IPNS-UPGRADE RF System Design*

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I. Introduction

The RF System for the rapid cycling synchrotron proposed for the IPNS-Upgrade design must generate a minimum of 116.8 kV to be able to operate at a phase stable angle of 45° at B_{max} and must deliver an average power to the beam of 900 kW. The system is designed to provide this voltage and power with six double-ended cavities. The amplifiers are push-pull, cathode-follower types to handle the beam loading. The amplifiers and cavities might be split into single-ended types depending on computer calculations which are now being done. If so, however, the total amount of ferrite and the number of power tubes will remain the same. The RF system design parameters are listed in Table 1.

II. Cavity Design

Each cavity is designed to be 2.6 meters long from flange face to flange face and to have a single accelerating gap in the middle. A cross-sectional drawing of the cavity is shown in Fig. 1. There are four ferrite assemblies in each cavity, two on each side of the accelerating gap. Each ferrite assembly consists of a stack of 14 Philips 8C12 ferrite rings and water cooled copper disks as shown in

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Fig. 2. The ferrite rings are the same material and roughly the same size as was used in the GSI Heavy Ion Synchrotron[1]. The copper and ferrite disks in each assembly are stacked together and tightly clamped in the axial direction to provide good thermal contact between the copper plates and ferrite disks.

The four ferrite assemblies are wound with six turns of busbar to provide the dc bias field. The bias winding direction is reversed in each assembly providing the typical "figure-8" configuration[2] so that the induced RF voltage is cancelled at the input terminals of the bias windings. The physical parameters for the cavity are listed in Table 2.

The frequency varies from 1.1013 Mhz at injection to 1.4562 Mhz at extraction. The cavity resonance is adjusted by varying the incremental permeability of the ferrite from 120 to 67. These operating points are shown on the graph in Fig. 3. The bias current varies from 47.1 amperes to 77.6 amperes to achieve the change in incremental permeability.

The cavity gap is loaded with 600 pF of low-inductance capacitors to resonate with the cavity inductance. The capacitors will be mounted in conducting strips around the accelerator gap in the configuration suggested by M. Plotkin[3]. This technique achieves a coupling impedance, Z/n, of 1 to 10 ohms.

III. Power Amplifier

The power amplifier is a push-pull design as shown in Fig. 4. This configuration has been studied by Hardek[4] and Puglisi[5]. The output impedance of this device is extremely low over a fairly broad frequency range and will compensate for beam loading due to the large circulating beam currents. There could be a problem with maintaining the proper bias on tubes in the push-pull configuration as indicated by Puglisi. This is being studied on the computer and, if necessary under our beam conditions, the cavities and amplifiers will be split into the single-ended configuration.

The RF output of the power amplifier is connected to the cavity by copper straps with blocking capacitors. The cavity and amplifier are designed to generate 23.1 kilovolts at $\dot{B}_{max}$. The plate voltage on the tubes is 25.0 kilovolts. The peak circulating beam current during acceleration is 61 amperes. In addition, the peak power at $\dot{B}_{max}$ into the ferrite is 27.1 kW, with 13.5 kW into the copper walls and cooling plates. The peak power delivered to the beam is 305.3 kW. The power to compensate for cavity losses adds as much as 19 to 20 amperes of plate current in the tube. In order to match these requirements, each cavity is supplied by a push-pull, cathode-follower amplifier using EIMAC 8973 tubes. The average power supplied by each tube is given by

$$\langle P\rangle = \frac{3}{4}\left\{\frac{1}{\pi}\int_0^\pi \sin^2\Theta \, d\Theta\right\}$$

where the 3/4 factor is a result of operating the synchrotron magnets with a 20 Hz acceleration cycle and a 60 Hz reset cycle. The average power from the amplifier under normal operation is 162.2 kW with an average beam current on target of 500 μa and the cavities operating at 19.45 kilovolts. The parameters for maximum operating conditions are listed in Table 3 for the cavity and Table 4 for the amplifier.

1. K. Kasper and M. Emmerling, "Development of the RF Accelerating System for the GSI Heavy Ion Synchrotron", IEEE Trans on Nuclear Science, Vol NS-28, No 3, June, 1981, 3028.

2. C. Fougeron, et al., "RF System for "MIMAS"", IEEE Trans on Nuclear Science, Vol NS-28, No3, June, 1981, 3028.

3. M. Plotkin, "Isabelle Cavity Gap Assemblies", IEEE Trans on Nuclear Science, Vol NS-28, No 3, June, 1981, 2752.

4. Thomas W. Hardek and William E. Chyna, 1979, "Common Anode Amplifier Development," IEEE Trans. on Nuclear Science NS-26 No. 3 June.

5. A. Luccio and M. Puglisi, 1981, "Behavior of Single-Ended vs. Push-Pull Amplifiers for the Accelerating Systems of High-Current Beam Storage Rings," Particle Accelerator 11.

Table 1
RF System Design Parameters

RF Frequency @ Injection, MHz	1.1013
RF Frequency @ $\dot{B}_{max}$, MHz	1.3791
RF Frequency @ Extraction, MHz	1.4562
Maximum voltage per turn, kV	116.8
Maximum Beam Current @ Extraction, A	61.03
Average Power Delivered to Beam from RF, kW	900.0
$\sin \phi_s$ @ $\dot{B}_{max}$	0.707
Maximum Accelerating Voltage per Turn @ $\dot{B}_{max}$, kV	83.55

Table 2

Physical Parameters of Cavity

Physical Length of Cavity, flange-to-flange, m	2.6
Inside Length of Cavity, m	2.2
Length of Accelerating gap, m	.04
Outer Radius of Cavity (inside dimension), m	.35
Inner/ Outer Radii of Beam Tube, m	0.068/0.078
Type of Ferrite	Philips 8C12
μQ of Ferrite	6000
Ferrite Ring Dimensions:	
Inner Radius, m	0.125
Outer Radius, m	0.250
Thickness, m	0.0254
Type of Cavity	Double Ended, Single Gap
Number of Ferrite Rings	56
Volume of Ferrite/Cavity, m^3	0.21
Thickness of Copper Cooling Plates, m	0.003

Table 3

Operating Characteristics of Cavity for Nominal Operation

Maximum Flux Density, T	0.01264
Maximum Voltage per Cavity, kV	19.45
Peak Power in Ferrite, kW/m^3	91.8
Average Power in Ferrite, kW/m^3	34.4
Average Power in Ferrite per Cavity, kW	7.2
Peak Power to Copper, kW	9.56
Average Power to Copper, kW	3.6

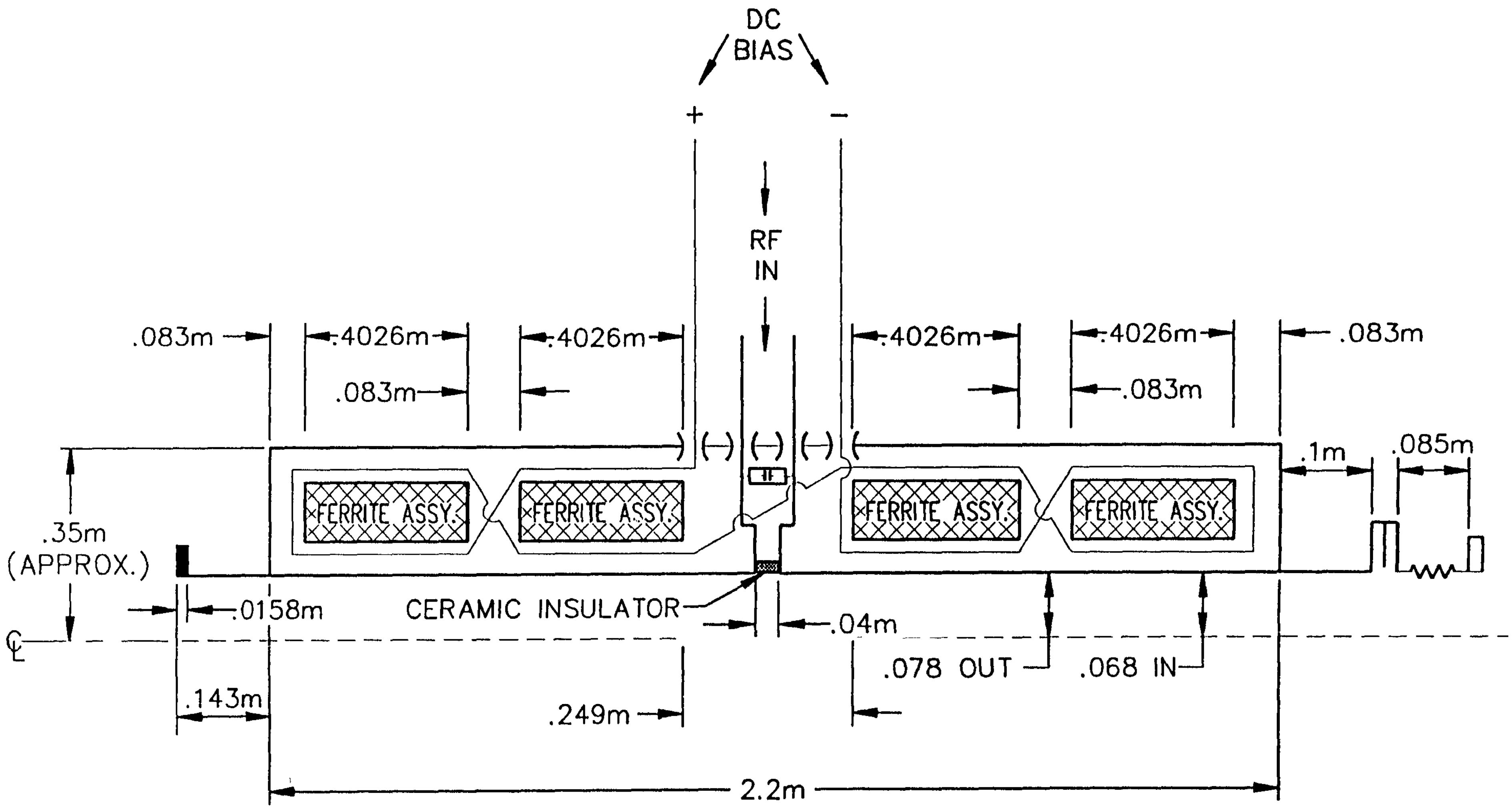
Table 4

Amplifier Characteristics

Type	Push-Pull Cathode Follower
Tube Types	Eimac 8973
Plate Voltage, kV	25.0
Maximum Gap Voltage, kV	23.1
Peak Plate Current to Beam, A	61.0
Peak Plate Current from Amplifier, A	~80.0
Peak Power to Beam per Amplifier, kW	305.3
Peak Power to Ferrite per Cavity, kW	27.1
Peak Power to Copper per Cavity, kW	13.5
Average Power from Amplifier, kW	162.2

Figure 1

CAVITY DESIGN



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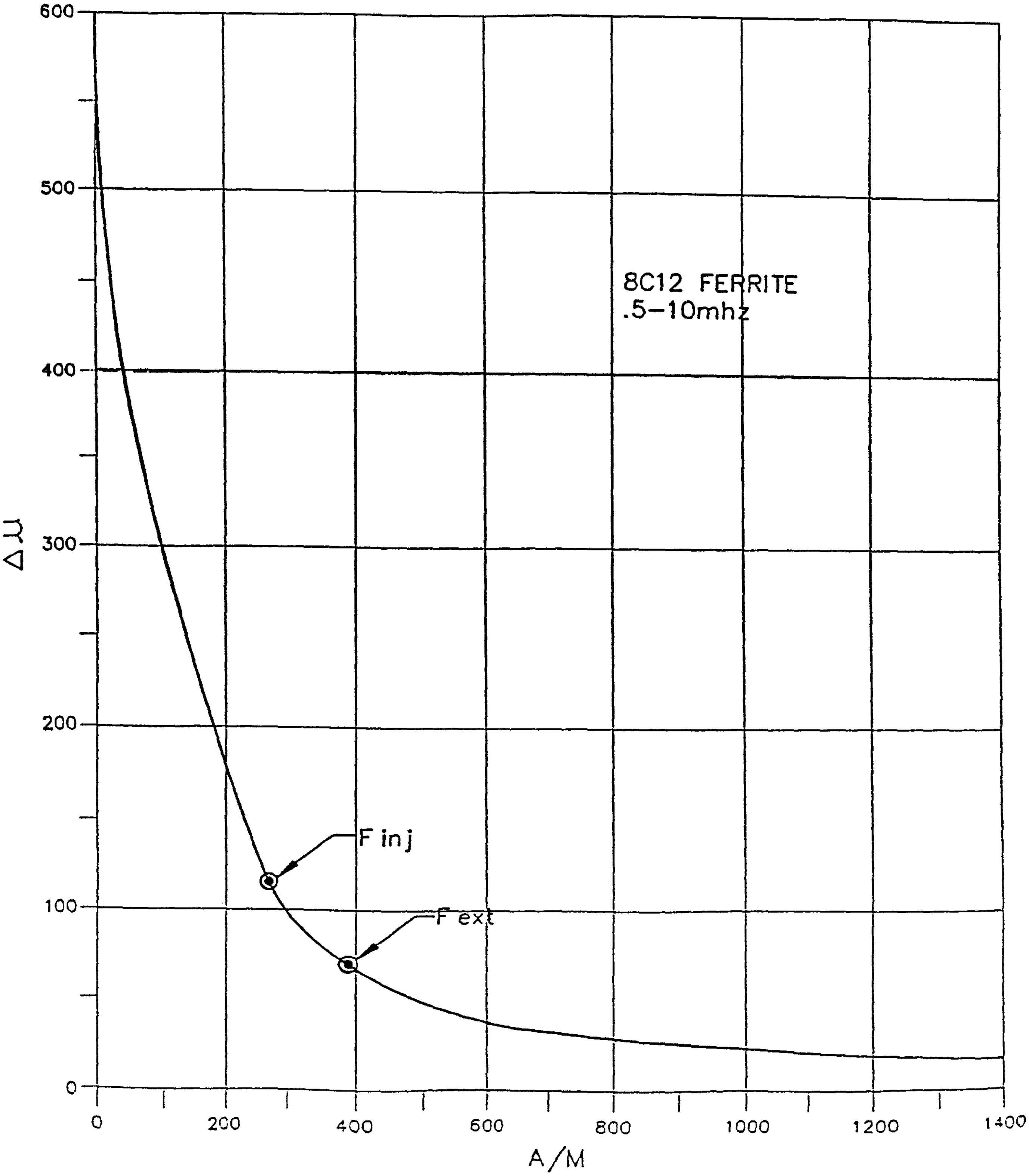

Figure 3 Incremental Relative Permeability vs DC Bias P003

Figure 2

FERRITE DISC DETAILS

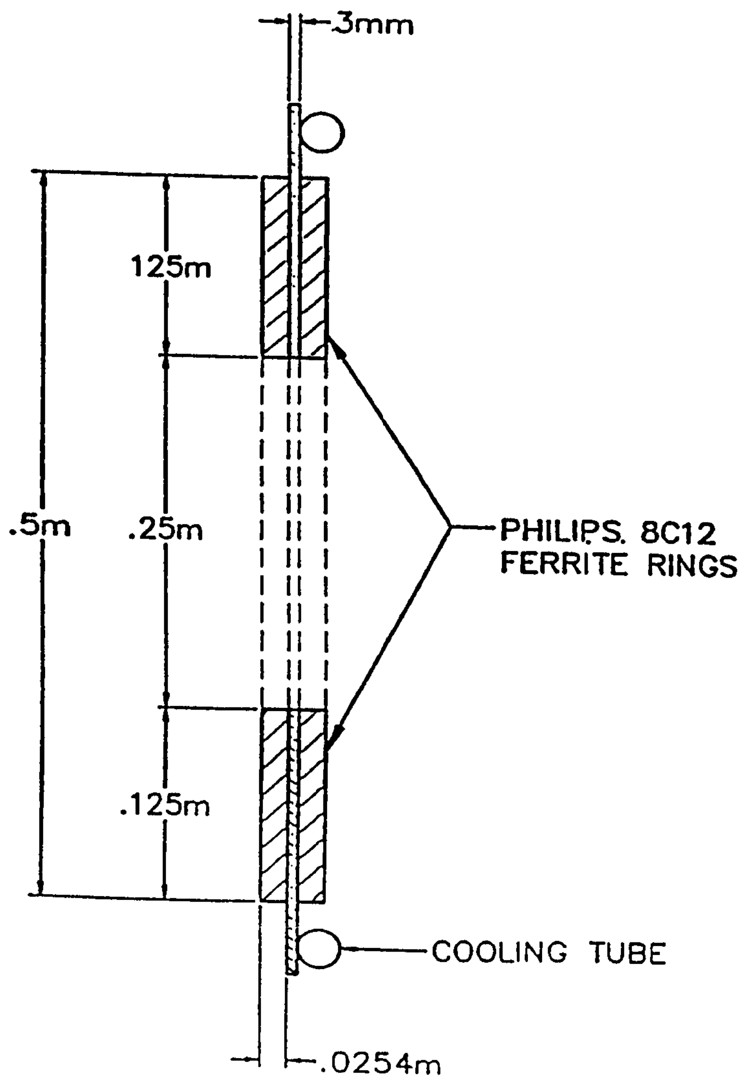

Figure 4

AMPLIFIER DETAILS