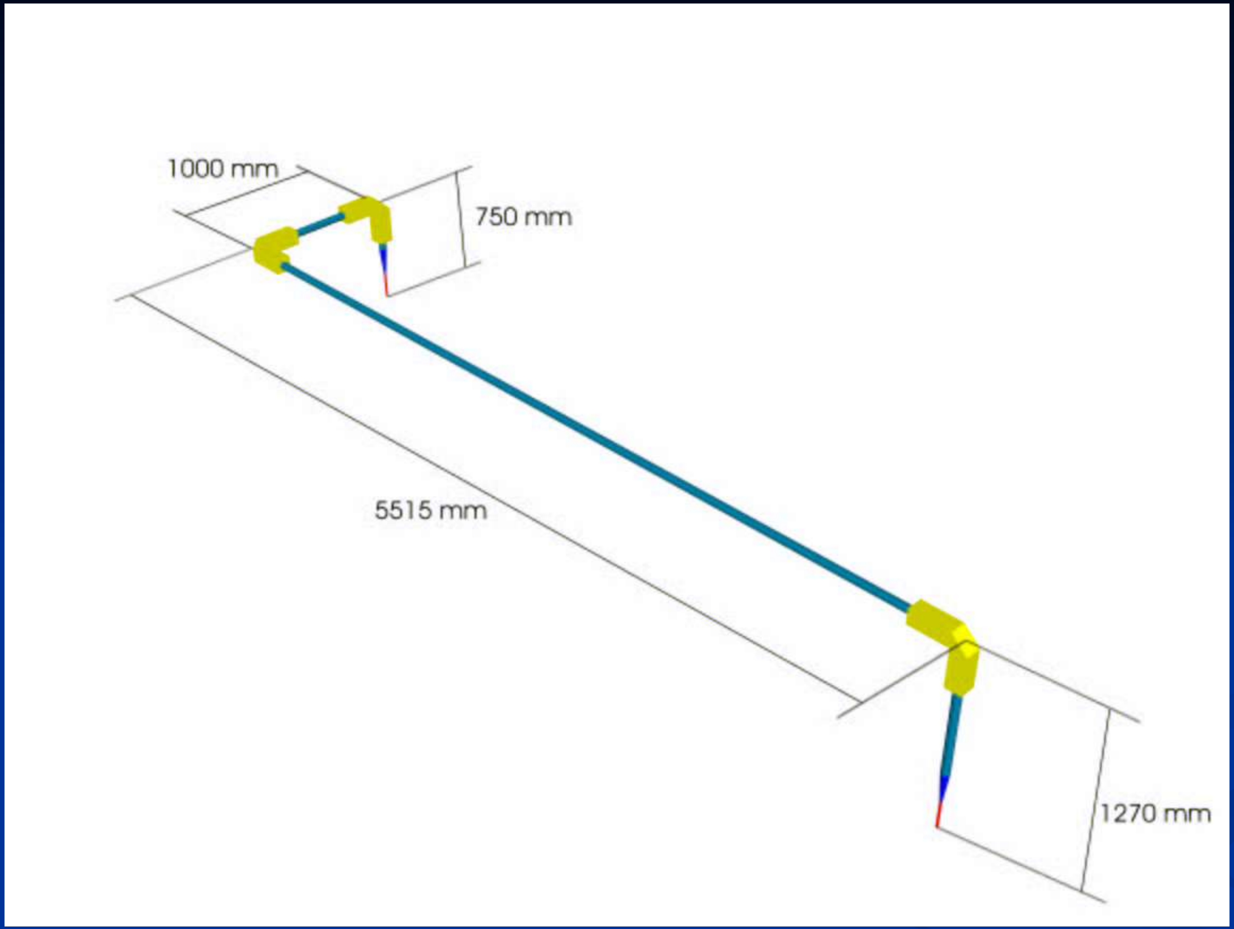
High-Power Low-Loss TE_{01} Transmission Line for CTF-3

S.V. Kuzikov, G.G. Denisov, I. Syratchev*, G. Carron* , S. Heikkinen*

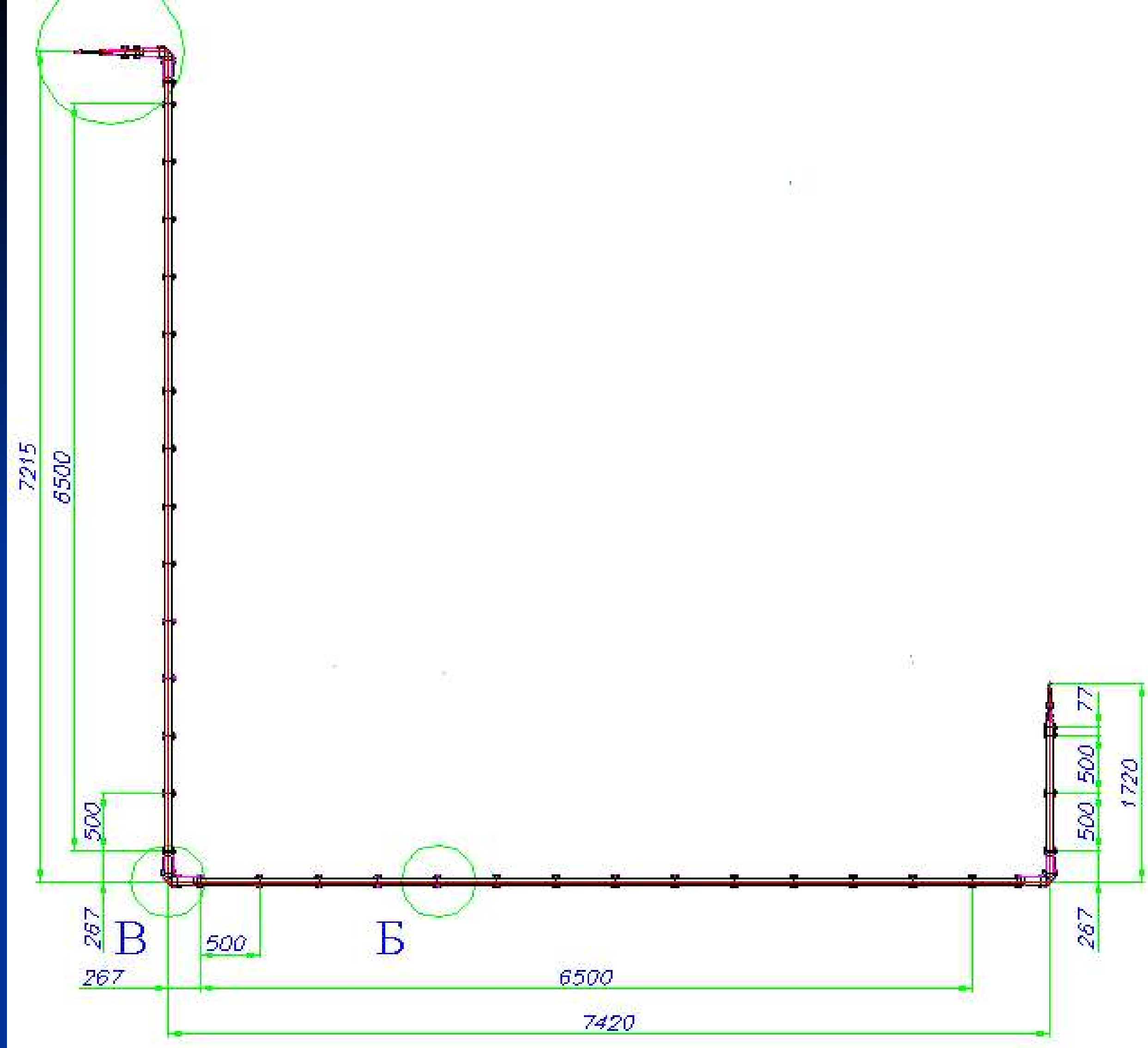
Institute of Applied Physics, Russian Academy of Sciences, Nizhny Novgorod, Russia
**CERN, Geneva, Switzerland*

Outline

1. Concept of the high-power low-loss transmission line
2. Components:
   - TE_{10} to TE_{01} serpent-like mode converter
   - Taper
   - TE_{01} miter bends
   - Sections of oversized waveguide
3. Low-power tests



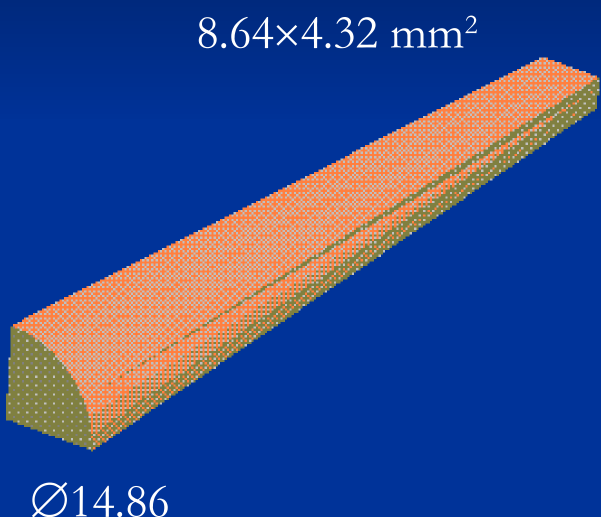
In order to reduce the Ohmic losses in the line, the TE_{01} mode in circular cross-section waveguide was chosen. This mode provides the lowest attenuation amongst the other modes in overmoded waveguides. Because the efficiency of the miter bends depends on waveguide diameter (the bigger diameter the higher efficiency), that is why, 50 mm average diameter was proposed.

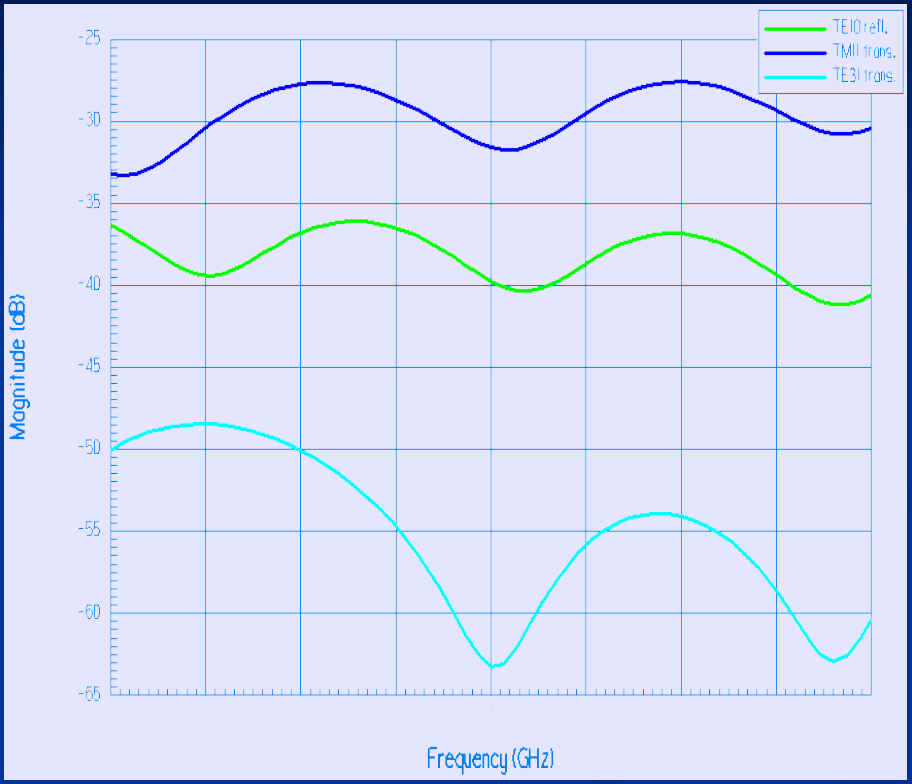


Technical drawing of the transmission line:
2 mode converters, 3 miter bends, 2 tapers, 32 waveguide sections.
In theory the total losses are 11 %.

$TE_{10}^{\square}$ to $TE_{01}^{\bigcirc}$ mode converter

The conversion exploits the scheme TE_{10} rect. – TE_{11} circ. – TE_{01} circ. The first step is actually the transducer of rectangular to circular cross-section.





Powers of spurious modes

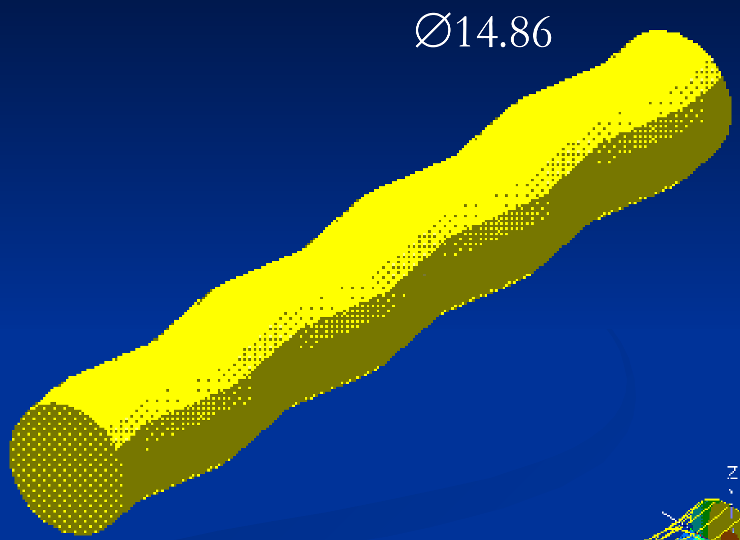
Calculations show that this component at 30 GHz will have ~6.6 cm length. The power losses are ~ 0.6% (0.1% diffraction losses + 0.5% Ohmic losses).

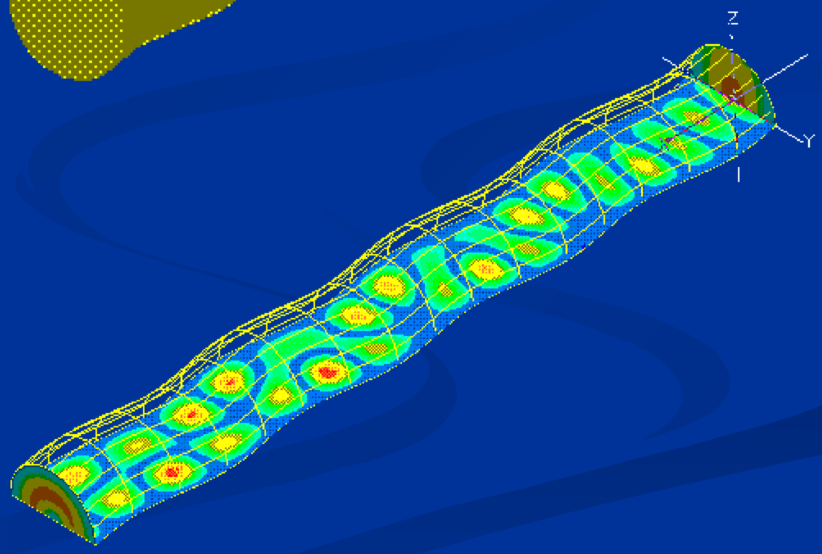
Serpent-like TE_{11} - TE_{01} mode converter

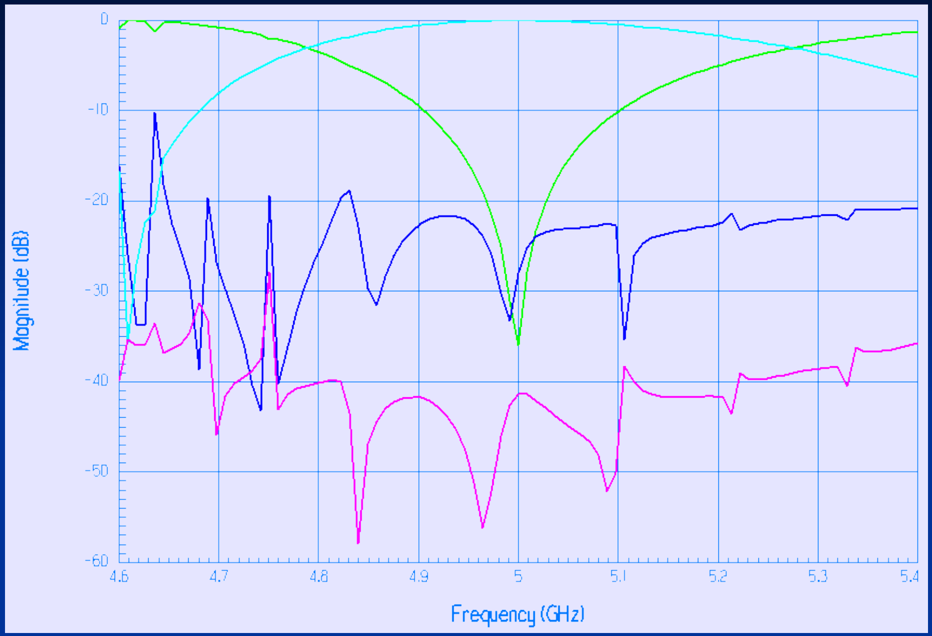
The second step in the mentioned conversion scheme is the so-called **serpent-like mode converter**. The conversion of the TE_{11} mode into the TE_{01} mode is provided by means of periodical bending of the primary circular waveguide of radius r_0. For this waveguide the surface of the converter in polar system of coordinates is given by formula:

$$r(z,\varphi)=r_0+l_0\times\sin(2\pi z/L)\times\cos\varphi,$$

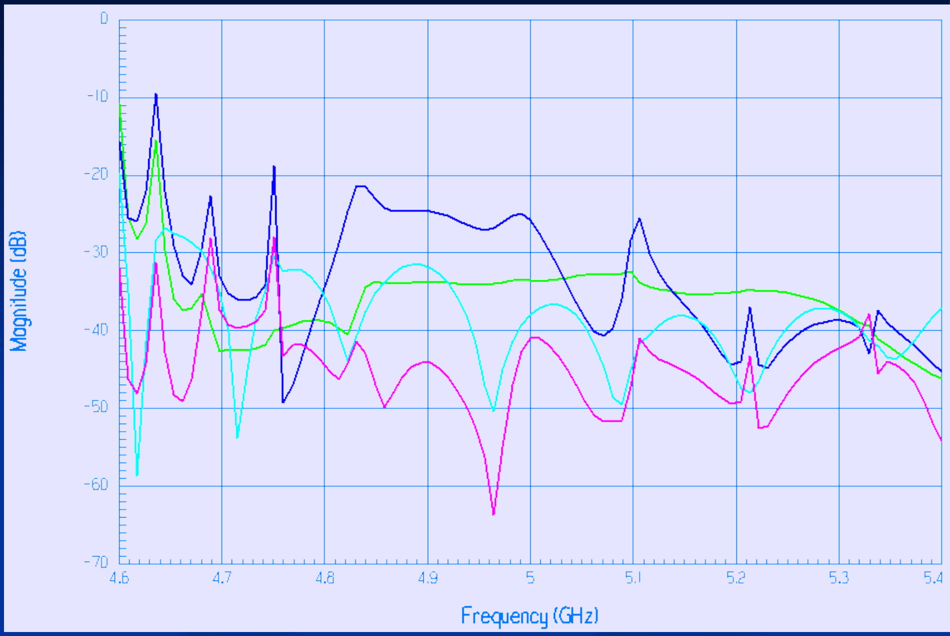
where r, z, φ are polar radius, axis, and angle correspondingly, L is a period, and l_0 is an amplitude of corrugation. The mentioned period of the perturbation is determined by the beating wavelength of the main TE_{11} and TE_{01} modes. The amplitude of corrugation is derived by the condition to obtain full conversion of one mode into other.





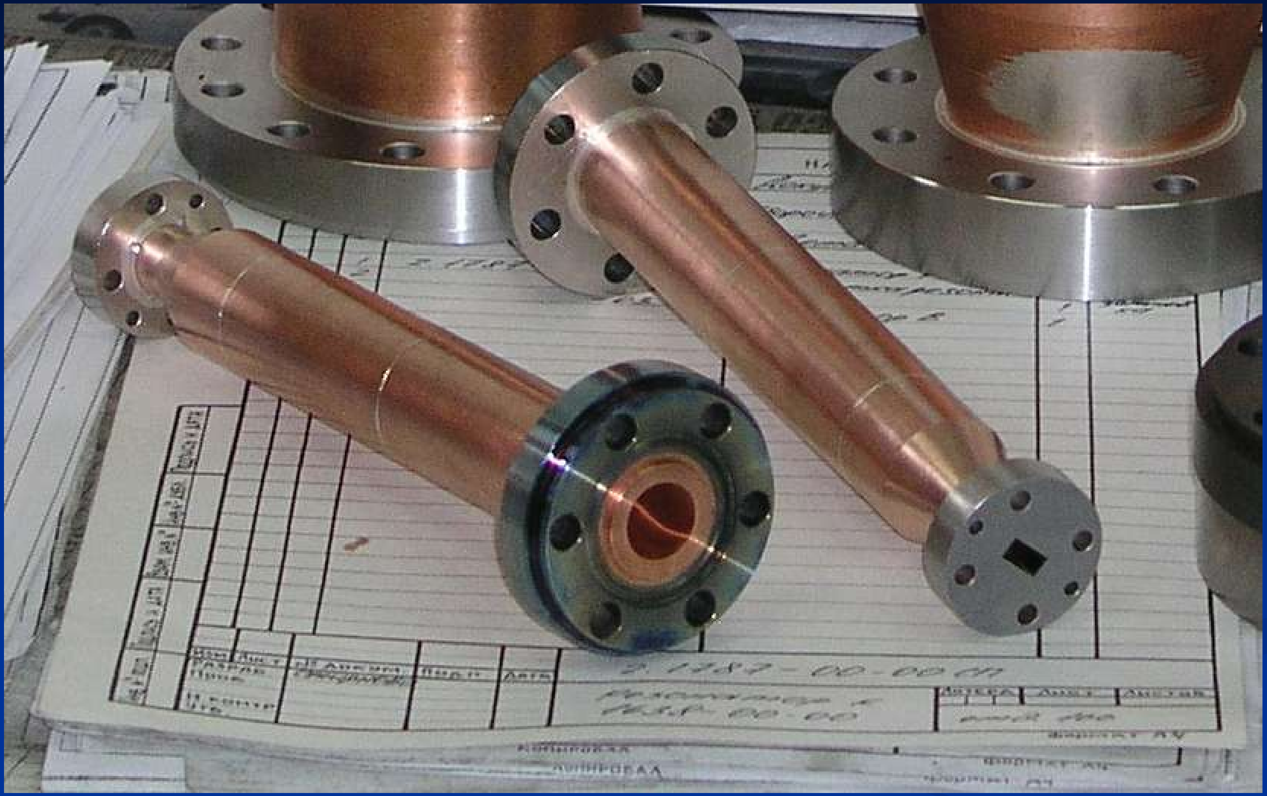


Magnitudes of the forward waves



Magnitudes of the reflected waves

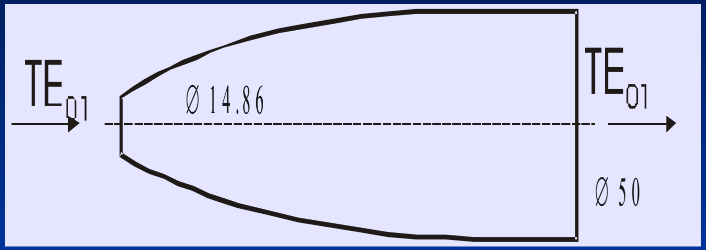
Efficiency of the converter is 98.5% including both diffraction (1%) and Ohmic (0.5%) losses.

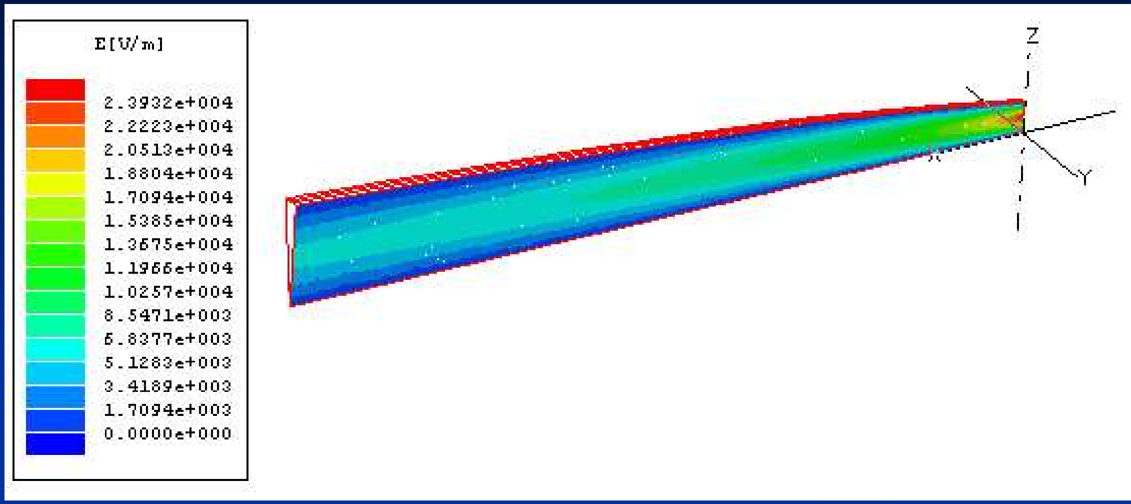


TE_{10} to TE_{01} mode converters

$$r(z) = \sqrt{2 \cdot r_0' \cdot r_0 \cdot z + r_0^2},$$

Taper

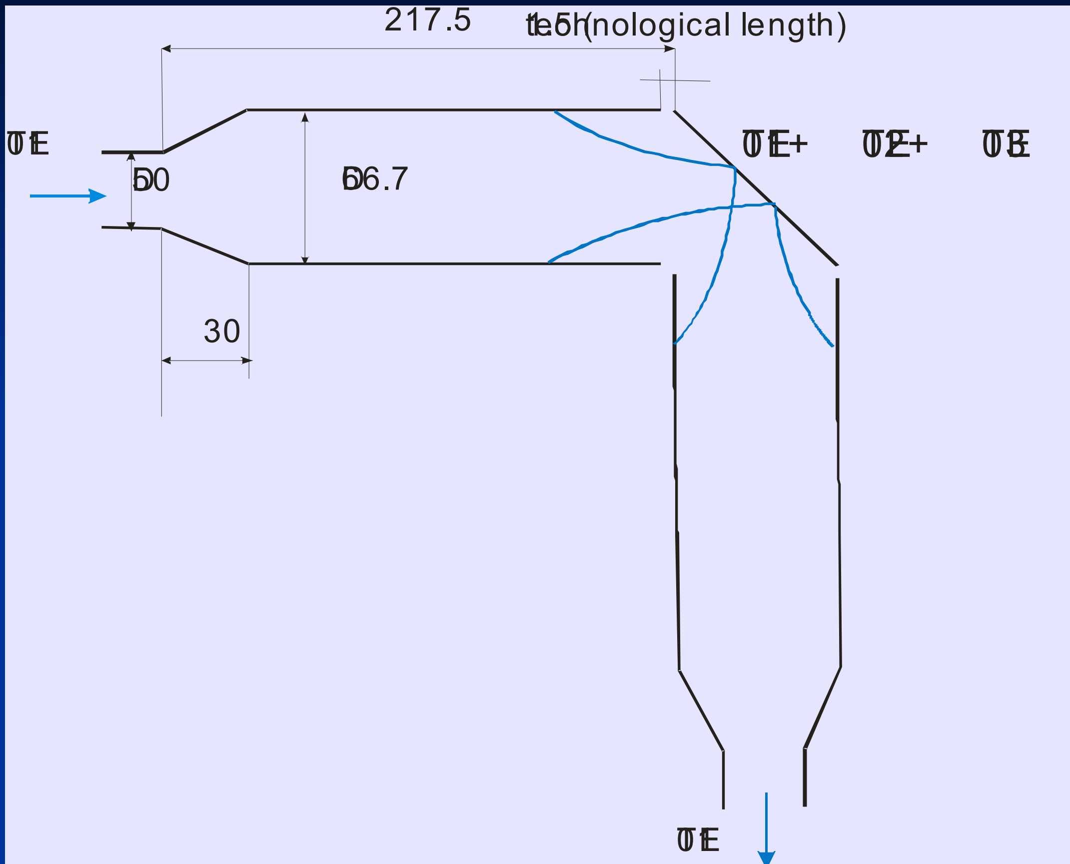


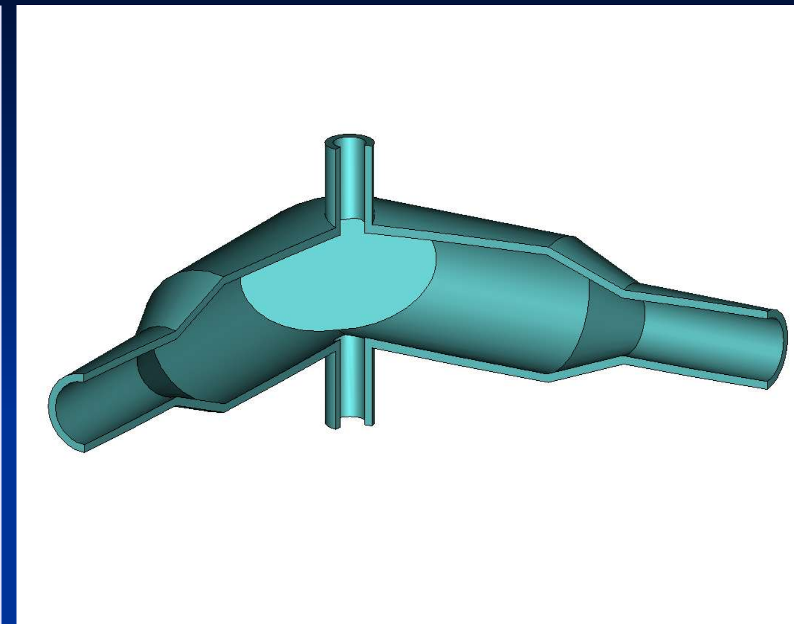


The axisymmetrical taper connects the converter's diameter 14.86 mm with diameter 50 mm of the main transmission line. In order to provide the highest efficiency, keeping minimum length, the optimal profile is given by the parabolic function.

At the 30 GHz taper should be ~ 200 mm in order to provide 99.4% efficiency (0.5% diffraction losses + 0.1% Ohmic losses).

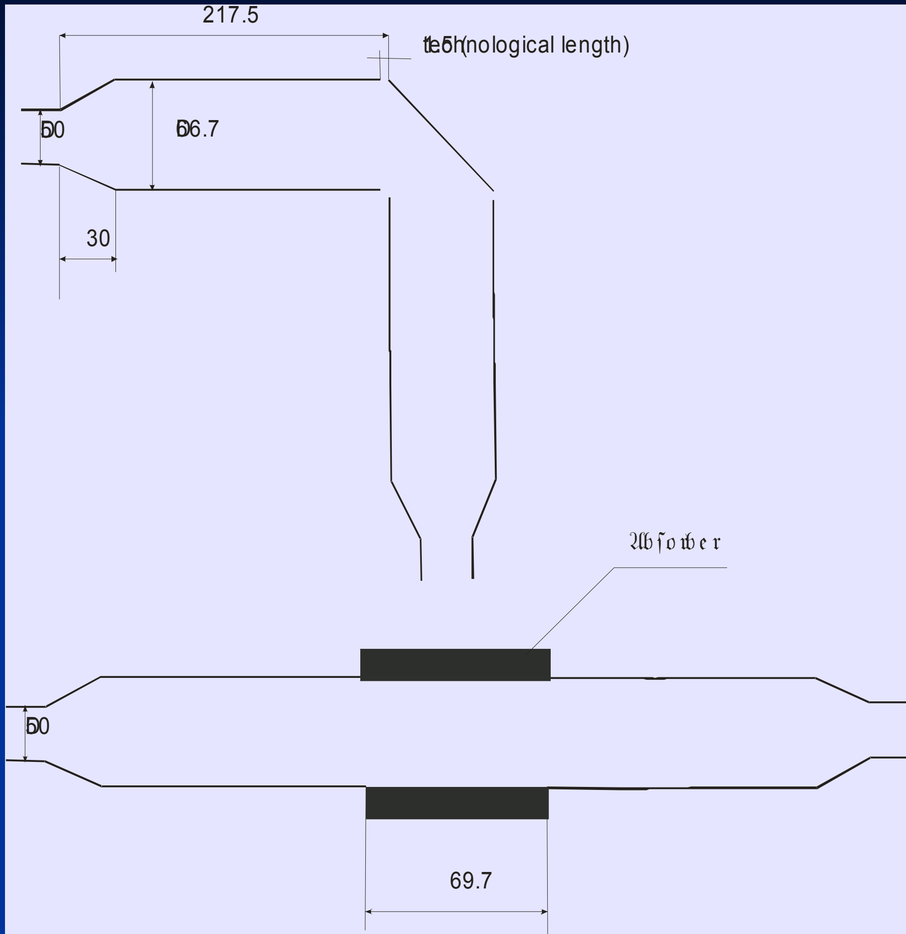
TE_{01} miter bend

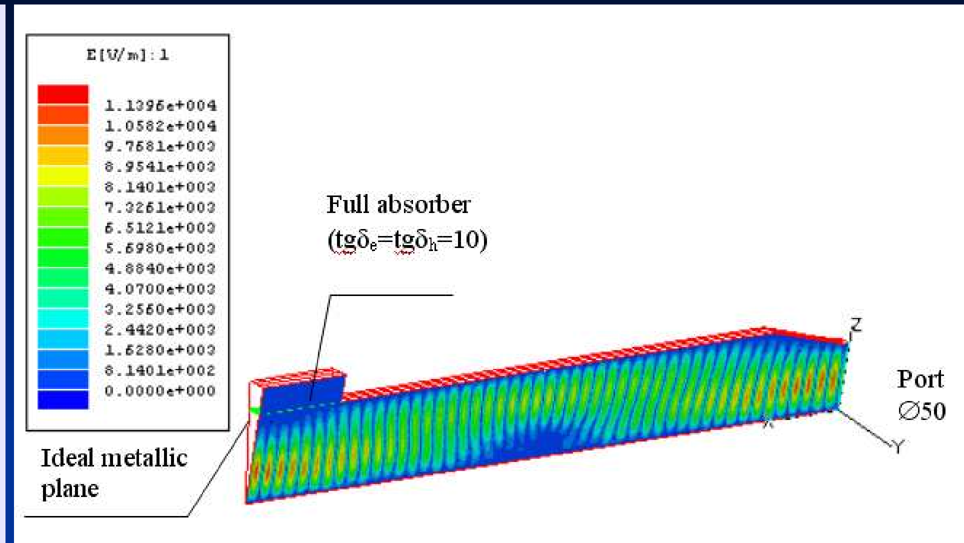




The component is a critical point for the TE_{01} circular cross-section transmission lines. To make diffraction losses in the miter bend lower, special mode mixture is prepared in the place of the bend. This mode mixture 75%TE_{01}+24%TE_{02}+1%TE_{03} provides local decrease of the fields near edges, which inevitably exist in any miter bend. According to this idea the improved miter bend consists of two symmetric mode converters and a plane mirror.

Calculation



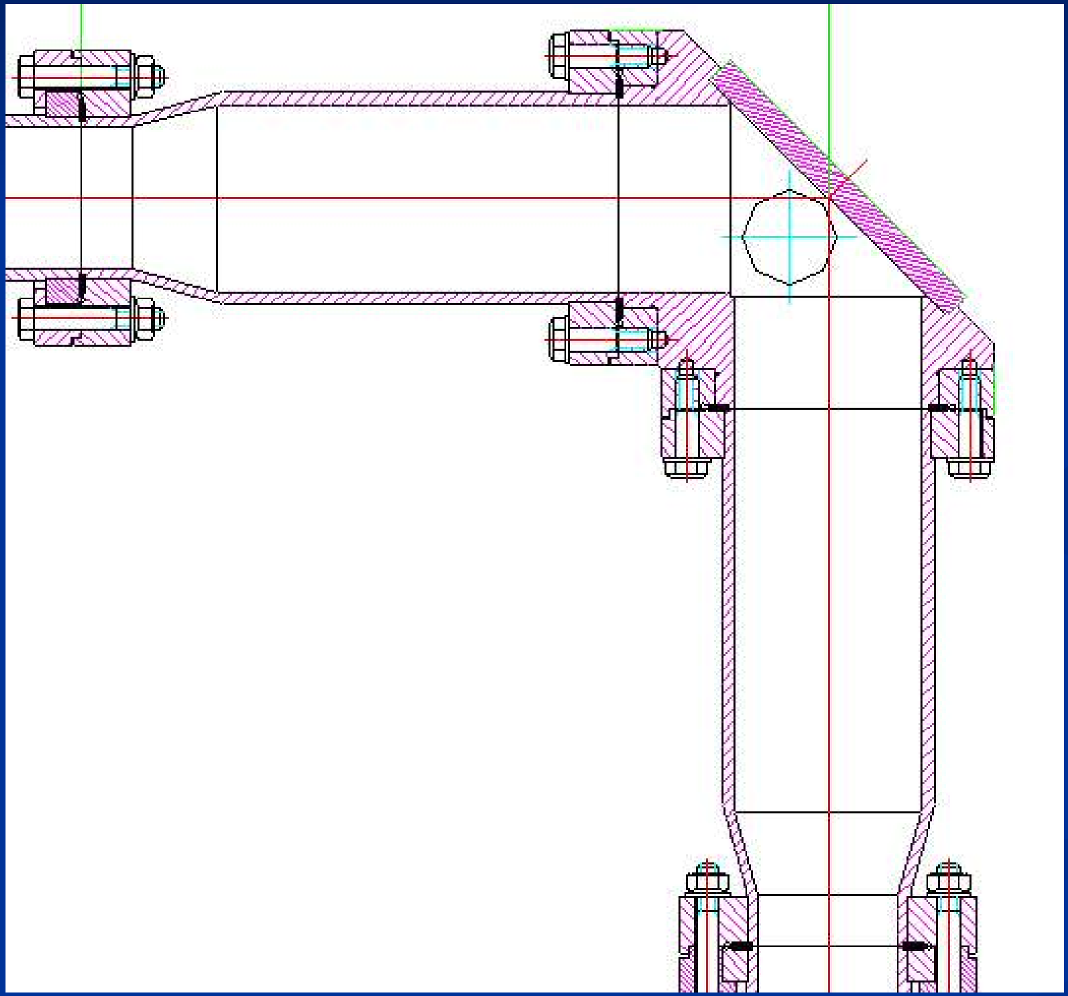


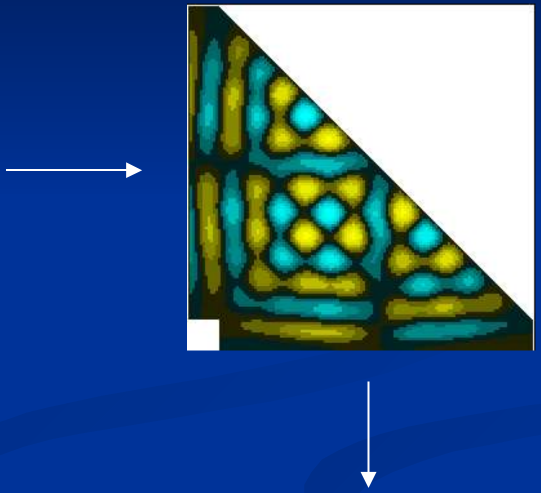
Diffraction effiiciency is determined as a level of the TE_{01} mode reflection into itself. Other modes like TE_{02}, TE_{03}, TE_{04} are very high absorbed if one launches them at input.

Total efficiency is 98.6% (1.2% diffraction losses + 0.2% Ohmic losses).

3D FDTD simulation

$TE_{01}+TE_{02}+TE_{03}$



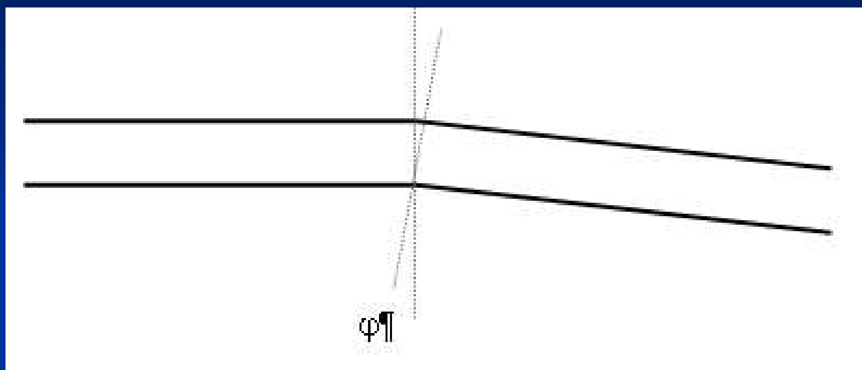


TE_{01} miter bend

$\delta = \frac{(kR)^2\varphi^2}{3} = \frac{(k\Delta)^2}{12}$.

Waveguide sections

Ohmic losses in the transmission line, consisted of ∅50 mm waveguides (17 m), equal 1%.



For a small inclination of waveguide sections power loss is given by estimation:

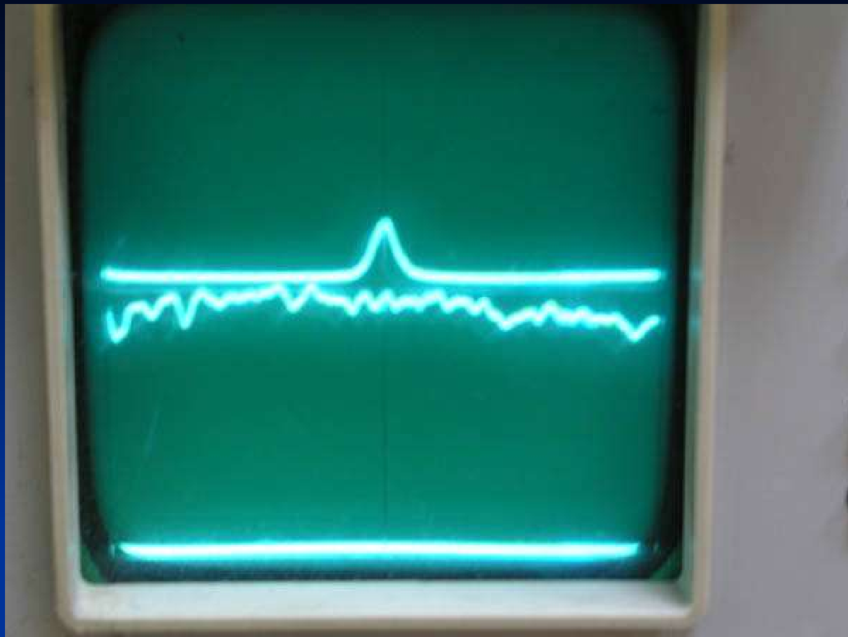
$$\delta=(kR)^2\varphi^2/3=(k\Delta)^2/12$$

where φ is an angle of the elementary inclination (radians), $\Delta=2R\varphi$ is a shift of upper and lower waveguide boundaries due to inclination, $k=2\pi/\lambda$, R is a waveguide radius.

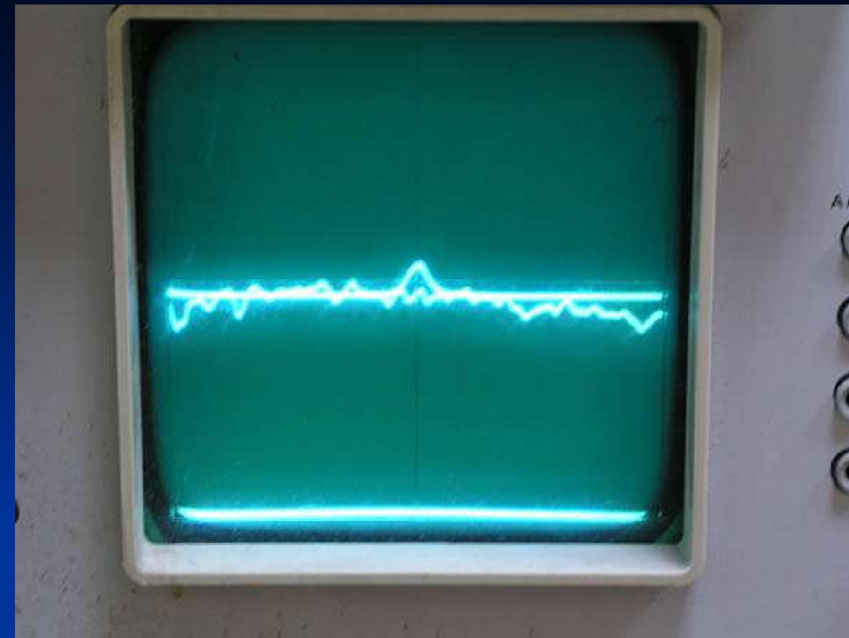
Example: Typically $\Delta=0.04$ mm, $R=50$ mm. For the elementary inclination we have $\delta=5\cdot10^{-5}$. For the line of 17000 mm length consisting of 34 waveguide sections we have $P=\cdot\delta\cdot N=1.7\cdot10^{-3}$. It means 0.17%.. In realistic case when each elementary discontinuity scatters power in random phase we have total losses $P=\delta\sqrt{N}=3\cdot10^{-4}$.

Low power tests in IAP

The tested system consisted of 2 converters, 2 tapers, 3 miter bends and 2 sections of (1 m) waveguides.



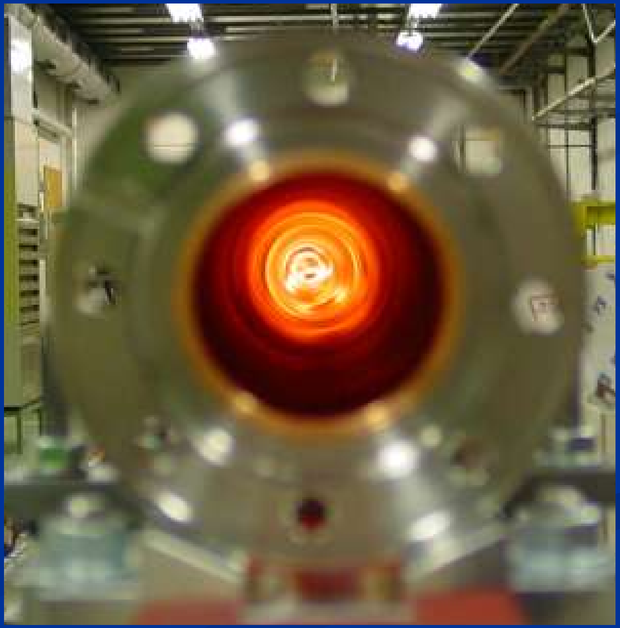
Transmission through the line: f_{min}=29.56 GHz, f_{max}=30.29 GHz; the upper line correspond 0 dB attenuation, the label in the upper line corresponds 30 GHz.



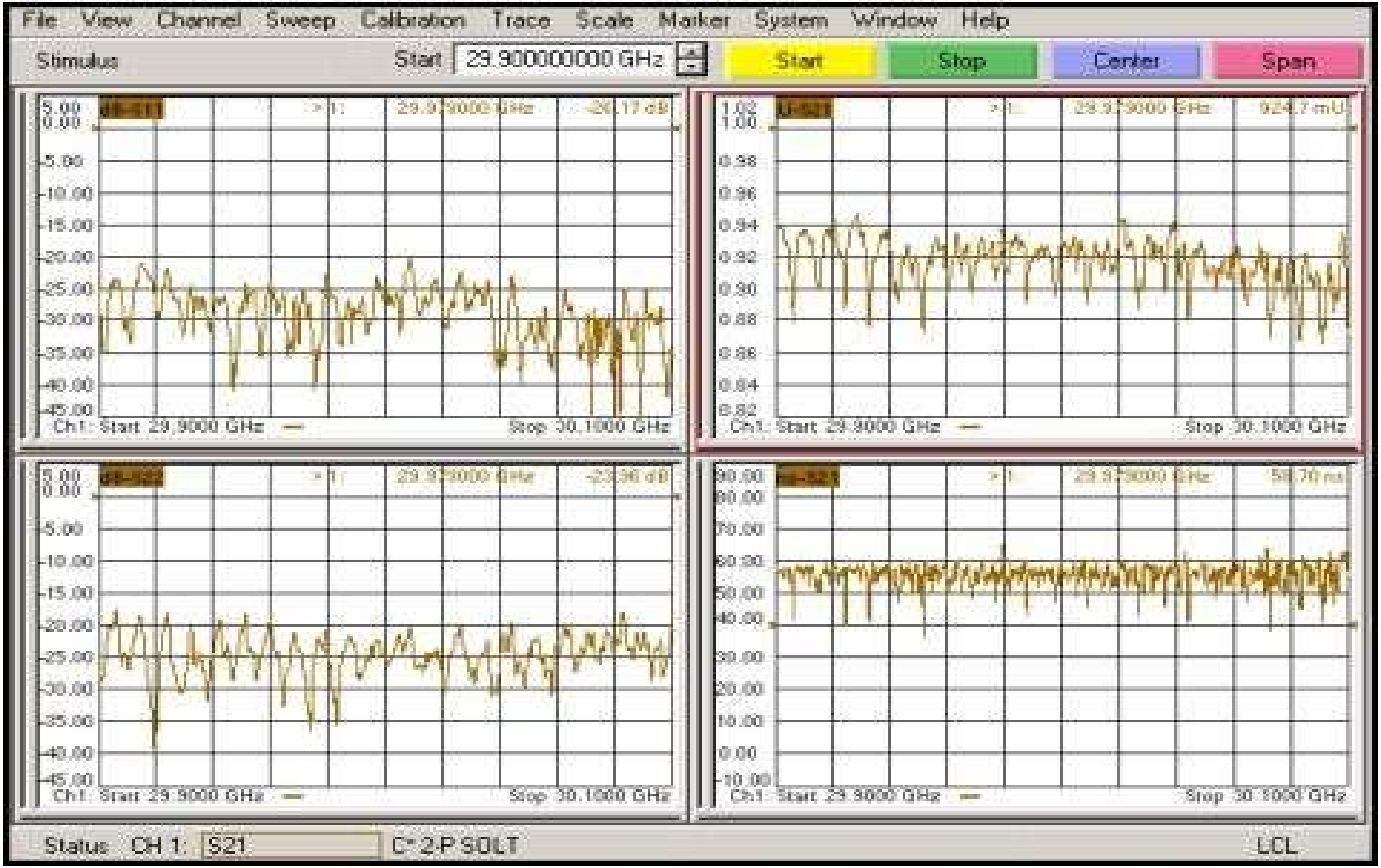
Transmission through the line: f_{min}=29.56 GHz, f_{max}=30.29 GHz; the upper line correspond -0.5 dB attenuation, the label in the upper line corresponds 30 GHz.

The highest efficiency is observed at frequency ~180 MHz lower than the operating frequency (~ -0.5 dB attenuation). This is caused by the mode converters those central frequency is shifted to low frequencies. The reason of this effect is the unexpected deviation of the converter's profile to a bigger "hole" (~0.03-0.04 mm regular deviation).

Low-power tests in CERN



Experimental setup



Overall measured efficiency at 30 GHz is 85.5%.

Reflection is -26 dB.

Conclusion

- The TE_{01} transmission line was designed, produced and tested at a low power level. Vacuum tests for each component were executed.
- Low power measurements demonstrated that transmission line parameters are very close to designed ones.