CEB for CMB

Nizhnij Novgorod State Technical University
Laboratory of Cryogenic Nanoelectronics

Chalmers University, MC2

Multichroic Seashell Antenna with Resonant Cold-Electron Bolometers for COrE

Leonid S. Kuzmin, Ekaterina A. Матрозова

In scope of the ESA Project **"Next Generation Sub-millimetre Wave Focal Plane Array Coupling Concepts"** - **multi-frequency arrays of bolometers**

In collaboration with:
Paolo de Bernardis, Silvia Masi & Maria Salatino (Rome University), Bruno Maffey (Manchester Un), Neil Trappe (Maynooth Un), Michail Tarasov (Chalmers), Alexander Sobolev (IREE), Alexander Chiginev and Anna Gordeeva (NSTU)

Outline

- **ESA-COrE, Multichroic Systems.**
- **Resonant Cold-Electron Bolometer (RCEB)**
- **Sinuous, Cross-slot and Seashell Antenna with RCEB**
- **Conclusions**

The ESA Tender "ESTEC ITT AO/1-7393/":

Next Generation Sub-millimetre Wave Focal Plane Array Coupling Concepts

(multi-frequency arrays of bolometers for COrE)

APC Paris, France,
Cardiff University, UK,
Chalmers Tech University, Sweden,
La Sapienza University of Rome, Italy,
Manchester University, UK,
NUI Maynooth, Ireland.

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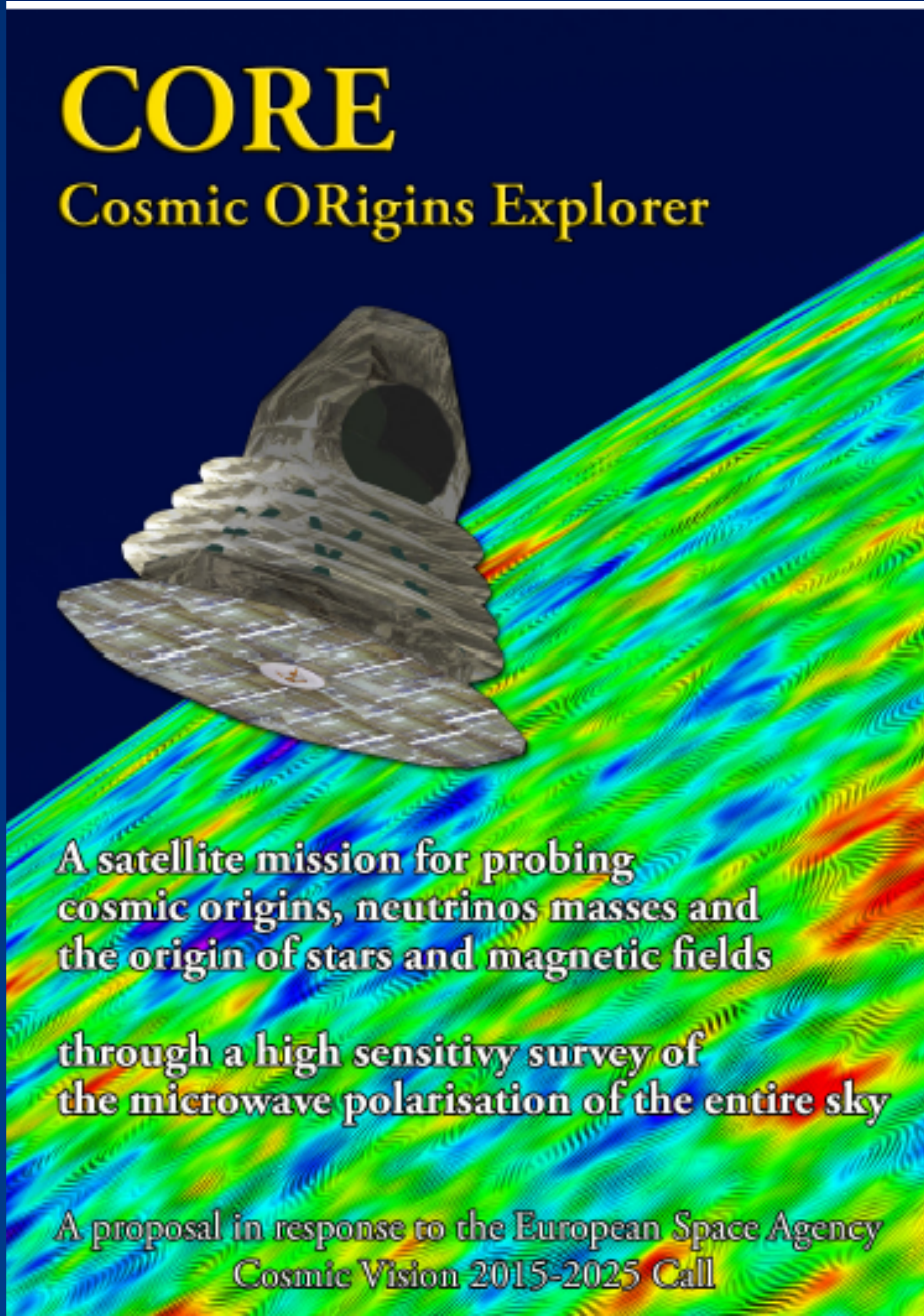
CORE
Cosmic ORigins Explorer
A satellite mission for probing
cosmic origins, neutrinos masses and
the origin of stars and magnetic fields
through a high sensitivy survey of
the microwave polarisation of the entire sky
A proposal in response to the European Space Agency
Cosmic Vision 2015-2025 Call

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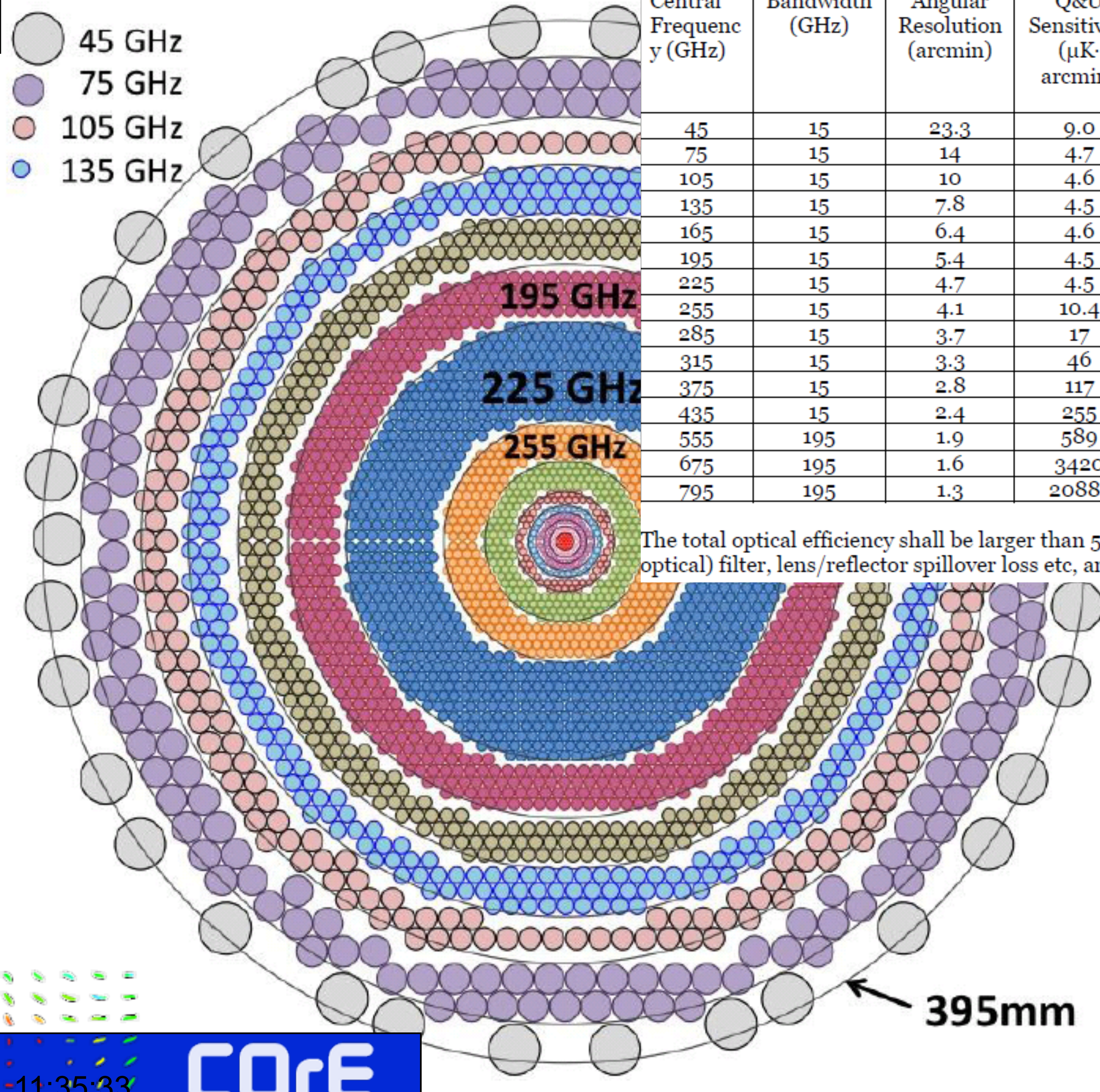
2)



Central Frequency (GHz)	Bandwidth (GHz)	Angular Resolution (arcmin)	Q&U Sensitivity (μK·arcmin)	Out of band Rejection (above 1THz)	Beam Ellipticity (% @-3dB)	Cross – polarisatio (dB)
45	15	23.3	9.0	> 120 dB	< 1%	< -30 dB
75	15	14	4.7	> 120 dB	< 1%	< -30 dB
105	15	10	4.6	> 120 dB	< 1%	< -30 dB
135	15	7.8	4.5	> 120 dB	< 1%	< -30 dB
165	15	6.4	4.6	> 120 dB	< 1%	< -30 dB
195	15	5.4	4.5	> 120 dB	< 1%	< -30 dB
225	15	4.7	4.5	> 120 dB	< 1%	< -30 dB
255	15	4.1	10.4	> 120 dB	< 1%	< -30 dB
285	15	3.7	17	> 120 dB	< 1%	< -30 dB
315	15	3.3	46	> 120 dB	< 1%	< -30 dB
375	15	2.8	117	> 120 dB	< 1%	< -30 dB
435	15	2.4	255	> 120 dB	< 1%	< -30 dB
555	195	1.9	589	> 120 dB	< 1%	< -30 dB
675	195	1.6	3420	> 120 dB	< 1%	< -30 dB
795	195	1.3	20881	> 120 dB	< 1%	< -30 dB

The total optical efficiency shall be larger than 50% (TBC). This includes any (quasi-optical) filter, lens/reflector spillover loss etc, and include the (bolometer) coupling.

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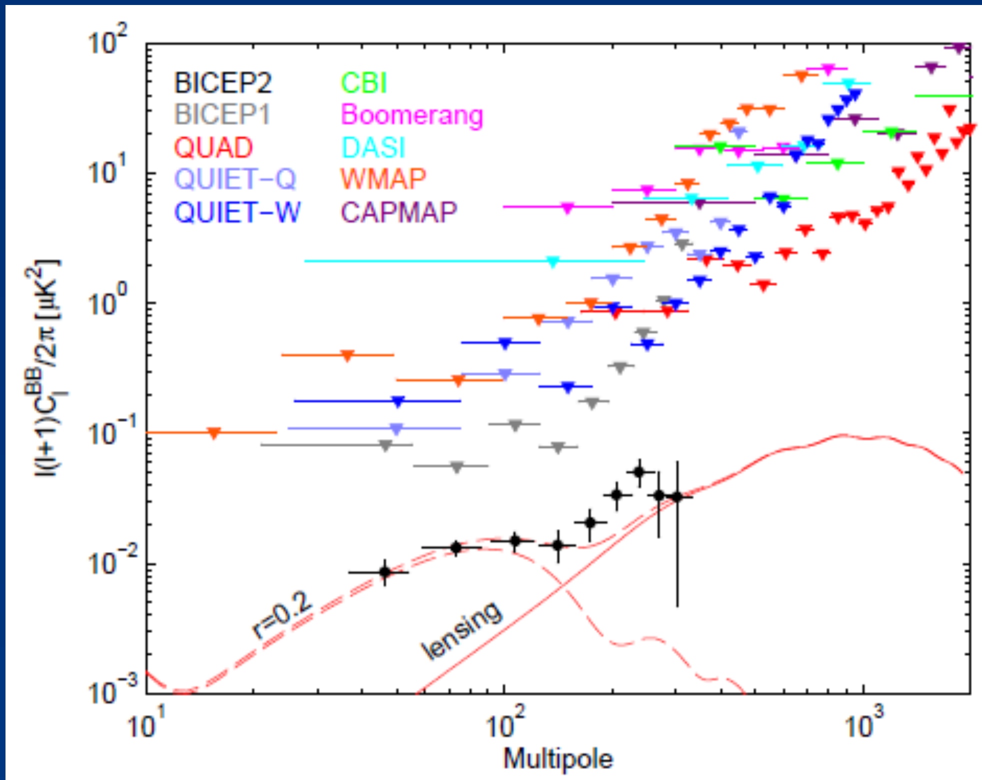
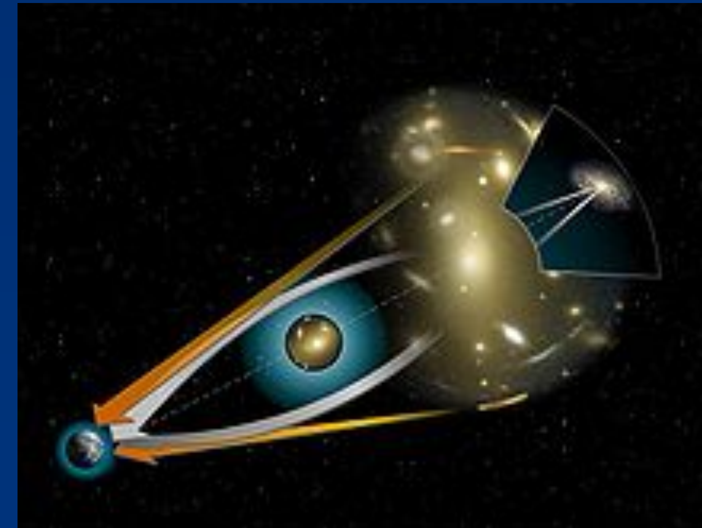
COrE
Cosmic Origins Explorer

BICEP2: B-mode polarization





Light from the early universe is deflected by the gravitational lensing effect of galaxies forming B-modes

The power in B-mode polarization as a function of scale on the sky ("Multipole").
The black dots are BICEP2′s detection;
all other points are non-detections by previous experiments.
The leftmost 3 or 4 points are the ones that give evidence for B-mode polarization from cosmic effects,
and therefore possibly for gravitational waves at early times,
and therefore, possibly, for cosmic inflation preceding the Hot Big Bang!

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Pros and Cons of Multifrequency systems

- Simultaneous data acquisition by multi-frequency pixel in the same point.
- Reducing size of the focal plane.

but

- Unavoidable degradation of some parameters

ESA Requirements for Multifrequency Systems:

Two frequency channels 75 & 105GHz	
F number of pixel	**2 – 2.5**
Bandwidth	**20 %**
Return loss max	**-25dB**
Cross-polarization max	**-20dB**
Beam ellipticity	**up to 5%**
Cross Talk	**Low**

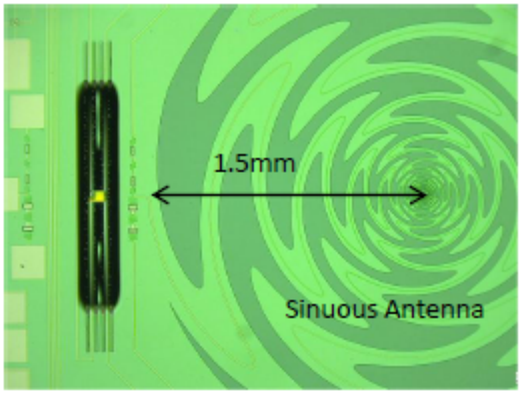
Adrian Lee et al., University of California, 2008, …

Components of Multi-Chroic Pixel

1) Lenslet (6mm diameter)

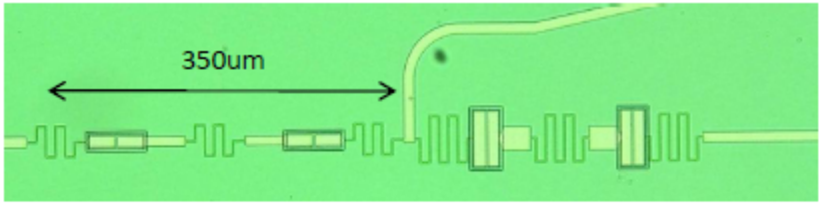
- Broadband anti reflection coated

2) Sinuous Antenna



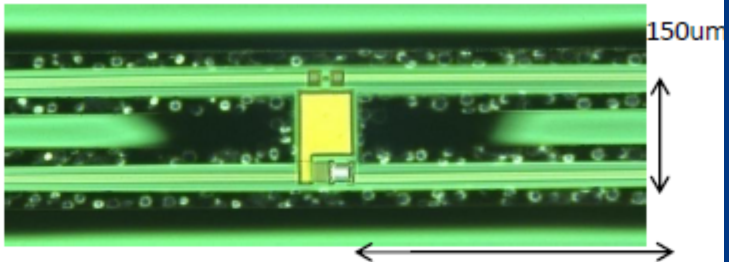
- Over octave bandwidth
- Sensitive to 2 linear polarizations

3) Microstrip Filter



- Splits signal into desired bands
- Lumped elements

4) TES Bolometer



- Operates @ 250mK bath temp
- Background Noise Limited

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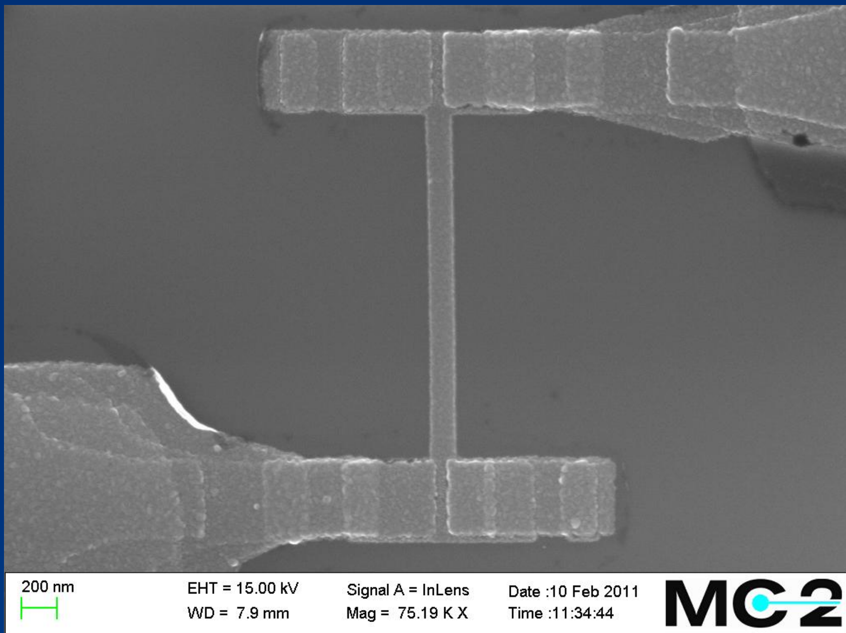
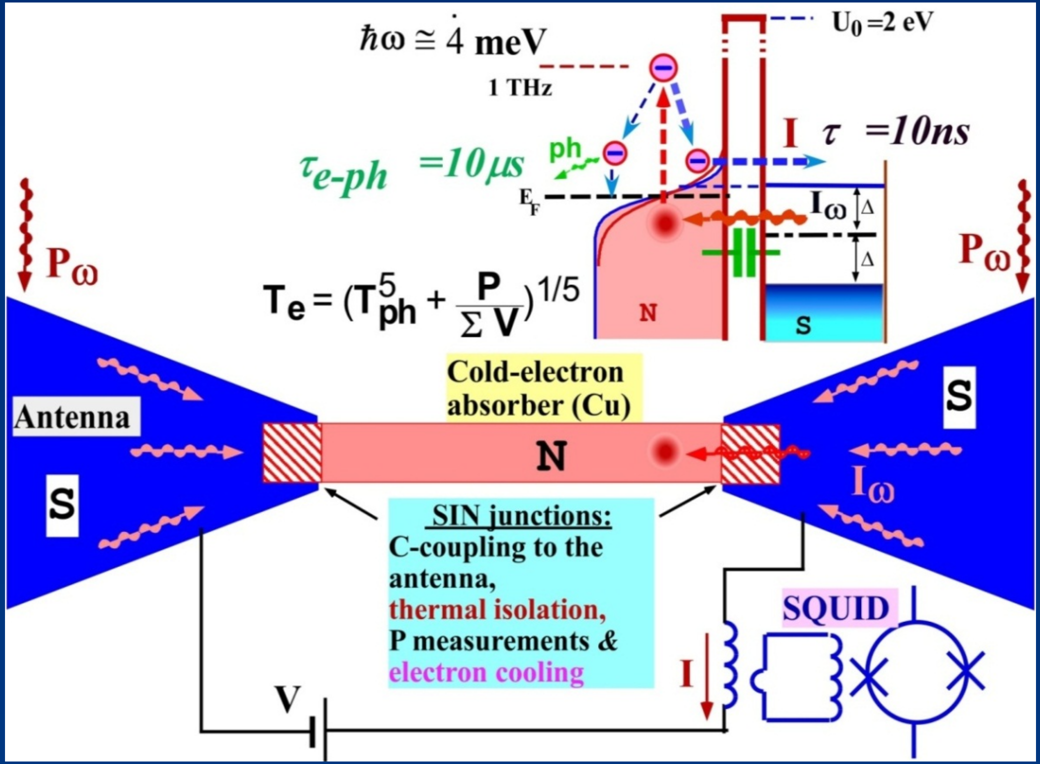
Wideband system

Cold-Electron Bolometer (CEB) with Capacitive Coupling to the Antenna





Main features of the CEB:

1. High sensitivity due to electron cooling effect:

2. High dynamic range due to direct electron cooling

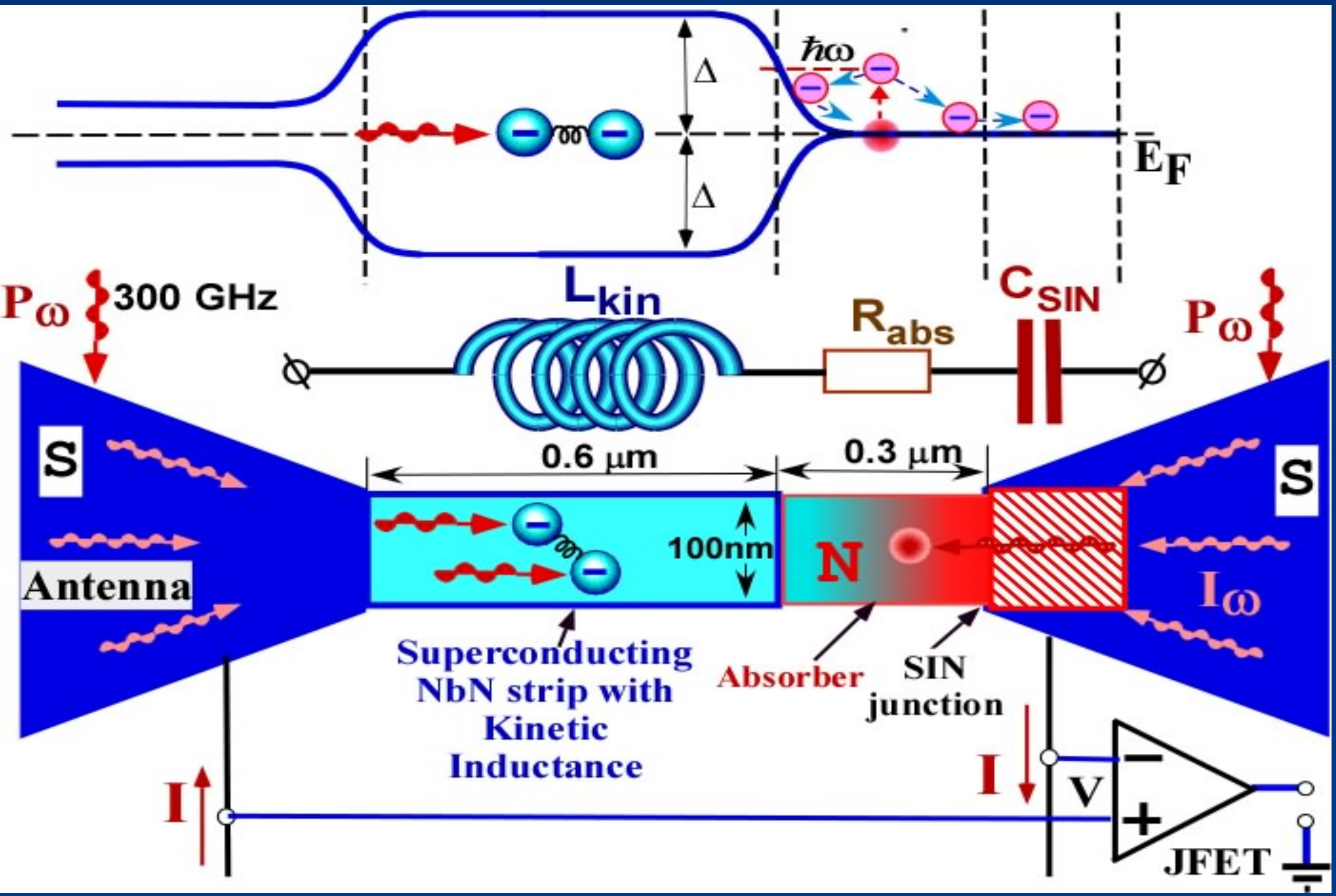
3. Insensitivity to Cosmic Rays (1 glitch/40 days(!) in contrast to 1 glitch/second for Planck)

4. Resonant Cold-Electron Bolometer (RCEB) for Multi-Frequency Pixels

Resonant Cold-Electron Bolometer (RCEB)

with a Nanofilter by a Kinetic Inductance of the NbN strip and a Capacitance of the SIN Tunnel Junctions

L. Kuzmin, ISSTT, April 2013



$$L_k = \frac{\mu_0 l}{w}\left[\frac{\lambda^2}{b}\right]$$

NbN: λ=400 nm, b=10 nm, Lkin =140 pH for *l*=0.6 μm

Q=10, Rabs=15 Ohm, ωLkin=300 Ohm @ 350 GHz, SIN: S=0.04 μm^2

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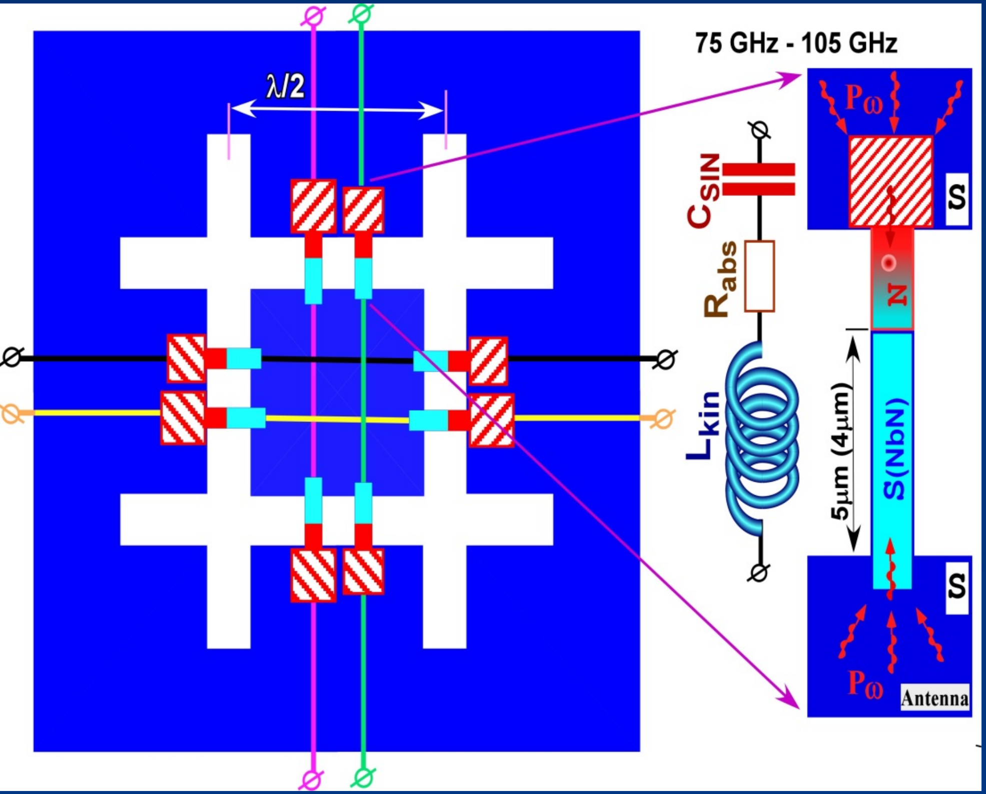
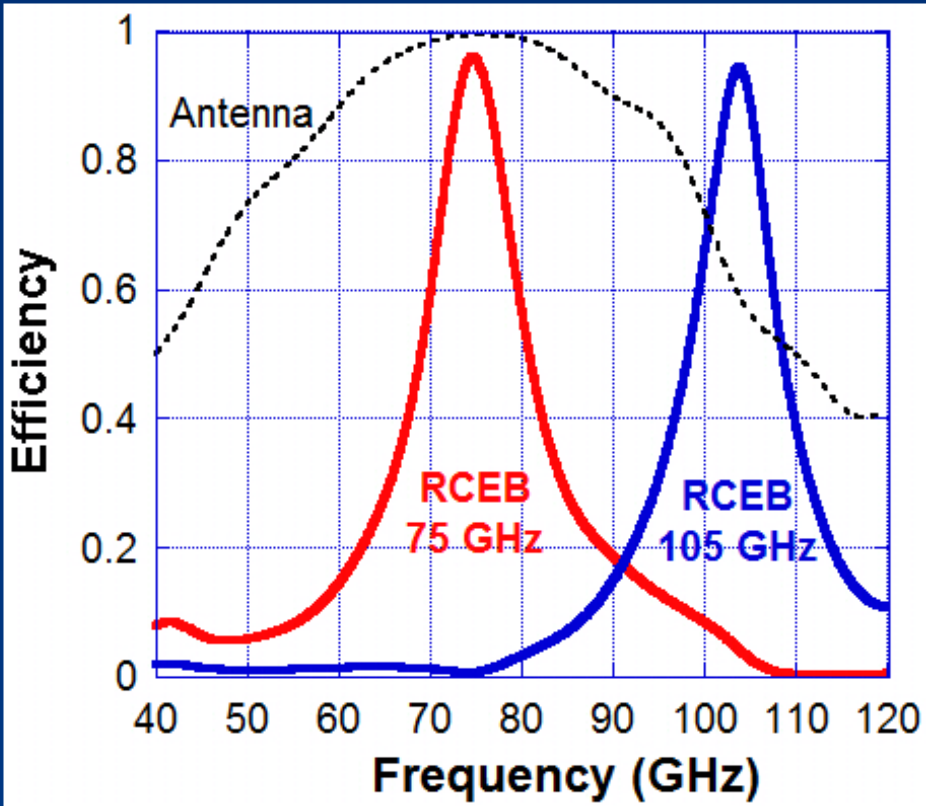
Cross-Slot Antenna with RCEB for 75 and 105 GHz



Cross-Slot Antenna - Zmuidzinas et al, 2000



CST simulations by A.Sobolev & L. Kuzmin

Preliminary frequency selection in each pixel is done by an antenna and the final selection is done by a CEB.

Lkin/sq=$4\pi\lambda^2$/b /H NbN: λ=300 nm,b=10 nm, Lkin/sq=20 pH/sq, Lkin =400 pH, l=2 μm, Q=10, ρ=20 Ohm, Rabs=20 Ohm, SIN: S=0.2 μm^2, C1=11fF,

Spectral filtering options with a lens.

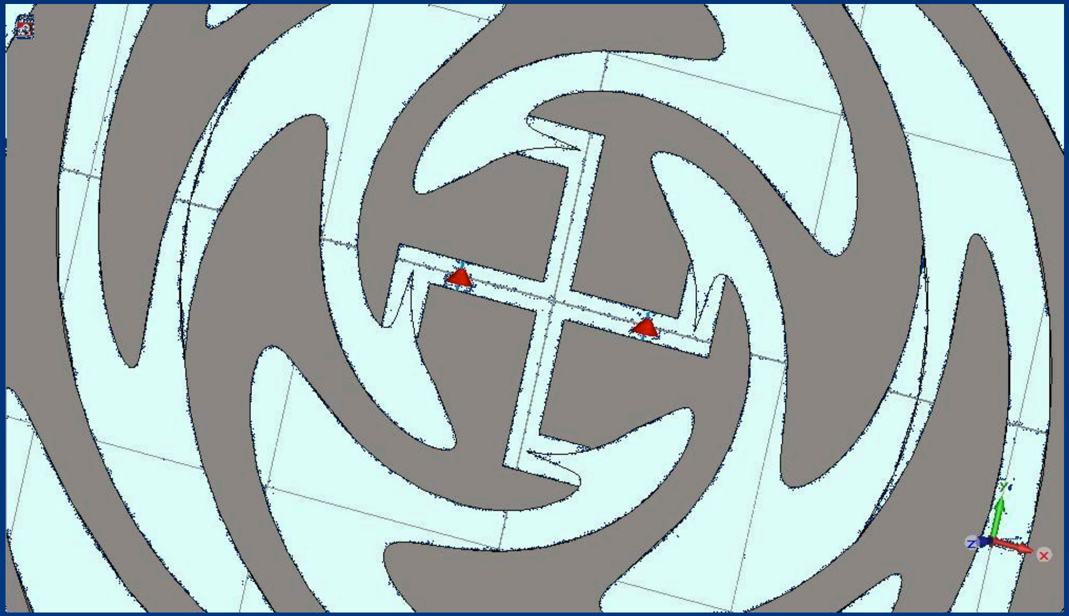
We analysed three different antenna and filter concepts for matching with the flat lens:

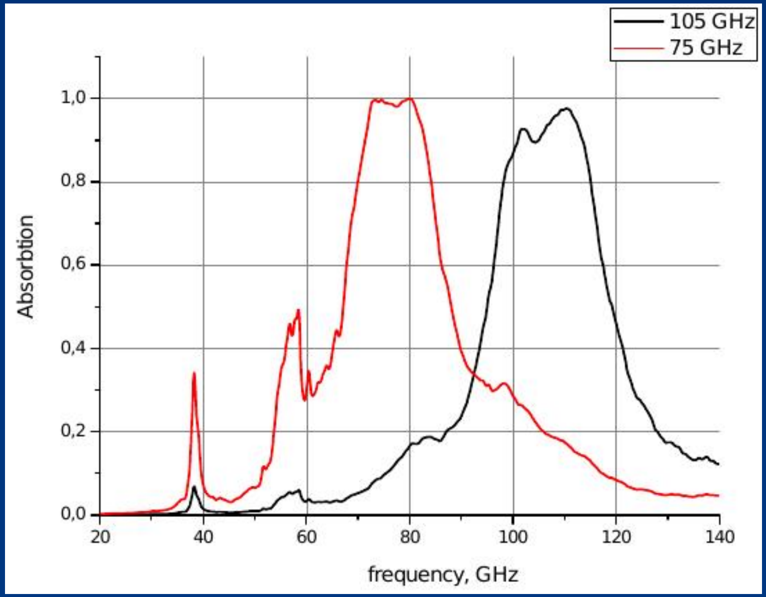
- Sinuous antenna with RCEBs,
- Cross-Slot antenna with RCEBs
- "Seashell" Slot antenna with RCEBs.

Sinuous Antenna with RCEBs inside the antenna

A. Chiginev, L, Kuzmin et al.

Sinuous antenna: DuHamel, United States Patent 4658262, 1987.
R. OBrient et al, Journal of Low Temperature Physics, 151 (1). 450–463 2008.





75 GHz filters: R = 10 Ohm ; C = 8 $\times 10^{-15}$ F, L = 557$\times 10^{-12}$ H

105 GHz filters: R = 10 Ohm; C = 4$\times 10^{-15}$ F, L = 557$\times 10^{-15}$ H

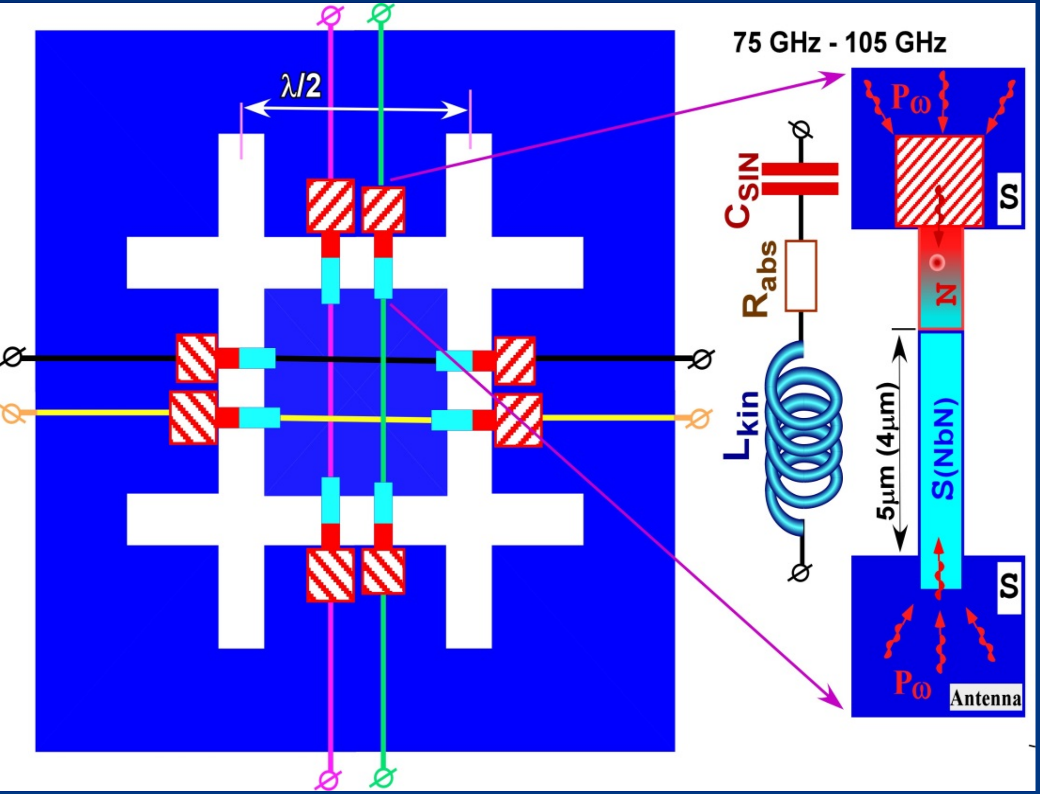
Advantages: Easy to combine 2-4 frequencies in wideband sinuous antenna

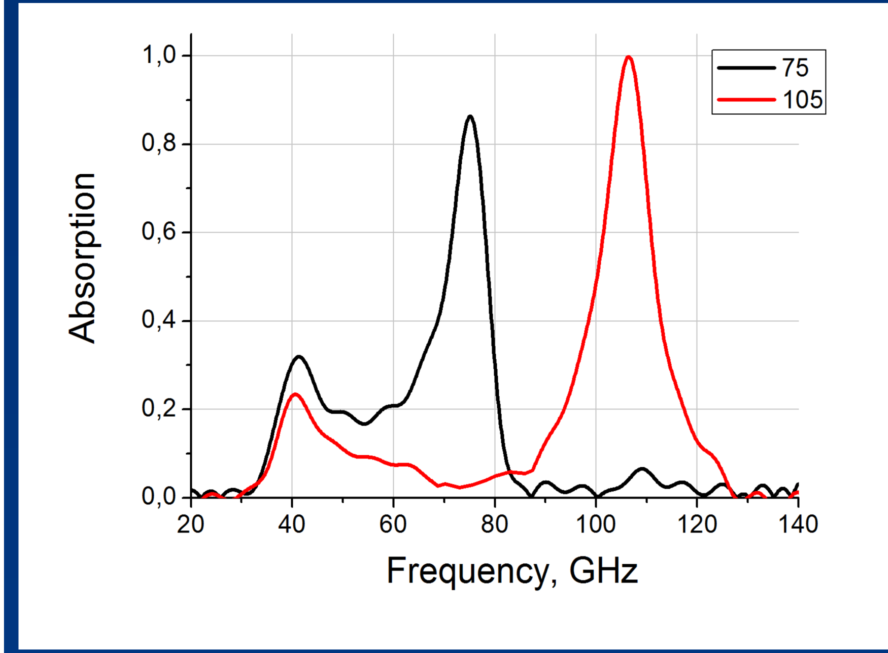
Disadvantages:

- Overcross of microstrip lines makes it very difficult for technological realization
- Parasitic resonances due to overcross of slots

Cross-Slot Antenna with RCEBs

A. Gordeeva, L. Kuzmin et al.





Cross-Slot Antenna - Zmuidzinas et al, 2000

Advantages:

Easy to combine 2 frequencies in wideband cross-slot antenna

Disadvantages:

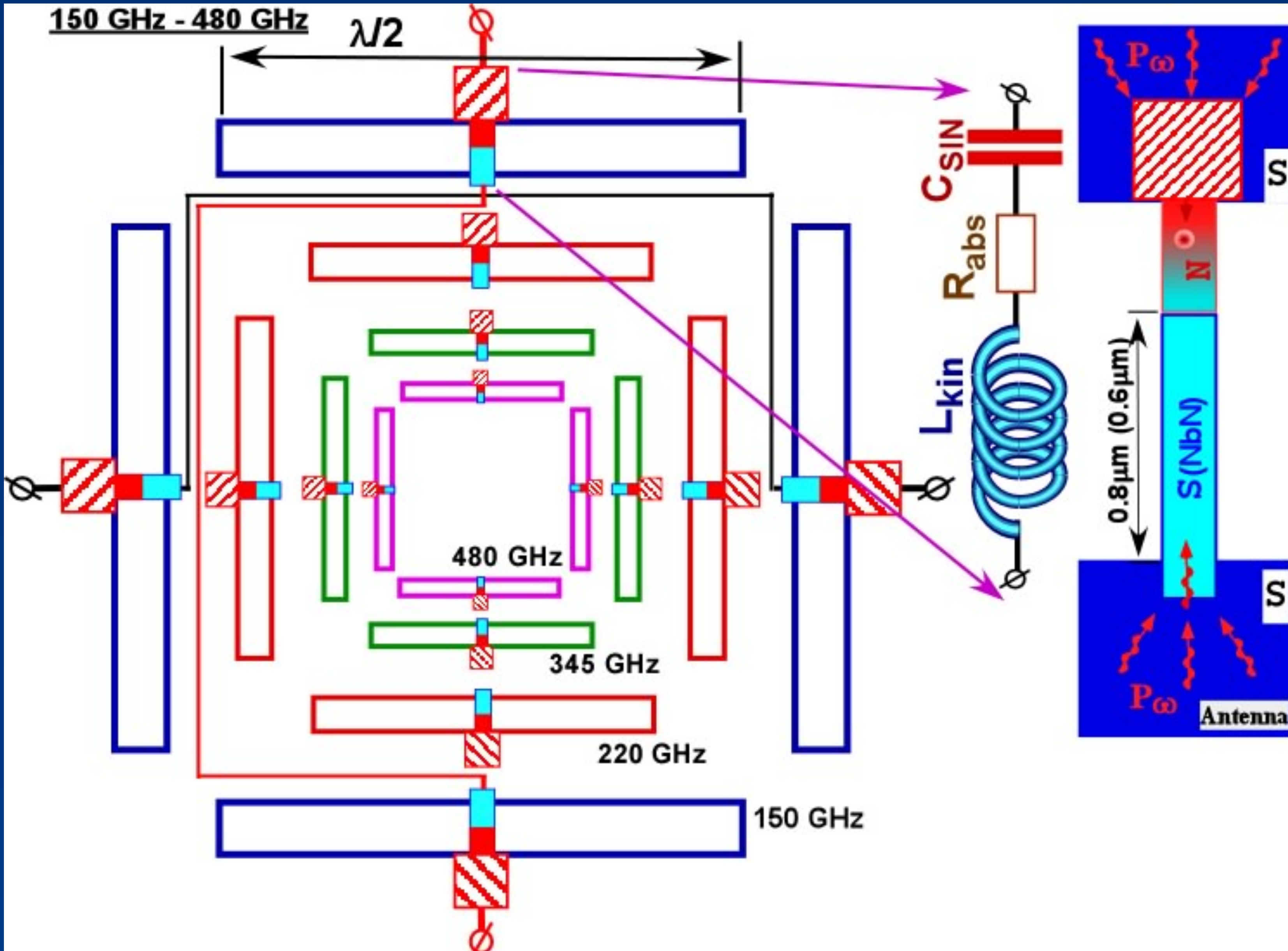
- **Overcross of microstrip lines makes it very difficult for technological realizatio**
- **Parasitic resonances due to overcross of slots**

“Seashell” Slot Antenna with RCEBs

For OLIMPO

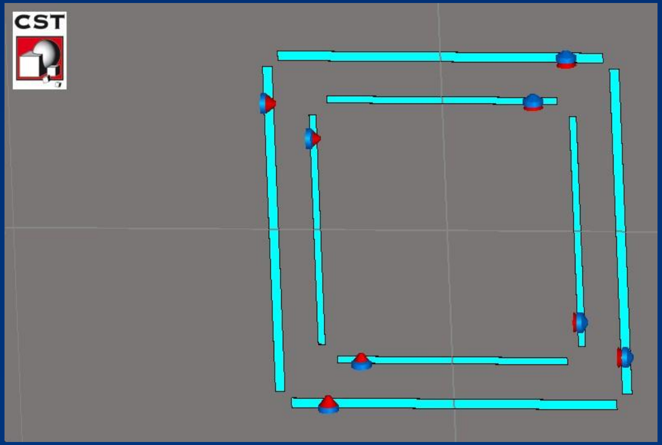
Leonid Kuzmin , Rome, 21 Sept 2013

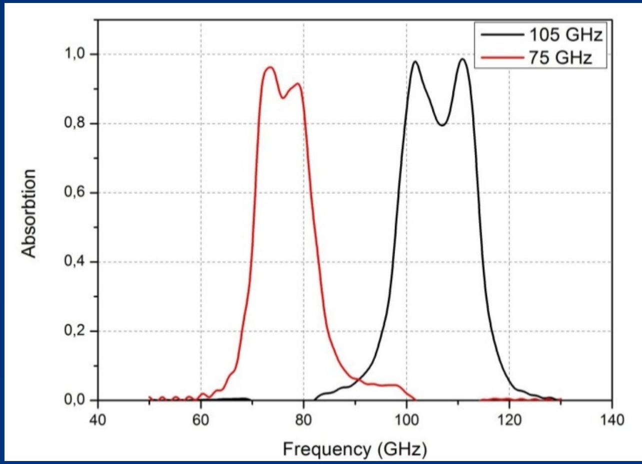
Stimulative discussion with Paolo de Bernardis is acknowledged

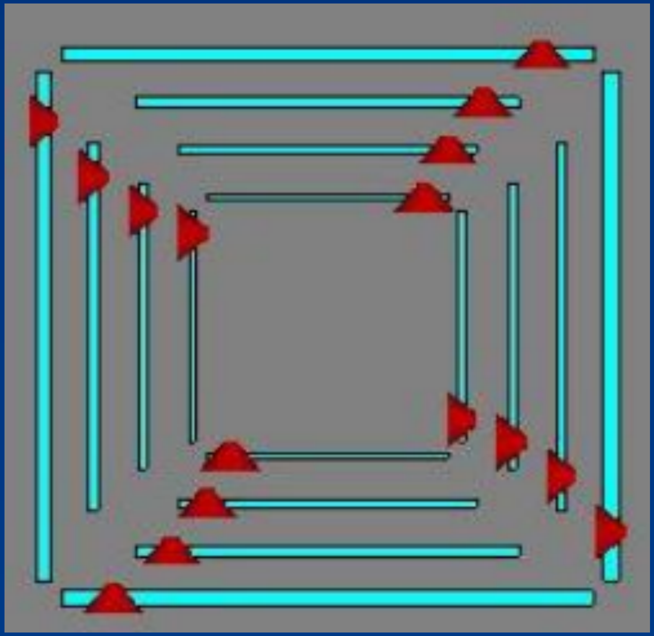


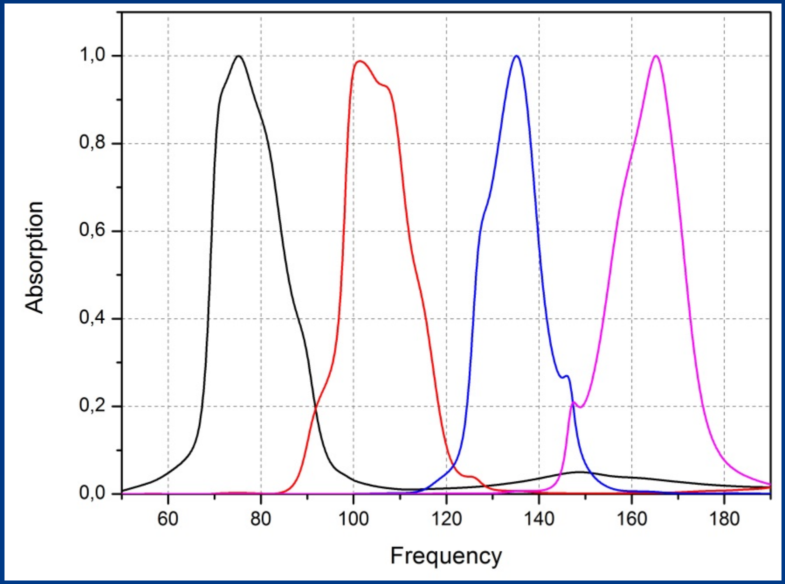
"Seashell" Slot Antenna with RCEBs

L. Kuzmin, E. Matrozova, et al., (2014)









Absorption in 4-Frequency Seashell Slot Antenna with RCEBs designed for 75, 105, 135, and 165 GHz

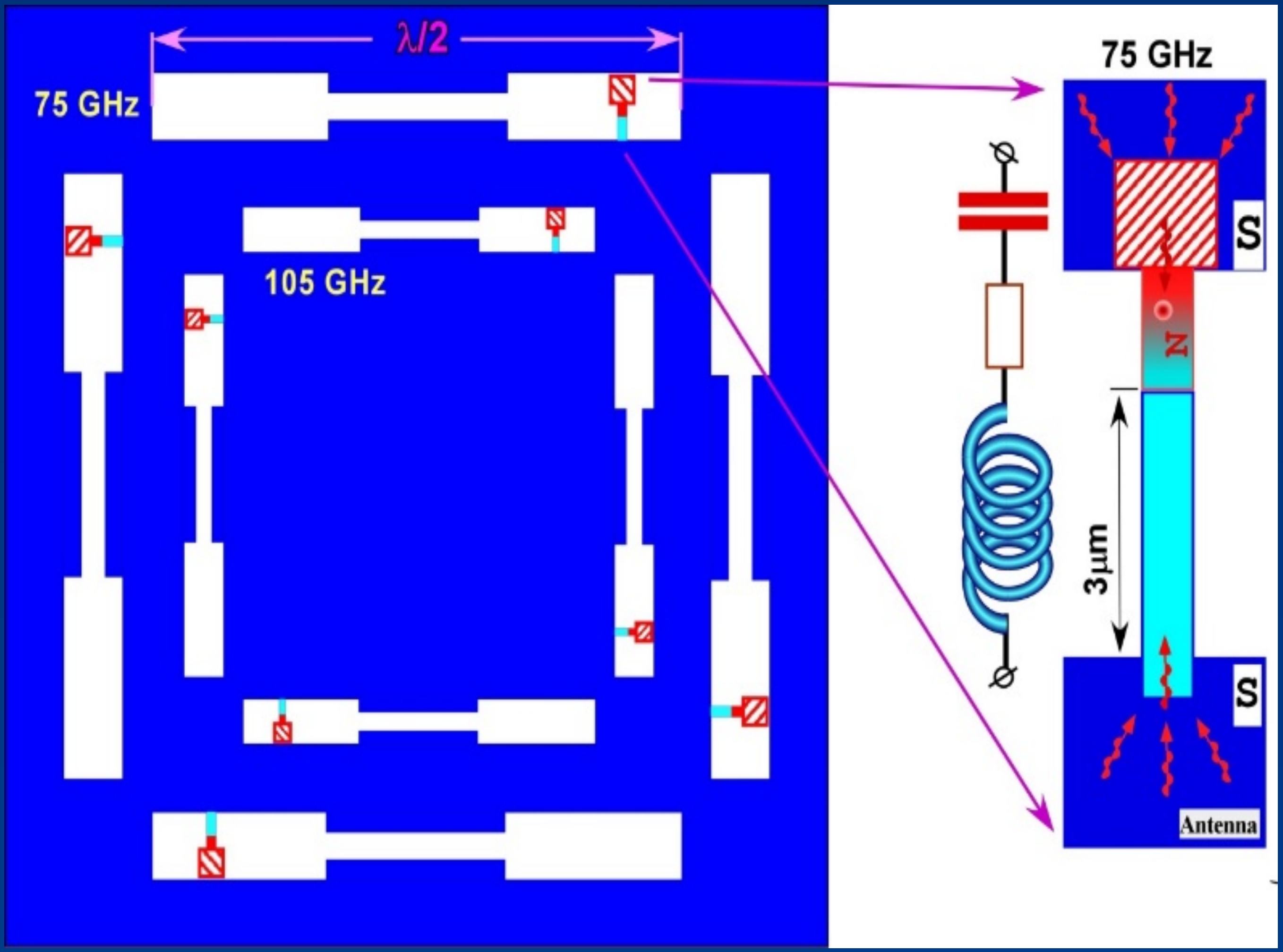
Summary of optical/RF performance

Parameter	Sinuous Antenna		Cross-Slot Antenna		Seashell Slot Antenna	
Frequency, GHz	75	105	75	105	75	105
Bandwidth (at -3 dB), GHz	21	24	13	35	12	16.5
Bandwidth (at -10 dB), GHz			4.5	8		
Presence of parasitic resonances, GHz			40	40; 83		Parallel at 105
In-band absorption- average in -50% of bandwidth	0.85	0.84	0.81	0.8	0.84	0.84
Lens	Si, 9mm; AR-quartz 430 um					
Beam FWHM, deg	24.1	16.2	22.4	17.5	23.7	15.4
Cross-polar, dB	-17	-15	-10	-17	-16	-14.7
Beam ellipticity (frequency band), %	2	4	2	7	4.8	8
Main lobe magnitude, dB	16.7	19.9	17.6	19.3	16.8	17.1
Side lobe level, dB	-18.9	-16.5	-18.6	-22.5	-17.6	-16.4

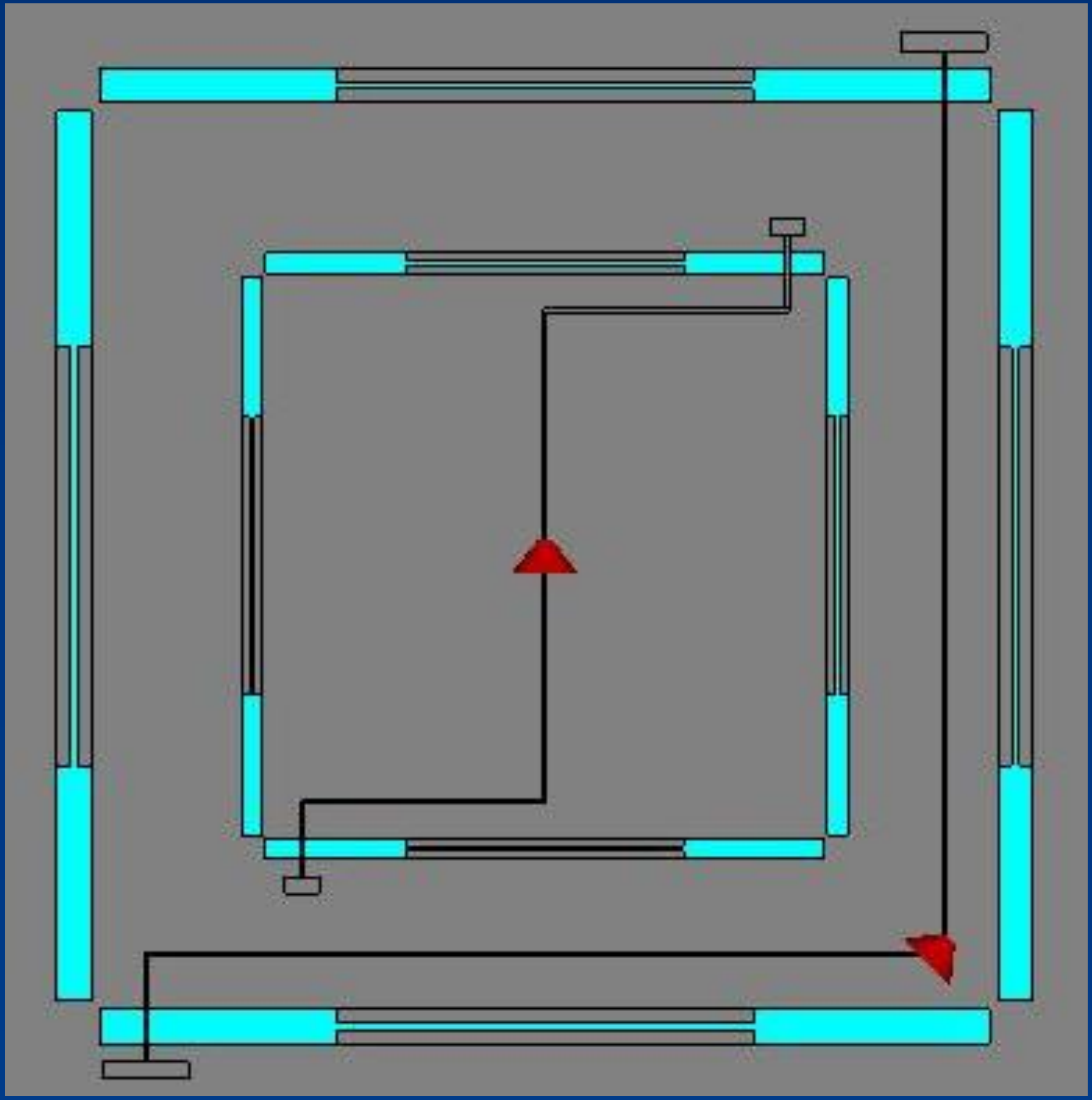
Seashell-Slot Antenna with H-slots and Lumped Elements

(the idea partly is from KIDs with lumped elements)

L. Kuzmin, E. Matrozova (2015)



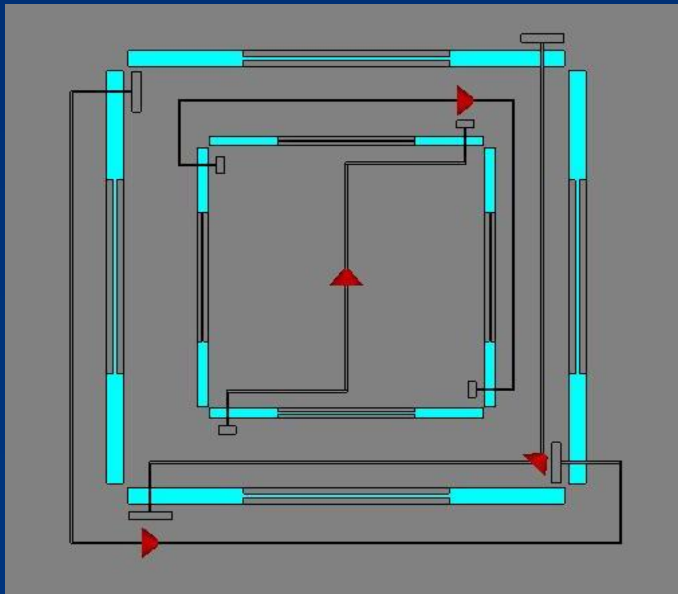
Seashell-Slot Antenna with H-slots and synphased excitation by MSL

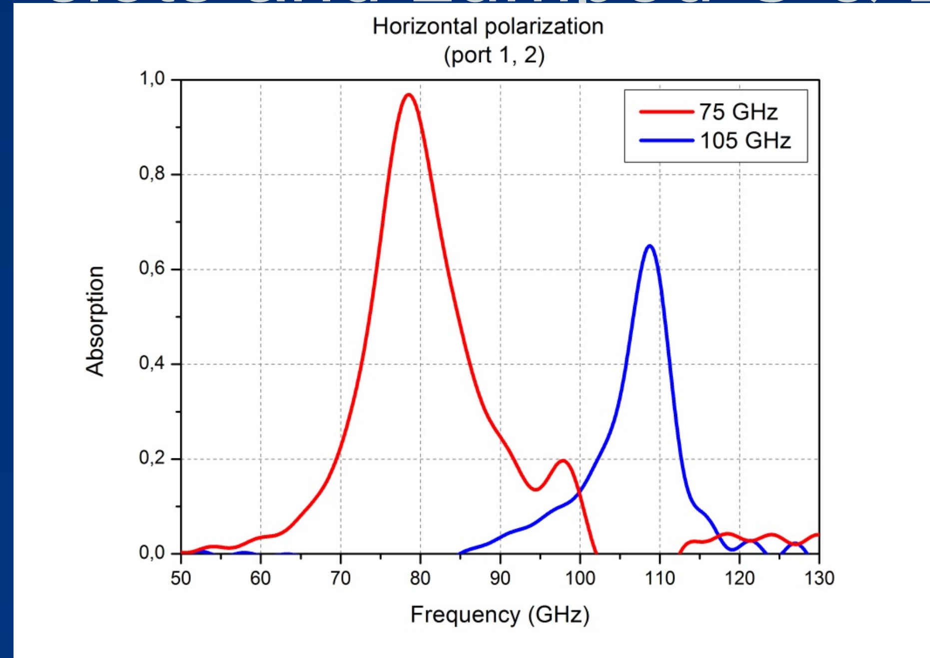


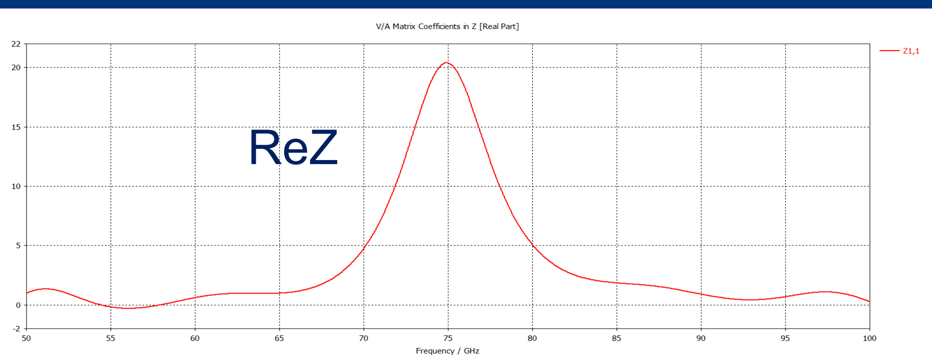
Summary of optical/RF performance with H-Slot Seashell

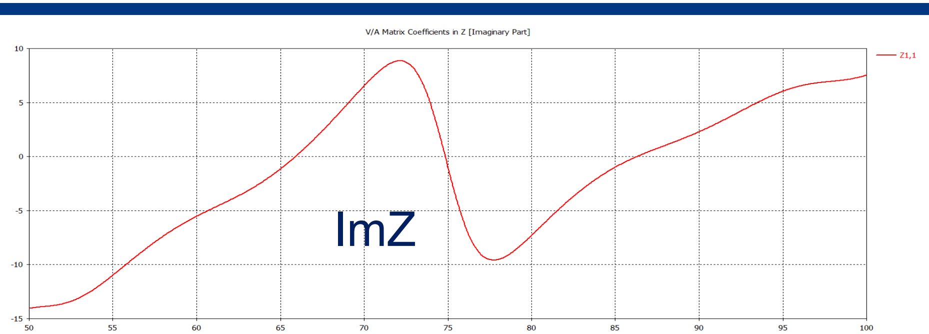
Parameter	**Sinuous Antenna**		**Cross-Slot Antenna**		**Seashell Slot Antenna**	
Frequency, GHz	75	105	75	105	75	105
Bandwidth (at -3 dB), GHz	21	24	13	35	12	16.5
In-band absorption-average in -50% of bandwidth	0.85	0.84	0.81	0.8	0.84	0.84
Lens	Si, 9mm; AR-quartz 430 um					
Beam FWHM, deg	24.1	16.2	22.4	17.5	23.7	15.4
Cross-polar, dB **H-slot, synphased** **H-slot, MSL phased**	-17	-15	-10	-17	**-16** **-17.7** **-18**	-**14.7** **21** **-24**
Beam ellipticity (frequency band), % **H-slot, synphased** **H-slot, MSL phased**	2	4	2	7	**4.8** **2** **1**	**8** **0.3** **3**
Side lobe level, dB	-18.9	-16.5	-18.6	-22.5	-17.6	-16.4

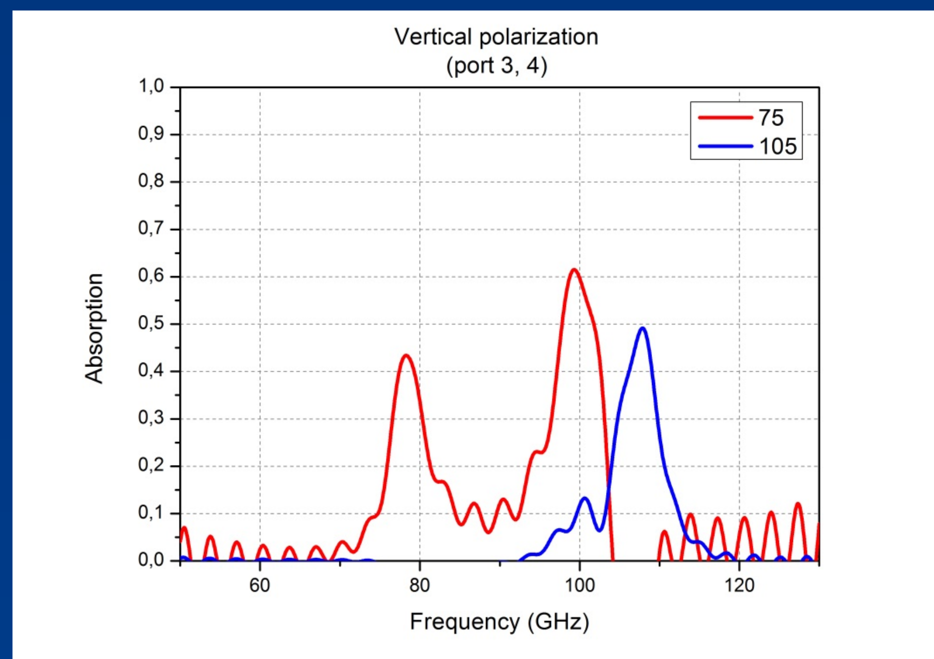
Seashell Antenna with λ- slots and Lumped C & L





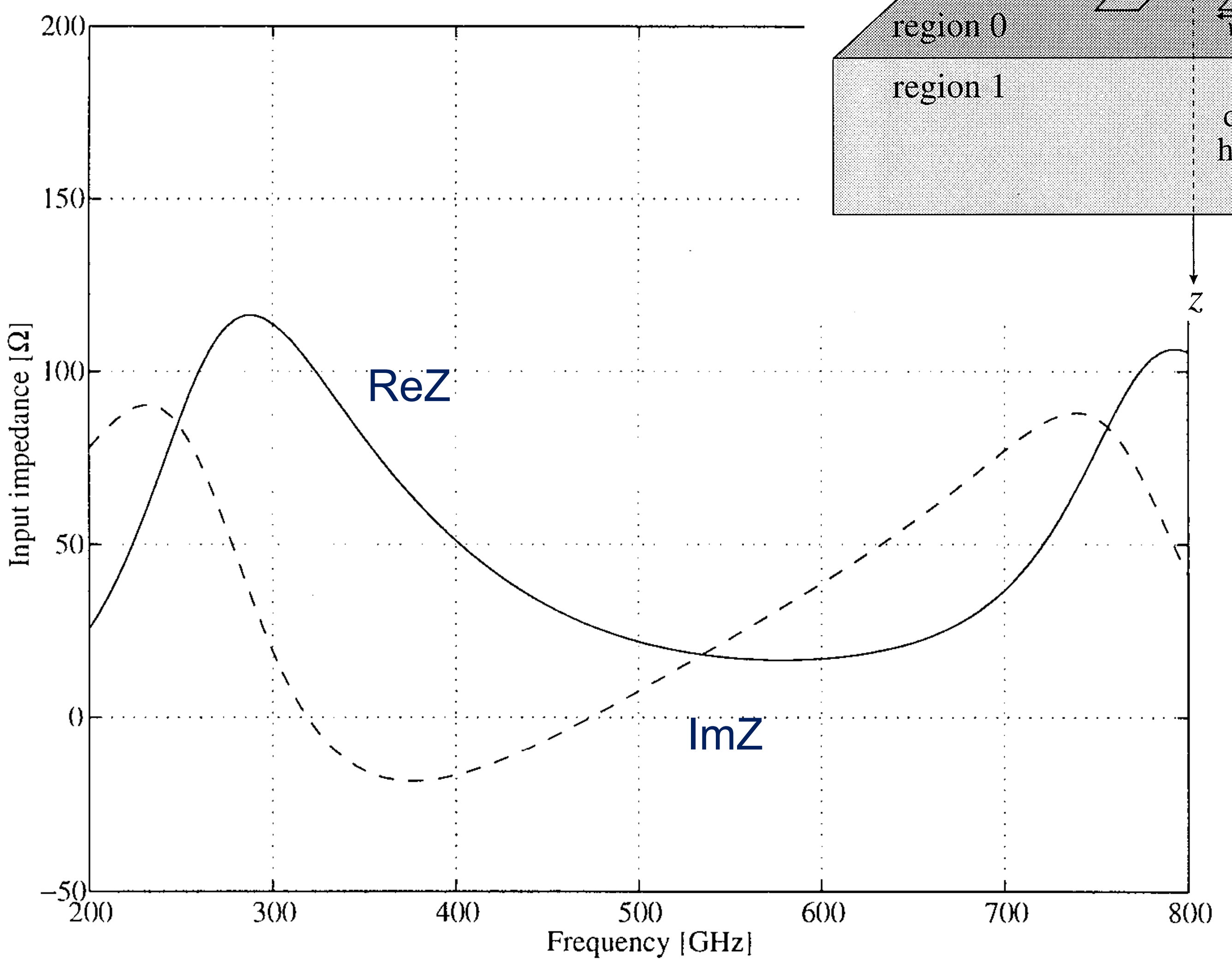


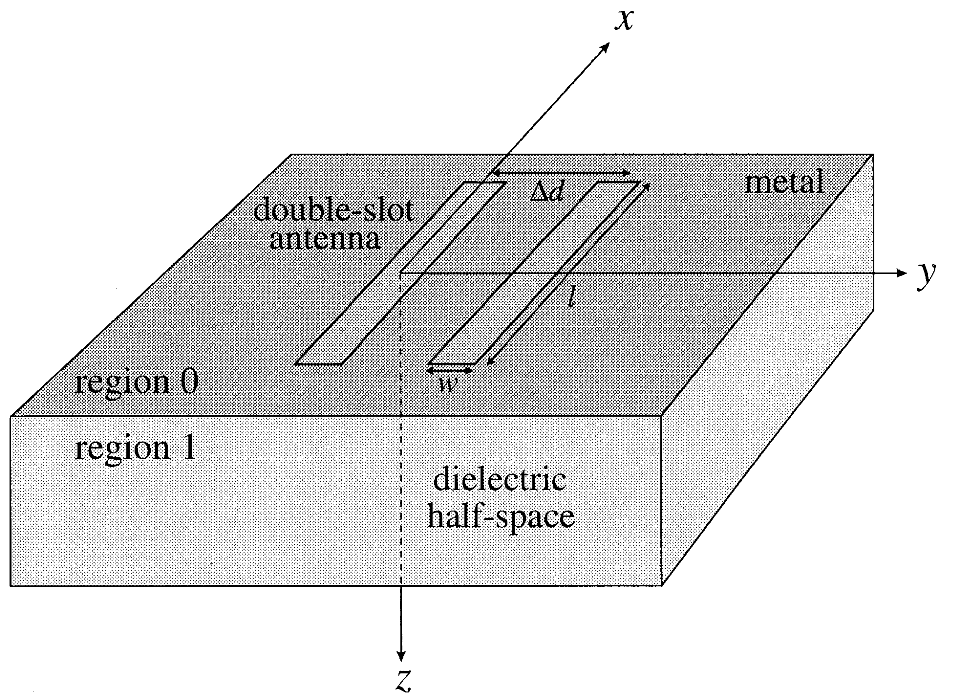




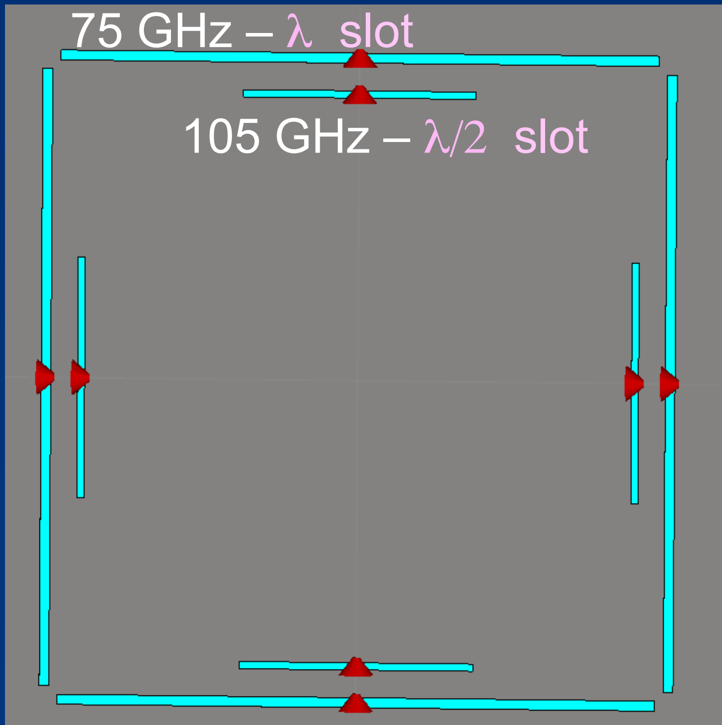
Imput impedance of a double-slot antenna

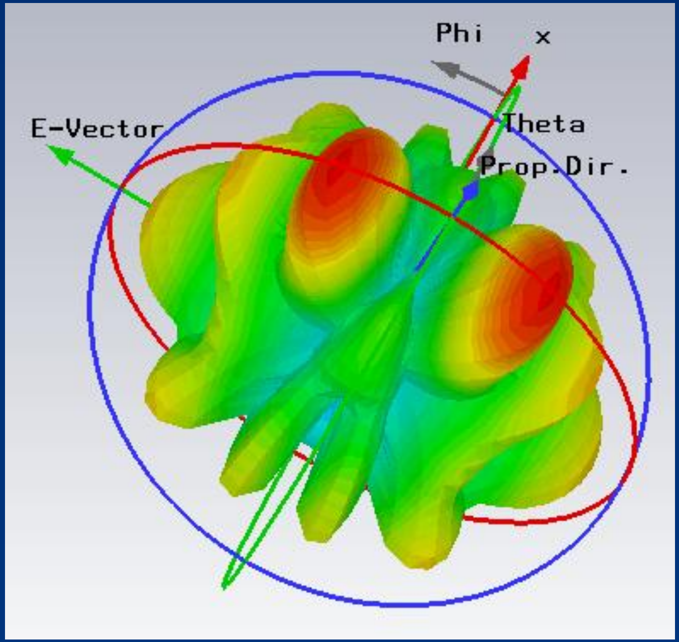
Maarten Van der Vorst

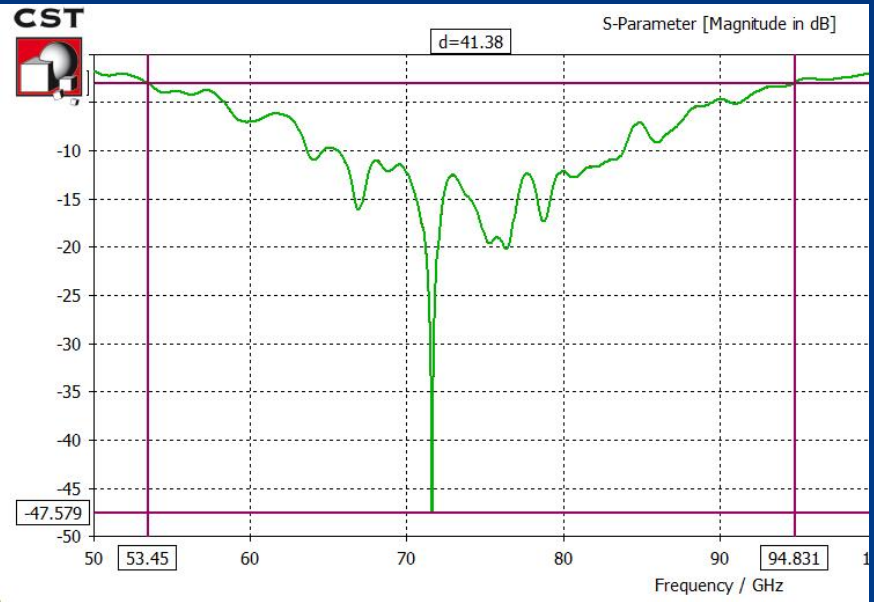


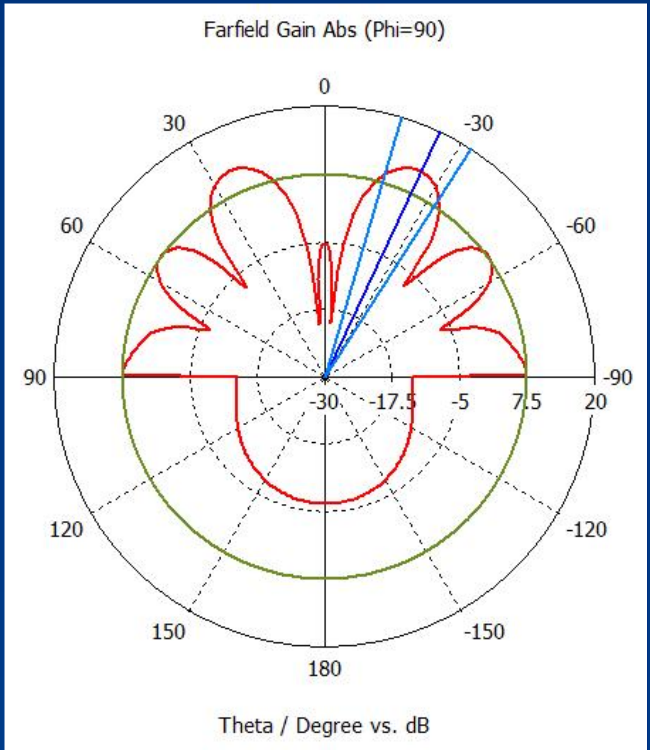


Seashell Antenna with λ- slots

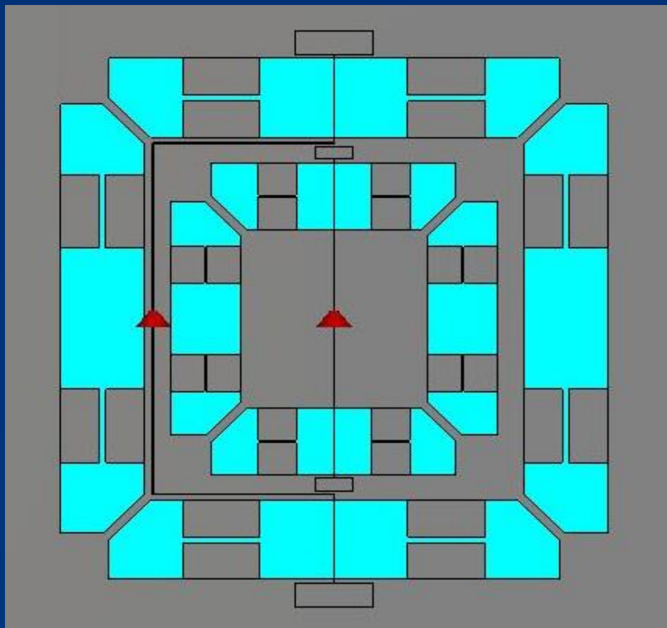


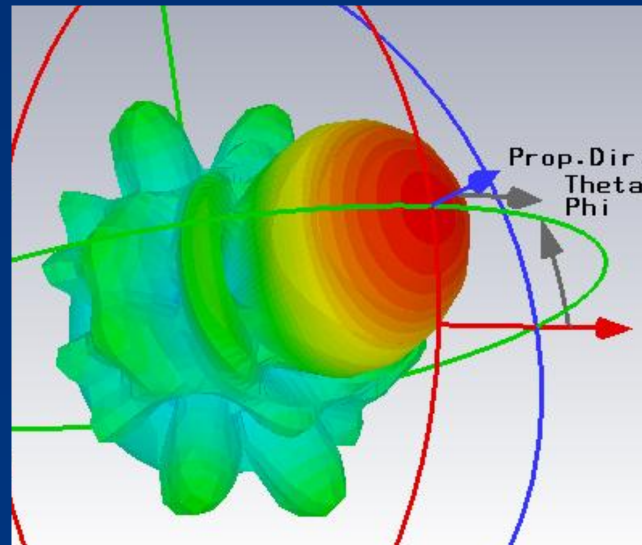


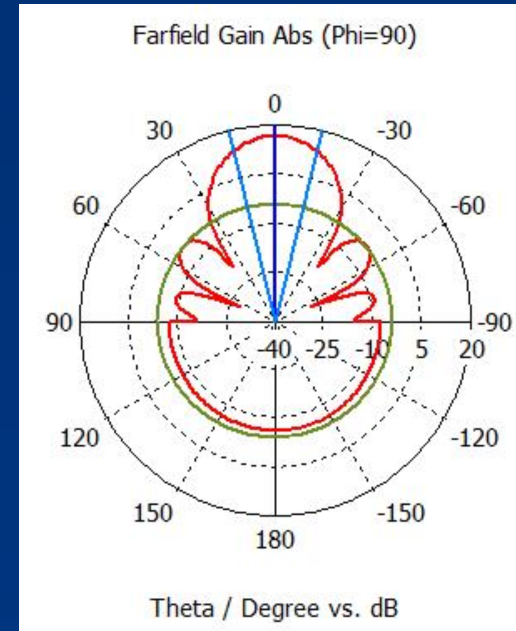


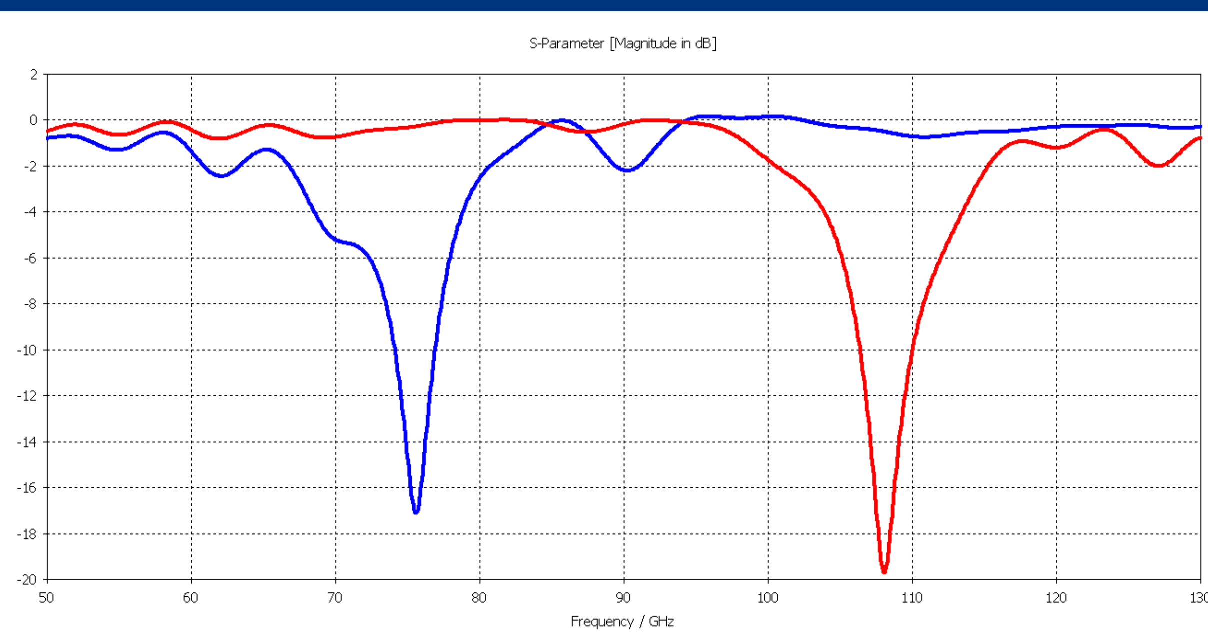


Seashell Antenna with λ- slots and Lumped C & L









	Freq, GHz	Seashell Antenna with RCEB filtering	Seashell Antenna with RCEB filtering/ MSL
Bandwidth at -3 dB, GHz	75	14	8
	105	21	12
Beam ellipticity, %	75	18	7
	105	3.3	3
Main lobe magnitude, dB	75	17	15.5
	105	20	19.3
Cross-pol, dB	75	-24	-29
	105	-32	-18

Заключение

ESA - COrE, Multifrequency Systems.

- Resonant Cold-Electron Bolometer (RCEB) - the main detector with nanofilter
- 1) Sinuous Antenna – impossible to insert RCEB without overcross of MSL + parasitic resonances.
- 2) Cross-Slot Antenna – impossible to insert RCEB without overcross of MSL + parasitic resonances.
- 3) Seashell Antenna with RCEBs:

- Great opportunity to optimize independently different frequency bands

- The optimal pixel is a Seashell Antenna with λ- slots and lumped capacitances