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Design and Optimization of Periodic Structures for Electromagnetic Wave Manipulation

Presenter

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Overview

- ➢ This research presents the design, simulation, and characterization of different resonator structures based on the principles of coupling electric fields using periodic metamaterial-inspired configurations.

- ➢ It also tries to derive the relation of complementary split ring resonators with microstrip transmission line antenna.

- ➢ Five such structures were simulated which consist of Double Square, Double Circular, Square-Circular, Arrow, and Diamond shaped CSRR.

- ➢ These structures were then employed with a slit/gap to study the devices behavior for sensing a chemical moiety.

- ➢ The achieved resonant frequencies and Q-factors signify promising advancements and optimization in the design of electromagnetic wave manipulation devices.

Reported studies on resonator structures

Ref.	Periodic structure	Resonant frequency	Frequency shift	Sensitivity
[1]	Hexagonal CSRR	8.28 GHz	920 MHz	11.11
[2]	Tilted metallic crosses	1.52 THz	200 GHz	13.157
[3]	CSRR	2.7 GHz	720 MHz	26.66
[4]	H-shaped resonator	9.38 GHz	520 MHz	5.54
[5]	CSRR	0.85 THz	70 GHz	8.235
[6]	A-G-MSRR/ C-G-MSRR	4.90 GHz/ 4.53 GHz	380 MHz/ 340 MHz	7.755/ 7.50
[7]	CSRR	2.54 GHz	170 MHz	
[8]	CSRR	6.65 GHz	285 MHz	10.7
[9]	Nested SRR	7.54 GHz	230 MHz	3.05
[10]	SRR	7.1 GHz	433 MHz	30.14

NOTE : References are attached at the last page

Theory and Design

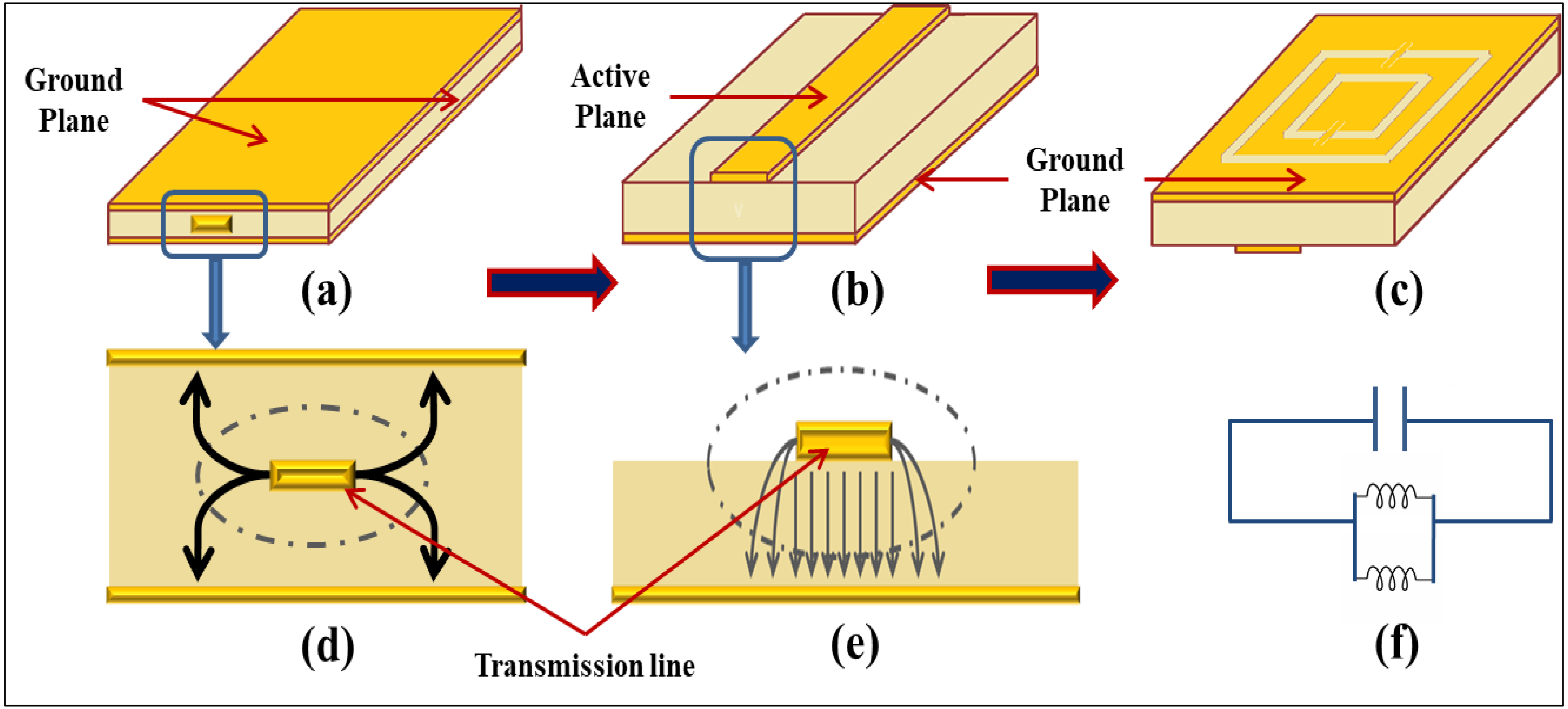

Figure 1: *(a) Stripline antenna structure with ground plane on both sides. (b) Microstrip line antenna with ground plane. (c) CSRR structure having periodic structure on ground plane. (d) Electromagnetic field distribution in stripline antenna. (e) Electromagnetic field distribution in microstrip line antenna (solid line- Electric field, dashed line- Magnetic field). (f) Electrical equivalent of a CSRR structure.*

Design Conditions

When, $t/h \leq 1$, then

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[\left(1 + 12\frac{h}{t}\right)^{-1/2} + 0.04\left(1 - \frac{t}{h}\right)^2\right] \ldots\ldots(1)$$

$$Z = \frac{60}{\sqrt{\epsilon_{eff}}} ln\left[\frac{8h}{t} + \frac{t}{4h}\right] \ldots\ldots(2)$$

When, $t/h \geq 1$, then

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[\left(1 + 12\frac{h}{t}\right)^{-1/2}\right] \ldots\ldots(3)$$

$$Z = \frac{120\pi}{\sqrt{\epsilon_{eff}\left[\frac{t}{h} + 1.393 + 0.667 ln\left(\frac{t}{h} + 1.444\right)\right]}} \ldots\ldots(4)$$

$$f_{resonant} = \frac{1}{2\pi\sqrt{L_{eff} C_{eff}}} \ldots\ldots(5)$$

where,

'ϵ_r', is the relative permittivity of the medium,

'h', is the thickness of substrate,

't' is the width of the microstrip transmission line.

'L_{eff}' is the effective inductance, and

'C_{eff}' is the effective capacitance of the lumped periodic structure

Simulated Structures

Here, we have used CAD Import Module, Design Module and RF Module for performing complete study.

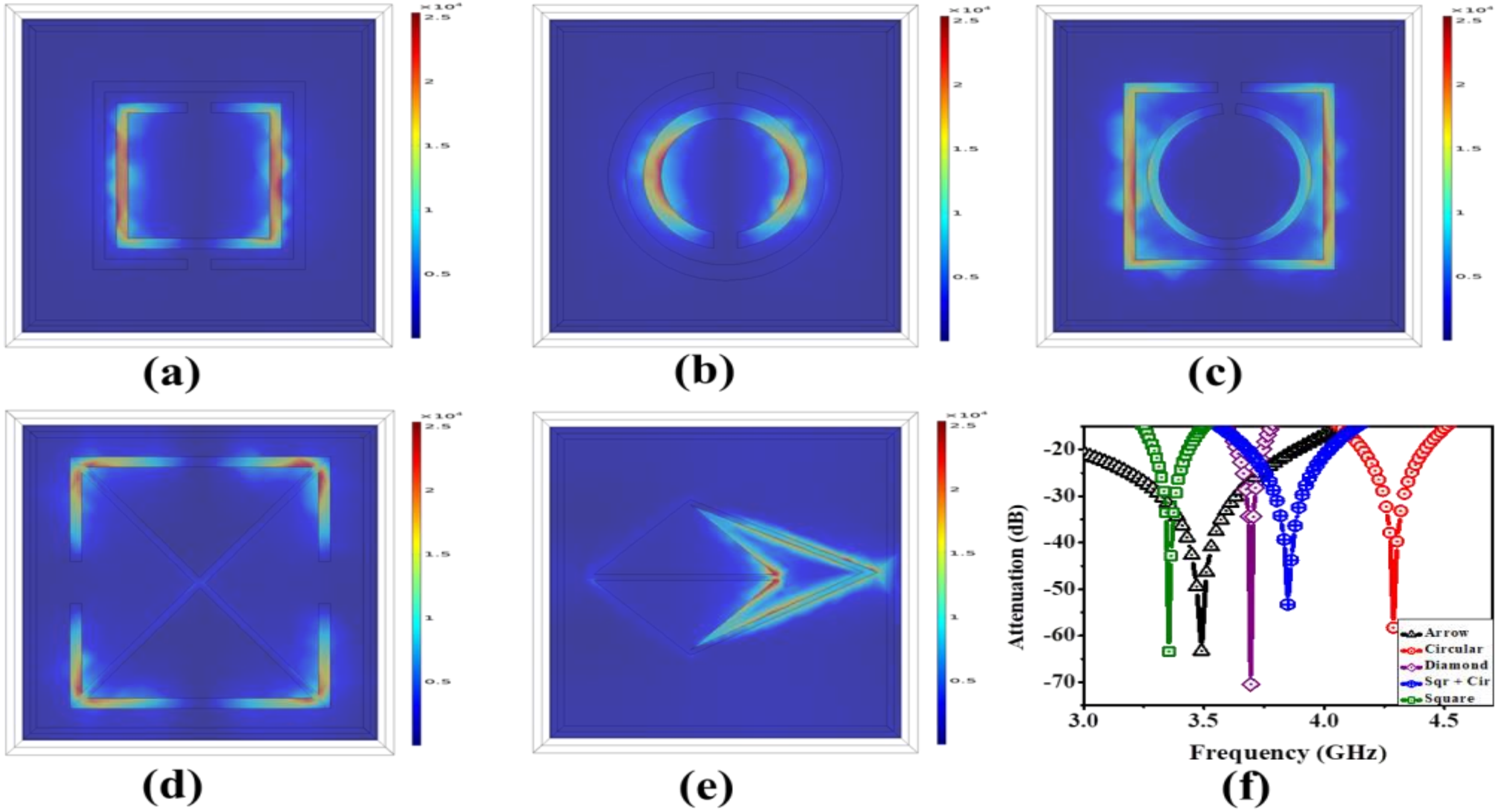

Figure 2: Electric Field Distribution along the surface of (a) DS-CSRR, (b) DC-CSRR, (c) SC-CSRR, (d) A-CSRR, and (e) D-CSRR. (f) Transmission spectrum for different CSRR structures.

Fabrication and Sensing

Type of CSRR	Surface Area (mm^2)	Number of Slit	Number of Loops
SC-CSRR	135.7	2	2
DC-CSRR	140.04	2	2
DS-CSRR	136	2	2
A-CSRR	143	2	1
D-CSRR	140.5	1	1

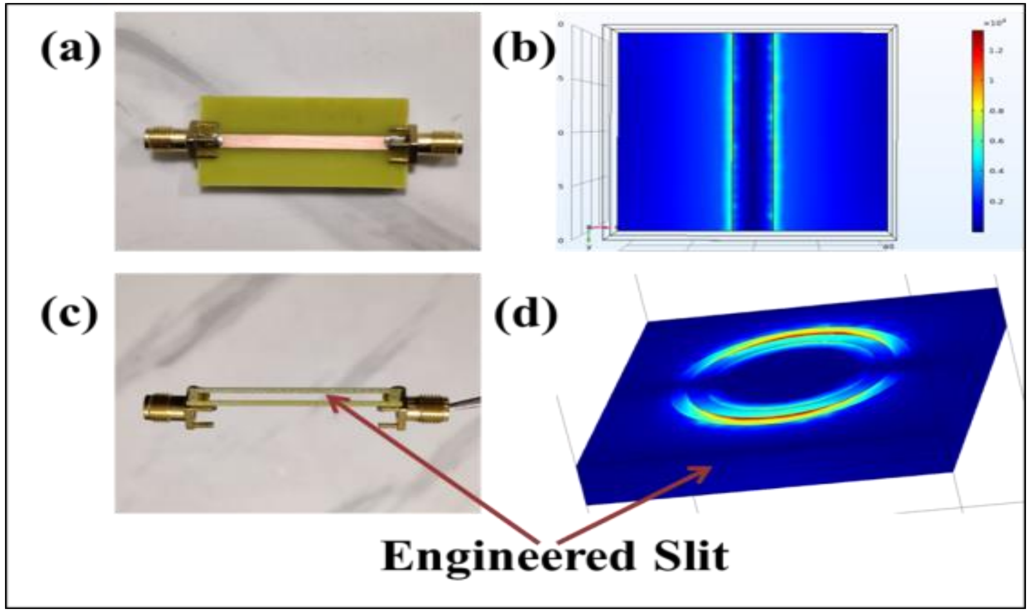

Figure 3: Fabricated sensor's (a) Microstrip transmission line, (b) Electric field distribution in simulated microstrip transmission line, (c) and (d) Engineered slit in fabricated and simulated sensor structure.

Obtained Sensor Parameters of all CSRR Structures

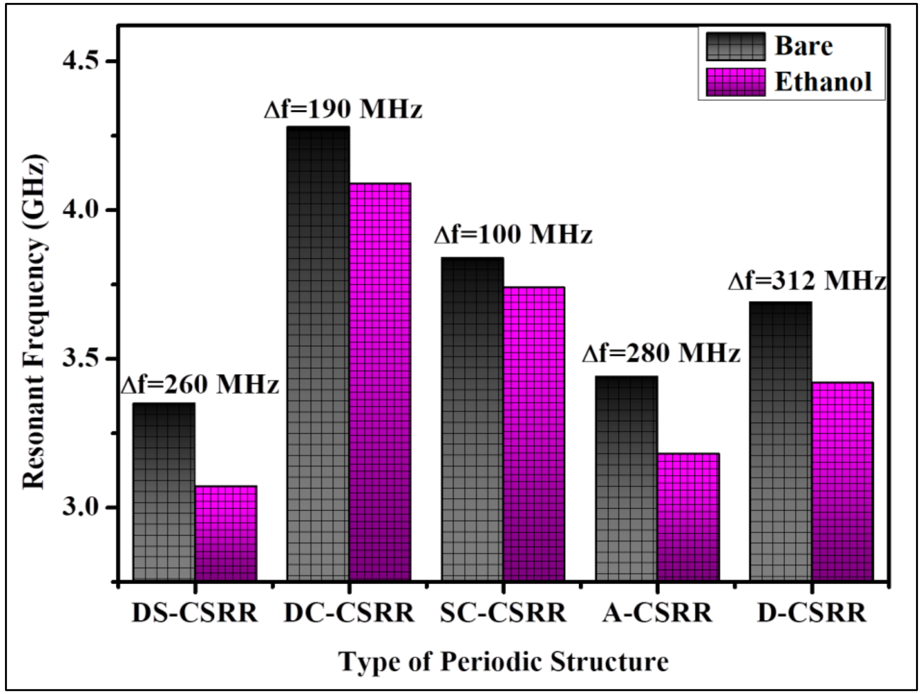

Figure 4: Difference in resonant frequency before and after sensing.

Type of CSRR	Sensitivity (MHz/µL)	Quality Factor (Q)	FWHM
SC-CSRR	70	24	0.16
DC-CSRR	125	48	0.09
DS-CSRR	166	112	0.03
A-CSRR	180	93	0.33
D-CSRR	189	181	0.02

- Among double looped resonators, DS-CSRR showed superior sensitivity and quality factor, which can be attributed to the higher values of its lumped electrical equivalent such as capacitance and inductance.
- The quality factor of A-CSRR was found to be smaller than that of DS-CSRR and this can be attributed to the presence of two slits in a single loop which led to broadening of transmission spectrum.
- In terms of FWHM, the best value among all these periodic structures was again shown by D-CSRR.

Conclusion

- Multiple periodic structures are simulated and explored for optimization of sensor parameters using COMSOL Multiphysics.
- During preliminary studies, it was observed that with increase in size or effective area for lumped electrical parameters, the resonant frequency of operation decreases exponentially.
- The microstrip transmission line was designed such that its impedance is about 50 Ω and this was achieved by using the strip width of 2.3 mm.
- A-CSRR and D-CSRR having single loop showed higher values of quality factor and sensitivity.
- D-CSRR is found to be the best among these five periodic structures based on obtained results.

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Thank You for Listening

Questions…?