NLC High-Power RF Component Development

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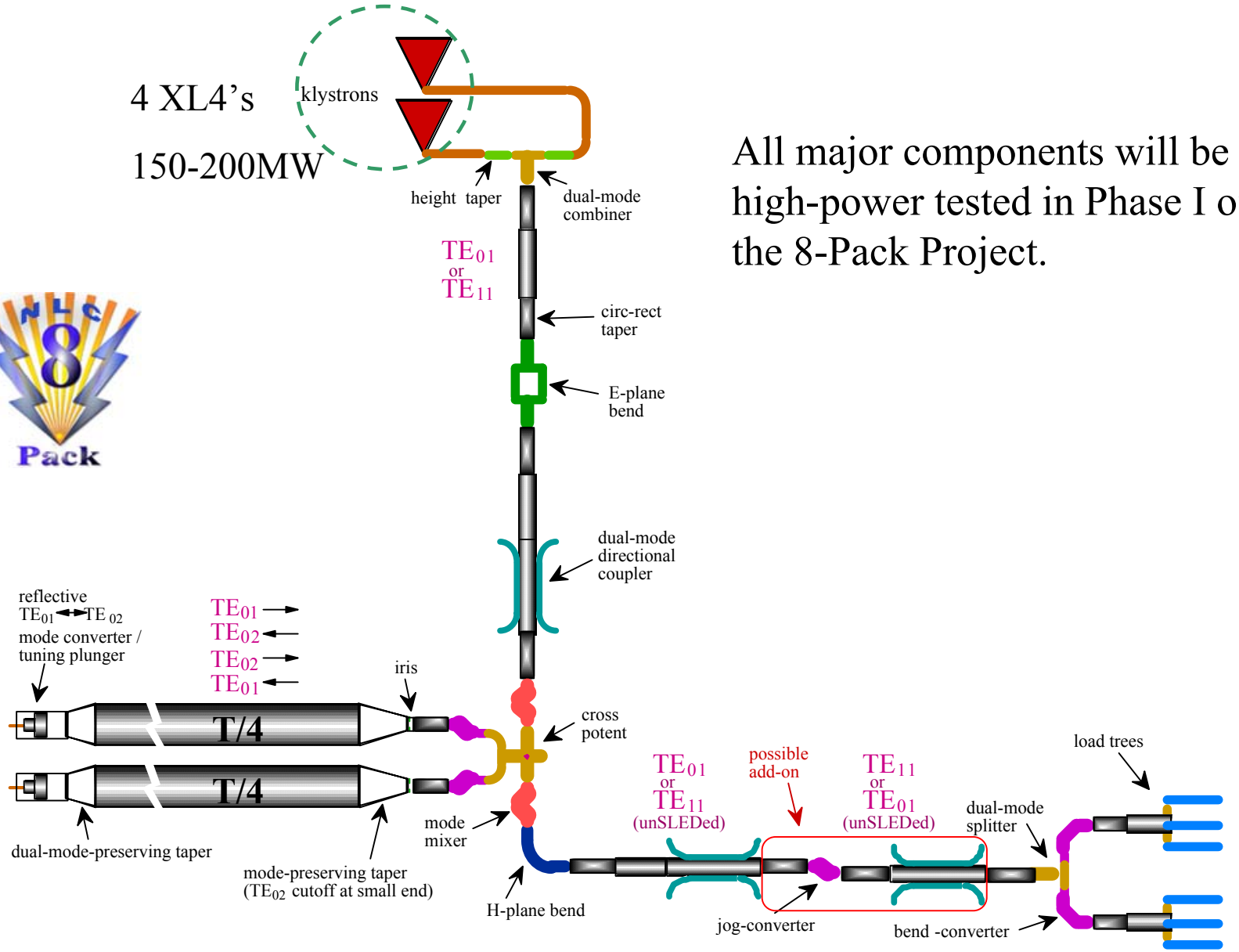
ISG8

SLAC

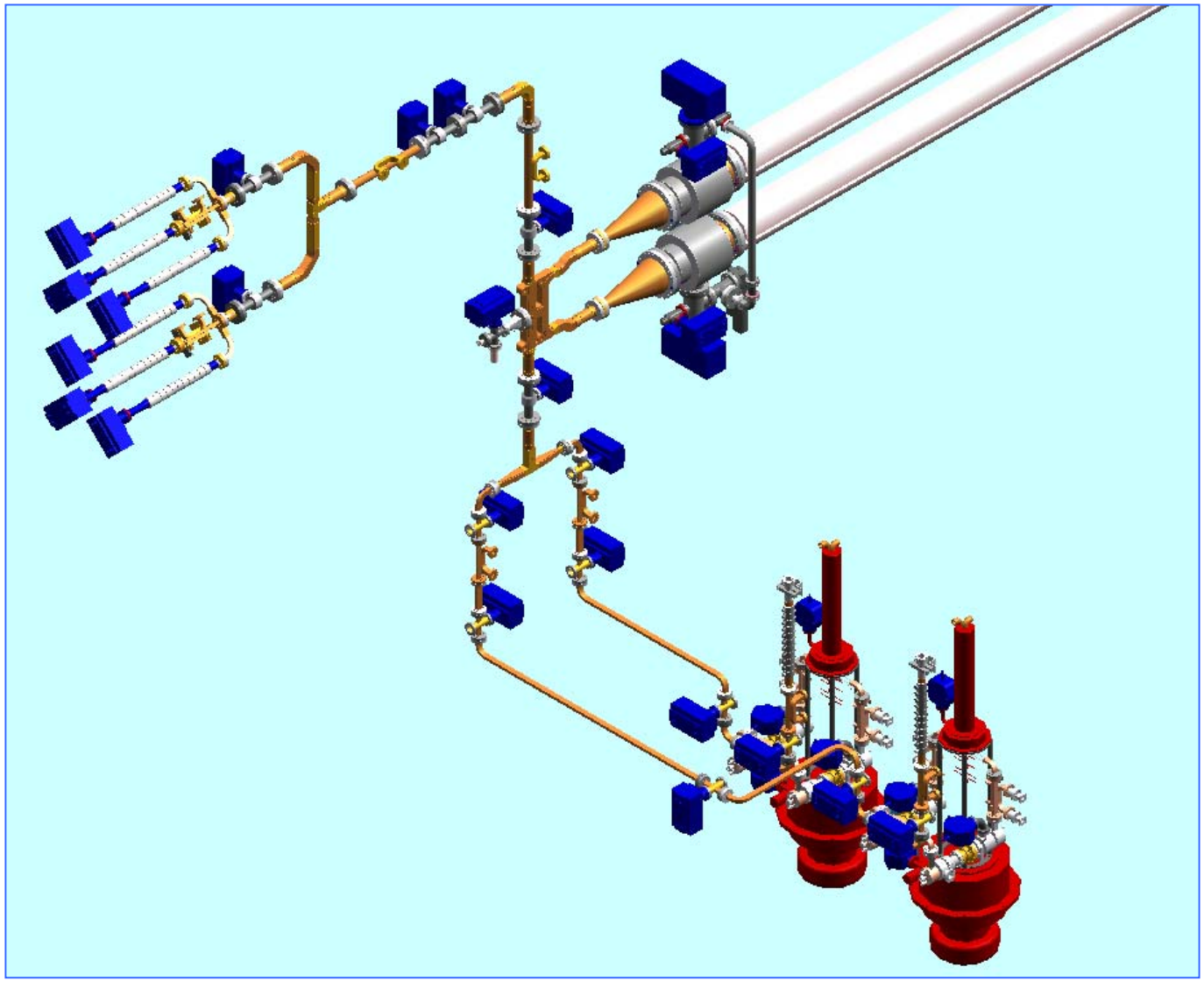
June 24-27, 2002

8-Pack Phase I Dual Mode SLED-II

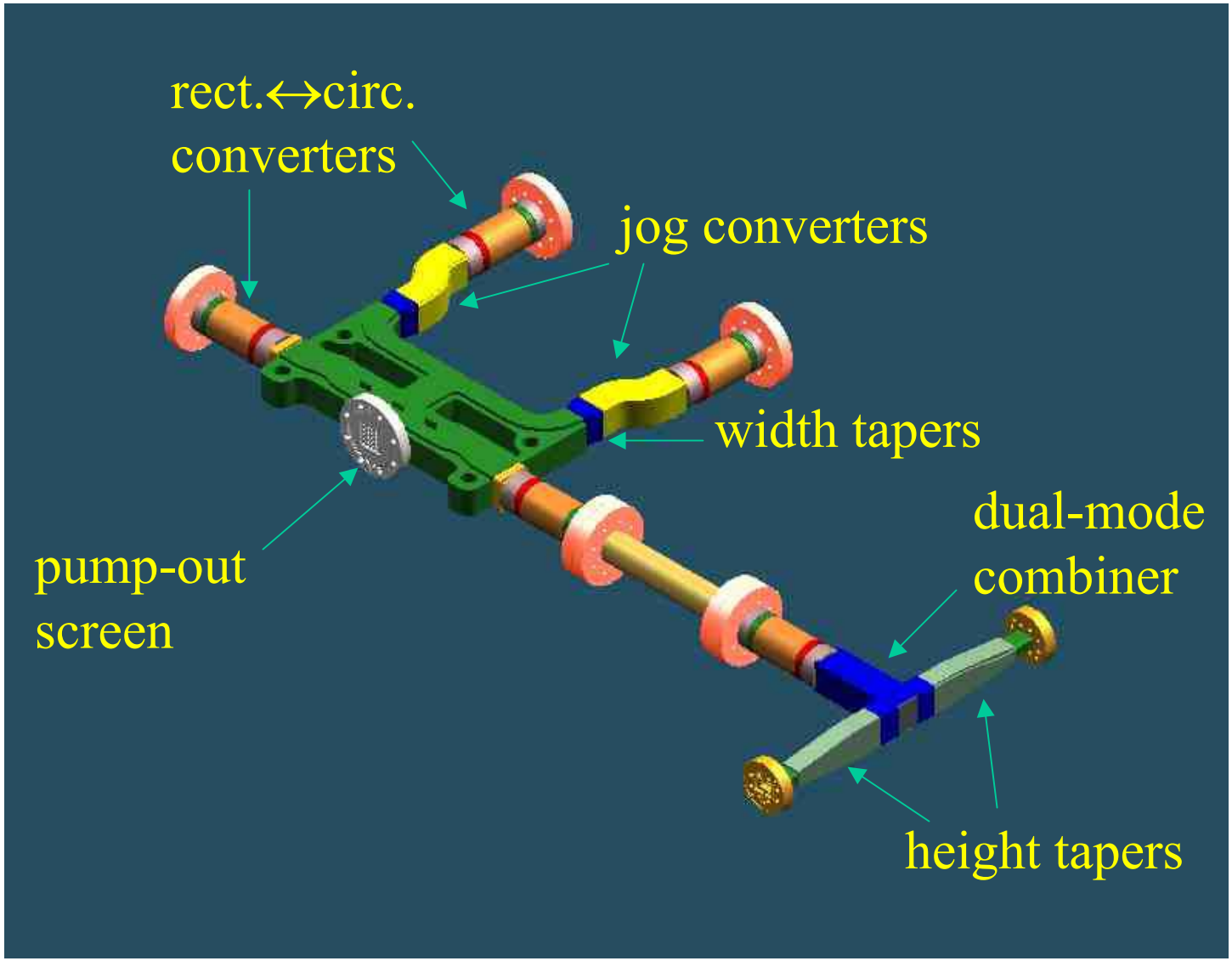


All major components will be high-power tested in Phase I of the 8-Pack Project.

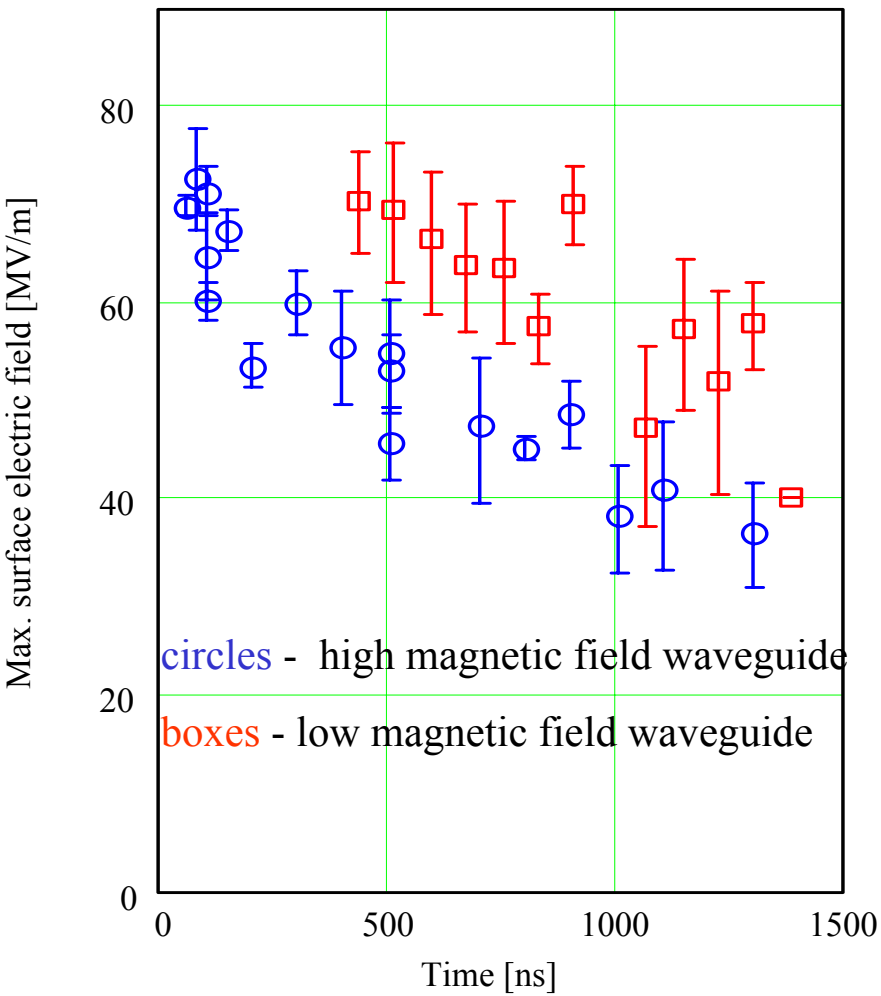
Isometric Engineering Graphic

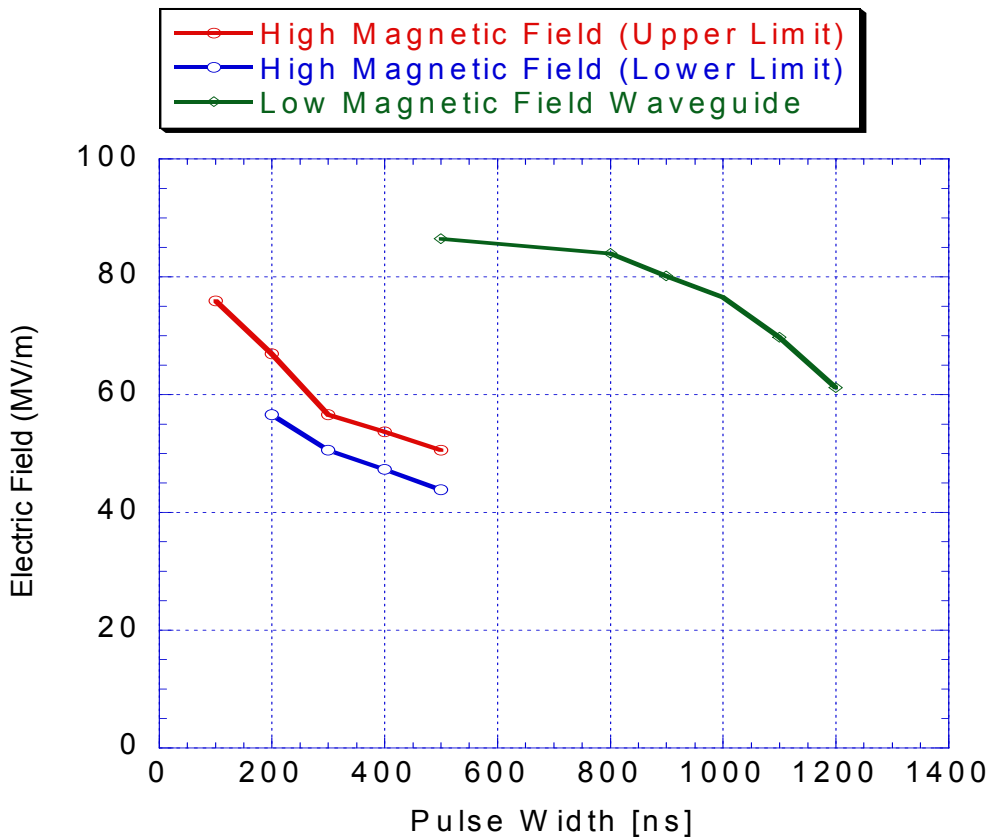


Cross Potent Subassembly



Breakdown Threshold Measurements for Copper Waveguide





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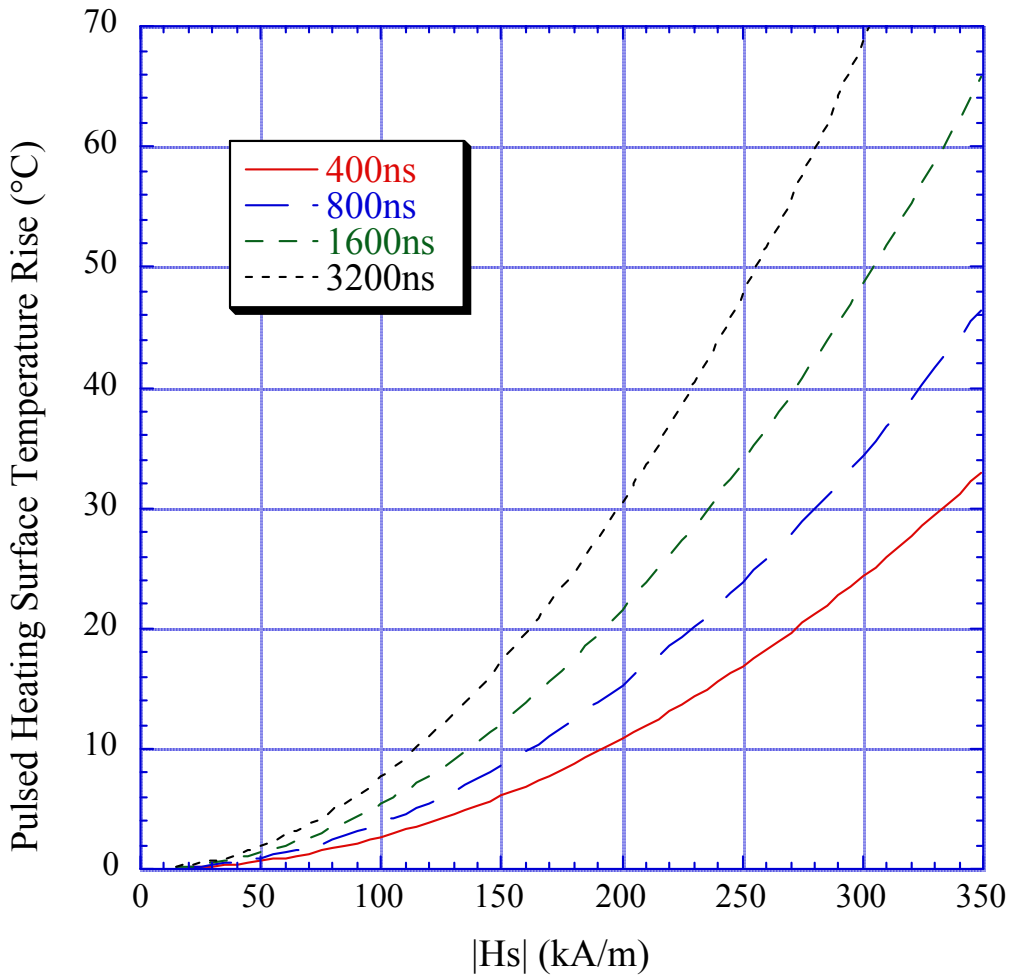
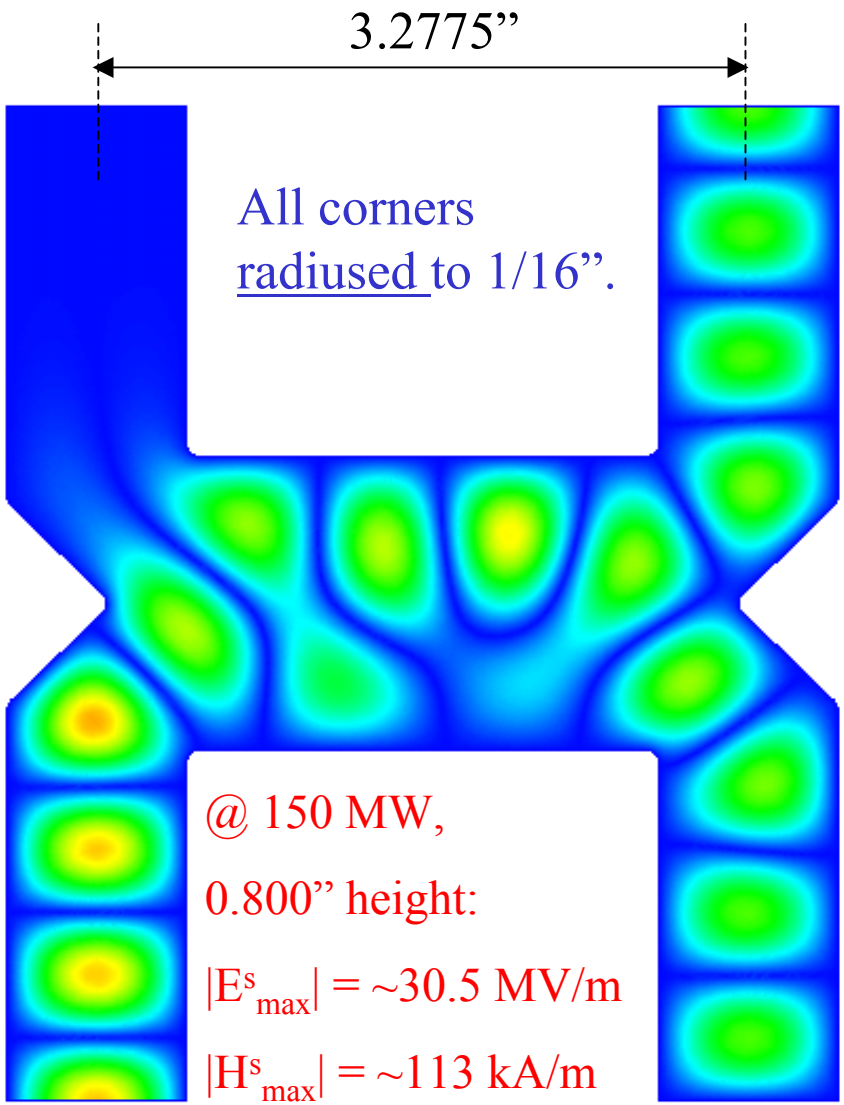
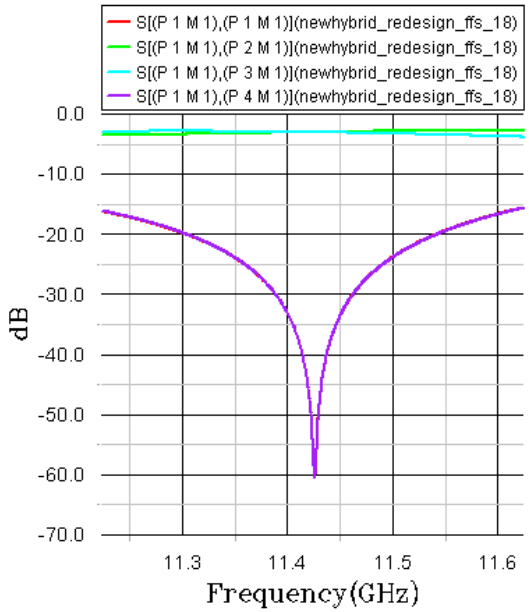
Pulsed Heating

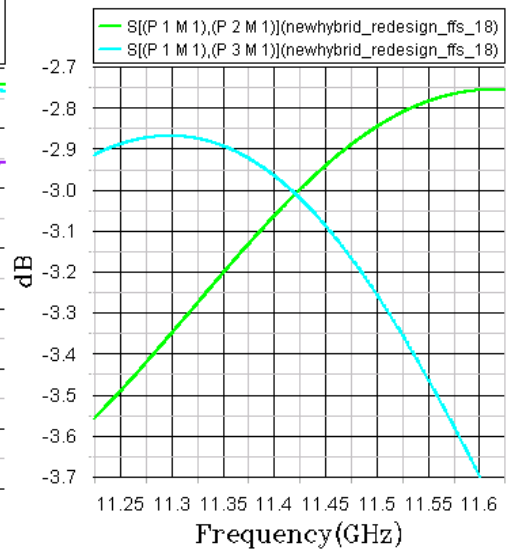


Redesigned Magic H Hybrid

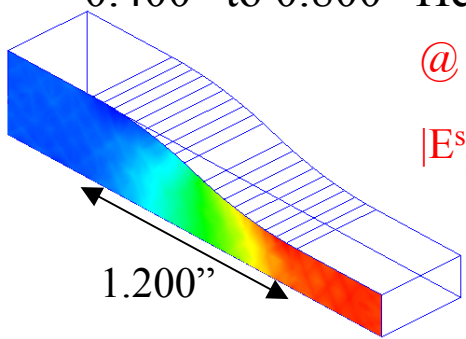


	(P 1 M 1)	(P 2 M 1)	(P 3 M 1)	(P 4 M 1)
(P 1 M 1)	0.0021	0.7077	0.7065	0.0021
(P 2 M 1)	0.7077	0.0021	0.0021	0.7065
(P 3 M 1)	0.7065	0.0021	0.0021	0.7077
(P 4 M 1)	0.0021	0.7065	0.7077	0.0021





0.400” to 0.800” Height Taper

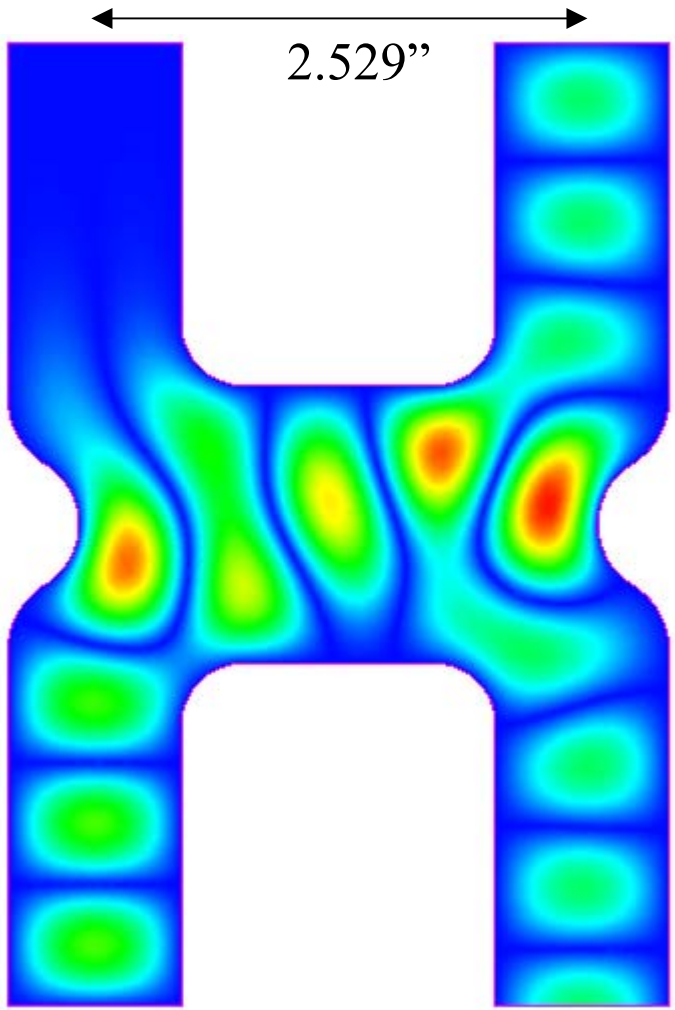


@ 150 MW,

$|E^s_{max}|$ = ~35.2 MV/m

$|S_{11}|$ = -47 dB

Alternative Design Attempt



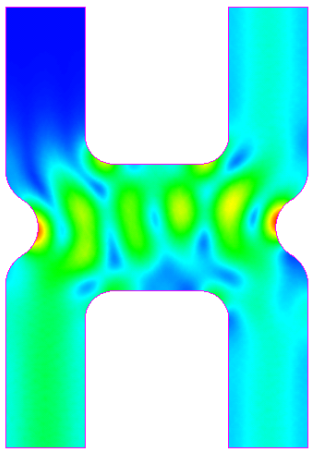
	(P 1 M 1)	(P 2 M 1)	(P 3 M 1)	(P 4 M 1)
(P 1 M 1)	0.0038	0.7066	0.7075	0.0037
(P 2 M 1)	0.7066	0.0038	0.0038	0.7075
(P 3 M 1)	0.7075	0.0038	0.0037	0.7066
(P 4 M 1)	0.0037	0.7075	0.7066	0.0038

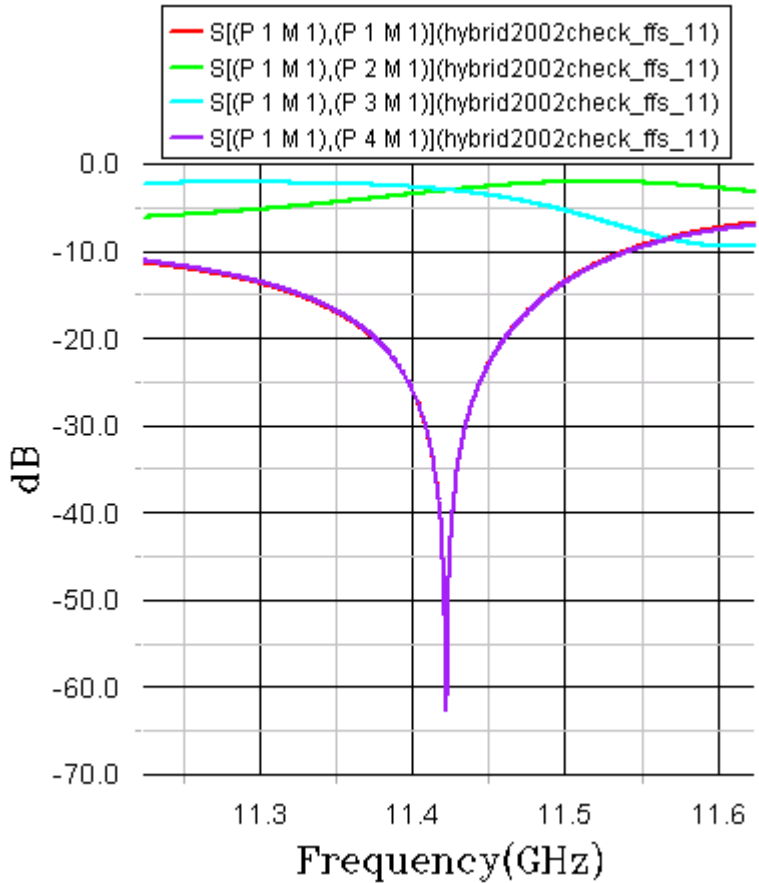
@ 600 MW,

0.800” height:

$|E^s_{max}| = \sim 43.6$ MV/m

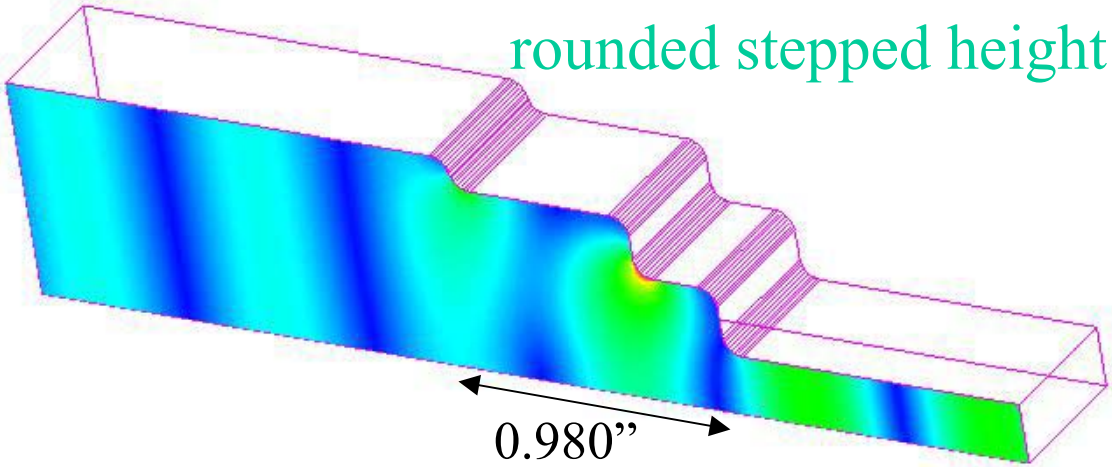
$|H^s_{max}| = \sim 131$ kA/m





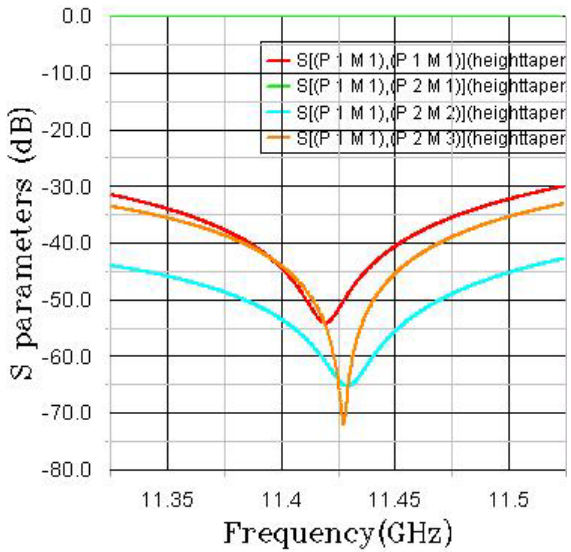
Height Tapers (0.400”→1.435”)

rounded stepped height taper

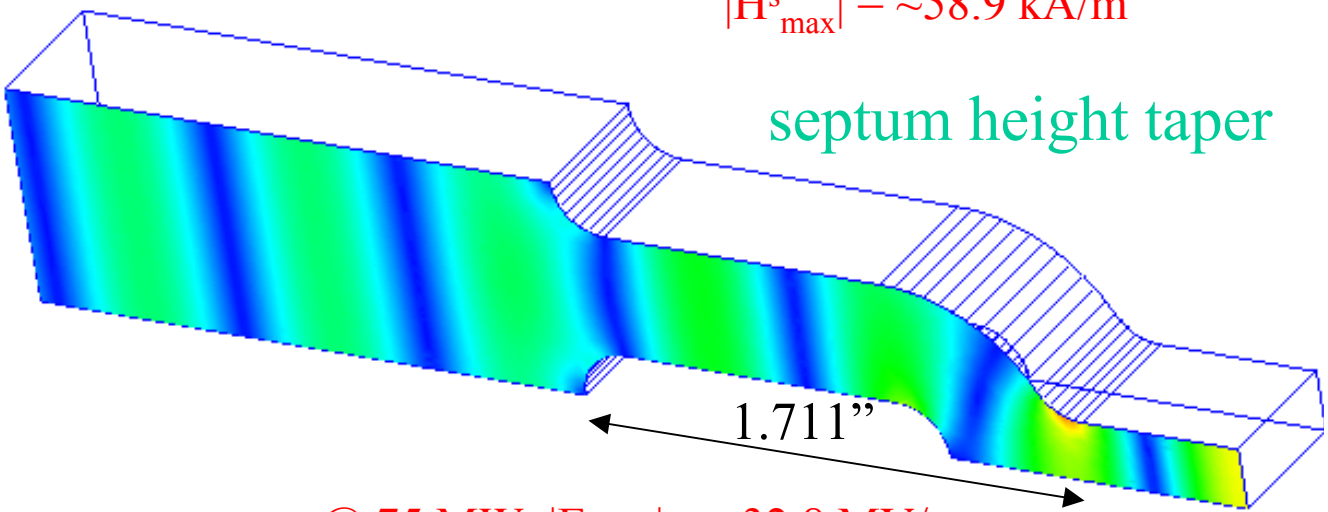


@ 75 MW $|E^s_{max}|$ = ~48.4 MV/m

$|H^s_{max}|$ = ~58.9 kA/m

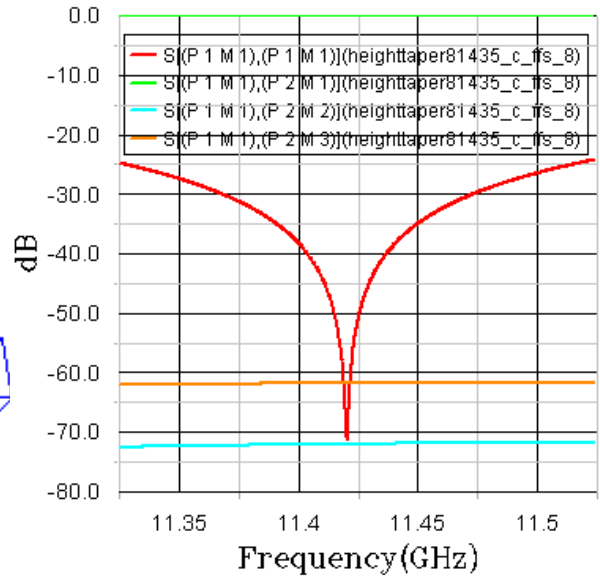


septum height taper



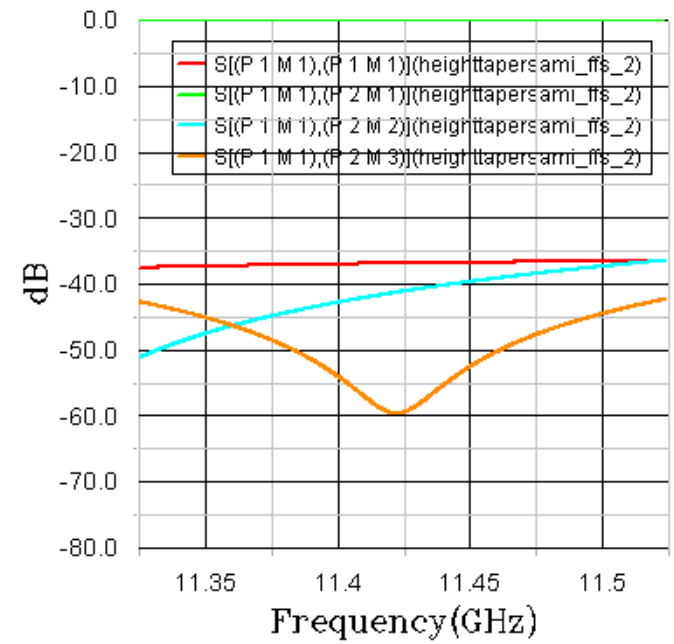
@ 75 MW $|E^s_{max}|$ = ~32.8 MV/m

$|H^s_{max}|$ = ~57.5 kA/m



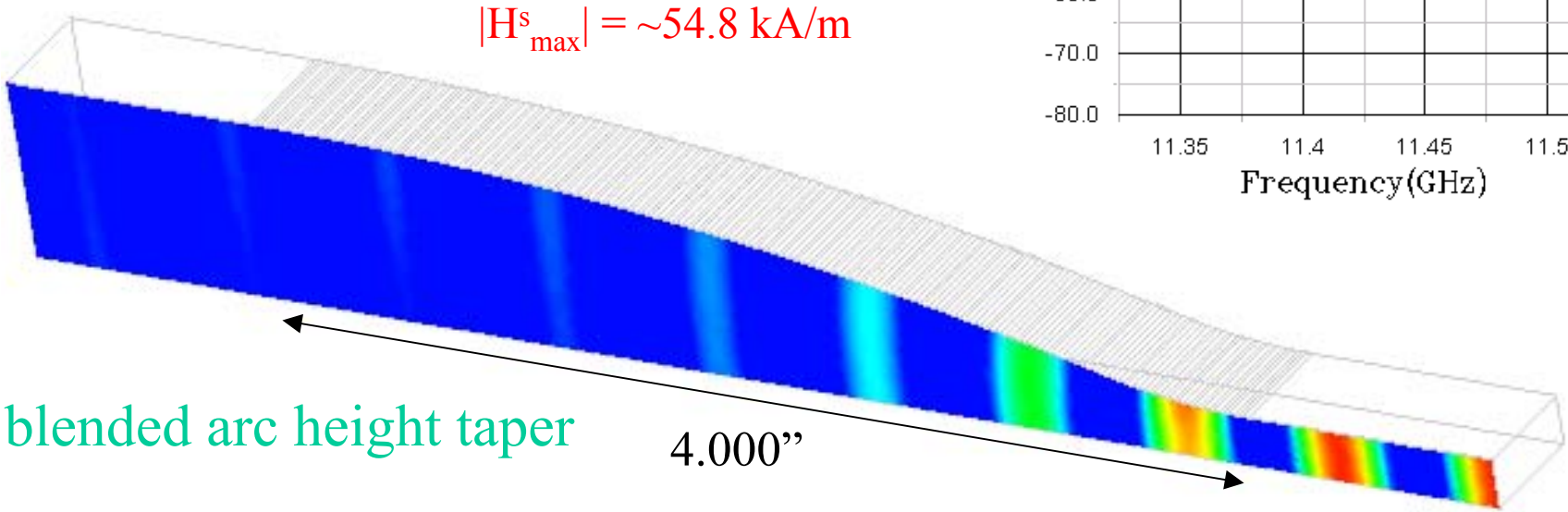
Height Tapers (cont.)

	(P 1 M 1)	(P 2 M 1)	(P 2 M 2)	(P 2 M 3)
(P 1 M 1)	0.0093	0.9998	0.0048	0.0157
(P 2 M 1)	0.9998	0.0096	0.0048	0.0155
(P 2 M 2)	0.0048	0.0048	0.8243	0.5662
(P 2 M 3)	0.0157	0.0155	0.5662	0.824



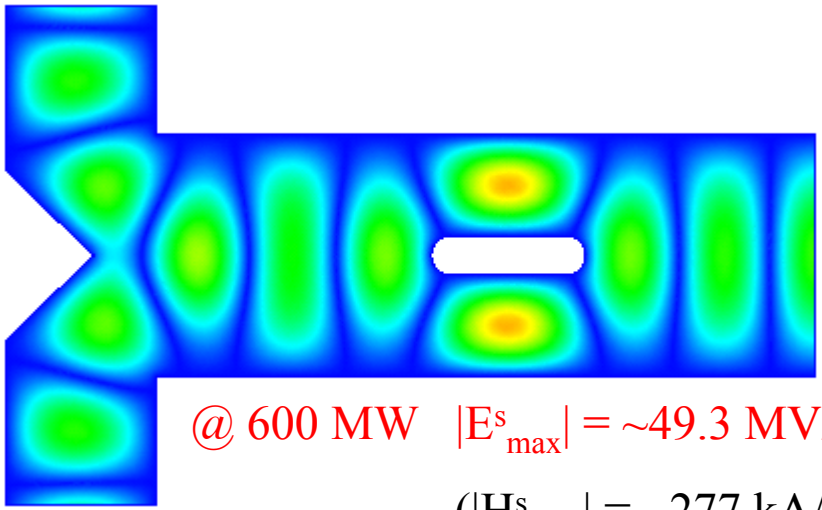
@ 75 MW $|E^s_{max}| = \sim 25.0$ MV/m

$|H^s_{max}| = \sim 54.8$ kA/m



blended arc height taper

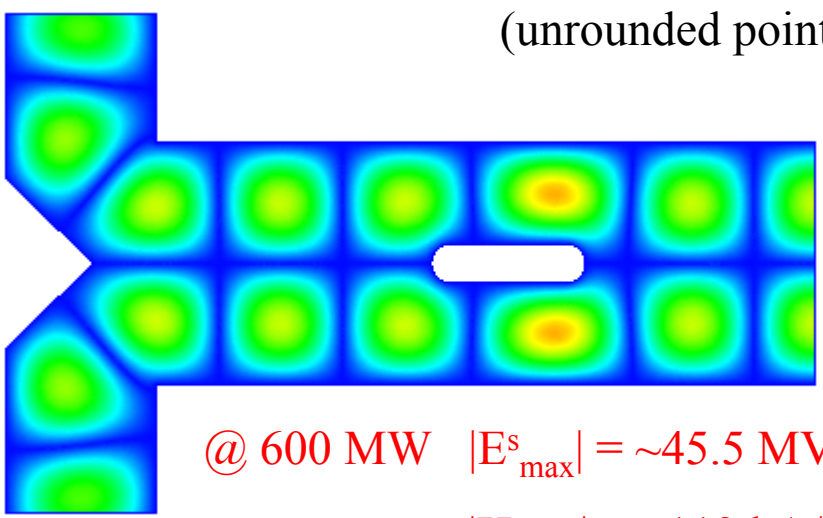
Dual-Mode Combiner/Splitter



@ 600 MW $|E^s_{max}| = \sim 49.3$ MV/m

($|H^s_{max}| = \sim 277$ kA/m?)

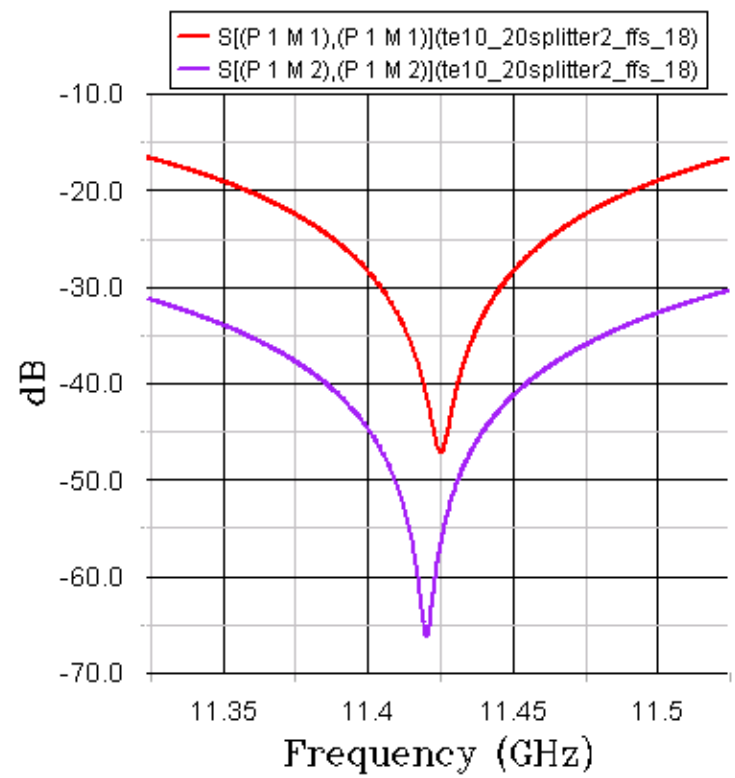
(unrounded point)



@ 600 MW $|E^s_{max}| = \sim 45.5$ MV/m

$|H^s_{max}| = \sim 113$ kA/m

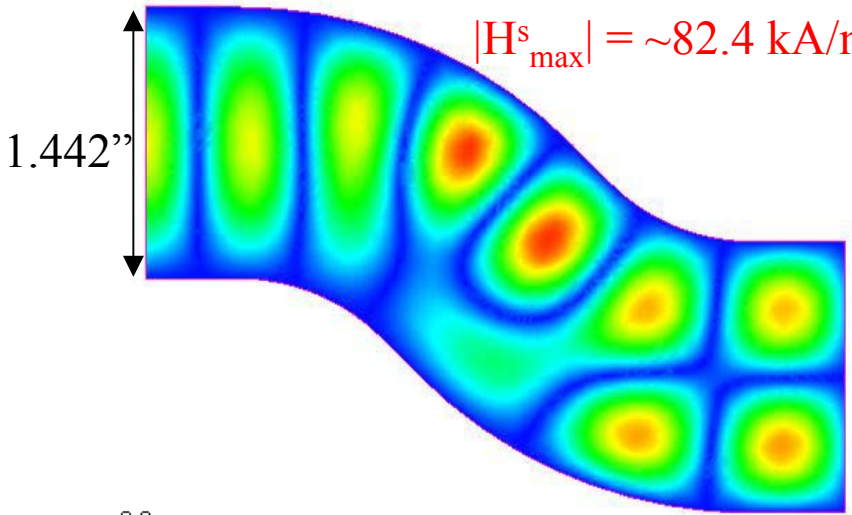
	(P 1 M 1)	(P 1 M 2)	(P 2 M 1)	(P 3 M 1)
(P 1 M 1)	0.0048	4.309e-006	0.7071	0.7071
(P 1 M 2)	4.309e-006	0.0011	0.7071	0.7071
(P 2 M 1)	0.7071	0.7071	0.0019	0.0029
(P 3 M 1)	0.7071	0.7071	0.0029	0.0019

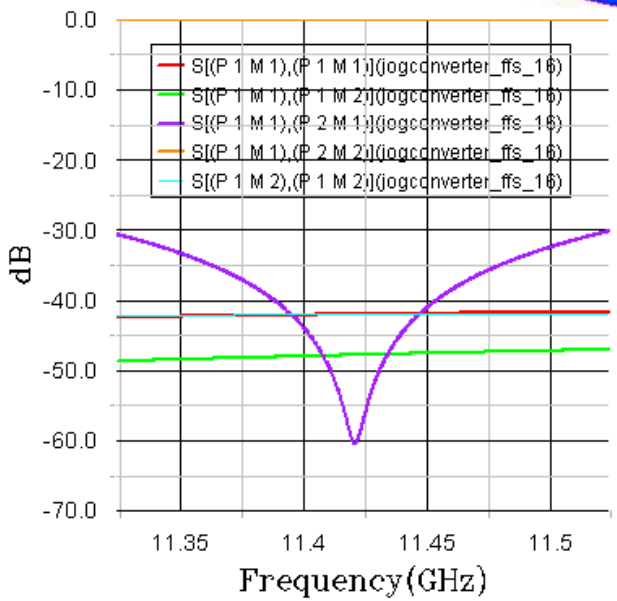


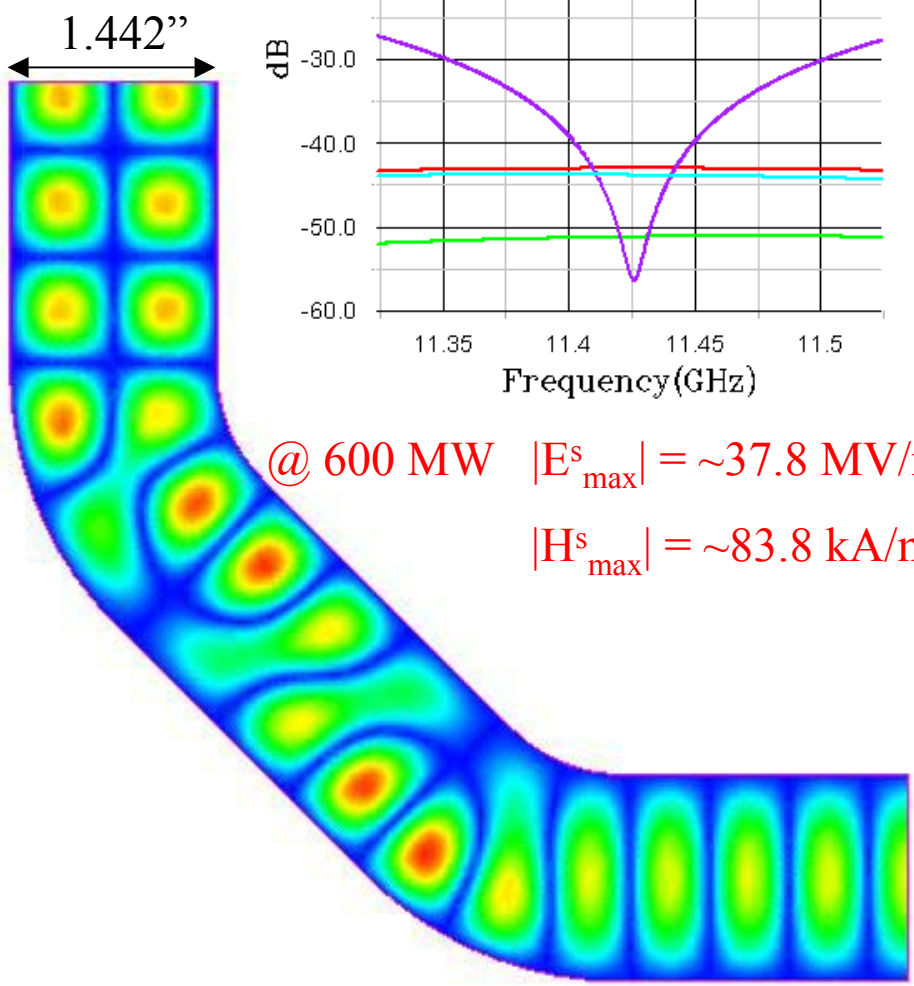
Jog Converter and Bend Converter

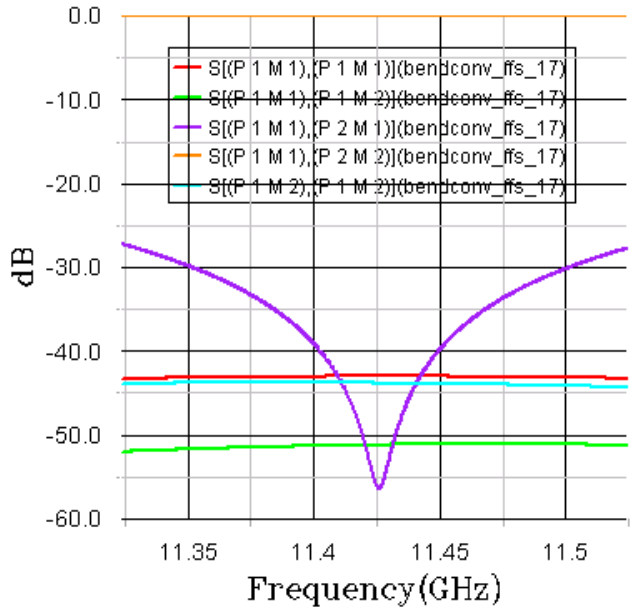
@ 600 MW $|E^s_{max}| = \sim 37.5$ MV/m

$|H^s_{max}| = \sim 82.4$ kA/m





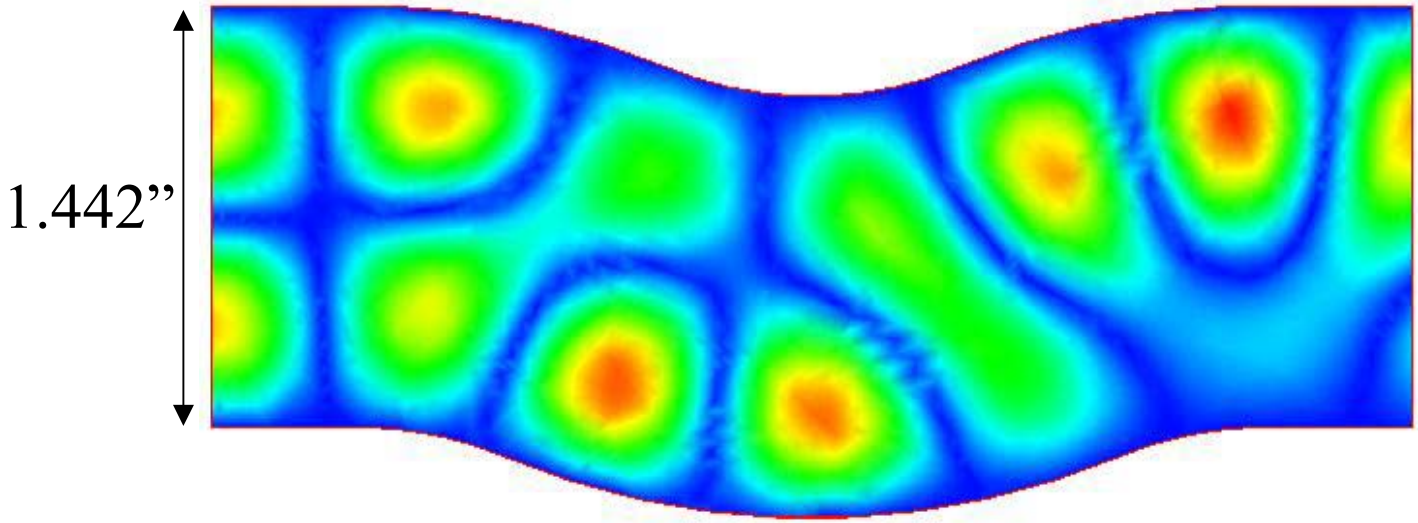




@ 600 MW $|E^s_{max}| = \sim 37.8$ MV/m

$|H^s_{max}| = \sim 83.8$ kA/m

Mode Mixer



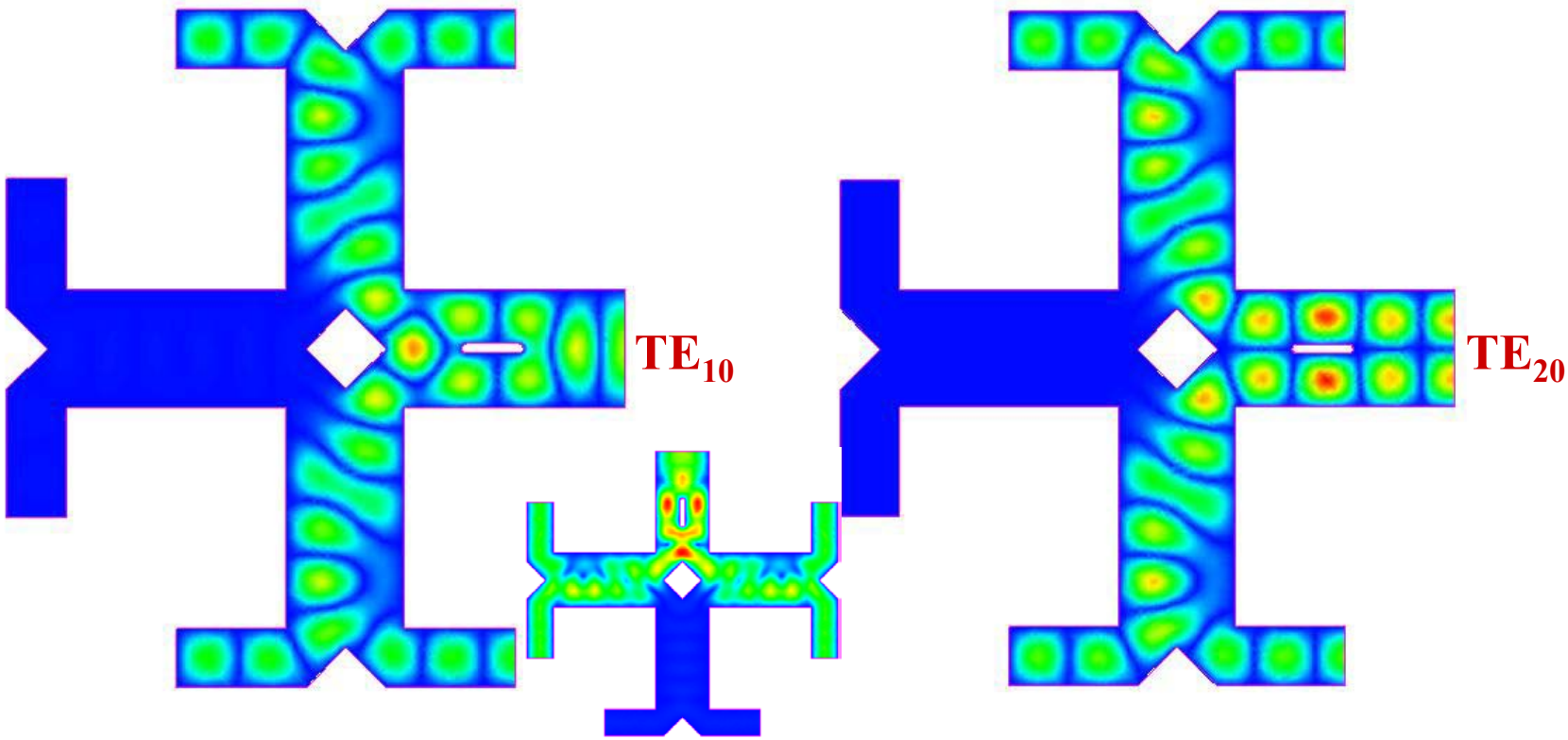
@ 600 MW $|E^s_{max}| = \sim 37.2$ MV/m

$|H^s_{max}| = \sim 83.0$ kA/m

	(P 1 M 1)	(P 1 M 2)	(P 2 M 1)	(P 2 M 2)
(P 1 M 1)	0.0129	0.0118	0.7036	0.7103
(P 1 M 2)	0.0118	0.0114	0.7103	0.7037
(P 2 M 1)	0.7036	0.7103	0.0129	0.0118
(P 2 M 2)	0.7103	0.7037	0.0118	0.0114

needs refinement.

Cross Potent Superhybrid as a Dual-Mode Launcher



@ 600 MW $|E^s_{max}| = \sim 42.9$ MV/m

$|H^s_{max}| = \sim 190$ kA/m

@ 600 MW $|E^s_{max}| = \sim 38.4$ MV/m

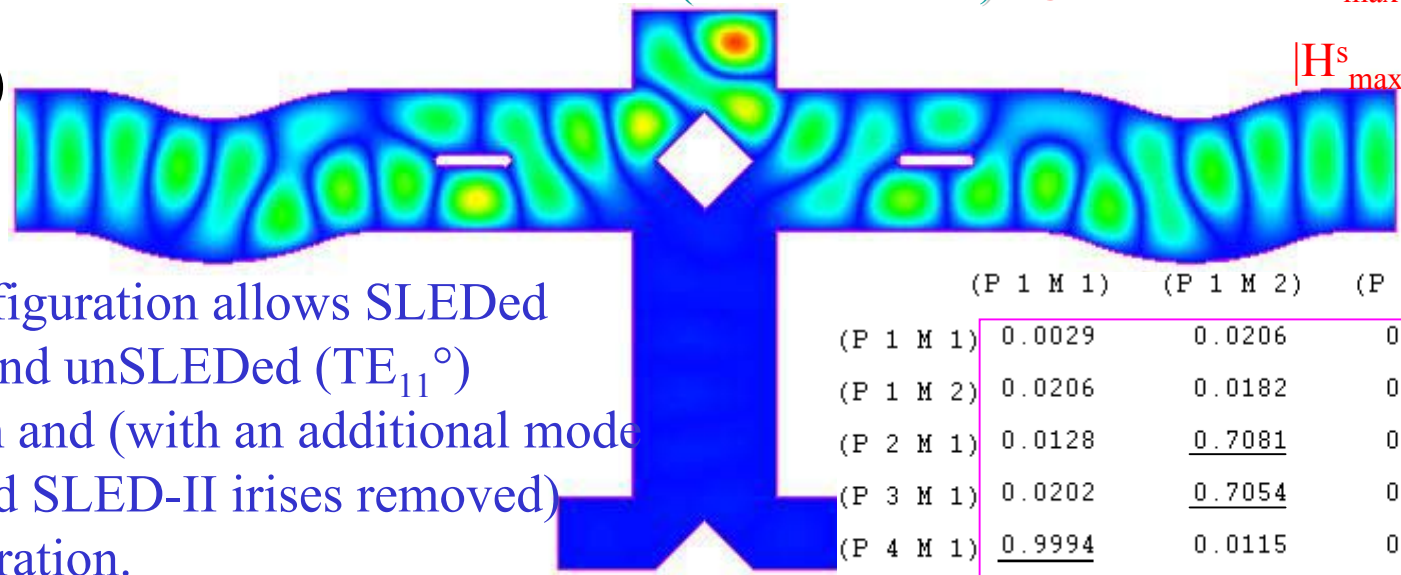
$|H^s_{max}| = \sim 104$ kA/m

8-Pack Phase I Cross Potent

TE_{10}
(TE_{11}°)

short (vacuum screen) @ 150 MW $|E^s_{max}|$ = ~29.8 MV/m

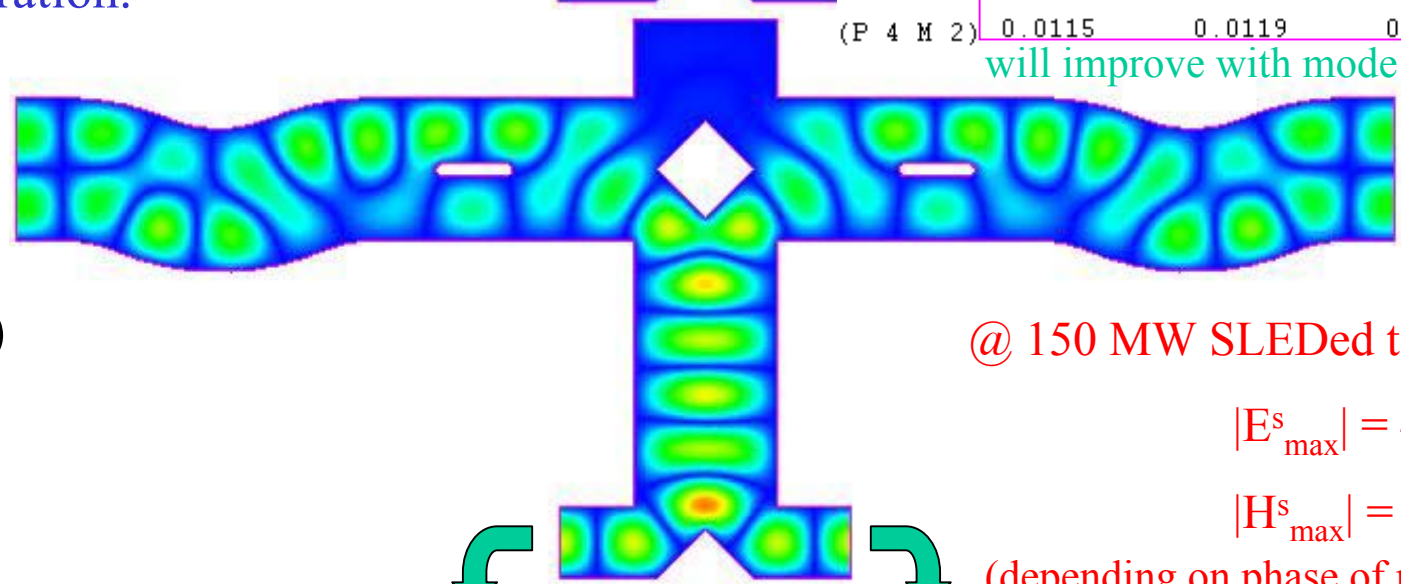
$|H^s_{max}|$ = ~190 kA/m



This configuration allows SLEDed (TE_{01}°) and unSLEDed (TE_{11}°) operation and (with an additional mode mixer and SLED-II irises removed) BPC operation.

	(P 1 M 1)	(P 1 M 2)	(P 2 M 1)	(P 3 M 1)
(P 1 M 1)	0.0029	0.0206	0.0128	0.0202
(P 1 M 2)	0.0206	0.0182	0.7081	0.7054
(P 2 M 1)	0.0128	0.7081	0.0116	0.0181
(P 3 M 1)	0.0202	0.7054	0.0181	0.0116
(P 4 M 1)	0.9994	0.0115	0.0202	0.0128
(P 4 M 2)	0.0115	0.0119	0.7054	0.7081

will improve with mode mixer refinement.



TE_{20}
(TE_{01}°)

@ 150 MW SLEDed to 600MW

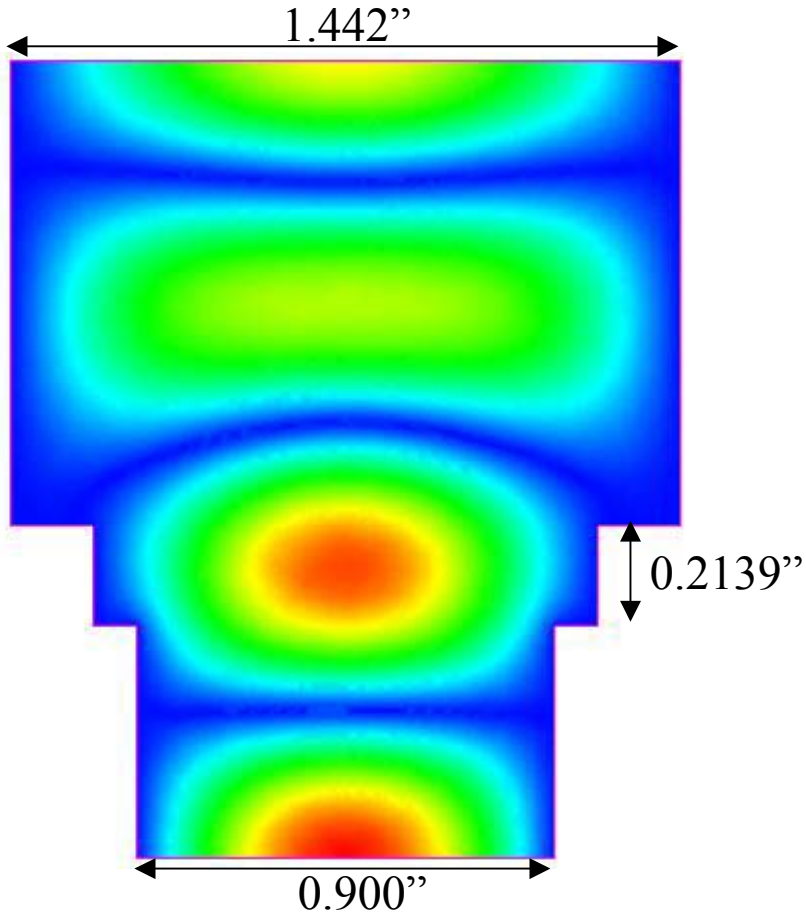
$|E^s_{max}|$ = ~48.5 MV/m

$|H^s_{max}|$ = ~256 kA/m

(depending on phase of reflected wave)

to SLED-II delay lines

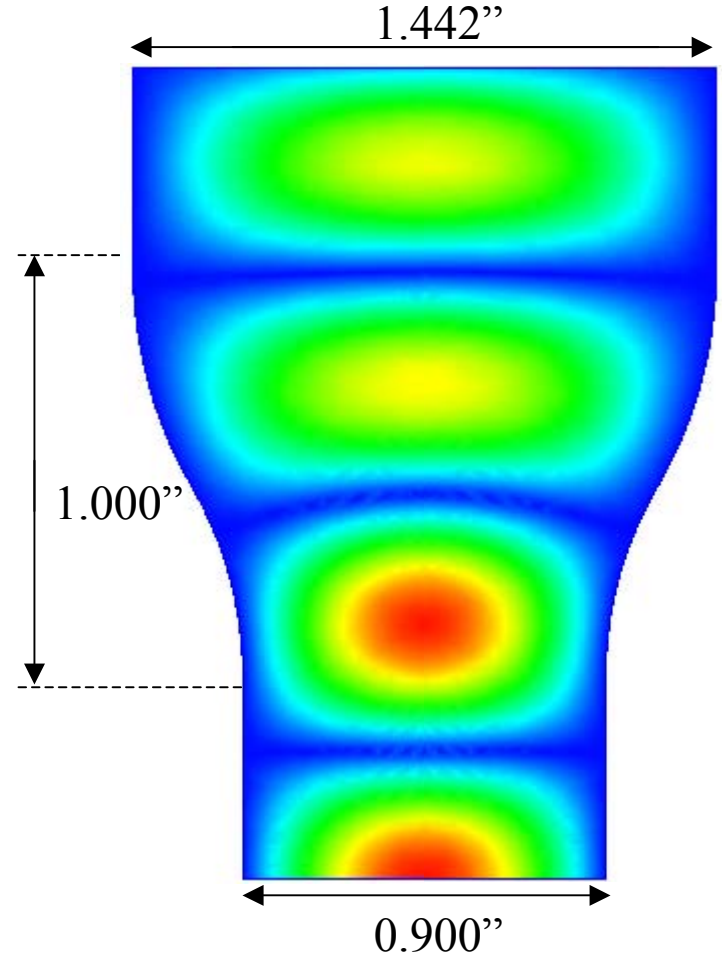
Width Taper (0.900”→1.442”)



@ 600 MW $|E^s_{max}| = \sim 36.8$ MV/m

$|H^s_{max}| = \sim 106$ kA/m

	(P 1 M 1)	(P 2 M 1)	(P 2 M 2)
(P 1 M 1)	0.0001	1	8.586e-006
(P 2 M 1)	1	0.0001	8.587e-006

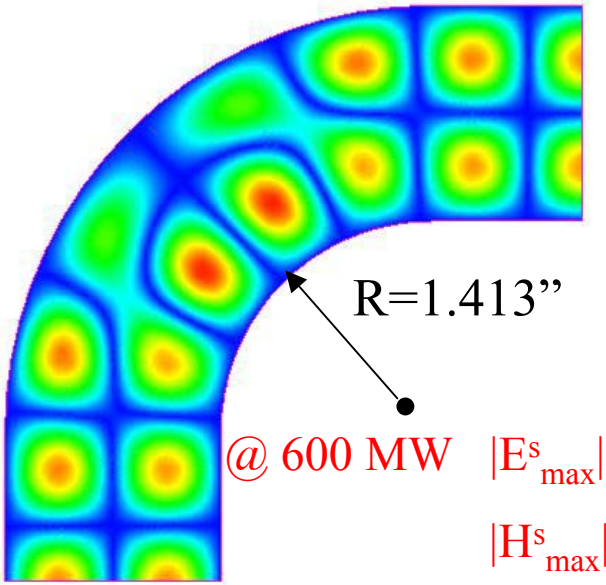


@ 600 MW $|E^s_{max}| = \sim 37.1$ MV/m

$|H^s_{max}| = \sim 116$ kA/m

	(P 1 M 1)	(P 2 M 1)
(P 1 M 1)	0.0060	1
(P 2 M 1)	1	0.0060

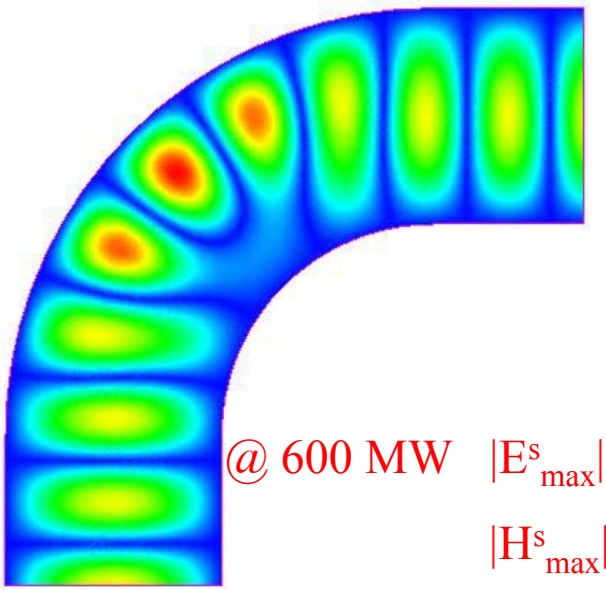
H-Plane Bend and E-Plane Bend



R=1.413”

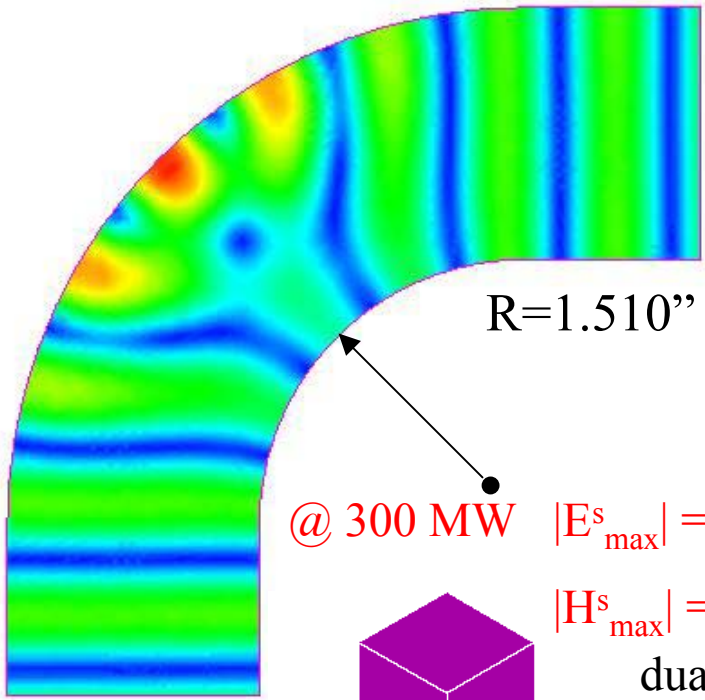
@ 600 MW $|E^s_{max}|$ = ~36.7 MV/m

$|H^s_{max}|$ = ~81.3 kA/m



@ 600 MW $|E^s_{max}|$ = ~37.1 MV/m

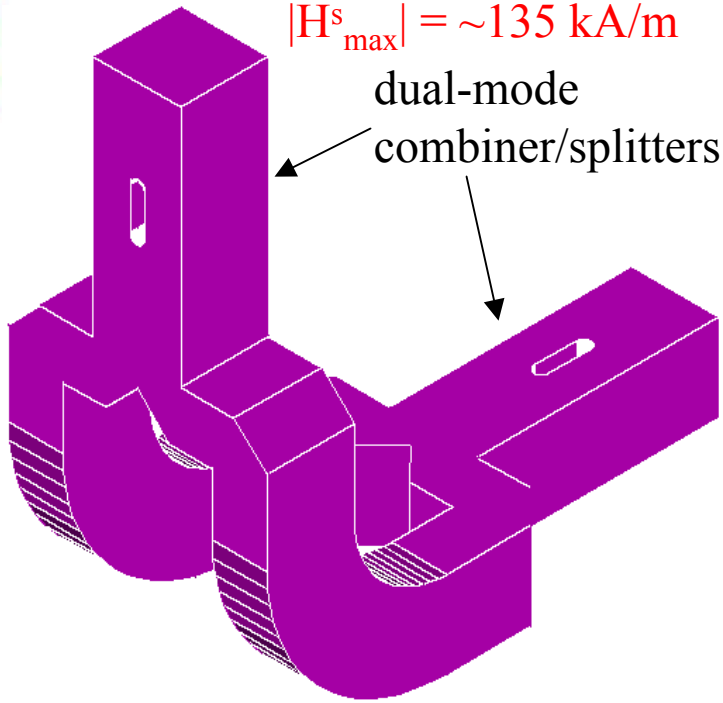
$|H^s_{max}|$ = ~79.0 kA/m



R=1.510”

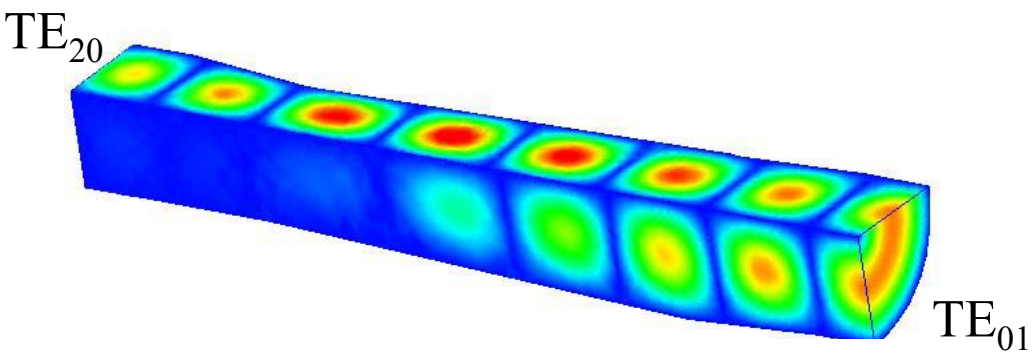
@ 300 MW $|E^s_{max}|$ = ~46.3 MV/m

$|H^s_{max}|$ = ~135 kA/m

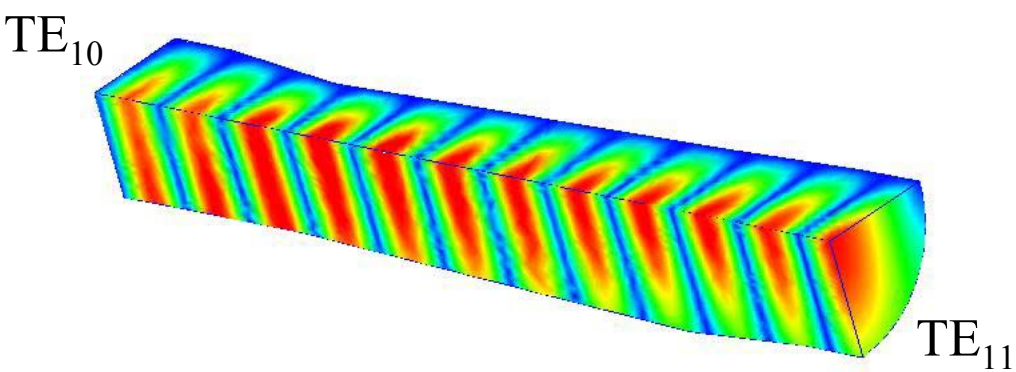


dual-mode combiner/splitters

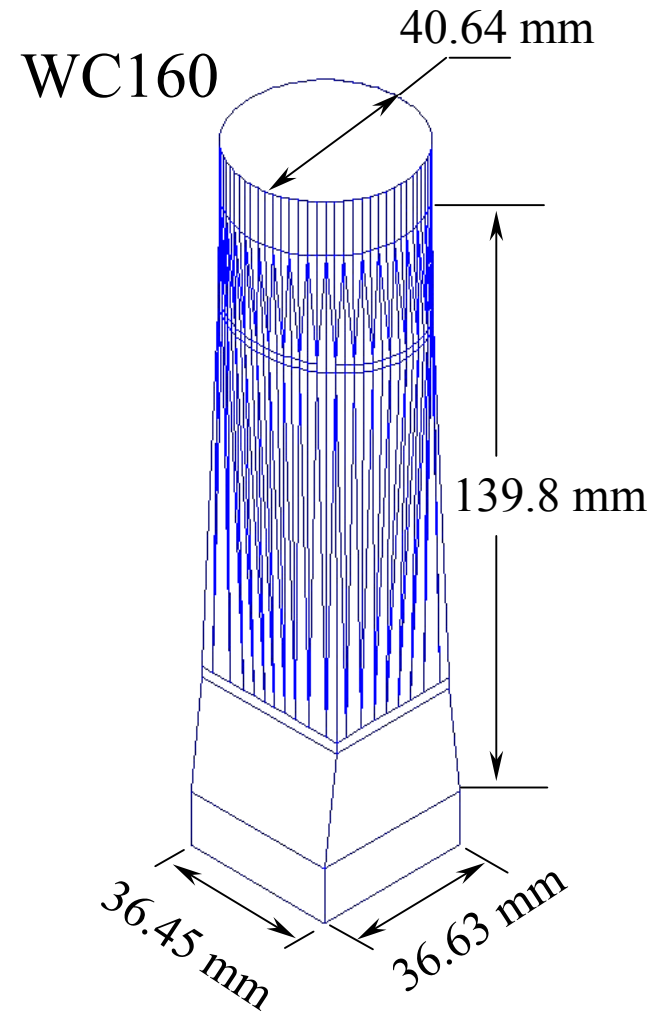
Dual-Mode Rectangular-to-Circular Taper



@ 600 MW $|E^s_{max}|$ = ~37 MV/m



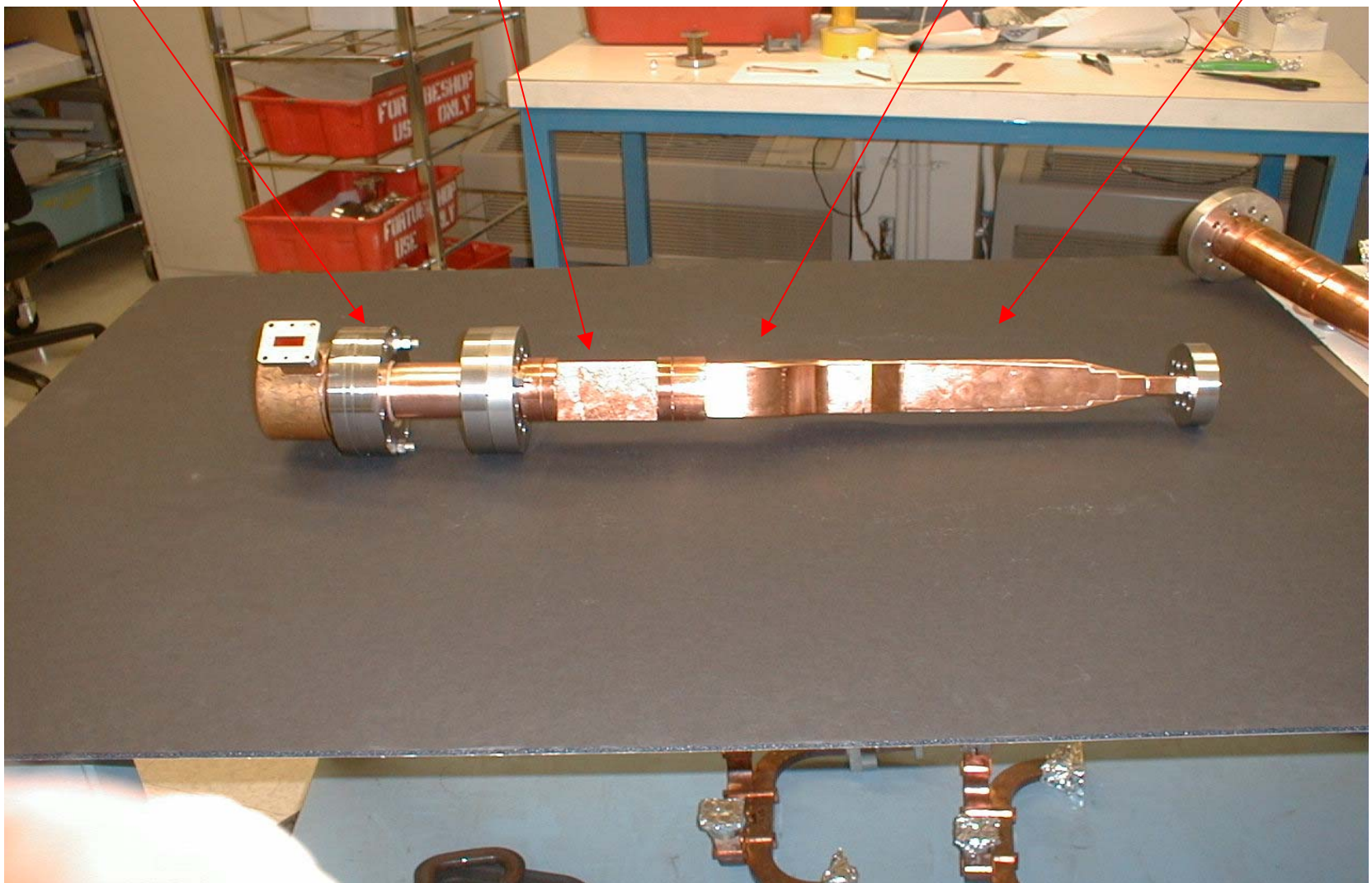
Simulated electric fields (HFSS)of the multi-moded circular to rectangular taper



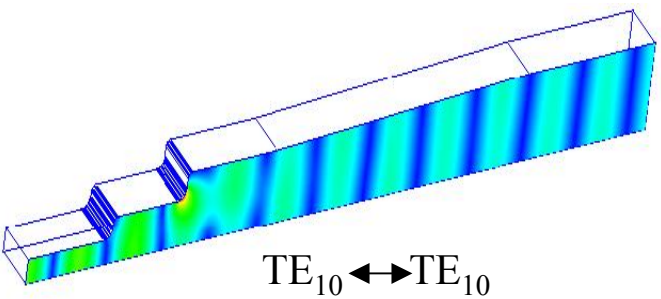
Taper Geometry

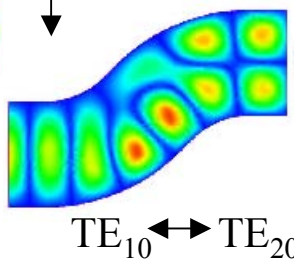
Prototype Component Testing

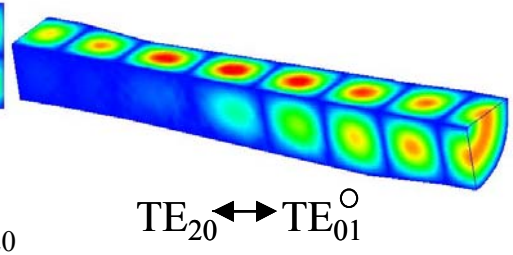
Wraparound mode converter, circular to rectangular taper, jog mode converter, height tapers,

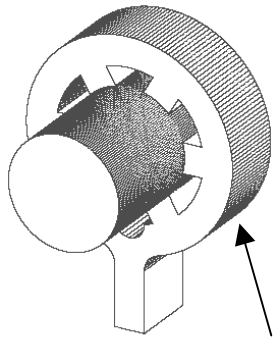


An Assembly to test new components and concepts: height tapers, jog mode converter, circular to rectangular tapers

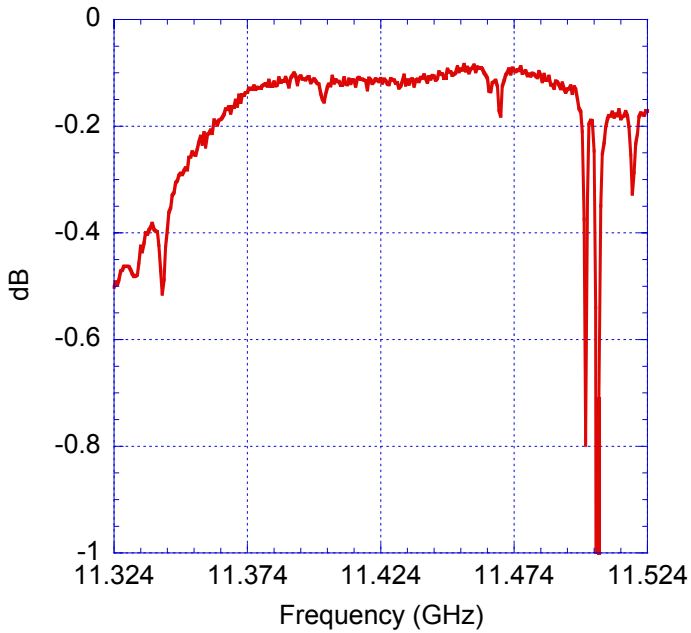




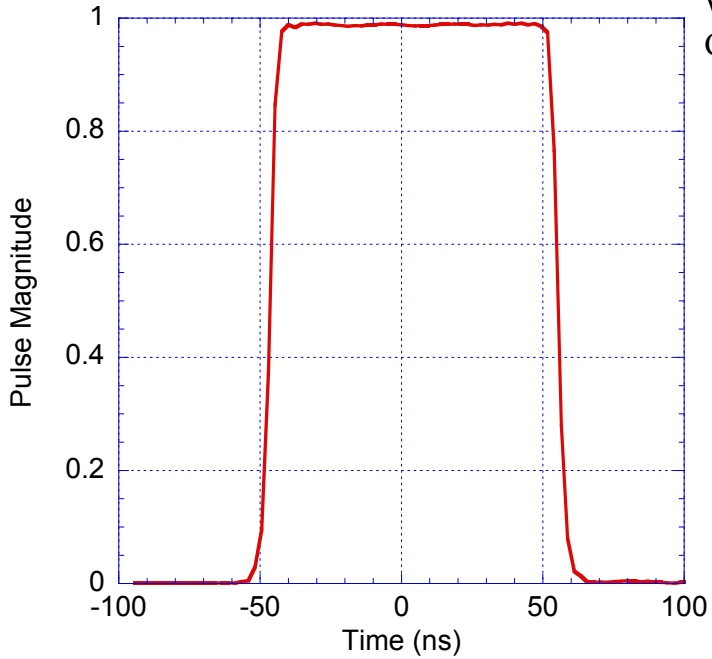




Wrap-Around Converter

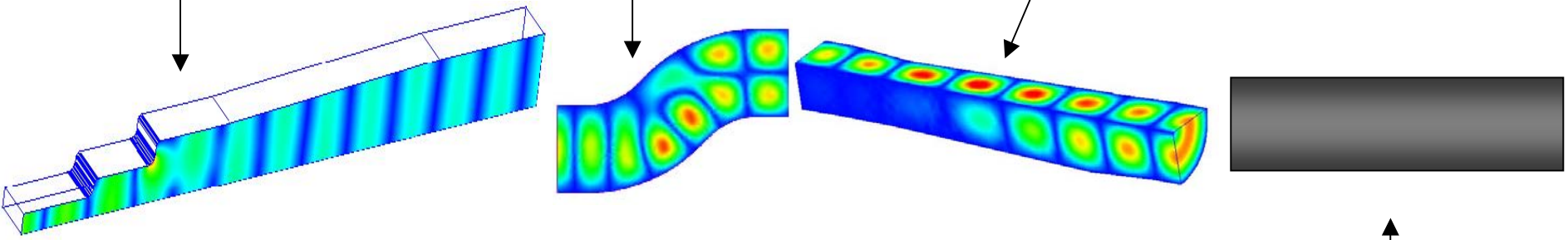


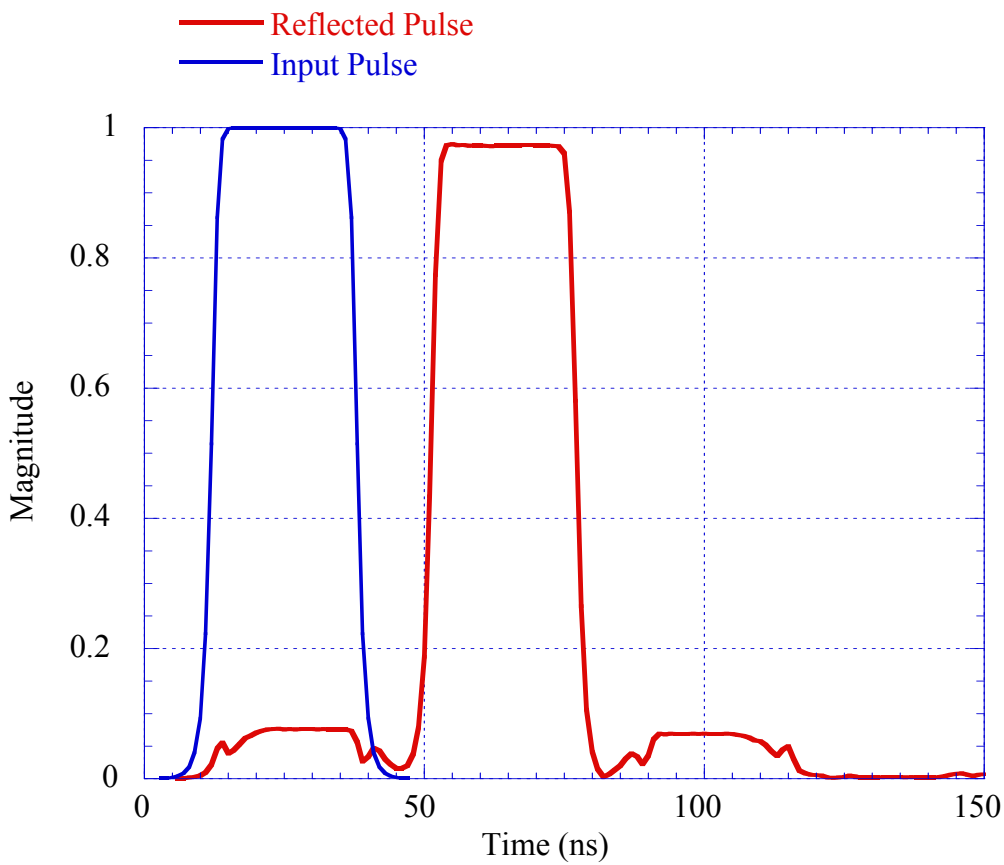
Frequency response of the assembly (S_{12})



Transmitted pulse through the assembly

height taper, jog converter, circular-to-rectangular taper

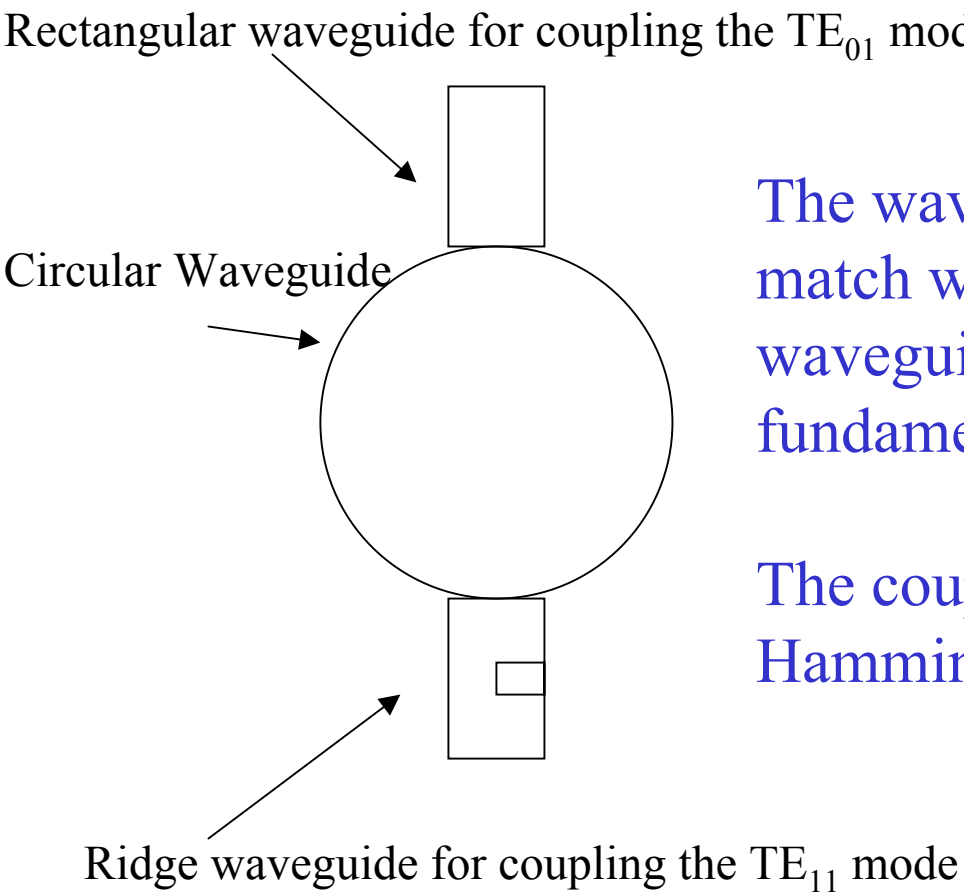




30 ns shorted transmission line

Reflection after an approximately 30 ns transmission line

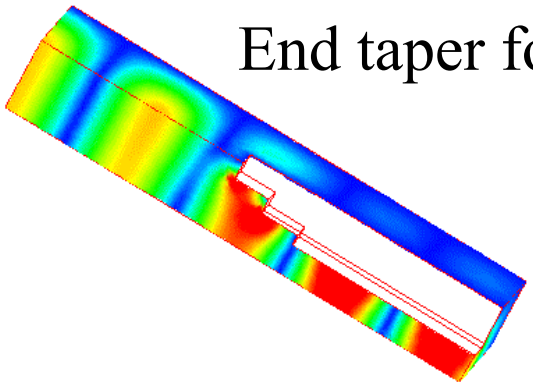
Dual Mode Circular Waveguide Directional Coupler



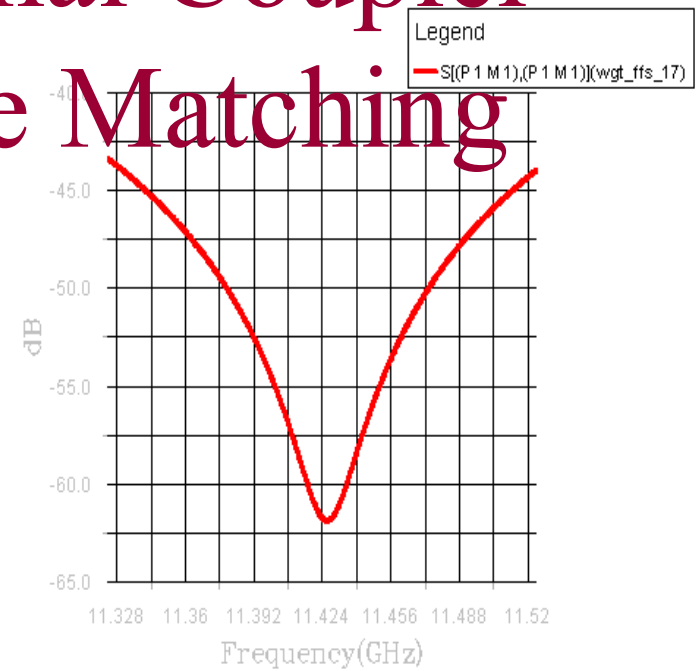
The waveguide sizes are chosen to match wavelengths between the circular waveguide modes and side waveguide fundamental mode

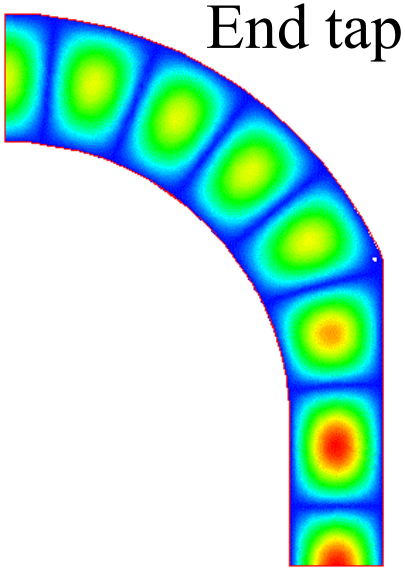
The coupling hole pattern represents a Hamming window.

Dual Mode Directional Coupler Coupled Waveguide Matching

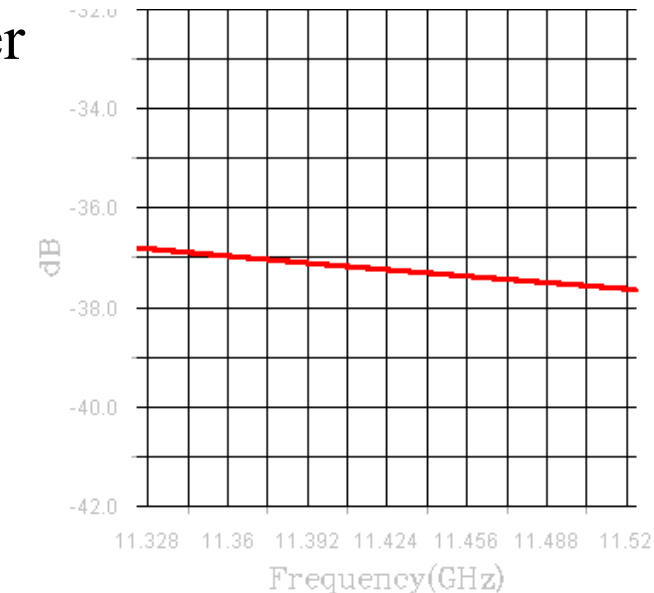


End taper for TE_{11} coupler





End taper for the TE_{01} coupler

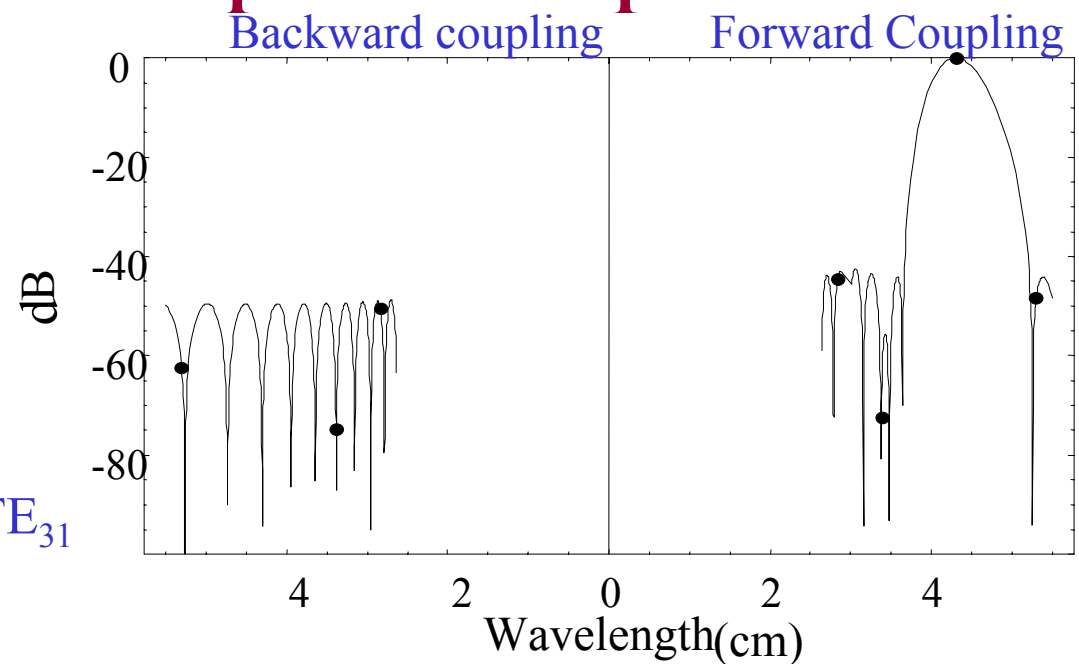


Directional Coupler Response

TE_{01} directional coupler response (relative)

Coupler Length =50.6 cm
Number of coupling holes=44

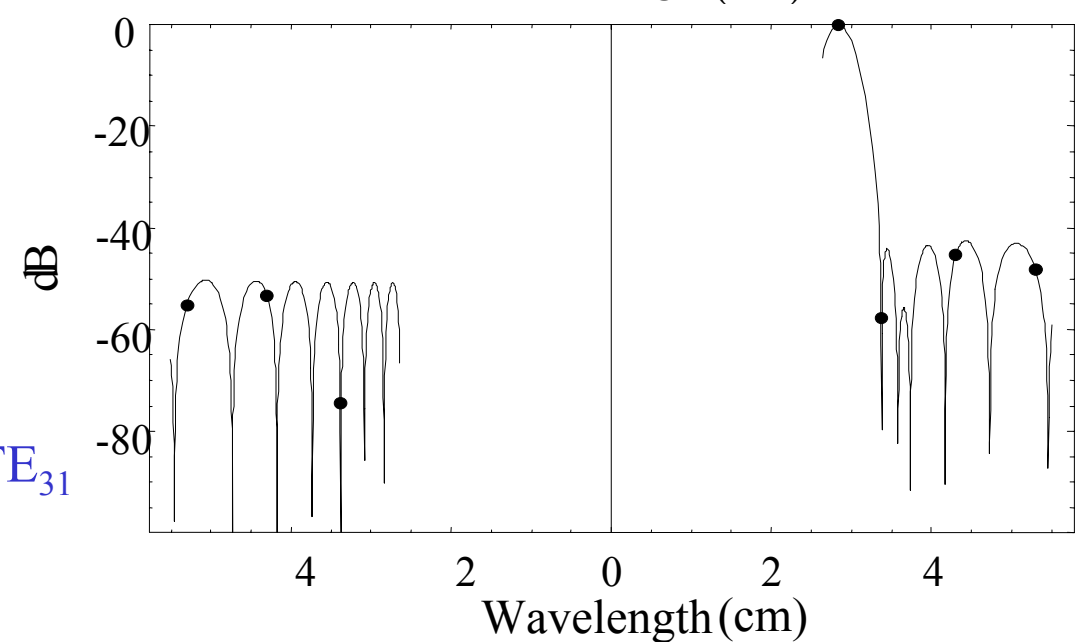
Points represent : TE_{11}, TE_{21}, TE_{01}, TE_{31}



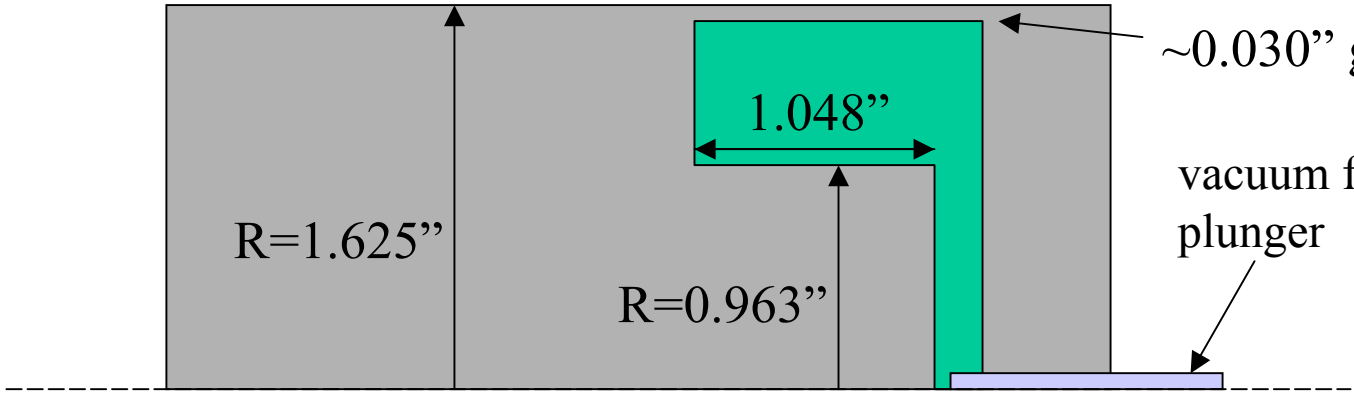
TE_{11} directional coupler response (relative)

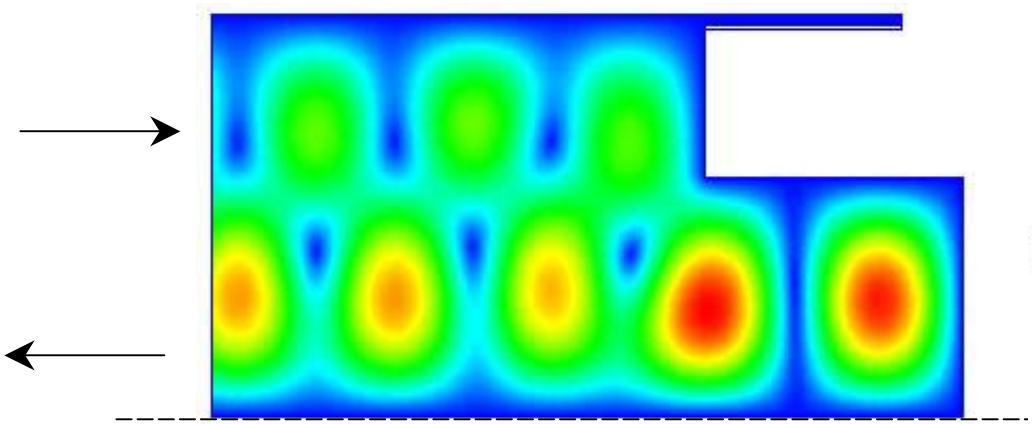
Coupler Length =38.3 cm
Number of coupling holes=51

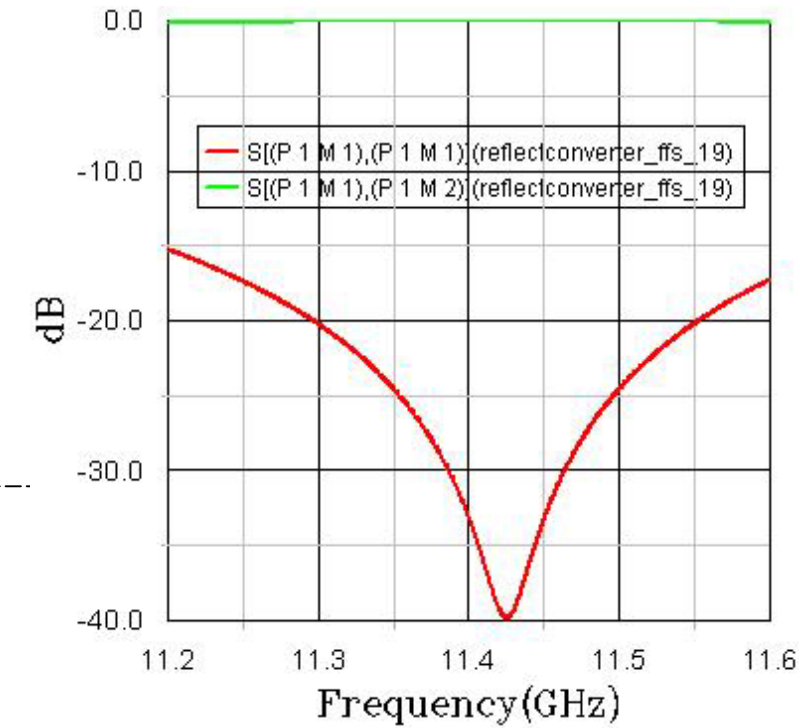
Points represent : TE_{11}, TE_{21}, TE_{01}, TE_{31}



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



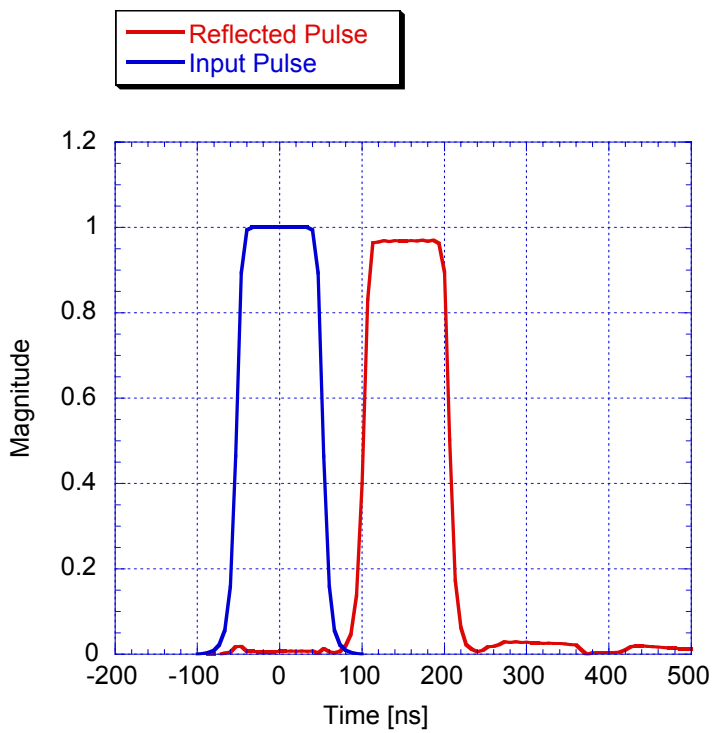




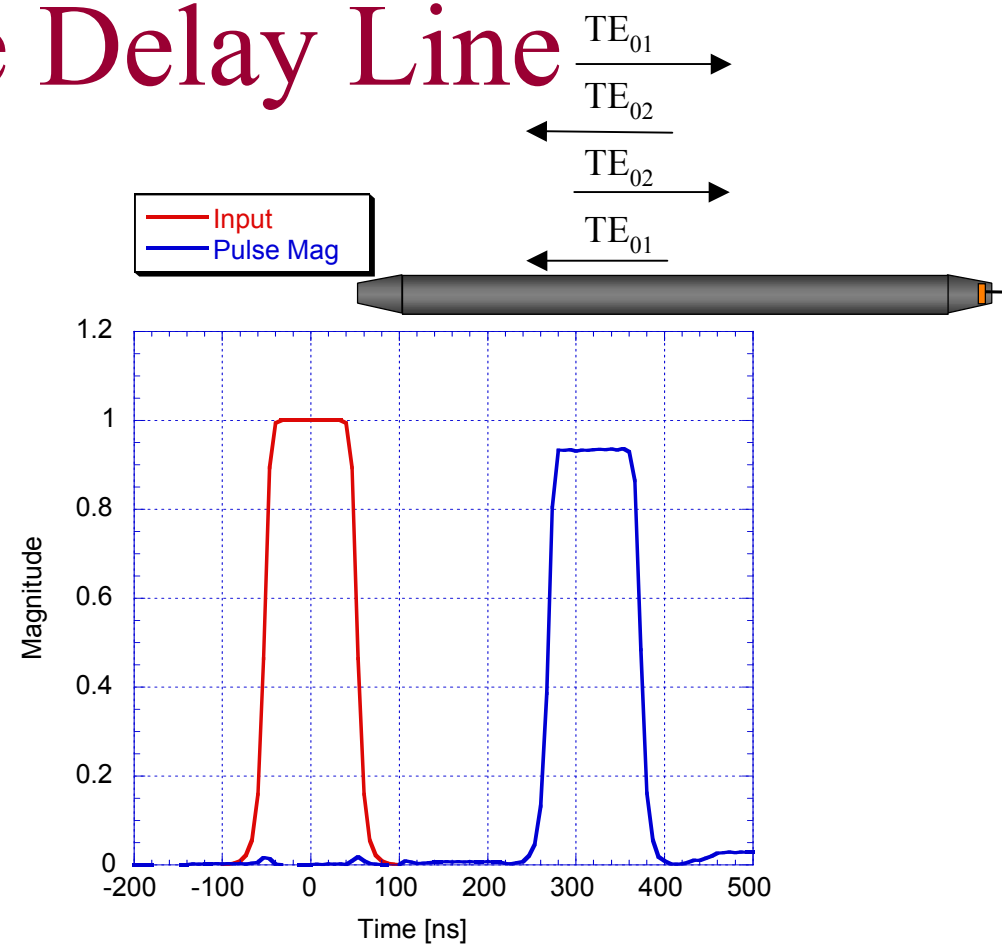
S =

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

Demonstration of Multimoded Reflective Delay Line



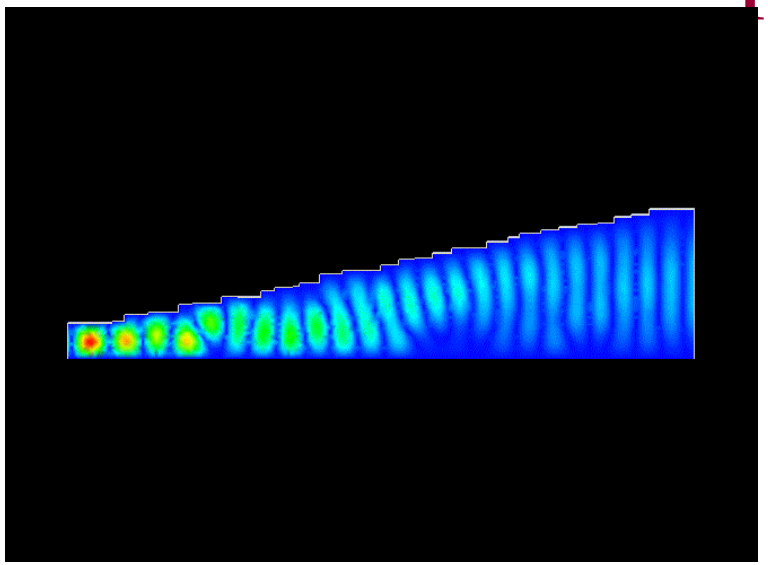
Measured Delay through 75 feet of WC475 waveguide terminated with a flat plate. The round trip delay time is 154 ns.

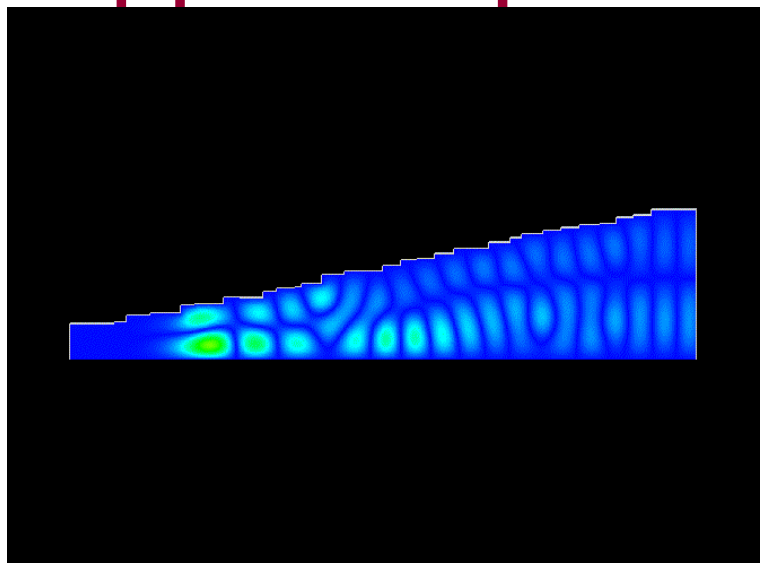


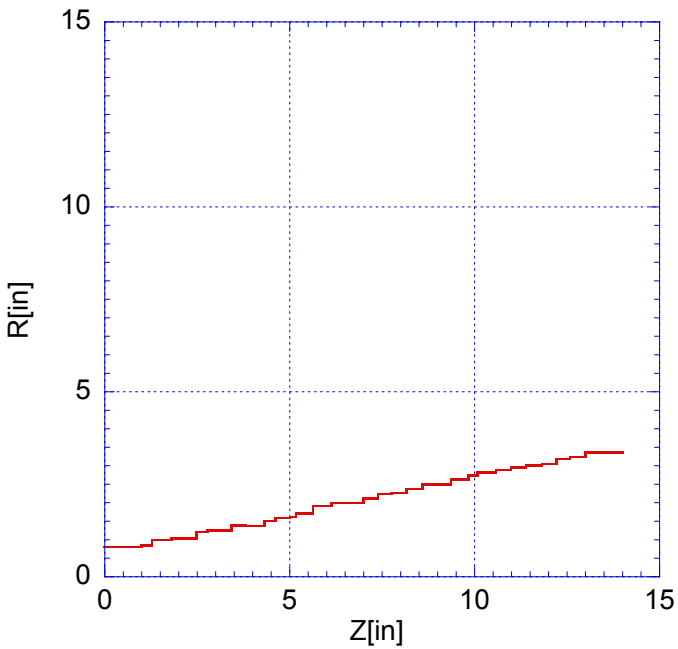
Measured delay through 75 feet of WC475 waveguide terminated with a TE_{01}-TE_{02} Mode converter. The round trip delay time is 320 ns.

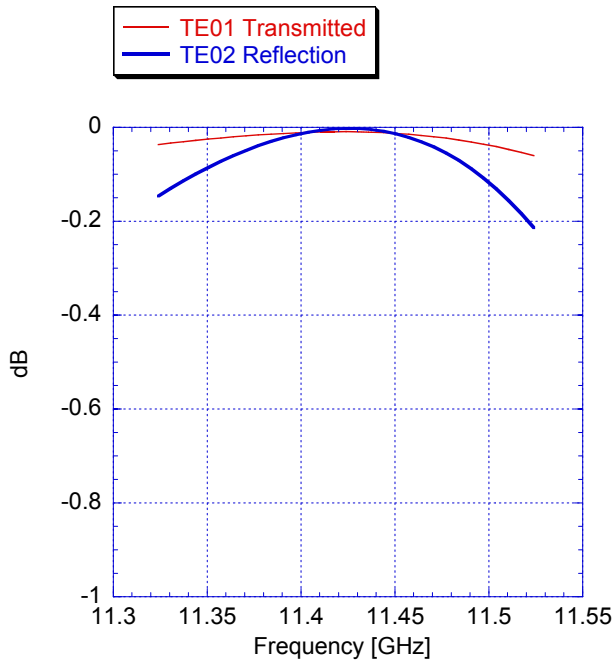
S. Tantawi

Dual Mode Input Stepped Taper

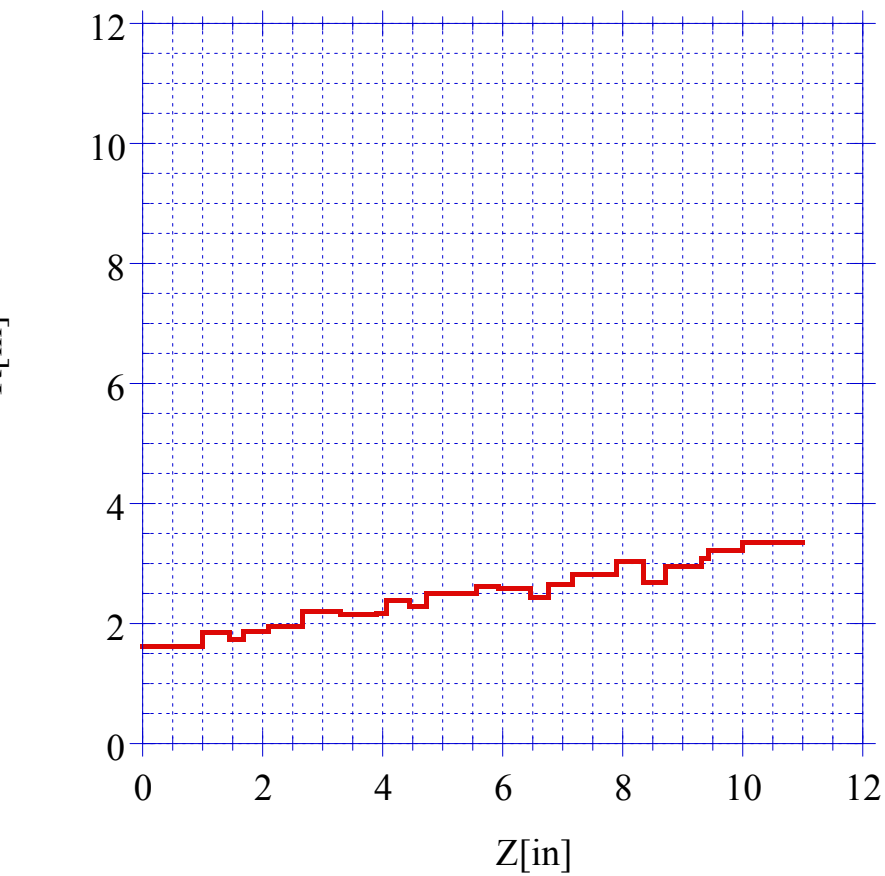


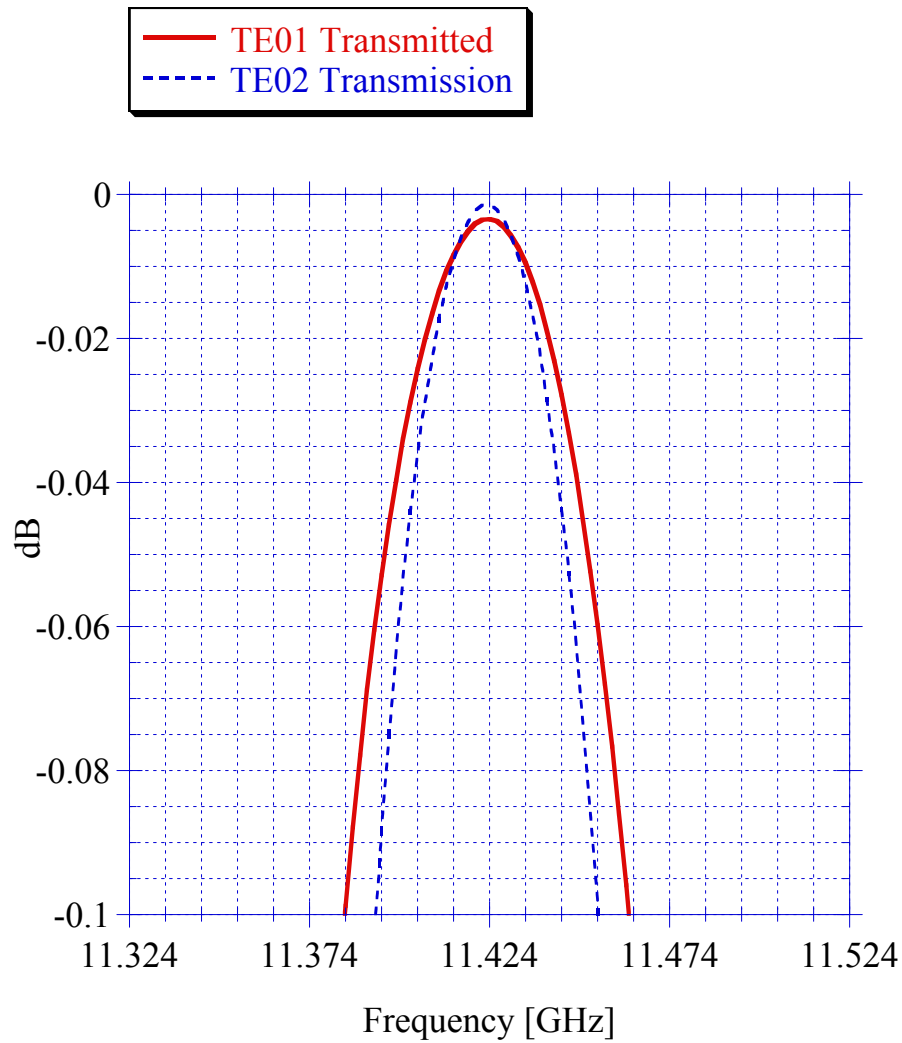






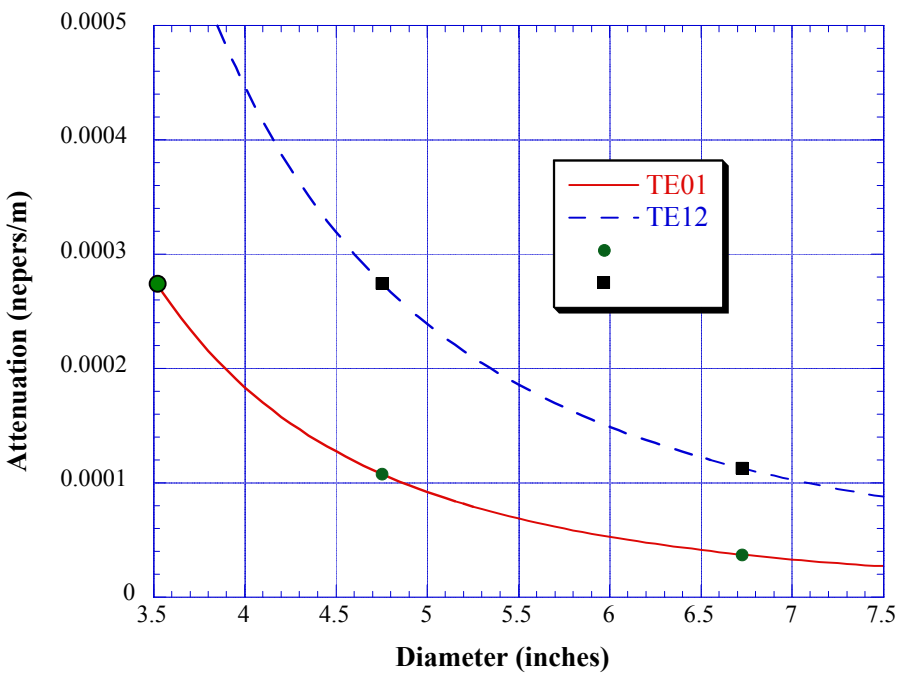
Dual Mode End Stepped Taper



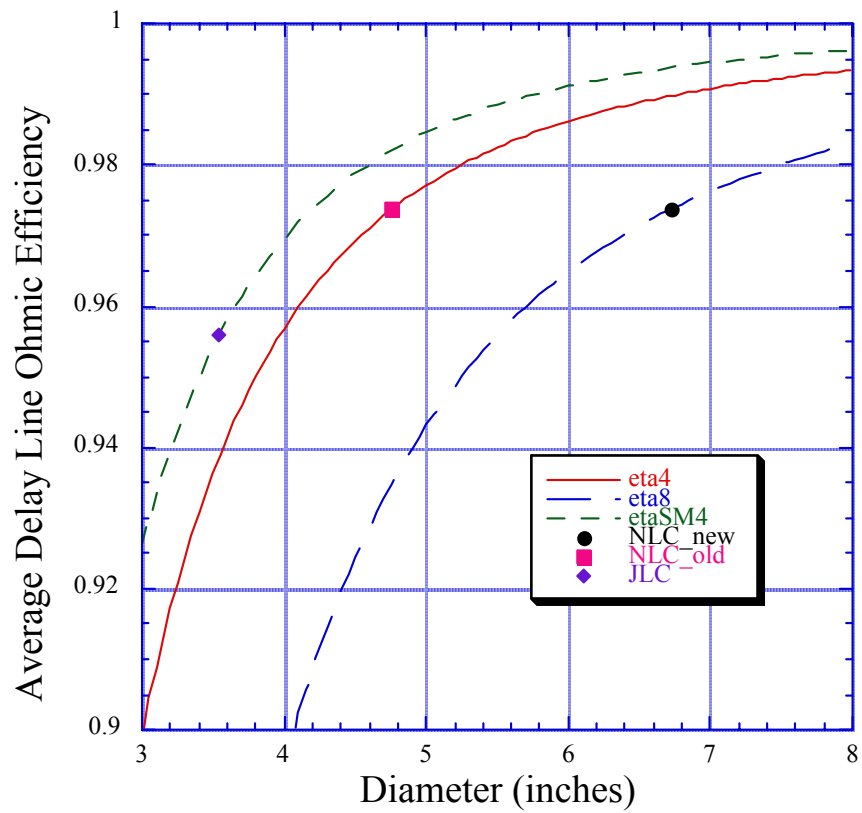


End Taper (before the TE_{01}-TE_{02} Mode converter)

Delay Line Losses



Ohmic attenuation constants versus copper waveguide diameter for TE_{01} and TE_{12}



Average delay line ohmic loss efficiency factor for dual-moded TE_{01}/TE_{12} DLDS systems with compression ratios of four and eight and for single moded DLDS versus delay line diameter.

Generalized Telegraphist's Equations

Mode coupling due to small perturbations of the circular waveguide wall can be analyzed by Fourier decomposing the deformation in ϕ and then integrating a set of coupled first-order differential equations along z. (see e.g. J.L. Doane, "Polarization converters for circular waveguide modes," Int. J. Electronics, 1986, vol. 61, no. 6, pp. 1109-1133.)

$$r(\phi,z) = a + \delta(\phi,z)$$

$$\delta(\phi,z) = a_0^c(z) + \sum_{l=1}^{\infty}\left[a_l^c(z)\cos l\phi + a_l^s(z)\sin l\phi\right]$$

ordinary polarization:

$$\frac{d}{dz}A_m^o(z) = \sum_n \left\{\left[K_{mnc}^{oo}a_{p-q}^c(z) + C_{mnc}^{oo}a_{p+q}^c(z)\right]A_n^o(z) + \left[K_{mns}^{ox}a_{p-q}^s(z) + C_{mns}^{ox}a_{p+q}^s(z)\right]A_n^x(z)\right\}e^{i\Delta\beta_{mn}z},$$

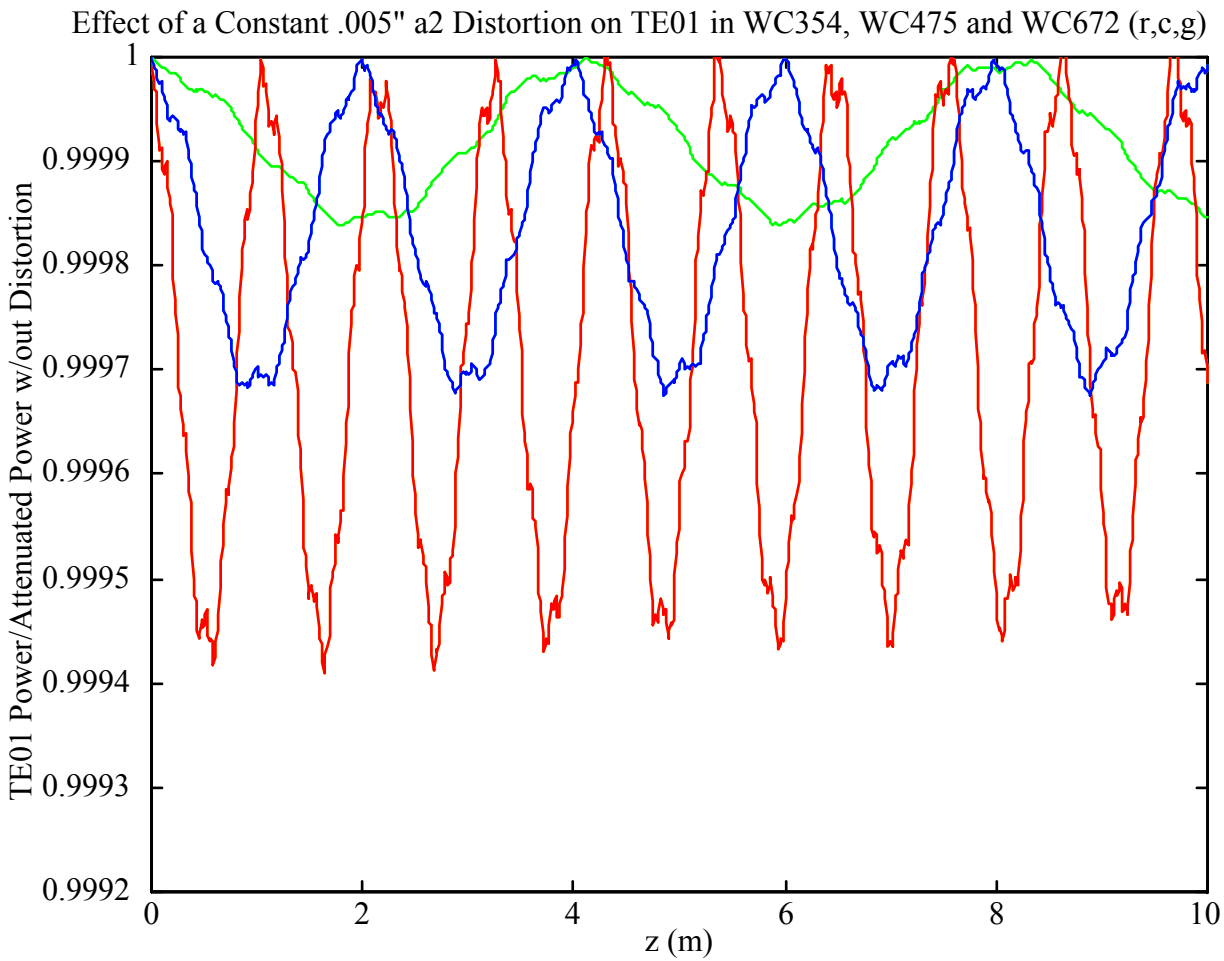
cross polarization:

$$\frac{d}{dz}A_m^x(z) = \sum_n \left\{\left[K_{mns}^{xo}a_{p-q}^s(z) + C_{mns}^{xo}a_{p+q}^s(z)\right]A_n^o(z) + \left[K_{mnc}^{xx}a_{p-q}^c(z) + C_{mnc}^{xx}a_{p+q}^c(z)\right]A_n^x(z)\right\}e^{i\Delta\beta_{mn}z}.$$

except that $a_0^c(z)$ is replaced by $a_0^{c\prime}(z)$ for diameter variation coupling ($a_0^s \equiv 0$), and $a_1^{c,s}(z)$ are replaced by $a_1^{c,s\prime\prime}(z)$ for curvature coupling.

p and q are the azimuthal indices of modes m and n.

Mode Conversion Sensitivity



diameter

Green – 6.725”

Blue – 4.75”

Red – 3.54”

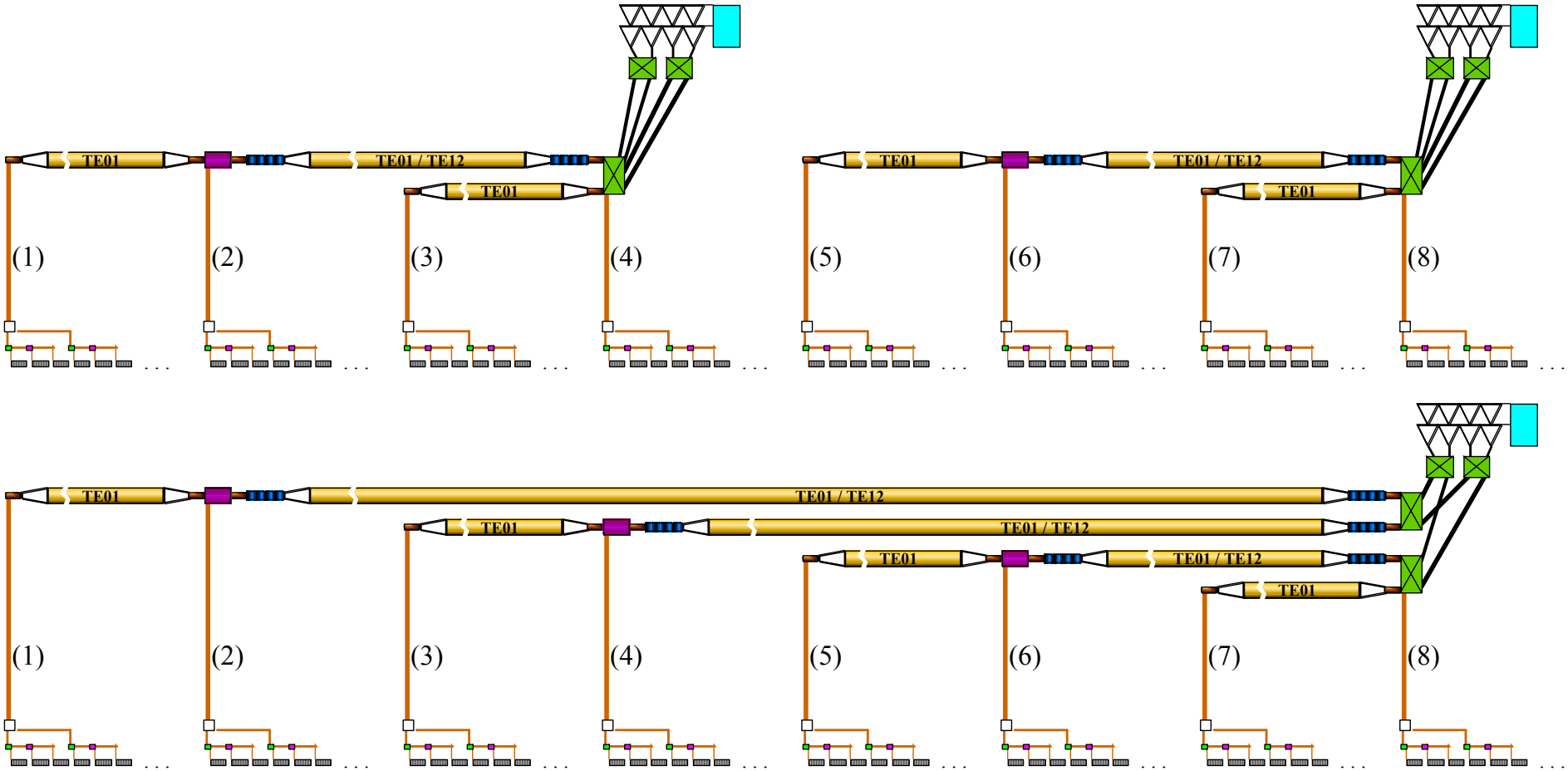
Dual-Moded DLDS Heads

8×4

8×8

×4 and ×8 MDLDS

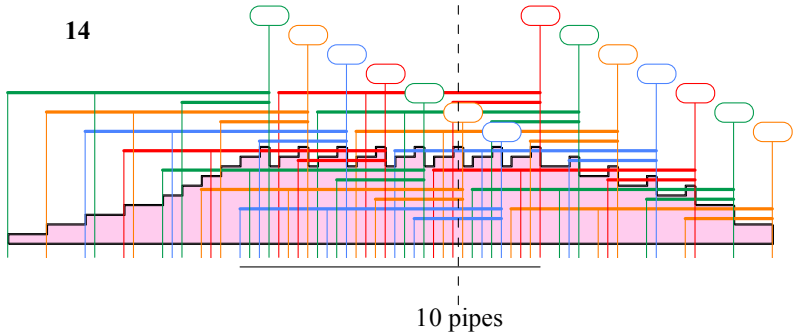
Normalized Delay Line Length	
DLDS4:	1
MDLDS4:	2/3
MDLDS8:	4/3



MDLDS4 & 8 w/ Distributed Klystrons

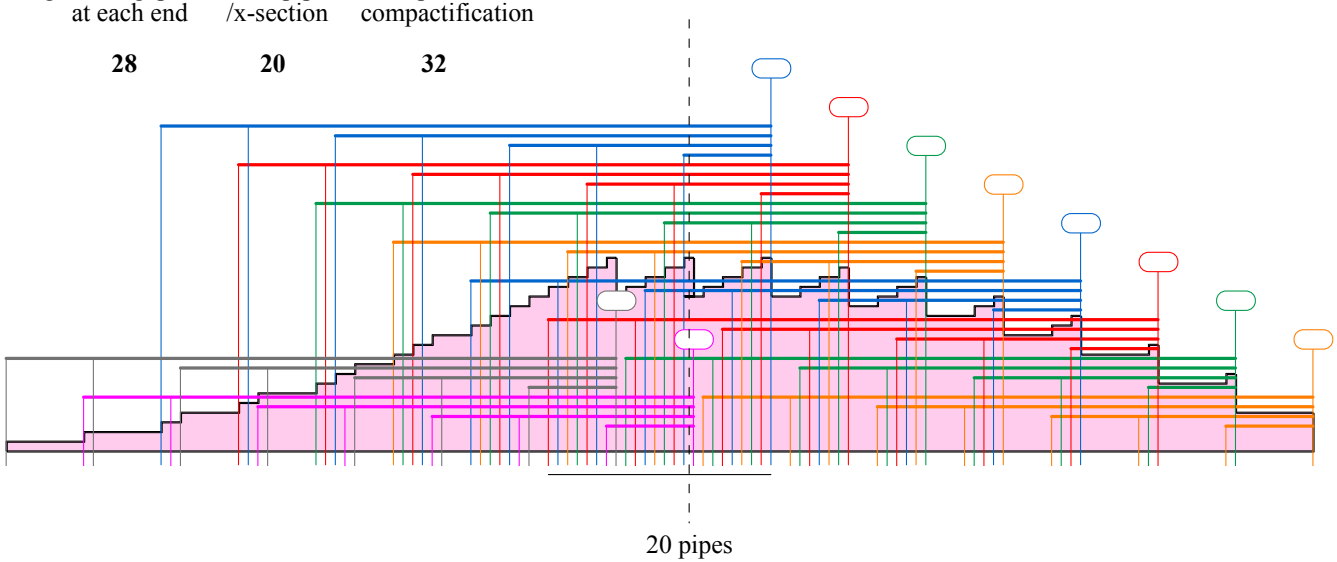
Dual-Moded x4 DLDS:

Module spacing	feed gaps at each end	max. pipes /x-section	footprint w/out compactification
4	**12**	**10**	**14**

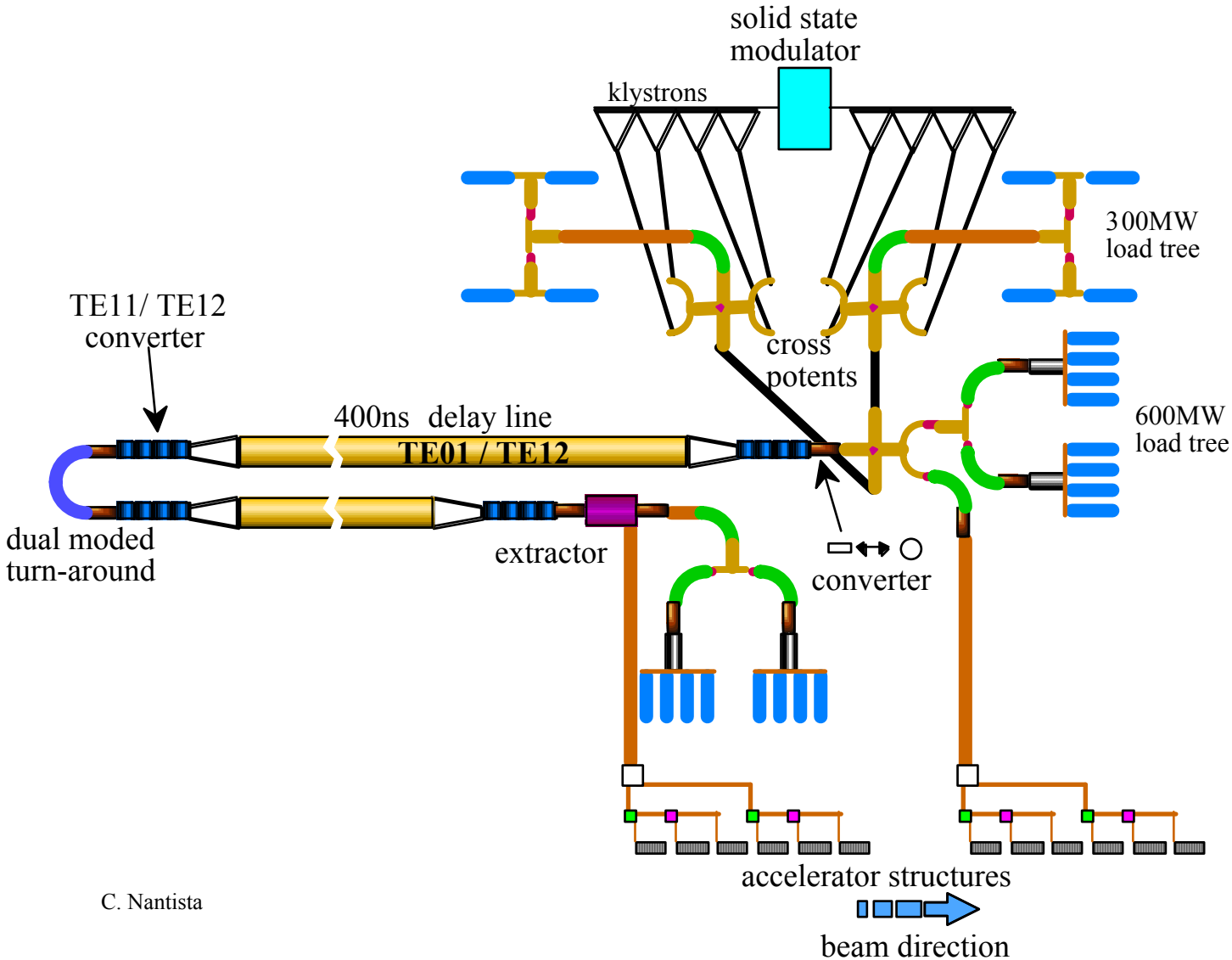


Dual-Moded x8 DLDS:

Module spacing	feed gaps at each end	max. pipes /x-section	footprint w/out compactification
8	**28**	**20**	**32**



8-Pack Phase II MDLDS Schematic



C. Nantista