A STRIPLINE DESIGN OF A FAST FERRITE TUNER (FFT)

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ABSTRACT

This paper presents the design of a ferrite tuner operating at 52.88 MHz which provides fast tuning of accelerator cavities. It consists of a stripline partially filled with microwave ferrite and is coupled to the cavity. The perpendicularly biased ferrite is placed at the inner conductor, where it can be excellently cooled and easily fixed. The special features include the combination of a permanent magnet with an electromagnet to select the operating point. Due to this arrangement, the ferrite is always in the low loss state and not destroyed in critical operating conditions, e.g. if the DC supply fails. Phase changes of the input reflection coefficient of 130 degrees can be obtained within 20 ms. The tuner can handle about 1 MVA of reactive power. The magnetic circuit is closed by a laminated iron and has a very low stray field.

INTRODUCTION

The application of high tuning speed accelerator cavities in the RF frequency range is an increasing challenge for high power system designers.
Due to beam variations affecting the resonance frequency of a cavity – e. g. de–tuning of optimal acceleration conditions, – means for stabilization of this process must be provided. Commonly, two different types of tuning elements are applied:

1. the *mechanical tuner*, which operates with moveable capacitive posts, being driven by a stepping motor, or
2. the *electromagnetic tuner*, which uses a microwave ferrite material for changing the propagation constant of the electro–magnetic waves.

Up to now, the first type is a component widely used, despite its low speed tuning capability, while the second tuner type is lacking in power handling capability. In addition higher dissipation losses occur.

This paper describes a new type of ferrite tuner which overcomes the above mentioned problems.

TUNER HIGHLIGHTS

The variation of the resonance frequency is done with a strip transmission line (stripline), which is

- partially filled with ferrite material
- short circuited at the output port
- inductively coupled to the cavity.

The interface between tuner and cavity is a coaxial flange of the 6 1/8" type (fig. 1).

The **design goals** are as follows:

- impedance swing within 20 ms tuning time
- effective water cooling (thermal flow > 10 $^{W}/_{cm^3}$)
- overall losses < 0.03 dB
- phase shift of input reflection coeff. > 130 degrees
- low magnetic stray field
- safe operation during power supply failure

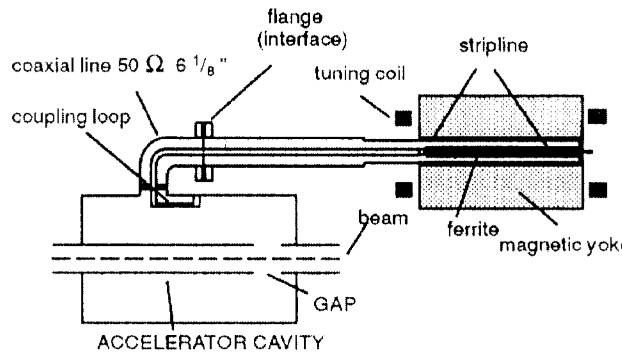

fig. 1: FFT and Cavity Connection

CIRCUIT MODELLING

The equivalent circuit of the tuner is a transmission line of variable length l, which is terminated by a resistor R (Fig. 2). The length l can be varied by a magnetizing current. The resistor R determines the maximum dissipation power and limits the maximum voltage and current at the input flange of the FFT as shown in fig. 3.

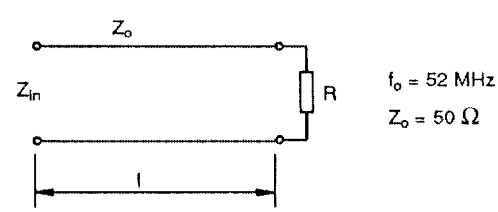

fig. 2: FFT equivalent Circuit

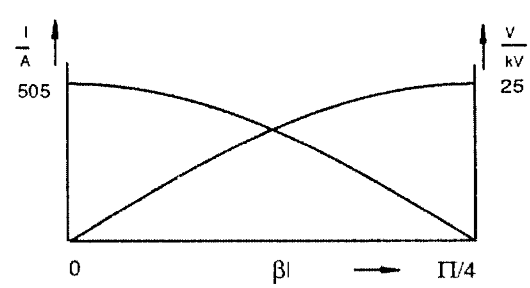

fig. 3: Voltage and Current at Flange

DESIGN CONSIDERATIONS

For a microwave ferrite material, the relationship between magnetic flux density and magnetic field is described by the permeability tensor

$$\overleftrightarrow{\mu} = \begin{bmatrix} \mu_1 & j\kappa & 0 \\ -j\kappa & \mu_1 & 0 \\ 0 & 0 & \mu_0 \end{bmatrix} = \mu_0 \begin{bmatrix} \mu & j\kappa & 0 \\ -j\kappa & \mu & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$\omega_m = -\frac{\gamma M_o}{\mu_o}$ material dependent reference frequency

$\omega_o = -\gamma H_i$ gyromagnetic resonance

$\frac{\gamma}{\mu_o} = 1.76 \; 10^{11}$ rad/sT = 28GHz/T = 2.8MHz/G

$$\mu = \left[1 + \frac{\omega_o \omega_m}{\omega_o^2 - \omega^2} \right] \qquad \kappa = -\frac{\omega \omega_m}{\omega_o^2 - \omega^2}$$

For an RF magnetic field perpendicular to Hi (internal magnetic-field) the effective permeability is:

$$\mu_{eff_\perp} = \mu_0 \frac{\mu^2 - \kappa^2}{\mu}$$

Fig. 4 shows the real and imaginary parts of μ_{eff} in dependence of the internal magnet field at an operating frequency of 52 MHz. As can be seen from the imaginary part, the dissipation losses are decreasing with increasing magnetization field.

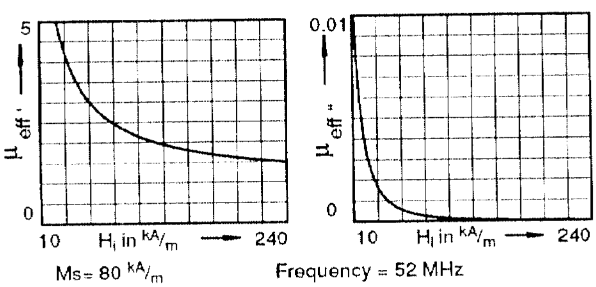

fig. 4: Complex Permeability of a Ferrite Material

Magnetization Principles

The realization of the perpendicular biasing mentioned above may be achieved principally by three different methods: *common coaxial–line design (fig.5):*

- 1. axial magnetization
- 2. radial magnetization

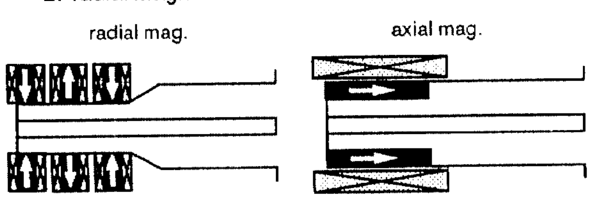

fig. 5: Coaxial–Line Ferrite Ring Designs

new stripline design (fig.6):

- 3. perpendicular magnetization

Resulting from conventional ring designs, the thermal removal of dissipation losses exhibits severe problems. Due to non homogeneous magnetization of ferrites and temperature gradients occurring across the ferrite rings under certain operating conditions the ferrites tend to crack, thus shutting down the whole acceleration system.

These failures will be avoided by the new design, because the usage of very thin ferrite plates as well as achievement of excellent homogeneous magnetization fields will provide secure operating conditions. The combination of conductor cooling and application of thin ferrite plates is a well known and proven technology in ANT's high– power Y–junction circulators.

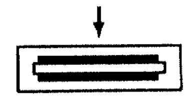

fig. 6 : Perpendicular Magnetization of Ferrite Plates

Fig. 7 shows the complete cross section of the FFT presented in this paper.

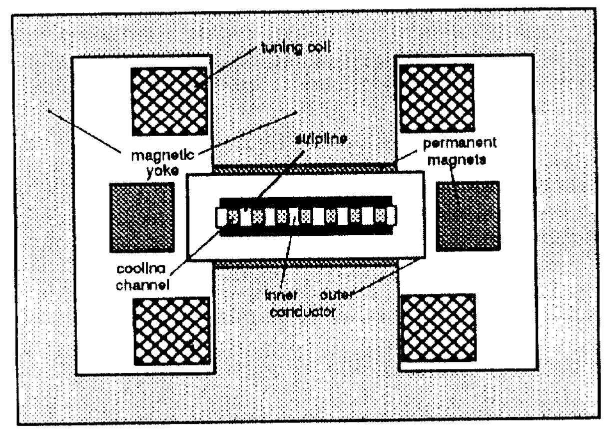

fig. 7: Cross Section of the Prototype FFT at 52 MHz

This design takes advantage of some important features:

- water–cooled inner conductor for thermal heat removal
- magnetization by a combination of permanent and electromagnet. Tuning is done by the electromagnetic part, while the permanent magnetic field keeps the operating point of he ferrites in the low loss region
- usage of thin ferrite plates, being magnetized homoge neously across the whole area, thus avoiding non–perpendicular magnetic biasing, e. g. optimizing losses

Power Considerations

The max. dissipated power determined theoretically is 22 kW. This results in a resistance of R= 0.086 Ω. The max. current is 505 A, while the max. voltage may be 25.2 kV.
The air gap between ferrites and housing is 15 mm, which leads to an electrical field strength of 16.8 kV/cm at a peak value of 1.4 · 16.8 kV/cm.
In practical operation, as calculated from BNL (Brookhaven National Lab.), the tuner is operated at V_{max}= 10.5 kV with a dissipation power of 3.7 kW, giving a sufficient back–off from worst case.
The optimized tuning range is attained by a 20 Ω stripline, because different impedances between coaxial– and stripline part increase the phase gradient as well as the absolute phase value of the tuning range. The optimum length calculated is 950 mm (fig.8).

MAGNETIZING EQUIPMENT

Fig. 9 shows the static magnetic field in the middle of the yoke without the ferrite. A minimum induction of 1000 G is necessary to operate the ferrites in the low loss region. In order to achieve a homogeneous field, two correction magnets of Bariumoxide are positioned on both sides of the stripline. Permanent magnets of rare earths and cobalt have been used at top and

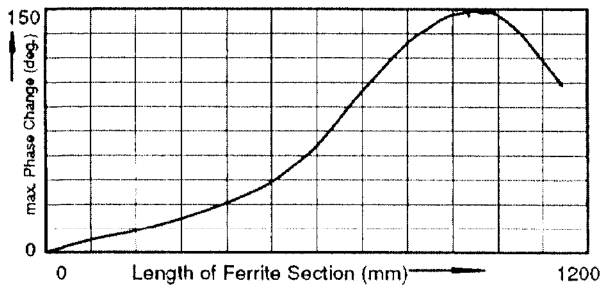

fig. 8: Max. Phase Change versus Ferrite Length

bottom of the stripline housing.

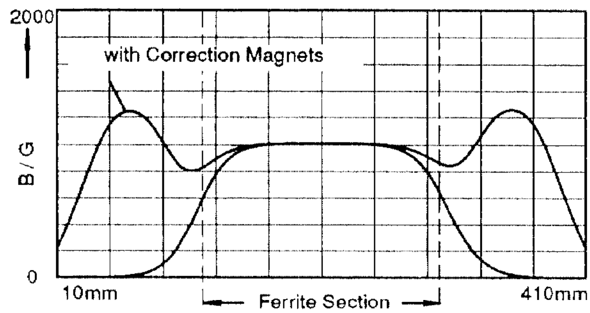

fig. 9: Static Magnetic Field

For the tuning coil the following conditions are realized:

- As results from permeability calculations, the magnetic flux density should vary about 1400 G.
- Two coils have been used to achieved the desired magnetic induction. The inductance of one coil is 10 mH and it has an resistance of 30 m Ω.
- The hole tuning range can be tuned in 20 ms by a power supply, which generate 150 V and 150 A in the first and second quadrant in an I/V plane.

The eddy currents are minimized by laminated iron in the yoke.

LOW POWER MEASUREMENT RESULTS OF THE 52 MHZ PROTOYPE

Fig. 10 shows the relative phase change of the input reflection coefficient of a scaled tuner model. A tuning range of more than 130 degrees is realized . The return loss is 0.06 dB which will decrease to about 0.03 dB at the full scale tuner.

Referring to a specific application, the impedance swing can be adjusted by an additional transformation line in front of the tuner. In fig. 11 this is shown principally , where the original tuner impedance range of

$$-j125\Omega < Z_{in} < +j\,54\,\Omega$$

is transformed into

$$+j\,15\,\Omega < Z_{in} < +j\,405\,\Omega.$$

CONCLUSION

The presented tuner design is a contribution to the realization of fast tunable RF accelerator cavities.
Specific features implemented therein, such as stripline design with usage of thin ferrite plates for excellent thermal heat removement or magnetization system for safe low loss operating lead to an improvement towards higher quality acceleration systems.
The installation of the prototype device as well as the high power

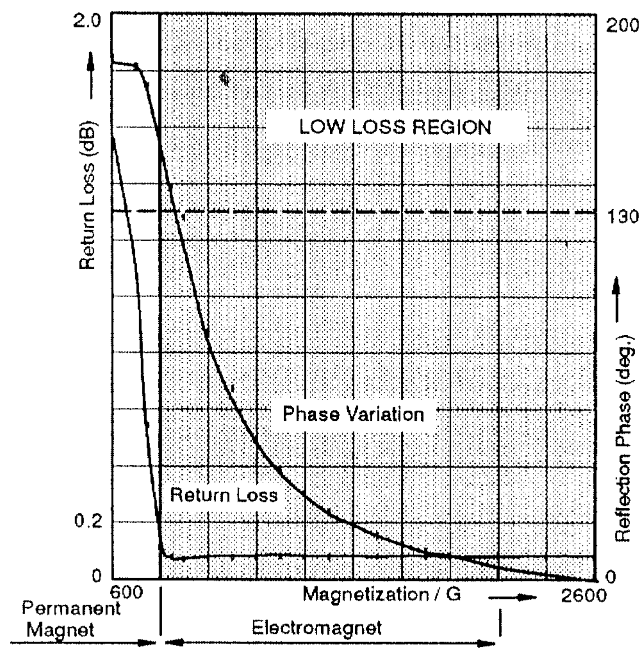

fig. 10: Model Measurement Results of the 52 MHz Prototype Tuner

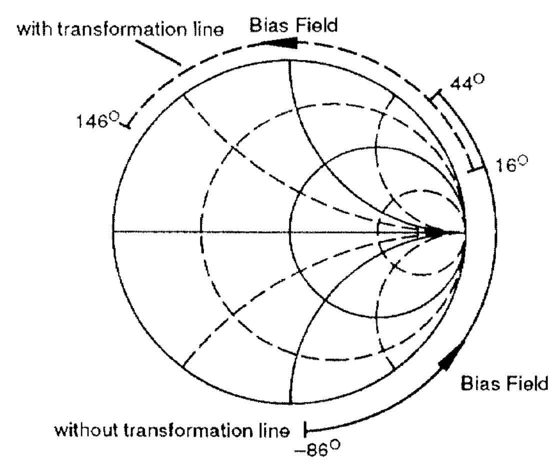

fig. 11: Impedance Swing on Complex Plane

testing will be done at BNL–USA in fall 1990. The authors would like to thank Mr. John Keene (BNL) for many helpful discussions concerning the application of the tuner within a 52 MHz acceleration cavity.

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