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RESEARCH ARTICLE

Microstrip leaky wave antenna for wide range of beam scanning in X band

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Abstract

In this work, design of a pattern reconfigurable antenna is presented for X-band applications as a leaky wave antenna (LWA) realization. Due to the advantages of simple design schematic, low profile, and easy impedance matching, LWA designs have been using as an efficient solution for reconfigurable antenna in many wireless communication applications. Optimization and simulation of the proposed LWA is carried out in 3-D Microwave simulation CST environment and Honey Bee Mating is used as the optimization algorithm. Dimensions of the proposed LWA is 130 × 30 mm, which is fabricated on Rogers 5880 as capacitive loaded eight identical rectangular microstrip patches operating over 9.5-12 GHz with a fractional bandwidth. The proposed LWA exhibits a measured peak gain of 11.8 dBi at 10 GHz with an overall gain characteristic of between 9.5 and 11.8 dBi over the range of 9.5 to 12 GHz with a steerable pattern characteristics between −45 and 50° as agreed with the theory. Furthermore, the fabricated LWA has been found to have the superior performance as compared with its counterparts.

KEYWORDS

beam scanning, leaky wave antenna, microstrip antenna, reconfigurable antenna

1 | INTRODUCTION

The need for reconfigurable antennas has been increasing with the ever increasing demands in wireless communication technologies. Reconfigurable antennas are designs that can change their performance characteristics such as operation band, radiation pattern characteristics using the design variables. One of the main advantages of pattern reconfiguration antennas is their ability to increase the efficiency of power consumption at transceiver stage without a hindrance at the transmission and coverage capacity.[1–3] Design of an antenna with the mentioned capabilities is a challenging problem which has been studied by many researchers for the last decades. Typical proposed solutions for this challenging problem are design with the mechanical parts,[4] the modified feeding phase designs,[5] the usage of switches for modification of surface currents[6–16] and the substrate integrated waveguide (SIW) design.[17]

LWA design is one of the attractive solutions which was proposed by W. Menzel in 1979 as microstrip design.[18] A LWA can be regarded as a type of traveling-wave structure based on a transmission line loaded with the radiating elements that gradually leak the energy out into free space. Being low profile, having easy procedure for impedance matching are some of the important advantages of a LWA design. It should be noted that periodic loading of the same components on each unit cell of the LWA leads to a high directivity and a frequency-dependent beam scanning ability. These unique characteristics make the LWA attractive in many applications such as frequency modulated continuous wave radar,[19] real-time spectrum analysis,[20] and field pattern synthesis.[21] Furthermore LWA designs have been used for gain enhancement in designs with simple radiating sources and pattern reconfiguration applications an efficient solution applications.[22–29]

Herein, design and realization of a frequency dependent beam scanning LWA are presented for X band applications.

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The proposed LWA operates over 9–12 GHz, and it exhibits a measured peak gain of 11.8 dBi at 10 GHz. The overall gain characteristic of the antenna is between 9.5 and 11.8 dBi over the range of 9.5 to 12 GHz with a steerable pattern characteristics between −45 and 50°. In the next section design and simulated results of the antenna will be presented. In section 3, the experimental results of the antenna alongside of its comparison with counterpart designs are given. Finally work ends with a brief conclusion section.

2 | DESIGN AND SIMULATION

The direction in which the energy is radiated from a leaky wave antenna θ is determined by the phase constant, β, of the leaky wave along the transmission line, which is function the operating frequency. A general schematic of LWA is presented Figure 1(A).[30]

It should be noted that the radiation beam direction of a LWA is mainly related to the geometrical design parameters of antenna. Besides, the following design features of LWAs should also be taken into consideration: (i) Increasing number of elements increases the overall gain and makes impedance matching much easier; (ii) The operation band is effected mainly by substrate height, permittivity and patch widths; (iii) Increase in the length of the antenna results in wider range of beam scanning. Optimization and simulation of the LWA have been carried out in 3-D Microwave simulation CST environment and its dimensions are resulted as 130 × 30 mm. In Figure 1(B) the schematic of proposed LWA design is presented. Design objectives are over the 9–12 GHz band (a) S_{11} is less than −13 dB; (b) Maximum gain is higher than 9 dBi. A meta-heuristic algorithm honey bee mating (HBMO) has been used as the optimization algorithm. HBMO is a population based algorithm inspired from the mating behavior of honey bees, so that the new born candidates of the colony are evaluated based on their fitness to become the new queen of the colony. In case of a member with better fitness than the current queen, this new member will be crowned as the queen. This process can be considered as a global search where there is no initial knowledge on the possible best solution for the handled optimization problem.[32] Furthermore, in order to increase accuracy, "Royal Jelly Feed" process[33] can be applied that minimizes the cost obtained from the global search. In this process, nurse bees feed the new queen with a special nutrition named as "Royal Jelly" which significantly increase the fitness and development rate of Queen, thus this process can be considered as a local search where the algorithm has an initial knowledge on the possible location of best solution and narrows the search space.[33] The hyper parameter settings of the HBMO algorithm are taken as $N_{Drone} = 20$,

TABLE 1 Parameter list of LWA design in mm

W1	30	L1	130
W2	9.33	L2	16.60
W3	4.26	L3	1.50
W4	5.94	L4	2.57
Roger 5880, h:0.79		Capacitive load	1 pF

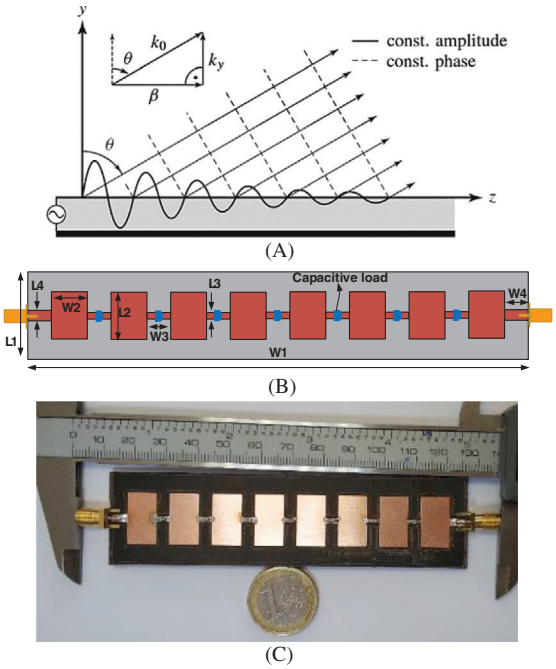


FIGURE 1 (A) Schematic of a general LWA,[31] (B) Proposed LWA design, (C) Fabricated LWA [Color figure can be viewed at wileyonlinelibrary.com]

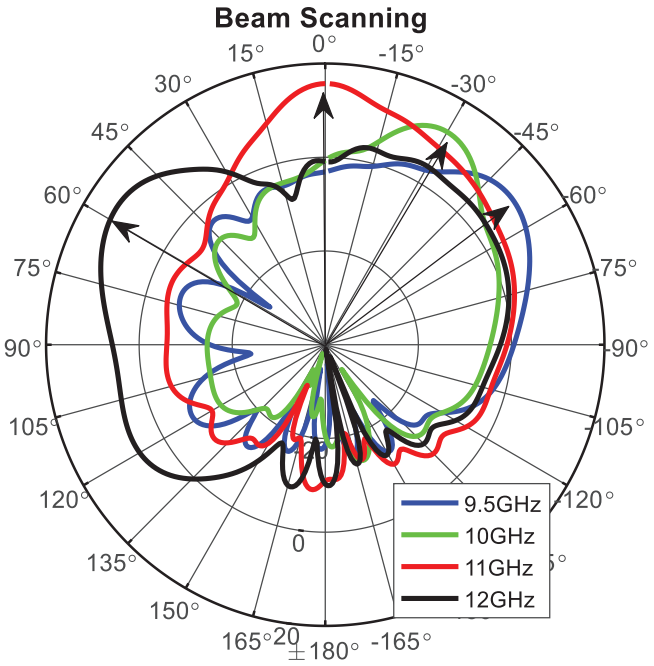
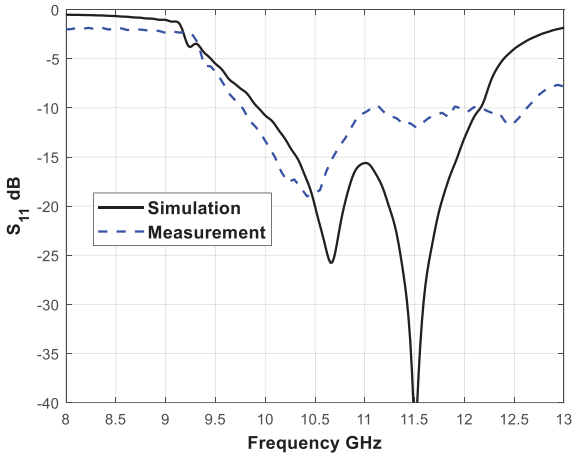
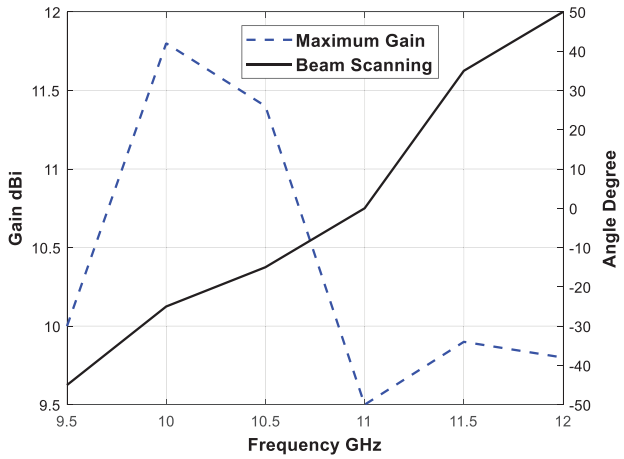


FIGURE 2 Simulated radiation pattern of LWA [Color figure can be viewed at wileyonlinelibrary.com]



(A)



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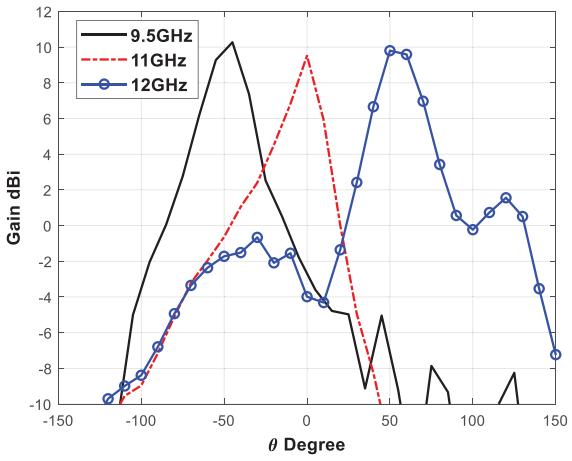

(C)

FIGURE 3 (A) Simulated and measured S_{11}, (B) Maximum gain and beam scanning characteristics, (C) Radiation pattern of the proposed antenna [Color figure can be viewed at wileyonlinelibrary.com]

$t_{max} = N_{Gen} = 10$, $N_{Gen} = 50$, $m_Q = 1000$, $m_D = 100$, $N_{Rj} = 30$, $E_{max} = 1$, $E_{min} = 0.2$, Royal jelly step size of ± 0.1, $cost_{req} = 0.1$. The cost function used for the HBMO optimization is presented in Equation (1):

TABLE 2 Measured performance of LWA

fr (GHz)	S_{11} (dB)	Main lobe angle	Gain (dBi)
9.5	−10	-45^0	10.2
10	−20	-20^0	11.8
11	−12	0^0	9.5
12	−18	50^0	9.8

$$\text{Cost} = \sum_{f_{\min}}^{f_{\max}} \frac{w_1}{|\text{Directivity}_i(f)|} + \frac{w_2}{|S_{11_i}(f)|} \quad (1)$$

weighing coefficients of the cost function are taken as $w_1 = 0.65$ while $w_2 = 0.35$ due to the possible great difference between S_{11} and directivity, since S_{11} may be as low as −30 dB while directivity of this design may be as high as 15 dBi. Ranges of the geometrical design variables of the LWA are taken as: *W2*↔[6-12]mm, *W3*↔[4-8]mm, *W4*↔[5 − 10]mm, *L2*↔[10-30]mm, *L3*↔[1-4]mm, *L4*↔[1-4]mm.

The used hardware setup for optimization process is Intel® Core™ i7-67000K CPU @ 4.0 GHz with 16 GB installed memory, alongside of GTX 1080TI on a 64-bit operating system. The total optimization process is taken around 10 h and 35 min. The optimal design values are given in Table 1. The capacitive load of the design is taken as 1 pF which has been chosen as a reasonable value after investigating effects of capacities between 0.1 and 10 pF on the mismatching and gain.

The proposed antenna achieves a simulated gain value of 12.5, 10.5, and 11 dBi at 10, 11, 12 GHz operation frequencies respectively. Thus the simulated maximum gain characteristic of the antenna is sufficient for having a prototype of the model.

Furthermore, the simulated beam scanning characteristic of the LWA design is given in Figure 2. As it can be seen form the figures in the frequency range of 9.5 to 12 GHz the design has a steerable radiation characteristics with range of almost 110° as from −50 to 60°. In the next section the experimental results of the prototyped LWA design is presented.

3 | EXPERIMENTAL RESULTS

Optimally designed antenna model has been prototyped (Figure 1(C)) using LPKF ProtoMat S series.[34] For the measurement, a Network Analyzer with a measurement bandwidth of 9 KHz−13.5 GHz and the reference antenna in[35] are used. In Figure 3(A) simulated and measured scattering parameters of the proposed LWA design are given. As it can be seen from the figures, the optimized simulated results are hand to hand with the measured characteristic of the prototyped design. In Figure 3(B), the measured maximum gain over the operation band has been presented. Although there is a slightly performance loss in radiation pattern at 11 GHz, the design still achieves the desired measured performance of

TABLE 3 Comparison of proposed work with counterpart design in literature

Work	f (GHz)	Scan angle range	Peak gain (dBi)	Length
LWA	9.5–12	-45^0 to 50^0	11.8	$4.3\lambda_0$
[30]	8–14	-65^0 to 15^0	12	$4.3\lambda_0$
[36]	9–14	-40^0 to 35^0	12	$5.46\lambda_0$
[37]	12.5–15.4	0^0 to 28^0	13.17	$13.8\lambda_0$
[38]	11.3–15.8	-60^0 to 38^0	15	$5.4\lambda_0$
[39]	9–10	0^0 to 27^0	12	$5.7\lambda_0$
[40]	12.5–15.4	0^0 to 28^0	13.17	—
[41]	11–17.5	-85^0 to 85^0	10.7	$12\ \lambda_0$
[42]	17.5–19	0^0 to 60^0	—	$4\ \lambda_0$
[43]	5.6–6	79^0 to 103^0	8.89	$4.2\ \lambda_0$

9.5 dBi. Furthermore the measured steering capability of design is measured as almost 100° in the range of 9.5 to 12 GHz. In Figure 3(C), the measured radiation pattern of the LWA design in Cartesian form are presented for the selected frequencies. As it can be seen from the Figure 3, the design achieves a good radiation and steering ability with variation of the operation frequency. Some of the measured characteristics of the prototyped design are presented in Table 2.

Furthermore, the performance of the proposed LWA design is compared with counterpart designs in literature in Table 3. The comparison are based on the operation range, beam steering capabilities, peak realized gain and size of the design. As it can be seen form the comparisons the proposed design not only operates in lower frequency band but also has a smaller length alongside of good steering capability.

4 | CONCLUSION

In this work, a design and realization of a microstrip LWA with wide range of beam scanning aimed at X band applications have been presented. The simulated and measured results of the proposed design have been found to be hand to hand. Furthermore the measured performance of the design is compared with the performance of the counterpart designs in literature. From the comparison results the proposed design has a smaller length alongside of good steering capability compared with the counterpart designs. The design achieves a measured peak gain of 11.8 dBi over the operation band of 9.5–12 GHz alongside of a steering capability of 95°.

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DATA AVAILABILITY STATEMENT

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

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