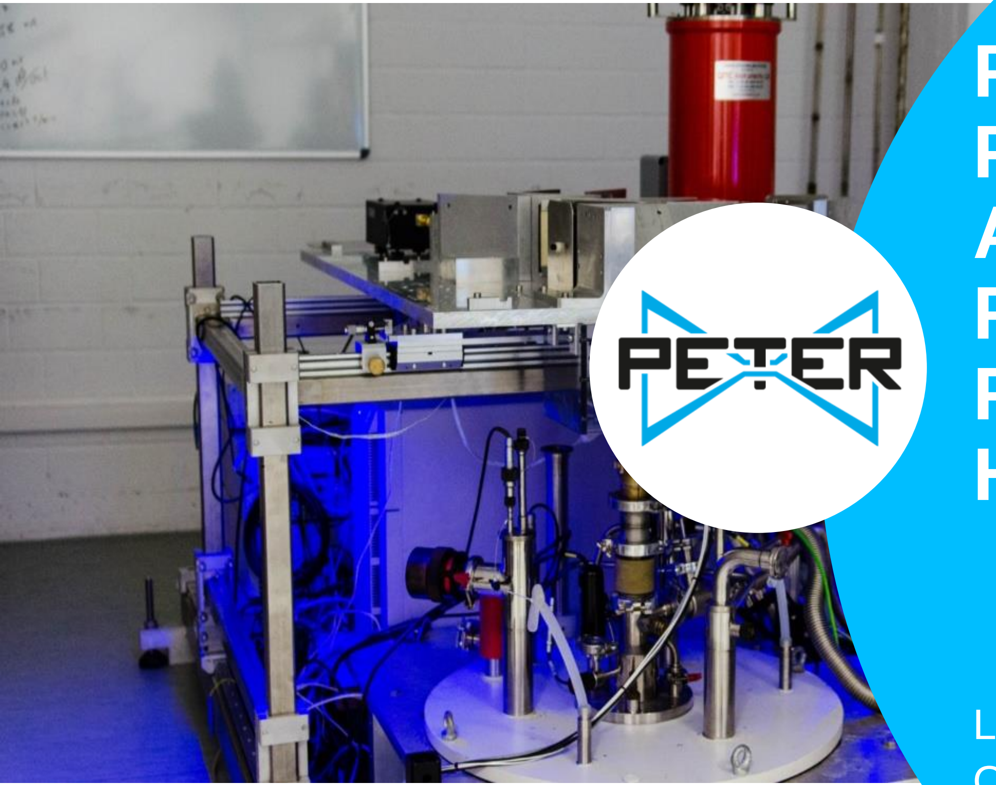
Universität Stuttgart
Institut für Physikalische Chemie



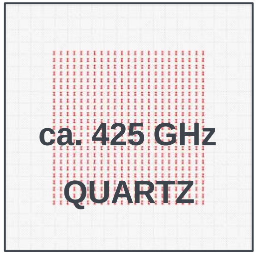
Preliminary Results on Plasmonic Antenna Arrays for Magnetic Field Enhancement. From Simulations to HF-EPR Measurements

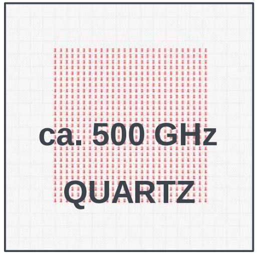
Lorenzo Tesi – PETER Meeting
October 2019

Part I
Experimental Characterization
and
Simulation of the NG Antenna Arrays Resonance

Part I – Antennas from Nanogune

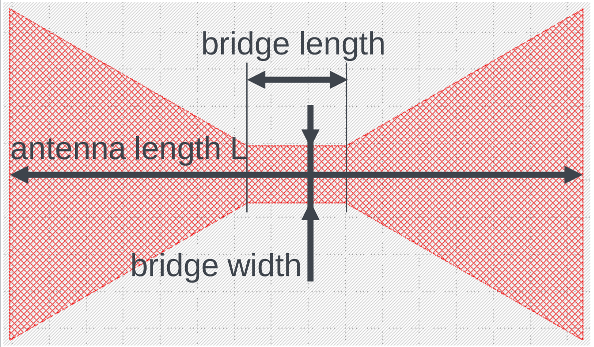
For Stuttgart

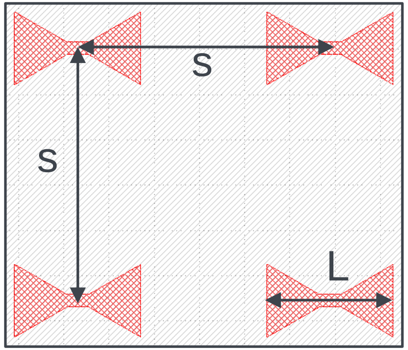




- fabricated
- measured with our TDS THz system
- delivered to Stuttgart

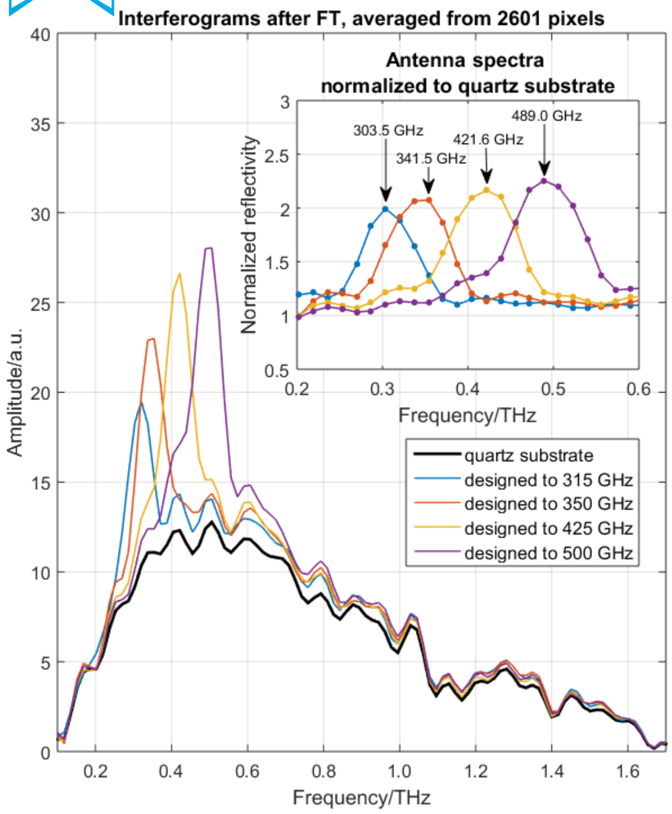
Notation explained:



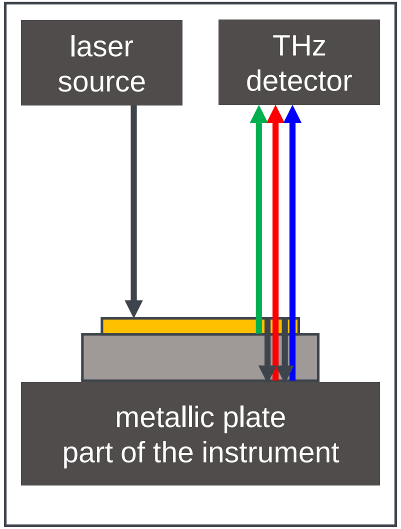


Fabrication shortly (direct laser writing):

- **quartz** substrate: thickness ca. 1000 µm, size 10x10mm
- **silicon** substrate: size 10x10mm, resistivity >10K, double-side polished
- **cleaning:** acetone, IPA and DI water ultrasound baths (5min), nitrogen for drying
- **spincoating**: pre-bake 100°C, 60s; AZ 1505 (positive photoresist) ca. 60 µl/cm^2 , acc 2000, 4000rpm, 60s; hard-bake 100°C, 60s; resulting into cca 500 nm thick photoresist layer
- **patterning**: Heidelberg µPG 101, resolution up to 1 µm, parameters: 5mW, 25%
- **development**: 30s in developer, 60s stopper DI water; post-bake: 100°C, 60s;
- **metal deposition**: 3nm Ti by e-beam evaporation
  140nm of Au by thermal evaporation
- **lift-off**: ca 16 hours in acetone, then quick ultrasound bath



Comment:
Spectral resolution of our setup is based on the time delay between the first (green) and the second (red) reflection shown in the scheme of the experimental setup – as that is the region we use for the Fourier transform. In this case, the spectral resolution is ca. 67 GHz – the actual measured points are marked in the graph inset.

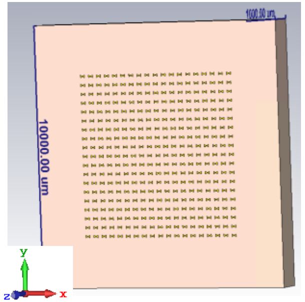


Antennas on QUARTZ for Stuttgart - overlook				
resonance / GHz		designed antenna dimensions / µm (real dimensions differ in ±1µm)		
designed	measured	antenna length	bridge length	bridge width
315	303.5	187.14	32.42	18.71
350	341.5	168.43	29.18	16.84
425	421.6	138.71	24.03	13.87
500	489.0	117.90	20.42	11.79

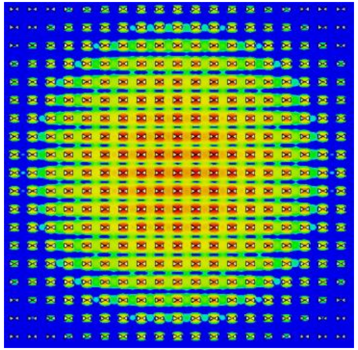
Part I – Simulations by CST Studio: 350 GHz Antenna

The electromagnetic behaviour of the antenna arrays (315, 350 and 425 GHz) of Nanogune have been simulated. The source is a polarized Gaussian Beam propagating towards the direction -z. The magnetic field is detected in a square of 10x10 mm in two positions (Near Field and Far Field) and when the antennas are active (E_0) or inactive (E_{90}).

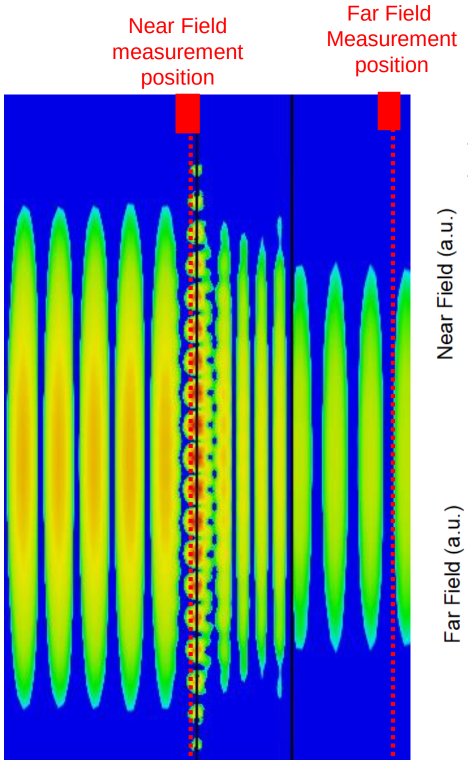
19x19 antennas array
+ 10x10x1 mm of quartz support
+ Gaussian beam (polarized)

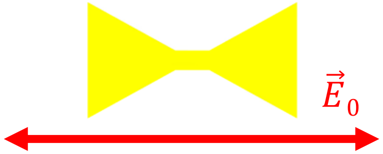


Magnetic Field
view from top (z direction)

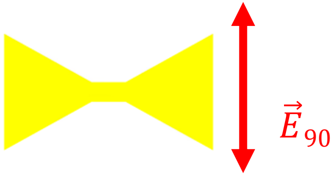


Magnetic Field
view from side (x direction)

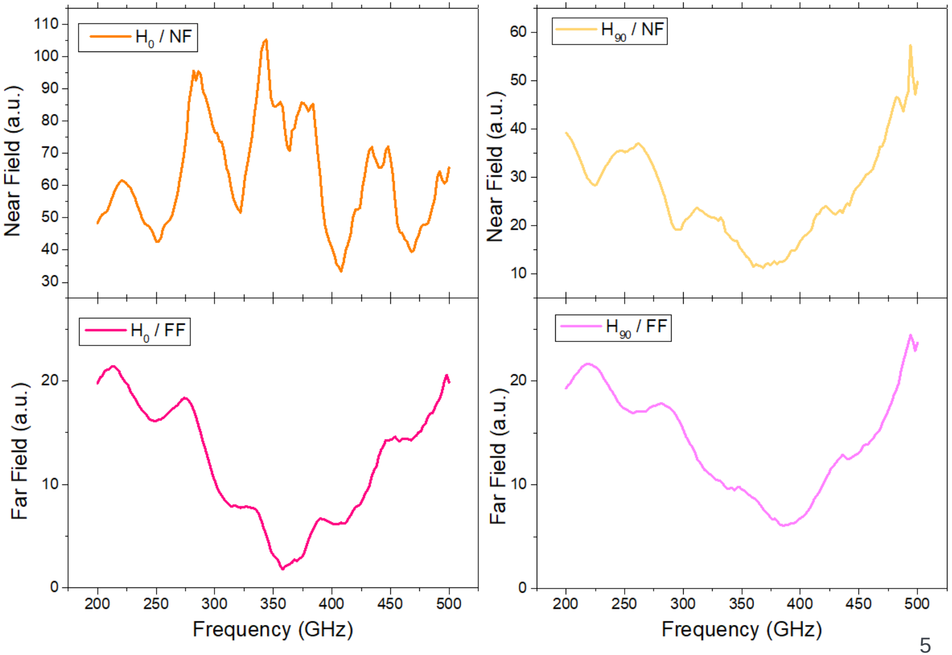




Electric Field coupled to antennas

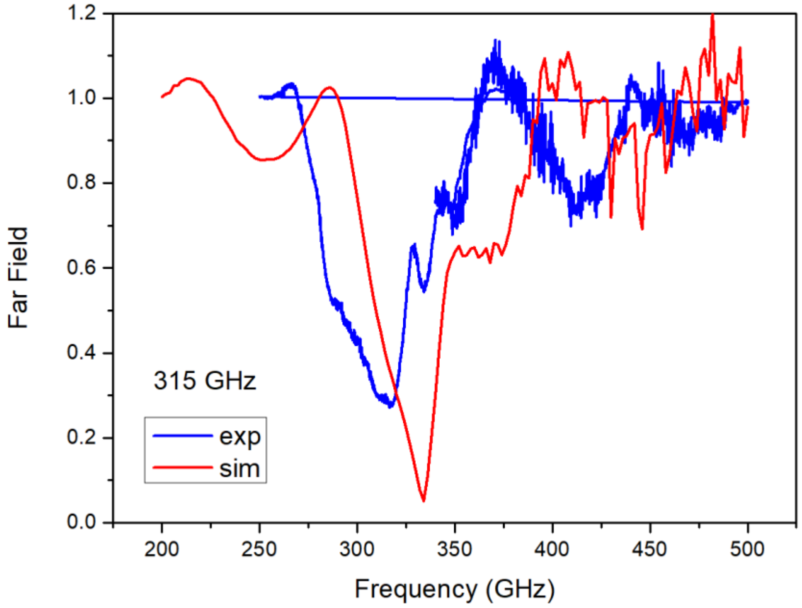


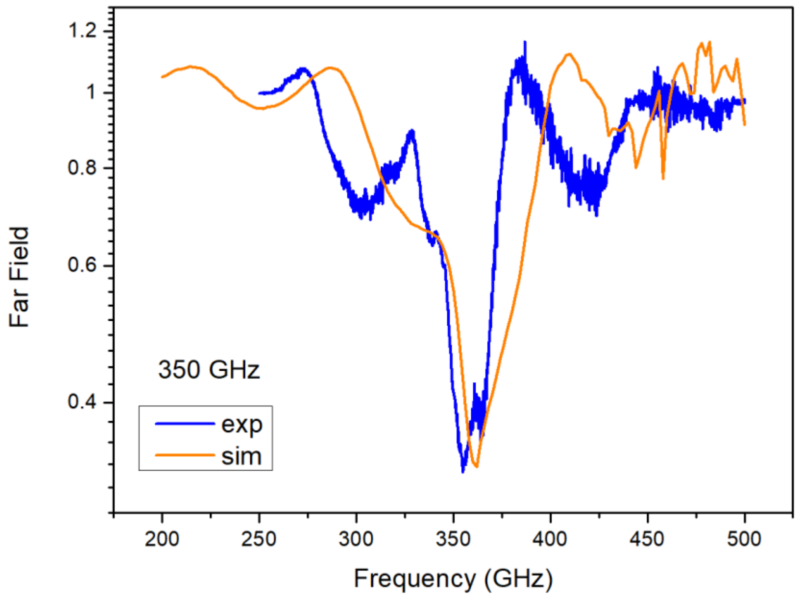
Electric Field not coupled to antennas



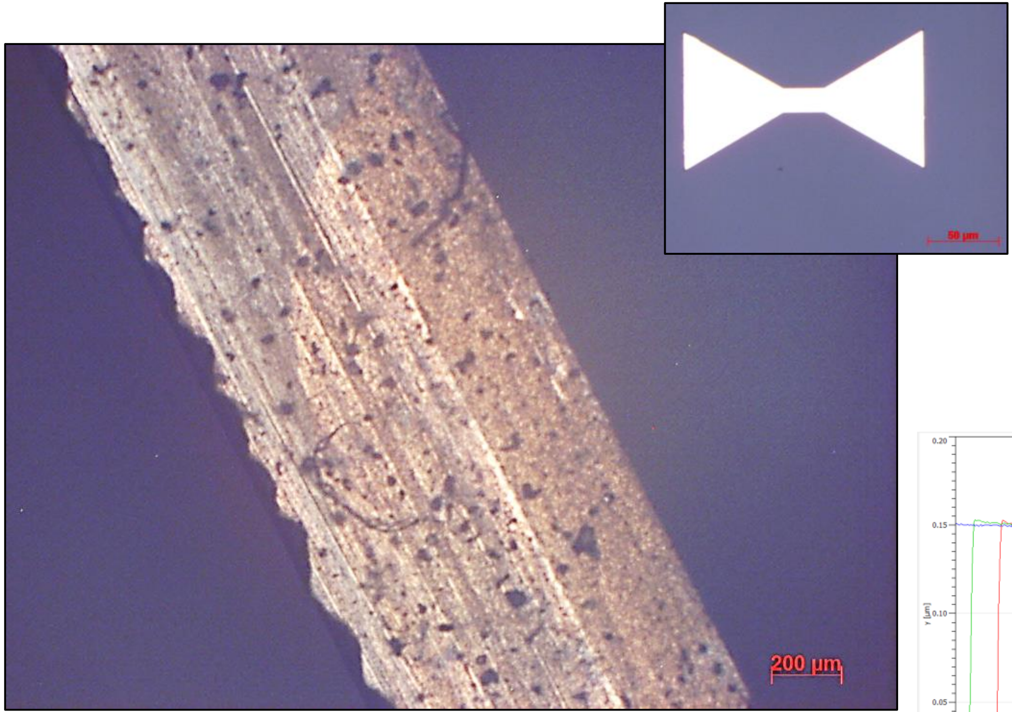
Part I – Simulations by CST Studio: 350 GHz Antenna

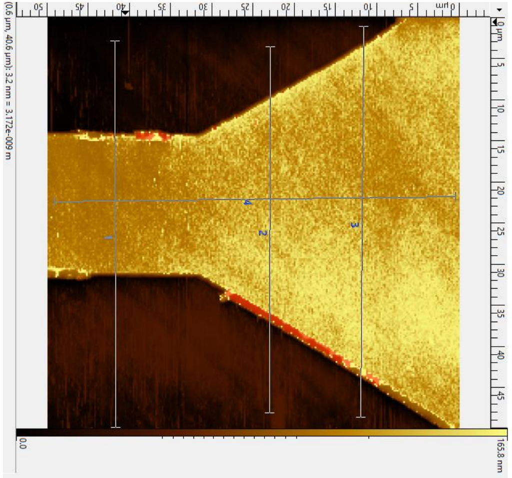
Ratio between 0 deg and 90 deg Far Field measurements for the 315 and 350 GHz antenna arrays, compared to the transmission measurements performed by Dominik → $\frac{H_{0\,FarField}}{H_{90\,FarField}}$

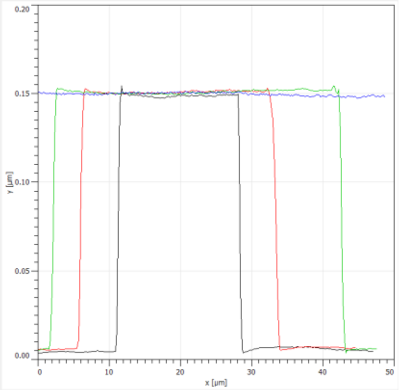


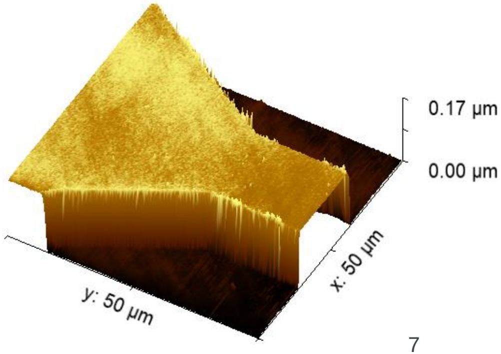


Optical Microscope + AFM Measurements on 350 GHz Antenna

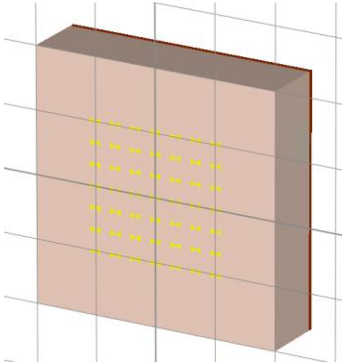






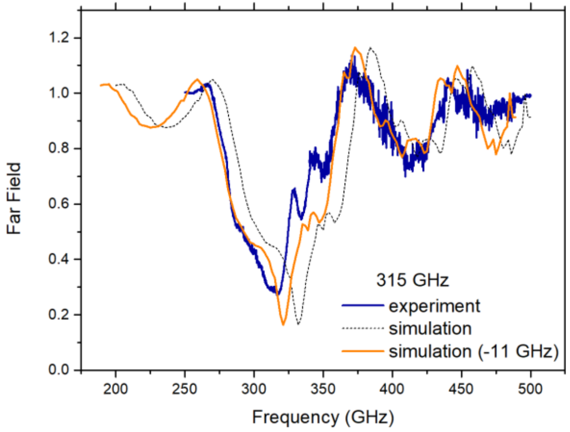


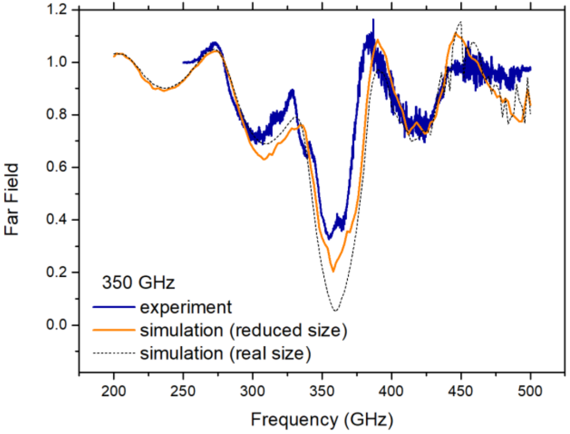
Part I – Simulations by CST Studio: 350 GHz Antenna

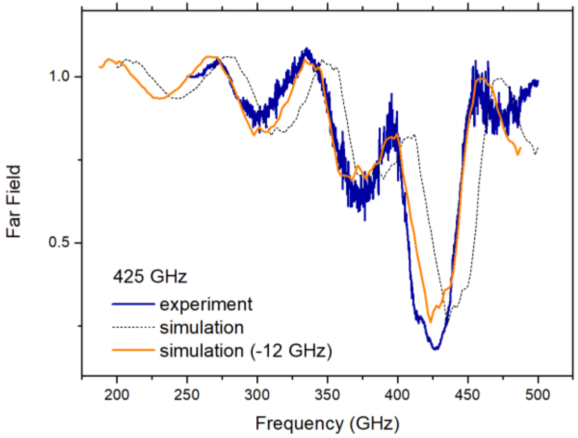


7x7 antennas array
+ 4x4x1 mm of quartz support
+ Gaussian beam (polarized)
+ ca. 60 μm of Epoxy Layer

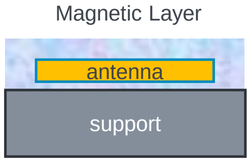
- Coating modelled as epoxy layer on the back of the support;
- With the inclusion of the epoxy layer, good match between experiment and simulation;
- The dimensions of the antenna array were reduced (from 19x19 to 7x7 antennas) since the result doesn't change (example shown for the 350 GHz antenna array);
- A systematic shift in x-axis still occurs: thickness of coating? Side of the support in which is present the coating? Coating material?





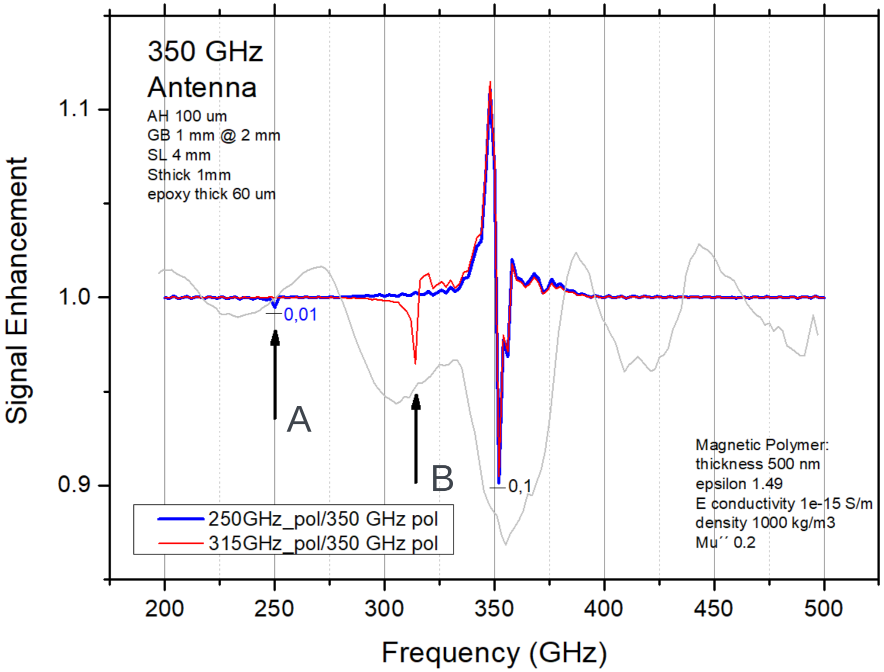


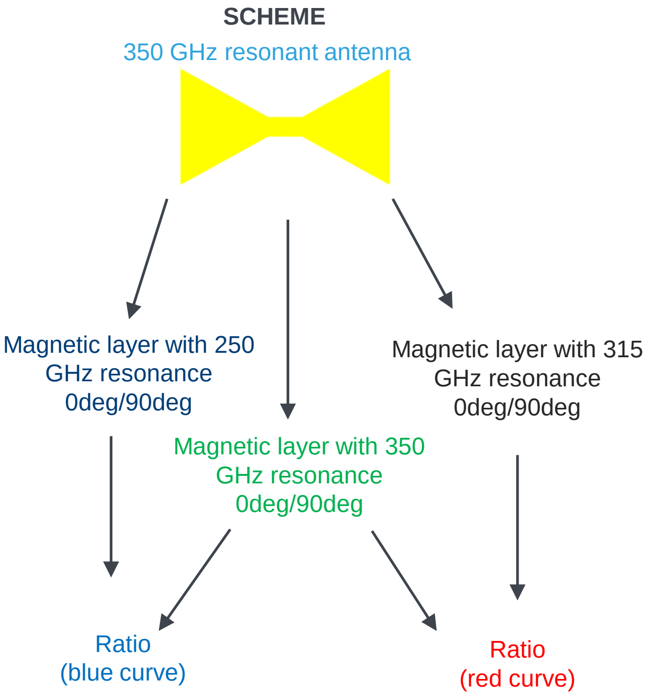
Part I – Simulations by CST Studio: 350 GHz Antenna + Magnetic Layer



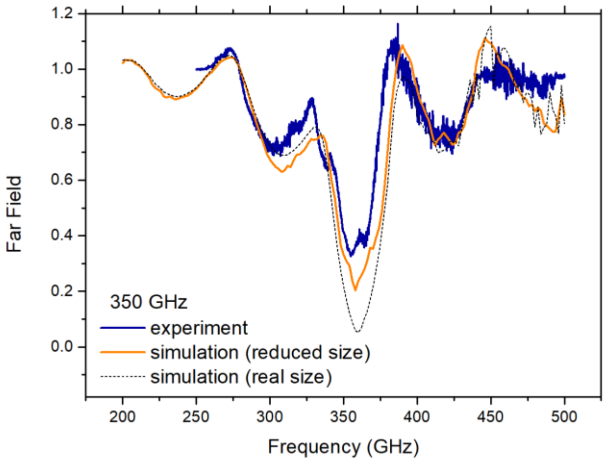
$$\frac{(H_{0,FF}/H_{90,FF})_{250GHz}}{(H_{0,FF}/H_{90,FF})_{350GHz}}$$

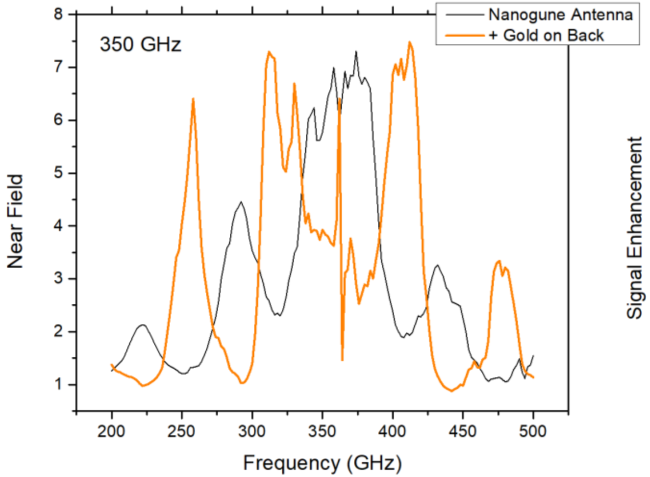
$$\frac{(H_{0,FF}/H_{90,FF})_{315GHz}}{(H_{0,FF}/H_{90,FF})_{350GHz}}$$

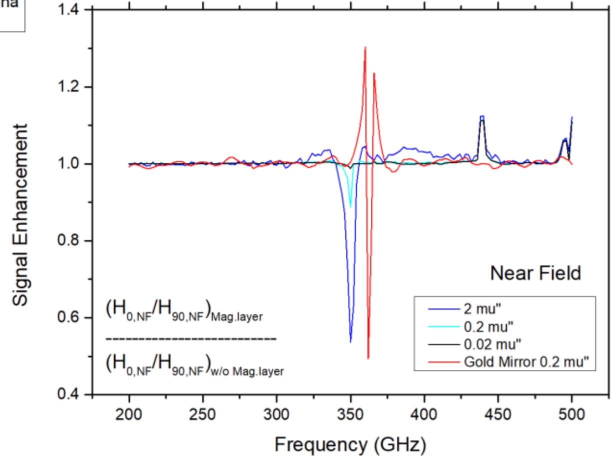




What happens if we have a Gold Mirror behind the Sample?

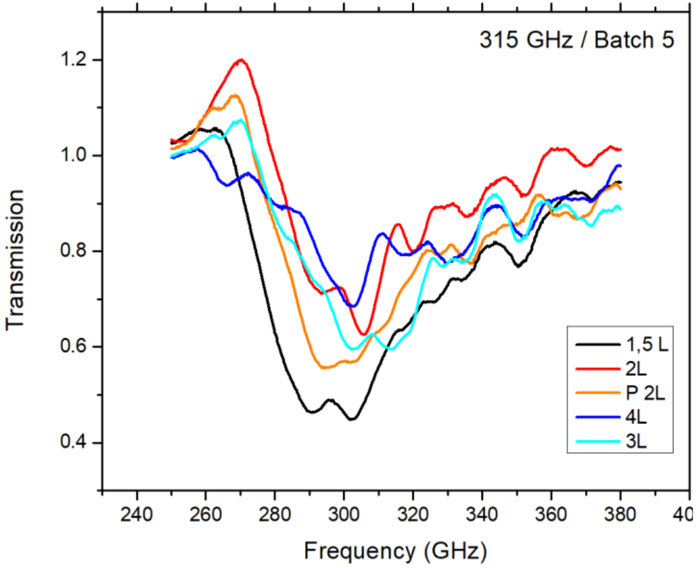




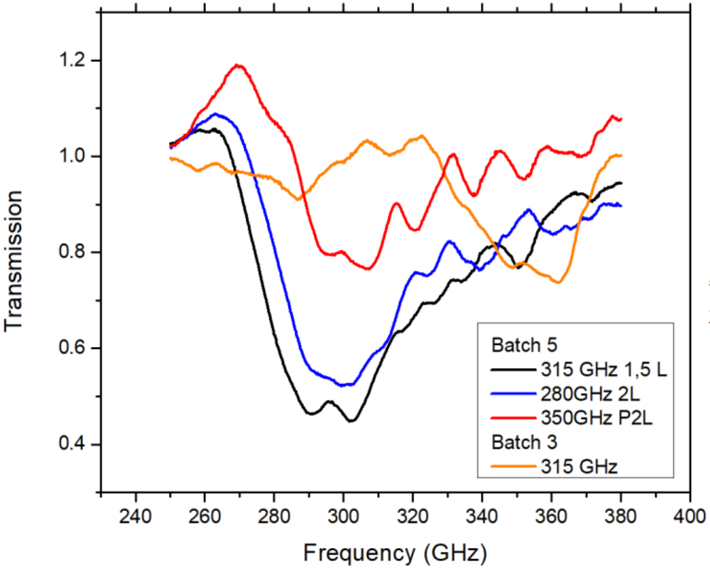


Part II
Experimental Characterization
and
Simulation of Brno Antenna Arrays Resonance

Part II – Transmission Measurements of Brno Antenna Arrays

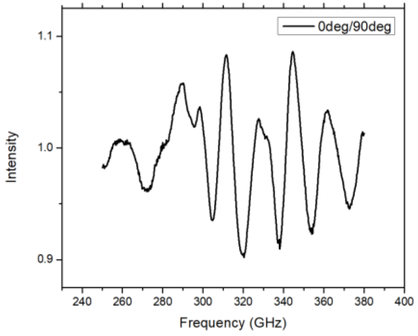


More antennas produce a better signal

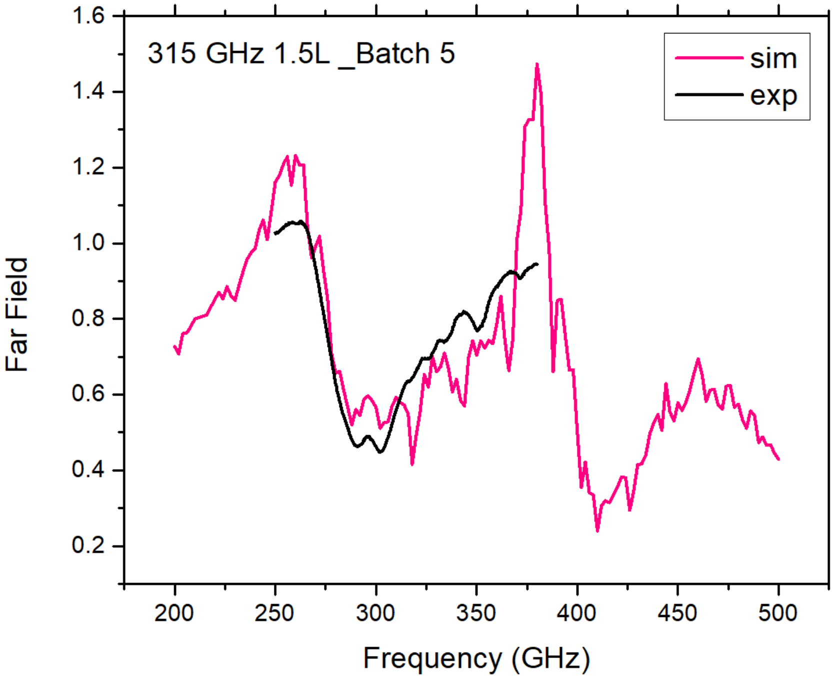


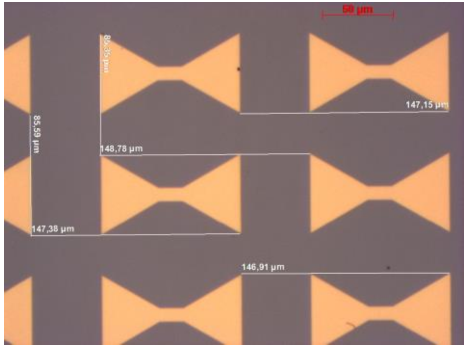
Problem: no changing in frequency!

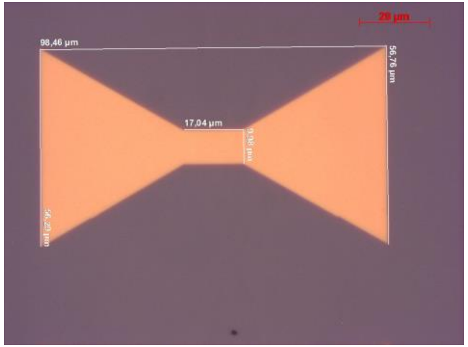
Si substrate as reference



Combining the info from Brno and the Optical Microscope Images







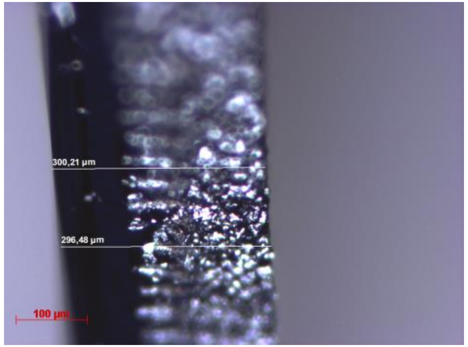
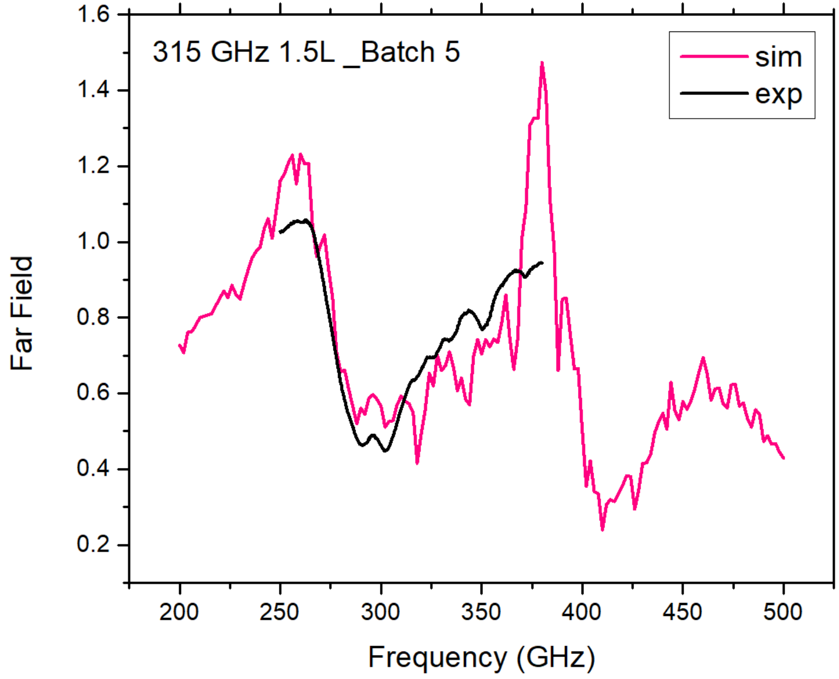


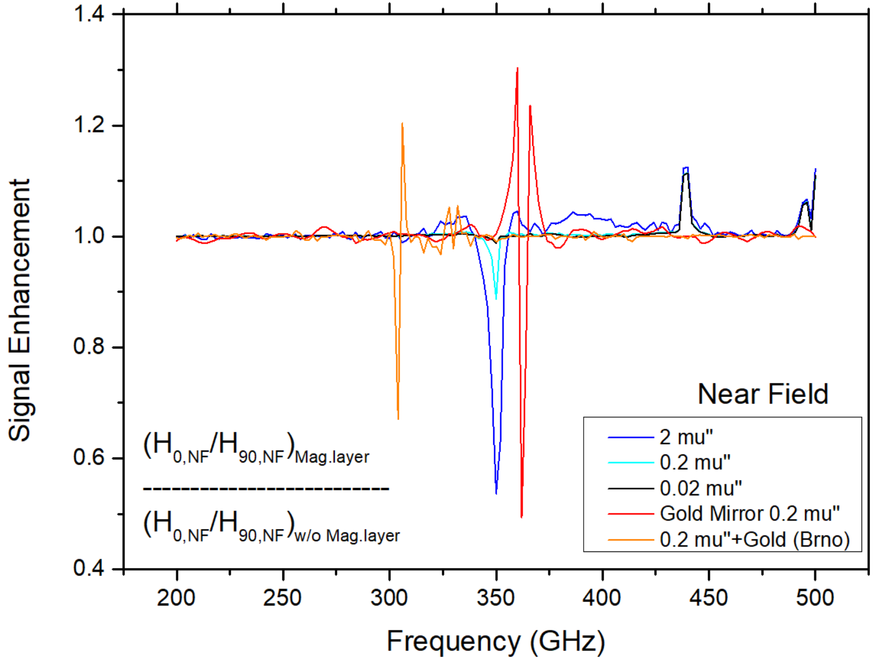
Table 2: The third set comparison of designed and measured (average of ten) antenna dimensions. The presented values correspond to fabrication of gold diabolo antennas on the silicon substrate via EBL

Frequency [GHz]	Designed		Measured	
	Antenna length [µm]	Bridge width [µm]	Antenna length [µm]	Bridge width [µm]
180	172.2	17.2	172.1 ± 0.2	17.2 ± 0.1
210	147.6	14.8	147.4 ± 0.1	14.8 ± 0.2
245	126.5	12.7	126.4 ± 0.2	12.7 ± 0.1
280	110.7	11.1	110.6 ± 0.3	11.1 ± 0.1
315	98.4	9.8	98.6 ± 0.2	9.8 ± 0.2
350	88.6	8.9	88.8 ± 0.1	8.9 ± 0.1
500	62	6.2	62.1 ± 0.2	6.3 ± 0.2

Part II – Simulations by CST Studio: Brno Antenna Arrays

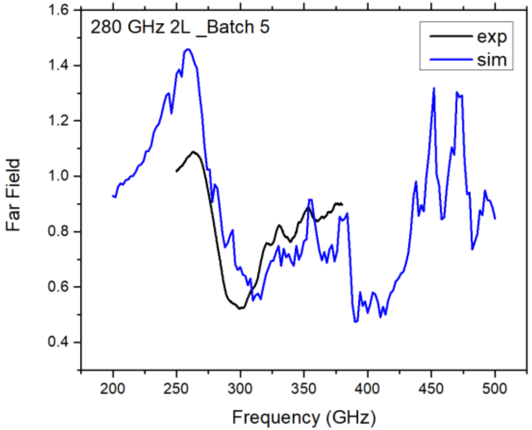
With the addition of Gold on the back and a magnetic layer

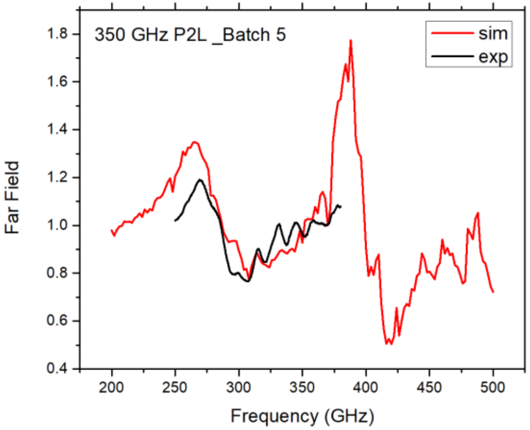


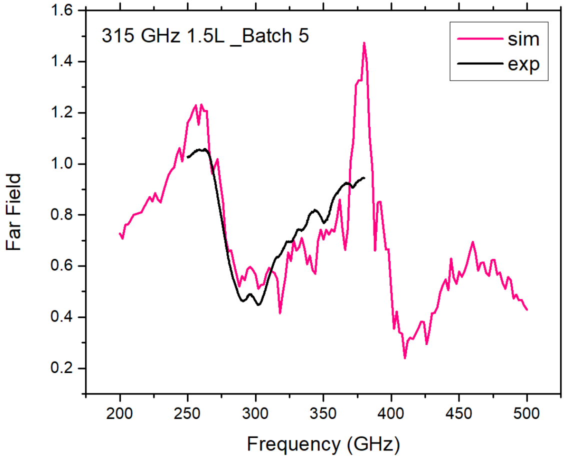


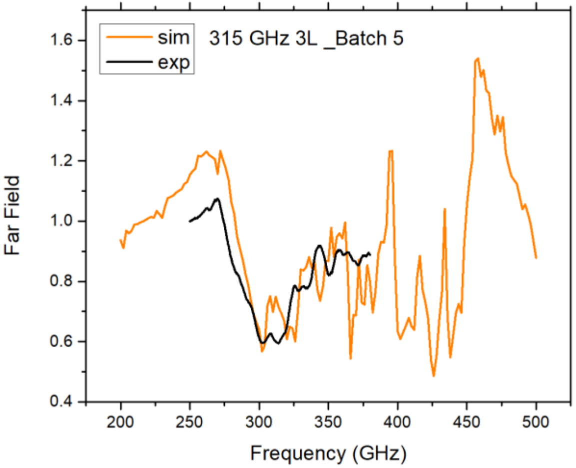
Part II – Simulations by CST Studio: Brno Antenna Arrays

To Summarize…





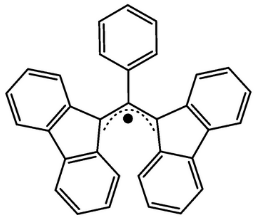




Part III

HF-EPR Measurements of the PE on a BDPA Magnetic Layer on NG Antenna Arrays

Measurements:

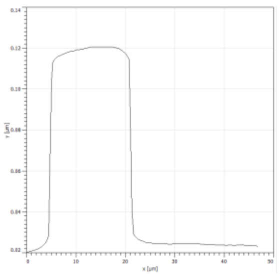


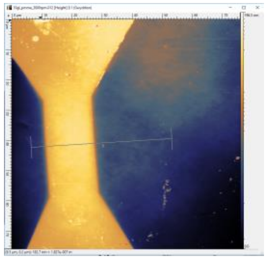
1,3-bisdiphenylene-2-phenylallyl (BDPA)

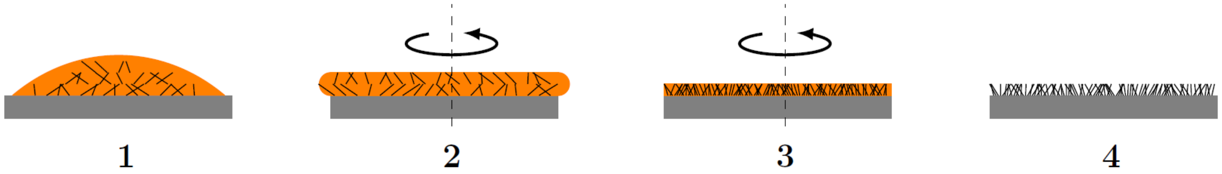
30% BDPA Spin-Coated with PMMA (ca. 100nm thick) on:

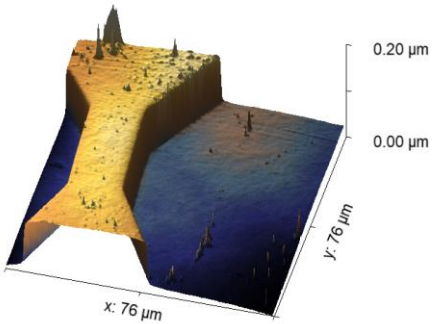
1. 350 GHz Nanogune Antenna (15 K and 60 K, 2 orientations);

2. Nanogune Quartz (60 K, 2 orientations);







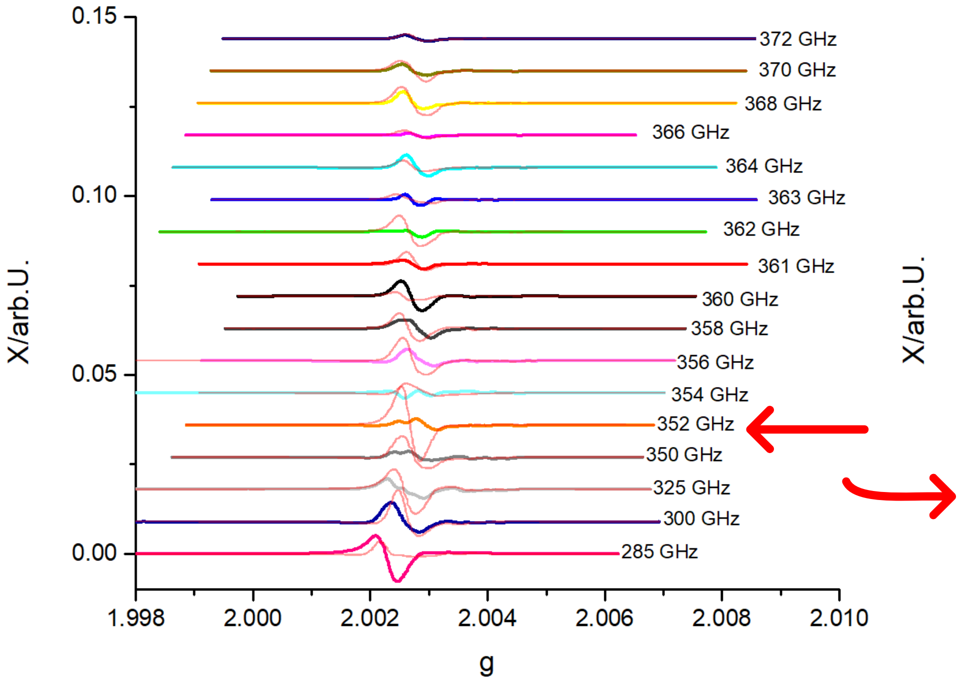


3. 350 GHz Nanogune Antenna without sample (60 K, 2 orientations)

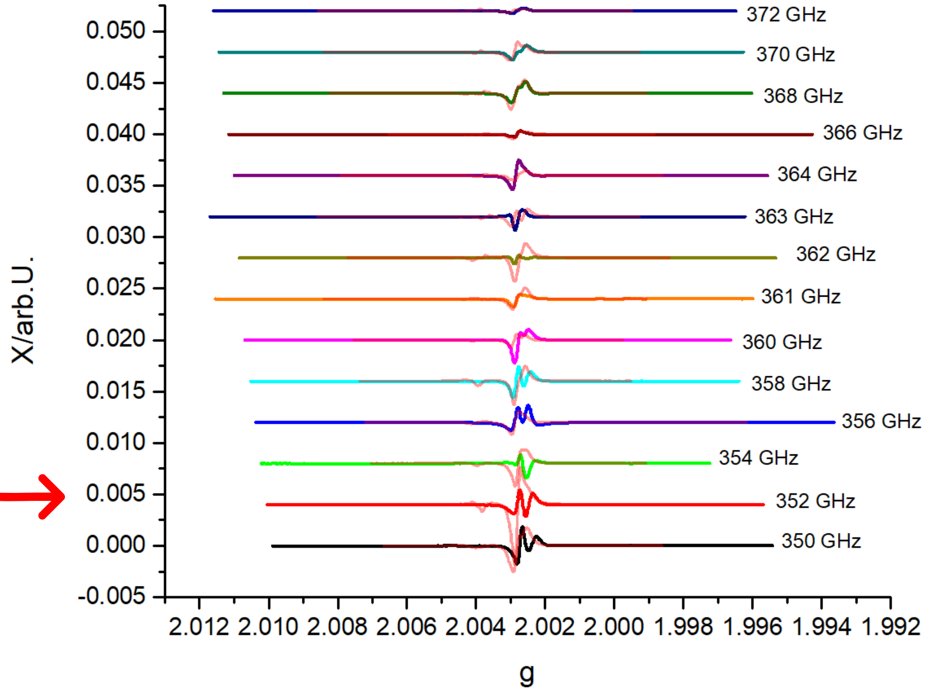
Part III – Measurements by HF-EPR of 350 GHz NG Antenna

30% BDPA Spin-Coated with PMMA (ca. 100nm thick) on 350 GHz Nanogune Antenna

15 K. Colour Non Active / Red Active



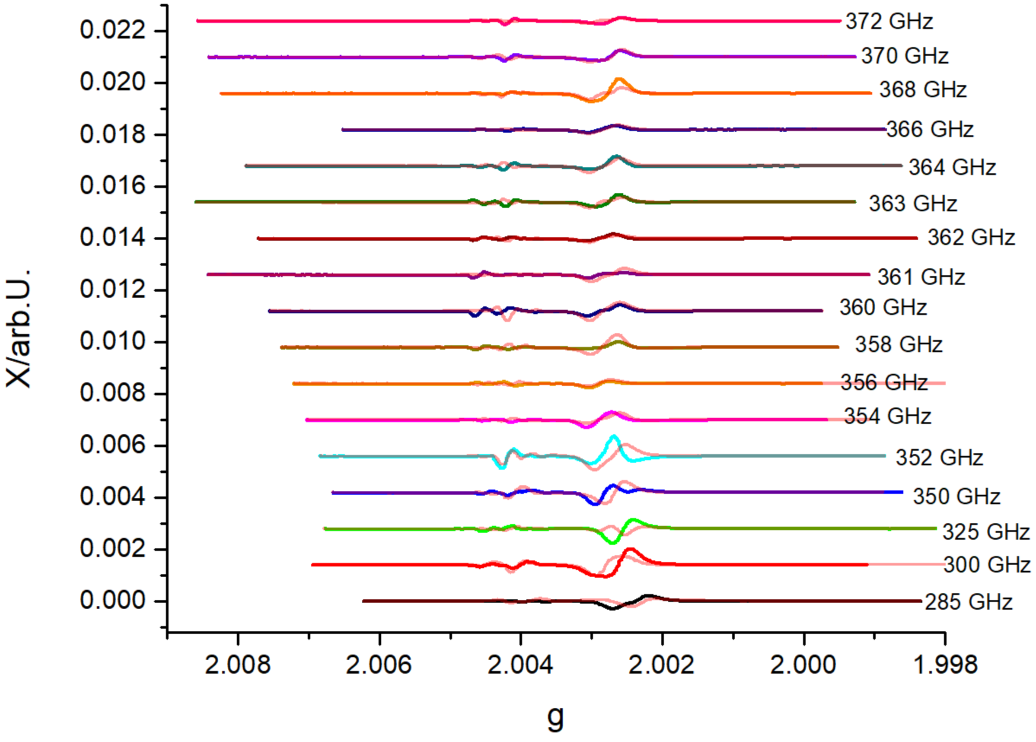
60 K. Colour Non Active / Red Active



Part III – Measurements by HF-EPR of 350 GHz NG Antenna

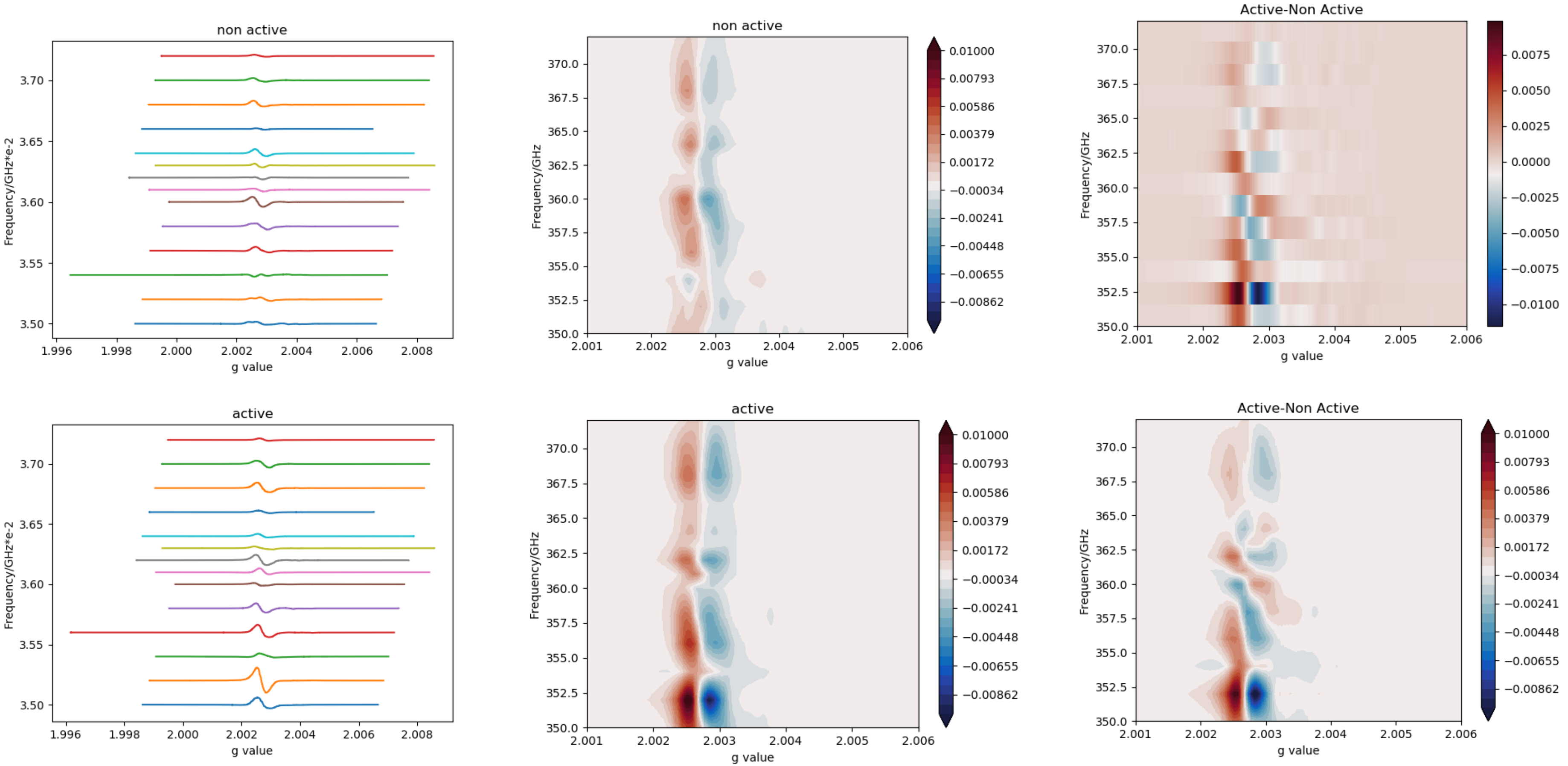
30% BDPA Spin-Coated with PMMA (ca. 100nm thick) on Nanogune Quartz

60 K. Colour Non Active / Red Active



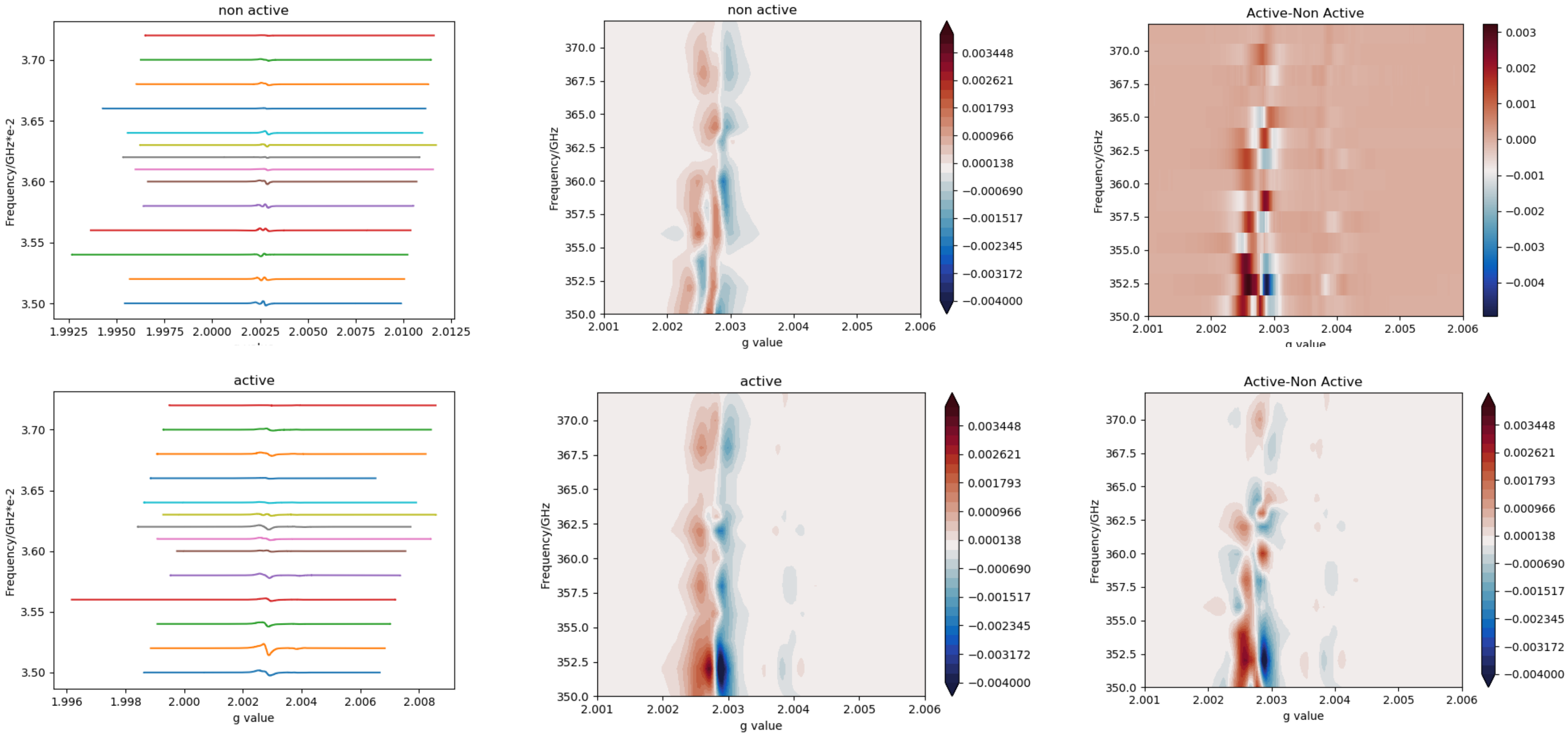
Part III – Measurements by HF-EPR of 350 GHz NG Antenna

30% BDPA Spin-Coated with PMMA (ca. 100nm thick) on 350 GHz Nanogune Antenna. 15 K.



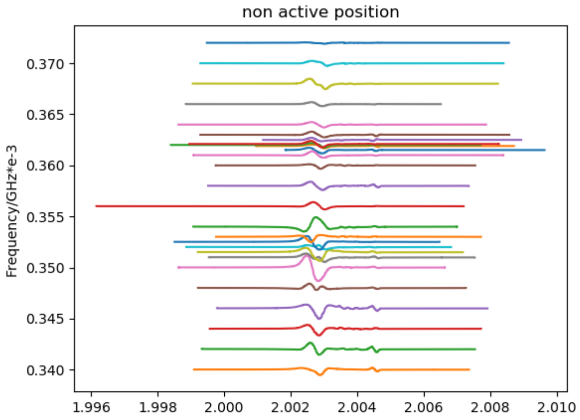
Part III – Measurements by HF-EPR of 350 GHz NG Antenna

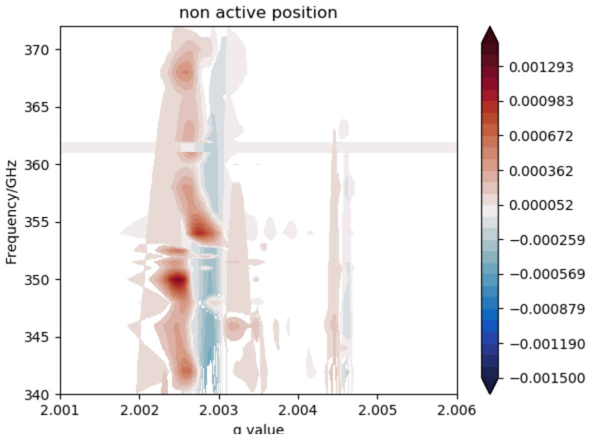
30% BDPA Spin-Coated with PMMA (ca. 100nm thick) on 350 GHz Nanogune Antenna. 60 K.

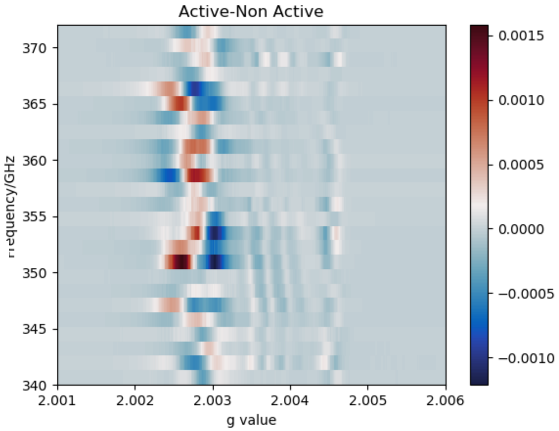


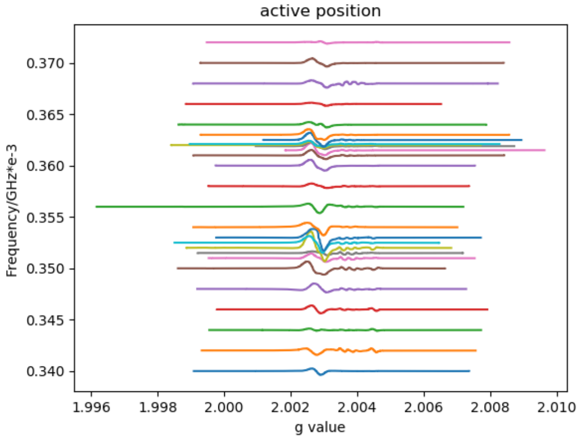
Part III – Measurements by HF-EPR of 350 GHz NG Antenna

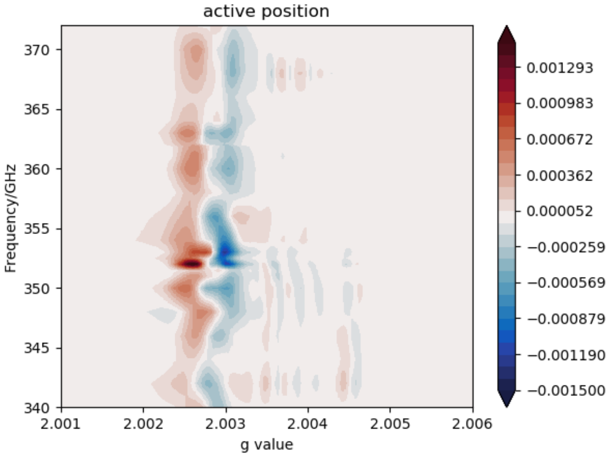
30% BDPA Spin-Coated with PMMA (ca. 100nm thick) on 350 GHz Nanogune Antenna. 60 K. Repeated 1 week after.





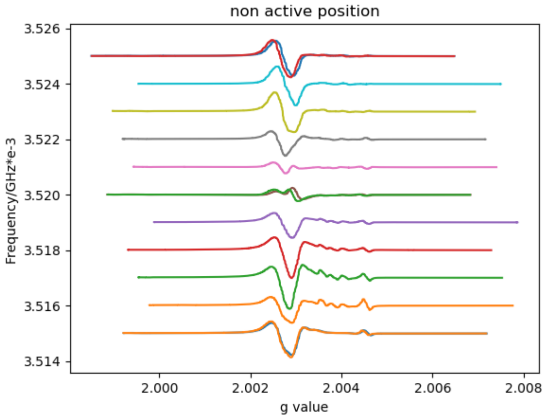


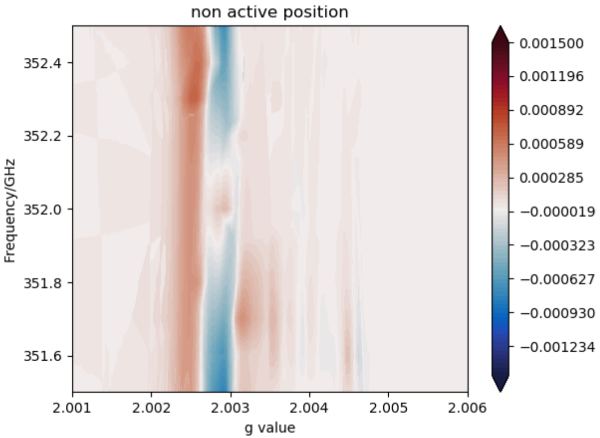


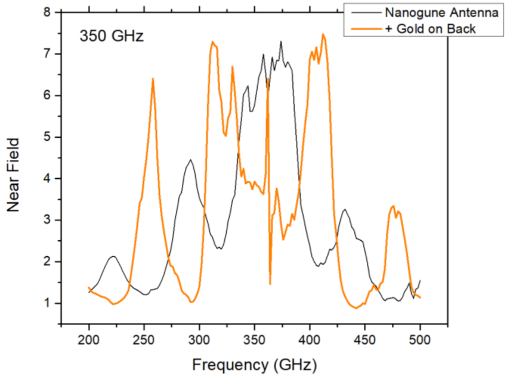


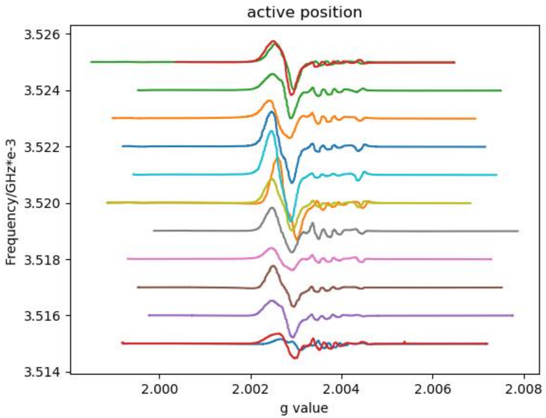
Part III – Measurements by HF-EPR of 350 GHz NG Antenna

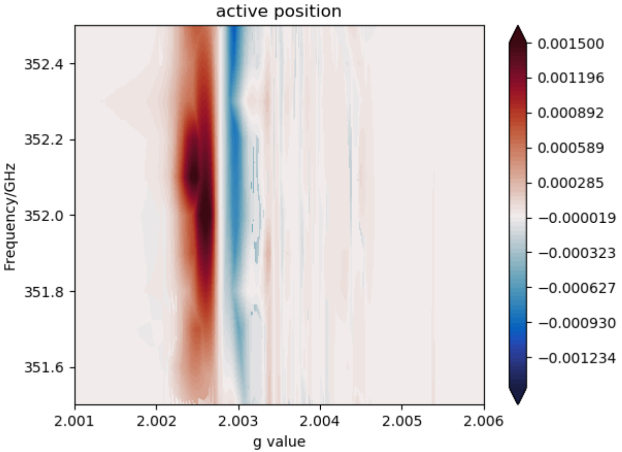
30% BDPA Spin-Coated with PMMA (ca. 100nm thick) on 350 GHz Nanogune Antenna. 60 K. Repeated 1 week after. Focus.





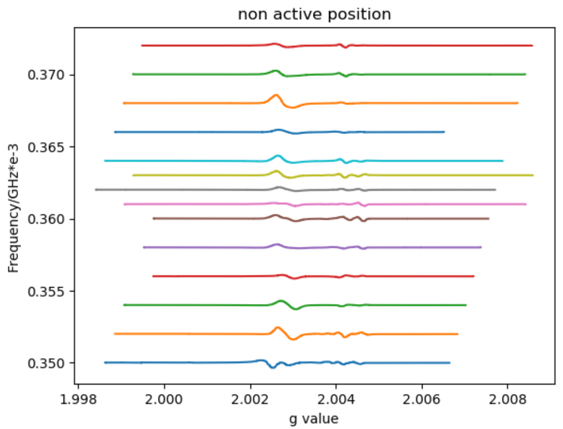


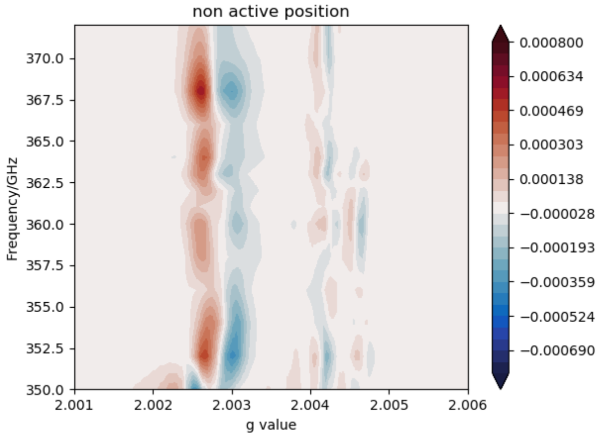


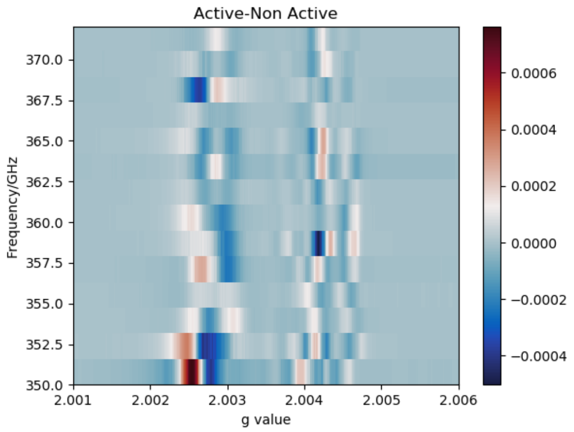


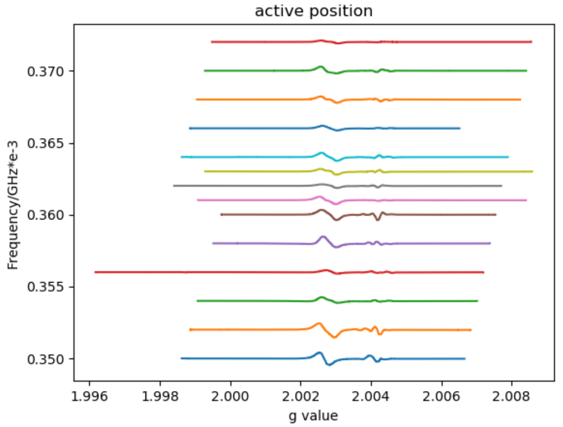
Part III – Measurements by HF-EPR of 350 GHz NG Antenna

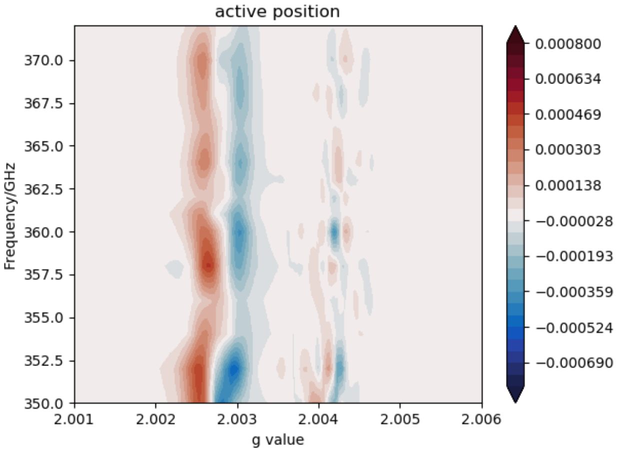
30% BDPA Spin-Coated with PMMA (ca. 100nm thick) on Quartz Support. 60 K.

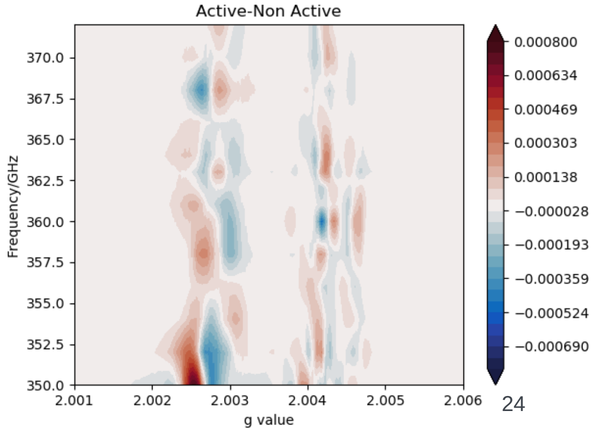






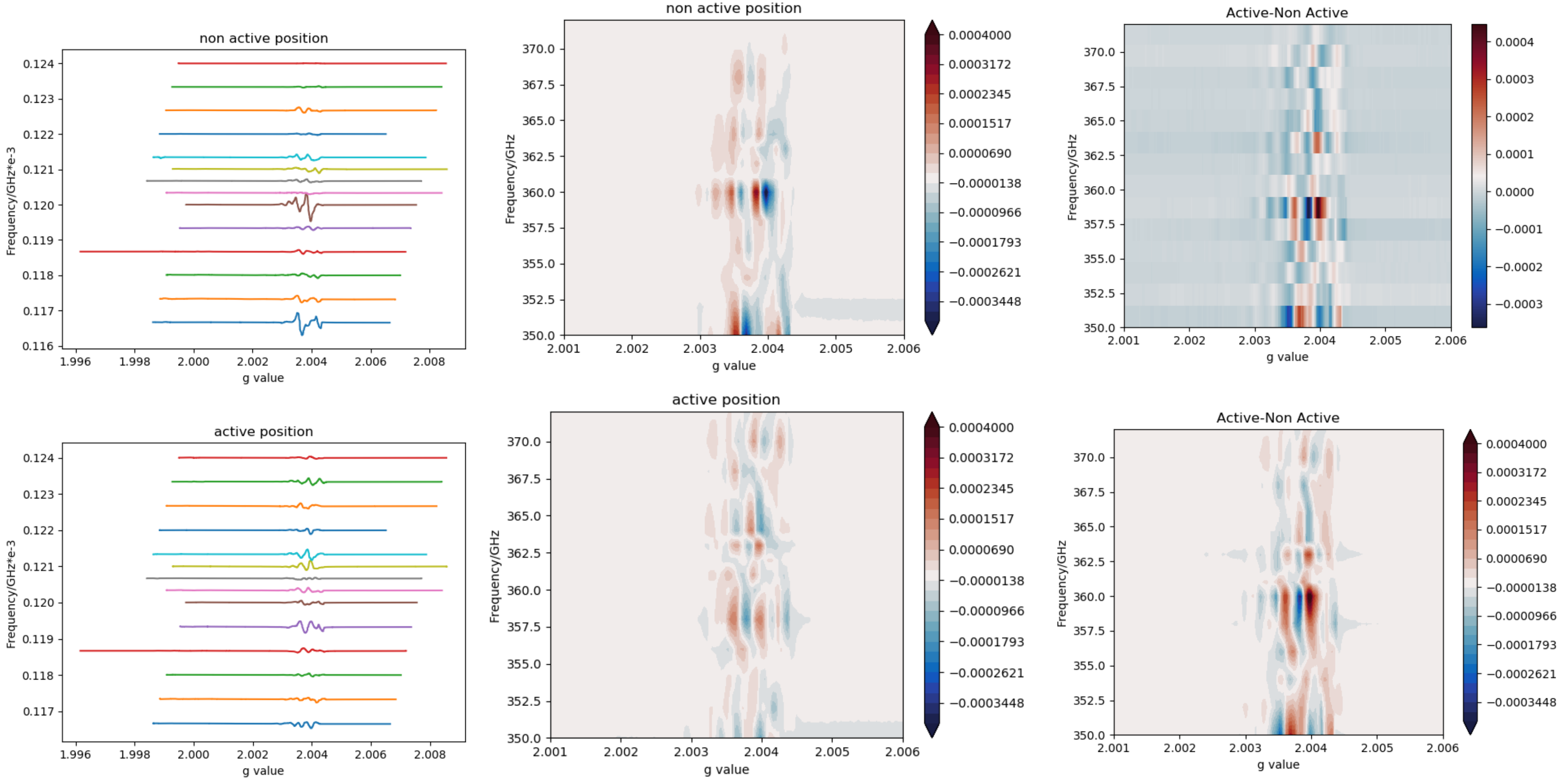






Part III – Measurements by HF-EPR of 350 GHz NG Antenna

350 GHz Nanogune Antenna without Sample. 60 K.



Thanks for the attention

and

Let's start the discussion!