RF and Electronics Research in Accelerator Research Department-A

Presented by Sami G. Tantawi
for the High Power RF Group, the Accelerator Structure Group and the Electronics Research Group

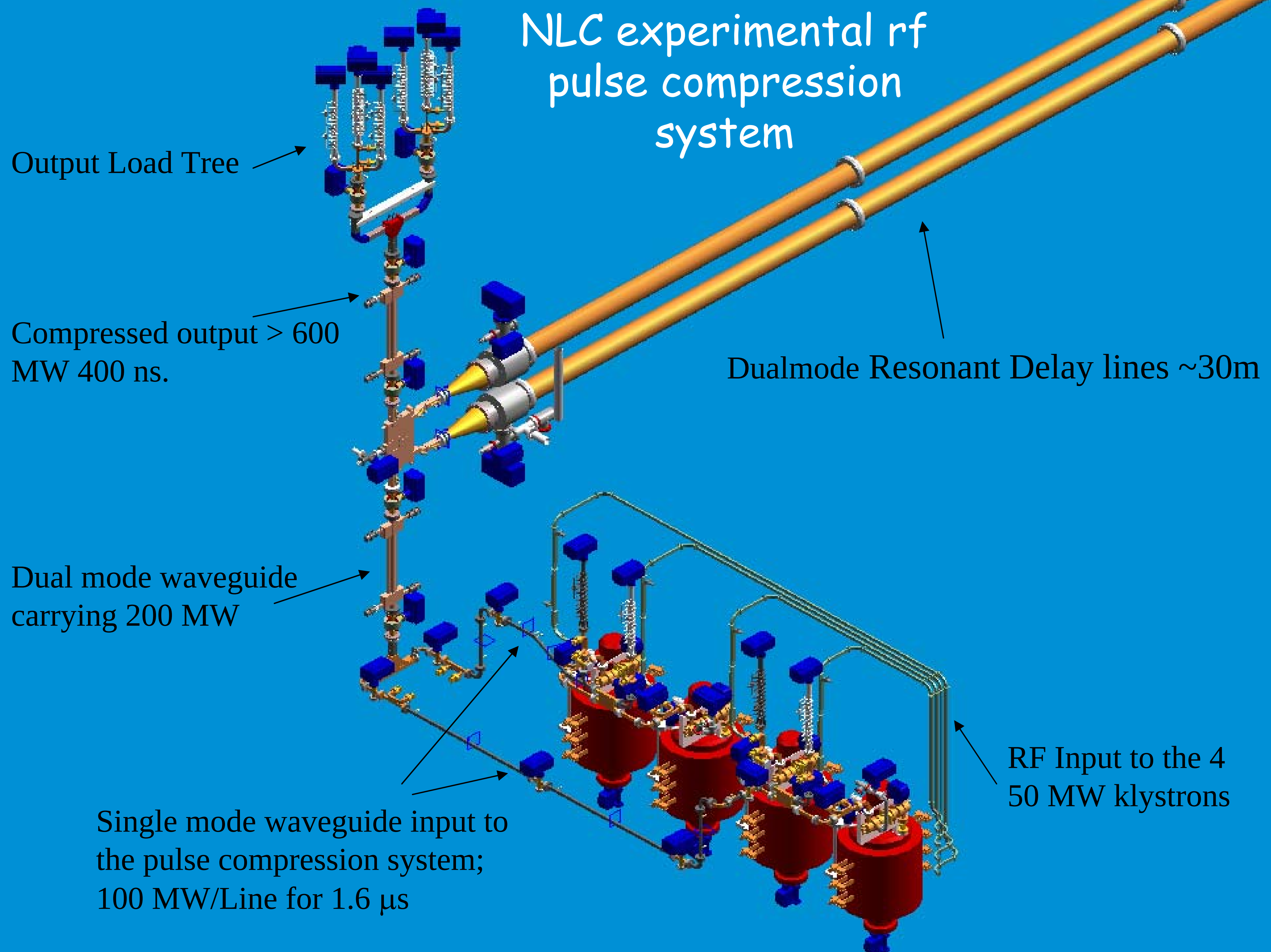
High Power RF Group

- Sami Tantawi
- Christopher Nantista
- Valery Dolgashev
- Perry Wilson
- David Farkas
- Anahid D. Yeremian
- Zhiyu Zhang
- Yasser Hussein
- Jiquan Go

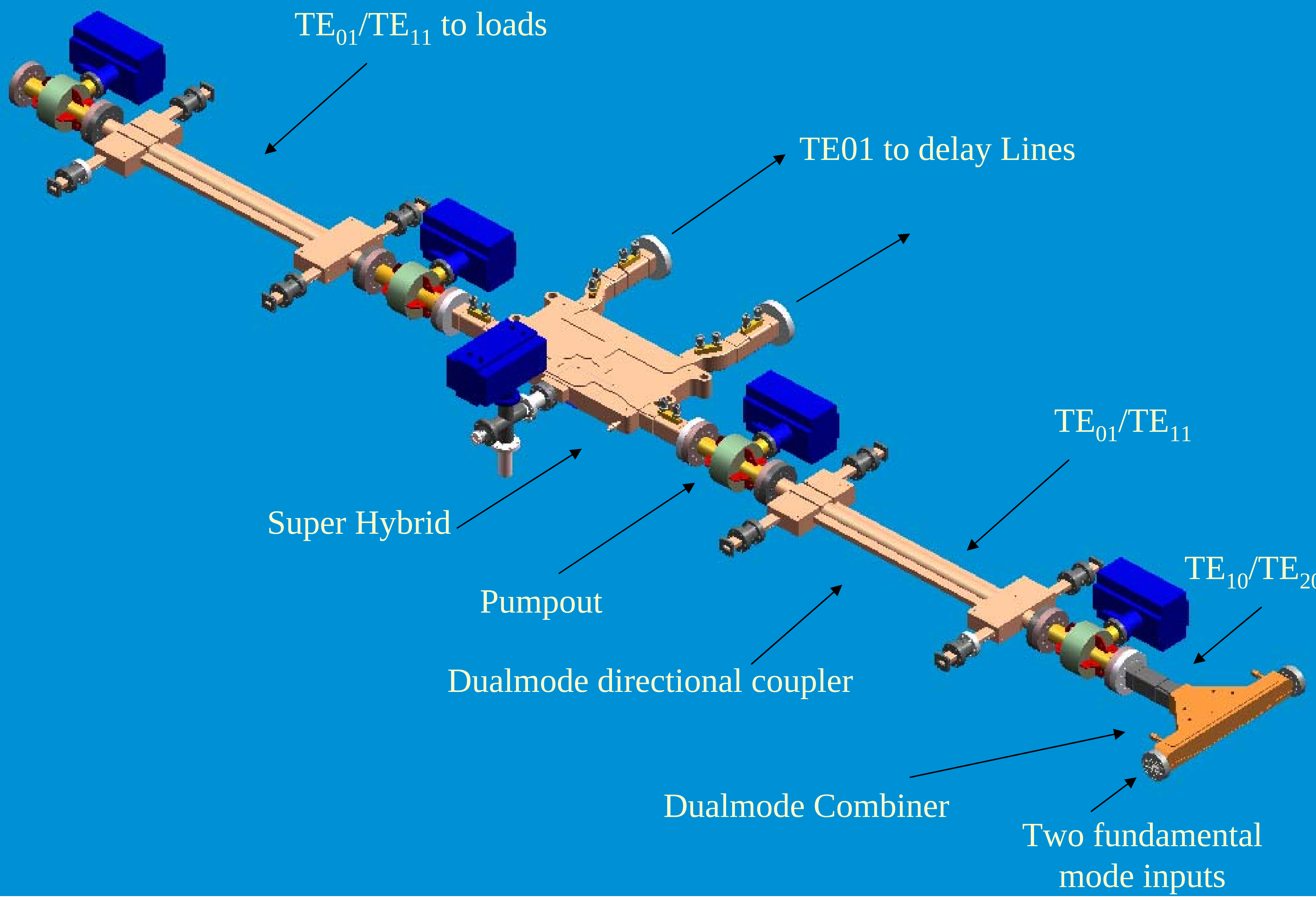
Our group goals is to advance the state of the art of high-power rf components and sources. These include:

1- Ultra-High-Power RF components at X-band frequencies and higher
2- Passive Pulse compression systems
3- Active RF components
4- Active Pulse compression systems
5- RF components and analysis codes for microwave tubes
6- RF components and analysis codes for Accelerator structures
7- Experimental and theoretical studies of RF breakdown phenomenon in high vacuum structure.

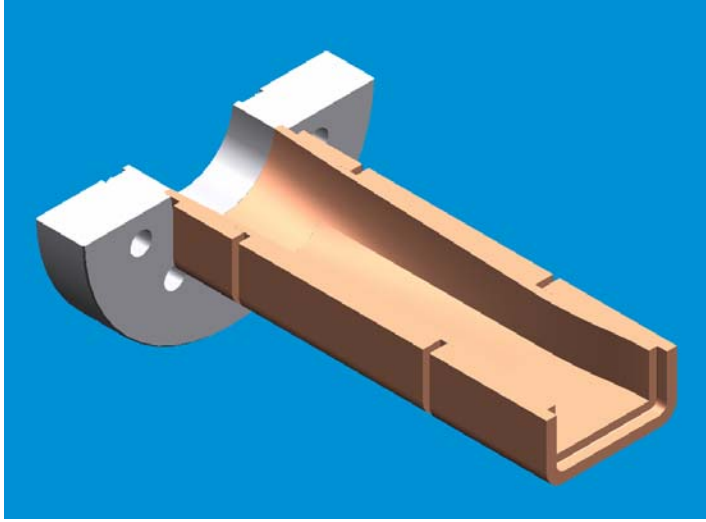
NLC experimental rf pulse compression system



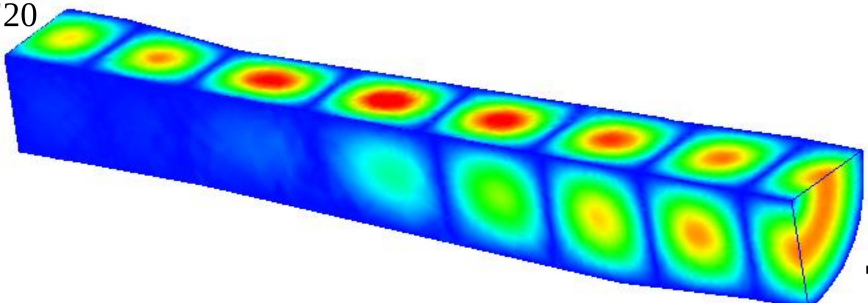
The Head of the pulse compression system



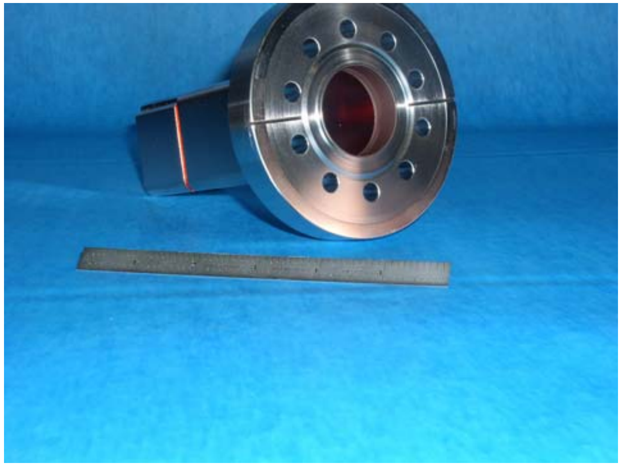
Dualmode Rectangular-to-Circular Taper



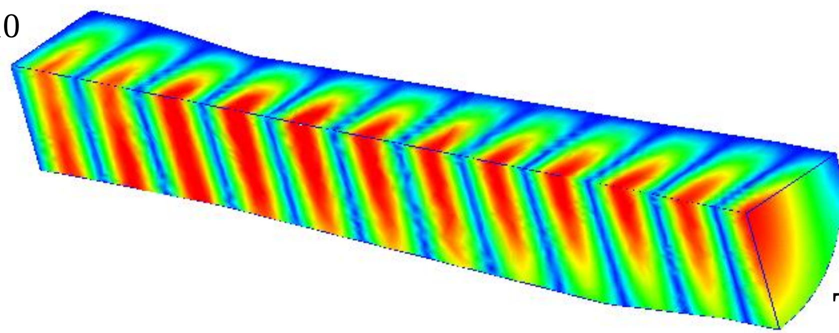
TE_{20}



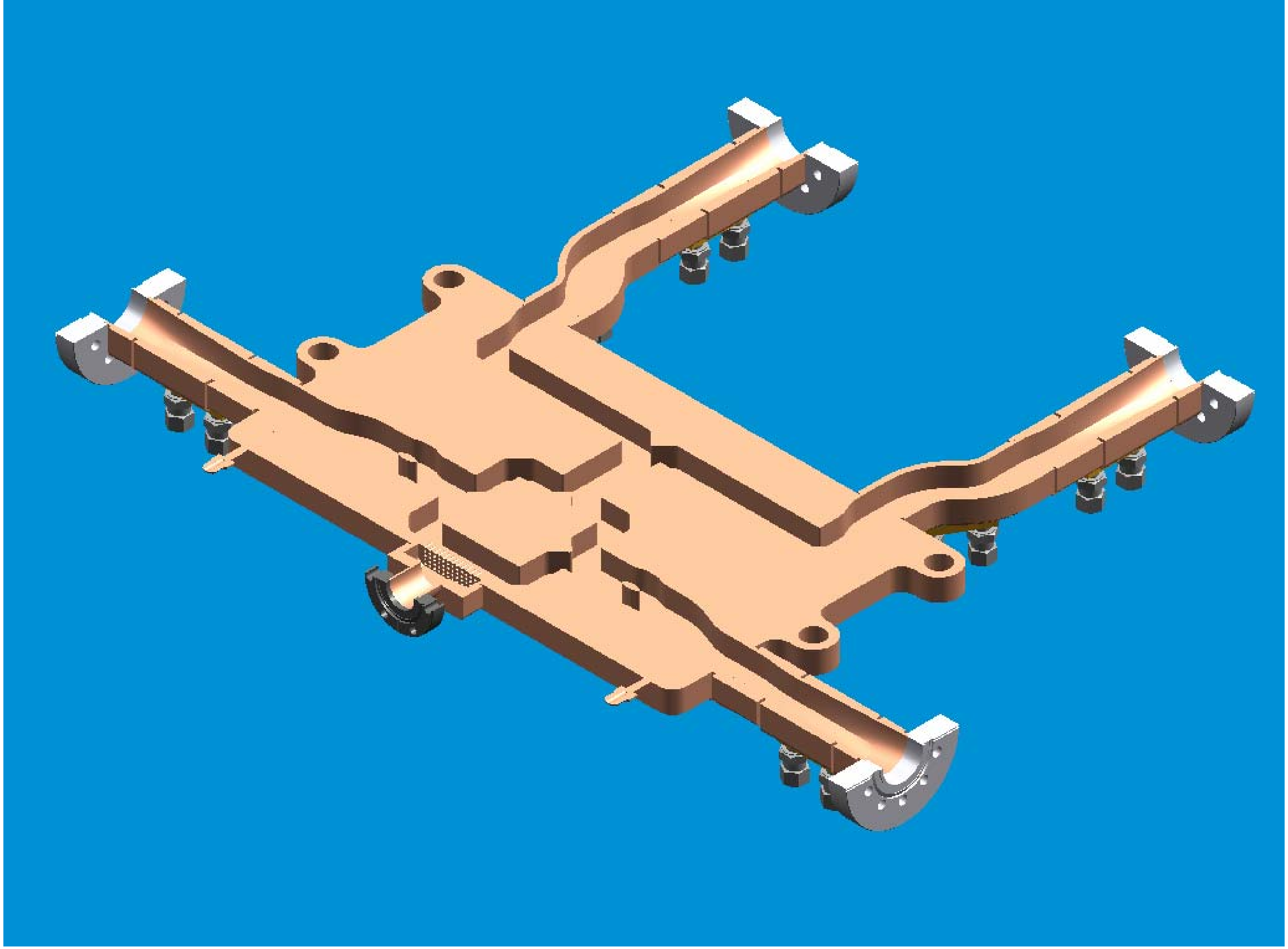
TE_{01}



TE_{10}



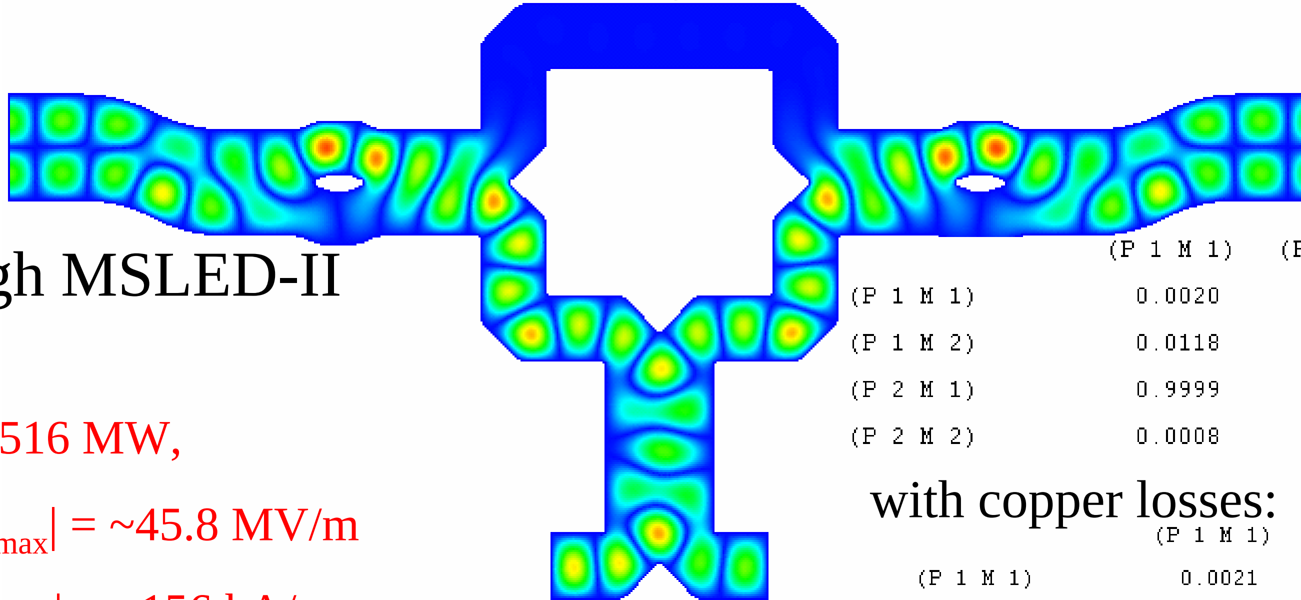
TE_{11}



Sled Head Design: Basically three planer hybrids on one single substrate

Sled Head Simulations

pumping holes



TE_{20}

through MSLED-II

	(P 1 M 1)	(P 1 M 2)	(P 2 M 1)	(P 2 M 2)
(P 1 M 1)	0.0020	0.0118	0.9999	0.0008
(P 1 M 2)	0.0118	0.0077	0.0008	0.9999
(P 2 M 1)	0.9999	0.0008	0.0020	0.0118
(P 2 M 2)	0.0008	0.9999	0.0118	0.0077

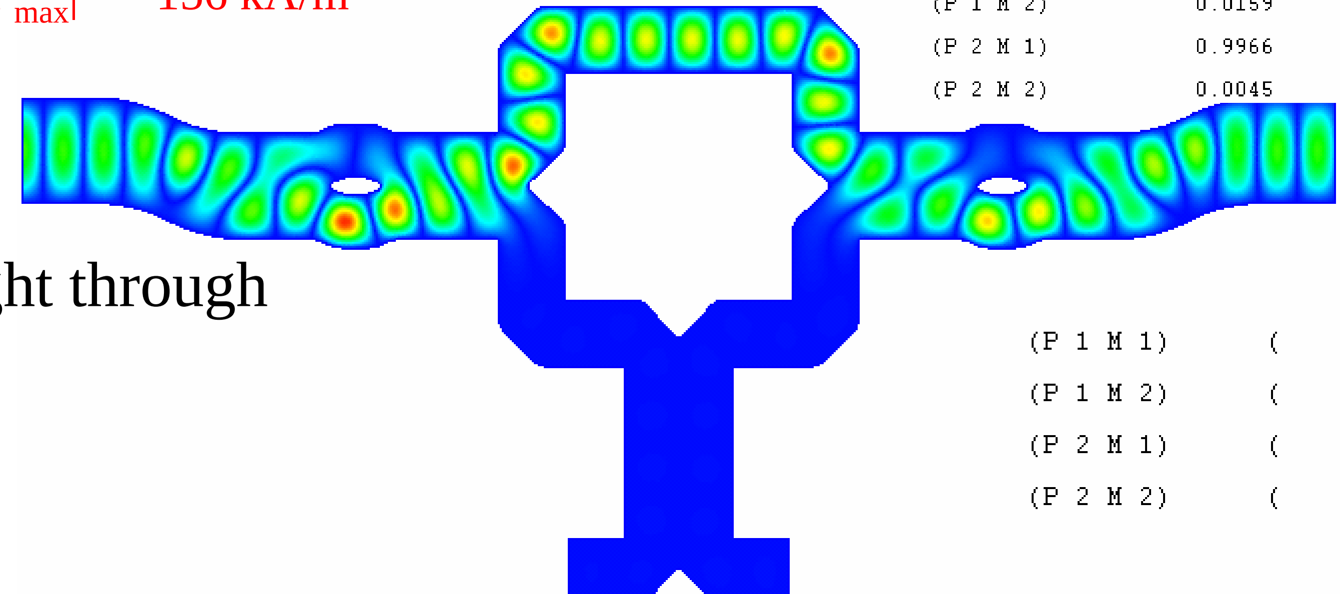
@ 516 MW,

$|E^s_{max}|$ = ~45.8 MV/m

$|H^s_{max}|$ = ~156 kA/m

with copper losses:

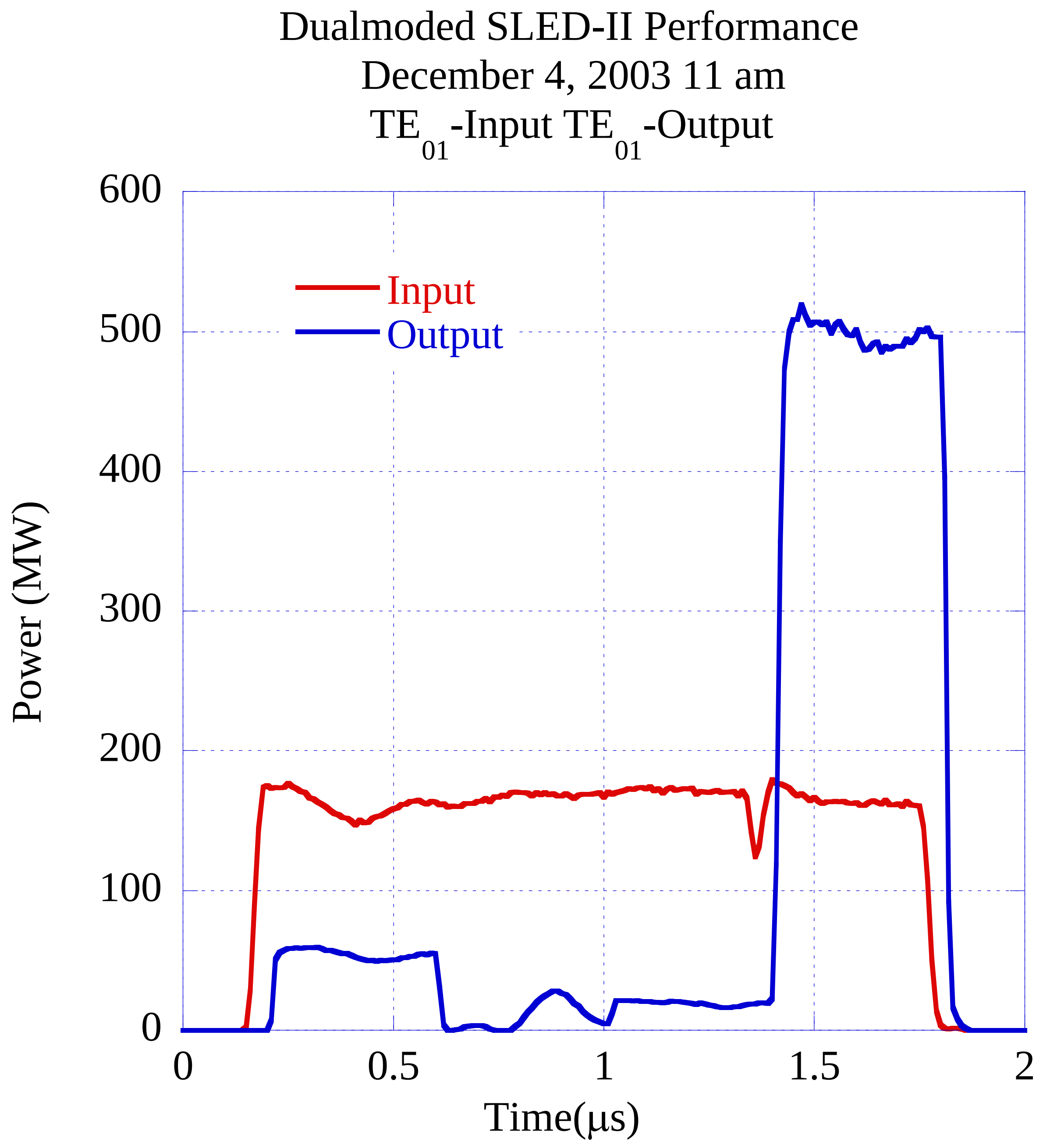
	(P 1 M 1)	(P 1 M 2)	(P 2 M 1)	(P 2 M 2)
(P 1 M 1)	0.0021	0.0159	0.9966	0.0045
(P 1 M 2)	0.0159	0.0010	0.0045	0.9942
(P 2 M 1)	0.9966	0.0045	0.0021	0.0159
(P 2 M 2)	0.0045	0.9942	0.0159	0.0010

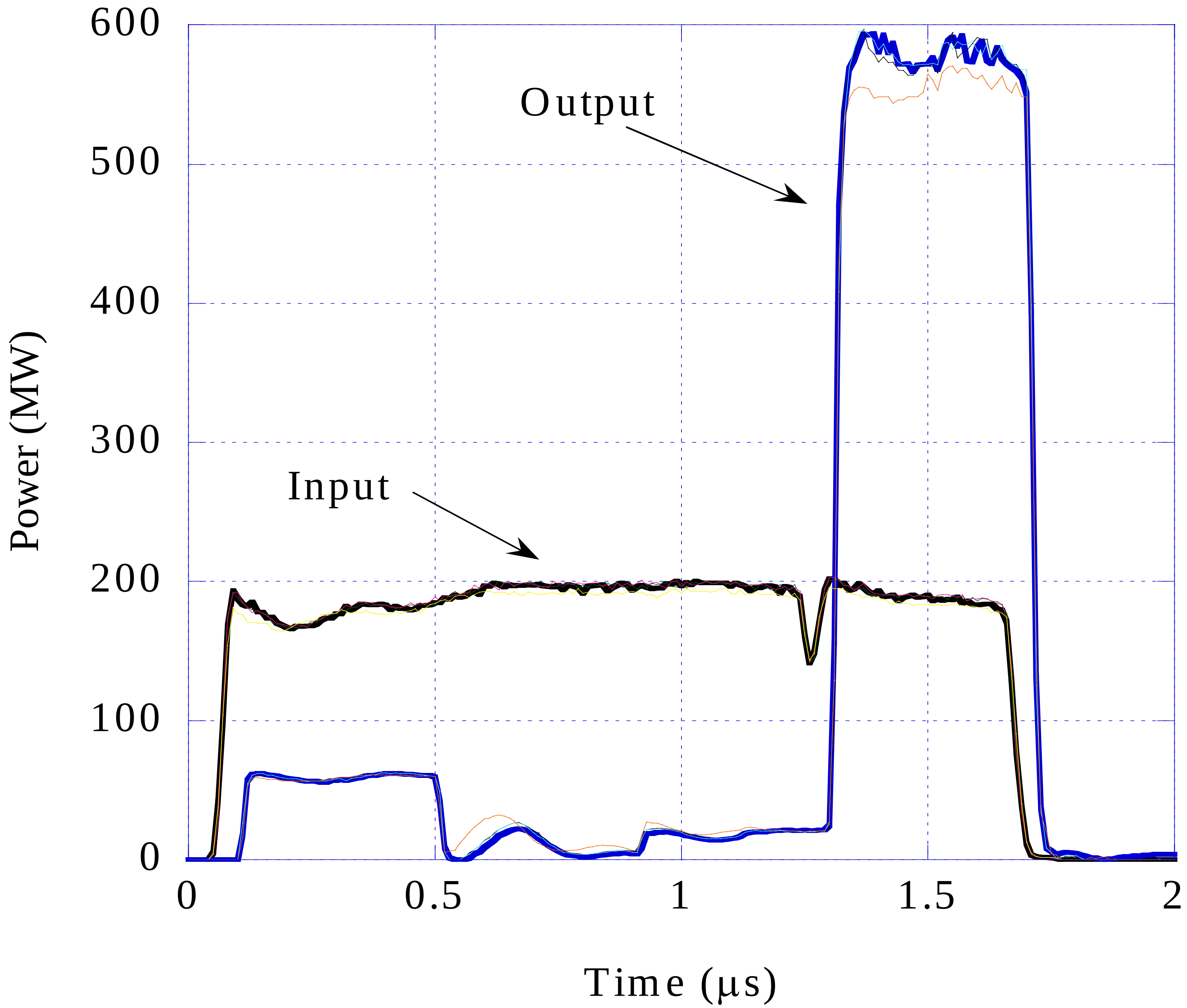


TE_{10}

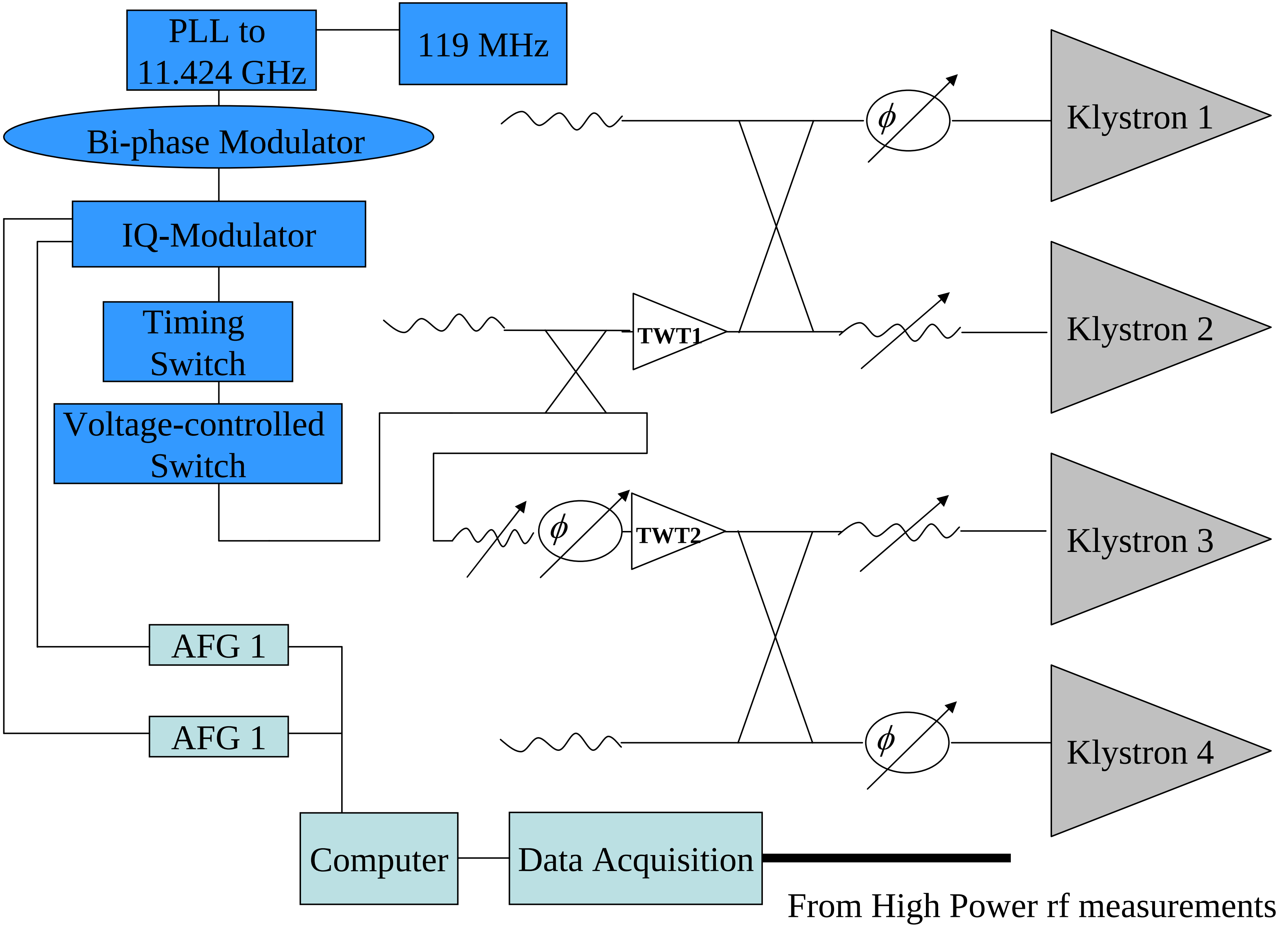
straight through

	Gamma	
(P 1 M 1)	(0.0031	223.5)
(P 1 M 2)	(0.0066	167)
(P 2 M 1)	(0.0031	223.5)
(P 2 M 2)	(0.0066	167)


Dualmoded SLED-II Performance
December 4, 2003 11 am
TE01-Input TE01-Output
Input
Output
Power (MW)
Time(μs)
0
100
200
300
400
500
600
0
0.5
1
1.5
2

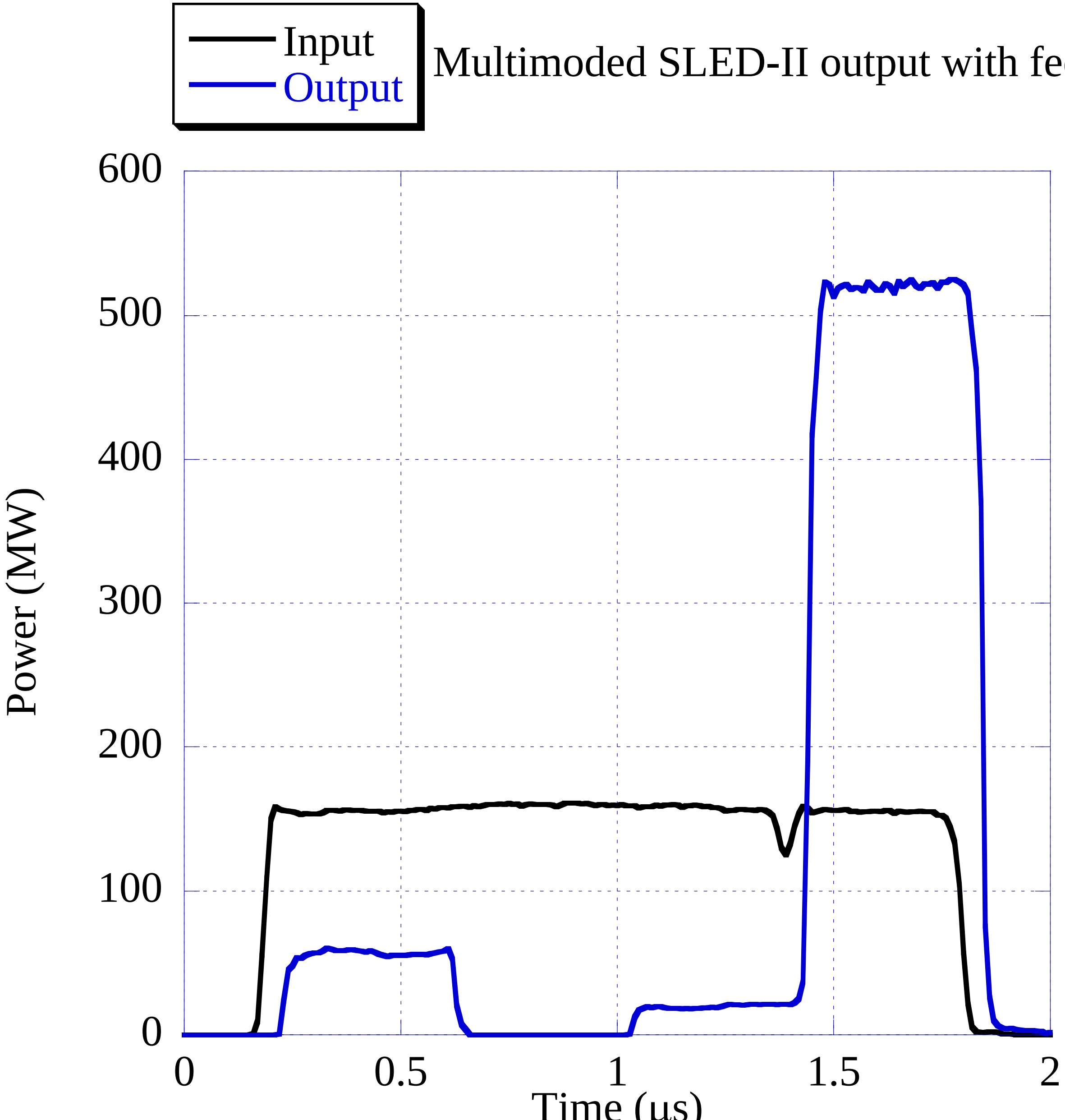


600
500
400
300
200
100
0
Power (MW)
Output
Input
0
0.5
1
1.5
2
Time (μs)



Low-Level RF Architecture

Multimoded SLED-II output with feedback



Sami Tantawi (1/27/2004)

Conclusion:

- We have introduce a fully dual mode rf system
- We have shown design and experimental data for over moded components that propagates two modes at the same time. These component perform all possible function found in single moded rf systems
- At the operating frequency of 11.424 GHz, the peak electric field is ~49 MV/m (400 ns) and the peak Magnetic field is ~0.17 MA/m (400 ns). This should be low enough for a reliable high power operation of the system (remain to be seen)
- We have invented several new measurement techniques and instrumental components needed for characterizing dual moded rf systems.

- Dual-mode rf pulse compression system achieved peak power of about 580 MW; 130% of NLC spec.

- Dula-moding reduce delay-line length by 50%.

- Modular multimode components allow multiple pulse compression configurations.

- Overmoded components keep electric field < 49 MV/m and Magnetic Field < 0.17 MA/m at power levels of 600 MW.

- The system had 14 trips due to the overmoded system after 39 million pulses at 400 ns and above 500 MW.

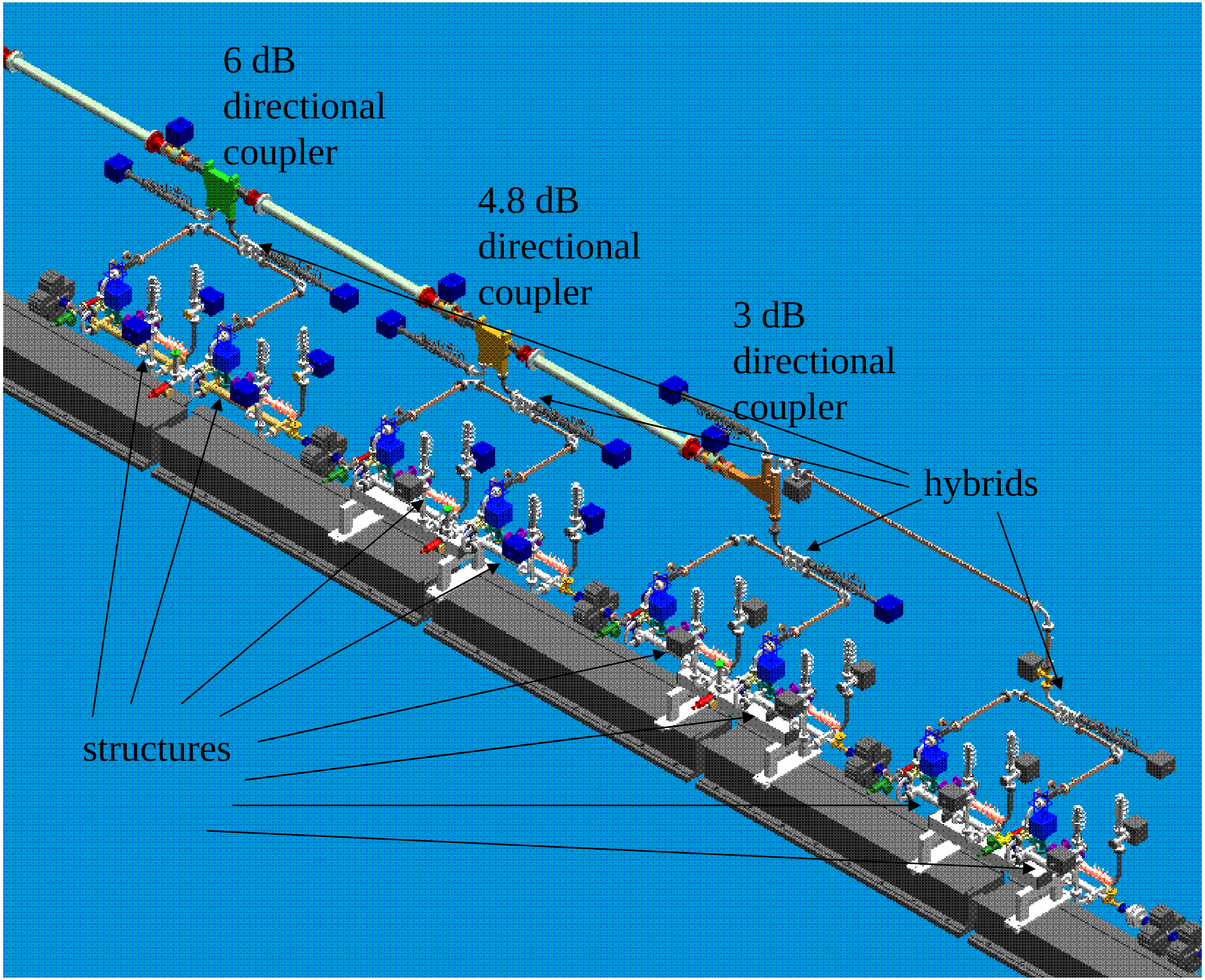
[1]Sami G. Tantawi et al, "Ultra-High-Power Multimode X-Band RF Pulse compression and Distribution System," to be submitted to Physical Review Special Topics-Accelerators and Beams.

[2] S. G. Tantawi, "Multimoded reflective delay lines and their application to resonant delay line rf pulse compression systems," Phys. Rev. ST Accel. Beams 7, 032001 (2004)

[3] S.G. Tantawi, *et al.*, "A Multimoded RF Delay Line Distribution System for the Next Linear Collider," Phys.Rev.ST Accel.Beams, vol. 5, March 2002.

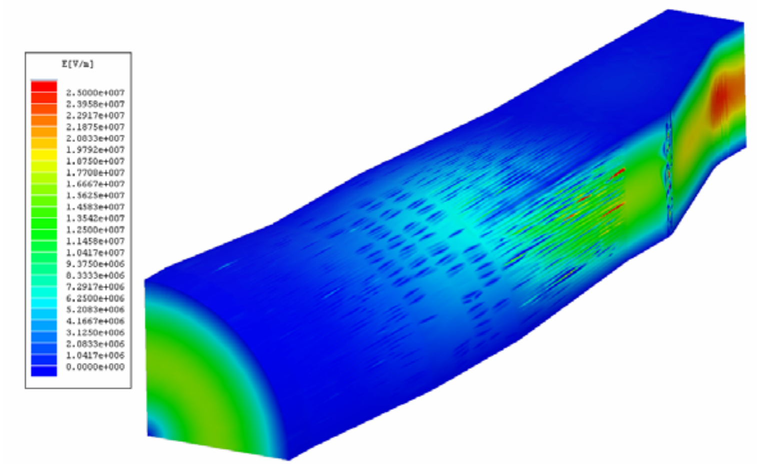
[4] Sami G. Tantawi, et. al. "The Generation Of 400-MW RF Pulses At X Band Using Resonant Delay Lines,", IEEE Trans. on Microwave Theory and Techniques, Vol 47, No. 12, December, 1999, p. 2539-2546

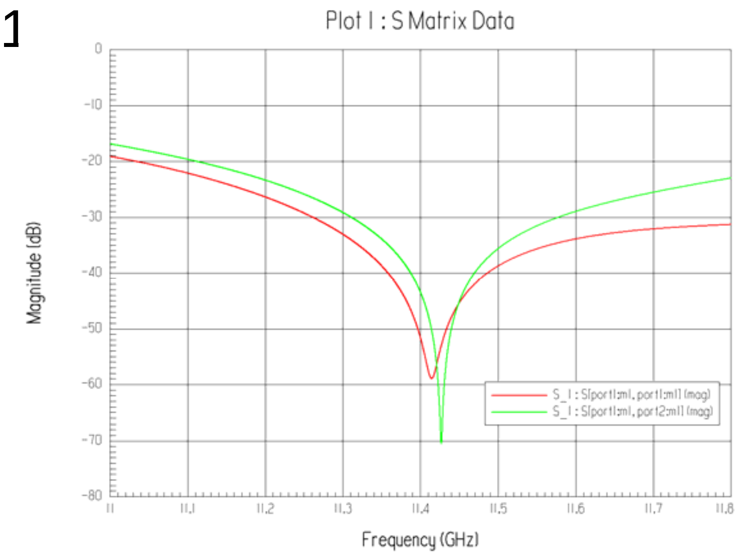
8-Pack Phase 2 Power Distribution



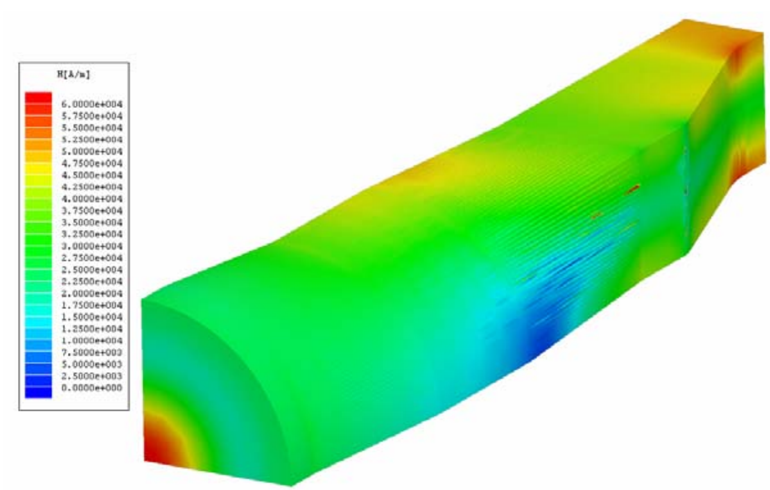
New Development of RF Components,
More Precession and Looser Tolerances

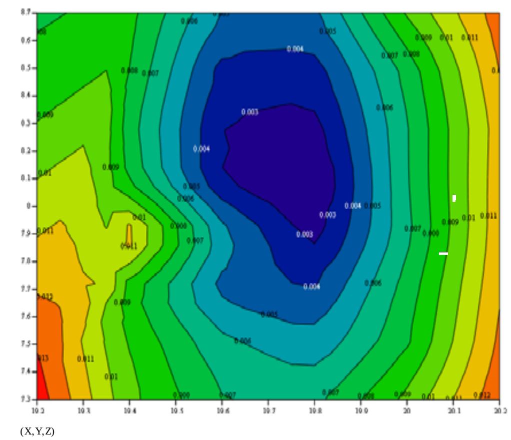
Height taper and rectangular (0.8 inch height) to circular mode converter, length 112.41





Electric field, max. 24.2 MV/m for 100MW input power





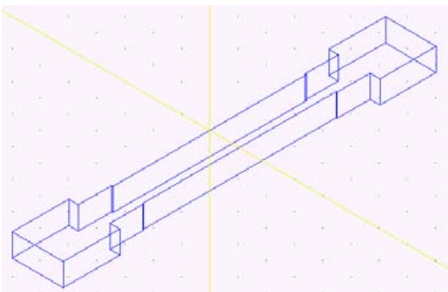
Tolerance analysis: length of "elliptical" part and rectangular part are ±0.1 mm for mode conversion < 50dB

Magnetic field, max. surface field ~50 kA/m

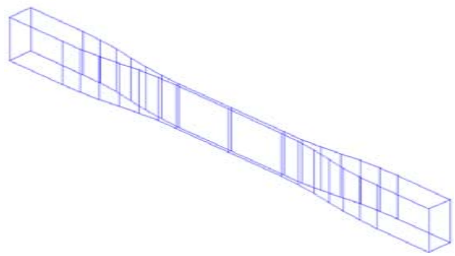
Waveguide high gradient study

Goals:

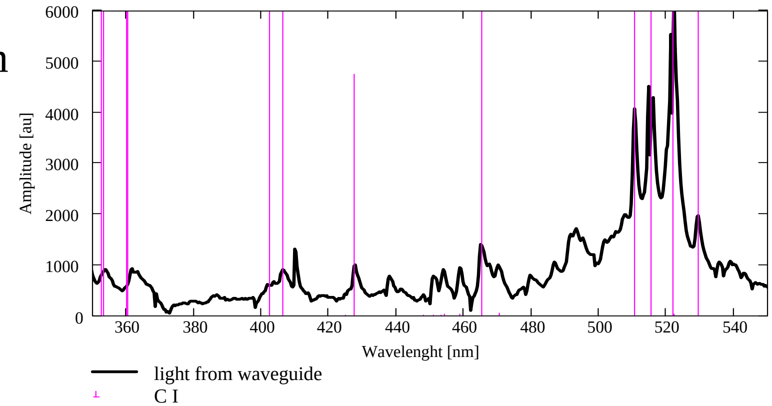
- RF breakdown *vs.* geometry (low magnetic field waveguide *vs.* high magnetic field waveguide); same electric field for same peak power and surface area
- Different materials: copper, gold , stainless steel, molybdenum
- 3D Particle-In-Cell simulations of the breakdown dynamics



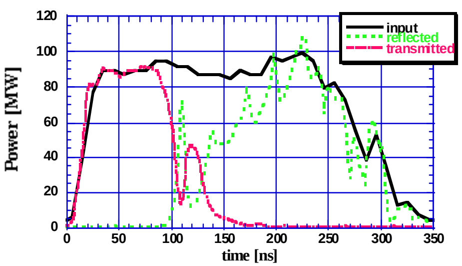
Low magnetic field waveguide, height 10 mm



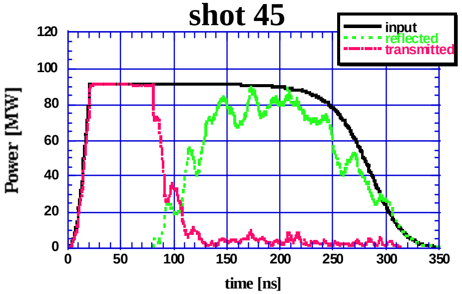
High magnetic field waveguide, height 1.3 mm



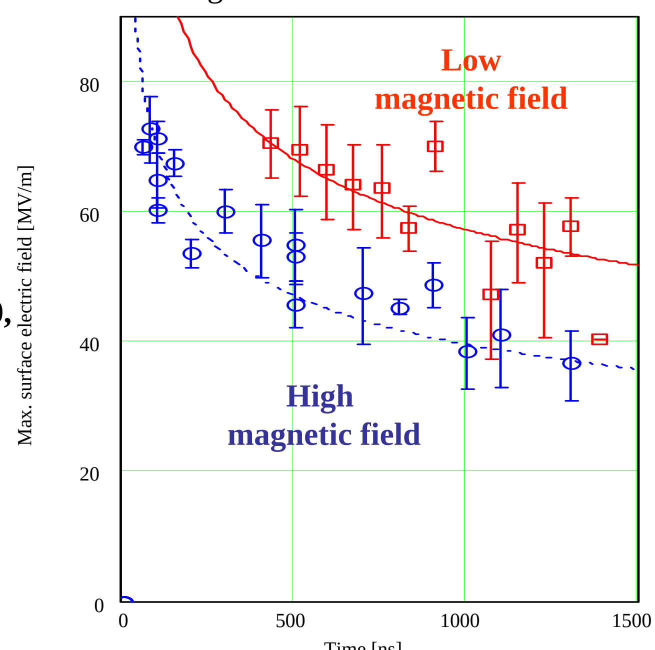
Light spectrum measured during breakdowns in copper waveguide



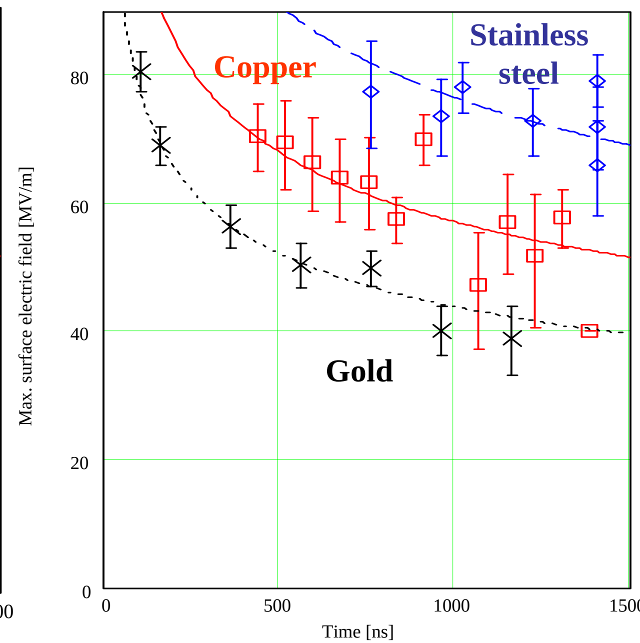
Measurements, 24 April 2001,18:13:40, shot 45



3D PIC simulations, 4x4 mm emitting spot, electron current 7kA, copper ion current 30A



Maximum breakdown electric fields copper waveguide of different geometries



Maximum breakdown electric fields for different materials

S. Tantawi and V. Dolgashev

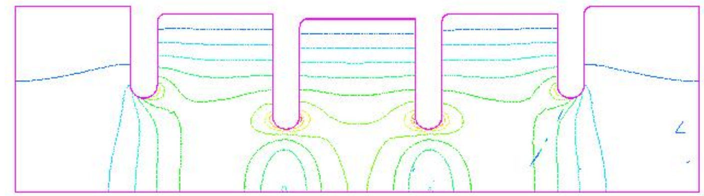
Single cell traveling (TW) and standing wave (SW) structure 11.4 GHz high gradient study

Goals:

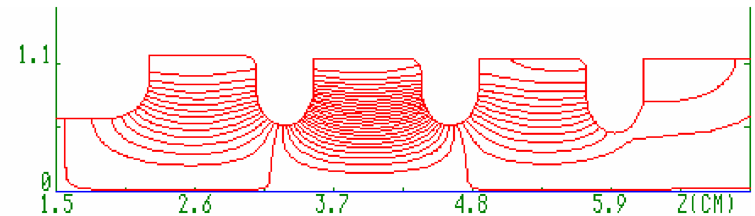
•RF breakdown *vs.* circuit parameters (SW *vs.* TW)

•RF breakdown *vs.* different surface processing technique (etching, baking)

•RF breakdown *vs.* different materials: copper, molybdenum, molybdenum-copper



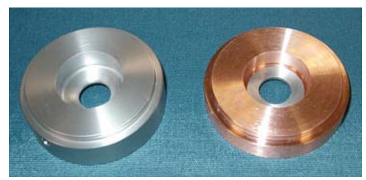
Electric field lines in single cell **traveling** wave structure



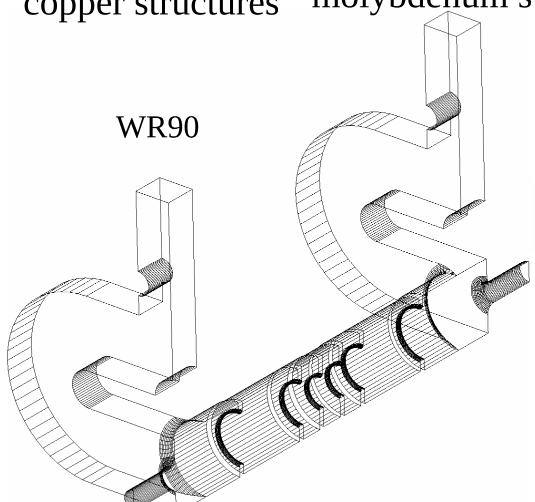
Electric field lines in single cell **standing** wave structure

TW SW
copper structures

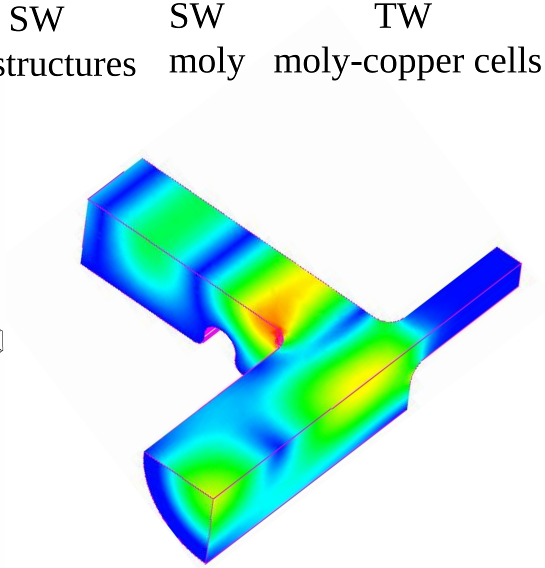
TW SW
molybdenum structures



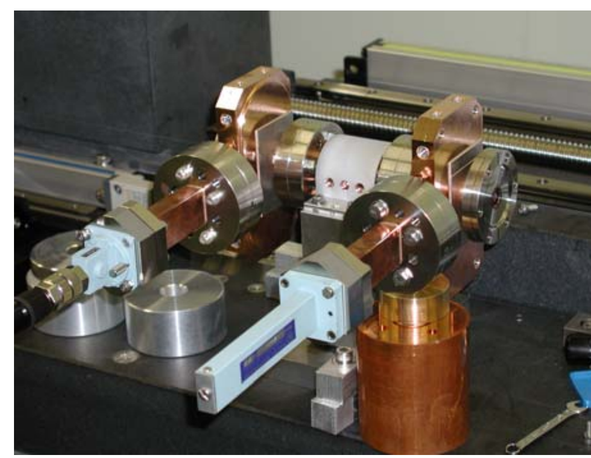
SW TW
moly moly-copper cells



Single cell TW structure with mode-launchers



Surface electric fields in the final mode launcher E max.= 49 MV/m for 100 MW

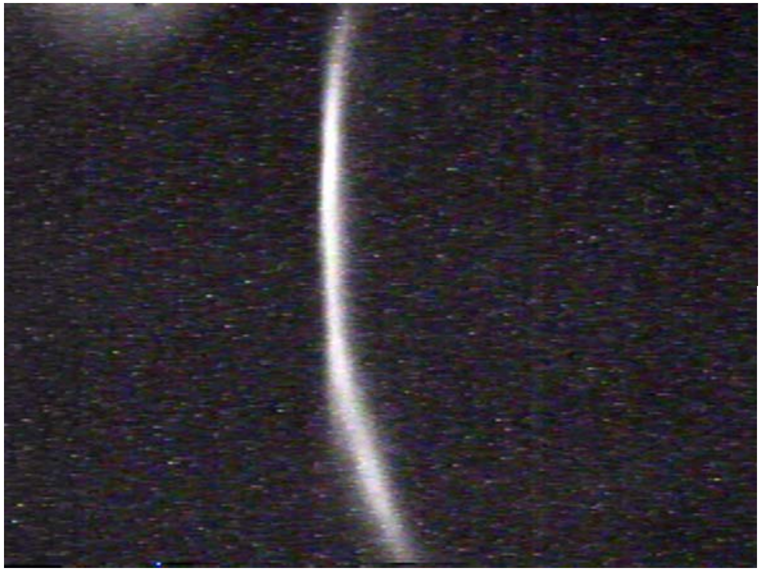


Bead-pull measurements of single cell TW structure

S .Tantawi, V. Dolgashev, C. Nantista (SLAC), Y.Higashi, T.Higo (KEK)

Beam image on a spectrometer-beam-profile-monitor

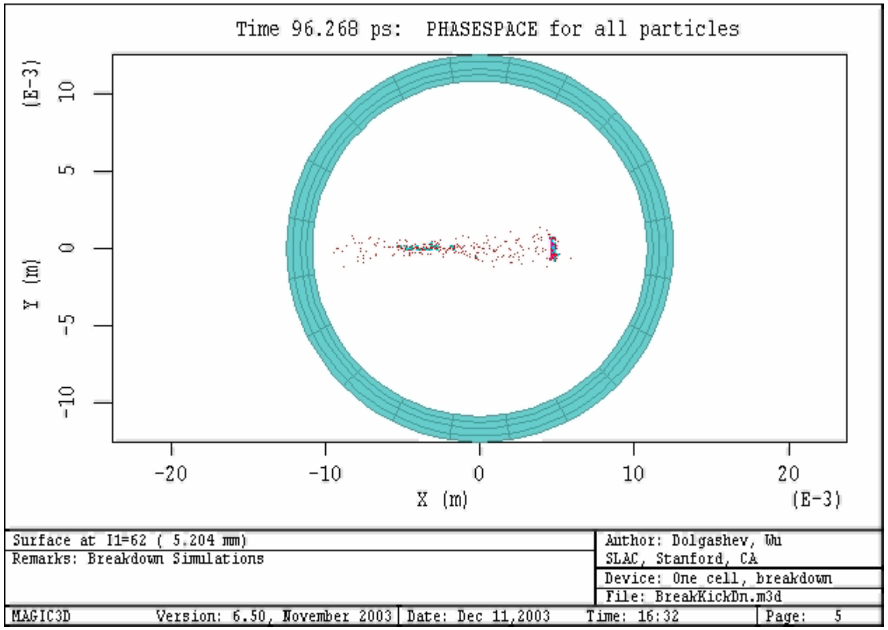
Before breakdown

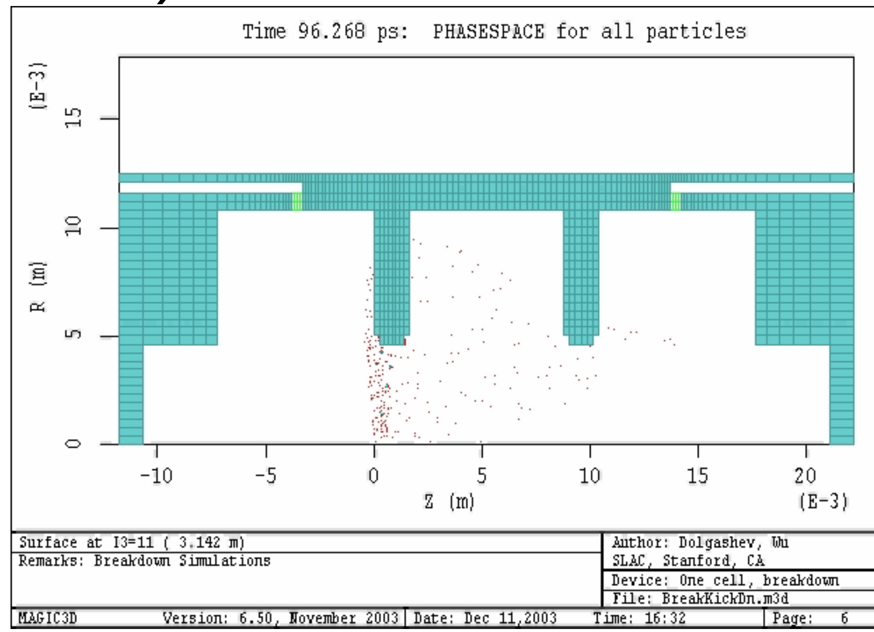


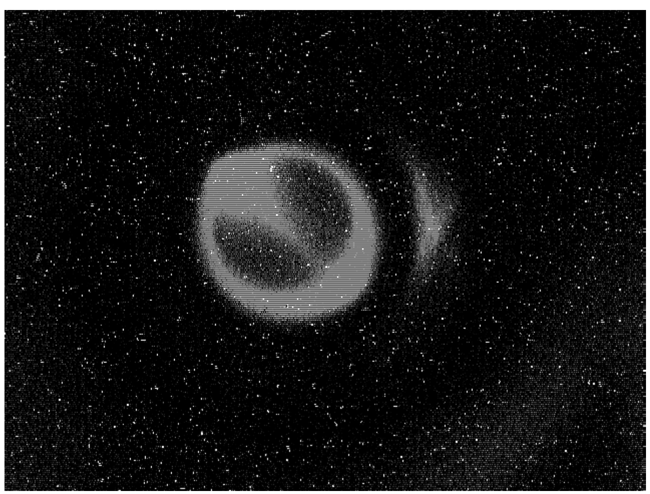
Profile of the beam during breakdown pulse,
horizontal shift dominated by the spectrometer dispersion

28_May_04_4:43, Chris Adolphsen, Steffen Doebert

3D PIC simulation of a breakdown in single-cell TW structure, emission from downstream side of the first iris (cell breakdown)

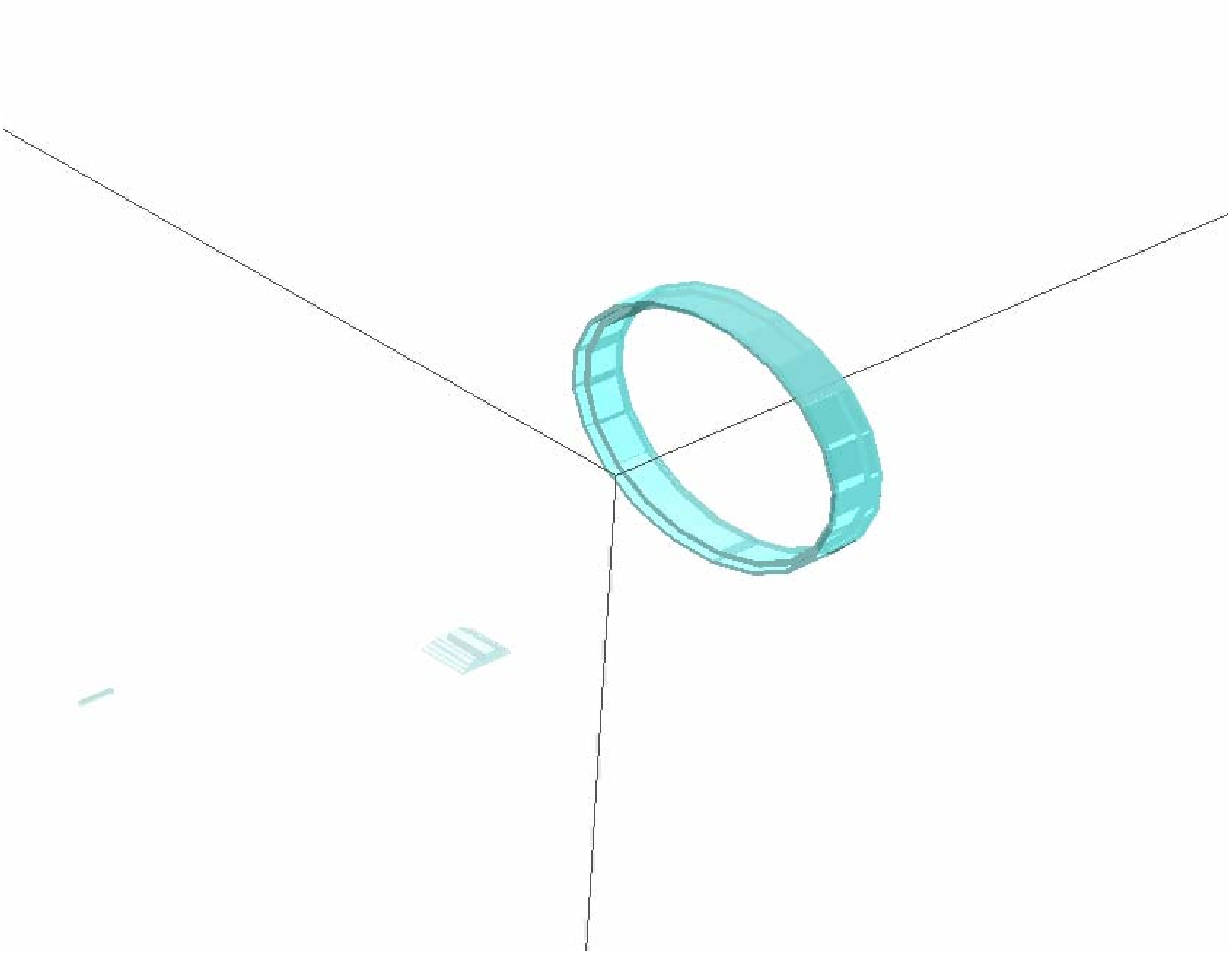




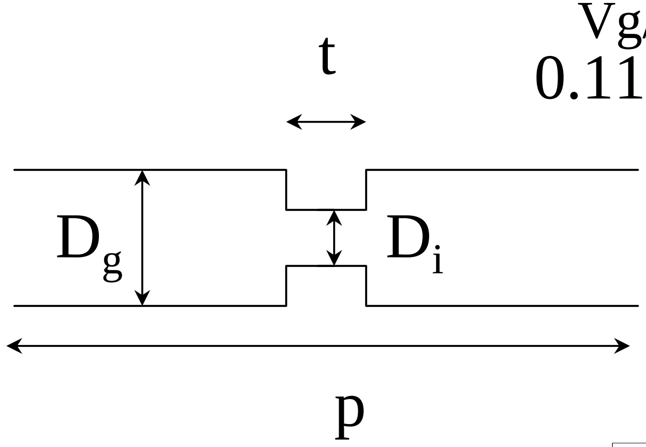


Video capture of a breakdown event in SW20PI,
Marc Ross,
Douglas McCormick
August 2001

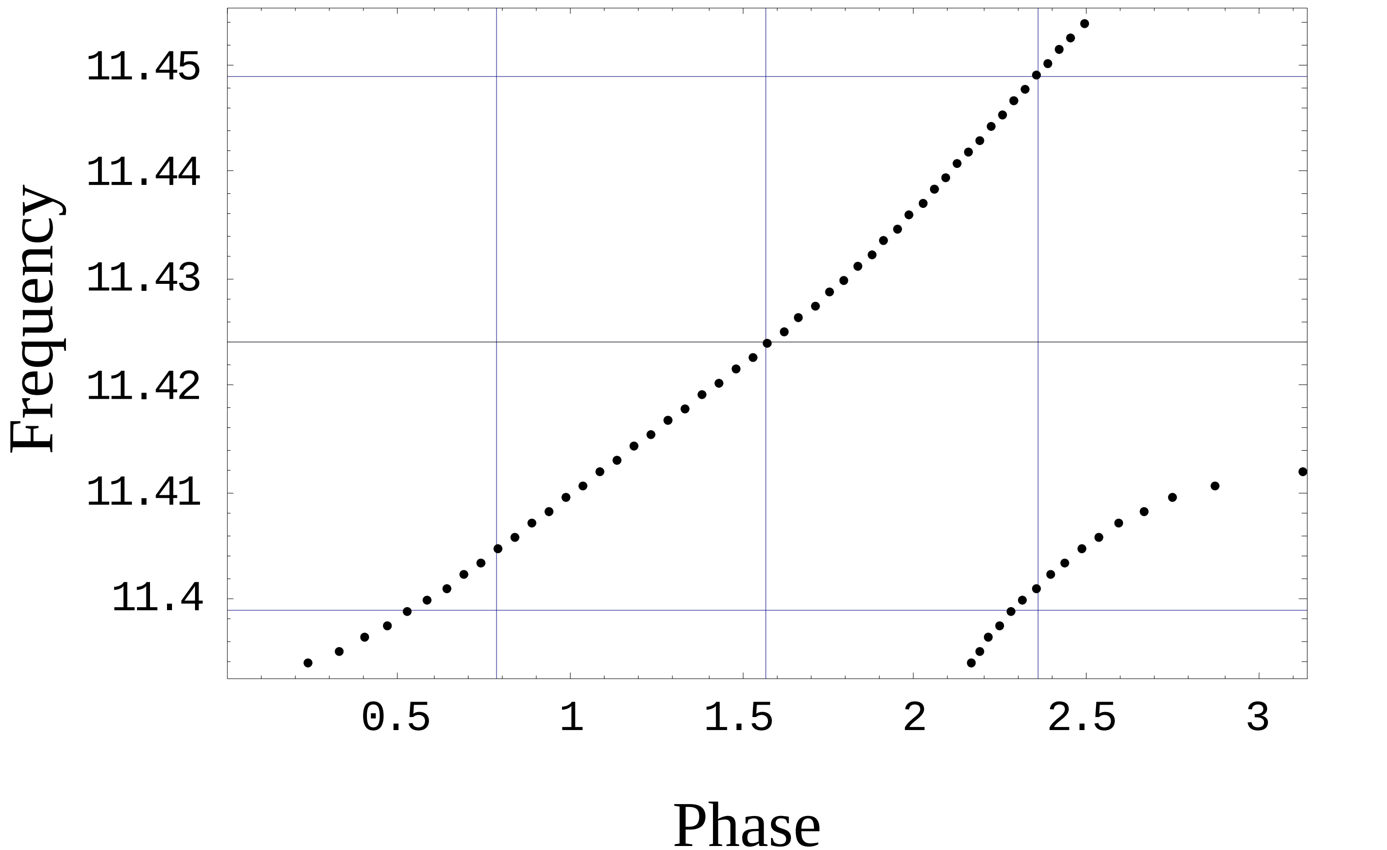
Breakdown currents and beam, 3D PIC simulations



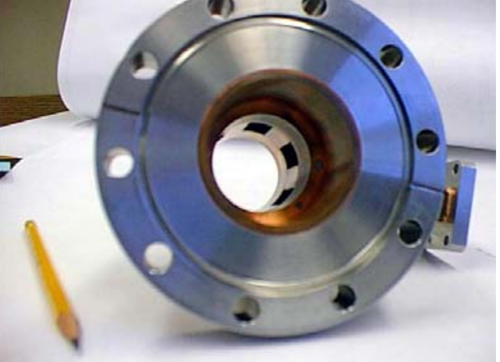
Vg/c	100ns Delay Length (cm)	Losses/100ns (%)
0.119911	359.484	2.78738

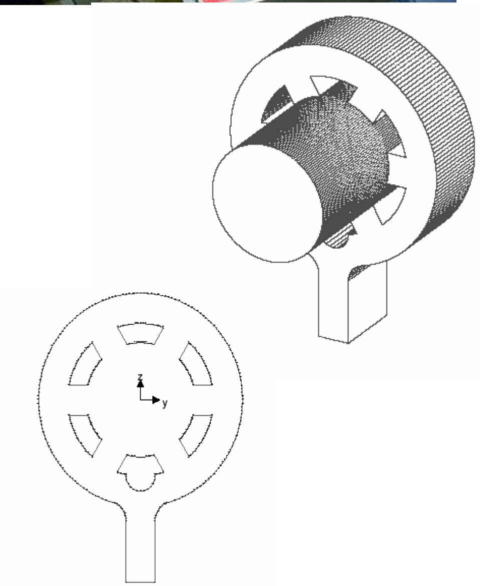


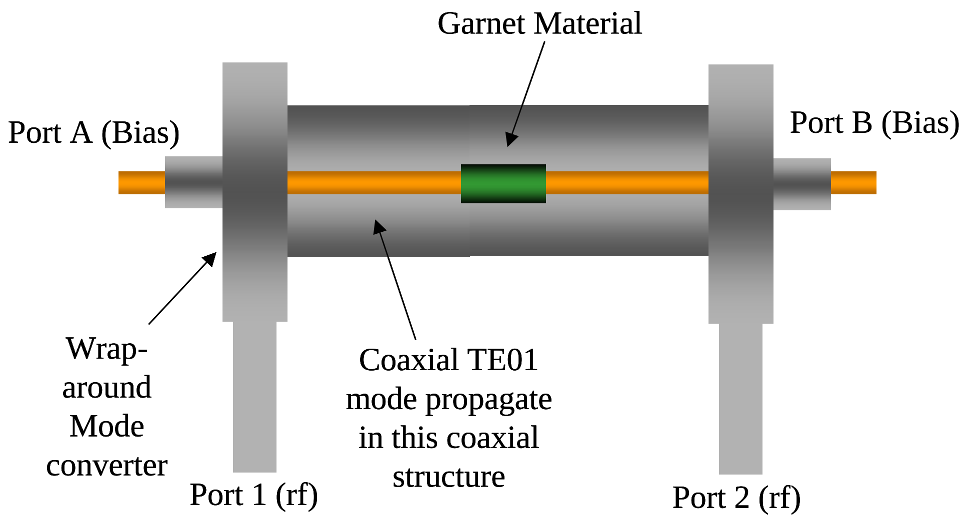
D_g=6.725”
T=0.1”
Di=3”
P=8.500”

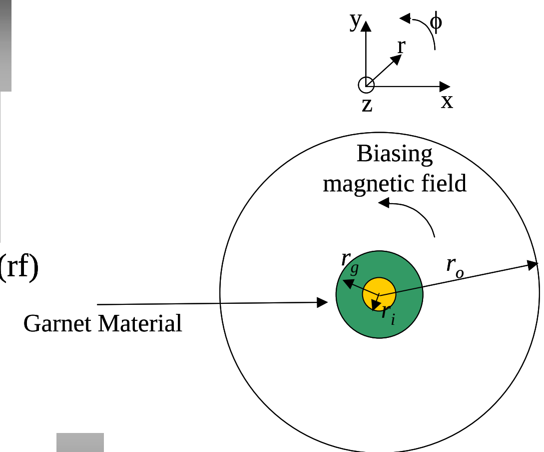


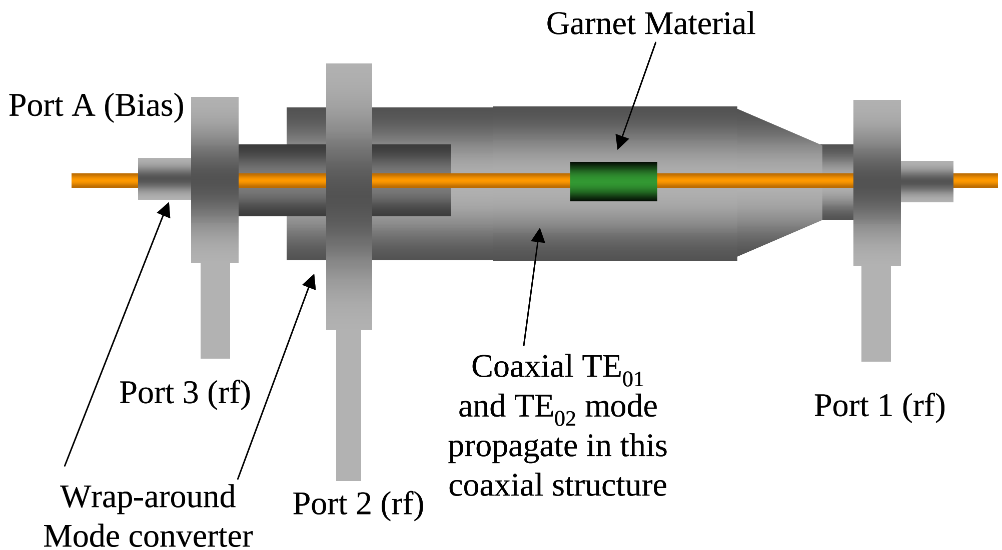
Compact Delay Line development



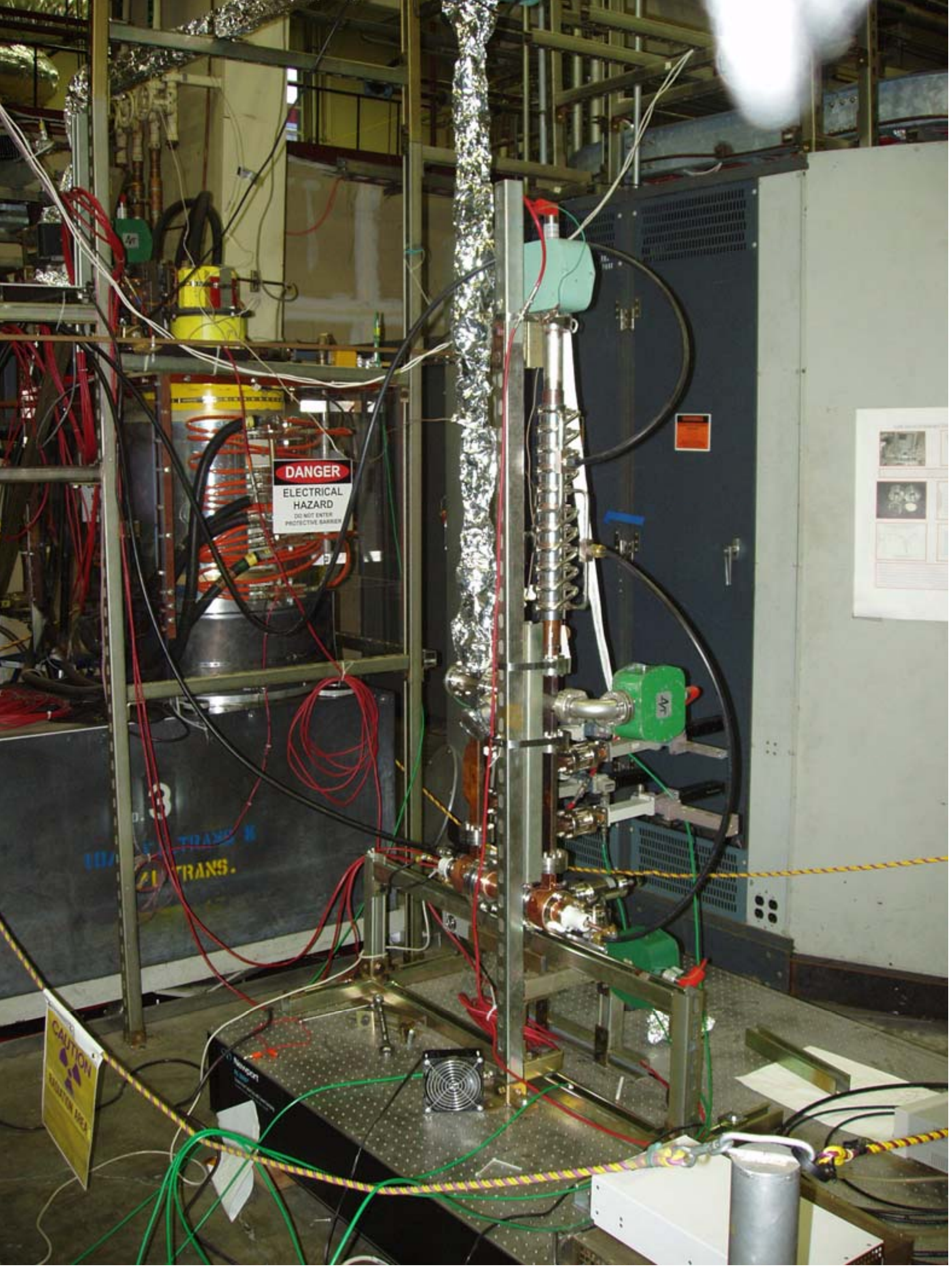


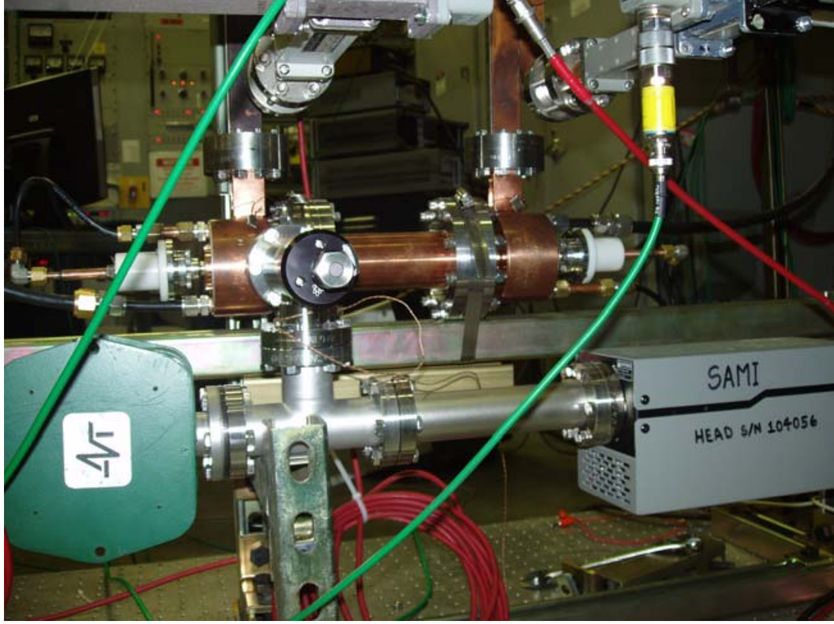






Wrap-Around Mode Converter for Tap-off, and extraction, tested to 470 MW

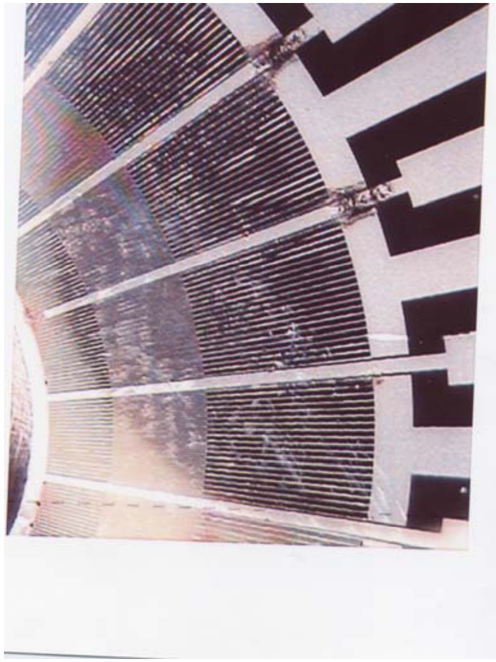




Experimental Setup for the high power testing of nonreciprocal overmoded device

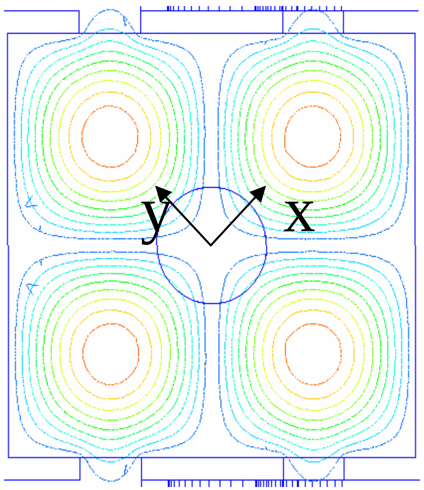
Semiconductor High-Power High Frequency rf switches

- Overmoded structure, spatially combined devices
- Tested to 13 MW/device at X-band
- Solved the contact problem
- The speed of the switch is still an open question

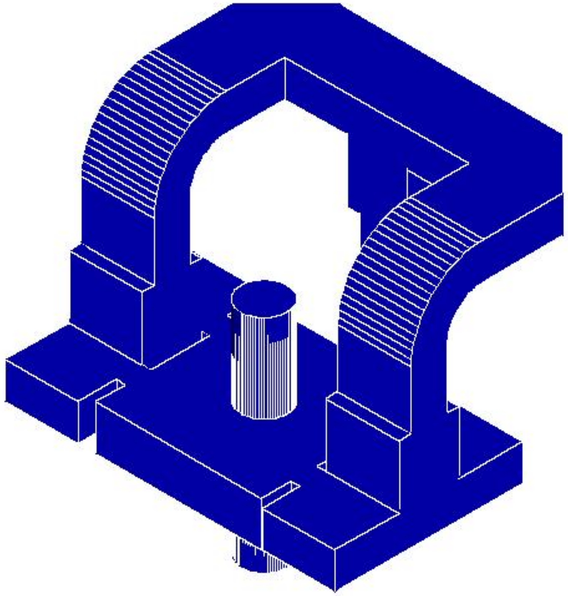


Beam Diagnostics Structures

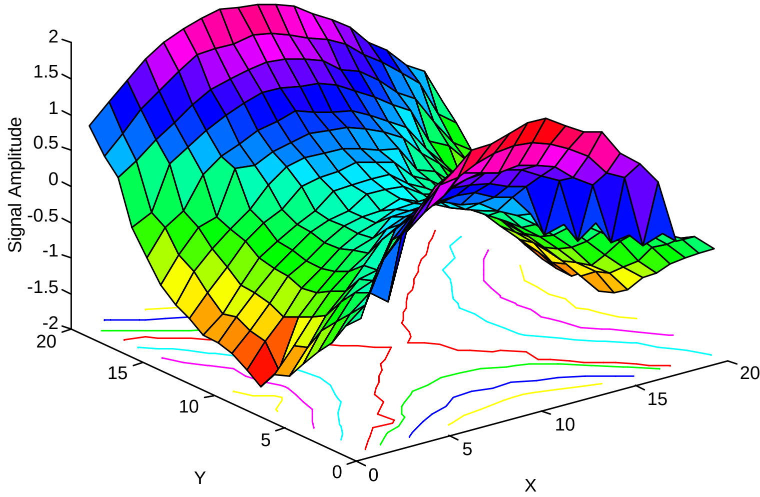
Beam quadrupole moment monitor for emittance measurement developed with Far-Tech, Inc. in SBIR collaboration:



Quad cavity magnetic field pattern.



Geometry of Quad cavity and waveguide circuit.



Signal mapped around axis with NLCTA beam.

C. Nantista

Follow-up collaboration with Far-Tech, Inc. proposed to develop and test prototype of their multi-cell structure design for measuring quadrupole and dipole (BPM) moments.

Last year

Our development of ultra-high-power RF components and pulse compression systems lead to the a successful demonstration of an RF system suitable for NLC

This year

1- Continue our development of RF components for NLC by adding a distribution system to the current RF pulse compression system

2- Converting two of the NLCTA station into dual-moded pulse compression system

3- We are performing a series of experiments on active RF components which we expect to push the state of the art of semiconductor rf switches and nonreciprocal Ferrite switches by a few orders of magnitude

4-We are performing a series of experiments on *single cell Traveling wave* accelerator structures to understand the breakdown phenomenon and the role of materials in determining the limits on high gradients.

RF Structures Group

- Juwen Wang
- Gordon Bowden
- Roger Miller
- Roger Jones
- Jim Lewandowski

Mission for RF Structures Group

Mission

We design, engineer and test accelerator structures for future linear colliders operating under extremely high gradient conditions with superior properties in higher modes suppression.

The activities

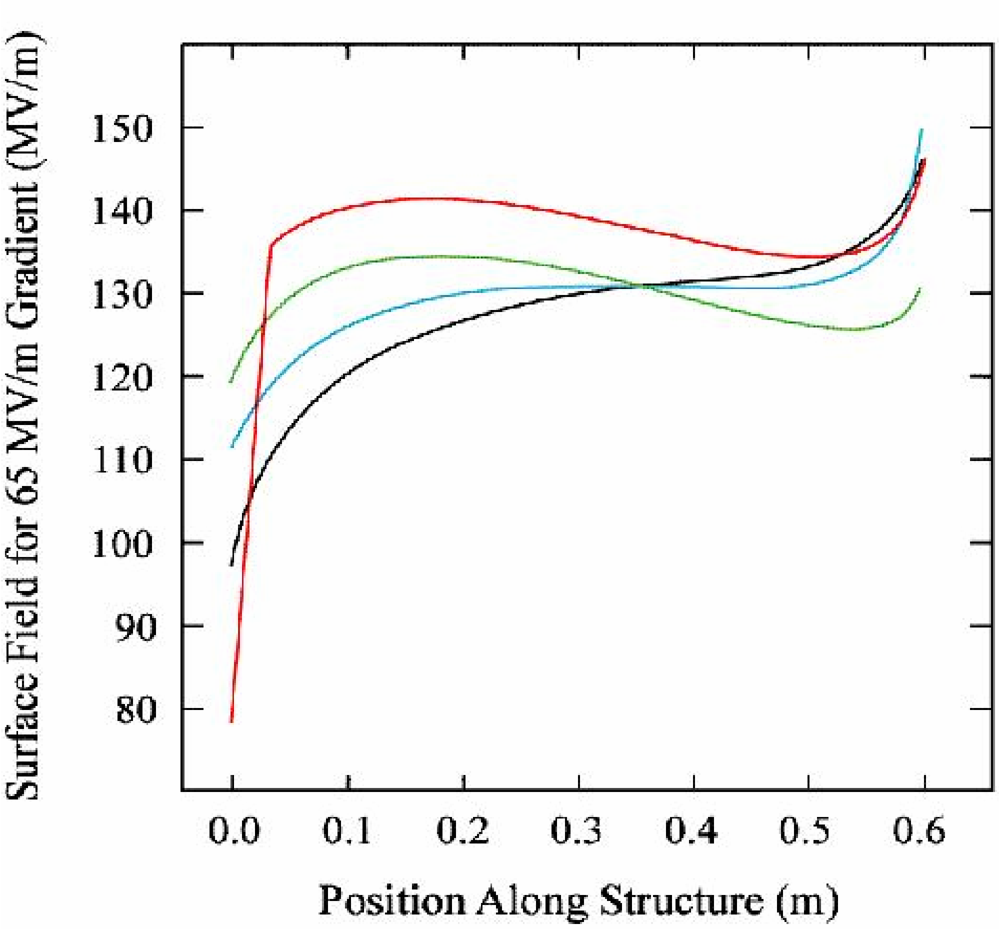
- Accelerator Theoretical Studies.
- Simulation and Computer Aided Accelerator Design.
- Mechanical Design.
- Fabrication Technologies Studies.
- Microwave Characterization.
- High Power Experiments.

Accomplishment in the Past Year for RF Structures Group

- Design, fabrication and tuning of nine testing accelerator structures for high gradient test at NLCTA.
- NLC prototype structures R&D.
  - Design optimization for efficiency and high gradient performance.
  - HOM studies: Design simulation and microwave measurement.
  - Trapped mode studies: Simulation and microwave measurement confirmation.
- Redesign of accelerator cavity for finalized NLC structures.
- Theoretical studies in beam dynamics issues related to frequency and alignment tolerances due to high order dipole wakefields..
- Wire measurement of wakefields for multi-cell accelerator structures.
- Ten structure related publications.

Structure Design Optimization for Efficiency and High Gradient Performance

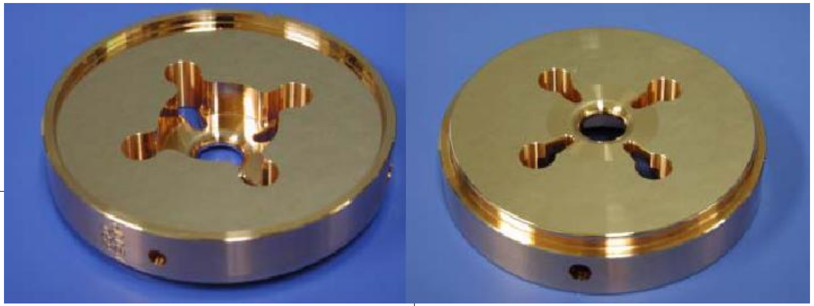
Comparison of maximum iris surface field for different structure designs at an unloaded gradient of 65 MV/m. The red curve is for H60VG3N (a/λ=0.18), which has rounded shaped irises – the others have elliptical shaped irises, which lowers the peak field. This structure also has a reduced field in the first several cells. The green curve is for H60VG3S18 (a/λ=0.18), which shows the effect of the elliptical shaped irises. The light blue curve is for H60VG3S17

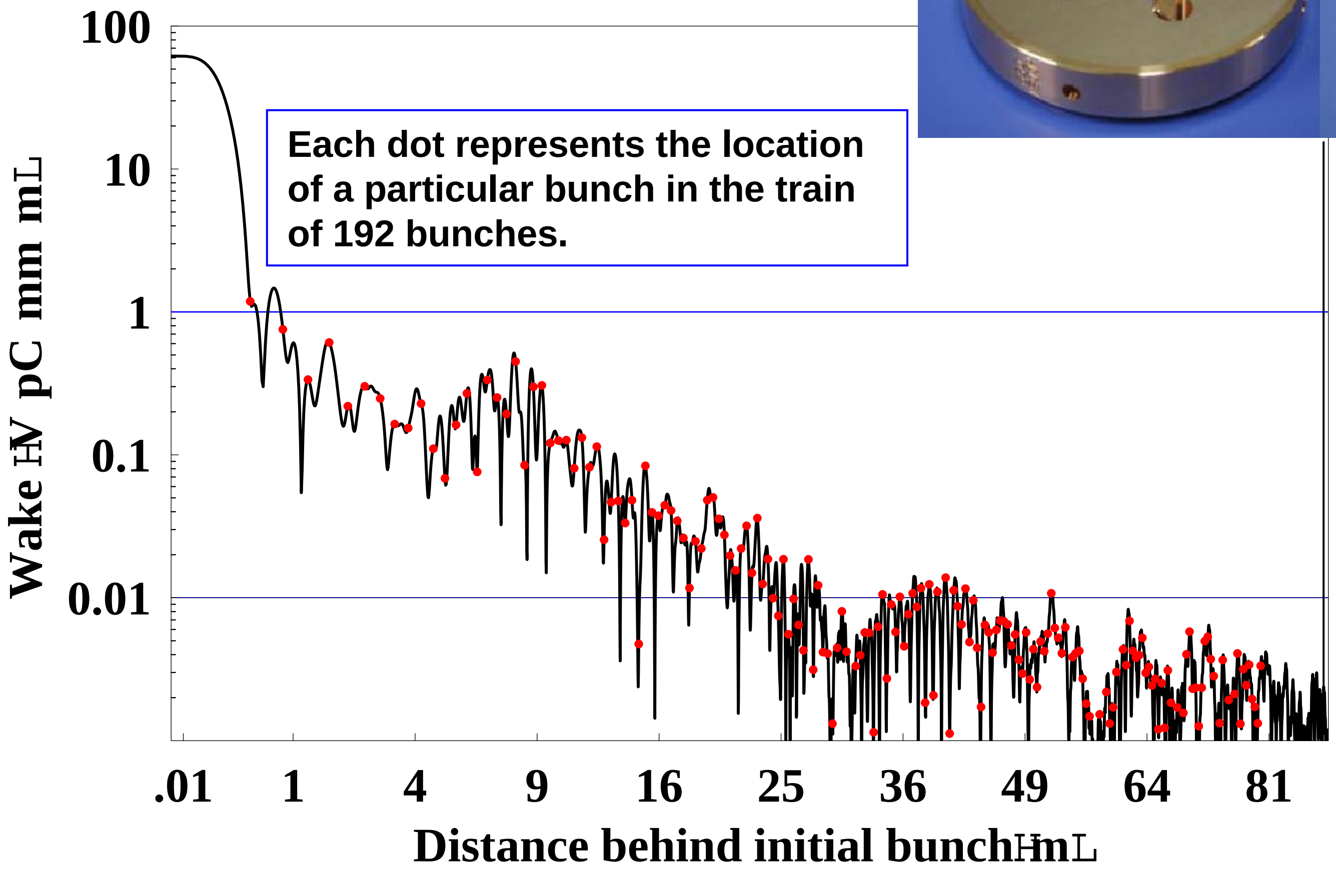


Basic RF Parameters of NLC Prototype Structures

Structure name	HDDS (H60VG4SL17)
Structure length	62 cm (including couplers)
Number of acceleration cells	53 cells + 2 matching cells
Average cell iris radius	$< a/\lambda > = 0.17$
Phase advance / cell	$5\pi/6$
Group velocity	4.0 ~ 0.9 % speed of light
Attenuation parameter τ	0.64
Filling time	118 ns
Q value	7000 ~ 6500
Shunt impedance	51 ~ 68 MΩ/m
Coupler	Wave Guide type
1st Band dipole mode distribution	$Sech^{1.5}$ distribution with Δf~ 11% (4σ)
Es/Ea	2.22 – 2.05
Required input power	59 MW
Gradient without beam $<E_0>$	65 MV/m
Beam loaded gradient $<E_L>$	52 MV/m

Envelope of Wake for Four-Fold Interleaving of GLC/NLC X-Band Accelerating Structures

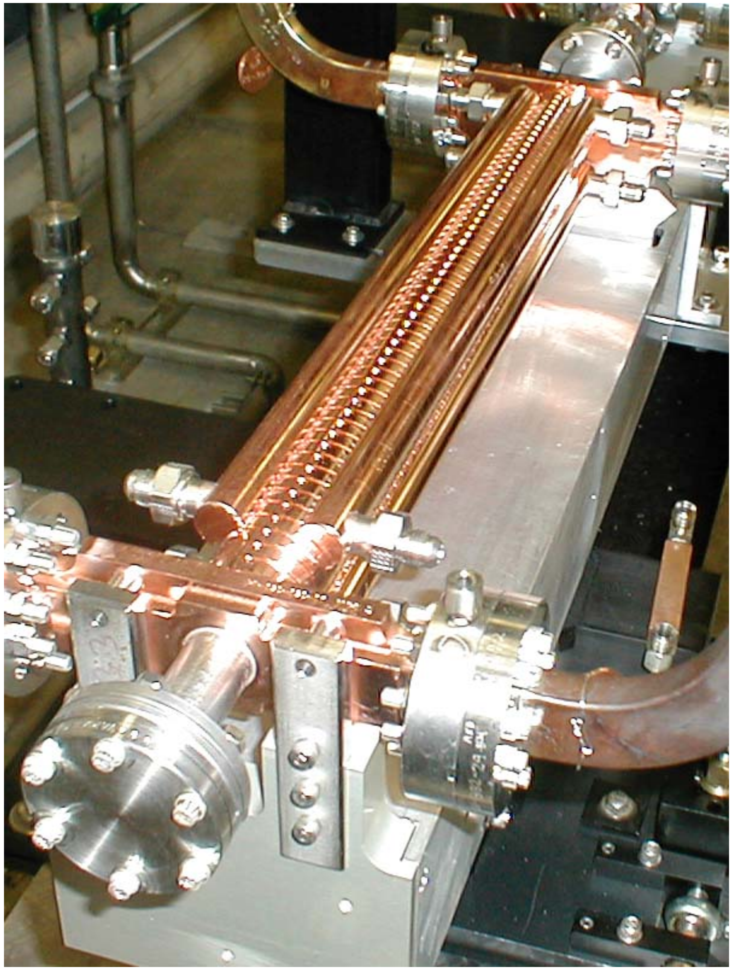




High Gradient Structure Development

- Designed, fabricated and tested 34 structures with over 20,000 hrs of high power operation.
- Improved structure preparation procedures - includes various heat treatments and avoidance of high rf surface currents.
- Found lower input power structures to be more robust against rf breakdown induced damage.
- Developed ‘NLC/GLC Ready’ design with required wakefield suppression features – it is 33% as long (60 cm) and requires 40% of the power of the 1.8 m design.

Traveling-Wave Structure

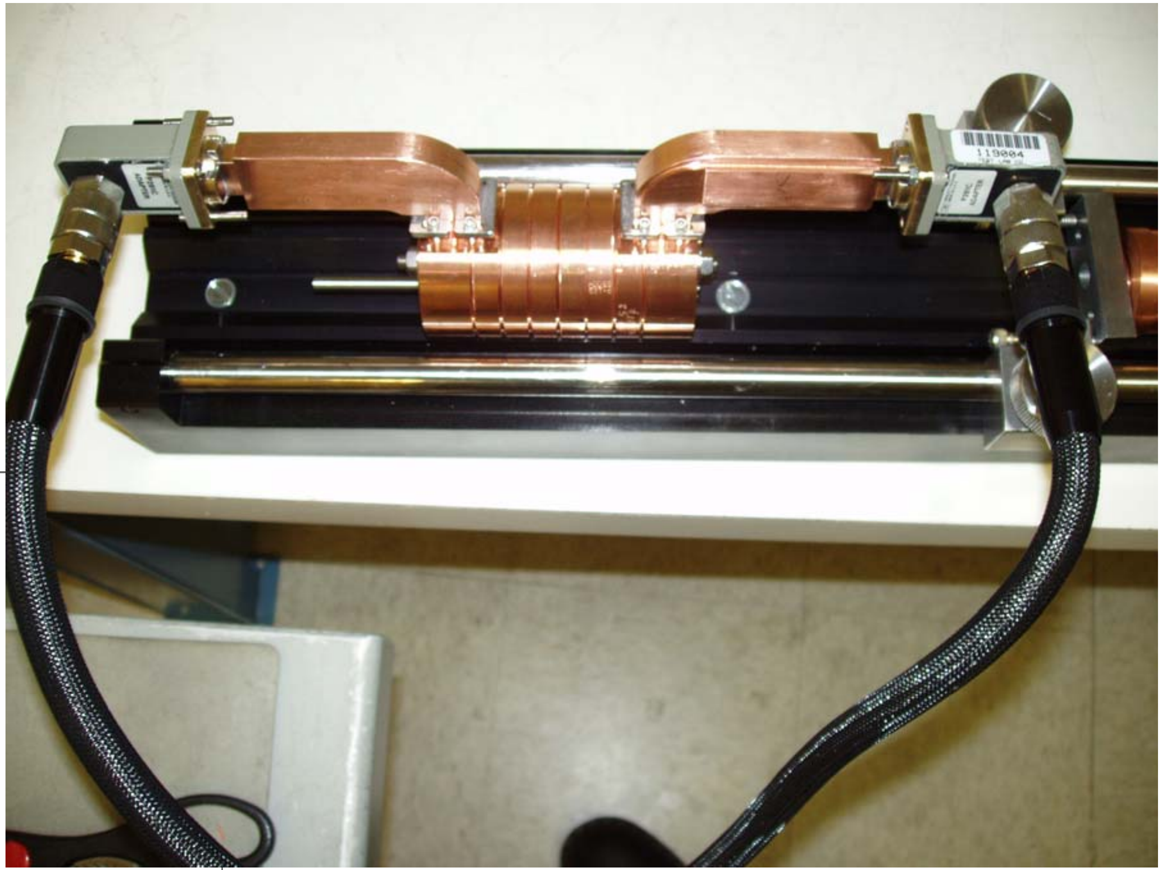


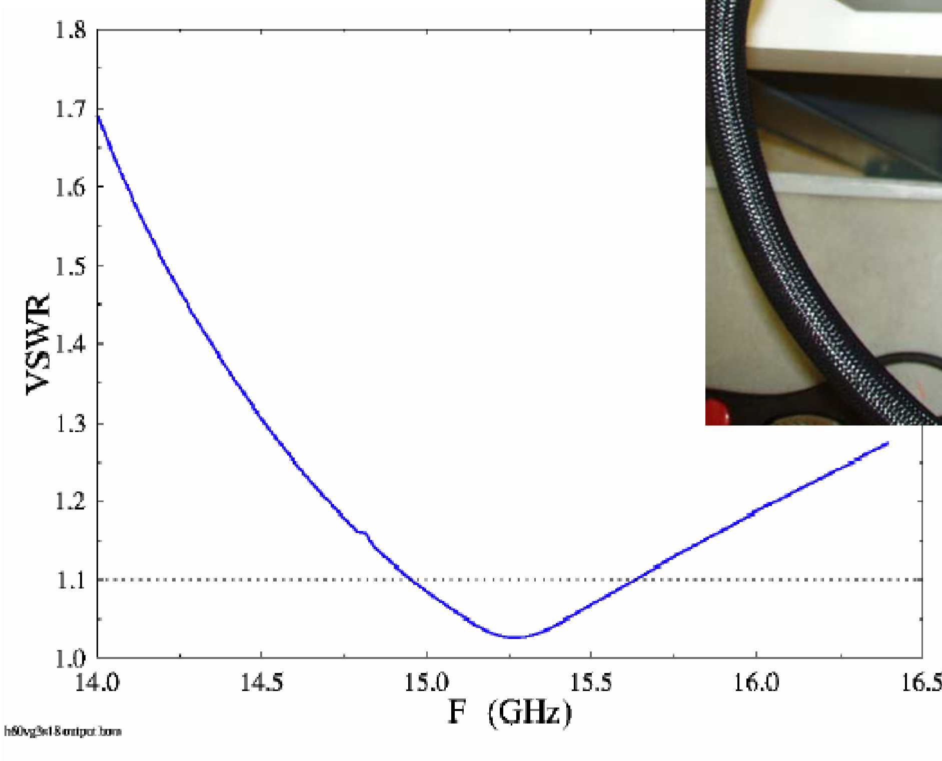
Structure Fabrication at SLAC

Ready for Final Braze

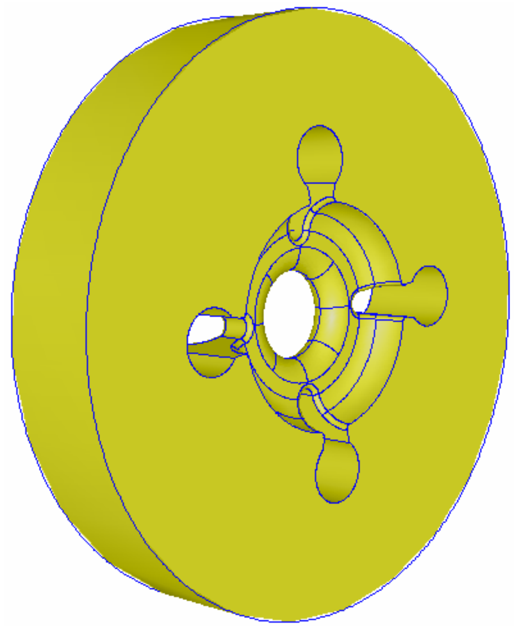
After Braze

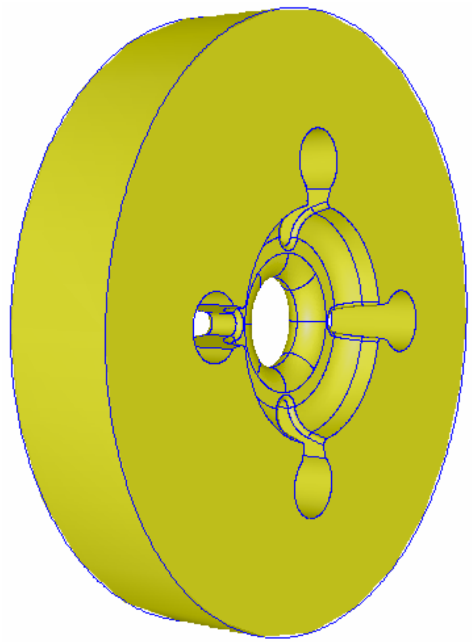
HOM Coupler Design and Microwave Measurement





Optimized accelerator cavities for future NLC structures





To improve the shunt impedance of the structures by 10 to 15%, a structure incorporating rounded cells is being studied and several test cups will be machined and tested in the coming year. Pictures show two types of proposed symmetric accelerator cups: full rounded cavity (left) and leek-head cavity (right).

Wire Measurement of Wakefields

- Using a 300-micron thick brass wire, measurements of the structure S-parameters are made to compute the impedances for the monopole band and higher dipole mode bands.

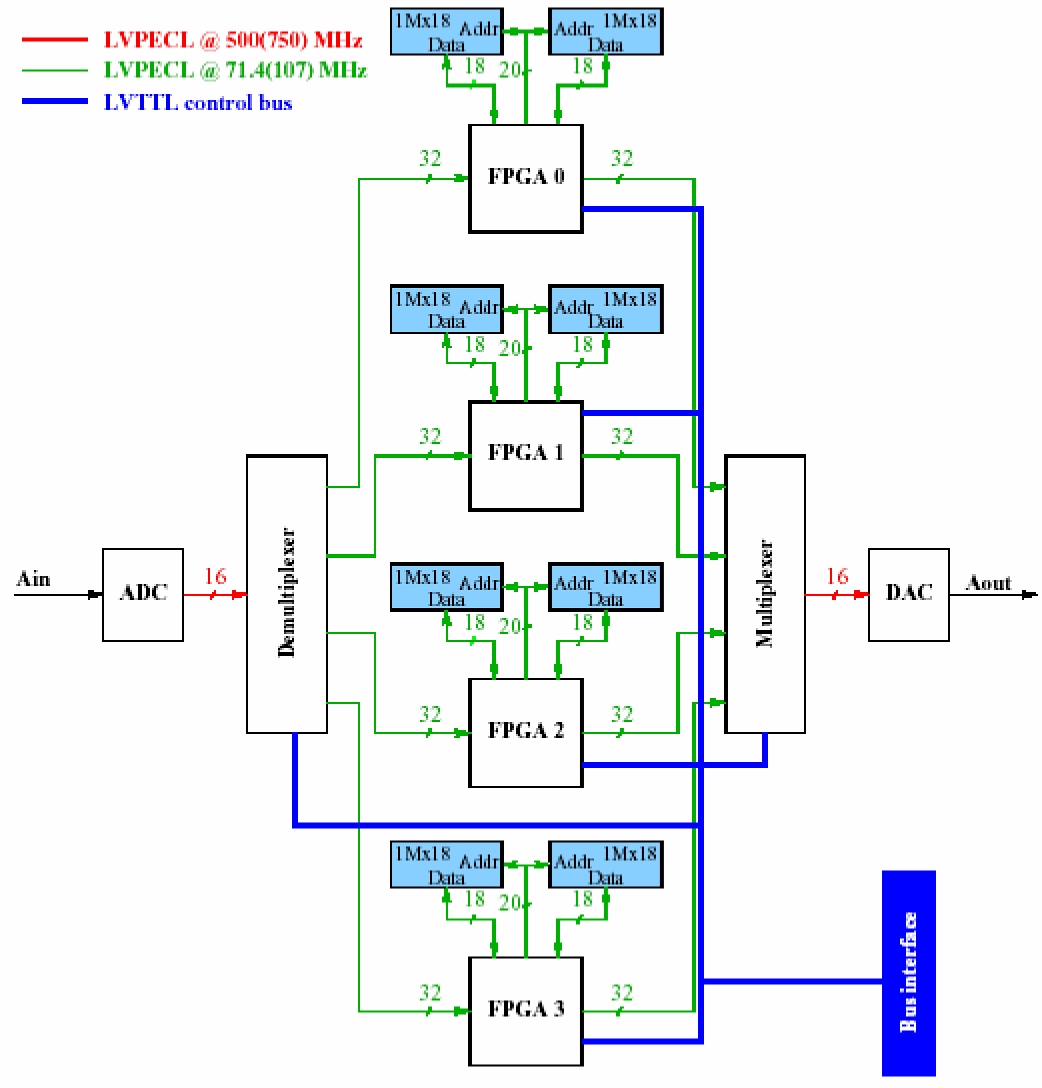
- The test results for a standing-wave structure, a short traveling-wave structure, and the RDDS1 structure show a reasonable agreement with computer simulations.

Advanced Electronics Group, ARDA

L. Beckman, J. Fox, T. Mastorides, D.Teytelman,D. Van Winkle, Y. Zhou

GBoard 1.5 GS/sec. processing channel

- Next-generation instability control technology
- SLAC, KEK, LNF-INFN collaboration - useful at PEP-II, KEKB, DAFNE and several light sources.
- Transverse instability control
- Longitudinal instability control
- High-speed beam diagnostics (1.5 GS/sec. sampling/ throughput rate)
- Builds on existing program in instability control and beam diagnostics.
- Significant advance in the processing speed and density previously achieved.
- US-Japan Cooperative Project

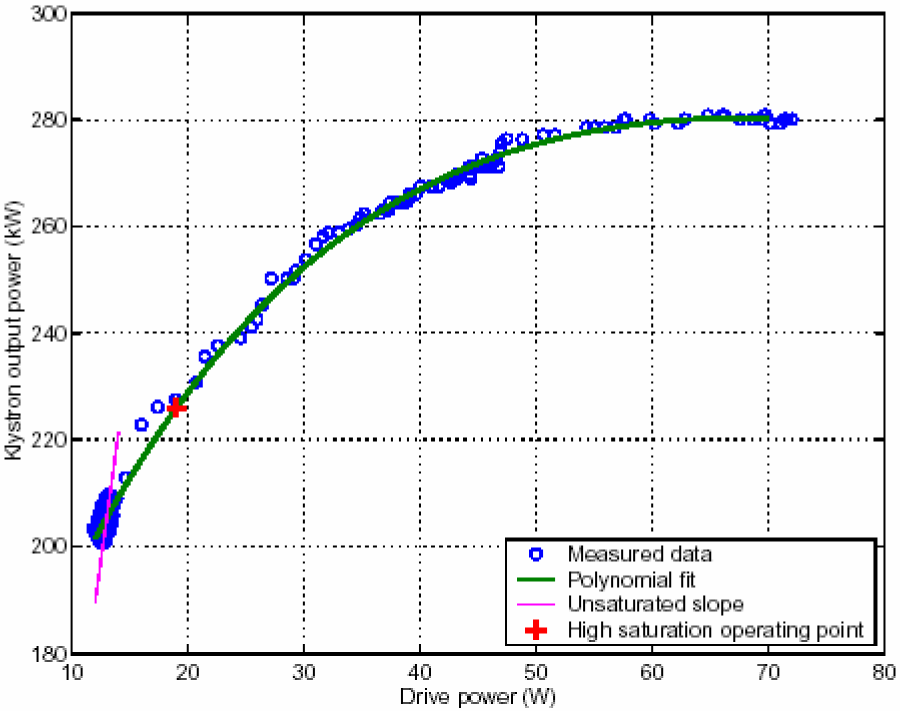


PEP-II fast impedance control loops -Limitations of cavity impedance control due to klystron saturation

A major effort by the group involves understanding the high-current instability limits in PEP-II. Our machine physics measurements have led to a better understanding of the limitations of impedance control in the PEP-II RF systems. Due to klystron saturation a linear impedance control model is not applicable.

For the HER at 1 A the growth rates rise from linear prediction of 0.12 ms^{-1} to actual 1-1.8 ms^{-1}.

These high growth rates were limiting HER currents above 1380 mA.



We are attacking this limitation through a new RF woofer channel in the longitudinal feedback paths, and a novel klystron linearizer within the low level RF processing

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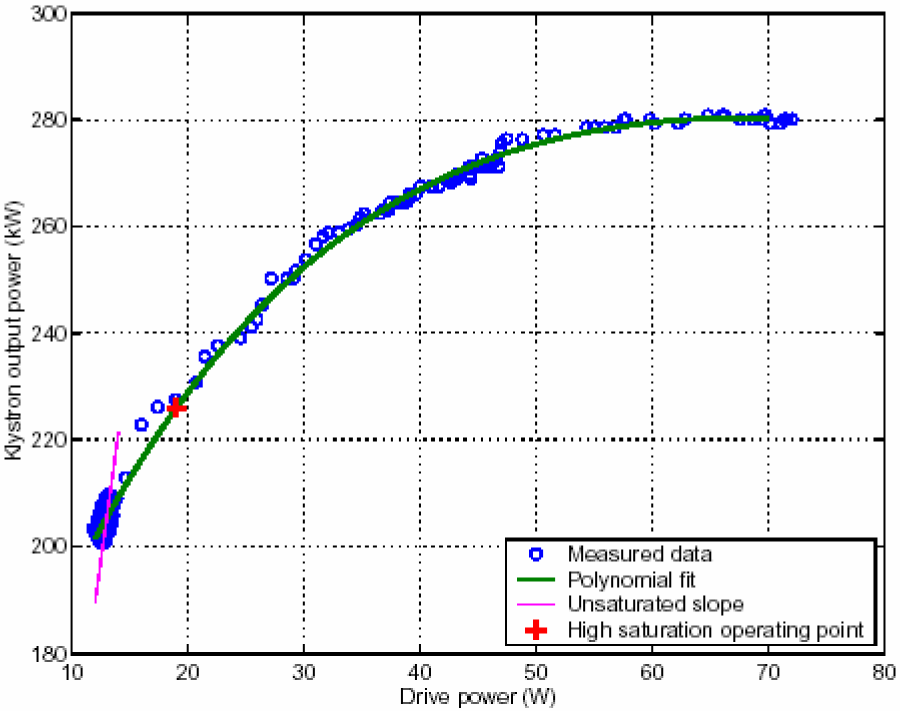


We are attacking this limitation through a new RF woofer channel in the longitudinal feedback paths, and a novel klystron linearizer within the low level RF processing

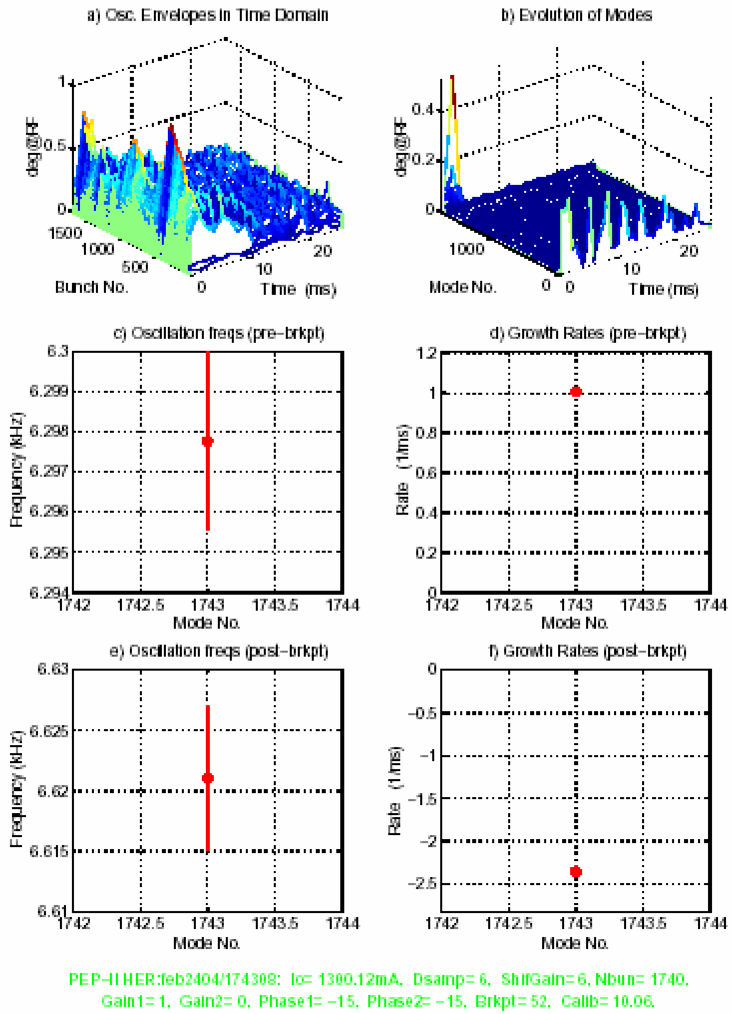
Grow/damp measurements for the low modes

During these measurements we turn off both wideband (LFB) and narrowband (LGDW) channels.

Measures open-loop growth and closed-loop damping for the fundamental driven modes

Due to optimized gain partitioning the system can recapture beam motion at larger amplitudes. For the grow/damp measurements this allows longer growth intervals and better SNR.

Larger dynamic range of the new woofer will allow it to handle significantly larger beam transients due to injection, RF, etc.



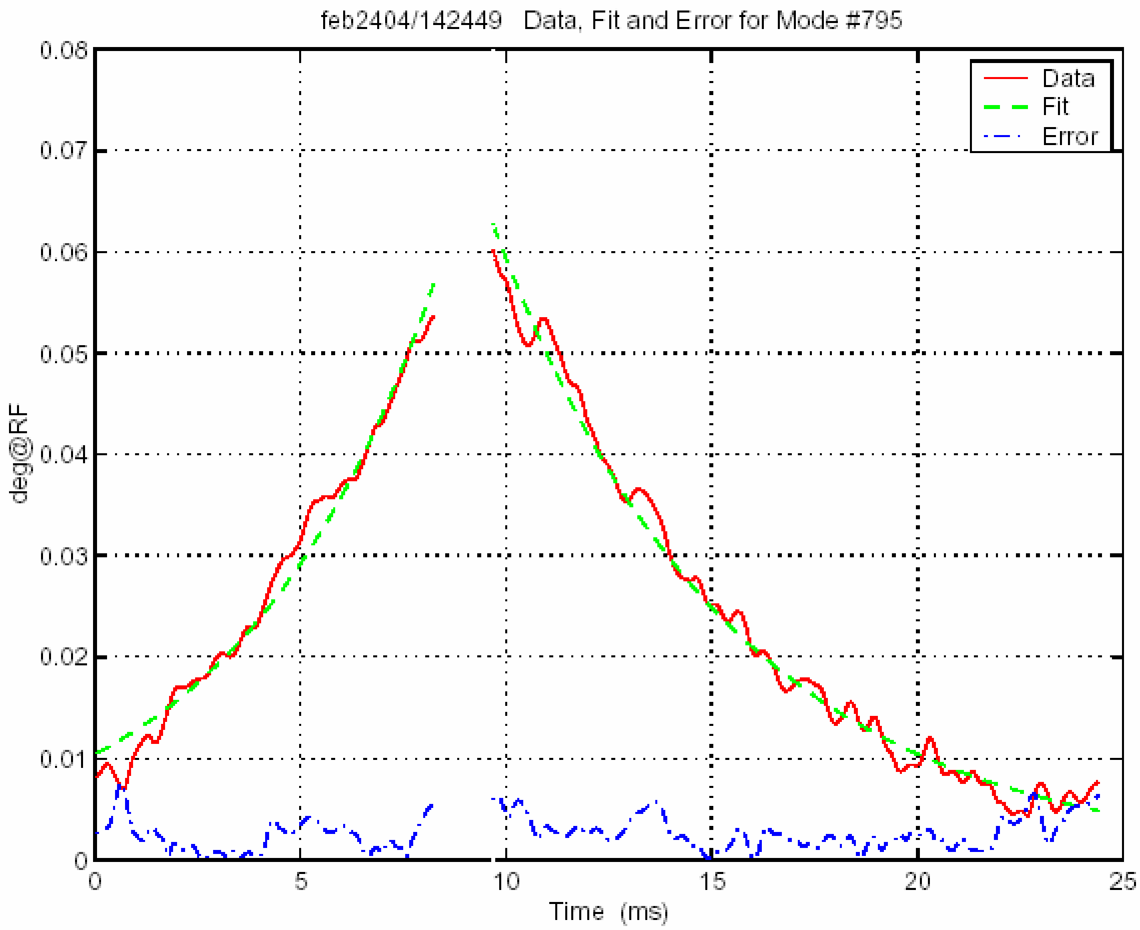
HOM growth and damping rates

Taken at 2x the normal operating gain

Growth rate of 0.2 ms^{-1} and damping rate of 0.17 ms^{-1}.

Very little margin, especially at the nominal gain.

A separate LGDW allows the wideband channel to run at this higher gain providing better HOM control.



LGDW Commissioning summary

This prototype has been tested twice for development MD efforts - it was commissioned in May 2004 and is now run as part of the HER machine configuration.

Commissioning in the HER involved:

- Woofer channel setup and control filter tuning
- Gain partitioning optimization
- Growth and damping rates for the low modes
- Growth and damping rates for the HOMs
- fine tuning of the broadband filter parameters for best partitioning between LGDW and broadband feedback, especially as they interact for the low modes.

The low group-delay woofer was tested up to 1550 mA.

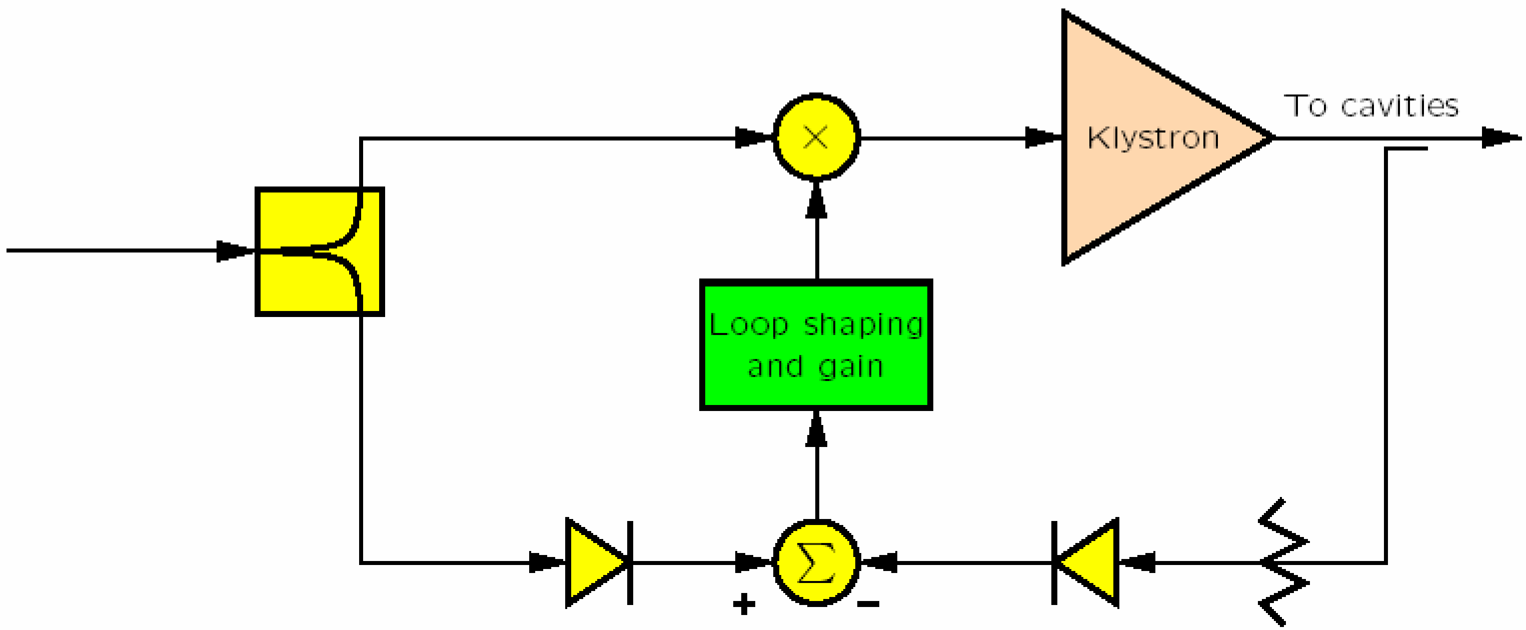
Prior to this LGDW commissioning we were limited to 1380 mA with very tight operational margins - running with 1 -3 longitudinal aborts per day.

Klystron linearizer: block diagram

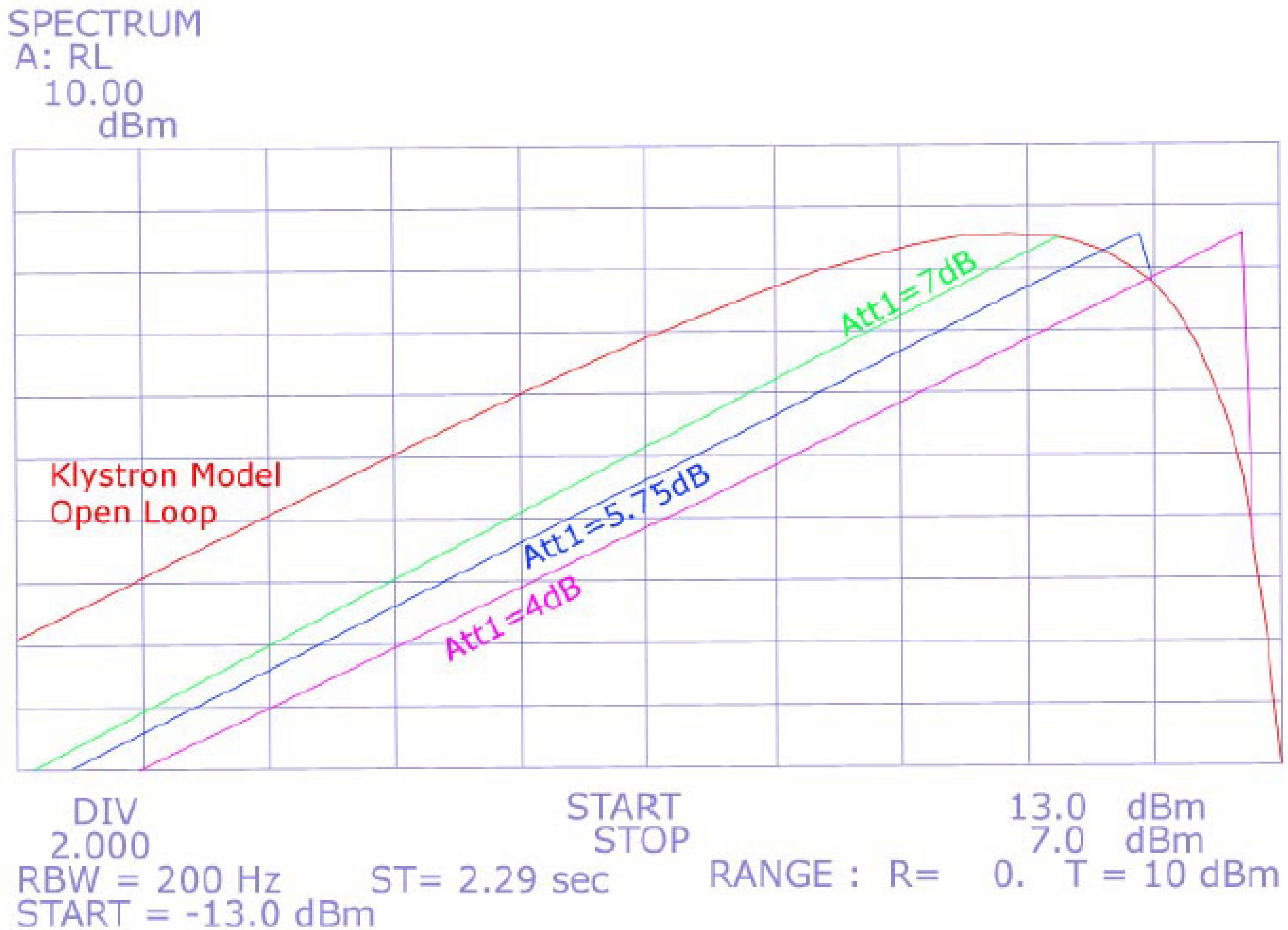
We have started a study to develop a technique to improve the impedance control

Compare the input of the klystron and the output, use amplitude modulator to make the two match. Linearizes the klystron so that large- and small-signal gains are identical. Feedback does increase the effective klystron delay.

Has been simulated, currently testing a bench prototype. We plan to test this idea on one of the PEP-II LER stations before the shutdown.



Dc power levels - klystron model and linearized output



Progress in 2003/2004 - Goals for 2004/2005

Significant accomplishments related to PEP-II high-current commissioning -

- Development and installation of the prototype low group delay woofer, Tests show the channel increases the stable stored current in the HER from 1380 to 1550 (plus) mA.
- Machine development related to measurement and control of coupled-bunch bunch instabilities - studies of transverse and longitudinal stability margins, identification of more optimal configurations for transverse feedback stability.
- Continued analysis of the low-level RF systems and feedback stability, understanding of RF saturation effects on impedance control. Development of klystron linearizer idea, possible applicability of single sideband comb archetecture in PEP-II LLRF systems.
- Transfer of system level knowledge of PEP-II RF to accelerator physicists and operations group via formal 2 day RF tutorial (over 48 particpants). Development of fault file analysis tools, techniques to better configure RF systems. Selection and recruitment of new SLAC staff with RF engineering expertise to stregthen expertise in this area.

GBoard Processing Channel

- Continued design and development of the 1.5 gigasample (GBoard) processing channel (joint development project with KEK and LNF-INFN). Simplification of ECL high speed mux-demux functions into FPGA based reconfigurable logic, initial lab tests of high speed links between ADC and FPGA components in this scheme.

Goals for 2004/2005

- commissioning of Gboard 1.5GS/sec. baseband channel, initial tests at PEP-II and other facilities
- Lab and Accelerator tests of the prototype klystron linearizer
- Commissioning of the production low group delay woofer channels for HER and LER
- High-Current PEP-II stability analysis and technology R&D for increased currents and luminosity