WIPE
COST IC1301

The driving force of IoT for the development of electronic technologies

Luca Roselli

Dipartimento d'Ingegneria
Departement of Engineering

HF lab

(Inter)net of things?

Yesterday

Today

What are the challenges of today?

Connectivity

Sensing capabilities

The today industrial strategies

*"**L'accordo** siglato oggi tra **Microsoft Italia ed STMicroelectronics** Srl rappresenta un passo importante per aiutare le aziende italiane a raggiungere il proprio potenziale grazie **all'Internet of Things**. Insieme intendiamo offrire una piattaforma aperta e scalabile che possa **supportare qualsiasi azienda**, dalle start up alle imprese consolidate. Il nostro obiettivo è renderle capaci di **trasformare i propri processi**, di cogliere nuove opportunità e perfino di dar vita a **nuovi modelli di business**",* – ha dichiarato **Eric Boustouller**, Corporate Vice President Microsoft Western Europe.

Just an example

LACIMBALI

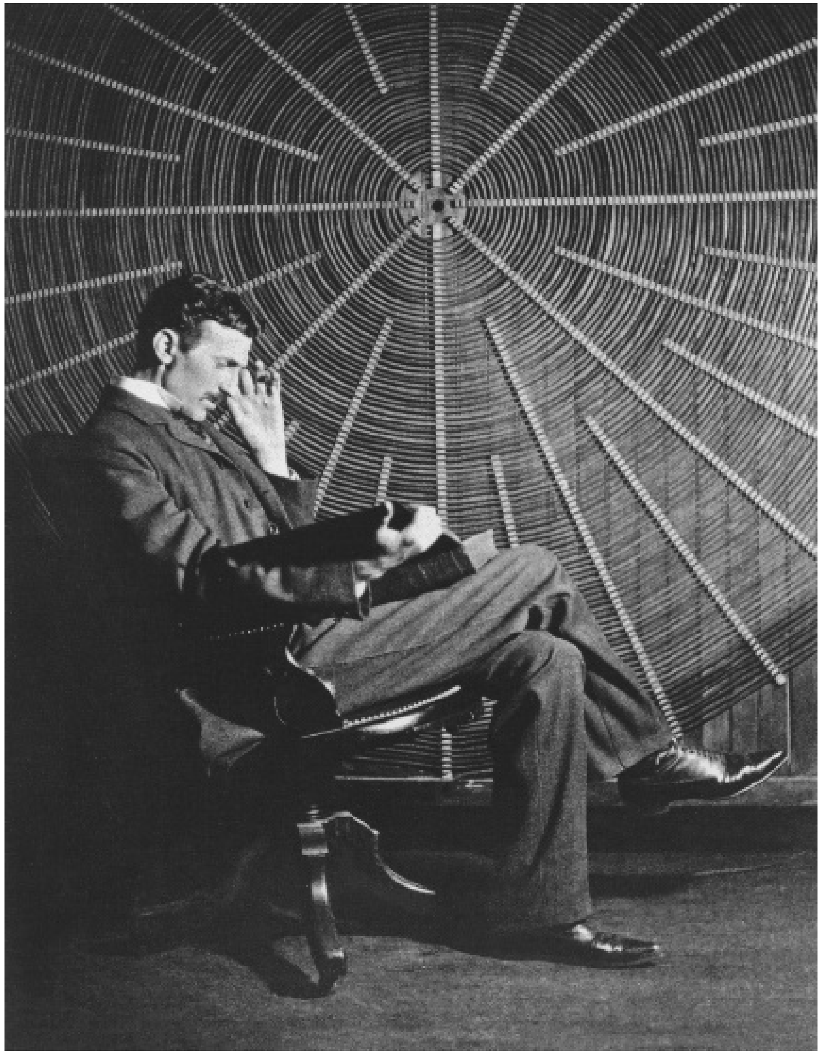
Microsoft

Tomorrow?

“When wireless is perfectly applied, the whole earth will be converted in a huge brain, which in fact it is, all things being particles of a real and rhytmic whole… and the instruments through which we shall be able to do this will be amazingly simple compared with our present telephone.

A man will be able to carry one in this vest pocket”

Nikola Tesla, 1926, Collier’s Magazine



Tomorrow?

Just a paradigm

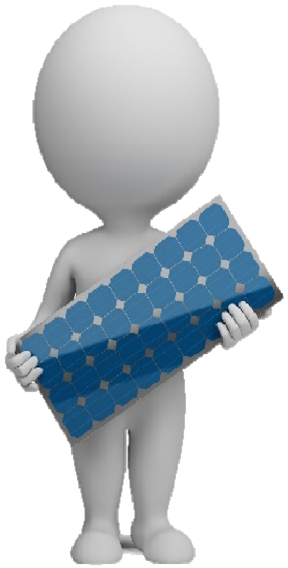
Just a paradigm

The additional challenges of tomorrow?

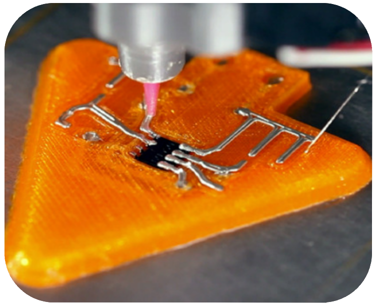
Reciclability

Manufacturing process compatibility

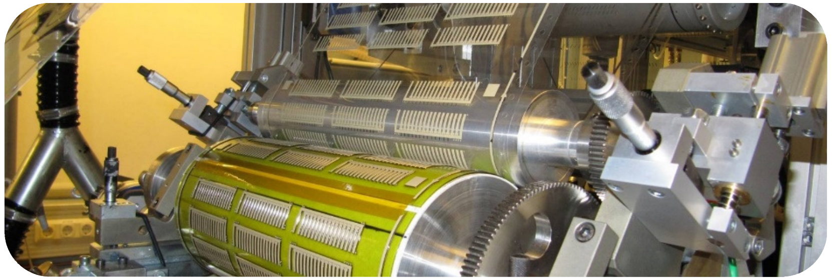
Autonomy



How to face these challenges?

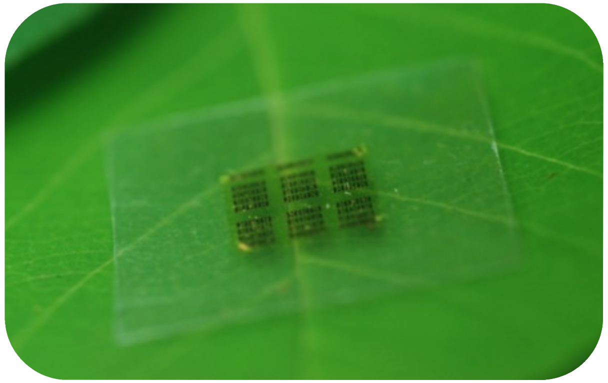


3D printing
R2R process

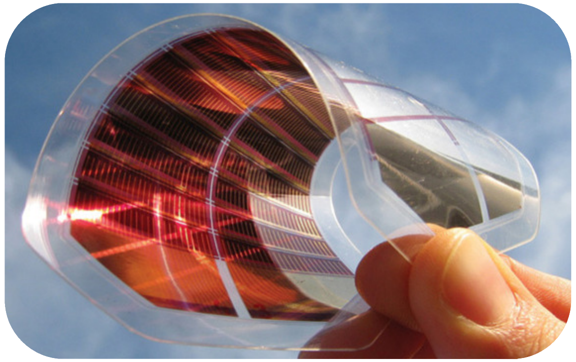


Wireless Power Supply

Bio-materials

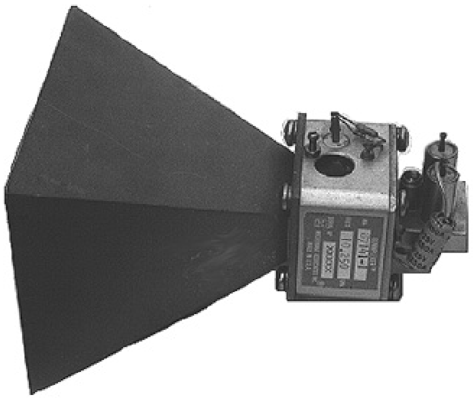


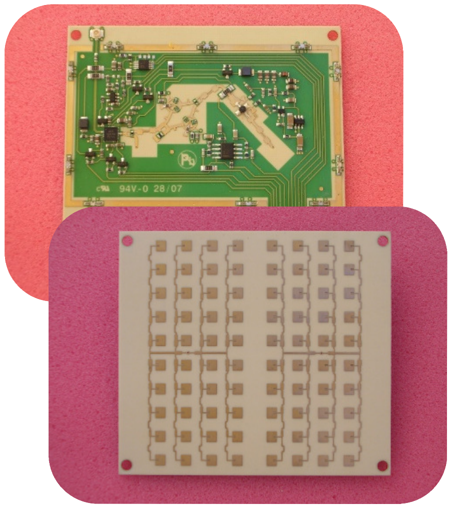
Organic solar panels

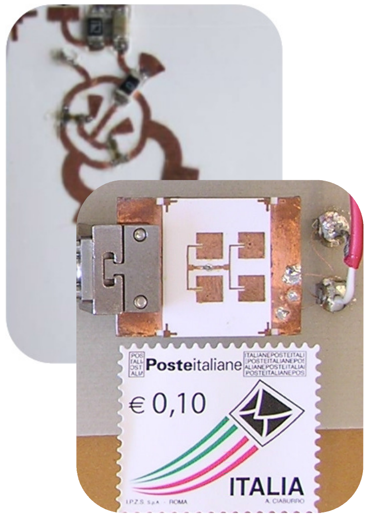


evolution (example)

1990 | 2000 | oggi

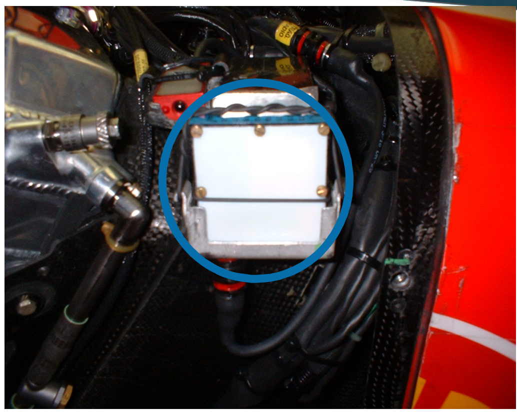


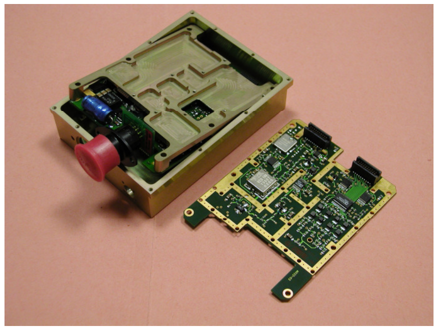




≈500 € | 60 € | <1 €

It is not by lucky ☺





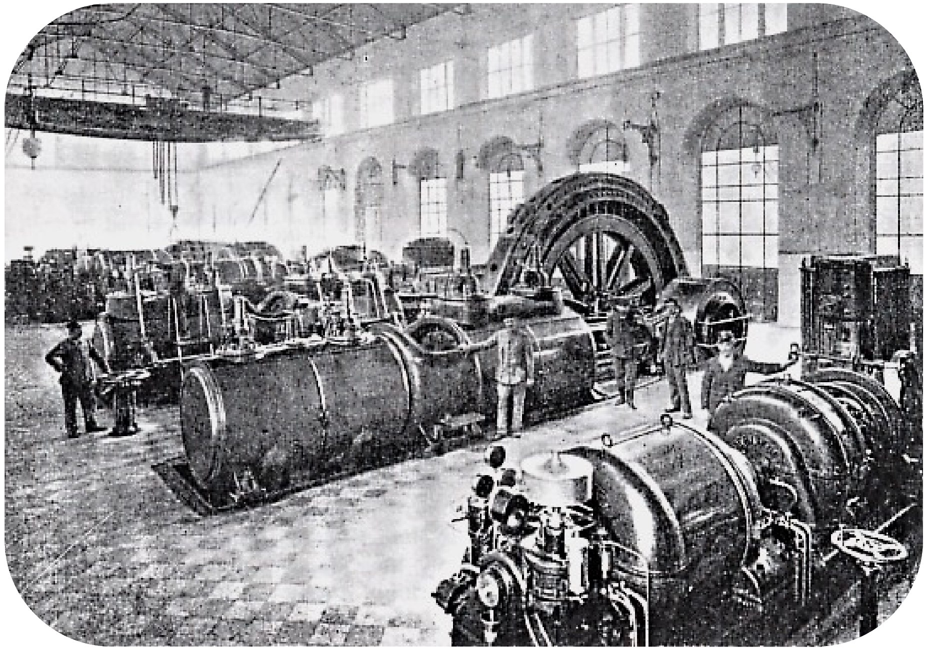
From F1 telemetry to IoT

The “force” of this vision

Before the advent of “homo sapiens”

From homo sapiens to the 1st Industrial revolution

1st Industrial revolution 1750 ->



2nd Industrial revolution 1870 ->

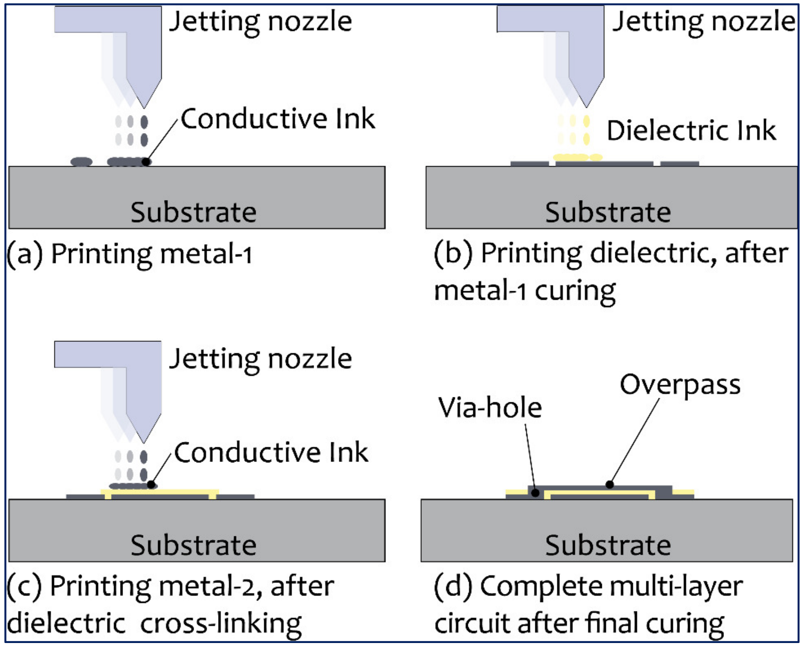
… in the future?

End of introduction ☺

Technologies

A bit of foolhardiness!

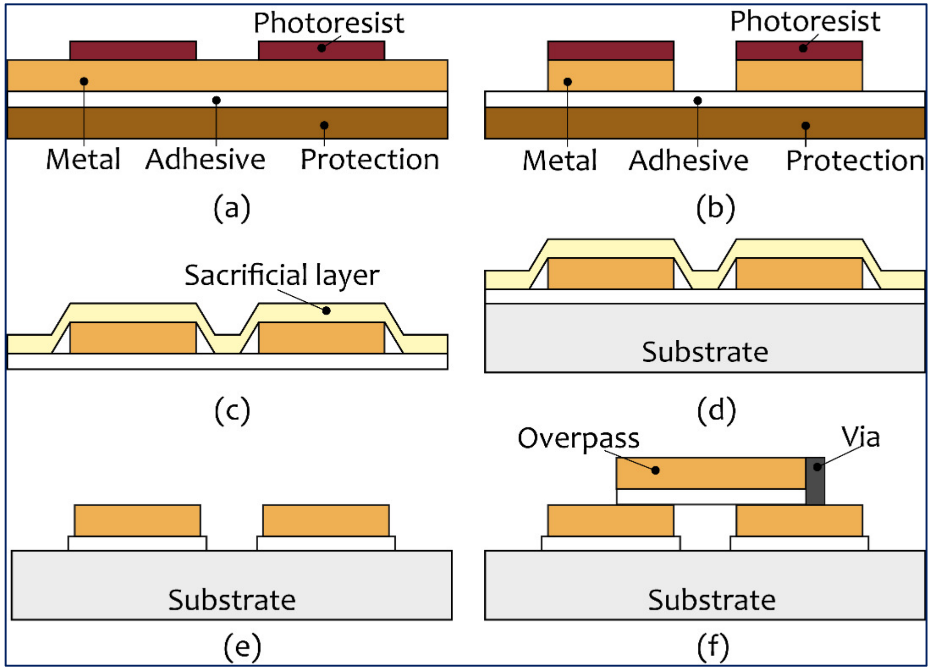
Multi-layer ink-jet printing

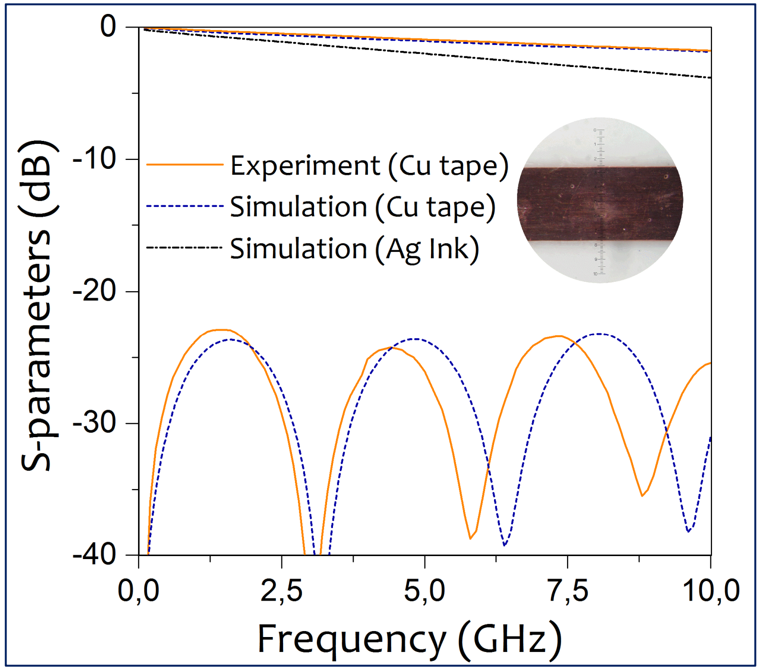


- Substrate independent
- Cleanroom free
- High control on electrical and physical properties of the inks
- Multi-layer
- Fully additive (no waste of chemicals)
- Compatible with rapid prototyping and R2R industrialization

Georgia Tech

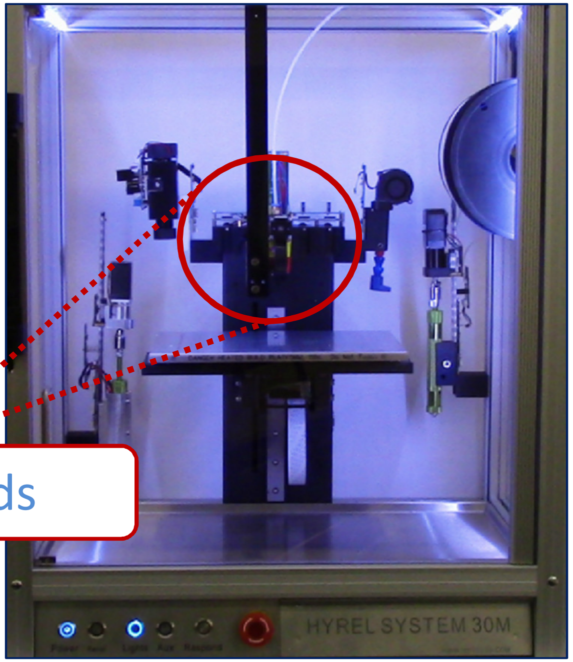
Metal adhesive laminate



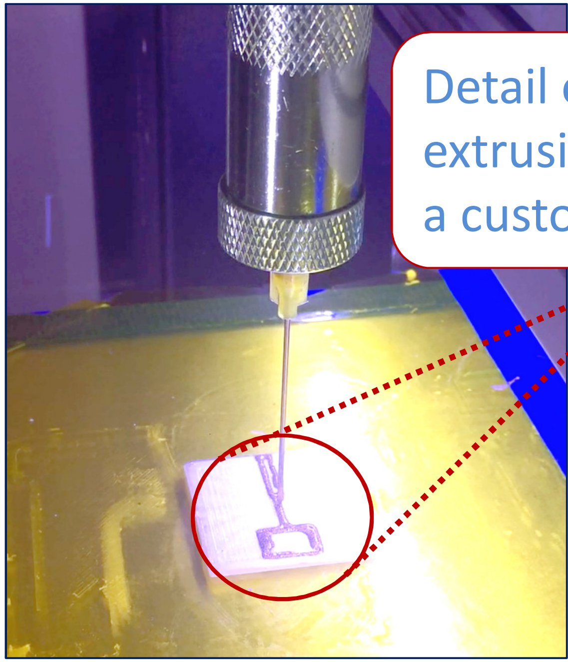


- Substrate independent
- Room temperature
- Compatible with R2R industrialization
- High-temperature solderability of packaged components
- Multi-layer (via holes are doable)
- High metal conductivity (σ=5.8e7 S/m)

3D printing



Multiple heads

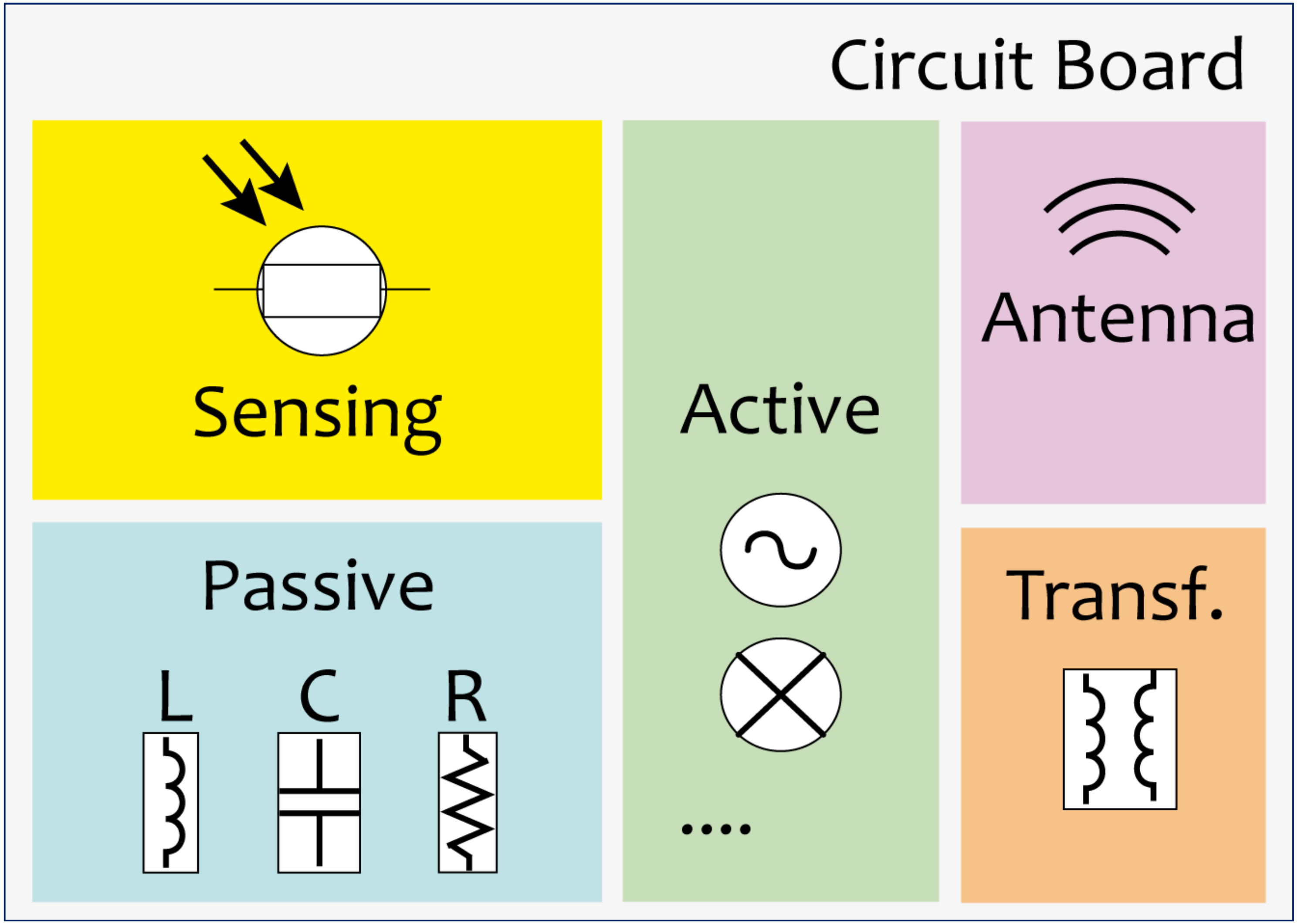


Detail of Cu-paint extrusion through a customized head

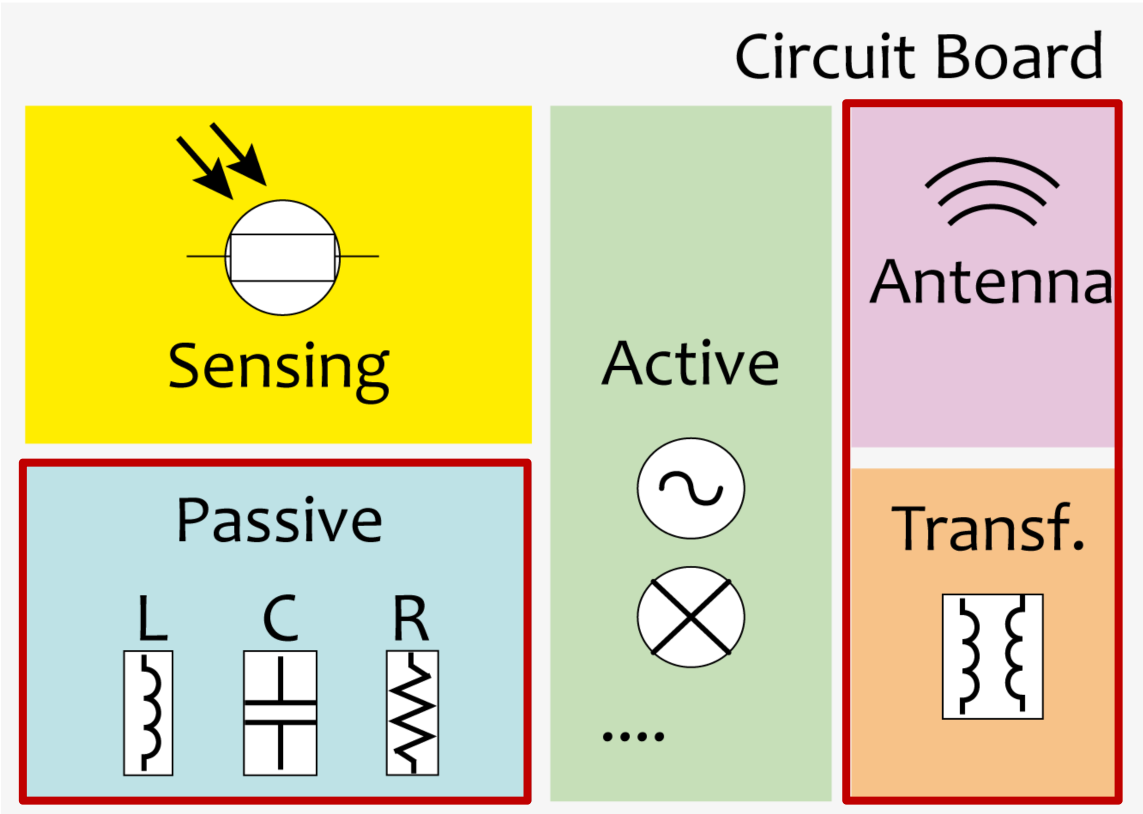
- High shape customization
- Room temperature
- Rapid prototyping
- Fully additive

WIPE
COST IC1301
Georgia Tech

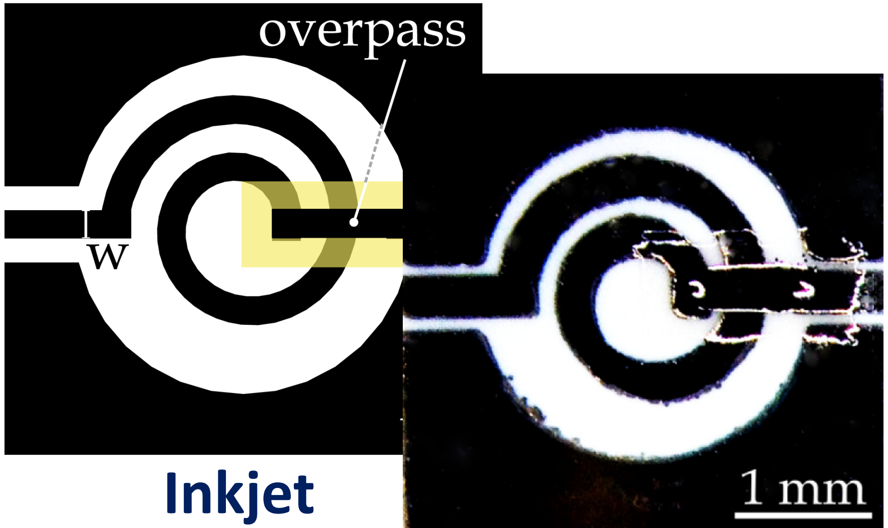
A reference structure



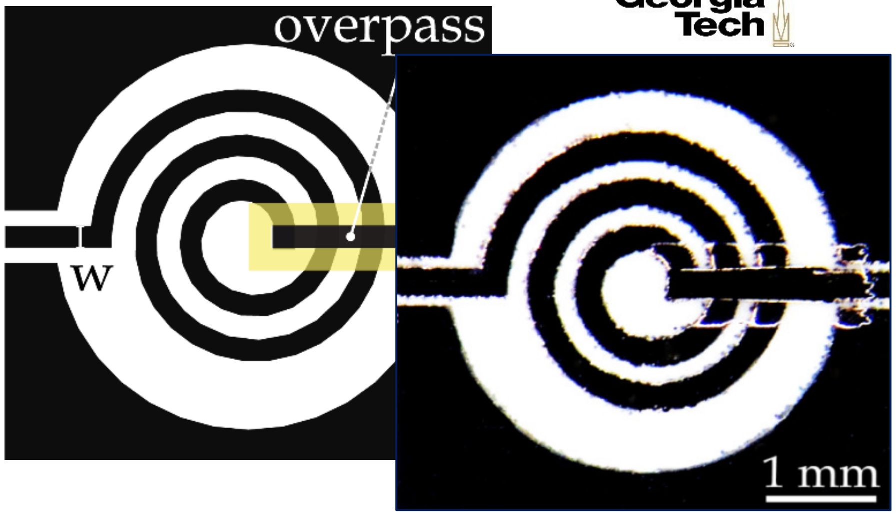
Passive Devices and Antennas

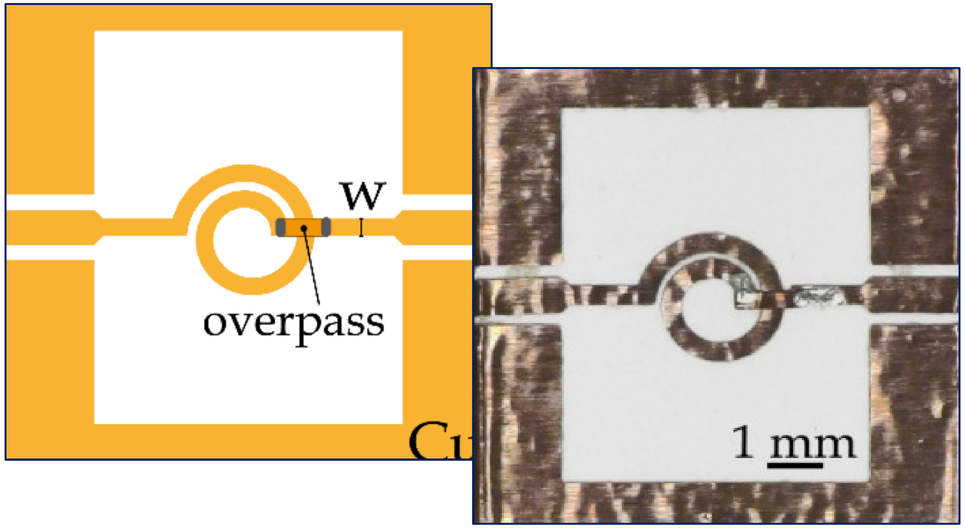


Inductors on paper

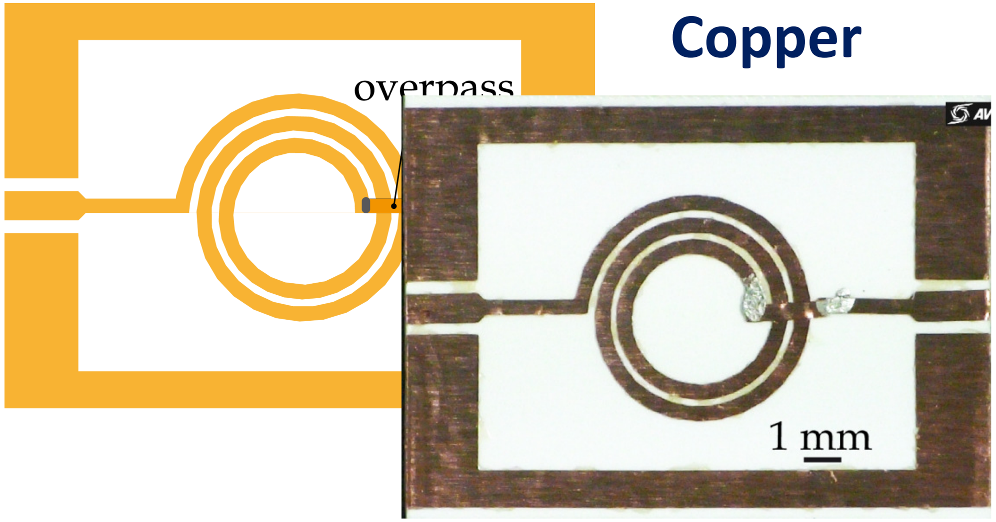


Inkjet

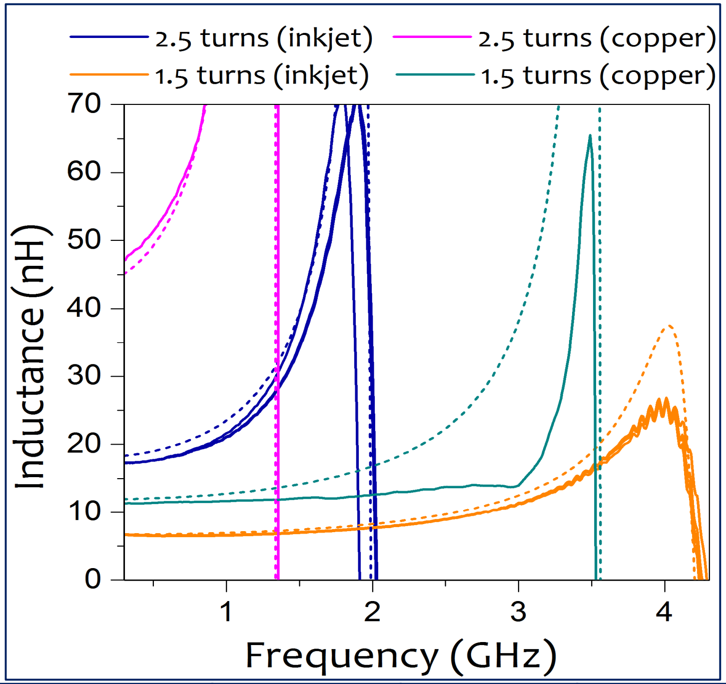


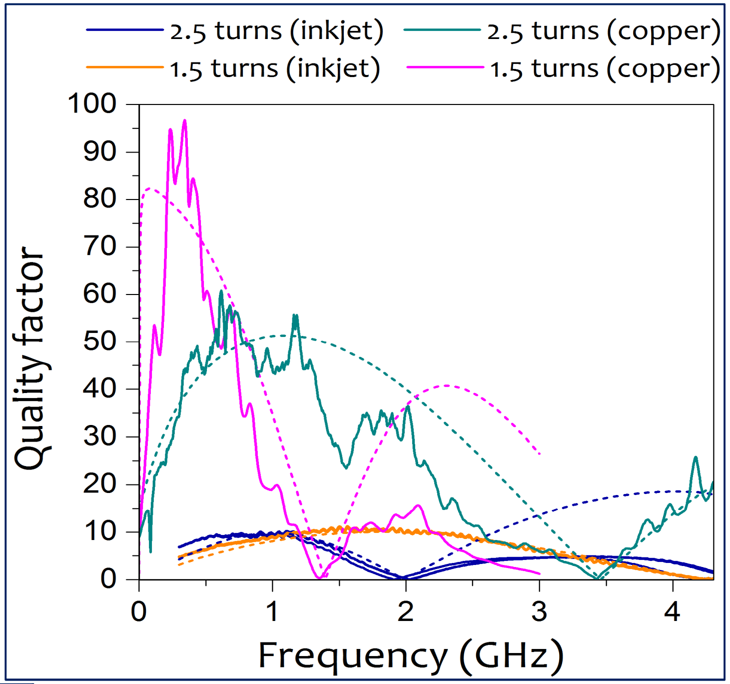


Copper



Results



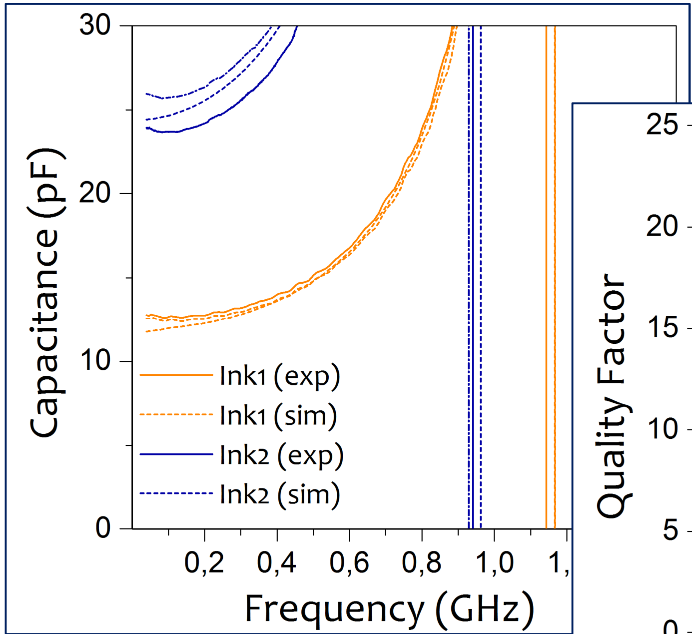


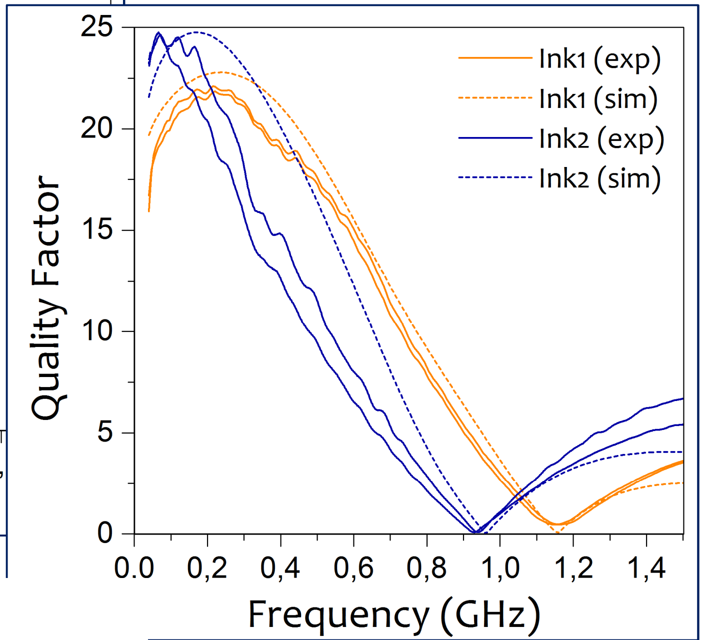
Ref.	type	tech.	L (nH/mm²)	maxQ
[Lee]	square	inkjet	0.04	n.a.
[Bidoki]	circular	Inkjet	0.002	n.a.
[Jung]	octog.	GaAs	190	20
this work-1	circular	inkjet	**0.6**	11
this work-2	circular	copper	0.4	**90**

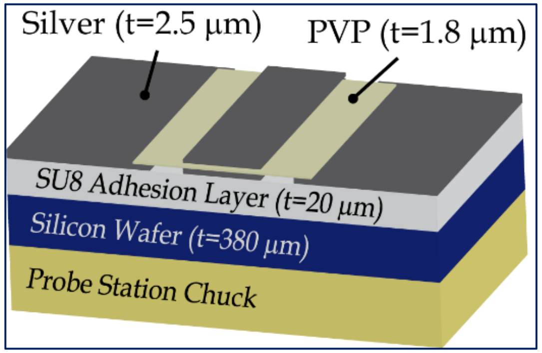
$$L = \frac{\mathrm{Im}\{Y_{11}\}}{2\pi f}$$

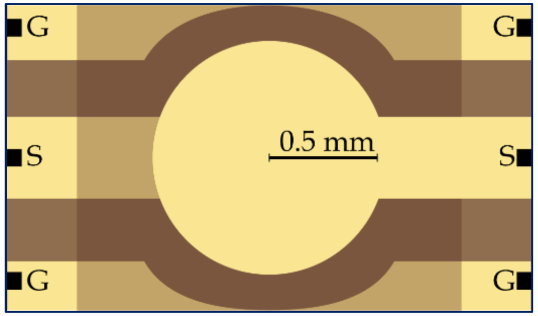
$$Q = \frac{\mathrm{Im}\{1/Y_{11}\}}{R}$$

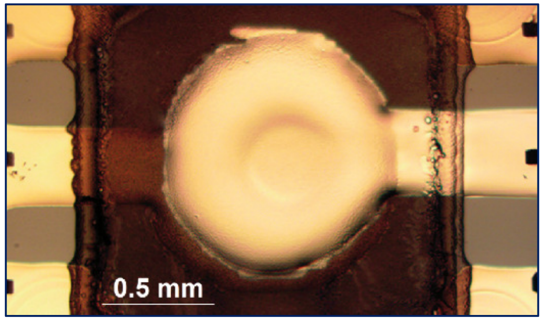
Capacitors on Si wafer



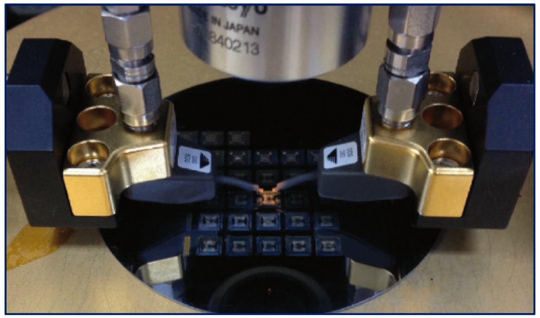




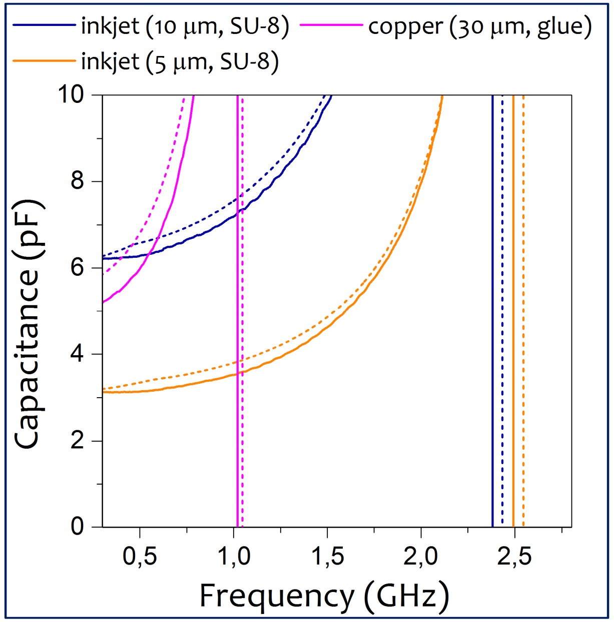


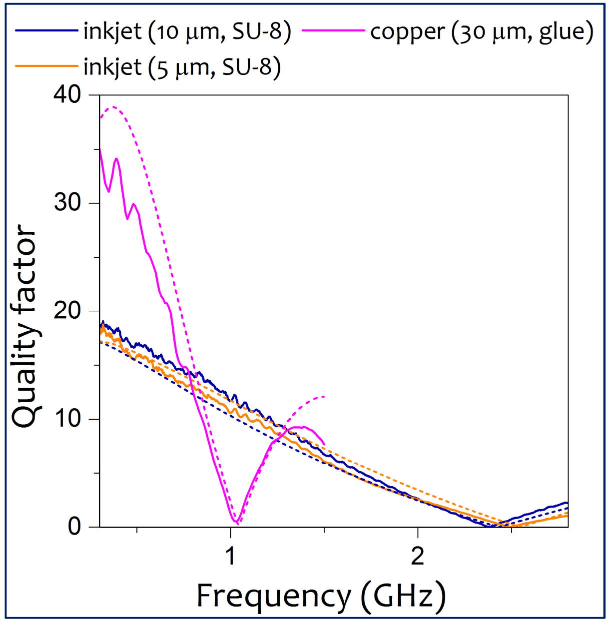


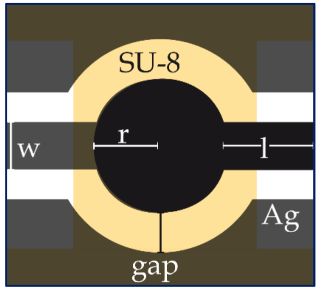
- C_{max} = **33 pF/mm²**
- SRF = **1.2 GHz**
- maxQ = **25** (300% higher than similar inkjet MIM capacitors [Cook, Liu, Li, Lim])

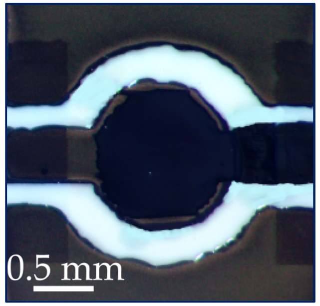


Capacitors on paper





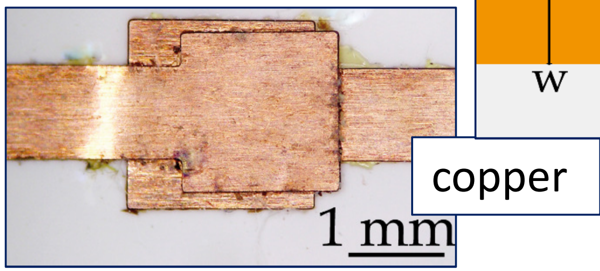


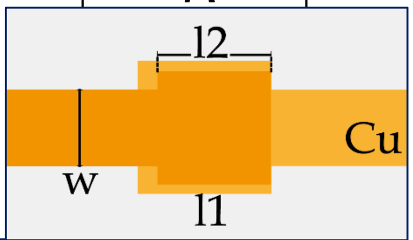


$$Q = \left| \frac{\mathrm{Im}\{1/Y_{11}\}}{R} \right|$$

Ref.	type	tech.	C (pF/mm²)	maxQ
[Bidoki]-1	square	inkjet	0.7	n.a.
[Bidoki]-2	Interdig.	Inkjet	n.a.	0.004
[Jung]	square	GaAs	480	100
this work-1	circular	inkjet	3.8	18
this work-2	square	copper	0.8	35

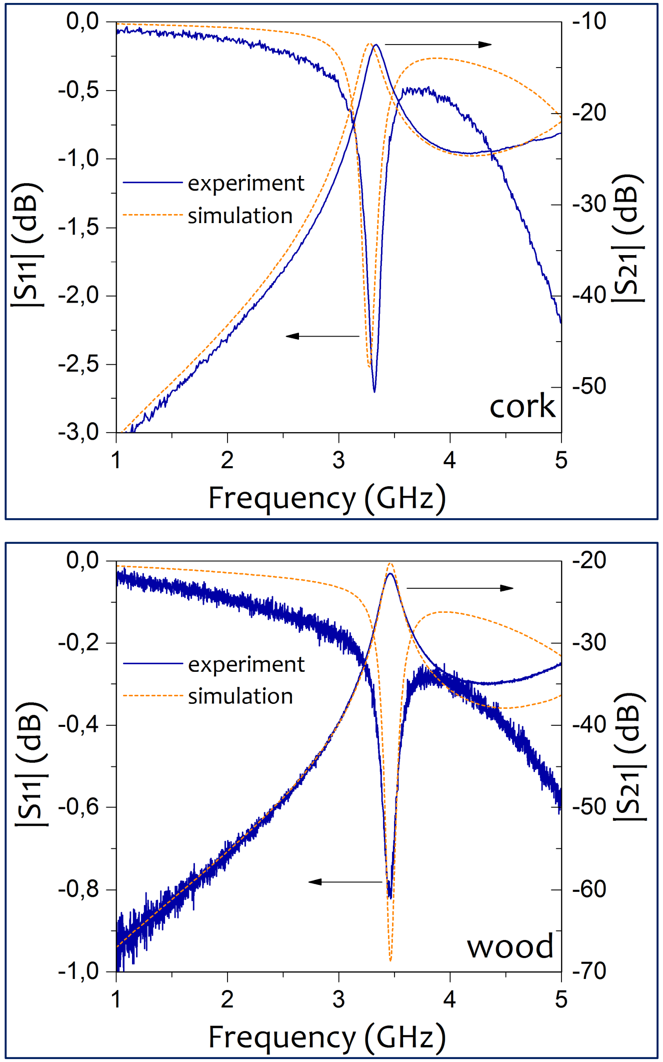
$$C = \frac{-1}{\mathrm{Im}\{1/Y_{11}\} \cdot 2\pi f}$$



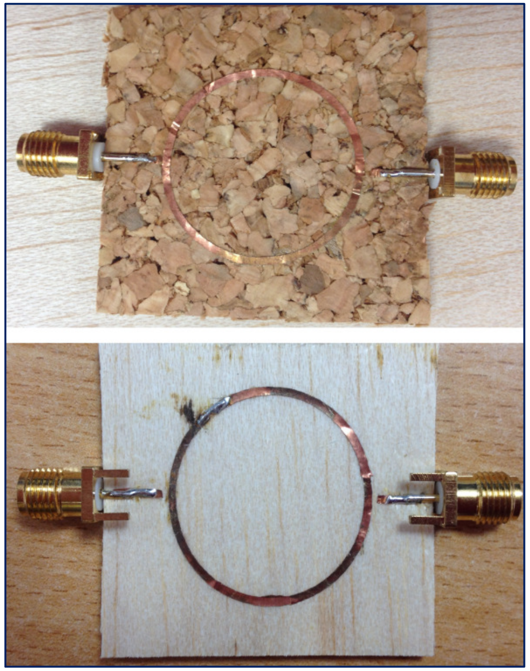


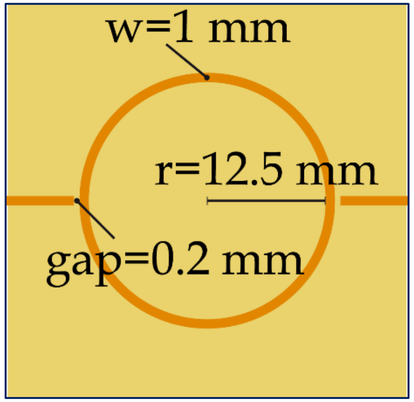
Georgia Tech

Cork and wood



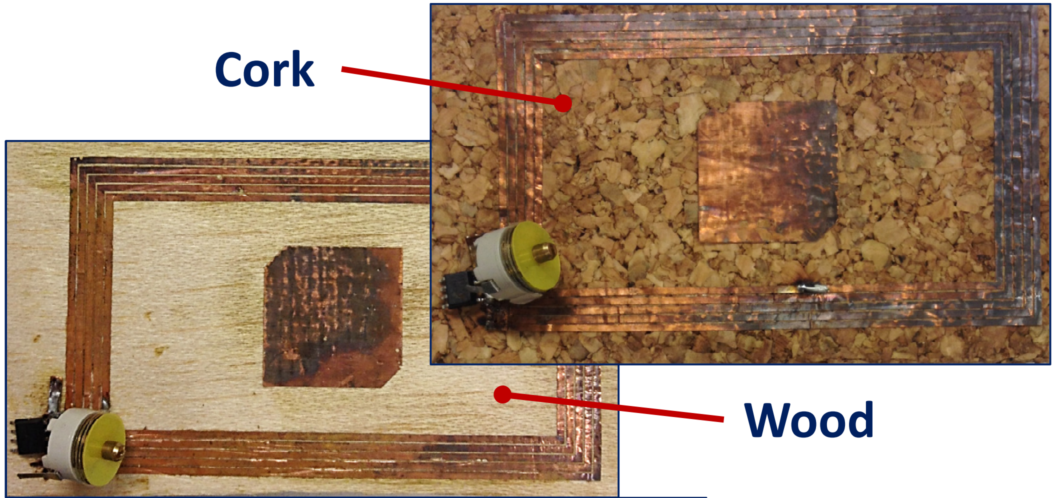
- First ever applicaton of circuits on such material substrates through the laminate method
- Very good matching between model and experiment, also considering the anisotropic nature of the materials



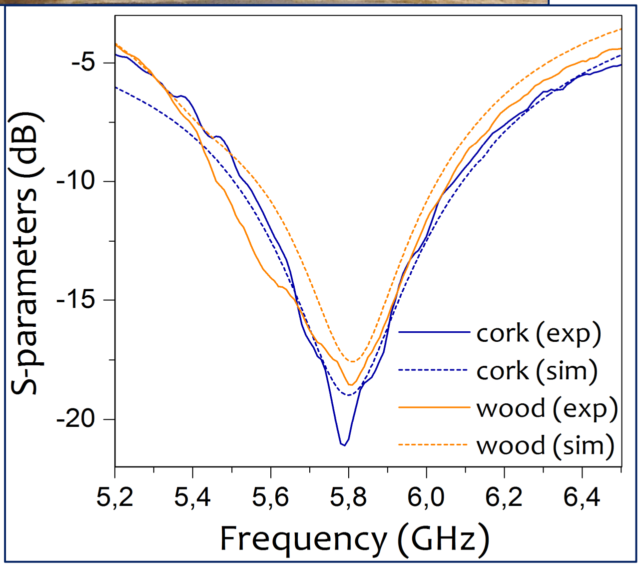


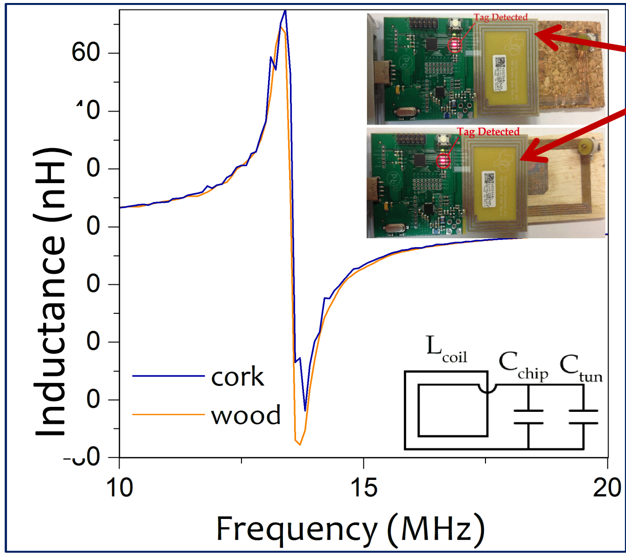
WIPE
COST IC1301
instituto de telecomunicações

Antennas on cork & wood



Circuits on cork and wood substrates for simple and low cost integrability in indoor applications





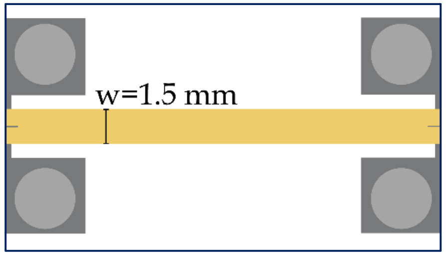
Tag detection
C_{tune}=13,5 pF

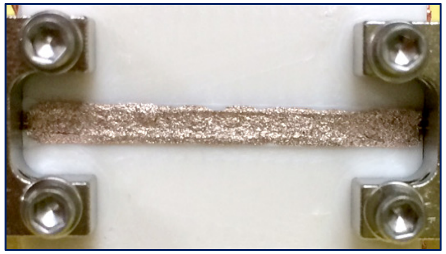
Sub.	L (μH)
Cork	3.31
Wood	3.34

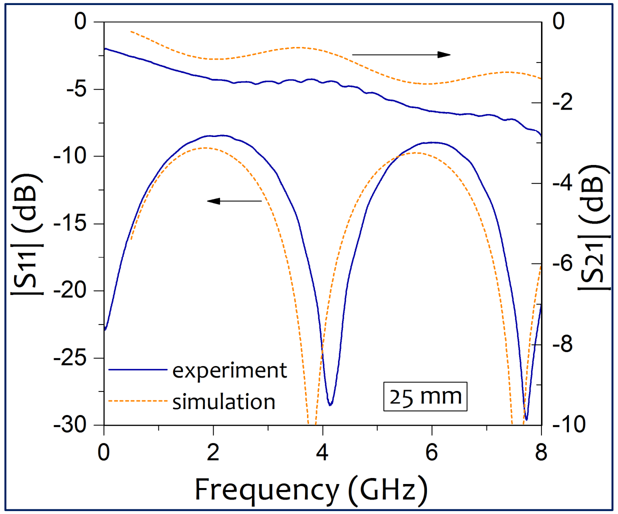
WIPE
COST IC1301

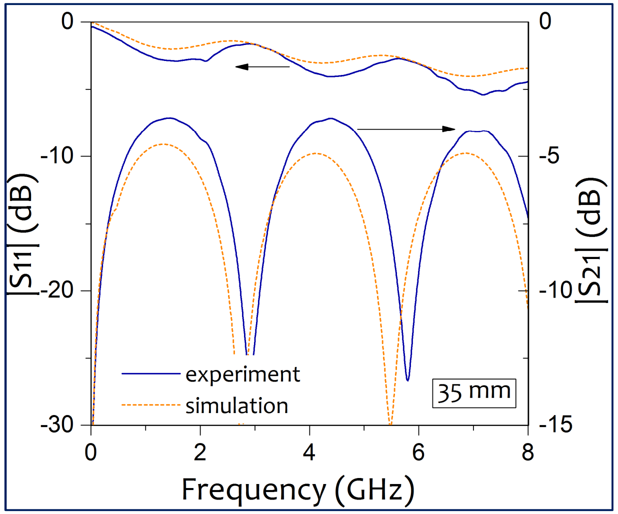
instituto de telecomunicações

ABS characterization

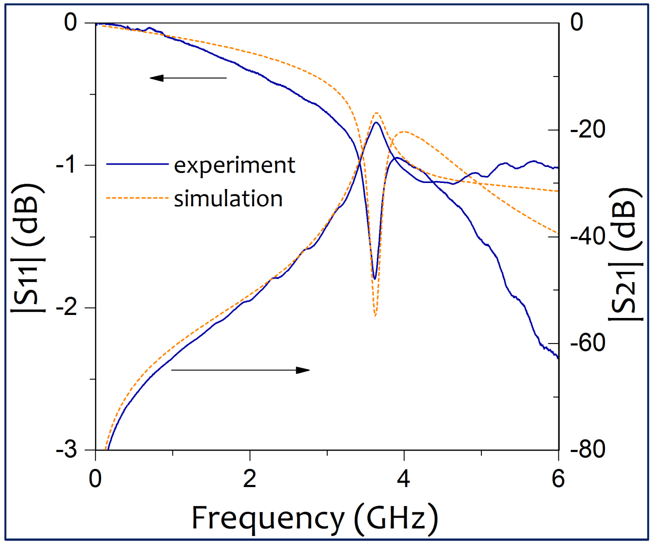


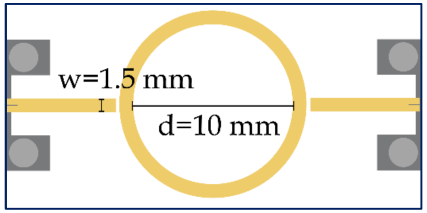






- Experiments confirm the simulation results obtained with the CAD model
- Cu paint is deposited exploiting ABS fence created with the 3D platform

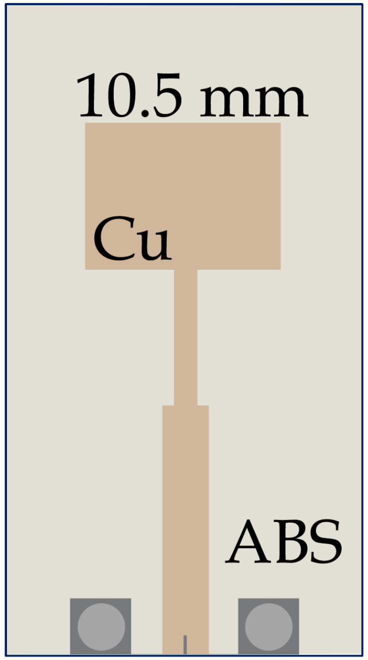


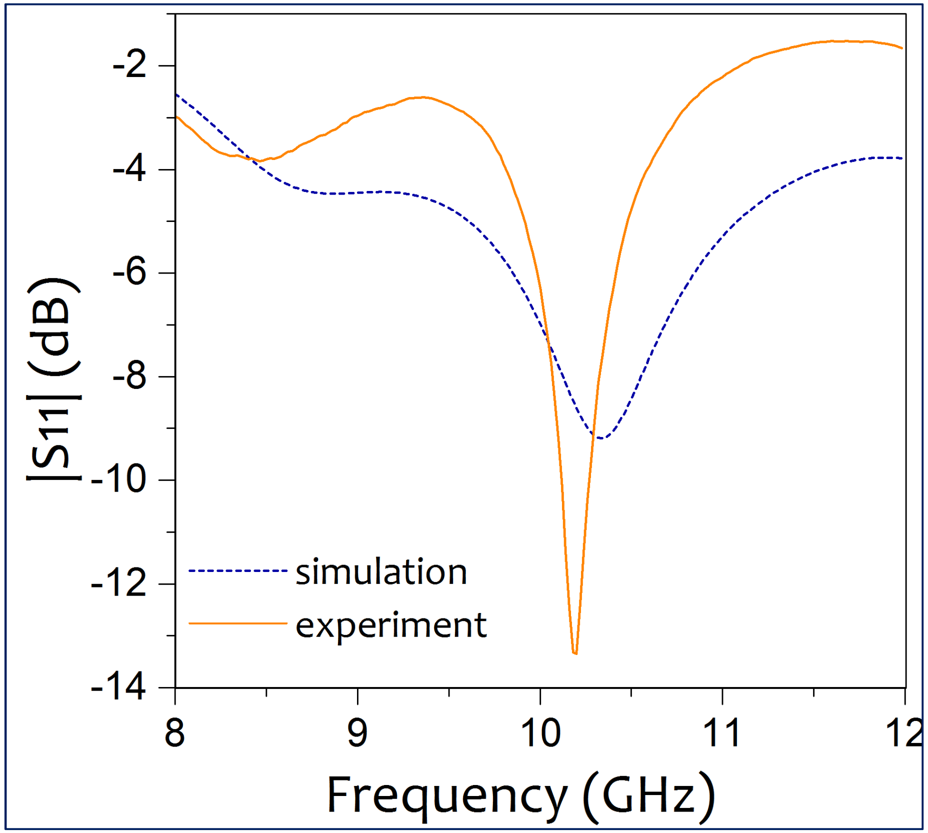


WIPE COST IC1301

Georgia Tech

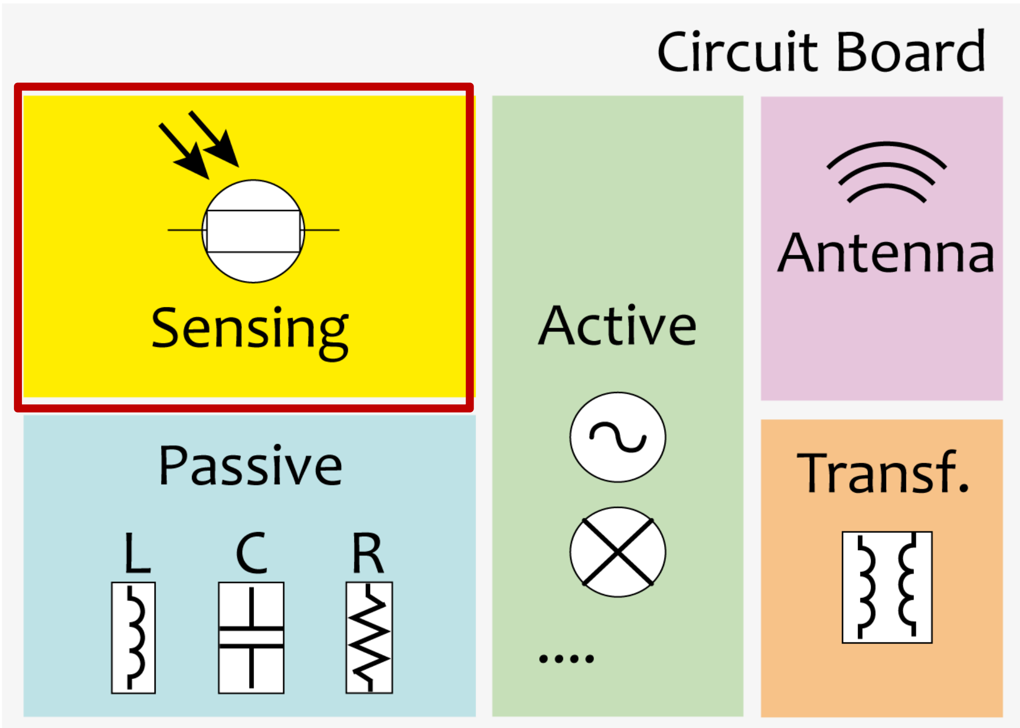
Antennas on ABS



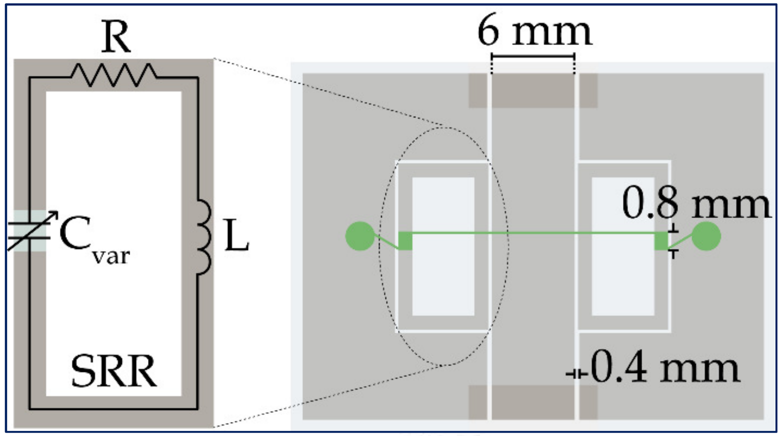


- **Fully 3D printed with a commercial, 1500$-platform..**
- Reflection coefficient below -13 dB at 10.2 GHz

Sensing/Tunable Modules



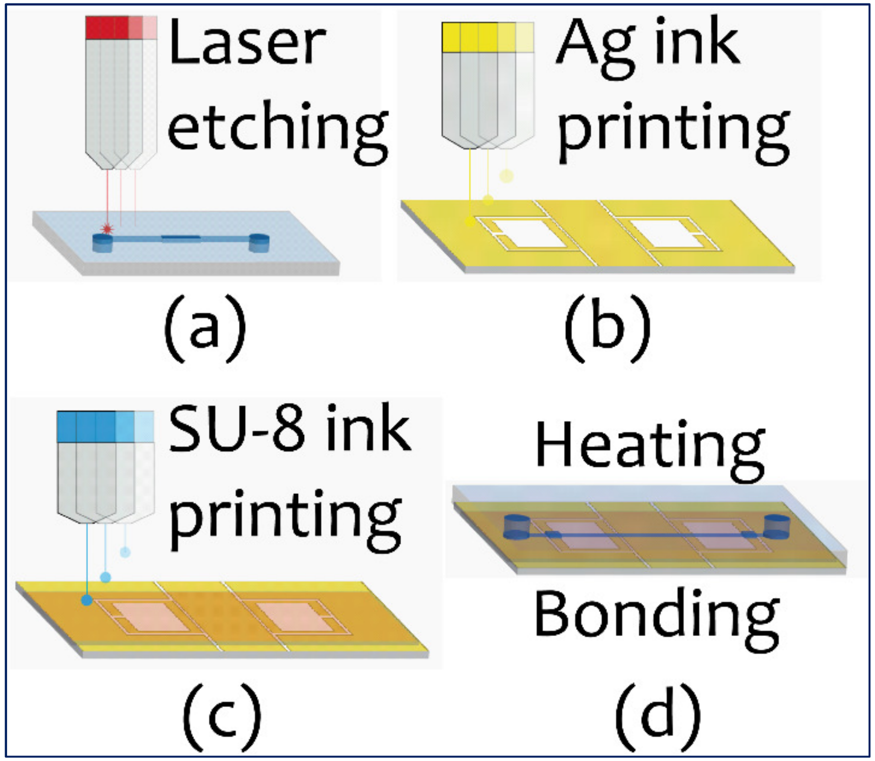
Microfluidics



Laser

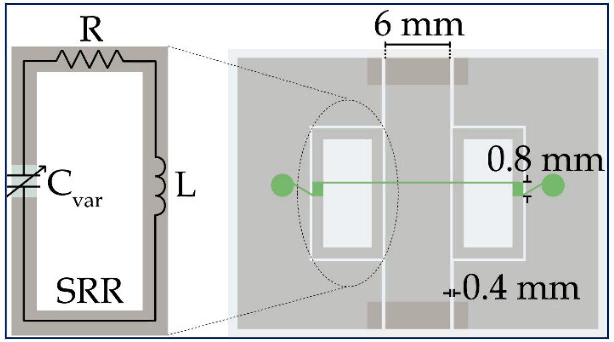
Printer

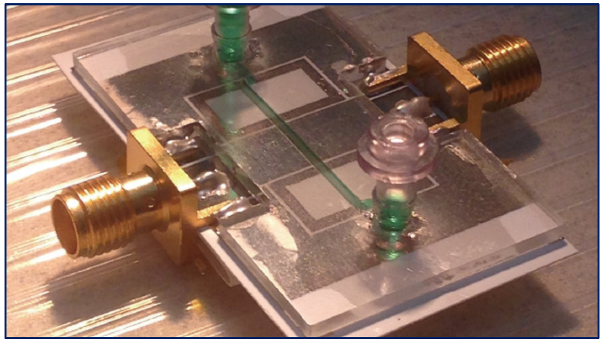
Proposed fabrication process:
- Cleanroom free
- Lower cost
- Lower waste (mostly additive)
- Eco-compatibility



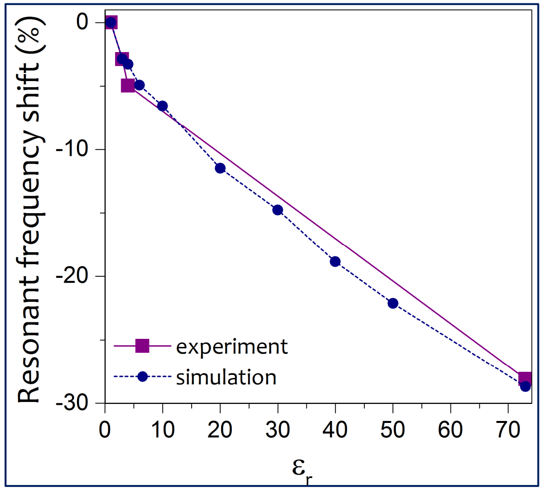
Georgia Tech

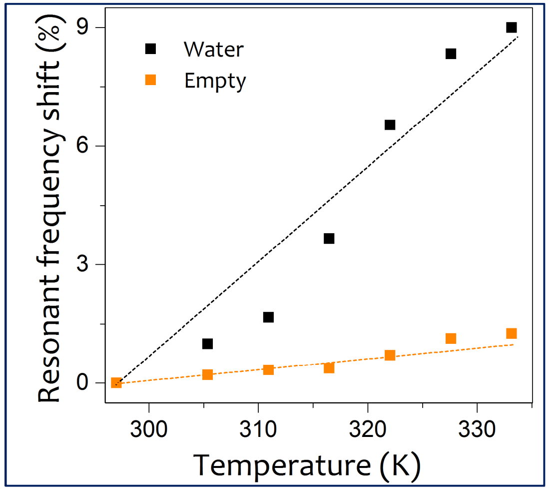
Bandstop filter





Fluid	ε_r'	ε_r''
Hexanol	3	2.5
Glycerol	4	0.4
Ethanol	6.3	7.1
Water	73	8

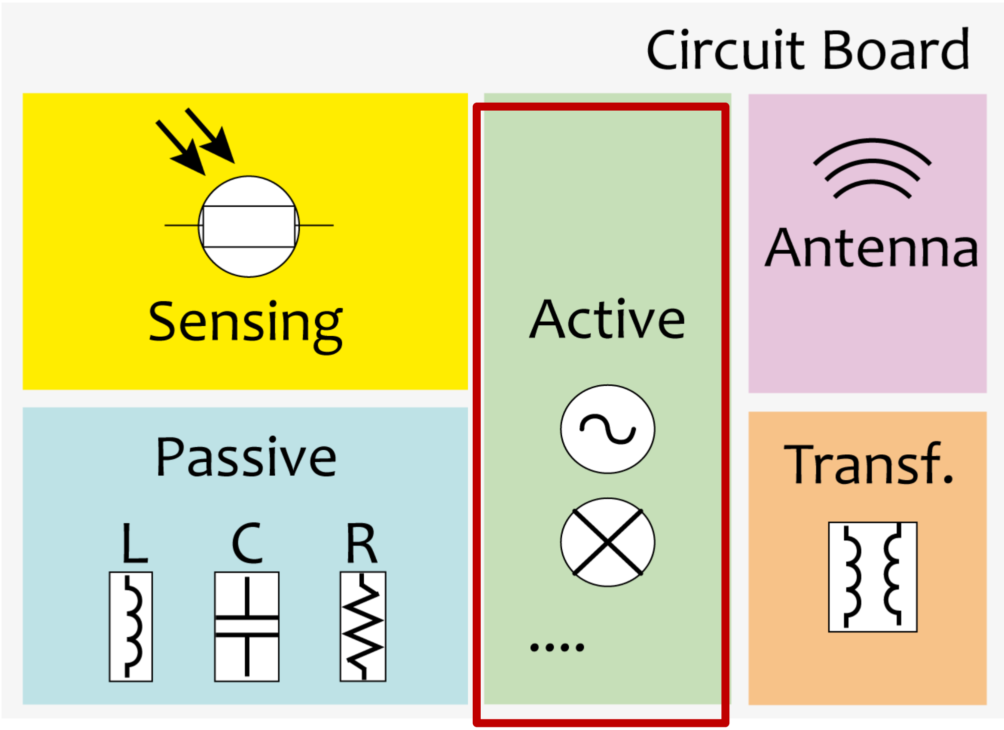




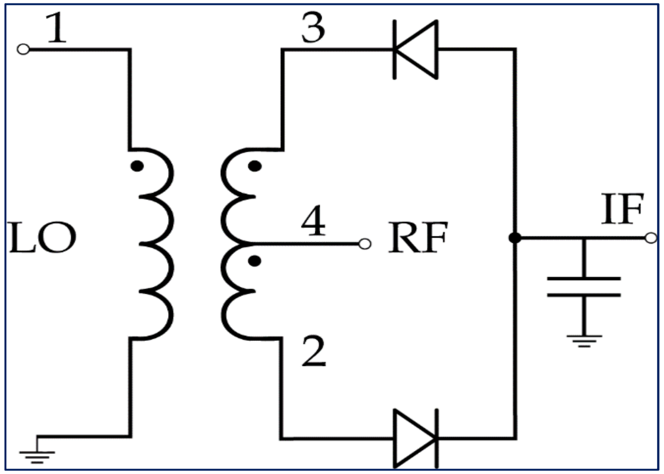
- Fluids and temperature based tunability/sensing
- Sensitivity (S) of **0.4%/ε_r**

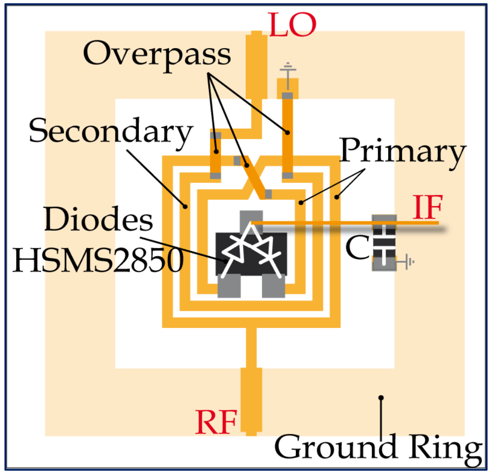
$$S=\left|\frac{f_{r,\,fluid}-f_{r,empty}}{f_{r,empty}\cdot\left(\varepsilon_{r,\,fluid}-\varepsilon_{r,empty}\right)}\right|$$

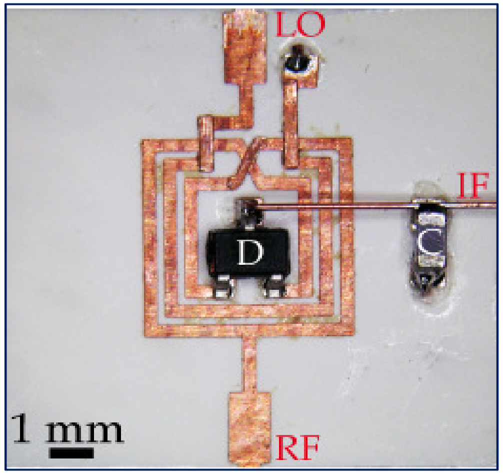
Sub-system Circuits

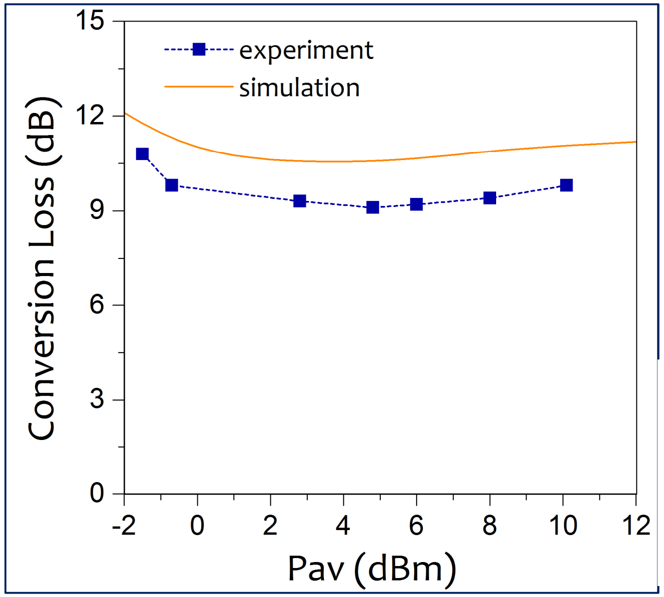


1-GHz Mixer





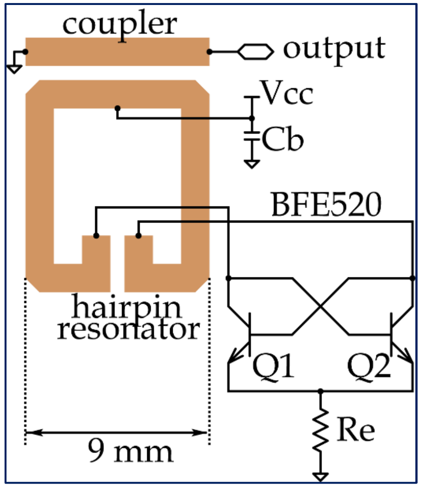


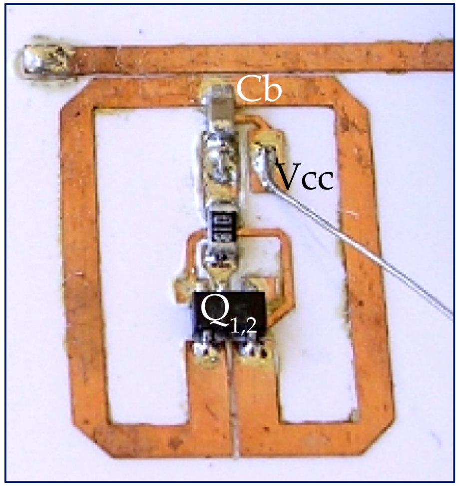


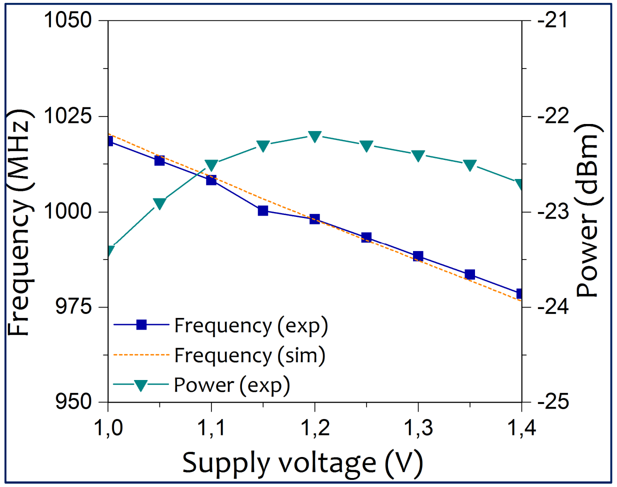
Ref.	f_0 (GHz)	minCL (dB)	technology
[Maity]	2-7	9	GaAs
[Maalik]	6-6.5	8-10	CNC
[Sudow]	2-3	12	MMIC
this work	1	9	copper

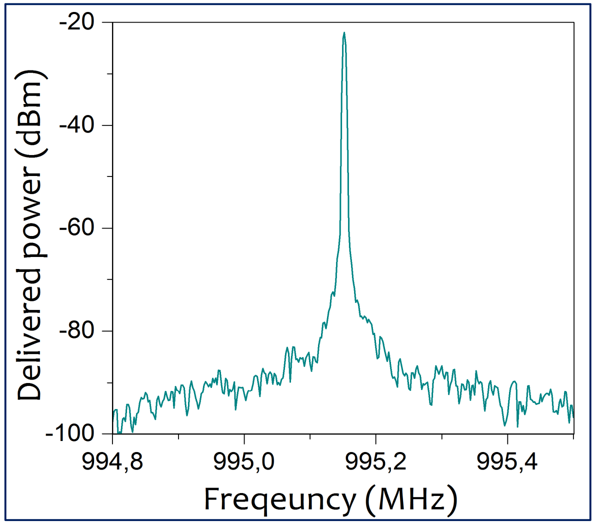
- Configuration: LO - primary, RF - secondary
- Diodes connected to Port-2 and Port-3
- Optimum working frequencies are:
  LO = 1 GHz --- RF = 900 MHz

Voltage controller Osc.





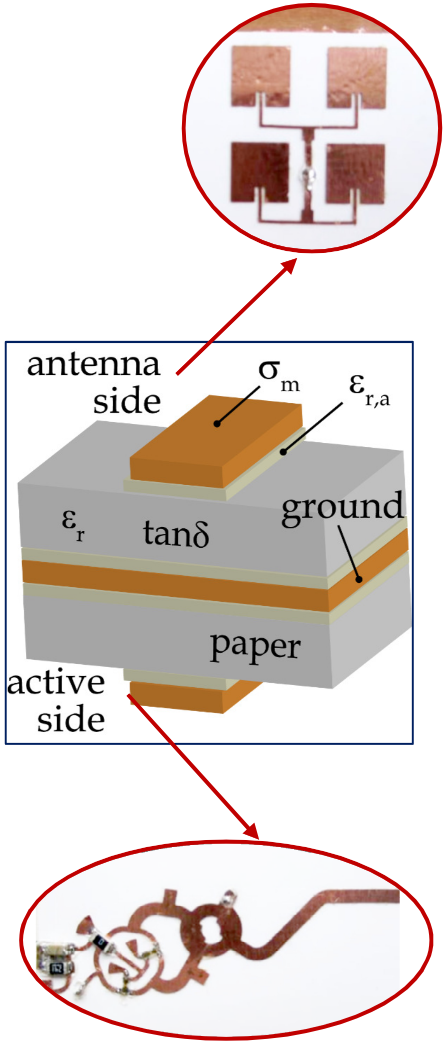


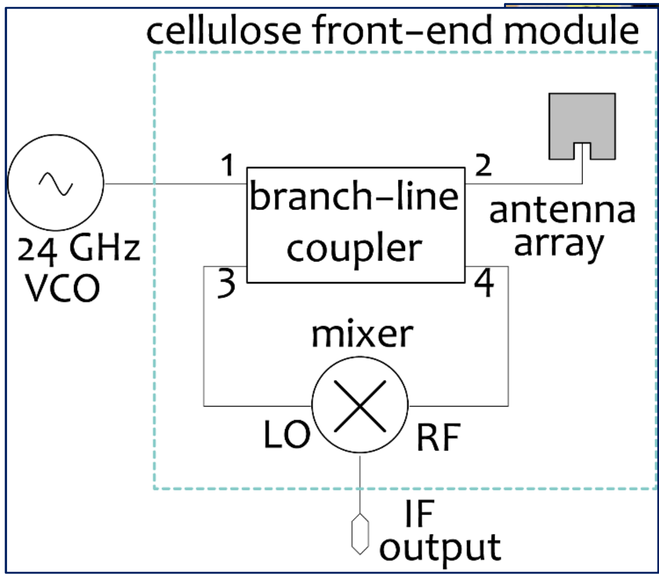


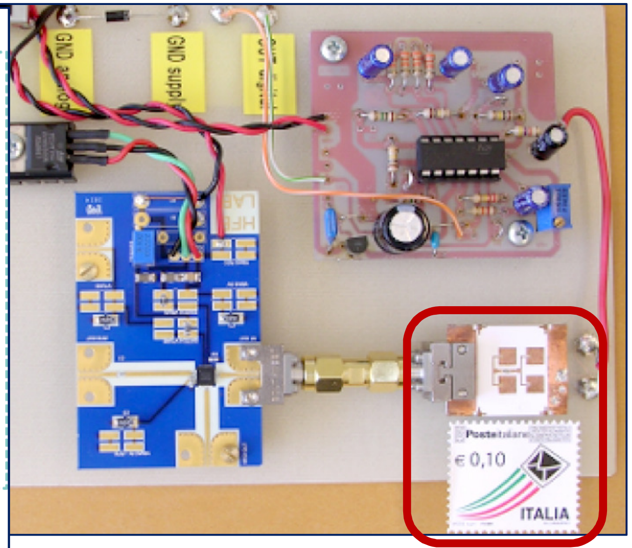
Ref.	f_0 (MHz)	V_{cc} (V)	P_{DC} (mW)	PN (dBc/Hz)	Nc
[Kim]	800	1.8	7.2	-100	8
this work	998	1.2	**0.9**	-99	**3**

System Level Integration

24-GHz Doppler radar





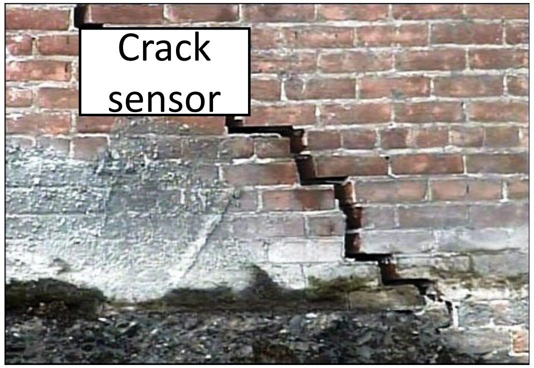


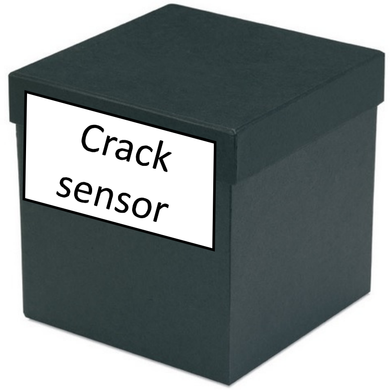
- LO signal split by the branch line
  - first half of the signal feeds the antenna
  - second half goes to the LO port of the mixer
- The signal coming from the antenna is sent to the RF port of the mixer and to the oscillator (receiving path)
- The IF is the mixer output from the received RF and the LO signal coming from the branch-line

Crack sensors

Crack sensors for:

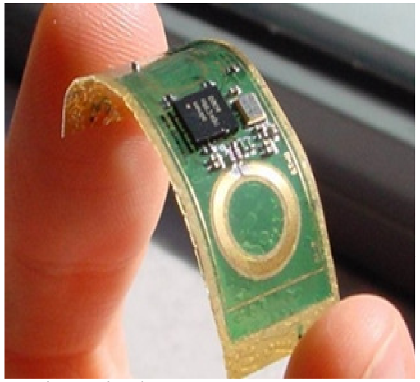
- Structural health monitoring
- Electronic sealing
- Supply chain monitoring



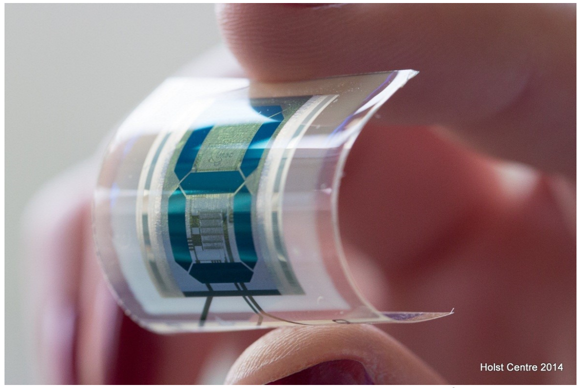


Wireless chipless sensors:

- Low-cost
- Flexible electronics
- Green issues

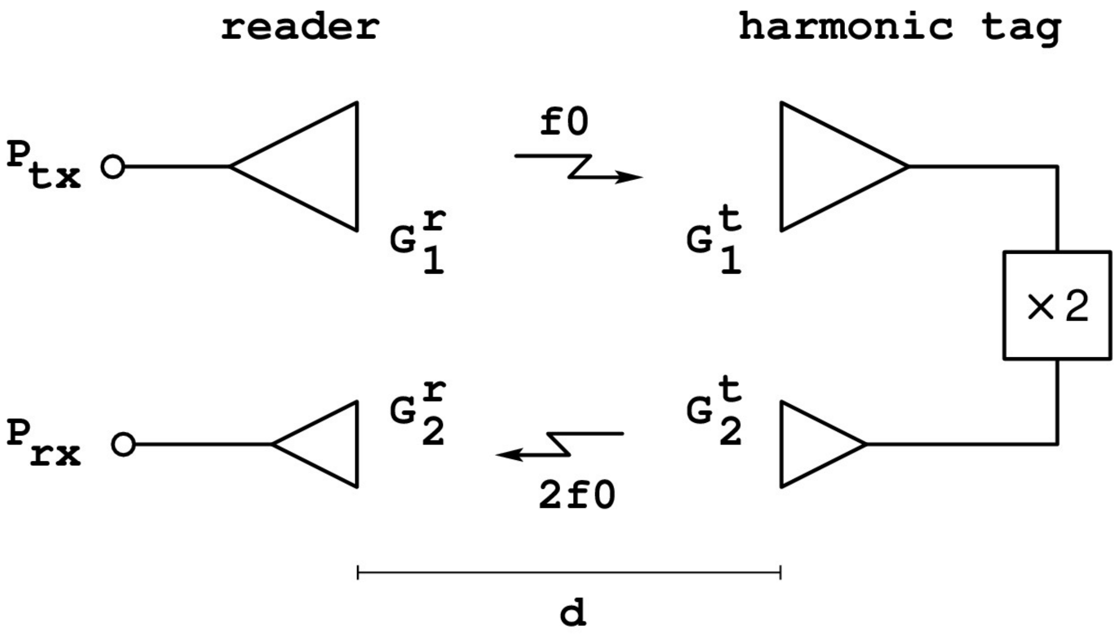


Universiteit Gent



Holst Centre

Harmonic RFID



✓ The **reader interrogates** the environment **at f0** (fundamental).

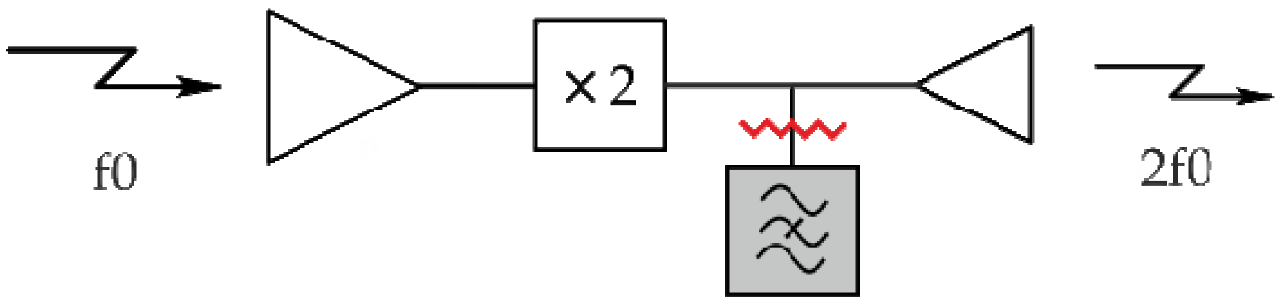
✓The tag contains a frequency multiplier (typically a frequency doubler) and **replies at n×f0** (for a doubler at 2×f0).

✓ **1-bit RFID system (it can determine the presence of the tag)**

✓ **It is insensitive to the environment backscattering**

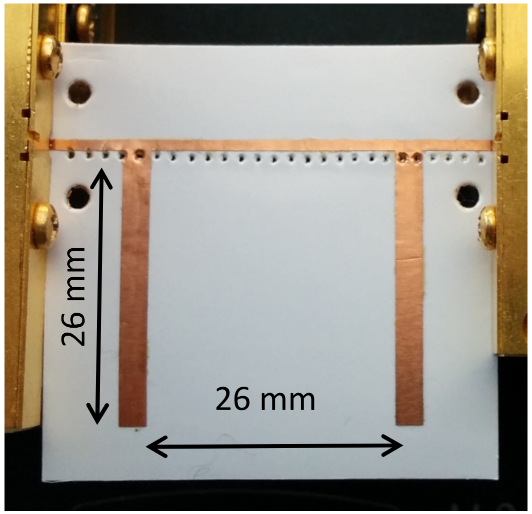
Proposed crack sensor tag

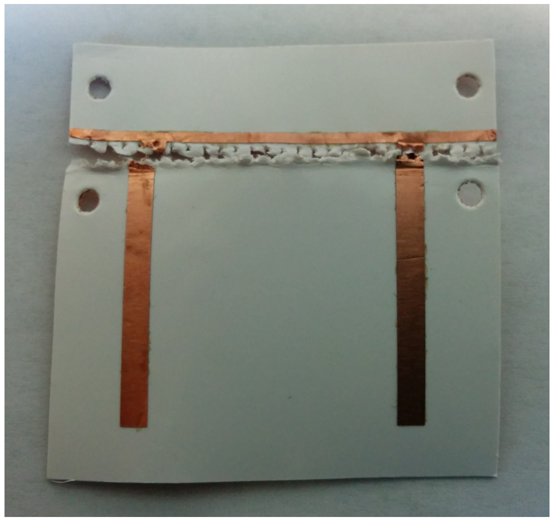
- Disposable band-stop filter
- Frequency doubler (to separate upling and downlink)
- Intact condition: the band stop filter short-circuits the second harmonic
- Cracked condition: the second harmonic can reach the output antenna -> alarm
- Single frequency system (f_0=1.04 GHz, 2f_0=2.08 GHz)



Crack detector in paper substrate

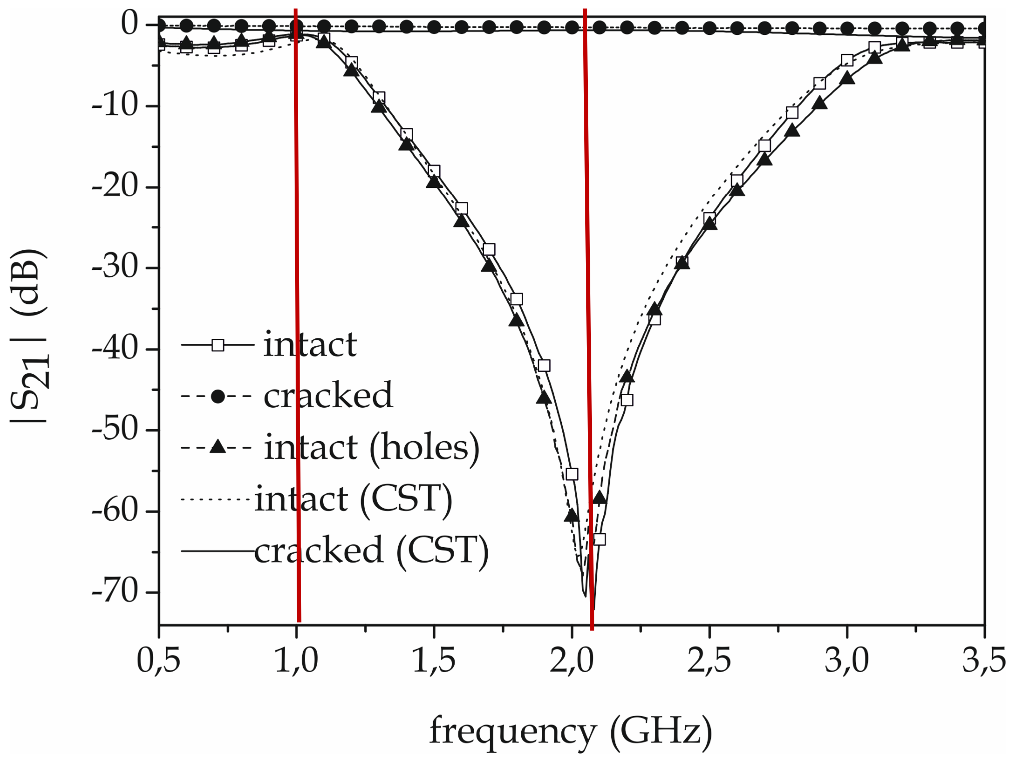
- Second-order band-stop filter, based on two quarter-wave open-circuited stubs connected in shunt and separated by a quarter-wave section of line
- Copper laminate technology in paper substrate
- A series of equispaced holes are introduced to ease the stub removal





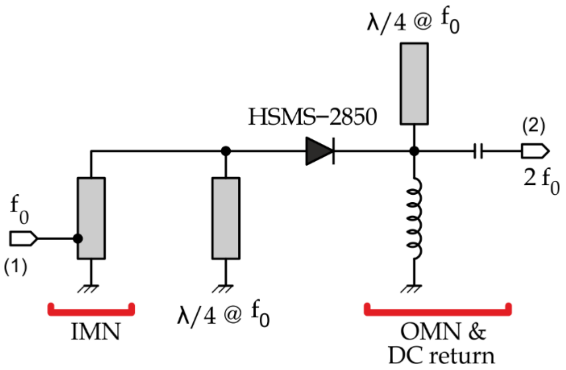
Experiment: Crack detector in paper substrate (metal laminate)

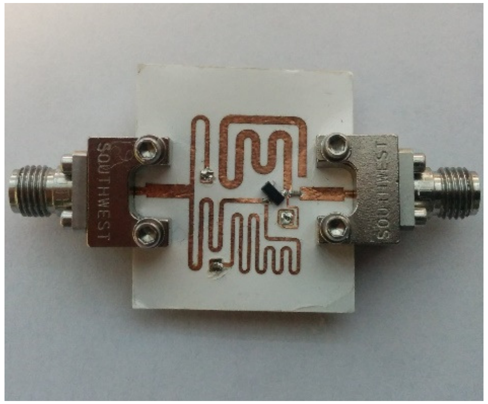
- Attenuation of 60 dB @ 2.08 GHz
- Fundamental frequency not affected

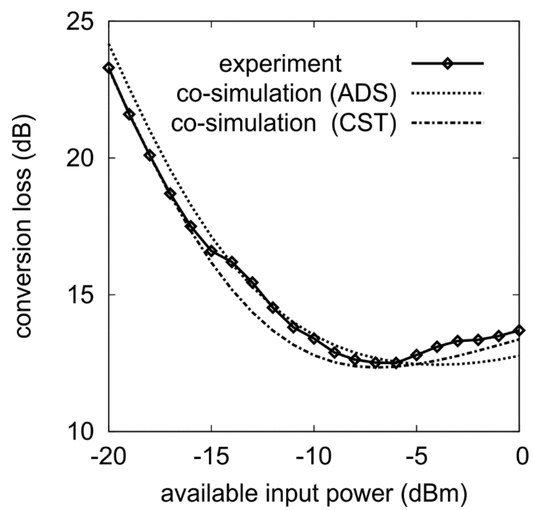


Frequency doubler

- Single low-barrier Schottky diode frequency doubler
- Two quarter-wave stubs behaving as harmonic filters
- Input and output matching to a 50 Ω impedance
- OMN optimized by load-pull simulations
- Zero bias
- Conversion loss of 13 dB @ -10 dBm input power



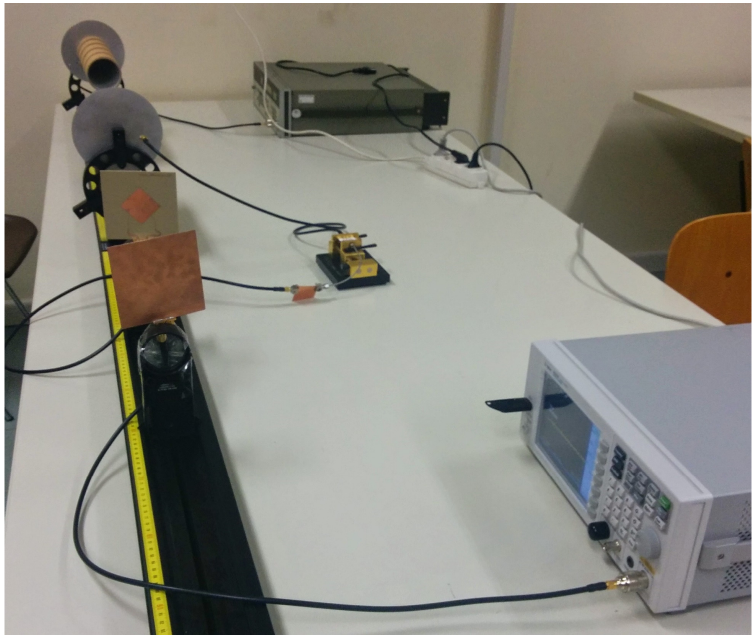


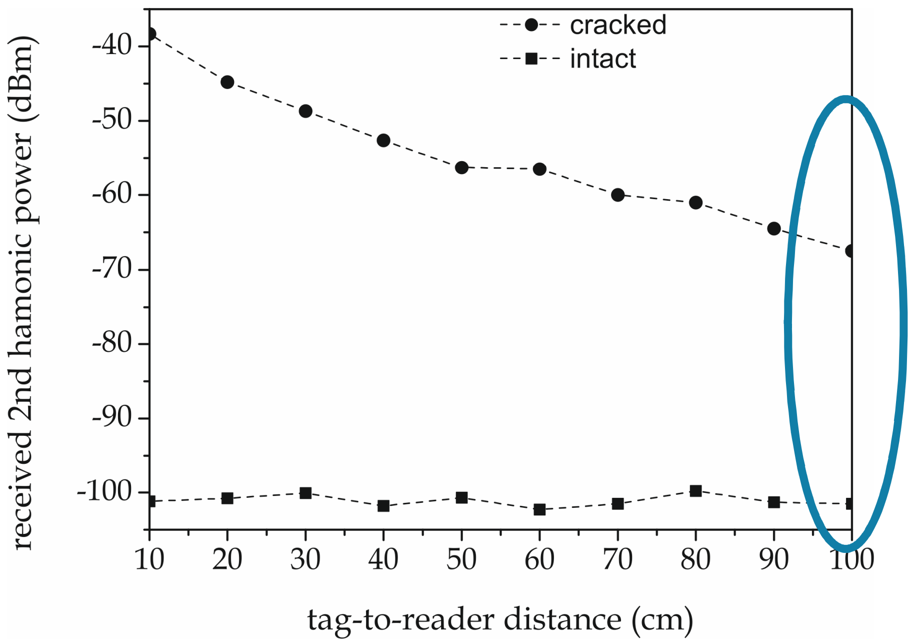


Whole tag: results

- P_{tx}=10 dBm
- Uplink: helix antennas, Gain=5 dBi
- Downlink: patch antennas, Gain=4.3 dBi
- Receiver noise floor=-100 dBm

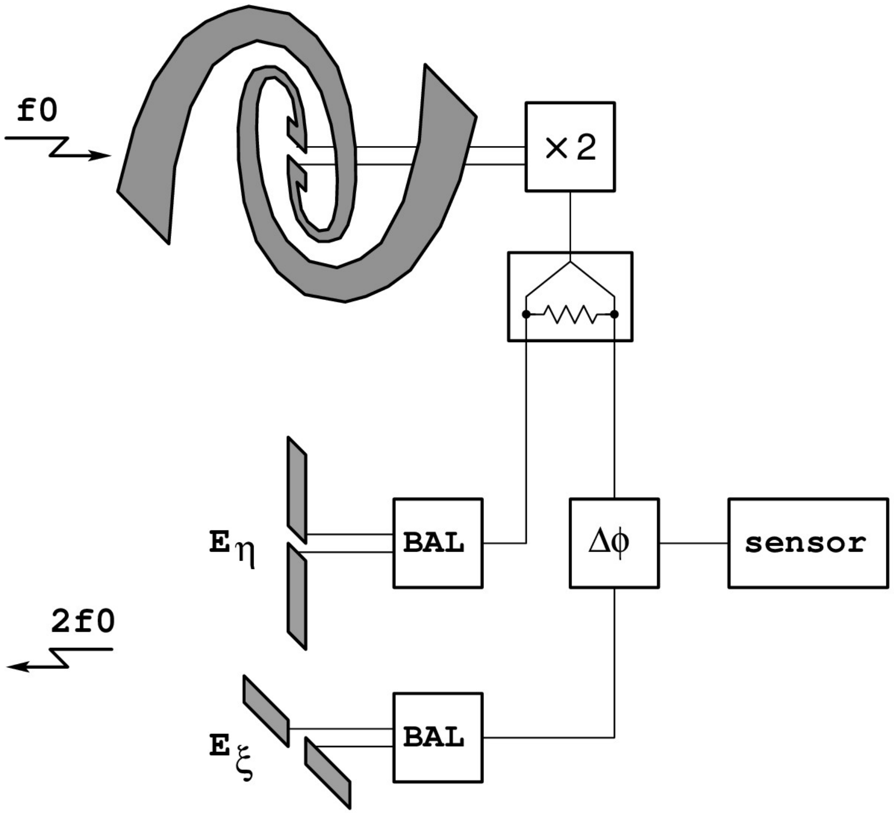
Operating range > 1 m





Novel harmonic RFID sensor (1/3)

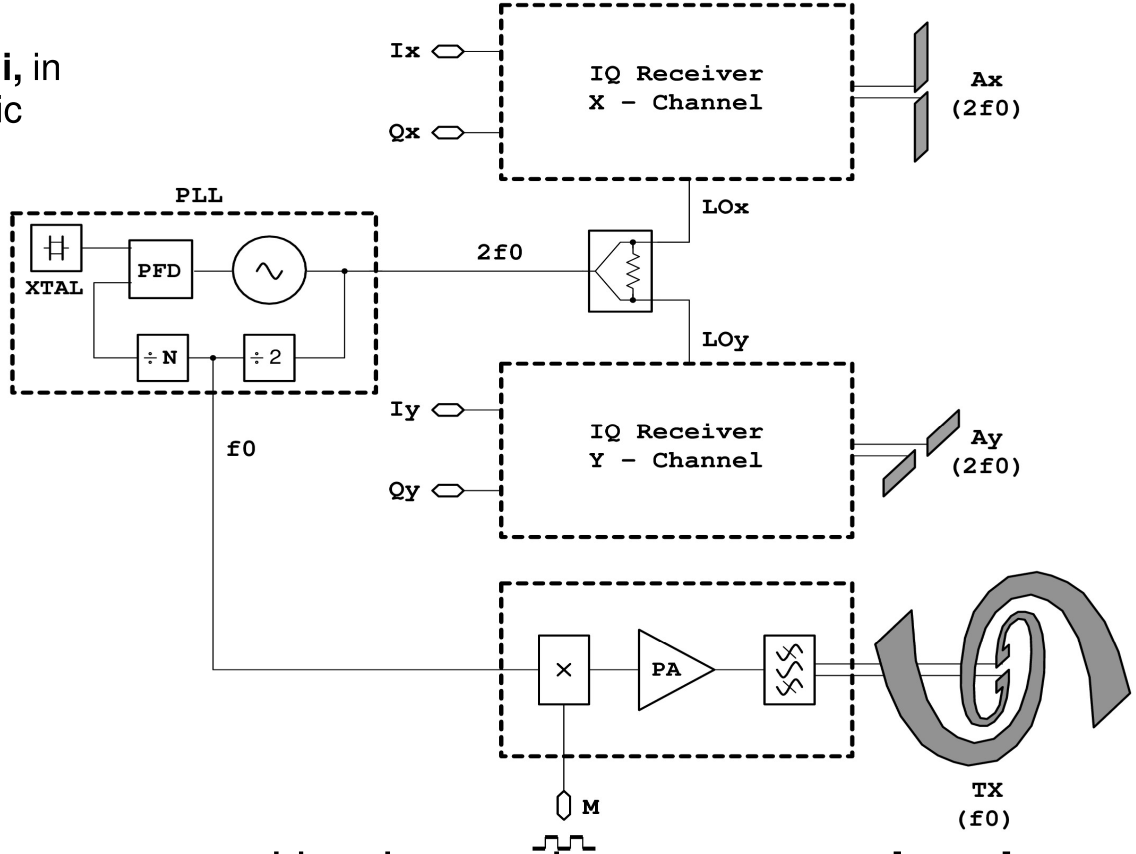
- ✓**f0**: received by an antenna insensitive to rotation
- ✓**2f0**: generated by a diode circuit and divided in two parts.
- ✓**First component**: transmitted in vertical polarization.
- ✓**Second component**: transmitted in horizontal polarization after a phase shifting.
- ✓**Phase shifting**: determined by the sensor.
- ✓**The two transmitted signals at 2f0 acts as the reference one to each other**



After **F. Alimenti, L. Roselli,**
European Patent EP13161946.2

Novel harmonic RFID sensor (2/3)

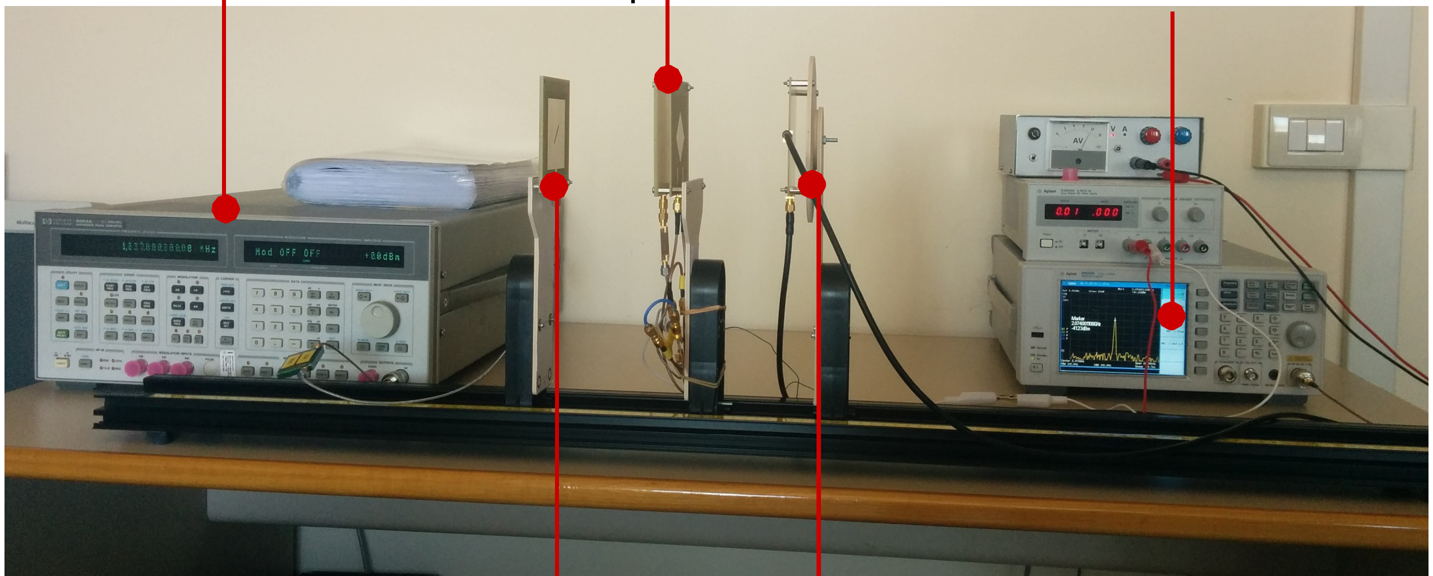
After **F. Alimenti, L. Roselli,** in Progress in Electromagnetic Research Journal, 2013



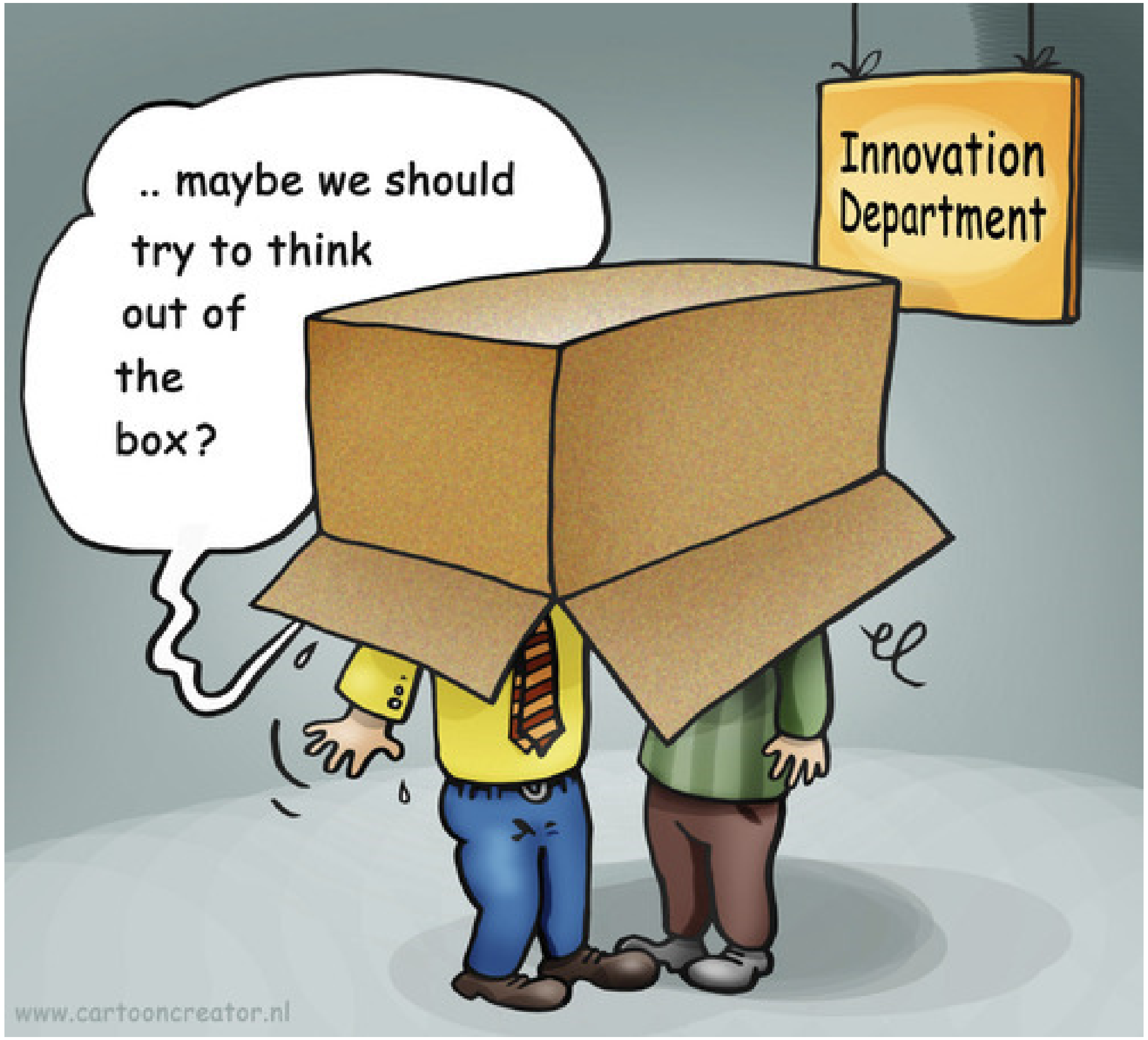
Two **vector receivers** are used by the reader to **extract the phase information** for both the vertical and the horizontal polarizations.

Novel harmonic RFID sensor (3/3)

- experimental characterization of the system (f0 ~ 1 GHz)
- received phase dependent on TAG encoding (and not on distance)
- **TX power: 0dBm; RX power: -80 dBm @ 60 cm**



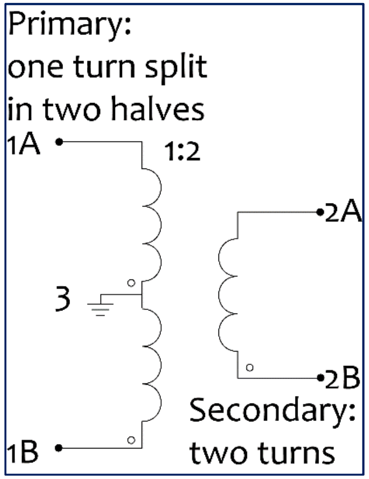
Just a stimulus…

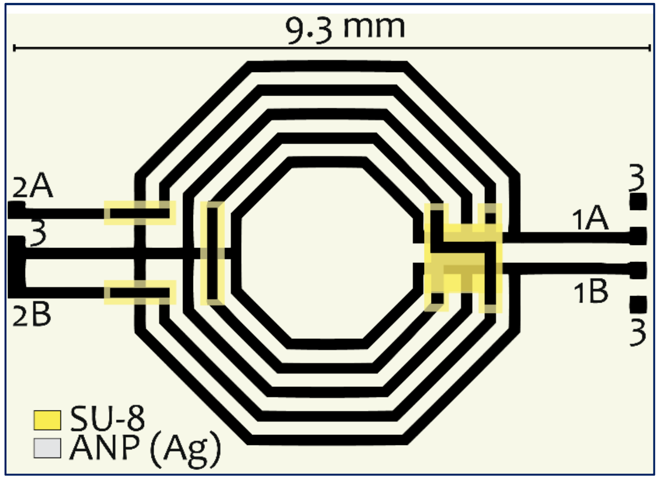


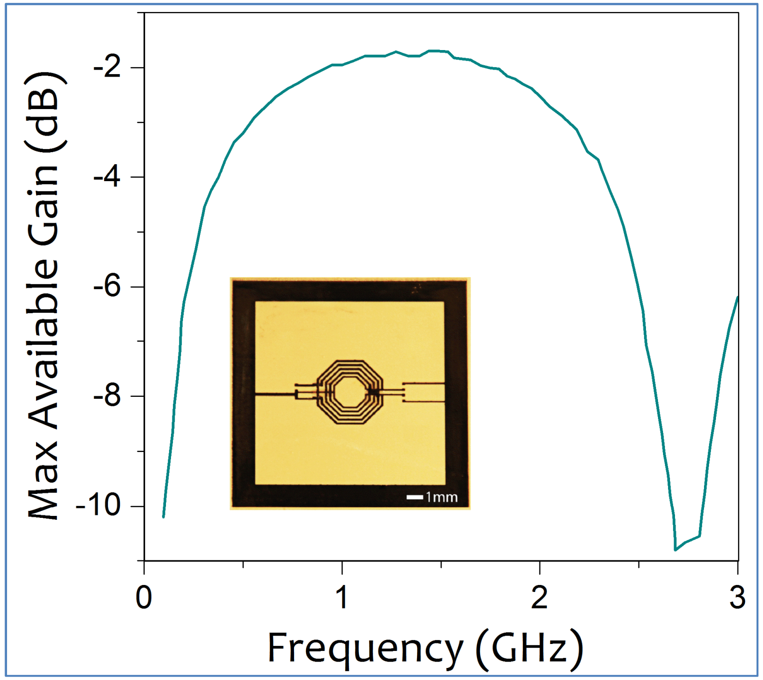
Think out of the box!

Thank you!

Transformer on LCP

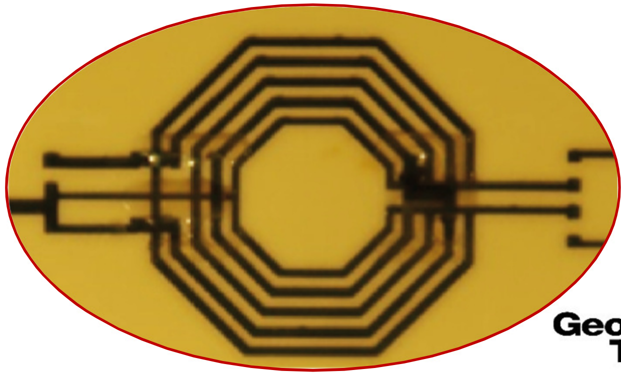






	Primary	Secondary
L (nH)	6.1	14.2
SRF (GHz)	4.8	2.4

- **5 fully inkjet printed separate layers**
- MAG of -**1.8 dB** at 1.4 GHz implies that **67%** of the the input power is transferred to the output (with I/O properly matched)



Georgia Tech