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Reduction of the Beam Breakup Mode Q Values in the ETA/ATA Accelerating Cells

Daniel L. Birx

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Lawrence Livermore Laboratory

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in the ETA/ATA Accelerating Cells*

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Abstract

Earlier Microwave Measurements of the ETA Accelerating Cells had uncovered eleven resonances in the frequency range of 0 → 850 MHz. The Q values of these modes ranged from 14 to 70(2).

Here we report a three phase program directed at substantially reducing these Q values. In particular the dampening methods described below resulted in a decrease of Q value from 40 to 5 for the beam breakup mode (TM_{110}) with a corresponding reduction for most of the other cavity modes.

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(2) See Reference 2.

DISCLAIMER

Introduction

An earlier investigation of RF resonances in the ETA accelerator structure uncovered eleven resonant modes in the frequency range of 0 → 850 MHz. The Q values of these modes varied from 14 to 70 the two components of the beam breakup mode (TM(+,-) 110) were identified and found to possess Q values of 20 and 40.

In anticipation that these resonances might result in intolerably large transverse oscillations of the accelerated electron beam in an ATA scale accelerator, a de-Q-ing program was initiated. In this work we report the effect of various modifications to the accelerating structure and their effect on the important RF modes.

The de-Q-ing program was conducted in three phases. First a one tenth scale model of the ETA accelerating cell was constructed. The modes of this model were measured using the procedures described in Ref. 2. As expected the frequencies of the modes were approximately 10 times higher than those of the ETA cavity. The "Q's" of corresponding modes, however, were similar. The model was used to investigate the effects on the modes of the similar cavities caused by various modifications to the structure. Because the small size of the model these modifications could be made rapidly and easily. Moreover, the high value ETA cavity was not in jeopardy. The information supplied by the model was weighted carefully to obtain a practical modification to the ETA cavity that yielded a low Q structure that would still accelerate electrons and thus could be incorporated into the ATA designs. Among the factors considered were the effects on the HV drive pulse, voltage holding, and the well being of the mechanical engineering staff, as well as the degree of Q reduction.

The second phase of the program consisted of applying the above modification to an actual ETA accelerating cell. We attempted both to further optimize the modification and obtain more accurate data on its effects.

Finally during Phase 3 these changes were incorporated into the design of the ATA accelerator cell. A prototype cell was constructed and its RF properties measured.

The success of the program was indicated by a reduction in Q values of the beam breakup modes (TM+,-) from values near 40 to values of approximately 5 and a corresponding Q reduction for most of the other resonant modes.

Phase I

Figure 1a presents a sketch of the ETA accelerating cell cross section and Fig. 1b the cross section of the 1:10 scale model use for initial testing. While small inaccuracies in scaling such as the omission of a porcelain insulator shed some doubt on the validity of these measurements, the major concern involved the dispersive nature of the enclosed ferrite.

The resonant frequency of any mode should vary linearly with the scaling factor, provided the electrical properties of the construction materials are independent of frequency. The RF losses in the ETA accelerating cell are dominated primarily by the ferrite losses. Hence the Q varies inversely with the ferrite loss tangent. If the loss tangent were independent of frequency then the Q should be for the most part independent of scale.

The TDK and stackpole ferrites used in the accelerator were known to be highly dispersive at low frequencies, but very little information was available on the high frequency behaviour.

Measurements on transmission lines containing samples of these materials yielded the results described in Appendix A. This data indicates that while the ferrite is highly dispersive below 100 MHz, the properties become relatively constant at higher frequencies. The measurements were discontinued at 1 GHz because of the difficulties involved in locating the RF again after it had entered into the ferrite. Above a few hundred megahertz the loss tangent began to approach unity and measuring the RF transmission properties might be compared to measuring the transmission of a water drop through a sponge.

A comparison between the RF properties of the model and the actual ETA cell is illustrated in Figure 2. It can be see that the scaling is far from ideal, but it was believed to be sufficiently accurate to examine the effects of various de-Q-ing strategies.

Two different techniques of de-Q-ing were applied to the model. Both methods were based on making best use of the large ferrite loss tangent. The first consisted of cutting away the reentrant stainless steel shroud to expose more of the enclosed ferrite.

Prior measurements of the RF modes in the ETA accelerating cell[Ref. 2] had resulted in fairly reliable field profile maps for these maps. These maps, in particular those corresponding to the beam breakup modes, were carefully examined for areas where the beam breakup fields could be strongly perturbed without influencing the accelerating fields. It was hoped that cutting away the reentrant shroud in these areas would force the RF fields into the underlying ferrite. The areas located near the bottom of the shroud and 90° from the drive blades were chosen, and the shroud was slowly cut away there. At various stages the cavity was returned to the test stand and the RF properties re-examined. A summary of these measurements appears in Appendix B. It can be seen that in the early stages the Q's began to drop and the results looked encouraging, but as more material was removed the "beam breakup mode" Q's began to rise until finally they lay higher than the original Q's. Even the lowest Q's obtained through this procedure were still unsatisfactory. Chalking this experiment up to another lesson in life's slow learning process, we decided to try something else.

This next something else involved adding more ferrite to the cell. Small pieces of ferrite were positioned at various locations in the model and the effects on both the RF modes and the drive pulse measured. The results of this procedure appeared much more promising. It was discovered that additional ferrite covering the HV drive blades and floor of the cell strongly damped the RF modes while leaving the HV drive pulse virtually uneffected.

Figure 3 presents a summary of the experiments conducted during Phase I.

Phase II

Based on the data received from the experiments described above, a decision was made to cover both the HV drive blades and the floor of the actual accelerator cell with additional ferrite. A description of the effect on the RF resonances can be found in Figure 4.

Figure 5 illustrates the effect of this modification on the beam breakup mode. The Q value of this mode was reduced from 40 to 5. The other resonances for the most part showed a corresponding Q value reduction. These Q values are believed to lie well within the limits for acceptable beam transport in an ATA scale accelerator(1).

Further testing of the cell with a HV drive pulse showed the additional ferrite to leave the cell response to the HV uneffected.

(1) V.K. Neil, L.S. Hall, R.K. Cooper, "Further Theoretical Studies of the Beam Breakup Instability", Particle Accelerators, 1979, Vol. 9, pp. 213-222.

Phase III

Finally a prototype cell for the ATA Accelerator was constructed. The cell incorporated mode dampeners designed on the basis of this research. A sketch of the cell showing the ferrite mode dampening ring and blade cover is shown in Fig. 7.

Figure 6 illustrates the improvement achieved with the ferrite dampeners. As was anticipated the results compare closely with those obtained during Phases I and II.

Summary

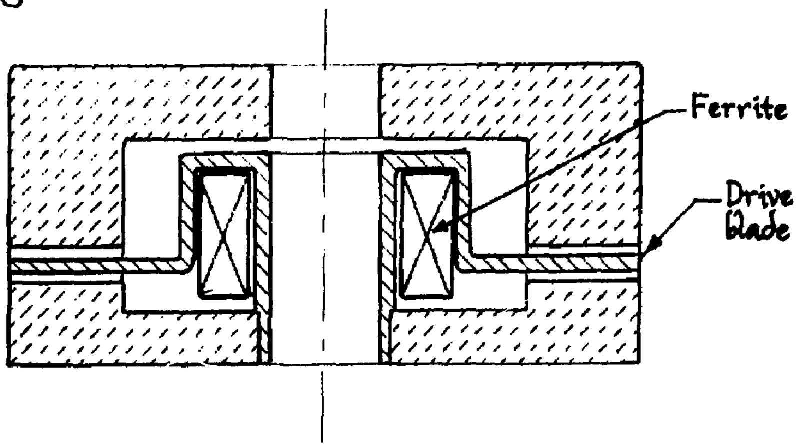
Earlier RF tests[(2)] on the ETA accelerating cell had revealed a large number of resonances. The beam-breakup mode (TM_{110}) was identified and found to possess a Q-value of 40. While this Q was low enough so as not to noticeably affect electron transport in the ETA accelerator, there was concern about beam transport in the longer ATA accelerator.

Before a final design for the ATA cells was complete a de-Q-ing program was initiated. This program included first research on a 1:10 scale model, then on the ETA cells, and finally on an actual ATA cell.

The success of this program was indicated by the reduction of Q value from 40 to 5 for the TM_{110} beam breakup mode. This Q value should be sufficiently low to allow successful beam transport in the ATA accelerator.

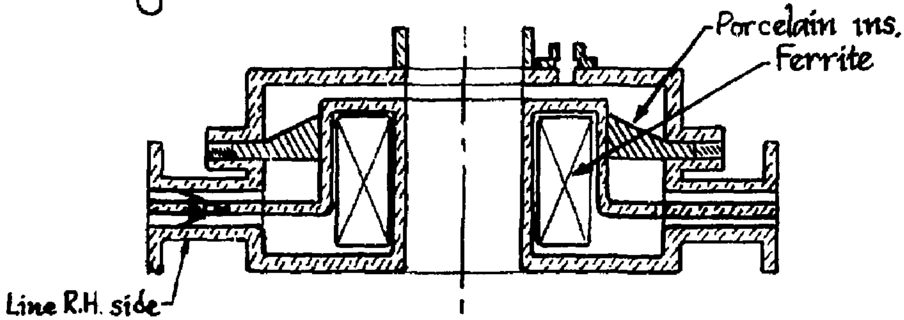
(2) UCID-18582
D. Birx -- Microwave Measurements of the ETA Accelerating Cavity

Fig. 1a



Cross section of 1:10 scale model accelerating cell.

Fig. 1b



Cross section of actual accelerating cell.

Figure 2

Mode	Model Resonant (MHz) frequency	Prot. ETA cavity Resonant (MHz) frequency	Highest Model Q	Highest ETA Cavity
TM_{010}	2500	220	10	14
TM_{-110}	3100	345	40	40
TM_{020}	3500	512	35	34
TM_{-120}	4800	590	30	50
TM_{210}	5400	647	25	46
TM_{030}	5600	752	30	70
TM_{-130}	6200	840	40	60

Comparison of RF properties between the model and the ETA cavities. Where a splitting degeneracy exists the highest Q's are compared.

Fig. 3

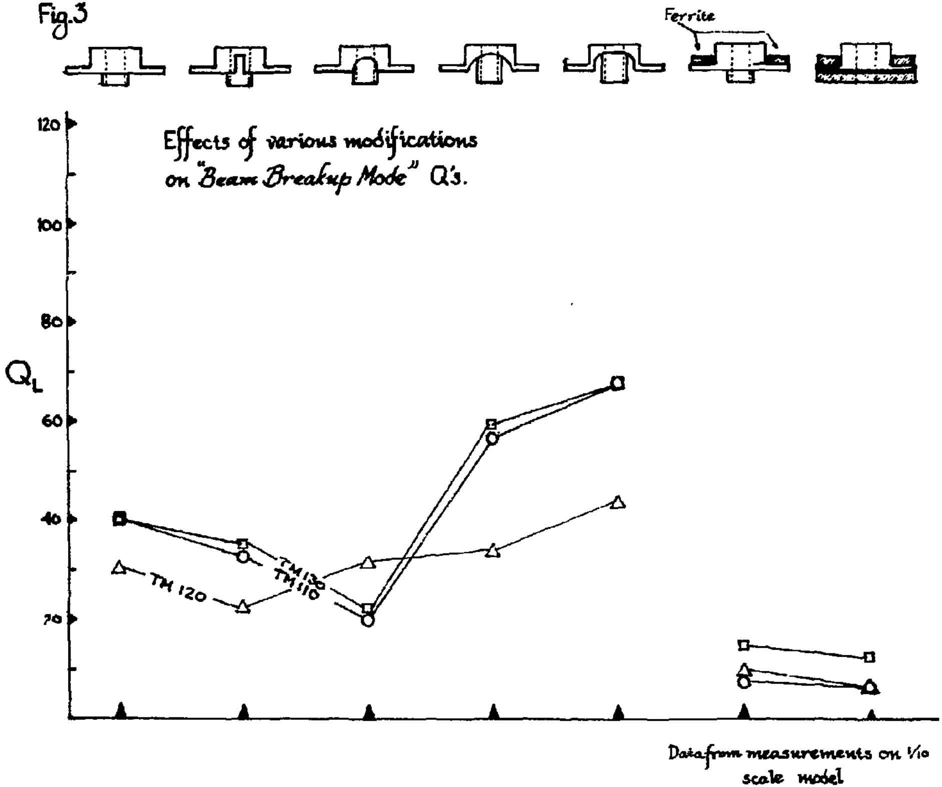

Ferrite
Effects of various modifications on "Beam Breakup Mode" Q's.
120
100
80
60
40
20
Q_L
TM 130
TM 110
TM 120
Data from measurements on 1/10 scale model

Fig. 4

Mode	Previous Q_{Lp}	Floor 90% covered Q_{fF}	Blades 90% covered Q_{fB}	Blades and Floor 90% covered Q_{LF}*
TM 010	14	35	not measurable	10
TM 110	40	13.3	10	5
TM 020	34	94	100	20
TM 120	50	11.3	10.9	5
TM 030	70	28	20	10
TM 130	60	42	17	12

(*) $\frac{1}{Q_{LF}} = \frac{1}{Q_{LP}} + \frac{1}{Q_{fF}} + \frac{1}{Q_{fB}}$

Effect of Ferrite on Resonances

Fig 5

Effect of Additional Ferrite on the "Beam Breakup" (TM110) Mode in the ETA Accelerating Cavity

ν center = 350 MHZ
$\Delta\nu$/div. = 20 MHZ
Q_0 = 40

ν center = 300 MHZ
$\Delta\nu$/div. = 20 MHZ
$Q_{Lo} = 10 = \frac{Q_0 Q_f}{Q_0 + Q_f}$
Q_f = 13.3
Floor 90% ferrite covered

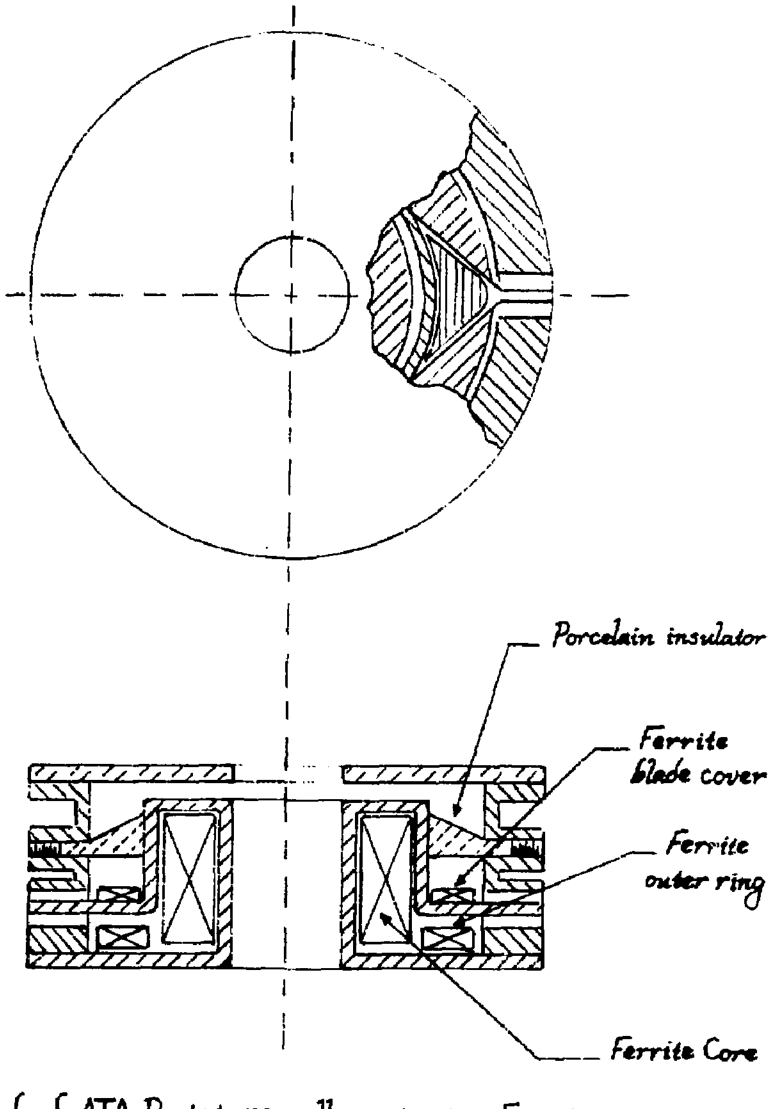
ν center = 300 MHZ
$\Delta\nu$/div. = 20 MHZ
$Q_{Lo} = 5 = Q_0 Q_f / (Q_0 + Q_f)$
Q_f = 5
Q_f blade = 10
Floor 90% ferrite covered
Drive blades 90% ferrite covered

Fig. 6

Mode	Q with ferrite dampeners in place	Q with ferrite dampeners removed
TM 110	5	30
TM 120	6	35
TM 130	10	70

Effect of Ferrite Mode Dampeners on *"Beam Breakup Mode"* in the ATA Accelerating cell.

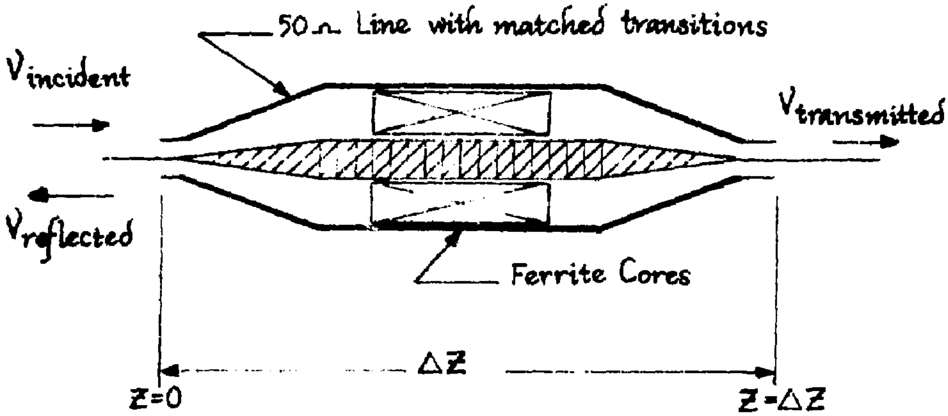
Fig. 7



Sketch of ATA Prototype cell containing Ferrite mode dampeners.

Appendix A

Ferrite Properties Measurement Technique



$$V_{inc} = V_{inc}(0)\, e^{ik_0 Z}$$

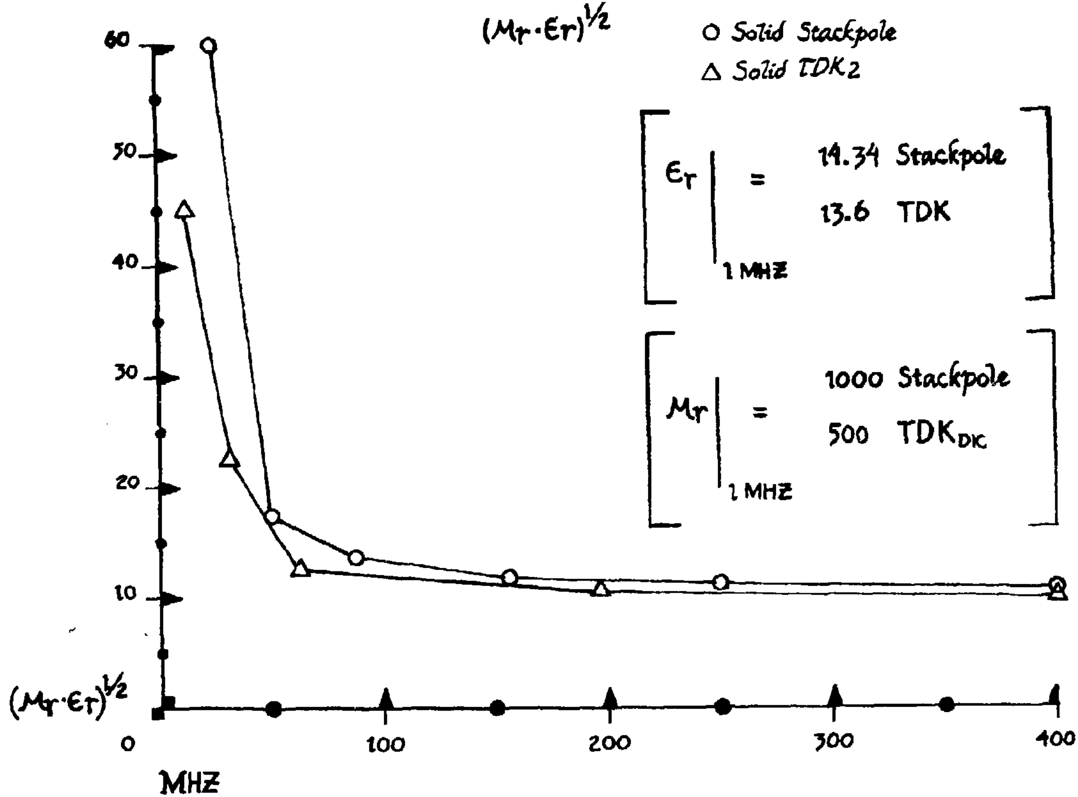
$$V_r = (1-\Gamma)\, V_{inc}(0)\, e^{-ik_0 Z}$$

$$V_t = \Gamma\, V_{inc}(0)\, e^{ik_0(\Delta Z - L_F) + ik_F L_F}$$

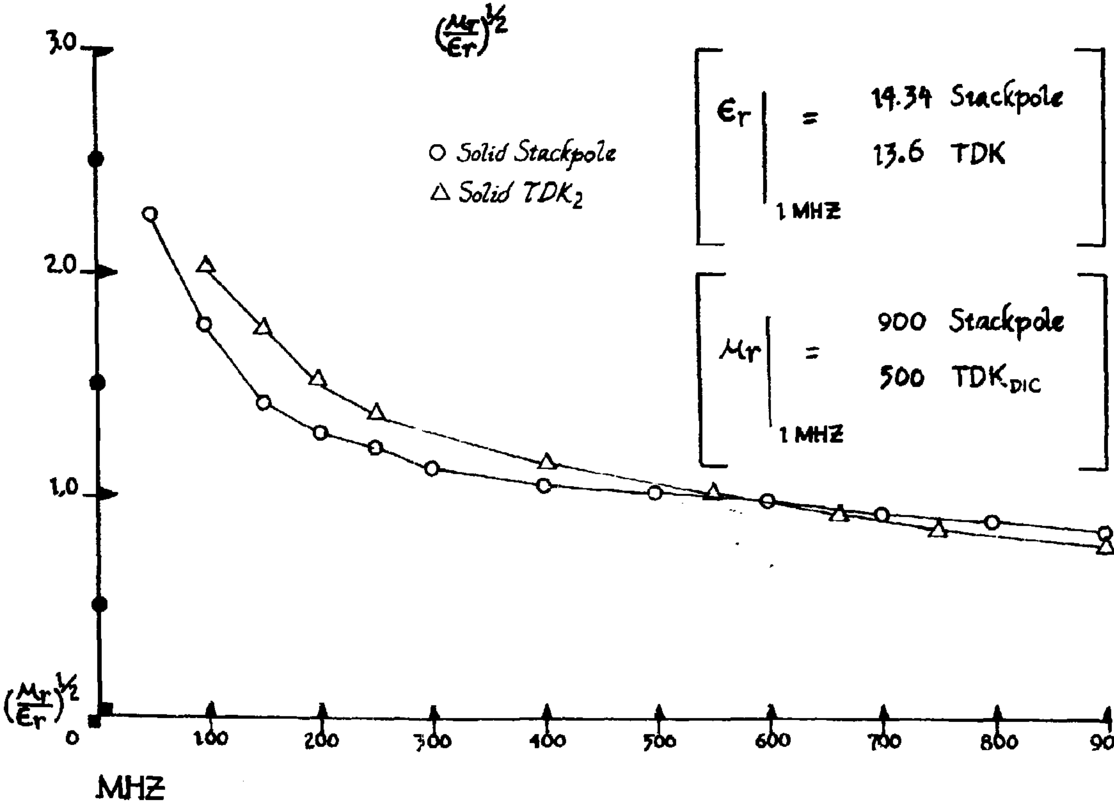
$$\therefore (\mu_r \epsilon_r)^{1/2} = 1 + (ik_0 L_F)^{-1} \cdot \ln \left(\frac{\dfrac{V_t(\Delta Z)}{|V_t(\Delta Z)|}}{\dfrac{V_{inc}(\Delta Z)}{|V_{inc}(\Delta Z)|}} \right)$$

$$\left(\frac{\mu_r}{\epsilon_r}\right)^{1/2} = \frac{1+\Gamma}{1-\Gamma}$$

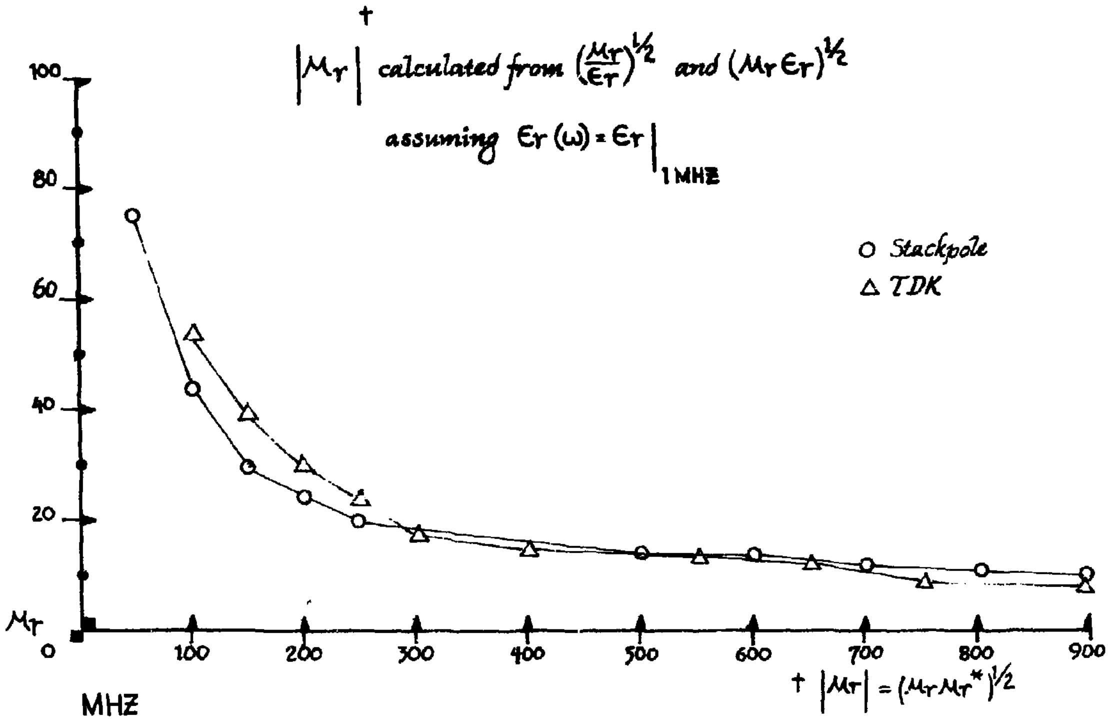
$$\text{Attenuation dB/cm} = \frac{20}{\Delta L_F} \cdot \log \left(\frac{\Gamma |V_{inc}(0)|}{|V_t(\Delta Z)|} \right)$$



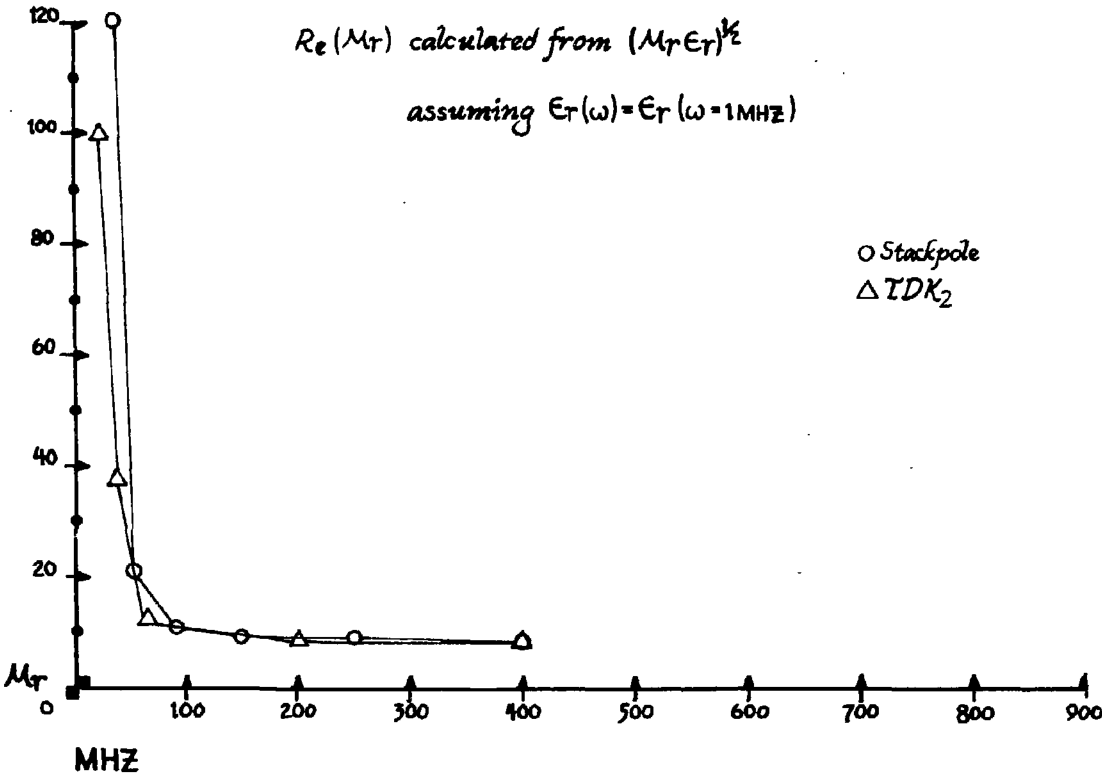
$(\mu_r \cdot \epsilon_r)^{1/2}$
○ Solid Stackpole
△ Solid TDK2
$\epsilon_r \big|_{1 MHZ}$ = 14.34 Stackpole
13.6 TDK
$\mu_r \big|_{1 MHZ}$ = 1000 Stackpole
500 TDK DK
60
50
40
30
20
10
0
100
200
300
400
MHZ



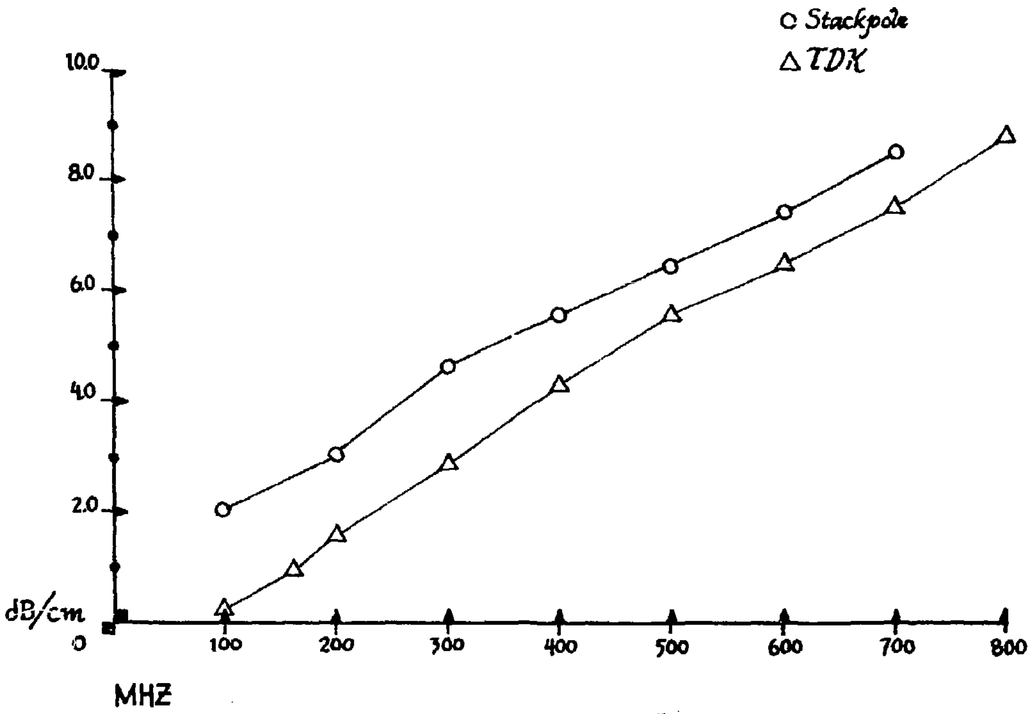
$(\frac{\mu_r}{\epsilon_r})^{1/2}$
3.0
2.0
1.0
0
○ Solid Stackpole
△ Solid TDK_2
$\epsilon_r \big|_{1 MHZ}$ = 14.34 Stackpole
13.6 TDK
$\mu_r \big|_{1 MHZ}$ = 900 Stackpole
500 TDK_{DIC}
100
200
300
400
500
600
700
800
900
MHZ



|μr|† calculated from (μr/εr)^½ and (μr εr)^½
assuming εr (ω) = εr|1 MHZ
○ Stackpole
△ TDK
100
80
60
40
20
μr
0
100
200
300
400
500
600
700
800
900
MHZ
† |μr| = (μr μr*)^½

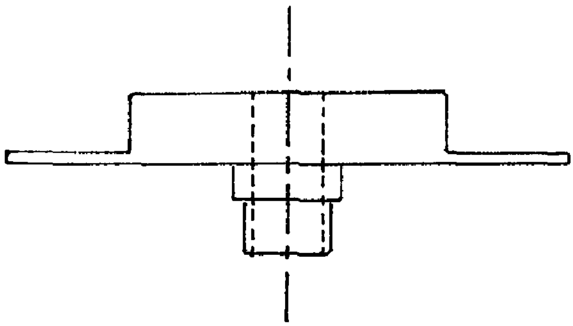

Re(μr) calculated from (μr εr)^½
assuming εr(ω) = εr(ω = 1 MHZ)
o Stackpole
△ TDK2
120
100
80
60
40
20
μr
0
100
200
300
400
500
600
700
800
900
MHZ

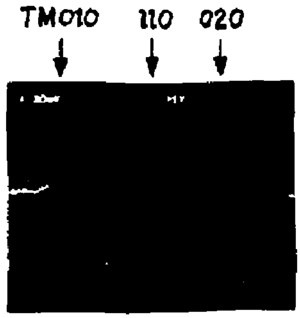
RF Attenuation in Solid Ferrite



Effect of Various Cavity Modifications
First Technique

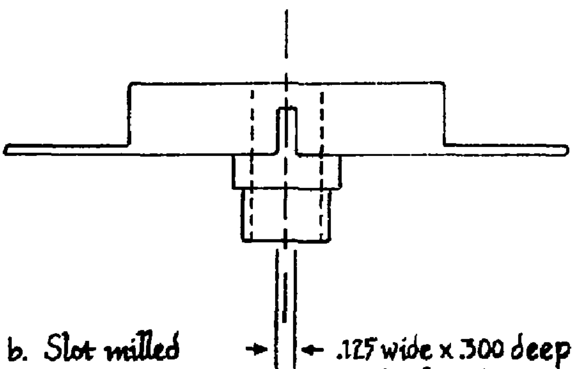
I) Changes to *Reentrant Cylinder*

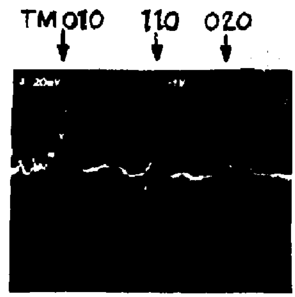




a. Attempt to model *Reentrant Cylinder* in currant ATA design.

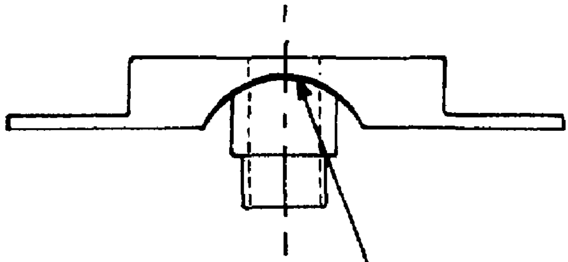
ν start = 2 GHZ
$\Delta\nu$/div. = .2 GHZ
diode response in square law range

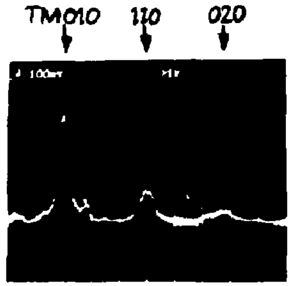




b. Slot milled → | | ← .125 wide x .300 deep on both sides

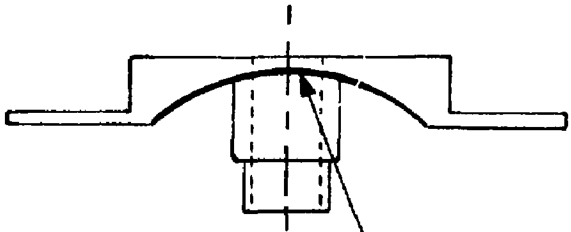
ν start = 2 GHZ
$\Delta\nu$/div. = .2 GHZ

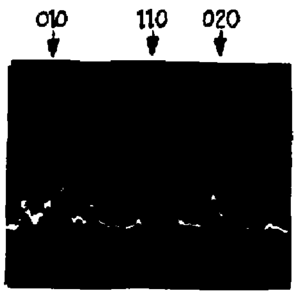




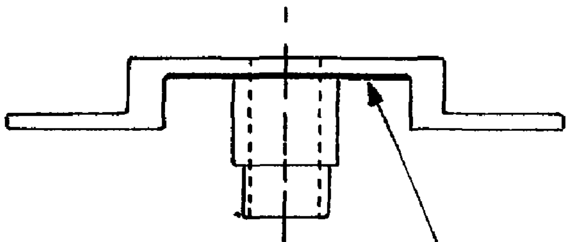
c. Semicircle .355 Dp.
Maximum width 1.00"

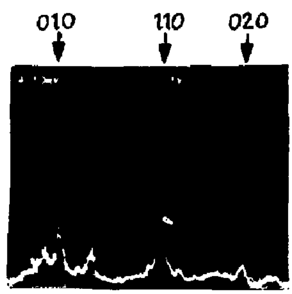
ν_{start} = 2 GHZ
$\Delta\nu$/div. = .2 GHZ





d. Semicircle .355 Dp.
Maximum width 1.70"





e. Section cutaway each side
.360" Dp. x 1.80" wide