

ACS FED ENHANCED GAIN DIRECTIVE ANTENNA FOR 5.2/5.8 GHZ WLAN AND ISM APPLICATIONS

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Abstract

A compact Asymmetric Coplanar Strip (ACS) fed planar monopole antenna suitable for 5.2/5.8 GHz WLAN and ISM applications is developed and discussed. Developed radiator possesses an enhanced gain and directional radiation pattern without any additional parasitic elements. Overall dimension of the antenna is $20 \times 9.1 \times 1.6$ mm³ when fabricated on an FR4 substrate having relative permittivity of 4.4, which is very compact when compared to other directional monopoles. The gain enhancement and directivity of the antenna is obtained without the help of any additional parasitic/reflective elements. Equivalent circuit modeling and FDTD analysis of the structure were also performed and the results obtained are compared with measured results. Compact Structure, Enhanced directivity and gain, minimum design parameters, stable and reliable radiation pattern and polarization, and high efficiency make this structure a potential candidate for upcoming high data rate 5G communication applications in ISM and WLAN field.

Keywords:

ACS, Monopole, High Gain, Self-Reflector, Equivalent Circuit Modeling

1. INTRODUCTION

Antenna is the most important part as far as a communication gadget is considered, because it opens the connectivity of the device to physical world. Rapid development in the field of communication increases the data rate capacity of the communication with an exponential reduction in size of the device. This makes a challenge to antenna designers, because they have to develop antennas with reduced size without any compromise to radiation characteristics. Directional antennas having high gain and directivity and with compact size finds many applications in these high data rate communication devices. Achieving this is a herculean task because; the gain enhancement is normally achieved through additional parasitic elements or through with artificial materials which makes the size very huge. Array arrangement of antennas also provides high gain but consumes more space. Another technique for gain enhancement is antenna backed with cavity resonators, which losses its planar characteristics. Various gain enhancement techniques are already discussed in literature and are discussed in the following session.

A planar antenna having high gain and conical beam is presented in [1] in which the high gain is obtained with the help of two circular reflectors. A planar multiple segmented antenna having multiple magnetic current paths with enhanced gain is discussed by the authors in [2]. A stepped horn antenna backed by a surface integrated waveguide structure is presented in [3] which possess a high degree of structural complexity. In [4], a corrugated antenna having two planar substrate layers is presented and the antenna structure is huge and complicated. A dual band

antenna for RADAR applications having enhanced gain is discussed in [5] which comprise of two different patches and parasitic elements. Z. Hua et al. In [6] introduces a high gain H plane horn antenna having two reflector to enhance the gain, but in this design, antenna is a 3D structure. A differentially fed CPW based cavity based planar aperture antenna is presented by authors in [7]. A microstrip antenna having defective ground and a T shaped slot is presented by T. O. Olawoye and P. Kumar in [8]. In [9], a planar array antenna for 5G communication is discussed but the size of the array is very high. Multiple Resonator array based on coupling metrics theory is discussed in [10]. In [11] authors are discussing about a two circular disc antenna with gain enhancement attained through mode super position techniques. An SIW with resonator fed antenna is discussed in [12]. Z. Hua and others are presenting a dual reflector based planar high gain antenna [13]. A differentially fed aperture antenna with gain enhancement is given in [14]. A four element antenna array with CMRC filter is discussed in [15] by S. H. Yeung et al. Fabry-Pérot cavity array antenna having four elements is presented [16] which also have higher gain due to array super positioning. Z. N. Chen, Y. Sun and Nasimuddin are discussing about a meta-material backed electromagnetic band-gap layer based high gain antenna [17]. A planar artificial magnetic conductor based narrow band antenna having some gain enhancement is reported in [18]. Anyhow in all the articles discussed here have either additional parasitic elements or huge size or arraying or artificial techniques used for gain enhancement.

In this paper we are discussing a compact planar ACS fed monopole antenna suitable for 5.2/5.8 GHz WLAN and ISM applications, with a high degree of gain enhancement and directivity, without the help of any additional parasitic elements. Overall dimension of the antenna is $20 \times 9.1 \times 1.6$ mm³ when fabricated on an FR4 substrate having relative permittivity of 4.4. Antenna exhibits linear polarization with a high gain of 6.5 dBi and with uniform efficiency of 94%. Parametric studies of the structure are performed to optimize the antenna to achieve maximum gain in the application band of interest. Equivalent circuit modelling and FDTD analysis of the structure were also performed and the results obtained are discussed and compared with measured results

2. GEOMETRY OF THE ANTENNA

Physical structure of the proposed high gain antenna with all its dimensional notations is given in Fig.1. It is a simple monopole antenna with a 50Ω standard asymmetric coplanar strip (ACS) feed, from the signal strip of which, a new branch is derived above the ground plane. The physical parameters of the antenna are given in Table.1. The overall dimension of the developed antenna is $20 \times 9.1 \times 1.6$ mm³ which is very compact compared to all other high gain designs.

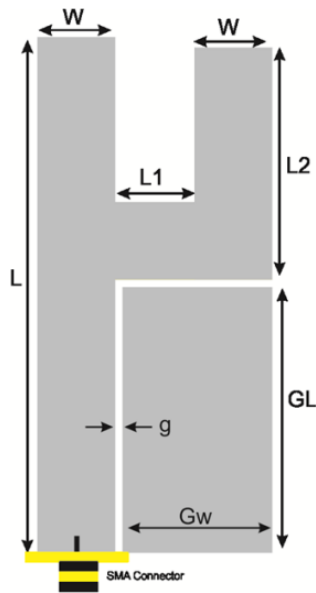


Fig.1. Antenna Structure

Table.1. Antenna Parameters

L	W	L1	L2
20 mm	3 mm	3.1 mm	9 mm
GL	Gw	g	h
5.8 mm	10 mm	0.3 mm	1.6 mm
Substrate Parameters	Name	ϵ	$\tan\delta$
	FR4	4.4	0.02

3. RESULTS AND DISCUSSIONS

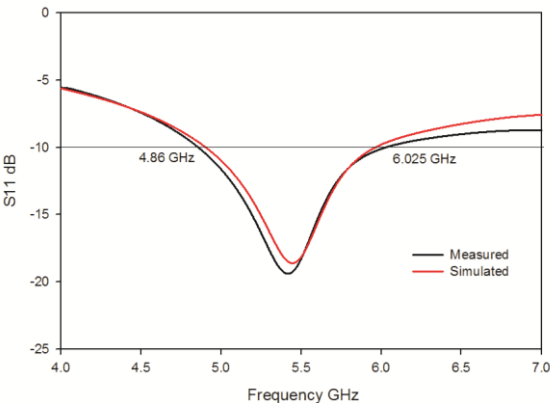


Fig.2. S11 of proposed antenna

Measurement of the antenna is done with the help of VNA HP8510C while the simulation studies are computed using the commercially available Ansoft HFSS software. The S11 curve obtained using experimental and simulation methods are shown in Fig.2. From the figure it may be noted that antenna offers a -10dB bandwidth of 1165 MHz starting from 4.86 GHz and with a resonant frequency of 5.455 GHz. The bandwidth is sufficient to cover both 5.2GHz and 5.8 GHz WLAN and ISM application bands.

Measured radiation pattern of the antenna in both E and H plane are depicted in Fig.3 (a) and (b) respectively. Both the pattern exhibits directional property.

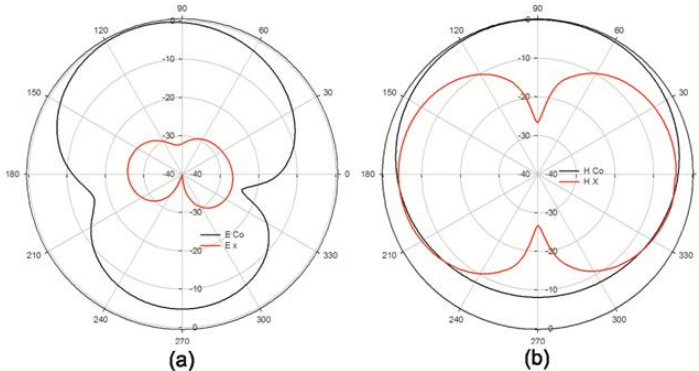


Fig.3. Measured Radiation pattern

In E plane, the front to back ratio in co polarized alignment is nearly 6 dB, while that in H plane is 9 dB which indicates the high directivity of the structure. Cross polar purity in E plane is very high of the order of -30 dB in bore sight direction. In H plane, the cross polar purity is -20 dB.

To get a clear view of spatial distribution of radiated energy in the vicinity of antenna, three-dimensional radiation pattern is obtained from simulation software and is plotted in Fig.4. From the figure, the directive property of the antenna can be easily captured.

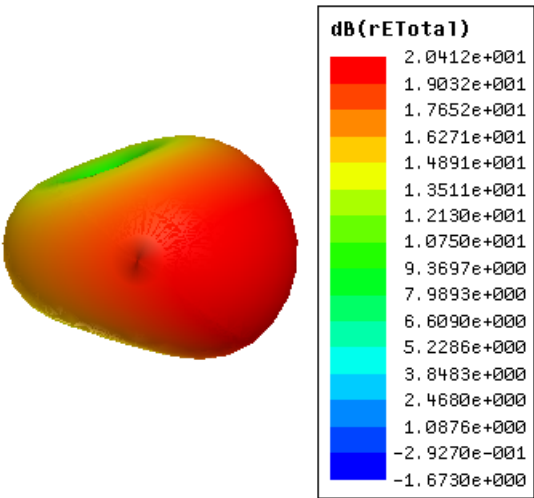


Fig.4. 3D radiation pattern

Radiation mechanism of the structure can be obtained from the surface current analysis of the antenna and the vector surface current density plot obtained from HFSS is given in Fig.5. Resonance is created due to a U shaped and approximately half wavelength long surface current path through the upper portion of the antenna structure. Almost all part of the monopole is take part in radiation and thus the radiation efficiency of the antenna will be very high.

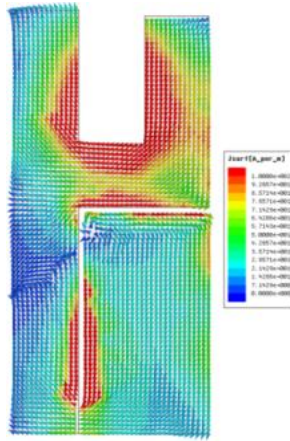


Fig.5. Surface current distribution

Combined plot of measured radiation efficiency and antenna gain compared to that of isotropic radiator is given in Fig.6. An enhanced gain of 6.5 dBi is obtained as peak value and this high gain is obtained without any additional parasitic elements. Efficiency of the antenna is around 94 % and is almost uniform in all the frequency of application.

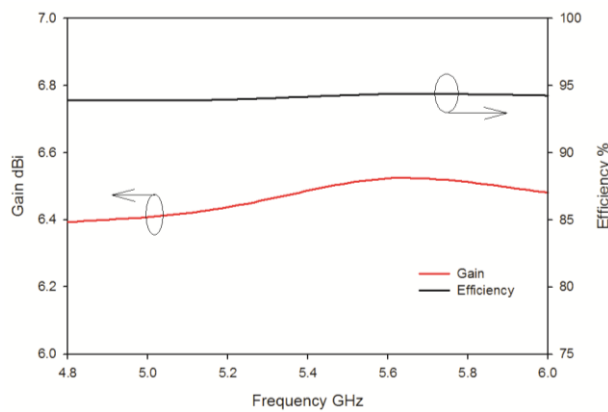


Fig.6. Measured gain and radiation efficiency

4. PARAMETRIC STUDIES

To analyse the characteristics of antenna with various dimensions, a group of parametric studies are performed and are discussed in this session. Variation in resonance and gain with monopole length L is depicted in Fig.7 and Fig.8 respectively.

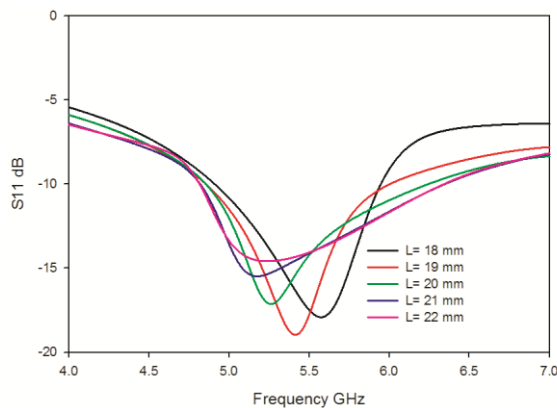


Fig.7. Effect of L on S11

Resonant frequency of the antenna is getting lowered with Land that is due to the increase in current path length. Matching is also slightly affected with this parameter.

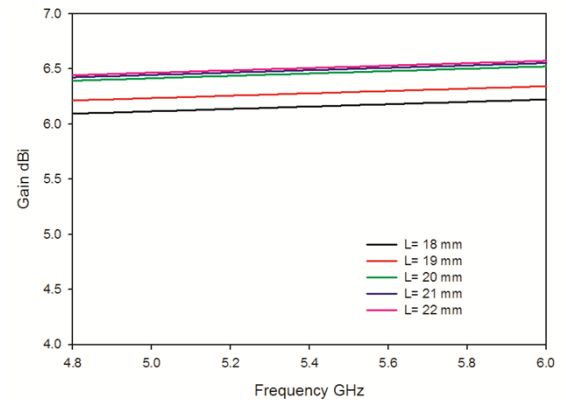


Fig.8. Effect of L on Gain

From Fig.8, it can be inferred that for small values of L , gain is slightly less but beyond some value, the gain is almost constant. Thus if the length of original monopole is less than additional vertical branch, the gain is reduced. This may be due to the self-reflector behaviour of upper part of the monopole. Effect of L_1 on S11 and gain is analysed as second step and is plotted in Fig.9 and Fig.10.

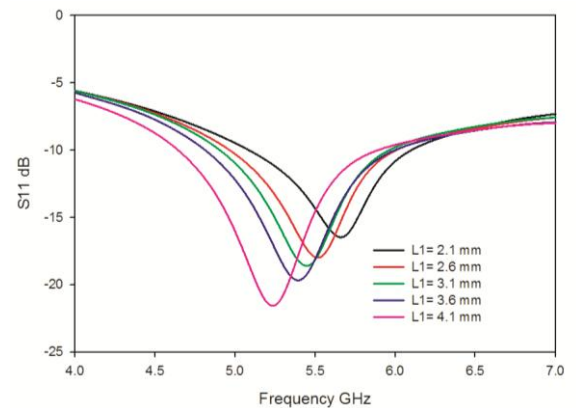


Fig.9. Effect of L1 on S11

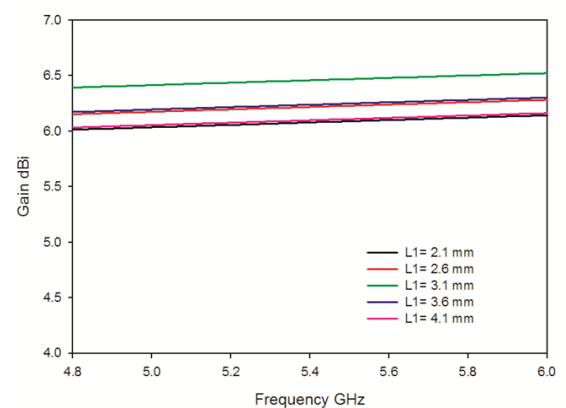


Fig.10. Effect of L1 on Gain

As explained in previous case, here also the resonant frequency shows a down shift with increase in L_1 and the

matching also increases with this parameter (Fig.9). This is also due to the increase in resonant current path length with increase in L1.

Variation in reflection parameter and gain with length of vertical section L2 is depicted in Fig.11 and 12. From the figure it can be noted that the resonant frequency get lowered with increase in L2 and the variation is predominant in here than previous two cases.

Variation in Gain plot (Fig.10) shows an interesting behaviour which confirms the reflector type character of monopole part of this structure. As L1 increases, gain increases, then attains a maximum value and then reduces. Maximum gain is obtained at L1=3.1 mm which is also used in optimized design when antenna is fabricated.

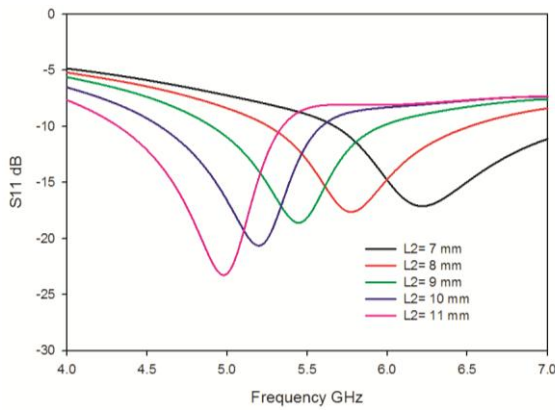


Fig.11. Effect of L2 on S11

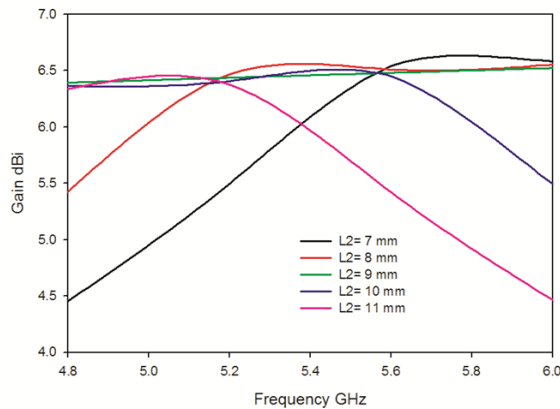


Fig.12. Effect of L2 on Gain

From Fig.12 it is clear that antenna gain varies drastically with L2 and is due to bandwidth shifting with this dimension. For our frequencies of interest maximum gain is obtained at L2 is 9 mm.

From the parametric studies performed, design equations of the antenna structure is developed and validated. Obtained equations are as follows

$$L - G_L + L_1 + L_2 \approx 0.659\lambda_g \quad (1)$$

$$G_w = L_1 + g \approx 0.107\lambda_g \quad (2)$$

In which the parameter λ_g is the wavelength in the substrate and is known as guided wavelength and is obtained as:

$$\lambda_g = \frac{\lambda}{\sqrt{\epsilon_{\text{eff}}}} \quad (3)$$

And here

$$\epsilon_{\text{eff}} = \frac{\epsilon_r + 1}{2} \quad (4)$$

To validate these equations, four different antennas in different substrates are designed and simulated. Parameters obtained using equations and the obtained results are given in Table.2. From the last two rows, we can find that both the designed and obtained frequencies are close to each other.

Table.2. Design Equation parameters and validation

Substrate Name	FR4	Arlon	Cyanate	Marble
ϵ	4.4	2.5	3.8	8.3
L (mm)	20	24.84	21.21	15.24
L1 (mm)	3.1	3.85	3.29	2.36
L2 (mm)	9	11.18	9.54	6.85
W (mm)	3	3.72	3.18	2.28
G1 (mm)	10	12.42	10.61	7.62
Gw (mm)	5.8	7.20	6.15	4.42
Designed frequency GHz	5.455	5.455	5.455	5.455
Resonates at GHz	5.455	5.471	4.398	5.483

5. EQUIVALENT CIRCUIT MODELLING

A mathematical circuit model of the antenna is developed using the technique explained in [19]. The lumped element electrical equivalent of the antenna is given in Fig.13 and the obtained parameters are listed in Table. 3.

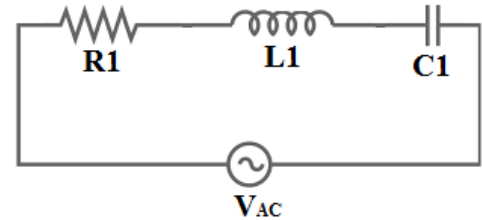


Fig.13. RLC Model of Antenna

Table.3. Equivalent circuit parameters

R (Ω)	L (nH)	C (pF)	Resonates at	BW
48	0.06561	0.001947	4.46 GHz	1.158 GHz

From the table it may be noted that the resonant frequency and bandwidth are in close proximity with measured result and thus fixes the validity of obtained circuit model.

6. FDTD MODELLING

To get further technical knowhow about the mechanism of radiation in this structure, FDTD model of the antenna is developed and results obtained are studied. The parameters used for the analysis are given in Table.4.

Table.4. FDTD parameters of computation domain

ΔX	ΔY	ΔZ	Δt
0.1 mm	0.1 mm	0.1 mm	0.5 pS
No. of Steps	Pulse	Pulse T	Pulse Delay
12500	Gaussian 1 ⁰	20 pS	100 pS

In our FDTD analysis, the boundary used is the first order perfect absorbing boundary condition (ABC) suggested by G Mur [20]. Obtained computation domain of the antenna structure with specification given in Table.3 is shown in Fig.14.

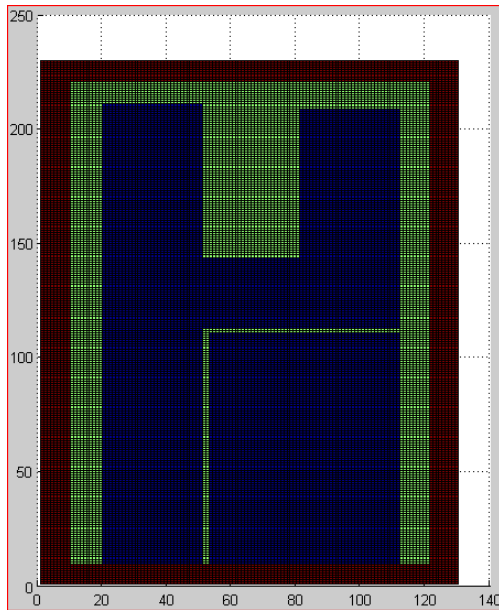


Fig.14. FDTD Computation domain

S11 curve obtained from FDTD computation is compared with both measured result and equivalent circuit computed values and the curves are depicted in Fig.15. All the three curves are of with very good cross correlation and thus the validity of finite difference time domain modelling.

Electric field plot obtained from FDTD analysis is also given in Fig.16. This figure also confirms role of U-shaped upper part of the monopole structure in radiation as explained in the surface current analysis session.

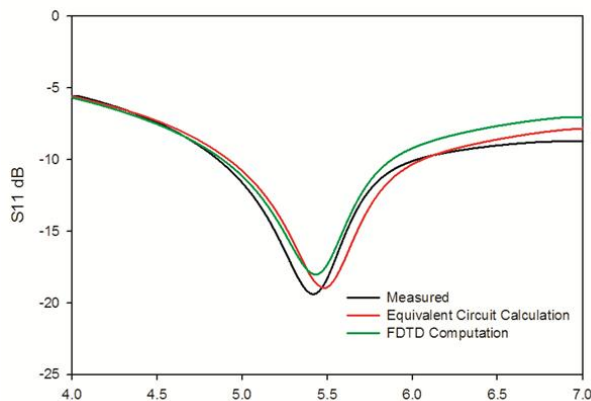


Fig.15. Comparison of Measured, Equivalent circuit and FDTD results

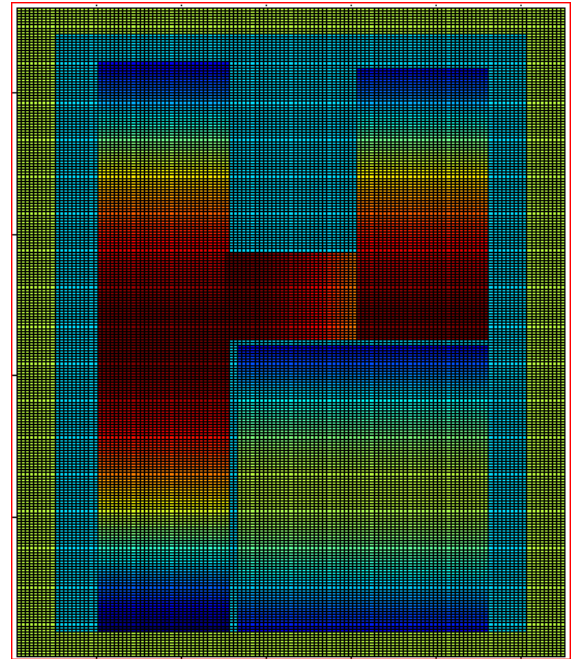


Fig.16. E field intensity plot from FDTD analysis

7. CONCLUSION

An ACS fed planar monopole antenna having an enhanced gain and directional radiation pattern without any additional parasitic elements and can be used for 5.2/5.8 GHz WLAN and ISM applications is developed and discussed. Antenna exhibits linear polarization with a high gain of 6.5 dBi and with uniform efficiency of 94%. Equivalent circuit and FDTD analysis of the structure are also performed and the results obtained are compared with measured results.

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