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22GHz MMIC Low Noise Amplifier. Housing EM analysis and solution for cavity resonances

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1 - Introduction

In order to build state of the art Cryogenic receiver for Radioastronomical applications, our institute has been involved in a R&D activity programme. Its paramount aim was to exploit MMIC InP technology, designing and realising competitive extremely low noise amplifiers. For such devices not only the RF design has to be considered as crucial. MMIC housing and assembly method are crucial phases of the production chain which can deadly waste the RF design effort. In this report, EM cavity effects are considered. When the carrier was designed, we hadn't the opportunity to simulate housing cavity EM behaviour. Only during the characterisation activity we discover a cavity housing tendency to resonate within the working frequency range. Aim of this activity is find a solution to oscillation which stand out when the MMIC LNA 22LNA_05A housed in a custom designed carrier is powered on with the cap on. Because 14 LNA have been already packaged and mounted inside the cryostat of the new 22GHz multifeed receiver installed in Medicina, the only possible solution, if we want avoid microwave absorber inside the housing cavity, is to operate on the cap shape, in order to reduce the propagation tendency in the 18-26GHz frequency range. At present the cavity shape cause oscillation tendency. From measurements it's clear that's a noise figure rise exactly at those frequencies. The same behaviour wasn't highlighted when on chip measurements were performed. Those elements focus our attention on the carrier.

2 - Executive summary

As reported in chapter 3, we compared noise performances measured of warm MMIC and Packaged cold and warm LNA. Is clearly described by data reported how much the package increase the noise floor and introduce a rising slope noise in the upper end of the working frequency band. Consequently, the housing EM behaviour has been measured and results are reported in fig.8. Then, 3D simulator has been adopted in order to find a possible solution. We imported in CST (the 3DEM simulator) the IGES file provided by mechanical designer, which contains carrier walls information. Next, we extruded the microstrip layers described in the GDS file imported from Microwave Office (the RF simulator). We built the coaxial wall through according to the physical dimension reported in connector datasheets. Then we assigned RF ports and start to try configurations in order to decouple input and output. We initially try to obtain with the simulator results comparable with the measurements. Then we worked on the cap shape in order to modify the cavity behaviour. In chapter 5 all trials are reported and in chapter 4 the best configuration, which reduce the resonance tendency in the working bandwidth, is widely described.

3 - Scenario Description

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In fig. 1 assembled LNA is presented. In the middle is visible the MMIC. Its noise response is represented in fig. 2. Wire and passive components in the upper side of the carrier are drain bias lines. Gate bias lines are in the bottom side of the carrier. Every MMIC stage is independently tuneable then separate bias lines are necessary. RF in is on the left (K connector) RF out is on the right (also K connector)

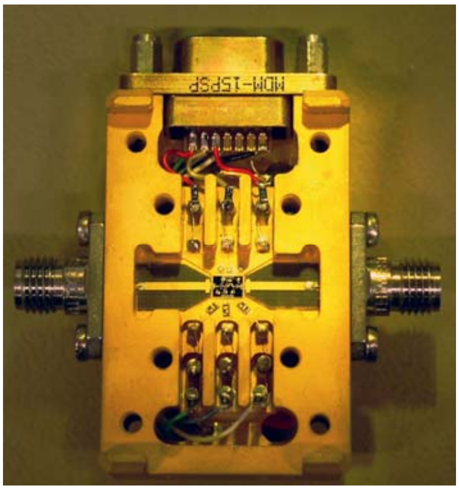


Fig.1 – Assembled 22GHz LNA

Fig 2 shows MMIC characterization performed with different accuracy level, compared with MMIC simulation. Noise contribution can be defined around 90K

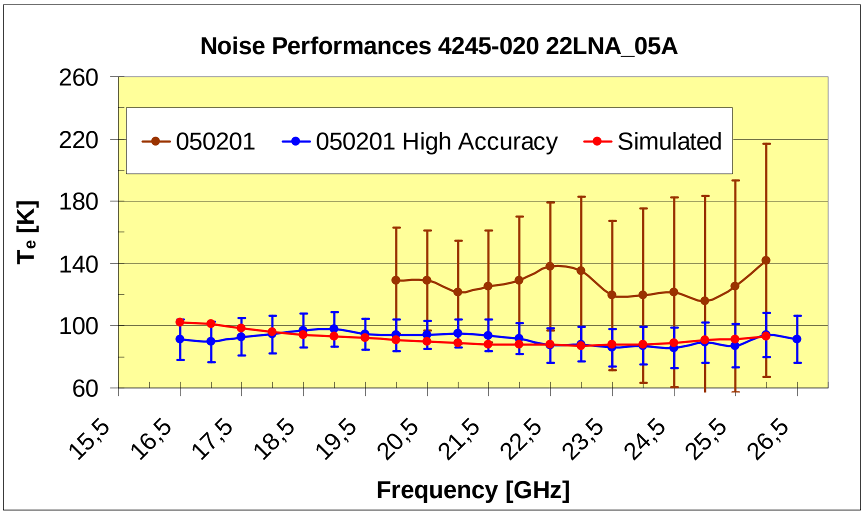


Fig.2 – MMIC Noise characterization

As previously announced, packaging and assembling are activities which introduce a relevant quantity of noise and waste the upper end of the working bandwidth as reported in fig 3.

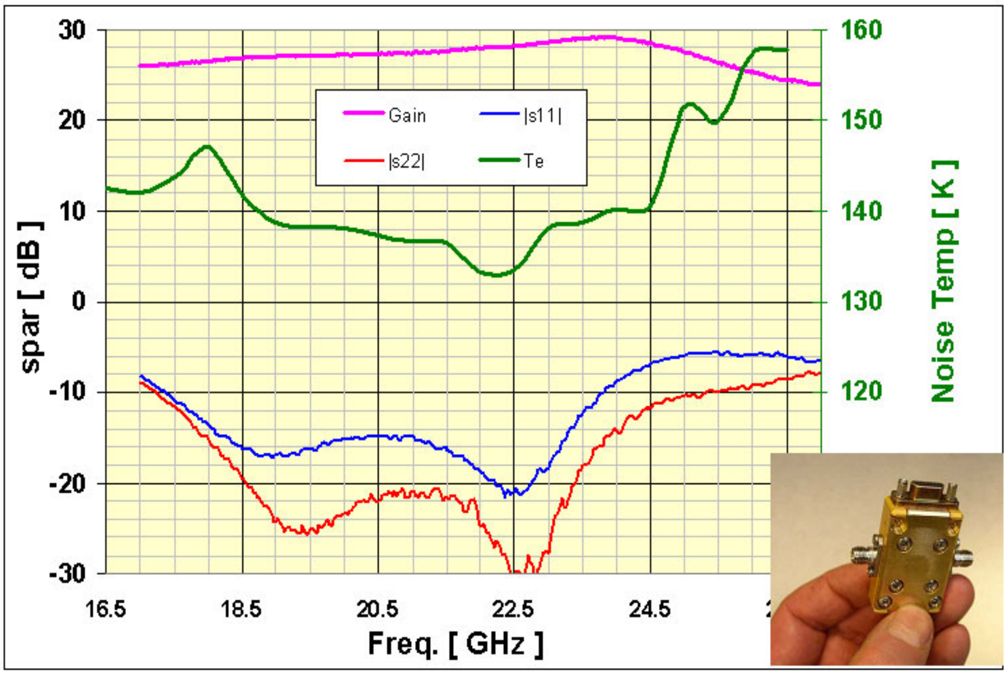


Fig.3 – LNA Characterization @290K

Effect on the noise floor are consistently reduced at 20K (fig 4) where the excess noise introduced by the package can be estimated in a few Kelvin, but the rising slope tendency remains.

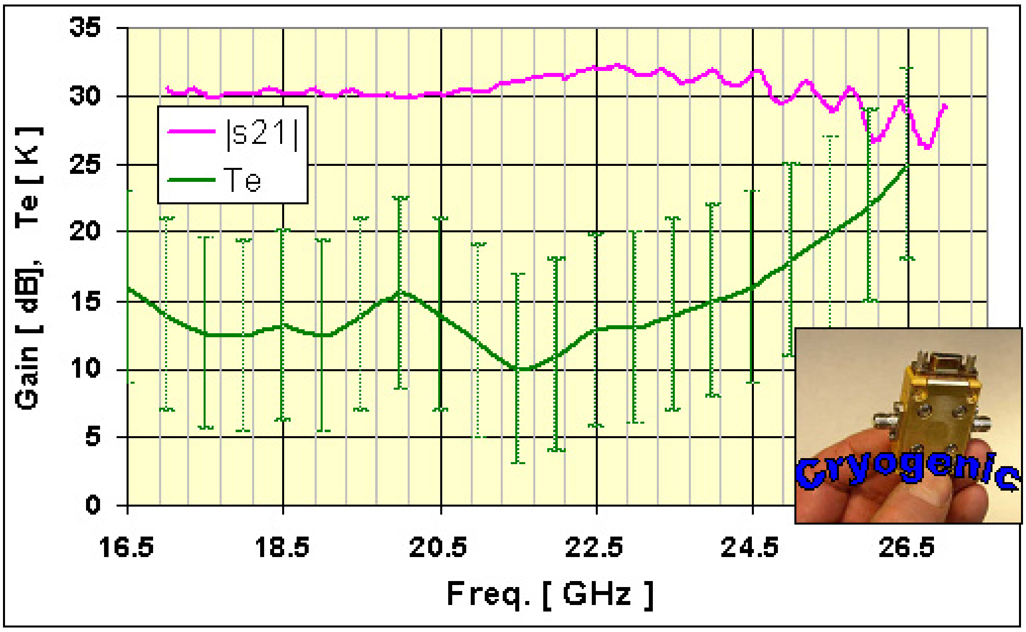


Fig.4 – LNA Characterization @20K

In Fig 5 channels noise of a 22GHz multifeed receiver are shown. It is clear that it is dominated by the LNA. Comparing it with the input match described in fig. 6 is evident that the noise peak corresponds to a worst input matching condition. The matching is certainly a cause of a noise peak but it could also depend by what happen inside the cavity by the electromagnetic point of view.

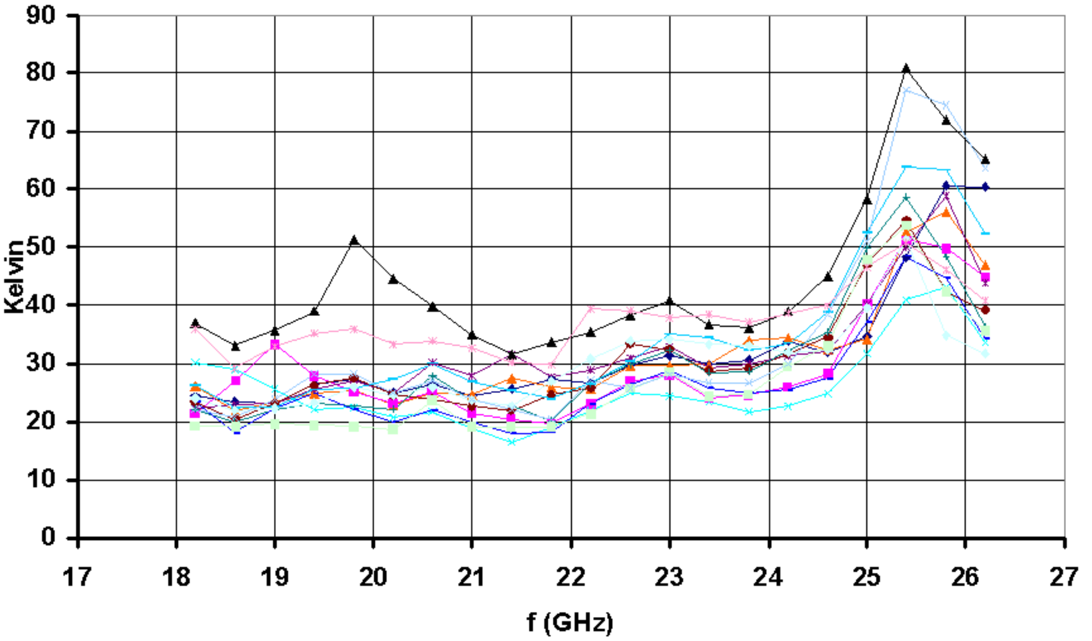


Fig.5 – LNA Multifeed Receiver Noise

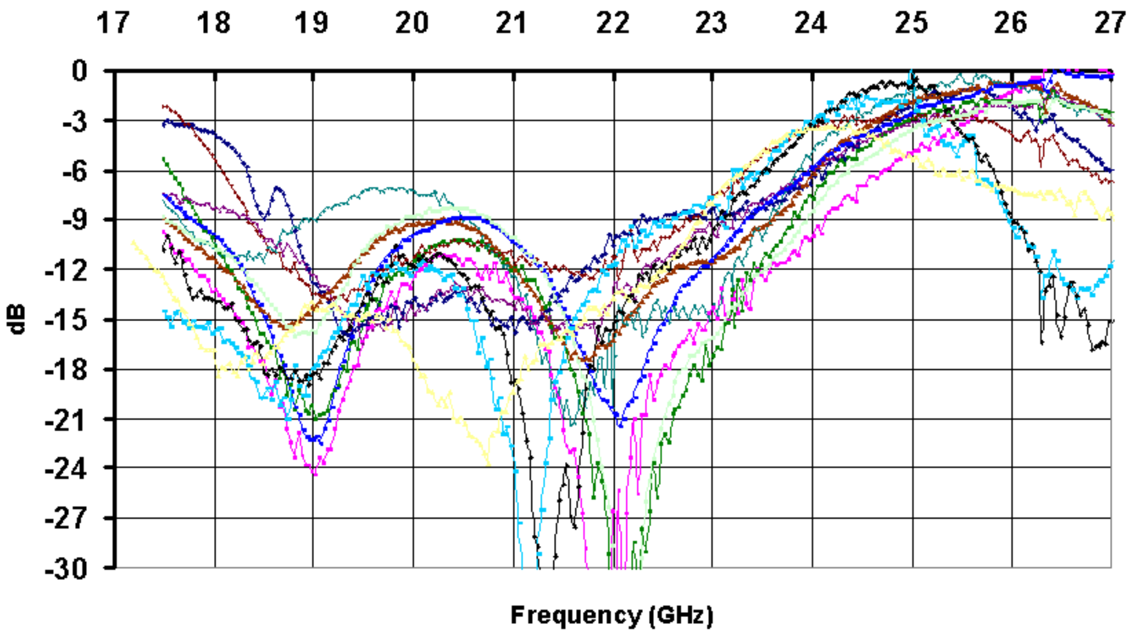


Fig.6 – LNAs Input matching

As already expressed before, the closed package behaves like a resonant cavity. Two connector's posts welded to the microstrips act like a probe launchers. Due to their physical dimensions, they can't launch fundamental modes but inside the cavity, higher order modes primes resonances. In order to test the house behaviour, transmission response S21, with only the microstrip and connector feedthrough has been measured, as showed in fig.7

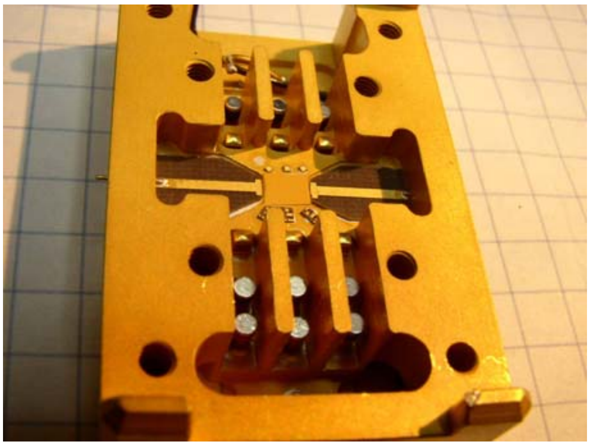


Fig.7 - carrier 22 GHz – Measurement scenario

Measurements are reported in Fig. 8 where the dark green trace represents the transmission response when the cap is open. Light green line report the transmission characteristic when the cap is on the MMIC house.

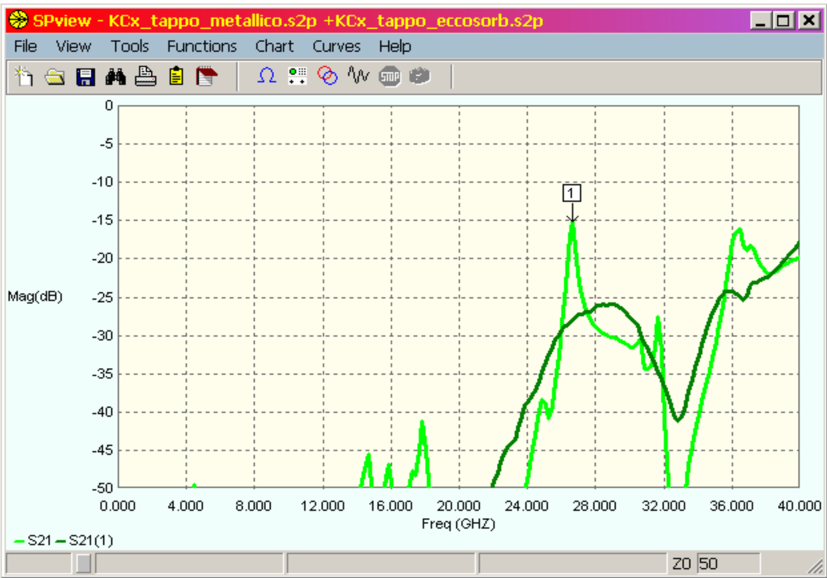


Fig.8 - S21 measurement between RFin e RFout with cap (light green) and without cap (dark green)

It's obvious the transmission tendency around 26 GHz (dark green line). This behaviour results emphasized when the box is closed (light green line).

4 - EM Simulation activity: prologue and final results

With CST, we rebuilt the cavity and open and close situations have been simulated. Consistently with a rough reality reconstruction, the simulator has provided comparable measurements results, showed in fig. 4 and fig. 5. As remark consider the two transmission responses S_{21} and S_{12} (green and blue lines). They are different, but it can't be possible because the measured element is reciprocal and theoretically they must appear identical. Since S_{11},S_{21} and S_{22},S_{12} are obtained by different simulations but adaptive meshing is calculated only for one of them, numerical errors are possible. More evidence of this effect can be noted in chapter 5.

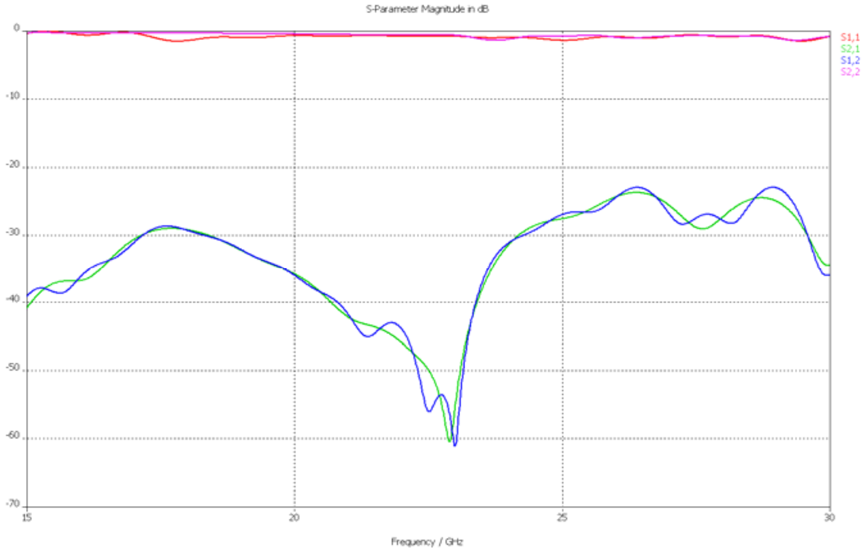


Fig.9 – CST Simulation - Open Carrier

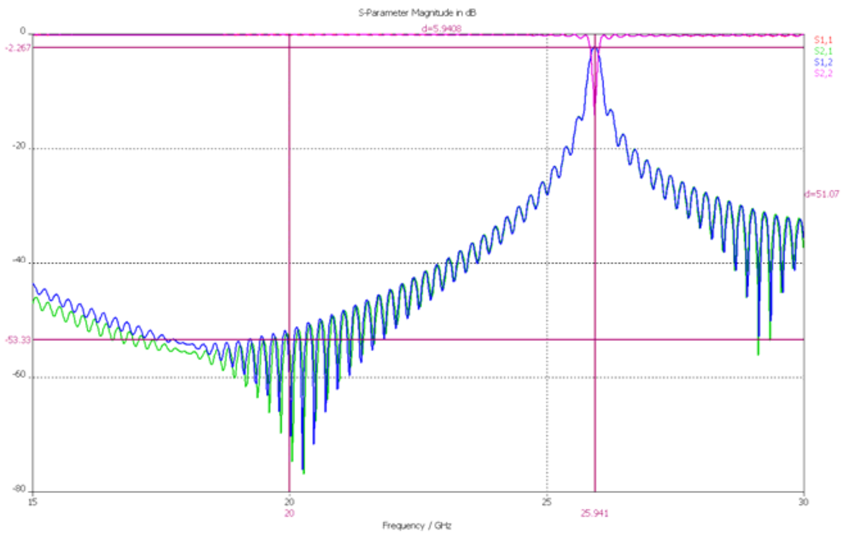


Fig.10 – CST Simulation - Carrier with flat cap (present state)

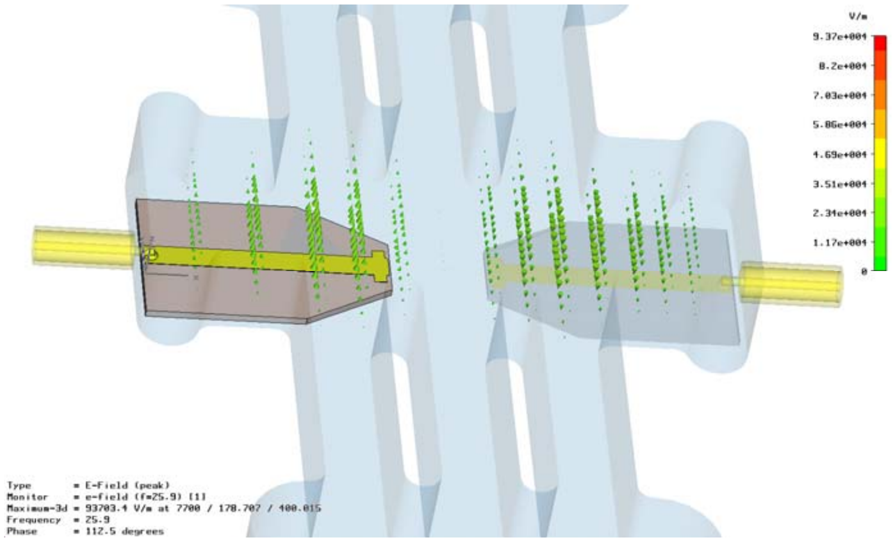


Fig.11 – 26 GHz E-field with flat cap

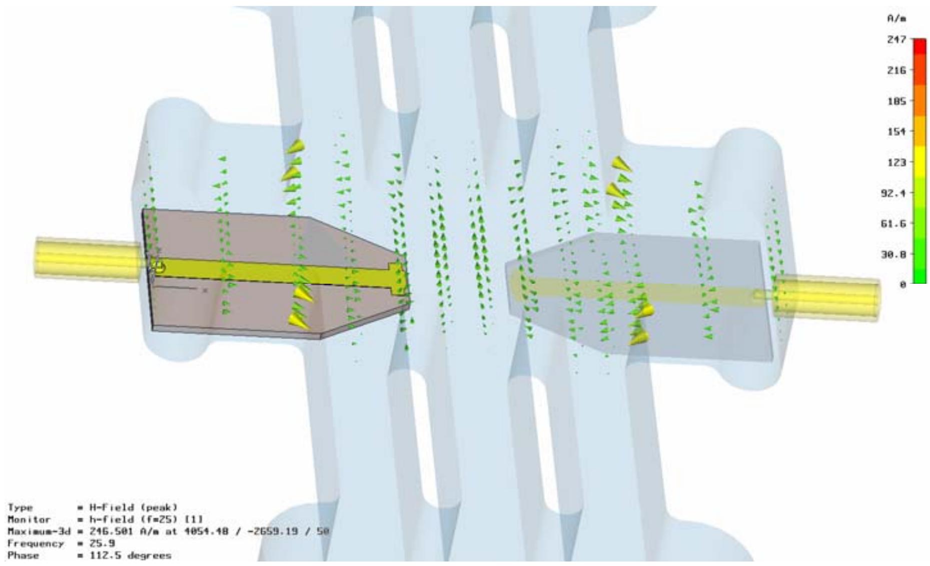


Fig.12 – 26 GHz H-field with flat cap

After several tentative, which will be illustrated in the chapter 5, we have defined a house cap with mechanical characteristic that seems to reduce the propagation inside the LNA cavity. The preferred topology has 4 diagonal septum which across the cavity and a 0.8 mm recessed area over the RF part of the cavity (fig. 13). Simulation in fig. 14 shows the cavity behaviour corrected by the shaped cap.

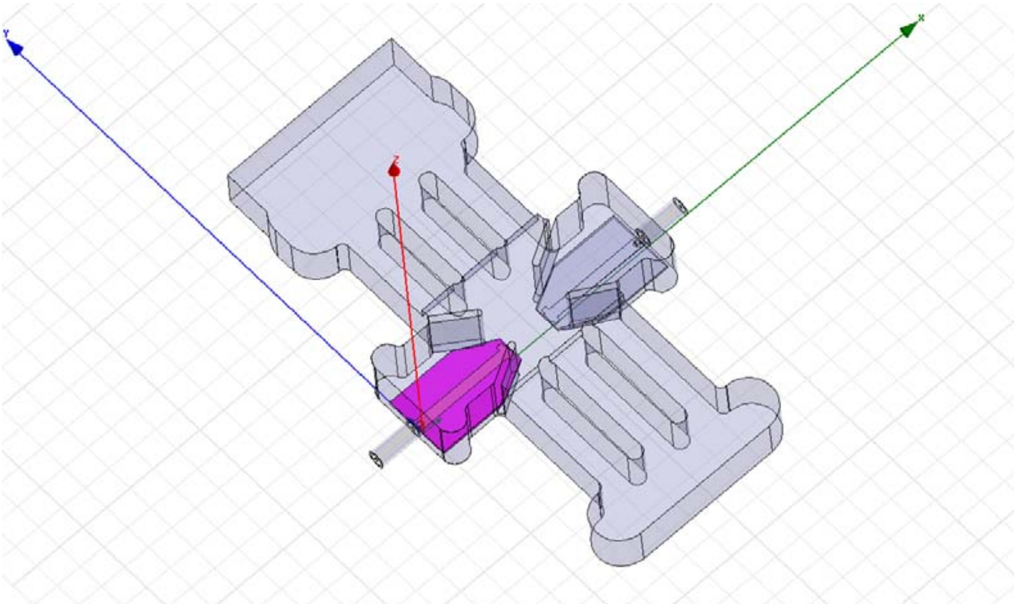


Fig.13 – Preferred CAP Version with short diagonal septum and 0.8 mm recessed ceiling

In order to verify that m2, m3, m4 resonances aren't numerical spurious responses, several simulation has been performed between 15 to 21 GHz (described by dotted lines).

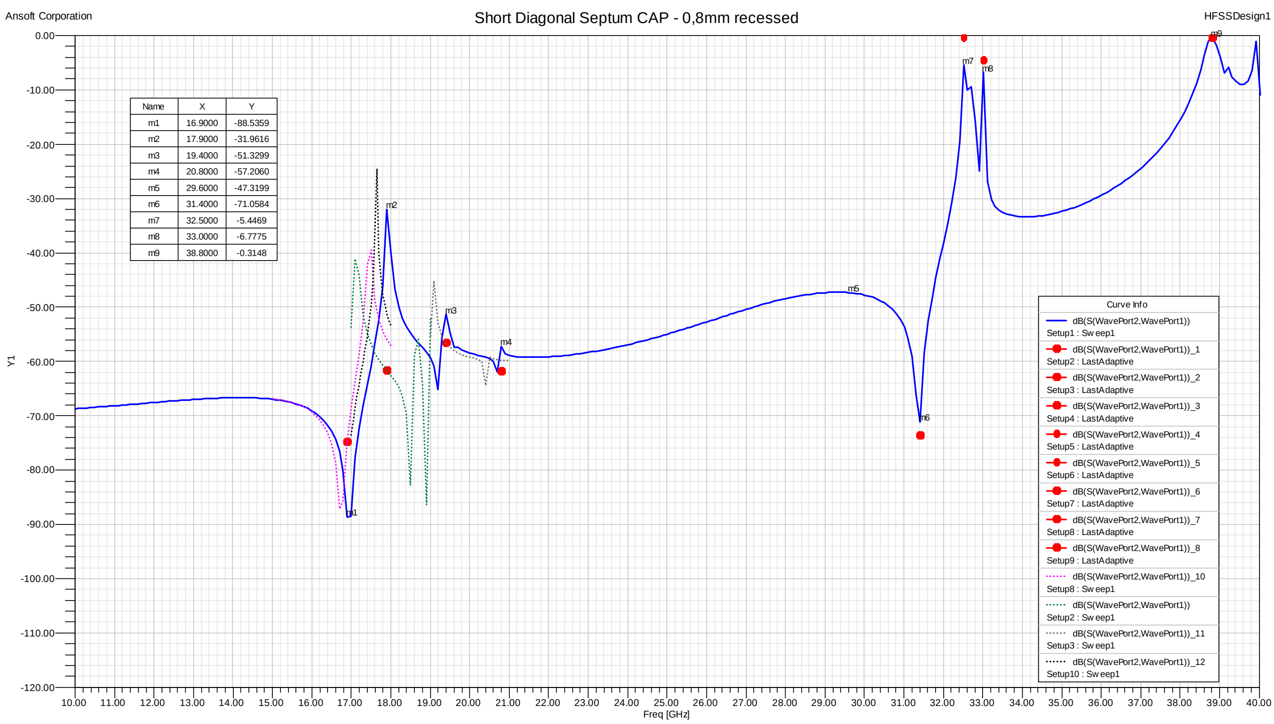


Fig.14 – Frequency response related to Fig. 8 configuration

5 - Study of different strategies in order to modify the cavity propagation

In this chapter all trials we made are reported, hoping that it could be useful for other designer which has to face the same similar situations. At the beginning we try to understand what happens if we place septum inside the cavity and how the cavity behaviour change with the position, dimension and number of it. We started placing a small baffle inside the cavity in proximity of RFIN. Effect is showed in fig. 16. The resonance frequency moved up but another peak start to appear around 21 GHz.

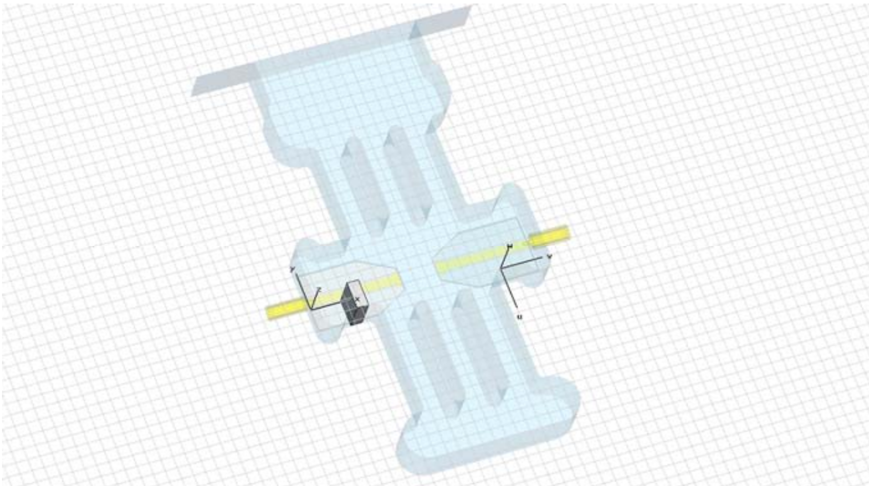


Fig.15 – cap with small baffle

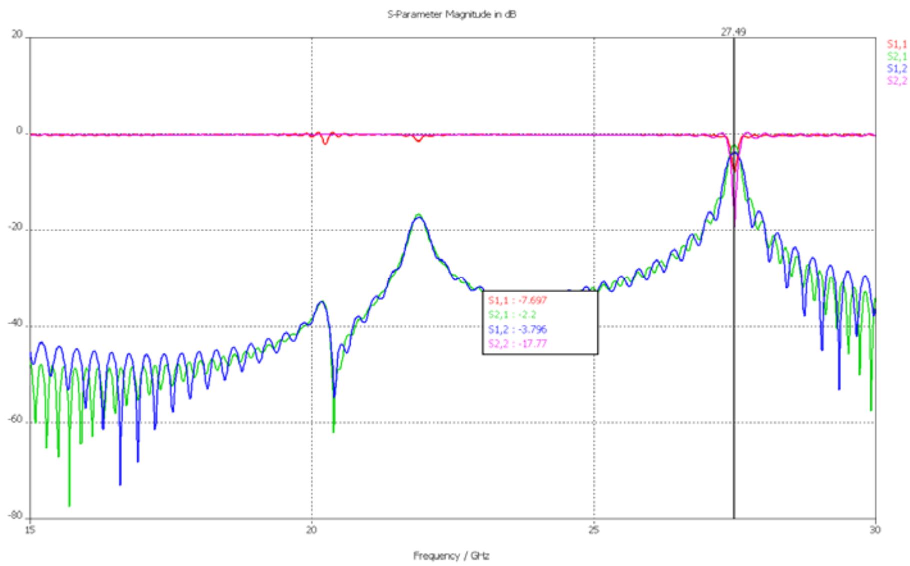


Fig.16 – Frequency response related to Fig. 15 configuration

Moving forward the baffle, shift up the frequency of resonance. This effect is shown in fig. 17- 20

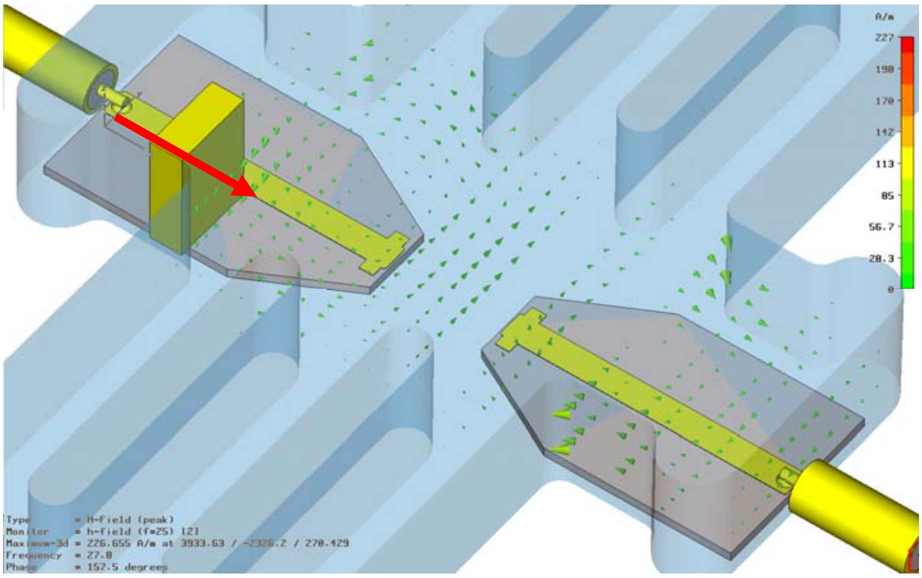


Fig.17 – cap with forwarded small baffle

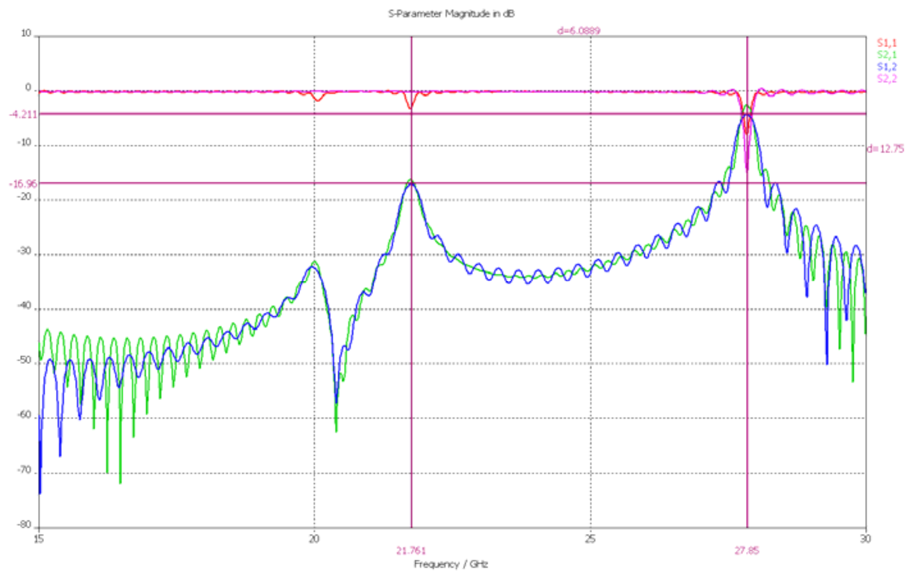


Fig.18 – Frequency response related to Fig. 17 configuration

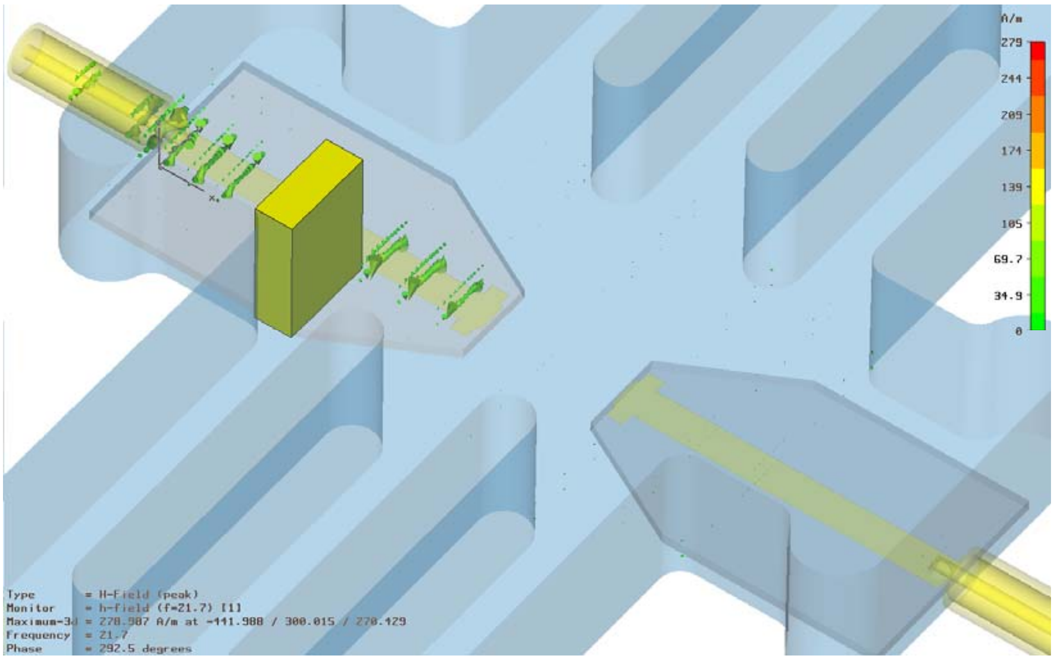


Fig.19 – cap with more forwarded small baffle

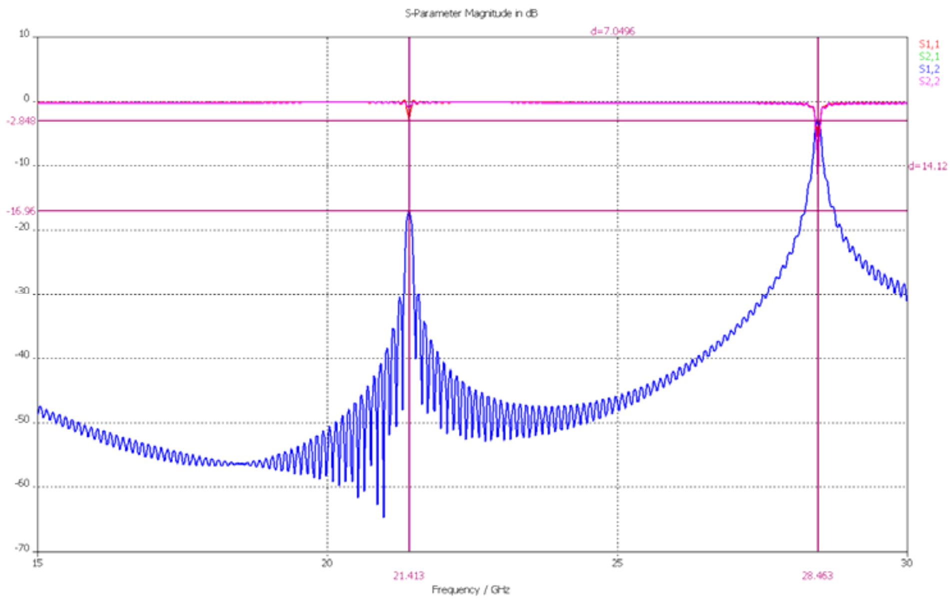


Fig.20 – Frequency response related to Fig. 19 configuration

Another septum is placed in the same position but referred to RFOUT. As Shown in fig.22 graph it appears a wrong way.

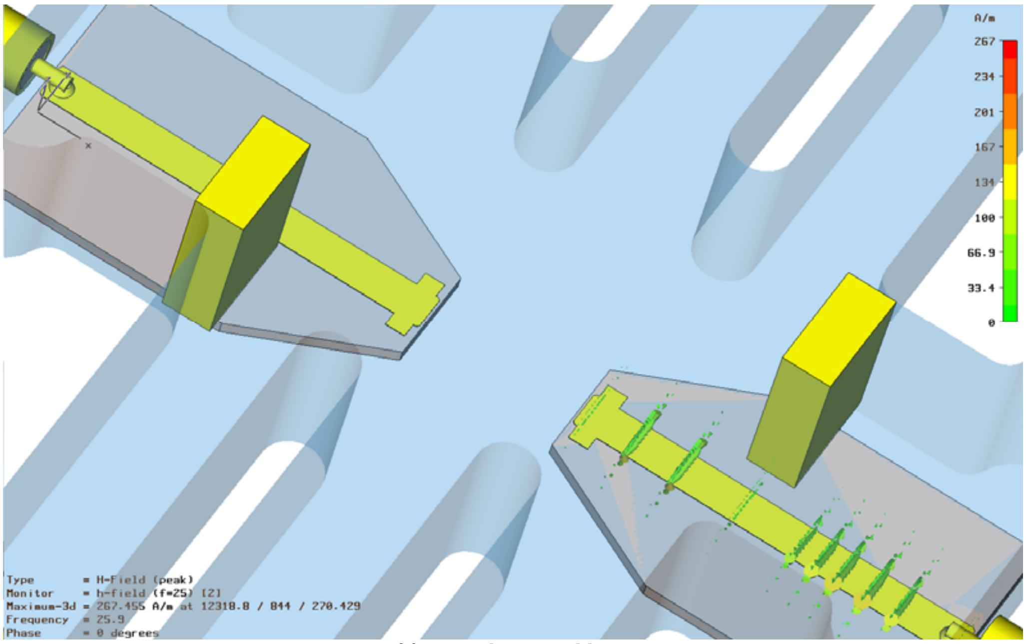


Fig.21 – cap of fig.19 and a mirror-like one on RF OUT

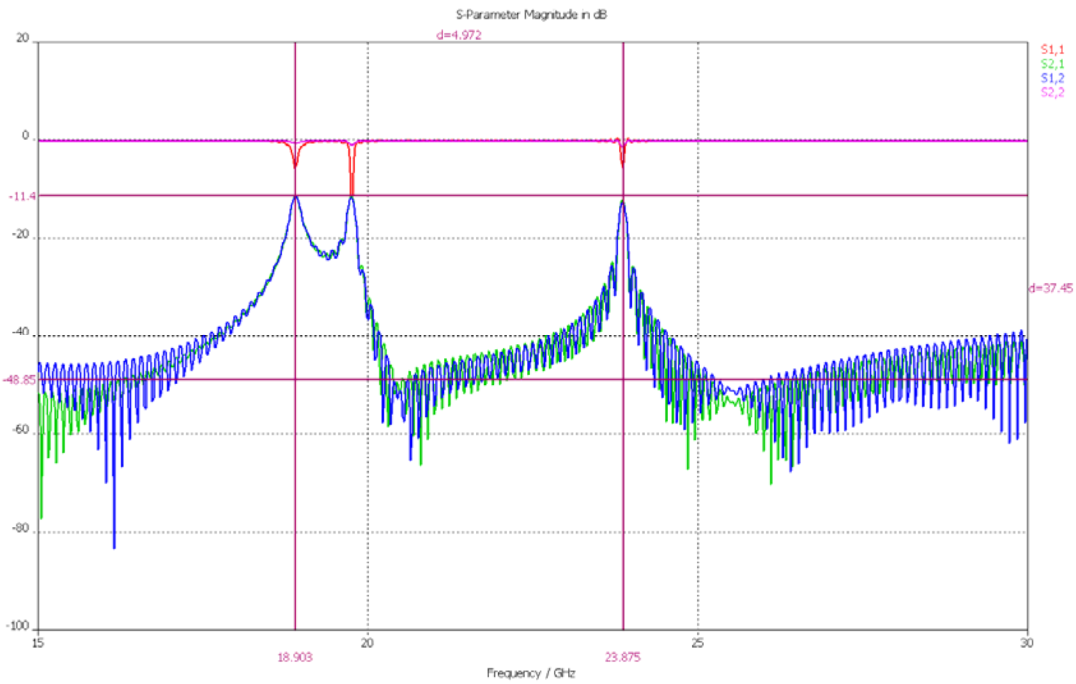


Fig.22 – Frequency response related to Fig. 21 configuration

Going back using a single baffle, reducing its thickness decrease the peak levels, especially at high frequency.

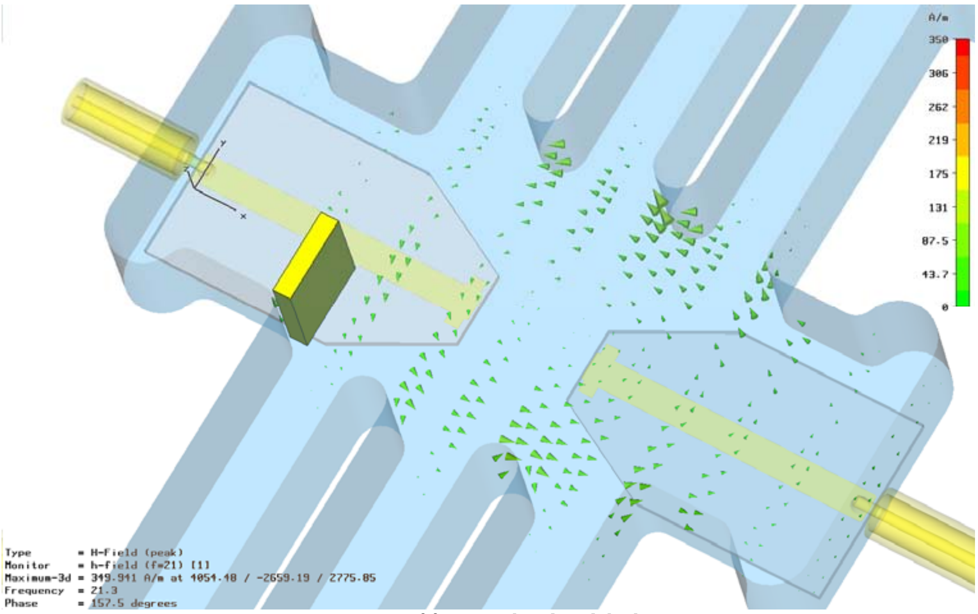


Fig.23 – cap of fig.19 with reduced thickness

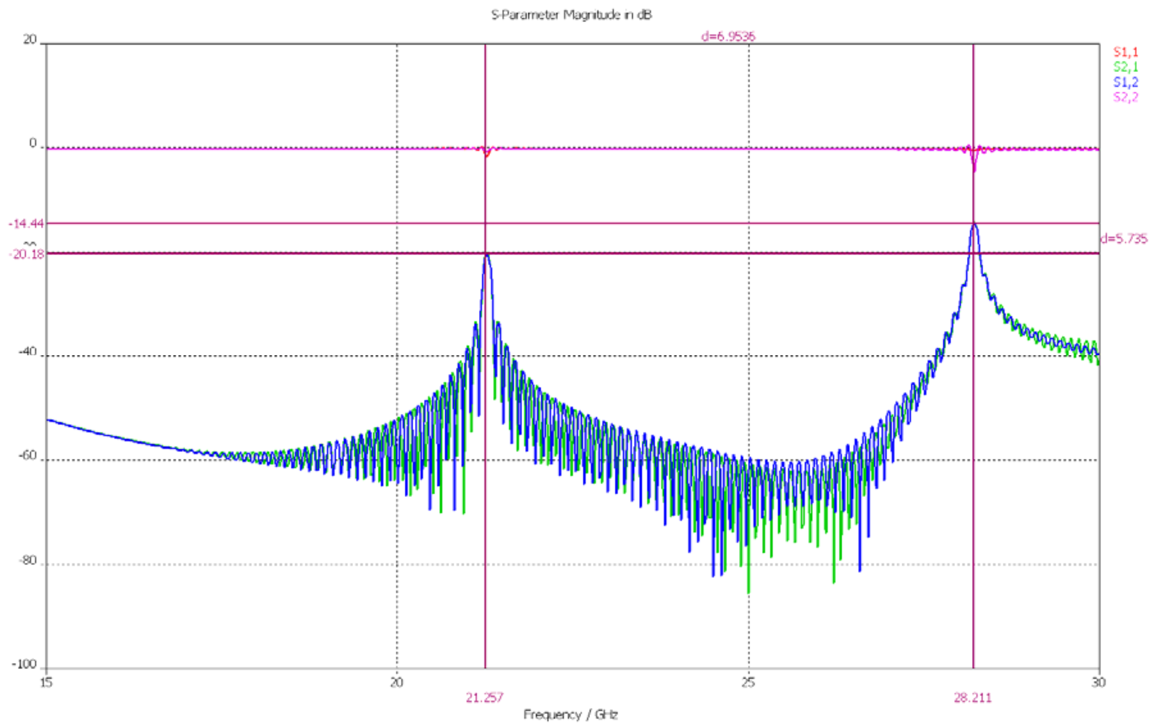


Fig.24 – Frequency response related to Fig. 23 configuration

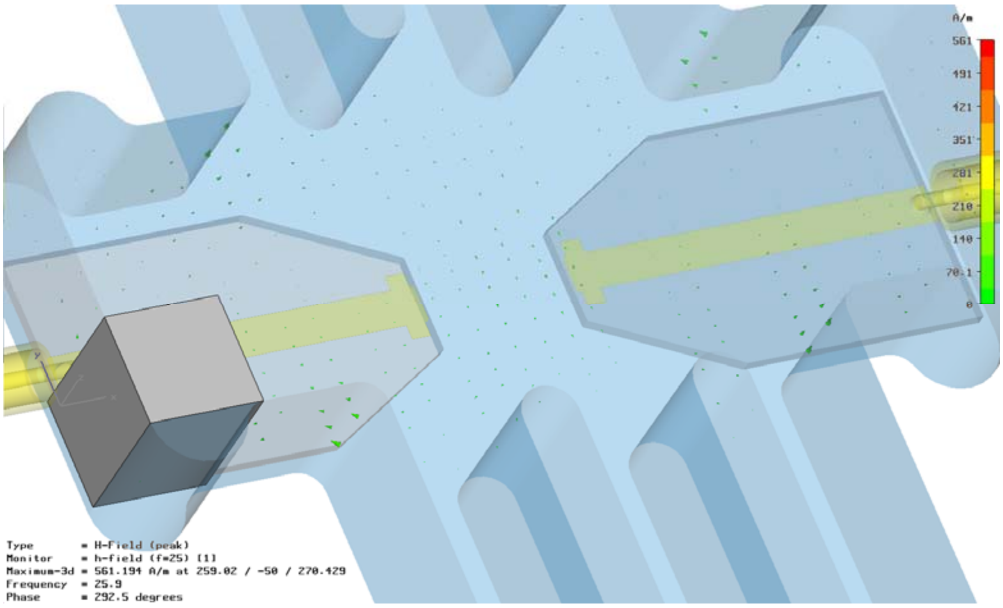


Fig.25 –Big septum near RF in connector post

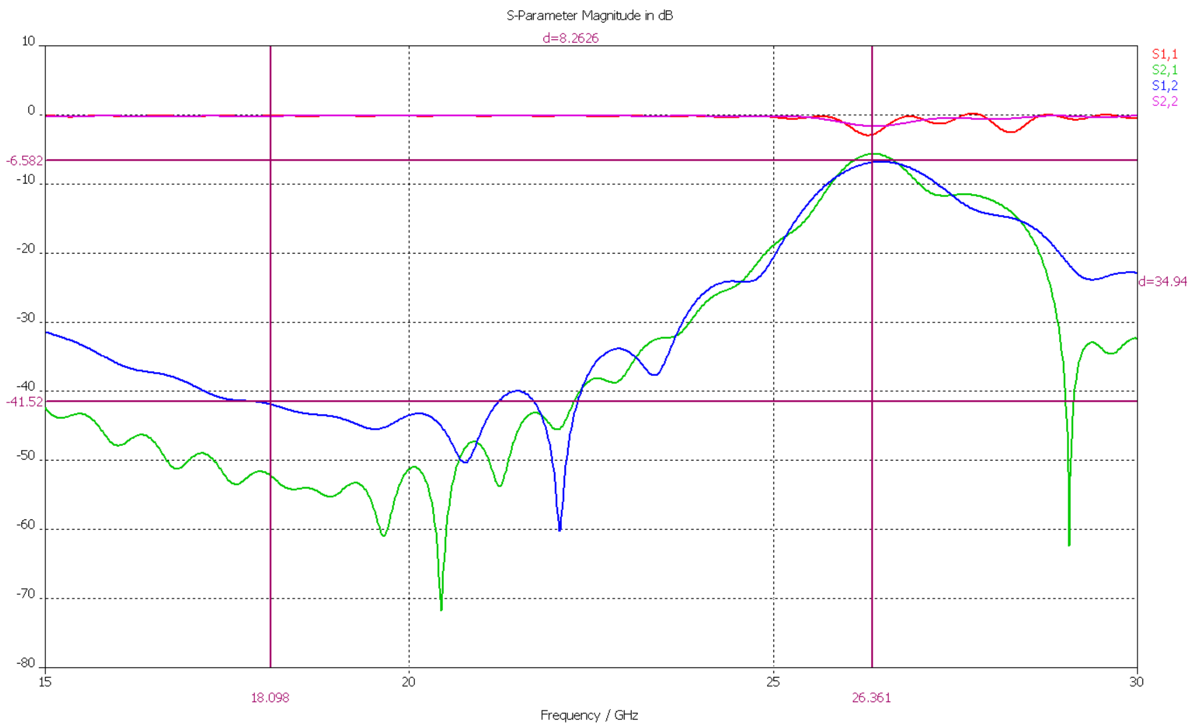


Fig.26 – Frequency response related to Fig. 25 configuration

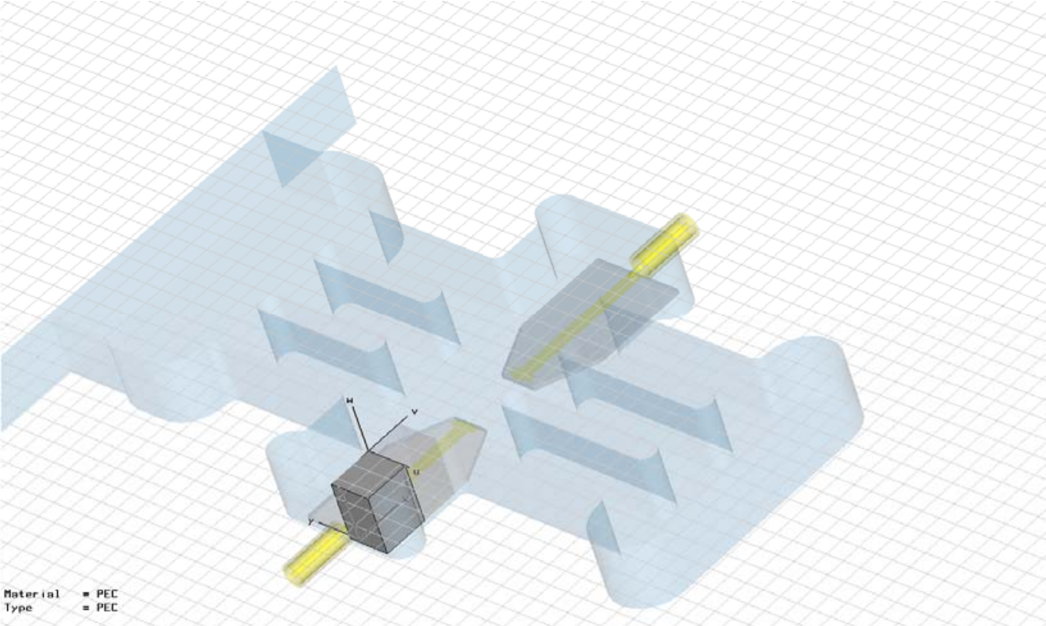


Fig.27 –Two Big septum near RF in connector post

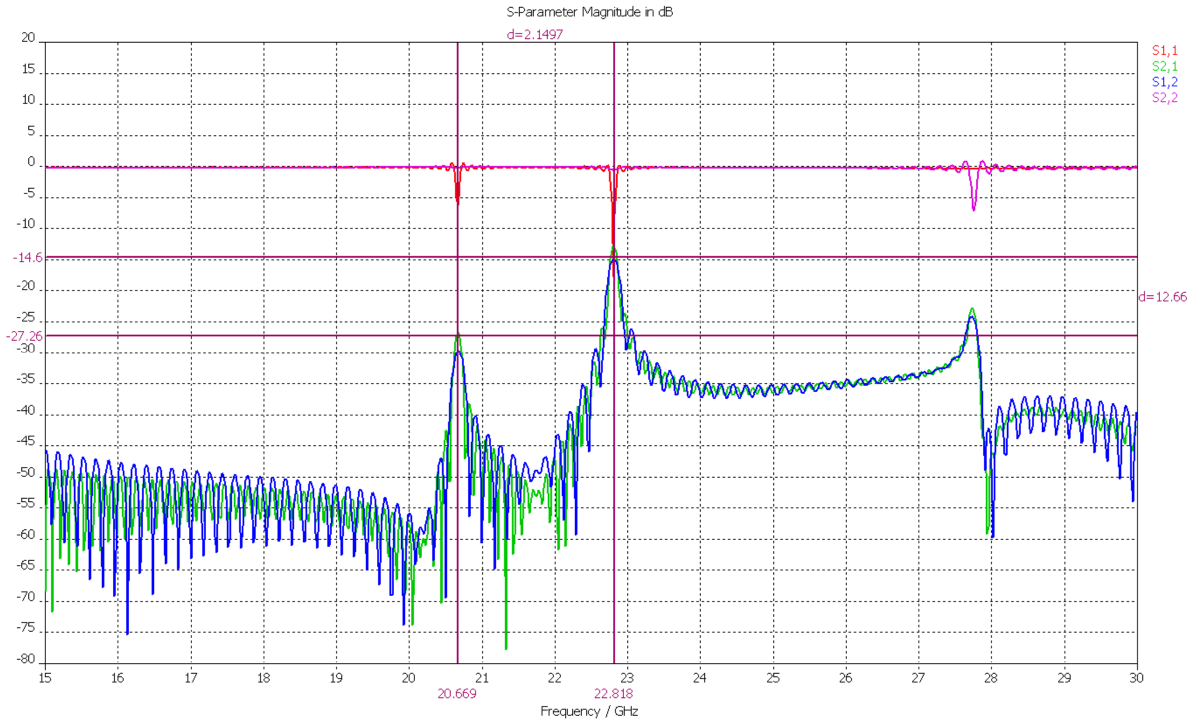


Fig.28 – Frequency response related to Fig. 27 configuration

A shield seems to produce positive result but we have to take into account not only the EM behavior of the cavity. We have to find a solution that change the cavity behavior without perturb the EM response of components placed in. The following solutions lie close to the microstrip and change it electrical responses.

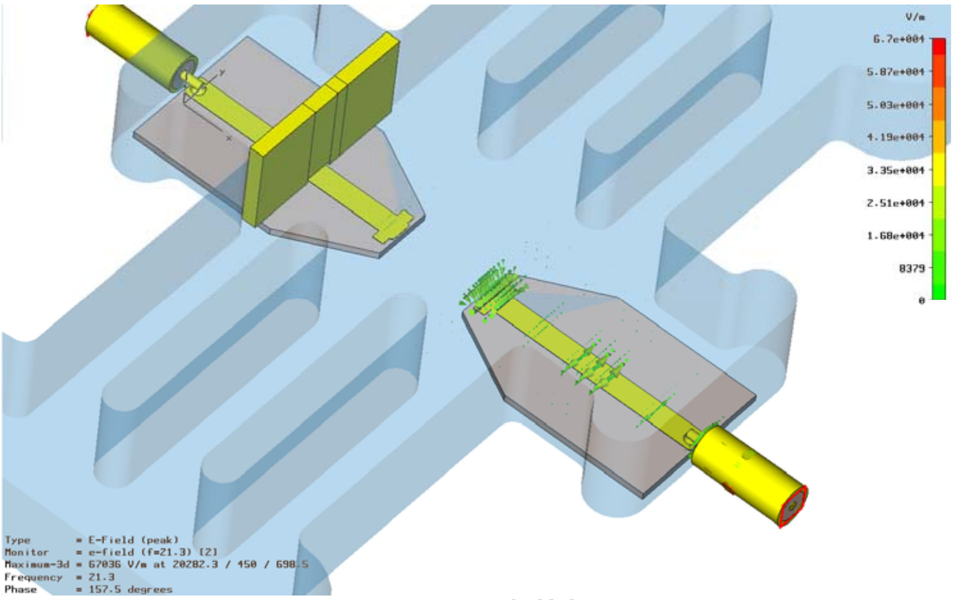


Fig.29 – RFIn shielded

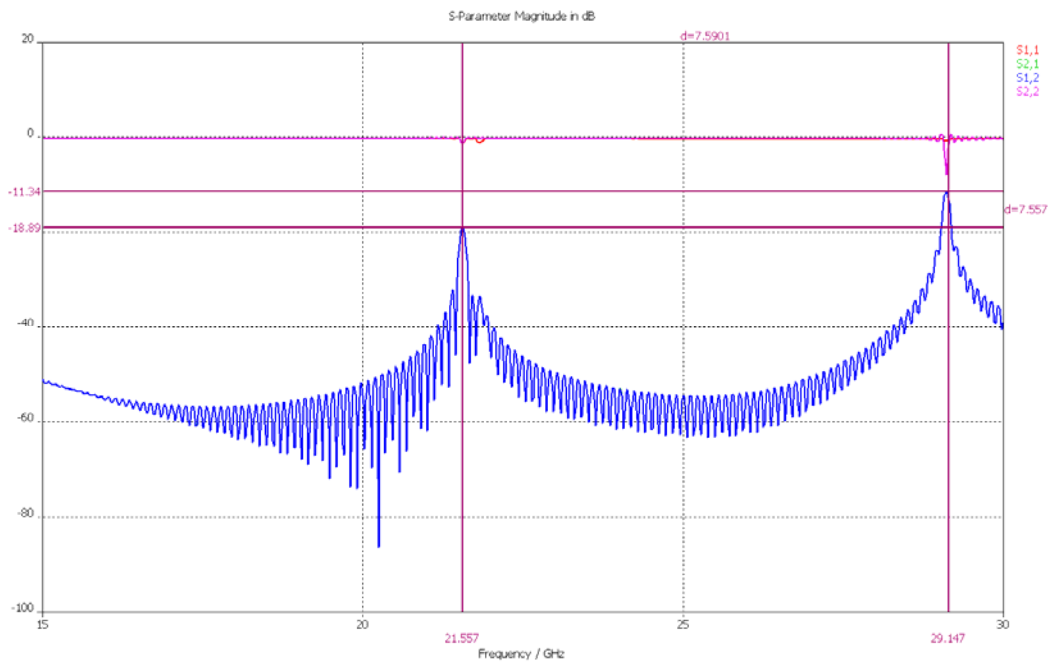


Fig.30 – Frequency response related to Fig. 29 configuration

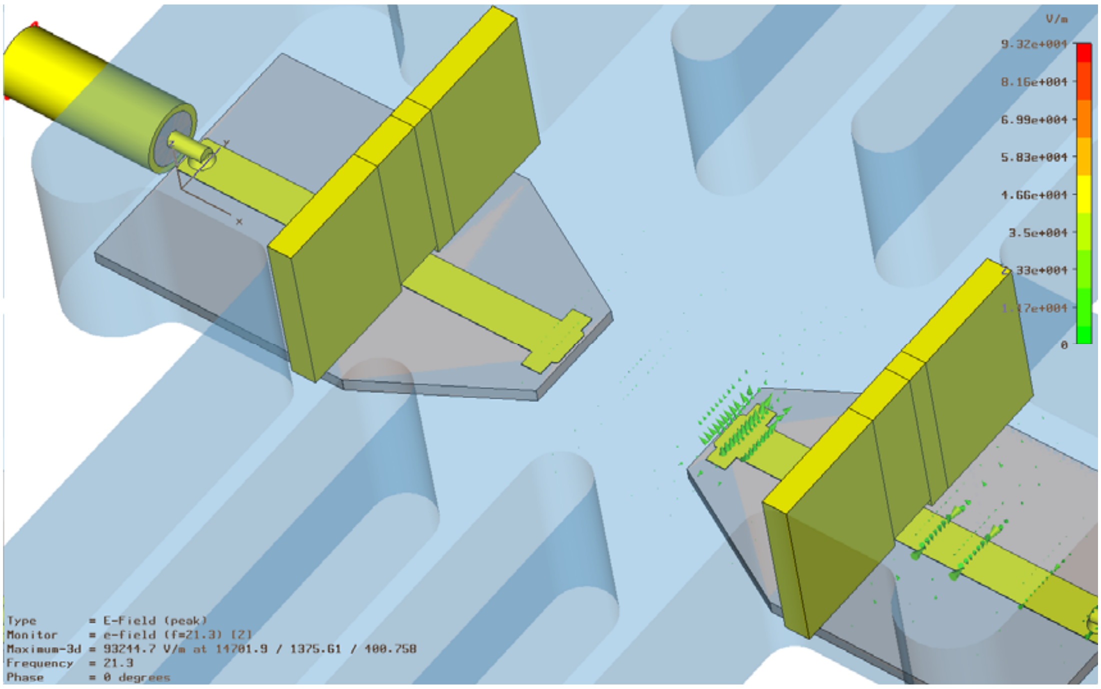


Fig. 31 – RFIn and RFOut shielded

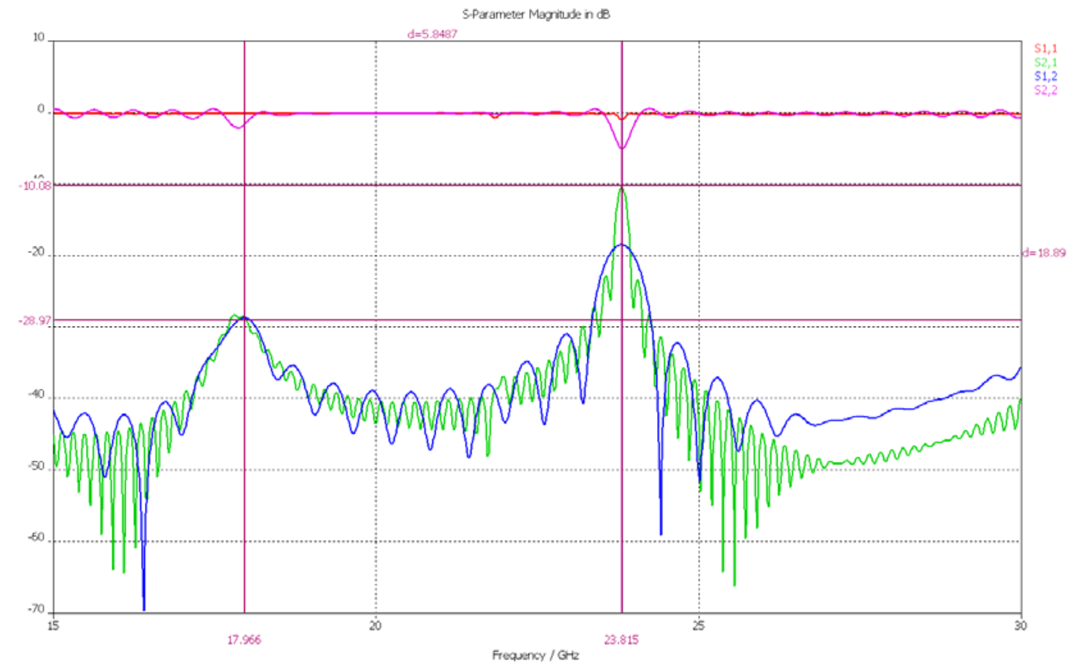


Fig.32 – Frequency response related to Fig. 31 configuration

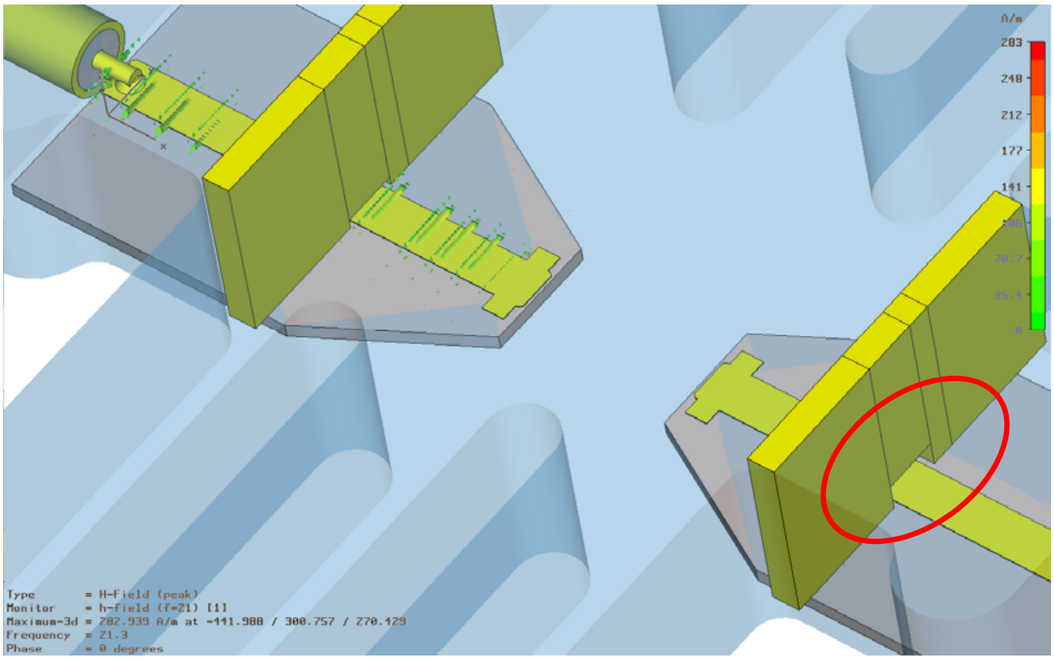


Fig.33 – RFIn and RFOut shielded (RFOut shield raised up)

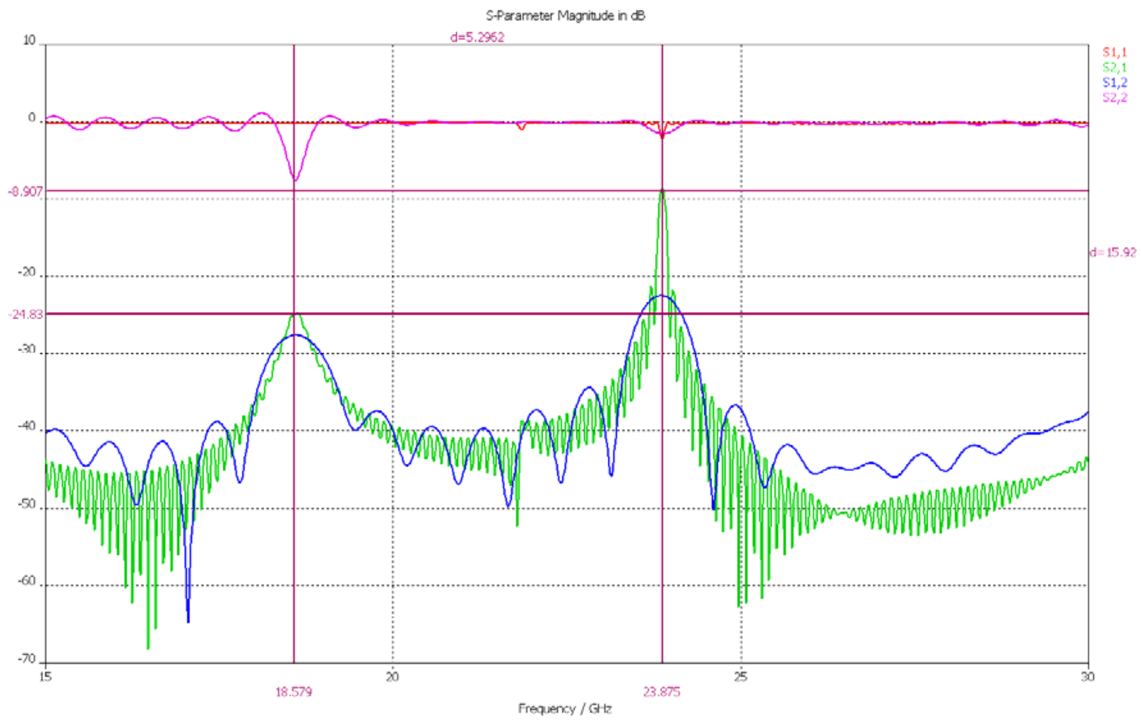


Fig.34 – Frequency response related to Fig. 33 configuration

Here we start to insert diagonal septum and encouraging results drive us to a possible solution.

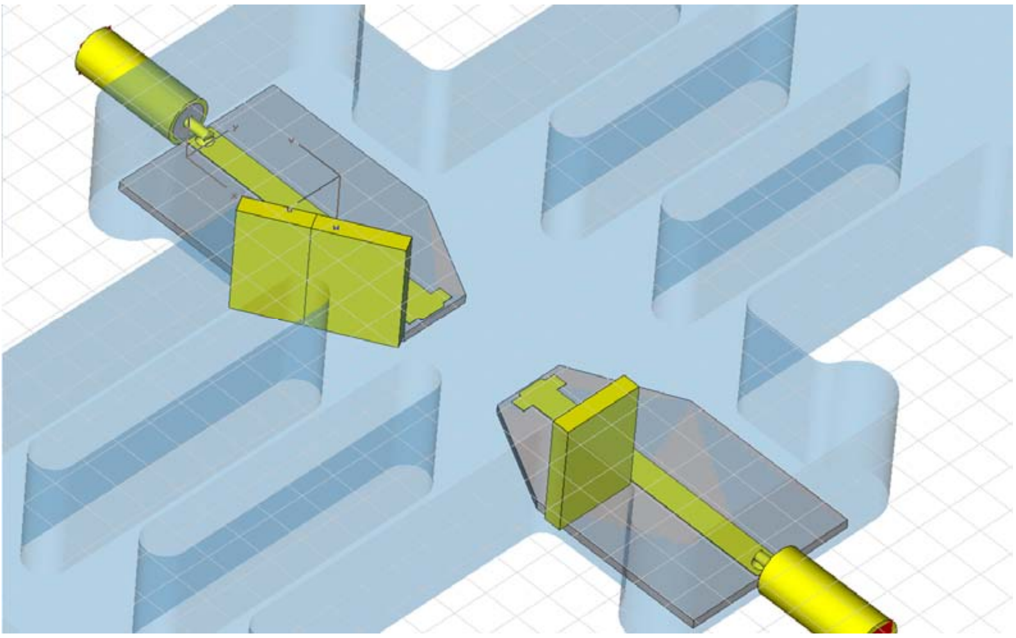


Fig.35 – Diagonal baffle input and septum to RF Out

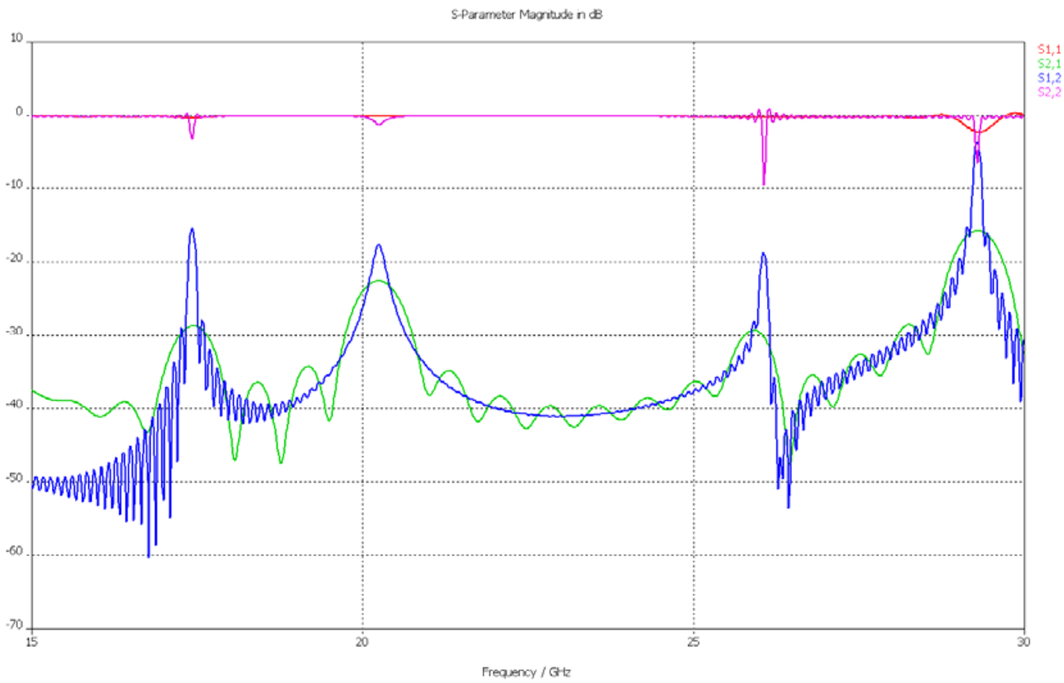


Fig.36 – Frequency response related to Fig. 37 configuration

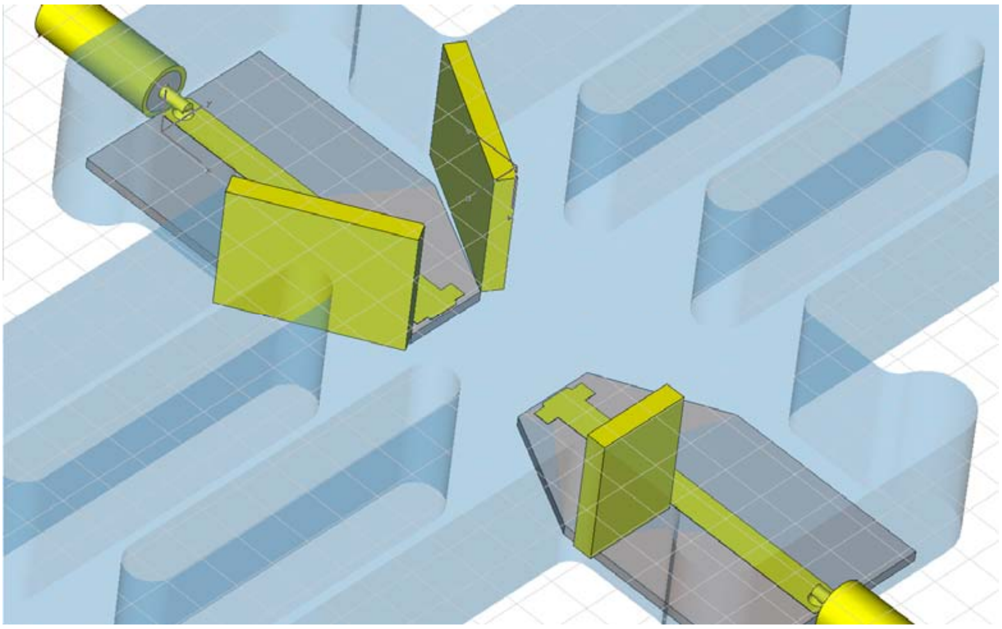


Fig.37 – Two Diagonal baffles input and septum to RF Out

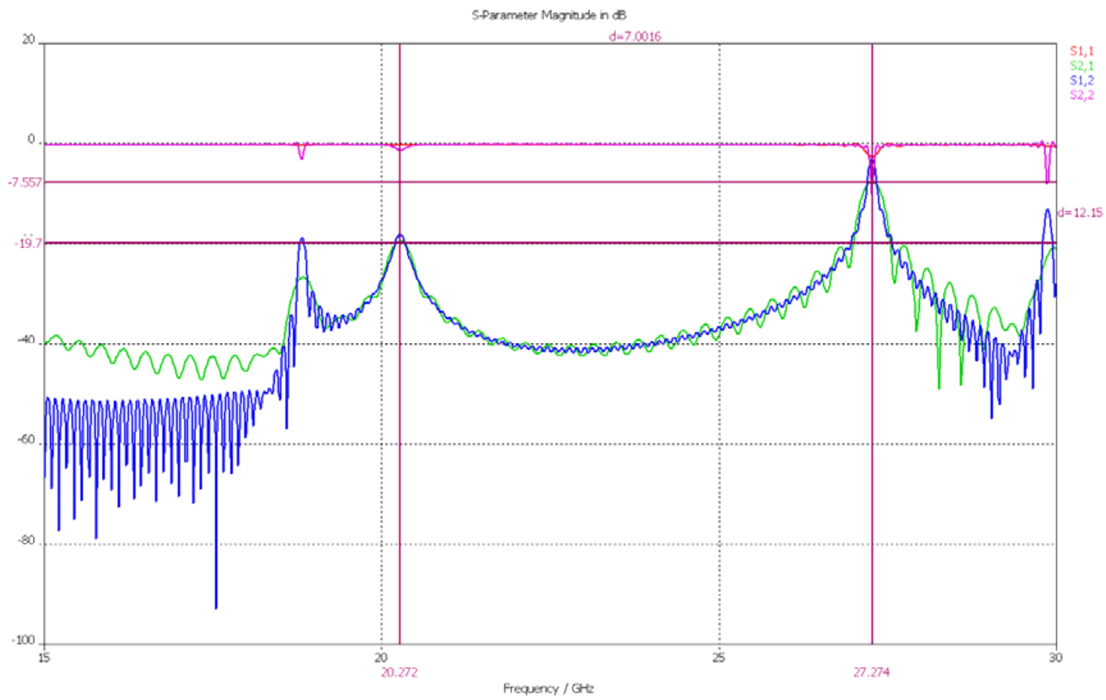


Fig.38 – Frequency response related to Fig. 37 configuration

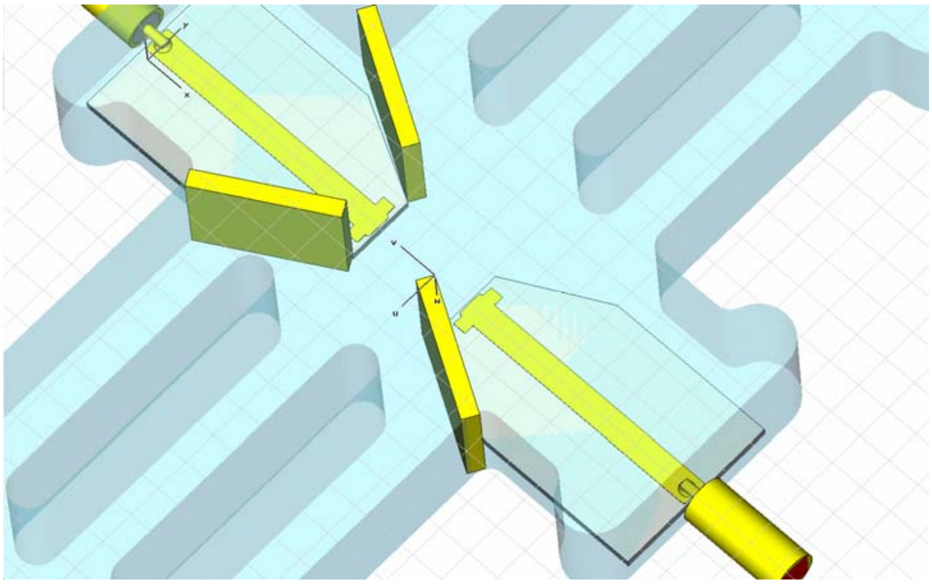


Fig.39 – Three Diagonal baffles

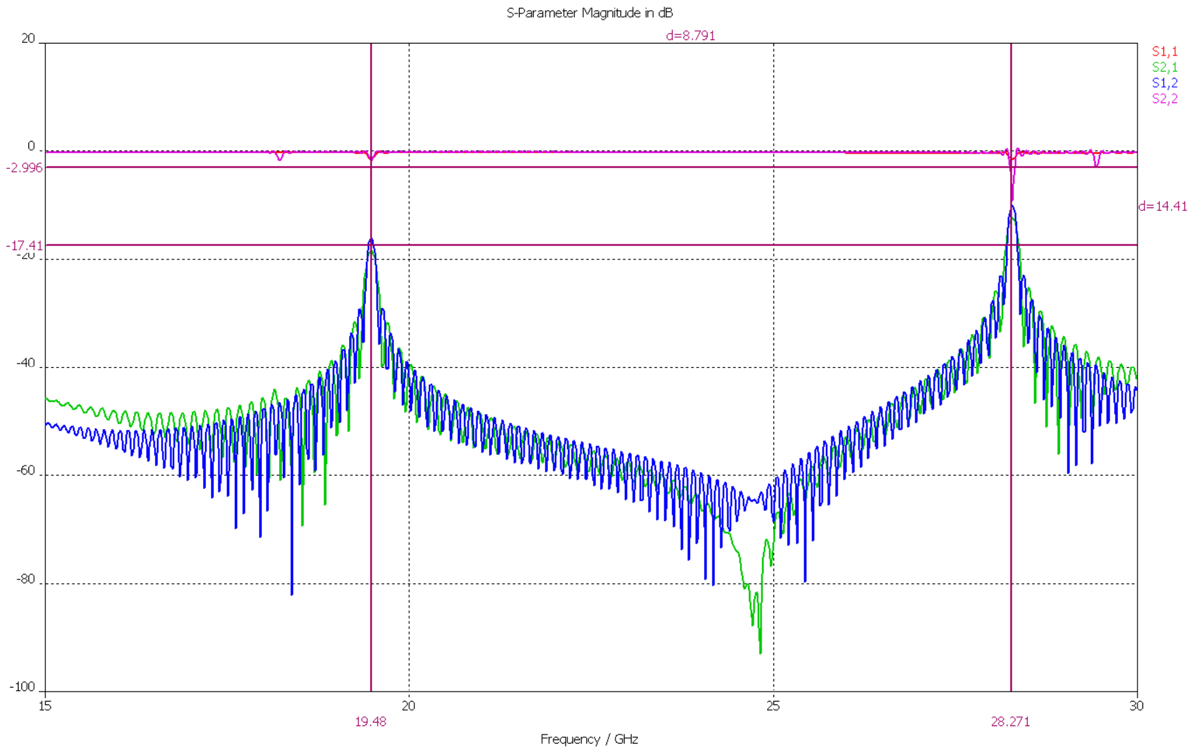


Fig.40 – Frequency response related to Fig. 39 configuration

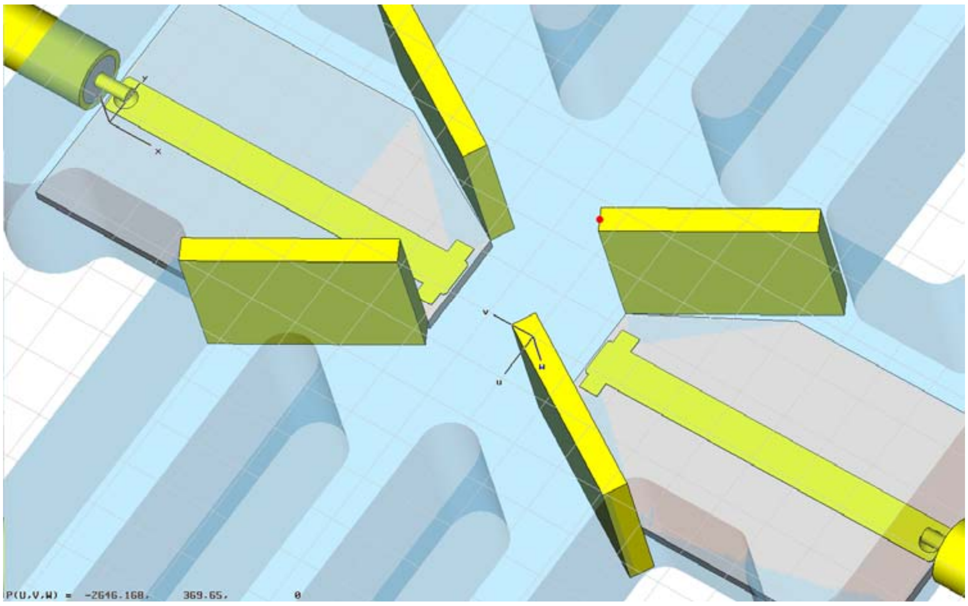


Fig.41 – Four Diagonal baffles

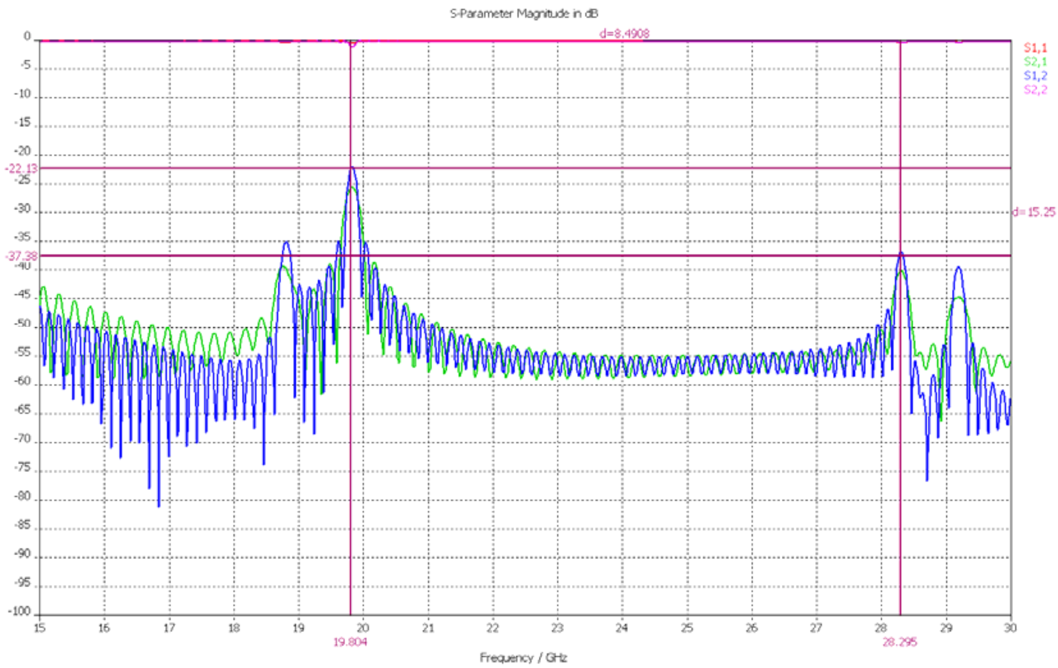


Fig.42 – Frequency response related to Fig. 41 configuration

We introduce here smooth surfaces instead of sharp edge.

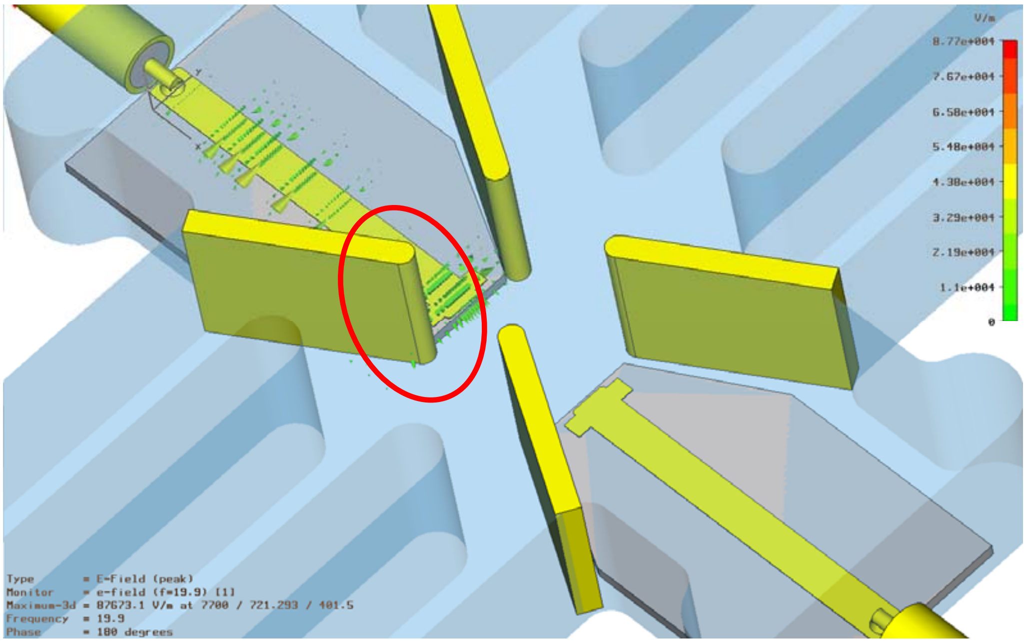


Fig.43 – Four Diagonal smoothed baffles

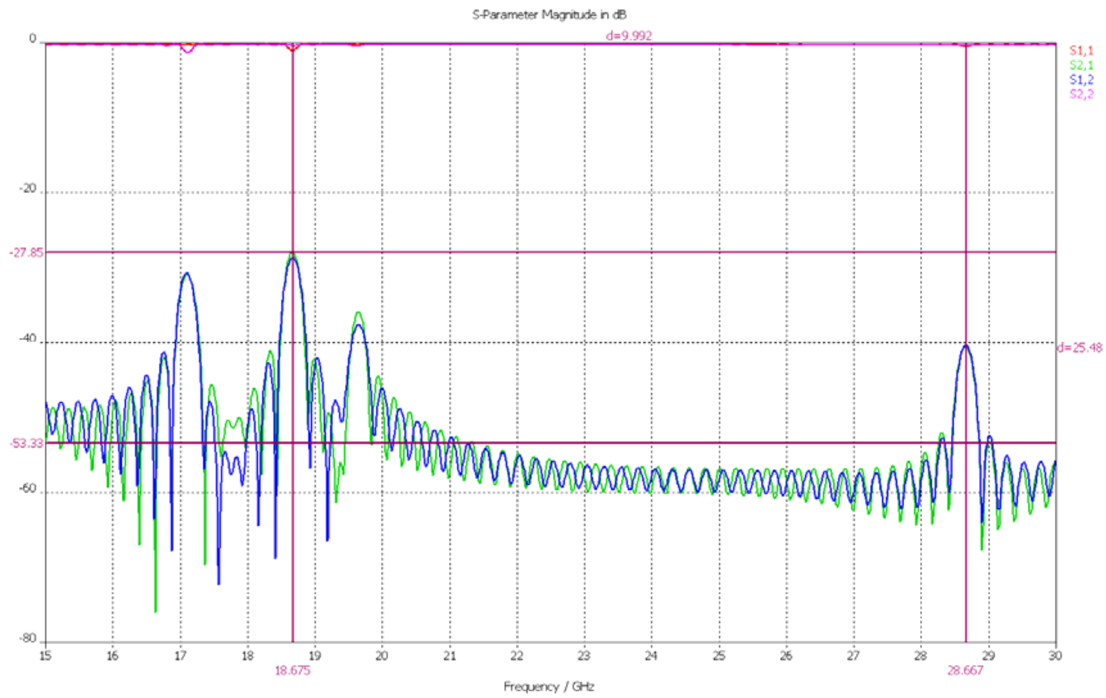


Fig.44 – Frequency response related to Fig. 43 configuration

We move back the baffle in order to avoid contacts with still assembled components on the carrier Here septum are shorted a little in order to guarantee more room between walls and the microstrip edges. This structure appears to be the best solution. We must verify if it is possible to mechanically realise it! In the following pages other solution.

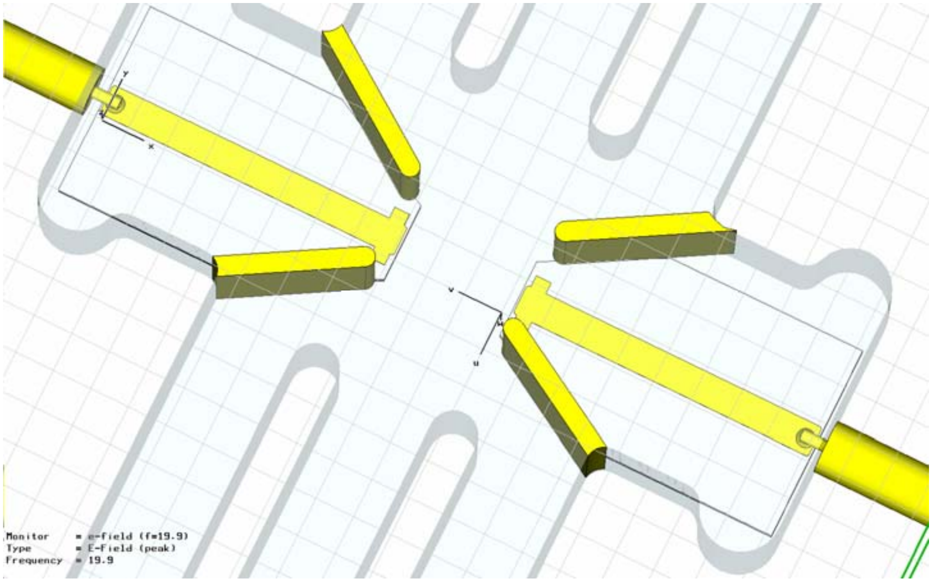


Fig.45 – Four Diagonal smoothed moved back baffles

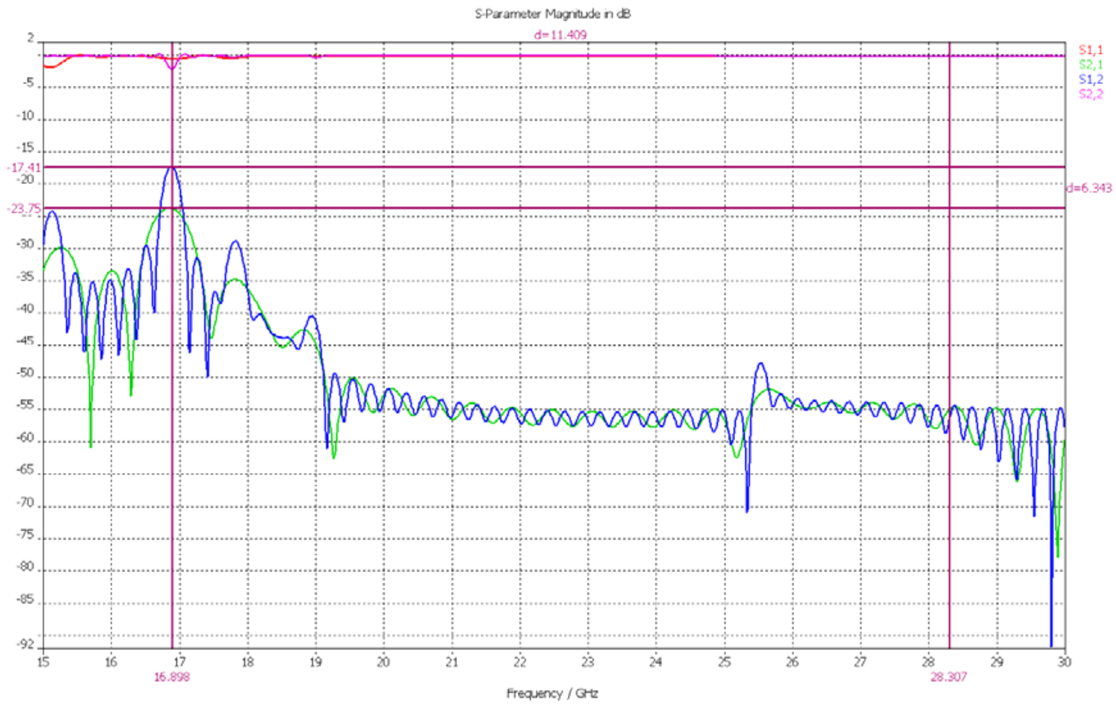


Fig.46 – Frequency response related to Fig. 45 configuration

The following solutions appear to be also interesting but they may perturb microstrip electrical behaviour.

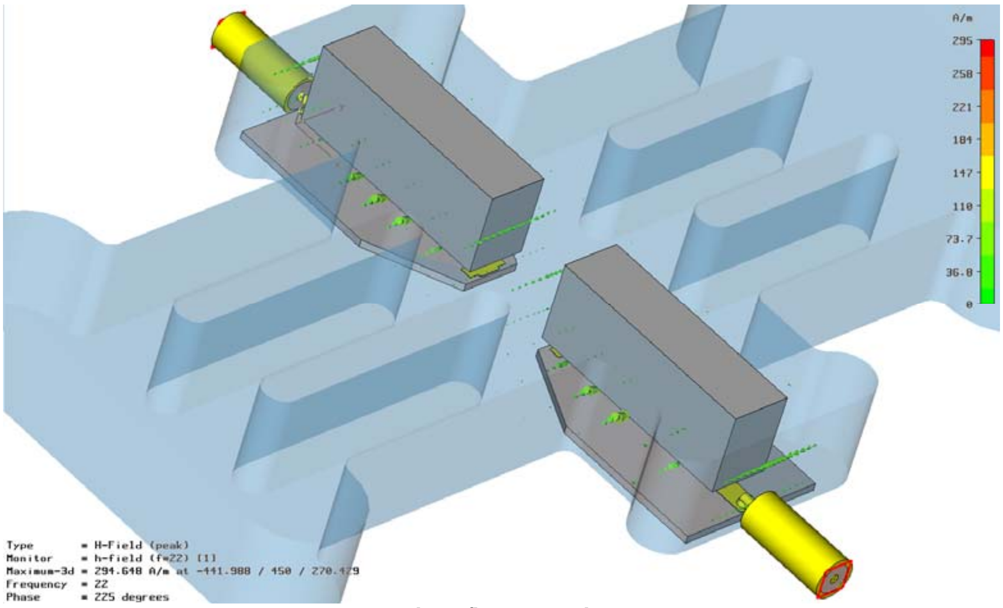


Fig.47 – Two big reflectors over the microstrips

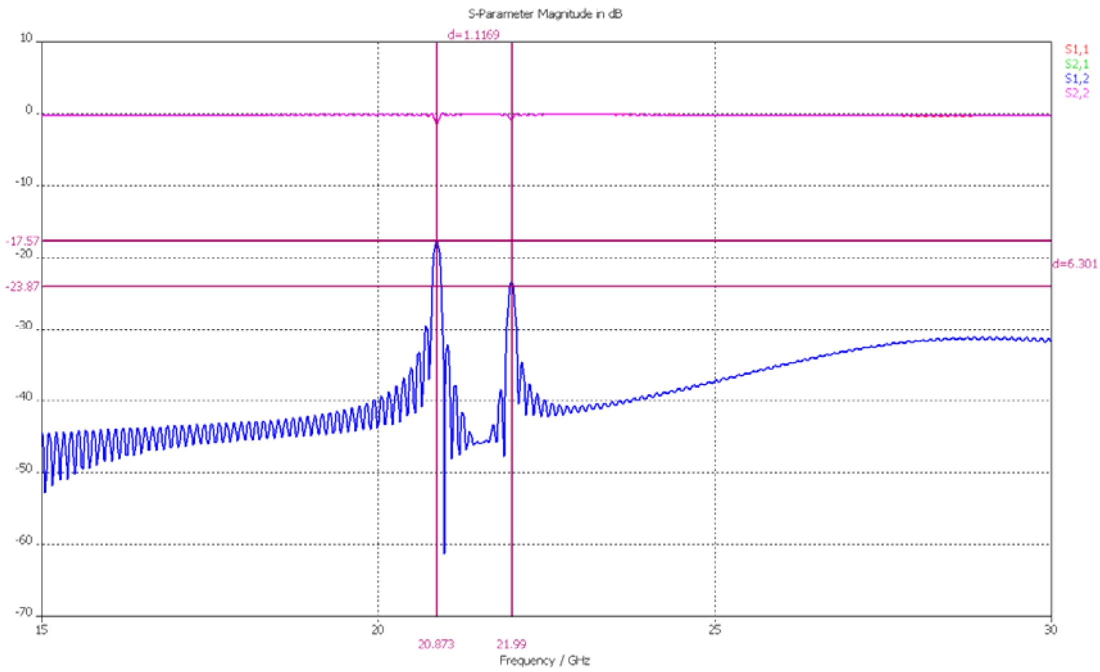


Fig.48 – Frequency response related to Fig. 47 configuration

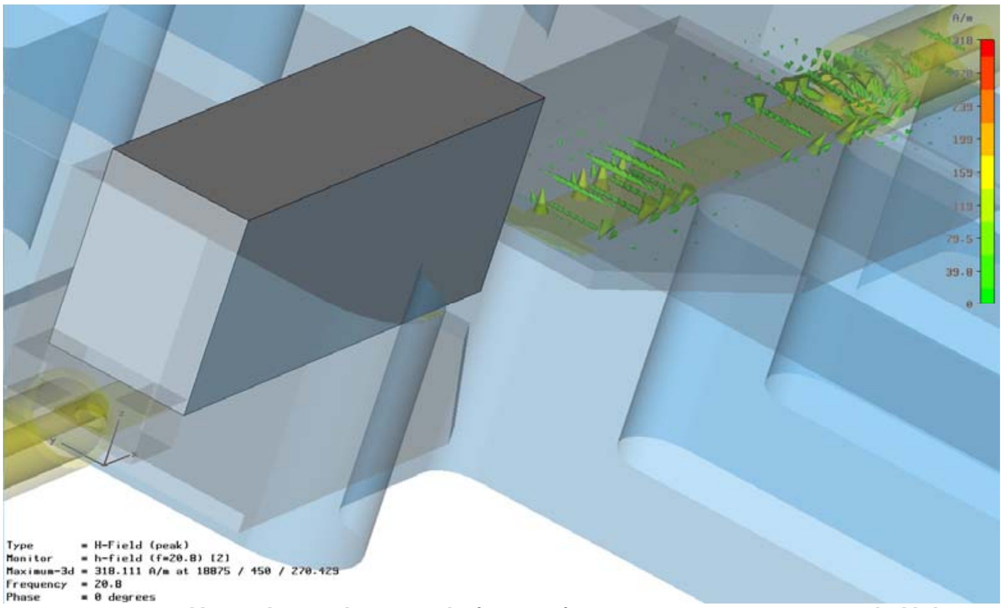


Fig.49 – We add a metal ring at the RFIn to the fig 47 configuration: RF Input connector post shielded

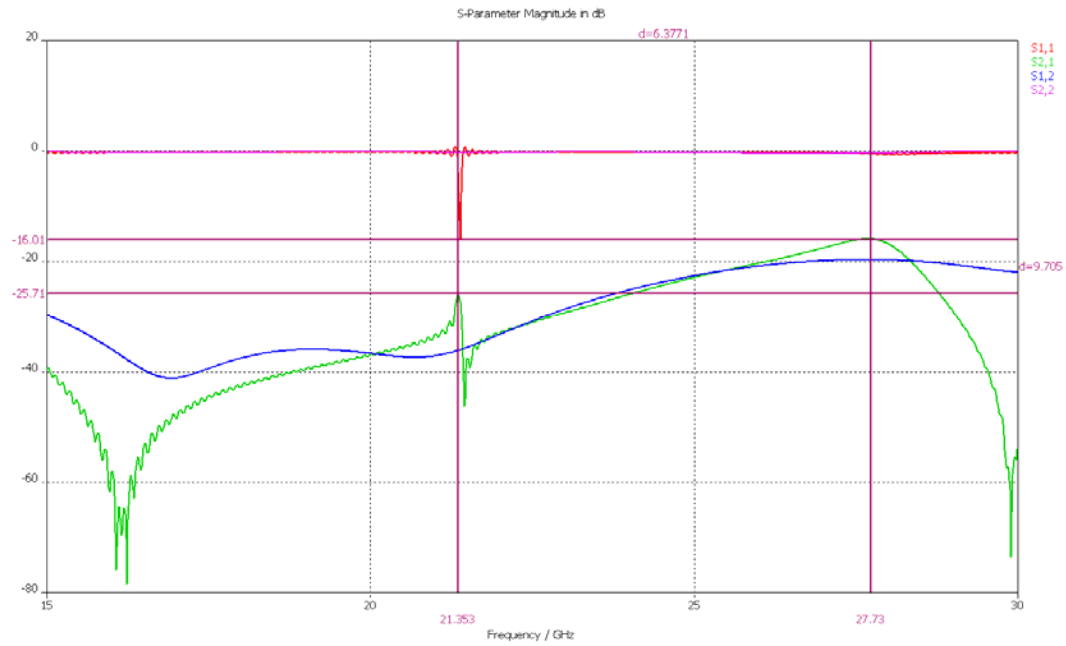


Fig.50 – Frequency response related to Fig. 49 configuration

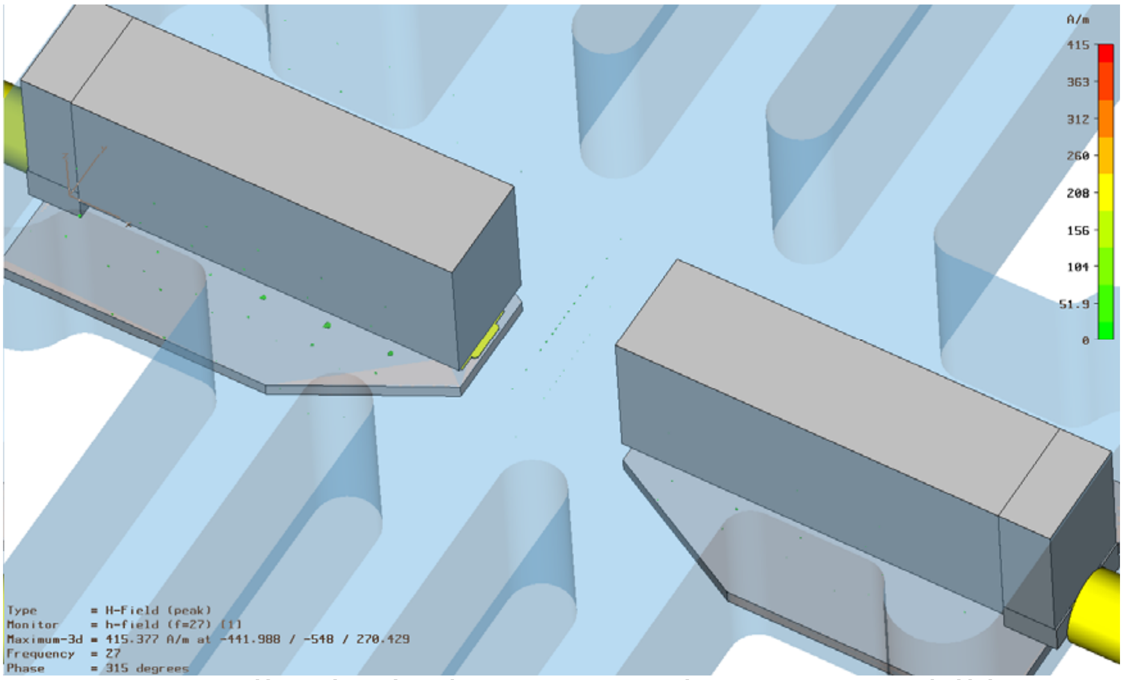


Fig.51 – We add a metal ring also at the RF Output: RF Input and RF Output connector post shielded

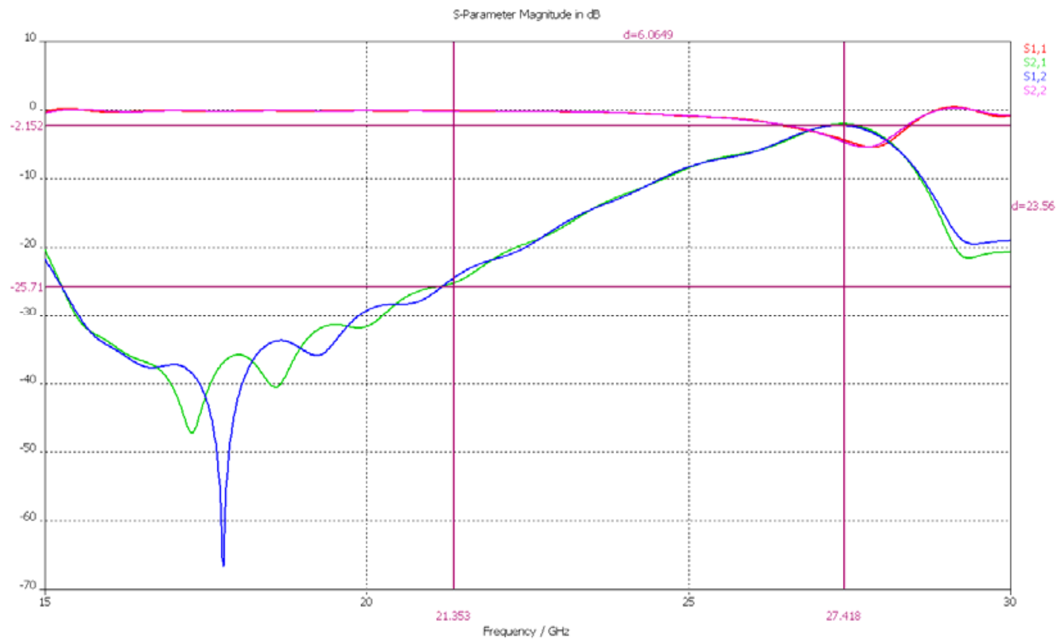


Fig.52 – Frequency response related to Fig. 51 configuration

6 - When a solution hide a mistake

In this chapter we would like to underline as a simulation could hide a mistake. We consider here the best solution achieved described in fig 45: Four diagonal septum and flat cap. Time domain simulation with CST and frequency domain HFSS simulation with 0.5 and 0.2 GHz resolution roughly gives comparable results. But HFSS simulation with 0.1 GHz resolution shows a critical behavior at the lower end of the working bandwidth (the most important for scientific observations). In the following pages tuning strategies are described.

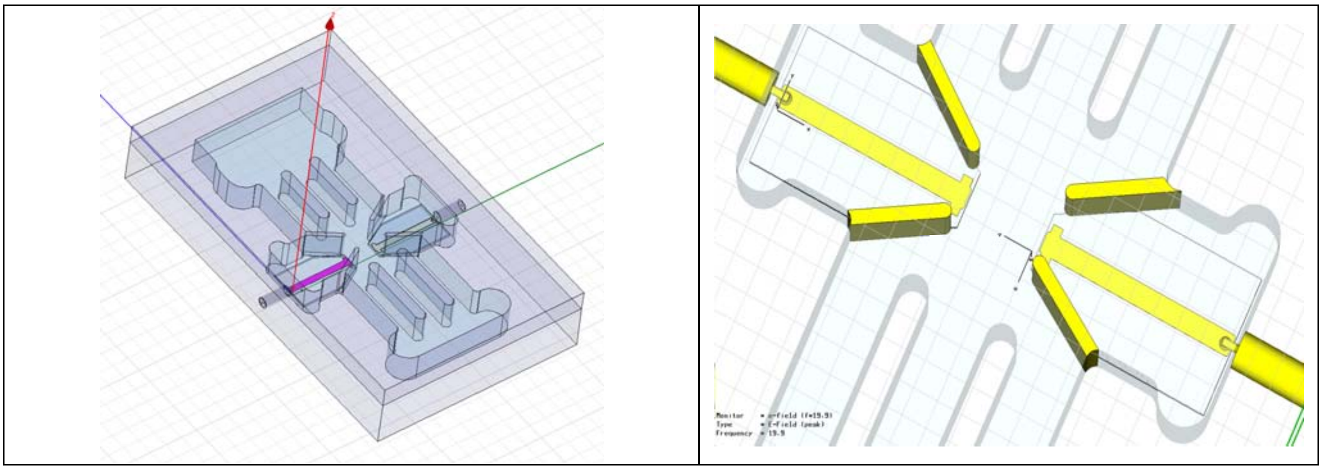


Fig.53 – four diagonal septum flat caps

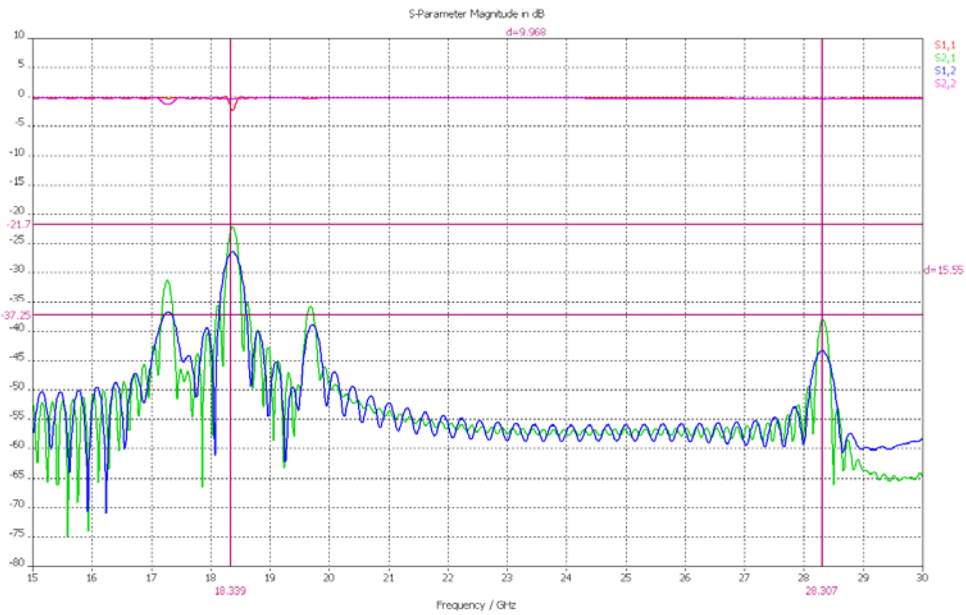


Fig.54 – CST Frequency response related to Fig. 53 configuration

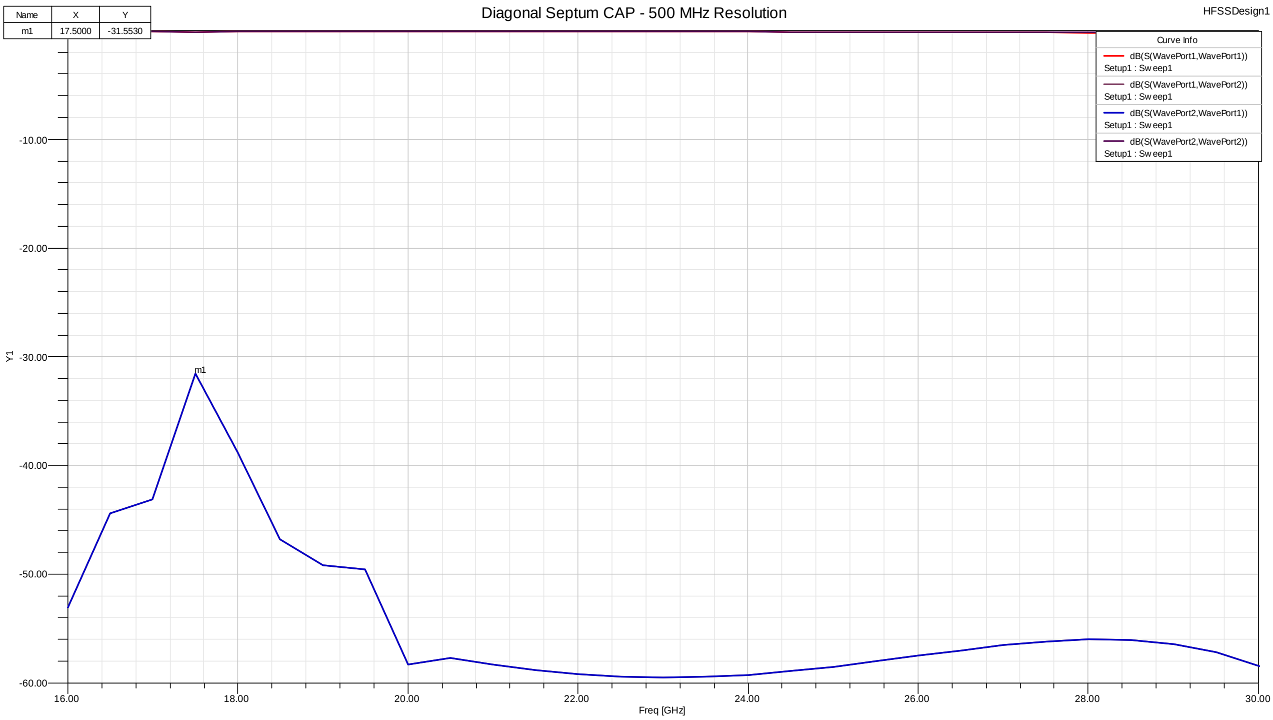


Fig.55 – HFSS Simulation of fig. 53 0.5 GHz Resolution

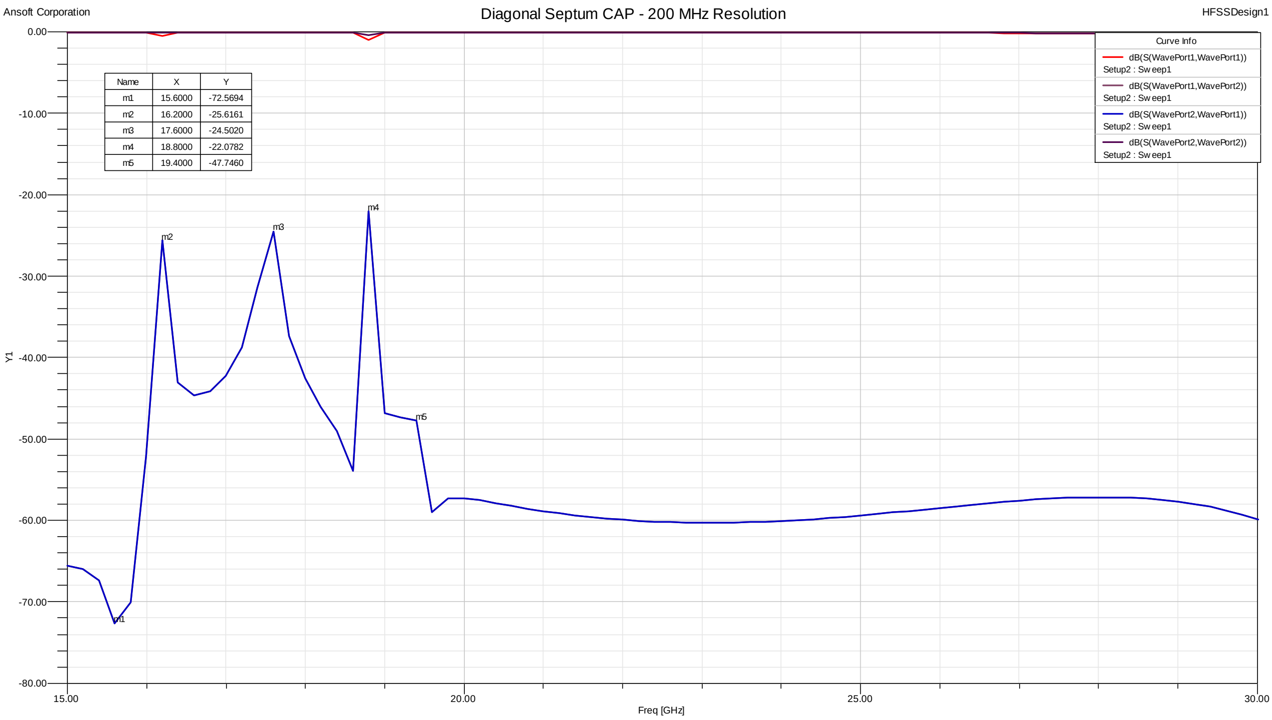


Fig.56 – HFSS Simulation of fig. 53 0.2 GHz Resolution

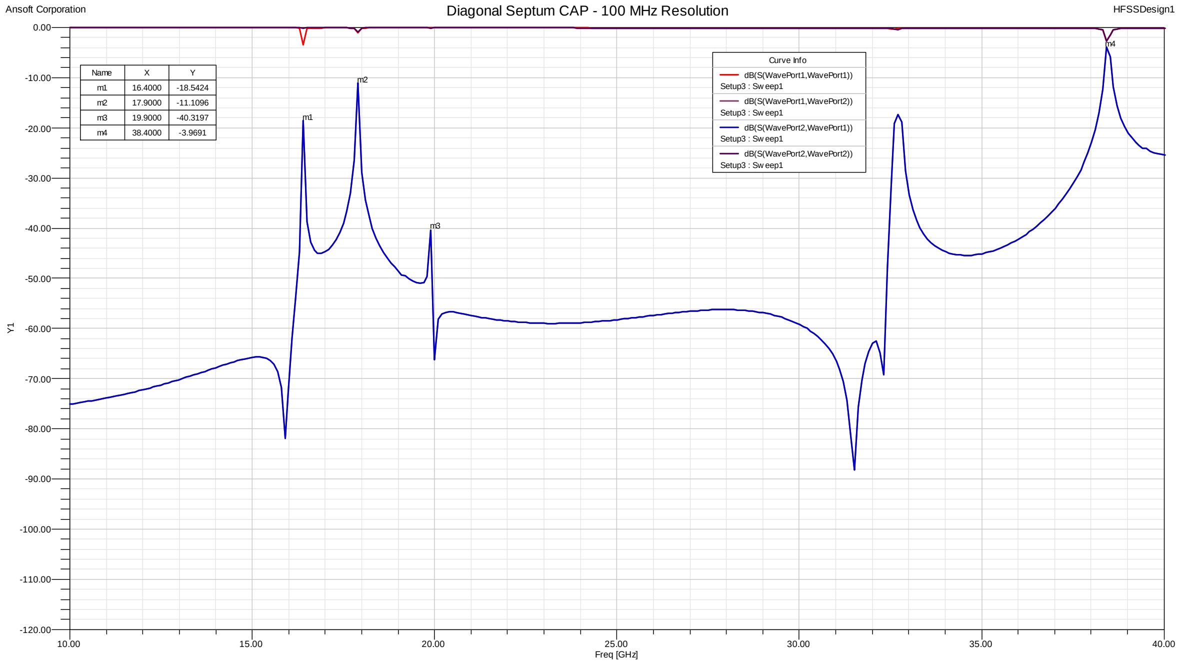


Fig.57 – HFSS Simulation of fig. 49 0.1 GHz Resolution

As shown in the graph of Fig. 57 the response a 17.9 GHZ could be dangerous. We now try to tune the response. We act on the cavity ceiling. Moving it down, reducing the volume of the cavity (Fig. 58-60) or up, increasing the volume of the cavity (Fig.61-63)

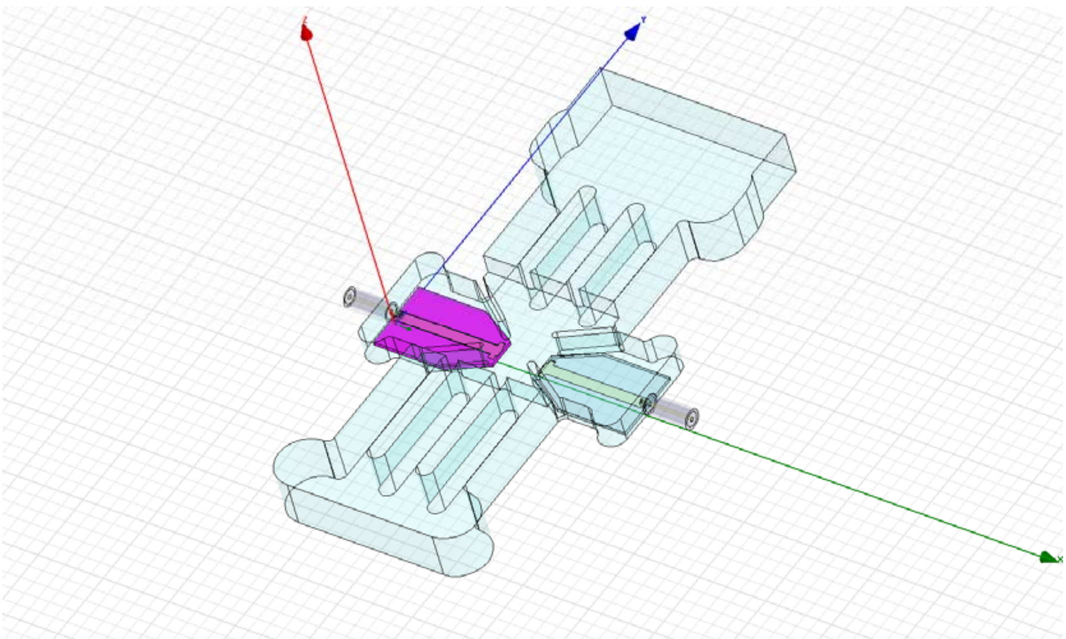
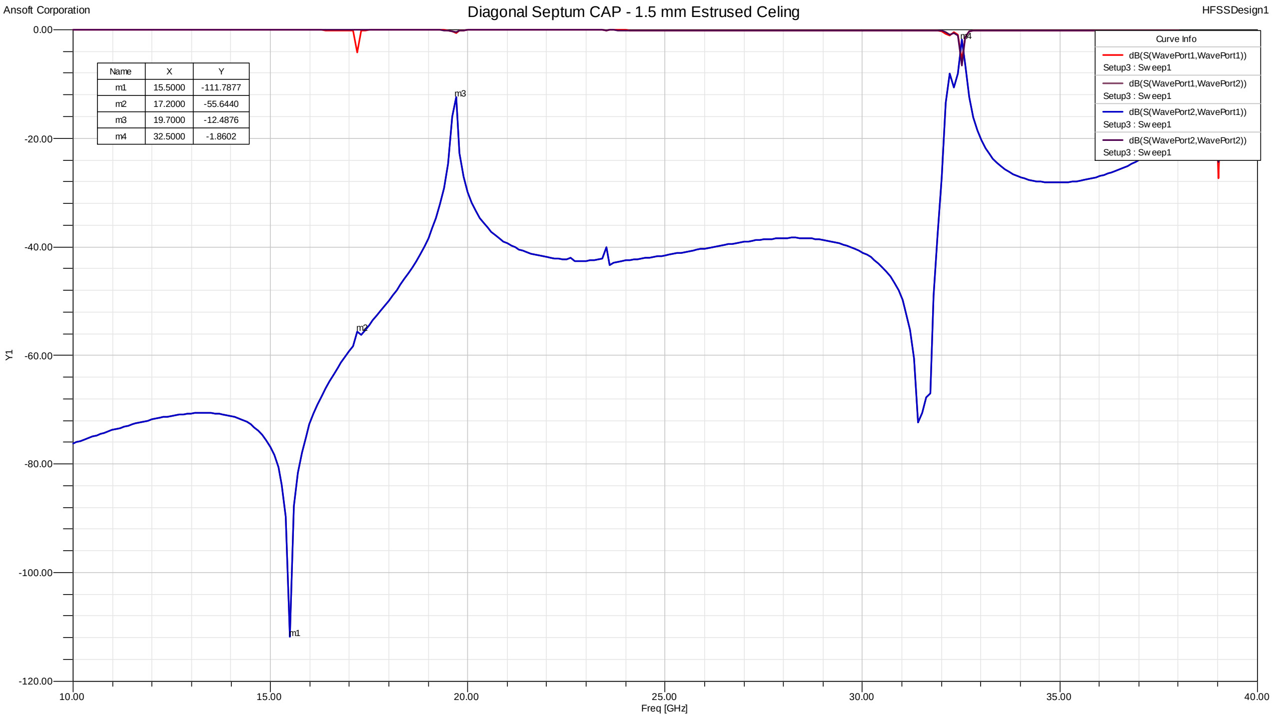
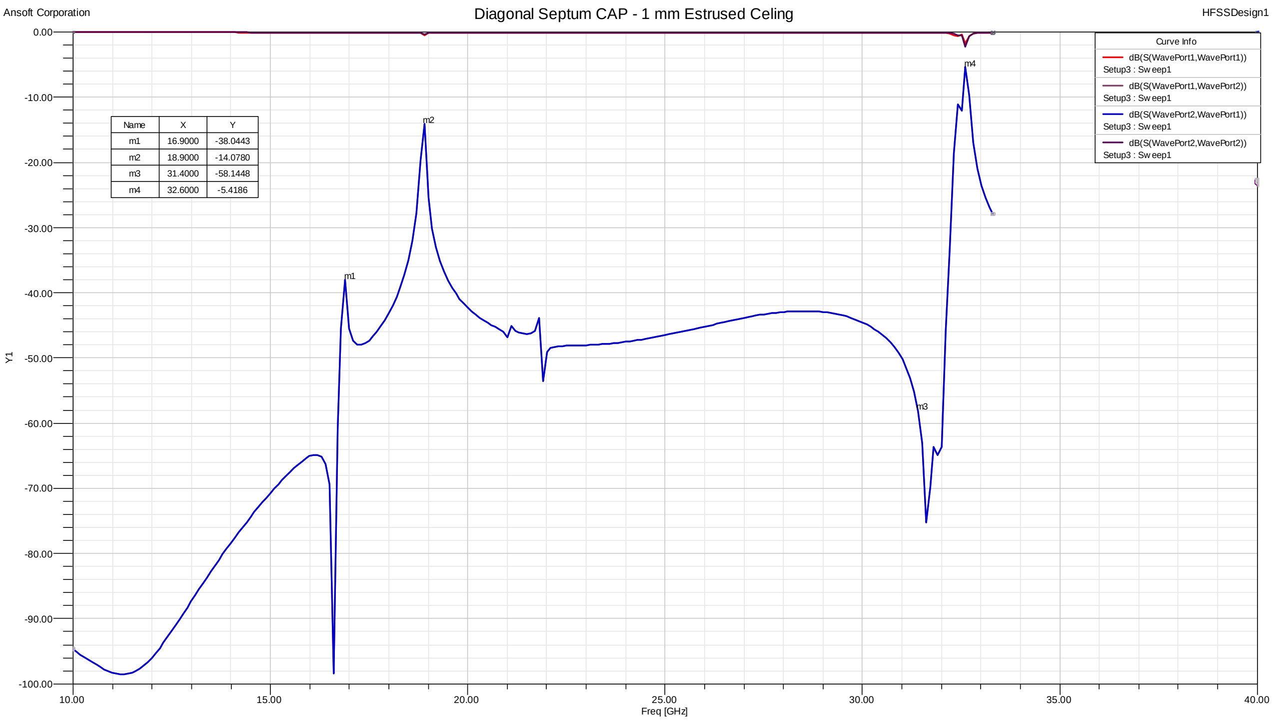


Fig.58 – Cap with diagonal septum and estruses ceiling



Name	X	Y
m1	15.5000	-111.7877
m2	17.2000	-55.6440
m3	19.7000	-12.4876
m4	32.5000	-1.8602

Fig.59 – Frequency response related to Fig. 58 configuration



Name	X	Y
m1	16.9000	-38.0443
m2	18.9000	-14.0780
m3	31.4000	-58.1448
m4	32.6000	-5.4186

Fig.60 – Frequency response related to Fig. 58 configuration

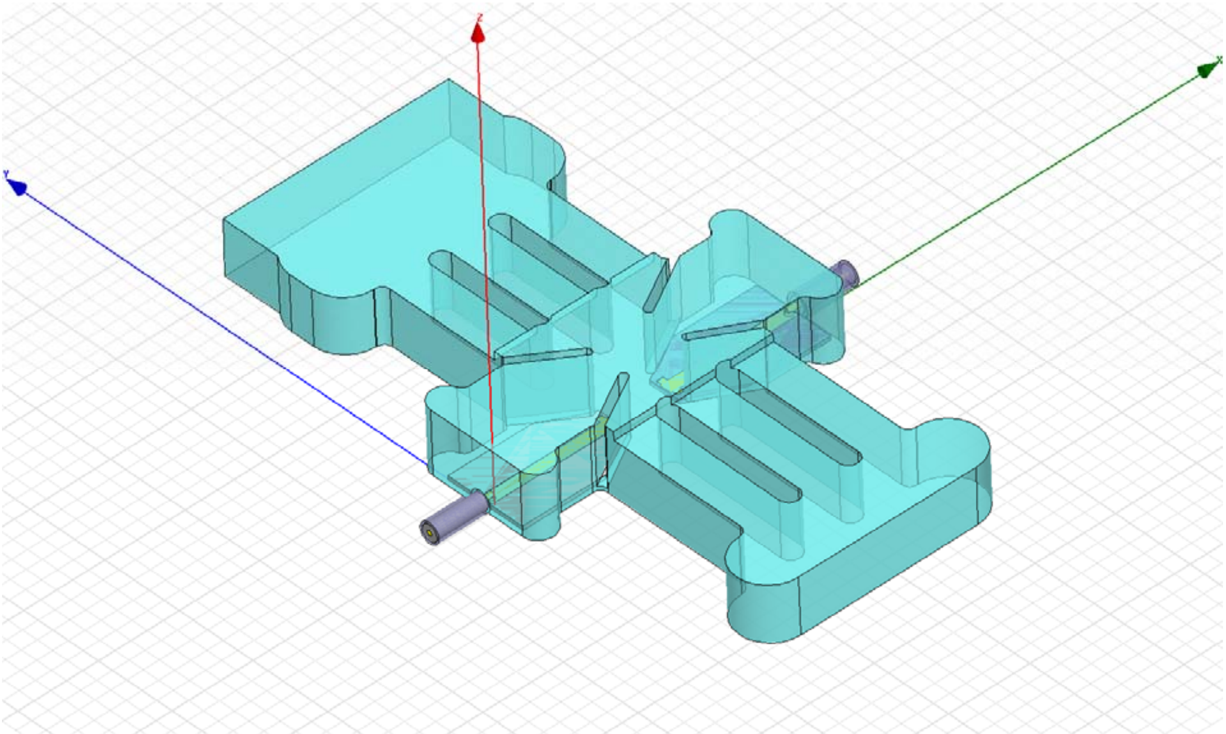


Fig.61 – Cap with diagonal septum and recessed ceiling

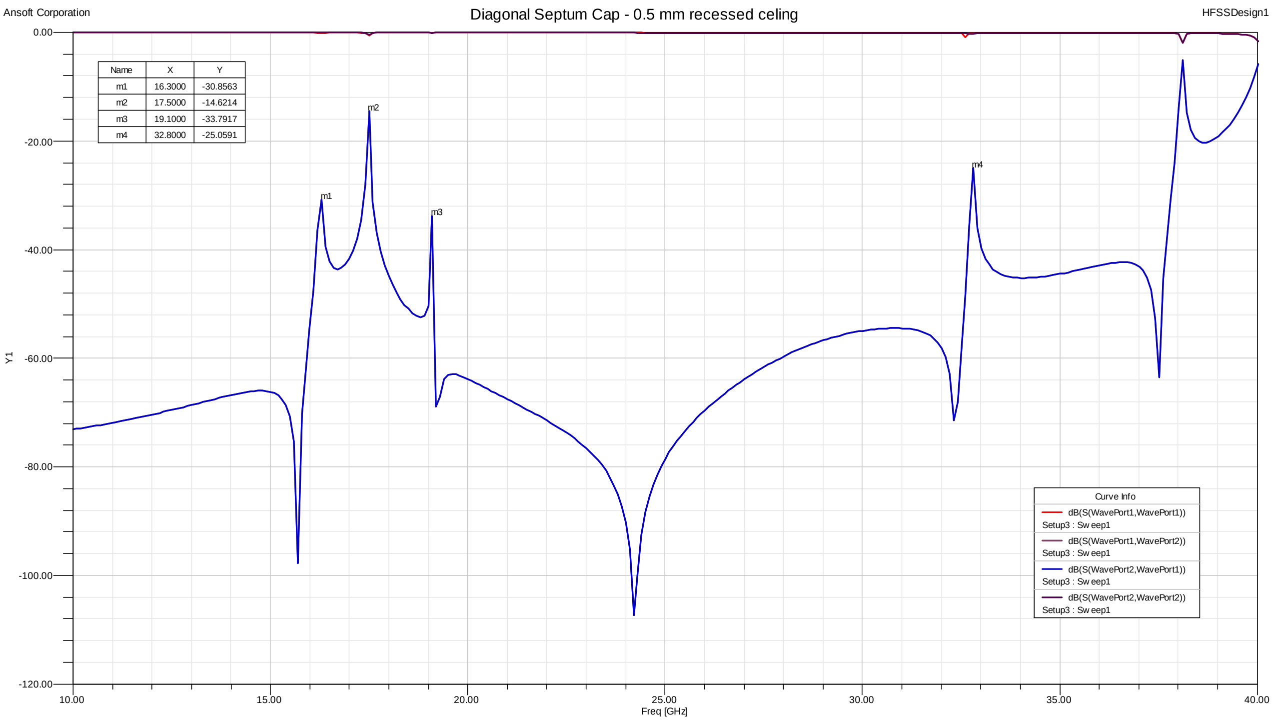


Fig.62 – Frequency response related to Fig. 60 configuration

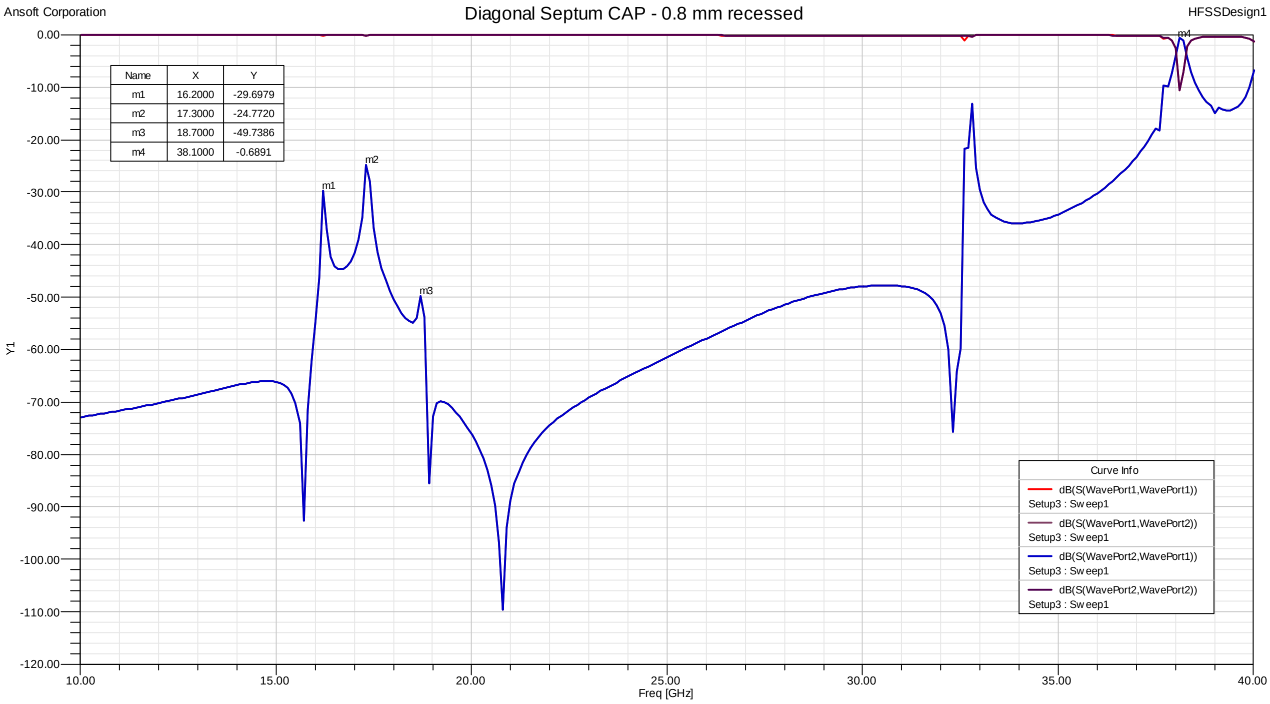


Fig.63 – Frequency response related to Fig. 60 configuration

This simulated response satisfies the requirements. We have only to short the septum in order to increase the room between walls and microstrip edges. Final shape is illustrated in the following chapter.

7 - And the winner is.....

When dimensions of the structure under analysis are far from the wavelength at which meshing has been optimised some fake spurious response could arise and predicted results could be not so accurate. In fig. 65 the cavity behaviour with the preferred cap shape is illustrated. In the frequency range between 15 to 21 GHz several simulations are reported. Continuous blue line is obtained with a broad sweep simulation based on meshing at 40 GHz. Red Dots are obtained with adaptive single point simulations at the markers frequencies. Dotted lines represent narrow band sweep simulation centred on red dots.

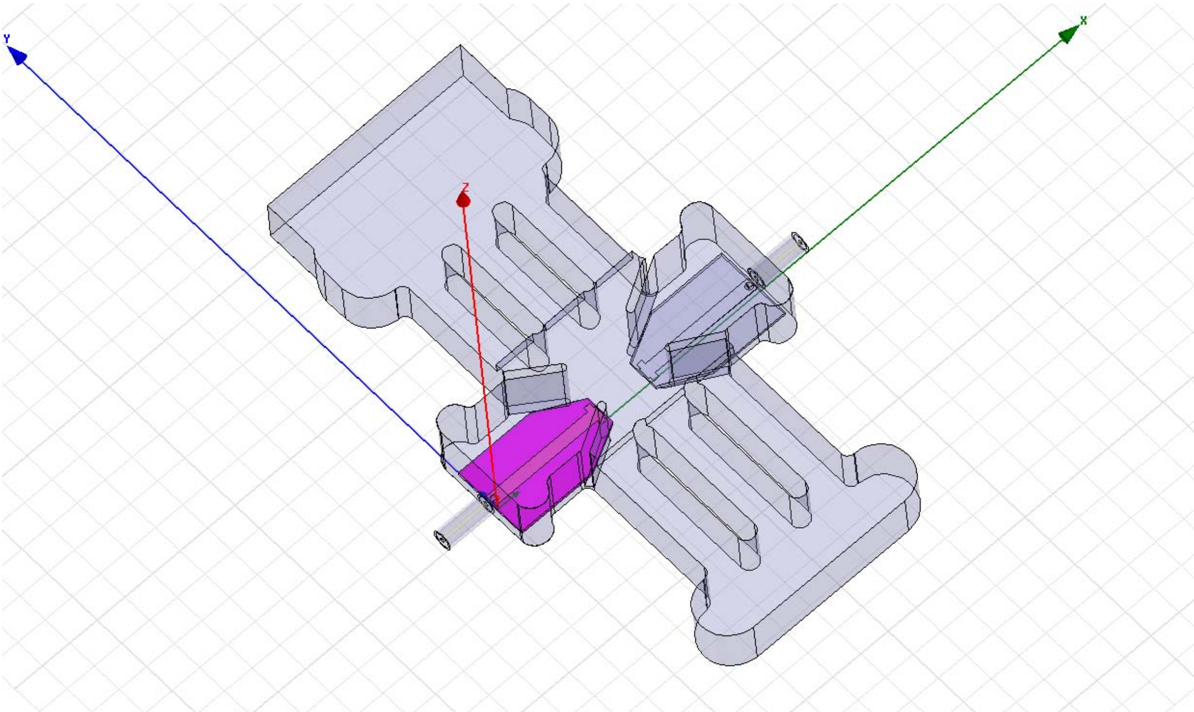


Fig. 64 – diagonal "short" baffle 0.8 mm recessed CAP preferred version

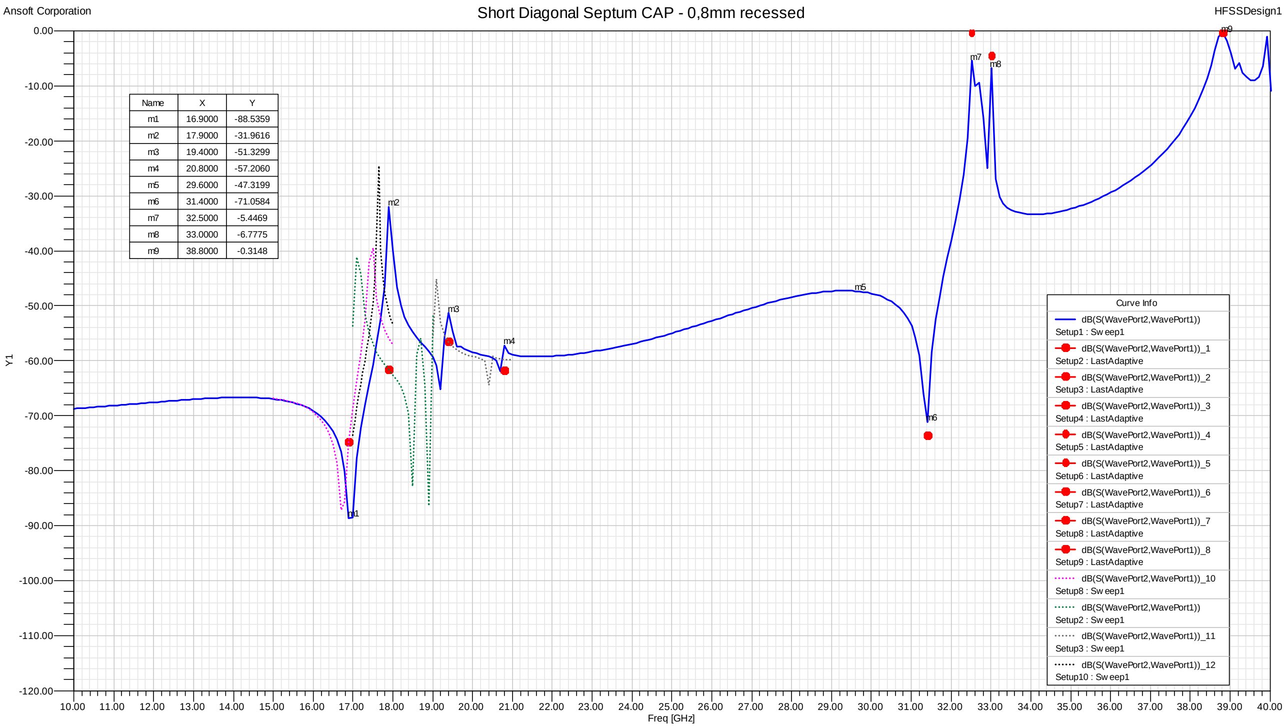


Fig. 65 – Frequency response related to Fig. 64 configuration