A compact, low-field, broadband matching section for externally-powered X-band dielectric-loaded accelerating structures

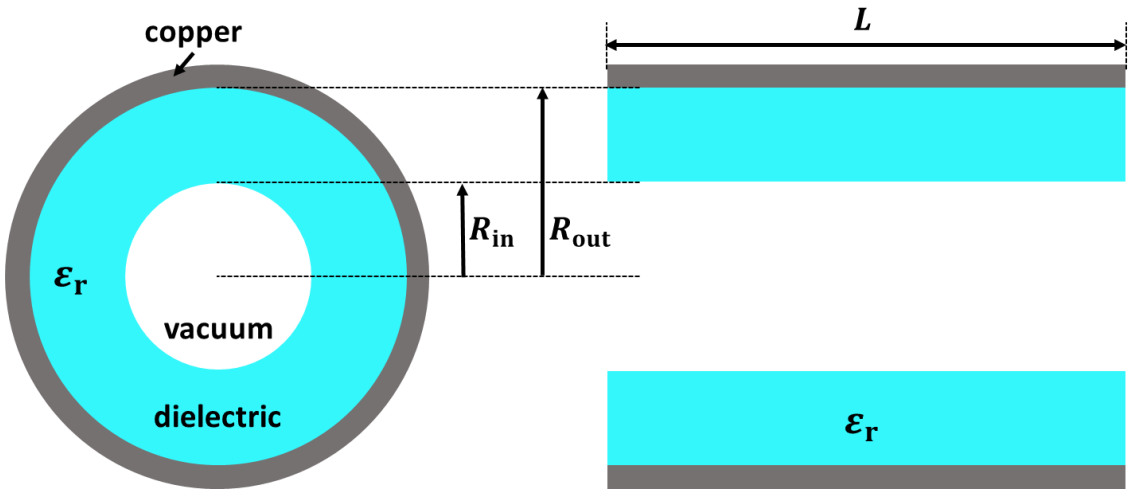
Y. Wei*, A. Grudiev, N. Catalan-Lasheras, R. Wegner, S. Gonzalez Anton, CERN, Geneva, Switzerland,
C. Jing, B. Freemire, Euclid TechLabs LLC, Solon, USA
H. Bursali, Sapienza University of Rome, Rome, Italy
J. Sauza-Bedolla, Lancaster University, Lancaster, UK
C. P. Welsch, Cockcroft Institute and University of Liverpool, UK
*also at Cockcroft Institute and University of Liverpool, UK

Presenter: Dr. Yelong Wei

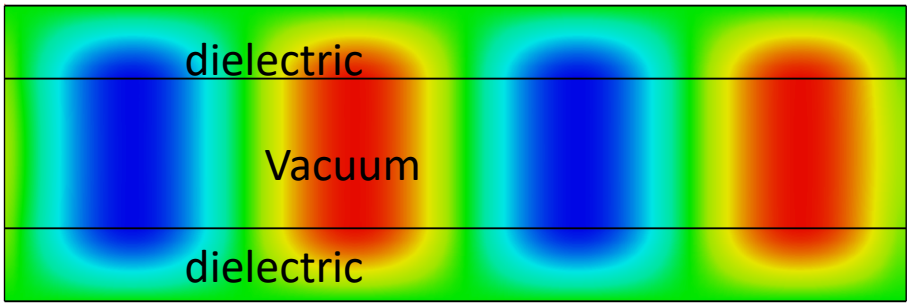
Email: yelong.wei@cern.ch or weiyealong1228@gmail.com

Introduction

- **Slow wave accelerators: dielectric-loaded accelerating (DLA) structures**



*E*z of the TM01 mode ($v_p = c$)



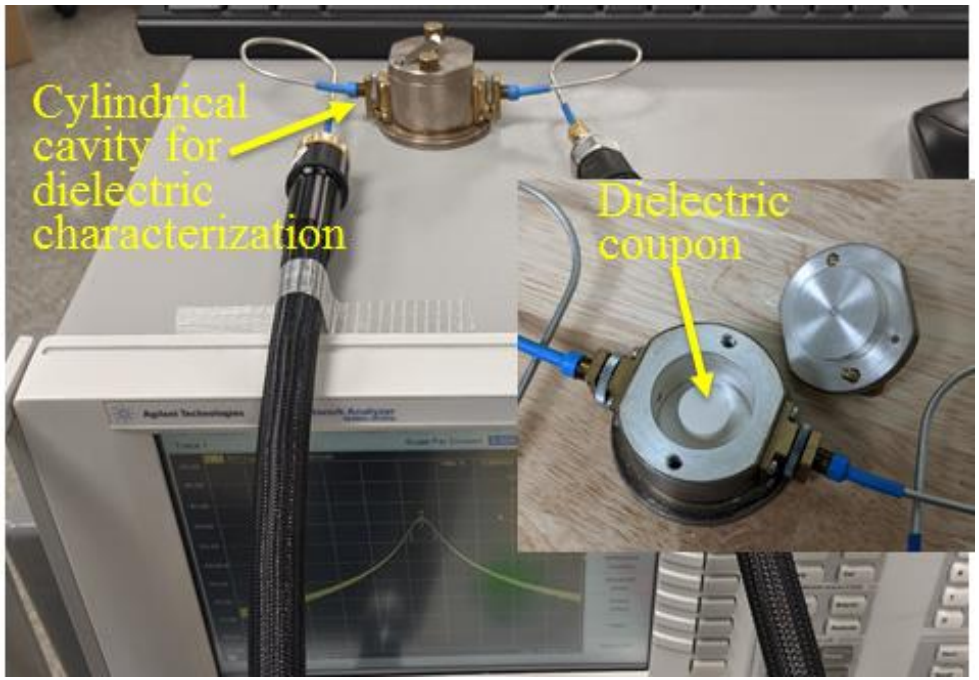
Advantages of DLA:

- ❖ Simple geometry for easy fabrication;
- ❖ No field enhancements on irises;
- ❖ Potential high gradient;
- ❖ Easy to damp HOMs;

Disadvantages of DLA:

- ❖ Low power efficiency due to high group velocity >10% of *c*

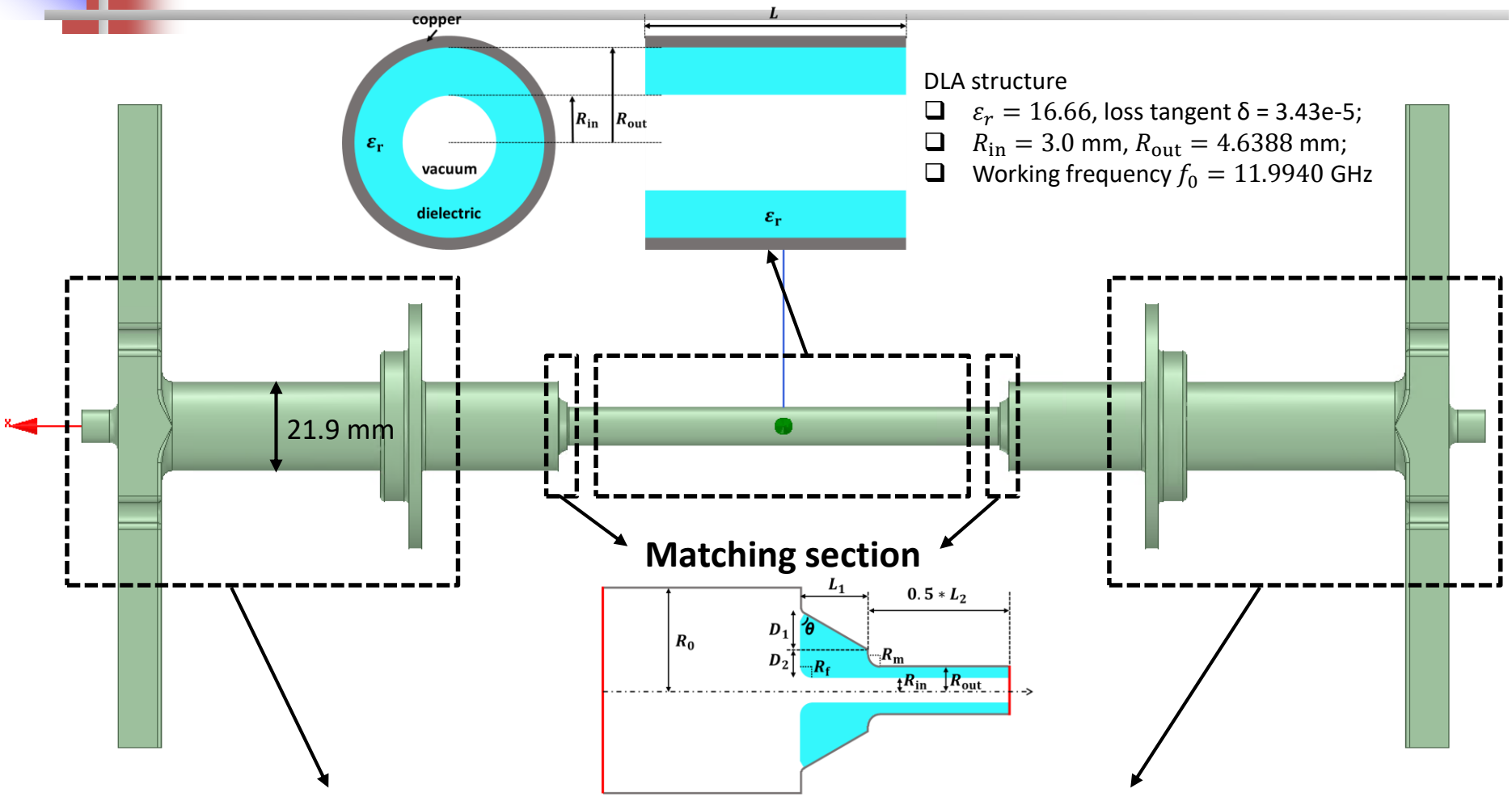
Dielectric RF property



Courtesy of photo from Dr. Chunguang Jing, Euclid Techlabs.

- A $TE_{01\delta}$ silver-plated resonator with a high quality factor, which is designed for testing ceramics at an X-band frequency, is used to measure the dielectric constant ε_r and loss tangent $\tan\delta$ of sample coupons.
- Four dielectric coupons made from the same dielectric rods as for the fabrication of the DLA structure are measured.
- A dielectric constant $\varepsilon_r = 16.66$ and an ultralow loss tangent $\tan\delta = 3.43 \times 10^{-5}$ (having error bars 0.6% of the nominal value) are obtained for the RF design of the DLA structure and matching sections which follows.

An X-band DLA structure

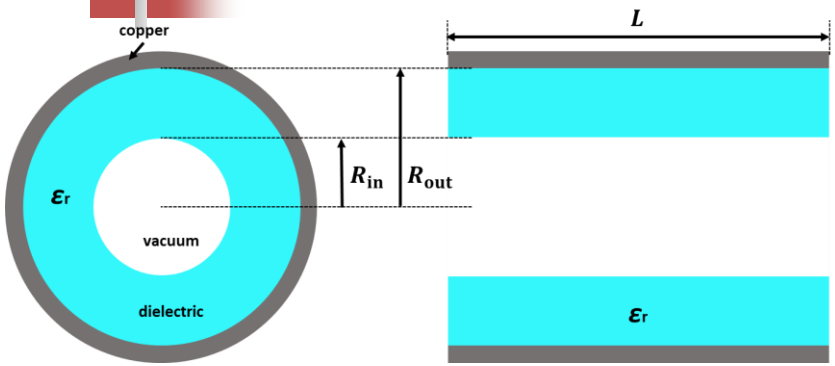


DLA structure

- $\varepsilon_r = 16.66$, loss tangent δ = 3.43e-5;
- $R_{\text{in}} = 3.0$ mm, $R_{\text{out}} = 4.6388$ mm;
- Working frequency $f_0 = 11.9940$ GHz

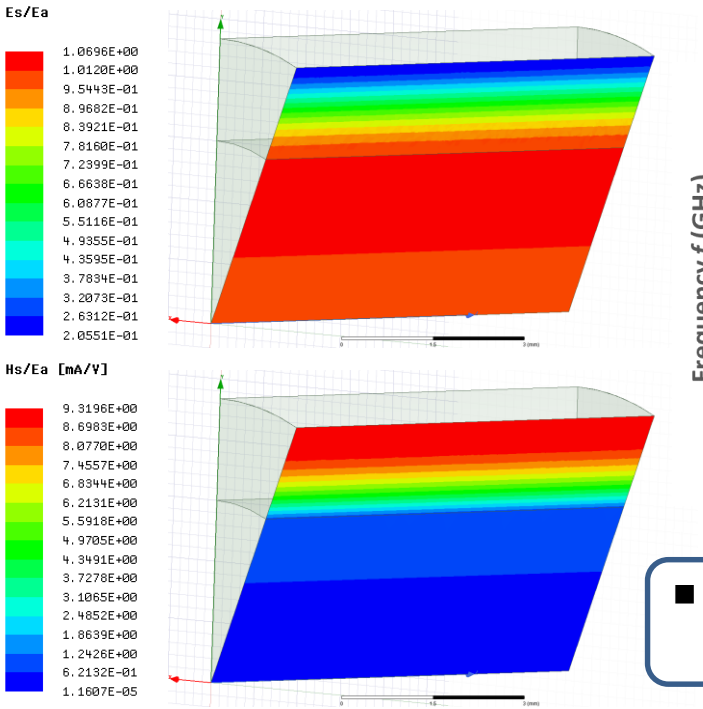
- An X-band mode converter (Converting TE10 mode into TM01 mode)
- A choke geometry is added to remove the contact issue and bonding joints for assembling two copper parts together

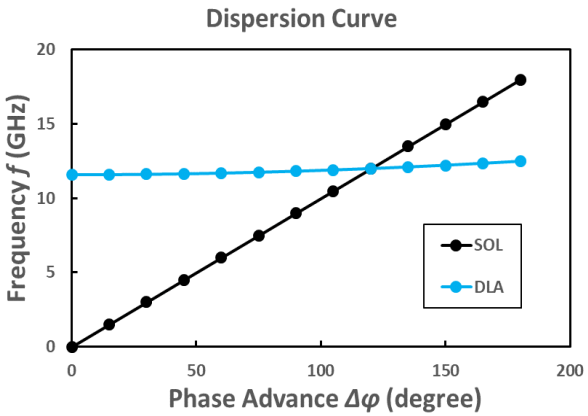
RF parameters for a DLA



E_{s_vacuum}/E_a	1.07
$E_{s\_dielectric}/E_a$	1.00
E_{s_metal}/E_a	0.206
H_{s_vacuum}/E_a [mA/V]	1.00
$H_{s\_dielectric}/E_a$ [mA/V]	9.32
H_{s_metal}/E_a [mA/V]	9.09

	MCT-16
Dielectric constant ε_r	16.66
Dielectric loss tangent δ	3.43e-5
Periodical length L [mm]	8.3333
Phase advance	120°
Inner radius R_{in} [mm]	3.0
Outer radius R_{out}[mm]	4.6388
Frequency [GHz]	11.9940
Unloaded Q_0	2829
r'/Q_0 [Ω/m]	9368
r' [MΩ/m]	26.5
v_g/c	0.066
E_s/E_a	1.07
H_s/E_a [mA/V]	9.32
Power required to generate 100 MV/m [MW]	280

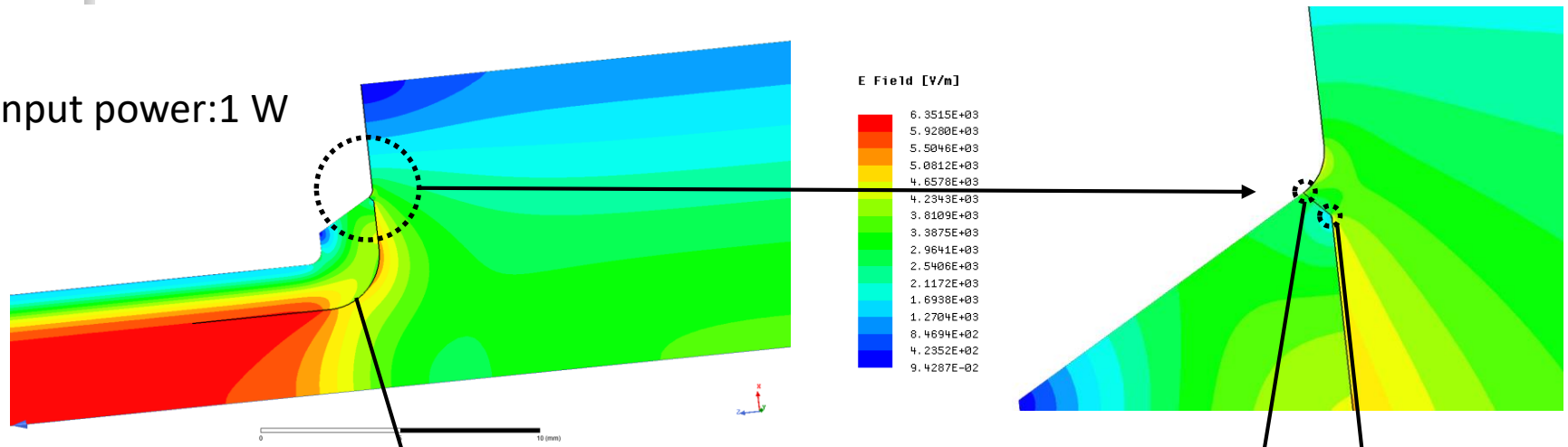


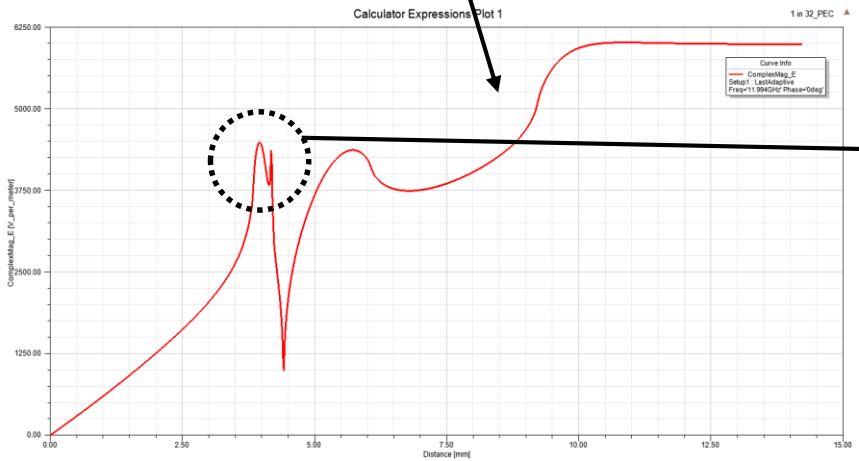


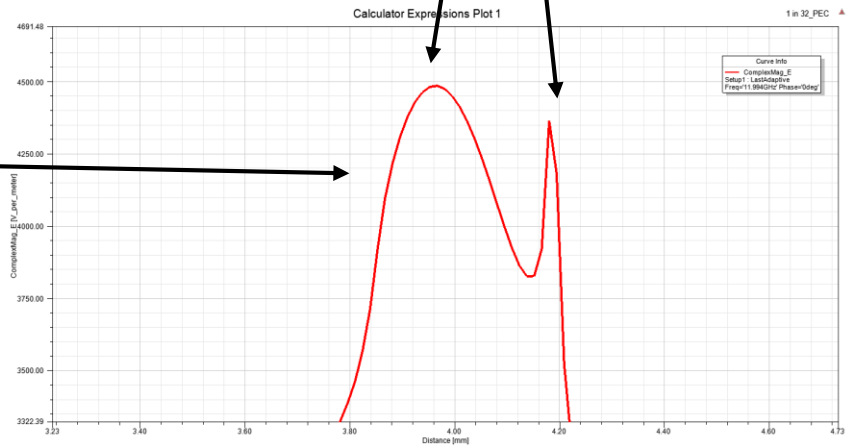
■ A DLA with a length of 100 mm is used for fabrication studies.

EM fields in matching section

Input power:1 W

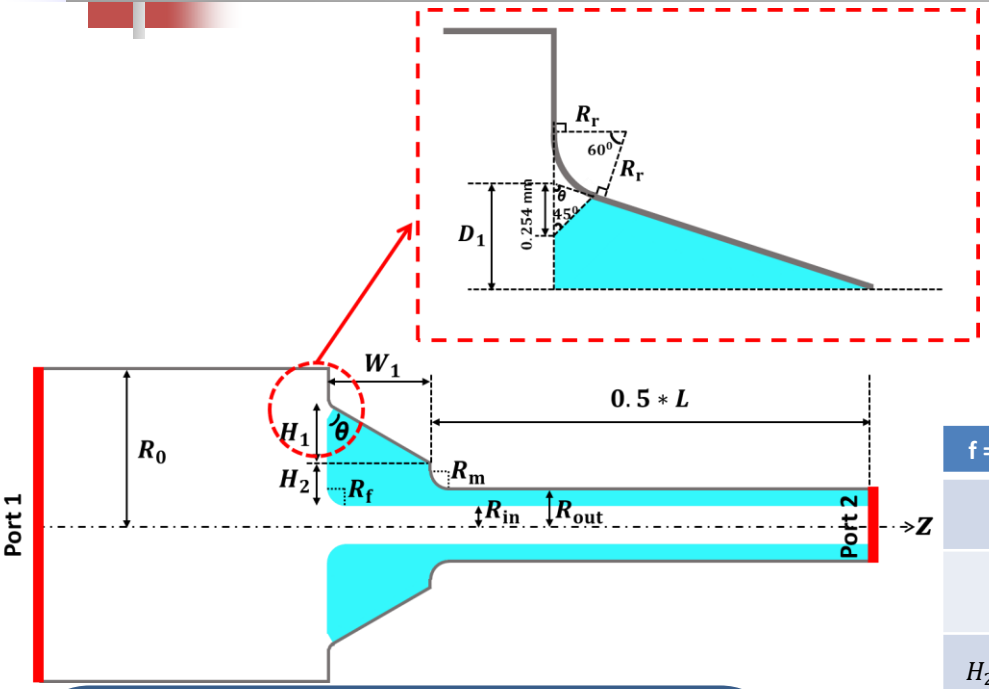


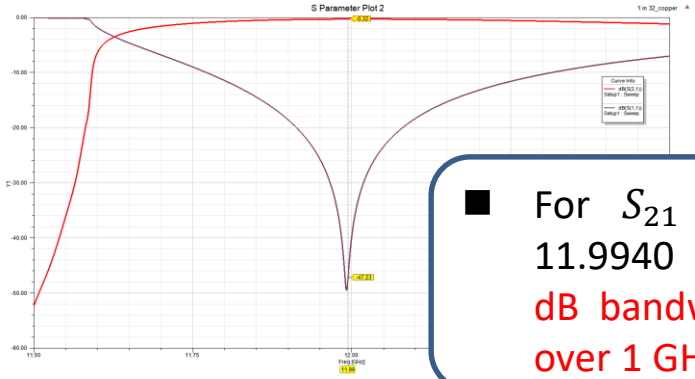




- **The fields in the matching section are weaker than those of DLA.**

Tolerance studies



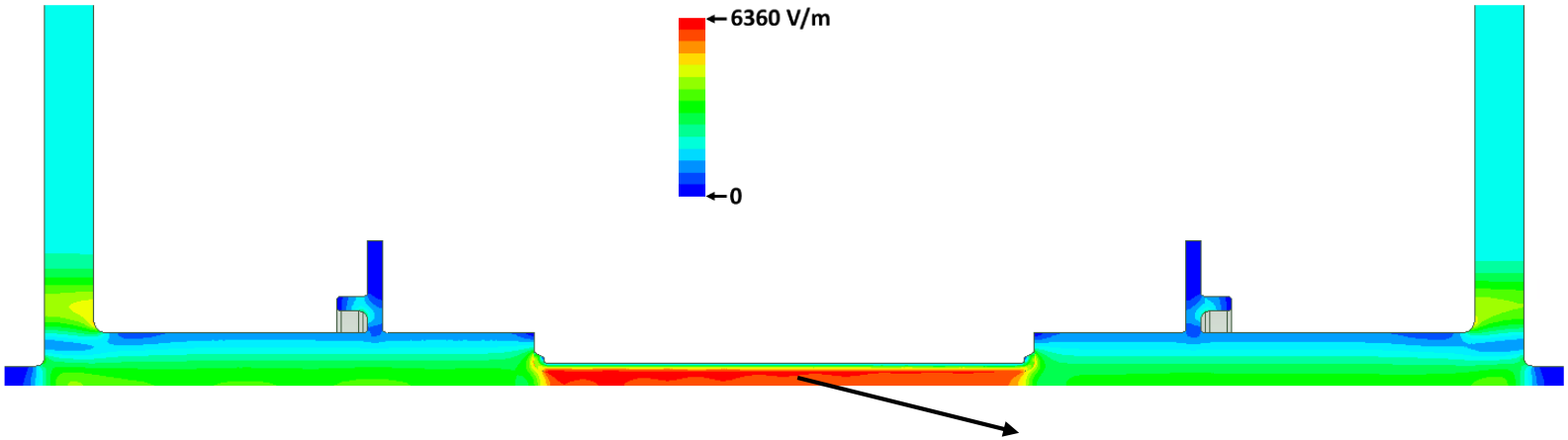


- For S_{21} at f = 11.9940 GHz, 3 dB bandwidth is over 1 GHz.

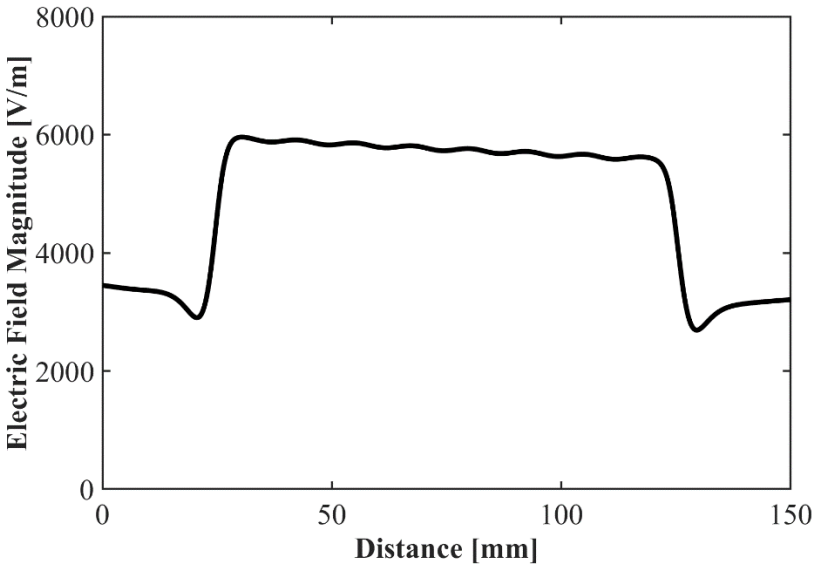
f = 11.9940 GHz	$S_{11} \leq -30$ dB	$S_{11} \leq -25$ dB	$S_{11} \leq -20$ dB
$\varepsilon_r = 16.66$	[-0.079, +0.081]	[-0.139, 0.148]	[-0.24, +0.27]
$W_1 = 2.035$ [mm]	[-0.007, +0.007]	[-0.012, +0.012]	[-0.022, +0.022]
$H_2 = 2.74$ [mm]	[-0.015, +0.017]	[-0.027, +0.030]	[-0.051, +0.054]
$\theta = 60^0$	[-2.5^0, +2.0^0]	[-4.3^0, +3.7^0]	[-7.3^0, +7.0^0]
$R_f = 2.0$ [mm]	[-0.042, +0.040]	[-0.076, +0.068]	[-0.140, +0.120]
$R_m = 0.5$ [mm]	[-0.061, +0.049]	[-0.118, +0.090]	[-0.245, +0.151]
$R_{out} = 4.6388$ [mm]	[-0.0076, +0.0065]	[-0.0123, +0.0127]	[-0.020, +0.025]
$R_{in} = 3.0$ [mm]	[-0.006, +0.007]	[-0.012, +0.012]	[-0.024, +0.020]

- S_{11} is most sensitive to W_1, R_{out}, and R_{in};
- S_{11} is least sensitive to H_2, θ, R_f, R_m, ε_r;
- Fabrication accuracy should be better than $\pm$ 0.02 mm in order to realize a $S_{11} \leq -20$ dB.

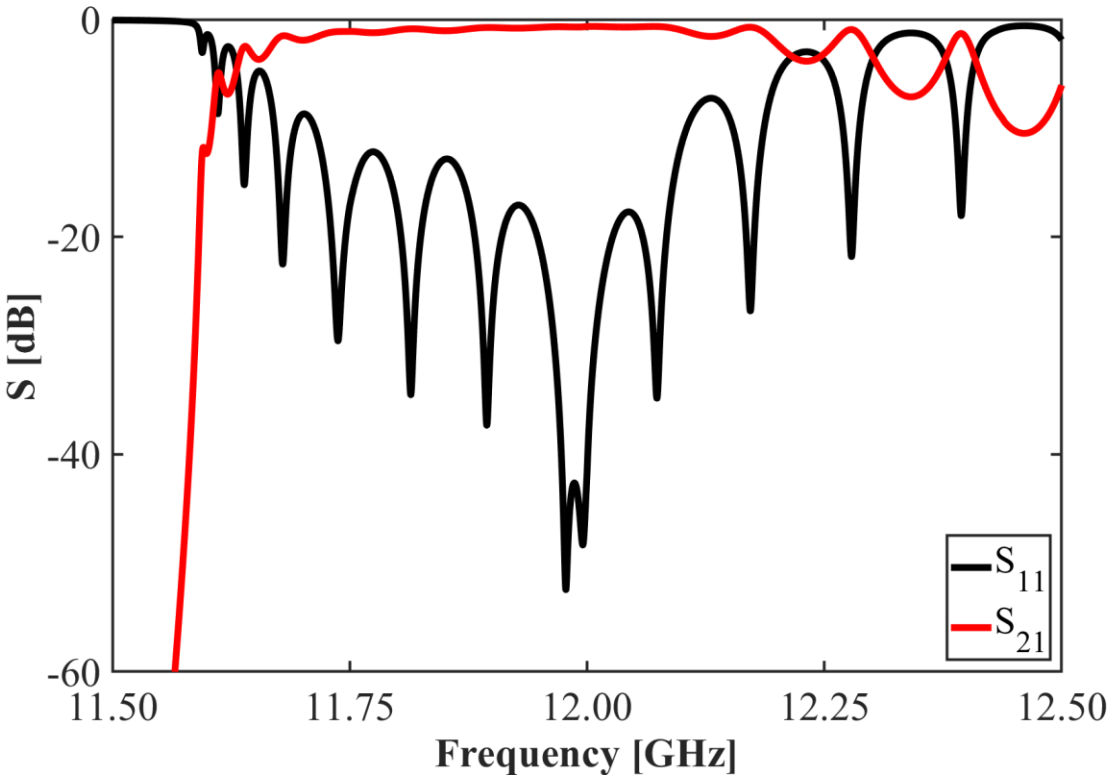
Accelerating field



Whole structure	
A DLA Length	100 mm
Voltage @ 1W	577.3 V
Average Gradient @ 1W	5773 V/m
Average Gradient @ 40 MW	36.5 MV/m

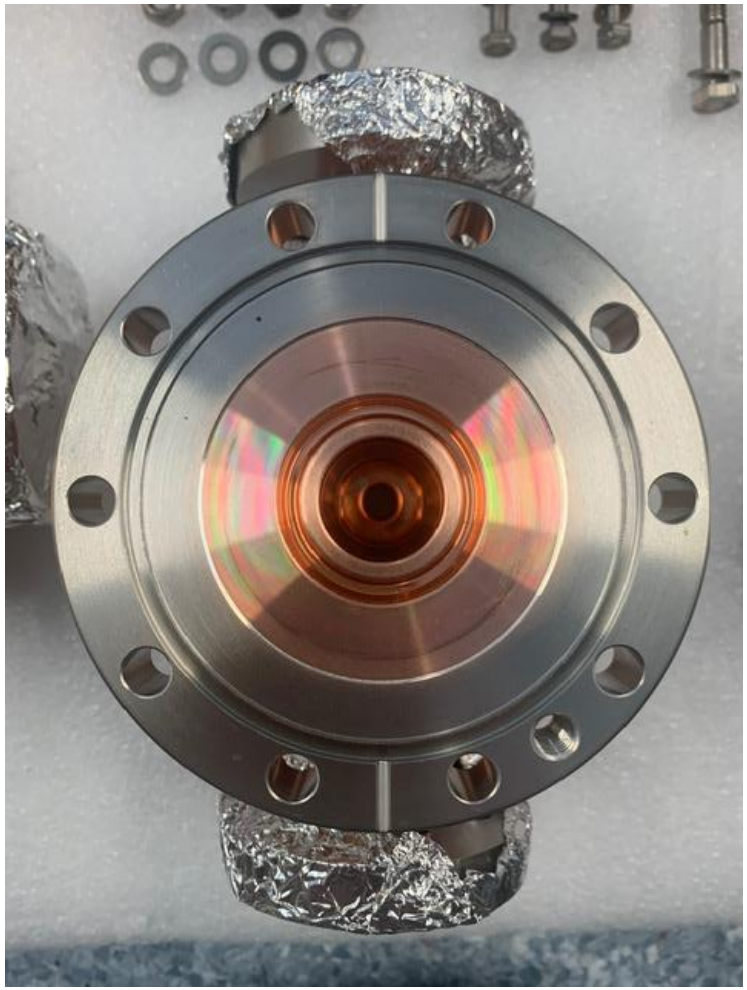


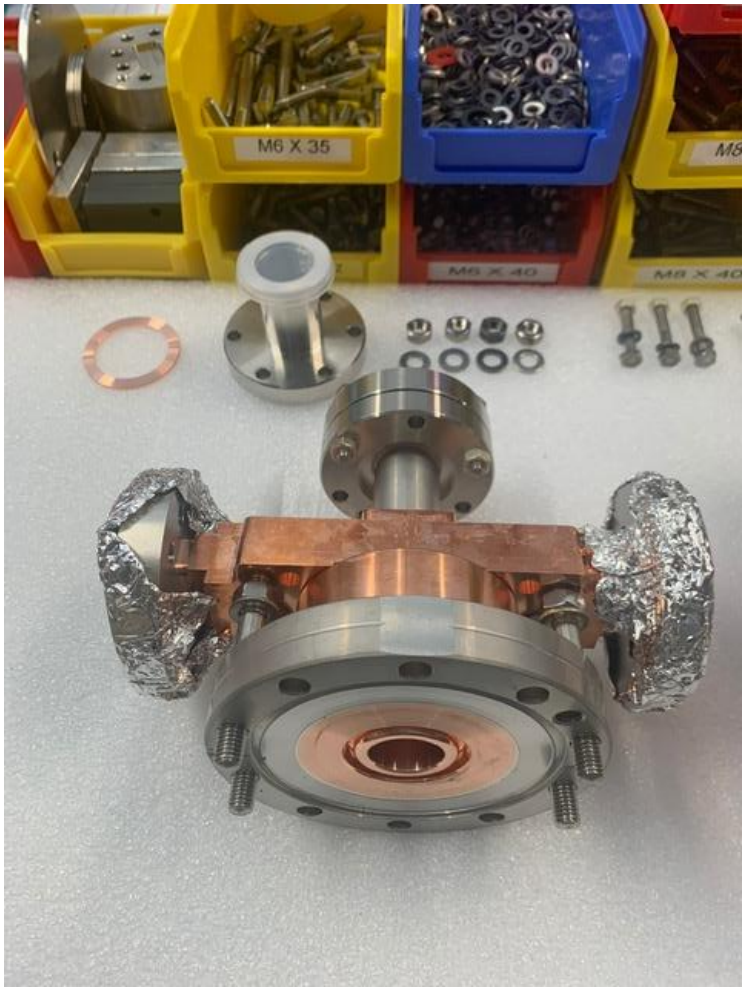
Simulated S-parameters



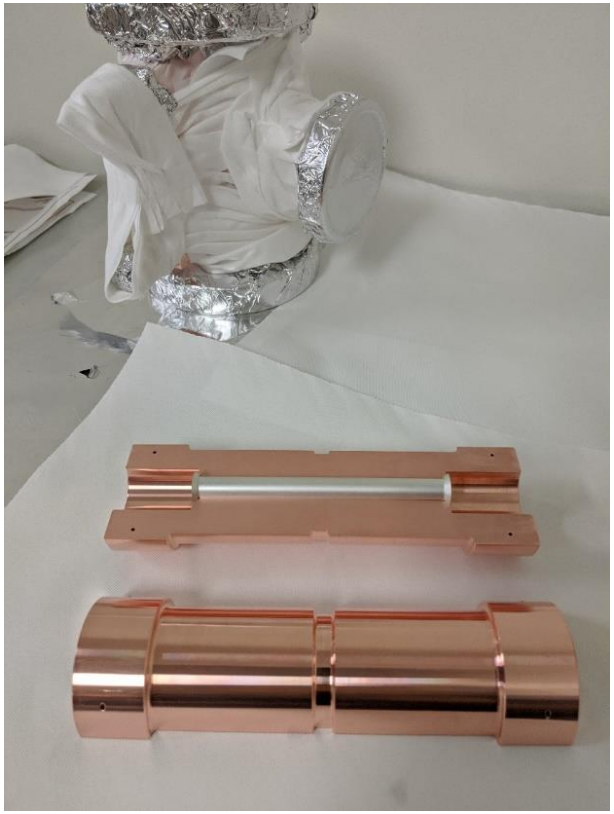
For an input power of 40 MW, a pulse width of 1.5 μs, and a repetition rate of 50 Hz	
S_{11}	< -40 dB
S_{21}	-0.67 dB
Power loss in dielectrics	36 W
Power loss in copper surface	390 W

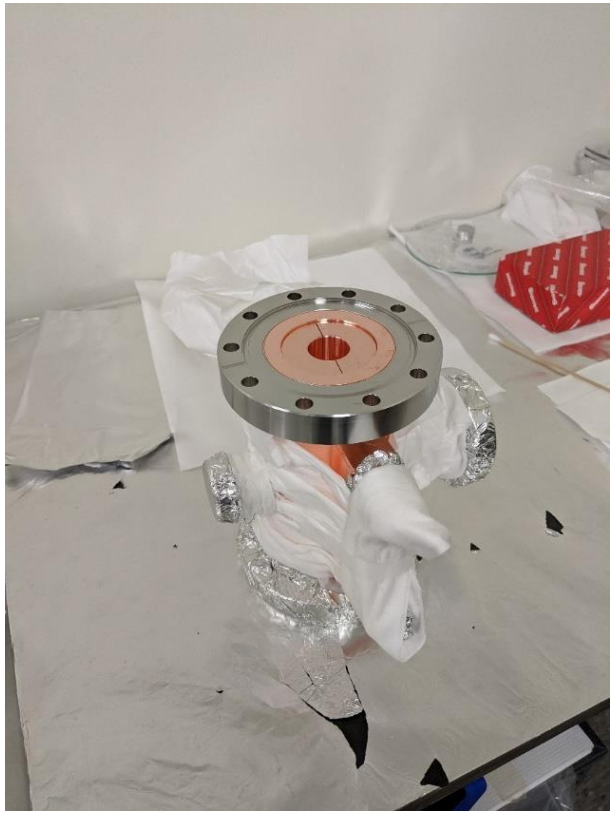
Mode converters with a choke





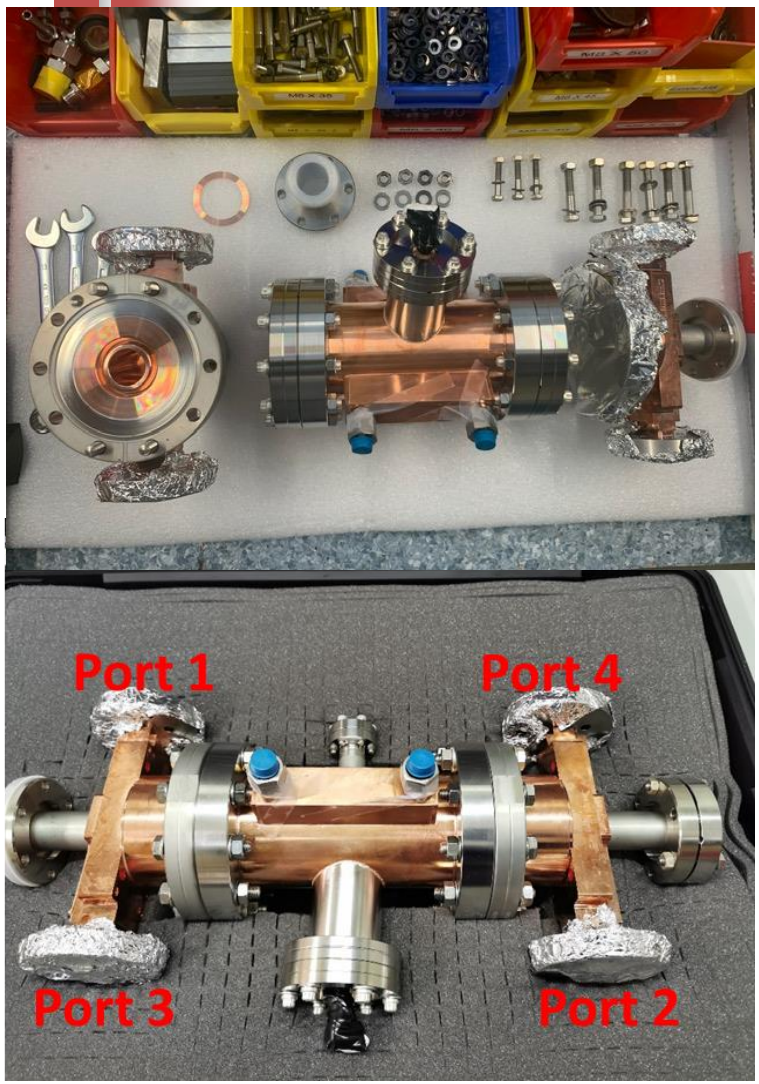
DLA structure

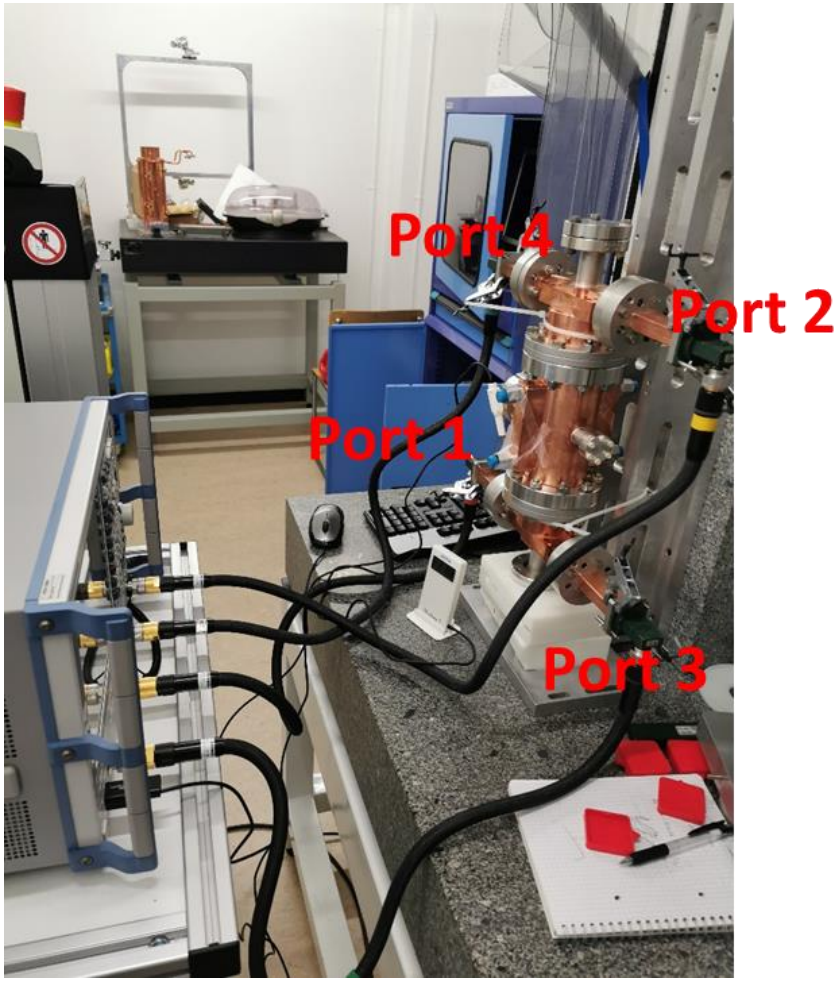




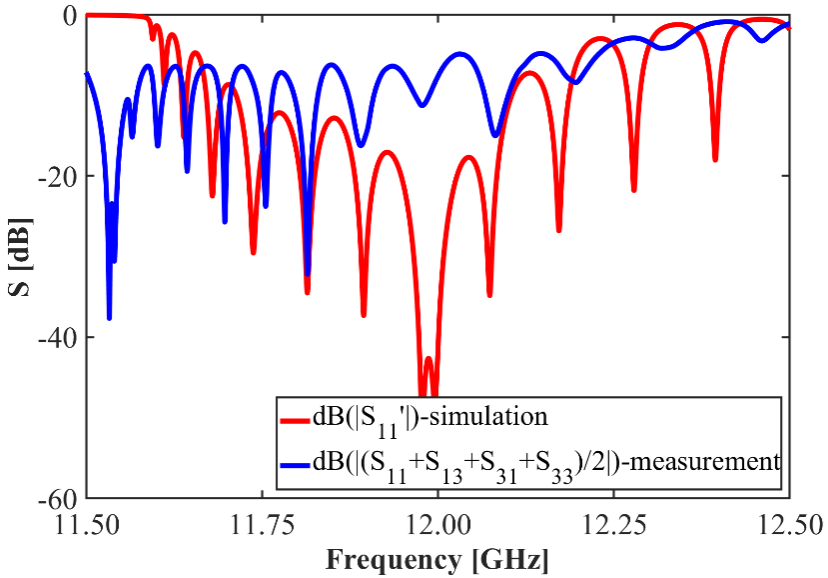
Courtesy of photos from Dr. Chunguang Jing, Euclid Techlabs.

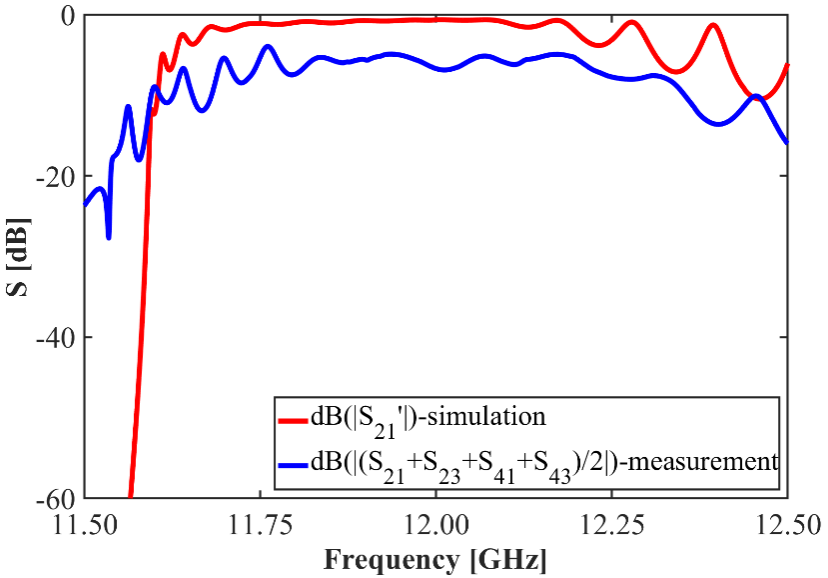
RF Measurement on assembly of two TE10-TM01 mode converters and the DLA structure

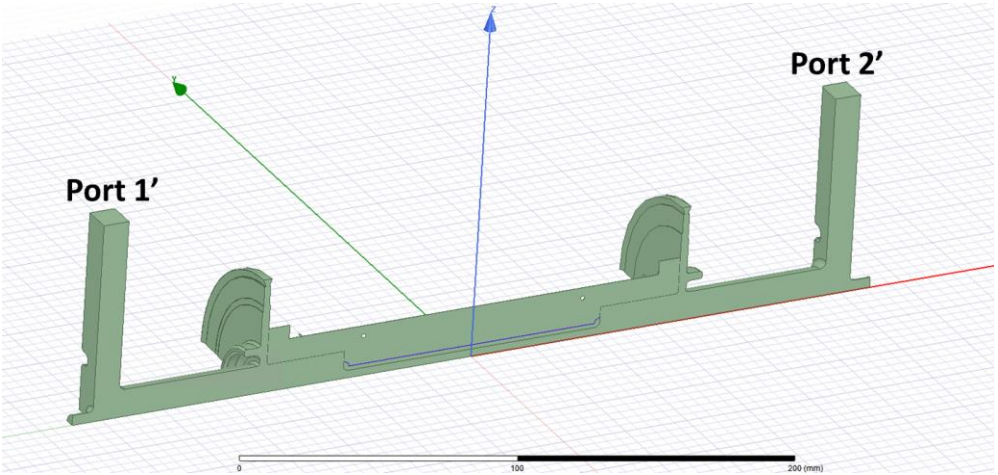




S-parameters comparison







- From the measurement blue line at the frequency of 11.994 GHz, $S'_{11} = -11.35$ dB, $S'_{21} = -6.34$ dB;
- There is a big discrepancy between the measured and simulated S-parameters.

Summary & Outlook

- An X-band DLA structure with the TE10-TM01 mode converters and matching sections is designed, fabricated, and low-power measured.
- The fabrication error may cause the big discrepancy between measured and simulated S-parameters.

- Using two power splitters for 2-port testing on the DLA structure (Large power loss results from HOMs' propagation due to the asymmetries in the 4-port testing).