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Planar Dipole Antenna with Integrated Loops and Connecting Patches for DTV Application

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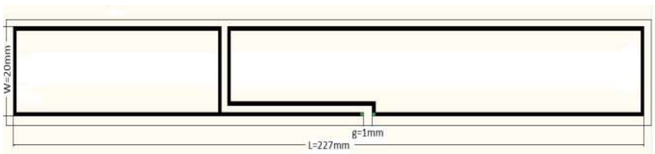
***Abstract*— Coaxial feed planar printed dipole antenna with UHF band operation for DTV signal reception application is presented. This antenna is composed of two asymmetric loops separated by step shape feed gap. These two asymmetric loops contains two smaller loops inside which are connected to external loops with the help of coupling patches. By carefully selecting the length of the antenna and length of step feed gap, two resonant modes are excited. Further bandwidth enhancement is achieved by the addition of the inner loop and coupling patch. Various parameters associated with antenna such as bandwidth, return loss, antenna gain, and radiation efficiency are well investigated, simulated and discussed. The simulated radiation pattern is omnidirectional matching to the typical dipole antenna. For the proposed antenna experimentally measured operating bandwidth is found to be 470-925 MHz which is more than 65% with return loss better than 7.35 dB. Therefore, the proposed antenna is very much compatible to digital television signal receiving applications.**

Keywords*— Broadband dipole antennas, Monopole antennas; Digital television (DTV) antennas; High definition television (HDTV); Dipole antennas; Microstrip antenna.

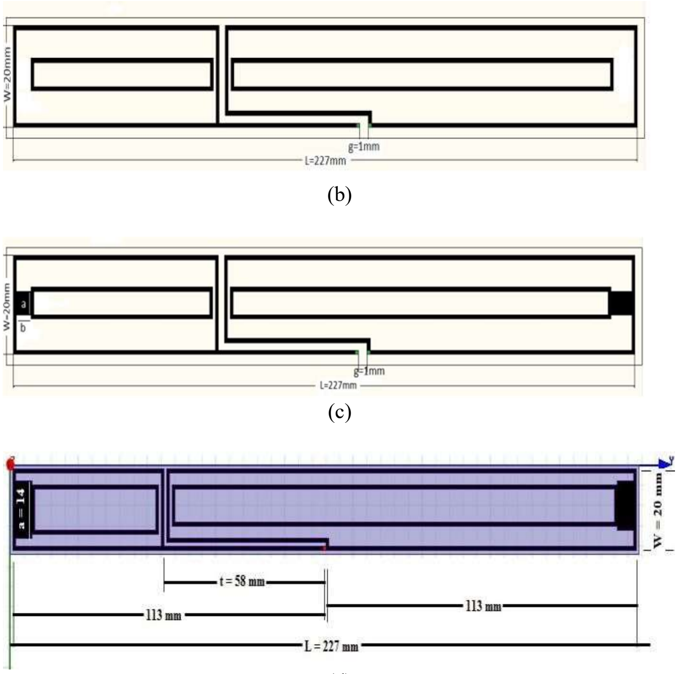
I. INTRODUCTION

IN In the last few years, more countries have offered digital television (DTV) broadcasting services in various portable devices like Laptop computers, Mobile phones [1]-[4]. In India also the government has made digitization mandatory in Mega cities like Mumbai, Delhi. Broadcasters can transmit television with high definition (HD) image and sound by using DTV system and furthermore, DTV broadcasting also offers multimedia and interactive services such as Music, Movies, Games [5]- [8]. Advanced evolution in technology has evoked a new technology called 4K which is capable of capturing a larger image size i.e four time than conventional HD with better picture quality and more information. This 4K transmission has then led to a requirement of wideband operation and High gain antenna. Thus Today, DTV signal reception has thus become very attractive for applications in many devices such as notebooks, tablet PC & vehicles, etc. [9]-[11]. Here we can observe that display devices are becoming Compaq day by day. Initially there were big televisions now we can have DTV application in small vehicle TVs or in tablet PCs. Thus, it is necessary to design new types of low profile DTV receiving antennas which will be smaller in size so as to fit in portable TVs, but at the same time will not compromise wide operating bandwidth covering the whole DTV band in the 470–862 MHz band. At present, some monopole antennas with broadband characteristics have been designed to operate in the DTV band which are small in size. However, it is observed that for most of monopole antennas, their ground-plane dimension greatly affects impedance characteristics as sufficient size of the ground plane is needed for achieving good impedance matching within the operating bandwidth. Also, conventional wire monopole antennas provide small impedance bandwidth of about 10% [12] -[14].

Here, we designed a broadband printed dipole antenna with a coaxial feed mechanism containing two external asymmetric loops separated by step shaped feed gap. The outer loop is coupled with inner loops by rectangular patches as shown in fig. 1c. for DTV broadcasting applications in the UHF band. Initially the printed planar antenna structure with a coaxial feed system is restructured with the inclusion of step shape feed gap to result in wide band DTV signal reception application.



(a)



(b)

(c)

(d)

Fig.1. Various configurations in development of proposed antenna. (a) Printed dipole antenna without inner loop and coupling patches. (b) Printed dipole antenna with inner loop, but without coupling patches. (c) Dipole antenna with coupling patches and inner loop. (d) Proposed Printed dipole antenna with inner loop and coupling patches.

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Two main resonant modes which are 0.5λ and 1λ are excited with the help of two different resonant lengths of antenna. Total length of the antenna i.e. 227mm gives rise to fundamental 1λ mode. Straight feed gap is replaced by step shape feed gap to excite an additional 0.5λ resonant mode. This 0.5λ mode will effectively combine with 1λ mode and their individual frequency responses add to each other in order to stretch the overall operating bandwidth which is improved as compared to the typical center-fed printed dipole antenna. Two more internal loops are added inside two external loops and are coupled with outer loops by coupling patches as shown in fig. 1d. Next, the contribution of two inner printed loops and coupling patches in increasing the operating bandwidth of the proposed dipole antenna is analyzed. By employing the inner loops and coupling patches, an antenna attains 65.23% impedance bandwidth (SWR < 2.5). This enhanced operation bandwidth is the composite of frequency responses of two individual printed loops. The specific frequency response of these individual printed loops combines to stretch operation bandwidth.

Various simulations in this paper are carried out by Ansoft HFSS 13 (High Frequency Structure Simulator based on the finite element method) [15]. This software performs full-wave three-dimensional EM simulation and helps to obtain the required antenna dimensions and performance. Simulated and measured results of antenna return loss are obtained and then compared to conclude the design of proposed antenna.

The structure of the proposed Printed Dipole Antenna is presented in Section II. Additionally, simulated surface current distributions of proposed antenna at various frequencies are addressed. Section III includes experimental results and discussions. Finally, Section IV concludes the design of the proposed antenna.

II. ANTENNA DESIGN

The proposed printed dipole antenna with inner loops and coupling patches is shown in fig. 1d. The antenna consists of rectangular box shape FR4 substrate with size of 227×20×0.4 mm. An antenna which is printed on it has dimension as length (L = 227mm) to excite fundamental (1λ) resonant mode centered at about 530 MHz. This covers lower frequency (470 MHz) of the DTV band considered here. However, to have wideband operation an extra resonant mode is needed to include upper band frequency (865MHz) of DTV band. This antenna is made up of two asymmetric loops separated by step shape feed gap. These loops known as external loops contains two smaller inner loops which are coupled to external loops with the help of rectangular patches. Two resonant modes i.e 1λ and 0.5 λ are excited due to whole antenna length (L= 227mm) and step feed gap length (t = 58mm). Development of proposed antenna is shown in Fig.1. Initially the antenna structure containing two asymmetric loops separated by step shape feed gap of g = 1mm is drawn on an FR4 substrate as shown in Fig. 1 (a). Then two concentric small rectangular inner loops are added as shown in Fig. 1 (b). Finally the structure is modified again by integrating rectangular coupling patches with width ‘a’ and length ‘b’. Improved impedance matching for the UHF band is obtained by coupling inner and outer loops with the connecting patches as shown in Fig. 1(c). On the other hand, An antenna design has been referred wherein multiple concentric rectangular loops (similar to concentric circles antenna topology) are employed. Each loop takes in a different length that give rise to a particular resonant frequency. These resonant frequencies corresponding to the individual loop interacted with each other and superimposed to generate a wideband operation [3].

A. Antenna Simulation in HFSS

Proposed Antenna has been simulated in HFSS 13 software. Rectangular box shape dielectric FR4 substrate of size 229mm×22mm×0.4mm is drawn. Dielectric constant and Loss tangent of substrate is set to 4.4 and 0.02 respectively. The proposed antenna structure shown in fig. 1d is developed on the substrate and then simulated in HFSS for frequency range of 400MHz to 1200MHz. Various simulation results like return loss, VSWR, Radiation pattern, Antenna Gain, Radiation efficiency obtained are discussed ahead. Fig. 2 (a), (b), (c) shows the simulated surface current distribution at 470 MHz, 650 MHz and 860 MHz. Ansoft High Frequency Structure Simulator (HFSS) software has been used to obtain the

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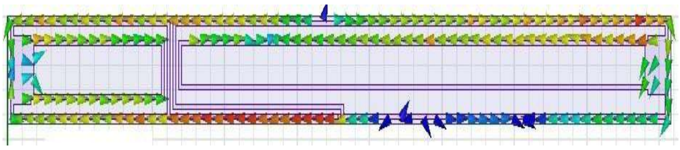
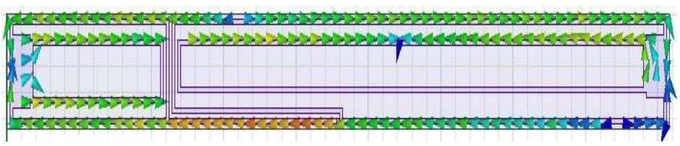
simulation results [15]. At 470 MHz it has been observed that the direction of excited surface currents distributed on L.H.S loop1 (arm 1) and R.H.S loop 2 (arm 2) is same and follows the current distribution of the two equal arms of the typical center-fed dipole antenna which is excited at the fundamental (0.5 λ) mode. If observed at 860 MHz, a zero current on two arms 1 and 2 along with the step-shaped feed gap is observed and the excited surface currents on arms 1 and 2 are found to be in the opposite direction. This is very much similar to the current distribution of the two equal arms of the typical center-fed dipole antenna which is excited at the second resonant (1λ) mode.



(a)



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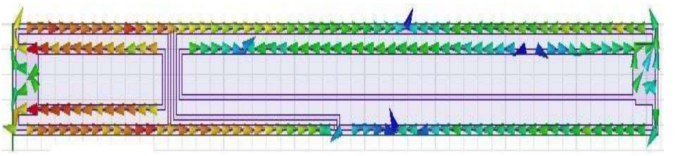

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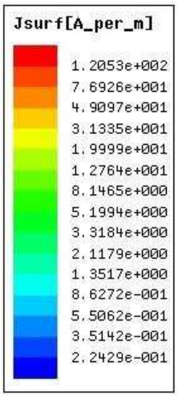


Fig. 2. Simulated surface current distributions of the proposed antenna under the parameters given in Fig. 1. (a) 470 MHz (b) 650 MHz (c) 860 MHz

III. EXPERIMENTAL RESULTS AND DISCUSSIONS

The Antenna is successfully developed and implemented in Simulation software HFSS. The photograph of the proposed Printed Dipole Antenna developed on 0.4mm-thick FR4 substrate is shown in Fig. 6. Proposed antenna is simulated to get the graph of antenna parameters like Return loss, Antenna gain, Radiation Efficiency and Radiation Pattern.

A. Return Loss and Impedance Bandwidth of Antenna

The proposed antenna is first simulated in HFSS by varying various parameters associated with an antenna like the width of the coupling patch ‘a’ and step feed gap offset ‘t’. It is then analyzed for best results. A comparative analysis, among various return loss graphs has been done and presented ahead. Fig. 3 shows the simulated return loss for various configurations of antenna shown in Fig. 1 (a), 1 (b) and 1 (c). Respective results are compared and tabulated in Table I. It can be observed that a PDA with inner loops and coupling patches gives highest bandwidth i.e. 697.5 MHz as compared to other two configurations. Thus the bandwidth is enhanced by coupling inner and outer loops with rectangular patches. Also dimensions of this coupling patch also affects the operating bandwidth. Effect on operating bandwidth due to changes in width ‘a’ of coupling patch is studied. Fig.4 shows simulated return loss for three different values of ‘a’. Respective results are tabulated in Table II. Slight variation in bandwidth is observed as ‘a’ varies from 10 mm to 14 mm. Highest bandwidth i.e. 455 MHz is obtained at ‘a’ = 14 mm. Fig. 5 shows a simulated return loss for various values of step feed gap offset ‘t’. Respective results are tabulated in Table III. As this offset ‘t’ is varied from 20 mm to 58 mm, a shift in resonant frequency is observed from right to left also when ‘t’ = 58 mm highest bandwidth i.e. 68.08% is obtained.

It is observed that, in dipole antenna fed at the center, a one resonant mode (0.5-wavelength mode) which is excited with at frequency 580 MHz, and the corresponding bandwidth (2.5:1 VSWR) is 165 MHz, or about 28% only centered at 580 MHz, which is very less than that of the proposed antenna and therefore cannot include the whole DTV band [4]. For the dipole antenna with center feed, its observed that the 1.0-wavelength mode cannot be excited [2] [4]. But in case of off center fed printed dipole two resonant modes (λ/2 and λ modes) are excited at about 600 and 1200 MHz, but over the 0.5λ mode poor impedance mismatch of frequencies is observed [4]. The step-shaped feed gap provides best excitation of the 0.5λ mode and also shifts the excited 1.0λ mode towards lower frequencies close to that of the 0.5λ mode to result in a wideband operation [4].

A prototype with the design dimensions shown in Fig. 1d was then manufactured. Photograph of proposed fabricated antenna is shown in Fig. 6. Then the fabricated antenna prototype is tested on vector network analyzer with a frequency range of operation from 300 kHz to 8 GHz to measure Return loss and VSWR of proposed antenna. Fig. 7 shows the comparison between simulated and measured return loss. A good approximation is obtained between the measured data and simulated result acquired using Ansoft HFSS i.e Antenna simulation software. Two excited resonant modes have better impedance matching, and the impedance bandwidth (2.5:1 VSWR) is 465 MHz (400–865 MHz) or about 65.23 % with center frequency at 697.5 MHz. This results in broadband operation which covers the 400–865 MHz band. This wide band covers the frequencies which come under DTV application and also provides the impedance bandwidth with 2.5:1 VSWR which is again acceptable for DTV signal reception. Fig. 8 shows grapf of simulated and measured VSWR of proposed antenna and it is below 2.5 for operating bandwidth 470-925 MHz.

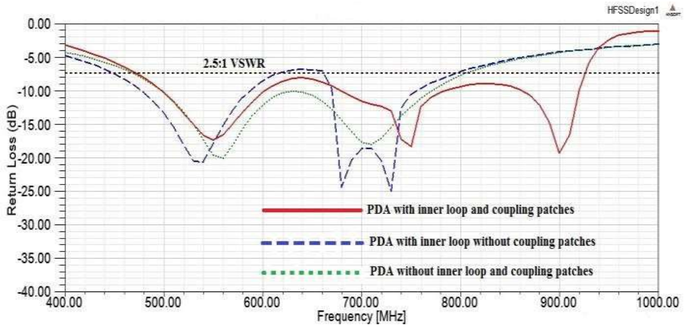


Fig. 3 Simulated return loss of the antennas in fig. 1a, 1b and 1c

TABLE I
CENTRAL FREQUENCIES AND BANDWIDTHS OF THE PROPOSED ANTENNA UNDER DIFFERENT CONFIGURATIONS

PDA Configurations	*fc* (MHz)	BW(= $f_H - f_L$) (MHz)
Without inner loop and coupling patches	636.5	339 (806-467)
With inner loop without coupling patches	619.5	343 (791-448)
With inner loop and coupling patches	697.5	455 (925-470)

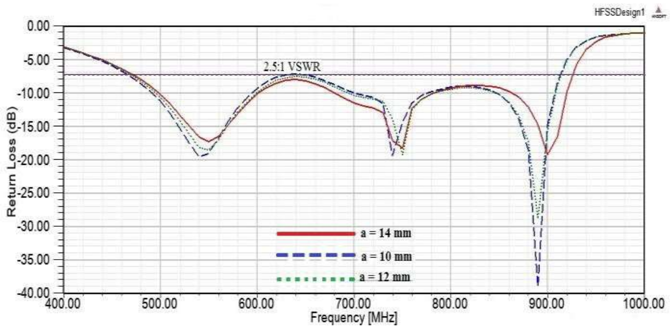


Fig.4. Simulated return loss of the proposed antenna for various values of ‘a’

TABLE II
CENTRAL FREQUENCIES AND BANDWIDTHS OF THE PROPOSED ANTENNA UNDER DIFFERENT VALUES OF ‘ a ‘

Coupling patch width ‘a’	*fc* (MHz)	BW(= $f_H - f_L$) (MHz)
a = 10	689	446 (912-466)
a = 12	690	444 (912-468)
a = 14	697.5	455 (925-470)

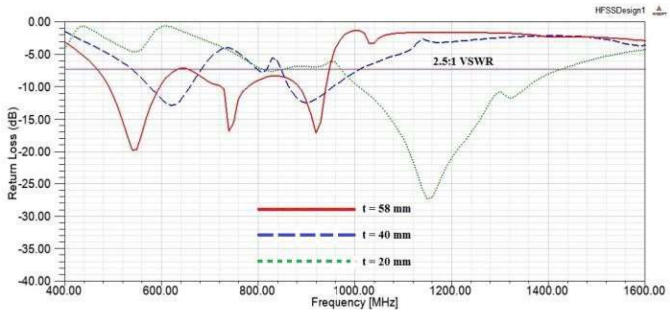


Fig.5. Simulated return loss of the proposed antenna for various values of ‘t’

TABLE III
CENTRAL FREQUENCIES AND BANDWIDTHS OF THE PROPOSED ANTENNA UNDER DIFFERENT VALUES OF ‘ t ‘

Step feed gap length ‘t’	*fc* (MHz)	BW(= $f_H - f_L$) (MHz)
t = 20mm	1195.5	451 (1421-970)
t = 40mm	608.5	145 (681-536)
t = 58mm	705	480 (945-465)

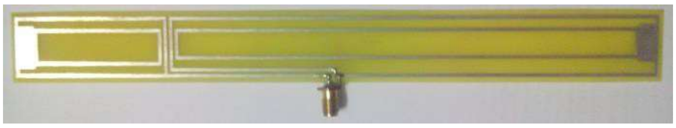


Fig. 6. Photograph of the proposed Printed Dipole Antenna

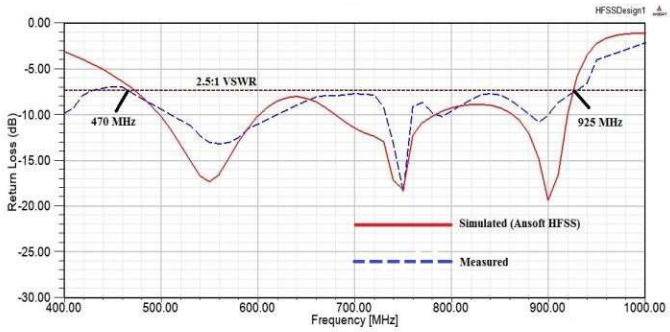


Fig.7. Measured and Simulated return loss of the proposed antenna.

B. Radiation Pattern

This section describes radiation characteristics of the antenna. Radiation patterns in 2D and 3D are obtained using Ansoft HFSS. Doughnut shape or 'figure of 8' 2D radiation pattern is expected to be suitable for DTV signal reception application. Fig. 9 shows 2D simulated radiation patterns at 470 MHz, 650 MHz and 860 MHz, which is similar to expected one. It looks like the radiation pattern of the conventional $\lambda/2$ center-fed dipole antenna. The same radiation pattern is obtained for other frequencies in a range of 470–925 MHz band. Fig.10 shows a 3D radiation pattern of proposed antenna which is omnidirectional in nature as required.

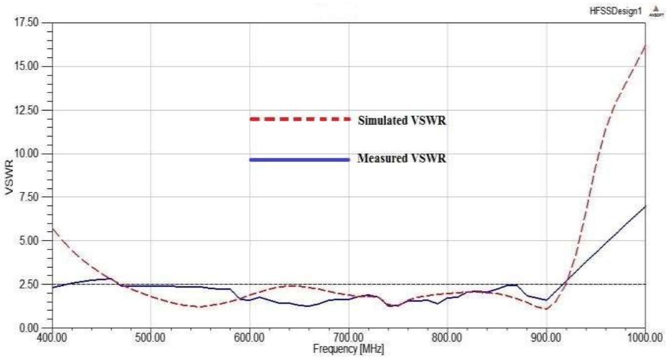
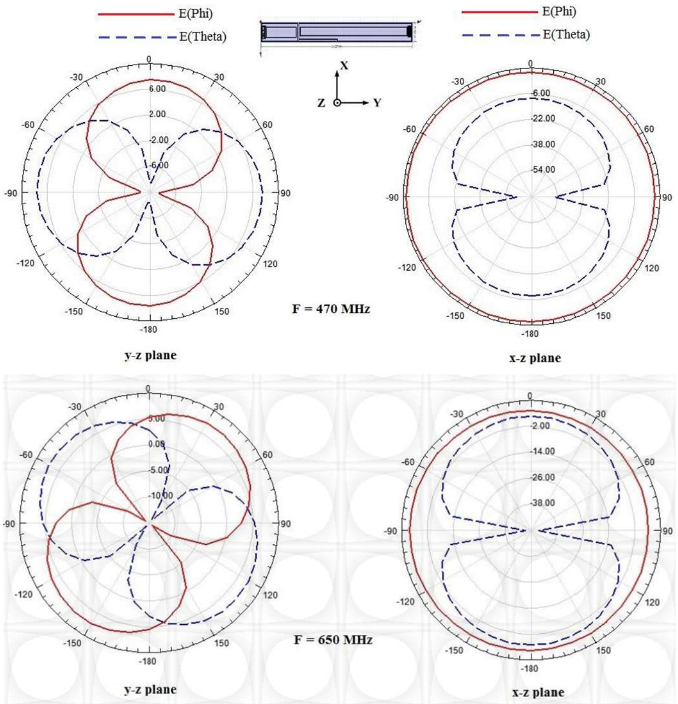


Fig.8. Measured and Simulated VSWR of the proposed antenna.



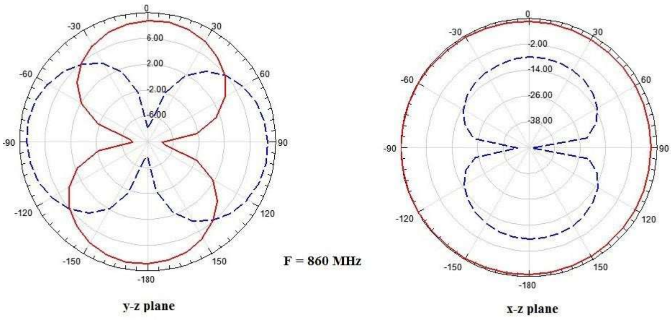


Fig. 9. Simulated radiation patterns of the proposed antenna. The design parameters are the same as Fig. 1d

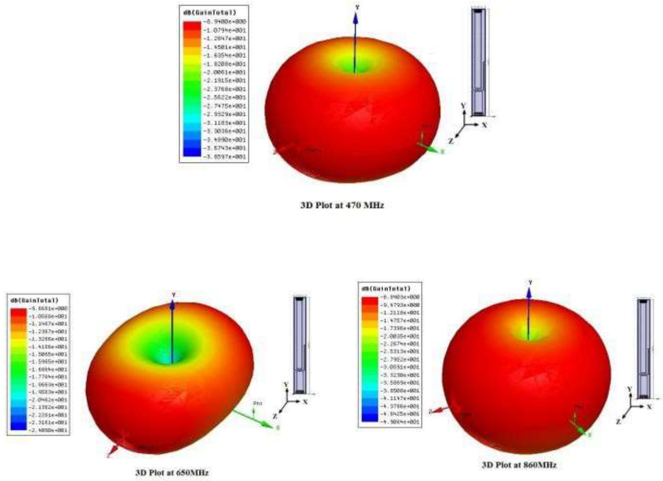


Fig.10. Simulated 3D Radiation Pattern of the proposed antenna under the parameters given.

C. Antenna Gain and Radiation efficiency

Fig.11 and Fig.12 indicates the simulated antenna gain and radiation efficiency of the proposed antenna. Lesser antenna gain variation, i.e. about -8.2 to -9.8 dB is obtained over a DTV band of 470-870 MHz, which satisfies the constant antenna gain criteria of good antenna and also the better radiation efficiency i.e. larger than 80% is obtained for frequencies over the operating band.

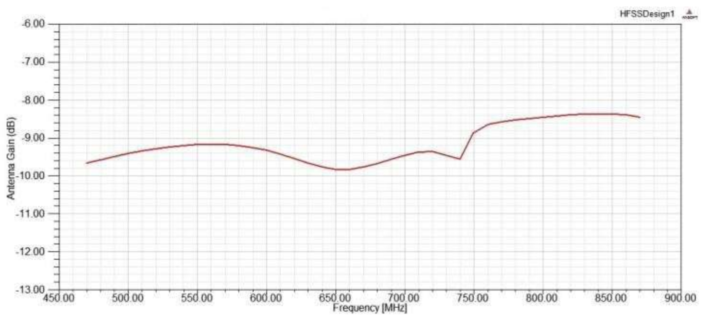


Fig.11. Simulated Antenna Gain of the proposed antenna under the parameters given

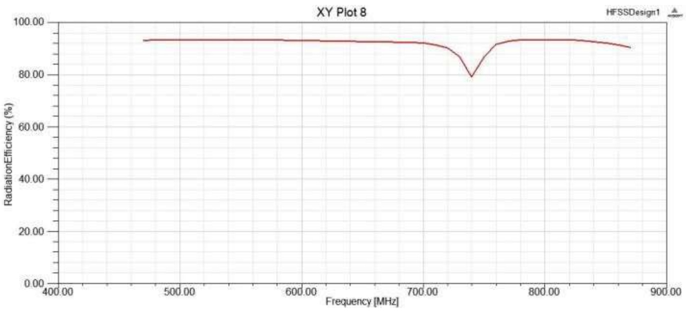


Fig.12. Simulated Radiation Efficiency of the proposed antenna under the parameters given

IV. CONCLUSION

A broadband printed dipole antenna with integrated external and internal loops coupled with rectangular patches for DTV signal broadcasting and reception application in the 400–865 MHz band has been proposed. 0.5λ and 1.0λ resonant mode give rise to two resonant frequencies whose individual response results in the wide band operation of the antenna which is controlled by the antenna length L and the total effective length (about 1.25 L) of the antenna's two radiating arms respectively. To enhance the bandwidth further inner loop with coupling patches are added at two sides of inner loop. The effect of varying length (a) of coupling patch has been observed. Also the effect of varying step feed gap offset parameter 't' is well studied and presented. The measured bandwidth of the proposed antenna with the return loss higher than 7.35 dB (VSWR < 2.5) is from 470-925 MHz. Stable radiation characteristics with omnidirectional i.e doughnut shape radiation pattern have also been obtained over the wide operating band which makes it suitable for DTV signal reception.

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