

Integrated Passive Antenna/Sensor Structures

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Motivation

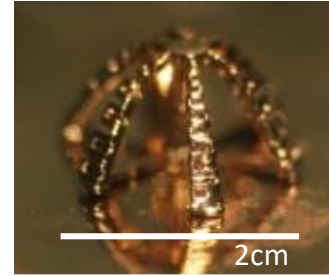
- Direct sensing of passive elements increases durability in harsh environments.
- Wireless sensing approach increases deployment flexibility.
- Passive sensors reduce sensor footprint and increase durability.
- Microwave frequencies provide sub-ns timescales and mm-scale dimensions.
- Microwave energy readily penetrates opaque dielectrics.



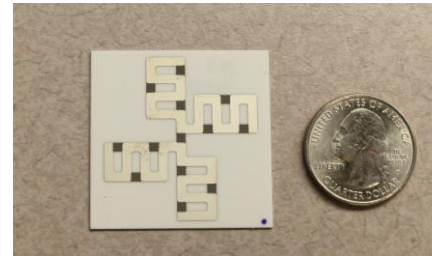
Antenna as Sensor

Sensor system based on microwave backscatter requires no power or electronics in the sensing element.

- Antenna's RF scattering behavior is dependent on attached load (sensor).
- 3D antenna geometry can allow interrogation from a variety of angles.



Prototype additively-manufactured antenna.



Antenna with integrated resistive pads.



Antenna with surface-mount component.

Theory of Operation

- Antennas act as scatterers and can be characterized by their radar cross-section, σ .
- Scattering behavior depends on the antenna structure and attached load.

$$\sigma = \left| \left(\sqrt{\sigma^s} - (1 + \Gamma_A) \sqrt{\sigma^a} e^{j\phi_r} \right) \right|^2$$

From C. A. Balanis, *Antenna theory: analysis and design*, 3. ed. Hoboken, NJ: Wiley-Interscience, 2005.

Theory of Operation

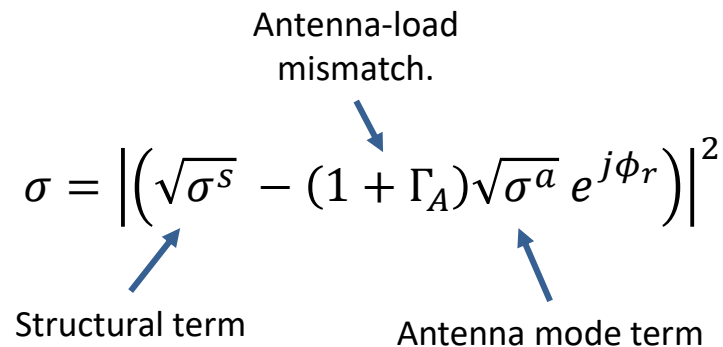
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Antenna-load mismatch.

Structural term

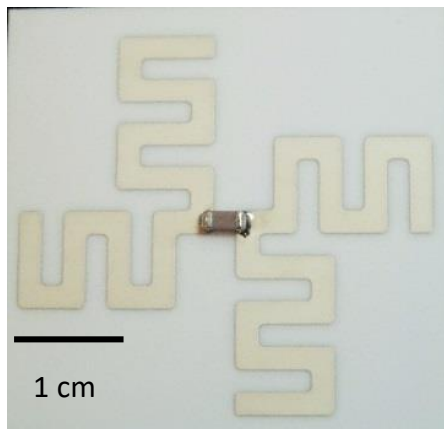
Antenna mode term



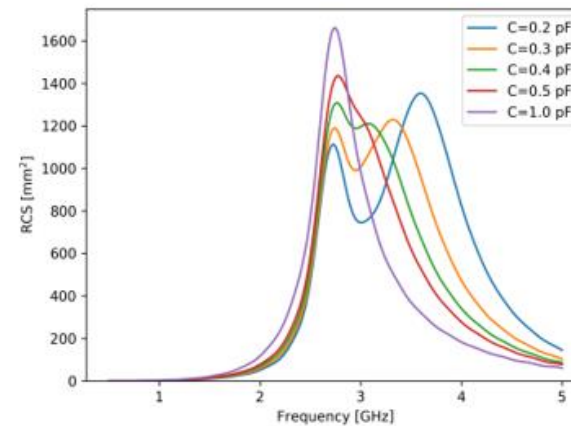
Antenna scattering response varies with frequency, structure, and attached load.

Simulation Results – Capacitor

Fabricated example



Simulated response

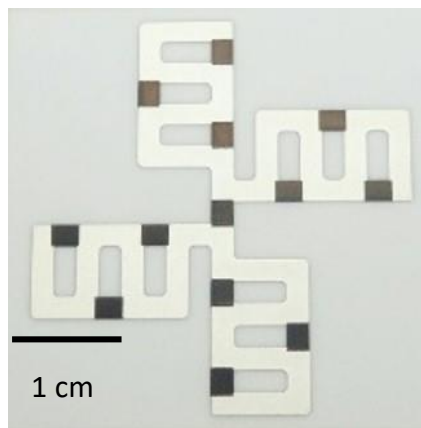


Capacitor at feed point (potential pressure sensor)

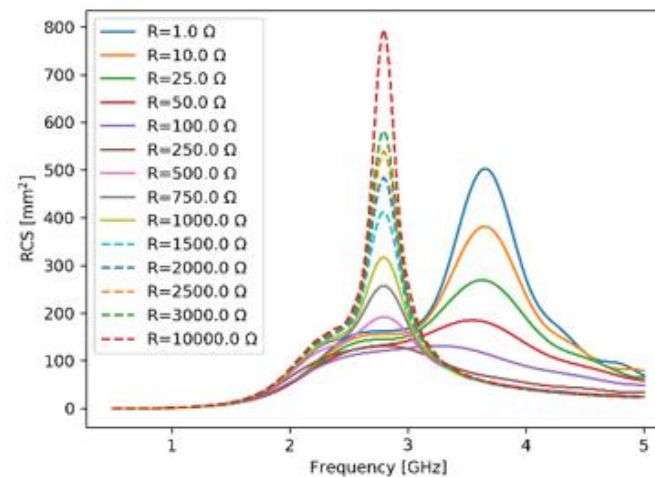
Changes in reactive lumped element values drive resonant frequency shifts.

Simulation Results – Resistors

Fabricated example



Simulated response

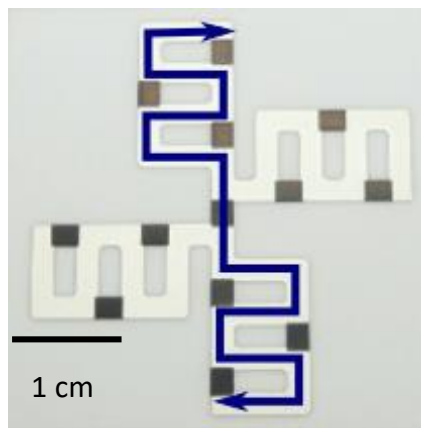


Sensing resistors along antenna arms
(possible temperature or chemical sensor)

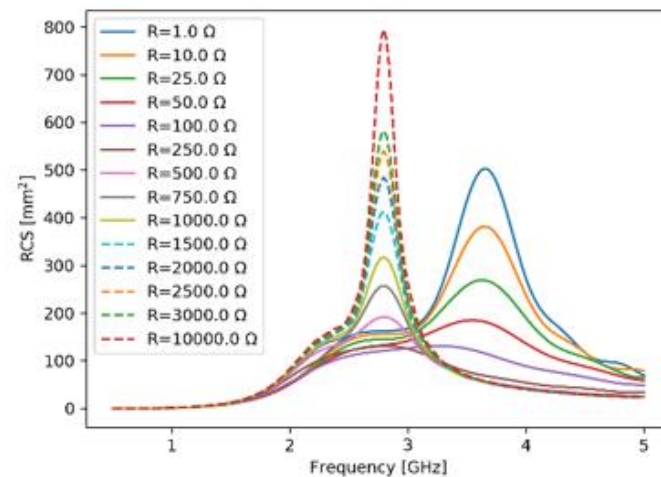
Changes in resistance alters current path, driving resonant frequency shifts.

Simulation Results – Resistors

Fabricated example



Simulated response

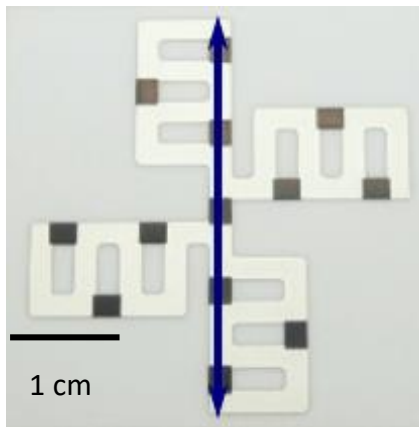


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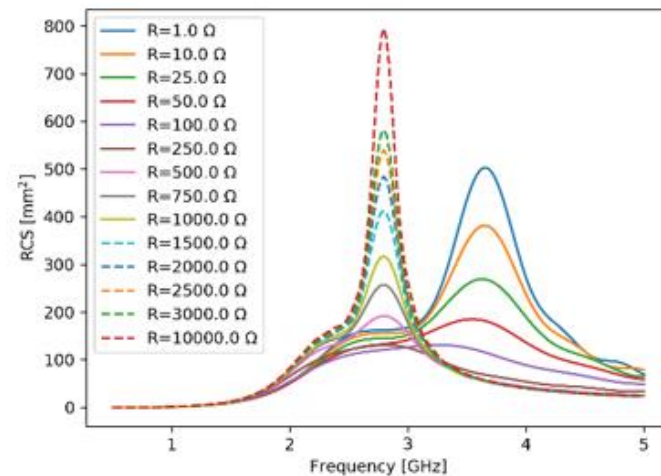
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Simulation Results – Resistors

Fabricated example



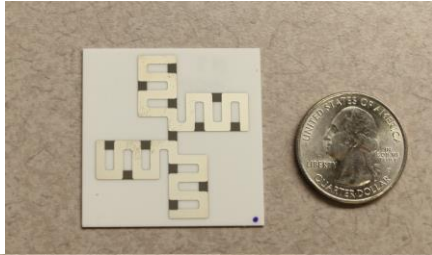
Simulated response



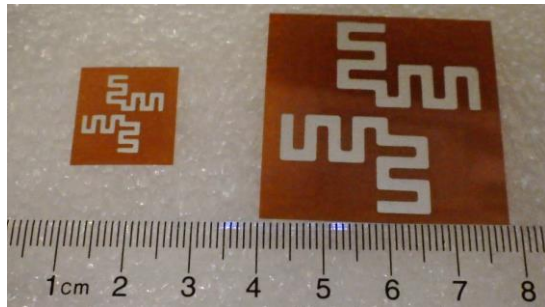
Sensing resistors along antenna arms
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Changes in resistance alters current path, driving resonant frequency shifts.

Antenna Fabrication – Size and Geometry



2D antennas with resistive pads.



2D antennas on flexible substrates.

- Three sizes of rigid planar antenna.
- Two sizes of flexible planar antenna – intermediate 3D.
- Experimental 3D antenna.



Silver painted 3D antenna.

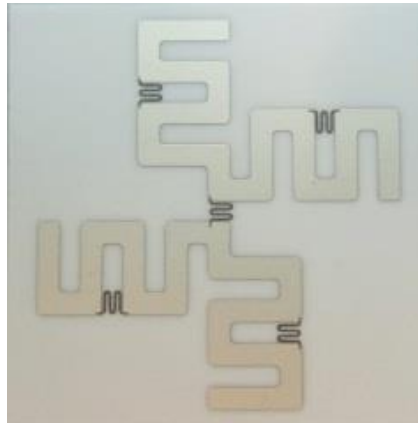
Antennas fabricated by Makel Engineering, Inc.

Antenna Fabrication – Sensor Precursors

- Fixed-value circuit elements as sensor precursors.
- Resistive films: palladium, platinum, and carbon of differing resistances and patterns.
- Surface-mount components: capacitors and resistors.



Resistive film patches.



Patterned resistive film.



Surface-mount component.

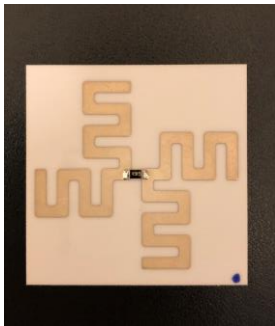
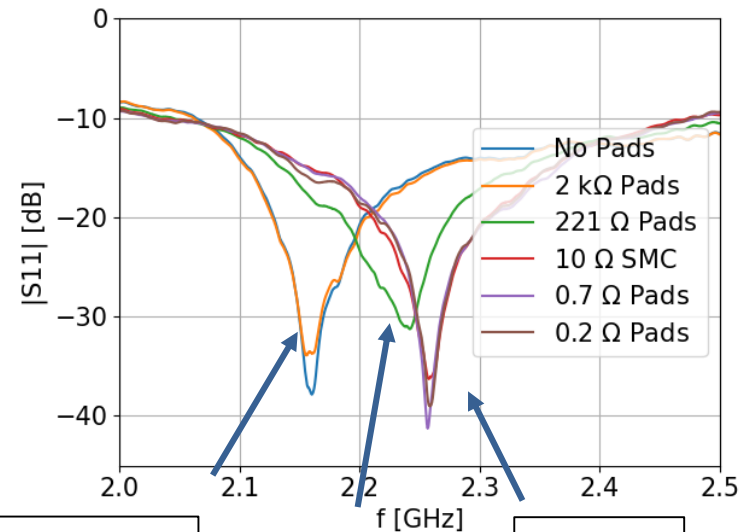
Resistive pads are screen or inkjet printed depending on material.

Near Field Measurement Configuration

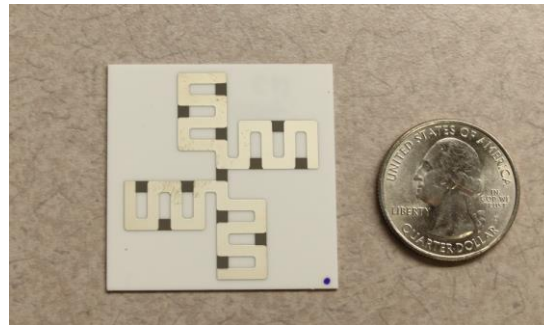


Near Field Measurements – Three Sensors

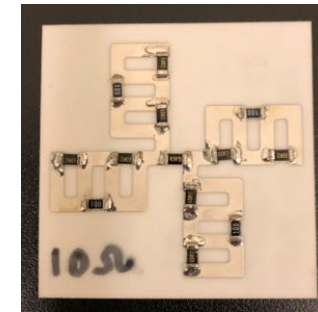
- Antenna response demonstrates dependence on resistor value.
 - Response can be used to measure pad/sensor resistance.
 - Resistors are fixed value at this stage.



Antenna with no sensing pads.



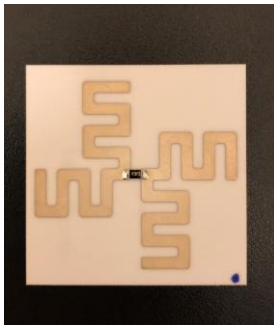
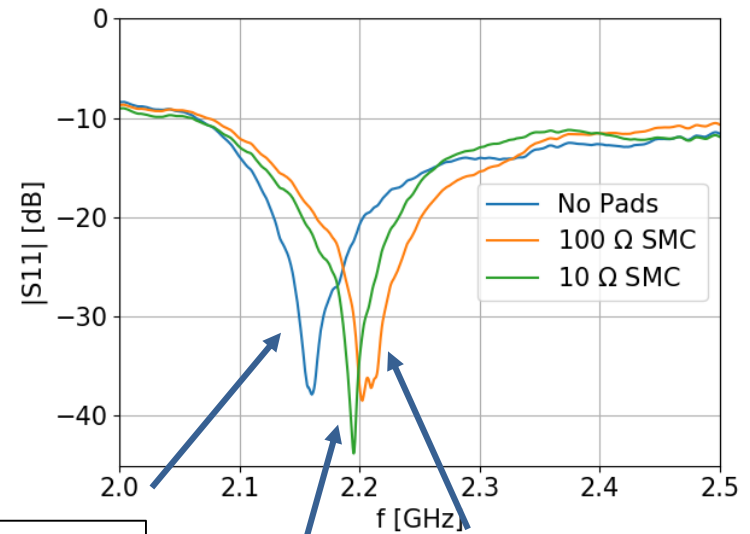
Antenna with 2 k Ω carbon resistive sensing pads.



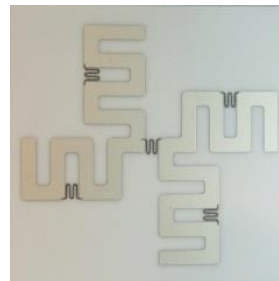
Antenna with 10 Ω sensing resistors.

Near Field Measurements – Single Sensor

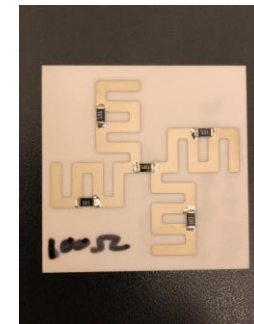
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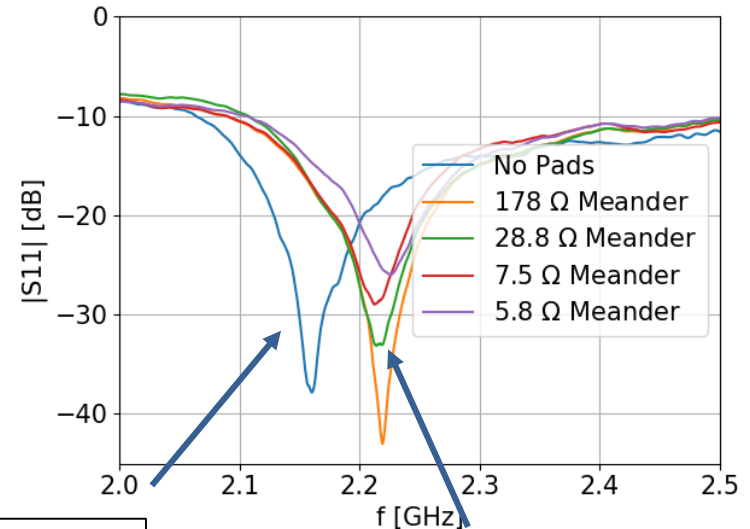
Antenna with 178 Ω platinum resistive sensing pads.



Antenna with 100 Ω sensing resistors.

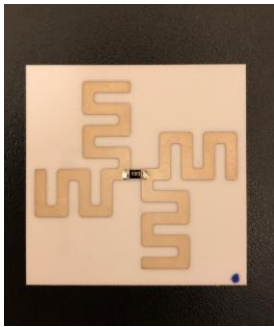
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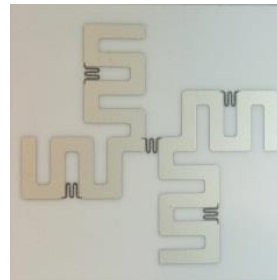


No Sensors

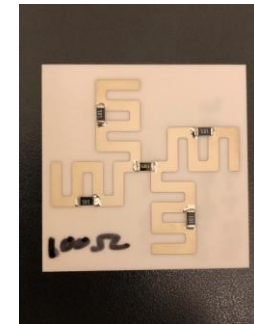
Meander



Antenna with no sensing pads.



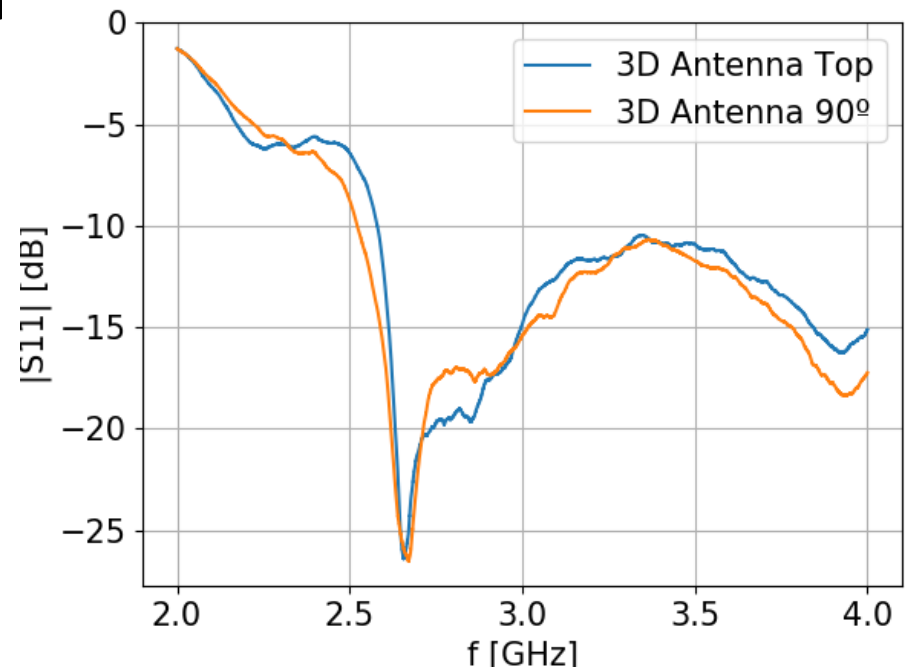
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Antenna with 100 Ω sensing resistors.

Large 3D Antenna Near Field Measurements

- Antenna interrogated from directly above (top) and from the side (90°).
- Response demonstrates orientation independence.



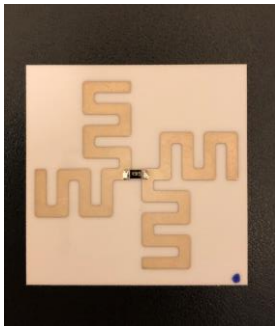
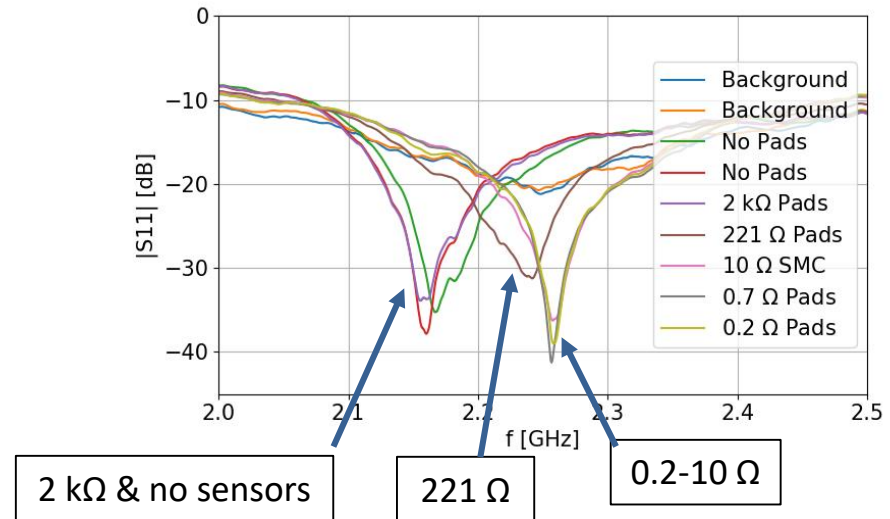
Conclusions

- Demonstrated fabrication capability with a variety of substrates and sensor materials.
- Demonstrated changes in antenna response due to directly integrated circuit elements.
- Demonstrated orientation flexibility with 3D antenna structure.

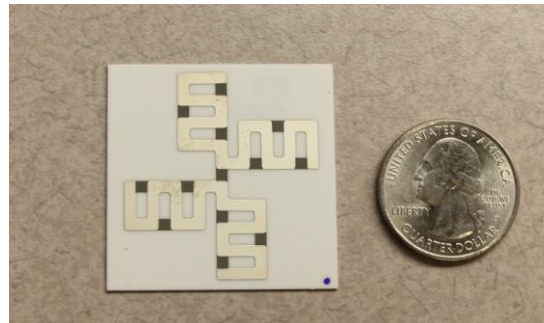


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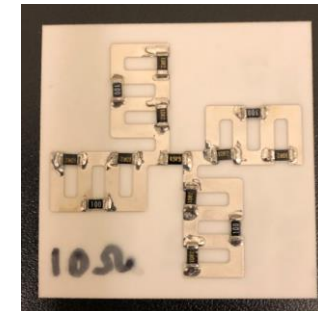
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Antenna with no sensing pads.



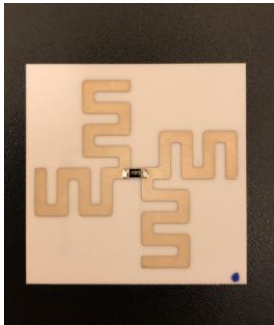
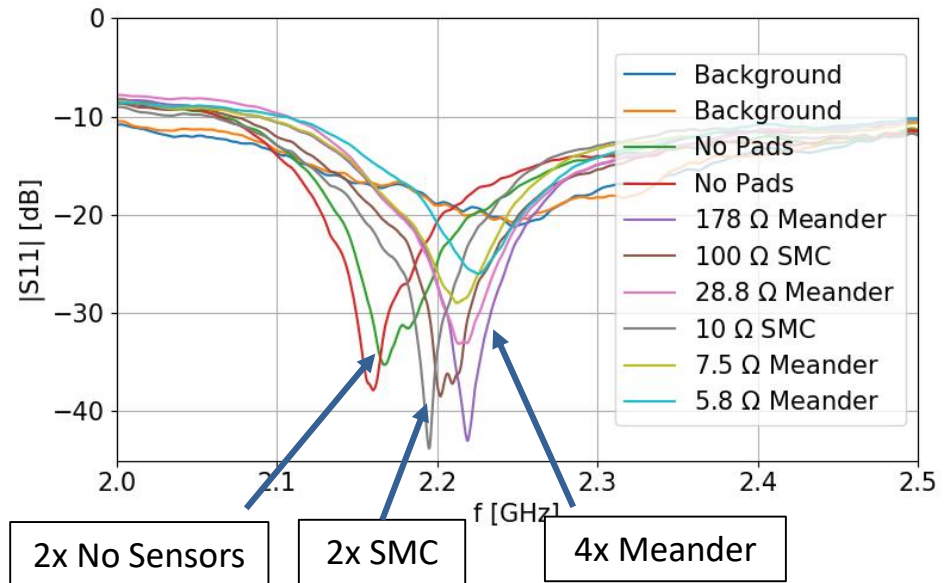
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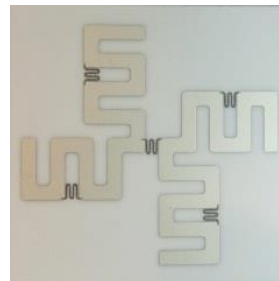
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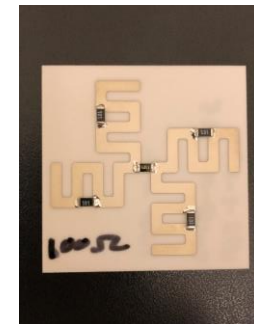
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Antenna with 100 Ω sensing resistors.

Small 2D Antenna Near Field Measurements

- Two antennas of each type were fabricated.
- Responses demonstrate frequency/size scaling compared to large 2D antennas (path forward for miniaturization).
- Antenna responses demonstrate dependence on fixed pad material.
 - Response can be used to measure pad resistance.
 - Pads are fixed value at this stage.

