MULTENNA BASED MULTIPLIERS FOR THz APPLICATIONS

EP/K038125/1

The Team

Queen Mary
University of London

RAL Space

QMUL:

- Dr. Rost Dubrovka (PI)
- **Dr. Mélusine Pigeon (PDRA)**
- Dr. Oleksandr Sushko (PDRA)
- Dr. Rob Donnan (CI)
- Dr. Theo Kreouzis (CI)
- Prof. Clive Parini (CI)

RAL:

- Dr. Peter Huggard
- Dr. Byron Alderman
- Dr. Hui Wang

Contents

- Introduction
  - State-of-the art
  - Proposed concept
- Early Work
  - Multenna single element Designs
  - Multenna and diode matching
  - Multenna prototype and measurements

Context for need of high-power THz Sources

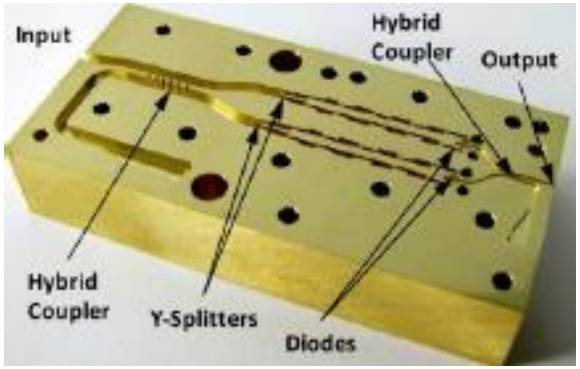
- **Urgent need** of THz sources for spectroscopy, bio-sensing, medical and pharmaceutical applications and potential industrial and security applications.
  - Unlike X-rays, non-ionising THz radiation does not damage organic material
  - Limitation: attenuation of incident energy by bulk water

- The **challenge** us to develop coherent THz sources that are:
  - Wideband-tuneable
  - Efficient
  - Compact
  - Relatively inexpensive (i.e. Buying a VNA compared with a p-Ge laser)

State-of-the art

- Frequency multiplier are:
  – Phase-lockable and frequency agile
  – No need of cryogenic cooling
  – Robust and compact
  – Long operational life

- Existing device:
  – Output powers in the range of milliwatts
    - Dimensions scaled (reducing parasitic and transit-time effects)
    - High cost, large dimensions, complex and need of cryogenic cooling photo-mixer
  – High frequency antennas and RF circuitry difficult to manufactured
    - Bulky waveguide multiplier blocks
  – Limited CAD tools taking into account coupling between antenna and active circuit
  – Individual tuning of array element impractical



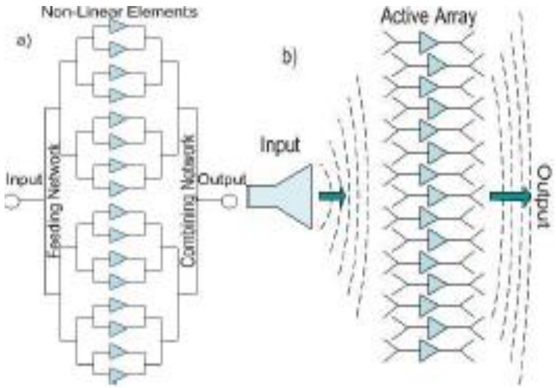
Ward et al, "Tuneable broadband frequency-multiplied terahertz sources", in proc. 33rd Int. Conf. Infrared, Millimeter and Terahertz Waves, Pasadena, CA, Sept. 2008

Proposed concept – revisiting old ideas

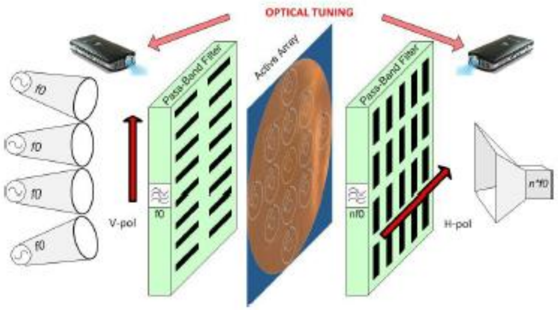
- Create a Quasi-optical multiplier array
  - No waveguide
  - Combine multiplied outputs from solid state devices
  - Antennas array coupled to non–linear devices (Schottky diode)
- Advantages:
  - Longitudinal compactness
  - Built-in frequency and polarization control elements
  - Simpler matching
  - Less ohmic losses
- Each element = a part of the total power - No risk of thermal breakdown
- Experimentally realised efficiency of QO = 60% at 800 GHz and 100% at 300 GHz

- Mm-wave oscillators illuminate a QO multenna array which coherently radiates a beam waist at 2 or 3 times the input frequency.
  - Based on planar Schottky diode multipliers (less than 1mm square)
- Multenna: innovative receive antenna, multiplier and output antenna
- Aims:
  - Prototyping a powerful QO THz source at 0.3THz (at least 100mW in a near Gaussian beam)
  - Fabrication and incorporation of optically addressable control elements made from organic semiconductors

QO power-combining using distributed networks:



a) Conventional power combining concept
b) spatial power combining concept

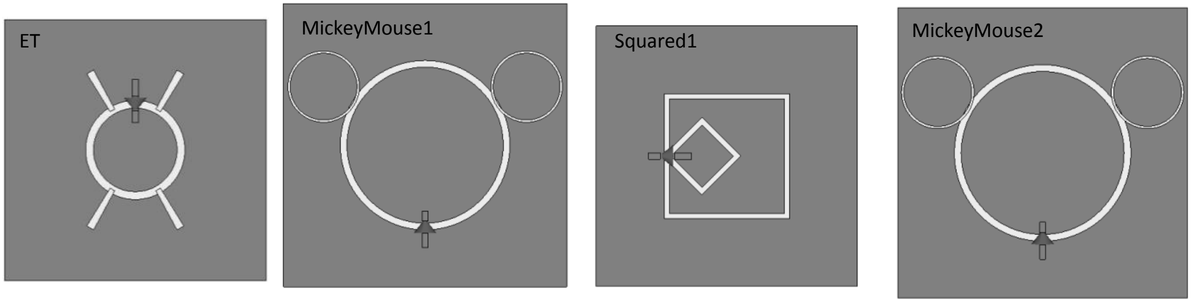


Novel integrated QO multiplier

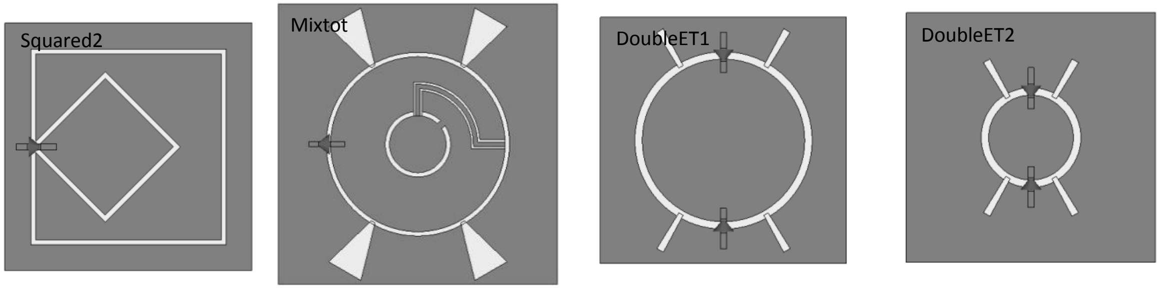
MULTENNA SINGLE ELEMENT DESIGNS

Multenna Proposed Design

- Multenna= slot ring
  - Proven working design
- Antenna designed at 100GHz
  - Tuned to radiates at 300GHz too
  - Incorporation of a tripler
  - Tripler= Schottky diode
- Single element of around 1*1mm^2 size
  - Simulated in free space



The top designs

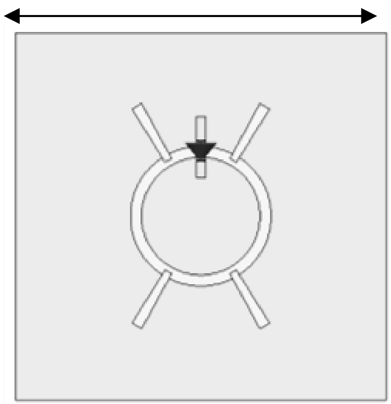


The designs to try

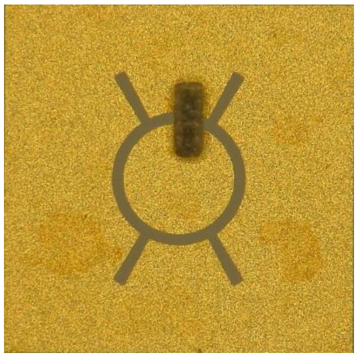
Yeap, S.B. *et al.*, "FDTD simulation and measurements of a 90GHz quasi-optical annular slot receiver," *IEE Proc. MAP*, **152** (2), 117-123 (2005)

ET ANTENNA

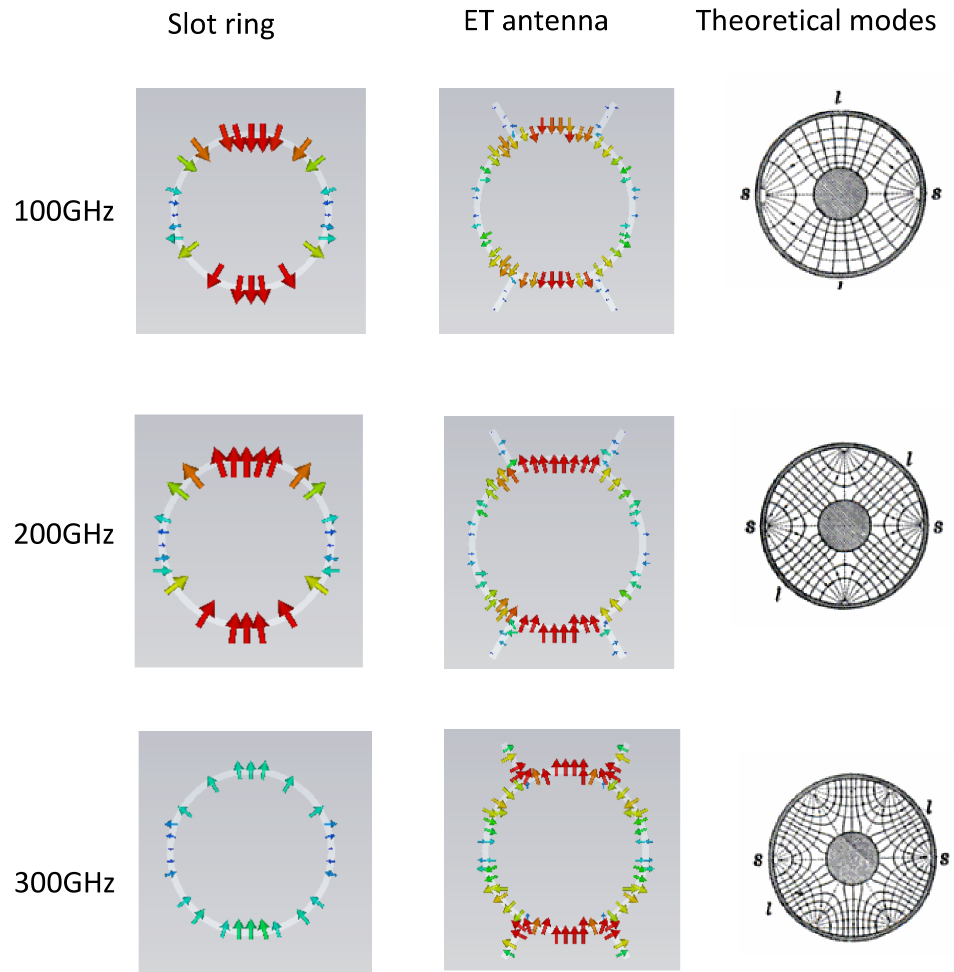
- Stubs placed at 30° to create zeros at 300GHz



Simulated antenna



Manufactured antenna



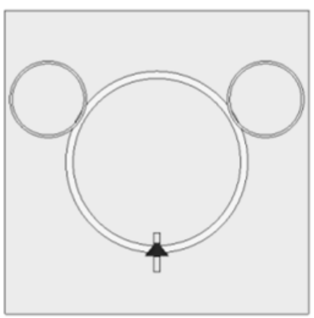
Pigeon. M, Donnan. R, Dubrovka. R, Kreouzis. T, Wang. H, Alderman. B, Huggard P. G,"Planar quasi-optic THz source: The multenna", 2015 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting, (2015)

Pigeon. M, Donnan. R, Kreouzis. T, Parini. C, Dubrovka. R "Improving Harmonics' Generation by "zeroing- Stubs" in a Slot-Ring Antenna", European Conference on Antenna and Propagation, Davos April (2016)

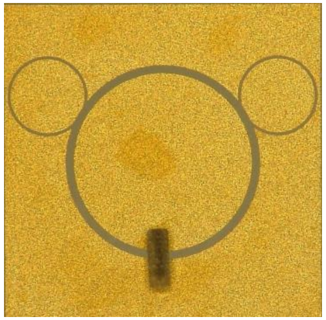
TOPOLINO ANTENNA

- 300GHz rings placed at 60° maxima of 300GHz

1.28mm



Simulated antenna



Manufactured antenna

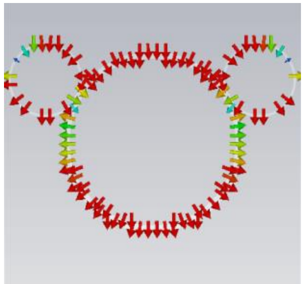
Theoretical modes

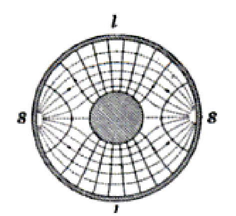
Topolino

Big ring

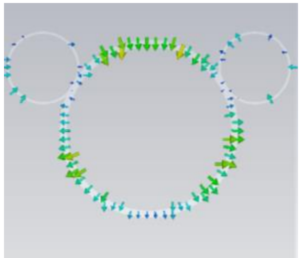
ears

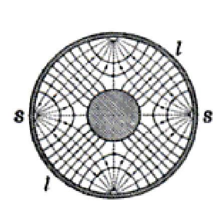
100GHz

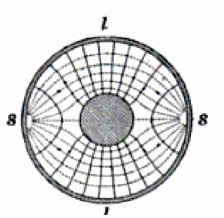




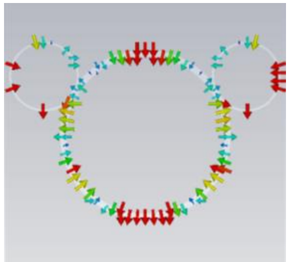
200GHz

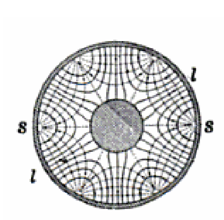


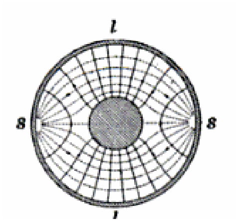




300GHz







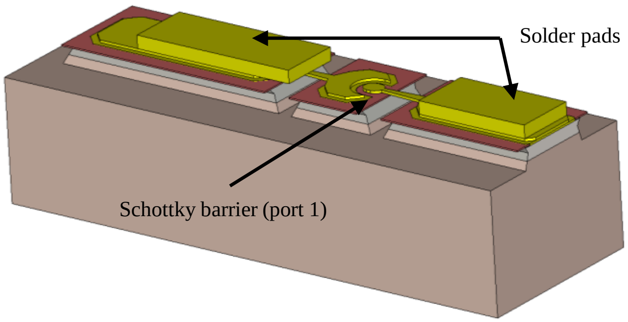
MULTENNA AND DIODE MATCHING

MULTENNA AND DIODE MATCHING

- Two ports are considered on the diode:
  - The schottky barier
  - The solder parts
- Diode=barrier+structural
- Impedance diode=Impedance barrier+impedance structural
- Impedance barrier:

F (GHz)	$Z_{barrier}$
100	27.5-75j
300	9.98-23.1j

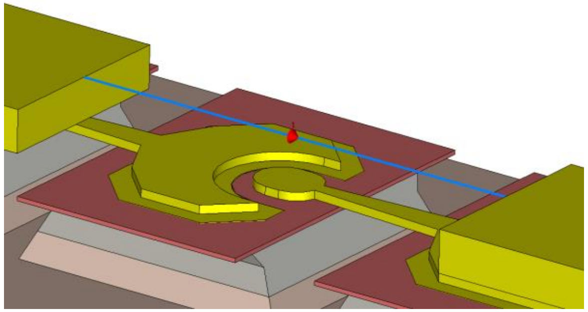
- Impedance structure ???
  - EM simulation



IMPEDANCES

- Waveguide port KO -> discrete port
- 2 different discrete ports: Wire or Face
- Impedance at port 2 when port 1 is loaded

Type of Port 2	Frequency (GHz)	Z_{port2}	R (Ω)	C (10^{-14}F) or L (10^{-11} H)	Z_{port1}
Wire	100	13.5-28j	13.5	5.68 (C)	27.5-75j
Wire	300	7.88+59j	7.88	3.13 (L)	9.98-23.1j
Face	100	12.7-41j	12.7	3.88 (C)	27.5-75j
Face	300	9.64+16j	9.64	0.85 (L)	9.98-23.1j



Wire port

- Impedance at port 1 when port 2 is loaded

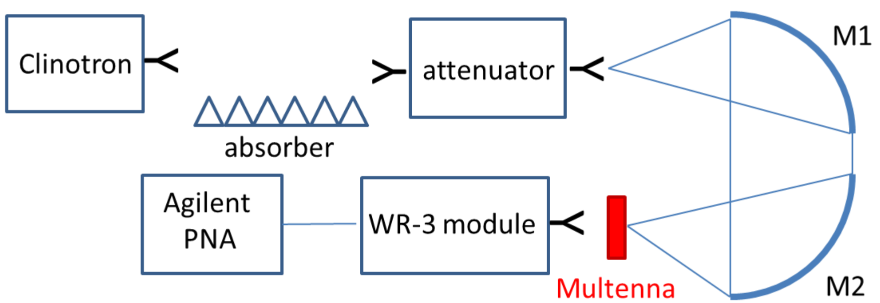
Type of Port 2	Frequency (GHz)	$Z_{junction}$	$Z_{junction}$ expected
Wire	100	29.5+74j	27.5+75j
Wire	300	13+23.2j	9.98+23.1j
Face	100	28.59+74.1j	27.5+75j
Face	300	12.68+23.9j	9.98+23.1j

Face port

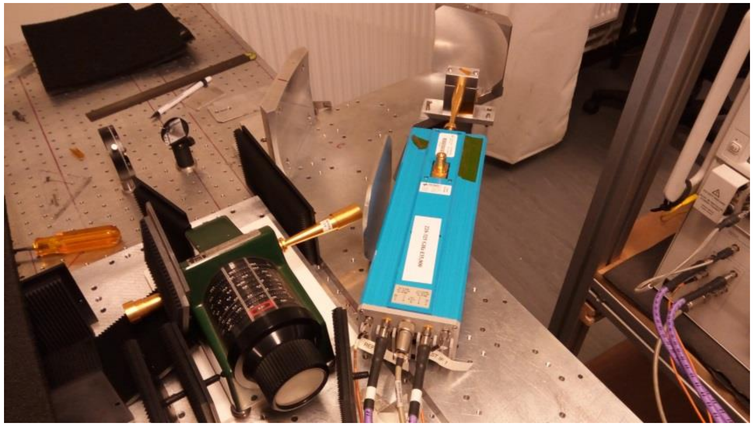
MULTENNA PROTOTYPE AND MEASUREMENT

Multenna Prototyping

- Quasi-optical measurement bench:
  - Very small size of prototype 1*1mm^2
  - Ease the manufacturing and the measurement process



Schematic of the bench

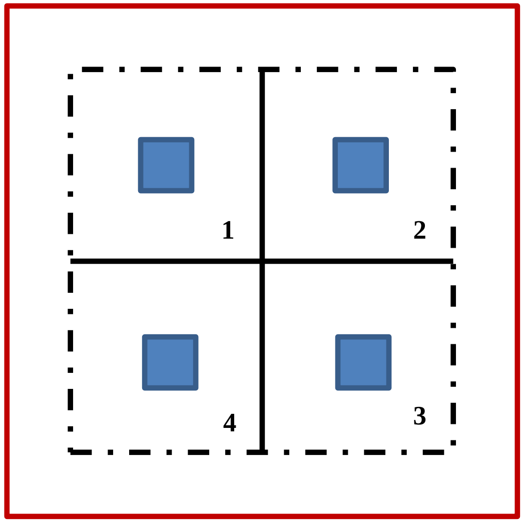


Real bench

Quasi-optical measurement bench

Prototype design

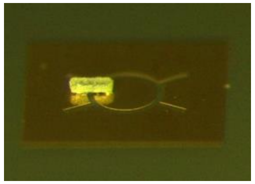
- Prototype design:
  - Quartz tile of 20*20mm
  - Active on 15*15mm
  - 4 elements per tile
  - Distance inter element of approximatively 10mm



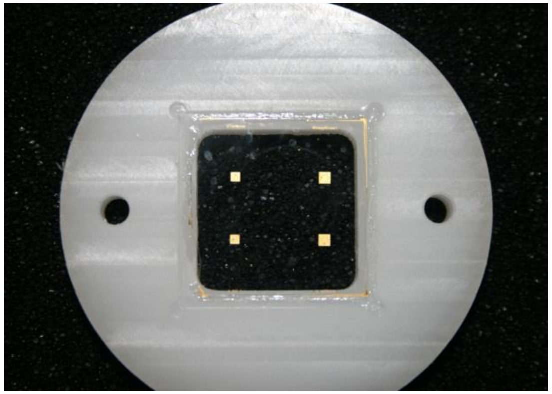
Schematic of the prototype tile

- Consequences
  - Increase substrate size for the Multenna from 1 to 10mm
  - Very low impact on impedances at both frequencies

Frequency (GHz)	1 mm² substrate	10 mm² substrate
100	7.2 + j43.7	7.3 + j42.6
300	10.8 - j16.9	10.8 - j16.2



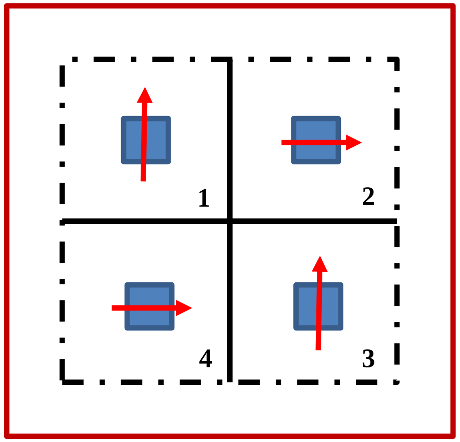
Manufactured antenna with Schottky diode



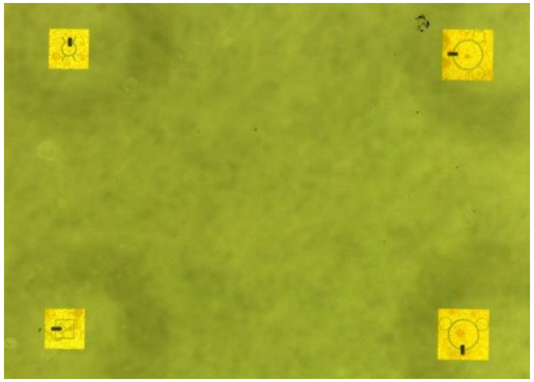
Manufactured tile

Depolarization of neighbour elements

- To increase isolation of elements:
  - Differentiation of the polarization of two neighbours elements
  - Vertically
  - Horizontally
  - 2 elements in diagonal have the same polarization



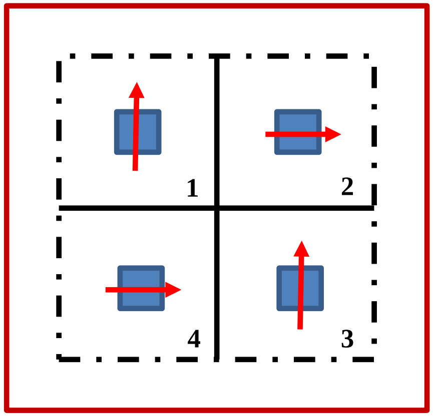
Schematic of the tile with polarization differentiation


Zoom on the manufactured tile

Results on decoupling

- If we compare:
  - Array1: all the samples have the same polarization
  - Array2: differentiation in the polarization of the samples

	100GHz		300GHz	
In dB	Array1	Array2	Array1	Array2
S1,2	-32.3	-48.7	-35.3	-56.7
S1,3	-37.2	-37.3	-40.3	-39.9
S1,4	-43.4	-56.3	-45.7	-53.5
S2,3	-43.4	-49.1	-45.7	-55.1
S2,4	-37.2	-37.4	-40.3	-39.9
S3,4	-32.9	-49.6	-35.8	-54

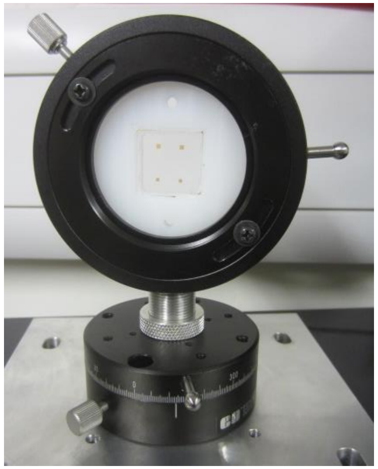


- Decoupling improved of between -6 and -21.4dB between neighbour's elements
- Horizontal decoupling much improved than vertical one (already low without depolarization)
- No change between diagonal elements

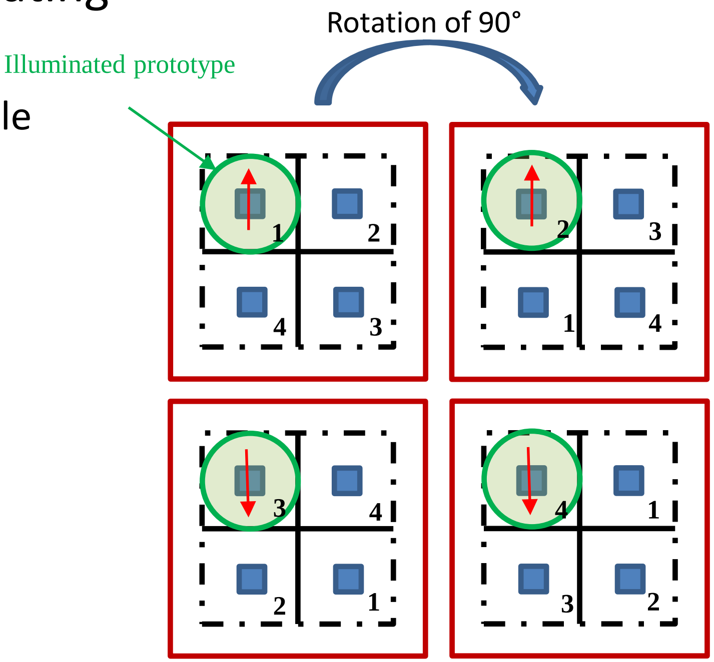
Rotation of the holder

When the quartz tile is placed in a rotating holder:

- Simple rotation of 90° illuminate the next sample
- No change in the measurement bench
- No need of realignment
- Polarization always ok



Manufactured tile in the rotating holder



Schematics of the rotation of the tile

Thank you for your attention