



Development of HTS filters at Yebes Observatory

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DE ESPAÑA

MINISTERIO
DE TRANSPORTES
Y MOVILIDAD SOSTENIBLE

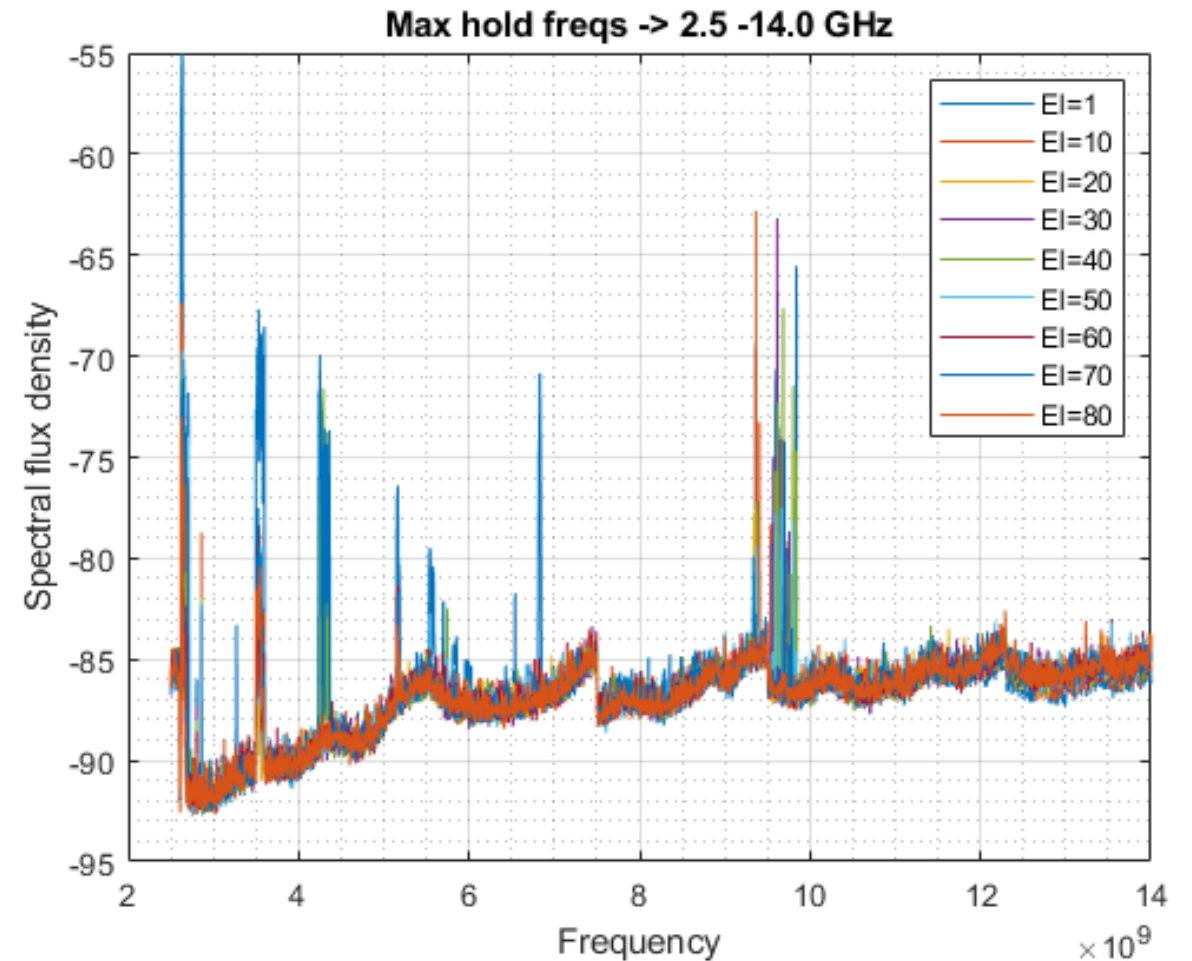
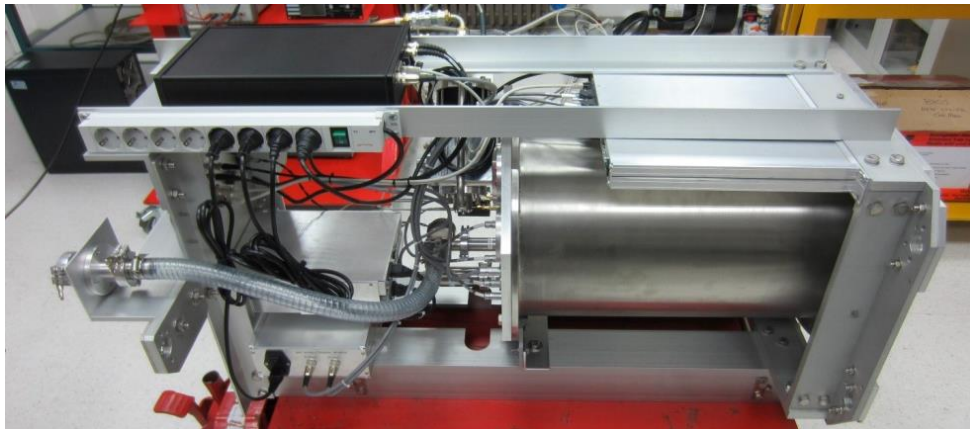


RAEGE
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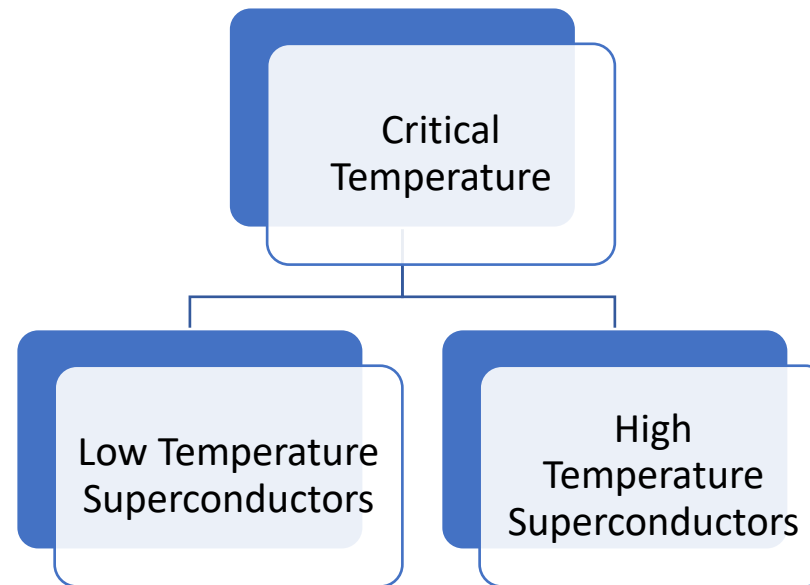
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- Introduction.
- High Temperature Superconductor (HTS) Filters.
- SLR Radar Notch Filter.
- S band Filter.
- CX Filter.
- RAEGE SMA Notch Filter.
- Conclusions.

- High sensitivity receivers with high gain.
- Very wide frequency band.
- Spectrum increasingly contaminated by RFI.
- Global coverage satellite networks.
- Degradation of receiver performance.



- Materials with the potential to conduct electrical current without resistance or loss of energy under certain conditions.
- Different types:

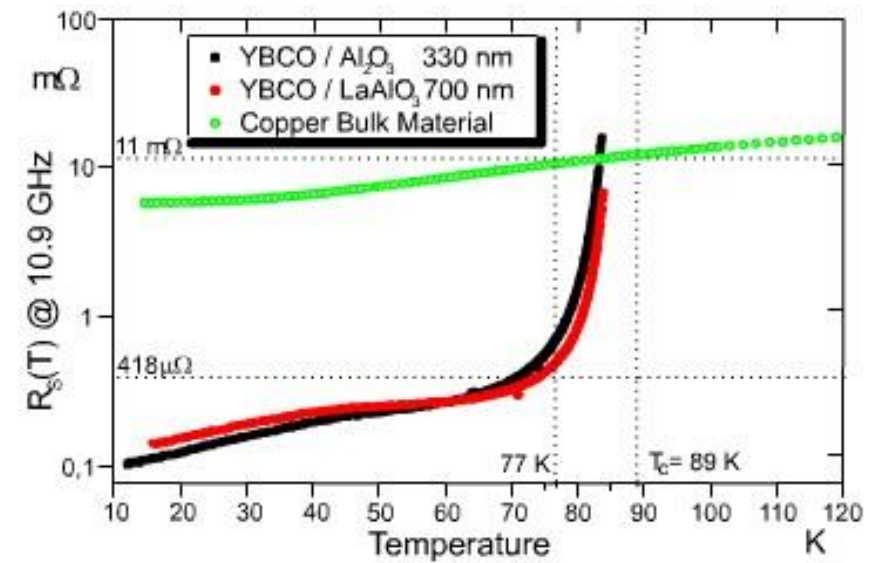
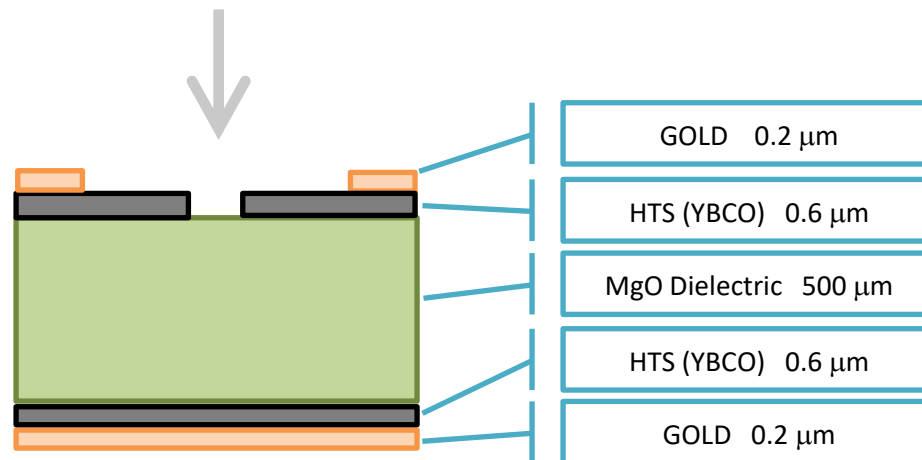


Substrates.

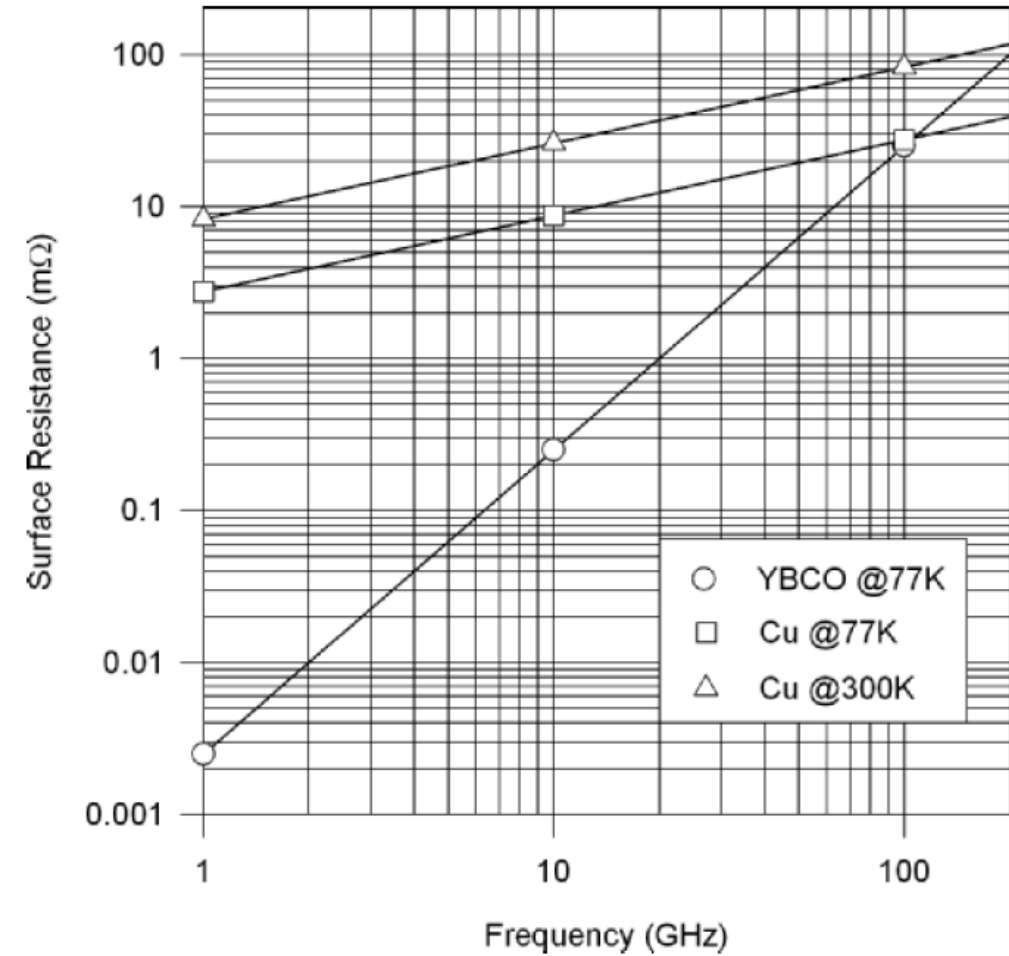
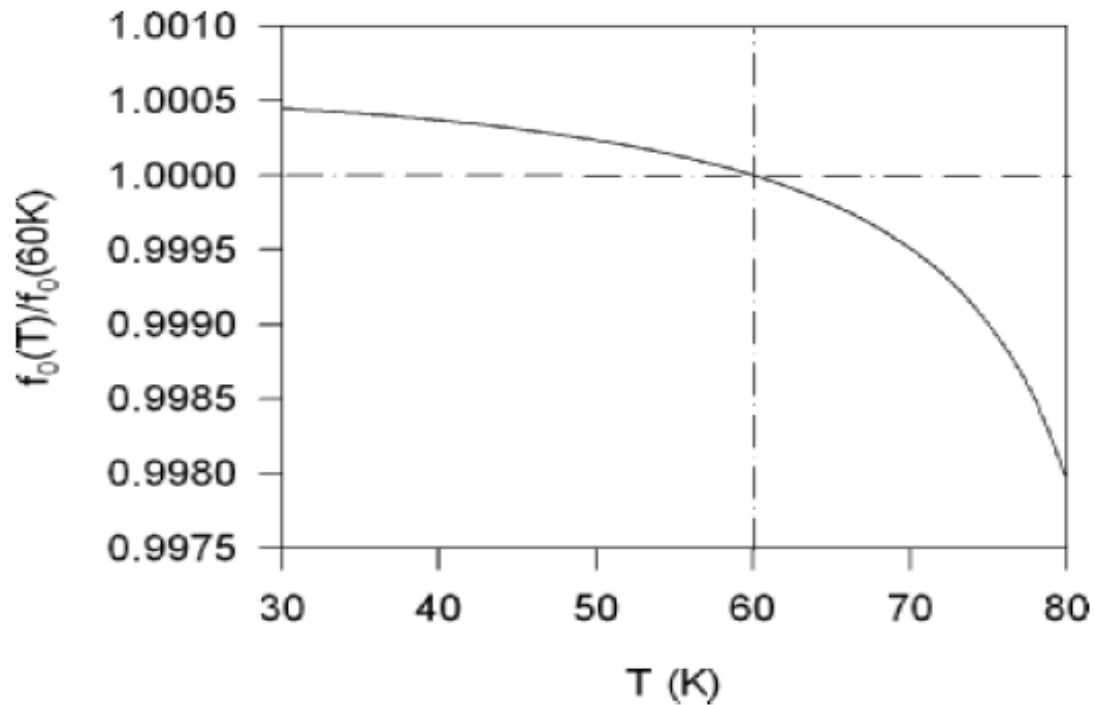
Substrate	Advantages	Disadvantages
MgO	<ul style="list-style-type: none">• Isotropic dielectric constant.• Low loss tangent.• Tolerances of less than 5 μm.	<ul style="list-style-type: none">• Prize.• Wafers limited to 7 mm or less.
Sapphire	<ul style="list-style-type: none">• Larger wafer size..• Prize.• Very good loss tangent.	<ul style="list-style-type: none">• Anisotropic dielectric constant.• Max film thickness limited to 330 nm
Lanthanum	<ul style="list-style-type: none">• Very high dielectric constant.	<ul style="list-style-type: none">• Small variations in dielectric constant.

- HTS: YBCO.
- Substrate MgO $\epsilon_r = 9.65$.
- Gold deposition to improve soldering.
- Very fragile.

Ion Beam Milling



Hong et al. "Microstrip filters for RF/Microwave applications". Wiley series. 2001

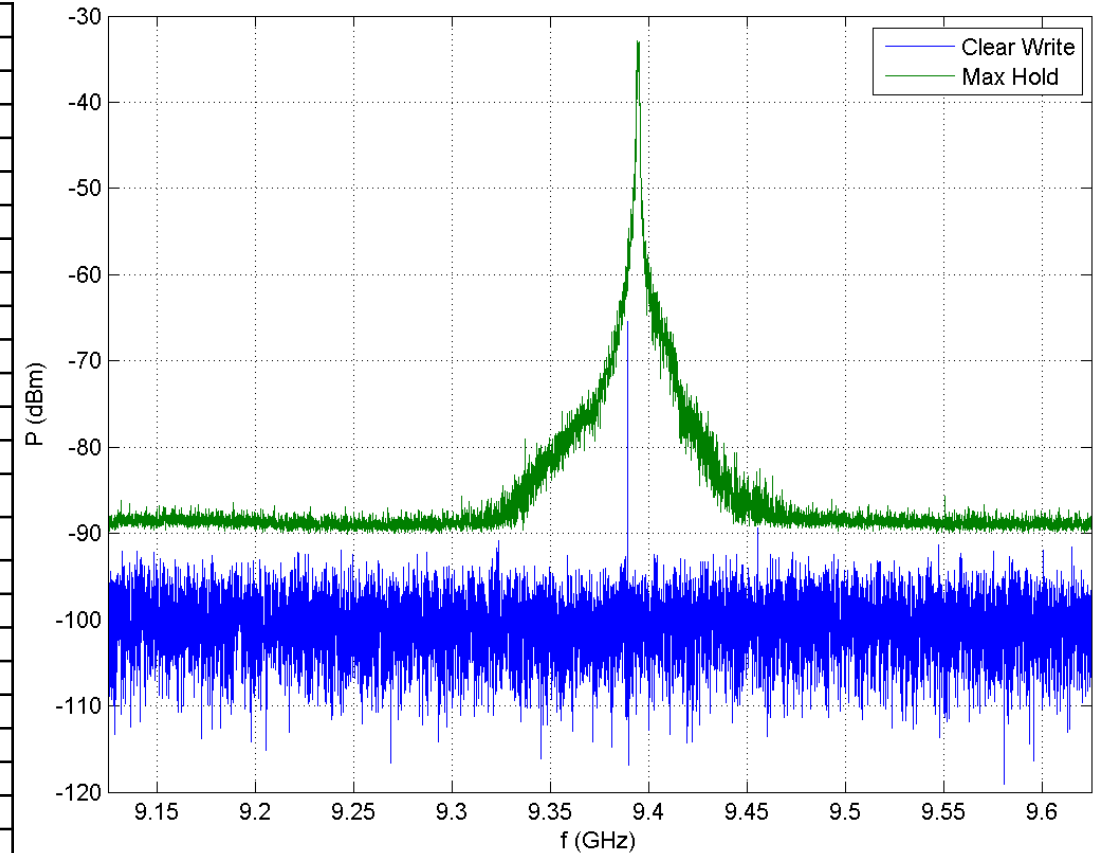


- The Yebes Observatory has made VGOS receivers for different stations of the network.
- HartRAO and Matera stations have an SLR station with active radar at 9.41 GHz.
- In [1] the Goddard station reports problems with this type of radar and shows an HTS filter design.
- Another solution was designed in Yebes optimised for these stations.

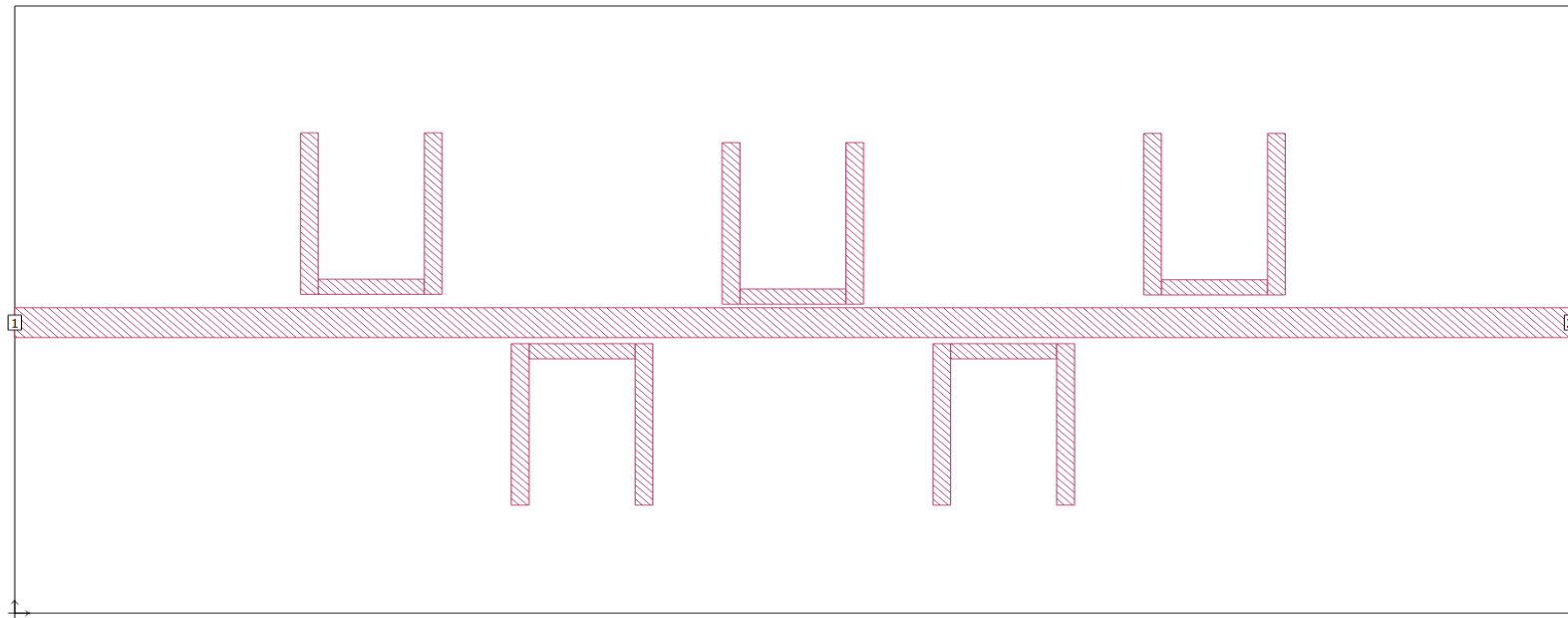
[1] Turner, Charles J., et al. "Superconducting Notch Filter for RFI Mitigation in Ground-Based Radio Telescope." IEEE Transactions on Applied Superconductivity (2023).



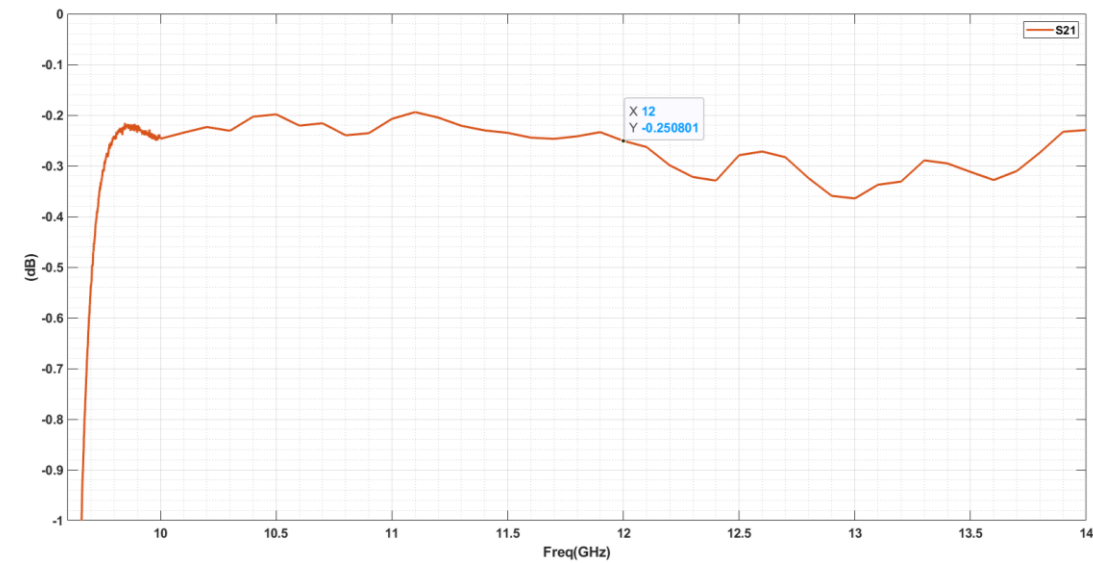
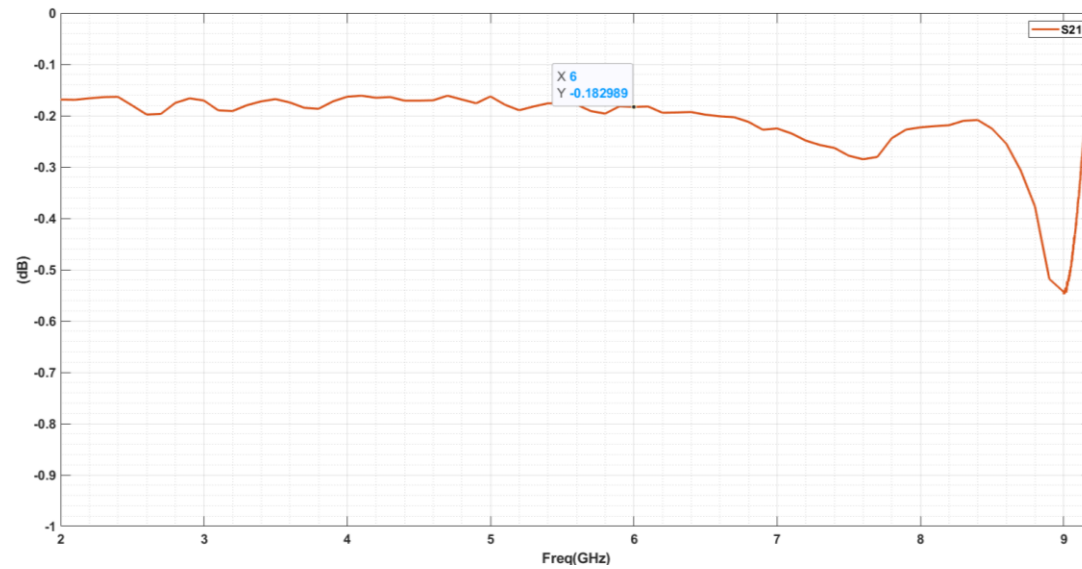
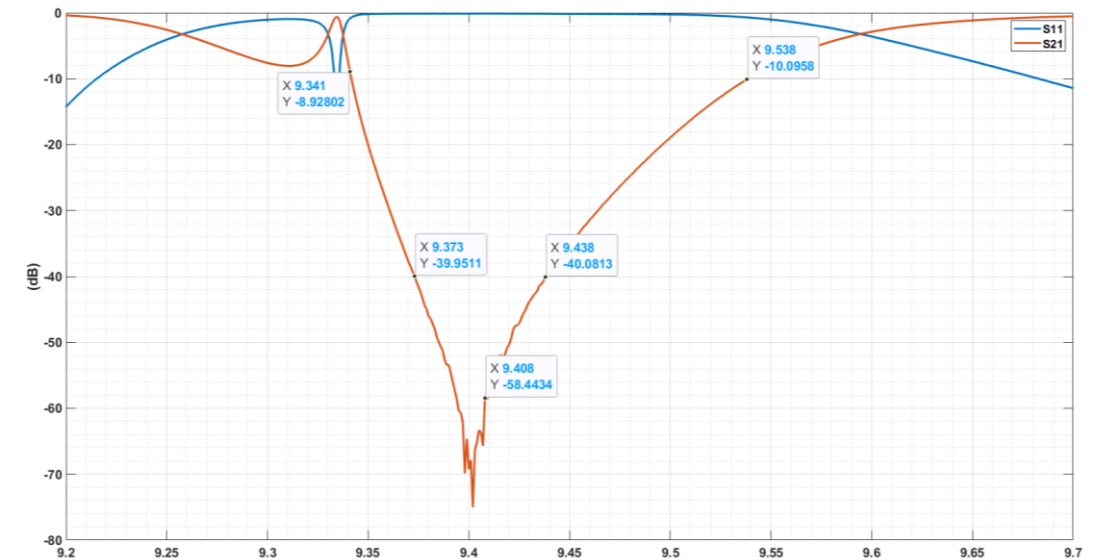
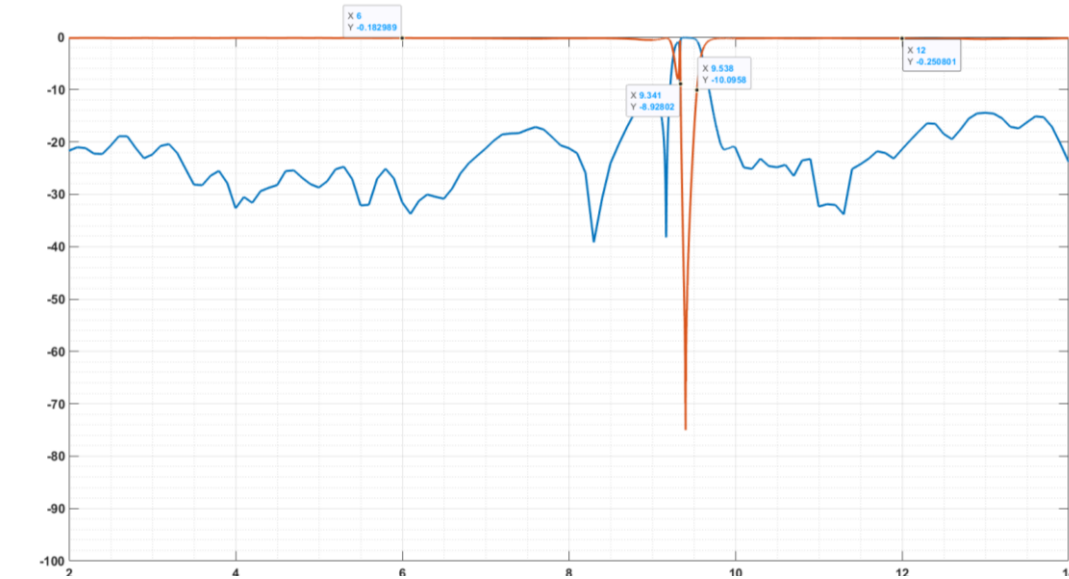
RF Characteristics	
Frequency	9410 MHz \pm 30 MHz
Peak Power Output	4kW (2.1 watts CW)
Pulse Repetition Frequency (PRF)	750 Hz
Pulse Width	700 nsec
Duty Cycle	0.000525 (1/1904)
IF Amplifier	
Center Frequency	60 MHz
Bandwidth	3 MHz at -3 dB
Overall Noise Figure	Under 6 dB
Antenna Dish	
Diameter	83.82 cm
Gain @ 9.4 GHz	36.5 dB
Beam Width @ -3 dB	2.8 degrees
First Side Lobe	-23 dB at 12 degrees
Second Side Lobe	-30 dB at 20 degrees
Tracking Characteristics	
Slaving Elevation	Above 10°
Transmit Elevation	Above 15°
Radome	
Insertion Loss	1 dB (2 to 10 GHz)



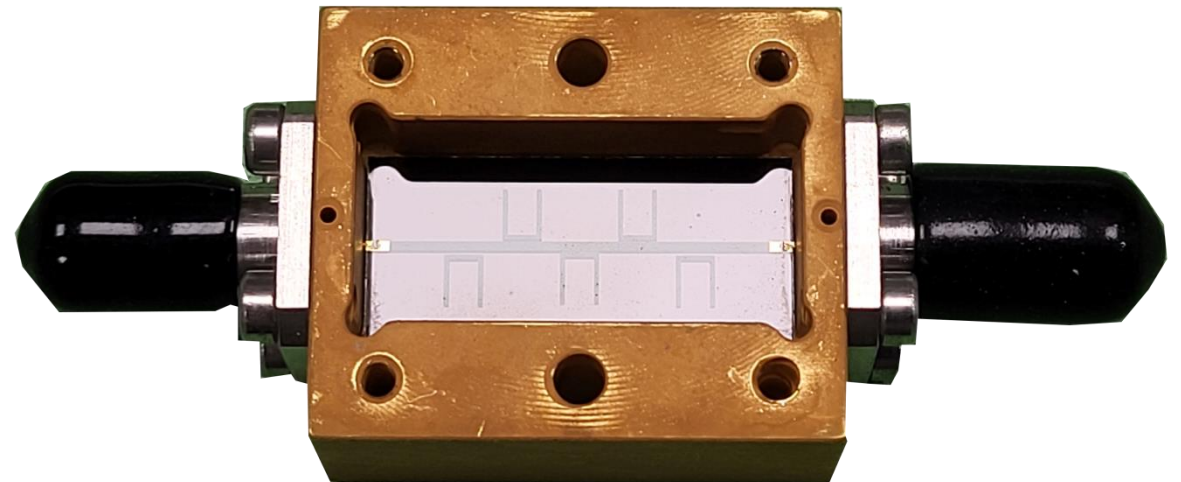
- $F_c=9410$ MHz.
- 22 mm x 10 mm.
- Hairpin Resonators.
- Order 5.



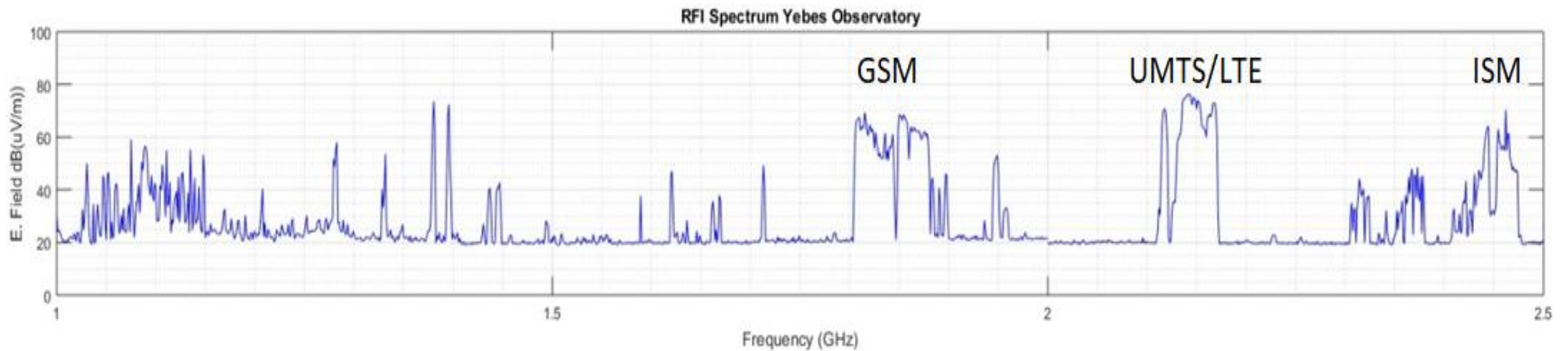
Results.



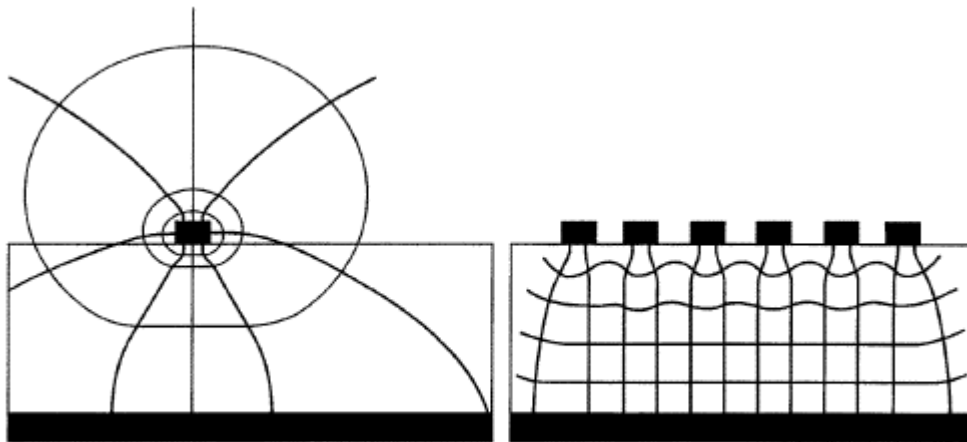
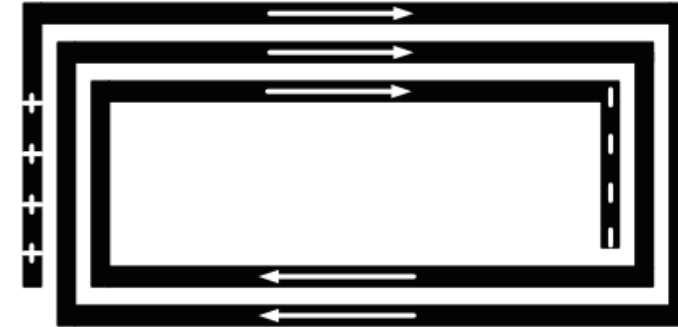
	Measured results.
Frequency	2 - 14 GHz
Matching	< - 14dB
IL	< 0.35 dB
IL (9.37 – 9.44 GHz)	> 40 dB
IL (9.385 – 9.42 GHz)	> 50 dB



- S band receiver.
- 2.2-2.37 GHz.
- Very close to high power RFI, 2.18 GHz and 2.4 GHz.

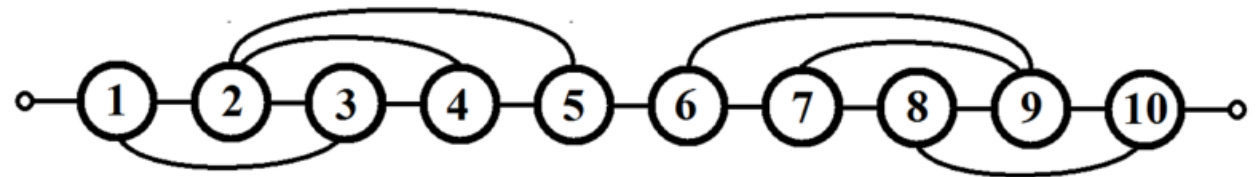


- Spiral resonators.
 - Miniaturisation.
 - Immunity to manufacturing tolerances.
 - High Q.
 - Reduction of second harmonic influence.
- Couplings obtained by simulations.
- Adjustment of cross couplings.

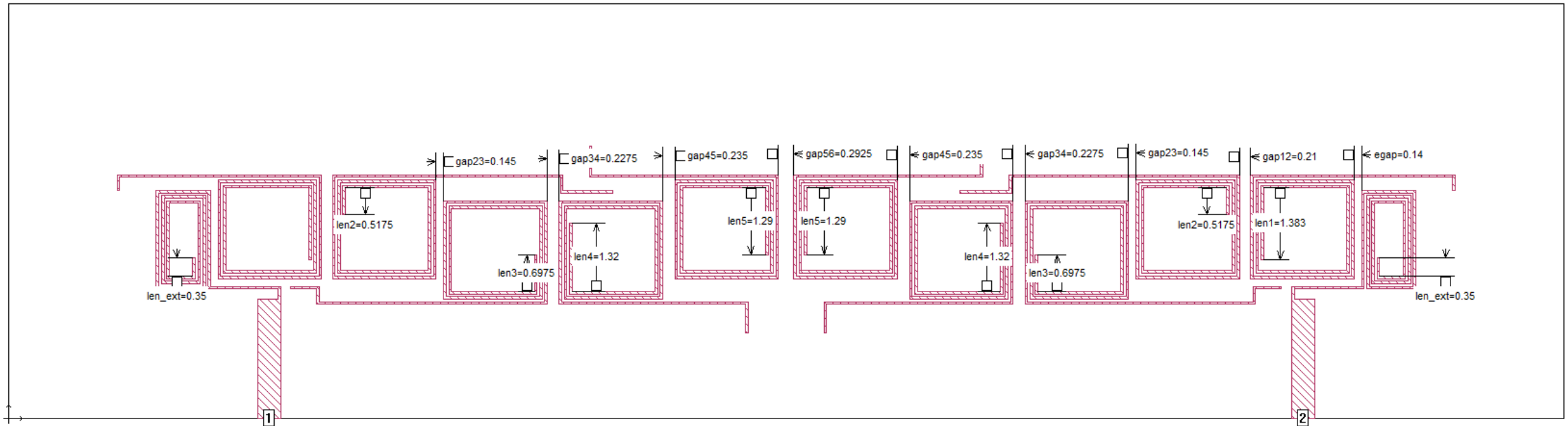


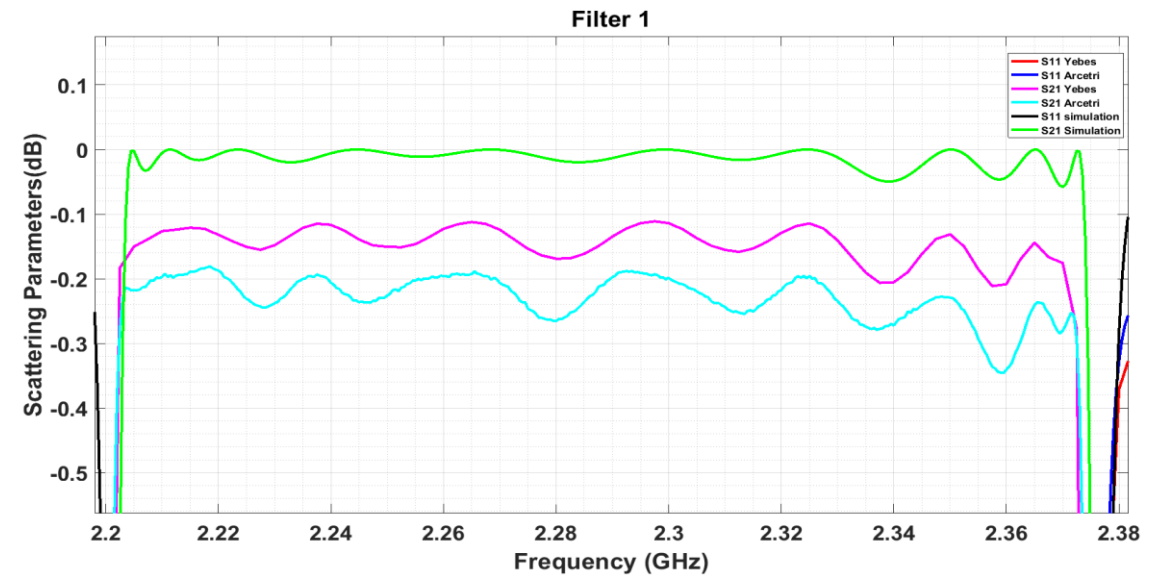
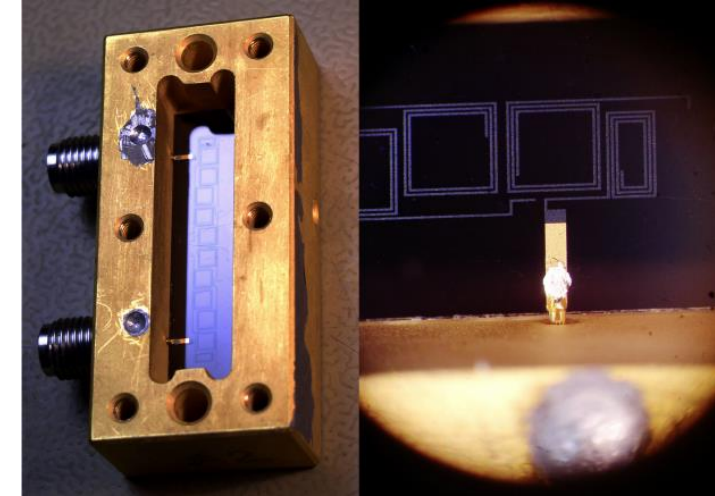
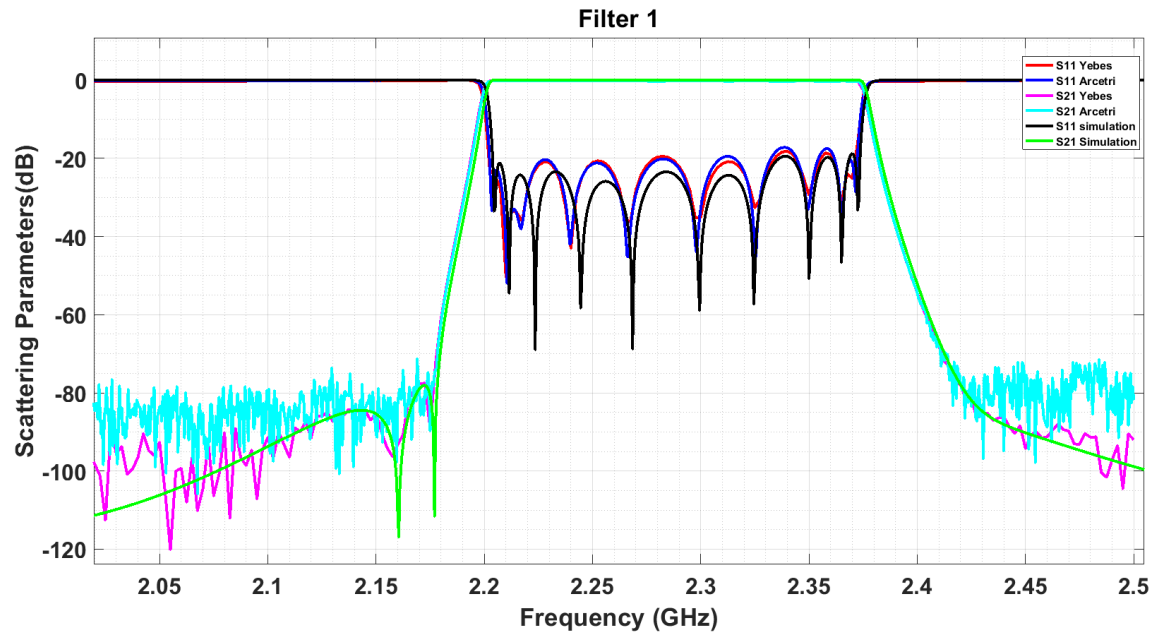
(a)

(b)



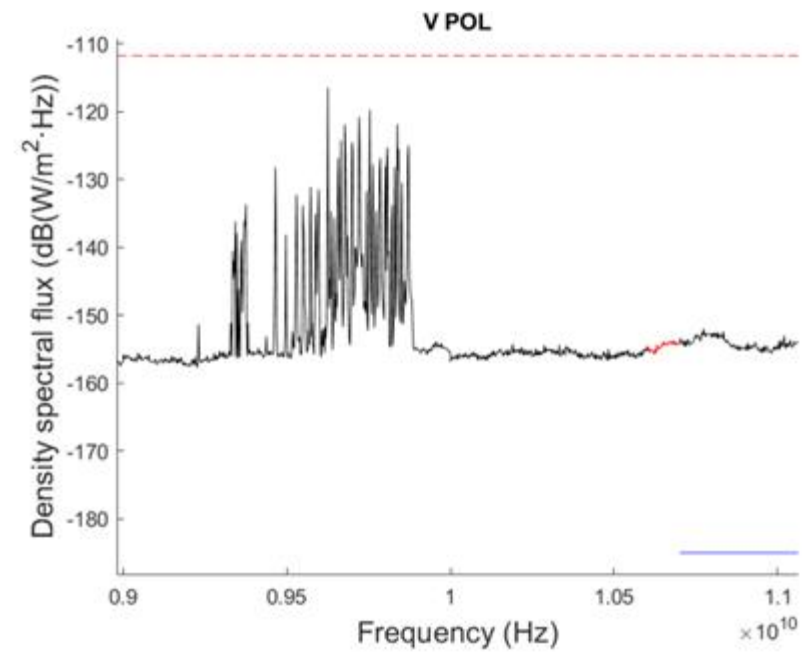
- $F_c = 2295$ MHz
- Order 10
- FBW= 7%.
- 30mm x 8 mm
- Att at 2.18GHz > 60dB
- Att at 2.4 GHz > 30 dB



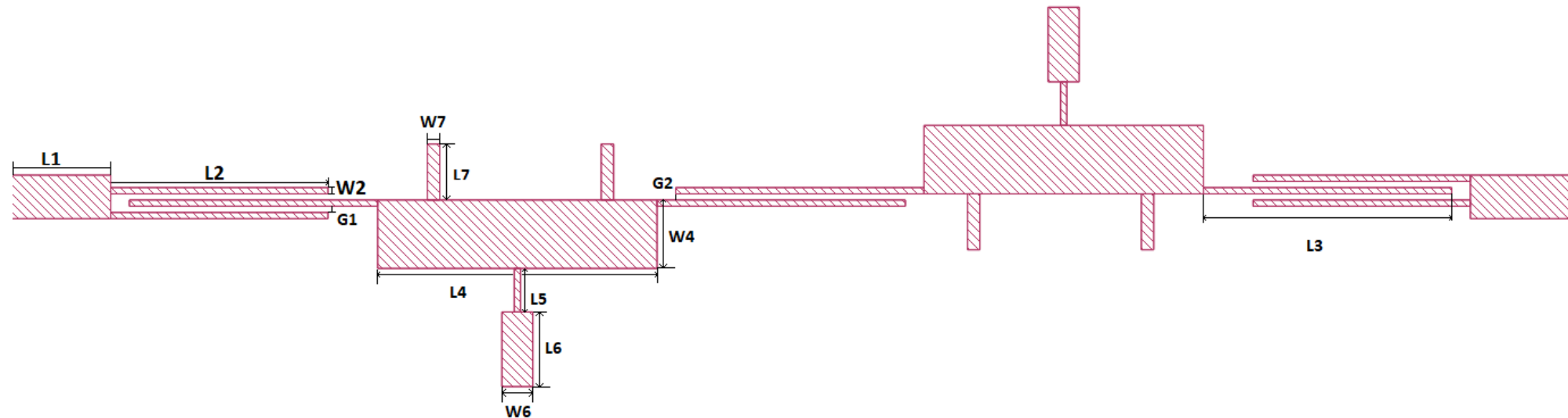


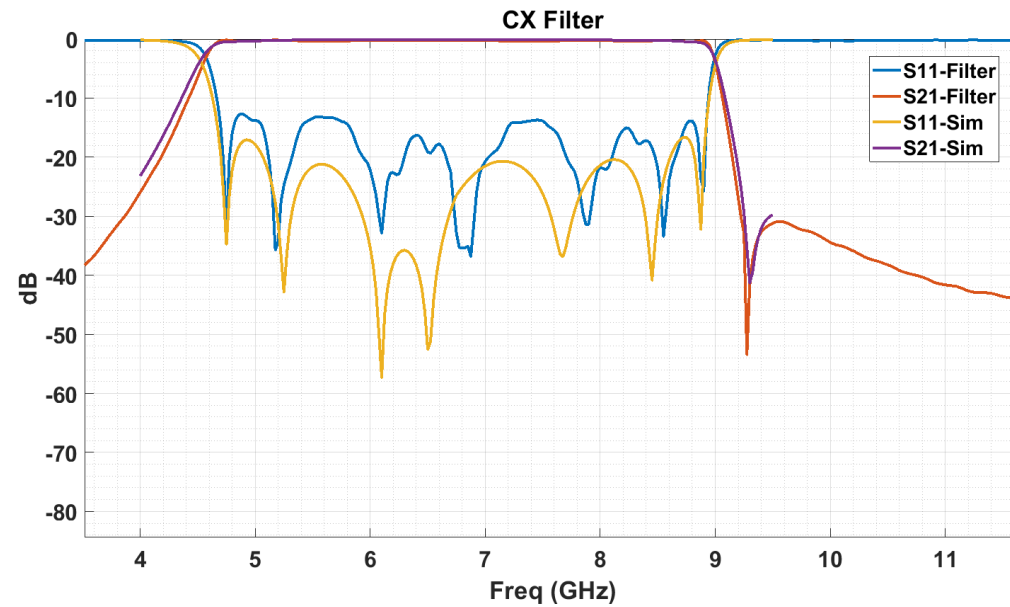
[1] Huang, F., et al. "Superconducting spiral bandpass filter designed by a pseudo-Fourier technique ." *IET Microwaves, Antennas & Propagation* (2018).

- CX Band.
- Receiver used in the EVN
- 4.5-9 GHz.
- Problems with RFI from air radars.

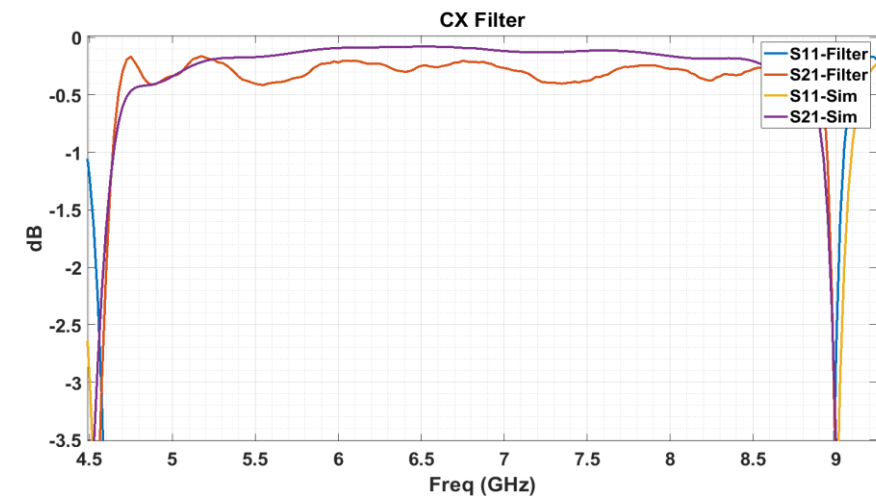
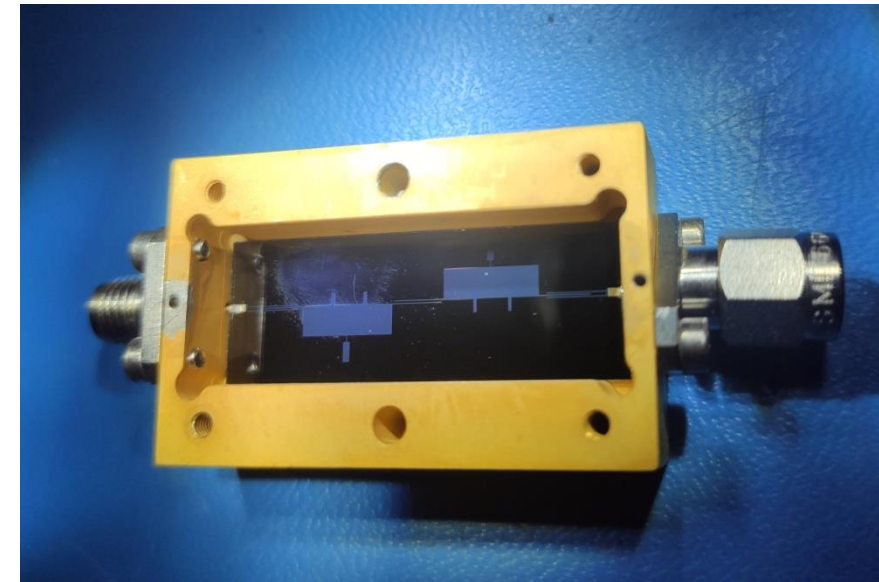


- $F_c=6750$ MHz
- FBW= 66.6%.
- 33.5mm x 6 mm
- MMR Structure
- Improved coupling by means of interdigital lines



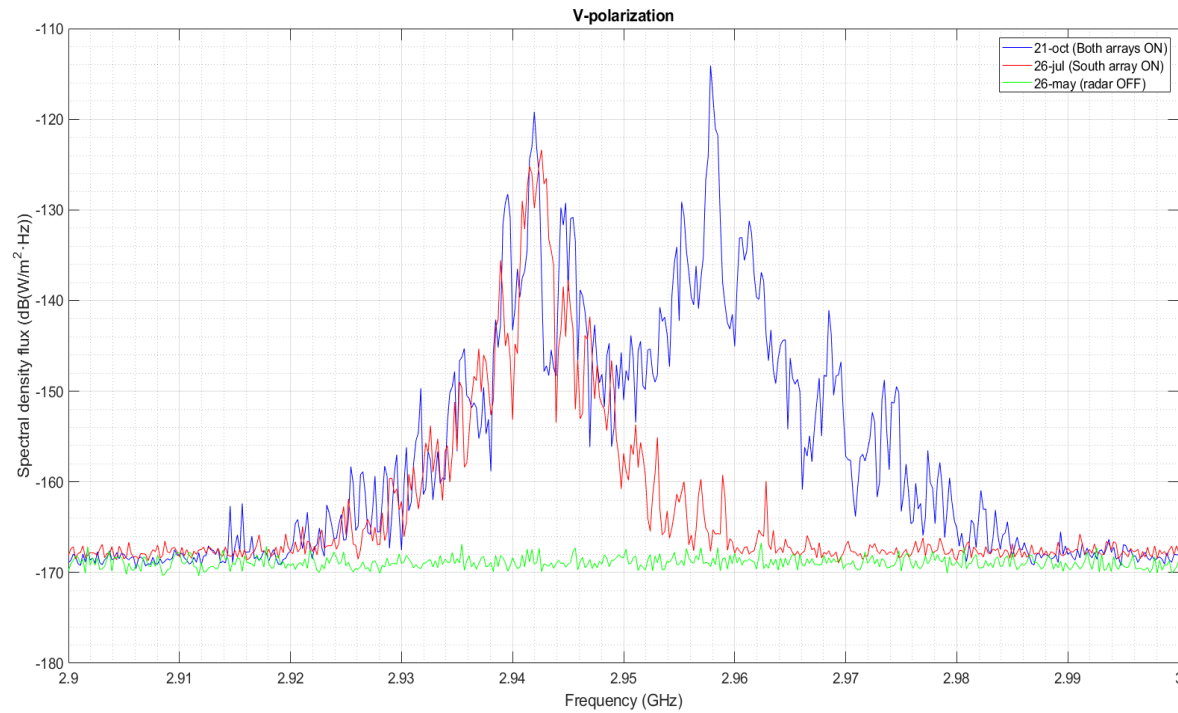


Filtro	IL, dB	RL, dB	3-dB FBW %
[48]	<0.4	>15	30
[69]	<0.35	>15.7	30
[84]	<1.3	>10.6	111
[85]	<0.9	>10	96.4
[86]	<0.3	>15.7	120.2
Filtro CX	<0.4	>13.2	66.6

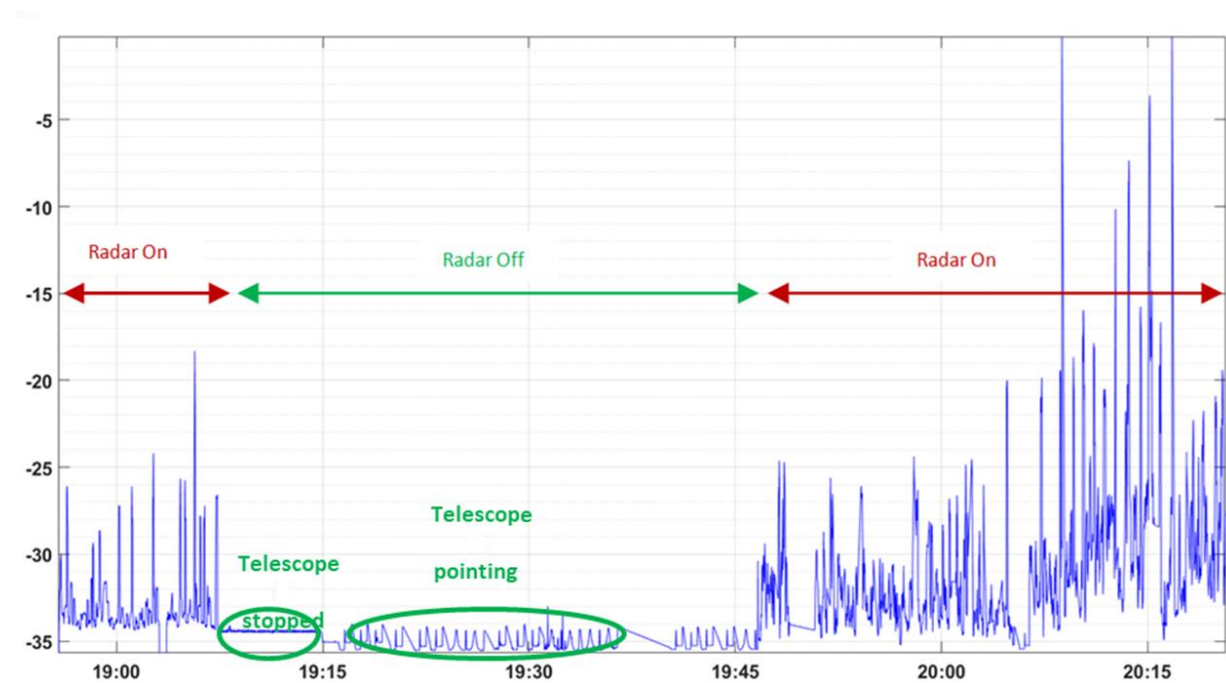


- RAEGE Sta Maria station is located next to space debris radar.
- Emission at 2.942 y 2.958 GHz.
- Saturated and intermodulated receiver.
- VGOS A-band 3-3.5 GHz.

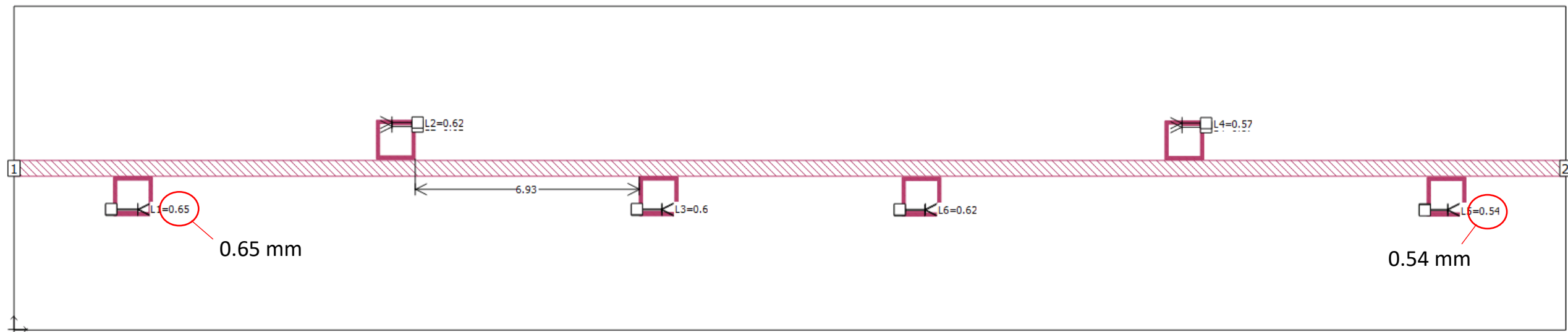




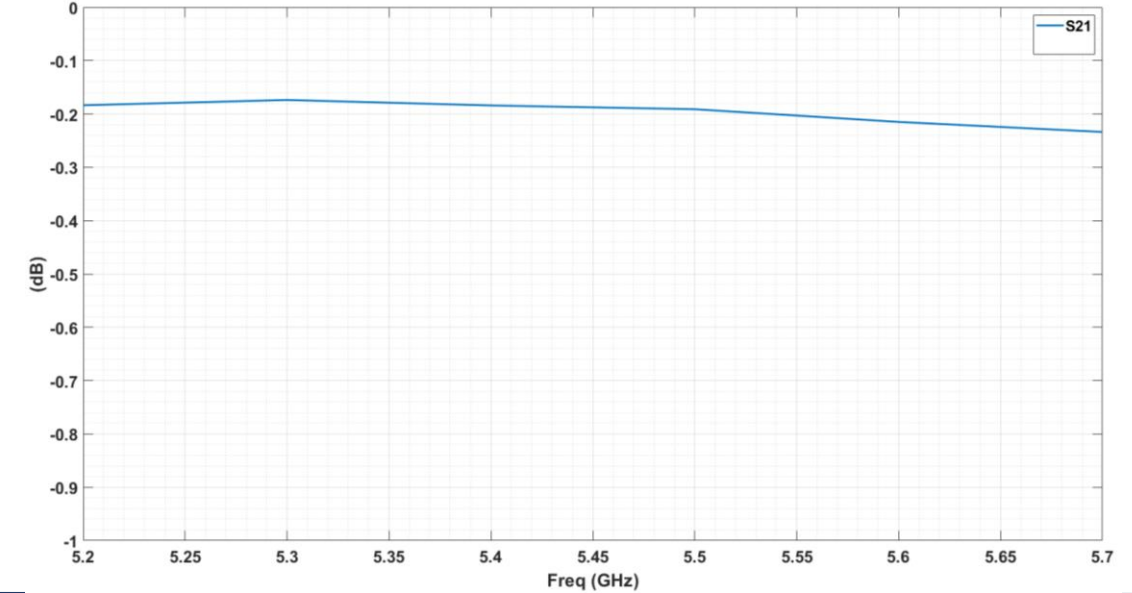
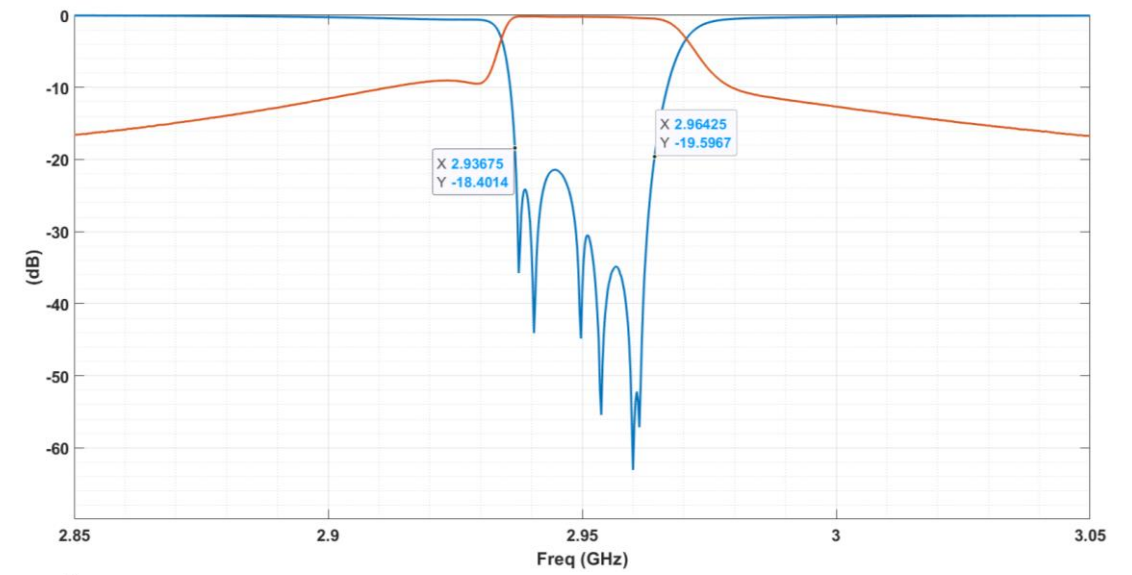
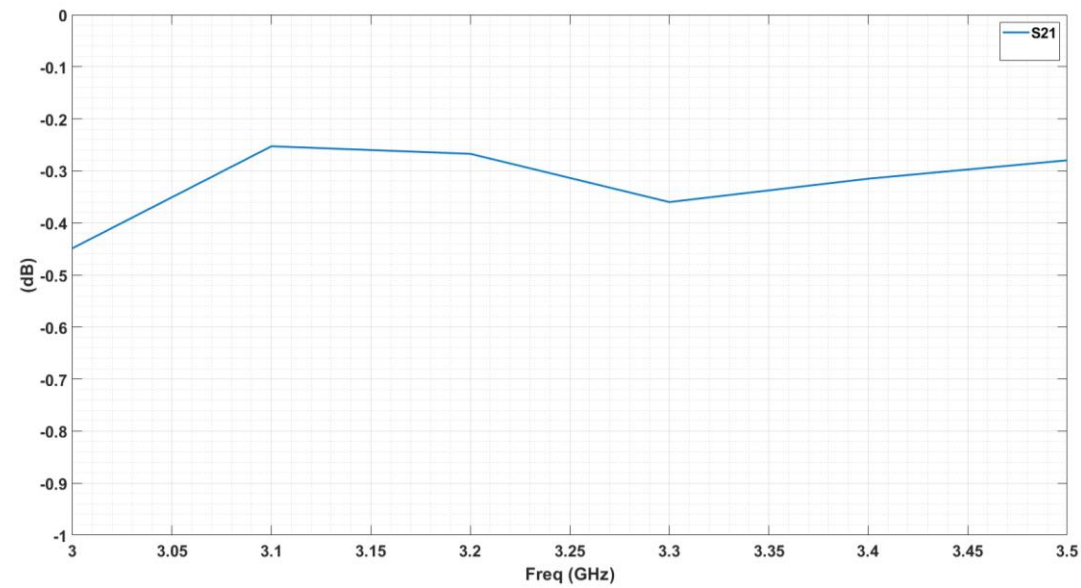
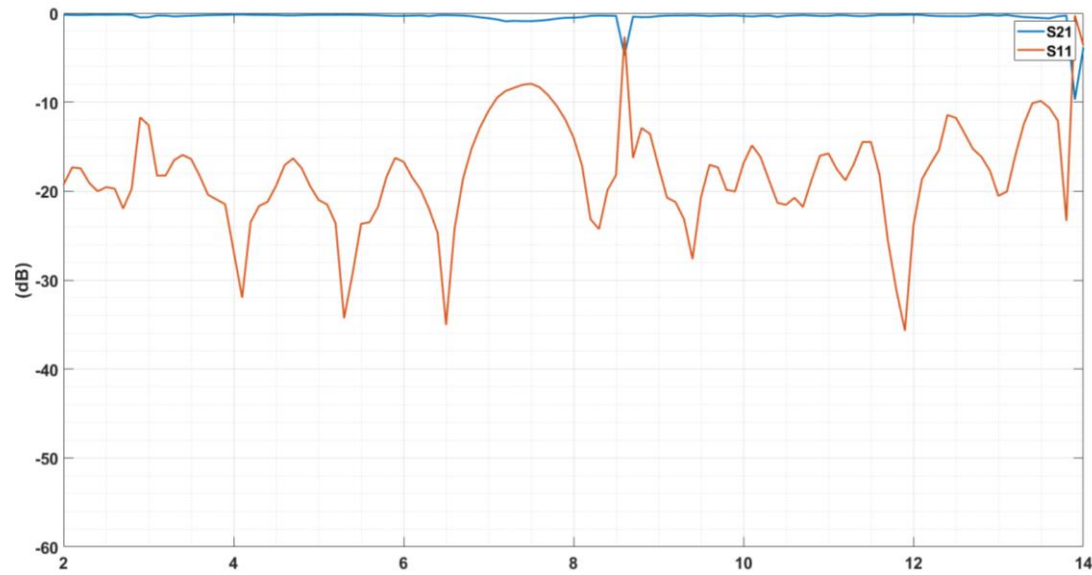
- First tests with VGOS receiver (Radar ON and OFF):



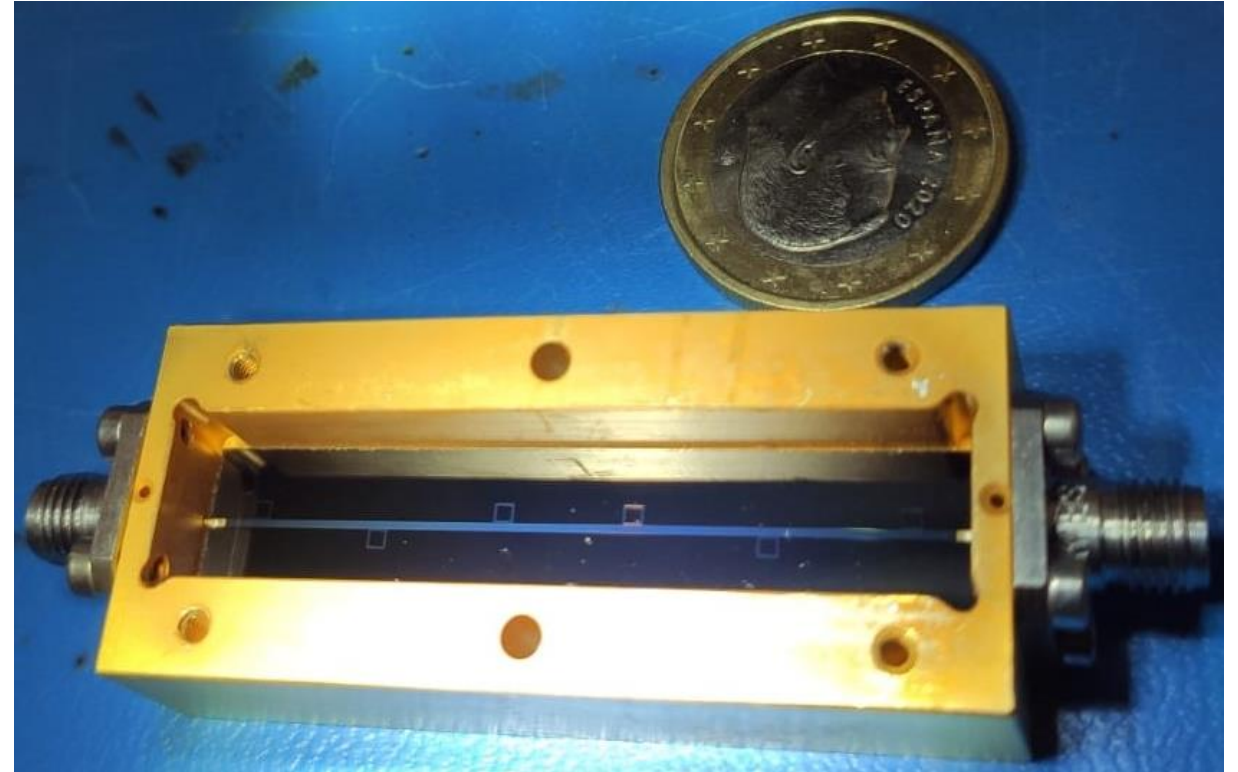
- $F_c=2950$ MHz
- 48 mm x 10 mm
- Coupling Spirals.
- Order 6

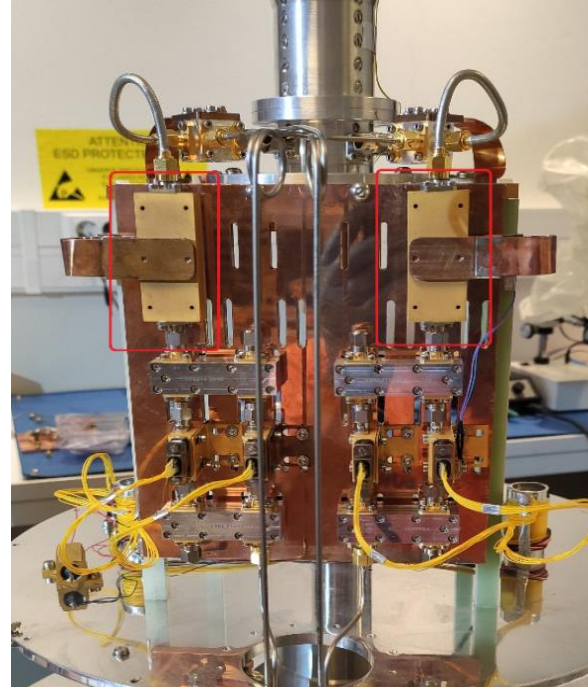
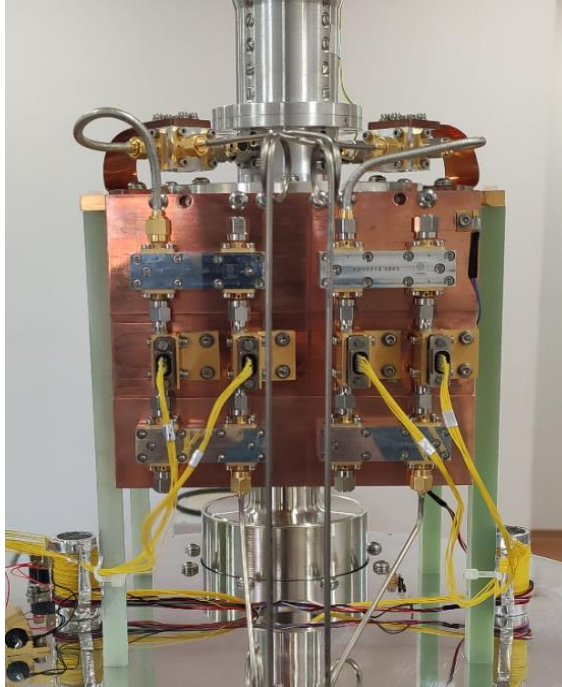


Results.



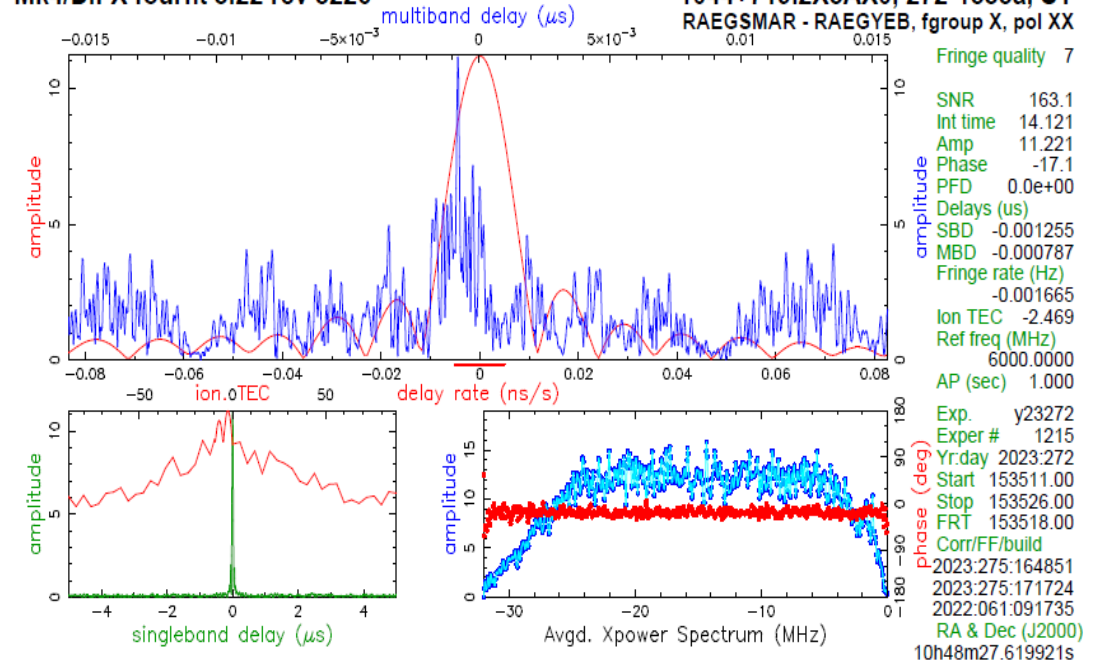
	Measured results.
Frequency	2 - 14 GHz
Matching	< -12 dB
IL	< 0.35 dB
IL (2.94 – 2.96 GHz)	> 20 dB





Mk4/DiFX fourfit 3.22 rev 3226

1044+719.2X5AX0, 272-1535a, SY
RAEGSMAR - RAEGYEB, fgroup X, pol XX



- RFI is a growing problem, therefore Yebes Observatory has initiated a line of development of HTS Filters.
- Very good results in terms of losses, however, difficult to work with.
- Valid designs for RFI suppression in RAEGE Sta Maria.
- Frequency limited, very difficult to adjust, topologies limited by not being able to use ground vias.
- Complex and fragile technology

- Currently working on new designs.
- UWB filter of FBW=150%.
- Methods for tuning highly resonant filters.
- Spurious rejection over a large bandwidth.
- Use of several notches to eliminate different interferences.
- Higher frequency work, cavities?, new substrates?
- Open to collaboration.



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