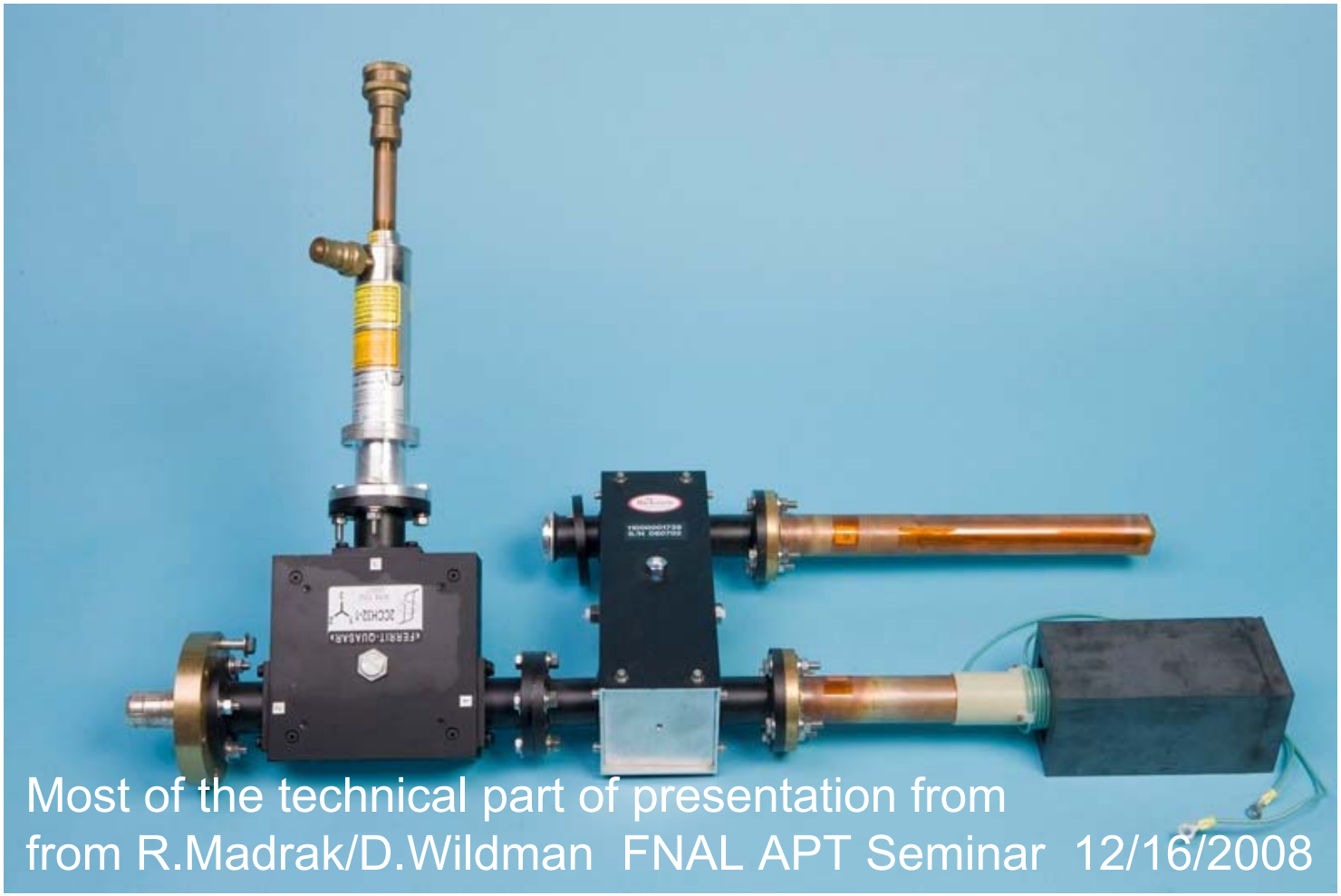
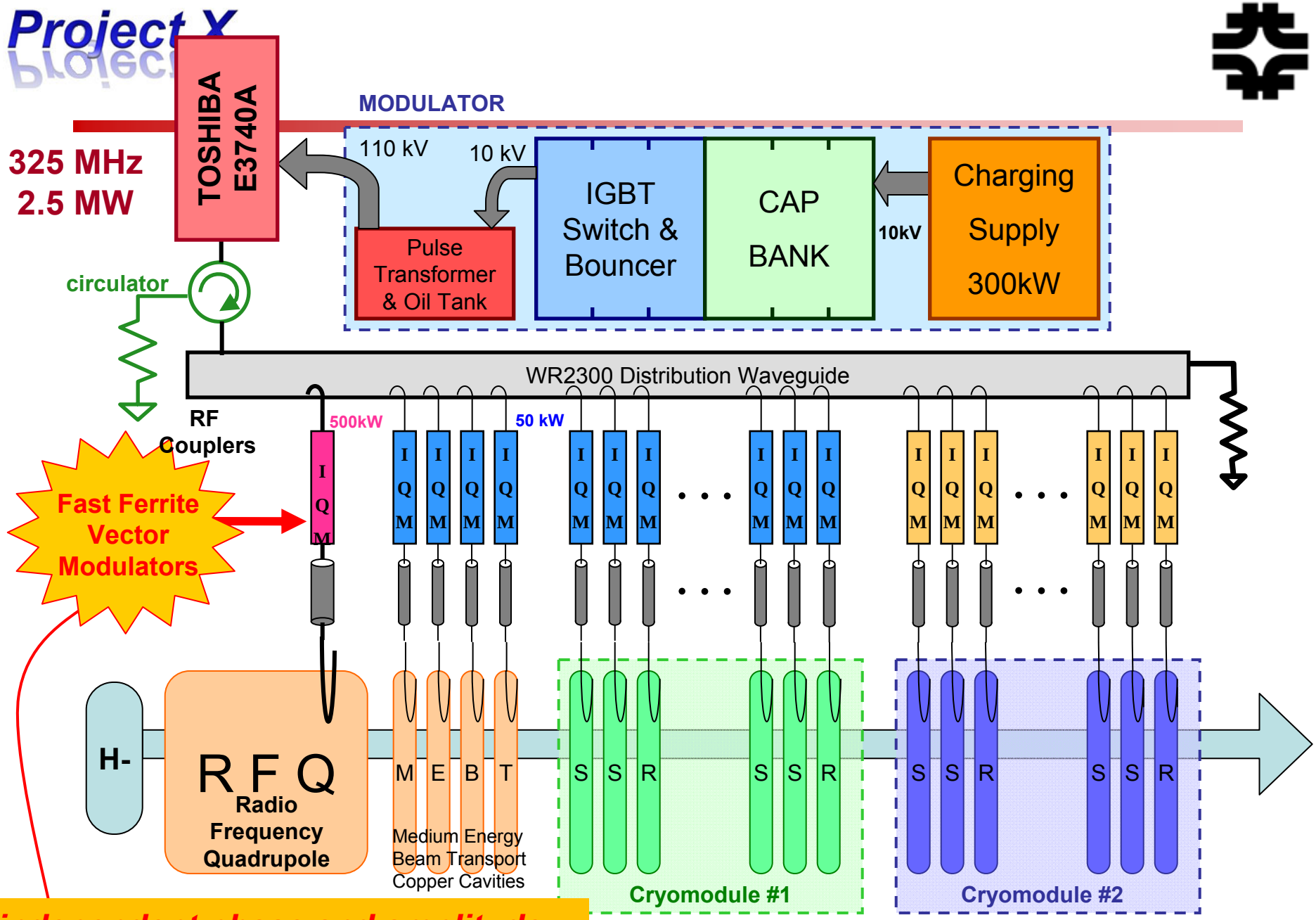
VM: performance specs, status, R&D plan





independent phase and amplitude control in each cavity

Specs

RF Phase and Amplitude Tuners	325 MHz	1300 MHz (Fast)	1300 MHz (Slow) *	* Slow Tuners are option needed for alternating electrons & H-
Included in Baseline	Yes	Yes	NO	
Phase / Amplitude Tuner Type	Coax	Waveguide	Waveguide	
Ferrite	YIG	YIG	YIG	Perpendicular Biased
Phase / Amplitude Tuner Locations	1/cavity	1 / cavity	1 / cavity	
Number of Phase / Amplitude Tuners	73 or 115*	132 or 84*	252	* for 3-spoke or ellip. med-beta
Phase Tuner Adjustment Range (deg)	90 deg	90 deg	360 deg	
Phase Tuner Settling Time (within 1 deg)	100 usec	100 usec	0.1 second	
Phase Tuner Slew Rate	1 deg/usec	1 deg/usec	N/A	
Amplitude Tuner Attenuation Range	6.0 db	6.0 db	none	
Amplitude Tuner settling time (1% F.S)	100 us	100 us	N/A	needs simulation
Tuner Peak Power	0.30 MW	0.60 MW	0.60 MW	worst case for ultimate scenario
Tuner Insertion Loss	0.2 db	0.2 db	0.2 db	Measured on Protos,&AFT Quote
Tuner Avg. RF Power Dissipation	71 W	142 W	142 W	worst case for ultimate scenario
Tuner Coil Average Power Dissipation	25 W	40 W	40 W	target for 1.5% RF Duty Factor
Static RF amplitude error	+/-1%	+/-1%		TBD needs simulation
Static RF phase error	+/-1 deg.	+/-1 deg.		TBD needs simulation
Dynamic RF amplitude error	+/-0.5%	+/-0.5%		TBD needs simulation
Dynamic RF phase error	+/-0.5 deg.	+/-0.5 deg.		TBD needs simulation

Source: ***DraftSCRF_PD_v56.doc***

Supporting documentation:

[131] "Requirements for the RF Control of the Vector Sum for Superconducting Proton Linacs", M. Huening et al., L98 http://accelconf.web.cern.ch/AccelConf/l98/PAPERS/TU4064.PDF

[132] "SIMULATION OF RF CONTROL OF A SUPERCONDUCTING LINAC FOR RELATIVISTIC PARTICLES", P.C. Bauer, M. Huening, G. W Foster, proc. EPAC04, http://accelconf.web.cern.ch/AccelConf/e04/PAPERS/THPLT133.PDF

[133] Superconducting Relativistic Particle Accelerator Simulation (SCREAM) – Program Documentation, P. Bauer, M. Huening, G.W. Foster, FNAL Tech Division Note TD-04-031, 2004 http://tdserver1.fnal.gov/tdlibry/TD-Notes/2004%20Tech%20Notes/TD-04-031.pdf

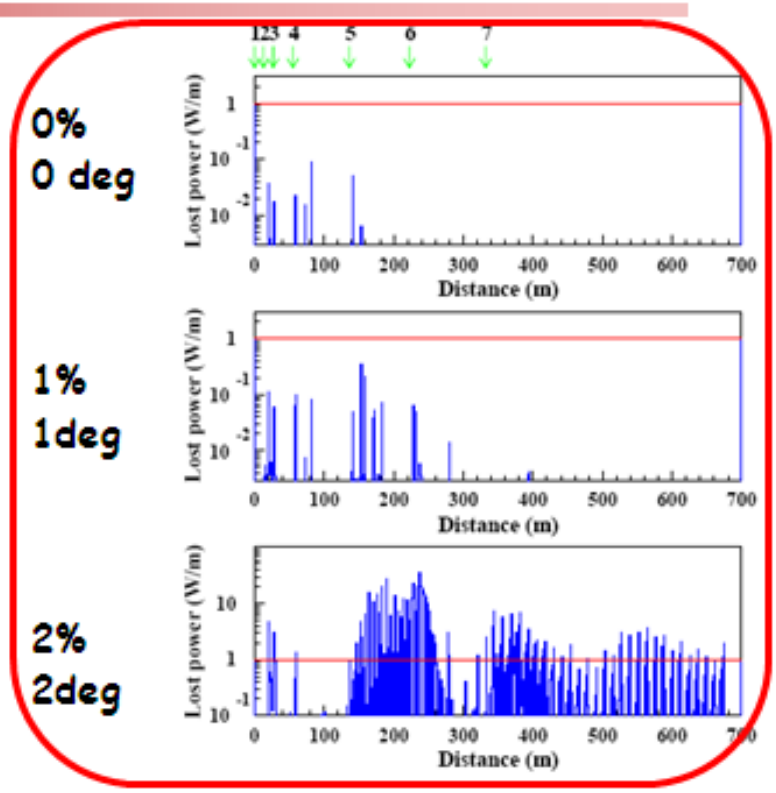
[134] "VECTOR SUM CONTROL OF AN 8 GeV SUPERCONDUCTING PROTON LINAC", M. Huening, G.W. Foster, proc. EPAC 2004, http://accelconf.web.cern.ch/AccelConf/e04/PAPERS/TUPLT150.PDF

[135] "FAST FERRITE PHASE SHIFTER FOR THE SNS LINAC", Yoon Kang SNS presentation, June 2000. http://tdserver1.fnal.gov/project/8gevlinac/useful_papers/ferrite_tuners/Kang_phaseshifter_June_2000.ppt

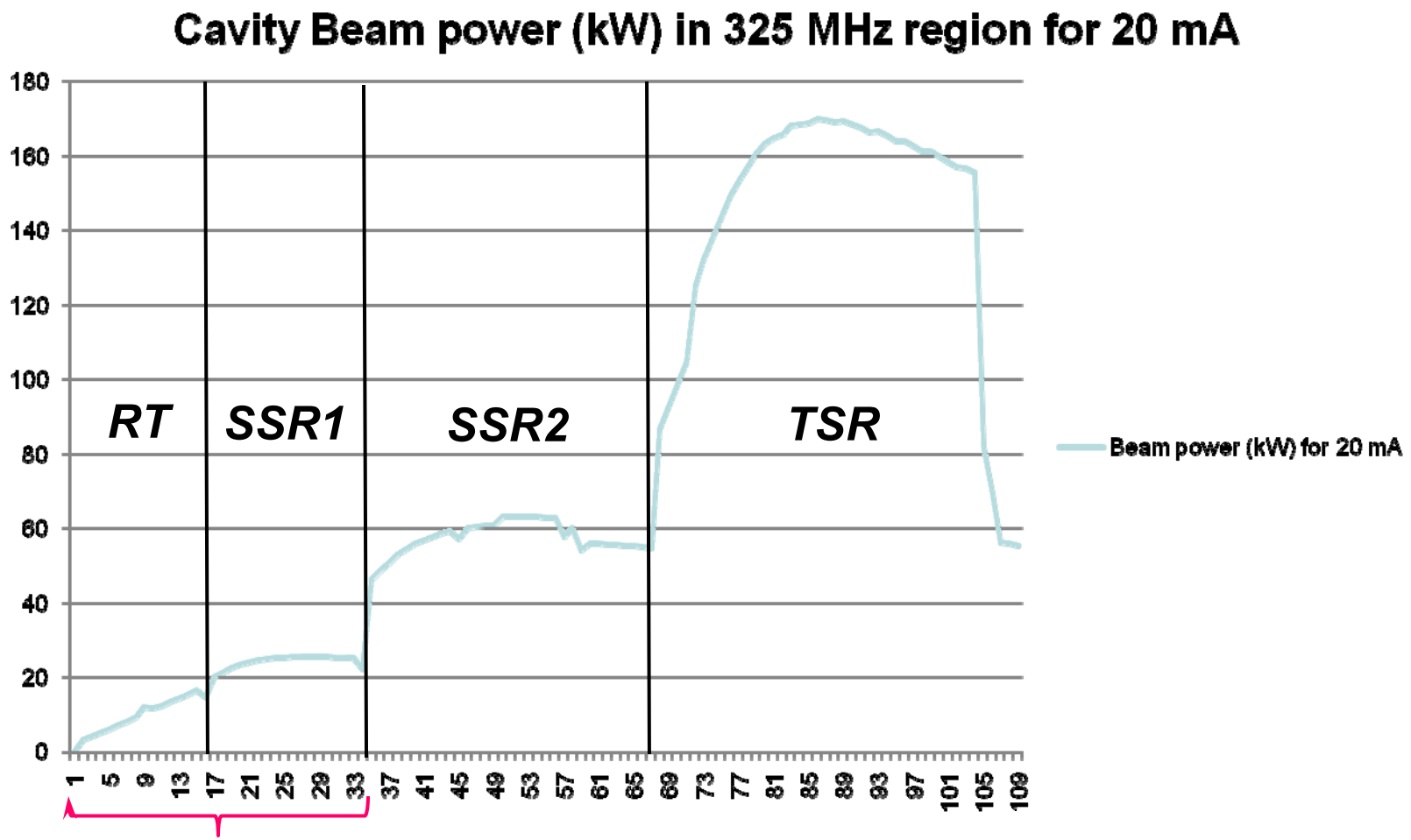
Specs (cont)

LE Cavities and Cryomodules
Interfaces

- Main interfaces with:
  - RF powering system
    - High Power RF
      - Ex: 1% amplitude, 1⁰ phase control
    - LLRF
  - Cryogenic System (4 K operation)
  - Beam Diagnostic
  - General Services
    - Magnet PS
    - Cooling Water (RT Section)
    - Interlocks



Specs (cont)

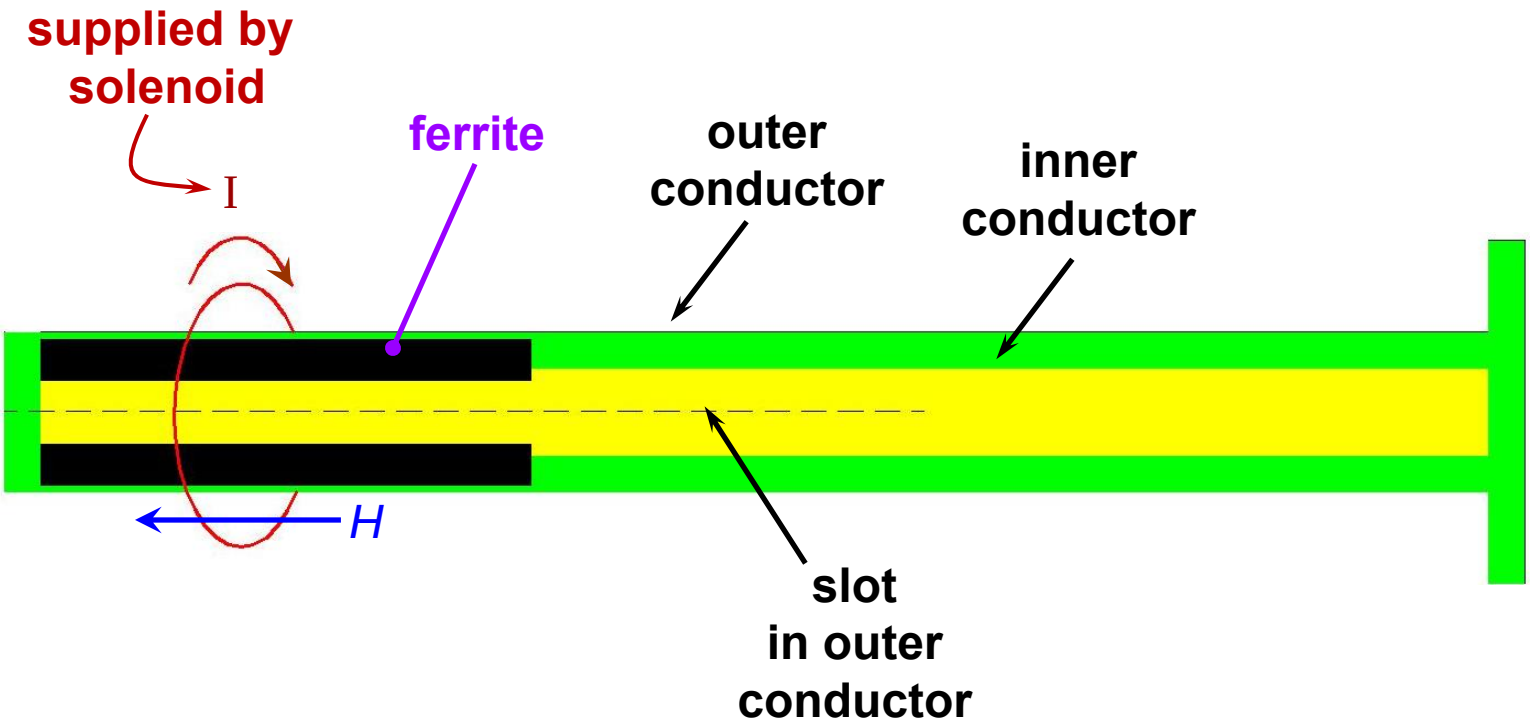

Cavity Beam power (kW) in 325 MHz region for 20 mA
180
160
140
120
100
80
60
40
20
0
RT
SSR1
SSR2
TSR
Beam power (kW) for 20 mA
1
5
9
13
17
21
25
29
33
37
41
45
49
53
57
61
65
69
73
77
81
85
89
93
97
101
105
109
HINS

Principle of operation

In a coaxial line filled with some dielectric (ε,μ)

$v = c/\sqrt{\varepsilon\mu}$

We vary μ and thus v and phase by varying H applied to the ferrite.



Principle of operation

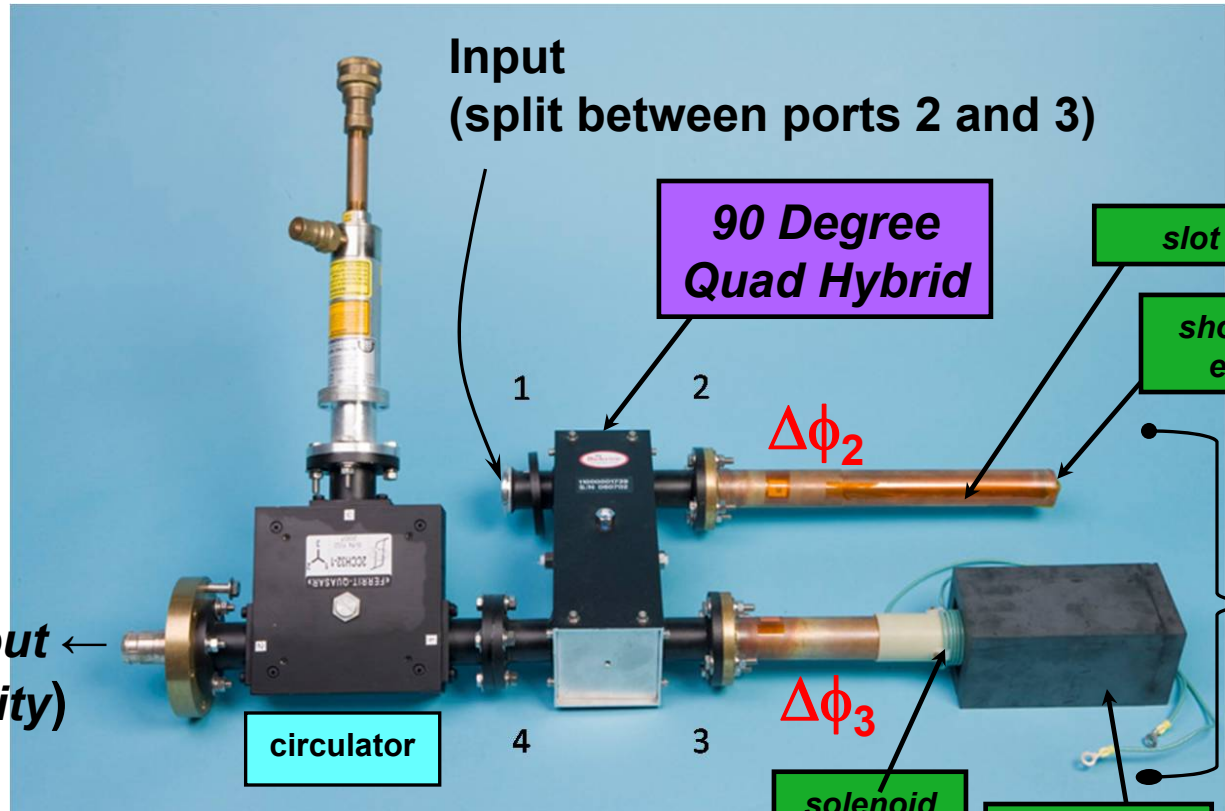
Modulates phase and amplitude independently:

With $\Delta\Phi = (\Delta\phi_2 - \Delta\phi_3)/2$

$\Phi = (\Delta\phi_2 + \Delta\phi_3)/2$

Output power ~ $\cos^2(\Delta\Phi)$

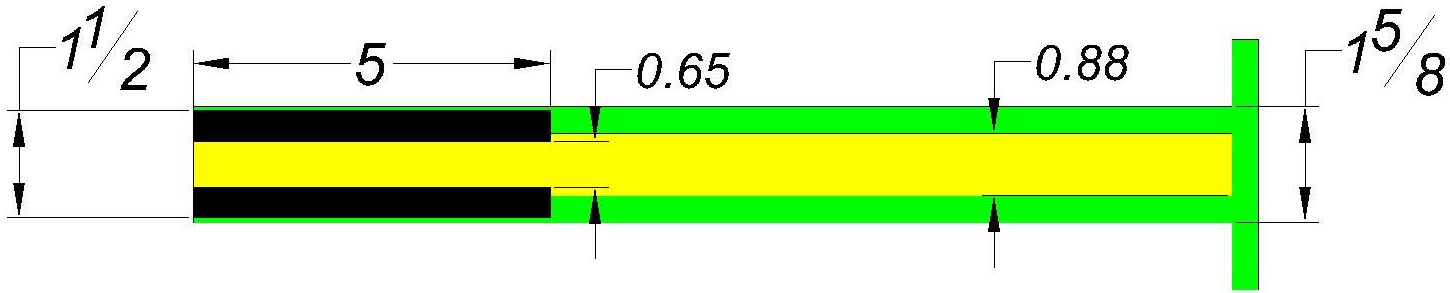
Phase shift ~ $\Phi + 3\Pi/2$



R&D within HINS: RFQ, RT & SSR1 Control

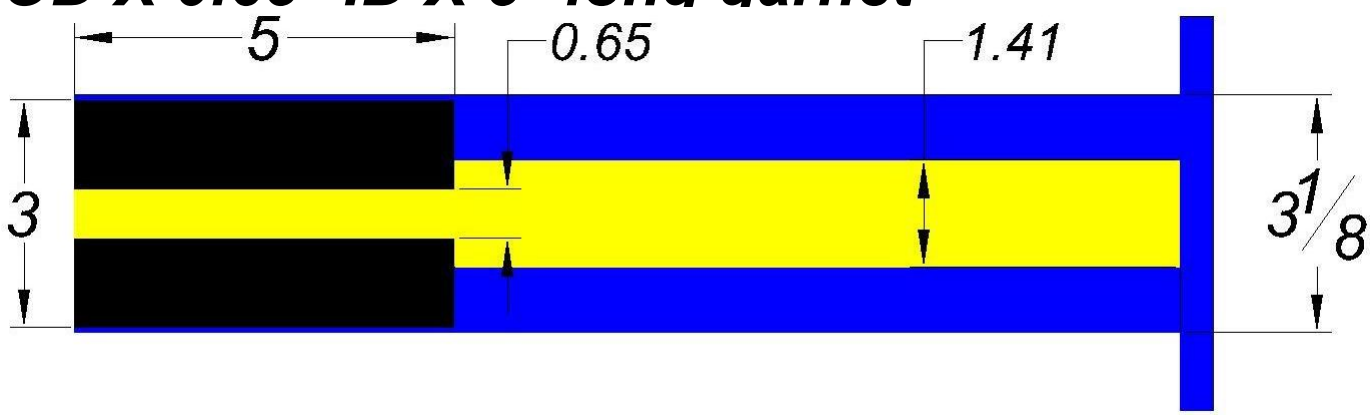
- ***For Cavities (~75 kW):***

1.5″ OD X 0.65″ ID X 5″ long garnet



- ***For RFQ (~500 kW):***

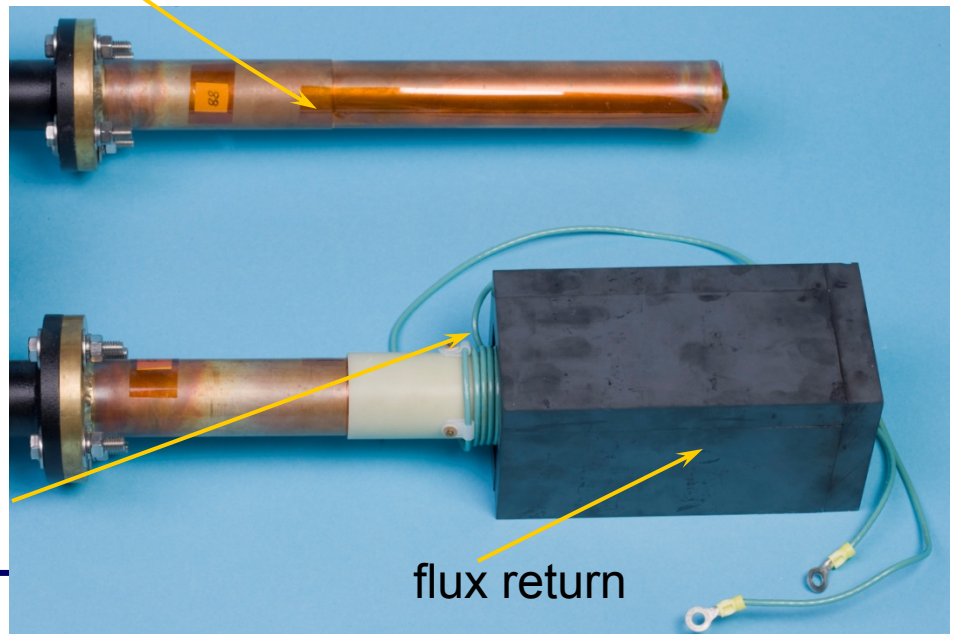
3″ OD X 0.65″ ID X 5″ long garnet



Shift Design Details (325 MHz)

solenoid
(12 awg wire around G10)

- Center conductor: shrink fit during assembly
- Use quarter wave matching section (for 50Ω)
- Outer conductor has 0.020″ slot (length = 9″) to reduce eddy currents (gives faster response)



Other VM Parts

hybrid for 1⅝ vm: Dielectric

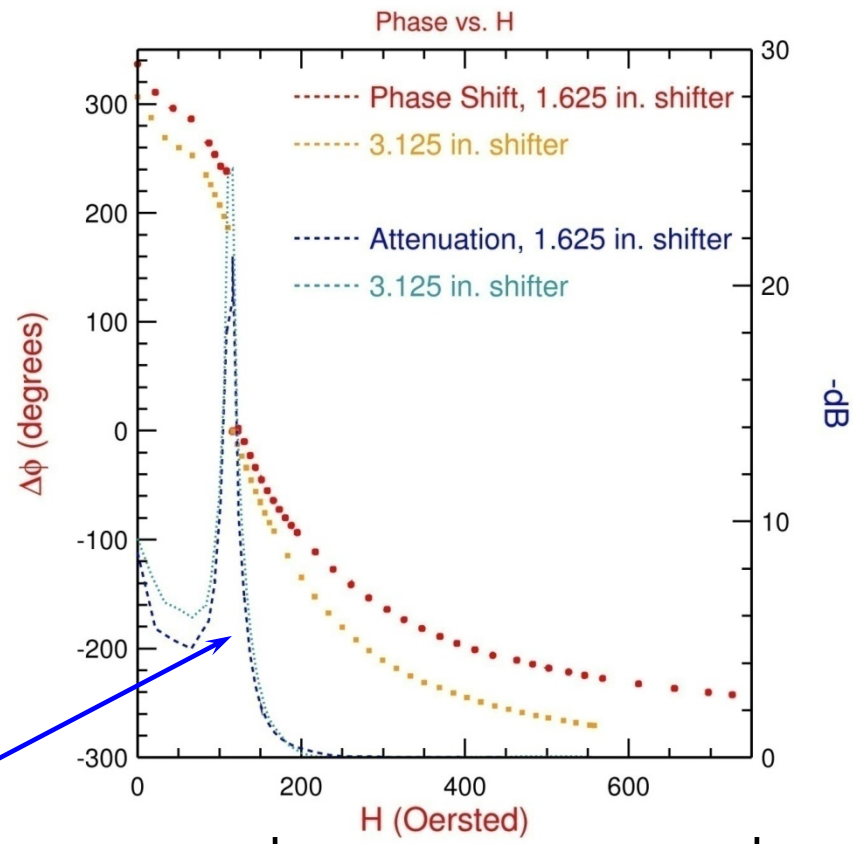
circulator for 1⅝ vm:
Ferrit-Quasar

6 ″hybrid for RFQ vm: MCI
Filled with SF_6 to prevent sparking

circulator load:
5kw CW
water cooled
Altronics

Phase vs. applied Field

325 MHz
Low Power meas:



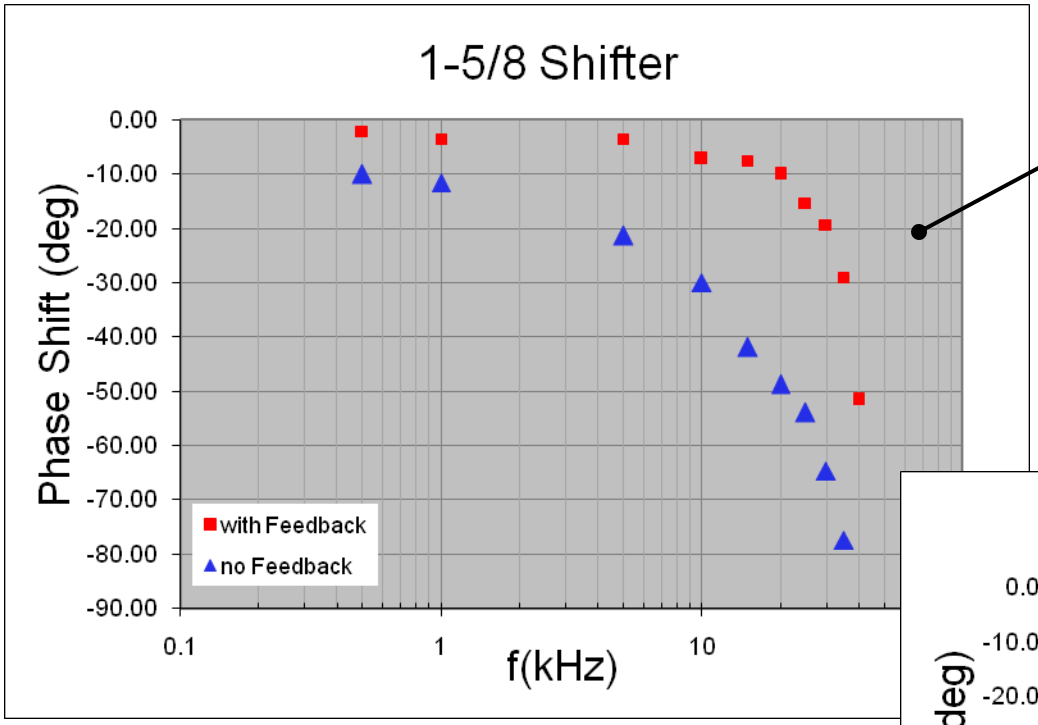
Gyromagnetic resonance
(lossy)
@ 2.8 MHz/Oe

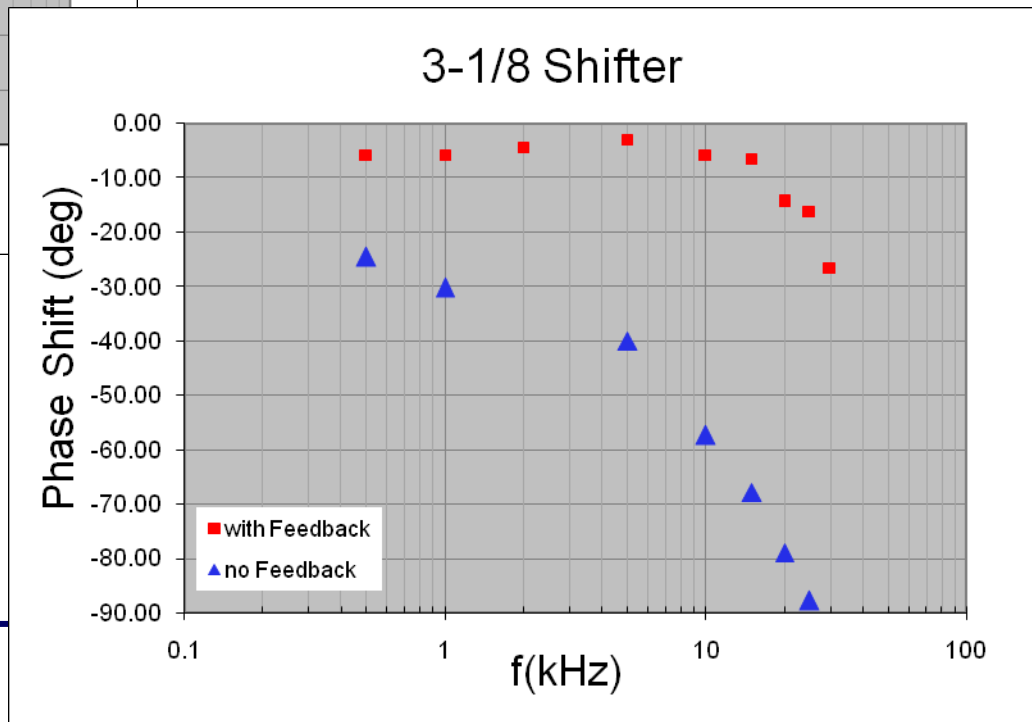
useful phase shift range ~120 deg. (loss < -0.2 dB)

Small Signal Frequency Response

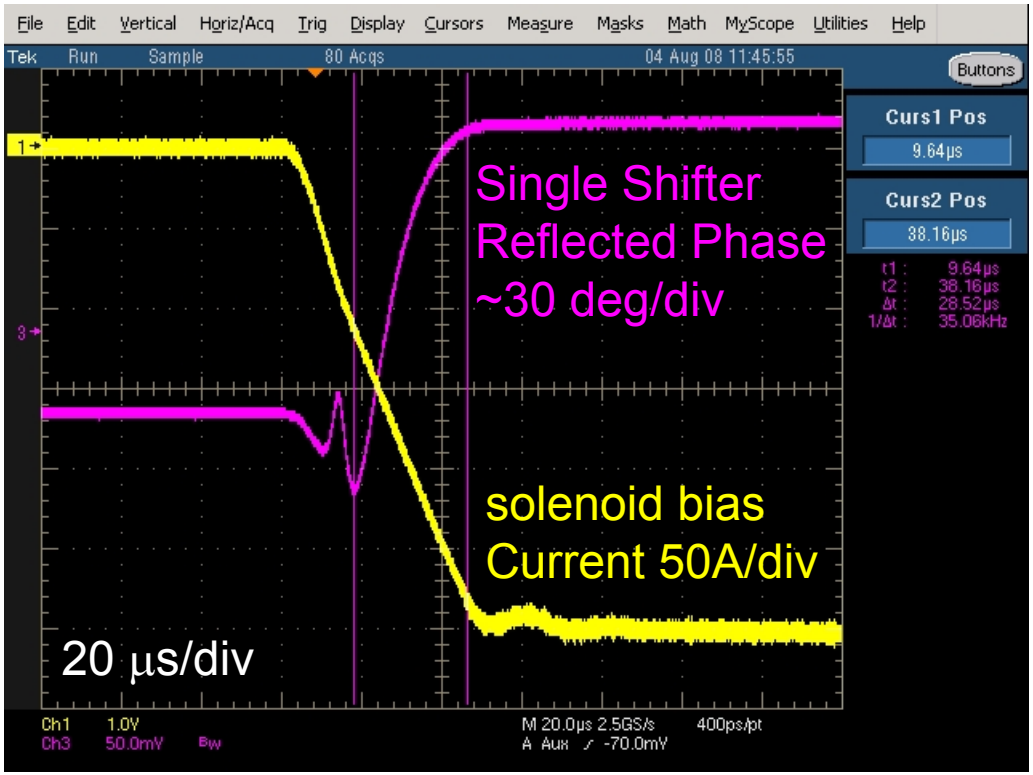
Open loop bandwidth: 15 kHz

> 35 kHz w/feedback





Slew Rate (325 MHz)

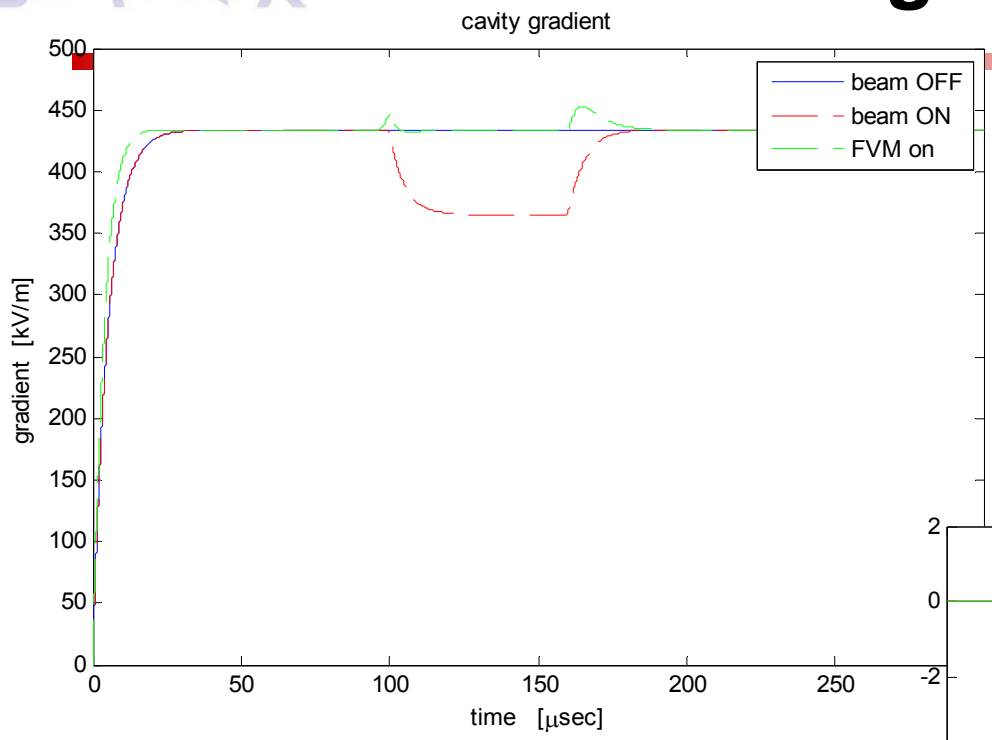


Phase Shifter Slew Rate:
(above resonance)
6 deg/µs

Current risetime limited by supply output, solenoid inductance

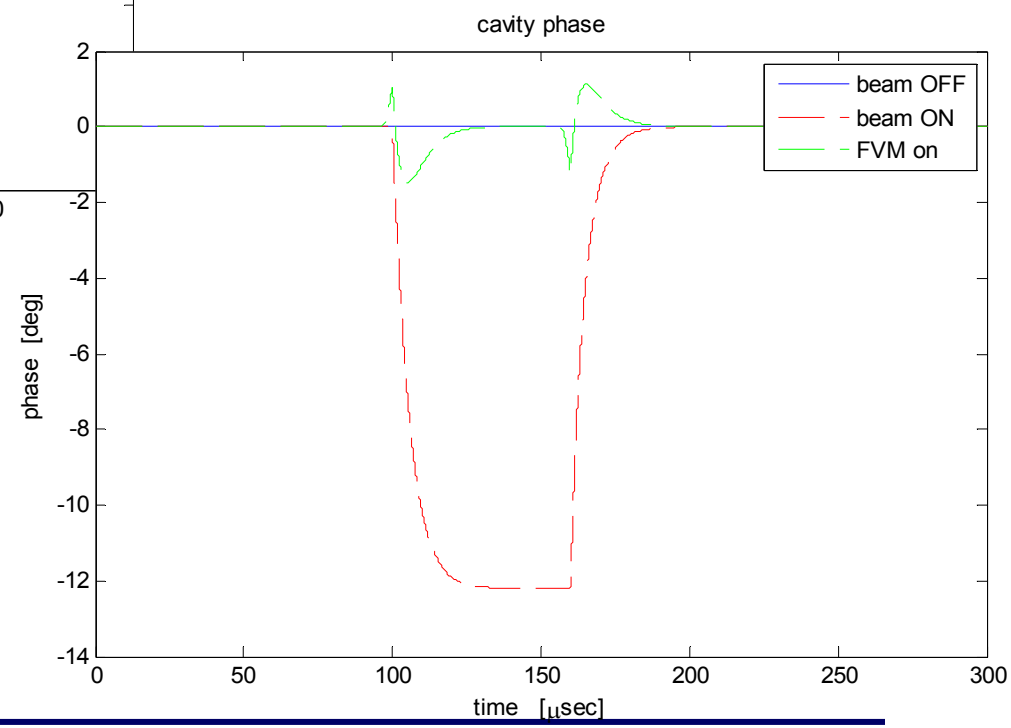
Fast 300A power supply thanks to Brad Claypool, Steve Hays, Howie Pfeffer

Beam Loading Simulation (SSR)



Cavity 6

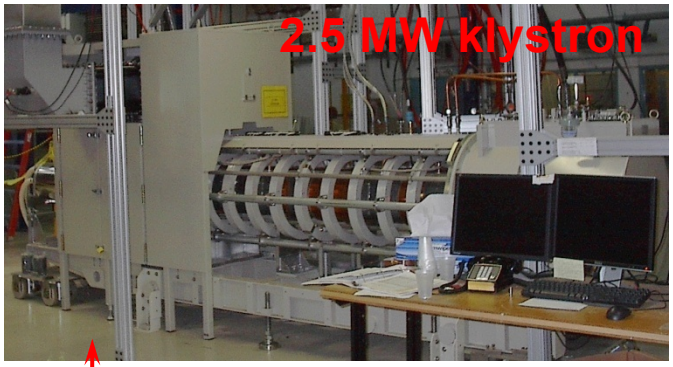
Results courtesy
Julien Branlard

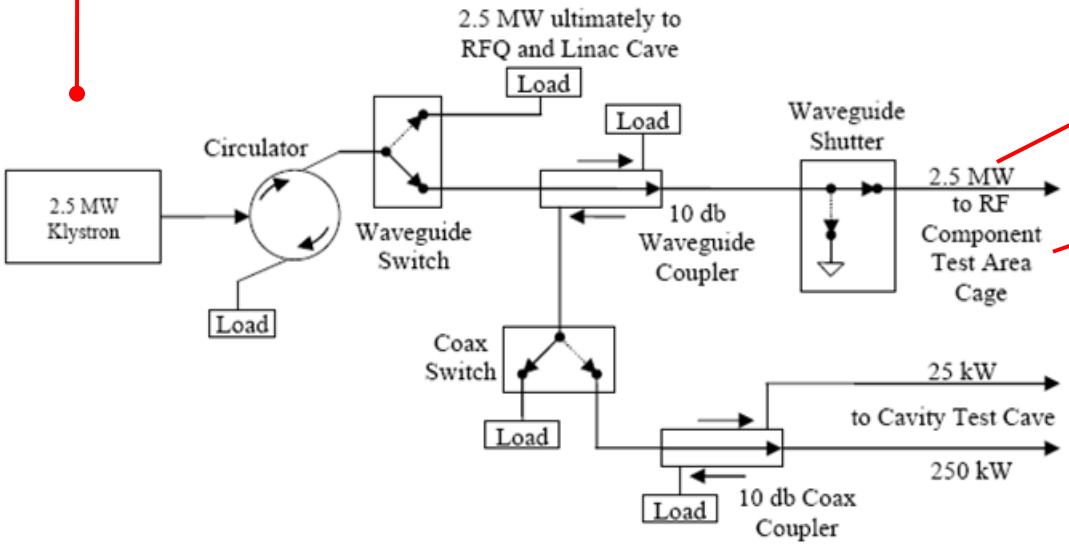


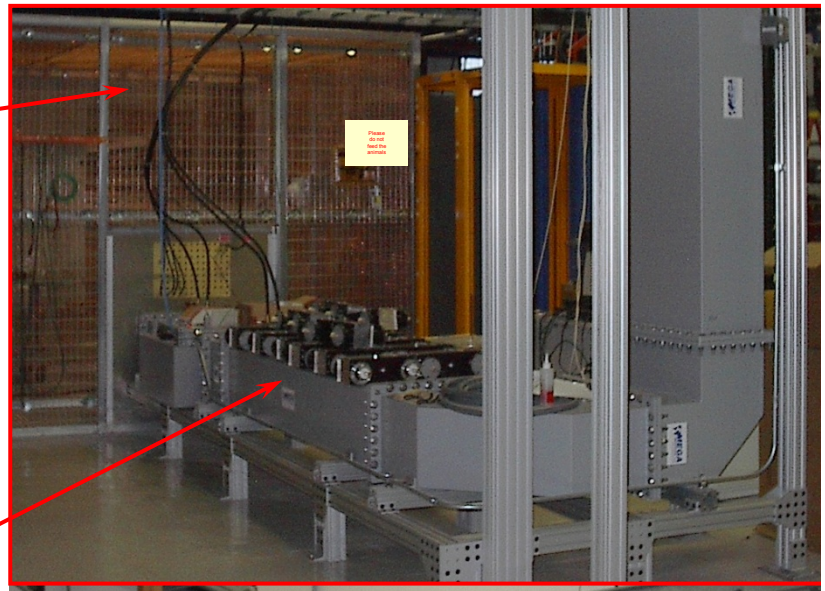
Starting and stopping the compensation 4 usec prior to beam arrival time

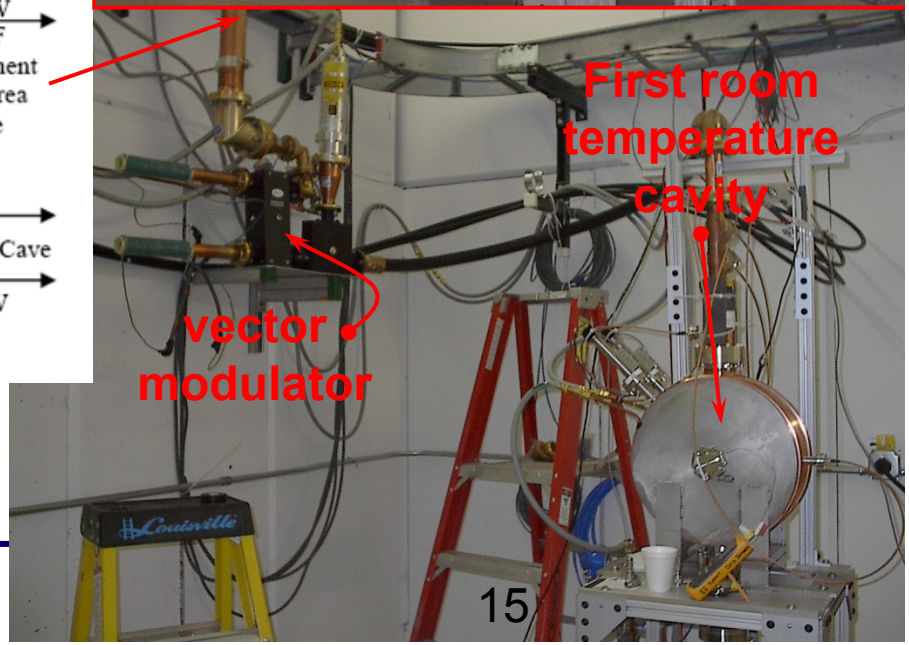
Beam current 26 mA
phiS = -45 deg

HINS Test Facilities (325 MHz)

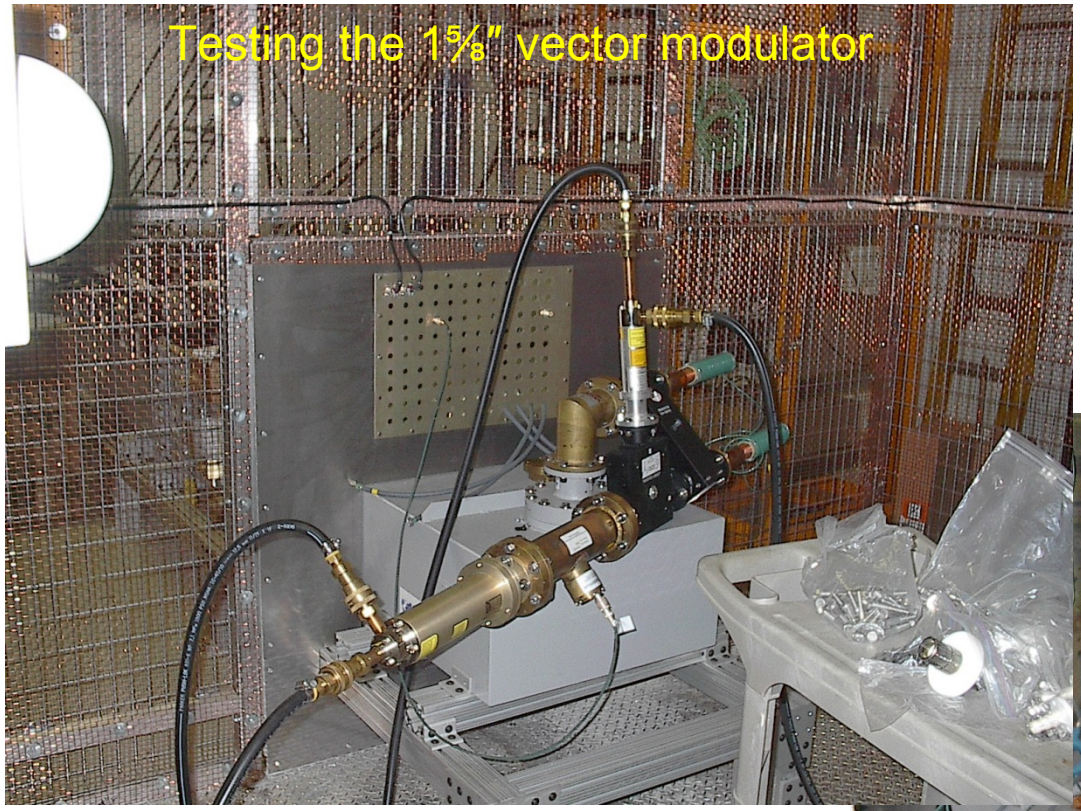


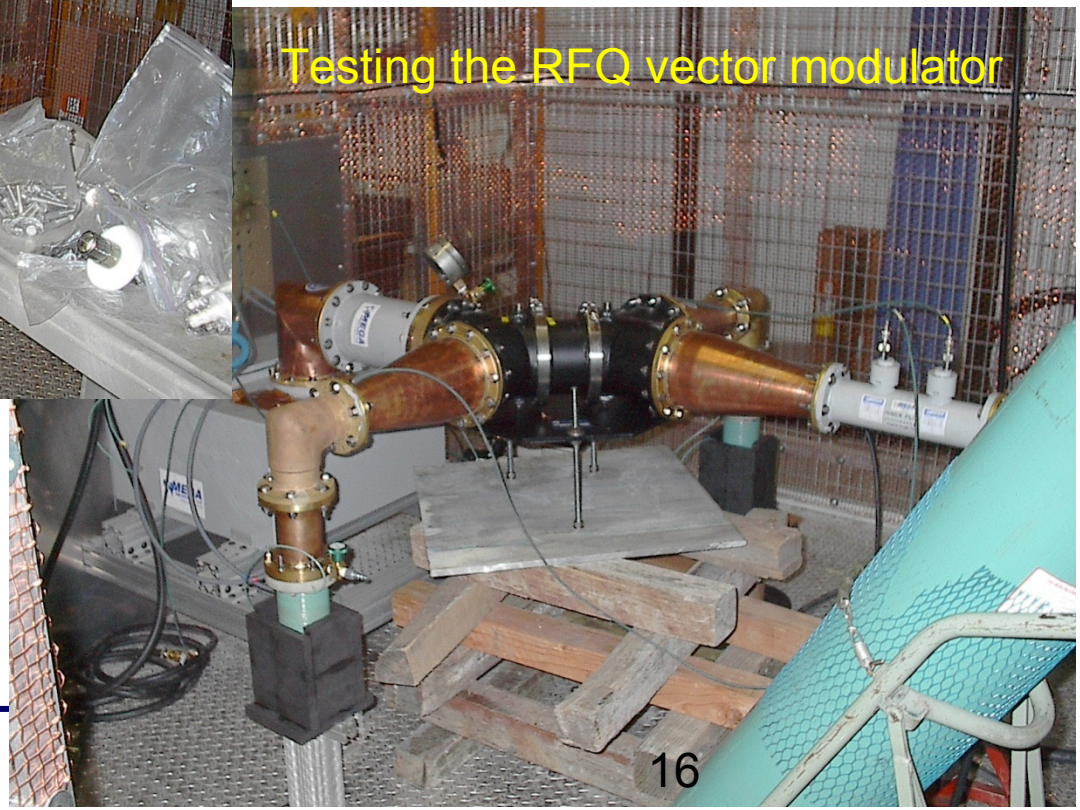






HINS Test Facilities (325 MHz)

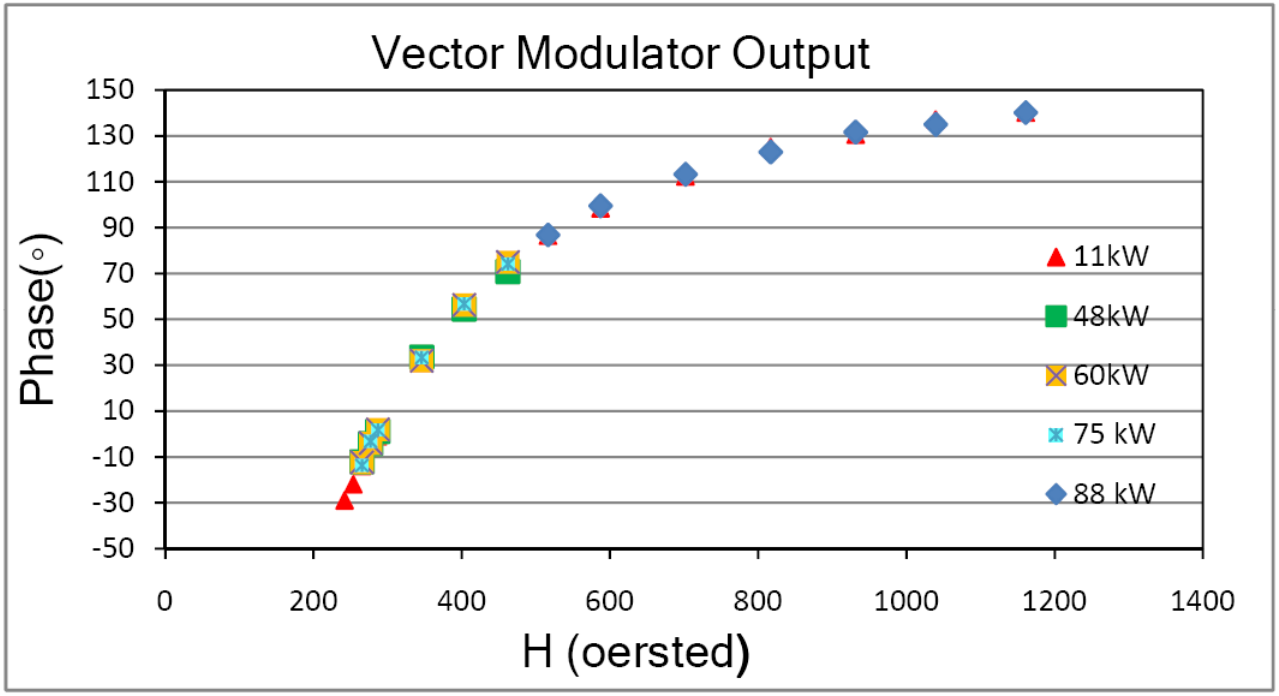




Power Capabilities (325 MHz)

here, both shifters' solenoids driven by one power supply
($\Delta\phi_1 = \Delta\phi_2$)

phase ~ ($\Delta\phi_1 + \Delta\phi_2$)/2

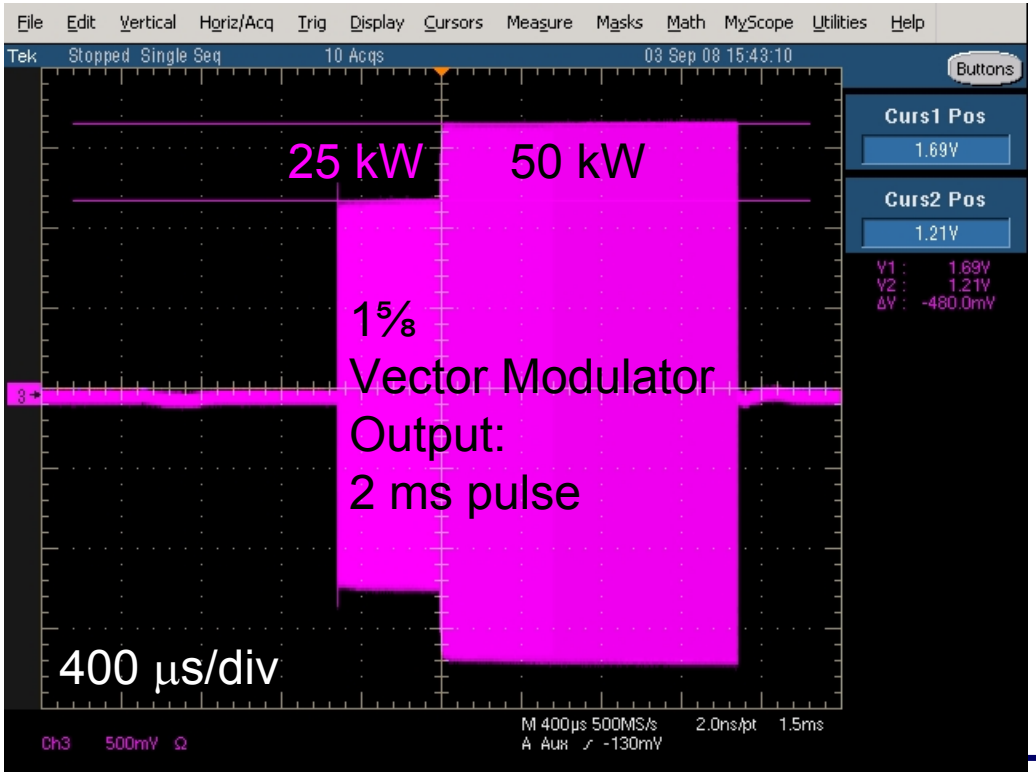


Power Capabilities (325 MHz)

1⅝ VM for cavities:

- good to >75 kW

- Shifters alone could be used in a 200 kW VM if used with oil in ferrite part of coax line (higher power quad hybrid & circulator would be needed)



RFQ VM

- Shifters and Hybrid filled with SF6: Good to > 500 kW

- Current hybrid is 6″

- Stripline “500 kW” Circulator failed: Getting a new one from Ferrite

Summary of HINS R&D

- ***The 1⅝" vector modulators can operate well up to 75 kW (more than needed for the RT, SSR1 & (almost) SSR2 cavities)***

- ***The RFQ vector modulator elements:***
  - *phase shifters good to ~600 kW*
  - *hybrid good to ~600 kW*
  - *initial circulator failed; new Ferrite™ model on order*

- ***The speed of the response for the cavity shifters is 6X as fast as the original spec***
  - *bandwidth > 35 kHz for a first attempt at feedback*

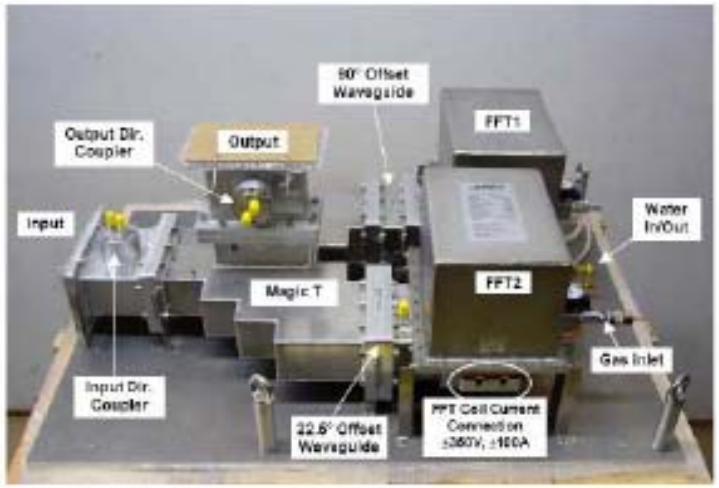
- ***For more details, see proceedings of Linac'08 :***

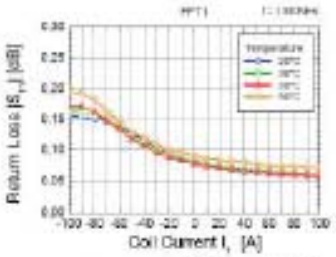
R. Madrak and D. Wildman, "High Power 325 MHz Vector Modulators for the Fermilab High Intensity Neutrino Source (HINS)"

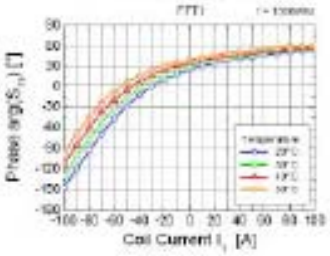
VM (1.3 GHz)

Fast Amplitude and Phase Control

(AFT prototype for FNAL PD)







Rated for 550 kW at 1.3 GHz and has a 30 us response time

VM Specs (1.3 GHz)

AFT microwave GmbH
Donaustr. 18
71522 Backnang, Germany

AFT microwave

Date: 29.08.06
Page: 5

3. Specifications

Article-No.	**3-0001300223-225-02**		
Configuration	Magic-T with 2 current-tunable reflection-type Fast Ferrite Phase Shifters (FFTs)		
Center Frequency	1300	MHz	
Bandwidth	± 1	MHz	
Forward/ Reverse Peak Power	550	kW	
Forward Average Power (max.)	8.25	kW	
Input Return Loss	< -26	dB	
Minimum Insertion Loss	< 0.2	dB	
Amplitude Modulation	0 to -3dB	dB	
Insertion Loss Modulation	0.2 to 3.2	dB	
Differential Phase Modulation	-45 to +45	°	
Response Time	30µs	for 63% of final values	
Waveguide	WR 650		
Microwave Waveguide Flanges	CPR650	flat	
Directional Couplers Connectors	N-Connector	female	FWD and REV
Directional Couplers Coupling	-60 ± 1	dB	
Directional Couplers Directivity	> 27	dB	
Cooling System	Demineralized Water		
Cooling Input Temp. for Optimum Operation	29.5	°C	
Cooling Temperature Range	29.5 ± 2	°C	
Cooling Connectors	9/16"	JIC 37°	
Cooling Flow	> 200	l/min	final value t.b.d.
Cooling Input Pressure	< 6	bar	
Ambient Air	15°C to 40°C		
Internal Pressurization of FFTs	1	bar (gauge)	dry air or Nitrogen
Weight	110	kg	
Dimensions	see Footprint		
I-Q-Modulator Controller	See separate documentation		
Power Supply Requirements for each FFT	± 86 A min., ± 350 V	± 100 A max. for full scale, for fast dynamic FFT tuning	

Owners Manual	**AFT**	written by	Dr.-Ing. C. Weil
			5

- ***VMs needed up to 2 GeV (all β=0.81 and few RF units in β=1.0 region)***

Technical Risks

- 1.3 GHz system
  - One Vector Modulator Designed and Manufactured by AFT exists at FNAL but not tested to date
- Description of the strategy to address these risks
  - Speed up High Power Tests at NML

Project X Director's Review, March 16, 2009
Oleg Nezhevenko
Page 11

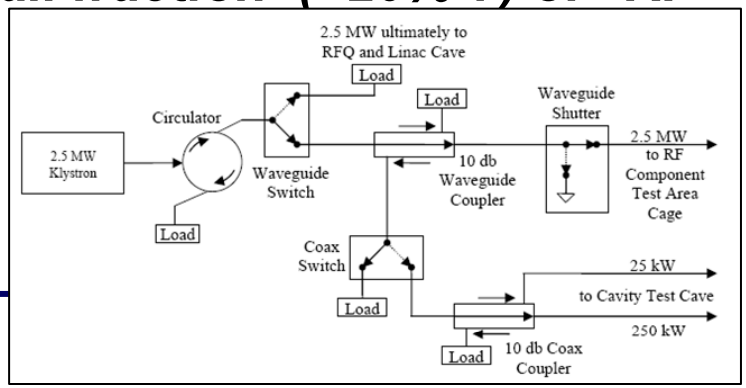
Project X RD&D Plan (LE)

- ***Need VMs operating at TSR power (~200 kW). Scaled down version of RFQ VM could be appropriate choice.***
- ***RD&D Plan contains task for development of RF distributions to SSR2 and TSR.***

Table III-3: LE linac summary

	FY09 $ and FTEs	FY09		FY10		FY11		FY12		Total	
		M&S	Labor	M&S	Labor	M&S	Labor	M&S	Labor	M&S	Labor
1.2	LE Linac	$0	0.25	$455	4.25	$700	9.00	$370	5.00	$1,525	18.50
1.2.1	Ion Source & LEBT	$0	0.00	$60	1.25	$150	2.25	$50	1.00	$260	4.50
1.2.2	RF Quad	$0	0.00	$0	0.00	$0	0.00	$0	0.00	$0	0.00
1.2.3	Beam Diagnostics (covered below)	$0	0.00	$0	0.00	$0	0.00	$0	0.00	$0	0.00
1.2.4	MEBT	$0	0.00	$0	0.00	$0	0.00	$0	0.00	$0	0.00
1.2.5	Room Temperature Section	$0	0.00	$0	0.00	$0	0.00	$0	0.00	$0	0.00
1.2.6	SSR1 Cryomodules	$0	0.00	$0	0.00	$0	0.00	$0	0.00	$0	0.00
1.2.7	SSR2 Cryomodules	$0	0.00	$160	0.88	$213	1.63	$75	1.13	$448	3.63
1.2.8	TSR Cryomodules	$0	0.00	$160	0.88	$213	1.63	$75	1.13	$448	3.63
1.2.9	325 MHz RF and Distribution	$0	0.25	$38	0.63	$63	1.75	$85	0.88	$185	3.50
1.2.10	325MHz LLRF	$0	0.00	$38	0.63	$63	1.75	$85	0.88	$185	3.25

- ***In HINS, VM development has been a small fraction (~20% ?) of "RF distribution" task which totaled 600 k$ in 2006-2009.***



Project X RD&D Plan (HE)

- ***RD&D Plan contains task for development of RF distributions to ILC-like cavities and testing in NML.***

Table III-5: HE linac Summary

	FY09 $ and FTEs										
		FY09		FY10		FY11		FY12		Total	
		M&S	Labor	M&S	Labor	M&S	Labor	M&S	Labor	M&S	Labor
1.3	HE Linac	$125	3.50	$650	8.50	$3,250	10.00	$1,350	10.00	$5,375	32.00
1.3.1	Beta = 0.81 Cryomodules	$125	2.00	$500	4.00	$2,500	7.00	$1,000	8.00	$4,125	21.00
1.3.2	Beta = 1.0 Cryomodules	$0	0.00	$0	1.00	$0	0.00	$0	0.00	$0	1.00
1.3.3	Debuncher Beta = 1.0 (copper) Ca	$0	0.50	$0	0.50	$0	0.00	$0	0.00	$0	1.00
1.3.4	1.3 GHz RF and Distribution	$0	0.75	$100	2.00	$500	2.00	$100	1.00	$700	5.75
1.3.5	1.3GHz LLRF and Global LLRF Syst	$0	0.25	$50	1.00	$250	1.00	$250	1.00	$550	3.25