Status of High-Power Tests of Dual Mode SLED-II Sysytem for an X-Band Linear Collider

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Outline

- Introduction
- System Layout
- Component Designs
- System Cold Tests
- High-Power Results
- Conclusions

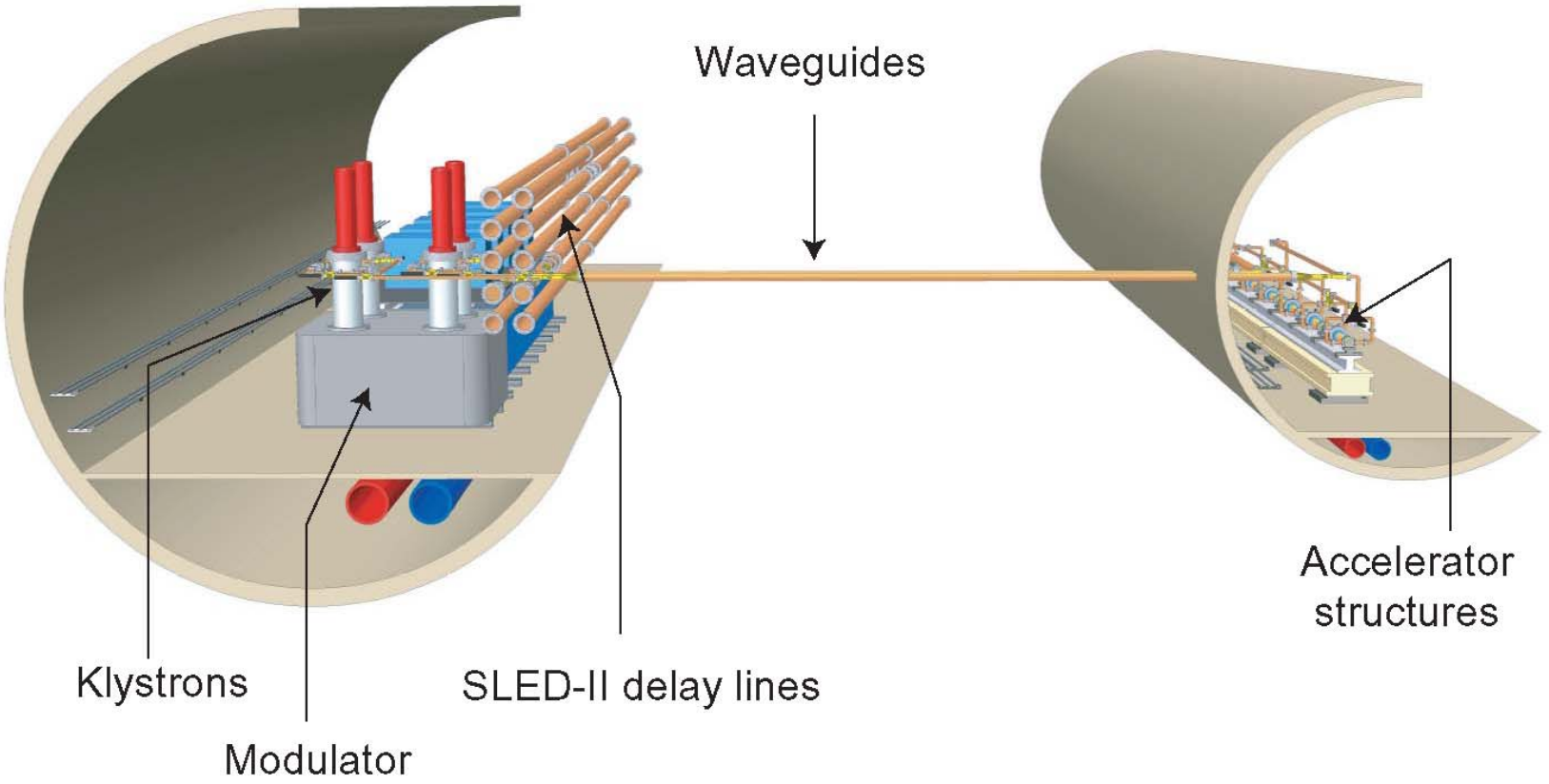
Motivation

- The X-band linear collider requires a waveguide system to compress, transmit, and distribute ultra high power rf pulses to the accelerating structures.
- Pulse compression is used to match the pulse width capability of klystrons to the pulse width requirement of the accelerator.
- The design, construction, and reliable operation of a prototype rf system, capable of handling peak power levels on the order of half a *gigawatt*, is the focus of this project at SLAC.

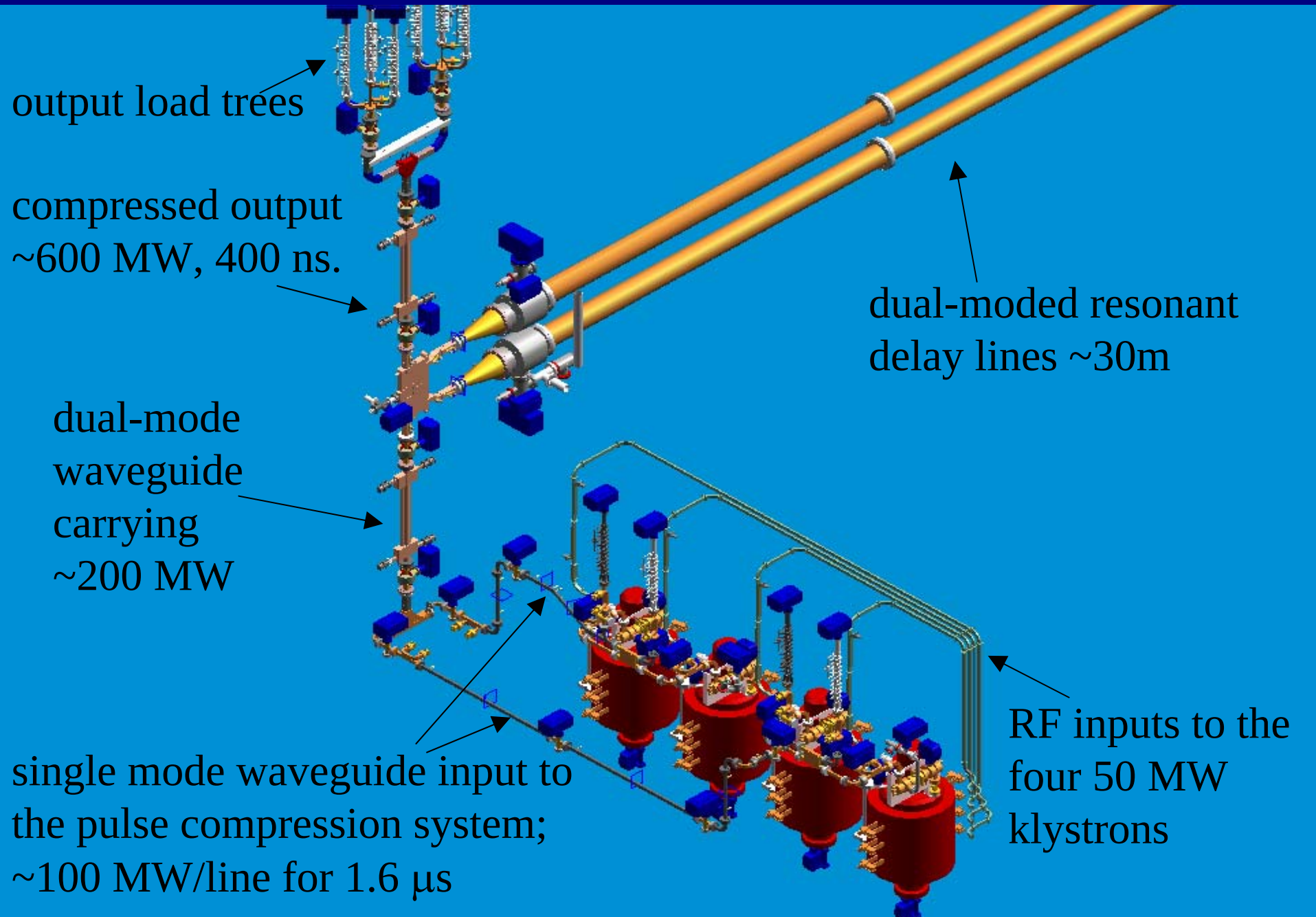
Highlights

- We have reliably produced and manipulated flat 400 ns rf pulses carrying over 500 MW.
- We have developed waveguide components capable of manipulating hundreds of megawatts.
- We have utilized dual-moding, both for power direction and for shortening delay lines.
- We have demonstrated an advanced X-band rf system which meets the basic requirements for the Next Linear Collider.

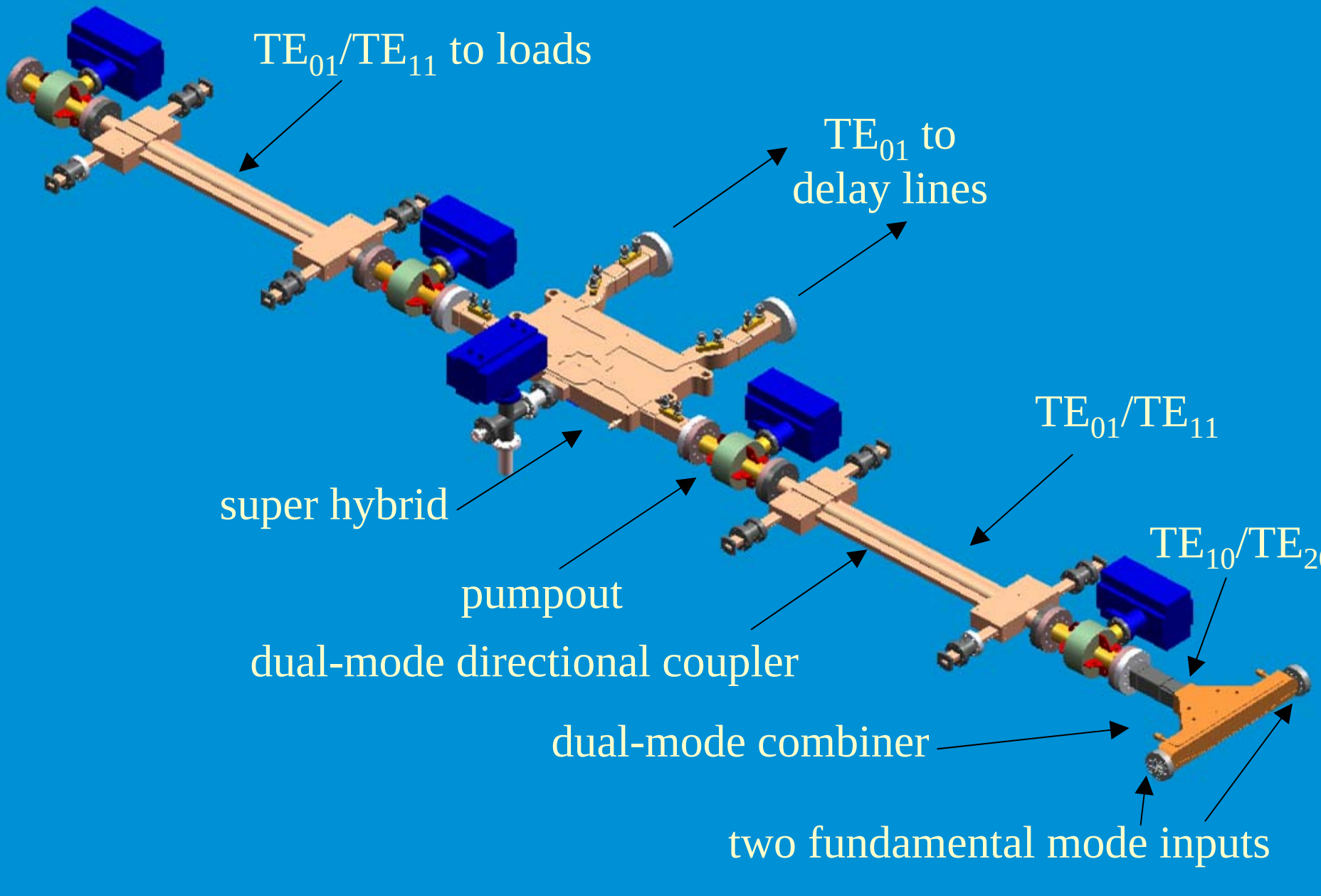
Linear Collider Cross-Section Layout



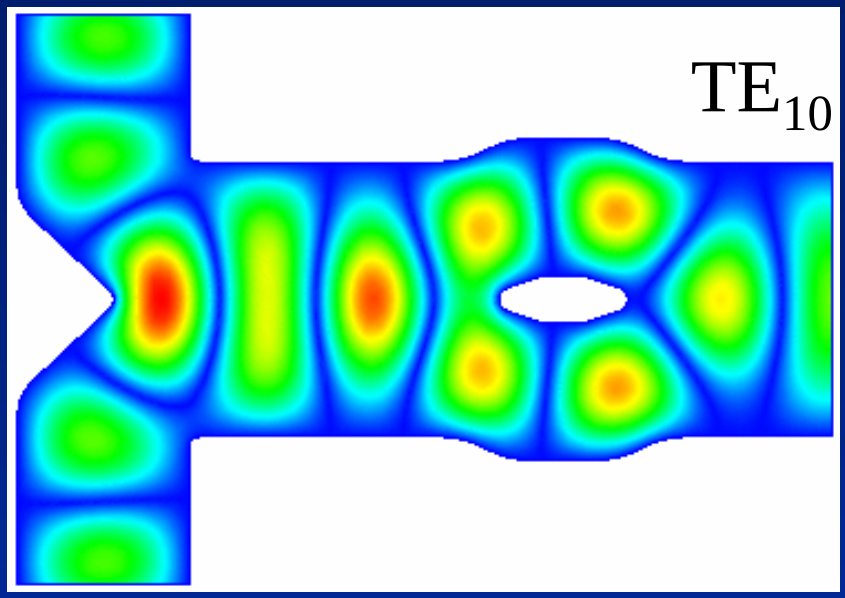
The Experimental RF Pulse Compression System

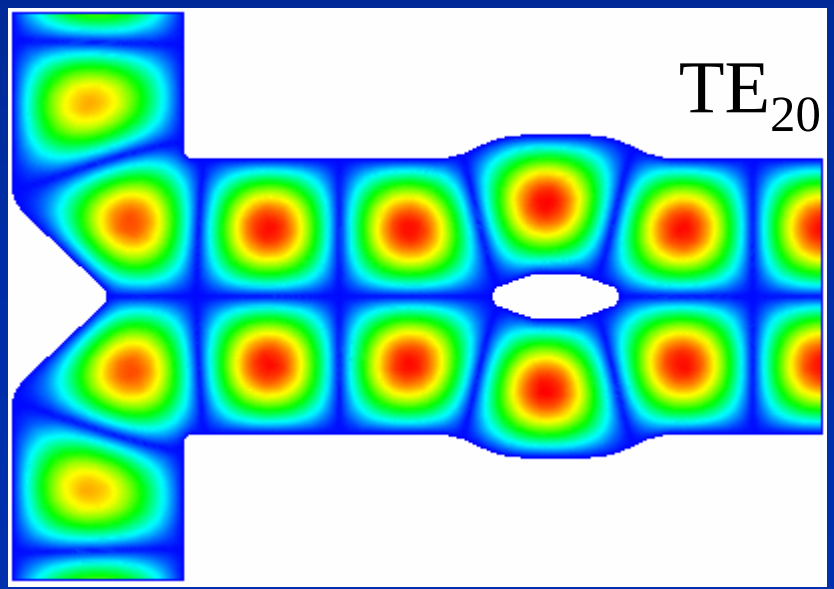


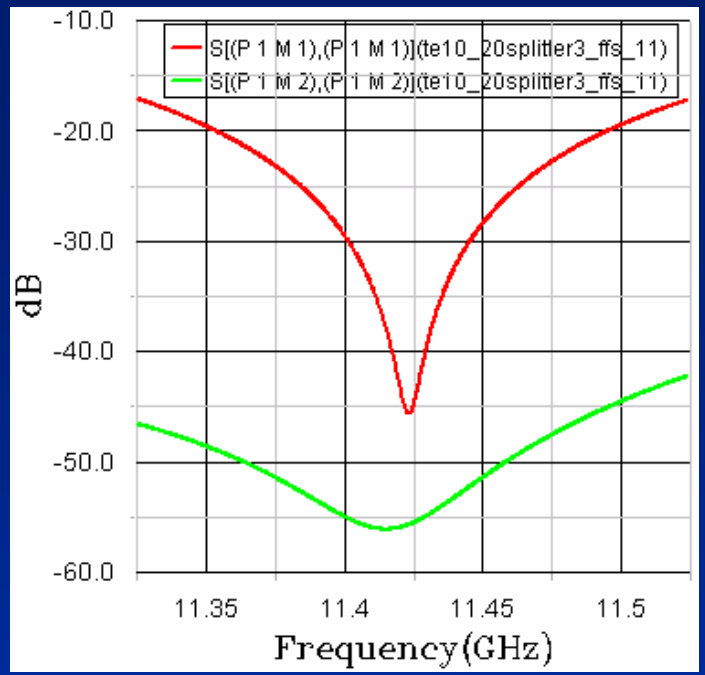
The Heart of the Pulse Compression System

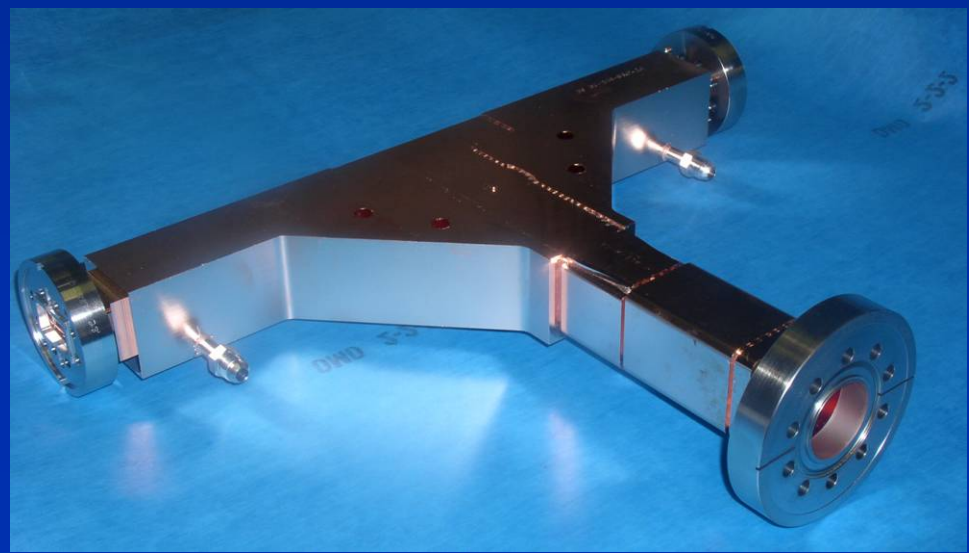


Dual-Mode Combiner

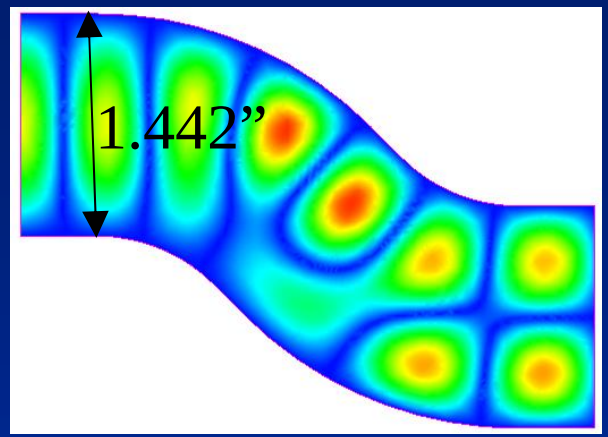


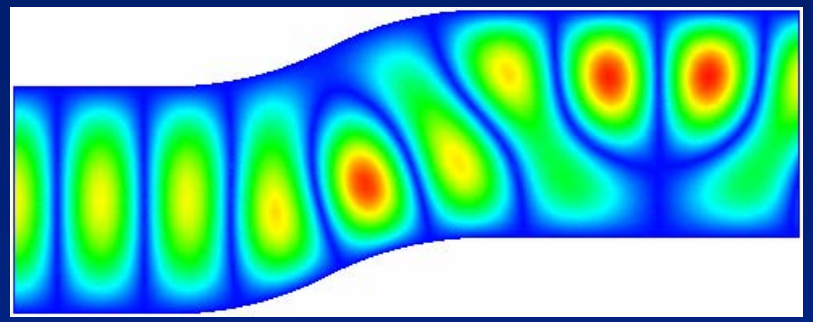




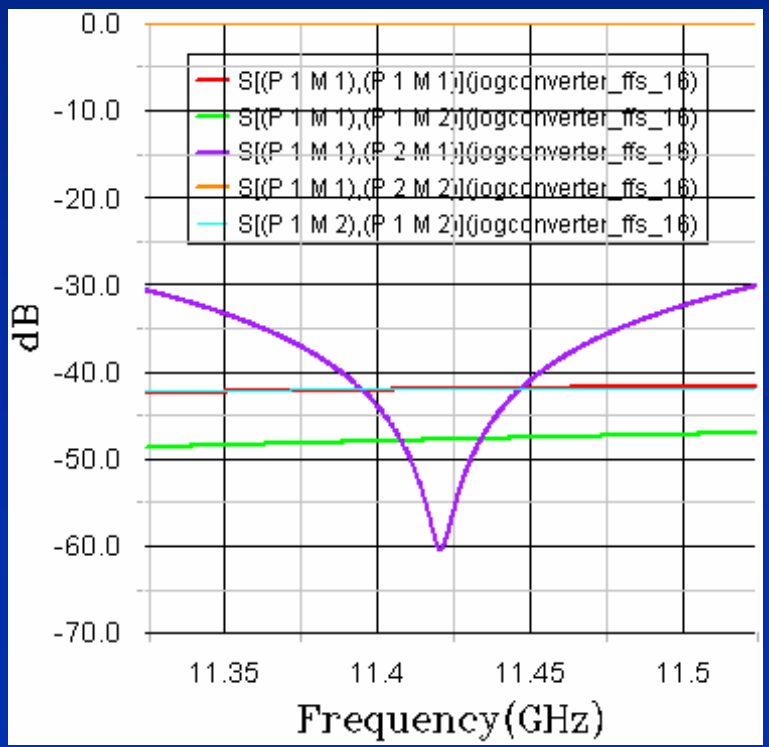


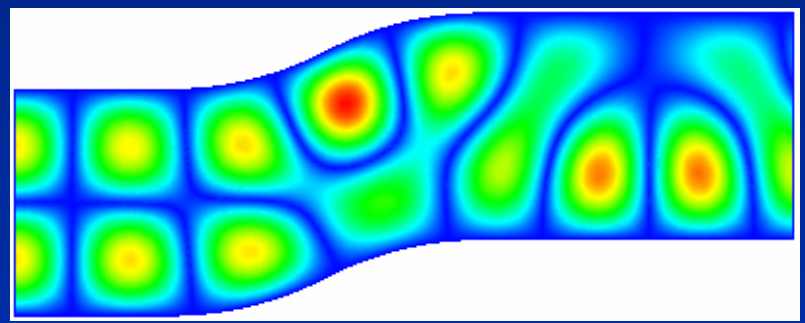
Jog Converter and Mode Mixer





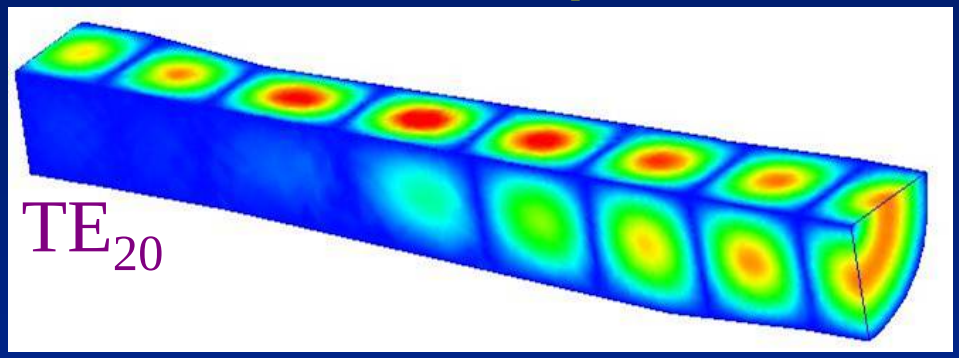
orthogonal
50/50 mixes



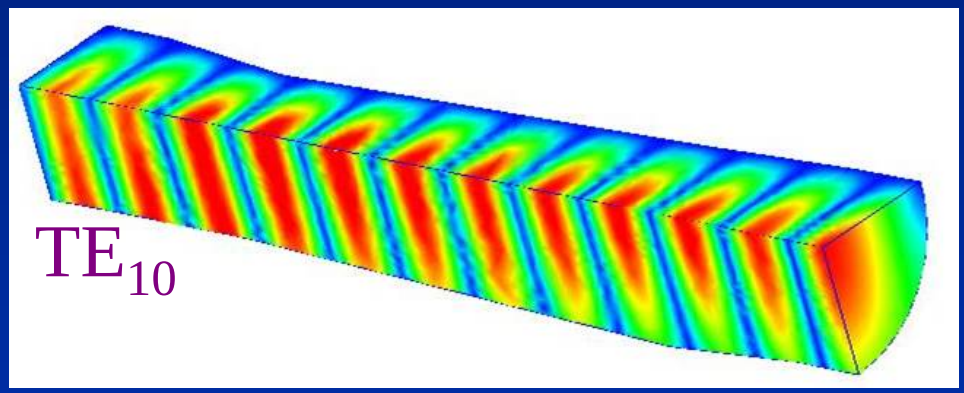


	(P 1 M 1)	(P 1 M 2)	(P 2 M 1)	(P 2 M 2)
(P 1 M 1)	0.0018	0.0048	0.707	0.7072
(P 1 M 2)	0.0048	0.0087	0.7072	0.707
(P 2 M 1)	0.707	0.7072	0.0019	0.0048
(P 2 M 2)	0.7072	0.707	0.0048	0.0087

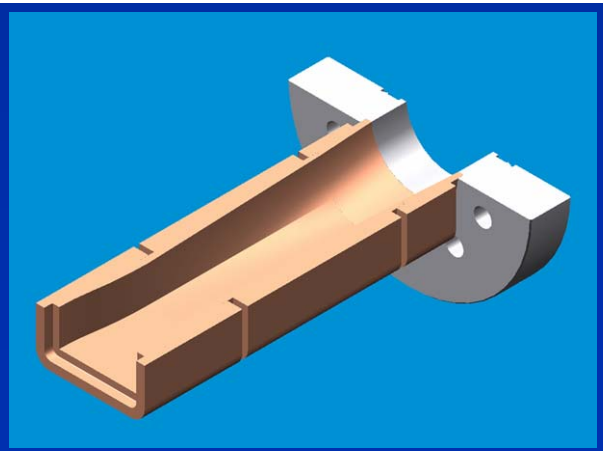
Dual-Mode Rectangular-to-Circular Taper Mode Converter

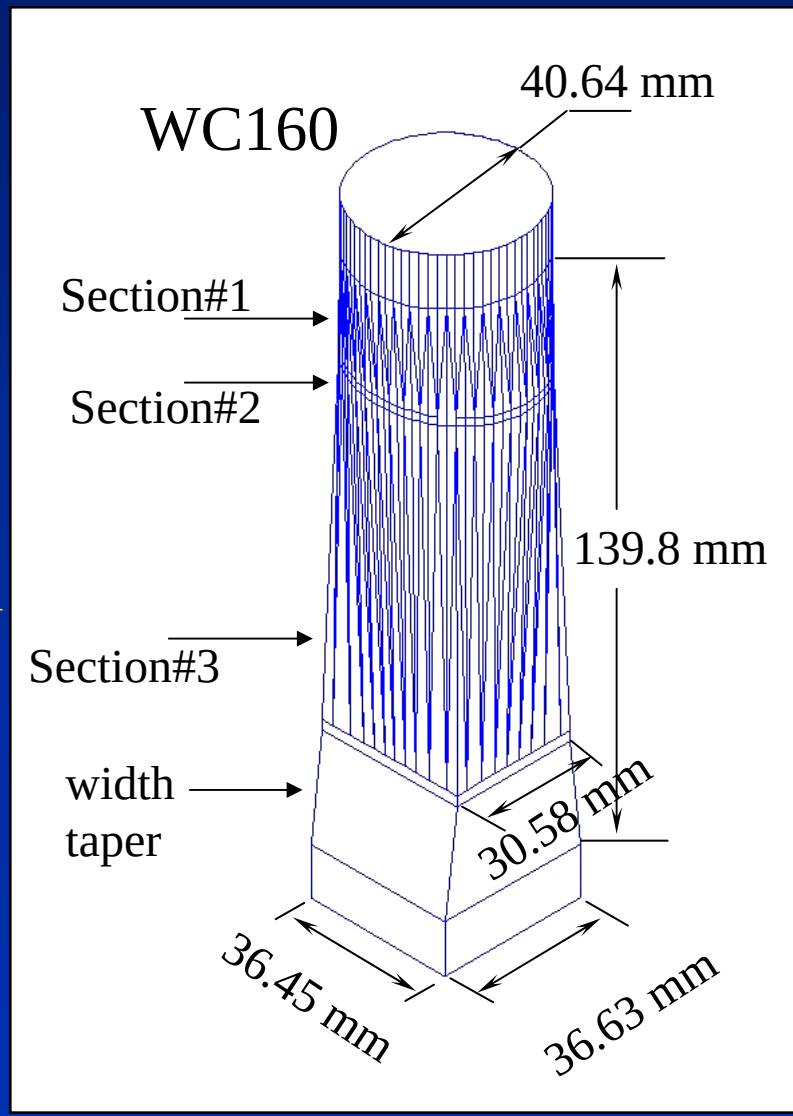


TE_{01}

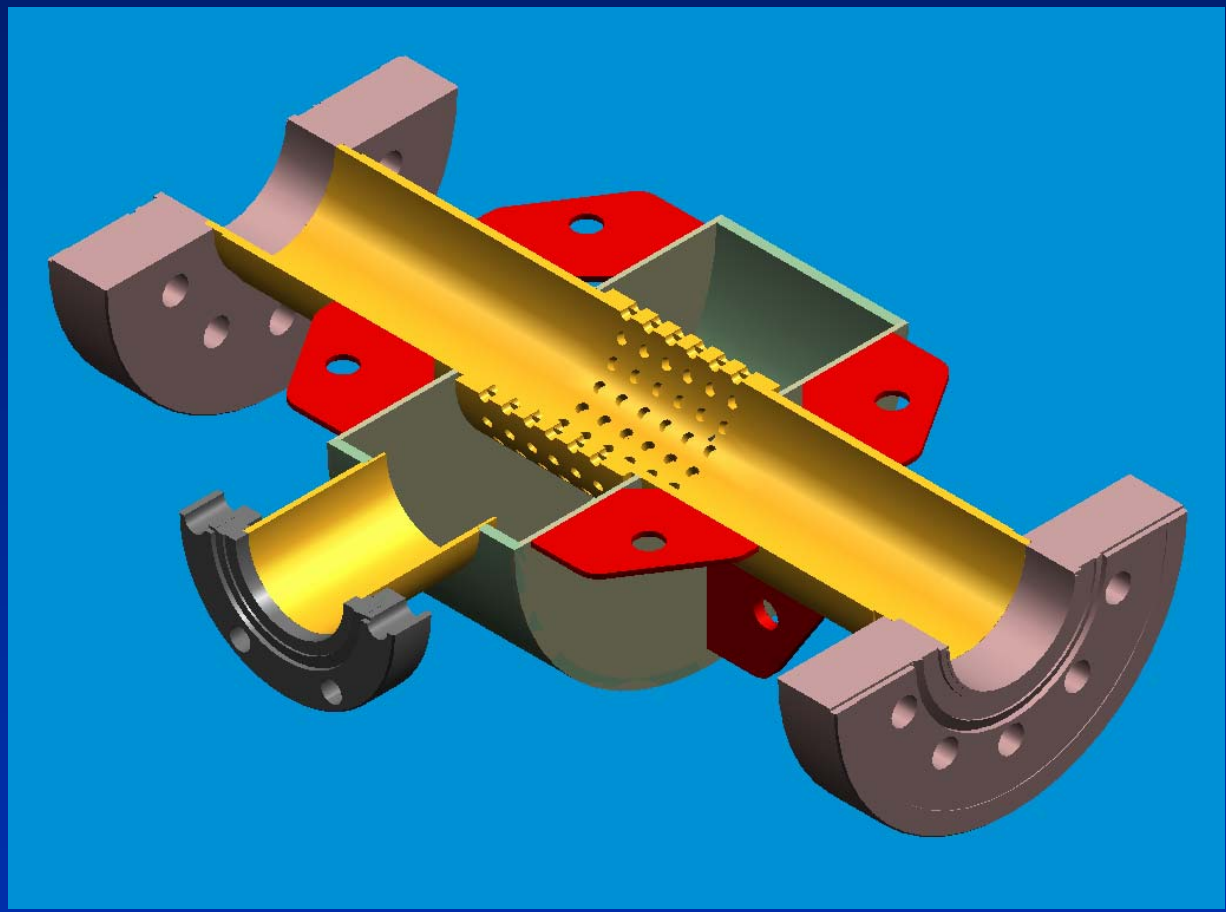


TE_{11}



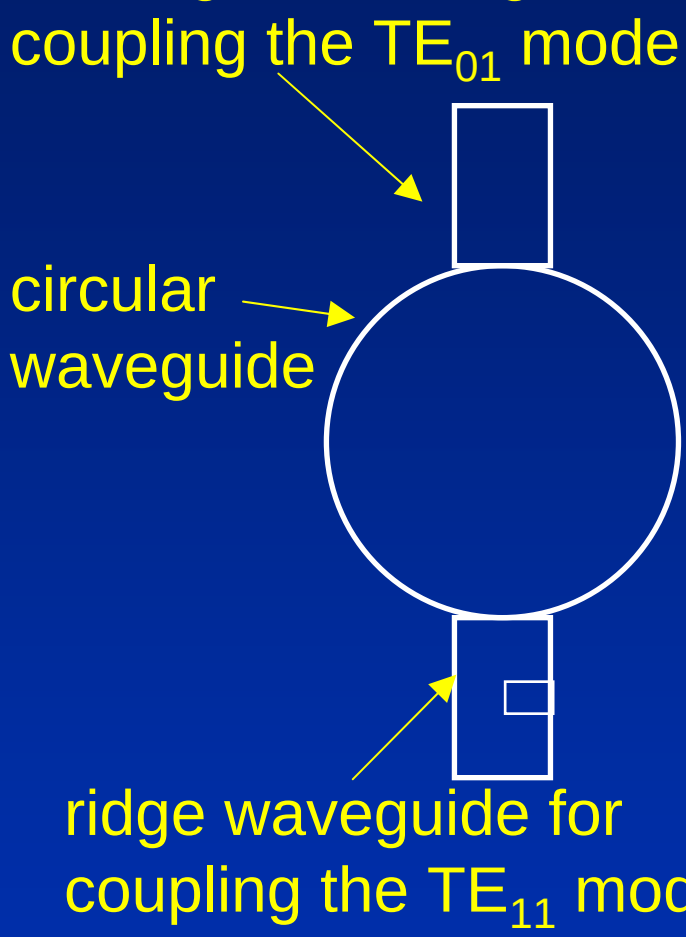


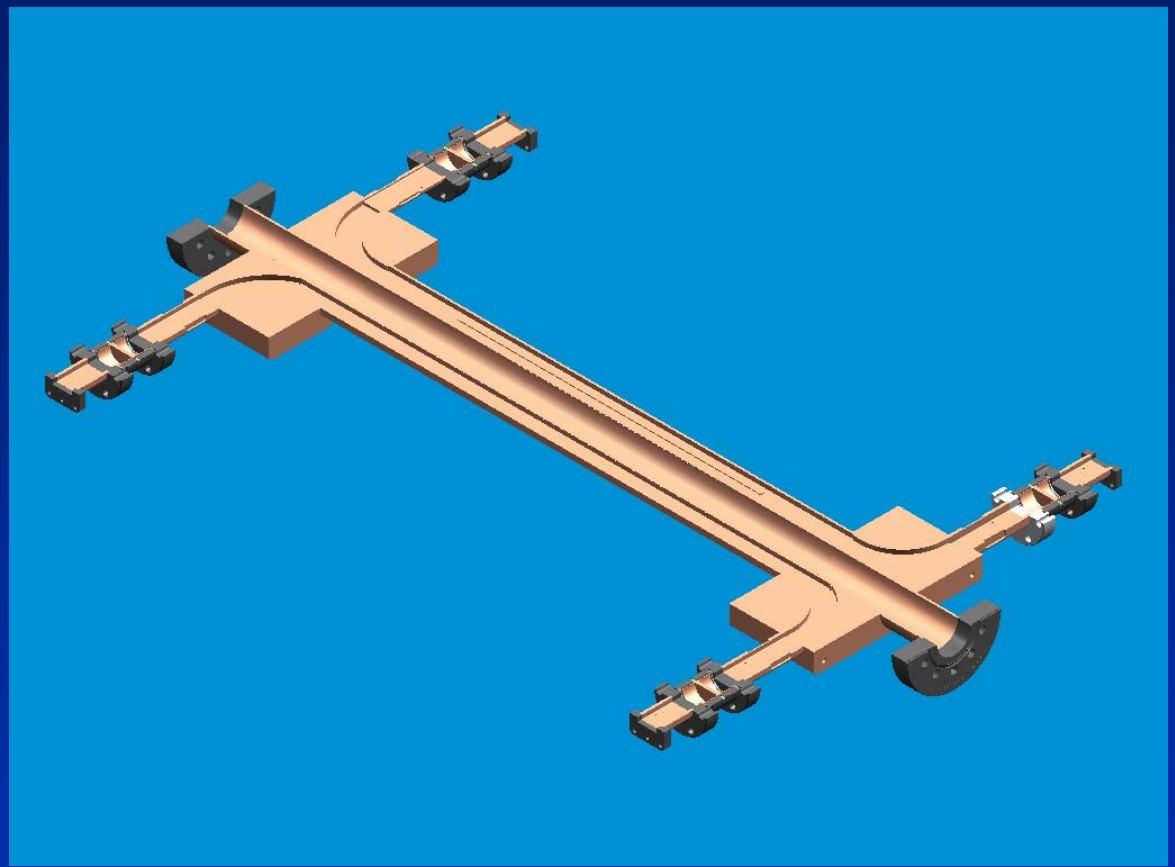
Dual-Mode Vacuum Pumpout



The hole pattern is designed to cancel any coupling or reflection for the TE_{01} and TE_{11} modes.

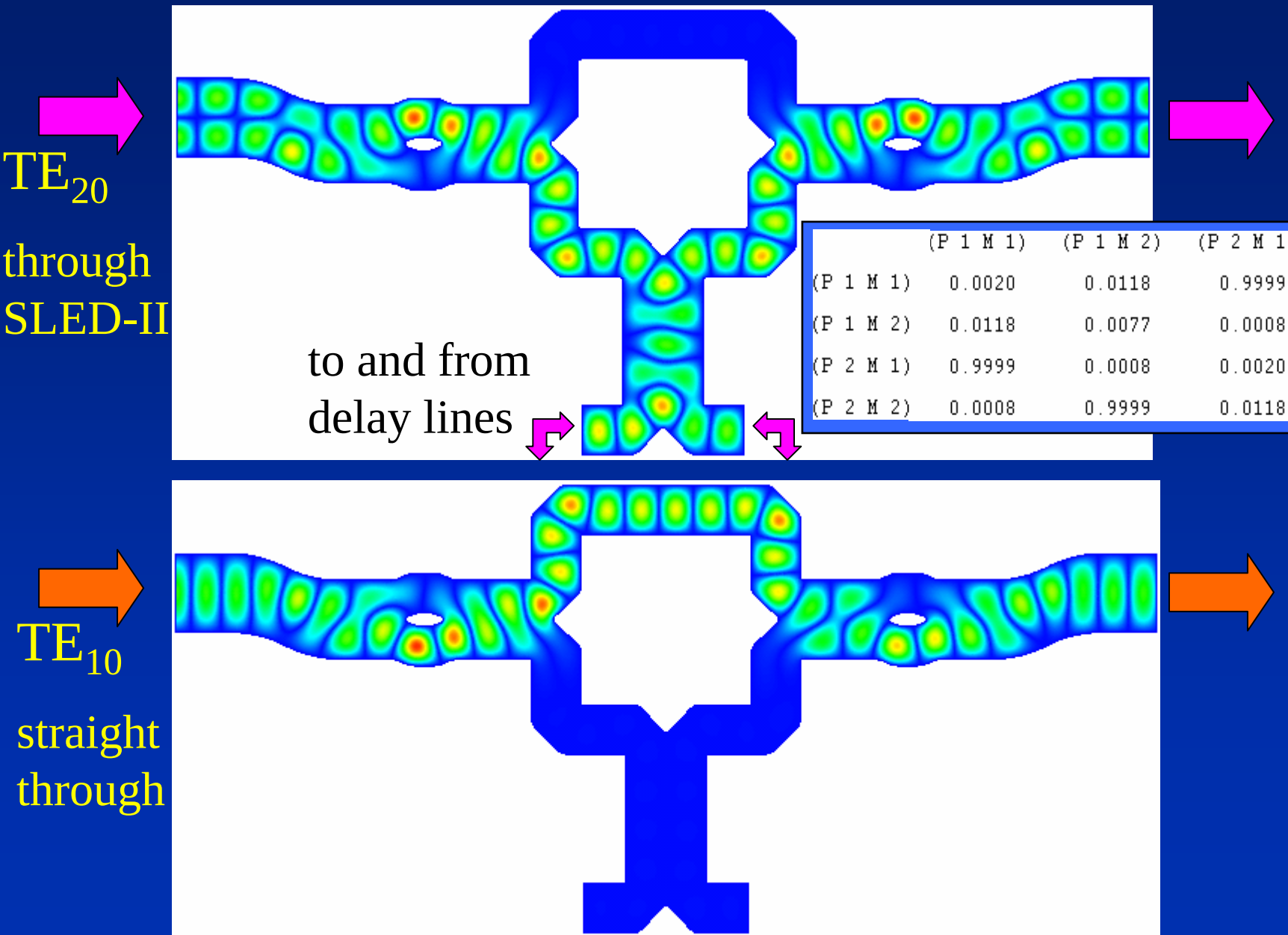
Dual-Mode Directional Coupler





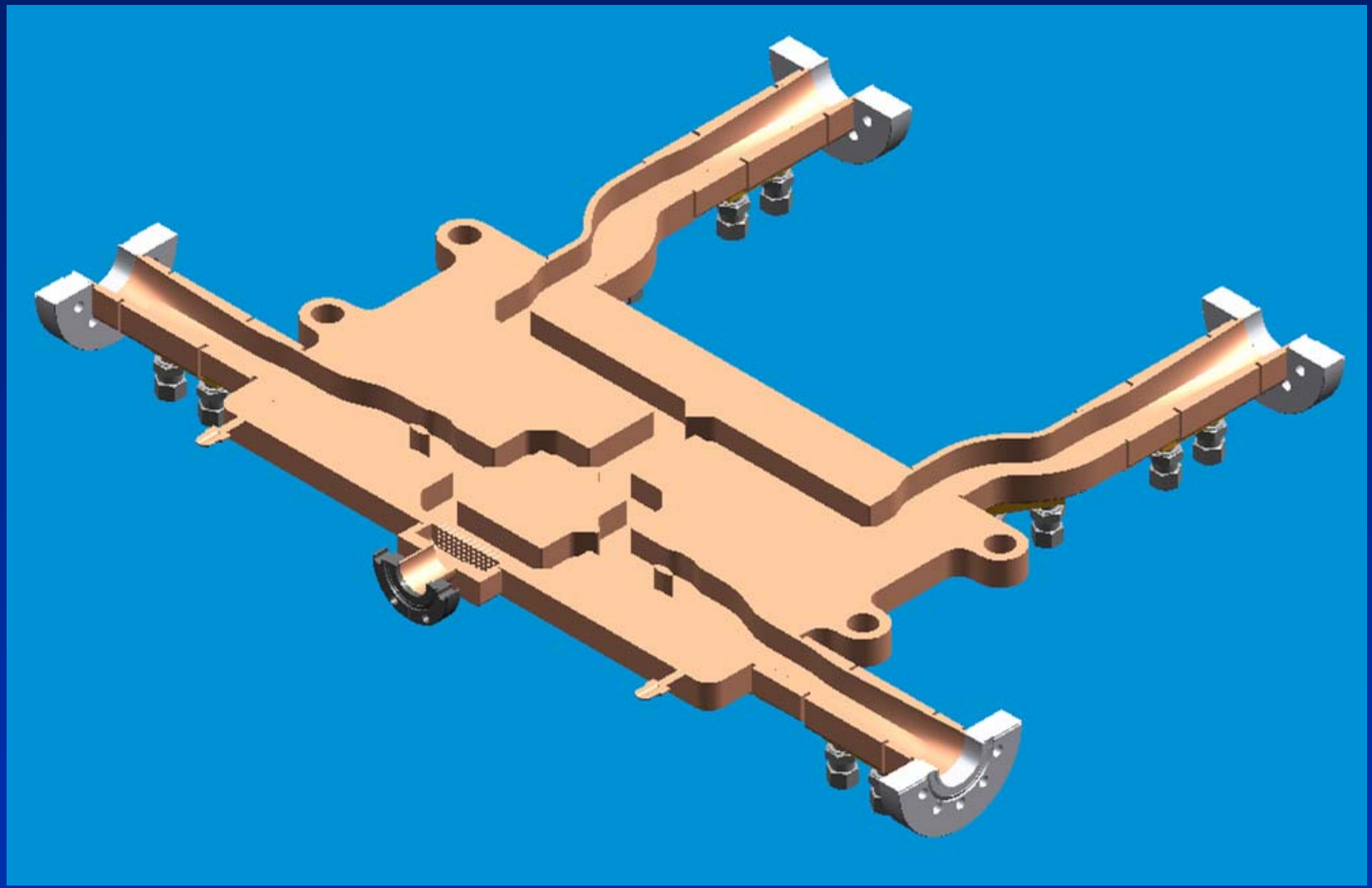
- **waveguide sizes chosen to match wavelengths in side waveguides to circular waveguide modes.**
- **coupling hole patterns represents Hamming windows.**

8-Pack Dual-Mode SLED Head



	(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

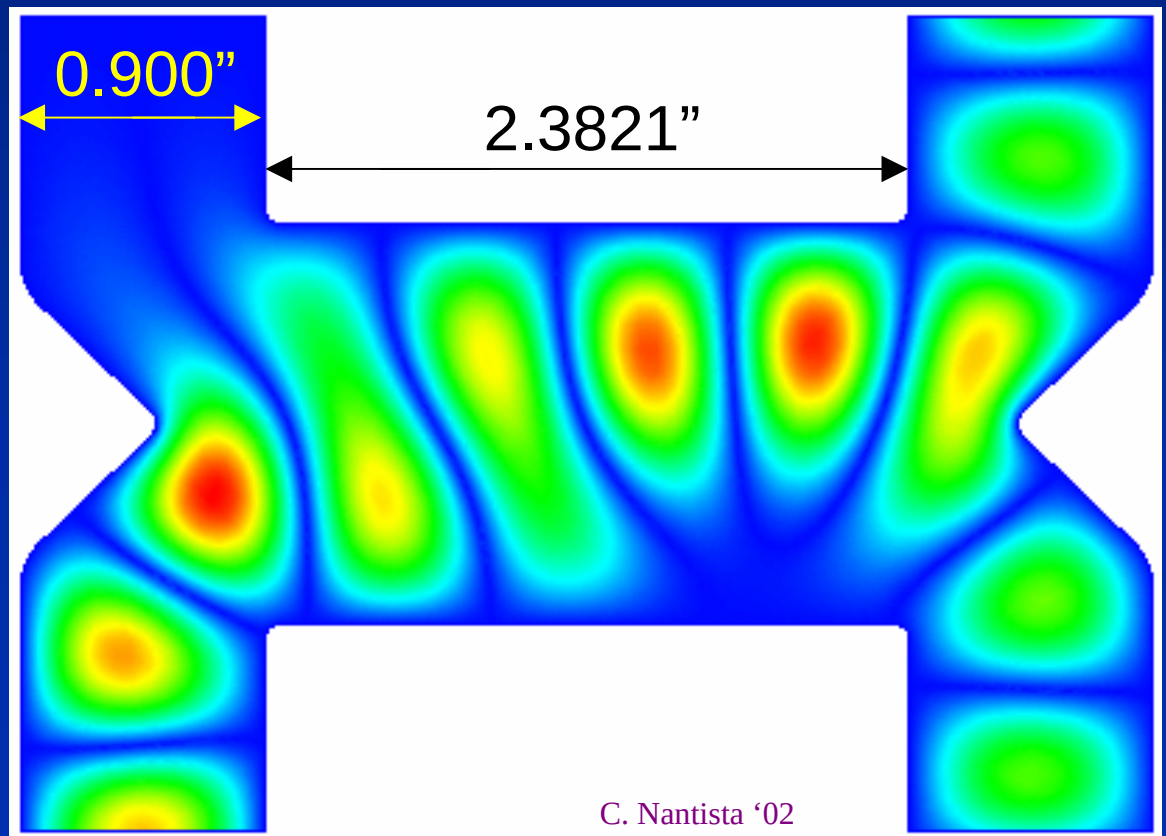
SLED Head Mechanical Design

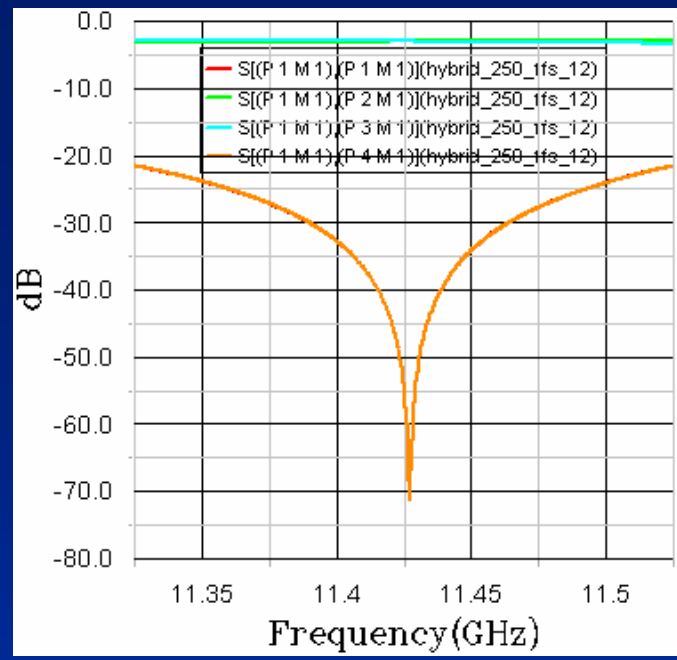


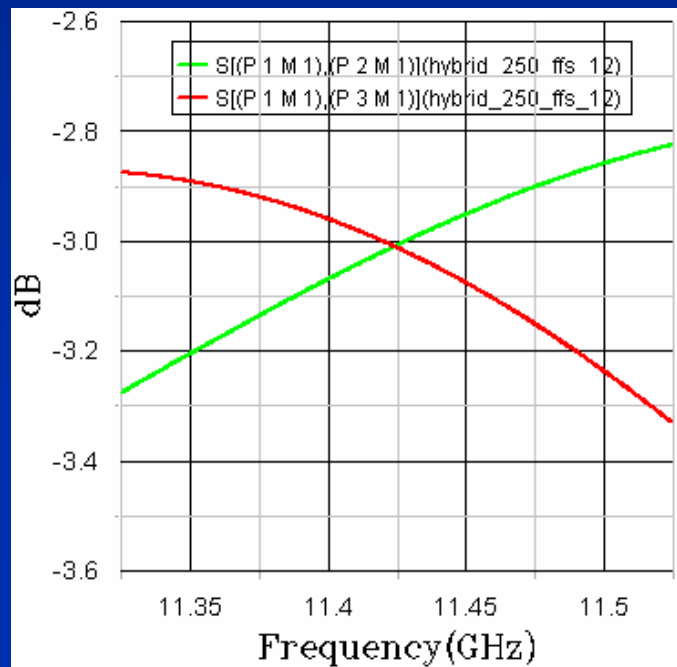
equivalent to three planar hybrids on one single substrate

Magic H Hybrid

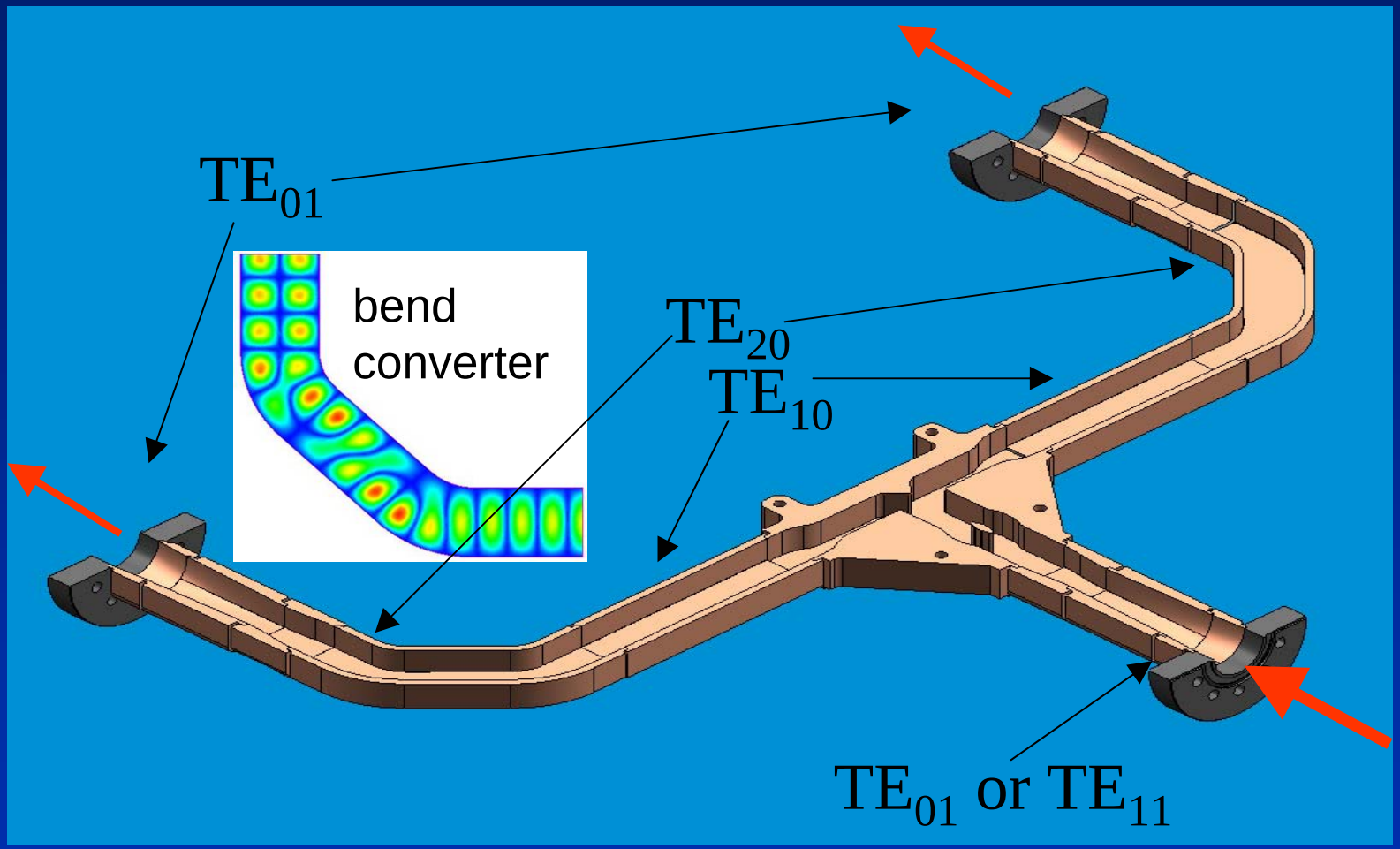
	(P 1 M 1)	(P 2 M 1)	(P 3 M 1)	(P 4 M 1)
(P 1 M 1)	0.0028	0.7071	0.7071	0.0028
(P 2 M 1)	0.7071	0.0028	0.0028	0.7071
(P 3 M 1)	0.7071	0.0028	0.0028	0.7071
(P 4 M 1)	0.0028	0.7071	0.7071	0.0028







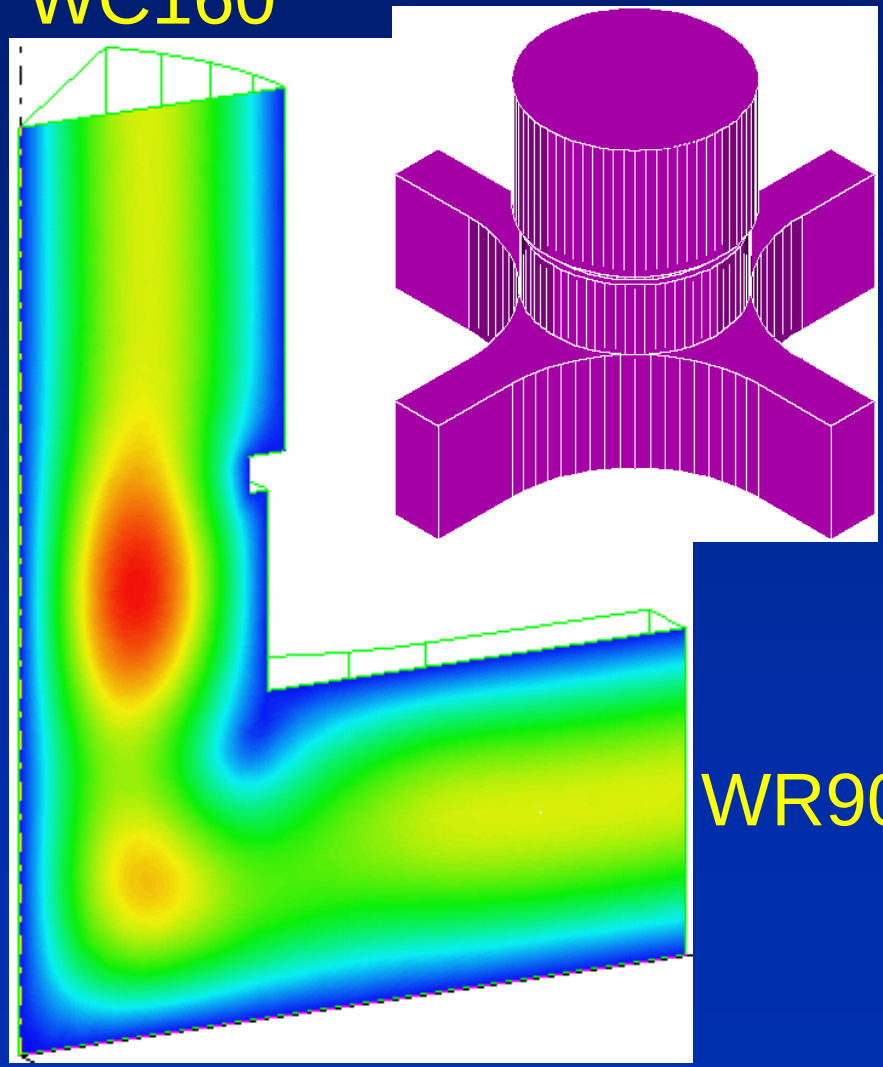
Dual-Mode Splitter



For either incident mode, power is evenly divided between the two output ports, which launch TE_{01}.

Quadrapus TE_{01} Four-Way Power Splitter

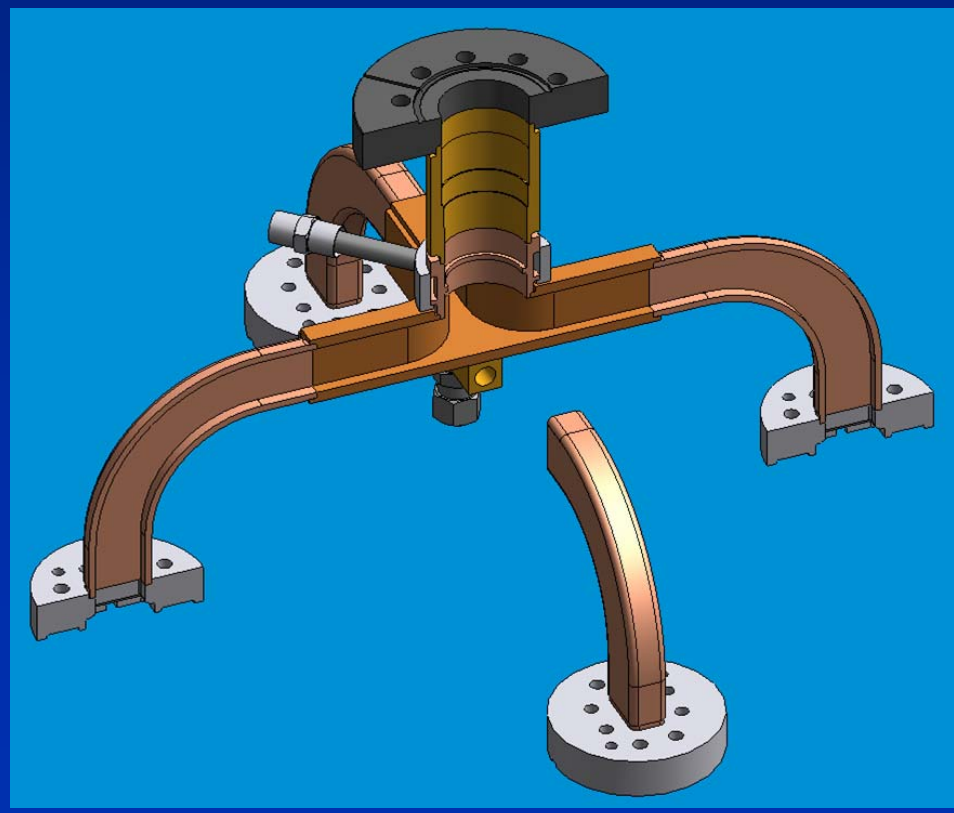
WC160

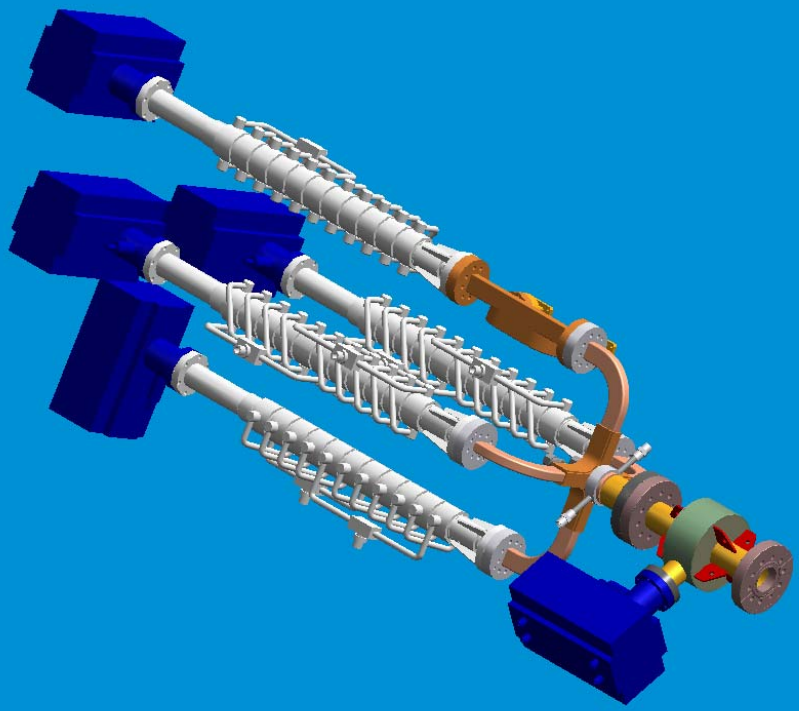


WR90

$|S_{11}| < -57$ dB @ 11.424 GHz

< -30 dB over ~180 MHz



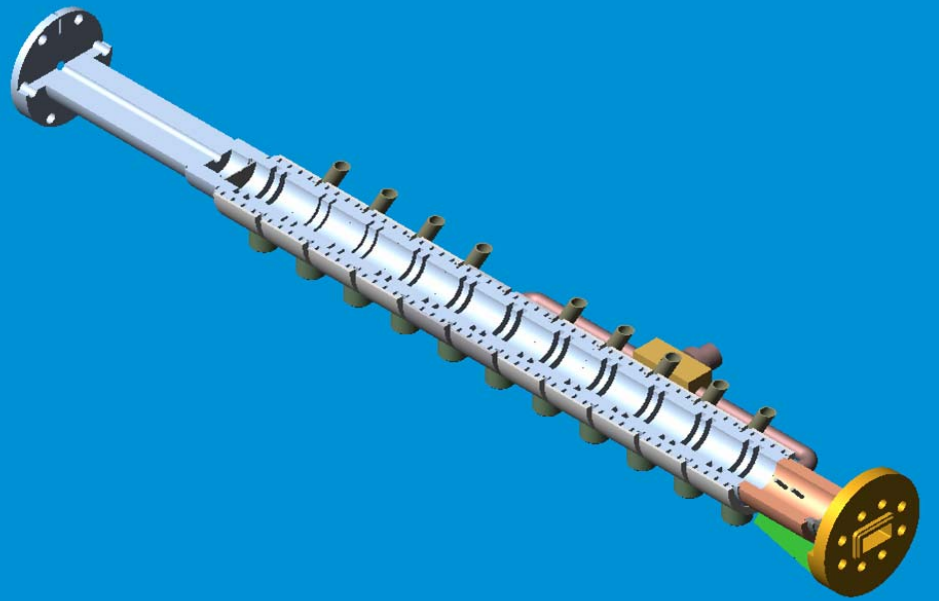


Load Tree

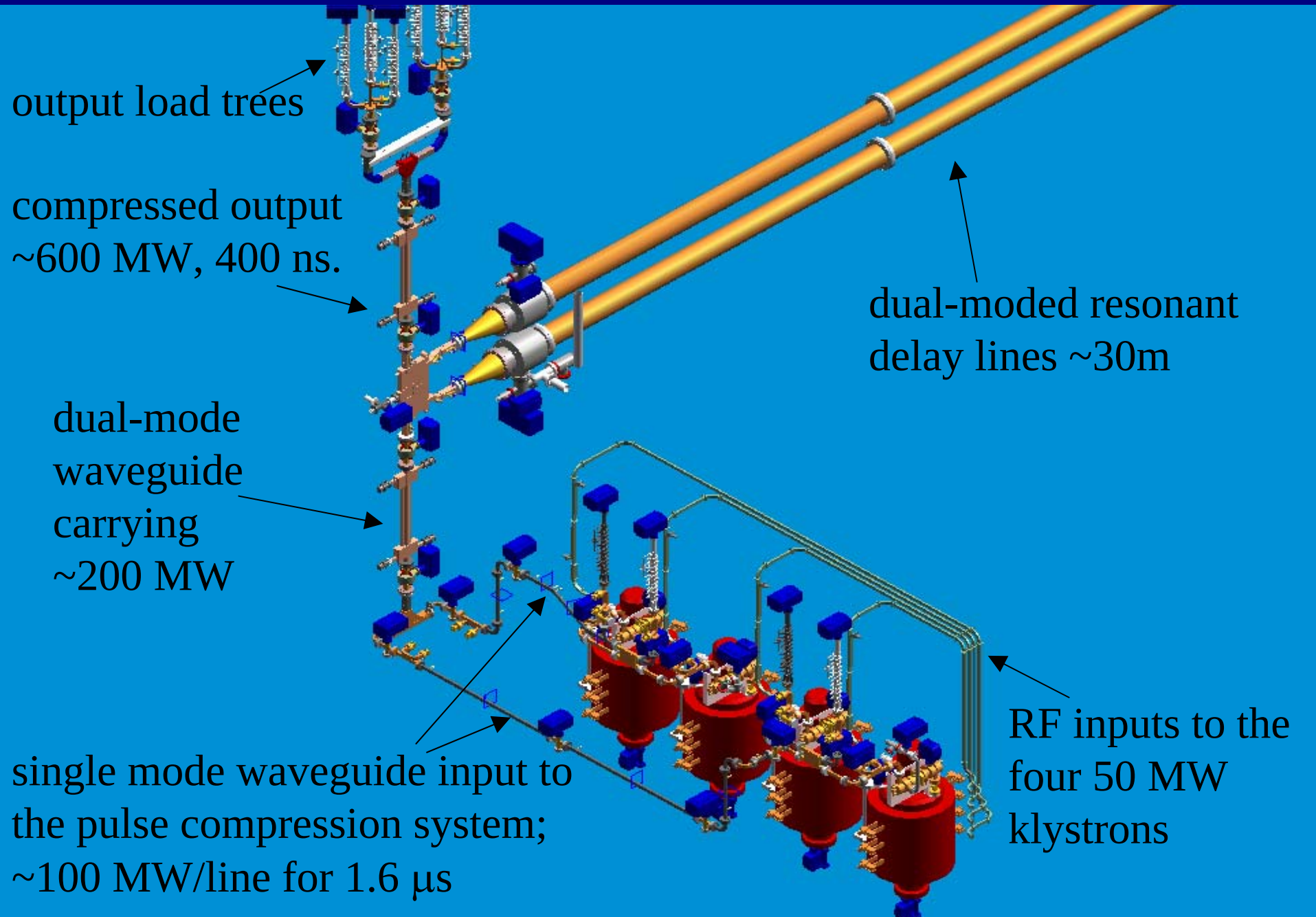
The input power, carried by the TE_{01} mode, is split 4 ways to be absorbed at the loads

High-Power Load

Magnetic stainless steel carrying circularly polarized TE_{11} past matched pairs of partial choke grooves.



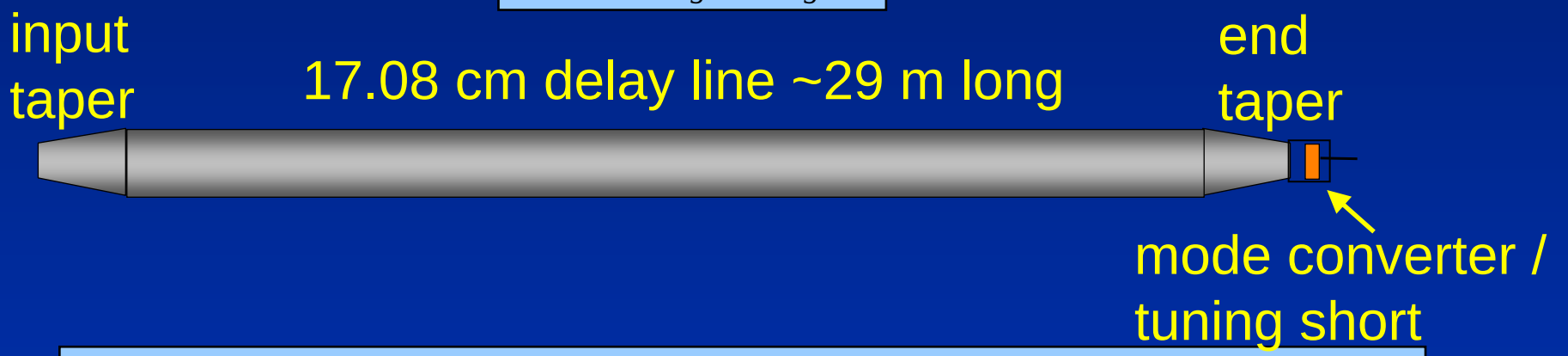
The Experimental RF Pulse Compression System

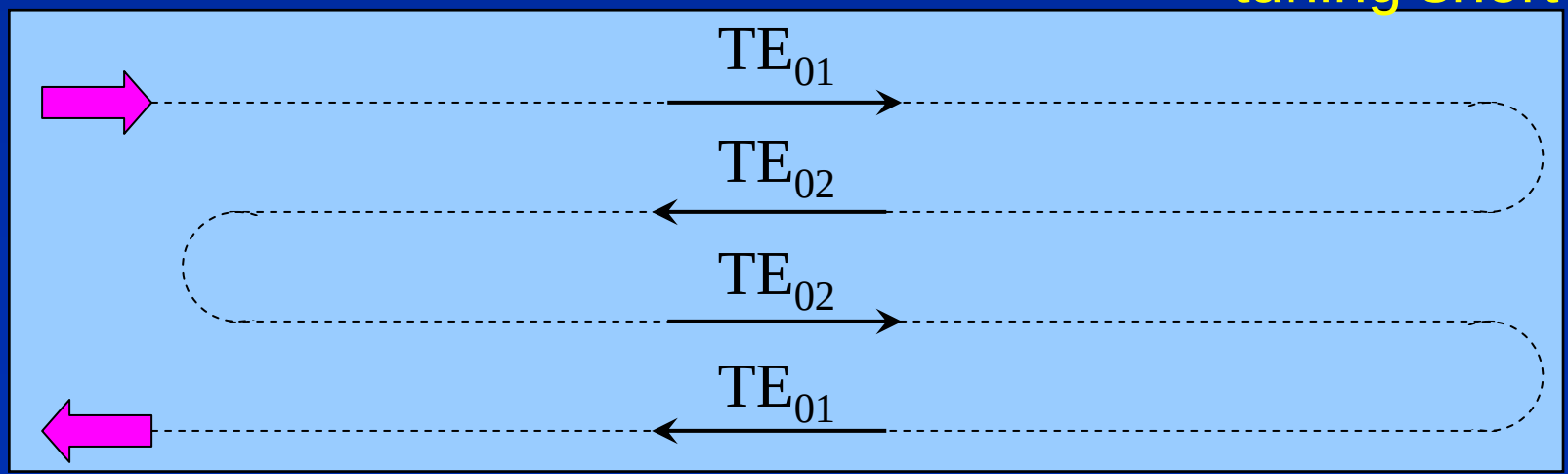


Dual-Moded Delay Line

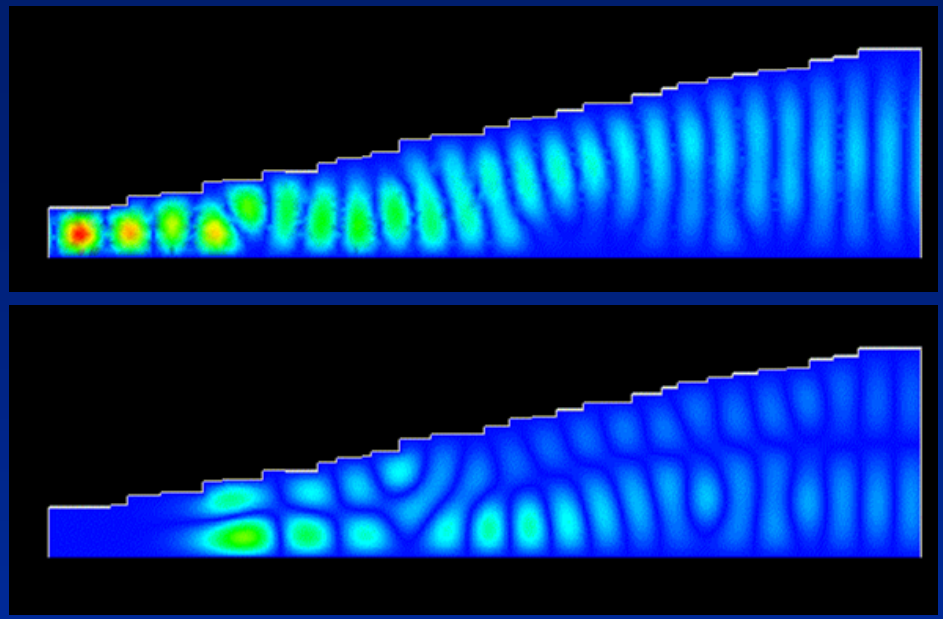
Dual-moding the delay lines cuts their required length approximately in half.

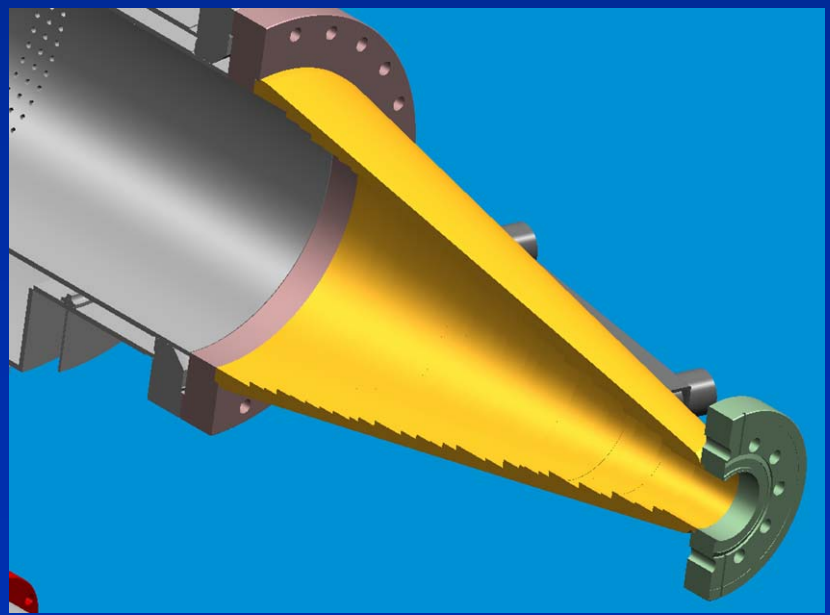
$$L = \frac{T}{2}\frac{v_{g1}v_{g2}}{v_{g1}+v_{g2}}$$

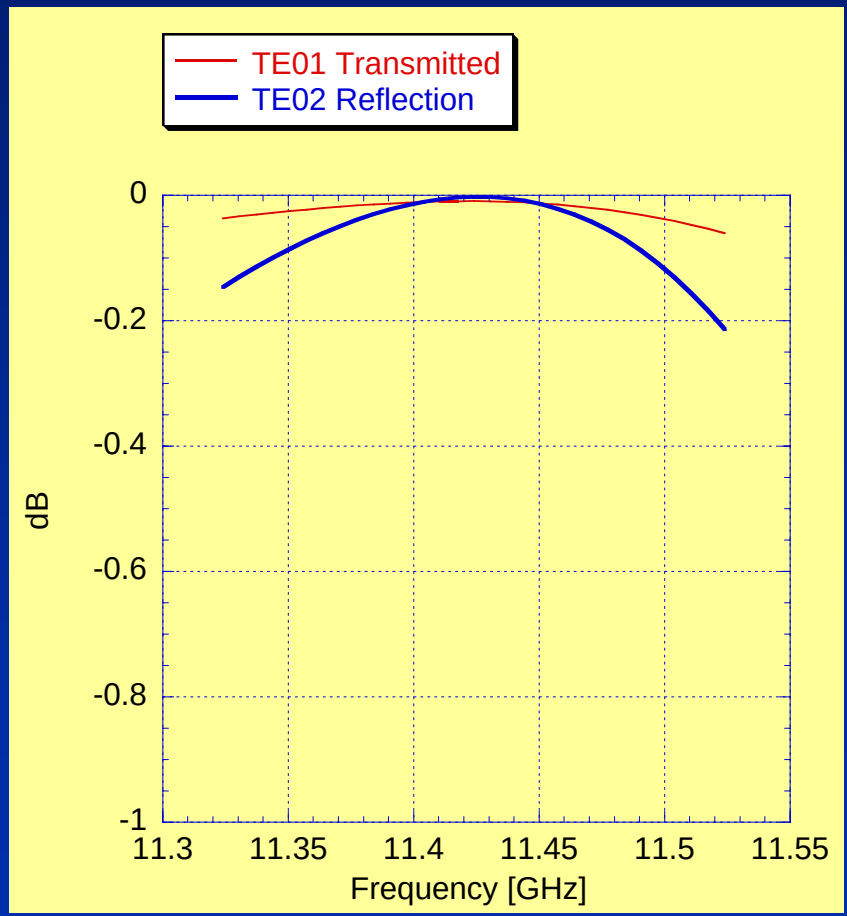




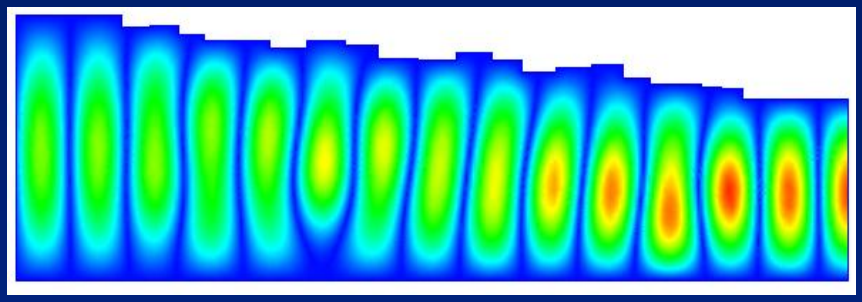
Input Taper

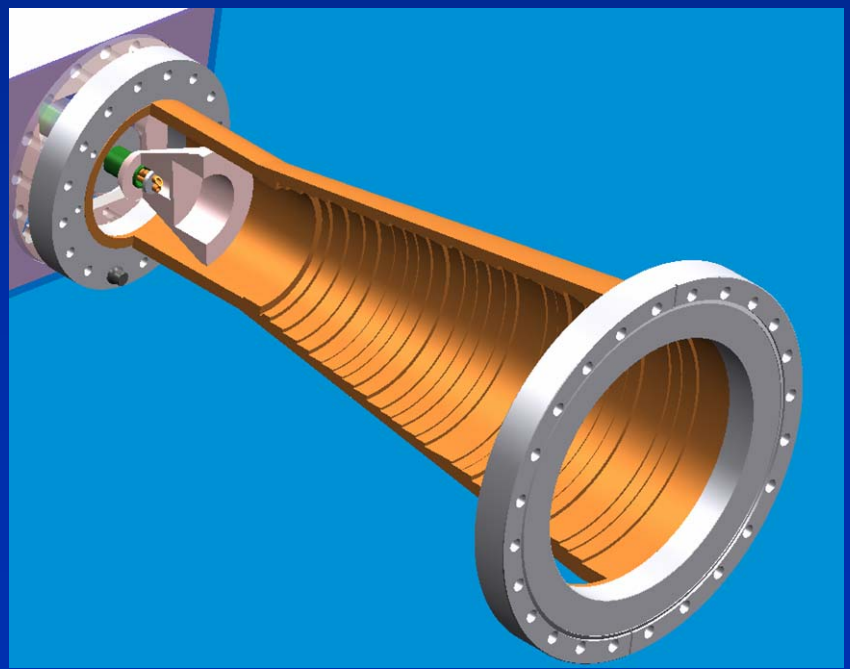


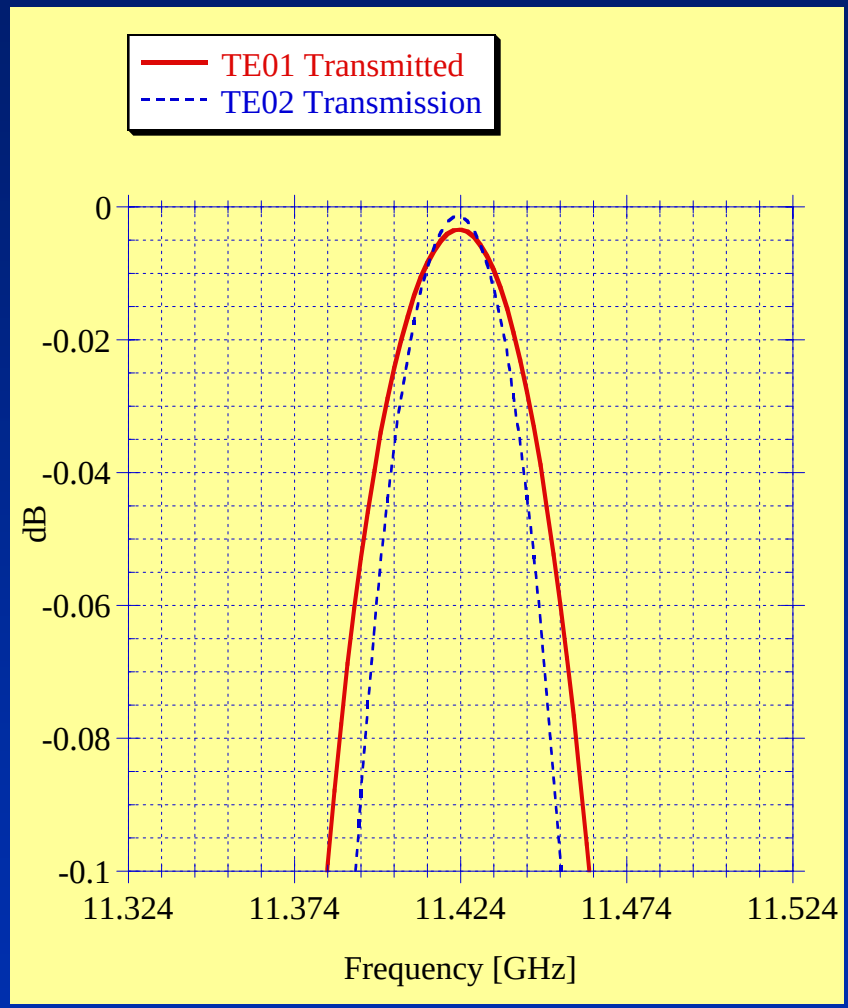



TE01 Transmitted
TE02 Reflection
0
-0.2
-0.4
-0.6
-0.8
-1
dB
11.3
11.35
11.4
11.45
11.5
11.55
Frequency [GHz]

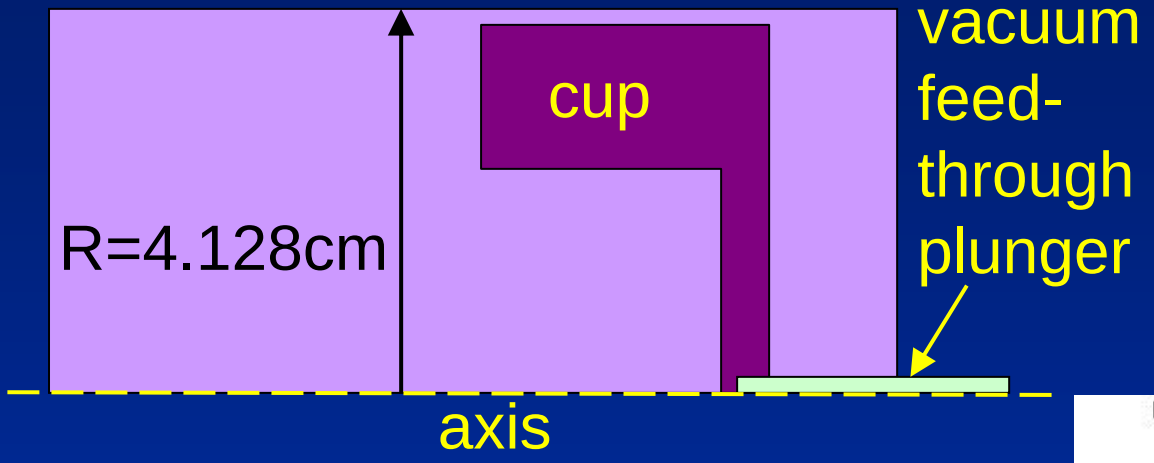
End Taper

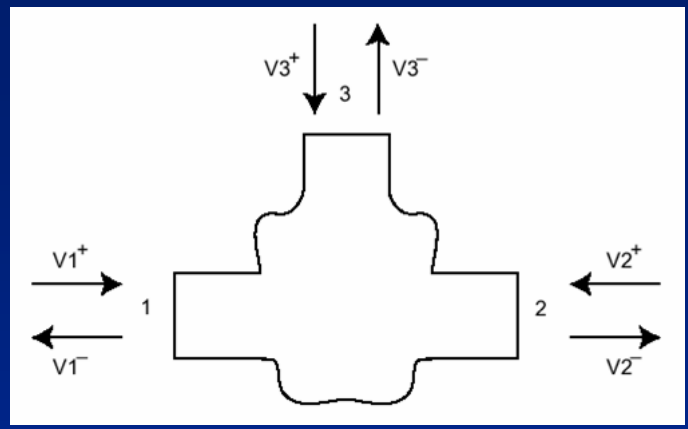


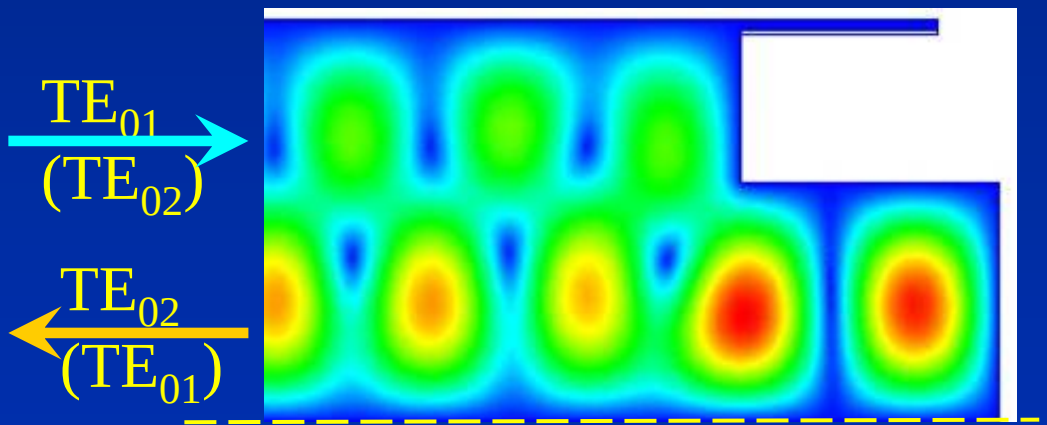



TE01 Transmitted
TE02 Transmission
0
-0.02
-0.04
-0.06
-0.08
-0.1
dB
11.324
11.374
11.424
11.474
11.524
Frequency [GHz]

Reflective TE_{01}/TE_{02} Mode Converter

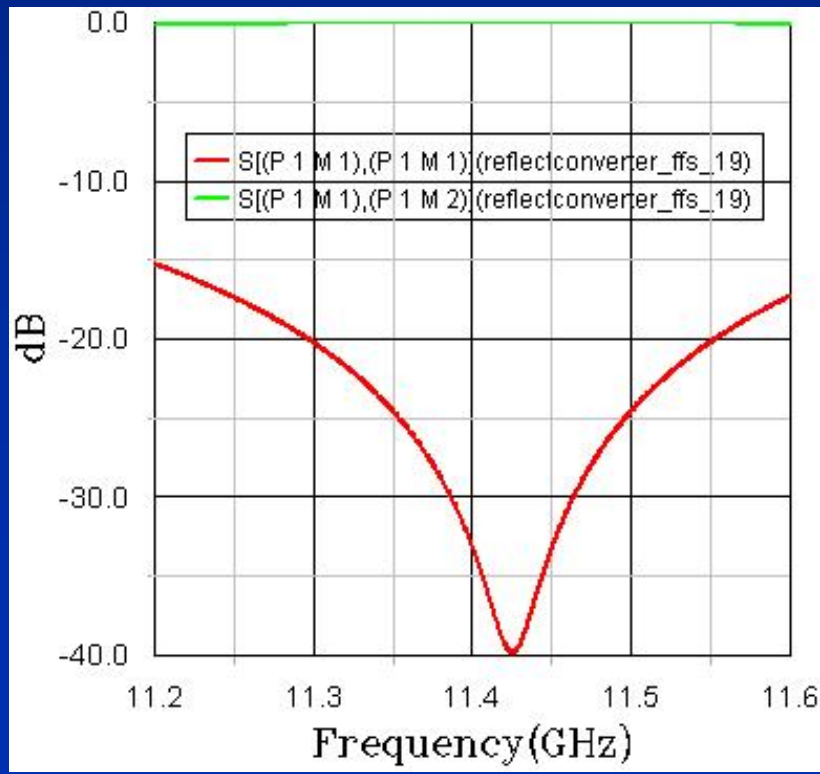




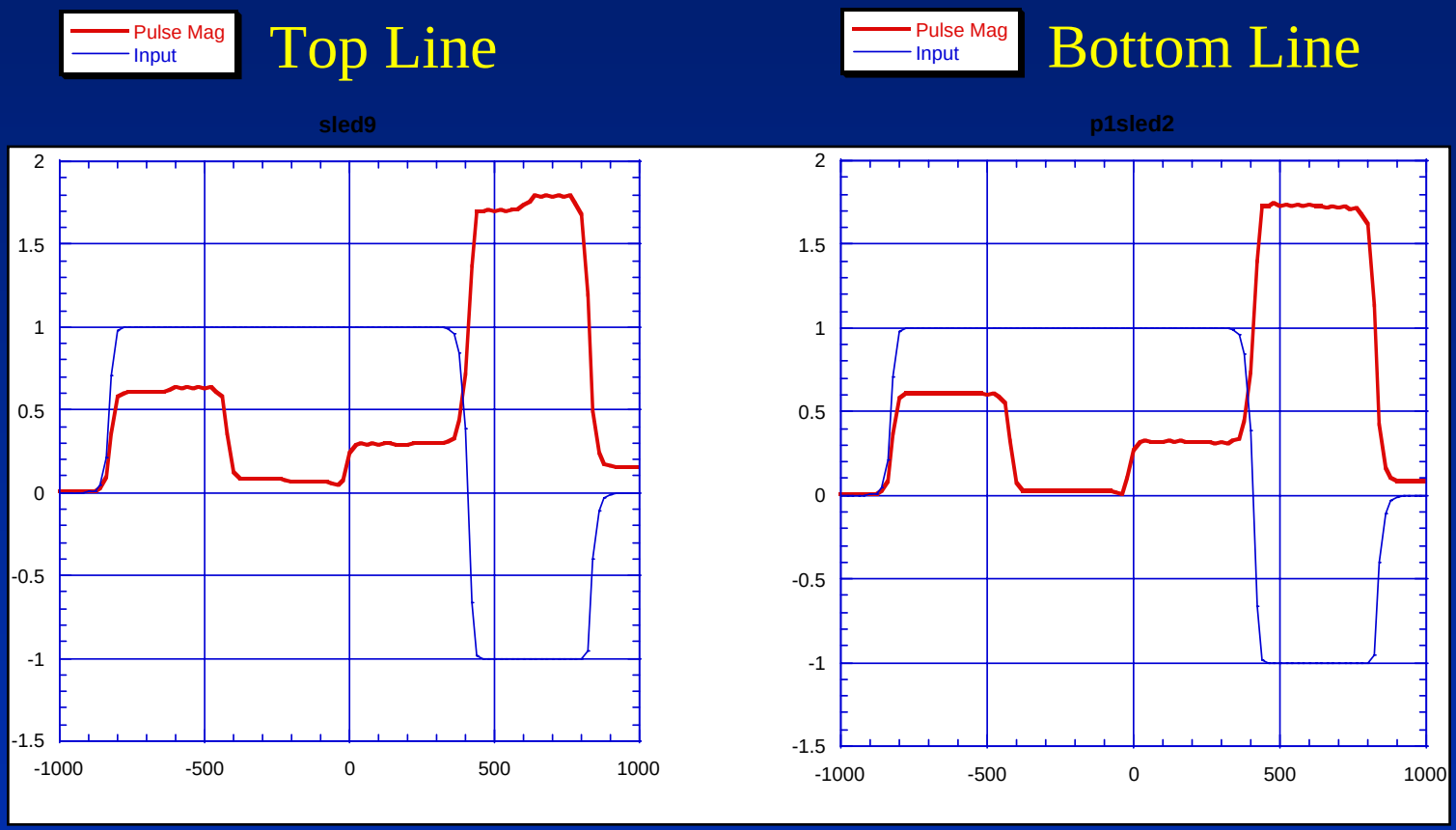


S =

	(P 1 M 1)	(P 1 M 2)
(P 1 M 1)	0.0102	0.9999
(P 1 M 2)	0.9999	0.0102



Delay Line Cold Tests

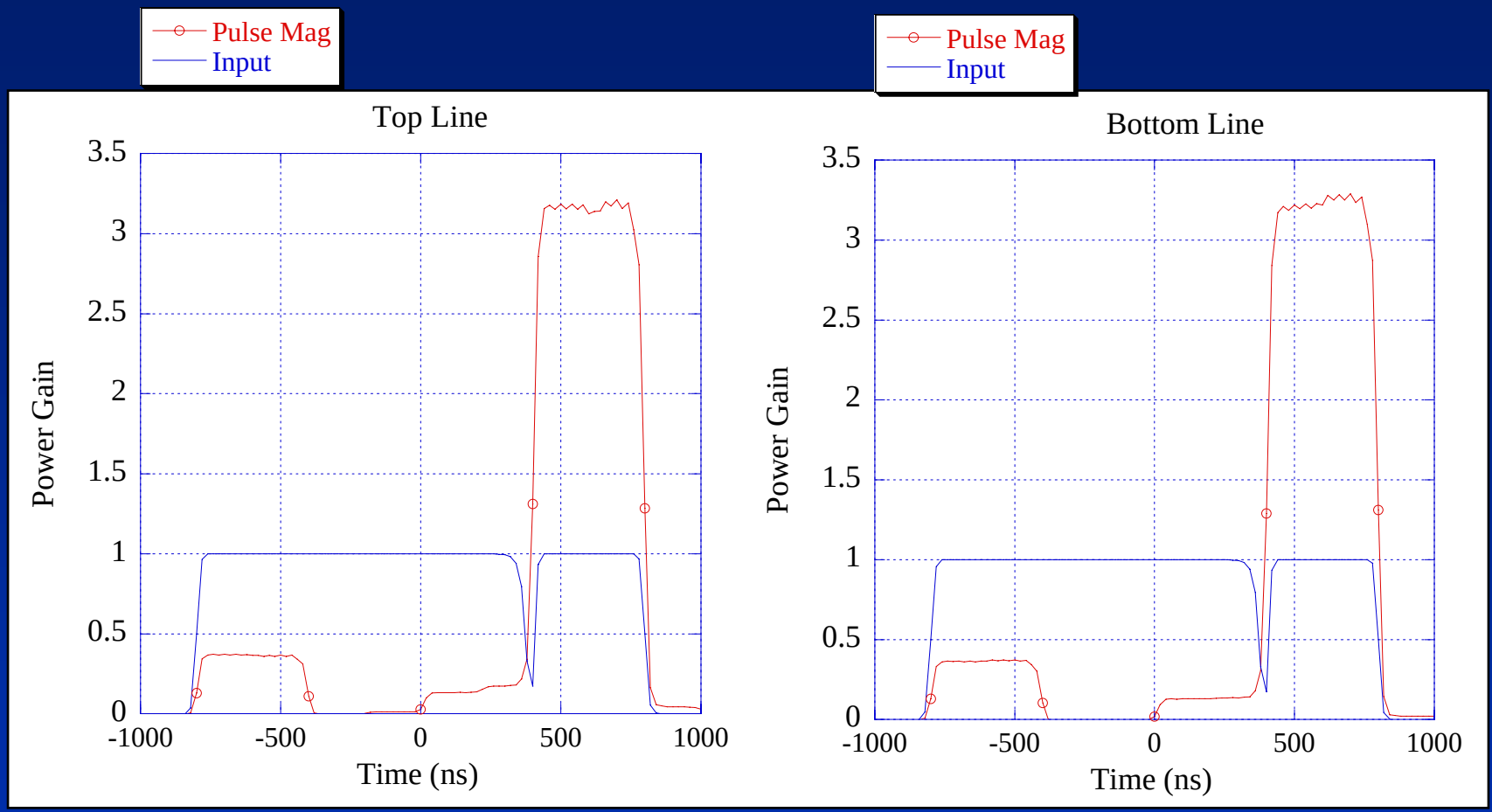


Small mid-time-bin steps indicate mode impurity.

Problem Fixed by:

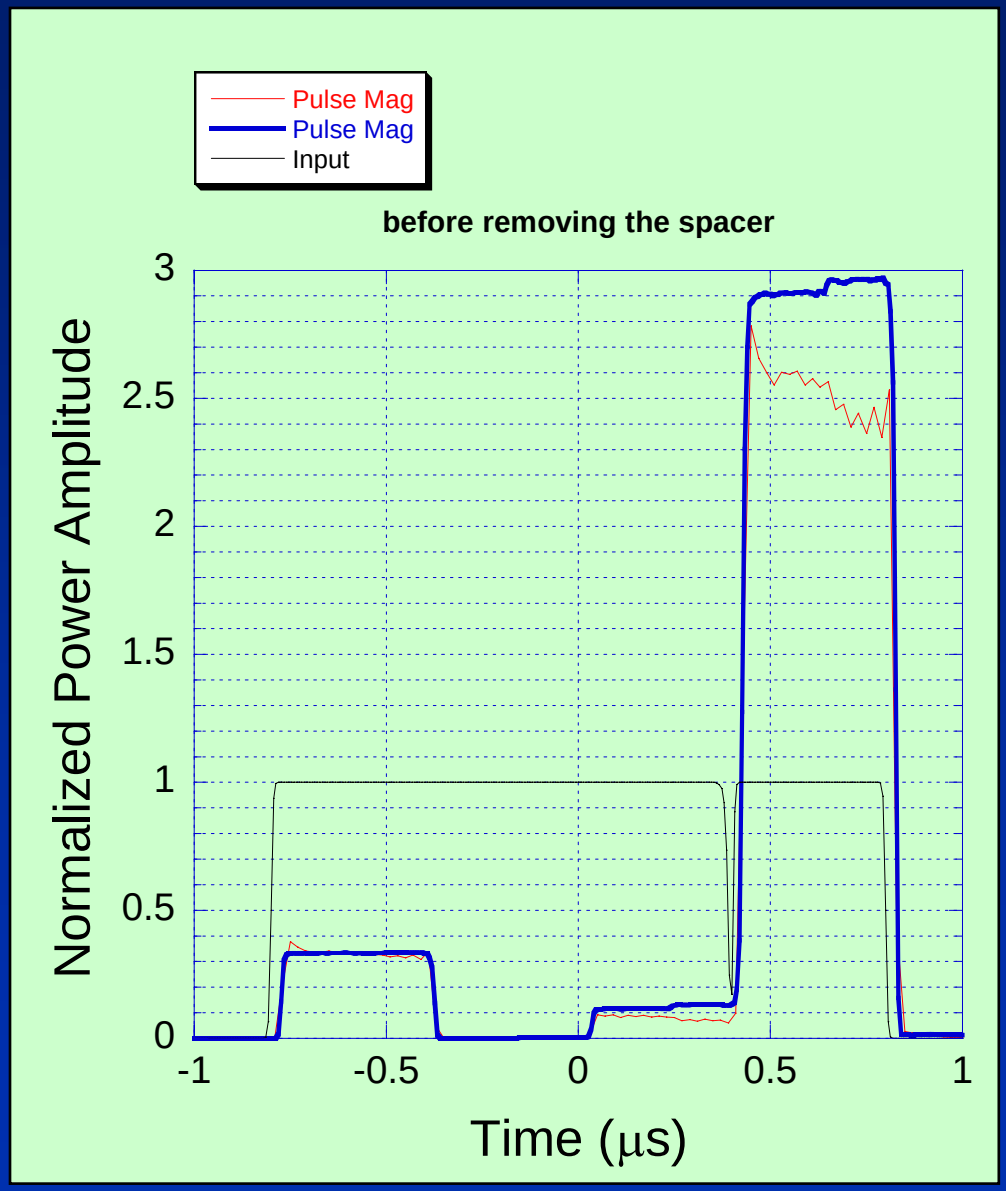
- Permutations of tapers
- Adjusting iris distance
- Choosing good resonant position for tuning plunger (3 within range of motion).

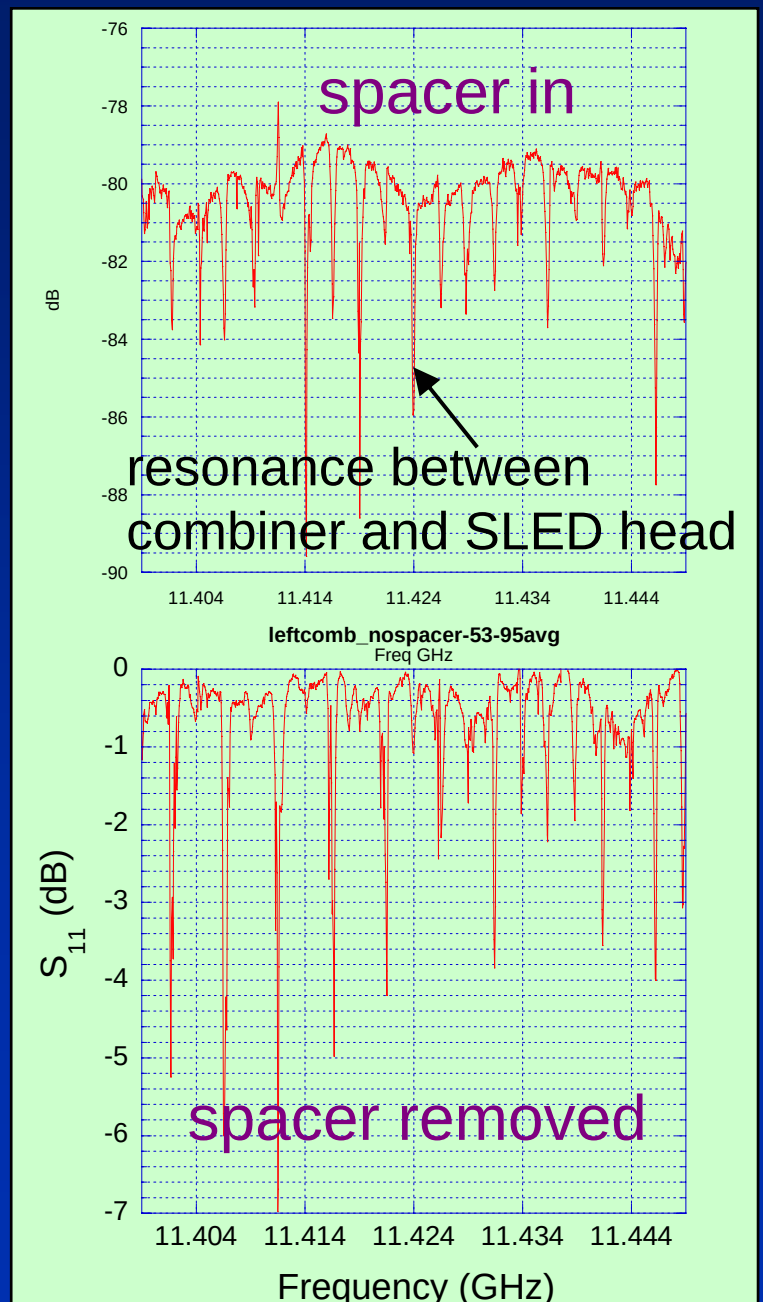
Individual Delay Line SLED Gain



Theoretical gain for a compression ratio of four is 3.44 (lossless).

System Cold Tests





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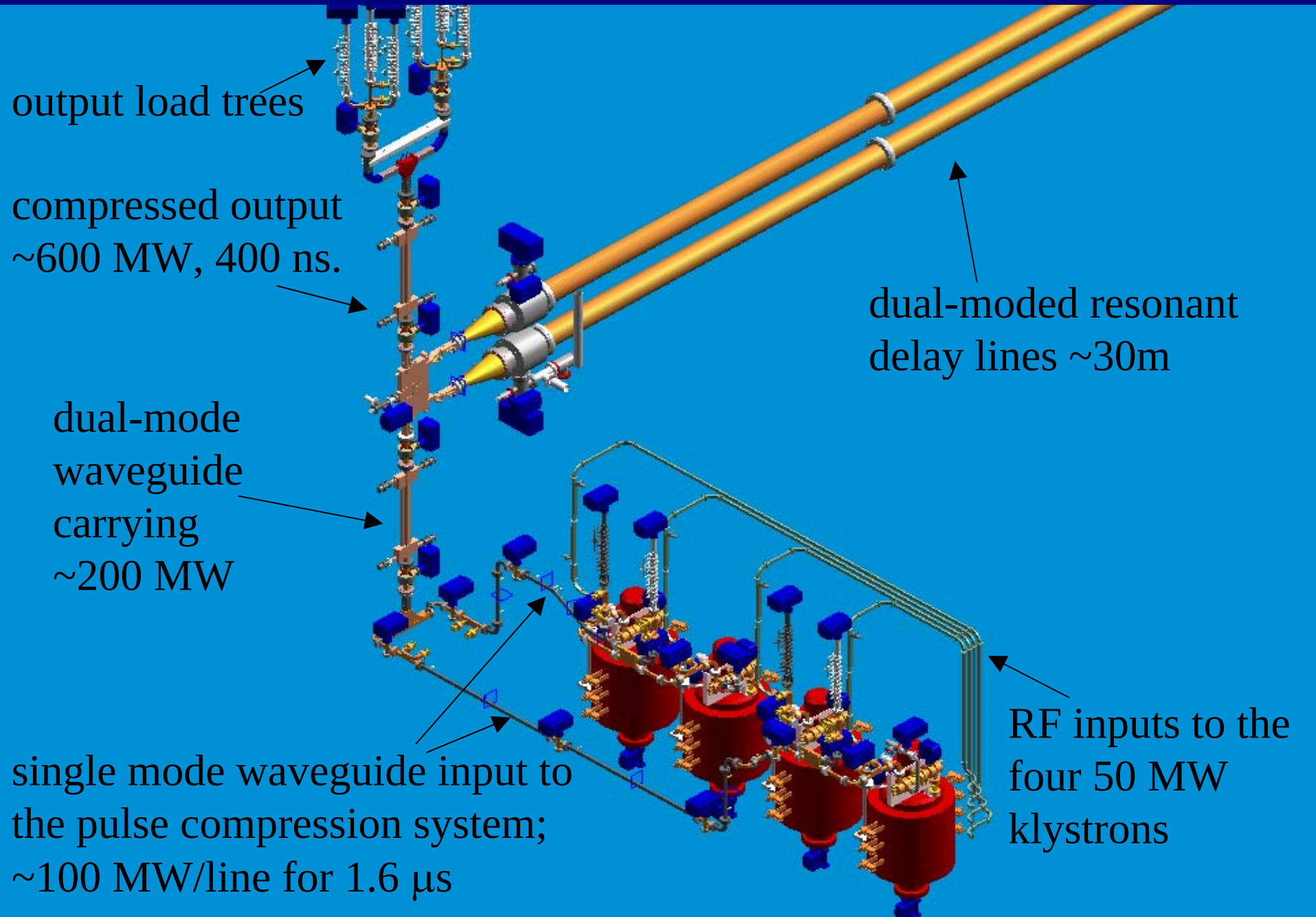
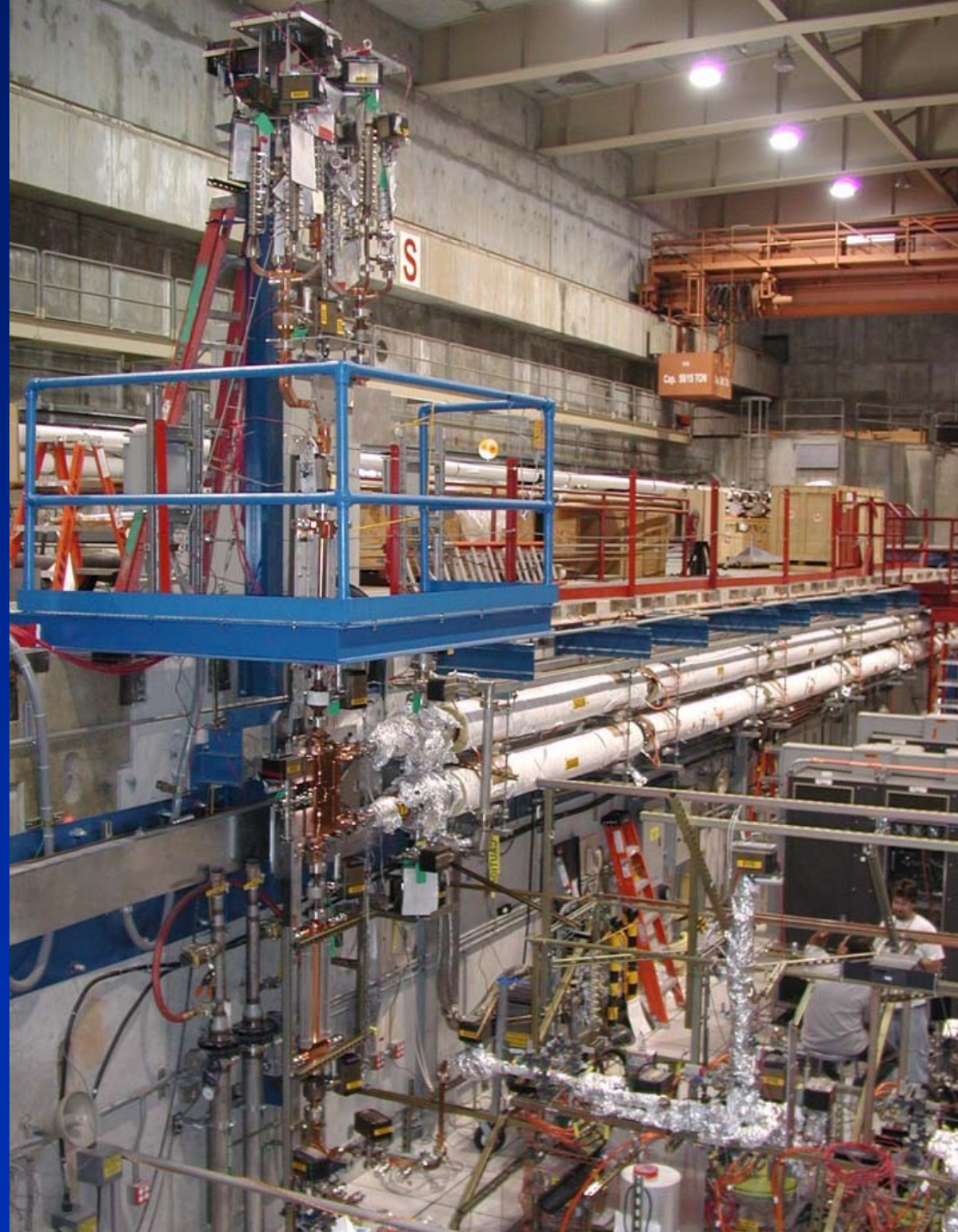
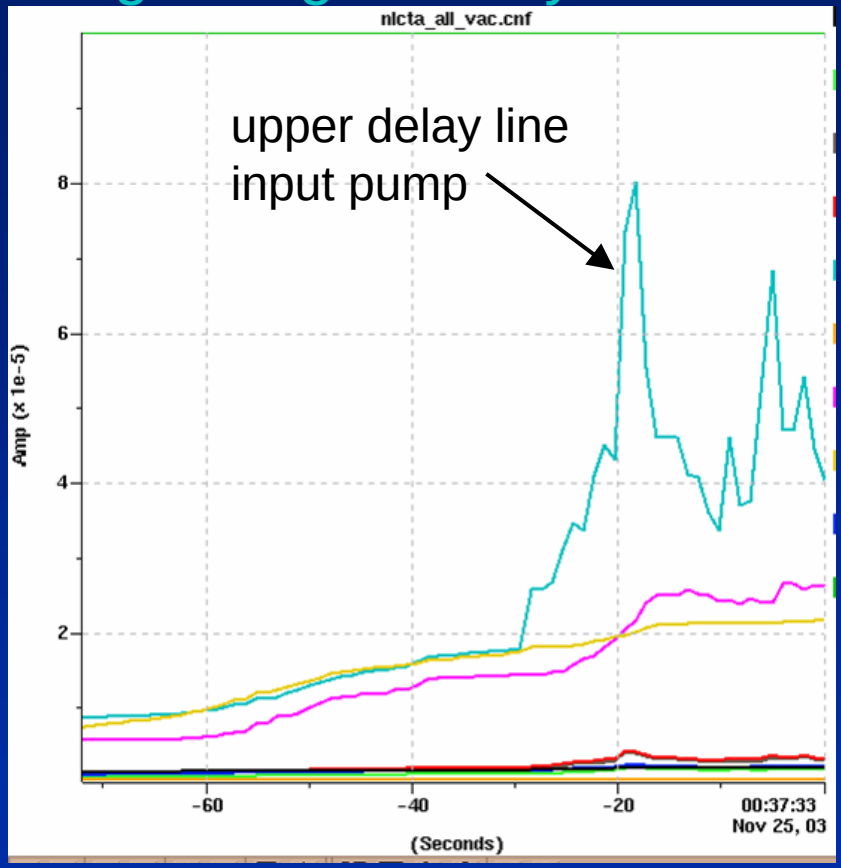


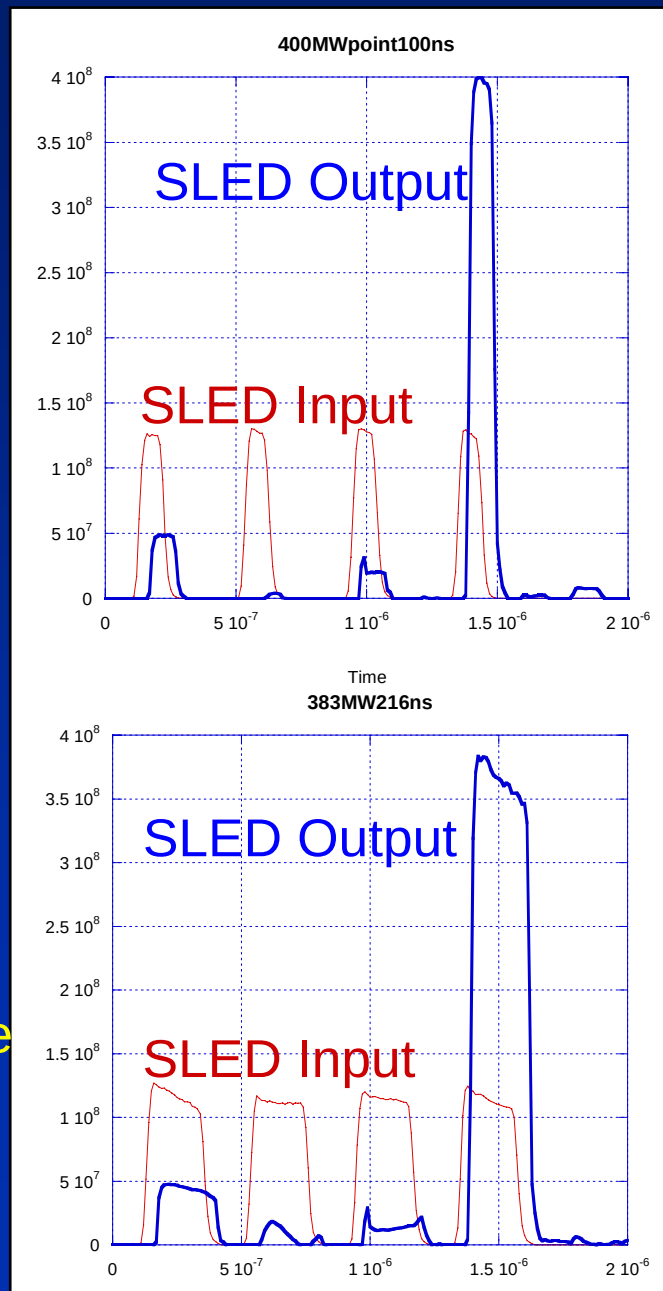
System Layout



High Power Tests

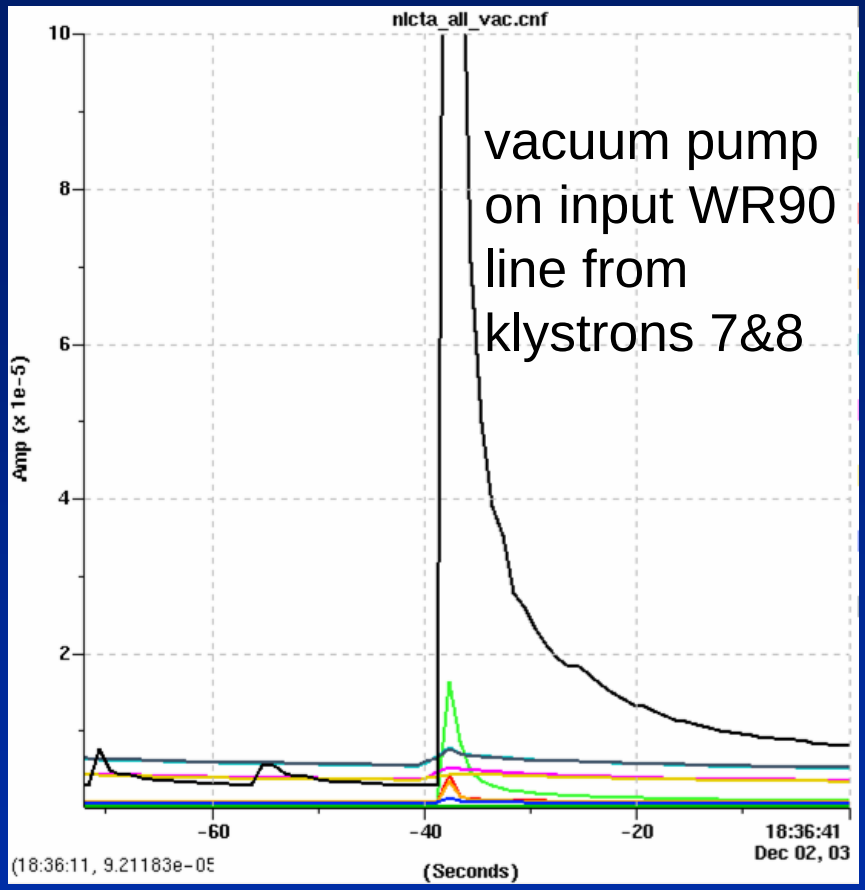
Outgassing of delay lines.





- Feedback program monitored pump currents while processing up power to avoid runaway.
- Processed with widening comb pulse structure.

Breakdown Bottleneck in Input WR90 Line.



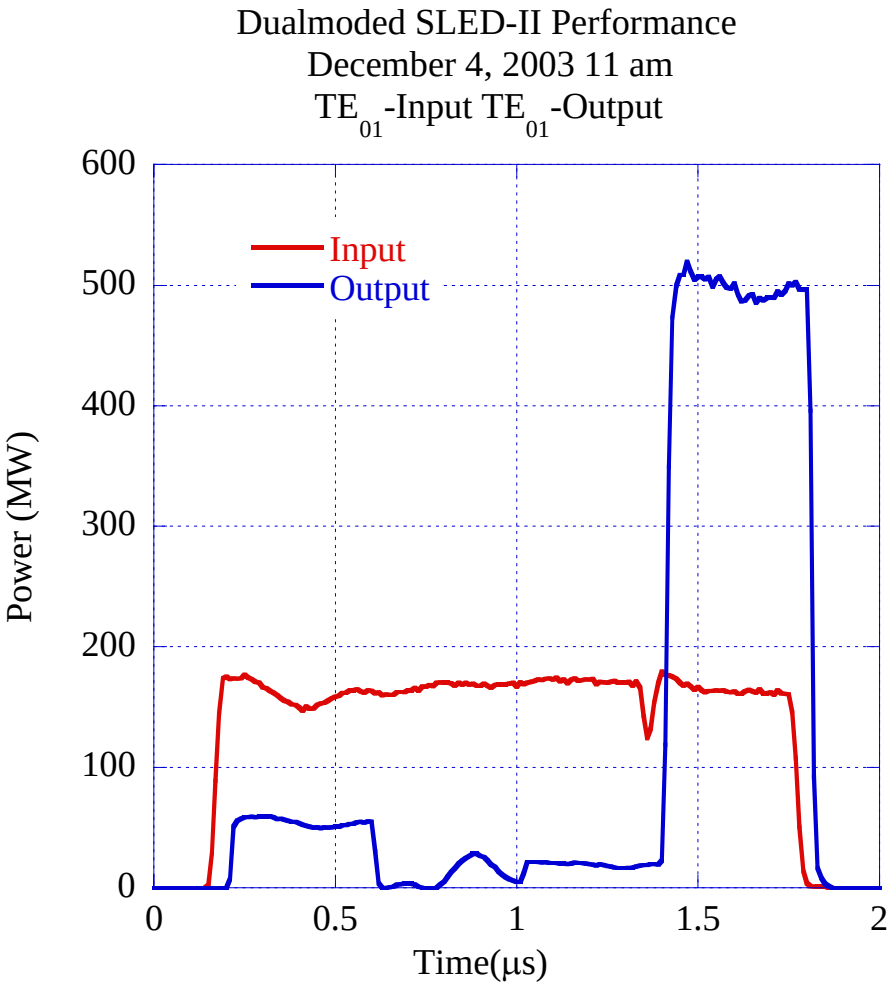
Autopsy of Waveguide:

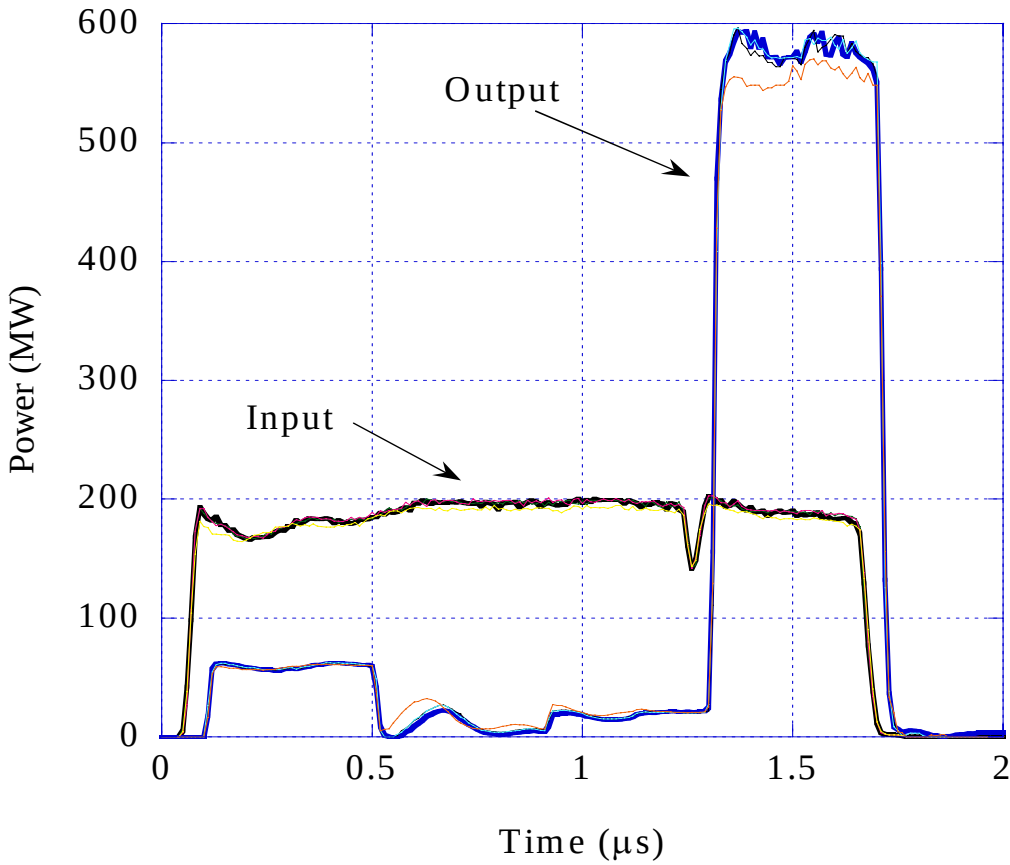
Flange joint leak during in-situ bake caused surface oxidation.

Modifications:

- replaced a pump T
- replaced long run of WR90
- cooled down remaining WR90 with fans
- *hard wired* the klystrons driver together

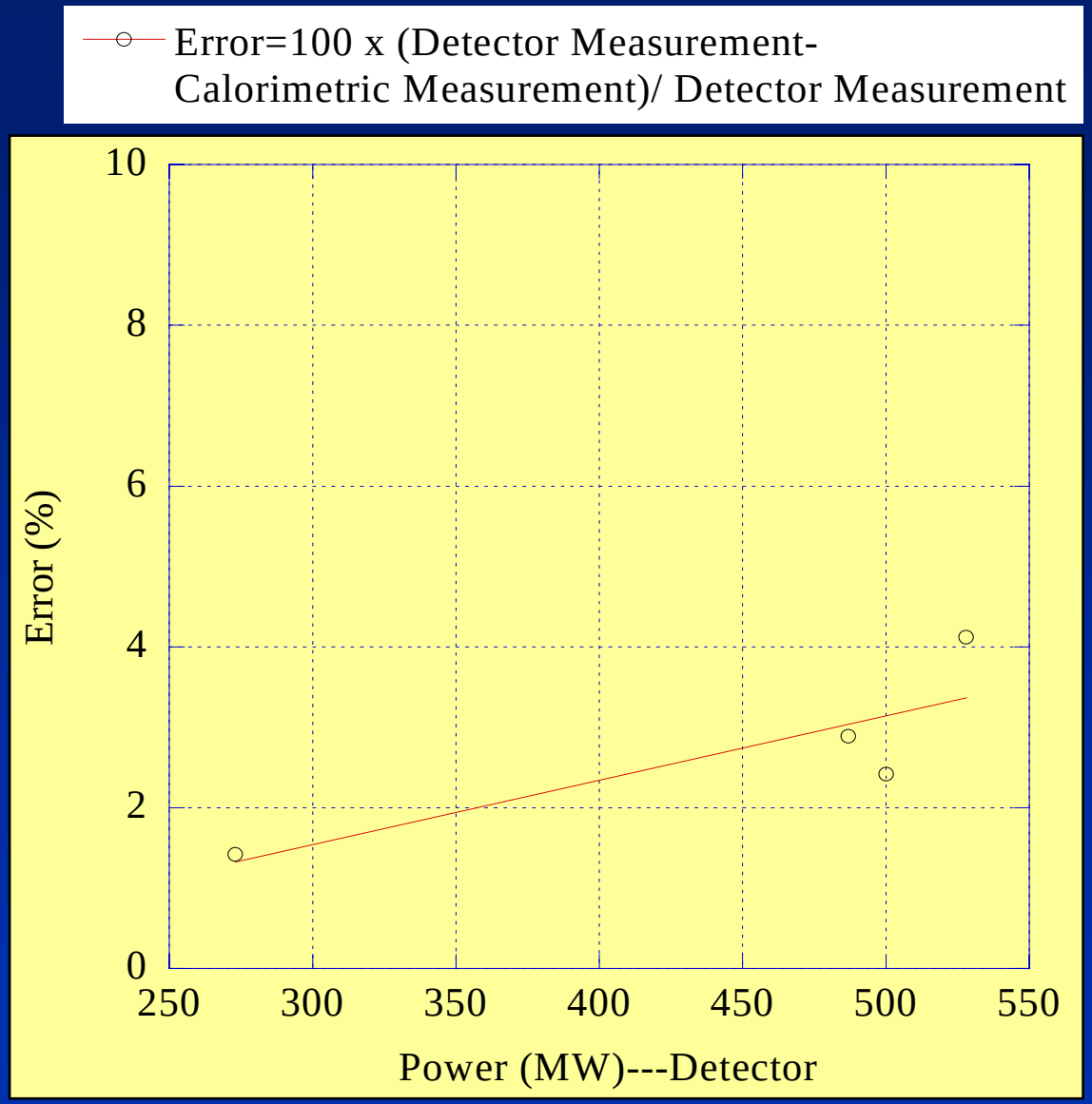
High Power Goal Reached



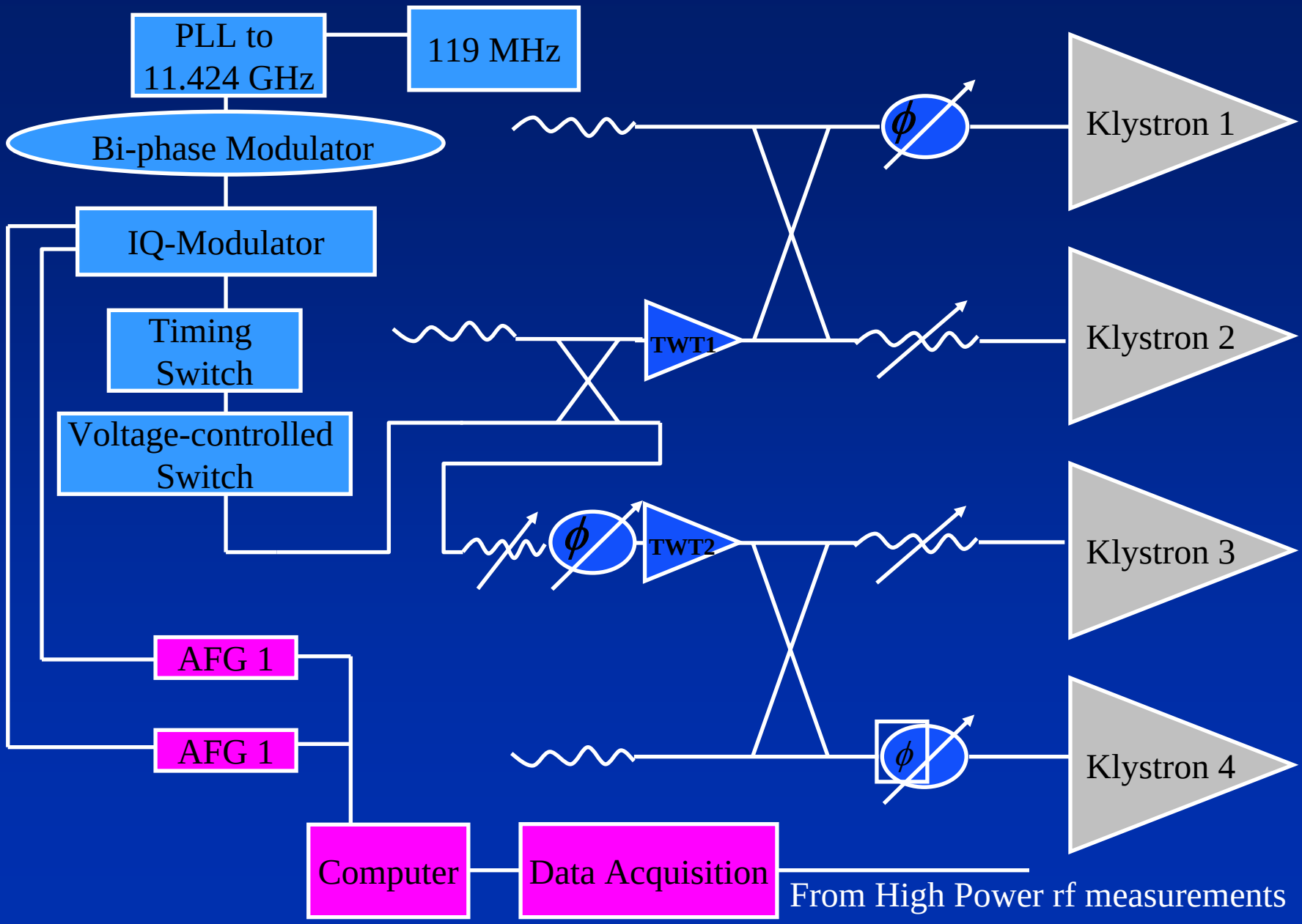


And Exceeded

Calorimetric Calibration Check



New Low-Level RF Architecture

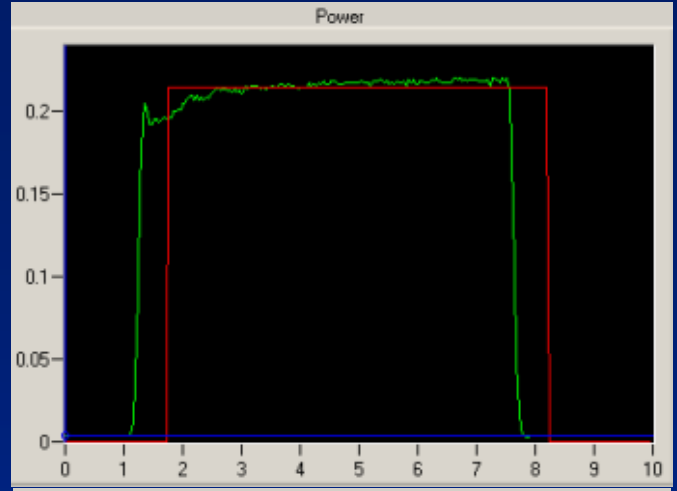


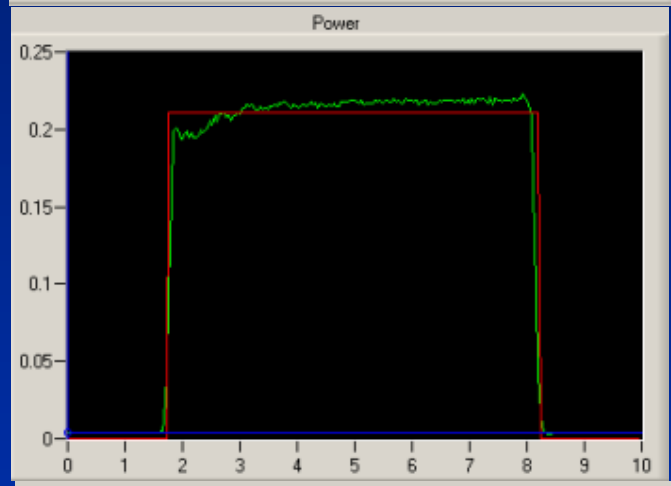
Pulse Flattening Program

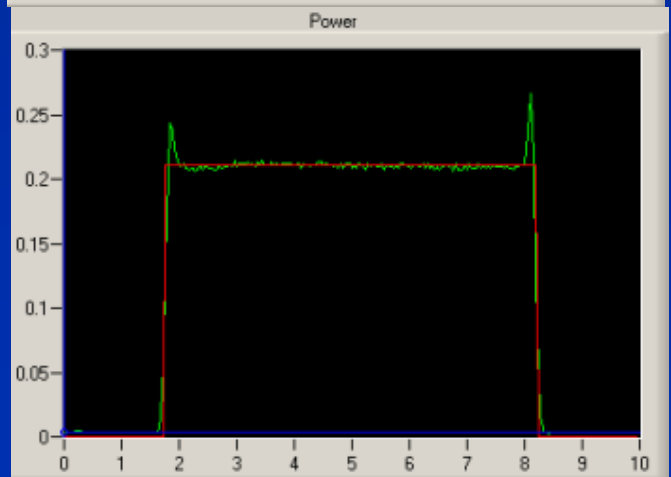
Generates ideal pulse and compares to measured pulse.

Aligns pulses temporally by maximizing overlap integral.

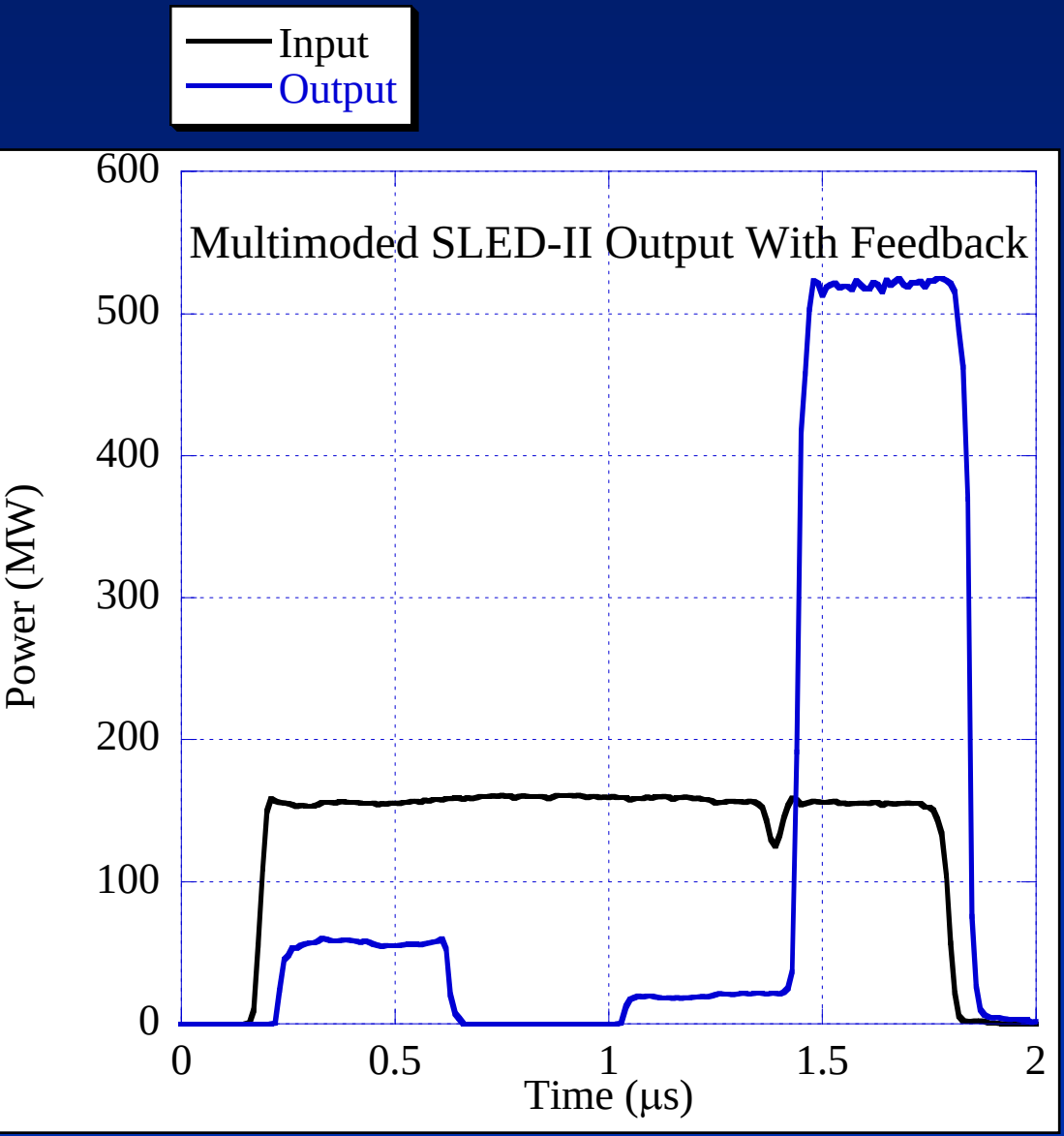
Adjusts generated pulse point by point (10 ns intervals) to approximate ideal.

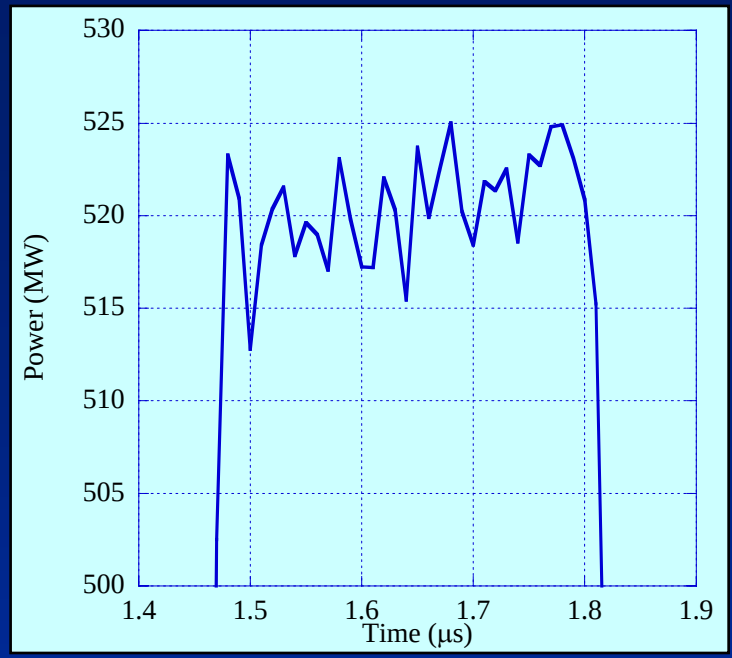


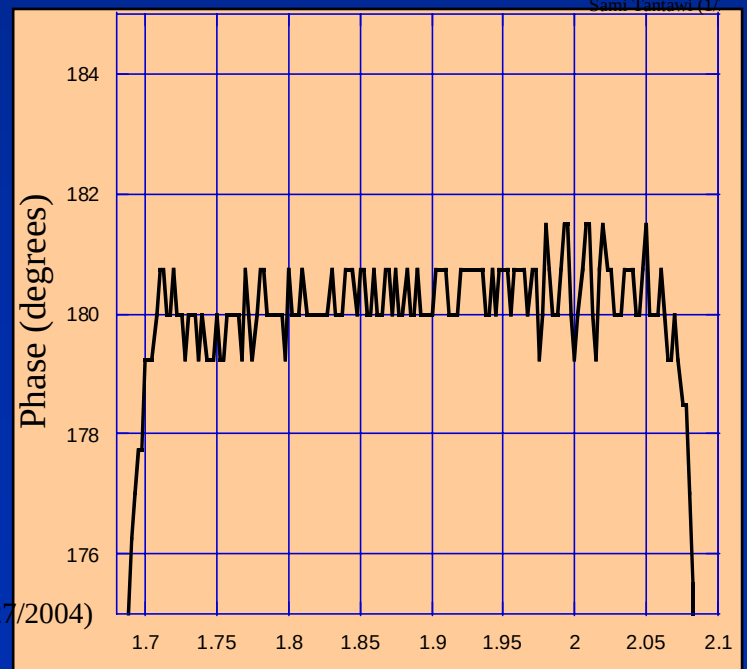




Flattened Pulse

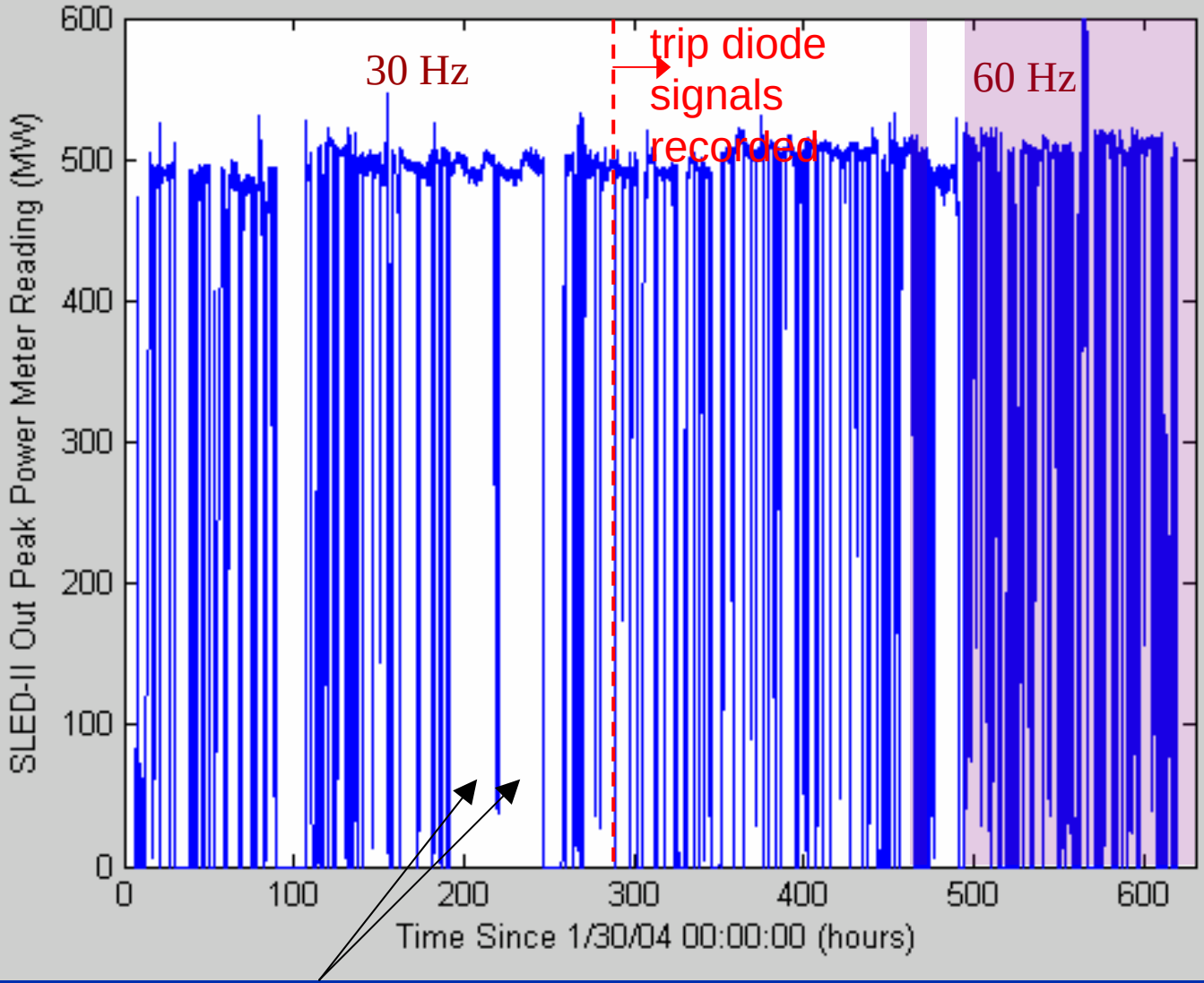






Sami Tantawi (1/27/2004)

Reliability Demonstration Run



Two 26 hrs. gaps w/ no trips.

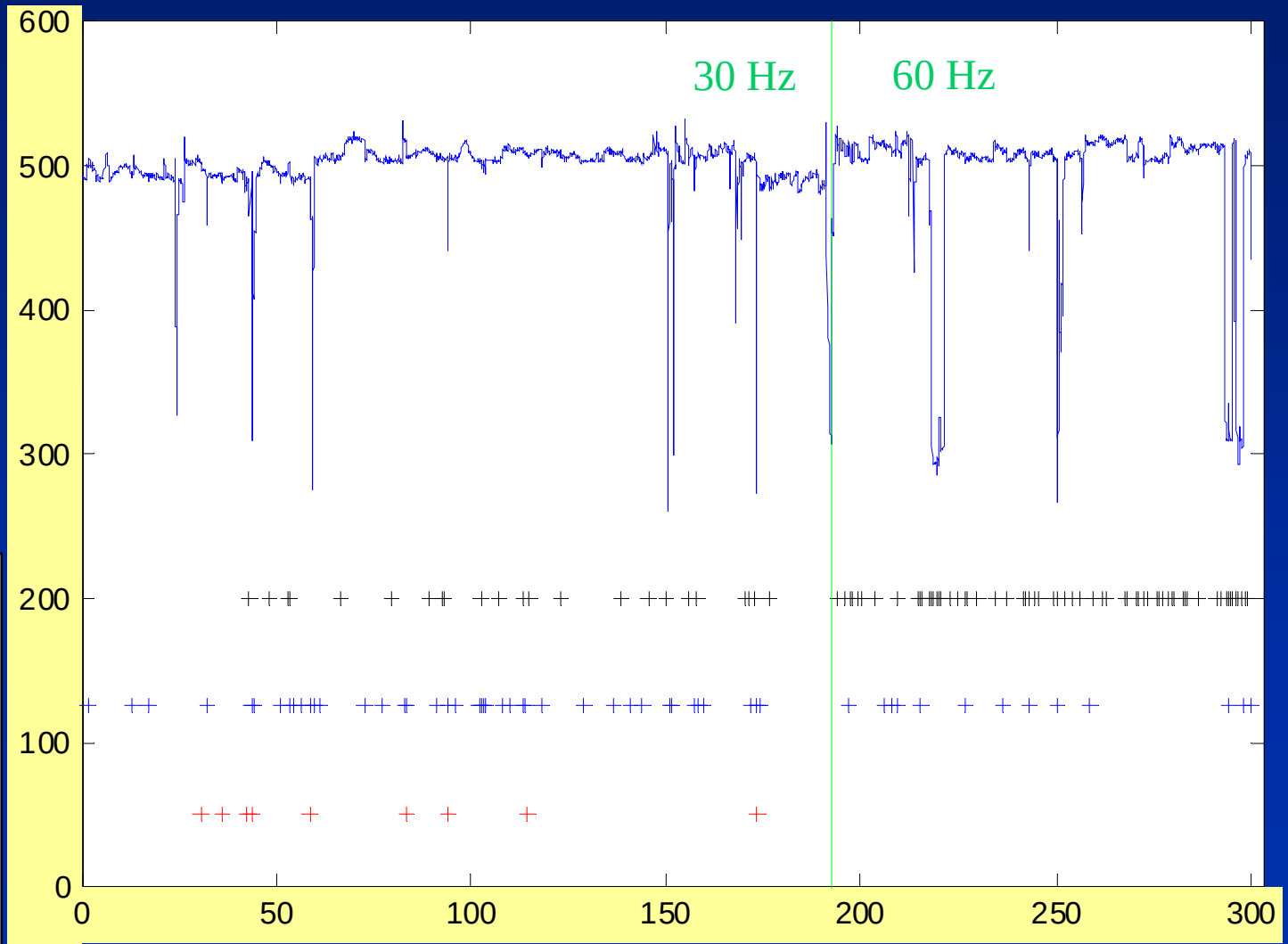
Diode Reflected Energy Trip Initial Analysis

Out of 211 trips in 365.65 hrs (30Hz equivalent)

- 29 -SLED or Combiner ?
- 1 - Klystron 5
- 15 - Klystrons 5&6
- 18 - Klystron 6
- 72 - Klystron 7
- 28 - Klystrons 7&8
- 38 - Klystron 8
- 1 – Loads
- 7 - ?

Analysis Corrected for SLED Mistuning and Human Interference

SLED Out Power (MW)

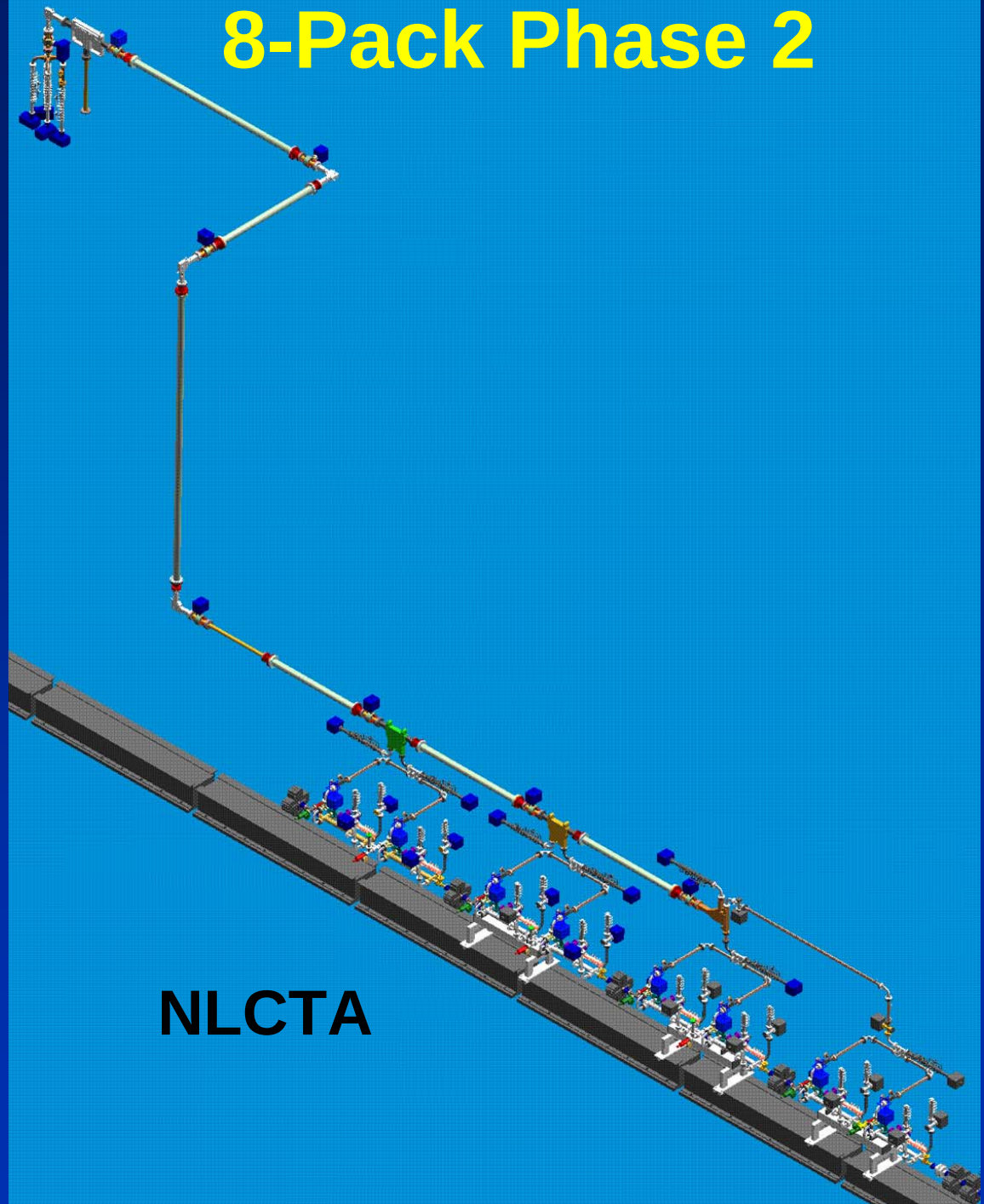


Klystron Tear (137)

WG and Tuning (76)

SLED (11)
0.03 / hr at 30 Hz
(< 0.08 / hr required)

8-Pack Phase 2



Conclusion

- We've demonstrated the feasibility of the type of rf system envisioned by proponents of a warm X-band linear collider.
- We've developed unique over-moded components and made use of the concept of dual moding.
- Years of high-power component development have born fruit in this pulse compression system which has finally tested their power-handling capability.
- The compressed half-gigawatt pulses carrying 200 J represent a major achievement in pulsed rf power.

Acknowledgment

This work is a result of a continuous effort by many researches and engineers over many years.

In particular, The efforts of C. Nantista, N. Kroll, R. Miller, P. Wilson, V. Dolgashev, K. Fant, C. Pearson, R. Ruth, were instrumental to the results achieved to date.

Jose Chan: A persistence efforts during the manufacturing and testing of components

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K. Ratcliffe and the Vacuum Assembly Team.

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