Status of the MI RF R&D Effort

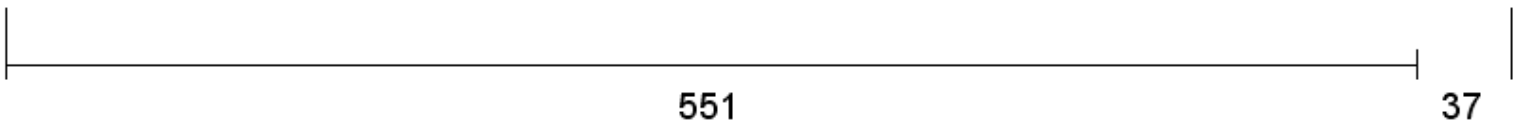
Joseph E. Dey
Project X Collaboration Meeting
September 11, 2009

MI RF System Specifications

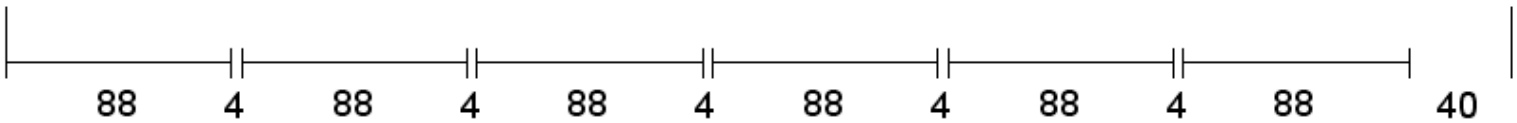
Parameter	Value	Units
Frequency	52.811-53.104	MHz
Max. Acceleration Rate	240	GeV/sec
Frequency slew rate	1.6	MHz/sec
Acceleration Voltage	2.7	MV
Beam Power	6.2	MW
Average Beam Power	3.0	MW
Peak Voltage	4.7	MV
Average Beam Current	2.3	A
Fundamental rf Current	3.7-4.1	A

Main Injector Beam Distribution

ICD-1



ICD-2

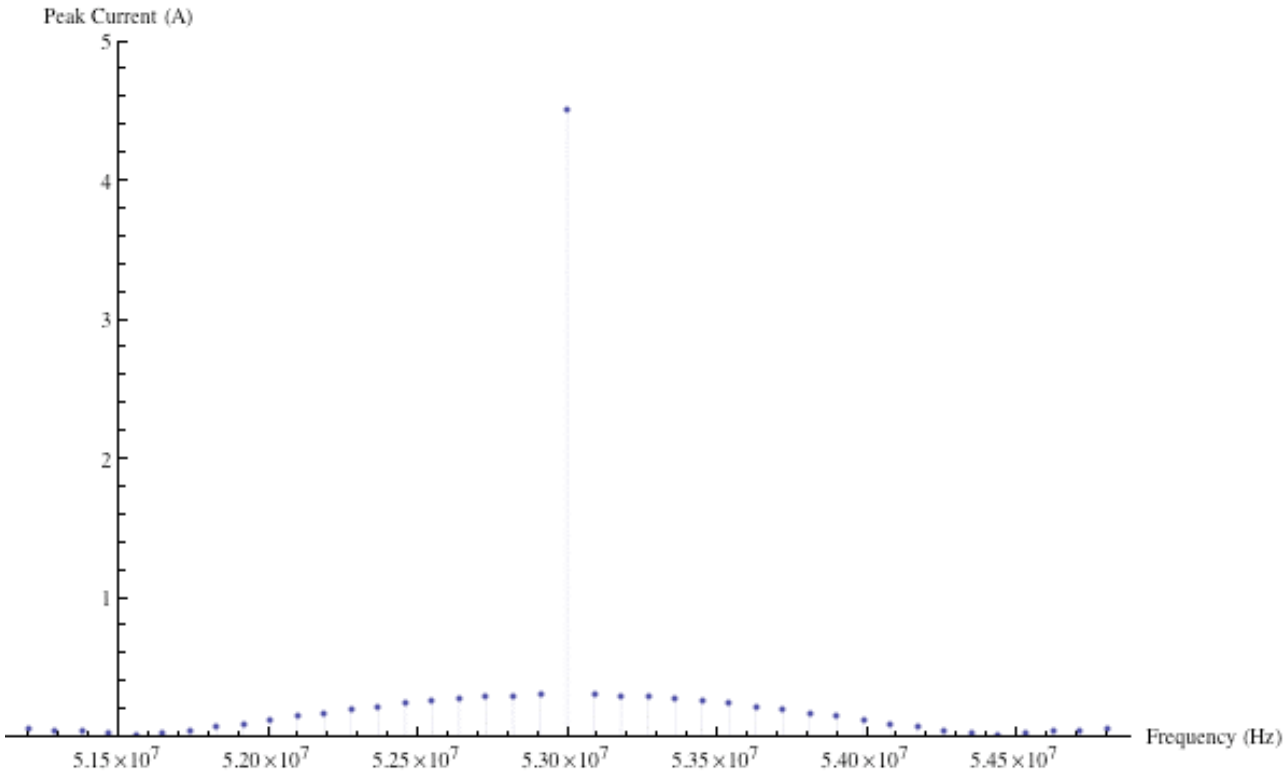


ICD-1: Painting in Recycler

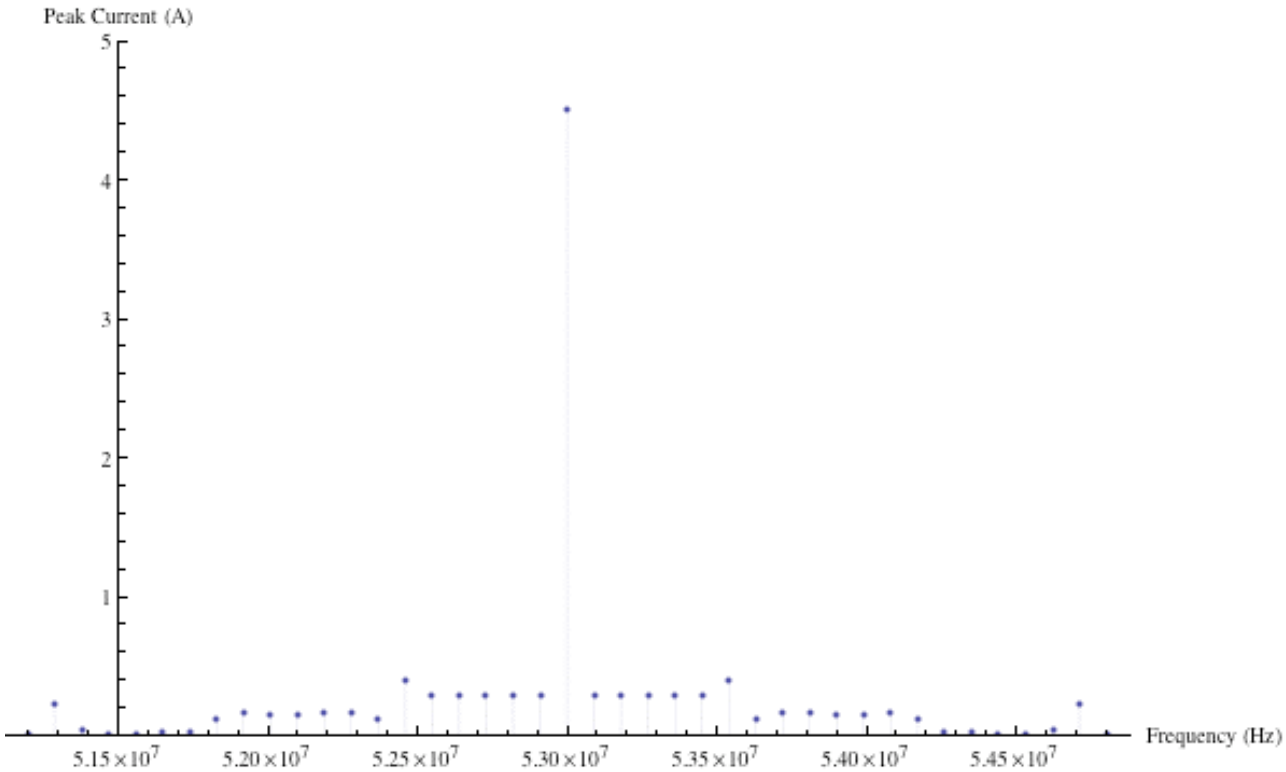
h = 588

ICD-2: Recycler Accumulates Beam while MI Ramps

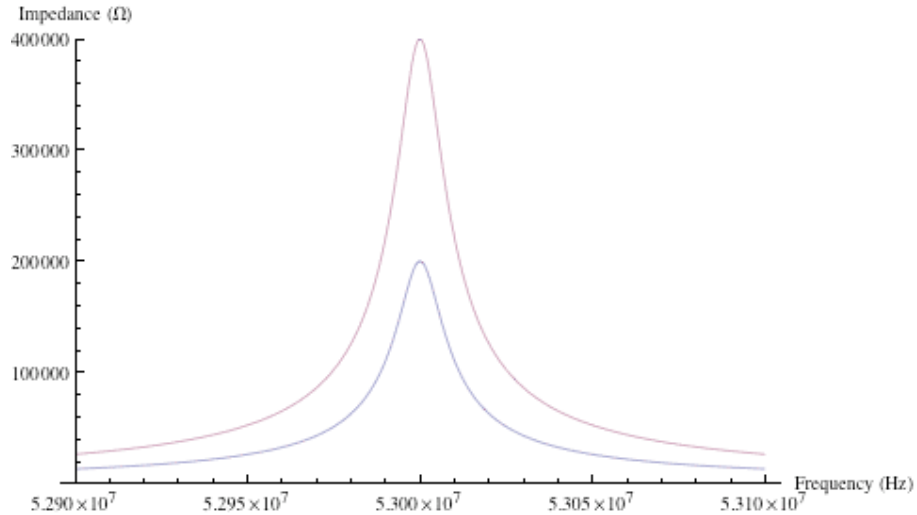
ICD-1 RF Current



ICD-2 RF Current



Cavity R/Q



Red Trace: R/Q =100 and Q = 4000

Blue Trace: R/Q = 50 and Q = 4000

Cavity Parameters

Joe Dey
8/5/09

	Project X New Cavity Design
Harmonic Number	588
Frequency	52.8114-53.104 MHz
Acceleration Ramp Slope	240 GeV/s
Peak Beam Current	4.51 A
Total Beam Accelerating Power	6.144 MW
Number of Accelerating Cavities	20
Cavity R/Q	50
Q	10000
Maximum Cavity Accelerating Voltage	240 kV/Cavity
Accelerating Voltage Required: $V\sin\phi_s$	2.66 MV
Total Accelerating Voltage Available	4.80 MV

Robinson Stability

ϕs = 33.6327 deg

Cavity Power Loss per Cavity = 57.6 kW

Total Apparent Power = 558.417×10^3 VA $\angle$ 50.209 degrees

Total Current = 4.65347 A $\angle$ 50.209 degrees

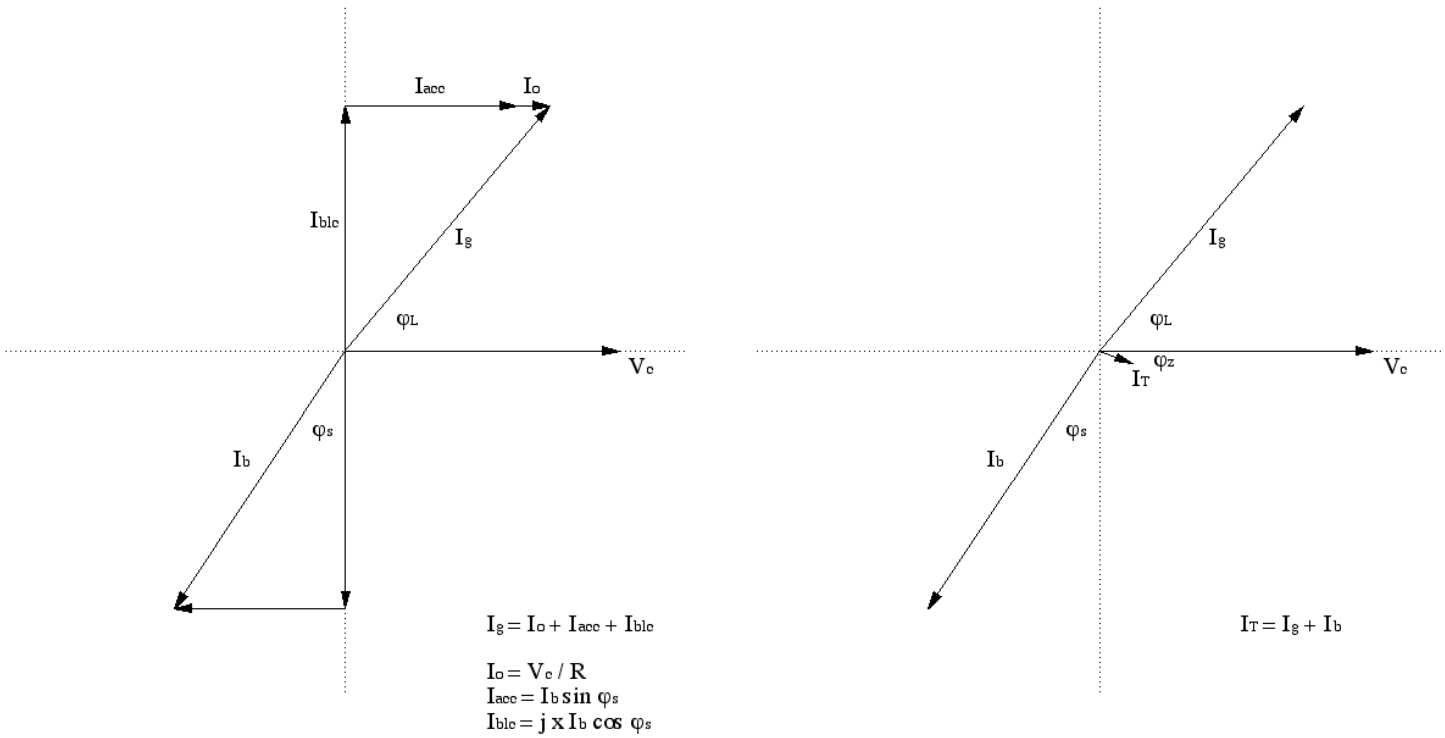
Percent of Induced Mode Compensated = 26.4 dB = 95.2137 %

Robinson Stable Limit = 4.01439

30 GeV Vector Diagram

Joe Dey
August 28, 2009

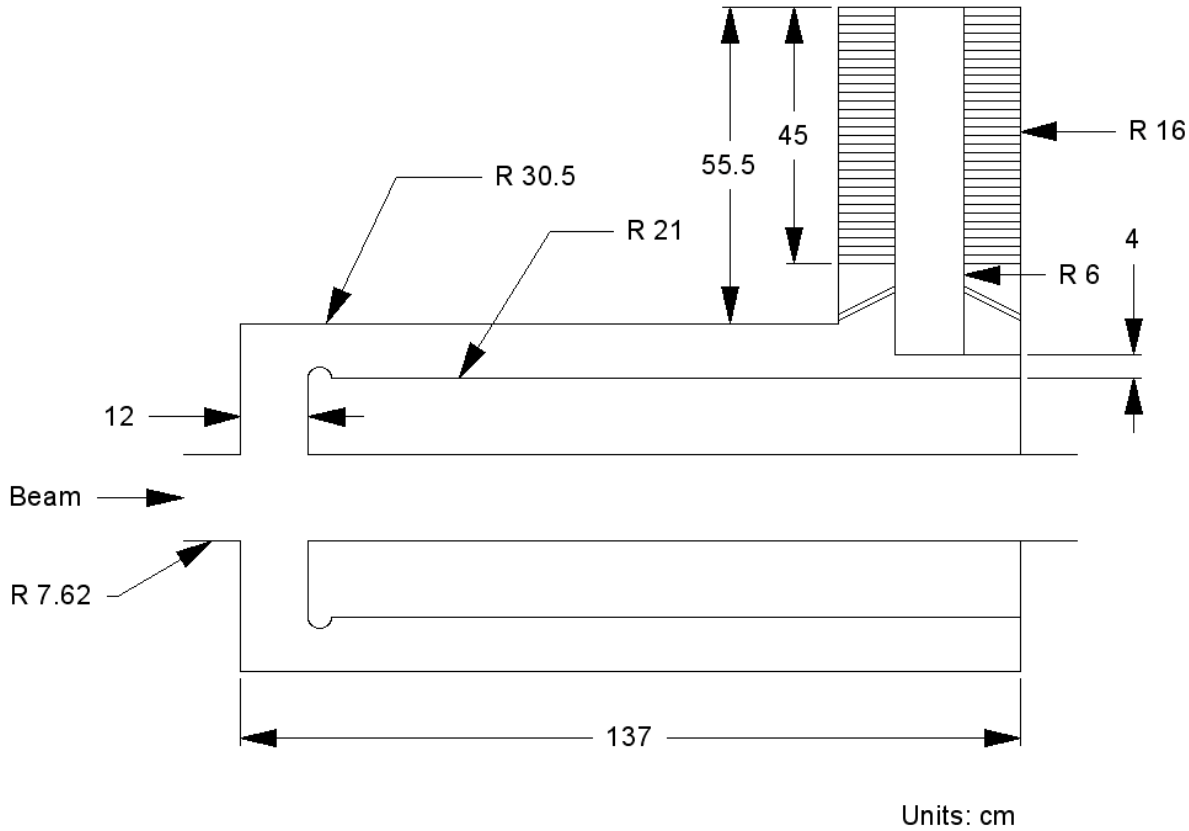
Robinson Stable = 4
95.2% Beam Loading Compensation
x = 0.952



Looking Back to Collaboration 2008

	Project X Collaboration 21-Nov-08 Design
Harmonic Number	588
Number of Filled Buckets	548
Frequency:	52.8114-53.104 MHz
Acceleration Ramp Slope:	240 GeV/s
Beam Intensity:	1.6e14 Protons
Beam Accelerating Power:	6.144 MW
Number of Accelerating Cavities:	18
Cavity R/Q:	25
Cavity Q:	4000
Accelerating Power per Cavity (beam):	450 kW/Cavity
Maximum cavity Accelerating Voltage:	300 kV/Cavity
Accelerating voltage required: $V\sin\phi_s$	2.66 MV
Total Accelerating Voltage Available:	5.4 MV
Total Peak Amplifier Power Required:(beam + cavity)	791.3 kW

Project X
MI Cavity



Microwave Studio Simulations

Project X
Main Injector Cavity
Microwave Studio Simulations Data

10-Aug-09

μ_r = 2.5

Frequency (MHz)	Q	R_{sh} (Ω)	R_{sh} / Q (Ω)
52.77	10300	530000	51.46
62.52	10300	65000	6.31
125.57	26500	3482	0.13
125.75	27700	0.26	9.39E-06
129.48	19400	10800	0.56
162.64	17600	398000	22.61
176.52	30900	0.86	2.78E-05
176.98	30400	8590	0.28
200.60	24300	5290	0.22
204.48	19600	34.8	1.78E-03

μ_r = 1.2

Frequency (MHz)	Q	R_{sh} (Ω)	R_{sh} / Q (Ω)
53.40	10000	568000	56.80
74.18	87900	15400	0.175
158.74	17500	233000	13.31
163.31	19200	1.07	5.57E-05
164.27	19100	44900	2.35
168.59	15000	122000	8.13
204.58	19700	32.7	1.66E-03
205.16	19200	481	0.025
226.90	22000	1.43	6.50E-05
227.50	22100	1250	0.057

Eimac 8973 Power Tetrode

8973

The 8973 is a power tetrode designed for very high powered medium frequency or high frequency broadcast service and a very low frequency communication in the half megawatt power range. The 8973 has a thoriated tungsten filament mounted on water-cooled supports. Large diameter coaxial terminals are used for the control grid and the RF filament terminals. Filament power and filament support cooling water connections are made through special couplings with threaded clamping rings.

CHARACTERISTICS

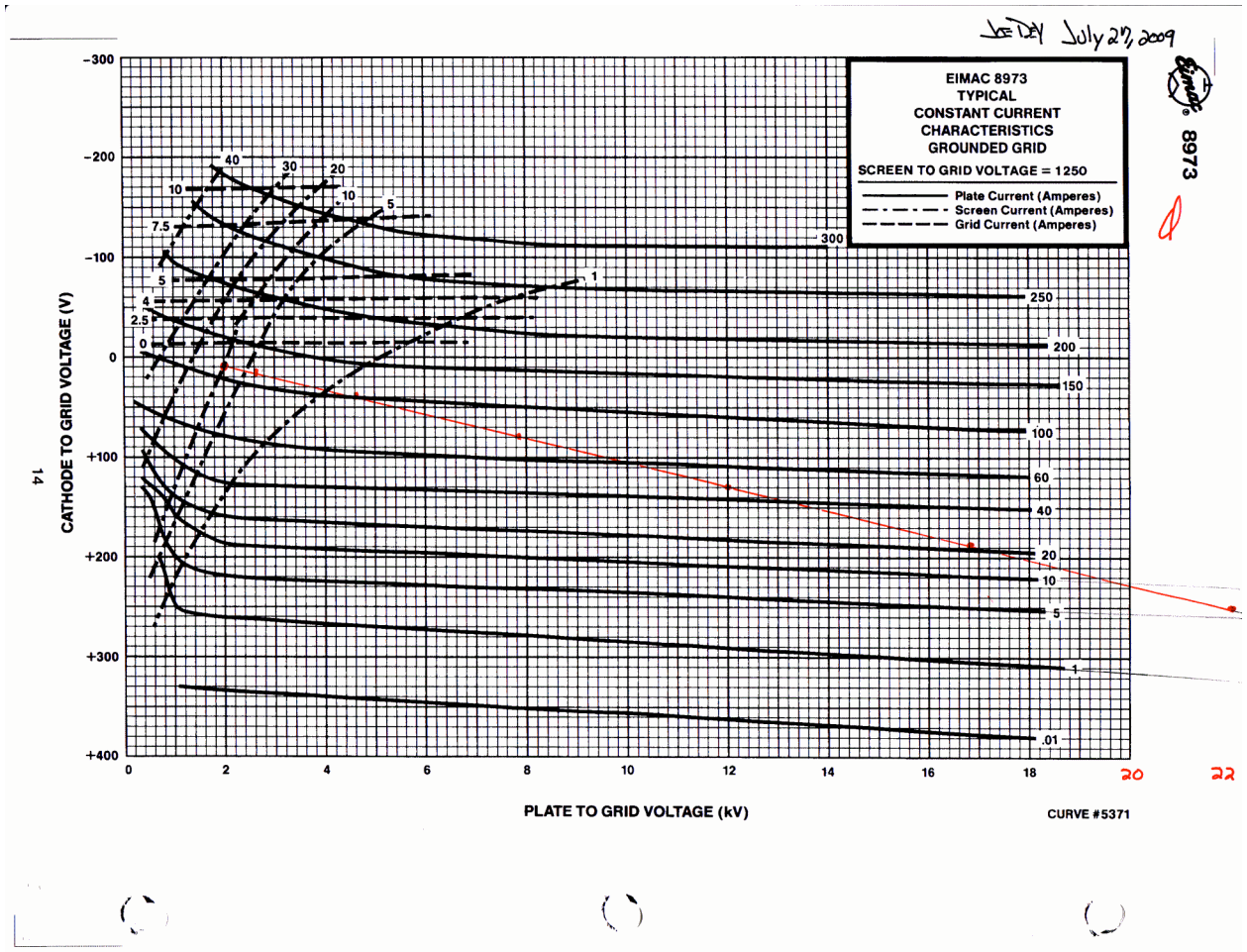
Plate Dissipation (Max.)	1,000 Kilowatts
Screen Dissipation (Max.)	7.5 Kilowatts
Grid Dissipation (Max.)	2.0 Kilowatts
Frequency for Max. rating (CW)	110 MHz
Amplification Factor	4.5
Filament/Cathode	Thoriated Tungsten
Voltage	16.3 Volts
Current	600 Amps
Capacitance	Grounded Cathode
Input	1000 pf
Output	165 pf
Feedthrough	5.0 pf
Capacitance	N/A
Input	N/A
Output	N/A
Feedthrough	N/A
Cooling	Water and Forced Air
Base	Special Coaxial
Air Socket	N/A
Air Chimney	N/A
Boiler	N/A
Length	18.75 in; 476.20 mm
Diameter	17.03 in; 432.60 mm
Weight	153.0 lb; 69.5 kg

		MAXIMUM RATINGS		TYPICAL OPERATION				
Class of Operation	Type of Service	Plate Voltage (Volts)	Plate Current (Amps)	Plate Voltage (Volts)	Screen Voltage (Volts)	Plate Current (Amps)	Drive Power (Watts)	Output Power (kiloWatts)
C	RF Amplifier	22,500	65.0	21,000	1,500	59.0	2,700	1,025.0
C	RF Amplifier Plate Modulated	17,500	50.0	17,500	800	50.0	2,400	700.0
AB1	RF Linear Amplifier	22,500	110.0	20,000	1,500	45.0	---	610.0
AB1	AF Amplifier or Modulator	22,500	110.0	17,500	1,500	78.0	---	950.0
B	RF Amplifier, Long Pulse, Grounded Grid	1,000	000	24,500	1,750	94.2	7,140	1,770.0

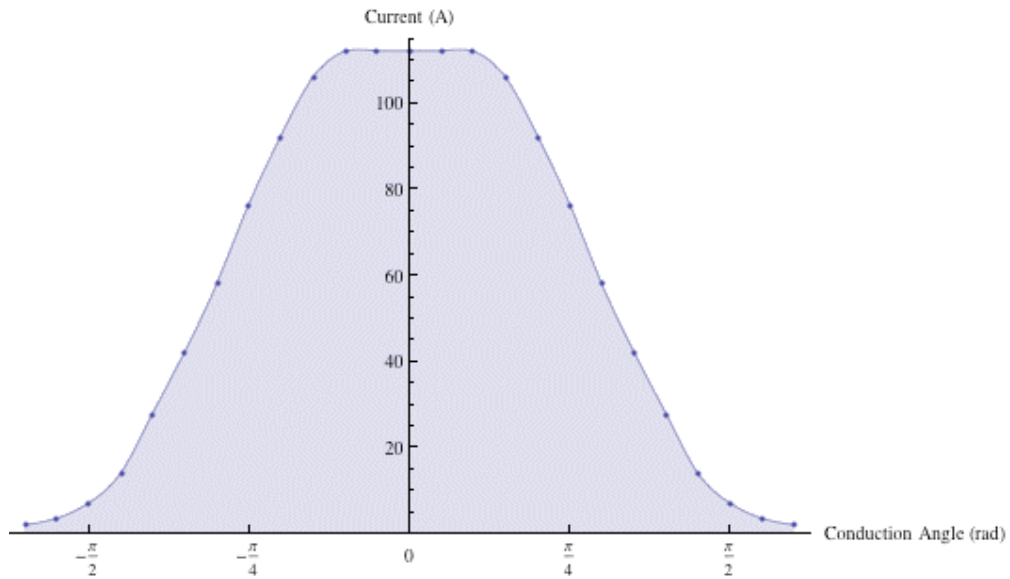
The values listed above represent specified limits for the product and are subject to change. The data should be used for basic information only. Formal, controlled specifications may be obtained from CPI for use in equipment design.

For information on this and other CPI MPP products, visit our website at: www.cpii.com,
or contact: CPI Microwave Products Division, Eimac Operation,607 Hansen Way, Palo Alto, CA 94303
TELEPHONE: 1(800) 414-8823. FAX: (650) 592-9988 | EMAIL: powergrid@cpii.com

Eimac 8973
Tube Curves



Eimac 8973 Tube Calculations



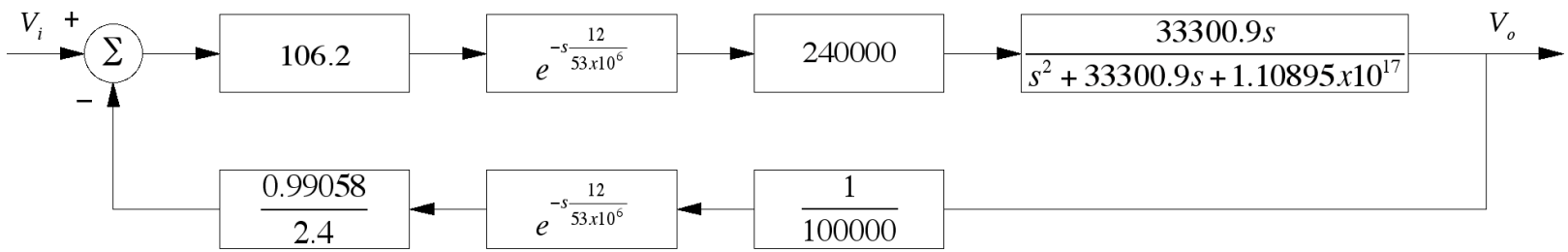
V_{DC} = 22 kV
V_{RF} = 20 kV

I_{av} = 35.36 A
I_{RF} = 2 x 0.791 x I_{av} = 55.94 A

P_{in} = 777.97 kW
P_{out} = 559.4 kW
P_{cath} = 6.7 kW

Normalized Fourier Amplitude = 0.791

MI Cavity Feedback Block Diagram



Phase Margin = 45 deg

Closed Loop Gain = 106.2

Total Time Delay = 452.8 ns

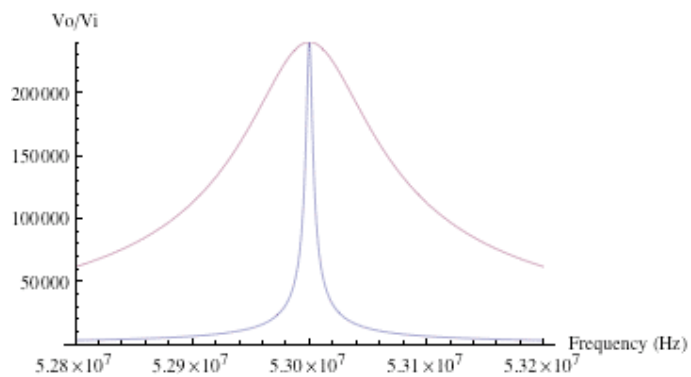
FY 2010 Plan

- Cavity
  - Build Copper Mockup of 53 MHz cavity
    - Look at Higher Order Modes, R/Q, and Coupling Issues
- Power Amplifier
  - Purchase Eimac 8973
    - Build Power Amplifier for Test Stand
- Higher Order Mode Damper
  - Investigate RHIC Design of High Pass Filter with Lumped Elements constructed from Coaxial Line
    - Reference Paper - RHIC 28 MHz Accelerating Cavity System, J. Rose et al, 2001 Particle Accelerator Conference, Chicago
    - Do Simulations of Damper
    - Realize a Design

FY 2010 Plan

- Cavity Tuner
  - Perpendicularly Biased Garnet Tuner
    - Issues; RF Tuner Loses, Cooling, Coupling and Tuning Range
    - Simulations of Tuner
    - Realize a Design
- Second Harmonic Cavity, 106 MHz
  - Start Initial Paper Design
  - Cavity Simulations
  - Review Design

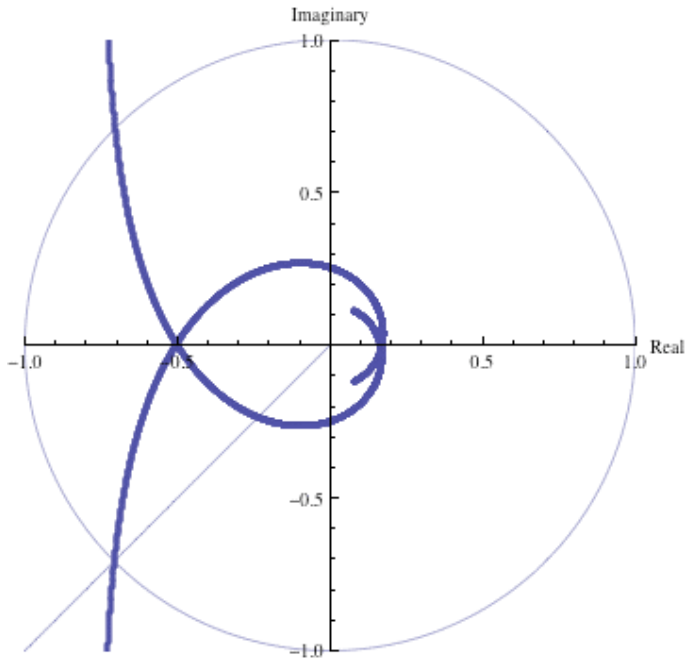
Appendix: Vo / Vi Plot



Blue: Cavity with no Feedback, Q = 10,000

Red: Cavity with Feedback, Closed Loop Gain = 20, Time Delay = 0 ns

Appendix: Nyquist Plot



Phase Margin = 45 deg

Open Loop Gain = 105.2

Total Time Delay = 452.8 ns