

AUTOMATED DESIGN OF MULTIMEGAWATT MODE CONVERTER USING ANSOFT HFSS

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Abstract:

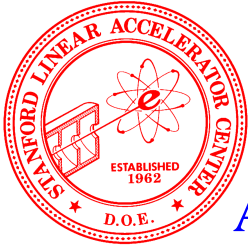
The next generation of linear accelerators requires highly efficient X-band rf power systems. These systems will have hundreds of kilometers of low-loss high power waveguide. We applied a multimode approach to reduce the length of the waveguide. We used Ansoft High Frequency Structure Simulator to design multimode waveguide components. One such component is a dual-function mode converter that transforms the TE₀₂ mode in rectangular waveguide into the axisymmetric TE₀₁ mode of circular waveguide, and the TE₀₁ mode of the rectangular waveguide into TE₁₁ mode of the circular waveguide. We developed an automatic design procedure using the C++ programming language and the HFSS macro language.

Outline

- ❑ RF pulse compression and distribution system
- ❑ Requirements for dual-mode converter
- ❑ Design procedure
- ❑ Automated optimization
- ❑ Results

Contributors:

Sami Tantawi
Christopher Nantista

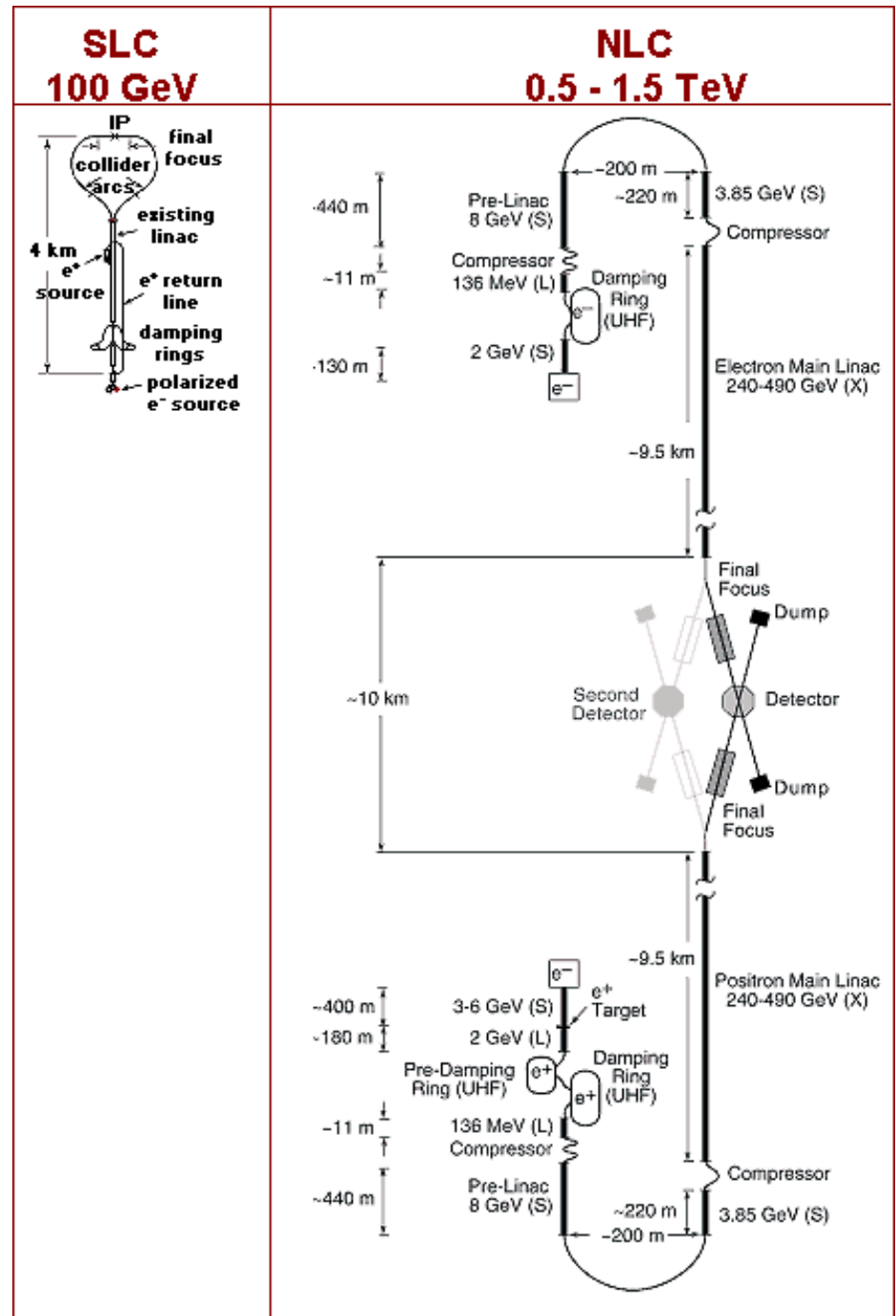


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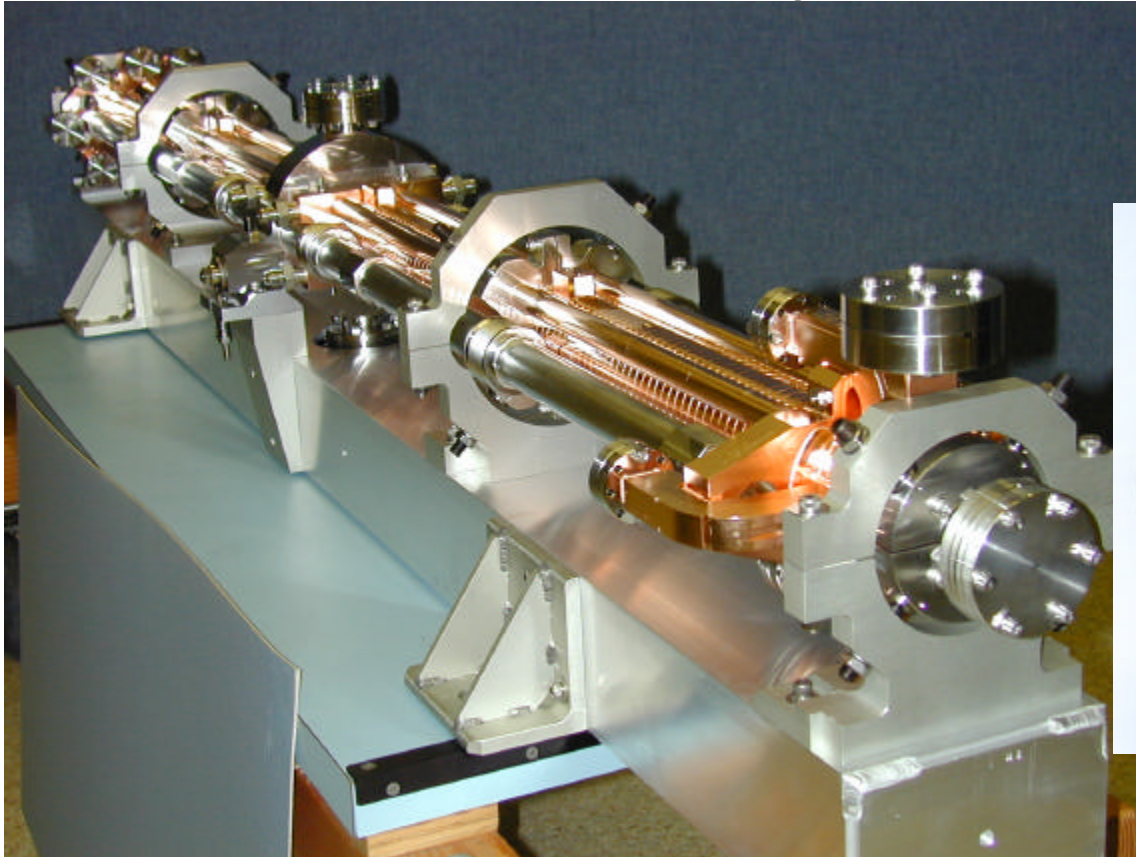
Schematic picture of the Next Linear Collider



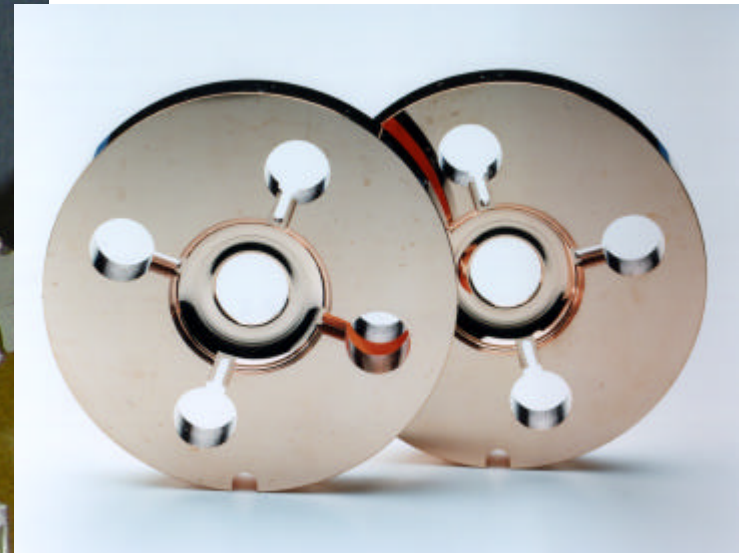
Accelerating structure

*Main part of the structure is an iris loaded circular waveguide that forms slow wave structure. This slow wave structure is used to accelerate electrons. The current NLC design requires a **flat-top 400 ns** rf pulse with a power **90 MW per meter of accelerating structure** at **11.424GHz**, with a repetition rate of **120 Hz**.*

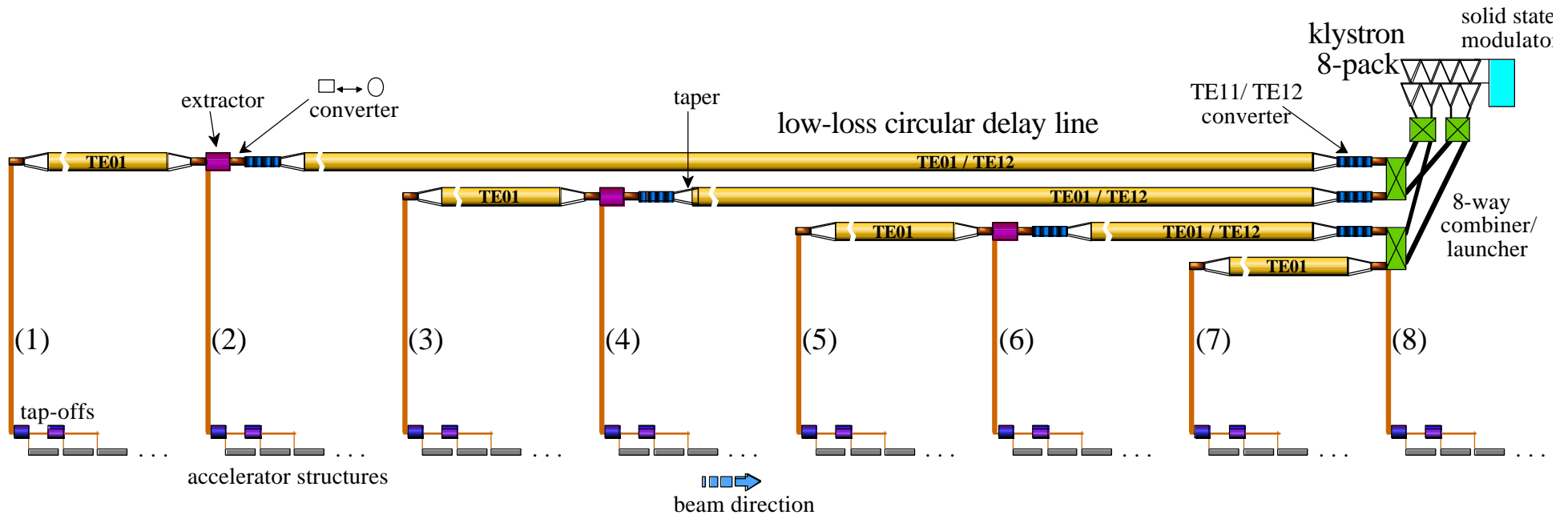
RDDS1 X-band accelerating structure



Cells of RDDS1



Unit of Dual-Moded Delay Line Distribution System



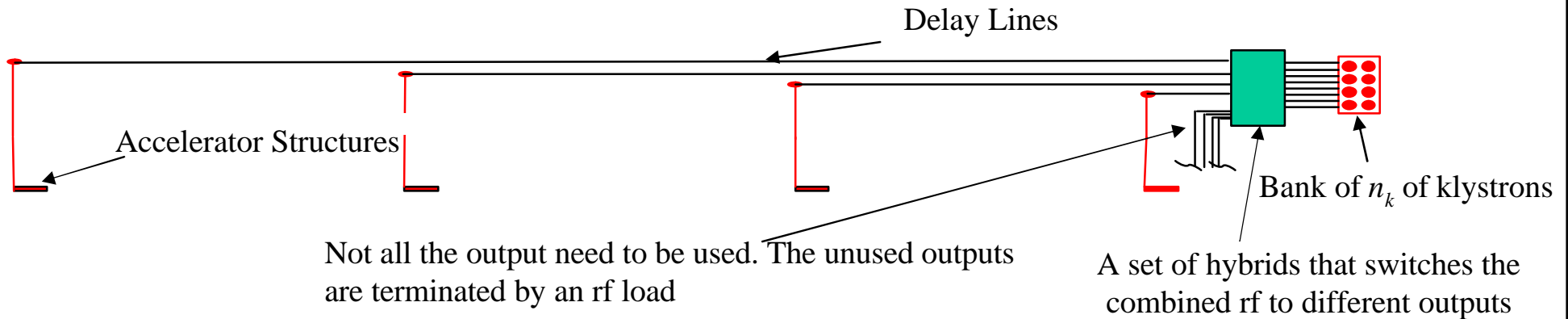
The current rf system design achieves an effective pulse compression ratio of 8 with an 8-feed multimoded DLDS utilizing TE_{01}° and TE_{12}° . Each feed powers six consecutive 0.9m structures.



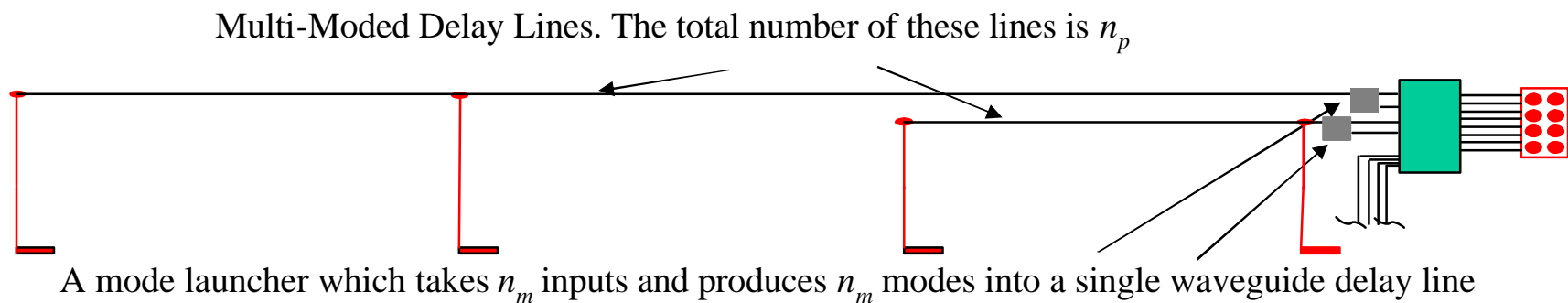
Application

Christopher Nantista
Animation: Michael Hyde

Why multi-moded?



Unit of a Single-Moded DLDS



Unit of Multi-Moded DLDS

Requirements for the dual-function mode converter

- ❑ Transform TE₀₂ mode in rectangular waveguide into the axisymmetric TE₀₁ mode of circular waveguide
- ❑ Transform TE₀₁ mode of the rectangular waveguide into TE₁₁ mode of the circular waveguide
- ❑ High efficiency, including copper losses: ~99%
- ❑ Maximum surface electric field level less than 40 MV/m at 600MW
- ❑ Compactness
- ❑ Manufacturability – tolerance analysis

Difficulties

- ❑ Complex 3D geometry described by analytical functions
- ❑ Tight tolerances ~10 μm

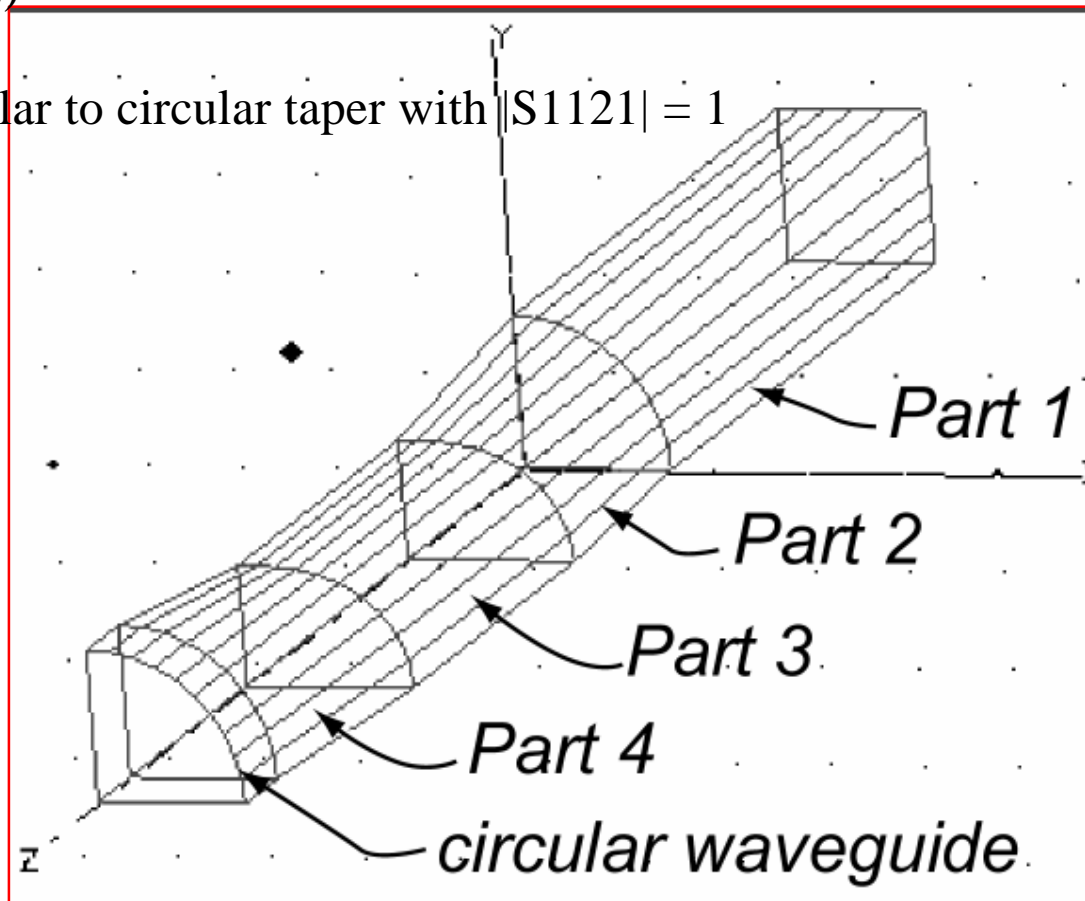
Approach: Automatic design and optimization

Steps in design TE₀₂ rectangular ? TE₀₁ circular

. Circular to “elliptical” taper (part 2 and 4) with transmission matrix $|S_{1121}| = 0.92388$, $|S_{1122}| = 0.382683$

. Circular to circular transition (parts 2 and 4) with matrix $|S_{1121}| = 1/\sqrt{2}$, $|S_{1122}| = 1/\sqrt{2}$

. Whole rectangular to circular taper with $|S_{1121}| = 1$



Geometry of mode-converter, parts 1 to 4

Optimization

Difficulties

- ❑ Complex geometry described by analytical functions

Tools

- ❑ Ansoft HFSS
- ❑ C++ compiler

Why HFSS?

- ❑ Macro language allows powerful control of HFSS

Why C++?

- ❑ Sophisticated and perfected developer environment
- ❑ Easy debugging
- ❑ Easy to apply any optimization method

Approach - *Do as much work as possible by C++ code*

- ❑ Building geometry and postprocessing
- ❑ External control of HFSS
- ❑ Optimization routine

ethod

- . C++ – program generates HFSS-macro with geometry, and lunches HFSS
- . HFSS calculates scattering matrix and saves data into a database file

Bonus: Tolerance analysis C++- program reads database and generates parameters for new geometry

Results

- **Tunable**

- Taper length ~ 10.2 in = 26 cm

- Mode conversion losses

- TE02 ? TE01, 0.27%

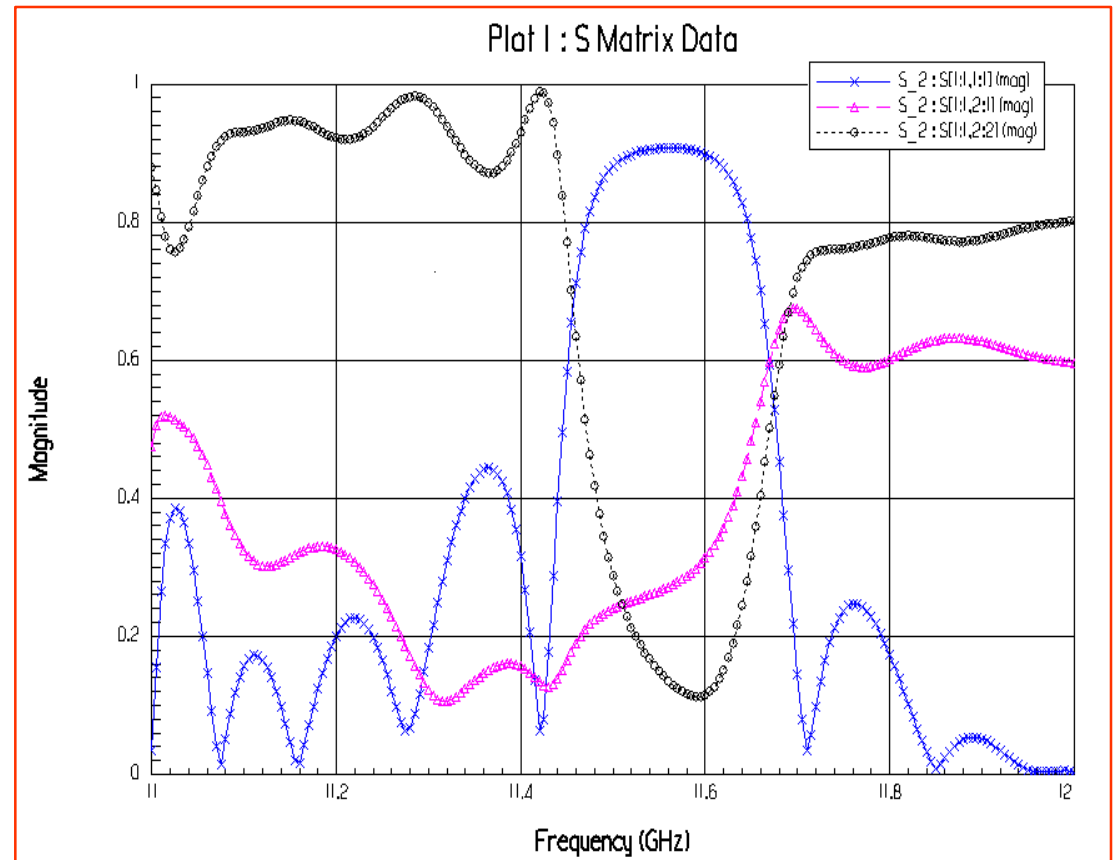
- TE01 ? TE11, 0.4%

- Copper losses TE02 ? TE01, 0.34%

- Maximum surface electric fields at 600 MW rf power

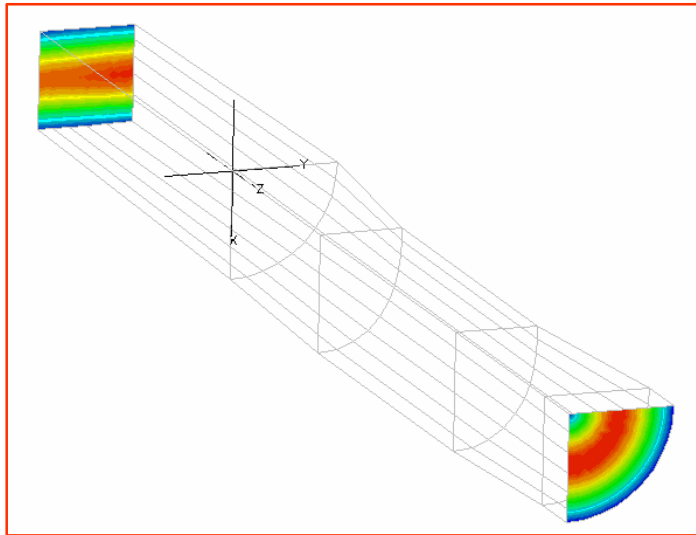
- TE02 ? TE01, <35 MV/m

- TE01 ? TE11, <28 MV/m

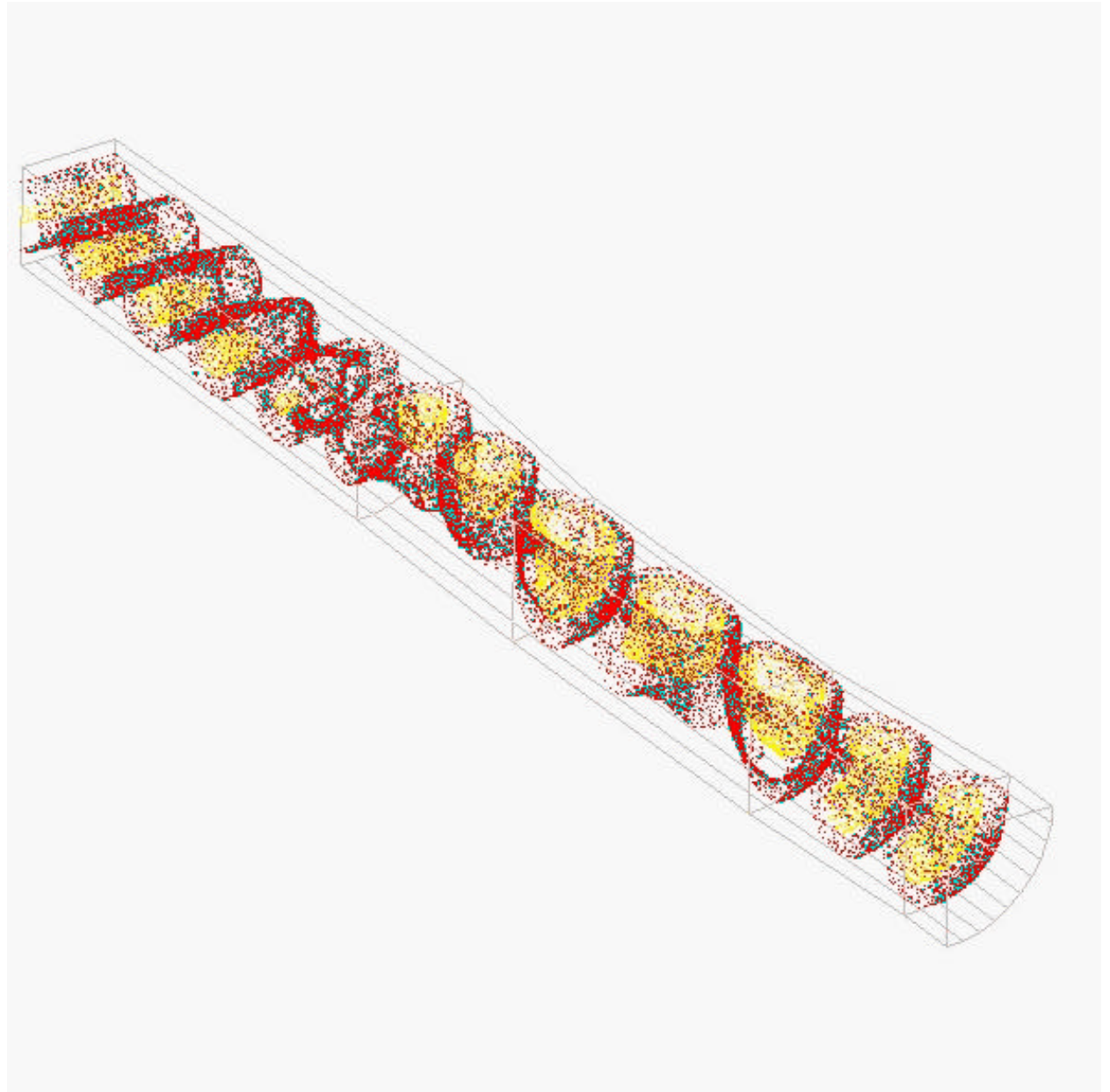


$S[1:1,1:1]$ is the reflection of TE02 rectangular waveguide mode. $S[1:1,2:2]$ is the transformation of TE02 rectangular waveguide mode into TE01 circular waveguide mode. $S[1:1,2:1]$ is the transformation of TE02 rectangular waveguide mode into TE21 circular waveguide mode.

Conversion TE₀₂ rectangular ? TE₀₁ circular

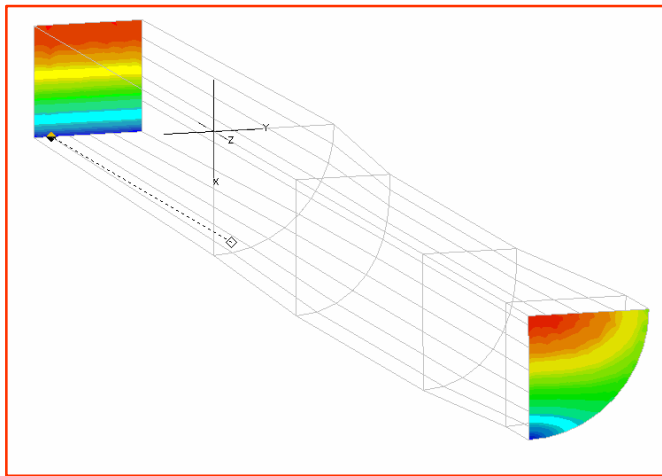


Electric field at ports of the converter

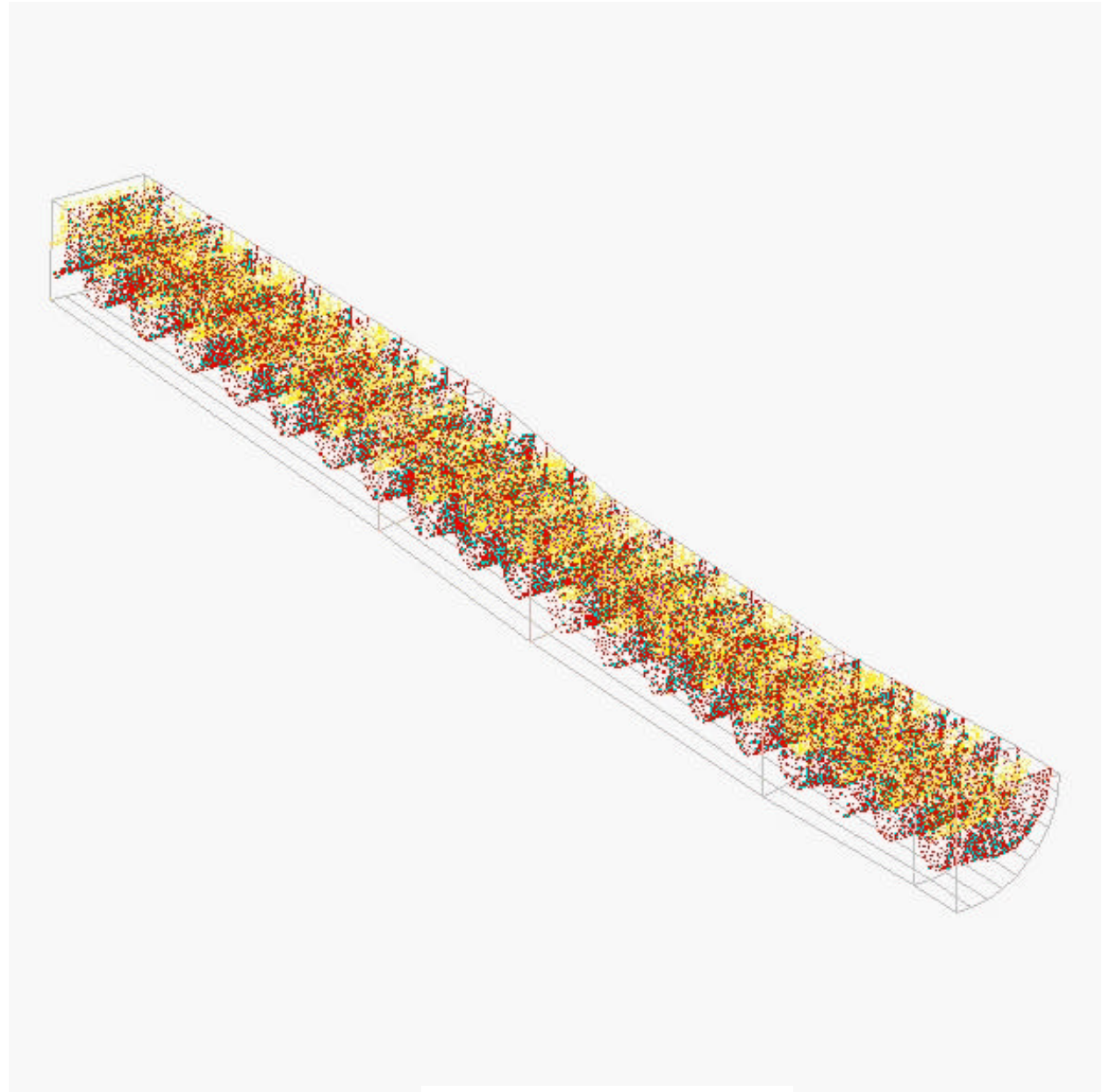


Volume electric field

Conversion TE01 rectangular ? TE11 circular

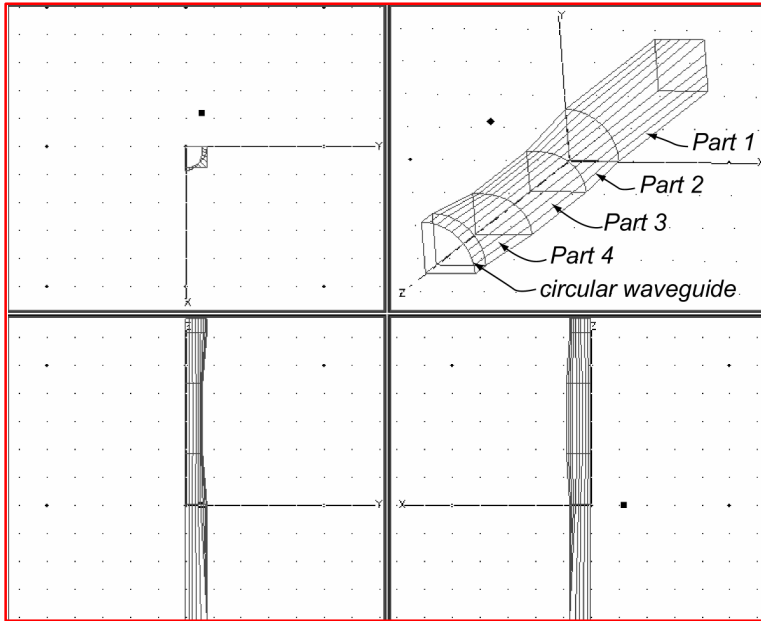


Electric field at ports of the converter

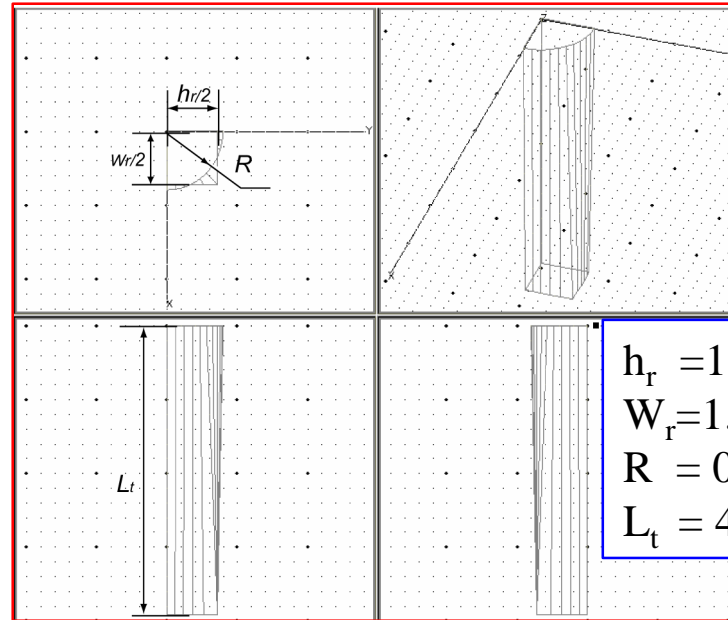


Volume electric field

Tolerances

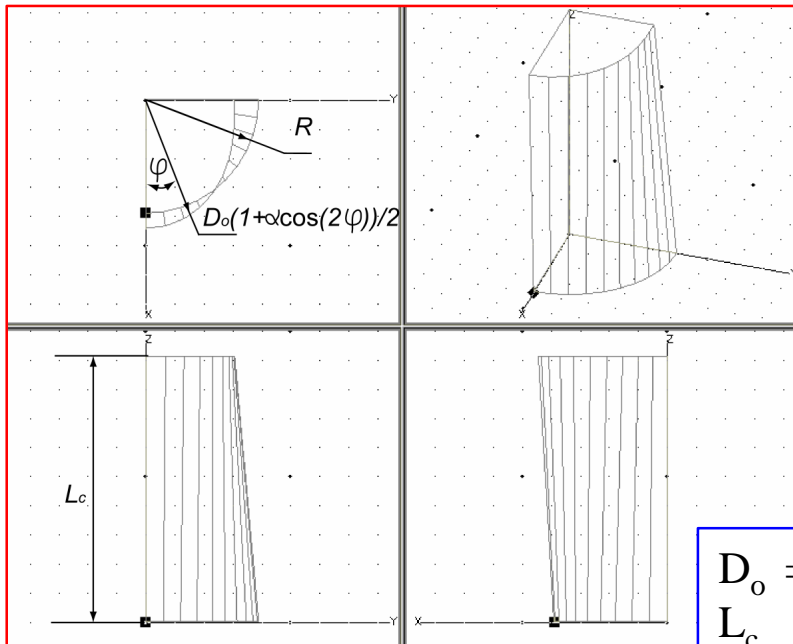


Whole geometry mode-converter, parts 1 to 4



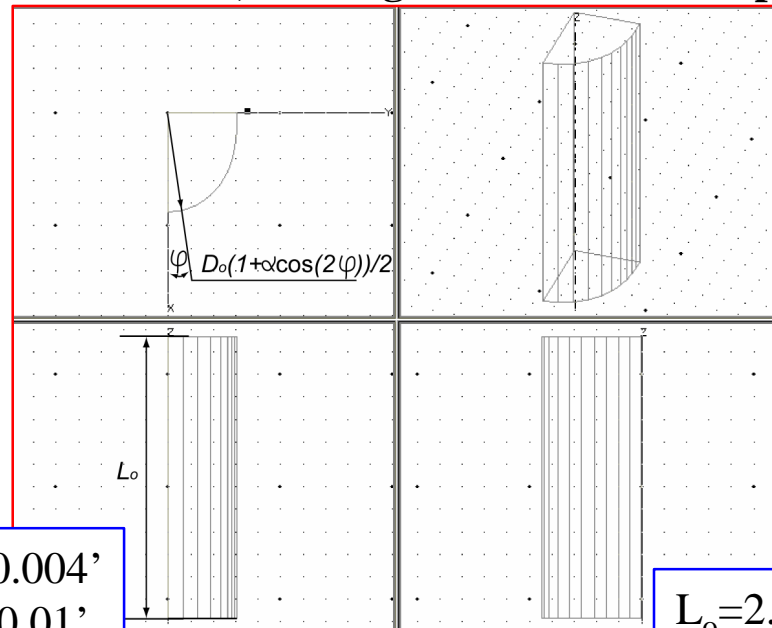
$$\begin{aligned}
 h_r &= 1.435' \pm 0.004' \\
 W_r &= 1.442' \pm 0.004' \\
 R &= 0.8' \pm 0.004' \\
 L_t &= 4.00 \pm 0.01'
 \end{aligned}$$

Part 1, rectangular-to-circular taper.



$$\begin{aligned}
 D_o &= 1.5' \pm 0.004' \\
 L_c &= 1.805' \pm 0.01' \\
 a &= 0.17 \pm 0.005
 \end{aligned}$$

Part 2 and 4, circular to oval taper

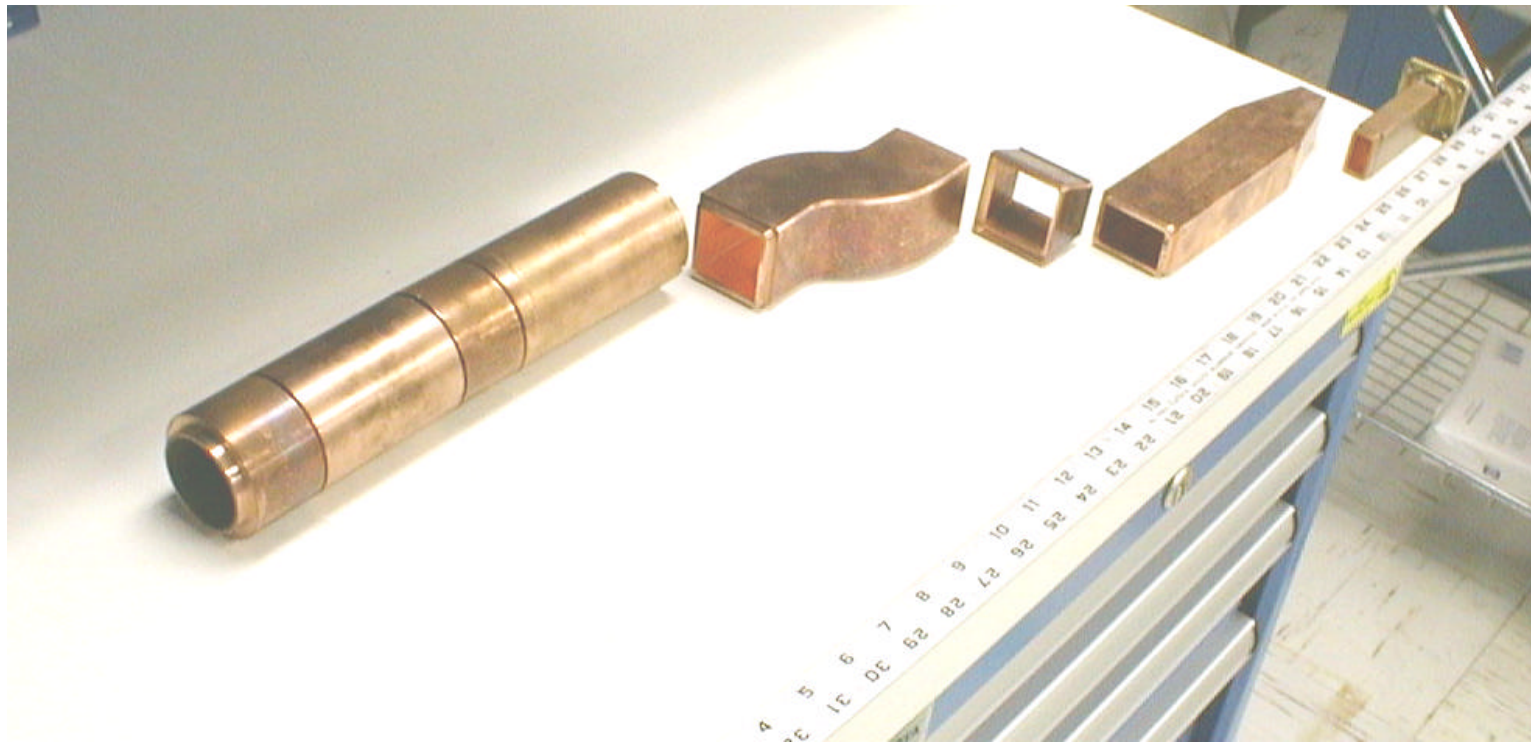


$$L_o = 2.770' \pm 0.01'$$

Par 3, oval waveguide



Two converters before brazing

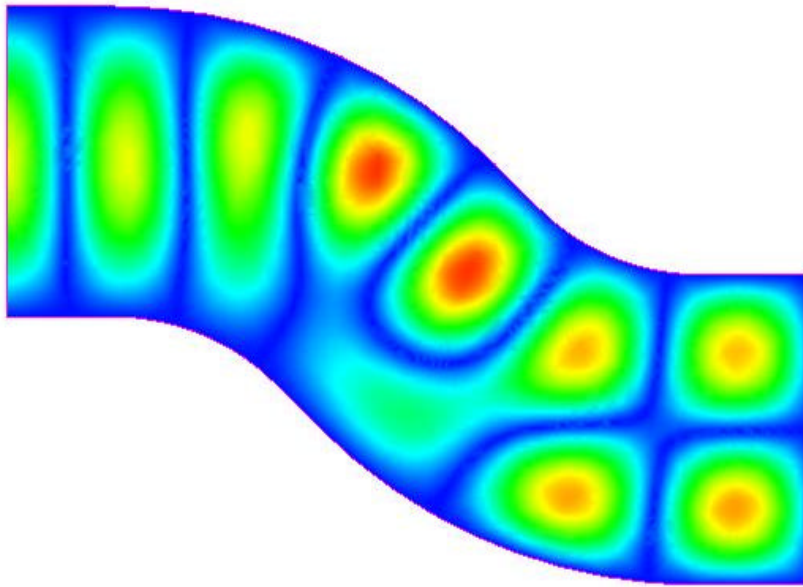


Dual-mode converter with planar TE01 ? TE02 jog converter and W90 height taper (*Christopher Nantista*)

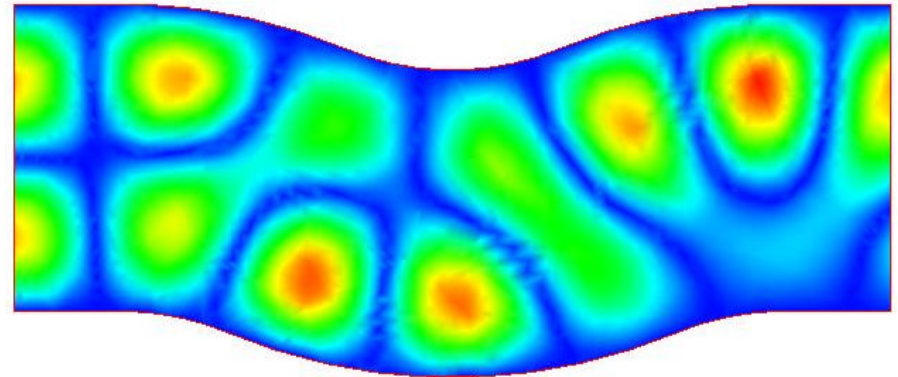
Summary

- ❑ HFSS is used for automated matching of the dual-mode converter
- ❑ The matching method is developed using HFSS macro language and C++ programming language
- ❑ The C++ routine provides optimization as well as external control of HFSS and postprocessing data
- ❑ The described procedure is suitable for problems with complex geometries and sophisticated postprocessing

Dual-Moded Rectangular Waveguide Mode Coupling



Jog Converter with HFSS simulated electric fields illustrating conversion from TE_{10} to TE_{20} (left to right) or from TE_{20} to TE_{10} (right to left).



Mode Mixer with HFSS simulated electric fields illustrating conversion from TE_{20} to an equal mixture of TE_{10} and TE_{20} .

Christopher Nantista

Combination $TE_{11}^{\circ} \leftrightarrow TE_{12}^{\circ}$ Converter / Dual-Moded Diameter Taper



The inner diameter follows a carefully designed, gently rippled profile, preserving the purity of TE_{01} while converting between TE_{11} and TE_{12} and tapering between 2" and 4.75".