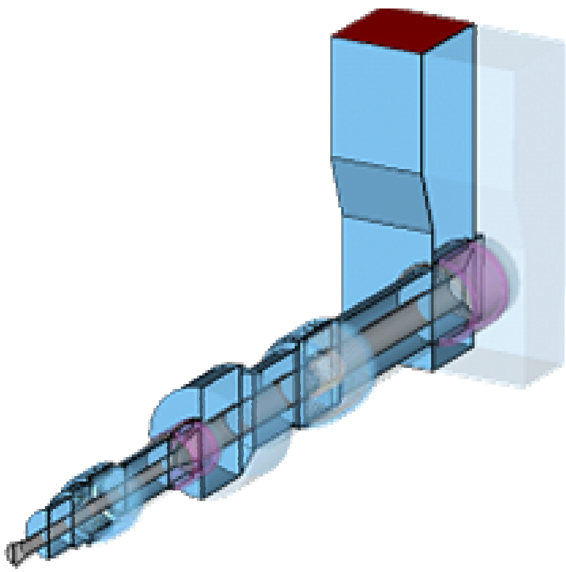
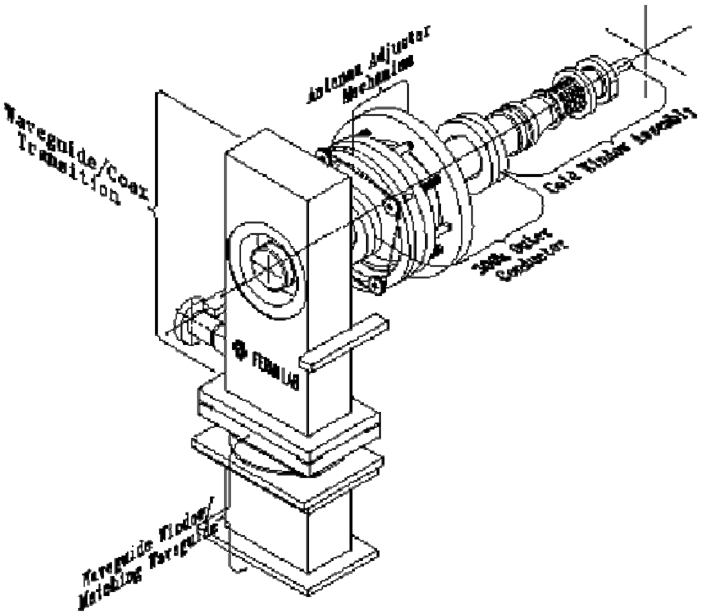
High Power RF Couplers





ELSRF Daresbury Laboratory

Aims

- Introduce high power RF couplers
- Design considerations
- Examples of coupler designs
- Modelling coupler designs using CST Microwave Studio©

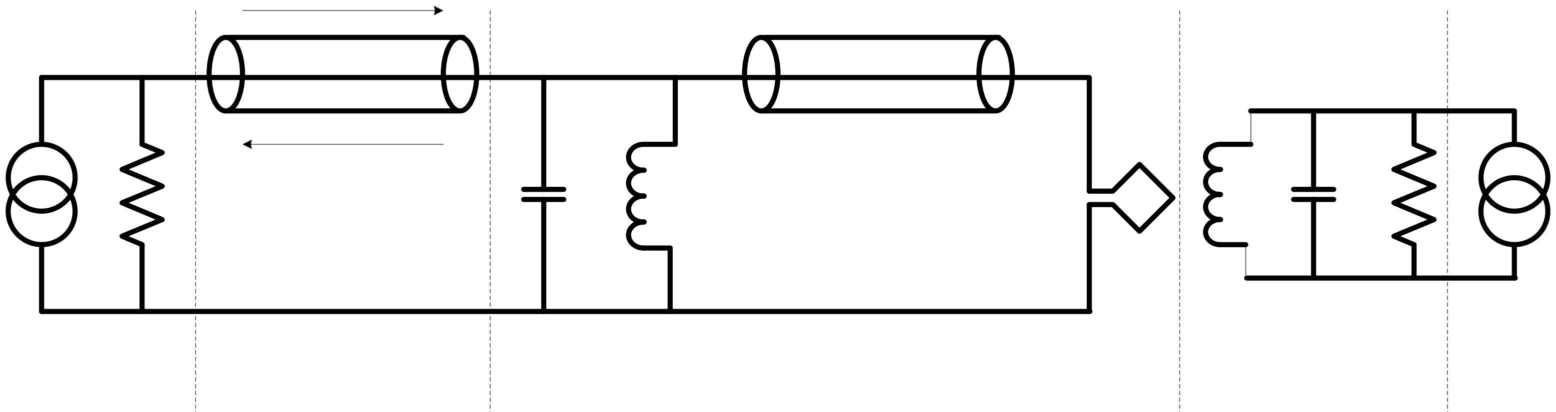
Introduction

What is a coupler ?

A coupler is a device whose primary function is to efficiently transfer RF power to a load.

To meet this requirement the device has to be impedance matched.

Equivalent Circuit of Coupler RF System



Challenges

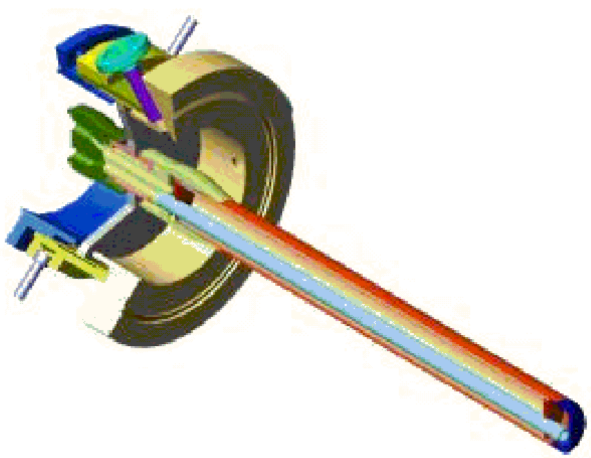
- Transitions.
- Vacuum requirements.
- Extremes of temperature.
- Load impedance variations.
- Electric field should not disturb beam.
- Should not suffer from voltage breakdown or multipactor.

Coupler Types

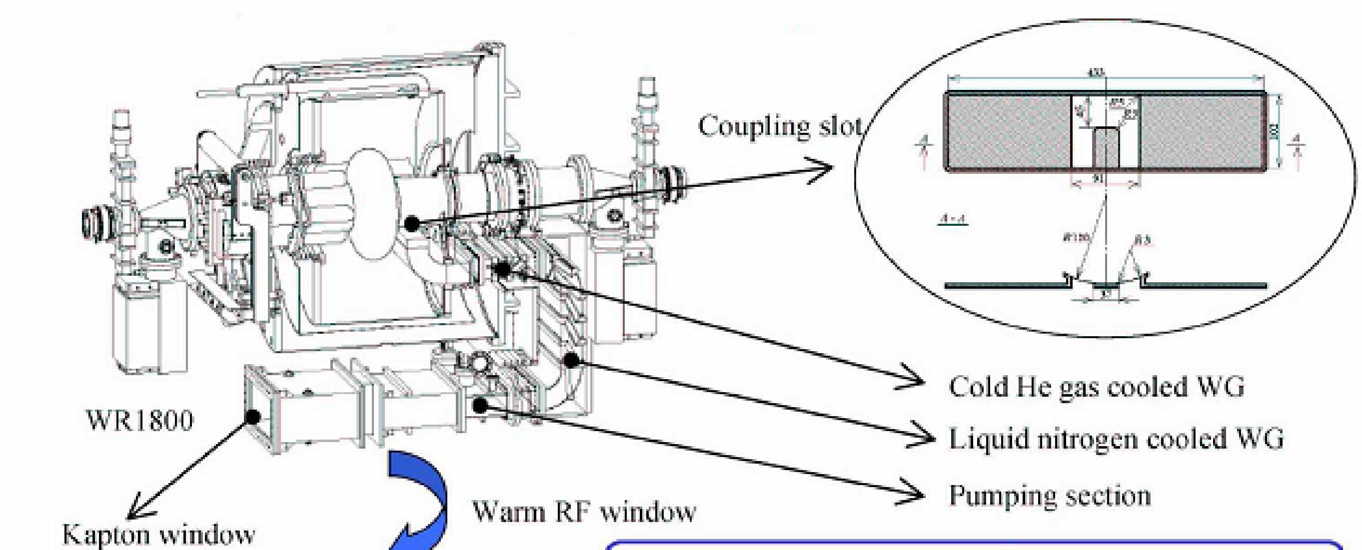
	Pros	Cons
Waveguide	• Simpler design • Higher power handling • Easier to cool	• Physically large • Increased heat leak • Difficult to make adjustable
Coaxial	• More compact • Smaller heat leak • Easier to make variable • Multipacting can be avoided	• Designs tend to be more complicated • Lower power handling • Harder to cool

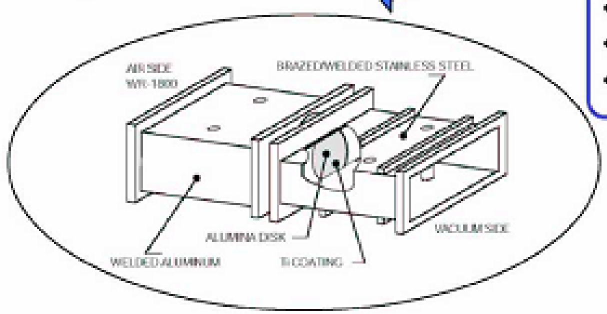
Example of a Coaxial Coupler

AMAC-1 SNS Couplers:

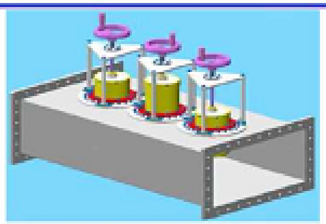


Example of a Waveguide Coupler

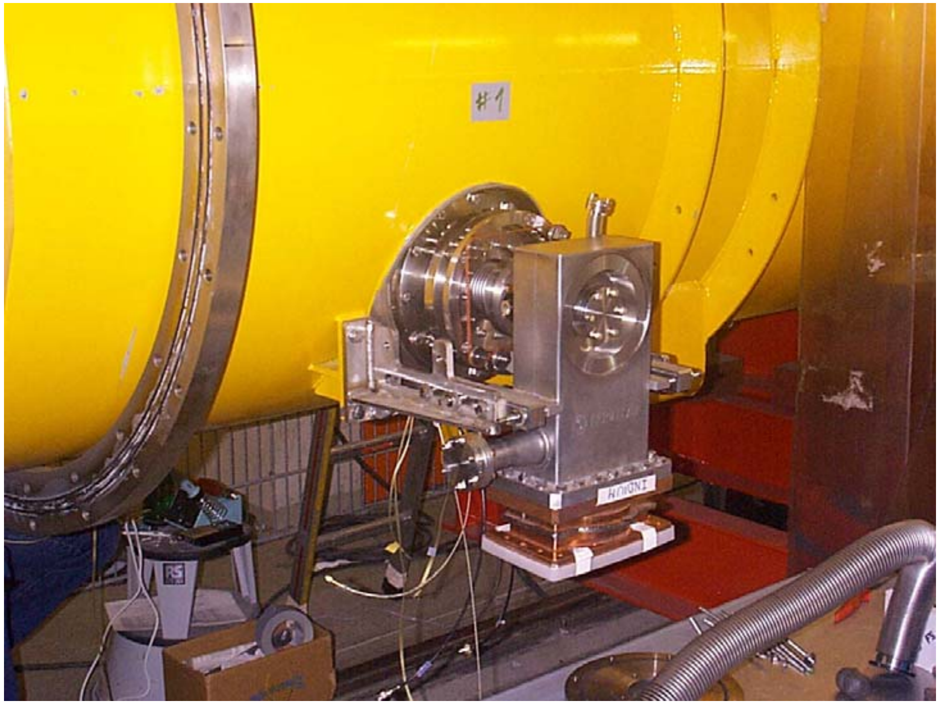


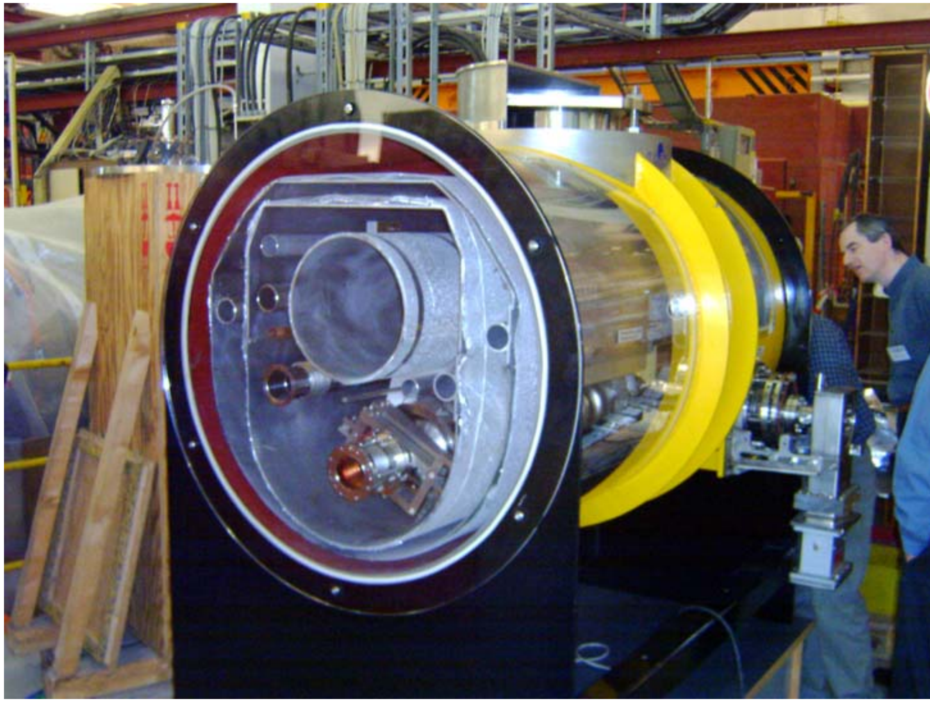


- **Fixed coupling @ Q_{ext}= 2×10^5**
- **Magnetic bias of the WG to suppress multipacting**
- **Adjustability is provided via a 3-stub WG transformer**

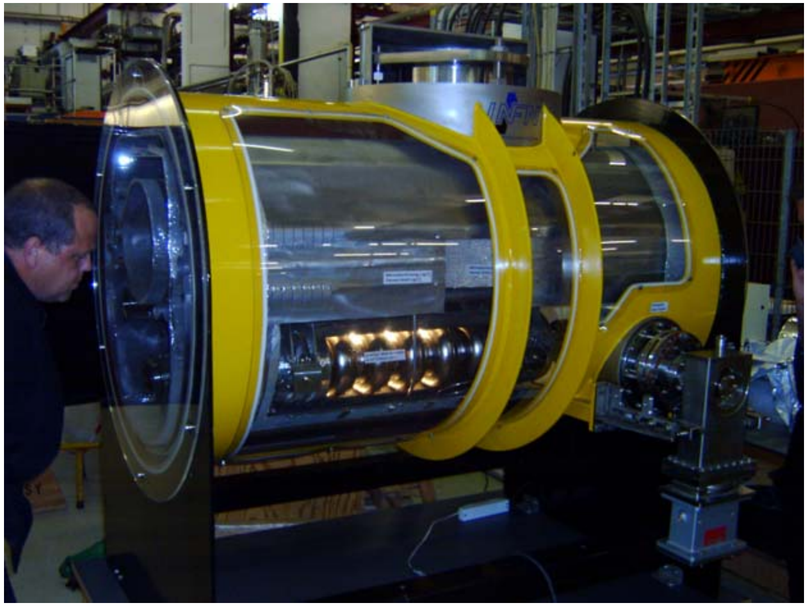


Tesla Coupler





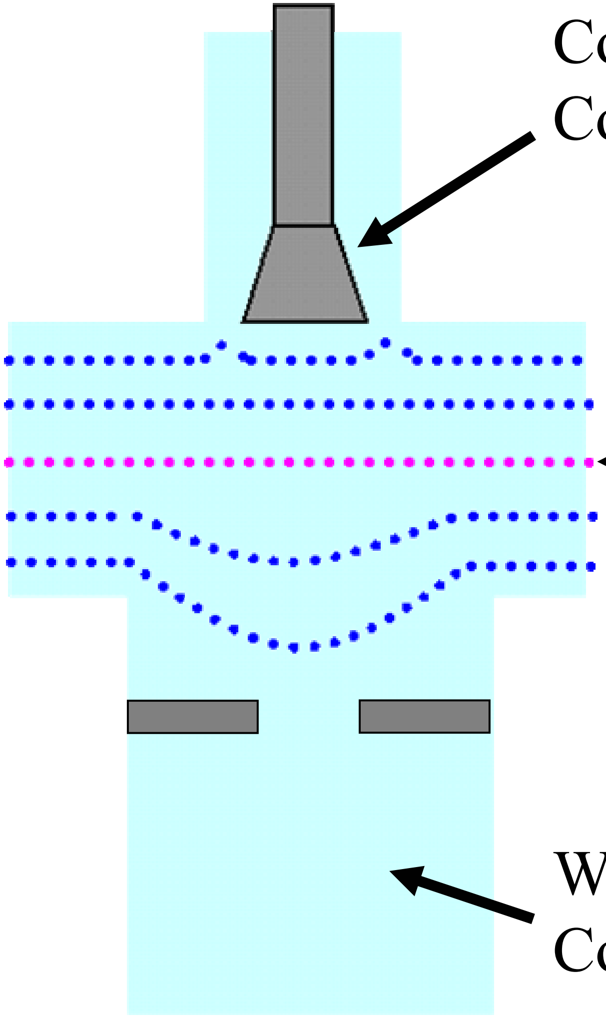
Tesla Coupler



Coupler Options for 4GLS

A coaxial type coupler would be most suitable.

- Easier to tune
- Less disturbance to the beam



Why Model RF Structures ?

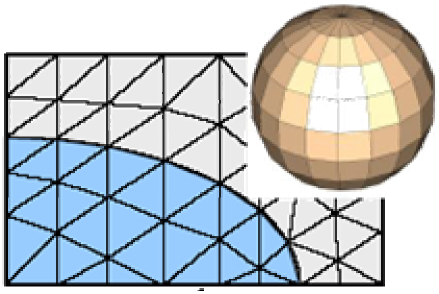
- Structures can be characterised prior to prototyping
- Right first time philosophy
- Cutting metal costs money
- Designs can be optimised or changed quickly
- Prototypes become less hit and miss
- Prompt testing of new ideas

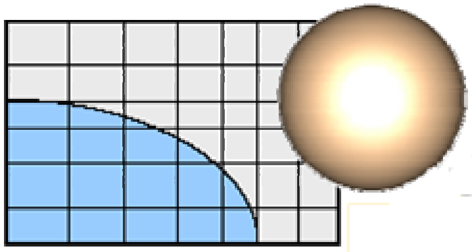
Types of code

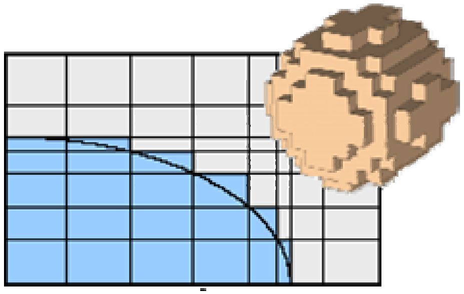
Finite Element (Frequency domain solver, HFFS)

Finite Difference (Time domain solver, Magic, MAFIA)

Finite Integration Technique (FIT, Microwave Studio)

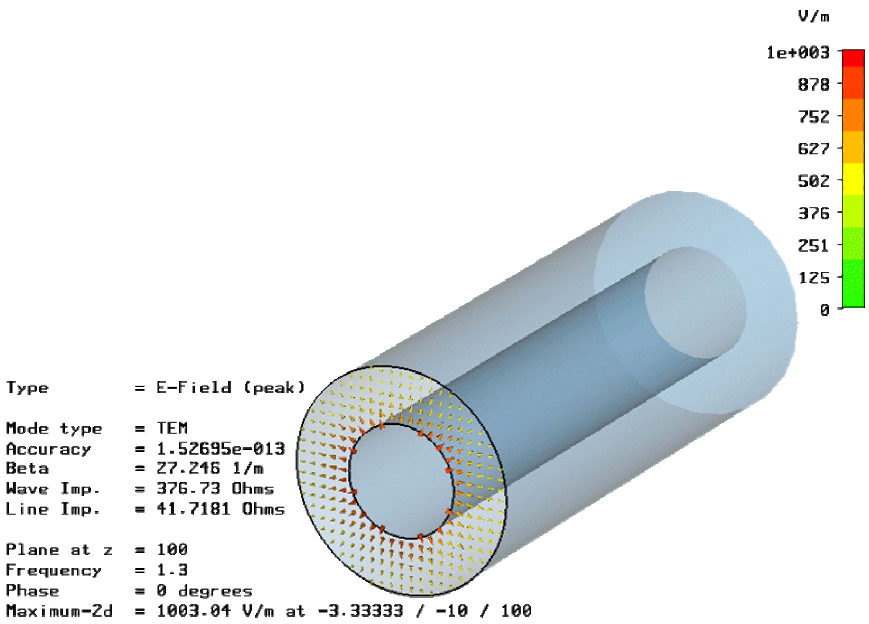




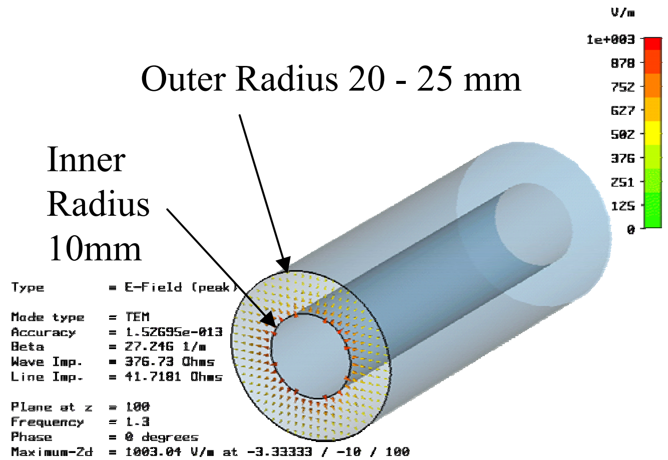


Model 1 : Coaxial Line

The aim of this model was to determine the correct dimensions for a coaxial line, to give a characteristic impedance of 50 ohms at 1.3 GHz.



The coax inner on the model was fixed at 10mm and the outer was changed between 20 to 25 mm.

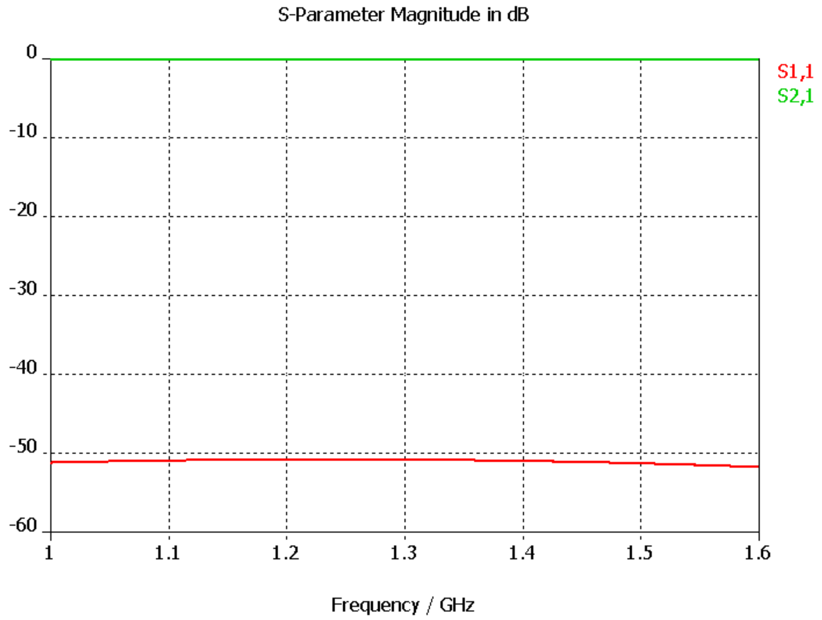


After each change a transient solve was run to determine the impedance of the model.

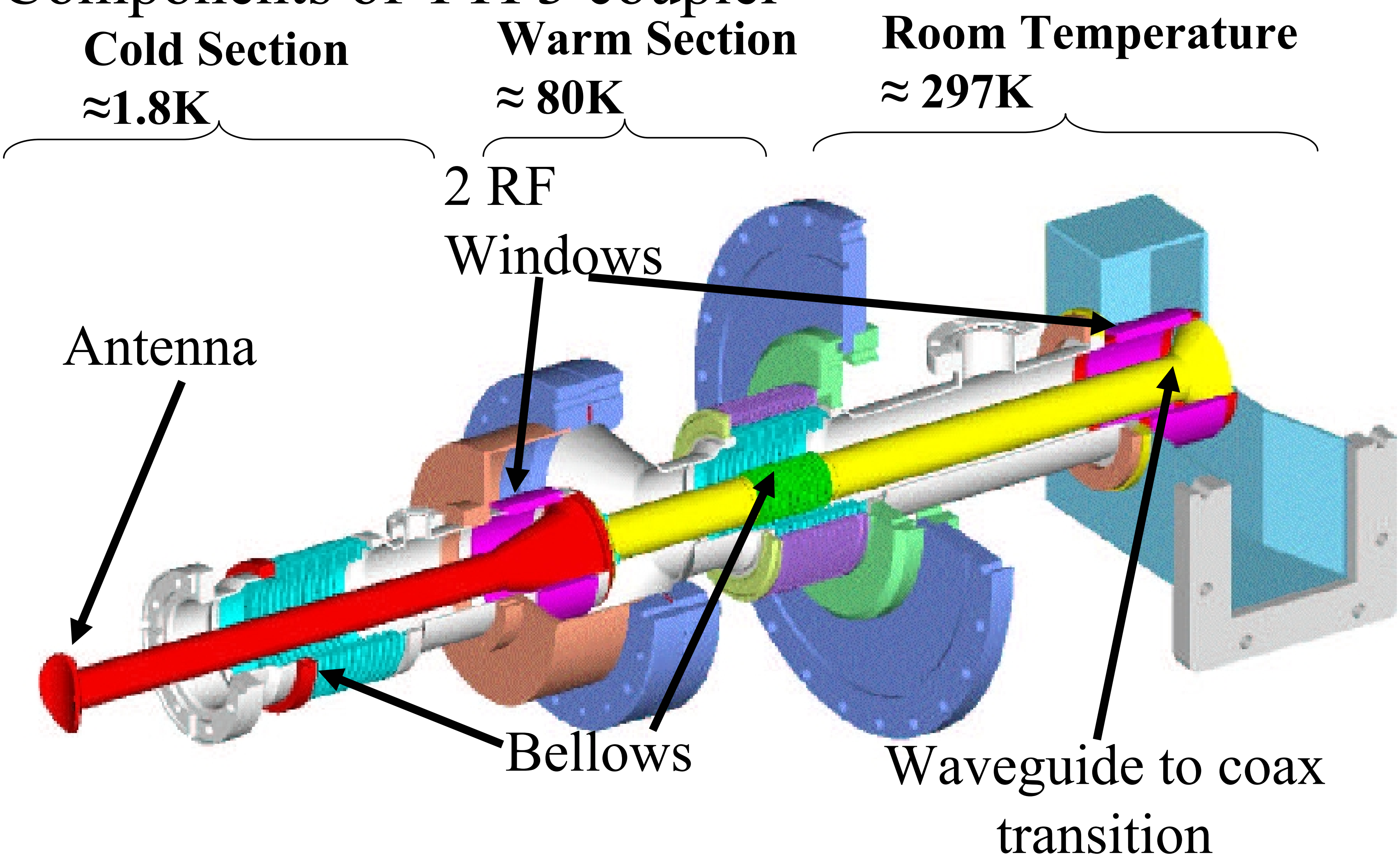
Results

Inner Radius (mm)	Outer Radius (mm)	Impedance (Ohms)
10	20	41.718
10	23	49.557
10	25	55

≈50Ω



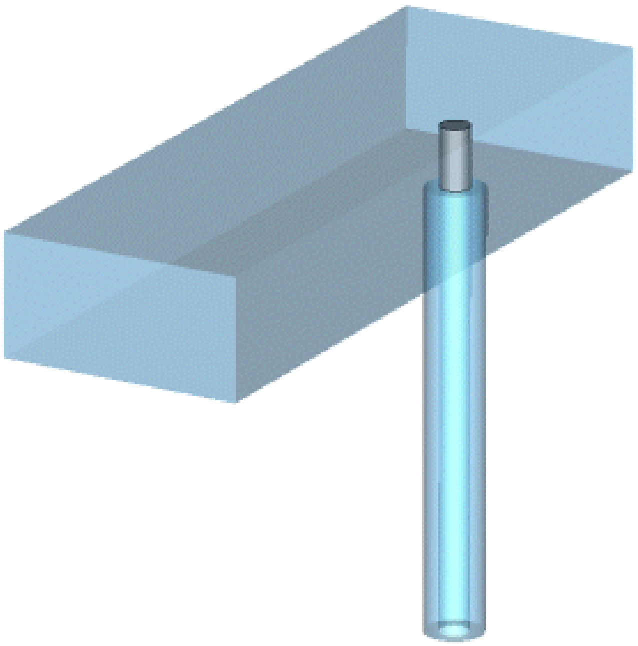
Components of TTF3 coupler

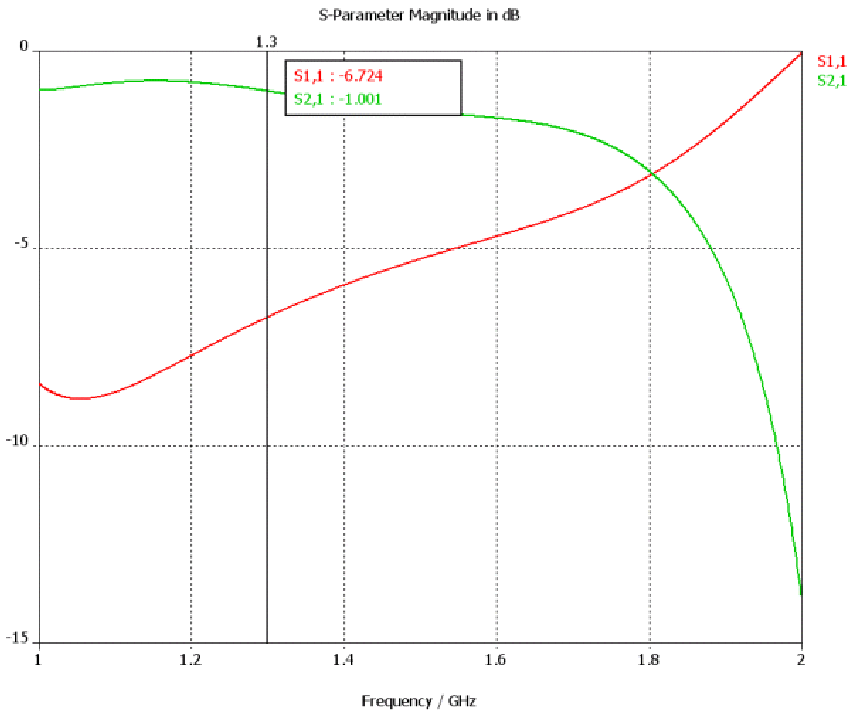


Model 2 : Waveguide to Coax Transition

Geometry

WR650:- 165.10mm X 82.55mm

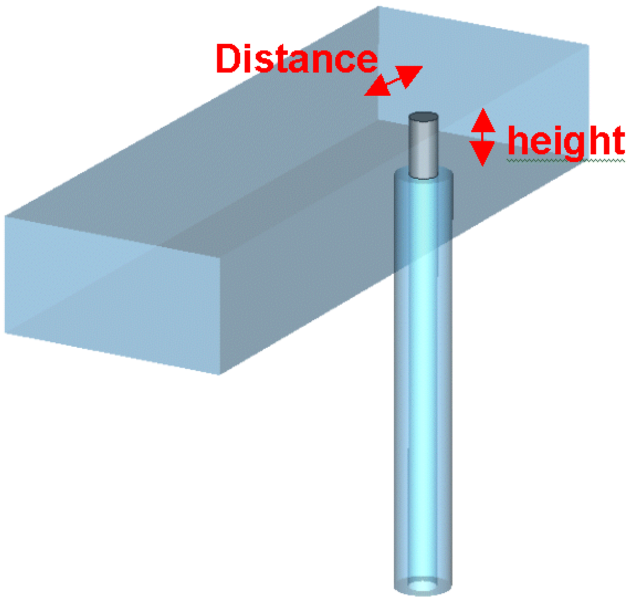




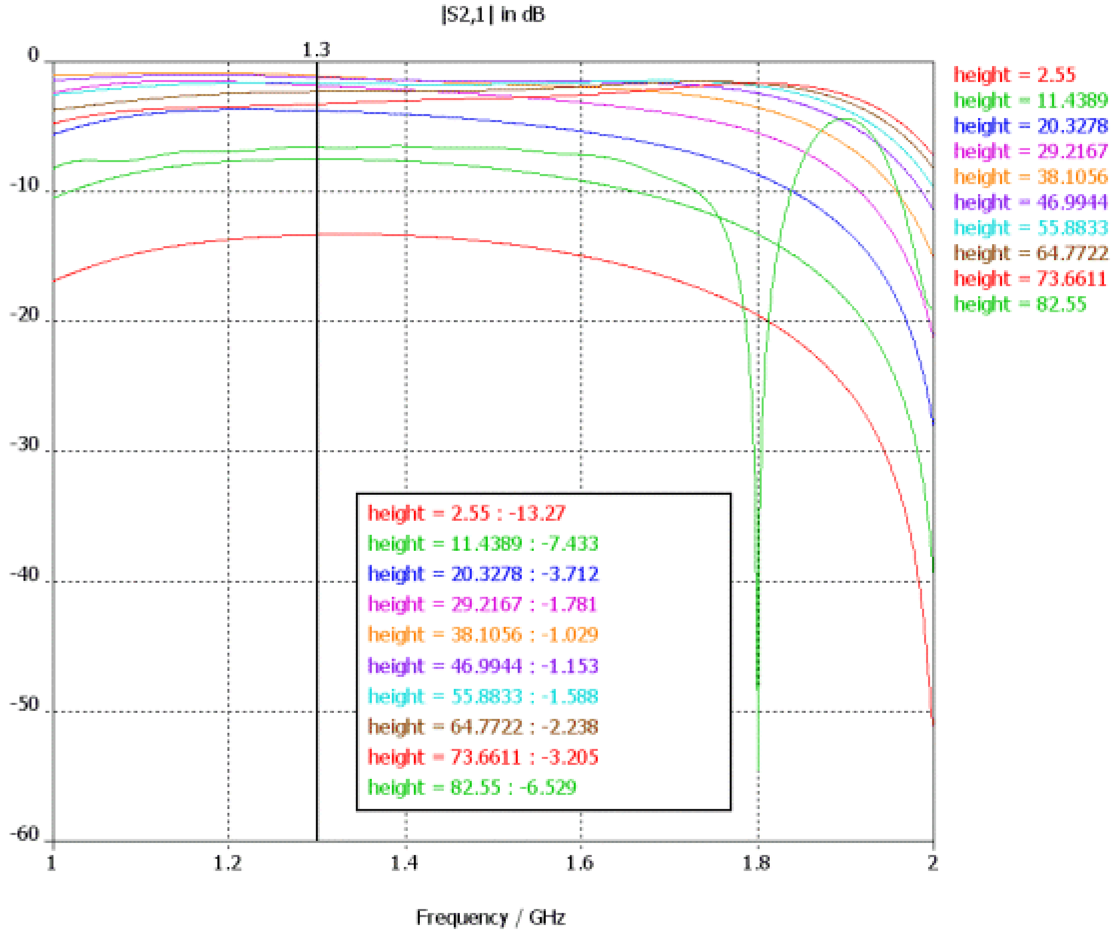
Aim

- To reduce transmission loss.

Sweep the height of the coax inner and the distance of the coax from the end of the waveguide.



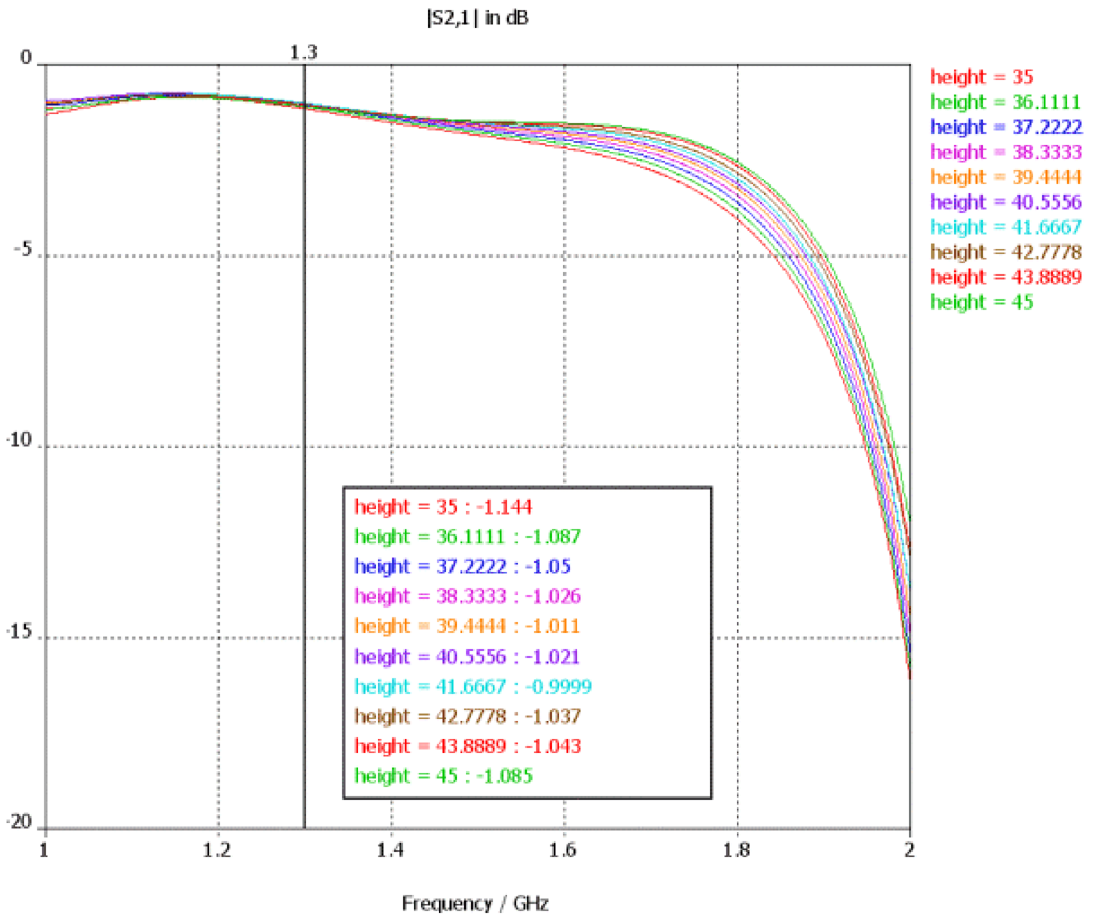
Results


|S2,1| in dB
1.3
0
-10
-20
-30
-40
-50
-60
1
1.2
1.4
1.6
1.8
2
Frequency / GHz
height = 2.55
height = 11.4389
height = 20.3278
height = 29.2167
height = 38.1056
height = 46.9944
height = 55.8833
height = 64.7722
height = 73.6611
height = 82.55
height = 2.55 : -13.27
height = 11.4389 : -7.433
height = 20.3278 : -3.712
height = 29.2167 : -1.781
height = 38.1056 : -1.029
height = 46.9944 : -1.153
height = 55.8833 : -1.588
height = 64.7722 : -2.238
height = 73.6611 : -3.205
height = 82.55 : -6.529

Reduce the range of sweep (35mm to 45mm)

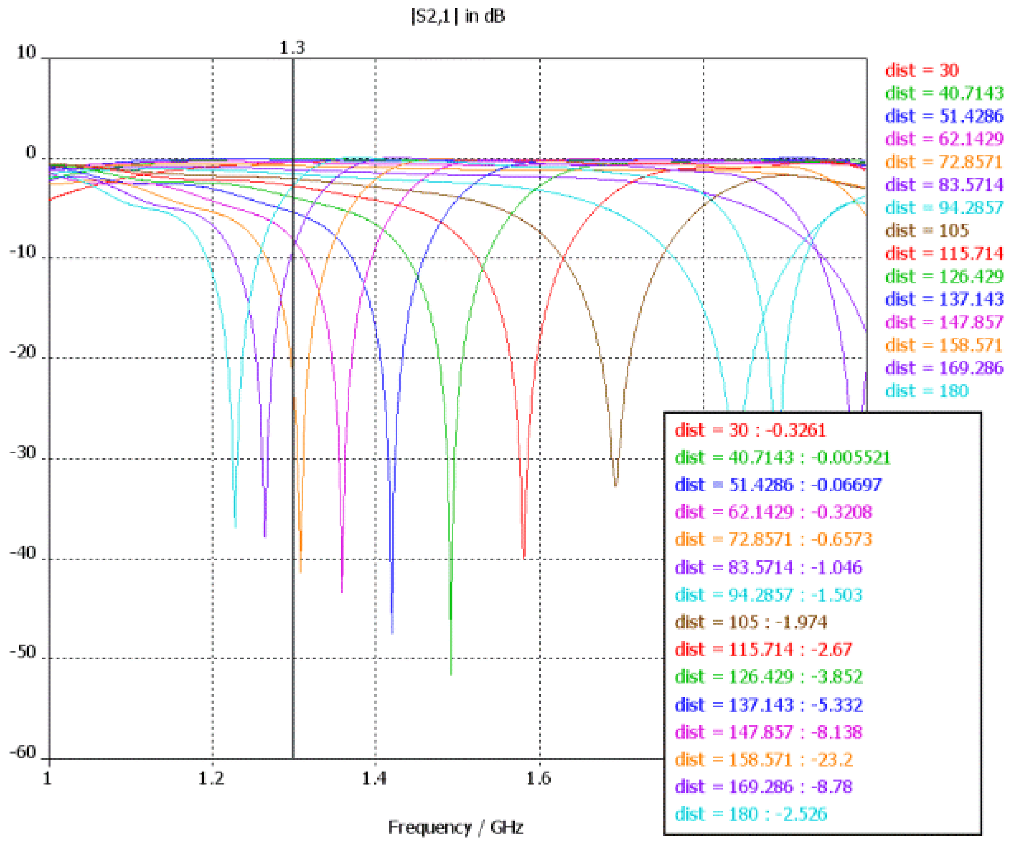
•Height alone is not sufficient to tune the transmission.

•Try varying distance from back wall of waveguide.



Results

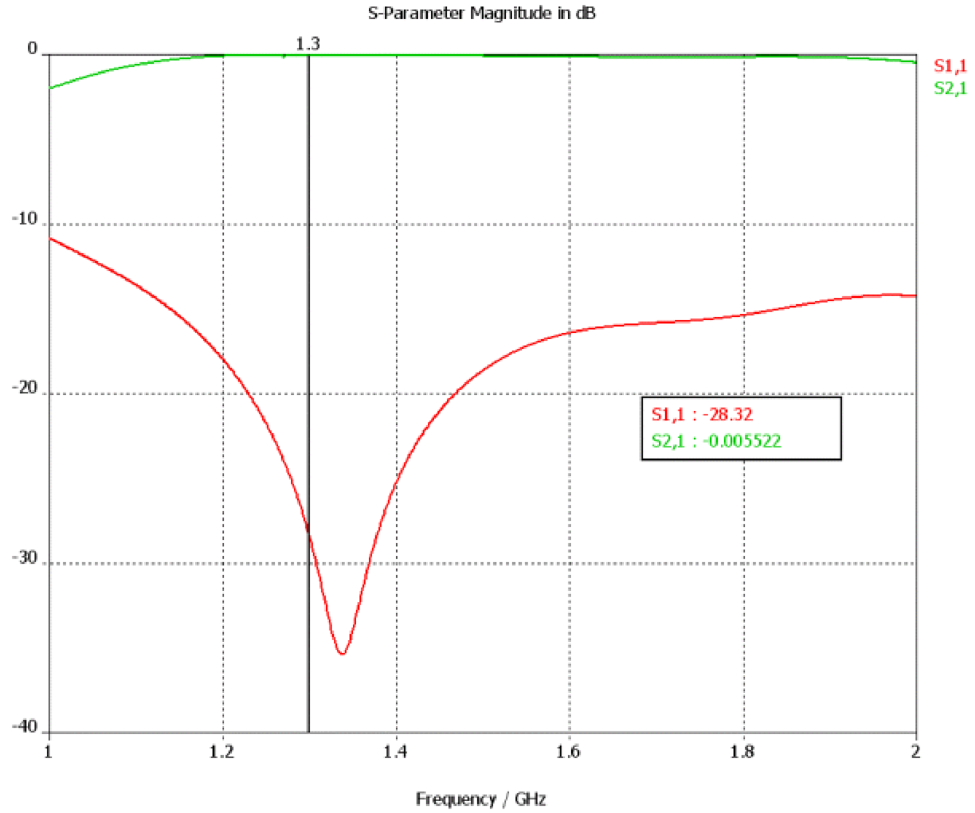
- Optimal transmission at distance ≈ 40.7143 mm.
- Reduce transmission loss further using optimiser.



Results

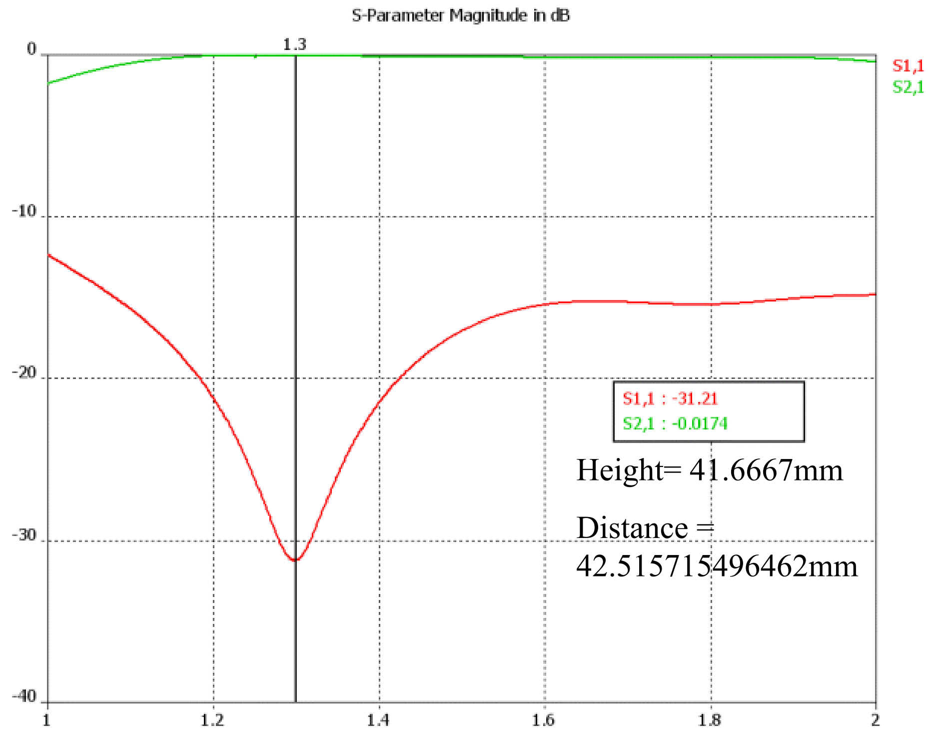
- Transmission loss successfully optimised(-0.005522 dB)

- Next stage optimise return loss



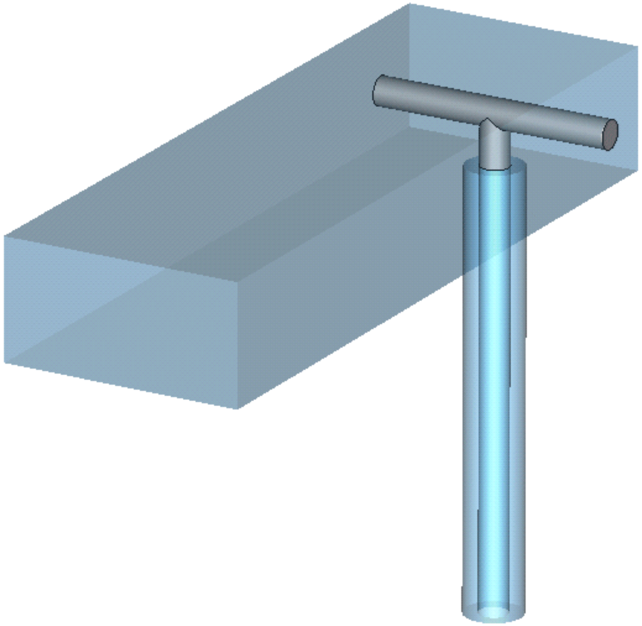
Results

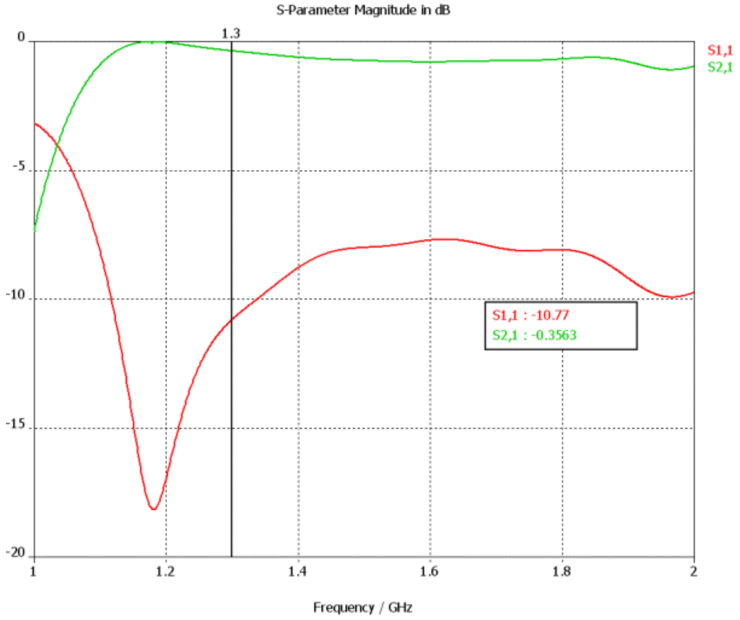
- Return loss successfully optimised maintaining low transmission loss



Improving the Performance

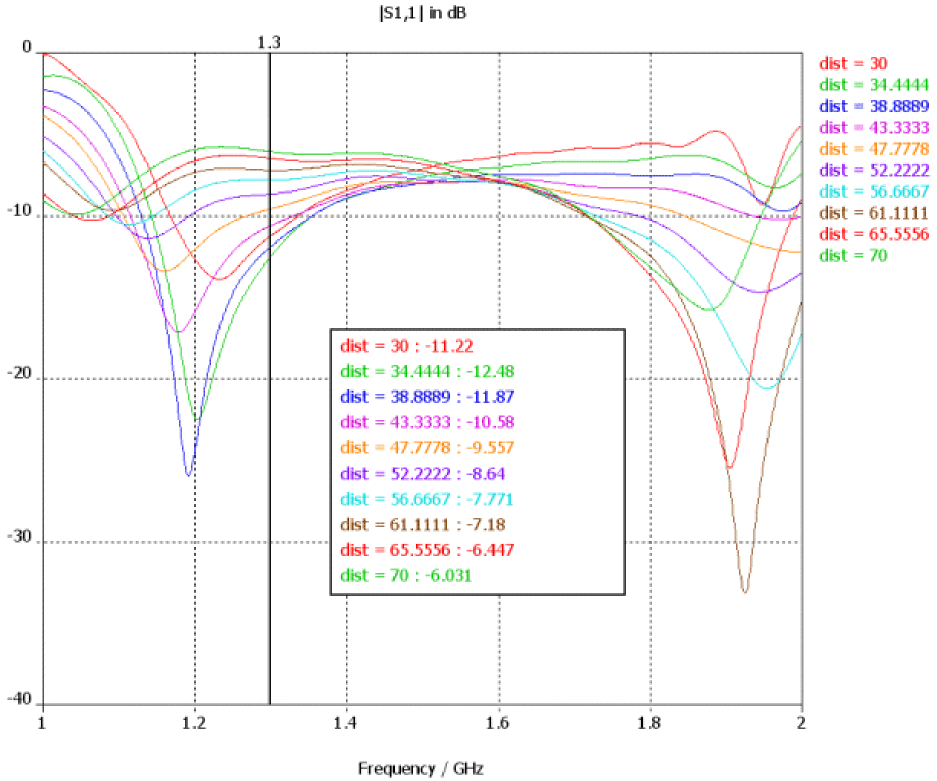
- The addition of a "T" bar adds mechanical strength and can improve the match and bandwidth of the system.





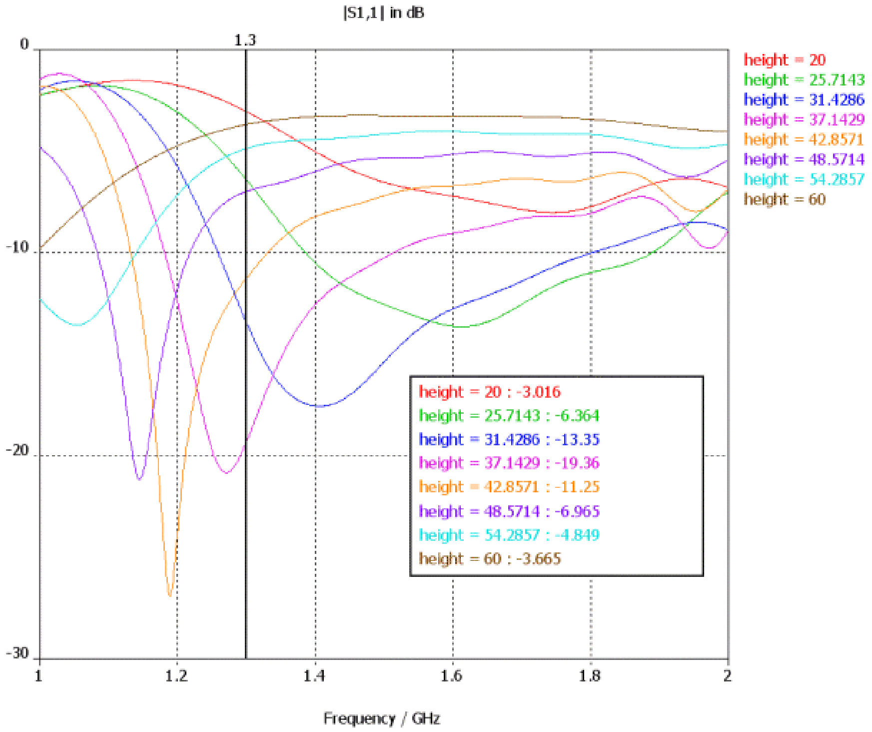
Results

- Sweeping the distance of the coax from the end wall of the waveguide doesn't change optimum frequency.
- Try changing height.



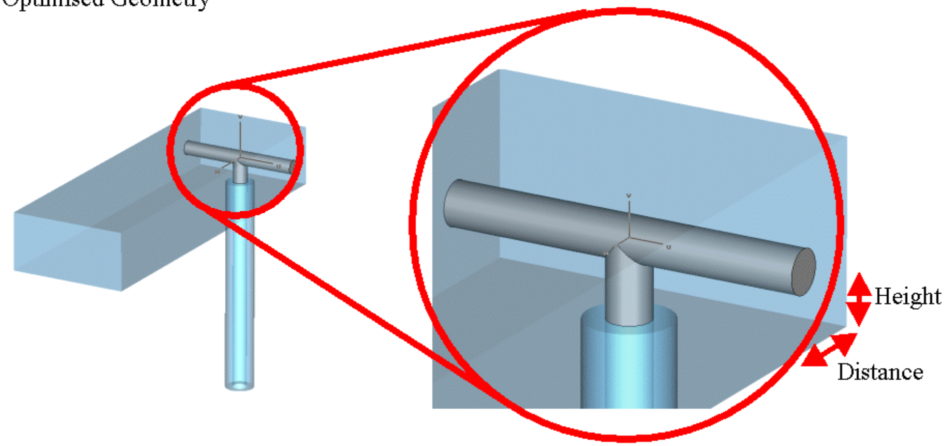
Conclusion

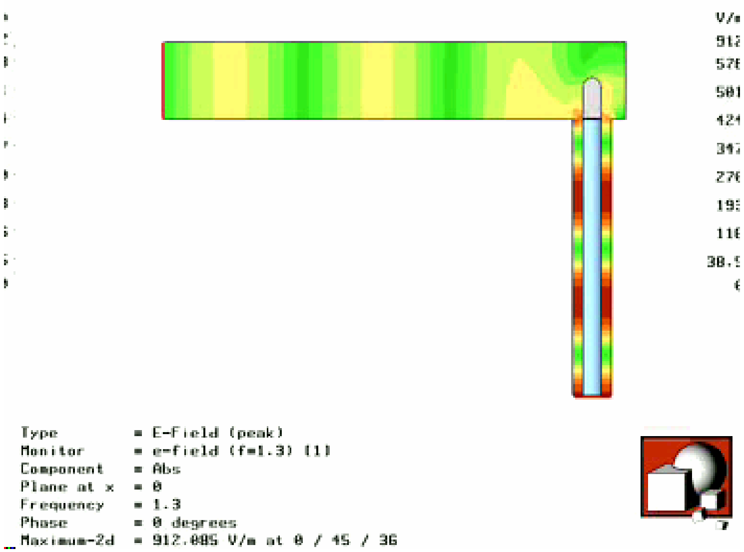
- Optimal dimensions lie between 35 and 45 mm for the height combined with 32 – 36 mm for distance to the back wall.

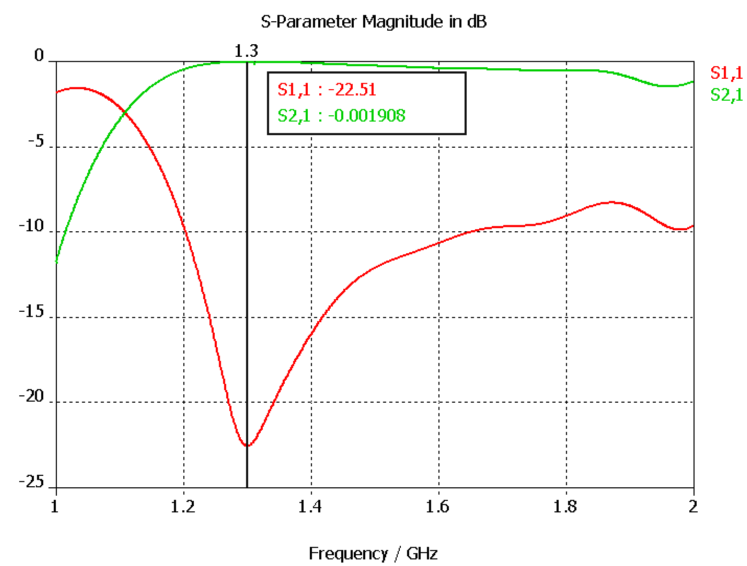


Results

- Optimal response obtained with a height of 35mm and a distance of 36mm.



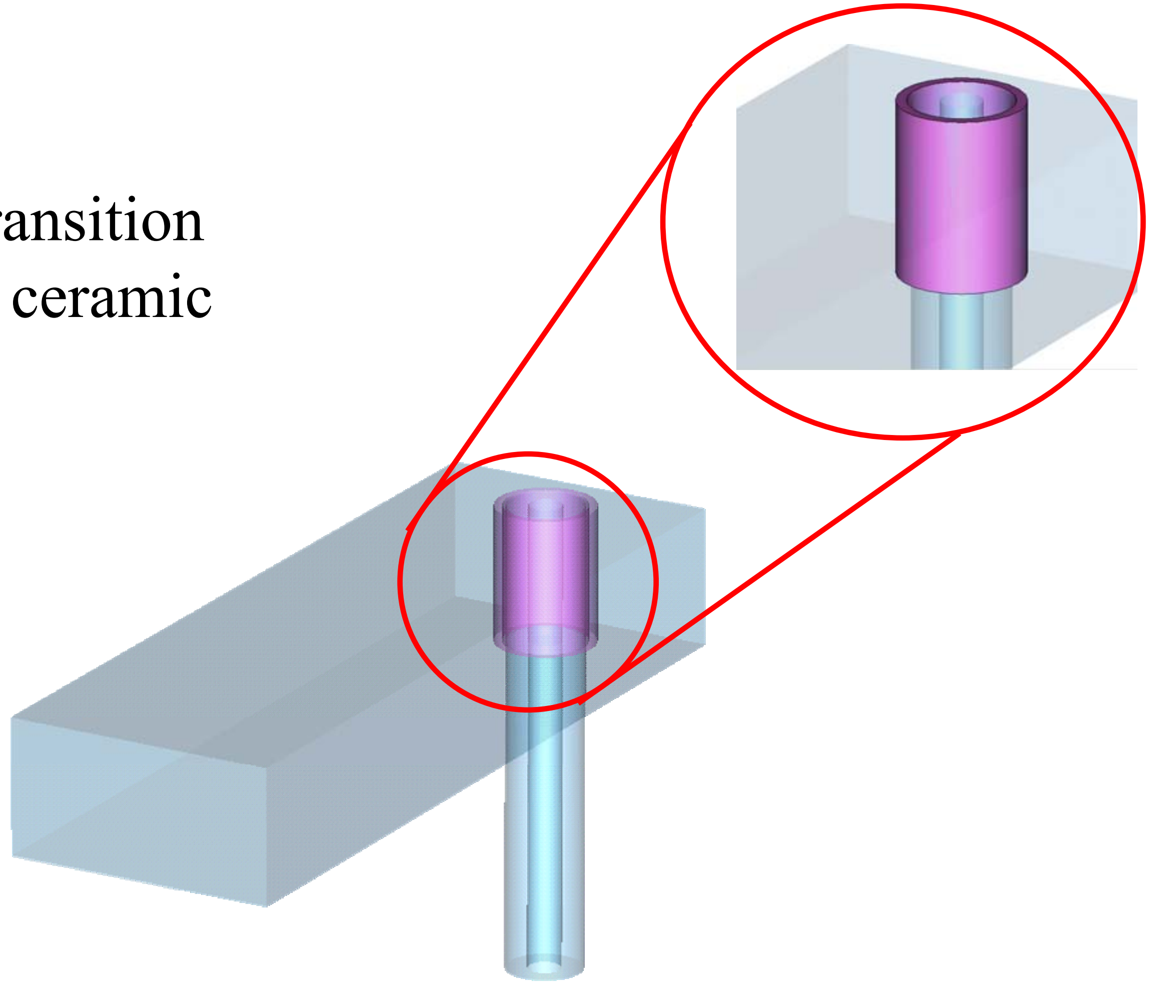


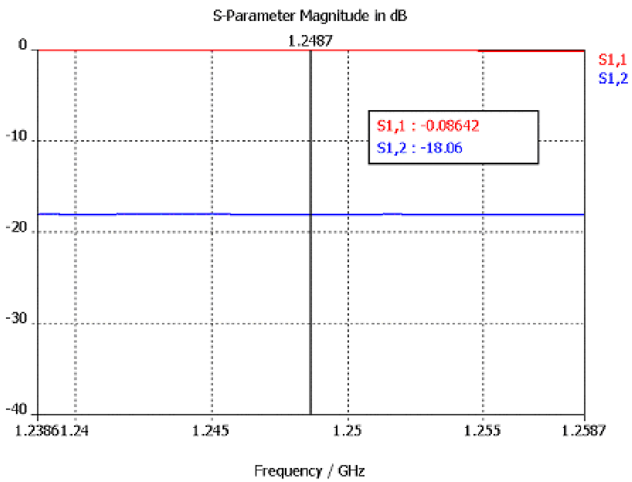


Model 3: Transition with ceramic window

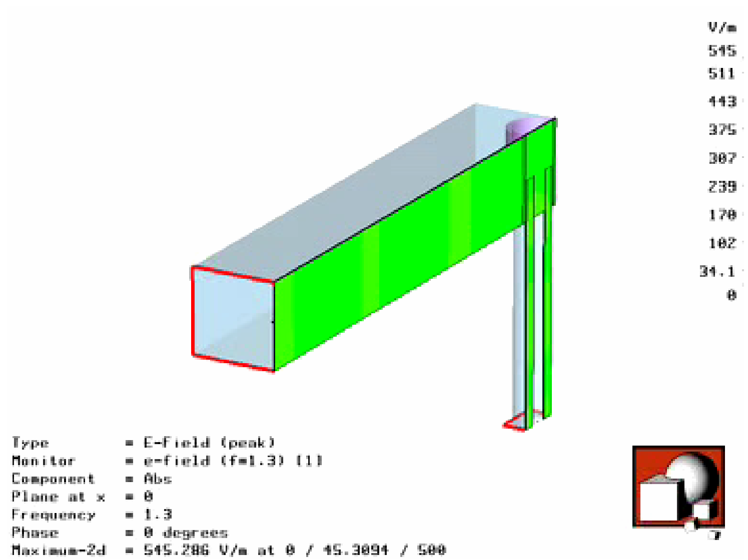
Aim

- To design a transition that contains a ceramic window.





S-Parameter with distance (8.68947mm) and depth (30mm) obtained from sweep.

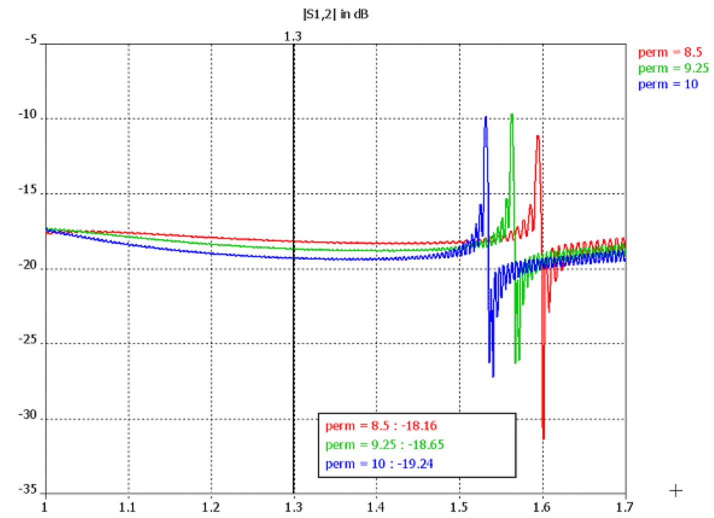


Unable to obtain acceptable performance from varying distance and depth alone

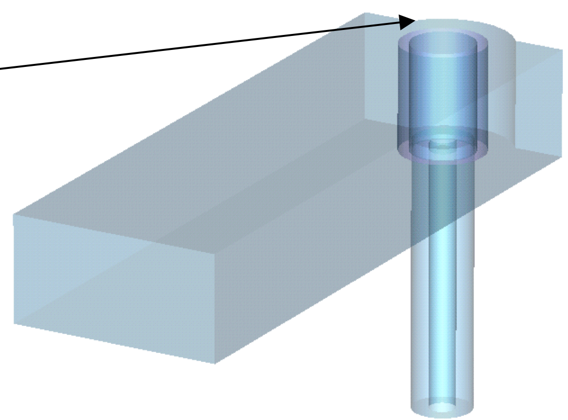
Try varying the permittivity of the ceramic material.

Results

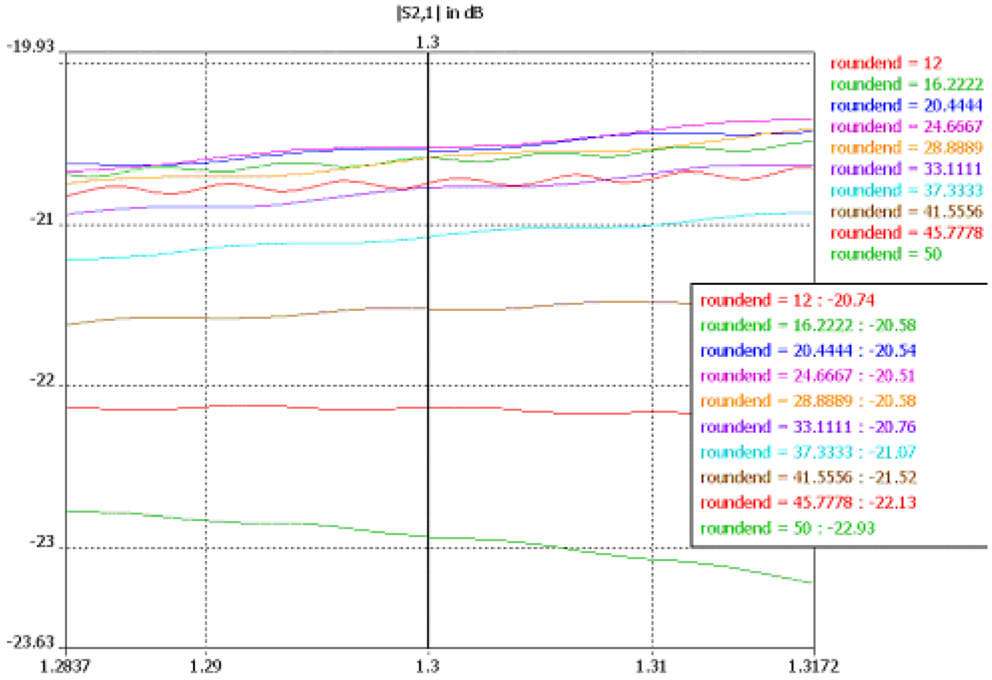
No real gain from changing the permittivity over this range.



Experiment with adding a radius to the end of the waveguide.

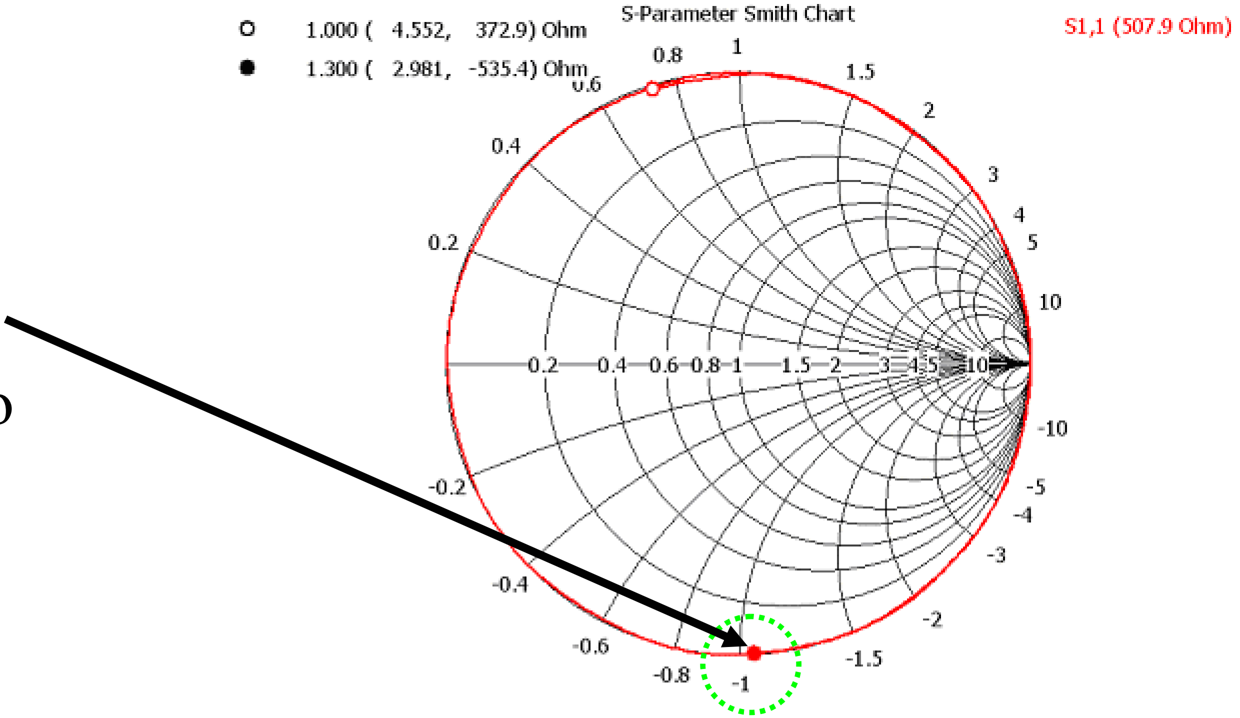


Still presents a poor match to the system and hence standing wave.

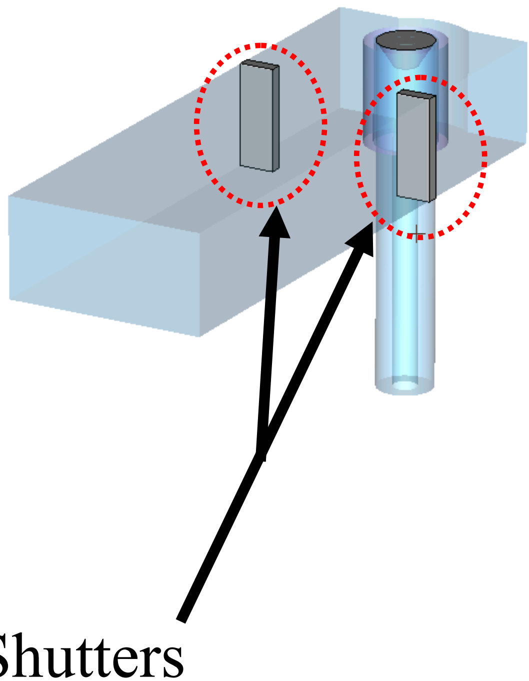


Further investigation into mismatch using Smith chart.

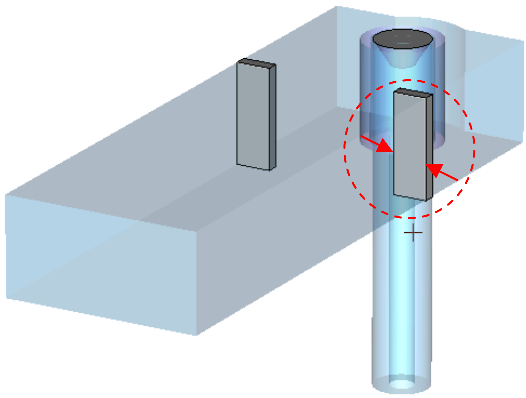
At 1.3 GHz mismatch is capacitive. Require additional inductance to improve the match.



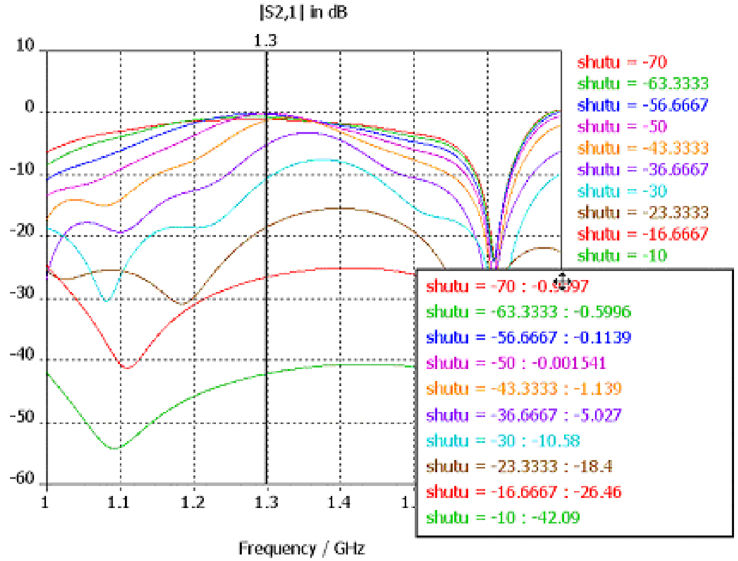
From classical waveguide theory shutters inside waveguide increase the inductive reactance of the circuit.



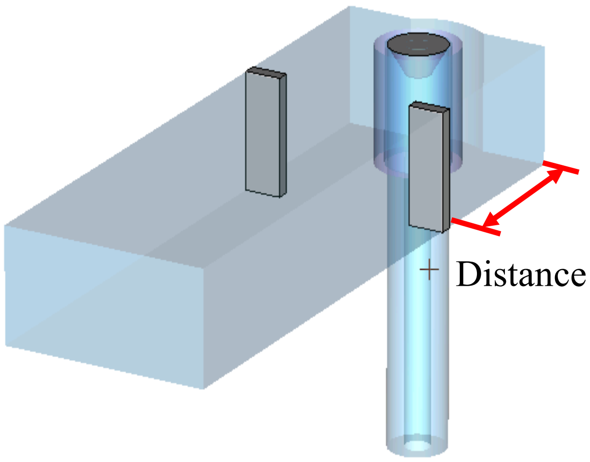
Huge improvement in performance

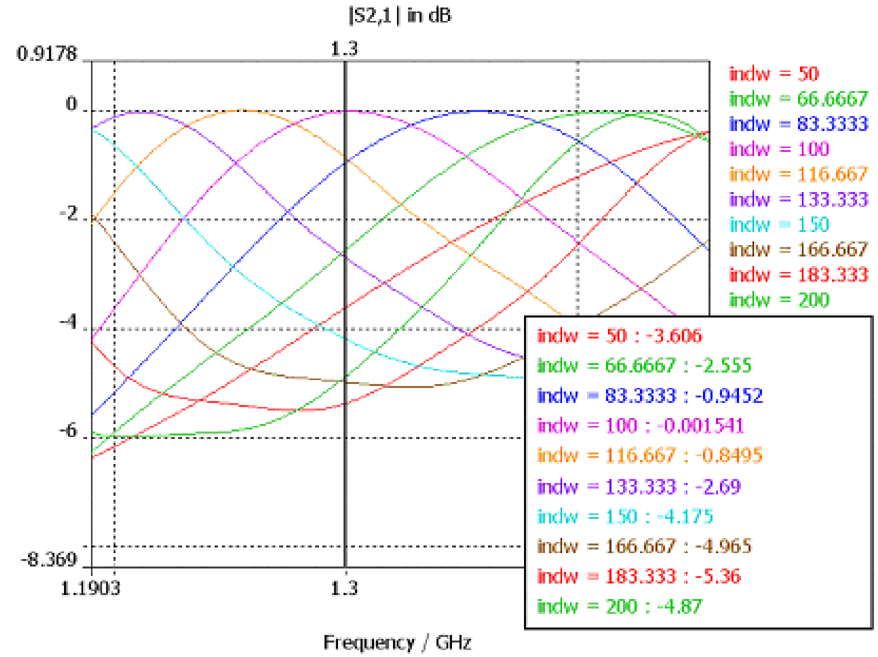


Next sweep the distance from the end of the waveguide to the start of the shutters.



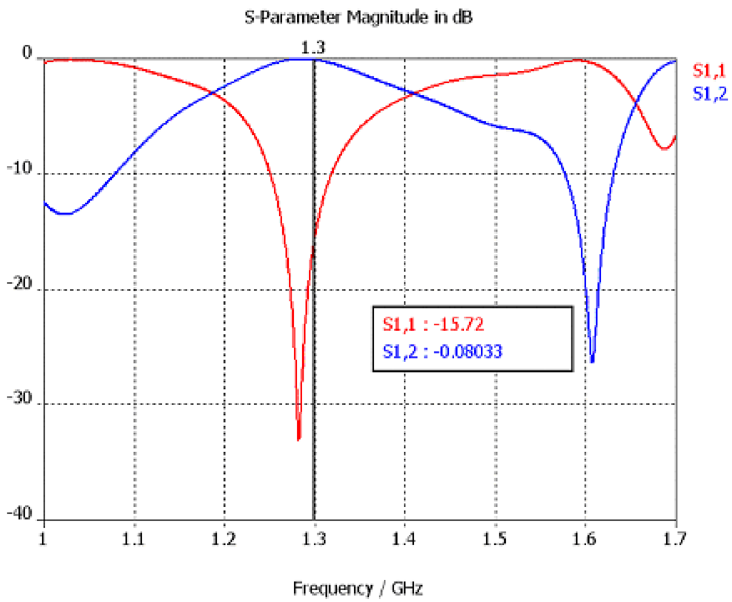
Optimum settings are somewhere between 27 and 40mm for width and a distance between 83 and 100mm from the end of the waveguide. Set optimiser to run using these ranges.



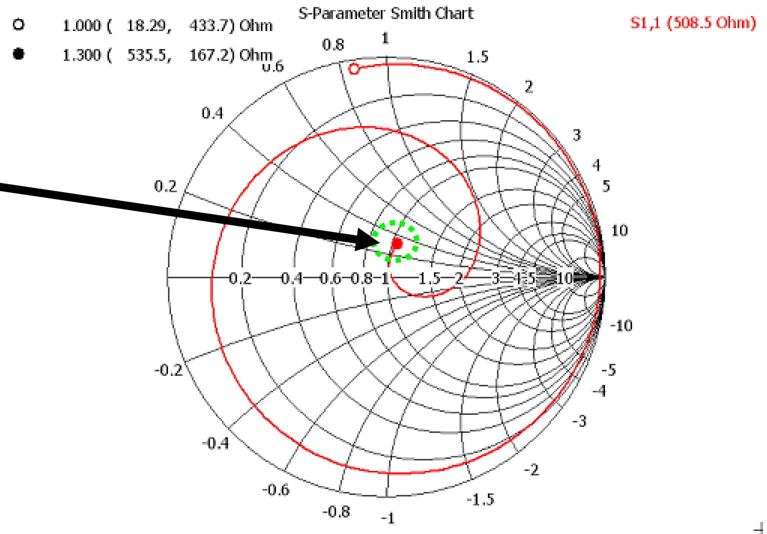


The optimal width for the shutters was found to be 30.83mm.

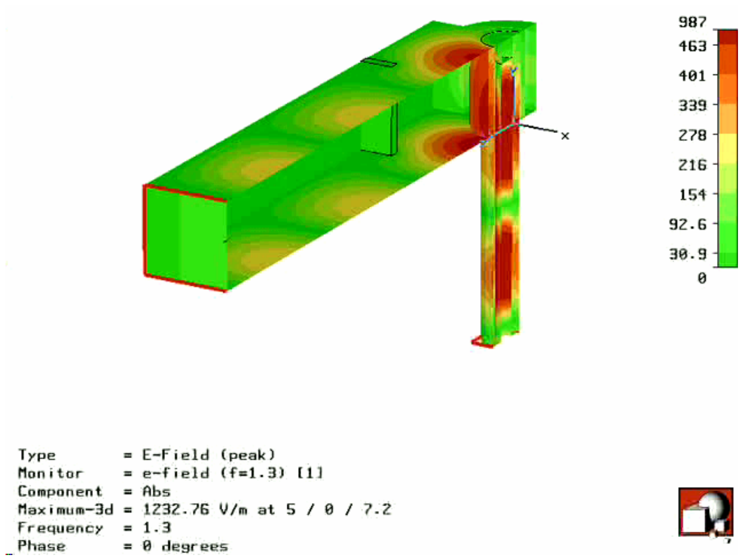
The optimal distance for the shutters from the rear end of the waveguide is 104.76mm.



Smith chart confirms that the system is well matched at 1.3 GHz

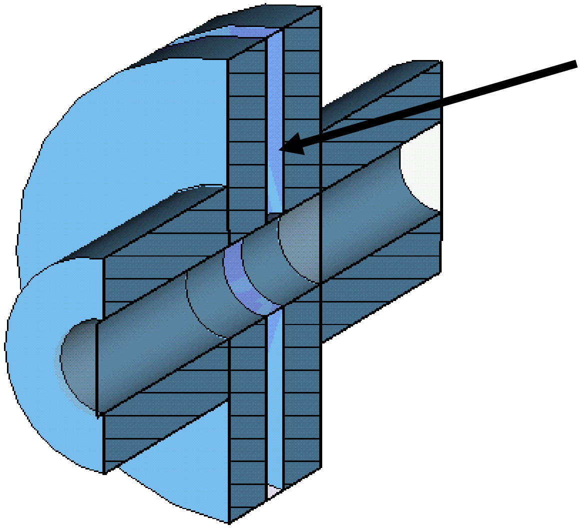


Animation of E field shows travelling wave within the structure



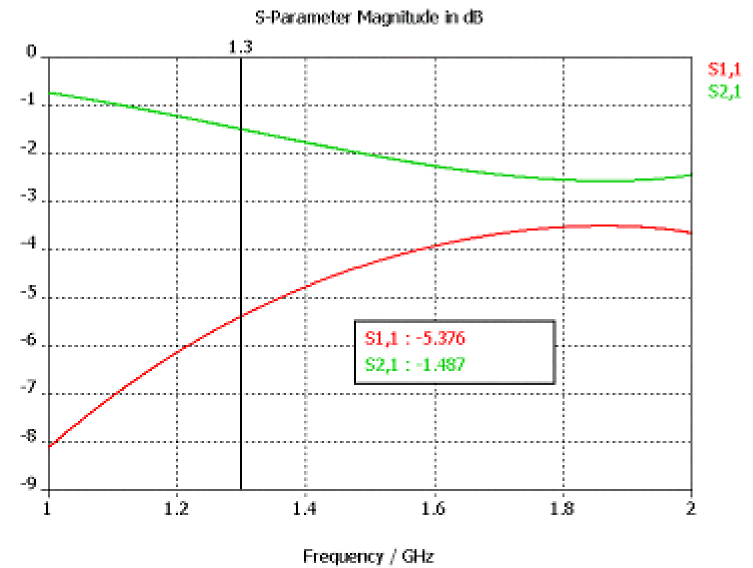
Model 4 : Coaxial Window

Using the dimensions gained from the previous modelling exercise a simple window can be easily constructed as shown below :-

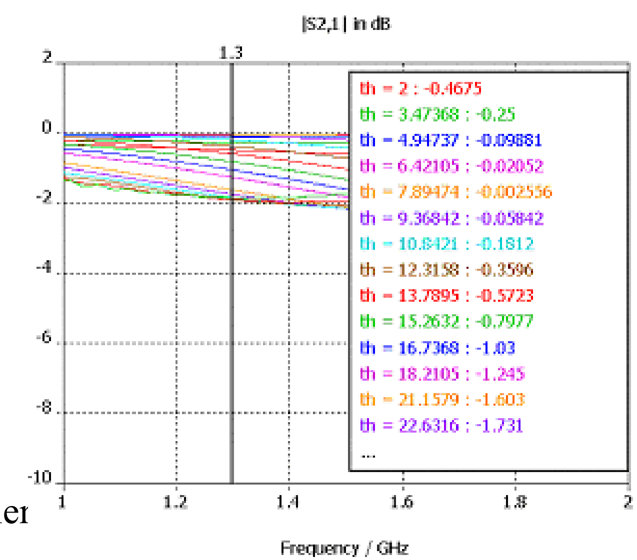


relative permittivity of 9 and an initial thickness of 20mm.

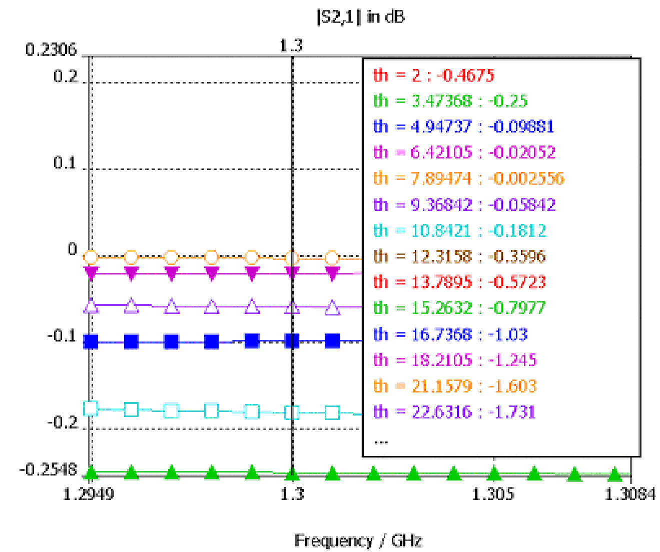
Initial S- Parameter plot shows transmission loss therefore performance needs improving.



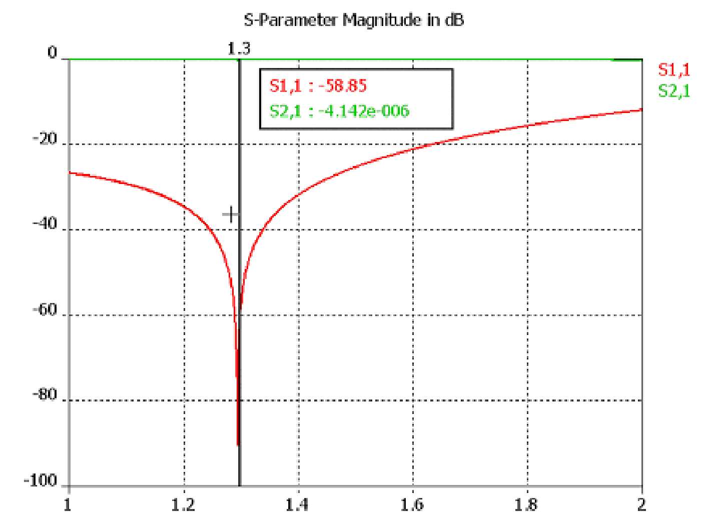
First step is to change the thickness of the ceramic material.

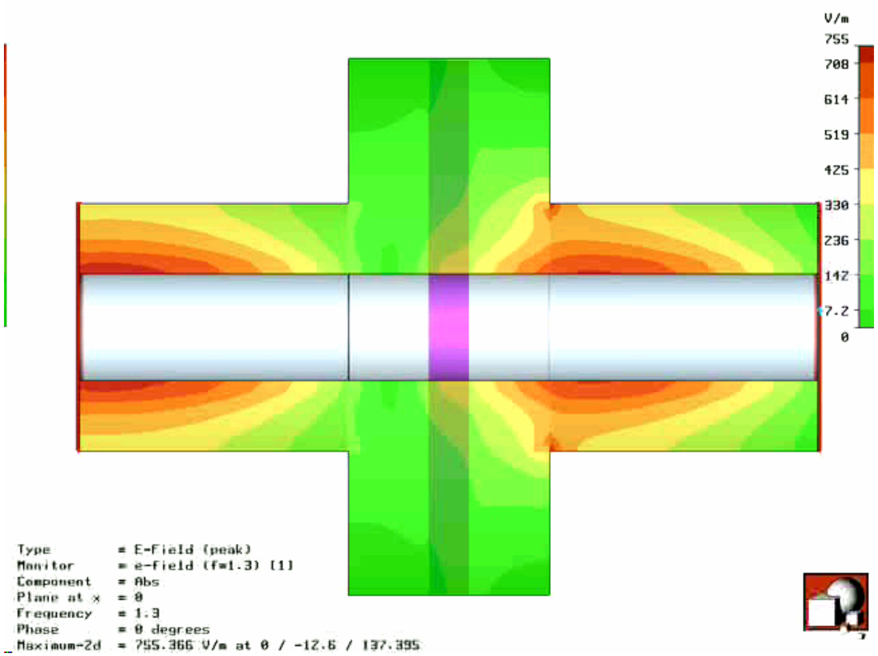


The optimuim thickness for the ceramic disc lies between 7 and 9 mm.

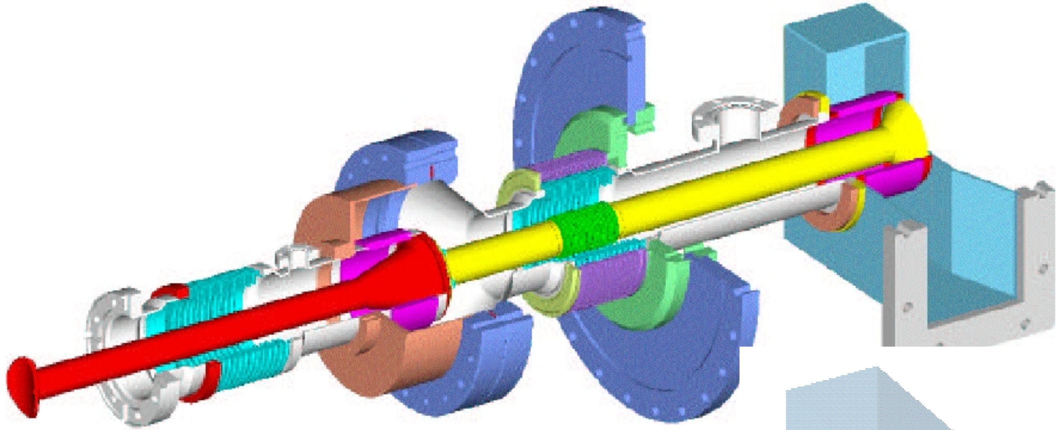


Optimal thickness calculated to be 7.39mm.

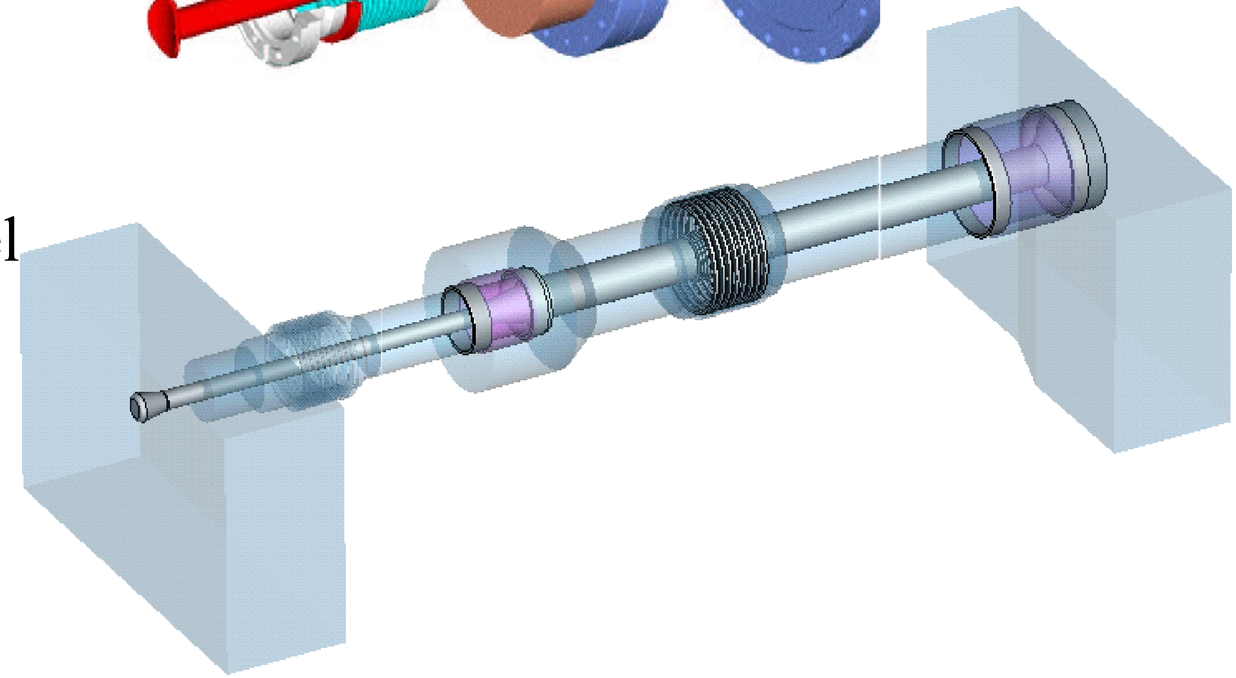



V/m
755
708
614
519
425
330
236
142
7.2
0
Type = E-Field (peak)
Monitor = e-field (f=1.3) [1]
Component = Abs
Plane at x = 0
Frequency = 1.3
Phase = 0 degrees
Maximum-2d = 755.366 V/m at 0 / -12.6 / 137.395

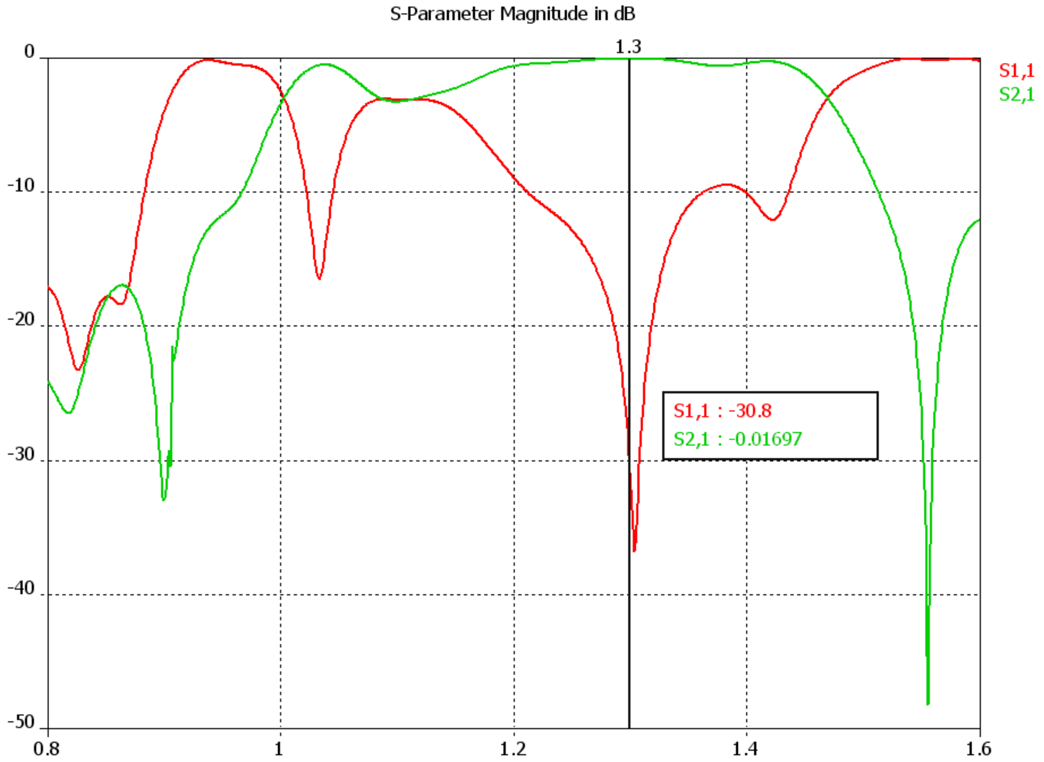
Model 5 The TTF3 High Power Coupler



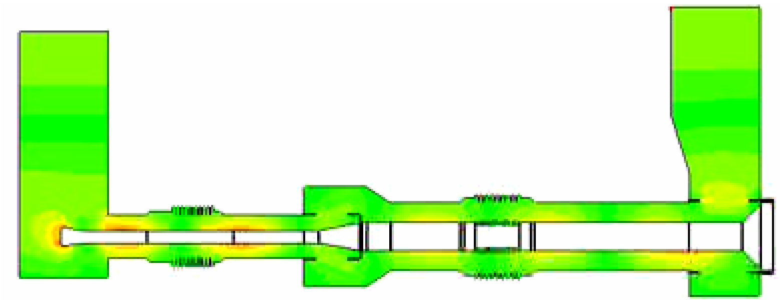
The RF Model



Optimised S-Parameter plot



Peak E field is 2521.49 V/m. This is normalised to an input power of 1 Watt.

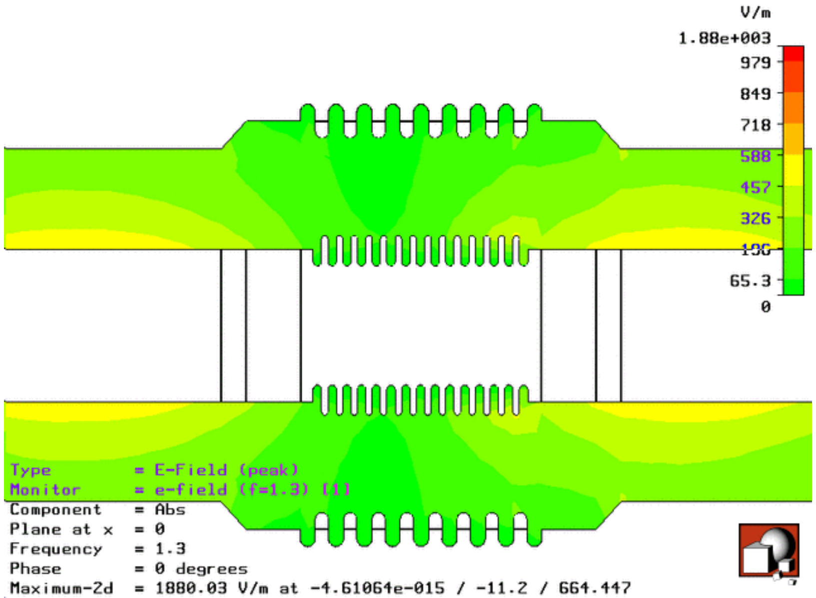


At 25kW the peak field will scale by a factor of $\sqrt{25\times10^3}$

so for this example:-

$2521.49 \times \sqrt{25\times10^3}$

$= 398.682 \times 10^3$ V/m

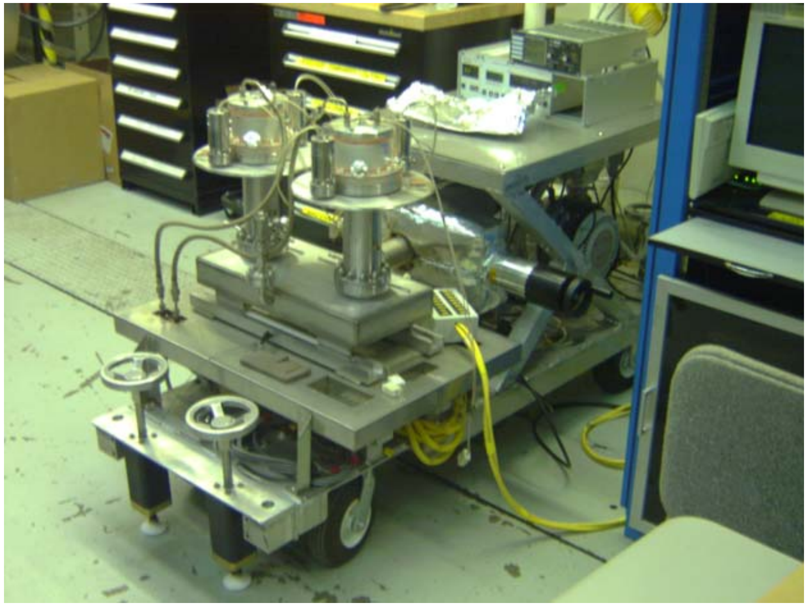


Break down in air filled coax occurs at approximately 30 kV/cm.

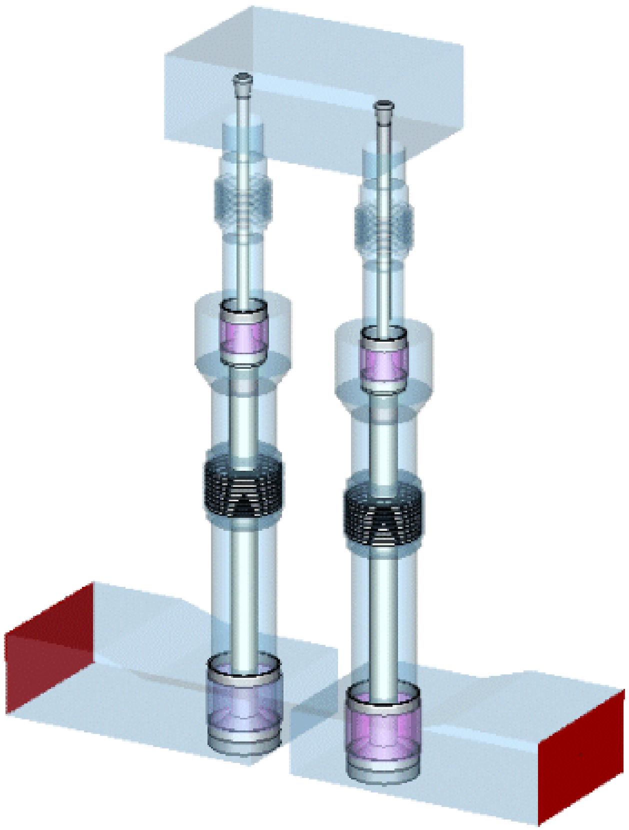
So with a maximum field of 3.986 kV/cm this model avoids voltage breakdown.

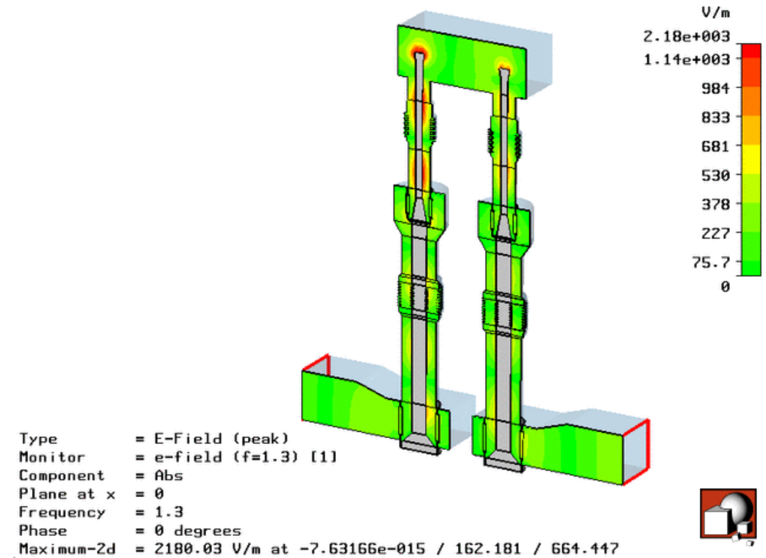
Testing Couplers

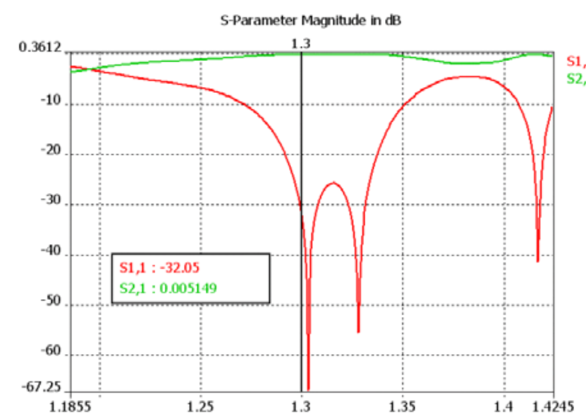
Couplers can be tested be connecting two back to back using a length of waveguide as a cavity.



Model 6 :- Testing TTF3 Couplers





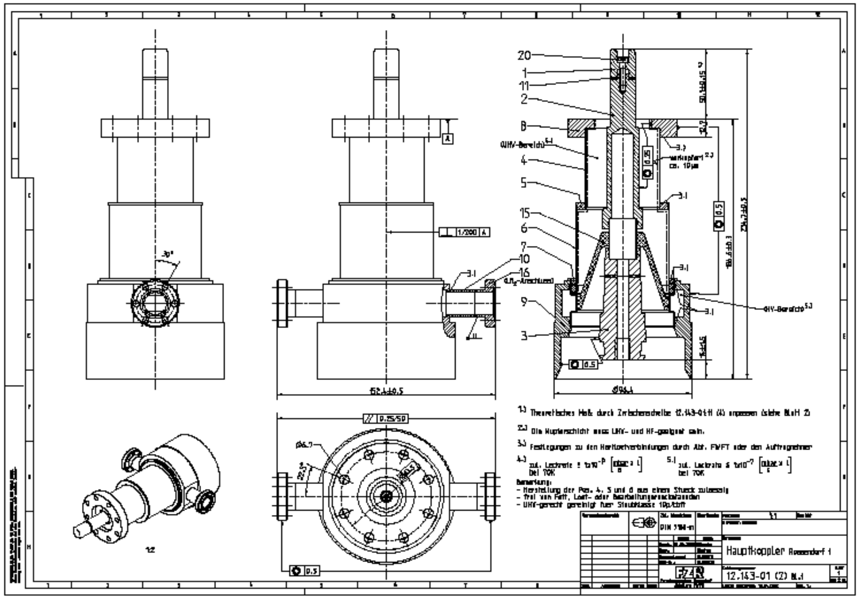


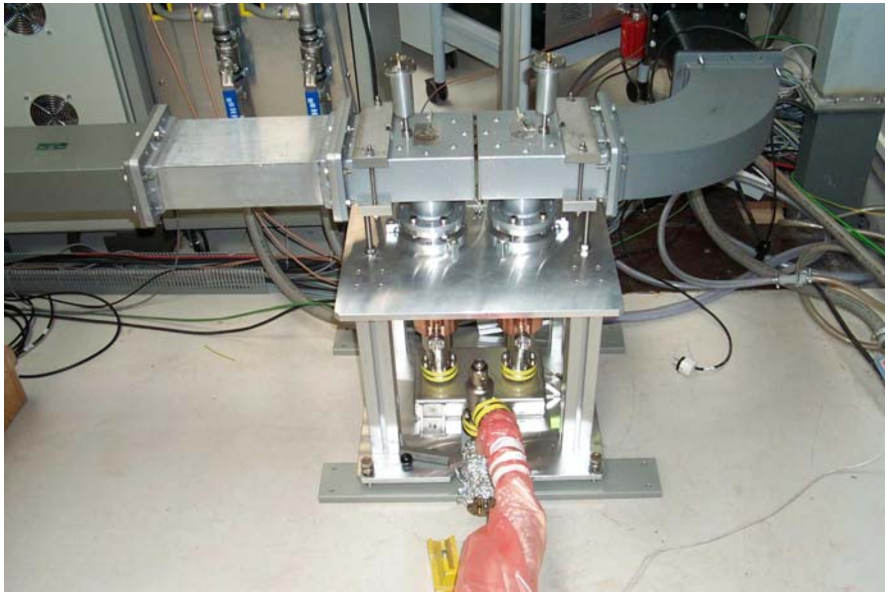
Couplers for ERLP

Testing and conditioning of couplers will be essential for the ERLP here at Daresbury.

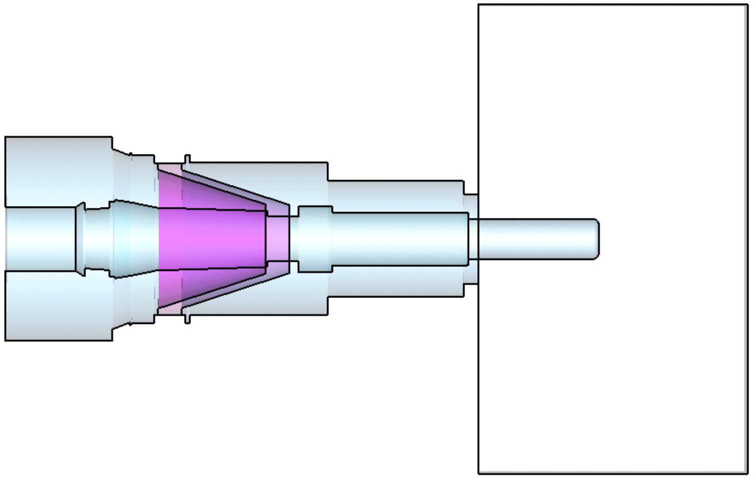
- 4 couplers need to be conditioned and tested up to 16 kW CW.
- The supplied couplers were designed for FZR, these are being manufactured by ACCEL.

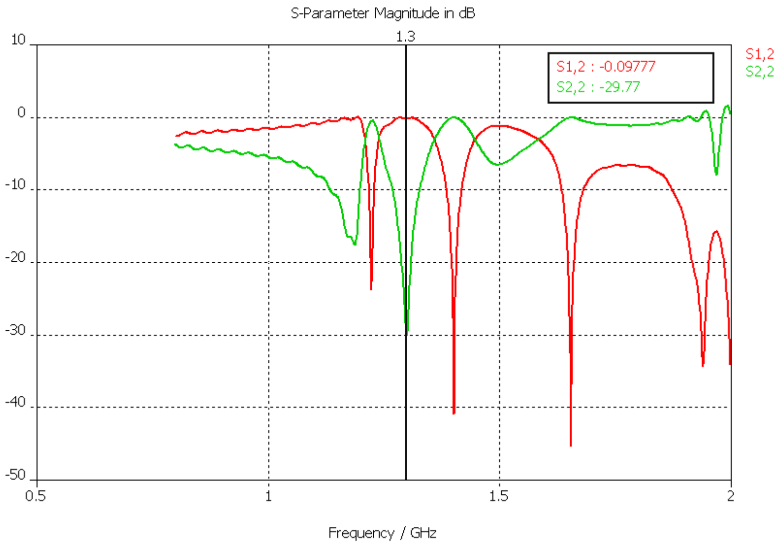
FZR Coupler



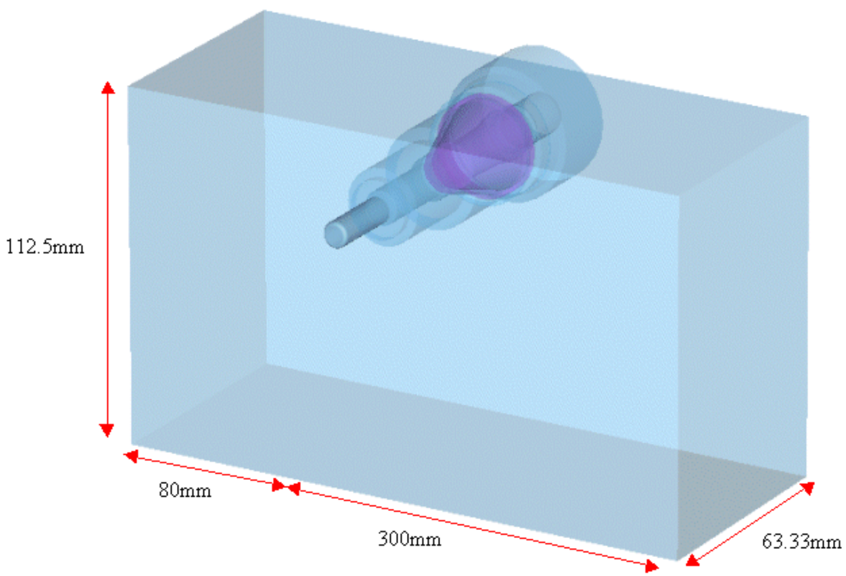


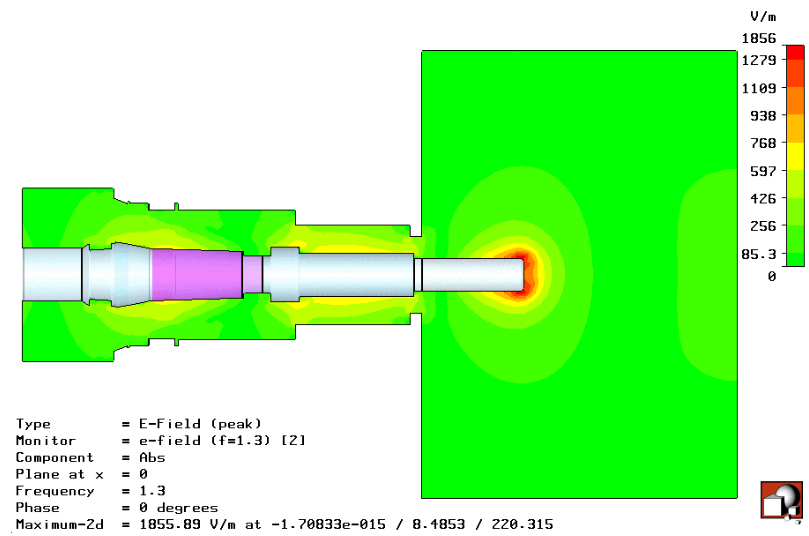
Model 7: The FZR Coupler





Optimised Waveguide Geometry





Summary

- RF couplers can be successfully designed and modelled using RF simulation codes.
- Further modelling of the FZR coupler with warm and cold sections will be required.
- Coupler test facility needs to be designed and commissioned to enable preparation and testing of couplers.