ENGTL based antenna for Wi-Fi and 5G

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ENGTL based antenna for Wi-Fi and 5G

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Abstract: This article reported patch antenna functioning at Wi- Fi and 5G bands. Wi-Fi band (2.4 GHz) is obtained by loading Epsilon Negative Transmission Line (ENGTL) metamaterials into the patch radiating at 5G band (3.5 GHz). To acquire Circular Polarization (CP) at 5G band, conventional square patch is embedded with poly fractals. The experimental and simulated data are in close proximity. The obtained impedance bandwidth is 4.01% at Wi-Fi and is 10.68% at 5G band. CP bandwidth is 2.43% at 5G. This mix of ENGTL as well as fractals provides good compactness appropriate for portable gadgets

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Introduction:

The present day hand held devices are required to operate with various standards thus forcing them to operate at different frequency bands. Instead of using multiple antennas, single Antenna with smaller dimensions which caters various applications like 5G, Wi-Fi and WLAN is desirable for daily life wireless portable devices [1].

Metamaterials are good choice for designing compact multifunctional antennas since they have special electromagnetic properties [2- 4]. These materials will support backward wave propagation, due to which left handed bands (zeroth order or negative order modes) are produced. Metamaterials or left handed materials are grouped into Mu negative (MNG), ENG and Double negative (DNG) materials. Split Ring Resonators (SRRs), Vertical metallic VIAs are used to construct metamaterials. The pioneers in this area analyzed the Composite Right/ Left Handed transmission lines (CRLH TL) based on transmission line theory. ENG TL is implemented by just removing series capacitance of CRLH TL. ENG TL has a special property which is called infinite wavelength property where $\beta=0$ and $\omega \neq 0$. The main advantage of ENG TL is the zeroth order resonant frequency which is independent of the wave length. In [5 and 6], single band patch antennas are designed based on ENG TL. Dual band patch antennas based on ENG TL are designed and analyzed in [7, 8, 9 and 10]. More size is required to design a traditional dual band MPA because the dimensions are related to lowest frequency band. Then the current on the patch is perturbed to obtain resonance at higher frequency band. Moreover, they offer only linear polarization at both the bands with a narrow bandwidth. But modern devices need to provide circular polarization at 5G band to avoid orientation problems. By the adoption of metamaterials, the designer can design a dual band patch antenna by selecting the dimensions for high frequency band with less size first and then the lower frequency band is obtained by disturbing the current with metmaterial

(this is reverse procedure compared to previous method). The CP at upper 5G band is achieved by using fractals at the boundaries [11].

Methods

In this article, ENGTL based patch antenna working at Wi-Fi and 5G bands is proposed. The detailed explanation of dual band operation is presented. We used Rogers RT/Duroid as substrate material to obtain good radiation characteristics. CP at patch mode is achieved by providing asymmetry to the patch through the fractal curves embedded at the edges of the square patch. HFSS software is used for simulation; the feed point location is identified using optometric analysis which available in HFSS.

Antenna Geometry

Shape of reported antenna with fractal contour is presented in Fig. 1. Patch is placed on a substrate (Rogers RT/Duroid) with $\epsilon = 2.2$. Four vertical VIAs with radius of 0.3 mm and height of 3.175mm are inserted in between patch and ground plane. These VIAs provide shunt inductance which is main cause for getting zeroth order band (left hand band). Dimensions are listed in Table 1.

Table 1: parameter values

parameter	Value in mm
L1	46
L2	30
Dx1=Dx2	3
0y1=0y2	30
h	3.175
rv	0.3

ENGTL theory:

From Fig.2, L_R and C_R are series inductance and shunt capacitance per meter, both are related to patch and L_L is per unit length shunt inductance due to VIAs.

According to Bloch Floquet theory

$$\gamma = \sqrt{ZY}$$

Where γ is propagation constant, Z is series impedance and Y is the shunt admittance

$$Z = j\omega L_R$$

$$Y = j\omega C_R - \frac{j}{\omega L_L}$$

We know that propagation constant is the combination of attenuation constant and phase constant

$$\gamma = \alpha + j\beta$$

$$\alpha + j\beta = \sqrt{ZY}$$

$$\alpha + j\beta = \sqrt{ZY} = \sqrt{(j\omega L_R)(j\omega C_R - \frac{j}{\omega L_L})}$$

$$\alpha + j\beta = \sqrt{ZY} = \sqrt{-\omega^2 L_R C_R + \frac{L_R}{L_L}}$$

$$\alpha + j\beta = \sqrt{ZY} = \sqrt{L_R C_R (-\omega^2 + \frac{1}{C_R L_L})}$$

$$\text{Assume that } \omega_R = \frac{1}{\sqrt{L_R C_R}} \text{ and } \omega_{sh} = \frac{1}{\sqrt{L_L C_R}}$$

$$\alpha + j\beta = \sqrt{ZY} = \sqrt{1/\omega_R^2 (-\omega^2 + \omega_{sh}^2)}$$

$$\alpha + j\beta = \sqrt{ZY} = j * \sqrt{(\omega^2 - \omega_{sh}^2) / \omega_R^2}$$

Apply cosh both sides

$$\cosh(\alpha + j\beta) = \cosh(j * \sqrt{(\omega^2 - \omega_{sh}^2) / \omega_R^2})$$

$$\cosh \alpha \cos \beta + j \sinh \alpha \sin \beta = (2 + j^2 * ((\omega^2 - \omega_{sh}^2) / \omega_R^2)) / 2$$

We know that for a loss less transmission line, the attenuation constant $\alpha = 0$

$$\cos \beta = 1 - 0.5 * \frac{(\omega^2 - \omega_{sh}^2)}{\omega_R^2}$$

Therefore the phase constant β is given by

$$\beta = \arccos(1 - 0.5 * \frac{(\omega^2 - \omega_{sh}^2)}{\omega_R^2})$$

The dispersion characteristics of the proposed antenna based on the above equation are shown in Fig. 3, which gives the information about zeroth order resonance (ZOR) frequency. Here 2.4 GHz is at ZOR which is independent of the wavelength of the patch (the ZOR frequency occurred at infinite wavelength which is the specialty of the ENG TL).

Results and Disucussion

Design procedure is presented in Fig. 4. At first the square patch (Ante1) is adopted as reference working at upper band. The CP at this band is obtained by replacing edges of the square patch with poly fractal curves. Ante3 is achieved by inserting the metallic VIAs along the circumference of Ante1, in which this antenna produces two bands with linear polarization. Finally, Ante4 can be designed by inserting VIAs in Ante2 to result in dual band

patch antenna with one band LP and another band with CP. S_{11} characteristics are plotted in Fig. 5. Bandwidth values are listed in the Table 2.

Table 2: Bandwidth values

S. No	Antenna	Impedance bandwidth (%)		AR bandwidth (%)
		Band1	Band2	At band2
1	Ant1	-----	5.76% (3.03- 3.21 GHz)	-----
2	Ant2	-----	8.97% (2.88- 3.15 GHz)	paint----
3	Ant3	5.04% (2.32- 2.44 GHz)	5.14% (3.41- 3.59 GHz)	-----
4	Ant4	4.01% (2.44- 2.54 GHz)	10.6% (3.19- 3.55 GHz)	2.43% (3.25- 3.33 GHz)

To interpret functioning of recommended antenna, current distribution diagrams from HFSS are given in Fig. 6. Upper 5G band is response of current located near to boundary of the patch and current at metamaterial is the cause for WI-Fi band.

Experimental results

Demonstrated antenna (Ante4) prototype is given in Fig. 7a and 7b. Copper VIAs are loaded into the patch. S_{11} is measured by using Keysight E5063A-2D5 ENA vector network analyzer. Radiation patterns are recorded in a chamber (22.5 x 12.5 x 11.5 m³) which is working at a range of 400 MHz to 18 GHz.

S_{11} plot is shown in Fig. 8. Experimental and HFSS data are highly matched. Measured return loss bandwidth of Poly fractal boundary patch antenna is 4.01% at lower resonating band and 10.68% at upper resonating band respectively. Kink at 5G band specifies the CP. AR characteristics plot is given in Fig. 9. AR bandwidth at 5G band is 2.43%.

Radiation patterns are shown in Figs.10 and 11. Pattern at Wi-Fi is like figure of eight because of current at VIAs; where as the pattern at 3.4 GHz is like uni directional which is due to fractal boundary patch. The gain plot is shown in Fig. 12, which indicates that the gain at left hand band is moderate where as the gain at patch mode band is high.

Presented antenna properties and existing literature are compared and are given in Table 3. The reported antenna is miniaturized and has good bandwidth contrast to remaining antennas listed.

Table 3: Comparison

Ante	Size of patch (mmxmm)	Board size (mmxmmxmm)	bandwidth	
			At ZOR	At patch mode
proposed	30x30	46x46x3.175	4.01% at 2.4 GHz	10.6% at 3.4 GHz
[5]	3.5x10.5	-----	Resonance at 10 GHz only	
[6]	18.4x18.4	22.4x22.4x1.5	Resonance at 5.162 GHz only	
[7]	26x26	50x50x1.5	5.25 GHz	8.325 GHz
[8]	24.4x12.2	50x50x1.524	2.5 GHz	3.74 GHz
[9]	46.8x46.8	76.8x76.8x3.175	2 GHz	2.4 GHz

Conclusion

A novel patch antenna functioning at Wi-Fi and 5G bands based on metamaterials is proposed. The bandwidth of presented patch antenna is 4.01% at Wi-Fi band and is 10.68% at the 5G band respectively. The AR bandwidth is 2.43%. By optimizing the position of VIAs, feed point and ploy fractal curves, dual band operation with good CP bandwidth is achieved.

List of abbreviation

ENGTL- Epsilon Negative Transmission Line

5G- fifth generation of wireless communication

Wi-Fi- Wireless Fidelity

CP- Circular Polarization

AR- Axial Ratio

HFSS- High Frequency Structure Simulator

WLAN- Wireless Local Area Network

DNG- Double Negative

MNG- Mu negative

SRR- Split Ring Resonators

CRLH TL- Composite Right/Left Handed Transmission Line

MPA- Microstrip Patch antenna

ZOR- Zeroth order resonance

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Contributions

SN proposed the innovation ideas and theoretical analysis and draft the manuscript. RS conceived of the study, and helped to draft the manuscript. Both authors read and approved the final manuscript.

Competing Interests

The authors declare that they have no competing interest

Availability of data and materials

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

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Figure titles:

Fig. 1 Patch Antenna Geometry

Fig. 2 ENGTL equivalent circuit diagram

Fig. 3 Dispersion characteristics

Fig. 4 In between the steps in the design

Fig. 5 S_{11} characteristics

Fig. 6 a. current distribution at Wi-Fi

Fig. 6 b. current distribution at 5G

Fig: 7 a Top view of prototype

Fig: 7 b bottom view of prototype

Fig. 8 S_{11} plot

Fig. 9 AR plot

Fig. 10 Radiation patterns at Wi-Fi (a) E Plane (b) H Plane

Fig. 11 Radiation patterns at 5G (a) E Plane (b) H Plane

Fig. 12 Gain plot

Figures

Figure 1

Patch Antenna Geometry

Figure 2

ENGTL equivalent circuit diagram

Figure 3

Dispersion characteristics

Figure 4

In between the steps in the design

Figure 5

S₁₁ characteristics. Ant 1 - dashed line. Ant 2 dotted line. Ant 3 Dotted and dashed line. Ant 4 - solid line.

A

B

Figure 6

a. current distribution at Wi-Fi b. current distribution at 5G

A

B

Figure 7

a Top view of prototype b bottom view of prototype

Figure 8

S_{11} plot. Dashed line - simulated. Solid line - measured.

Figure 9

AR plot. Dashed line - simulated. Solid line - measured.

A

B

Figure 10

Radiation patterns at Wi-Fi (a) E Plane (b) H Plane. Dashed line - simulated. Solid line - measured.

A

B

Figure 11

Radiation patterns at 5G (a) E Plane (b) H Plane. Dashed line - simulated. Solid line - measured.

Figure 12

Gain plot. Dashed line - simulated. Solid line - measured.