Design and Analysis of Reactive Load Dipole Antenna using Genetic Algorithm Optimization

K. Kayalvizhi and S. Ramesh

Department of Electronics and Communication Engineering
SRM Valliammai Engineering College, Kattankulathur, Chennai - 603203, Tamil Nadu, India
kayal_sacet@yahoo.co.in, rameshs.ece@valliammai.co.in

Abstract **─** This article presents a reactive load dipole antenna and it is working in the frequency range from (10 MHz- 600 MHz). The LR Load can improve the antenna characteristics to produce maximum gain. The loads are in the combination of parallel and series LR circuits. Genetic Algorithm is used to obtain the optimum values of loads and their optimum position along the dipole. The proposed design is simulated using 3D EM CST Microwave Studio tool. In the working band, the S_{11} parameter and gain of the loaded antenna are -15.73 dB at 328 MHz and from -15 dBi at 10 MHz to 2.80 dBi at 600 MHz. An optimized reactive load dipole antenna were fabricated and tested. Good agreement were attained among the measured and simulated results.

Index Terms **─** dipole antenna, genetic algorithm, loading antenna, reactive loading.

I. INTRODUCTION

Recent advances in broadband communication system are generating a great interest in miniature, efficient and broadband antennas. Antenna designers used a lumped element to improve impedance matching and the antenna bandwidth. A loaded wire antenna can be obtained by placing reactive element on wire radiator such as bifold monopole [1], long wire stub loading [2], in order to modify the current distribution along the conductors to enhance the antenna performance. In [3], an inductor and resistor is loaded wire monopole antenna with a matching network were designed by using genetic algorithm optimization with VSWR less than 3. In [4], an antenna consists of loaded wire monopole, a sleeve pedestal and an on body matching network and they are optimized by using Genetic algorithm to enhance the system gain and increase the antenna bandwidth. In [5], presents a new technique for wideband impedance matching of short monopole antenna in HF/VHF band is designed to improve VSWR of antenna and a resistor is located between the two parts of the antenna.

Discretely loaded resistive dipoles [6], were implemented and analyzed for use of short pulse radiation and reception application. Discretely loaded Vee dipole [7], and durable 2-arm resistor cross dipole antenna [8] were designed for use of Ground penetrating Radars. In [9], a non-foster matching network using an operational amplifier is designed to reduce the reflection in resistive loaded Vee dipole antenna. In [10], to broader an antenna input impedance bandwidth, a frame work based on reactive loading using NCM is presented. In [11-13], designed a dipole with left handed topology to realize matched input impedance values and a miniaturized antenna with enriched performance. In [14], discussed about the single feed cross dipole antenna loaded with different NFPR element to implement compact polarized reconfigurable antenna which is used in wireless communication. In [15,16], investigates to achieve circular polarization operating bandwidth between of the broad band cross over dipole antenna loaded with parasitic elements will be used for broadband wireless communication system. In [17], designed a RL loaded dipole antenna by using genetic algorithm. In [18-20], present a dual polarized linear TCDA loaded with resistive loops and to achieve a wide bandwidth and low profile, a resistors were introduced in the array to reduce a ground plane interference. In [21], an antenna design method based on genetic algorithm optimization and it is applied to the wire antenna loaded with lumped components. In [22], a broadband six LR loaded dipole antenna is designed and the load values and position are optimized by using Genetic Algorithm. In [23], an antenna with resistive loading is designed on a printed circuit board and the performances were realized for pulse radiation. In [24], a planar sleeve monopole antenna is designed and its antenna performance is enhanced by using passive lumped element loading. In [25], a mode matching analysis of dipole antenna loaded with metamaterial inclusion has been examined analytically.

In this article, we consider the use of genetic algorithm optimization for a dipole antenna with matching network. The designed antenna consist of a loaded wire dipole and matching network, in which loads and matching network are optimized by the genetic algorithm in order to enhance the antenna performance. The article is prepared as follows. In Section II, it

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deliberate about the antenna design. Section III, discuss about the antenna optimization, modelling and component. Section IV, discuss about results and its performance. Section V discuss about antenna fabrication and measurements results and finally conclusion of the paper are discussed in Section VI.

II. ANTENNA DESIGN

The steps for designing an initialized unloaded and optimized loaded dipole antenna, as described in Fig. 1 in detail, are summarized in the following: Design an initialized unloaded dipole antenna and it is operated over frequency range from 10 MHz - 600 MHz is simulated using 3D EM CST Microwave studio tool to evaluate the performance of S_{11} parameter, gain and radiation pattern of the antenna. The reactive load is employed in the dipole antenna to improve the antenna characteristics performance with respect to the desired frequency range. The optimized loaded and unloaded dipole antenna are symmetrical in its length (h) and diameter (D) [17]. The loaded dipole antenna is designed by using two different software's, simulation done by using 3D EM CST Microwave studio software and the load values and their position are optimized by using MATLAB Genetic Algorithm optimization technique. Then the optimized antenna parameters are updated to 3D EM CST Microwave studio software to extract the antenna performance of the simulated result.

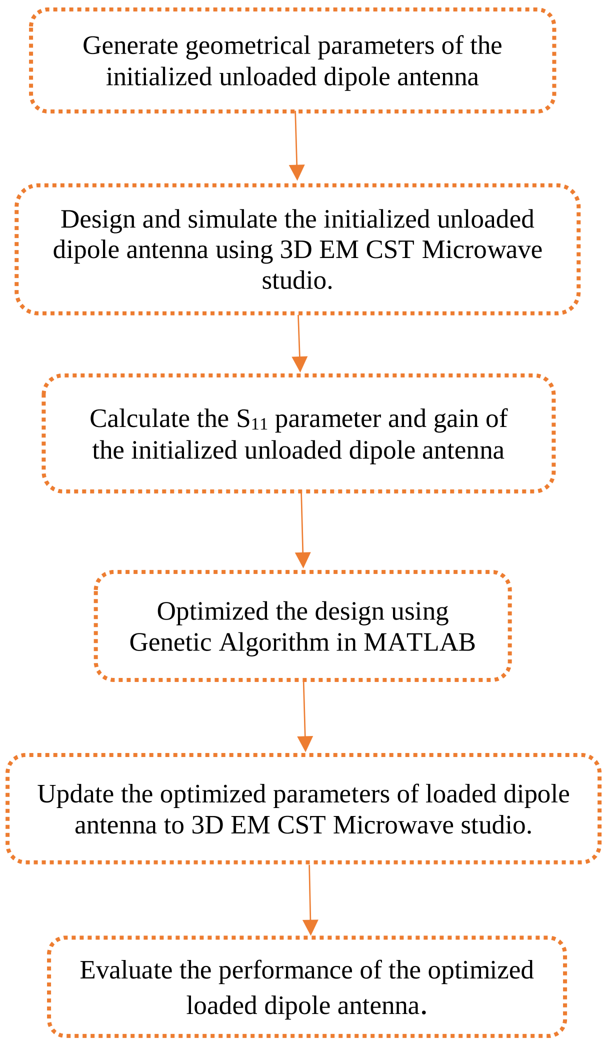


Fig. 1. Steps for designing an initialized unloaded and an optimized loaded dipole antenna.

III. GENETIC ALGORITHM BASED ANTENNA OPTIMIZATION

The Fig. 2 (a) illustrate the geometry and dimension of the unloaded dipole antenna, Fig. 2 (b) illustrates the geometry of the proposed LR loaded dipole antenna and the Fig. 2 (c) represents the geometry of the LR loaded antenna which, has a single inductor as a load 1, one parallel LR circuit for load 2, a matching network that is 1:4 impedance transformer connected to an inductor in parallel with the antenna terminal and two series LR circuits for load 3 and load 4.The dipole length and diameter is h and D. Reactive loads of definite partition of the dipole antenna is effort to adjust the characteristics performance with esteem to a desired frequency band. Designing a loaded dipole antenna system to satisfy certain requirements generally entails the solution of a nonlinear optimization problem. The optimizer has to determine the large set of optimal parameter such as position, parameter values of the LR circuits and the element of the equivalent network.

In our design, an antenna loaded with four LR circuits and matching network involves a simultaneous optimization of parameters. The number of loads, their location and the load parameter values are specified using Genetic Algorithm Optimization. Genetic algorithm is used to solve the number of electromagnetic problem and finding optimum antenna design that maximize or minimize the certain radiation property. It is prevalent for its perception, experimentation, easiness and the competency to crack nonlinear and optimum problem.

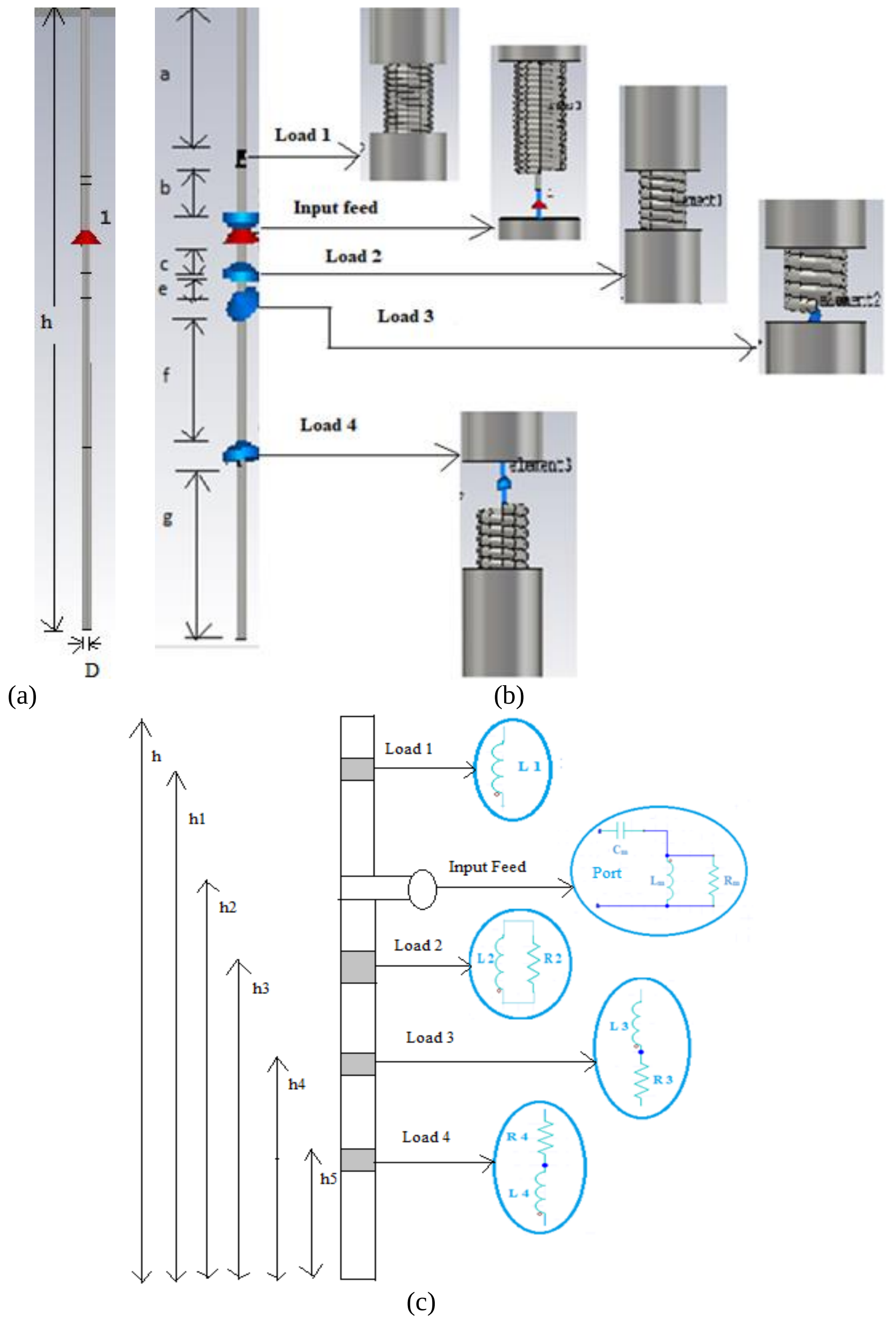


Fig. 2. Geometry of the: (a) top view of unloaded dipole antenna, (b) proposed LR loaded dipole antenna, and (c) LR loaded antenna, matching network and 1:4 impedance transformer.

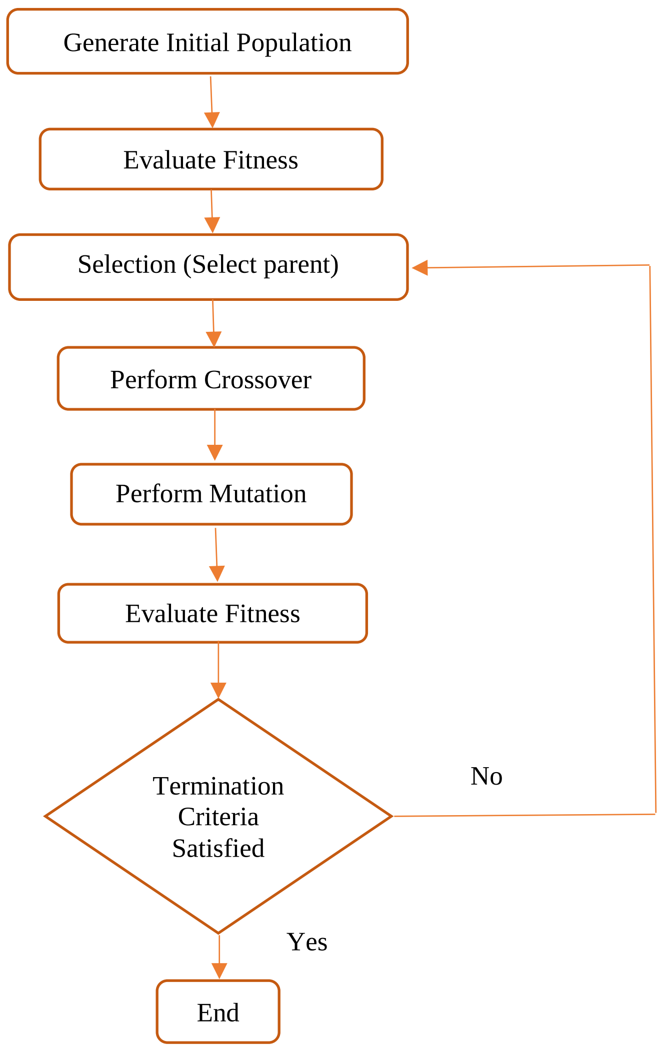


Fig. 3. A data flow for optimizing the dipole antenna using genetic algorithm optimization.

The Fig. 3 illustrate the data flow for optimizing the dipole antenna using Genetic Algorithm. The Genetic Algorithm is a search procedure and provide optimal solution by successively creating population that improve over many generation. Genes are the binary encoding of each problem variable and all the genes are referred as chromosomes. A set of chromosomes are named as population. Chromosomes are the main concern of genetic algorithm. Every chromosomes have two fragments. Segment chromosomes tagging the load position and a value chromosomes tagging the load value in genetic algorithm execution, every one of the alignment entailing N connected fragments are encrypted into 0 and 1 chromosomes. If the LR circuits positioned in any of the N fragments the identical fragments will fixed as 1 else 0. Mutation is permitted to transpire at a small possibility.

Synchronously each component value X, being either capacitance or inductance or resistance [19], is given:

$$X = X_{min} + \frac{X_{max} - X_{min}}{2^{N^X-1}} \sum_{n=o}^{N^X} b_N^X \;\; 2^n \, . \qquad (1)$$

Where, N^X is a bit string:

$b_0^X \ldots b_{N^X}^X - 1$ is the binary representation of X.

X_{max} and X_{min} are the maximum and minimum value for X.

The objective function [3], is given by:

$$\mathrm{ObjV} = \frac{1}{N_f} \sum_{n=1}^{N_f} \left[C_g w_g^{(n)} F_g^{(n)} + C_b w_b^{(n)} F_b^{(n)} \right] . \qquad (2)$$

Where, N_f is the total number of frequency samples in the selected ranges and $F_g^{(n)}$ and $F_b^{(n)}$ are the function which controlling antenna bandwidth and gain [3] is given by:

$$F_b^{(n)} = \begin{cases} 0, & \text{if } VSWR^{(n)} < B_0 \\ \frac{VSWR^{(n)} - B_0}{VSWR^{(n)}}, & \text{Otherwise} \end{cases} , \qquad (3)$$

$$F_g^{(n)} = \begin{cases} 0, & \text{if } G^{(n)} > G_0 \\ \frac{G_0 - G^{(n)}}{G_0}, & \text{otherwise} \end{cases} . \quad (4)$$

In these functions, B_0 and G_0 are frequency independent constants, VSWR has to be constrained under B_0 and gain has to be confined above G_0. $w_g^{(n)}$, $w_b^{(n)}$ are selective weights. $F_b^{(n)}$ and $F_g^{(n)}$ are indifferent part of band. Coefficient C_g and C_b are frequency independent weights.

Table 1: Parameter ranges for GA optimization of antenna

	Min	Max	# Bits	Resolution
L	0.23 µH	1.5 µH	8	0.0025 µH
R	0 Ω	1 KΩ	8	390 Ω
L_m	0.23 µH	1 µH	8	0.35 µH
R_m	0 Ω	1 KΩ	8	680 Ω
C_m	0.01 pF	50 pF	8	20 Pf

Table 2: GA settings and resulting number of objective function evaluation

Genetic Algorithm Parameters	Genetic Algorithm
Number of Individual	100
Crossover Probability	0.8
Mutation Rate	0.1
Generation Gap	0.9
Number of Generation	480

IV. RESULTS AND DISSCUSSION

Based on the Genetic algorithm optimization, the load parameter value, location and matching network element value has to be determined. Listed in Table 1 are the range and resolution of each of the ten parameters in the loaded antenna. Table 2 shows the how to set the Genetic Algorithm parameters, which include number of individual, crossover probability, mutation rate, generation gap and the number of generation. The 3D EM CST Microwave Studio tool is used for all simulation works to calculate the antenna performance.

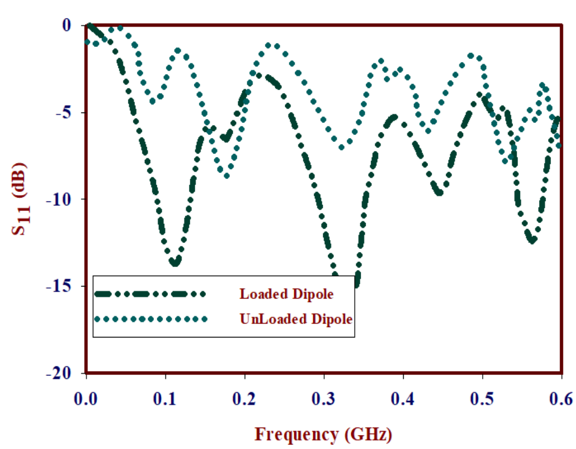


Fig. 4. Computed results comparison of S_{11} for LR loaded and unloaded dipole antenna.

The S_{11} parameter diagram of an unloaded dipole antenna is compared with LR loaded dipole antenna is shown in Fig. 4. The unloaded dipole antenna is same to the LR loaded dipole antenna with identical length and diameter. As it is shown, the prior explain the result of S_{11} parameter for loaded dipole antenna is -15.73 dB at 328 MHz [17].

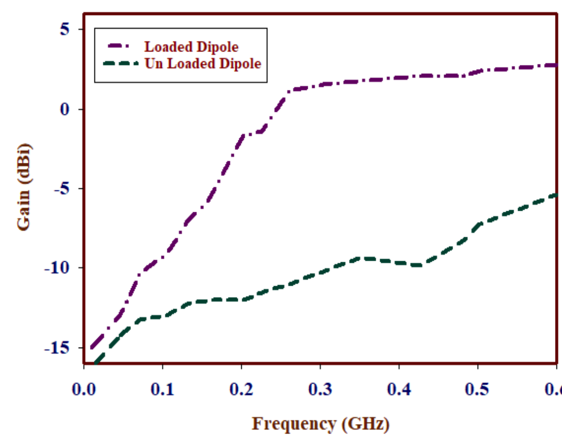


Fig. 5. Computed results comparison of gain for loaded and unloaded dipole antenna.

The Fig. 5 which illustrate the computed gain of loaded and unloaded dipole antenna. The gain of unloaded dipole antenna is decreases at higher frequencies. This problem can be solved by Genetic Algorithm optimization of the antenna profile and these drops at higher frequencies are considerably increased in the loaded dipole antenna. The maximum value for antenna gain can be achieved at higher frequencies and in this case at 600 MHz. For this loaded dipole antenna gain is gradually increasing from -15 dBi at 10 MHz to 2.80 dBi at 600 MHz.

V. ANTENNA FABRICATION AND MEASUREMENT RESULTS

Table 3 shows the antenna parameter values for the Genetic Algorithm optimization. The resulted load parameter are presented in Fig. 2 (b). A loaded dipole antenna is fabricated from the thin wall copper tubing with 10 mm diameter are shown in Fig. 6. In the antenna, the helical coil can be modeled as a series of parallel wire loops and the coil used in this article were constructed by winding 14 American Wire Gauge (AWG) wire with 2 mm diameter. The ½ W resistors were used in the LR circuits. The loads for the numerical design of Table 1 were constructed based on the optimization algorithm.

Table 3: Parameter values for the Genetic Algorithm optimization of dipole antenna and matching network of Fig. 2. (h = 169 cm, D = 10 mm, a = 40 cm, b = 13 cm, c = 6 cm, e = 3 cm, f = 35 cm, g = 40 cm, h1 =129.1cm, h2=110.9 cm, h3=96.9 cm, h4 = 88.8 cm, h5 = 47.8 cm)

Load Parameters	**Load 1**	**Input**	**Load 2**	**Load 3**	**Load 4**
Load position (cm)	6.10	8	5.10	6	7.8
No. of turns	5	18	4.5	6	6
Winding Gauge (AWG)	14	14	14	14	14
Core material	Air	Air	Air	Air	Air
Wire diameter (mm)	2	2	2	2	2
Coil diameter (mm)	9.8	13	9.8	9.8	20.4
Length of the coil (mm)	19	35	13.2	15	15
Resistor value	-	680 Ω	390 Ω	56 Ω	390 Ω
Capacitor value	-	20 pF	-	-	-

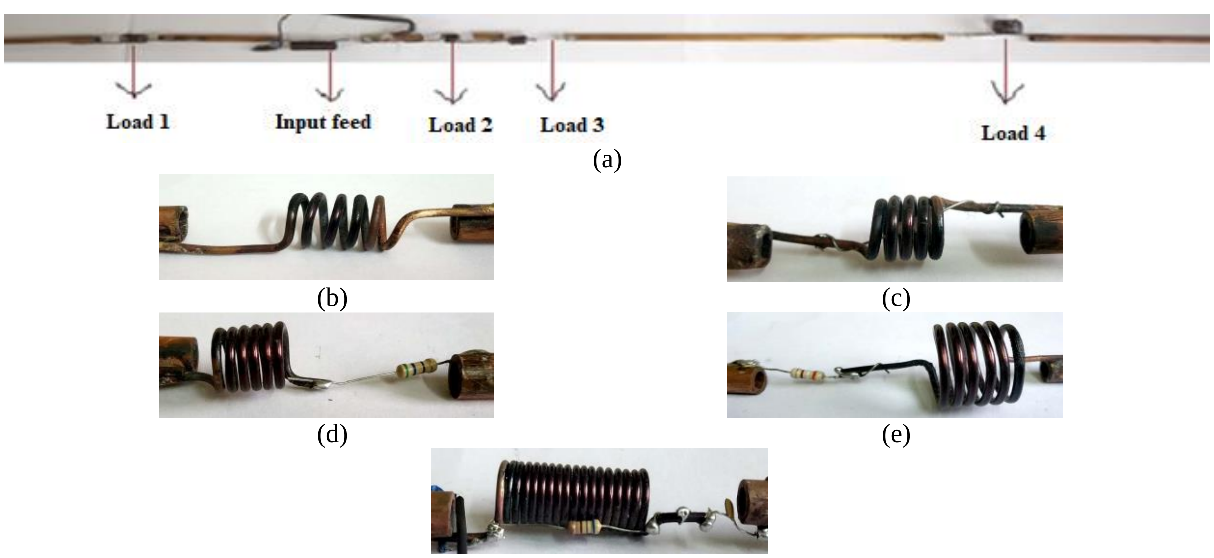


Fig. 6. Fabricated Loaded Dipole Antenna, (a). Antenna with load which listed in the Table 3, (b). Load 1, (c). Load 2, (d). Load 3, (e). Load 4 and (f). Input feed.

A prototype of loaded dipole antenna is shown in Fig. 6 (a). In Load 1 the inductor was realized in air core coil made up of 6 turns of 14 AWG wire with 2 mm diameter which is shown in Fig. 6 (b). In Load 2, the inductor and resistor are in parallel .The inductor that was realized in air core coil made up of 4 turns of 14 AWG wire with 2 mm diameter, which is shown in Fig. 6 (c). In Load 3 and Load 4 the inductor and resistor are in series, in which inductor was apprehended in air core and coil is made up of 6 turns of 14 AWG wire with 2 mm diameter, which is shown in Fig. 6 (d) and 6 (e).The input feed region is shown in Fig. 6 (f), which consists of balun and 1:4 impedance transformer. The S_{11} parameter and gain of the loaded dipole antenna were measured.

The measured and computed results of S_{11} parameter and gain for the proposed antenna is shown in Fig. 7 and Fig. 8. The good agreement was achieved between measured and computed results. As a result the measured antenna operate in 10 MHz – 600 MHz. Moreover the antenna gain has a maximum gain of 2.80 dBi at 600 MHz while minimum gain -15 dBi at 10 MHz [17].

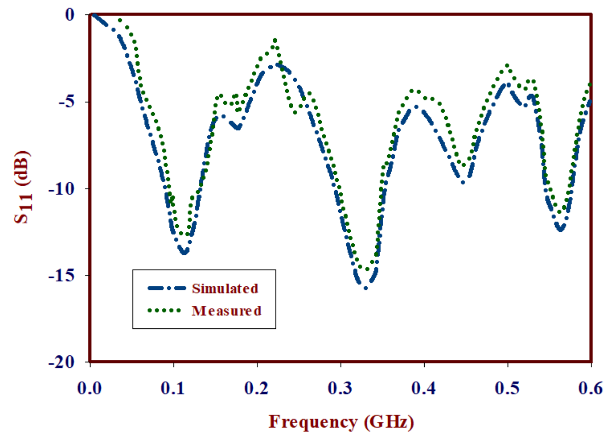


Fig. 7. Comparison of S_{11} parameter for the proposed dipole antenna.

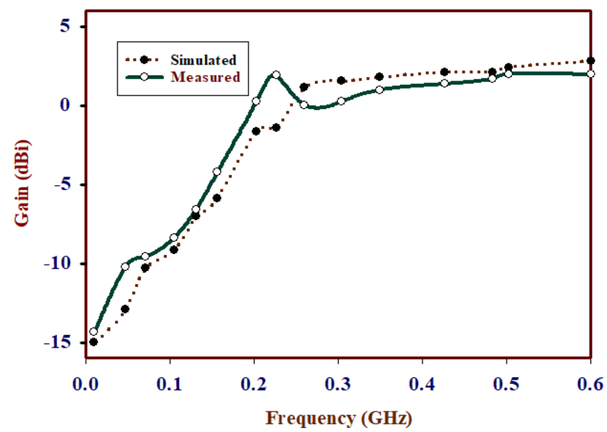
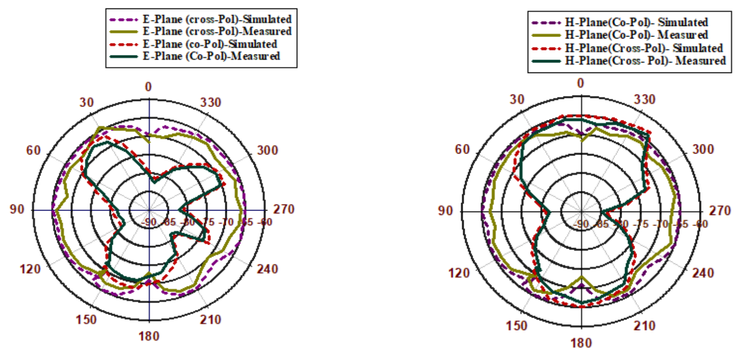
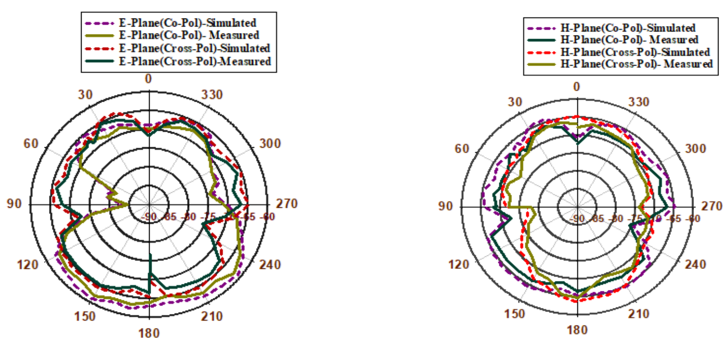


Fig. 8. Comparison of gain for the proposed dipole antenna.



(a) (b)

Fig. 9. Measured and computed radiation pattern for proposed dipole antenna at frequency of 305 MHz: (a) XZ plane and (b) YZ Plane.



(a) (b)

Fig. 10. Measured and computed radiation pattern for proposed dipole antenna at frequency of 600 MHz: (a) XZ plane and (b) YZ Plane.

The measured and computed radiation pattern in the E-plane and H-plane of dipole antenna in two selected frequencies (305 MHz and 600 MHz) are shown in Figs. 9 and 10.The results demonstrate both in co-polarization (Co-pol) and cross- polarization (Cross-pol). Thus it can be seen that the loaded dipole antenna radiation patterns are almost omni-direction in H-Plane and the maximum gain is also at the horizontal radiation direction

VI. CONCLUSION

In this article, a Genetic Algorithm is used to optimize a HF/VHF/UHF antenna for improving gain of straight wire dipole antenna loaded with single inductor, one parallel LR circuit and two series LR circuits and it is driven through an equivalent network. Guided by optimization and realization techniques discussed, the authors constructed dipole antenna system with gain from -15 dBi at 10 MHz to 2.80 dBi at 600 MHz. A reactive loaded dipole antenna is fabricated and measured, which shows good agreement with simulated results. The designed antenna can be used in Portable Applications.

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REFERENCES

[1] L. Mattioni and G. Marrocco, "Design of a broadband HF antenna for multimode naval communication-Part II: Extension on VHF/UHF ranges," *IEEE Antennas Wireless Propagation Letters*, vol. 6, pp. 83-85, 2007.

[2] P. L. Werner, Z. Bayraktar, B. Rybicki, D. H. Werner, K. J. Schlager, and D. Linden, "Stub-loaded long-wire monopoles optimized for high gain performance," *IEEE Transactions on Antennas and Propagation*, vol. 56, no. 3, pp. 639-645, 2008.

[3] X. Ding, B. Z. Wang, G. Zheng, and X. M. Li, "Design and realization of a GA-optimized VHF/UHF antenna with 'on-body' matching network," *IEEE Antennas Wireless Propagation Letters*, vol. 9, pp. 303-306, 2010.

[4] S. D. Rogers, C. M. Butler, and A. Q.Martin, "Design and realization of GA-optimized wire monopole and matching network with 20:1 bandwidth," *IEEE Transaction on Antennas and Propagation*, vol. 51, no. 3, pp. 493-502, 2003.

[5] M. KarimiMehr and A. Agharasouli, "A miniaturized non-resonant loaded monopole antenna for HF-VHF band," *International Journal of Scientific & Engineering Research*, vol. 8, no. 4, pp. 1092-1096, 2017.

[6] W. Kang, K. Kim, and I. Kim, "Implementation and analysis of discretely loaded resistive dipoles using planar resistor technology," *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 11, pp. 5088-5093, 2015.

[7] K. Kim and W. R. Scott Jr., "Design and realization of a discretely loaded resistive Vee dipole for ground-penetrating radars," *Radio Science*, vol. 39, pp. 1-9, 2004.

[8] E. Noh, J. Kang, B. Kim, S. Choi, and K. Kim, "Durable 12-arm resistive cross-dipole for use in ground-penetrating radar," *IET Journals & Magazines*, vol. 53, pp. 1235-1236, 2017.

[9] H. Yang, I. Kim, and K. Kim, "Non-foster matching of a resistively loaded Vee dipole antenna using operational amplifiers," *IEEE Transactions on Antennas and Propagation*, vol. 64, no. 4, pp. 1477-1482, 2016.

[10] E. A. Elghannai, B. D. Raines, and R. G. Rojas, "Multiport reactive loading matching technique for wide band antenna applications using the theory of characteristic modes," *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 1, pp. 261-268, 2015.

[11] H. Iizuka and P. S. Hall, "Left-handed dipole antennas and their implementations," *IEEE Transaction on Antennas and Propagation*, vol. 55, no. 5, pp. 1246-1253, 2007.

[12] W.-P. Cao, L. Shafai, B.-Z. Wang, S.-M. Li, and B.-B. Li, "A small and bandwidth-extended dipole antenna with nonperiodic left-handed transmission line loading," *IEEE Antennas and Wireless Propagation Letters*, vol. 13, pp. 1019-1022, 2014.

[13] L. Borja, "Dipole antenna with left-handed loading operating at a zero order mode," *Progress in Electromagnetics Research C*, vol. 19, pp. 85-92, 2011.

[14] S. X. Ta, "Polarizations of crossed-dipole antenna loaded with different NFRP elements," *Progress in Electromagnetics Research M*, vol. 75, pp. 131-140, 2018.

[15] L. Chang, L. L. Chen, J. Q. Zhang, and D. Li, "A broadband dipole antenna with parasitic patch loading," *IEEE Antenna and Wireless Propagation Letters*, vol. 17, pp. 1717-1721, 2018.

[16] G. Feng, L. Chen, X. Wang, X. Xue, and X. Shi, "Broadband circularly polarized crossed bowtie dipole antenna loaded with parasitic elements," *IEEE Antenna and Wireless Propagation Letters*, vol. 17, pp. 114-117, 2018.

[17] N. Amani, A. Jafargholi, and R. Pazoki, "A broadband VHF/UHF loaded dipole antenna in the human body," *IEEE Transaction on Antennas and Propagation*, vol. 65, no. 10, pp. 5577-5582, 2017.

[18] S. Ramesh and T. Rama Rao, "Dielectric loaded exponentially tapered slot antenna for wireless communication at 60 GHz," *Progress in Electromagnetics Research*, vol. 38, pp. 43-54, 2013.

[19] H. Zhang, S. Yang, S. Xiao, M. Huang, L. Zhou, Y. Chen, and S. Qu, "A compact wideband dual-polarized linear array with hybrid structure and resistive loadings," *International Journal of RF and Microwave Computer-Aided Engineering*, pp. 1-10, 2019.

[20] S. Ramesh and T. Rama Rao, "Indoor radio link characteristics wireless communication utilizing dielectric loaded exponentially tapered slot antenna," *Taylor & Francis-Journal of Electromagnetic Waves and Applications*, vol. 29, no. 4,

pp. 551-564, Apr. 2015.

[21] A. Boag, A. Boag, E. Michielssen, and R. Mittra, "Design of electrically loaded wire antenna using genetic algorithm," *IEEE Transactions on Antennas and Propagation*, *vol.* 44, no. 5, pp. 687-696, 1996

[22] M. Bod, M. Ahmadi-Boroujeni, and K. Mohammadpour-Aghdam, "Design of a low-cost broadband loaded dipole antenna for VHF/UHF frequency range," *IET Microwaves, Antennas & Propagation*, vol. 13, pp. 1983-1988, 2019.

[23] W. Kang and K. Kim, "Design and implementation of complementary dipoles with continuous resistive loading," *Journal of Electromagnetic Waves and Applications*, pp. 1583-1595, 2017.

[24] Y. Xia, Y. Li, and W. Xue, "A low profile miniaturization low frequency wideband antenna using passive lumped elements loading," *ACES Journal*, vol. 35, no. 1, pp. 31-37, Jan. 2020.

[25] A. Jafargholi and M. Kamyab, "Fullwave analysis of loaded dipole antenna using mode matching theory," *ACES Journal*, vol. 26, no. 11, pp. 915-921, Nov. 2011.

K. Kayalvizhi received the B.E. degree in Electronics and Communication Engineering from Shri Angalamman College of Engineering and Technology, Trichy, in 2009, and M.E. degree in Communication Systems from Saranathan College of Engineering, Trichy, in 2011. She is currently pursuing the Ph.D. degree at Anna University, Chennai. Her current research interests include Antennas and Wireless Communication.

S. Ramesh received his B.E. in Electronics and Communication Engineering from University of Madras, M.Tech. in Communication Engineering from VIT University, Vellore and received his Ph.D. degree on from SRM University, Chennai, in 2001, 2004 & 2015 respectively. He is currently, working as an Associate Professor in the Department of Electronics and Communication Engineering, SRM Valliammai Engineering College, Chennai with experience of 16 years. He is a senior member (S'10-M'17-SM'18) of IEEE Antennas & Propagation Society, Life member in IETE, ISTE, SEMCE, BES. He authored papers in reputed journals and international/national conferences. His area of interest includes Antennas & Propagation and Wireless Communications. He is guiding research scholars in the field of antennas & RF Filter under Anna University, Chennai. He is associated with IEEE AP-S Madras chapter as a member in executive committee during 2018-2019 and IEEE MTT-S Madras Chapter for the year 2017.