Where W is the stored energy. Once the magnetic stored energy is determined, the power loss in the ferrite is found from the relation to the magnetic Q.

$$P_{dissipated}=\frac{\omega*W}{Q}$$

This method was used explicitly for the first and last radial line section, and scaled for the regions in between. A check of the stored energy in the ferrite calculated by this method gave close agreement to that calculated by SUPERFISH in the post processor SFO1. This was then used to calculate the peak power densities by narrowing the volume integral to a cubic centimeter over the region of interest.

Final Ferrite Tuner Specifications for Tuning Range of 320 kHz (1.2%)
[Data is for each of three tuners required for given frequency shift]
Current, voltage and power values are with respect to 300 kV gap voltages

Relative Permeab -ility	Input Current (ampere)	Input Voltage (kvolt)	Terminal Impedan-ce (ohm)	Ferrite Magnetic Q	Ferrite Power Dissip.	Peak Fer Dissip. (W/cc)	Ferrite Volume (liter)	Copper Losses (kW)
μ_r=1.2	490.5	20.6	42	2500	3.3 kW	3.9	2.13	4.60
μ_r=3.2	762.3	8.38	11	10,000	2 kW	2.4	2.13	4.27

Table I

Biasing Magnet:

The magnet requirement (assuming Trans-Tech ferrite G810, and μ_r of 1.2) is for 250,000 amp/meter over a 140 mm (5.5 inch) bore. The magnet has not been designed yet however the requirements are less stringent than those for a magnet made by industry[2] for gyro-klystron focusing. A magnet with a 160 mm (6.3 inch) bore 300 mm long with a steel return yoke of 457 mm (18 inches) diameter can achieve the required field on axis. It would require 6600 watts of bias power. These requirements can be reduced by using a ferrite material with a lower saturation magnetization, which have recently been tested and found to have higher magnetic Q at low bias as well. The trend of the aluminum doped garnet ferrites is to trade lower saturation magnetization with lower Curie temperatures, so this must be looked at in more detail.

Alternate Design:

A second tuner design was developed with a 220 kHz tuning range to reduce cost and dimensions. In addition to having a smaller outside diameter (just over 4 inches) it requires less bias field since it operates in the range of relative permeabilities of 3.7 to 1.6. At $\mu_r=1.6$, the ferrite G810 requires only 127000 ampere turns, as opposed to 250000 for $\mu_r=1.2$. Recent measurements[3] suggest materials which can improve on this even further.

The tuner specifications follow in Table II.

Table II Alternate Tuner Design for 220 kHz Tuning Range

Ferrite Tuner Specifications for Tuning Range of 220 kHz (0.85%)
[Data is for each of three tuners required for given frequency shift]
Current, voltage and power values are given with respect to 300 kV gap voltages

Relative Permeab-ility	Input Current (Ampere)	Input Voltage (kVolt)	Terminal Impedance (ohm)	Ferrite Magnetic Q	Ferrite Power Dissip. (W)	Peak Fer Dissipation (W/cc)	Ferrite Volume (liter)	Copper Losses (W)
$\mu_r=3.7$	661.6	12.95	19.6	2500	1396	2.2	1.02	2300
$\mu_r=1.6$	860	3.896	4.5	>5000	<1396	<2.2	1.02	<2300

Conclusions:

A conceptual design of a de-mountable ferrite tuner has resulted in a system of three radially mounted tuners providing a 320 kHz frequency shift of the RHIC accelerating cavity. Peak power densities have been kept under 4 watts/cc and overall power consumed less than 8 kw per tuner exclusive of magnet bias power supply. The three tuners therefore require an additional 24 kilowatts of rf power per cavity, in addition to the 48 kilowatts required for cavity copper losses the total power dissipated becomes 72 kW , with 30% going into the tuners. Even though the tuners have about 2% of the stored energy (two orders of magnitude down) the Q of the tuners is three orders of magnitude lower, and so the losses are comparable. Significant savings could be realized by reducing the tuning range required of the ferrite tuners to cover the dynamic range of 93 kHz, and rely on fixed tuners and temperature control to keep the cavity within the range of the ferrite tuners.

References:

1) C. C. Friedrichs "Analytic Evaluation of the LAMPF II Booster Cavity Design" IEEE Transactions on Nuclear Science Vol. NS-32, No. 5 October 1985
2) GAMMA Microwave , L. Nielson, private communication
3) W.R. Smythe and D. Van Westrum "Measured Properties of Ferrite Samples for the LEB RF Cavity Tuner" TRIUMF-SSC RF Workshop, June 26, 1992, Waxahachie, Texas

ANNULAR DISK-LOADED TUNER
Length=22cm, dia.=7.62cm
Volume=2.85 liters ea (8.55l tot.)
δf=188kHz, Peak Power dis.=3.1W/cc
Total ferrite power (xxx)

$23k Ferrite;
18 pieces, 6"O.D.
1.09"I.D., 0.39"thick

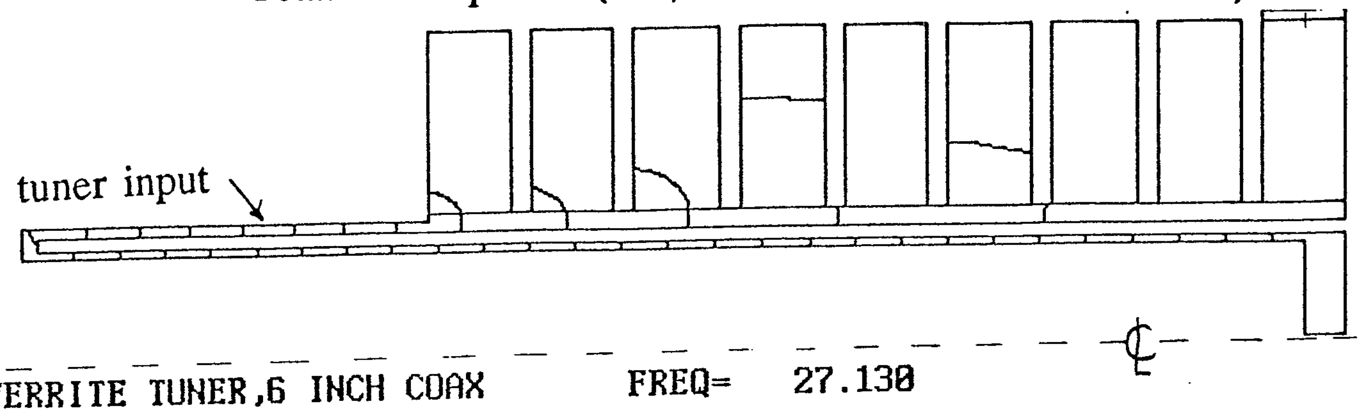


Figure 5

FOLDED COAX TUNER
Length=17cm, dia.=8.62cm
Volume=2.55 liters ea (7.65l tot.)
δf=210kHz, Peak Power dis.=3.65W/cc
Total ferrite power 4.21kW (Q=2500,300kVgap)

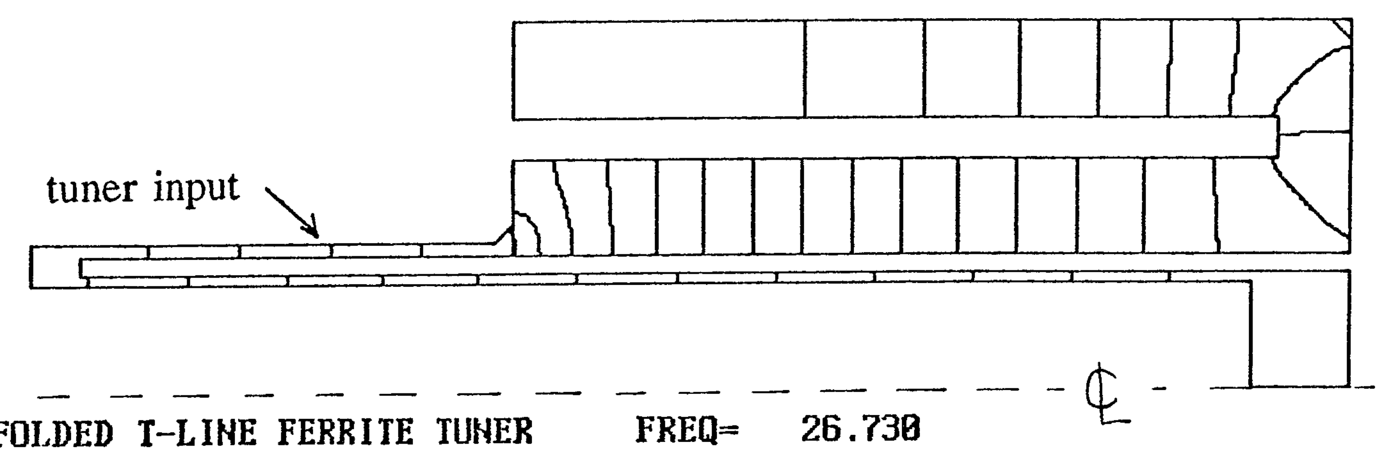
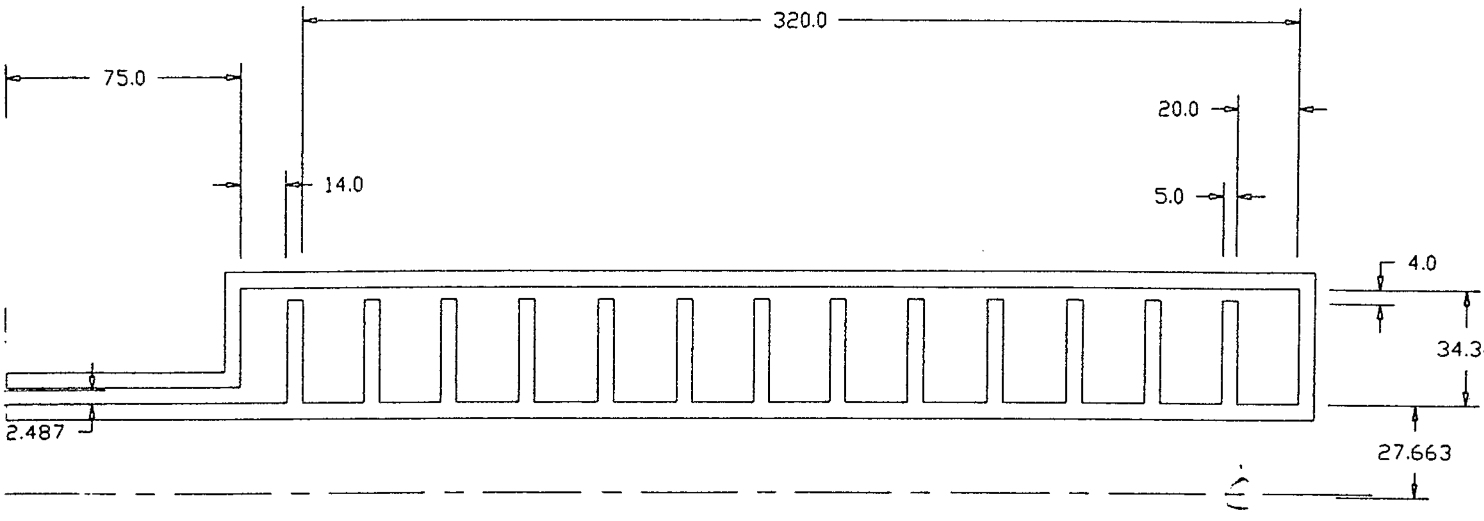
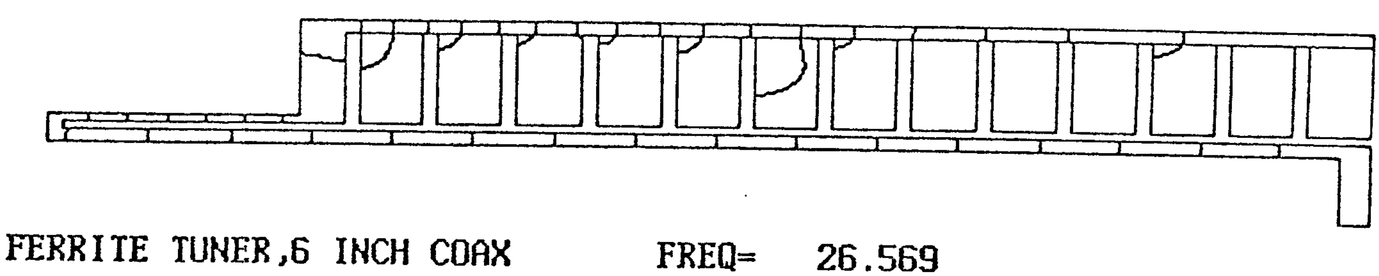


Figure 6



FINAL TUNER DESIGN DIMENSIONS
(ROTATIONALLY SYMMETRIC)



SUPERFISH PLOT OF TUNER WITH CAPACITANCE
ADDED TO RESONATE AT 26 MHz

Figure 7

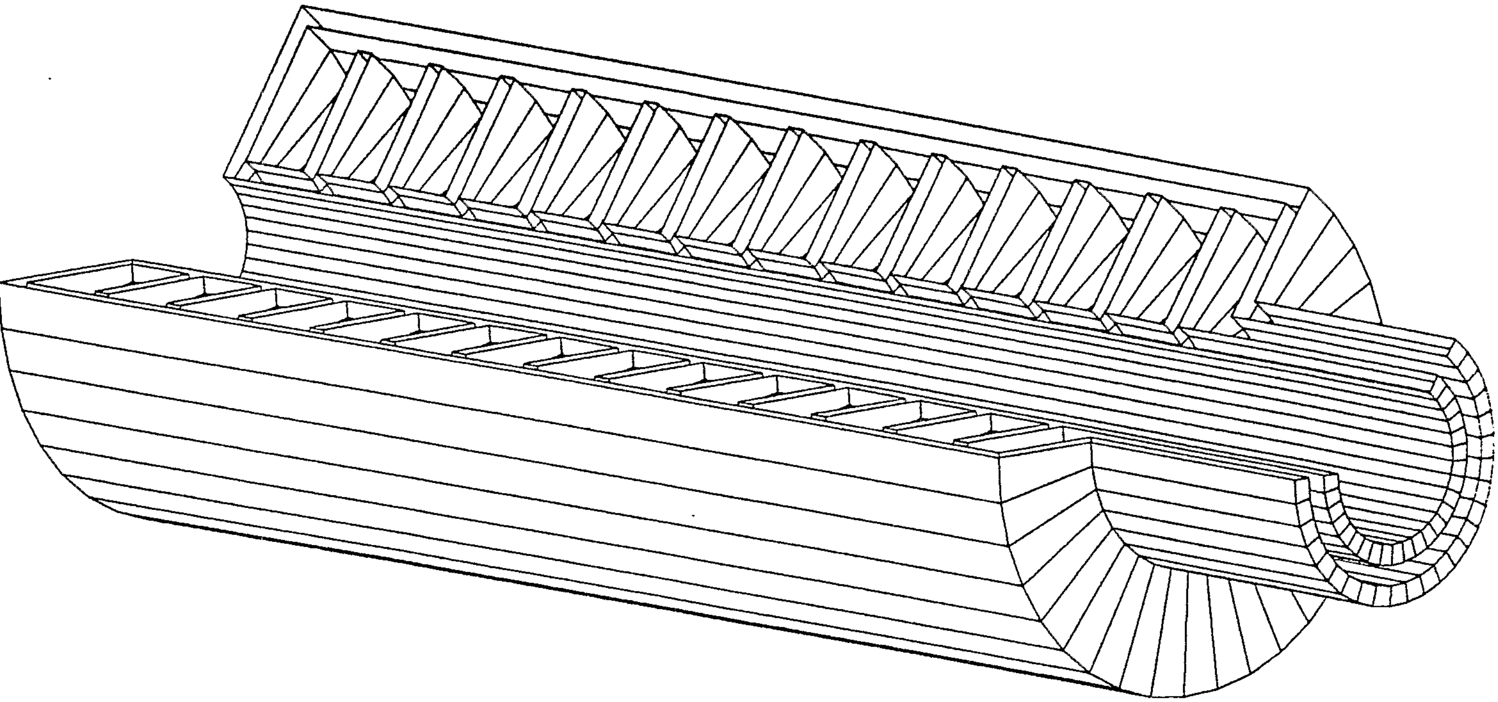


Figure 8 3-D CUTAWAY VIEW OF FINAL TUNER DESIGN

APPENDIX A: SUPPORTING CALCULATIONS AND INPUT FILES

```
ce Input File for 26MHz Ferrite Tuner
 1  0  ac  1.
ss 1  0  704k
end trimmed to obtain sfish freq. for lcav=200cm
d  1   0 23e-12
el 1   0   2   0   z0=18.6  td=1.1341E-9
2  2   4   3   0   z0=47.6  td=0.56705E-9
3  3   0   0   0  z0=47.6  td=0.56705E-9
e4 4   0   5   0   z0=80.38 td=3.5024E-9
 ***disk loading.... (black box)
ck67  5   6   9.448E-9
ck    6   0   189.01E-12
ck78  6   7   9.448E-9
****************************
****Cavity Continued
e6 7   0   8   0   z0=28.77 td=1.101e-9
d      8   0   1E-13
**TUNER CONNECTION
ayA 6  11  132.0E-9
ayB 6  12  132.0e-9
ayC 6  13  132.0e-9
nerA  11   0   0   0  z0=19.8697 td=6.9434E-9
nerB 12   0   0   0  z0=19.8697 td=6.9434E-9
nerC 13   0   0   0  z0=19.8697 td=6.9434e-9
**************
C  lin   4000  25.860E6  26.860E6
ROBE
PTIONS numdgt=6
```

NAL PSPICE INPUT FILE (μ_R = 3.2)

```
Spice Input File for 26MHz Ferrite Tuner
iin  1   0   ac   1.
rloss  1   0   704k
**cend trimmed to obtain sfish freq. for lcav=200cm
cend   1   0  23e-12
tline1 1   0   2   0   z0=18.6  td=1.1341E-9
tser2  2   4   3   0   z0=47.6  td=0.56705E-9
tser3  3   0   0   0  z0=47.6  td=0.56705E-9
tline4 4   0   5   0   z0=80.38 td=3.5024E-9
******disk loading.... (black box)
lblack67   5   6   9.448E-9
cblack     6   0   189.01E-12
lblack78   6   7   9.448E-9
*******************************
******Cavity Continued
tline6 7   0   8   0   z0=28.77 td=1.101e-9
lend      8   0   1E-13
*****TUNER CONNECTION
lstrayA 6   11   132.0E-9
lstrayB 6   12   132.0e-9
lstrayC 6   13   132.0e-9
ttunerA 11   0   0   0  z0=12.1677 td=4.4653E-9
ttunerB 12   0   0   0  z0=12.1677 td=4.4653E-9
ttunerC 13   0   0   0  z0=12.1677 td=4.4653e-9
****************
.AC  lin   4000  25.860E6  26.860E6
.PROBE
.OPTIONS numdgt=6
```

FINAL PSPICE INPUT FILE (μ_R = 1.2)

SUPERFISH INPUT FILE

```
'unerfin.dat FINAL FERRITE TUNER 5.8cm O.D. 42 cm Long
:EG NREG=15, NPOINT=65, XMAX=42.0, YMAX=6.20, DX=0.12, NDRIVE=1 $
)o x=0.5, y=2.7663 $
po x=9.5, y=2.7663 $
po x=9.5, y=5.80 $
po x=10., y=5.80 $
po x=10., y=2.7663 $
po x=12., y=2.7663 $
po x=12., y=5.80 $
po x=12.5, y=5.80 $
po x=12.5, y=2.7663 $
po x=14.5, y=2.7663 $
po x=14.5, y=5.80 $
po x=15., y=5.80 $
po x=15., y=2.7663 $
po x=17., y=2.7663 $
po x=17., y=5.80 $
po x=17.5, y=5.80 $
po x=17.5, y=2.7663 $
po x=19.5, y=2.7663 $
po x=19.5, y=5.80 $
po x=20., y=5.80 $
po x=20., y=2.7663 $
po x=22., y=2.7663 $
po x=22., y=5.80 $
po x=22.5, y=5.80 $
po x=22.5, y=2.7663 $
po x=24.5, y=2.7663 $
po x=24.5, y=5.80 $
po x=25., y=5.80 $
po x=25., y=2.7663 $
po x=27., y=2.7663 $
po x=27., y=5.80 $
po x=27.5, y=5.80 $
po x=27.5, y=2.7663 $
po x=29.5, y=2.7663 $
po x=29.5, y=5.80 $
po x=30., y=5.80 $
po x=30., y=2.7663 $
po x=32., y=2.7663 $
po x=32., y=5.80 $
po x=32.5, y=5.80 $
po x=32.5, y=2.7663 $
po x=34.5, y=2.7663 $
po x=34.5, y=5.80 $
po x=35.0, y=5.80 $
po x=35.0, y=2.7663 $
po x=37.0, y=2.7663 $
po x=37.0, y=5.80 $
po x=37.5, y=5.80 $
po x=37.5, y=2.7663 $
po x=39.5, y=2.7663 $
po x=39.5, y=5.80 $
po x=40.0, y=5.80 $
po x=40.0, y=2.7663 $
po x=42.0, y=2.7663 $
po x=42.0, y=6.20 $
po x=8.00, y=6.20 $
po x=8.00, y=3.015 $
po x=0.00, y=3.015 $
$po x=0., y=2.12 $
$po x=41.00, y=2.12 $
$po x=41.00, y=0.000 $
$po x=42.0, y=0.000 $
$po x=42.0, y=2.55 $
$po x=0.5, y=2.55 $
$po x=0.5, y=2.7663 $
$reg npoint=1 $
$po x=42.0, y=6.00 $
$reg mat=3, npoint=5 $
$po x=10., y=5.80 $
$po x=10., y=2.7663 $
$po x=12., y=2.7663 $
$po x=12., y=5.80 $
$po x=10., y=5.80 $
$reg mat=3, npoint=5 $
$po x=12.5, y=5.80 $
$po x=12.5, y=2.7663 $
$po x=14.5, y=2.7663 $
$po x=14.5, y=5.80 $
$po x=12.5, y=5.80 $
$reg mat=3, npoint=5 $
$po x=15., y=5.80 $
$po x=15., y=2.7663 $
$po x=17., y=2.7663 $
$po x=17., y=5.80 $
$po x=15., y=5.80 $
$reg mat=3, npoint=5 $
$po x=17.5, y=5.80 $
$po x=17.5, y=2.7663 $
$po x=19.5, y=2.7663 $
$po x=19.5, y=5.80 $
$po x=17.5, y=5.80 $
$reg mat=3, npoint=5 $
$po x=20., y=5.80 $
$po x=20., y=2.7663 $
$po x=22., y=2.7663 $
$po x=22., y=5.80 $
$po x=20., y=5.80 $
$reg mat=3, npoint=5 $
$po x=22.5, y=5.80 $
$po x=22.5, y=2.7663 $
$po x=24.5, y=2.7663 $
$po x=24.5, y=5.80 $
$po x=22.5, y=5.80 $
$reg mat=3, npoint=5 $
$po x=25., y=5.80 $
$po x=25., y=2.7663 $
$po x=27., y=2.7663 $
$po x=27., y=5.80 $
$po x=25., y=5.80 $
$reg mat=3, npoint=5 $
$po x=27.5, y=5.80 $
$po x=27.5, y=2.7663 $
$po x=29.5, y=2.7663 $
$po x=29.5, y=5.80 $
$po x=27.5, y=5.80 $
$reg mat=3, npoint=5 $
$po x=30., y=5.80 $
$po x=30., y=2.7663 $
$po x=32., y=2.7663 $
$po x=32., y=5.80 $
$po x=30., y=5.80 $
$reg mat=3, npoint=5 $
$po x=32.5, y=5.80 $
$po x=32.5, y=2.7663 $
$po x=34.5, y=2.7663 $
$po x=34.5, y=5.80 $
$po x=32.5, y=5.80 $
$reg mat=3, npoint=5 $
$po x=35.0, y=5.80 $
$po x=35.0, y=2.7663 $
$po x=37.0, y=2.7663 $
$po x=37.0, y=5.80 $
$po x=35.0, y=5.80 $
$reg mat=3, npoint=5 $
$po x=37.5, y=5.80 $
$po x=37.5, y=2.7663 $
$po x=39.5, y=2.7663 $
$po x=39.5, y=5.80 $
$po x=37.5, y=5.80 $
$reg mat=3, npoint=5 $
$po x=40.0, y=5.80 $
$po x=40.0, y=2.7663 $
$po x=42.0, y=2.7663 $
$po x=42.0, y=5.80 $
$po x=40.0, y=5.80 $
```

Take.prn
Data file read by Pdiss3.mcd program-The first column is the radius in cm and the second is the magnetic field in kiloamps/meter as calculated by SFO1.

2.7663	3.0168
2.9042	2.8723
3.0421	2.7426
3.1800	2.6229
3.3179	2.5141
3.4558	2.4130
3.5937	2.3204
3.7316	2.2339
3.8695	2.1541
4.0074	2.0792
4.1453	2.0096
4.2832	1.9441
4.4210	1.8830
4.5589	1.8251
4.6968	1.7709
4.8347	1.7194
4.9726	1.6710
5.1105	1.6249
5.2484	1.5815
5.3863	1.5399
5.5242	1.5007
5.6621	1.4630
5.8000	1.4274
5.9253	1.3970
6.0000	1.3797

Pdiss3.mcd : A program for finding the polynomial coefficients to approximate the magnetic field distribution, and then integrate the field squared to find the stored energy in the region.

$D := 3 \qquad d := 0 \,..D \qquad N := 26$

Set Magnetic field to correspond to input current from spice by multiplying by "Norm"

$Hr := \mathrm{READPRN}(TAKE)$

$Norm := 2.356$

$radius := Hr^{\langle 0 \rangle} \cdot 0.01$

$N := \mathrm{length}(radius)$

$i := 0 \,..N - 1$

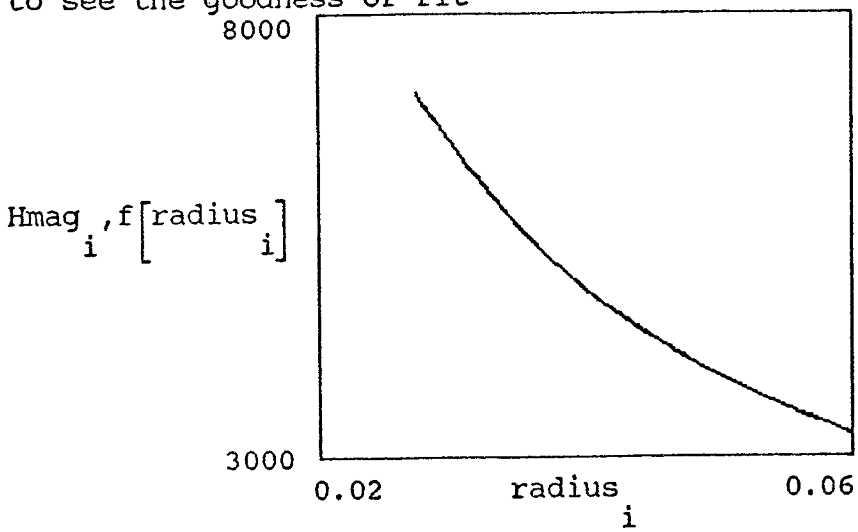
$Hmag := Hr^{\langle 1 \rangle} \cdot 1000 \cdot Norm$

$r^{\langle d \rangle} := \overrightarrow{\left[radius^{d}\right]}$

$coeff := \left(r^{T} \cdot r\right)^{-1} \cdot \left(r^{T} \cdot Hmag\right)$

$f(t) := \sum_{d} \left[coeff_{d} \cdot t^{d}\right]$

Plot the data (Hmag) and the function f(radius) to see the goodness of fit



$coeff_0 = 1.93159 \cdot 10^{4}$

$coeff_1 = -6.94389 \cdot 10^{5}$

$coeff_2 = 1.08379 \cdot 10^{7}$

$coeff_3 = -6.21896 \cdot 10^{7}$

Integrate the field squared to get the stored energy "W"

$\mu := 4 \cdot \pi \cdot 10^{-7} \cdot 3.2$

$Q := 2500$

$\omega := 2 \cdot \pi \cdot 26.7 \cdot 10^{6}$

$$W := \left[\frac{\mu}{\pi \cdot 4}\right] \cdot \int_{0.0}^{0.02} \left[\int_{0.027663}^{0.058} f(t)^{2}\, dt\right] dl$$

Calculate the Power dissipated in the ferrite

$Power := \dfrac{\omega \cdot W}{Q}$

$$vol := \int_{0.}^{0.02} \left[\int_{0}^{2 \cdot \pi} \left[\int_{0.027663}^{0.058} ra\, dra\right] d\Phi\right] dz$$

$W = 0.00466$

$Power = 312.87717$ (watts)

$volcc := vol \cdot 10^{6}$

$volcc = 163.28481$ = volume of ferrite region

$\dfrac{Power}{volcc} = 1.91614$ = power per cubic centimeter

Pdiss3.mcd : A program for finding the polynomial coefficients to approximate the magnetic field distribution, and then integrate the field squared to find the stored energy in the region.

$D := 3 \qquad d := 0 ..D \qquad N := 26$

Set Magnetic field to correspond to input current from spice by multiplying by "Norm"

$Hr := \mathrm{READPRN}(TAKE)$

$Norm := 2.356$

$radius := Hr^{<0>} \cdot 0.01$

$N := \mathrm{length}(radius)$

$i := 0 ..N - 1$

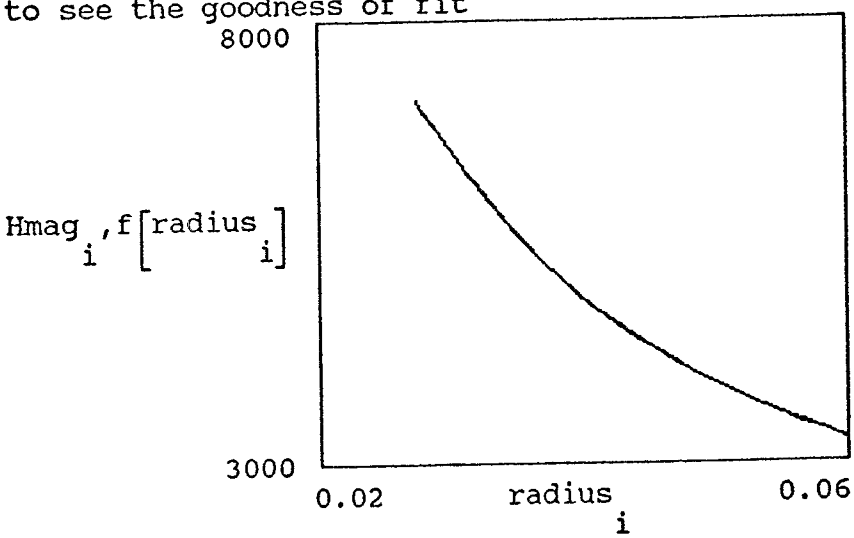
$Hmag := Hr^{<1>} \cdot 1000 \cdot Norm$

$r^{<d>} := \overrightarrow{\left[radius^{d}\right]}$

$coeff := \left(r^{T} \cdot r\right)^{-1} \cdot \left(r^{T} \cdot Hmag\right)$

$f(t) := \sum_{d} \left[coeff_{d} \cdot t^{d}\right]$

Plot the data (Hmag) and the function f(radius) to see the goodness of fit



$coeff_0 = 1.93159 \cdot 10^{4}$

$coeff_1 = -6.94389 \cdot 10^{5}$

$coeff_2 = 1.08379 \cdot 10^{7}$

$coeff_3 = -6.21896 \cdot 10^{7}$

Integrate the field squared to get the stored energy "W"

$\mu := 4 \cdot \pi \cdot 10^{-7} \cdot 3.2$

$Q := 2500$

$\omega := 2 \cdot \pi \cdot 26.7 \cdot 10^{6}$

$W := \left[\frac{\mu}{\pi \cdot 4}\right] \cdot \int_{0.0}^{0.02} \left[\int_{0.027663}^{0.037663} f(t)^{2}\, dt\right] dl$

Calculate the Power dissipated in the ferrite

$Power := \frac{\omega \cdot W}{Q}$

$vol := \int_{0.}^{0.02} \left[\int_{0}^{2 \cdot \pi} \left[\int_{0.027663}^{0.037663} ra\, dra\right] d\Phi\right] dz$

$W = 0.00238$

$Power = 159.48763$ (watts)

$volcc := vol \cdot 10^{6}$

$volcc = 41.04554$ = volume of ferrite region

$\frac{Power}{volcc} = 3.88563$ = power per cubic centimeter