# WIDE BAND HIGH GAIN DIRECTIONAL ANTENNA FOR 5G APPLICATIONS

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***Abstract***
***ACS fed directional monopole suitable for high data rate communication with simple and compact structure, high gain and heavy bandwidth is presented. Antenna's bandwidth ranging from 3.8 to 10.29 GHz, with uniformly oriented directional radiation pattern and polarization make it suitable for high data rate communication applications such as ISM5.2 and ISM5.8 WLANs, HIPERLAN2 and HiSWANa. It also covers 95% of FCC specified UWB band too. The peak gain of the antenna is obtained as 7.84 dBi with efficiency greater than 88 %. Electrical equivalent circuit modeling of the antenna is also developed and the results obtained are discussed.***

***Keywords:***
***Asymmetric Coplanar strip (ACS), Monopole, Wide Band, High Gain, Directional***

## 1. INTRODUCTION

The most important part as far as a communication gadget is concern is nothing but Antenna. This passive element acts as the eye and year of the communication system which radiate/receive energy from and to physical world. As technology grows, data rate capacity increases with a sharp decrease in size of the communication device. This scenario can only be attained with the innovations of new antennas with high data rate capacity/ bandwidth with compacts size and with good radiation characteristics. Thus, the size reduction of antenna cannot compromise the radiation performances. Thus, this is simultaneously a challenge and opportunity for antenna designers. They must design a high-performance antenna with compact size. Different wide banding techniques are already presented in various literatures and the recent trends are discussed as follows.

A complex SIW fed D band Wide band horn antenna with a huge size applicable for short distance communication is presented in [1]. CPW fed flexible antenna with 57% BW and moderate gain is discussed in [2]. M. Amjadi and K. Sarabandi in [3] presents a cavity backed slot line fed two aperture UWB with enhanced gain, but structural complexity makes this design very hard. A magnetoelectric antenna based on a meta surface structure for high data rate communication is presented in [4].

In [5] the Authors discussing about a lens antenna which comprises of two Vivaldi structures, thus the losses its planar characteristics and compactness. A pencil beam antenna operating at 28 GHz with enhanced gain is discussed in [6]. A microstrip antenna operating at very high frequency and having additional parasitic elements to enhance the gain is presented in [7]. A semicircular antenna with an array of parasitic hexagonal patch back upped antenna with high gain and huge size is presented in [8]. H. Attia et al. [9] presents a Fabry-Perot cavity frequency selective structure based wide band high gain antenna. Here also the structure is very complex.

In [10], a Plasmon Polaritons based Spoof Surface antenna with wide band and end fire radiation pattern is presented. A low-profile folded dipole antenna with complex parasitic patches and shorting vias are presented in [11]. Another meta-surface based octagonal shaped antenna for wide band application is discussed in [12].

A combined antenna having magnetic dipoles and TEM Horn is presented in [13] to achieve super wide band and enhanced gain in which the design is too complicated. A slotline fed compact wide band antenna with enhanced gain is presented in [14]. In [15], R. Singh and D. Karia presents UWB MIMO antenna in which the maximum gain is 5 dBi. A stepped slot based microstrip fed wide band antenna having a triple layer structure is presented in [16]. M. A. Jamlos et. al. In [17] presents a circular patch-based antenna with wide band and enhanced gain, in which the gain enhancement is achieved using additional parasitic elements.

In this paper we are introducing an ACS fed simple monopole antenna having minimum dimensional parameters and compact size capable of operating in a wide range of frequencies with high directional radiating properties. The heavy directivity in this structure is obtained without any additional parasitic structures/ reflectors and which is the main importance of the desing. One portion of the monopole itself acts as the reflector in this antenna. The developed antenna offers a huge operating bandwidth of 6.49 GHz ranging from 3.8 GHz to 10.29 GHz with this directive behaviour.

The radiation patterns and polarization behaviour in the frequencies of operation are uniform. The peak gain of the antenna is founded as 7.84 dBi with an average efficiency 88 %. With this simple and compact structure, none of the wideband antennas presented in literatures till date has obtained this much of directional gain. All these parameters make the developed antenna a suitable candidate for various wireless communication applications such as applications such as ISM5.2 and ISM5.8 WLANs, HIPERLAN2 and HiSWANa in high data rate domain. Equivalent circuit model of the antenna is also developed, and result obtained is compared with measured results.

## 2. STRUCTURAL EVOLUTION

The high directional wide band antenna structure is derived from a compact asymmetric coplanar strip (ACS) fed monopole having standard input impedance of 50Ω. A horizontal strip parallel to width of the ground plane is introduced first in the ACS fed monopole. Then from the tip of newly added strip, a narrow vertical strip is introduced to obtain the final structure. The development process of the antenna from conventional ACS monopole is depicted in Fig.1.

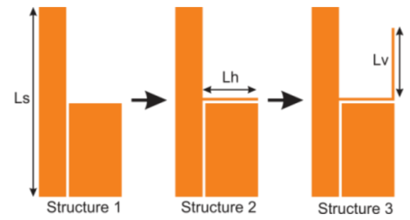


Fig.1. Evolution of wide band radiator from conventional ACS Fed Monopole

$S_{11}$ of all the three structures are given in Fig.2 and it is clear from the figure that the introduction of the narrow strips will lower the first resonance and create additional resonances and on merging these resonances, a wide band response is created.

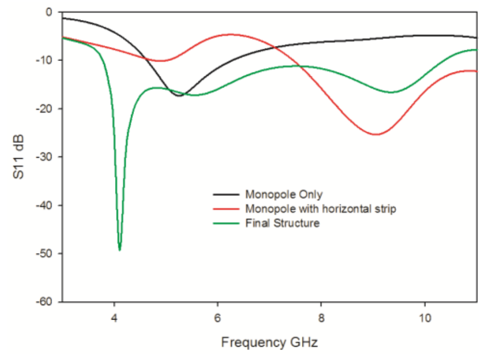


Fig.2. $S_{11}$ of various stages of antenna evolution

The structure of the antenna with dimensional notations is given in Fig.3.

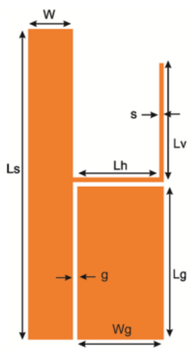


Fig.3. Antenna Structure with dimensional Notations

## 3. DIMENSIONAL OPTIMIZATION

With the help of Ansoft HFSS, a set of parametric analysis of the antenna is performed to optimize the antenna dimension for obtaining maximum favourable responses.

### 3.1 EFFECT OF $L_s$ ON RESONANCE AND BANDWIDTH

The effect of monopole length ($L_s$) on impedance bandwidth is analysed first and the curves obtained are depicted in Fig.4. From the figure the first two resonances lowered with this parameter while the third one is unaltered. Thus, we can conclude from this study that the surface current path corresponding to first and second resonance will increase with increase in $L_s$ while $L_s$ has no effect on current path length of third resonance.

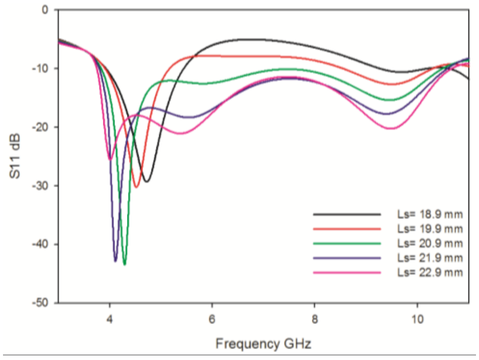


Fig.4. Effect of Ls on impedance bandwidth

### 3.2 EFFECT OF $L_h$ ON RESONANCE AND BANDWIDTH

As the next step, effect of horizontal strip ($L_h$) on resonance is studied. The $S_{11}$ curves obtained from this study are given in Fig.5. From the figure it is evident that first and third resonance has a lower shift with increase in this parameter while the second resonance remains as a constant. Thus, the surface current path length of first and third resonance increases with increase in $L_h$ while $L_h$ has no effect on second resonance surface current.

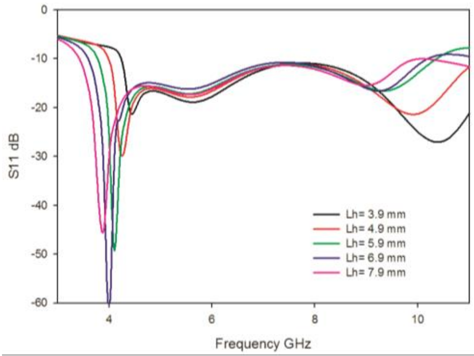


Fig.5. Effect of $L_h$ on impedance bandwidth

### 3.3 EFFECT OF $L_v$ ON RESONANCE AND BANDWIDTH

Effect of vertical narrow strip ($L_v$) on resonance and bandwidth is also analysed and the plots obtained are given in Fig.6. All the three resonant frequency gets a down shift with this parameter and the matching of the antenna structure is also affected with this dimensional parameter. Thus, all the three-resonance surface current paths increase with $L_v$.

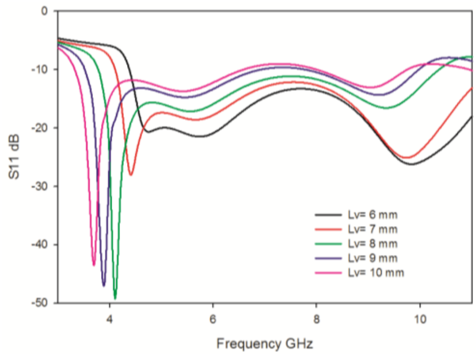


Fig.6. Effect of $L_v$ on impedance bandwidth

### 3.4 EFFECT OF $L_g$ ON RESONANCE AND BANDWIDTH

Effect of ground plane length ($L_g$) on resonance is analysed as next step. From the studies it is noted that all the resonance point are unaltered with $L_g$ while the matching of the antenna affected drastically with this parameter. The $S_{11}$ curves obtained from this analysis is given in Fig.7.

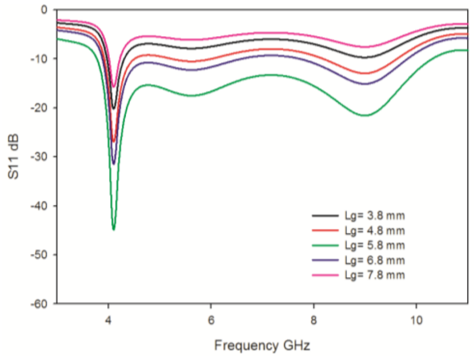


Fig.7. Effect of $L_g$ on impedance bandwidth

## 4. DESIGN EQUATIONS

From the above discussed parametric analysis session, design equations of the antenna structure is developed and are as follows

$$(L_s-L_g)+L_h+L_v \approx 0.6458\lambda_{g1} \quad (1)$$

$$(L_s-L_g)+L_v \approx 0.7111\lambda_{g2} \quad (2)$$

$$L_h+L_v \approx 0.6742\,\lambda_{g3} \quad (3)$$

In which the parameter $\lambda_{gn}$ is the wavelength in the substrate corresponding to $n^{th}$ resonance and is known as guided wavelength and is obtained from free space wavelength as

$$\lambda_{gn} = \frac{\lambda_n}{\sqrt{\varepsilon_{eff}}} \quad (4)$$

and here

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} \quad (5)$$

Developed equations are validated for different substrates by designing four different antennas in different substrates and simulating those using Ansoft HFSS. The parameters 'g' and 'W' are selected to obtain 50Ω input impedance for the structure. All the physical and dimensional parameters are given in Table.1.

Table.1. Antenna parameters for validation of Design equations

| | Antenna 1 | Antenna 2 | Antenna 3 | Antenna 4 |
|---|---|---|---|---|
| **Laminate** | **Rogers 6010LM** | **Rogers RO3006** | **FR4 Epoxy** | **Rogers 5880** |
| ***h* (mm)** | 0.635 | 1.28 | 1.6 | 1.57 |
| $\varepsilon_r$ | 10.2 | 6.15 | 4.4 | 2.2 |
| ***g* (mm)** | 0.775 | 0.65 | 0.3 | 0.1 |
| ***W* (mm)** | 2.08 | 2.61 | 3 | 3.9 |
| **$L_s$ (mm)** | 14.51 | 18.16 | 20.9 | 27.15 |
| **$L_h$ (mm)** | 4.03 | 5.04 | 5.8 | 7.53 |
| **$L_v$ (mm)** | 5.55 | 6.95 | 8 | 10.39 |
| **$L_g$ (mm)** | 4.03 | 5.04 | 5.8 | 7.53 |

Simulated $S_{11}$ curves of all the four designed antenna are given in Fig.8 and are in very good agreement, which indicates the supreme validity of developed design equations.

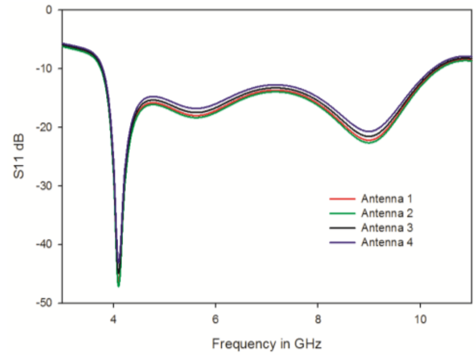


Fig.8. $S_{11}$ Curves of Antennas with dimensional specification given in Table.1.

### RESULTS AND DISCUSSIONS

From the validation of design equation performed, an antenna structure with optimum characteristics is physically fabricated using photolithographic etching method. A UV based negative photo resist is used to create the mask of the antenna above a commercially available FR4 substrate. On chemically reacting the masked substrate with ferric chloride, our antenna structure is obtained. Developed structure is tested using HP8510C vector network analyser. The optimized structural parameters obtained from design equations are depicted in Table.2.

Table.2. Optimized Dimensions of developed antenna

| $L_s$ | $W$ | $L_h$ | $L_v$ |
|---|---|---|---|
| 20.9 mm | 3 mm | 5.8 mm | 8 mm |
| **$L_g$** | **$W_g$** | **$s$** | **$g$** |
| 5.8 mm | 5.5 mm | 0.3mm | 0.3 mm |
| **$h$** | **$\varepsilon$** | **tan$\delta$** | **Substrate** |
| 1.6 mm | 4.4 | 0.02 | FR4 |

Simulated and measured $S_{11}$ curve of the antenna are compared and found to be with very good matching and the same is given in Fig.9.

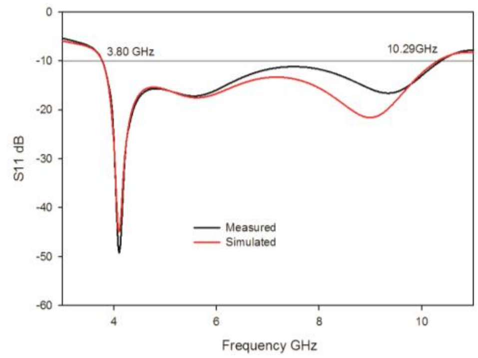


Fig.9. Measured and Simulated $S_{11}$ curve

From the figure it can be noted that the antenna has three resonances which are merged to gather to form a huge bandwidth starting from 3.8 GHz to 10.29GHz. First resonance is placed at 4.08 GHz which is highly matched resonance with narrow bandwidth and very high quality factor. Second and third resonances are found to be at 5.62 and 8.92 GHz respectively. They are relatively with smaller Q factor and thus having heavy bandwidth.

Radiation patterns are measures using conventional turn table assembly. The potential challenges faced during the radiation pattern measurement are to avoid unwanted reflections from surfaces other than antenna. For that a semi anechoic chamber is used and the network analyser is kept in gating mode to avoid unwanted signals.

Measured principal plane radiation pattern of the antenna at first, second and third resonances are depicted in Fig.10,(a), (b) and (c) respectively. The main attraction that we can easily find in the pattern is the directional behaviour. All the patterns are highly directional towards positive X direction. At first resonance, the front to back ration is nearly 10dB and the cross polar purity is better than -20 dB. At 5.62 GHz, antenna is highly directional with an F/BV ratio of 9 dB and a cross polar purity of -40 dB. Similar characteristics are obtained at third resonance also.

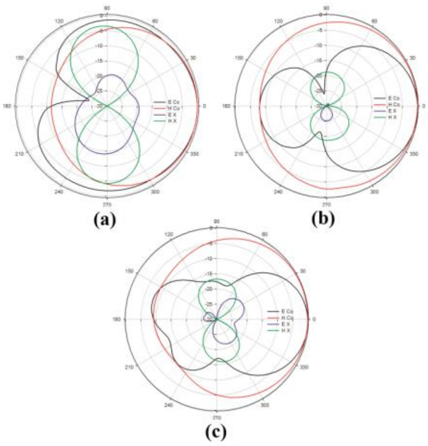


Fig.10. Measured Radiation Patterns

To get a complete knowhow about the spatial energy distribution around the antenna structure and to validate the measured results, 3D far field radiation patterns are created using HFSS simulation software, which are shown in Fig.11. It is found from the figure that the measured and simulated radiation patterns are of with good matching.

From the radiation pattern analysis, it can be concluded that the developed wide band radiator is a highly directional antenna with beam maxima pointing towards positive X direction.

To find out the reason for radiation and directional characteristics, surface current of the antenna is analysed. The magnitudes of surface currents at the three resonant frequencies are shown in Fig.12. It is clear from the figure that all the resonances are created due to the currents at horizontal and vertical narrow strip. In all the resonances, the signal strip has minimum current density. Thus, it has minimum effect on resonant frequency, but it can be acts as a reflector to create the directivity of the antenna. The radiated power towards negative X direction is pushed towards positive X direction by the upper portion of signal strip.

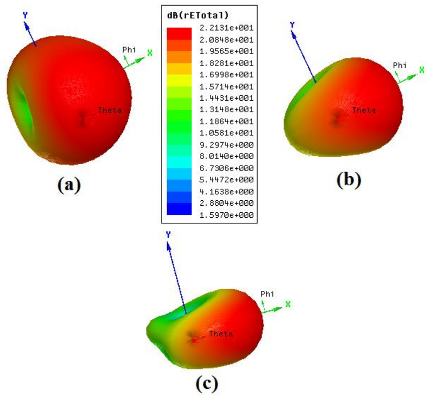


Fig.11. Simulated Radiation Patterns

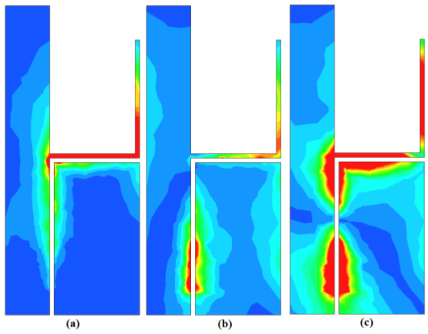


Fig.12. Surface Current Density

Since the upper portion of signal strip acting as a reflector, the spacing between radiating vertical narrow strip and the reflector ($L_h$) will be an important parameter which determines the gain and directivity of the antenna. The simulated gains with to various $L_h$ is depicted in Table.3.

Table.3. Variation of Gain with $L_h$

| Lh (mm) | Peak Gain (dBi) | Average Gain (dBi) |
|---|---|---|
| 3.8 | 7.29 | 7.24 |
| 4.8 | 7.64 | 7.58 |
| 5.8 | 7.83 | 7.76 |
| 6.8 | 7.71 | 7.68 |
| 7.8 | 7.56 | 7.47 |

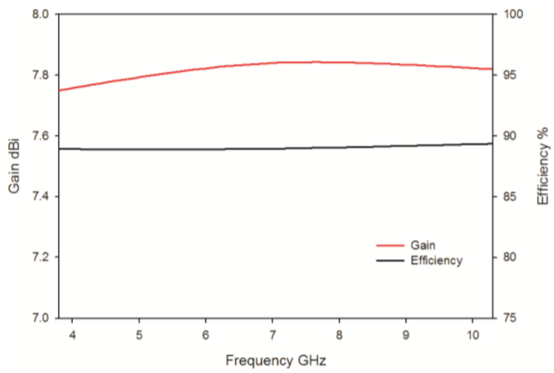


Fig.13. Gain and efficiency plot

Radiation efficiency of the antenna is measured using wheeler cap method and the gain is measured using standard horn gain comparison chart. Measured values of both these parameters are given in Fig.13. Antenna offers a nearly uniform radiation efficiency of 88% and above in all the frequency of operation. The peak gain of the antenna is found to 7.84dBi with an average value of 7.79 dBi.

### 4.1 EQUIVALENT CIRCUIT MODELLING

An equivalent circuit model of the antenna is developed by the method discussed in [18]. Since the antenna has, three resonances, antenna is approximated to three series RLC networks which are connected in parallel to an AC source as shown in Fig.14.

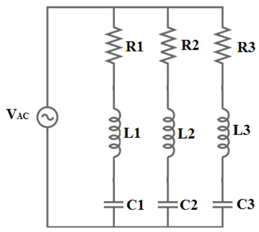


Fig.14. Equivalent circuit modeling of the antenna

The values of lumped elements are obtained from the resonant frequencies and the bandwidth of each individual resonance using the calculation methods specified in [18]. From the measured $S_{11}$ curve Q factor of each resonance will be calculated first and from that the lumped R, L and C values are calculated, and the obtained values are depicted in Table.4.

Table.4. Calculated Lumped Parameters

| Resonance | R (Ω) | L (nH) | C (pF) |
|---|---|---|---|
| 1st | 48 | 1.3648 | 0.0111601 |
| 2nd | 41 | 0.283855 | 0.0282821 |
| 3rd | 43 | 0.249895 | 0.0127524 |

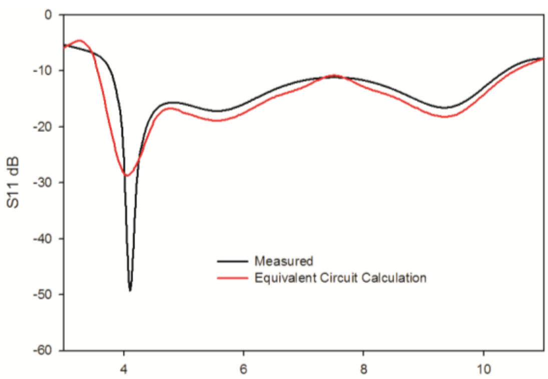


Fig.15. Measured and calculated $S_{11}$ comparison

Measured $S_{11}$ curve is compared with that calculated from the equivalent circuit parameters and both the curves are shown in Fig.15. From the figure it can be noted that positions of three resonances in both the curves are same with approximately same bandwidths for each resonance. The matching slightly varies in the curves and that may be due to the reduced number of calculating points used for the convenience of calculations. Both the curves are in good agreement in case of resonance and bandwidth parameters, which confirm the validity of developed equivalent circuit.

## 5. CONCLUSION

A high gain and highly directive ACS fed monopole with simple and compact structure for various high data rate wide band application is developed and discussed. Antenna offers a wide bandwidth ranging from 3.8 to 10.29 GHz, with uniformly oriented directional radiation pattern and polarization in all the frequencies of operation. The peak gain of the antenna is obtained as 7.84 dBi with efficiency greater than 88 %. This high gain in entire bandwidth is obtained without any additional/parasitic elements. This antenna is considered to me the most compact antenna having this much of gain in the entire operating frequencies. Equivalent circuit modelling of the antenna is also developed, and results obtained are compared and found to be in good agreement with measured results.

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