The Bioscan
AN INTERNATIONAL QUARTERLY JOURNAL OF LIFE SCIENCES
20(3): 903-907, 2025 www.thebioscan.com

Analysis of Lumped Network Equivalent Circuit Model for Meander Line Antenna

M.Pandimadevi[1], R. Tamilselvi[2], M. Parisa Beham[3]

[123]Department of ECE, Sethu Institute of Technology

[1]*e-mail ID:* pandimadevim967@gmail.com

DOI: 10.63001/tbs.2025.v20.i03.pp903-907

KEYWORDS
Meander line, T-network, LTspice, S11 parameter.

Received on:

22-05-2025

Accepted on:

20-06-2025

Published on:

18-07-2025

ABSTRACT

Meander Line antennas have gained popularity in recent years when miniaturization is needed in radio frequency circuits. The widespread use of this antenna has led to the lack of simple analytical models, except for those that utilize sophisticated numerical methods. This paper proposes a circuit design for a meander line patch antenna that utilizes the lumped network phenomenon. The circuit model being proposed has twenty sections, which incorporate T-networks of inductor and capacitors. A dual band frequency of 2.1 GHz and 3.2 GHz was obtained through circuit theory analysis, which was modelled and solved. The circuit modelling is also done using LTspice software. It is observed that S_{11} parameter obtained from the circuit modelled in LTspice is also approximately resonant at dual frequencies computed from the circuit analysis thereby validating the proposed approach.

INTRODUCTION

With today's increasing demand for miniaturized technology, antenna engineers must create simple antennas that operate comparably better with the traditional designs [1]. There have been several recent attempts to minimize the size of microstrip antennas. Size reduction can be achieved by using an edge shorted patch [2] or a short pin. The insertion of slot [3-5] in the patch is also a typical approach in minimizing the size of the patch. However, the slot introduces parasitic capacitance which decreases the operating frequency of the antenna. In recent years, meandering [6-8] the patch is a popular approach to downsize the antenna without compromising its performance. Several attempts have been made to analyze the meander line antenna [9]. But however, a basic circuit model has yet to be developed. In this paper, we present a simple and easy circuit model of a Meander line patch antenna. The operating frequency of the antenna using equivalent circuit design has been compared with simulated S_{11} parameter of the antenna using LTspice software [10].

2 Antenna design

The first step in designing a patch antenna is choosing the material for the substrate. In this design, textile material is chosen as substrate with dielectric constant as 2.3 and its height as 1 mm. Initially, the operating frequency is selected as 3.2 GHz. Then the dimensions of the patch are calculated using the standard design equations of the patch antenna as in Table 1 from the work [8] . The layout of the meander line antenna is shown in figure 1.

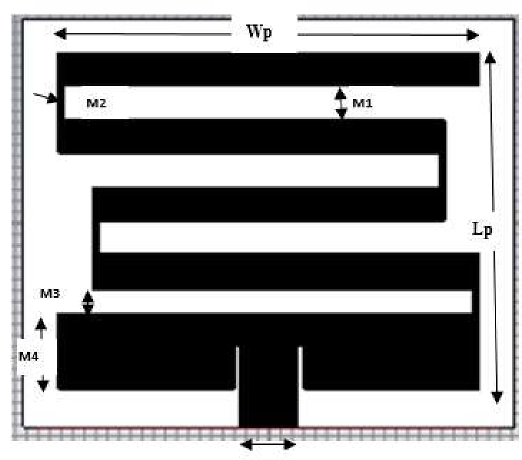

Fig. 1 Meander line antenna [Courtesy M Pandimadevi et. Al [8]

3 Modelling of line segments

In order to model the Meander line proposed antenna using lumped circuit elements, the antenna needs to be viewed as a cascade of individual segments [11]. Additionally, right-angled bends should be taken into account separately.

Table 1. Dimensions of the Meander Line Antenna

Parameters	Dimensions (mm)
Width of the Patch Wp	36.47
Meander line M1	3
Meander line M2	0.5
Meander line M3	2
Meander line M4	6
Meander line M5	30.47
Meander line M6	33.47
Length of the Patch Lp	30.44
Feed line Width F1	5
Inset feed Gap	0.5
Copper Thickness	0.03
Substrate thickness	1

The segmented representation of the meander line proposed antenna is shown in Figure 2. The next step is to create a lumped circuit model of each segment and then to perform a capacitive termination to handle the fringing fields caused by open-ended lines.

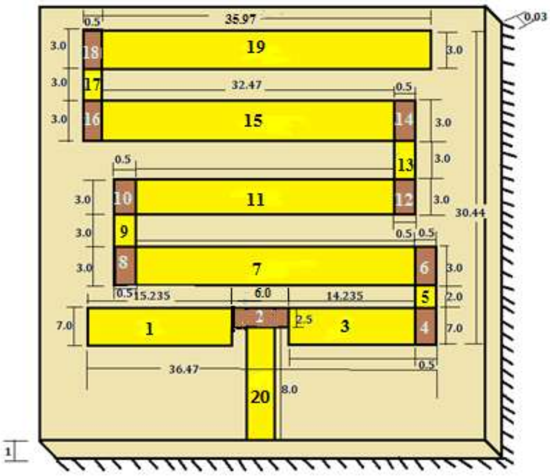

Fig. 2 Segmented representation of Meander line antenna

The segments 1,3,5,7,9,11,13,15,17 represent line segments that can be regarded as distributed transmission lines of respective lengths. The remaining line segments are considered as right angled bends. For each segment of the line, the lumped-parameter equivalent is used. Figure 3 shows the T-equivalent network for a two port distributed transmission line.

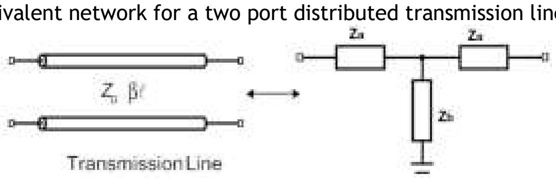

Fig. 3 T-equivalent model of transmission line

Transmission Line section and its equivalent Lumped T network [12] is also shown in figure 3. In figure 3,

$$Z_a = Z_0 \tanh\left(\frac{\gamma l}{2}\right) \; and \; Z_b = \frac{Z_0}{\sinh \gamma l} \quad (1)$$

where, l denotes the length of the line segment and Z_o is its characteristic impedance. The strip is considered to be loss free, the above equation is modified as:

$$Z_a = jZ_0 \tan\left(\frac{\beta l}{2}\right) \; and \; Z_b = -\frac{jZ_0}{Sin\,\beta l} \quad (2)$$

When the relation $l << \lambda g/4$ is satisfied, equation 2 is modified to

$$Z_a = jZ_0 \frac{\beta l}{2} \quad and \quad Z_b = -\frac{j Z_0}{\beta l} \quad (3)$$

It is known that,

$$Z_0 = \sqrt{\frac{L}{C}} \quad \text{and} \quad \beta = \omega\sqrt{LC} \quad (4)$$

Z_a and Z_b from equations 3 and 4 can now be expressed in

$$Z_a = \frac{j\omega L_a l}{2} \quad and \quad Z_b = \frac{1}{j\omega C_a l} \quad (5)$$

where, L_a represents Inductance per unit length, C_a represents Capacitance per unit length, and ω represents the angular frequency.

Comparing Z_a from equation 3 & 5, we get

$$\frac{jZ_0 \beta l}{2} = \frac{j \omega L_a l}{2} \quad (6)$$

Substituting,

$$\beta = \frac{2\Pi}{\lambda e_{ff}}, \quad \lambda_{eff} = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}}, \quad \lambda_0 = \frac{c}{f}, \quad \omega = 2\Pi f$$

Where, λ_{eff} denotes the effective wavelength and λ_o denotes free space wavelength, f denotes the operating frequency, and c denotes the speed of light in free space.

The effective permittivity, ε_{eff} is given by

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \times \frac{1}{\sqrt{(1 + 12\frac{h}{w})}} \quad (7)$$

Where, ε_r denotes the relative permittivity of the substrate, h denotes the height of the substrate and w denotes the width of the strip.

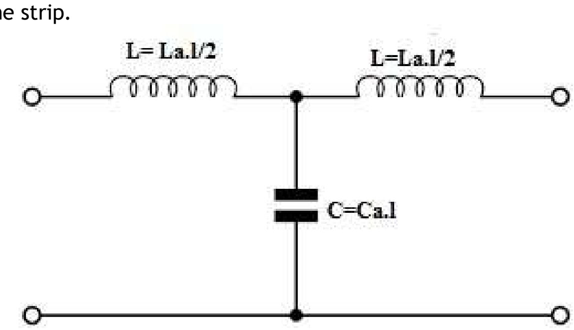

Fig. 4 Lumped equivalent model of T-network

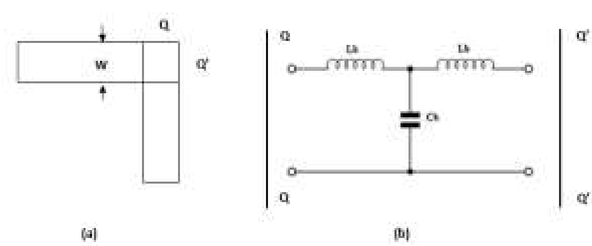

Fig. 5 (a) Right angled bend QQ' (b)Equivalent model of right angled bend

Figure 4 shows the lumped equivalent circuit of T network, Right angle bend and its equivalent model. In figure 5(a), L,C, L_b, C_b denotes inductance and capacitance of simple line segment and line segment with bend respectively. These parameters are calculated from the upcoming equations.

From equation 6,

$$L_a = \frac{Z_0 \sqrt{\varepsilon_{eff}}}{c} \qquad (8)$$

Similarly, from equation 3 and 5,

$$C_a = \frac{\sqrt{\varepsilon_{eff}}}{c\, Z_0} \qquad (9)$$

From the values of L_a and C_a, the value L and C in figure 4 can be easily calculated from the equation 10 as,

$$L = L_a \frac{l}{2} \quad and \quad C = C_a\, l \qquad (10)$$

3.1 Formation of Equivalent circuit

The lumped equivalent circuit for each line segments were cascaded in proper order and also terminated by open circuit capacitance Coc. The overall circuit representation of the proposed antenna using lumped models is shown in figure 5. The antenna structure when segmented gives 20 sections. Each sections are replaced by equivalent T-network.

3.2 Modelling of right –angled bends

The right-angled bends can also be designed as equivalent lumped T-network as shown in figure. The equation 11 shown below represents the closed-form formulae for determining bend capacitance and inductance.

$$\frac{C_b}{w}(pF/m) = \begin{cases} \dfrac{\dfrac{(14.\varepsilon_r + 12.5)w}{h} - (1.83\varepsilon_r - 2.25)}{\sqrt{(w/h)}} + \dfrac{0.02\,\varepsilon_r}{\dfrac{w}{h}}, \; for\ \dfrac{w}{h} < 1 \\ \dfrac{(9.5\,\varepsilon_r + 1.25)w}{h} + 5.2\,\varepsilon_r + 7 \,,\; for\ \dfrac{w}{h} \geq 1 \end{cases} \qquad (11)$$

$$\frac{L_b}{h}(nH/m) = 100\,(4\sqrt{\frac{w}{h}} - 4.21) \qquad (12)$$

Where C_b represents the bend capacitance, L_b represents the bend inductance, W represents the width of the strip and h denotes the height of the substrate with permittivity ε_r.

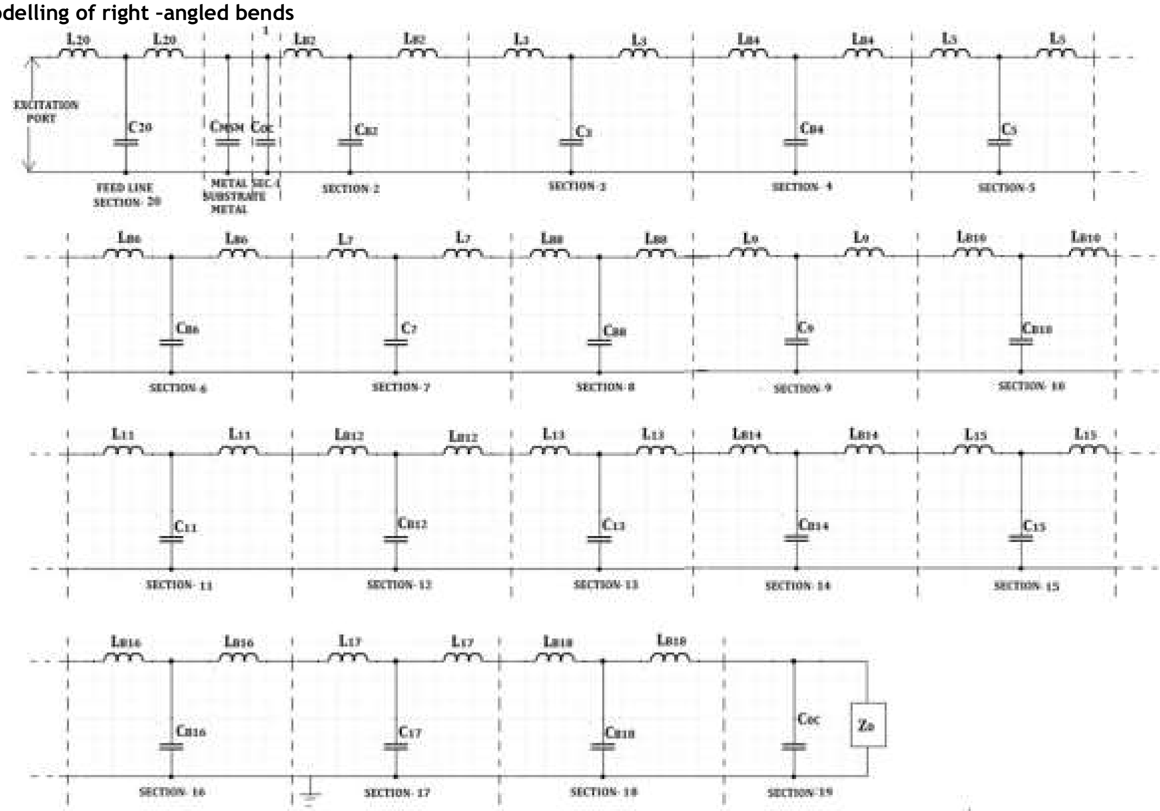

Fig. 5 Equivalent circuit representation of the proposed antenna using lumped models

3.3 Modelling of the open end line segment

The open end effect can be modeled with equivalent capacitance at that end due to fringing fields. The expression for the open circuit capacitance Coc has been formulated as

$$\frac{Coc}{w}(pF/m) = \exp\left(2.3026 \sum_{i=1}^{5} C_i(\varepsilon_r)\left[\log\frac{w}{h}\right]^{i-1}\right) \qquad (13)$$

Thus from these above equations, the inductance and capacitance values are calculated by computing the value of ε_{eff} using equation 7 for different values of the width of the strip. Table 2 shows the calculated values of inductance and capacitance for all line segments in the equivalent circuit..

3.4 Simplified Model

The complicated equivalent circuit is simplified by using Network theorem [12]. The circuit as in figure 6 is solved from left to right that is starting L_{20} from section 20,1,2 upto C_{13} in section 13, the equivalent capacitance and inductance is solved and calculated as 17.051pF and 0.3265 nH respectively and the resonant frequency f_r upto the section 13 is computed from the equation 13,

$$f_r = \frac{1}{2\Pi\sqrt{L_{eq}.C_{eq}}} \qquad (14)$$

The resonant frequency, f_r upto section 13 is calculated as 2.13 GHz. The equivalent capacitance and Inductance values of the remaining portions that is from L_{13} in section 13 to C_{oc} in section 19 is simplified and calculated as 7.73pF and 0.3265 nH respectively. The resonant frequency for that sections are calculated from equation 14 and taken as 3.169 GHz. The simplified equivalent circuit for the proposed antenna is shown in figure 6.

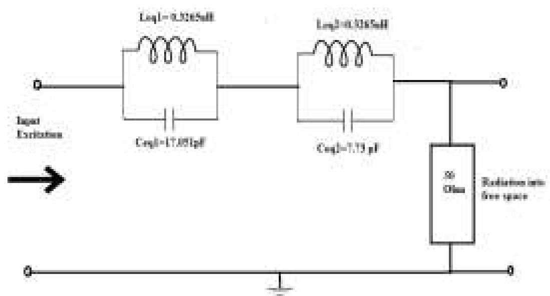

Fig. 6 Simplified Equivalent circuit of proposed antenna

Table 2 Values of L & C parameters in equivalent circuit model

Section/Bend no.	Inductance (nH)	Capacitance (pF)	Description
Metal Substrate Metal	-------------	C_{MSM}=9.83	Capacitor between Patch and whole Ground
1	------------	0.071	Open circuit end section of length <λ/4, due to fringing effect
2	0.21	0.192	T-Network of 90° bend. Capacitance arises from accumulated charges at the corners, whereas inductances are caused by interruptions of current flow.
3	1.698	1.35	section
4	0.64	1.26	90° bend
5	0.223	0.178	section
6,8,10,12,14,16,18	0.027	0.265	90° bend
7	3.82	3.03	section
9,13,17	0.33	0.27	section
11	3.28	2.62	section
15	3.61	2.89	section
19	-------	0.43	Open circuit end section. capacitor due to fringing effect
20	0.942	0.075	50 ohm line

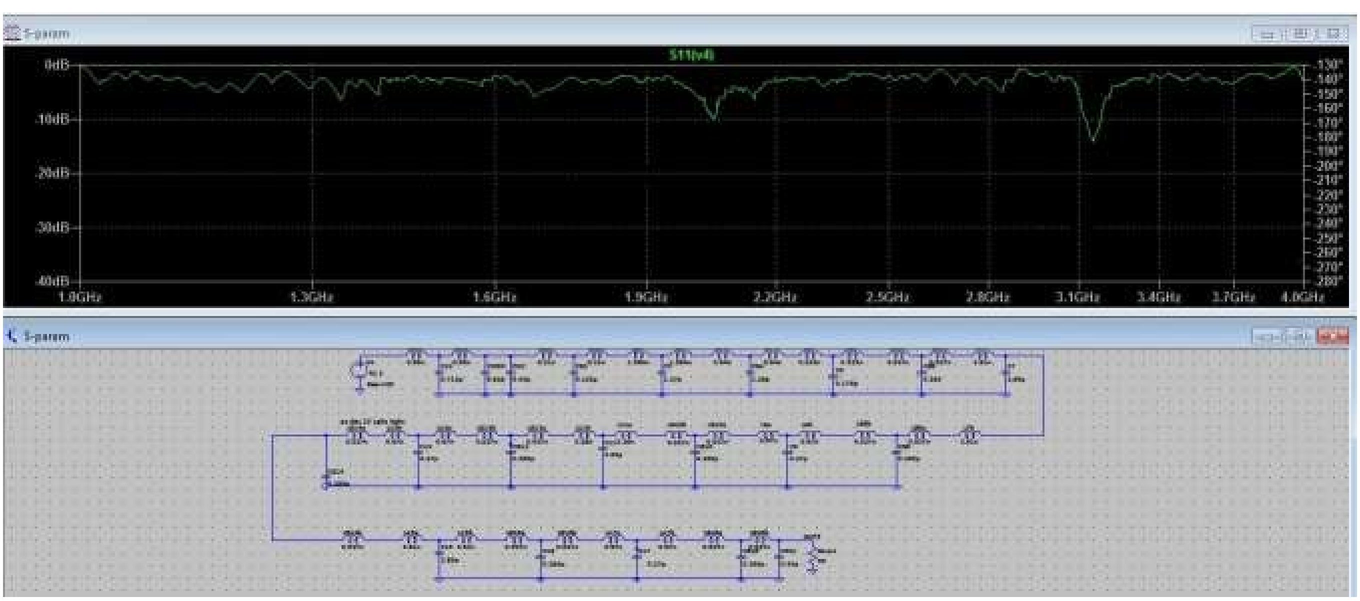

Fig. 7 S-Parameter result using LTspice

4 Results and discussions

4.1 Simulation using LTspice

LTspice® 10" is a high-performance, high-speed simulation software, schematic capture and waveform viewer [10]. It includes enhancements, models, and tools to simulate analog circuits. In addition to a large selection of Analog Devices switching regulators and amplifiers, LTspice includes a library of general circuit simulator devices. The computed equivalent circuit model is designed using LTspice software and its S-parameter result is also simulated as in figure from the result. it is evident that the designed equivalent circuit resonates dually around 2.1 GHz and 3.15 GHz. From the results, it is proved that the simulated S-parameter result and circuit theory analysis of the meander line antenna shows comparatively the similar values of the operating frequency.

CONSLUSION

This paper proposes the simplified analytical equivalent circuit model of a meander line antenna with varied width and length for a dual operating frequency (2.13 GHz and 3.169 GHz) for wireless applications such as WLAN, WiMAX, GPS, etc. The resultant equivalent circuit is designed using LTspice software and its S-parameter is also simulated. The simulated results also show the circuit resonates at dual band frequency (2.1 GHz and 3.15 GHz) which correlates well with the circuit theory results.

Authors Profile

M.Pandimadevi has completed her B.E in Electronics and Communication Engineering in 2005 and M.E in Optical communication in 2007 and completed her Ph.D in Antenna design in Anna University in 2022. she has more than 15 years of teaching experience. She is working as Associate Professor in the Department of Electronics and Communication Engineering, Sethu Institute of Technology, Virudhunagar, India.

R.Tamilselvi, received the B.E (Electronics and Communication Engineering) from Bharathidasan University, Trichy, in 2002, M.Tech degree in Advanced Communication Systems from SASTRA University, in the year2004. She received her PhD from Anna University, in the year 2014. She is working as Professor in the Department of Electronics and Communication Engineering, Sethu Institute of Technology, Virudhunagar, India. Her interests include image processing, signal processing and neural network. She is a life member of ISTE, BMESI & IACSIT.

M. Parisa Beham received UG degree in Electronics and Communication Engineering from Institution of Engineers, India, in 2000, PG degree in Applied Electronics from Mohamed Sathak Engineering college, Ramnad, in 2006. She received her Ph.D from Anna University, Chennai in the year 2016.Currently she is working as a Professor in the department of Electronics and Communication Engineering, Sethu Institute of Technology, Virudhunagar, India. Her areas of research include: Computer vision, Pattern recognition, Image analysis and image processing.

REFERENCES

- [1] Fayyaz, N., Shin, E., Safavi-Naeini, S. “A novel dual-band patch antenna for GSM band”, Antennas and Propagation for Wireless Communications, pp. 156-159, 1998.
- [2] Sanega A., Kumar P,”A Compact Microstrip Patch Antenna for Mobile Communication Applications”, Micro-Electronics and Telecommunication Engineering, Lecture Notes in Networks and Systems, vol 106. Springer, Singapore 2020.https://doi.org/10.1007/978-981-15-2329-8_58.
- [3] Roy.A,Bhunia. S, Sarkar.D and Sarkar.P,”Slot loaded compact microstrip patch antenna for dual band operation”, Progress In Electromagnetics Research C. 73. 145-156,2017. 10.2528/PIERC17020903.
- [4] Pandimadevi, M., and N. Logasri. "Felt based Performance Improvement of Patch Antenna for WLAN Applications." Journal of Electrical Engineering and Automation 5, no. 2 (2023): 182-190,2023. DOI: 10.36548/jeea.2023.2.003.
- [5] D. Misman, M. Z. A. Abd. Aziz, M. N. Husain and P. J. Soh, "Design of planar meander line antenna," 2009 3rd European Conference on Antennas and Propagation, 2009, pp. 2420-2424.
- [6] Yosif B,Sadiq M and Abdelrazzak M,” Design and Simulation of Meander Line Antenna For LTE Communications Based on Defected Ground Structure”, Ciência eTécnica Vitivinícola. 30911):15,2015.
- [7]Soham Ghosh,Sohom Das,Diptiranjan Samantaray and Somak Bhattacharyya, ”Meander-line-based defected ground microstrip antenna slotted with split-ring resonator for terahertz range”, Engineering Reports,2020. ,https://doi.org/10.1002/eng2.12088.
- [8] M Pandimadevi, R Tamilselvi, M Parisa Beham,” Development of nano ferrite coated miniaturized jute antenna for wireless applications” Industria Textila, Vol.75, Issue:03, pp:259-266, 2024. DOI: 10.35530/IT.075.03.202358.
- [9] Das, Arkaprovo et al. “Lumped Circuit Model Analysis of Peano Line Antennas.” International Symposium on Antennas and Propagation (ISAP) At: Jeju, South Korea , Volume: ISAP 2011, Oct 2011.
- [10]https://www.analog.com/en/design-center/design-tools-and-calculators/ltspice-simulator.html.
- [11] A. Das, S. Dhar and B. Gupta, "Lumped circuit model analysis of meander line antennas," 2011 11th Mediterranean Microwave Symposium (MMS), 2011, pp. 21-24, doi: 10.1109/MMS.2011.6068520.
- [12] John D.Ryder 1978, “ Networks, Lines and Fields”, Prentice Hall India Learning Private Limited, ISBN-10:8120302990.