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Artificial Transmission Line Loaded Dual-polarized Electrically Small Antenna for Wireless Applications

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Presentation Outline

- Research Objective
- Metamaterial Fundamentals
- Zeroth Order Resonance
- Circular Polarization
- Literature Survey
- Design of the Proposed Electrically Small Antenna
- Results and Discussions
- Electrically Small Antenna Considerations
- Comparison with Existing Works
- Conclusion
- References

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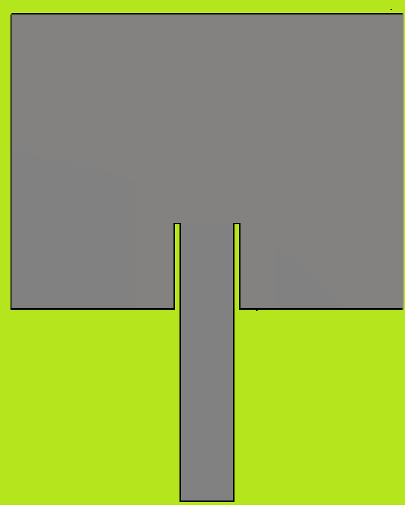
Research Objective

- **Day-to-day technology advancements:** Need of Electrically Small Antennas
- **Current systems:** Need compactness with better system performance, and cost effectiveness
- **Possible Solution:** **"Metamaterials"**

Conventional Patch Antenna



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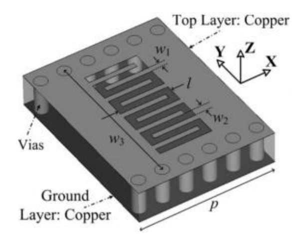
Bandwidth ↓
Gain ↓
Axial Ratio ↓
Efficiency ↓

Metamaterial CRLH-TL Antenna



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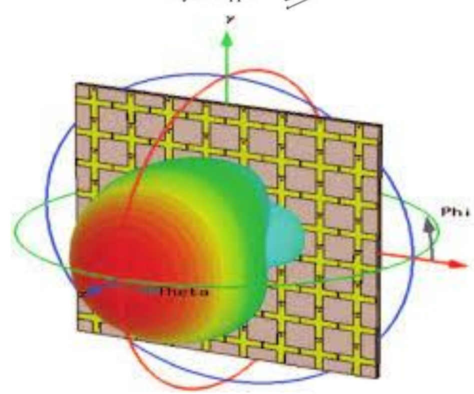

Size ↓
Bandwidth ↑
Gain ↑
Axial Ratio ↑
Efficiency ↑

Metasurface Loaded Antenna

Source: C. Zhou, *et al.*, "CPW-fed dual-band linearly and circularly polarized antenna employing novel composite right/left-handed transmission line," *IEEE Antennas Wireless Propag. Lett.*, vol. 12, pp. 1073–1076, Sept 2013.

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Metamaterials

- ✓ **What are Metamaterials ?**
- ✓ **Why is it important?**

- Themes of definition
  - ✓ Engineered composites
  - ✓ Properties are derived from their physical structure
  - ✓ Exhibit properties not observed in nature
  - ✓ Exhibit properties not observed by their constituent materials
  - ✓ Average cell size $d < \lambda_g/4$
- A composite material that is purposely engineered to provide material properties that are not otherwise attainable with ordinary materials

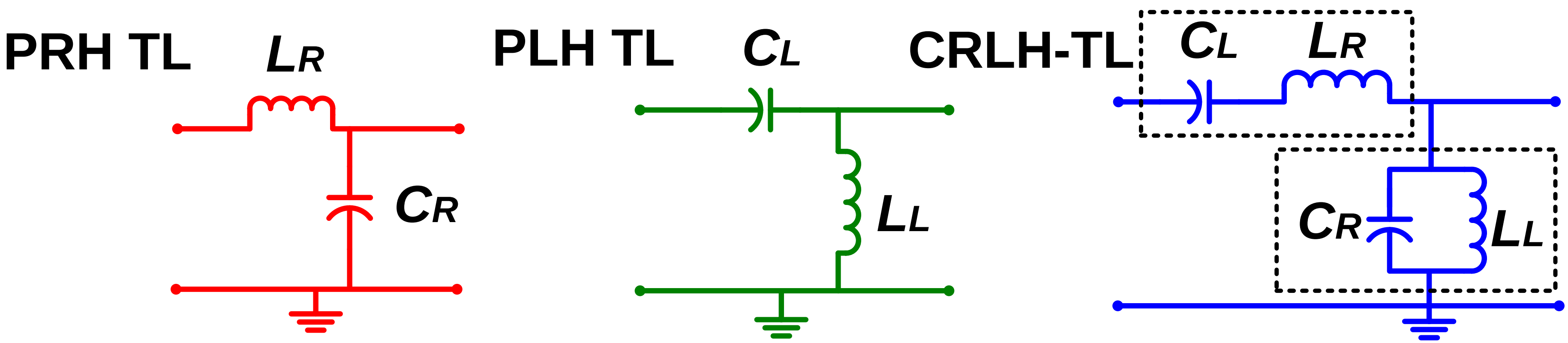
Brief Introduction to Metamaterials

- **Itoh & Caloz:**

✓ Inspired by the backward wave equivalent circuit, and motivated to realize the DNG phenomenon as a transmission line form instead of volumetric Pendry structure

"Backward waves = Left Handed waves"

✓ Left handedness goes together with Right-handedness due to the intrinsic RH behavior of nature coined as **"CRLH"**



Source: C. Caloz, and T. Itoh, *Electromagnetic Metamaterials: Transmission Line Approach and Microwave Applications*. Hoboken, NJ, USA: Wiley, 2005.

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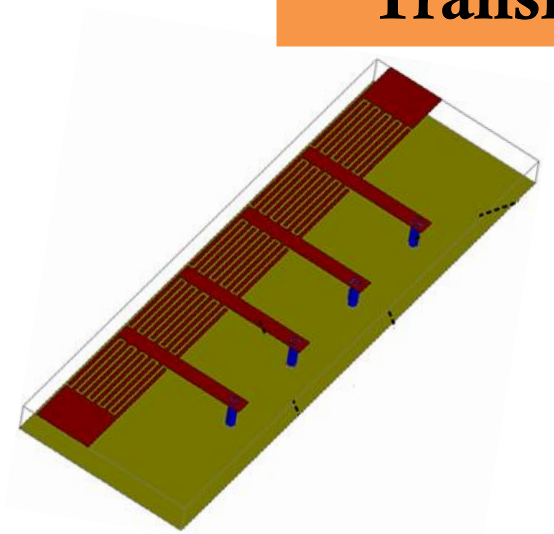
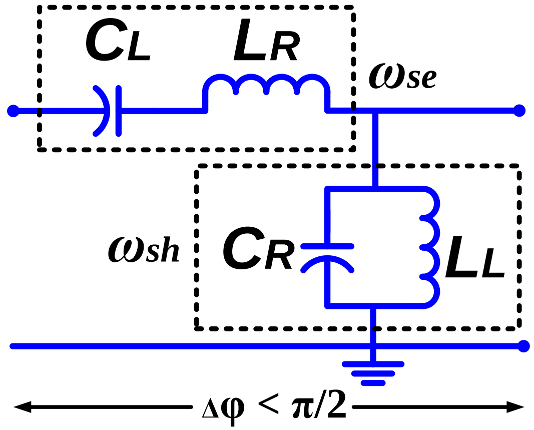
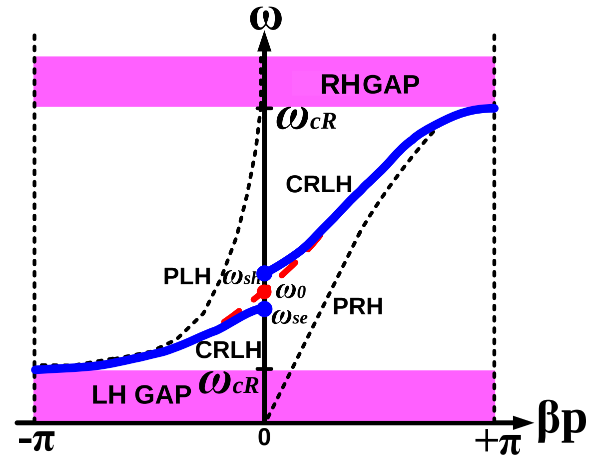
Composite Right/Left Handed Transmission Line (CRLH-TL)







- At the low frequency the circuit is of high pass nature
- At the high frequency the circuit is of low pass nature
- Two cases:
  - ✓ Unbalanced: $\boldsymbol{\omega_{se} \neq \omega_{sh}}$
  - ✓ Balanced: $\boldsymbol{\omega_{se} = \omega_{sh}}$

$$\boldsymbol{\omega_{res}(short) = \omega_{se} = \frac{1}{\sqrt{L_R C_L}}} \qquad \boldsymbol{\omega_{res}(open) = \omega_{sh} = \frac{1}{\sqrt{L_L C_R}}}$$

Source: C. Caloz, and T. Itoh, *Electromagnetic Metamaterials: Transmission Line Approach and Microwave Applications*. Hoboken, NJ, USA: Wiley, 2005.

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Zeroth Order Resonance

- If the CRLH TL is unbalanced, it exhibits two resonance frequencies, ω_{se} and ω_{sh} , when it is terminated by matched load (i.e., used as a propagating transmission line) where ω_{se} and ω_{sh} are series and shunt resonating frequencies.

- If the line is open-ended or short-ended to form a resonator, there is only one resonance frequency. CRLH TL resonance occurs when

$$\boldsymbol{\beta = \frac{n\pi}{l}} \quad \textbf{where } \boldsymbol{n} \textbf{ = 0, ± 1, ± 2 …….. ± (}\boldsymbol{N}\textbf{-1)}$$

- $\boldsymbol{n}$ is order of mode, $\boldsymbol{N}$ is number of unit cells, $\boldsymbol{\beta}$ is phase constant and $\boldsymbol{l}$ is length of Transmission line.

- When $n = 0$, $\boldsymbol{\beta = 0}$, $\boldsymbol{\lambda_g = \infty}$ which implies that ZOR is independent of transmission line length.

Source: C. Caloz, and T. Itoh, *Electromagnetic Metamaterials: Transmission Line Approach and Microwave Applications*. Hoboken, NJ, USA: Wiley, 2005.

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Polarization

- Polarization of electromagnetic (EM) waves is well specified by the behaviour of the electric/ magnetic fields in the time-space domain.
- There are two categories of polarization: **(i) co-polarization, and (ii) cross polarizations.**
- The polarization of the antenna can be classified as **linear, circular, and elliptical polarization.**
- **Linear and CIRCULAR POLARIZATIONS** are special cases of elliptical polarization, and can be obtained if ellipse becomes a straight line or a circle

CIRCULAR POLARIZATIONS

- **Circularly polarized at a given point in space if the field (electric- or magnetic-field) vector at that point traces a circle as a function of time.**

- **It has two orthogonal linear field components**
- **The two linear field components must have the same magnitude**
- **These two linear field components must have a time-phase difference of odd multiples of 90°**

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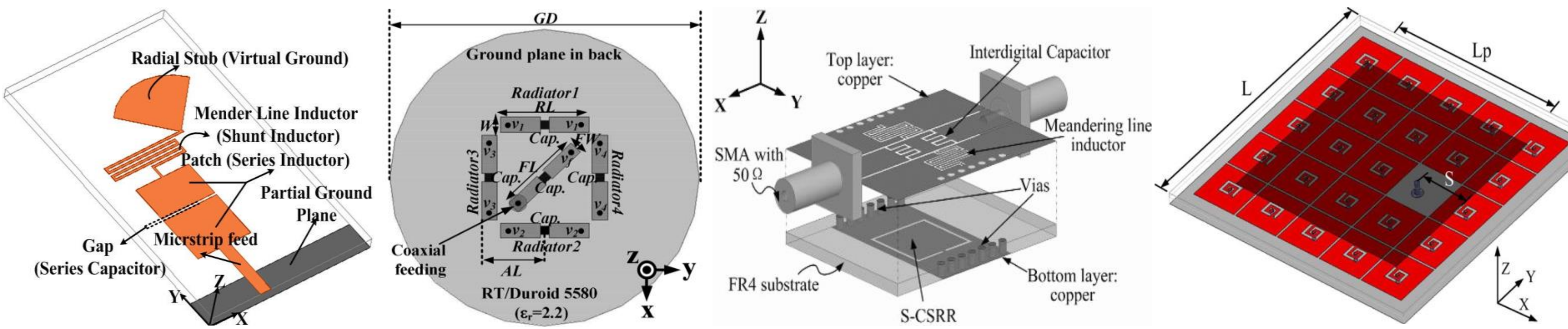
Literature Survey

Ref. No.	Frequency (GHz)	Overall size ($L \times W \times H$ mm)	IBW (%)	AR (%)	Gain (dBi)	Radiation Eff. (%)	Year Published
[1]	1.5/2.2	30 × 50 × 1.6	5/59.9	-	1.73/2.26	74/89	**2015**
[2]	1.59	D^{*} = 45, $h^{\#}$ = 3.175	1.1	0.25	3.8	68	**2016**
[3]	1.95/2.61	24.8 × 22 × 1.6	1.28/5.3	-/0.7	-6.9/-1.1	28/58	**2013**
[4]	1.33/1.8/ 2.41	70 × 70 × 2.5	1.88/3.24/ 10.03	1	2.1/0.6/ 5.7	27/45/66	**2012**



[1] [2] [3] [4]

Figure 1. Literature survey [1] multiband CRLH-TL, [2] MNG-TL, [3] Dual polarized MTM, [4] Patch with MTM EBG

1. S. K. Sharma and R. K. Chaudhary, "A compact zeroth-order resonating wideband antenna with dual-band characteristics," *IEEE Antennas Wirel. Propag.*, vol. 14, pp. 1670–1672, August **2015.**
2. B. C. Park, and J. H. Lee, "Compact circularly polarized antenna with wide 3-dB axial-ratio beamwidth," *IEEE Antennas and Wireless Propag. Lett.*, vol. 15, pp. 410–413, February **2016**.
3. C. Zhou, G. Wang, *et al.*, "CPW-fed dual-band linearly and circularly polarized antenna employing novel composite right/left-handed transmission line," *IEEE Antennas and Wireless Propag. Lett.*, vol. 12, pp. 1073–1076, Sept **2013**.
4. W. Cao, B. Zhang, A. Liu, *et. al*, " Multi-frequency and dual mode patch antenna based on electromagnetic band-gap (EBG) structure," *IEEE Trans. Antennas Propag.*, vol. 60, no. 12, pp. 6007–6012, December **2012**.

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Antenna Geometry and Design

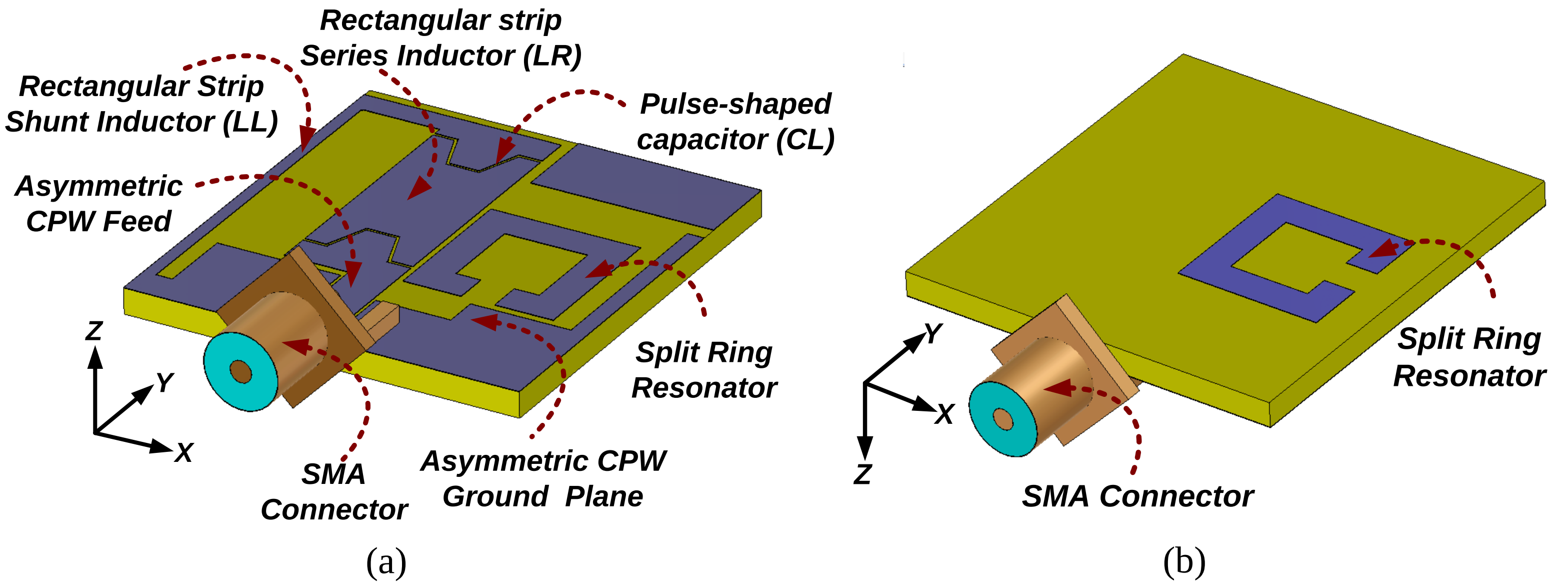

Figure 2. 3D view of the proposed ATL based electrically small antenna (a) Front view, and (b) back view.

- The **ATL or CRLH-TL** consists of a **series inductor (L_R), series capacitor (C_L), shunt inductor (L_L) and shunt capacitor (C_R)**
- **A compact SRR is introduced in the antenna top side and an additional SRR of same dimension introduced beneath the topside SRR**
- **Two asymmetric ground planes** are introduced between the feed line and directly connected to the ATL line
- The entire dimensions of the antenna is **23.7 mm × 25 mm × 1.52 mm** with overall electrical dimensions of **$0.09\ \lambda_0 \times 0.10\ \lambda_0 \times 0.006\ \lambda_0$ at 1.23 GHz**

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Antenna Geometry and Design

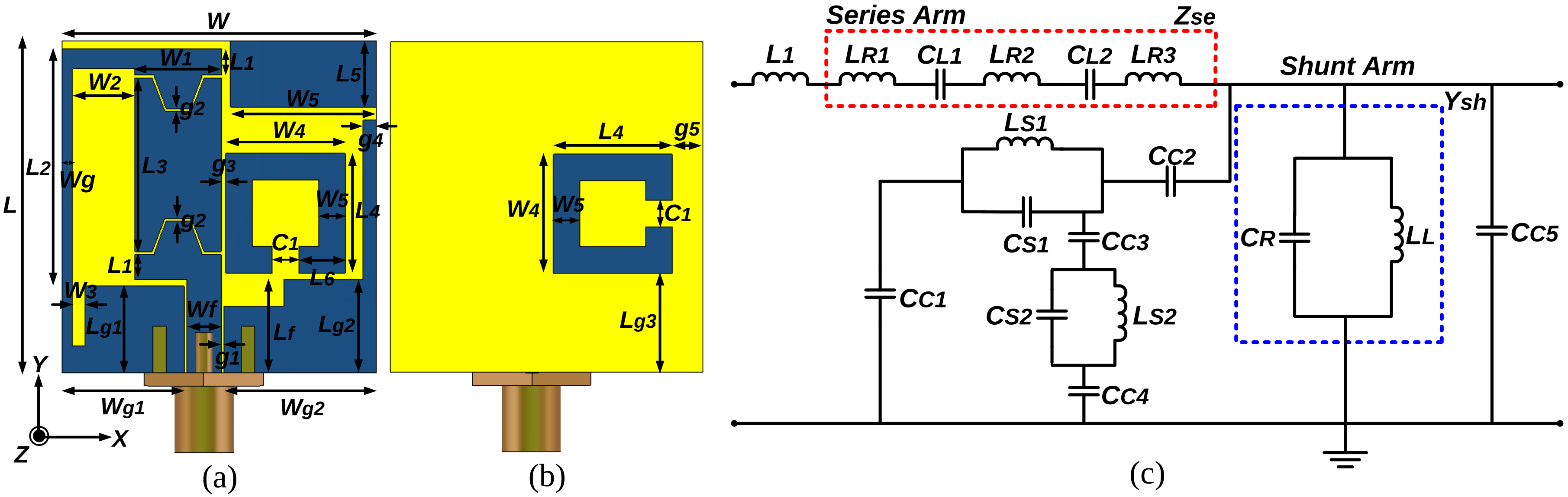

Figure 3. Schematic of triple-band antenna (a) Front view, (b) back view, and (c) eq. circuit diagram. L_{g1} = 6.5, L_{g2} = L_f = 7, L_{g3} = 7.5, L_1 = 1.8, L_2 = 18.1, L_3 = 13, L_4 = 9, L_5 = 5, L = 25, W = 23.7, W_{g1} = 9.2, W_{g2} = 11.5, W_g = 0.75, W_1 = 6.5, W_2 = 4.65, W_3 = g_4 = 1, W_4 = 9, W_5 = 11, W_f = 2.6, g_1 = g_2 = 0.2, g_3 = 0.35, g_5 = 2.35, C_1 = 2 (All dimensions are in mm).

- The series arm consists of rectangular strip ($W_1 \times L_1$) introduces **series inductor L_{R1},** pulse-type slot (g_2) introduces the **series capacitors C_{L1} and C_{L2},** rectangular strip ($W_1 \times L_3$) introduces **series inductor L_{R2},** rectangular strip ($W_1 \times L_1$) **introduces series inductance L_{R3}**
- The shunt arm consists of a rectangular strip ($W_g \times L_2$) that **provides the shunt inductance L_L** and the coupling between the microstrip feed and asymmetric ground ($W_{g1} \times L_{g1}$) **provides the shunt capacitance (C_R)**

CRLH-TL Behavior of Antenna

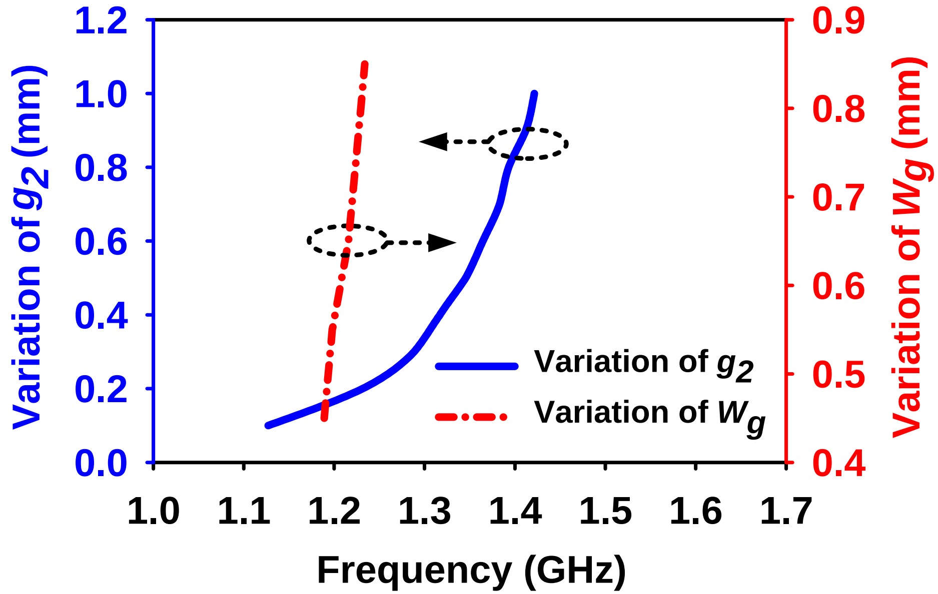

Figure 4. Parametric studies on S_{11} for the series element (C_L) and shunt element (L_L) of the intended antenna.

- Parametric investigation are done by varying the **shunt and series elements (L_L and C_L)**
- The ZOR is changing by varying g_2 values from 0.1 mm to 0.9 mm.
- The change in shunt inductor (L_L) by varying the Wg = 0.45 mm to 0.85 mm and observed that there is no variation in ZOR.
- **The ZOR is obtained by changing the series parameter (C_L) and not the shunt parameter (L_L)**

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Results and Discussions

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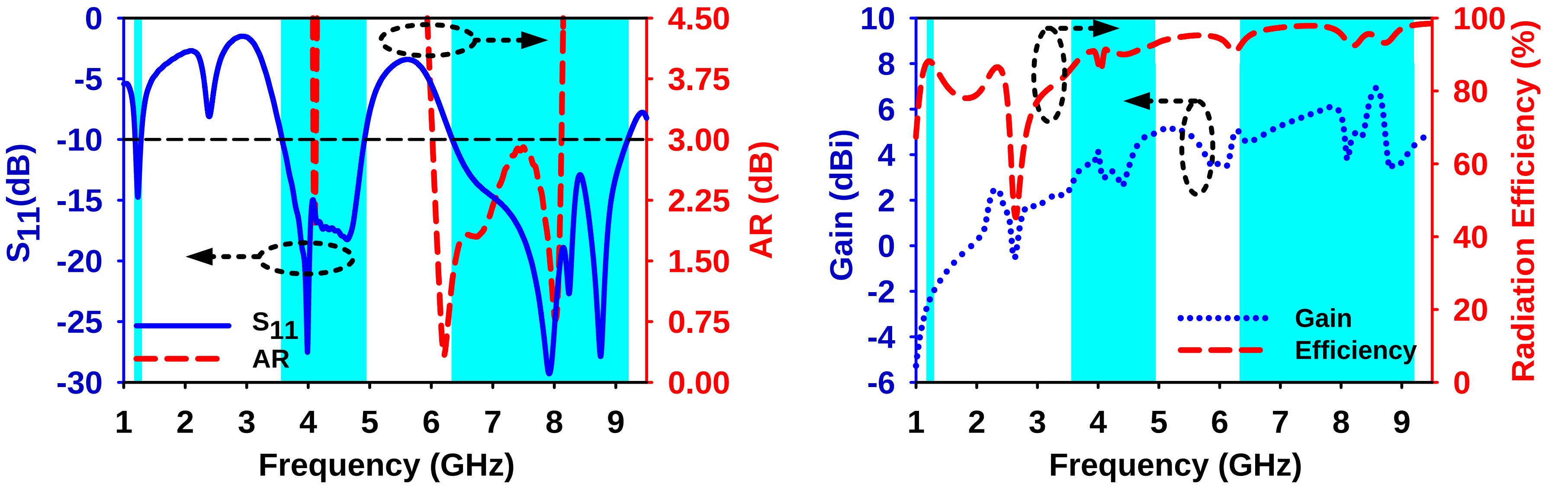

(a) (b)

Figure 5. Proposed antenna results (a) S_{11} and AR, (b) Gain and radiation efficiency.

- Impedance bandwidths of **(1.18–1.29 GHz) 8.94%, (3.56–4.94 GHz) 32.47%,** and **(6.33–9.20 GHz) 36.98%** at 1.23 GHz, 4.25 GHz, and 7.76 GHz
- An ARBW of **50 MHz (4.07–4.12 GHz) 1.22% and 1840 MHz (6.33–8.17 GHz) 25.37%** is obtained
- Peak gain of **-2.3 dBi, 3.5 dBi, and 6.6 dBi at** 1.26 GHz, 3.95 GHz and 8.5 GHz
- Radiation efficiency better than **86%** is observed for the three frequency bands

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Radiation Pattern of the Antenna

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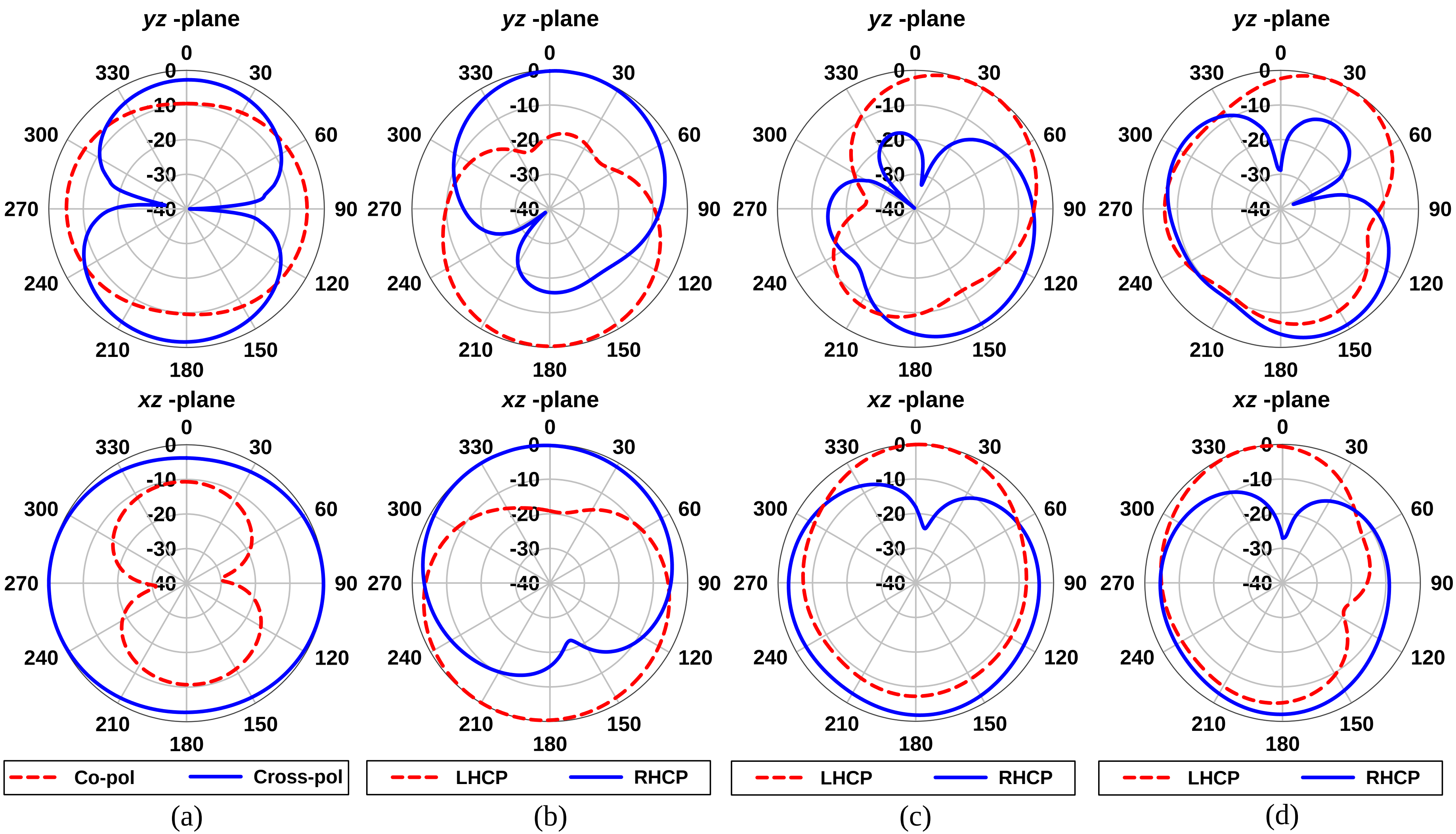

Figure 6. Simulated radiation patterns (a) 1.23 GHz, (b) 4.1 GHz, (c) 7 GHz, and (d) 8 GHz.

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ESA Considerations

- For **electrically small antennas** (ESA), Chu [*] and Mc Lean [#] have introduced a factor given by

$$Q_{min} = \frac{1}{k^3a^3} + \frac{1}{ka}$$

$$FBW_{max} = \frac{VSWR - 1}{Q_{min}\sqrt{VSWR}}$$

- Proposed antenna, *a* = 20.5 mm, *k* = 35.58 rad/m at 1.66 GHz.

***ka* = 0.44<1** → **Electrically Small Antenna**

- Using above equations, for ***VSWR* = 2**, the maximum obtainable BW is **5.04%**, and the obtained BW of **8.94%** at ZOR mode.
- Maximum realizable gain of ESA given by “Hamming Bound” [$]

$$G_{dBi} = 10log_{10}\left((ka)^2 + 2ka\right)$$

- Maximum feasible gain of **0.3 dBi** obtained at 1.55 GHz, and simulated gain is **-2.3 dBi** is obtained

* L. J. Chu, “Physical limitations of omnidirectional antennas,” *J. Appl.Phys.*, vol. 19, pp. 1163–1175, 1948.

J. S. McLean, “A re-examination of the fundamental limits on the radiation Q of electrically small antennas,” *IEEE Trans. Antennas Propag.*, vol. 44, no. 5, pp. 672–676, 1996.

$ R. F. Harrington, “Effect of antenna size on gain, bandwidth, and efficiency,” *J. Res. National Bureau of Standards-D. Radio Propag.*, vol. 64D, no. 1, pp. 1–12, 1960.

Comparison Between Existing Antennas

Reference Number	Frequency (GHz)	Antenna size (mm^3)	*ka* value	Impedance Bandwidth (%)	ARBW (%)	Gain (dBi)
[1]	1.95	24.8 × 22 × 1.6	0.67	1.28	–	-6.9
	2.61			5.3	0.7	-1.1
[2]	1.85	70 × 70 × 3.175	1.91	0.49	NA	-0.24
	2.86			1.33	NA	-0.51
[3]	2.89	60 × 60 × 3.175	2.56	2.94	0.41	6.26
	3.825			0.62	0.9	6.97
[4]	1.38	115 × 115 × 7	2.34	2	–	2
	1.57			1	1.27	7
[5]	1.33	70 × 70 × 2.5	1.37	1.88	–	2.1
	1.8			3.24	–	0.6
	2.41			10.03	1	5.7
Prop.	**1.23**	**23.7 × 25 × 1.52**	**0.44**	**8.94**	**–**	**-2.3**
	4.25			**32.47**	**1.22**	**3.5**
	7.76			**36.98**	**25.37**	**6.6**

1. C. Zhou, G. Wang, Y. Wang, B. Zong and J. Ma, "CPW-Fed Dual-Band Linearly and Circularly Polarized Antenna Employing Novel Composite Right/Left-Handed Transmission-Line," *IEEE Antennas Wireless Propag. Lett.*, **12**, September 2013, pp. 1073–1076.
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Conclusions and Future Work

- **A compact electrically small (*ka* = 0.44) and dual-polarized multiband ATL loaded antenna is designed**
- The antenna provides **IBWs of 8.94%, 32.47% and 36.98%** for the three bands centered at 1.23 GHz, 4.25 GHz, and 7.76 GHz respectively
- **The multiple CP characteristics achieved due to the asymmetric CPW ground plane and split ring resonator loadings**
- The antenna provides smaller size of **23.7 mm × 25 mm × 1.52 mm** with an electrical size of **$0.09\ \lambda_0 \times 0.10\ \lambda_0 \times 0.006\ \lambda_0$ at 1.23 GHz.**
- **The electrically small antenna is suitable for L, S, C and X-band applications**

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Thank You

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