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Design a Wideband Aperture Coupled Stacked Microstrip Antenna at 28 GHz for 5G Applications

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Abstract- ***A wideband stacked microstrip antenna at 28 GHz for 5G applications is presented. In this paper, two antenna rectangular microstrip as a reference antenna and stacked microstrip as propose antenna are design and simulate using ANSYS HFSS 2019R1 at 28 GHz. An Aperture coupled feed technique is used in this work. The proposed antenna resonates from 26.98 GHz to 30.41 GHz with a return loss ≤ -10 dB. The proposed antenna having 3.43 GHz bandwidth which is ≈ 12% wider as compared to reference antenna bandwidth 2.27 GHz. Gain of proposed antenna 6.36 dB and efficiency of 99.53%. In this design, two substrate Roger RT/Duroid 6006 and Roger RT/ Duroid 5880 which has dielectric constant of 6.15 and 2.2 with loss tangent 0.0009 with a height of substrate are 0.635 mm and 1.6 mm was used. The performance of proposed antenna in terms of bandwidth its good agreement for 5G applications.***

Keyword- ***Aperture coupled microstrip antenna, Stacked patch, 5G application.***

I. INTRODUCTION

According to FCC (Federal Communications commission) the frequency band for 5G applications for the high profile band 24 GHz to 60 GHz. The fifth-generation network is expected to enhance high communication capacity by exploiting the vast amount of spectrum in the millimeter wave and It's also expected to be able to provide and support very high data rates as much as compared to previous generation capacity [1-3].This leads to new challenging network requirements as well as in the antenna design for 5G communication systems in order to meet the expected data rate and capacity.

The 5G application in wireless communication systems require wide bandwidth and high gain of antenna, by which the voice, data, and video information can be transmitted. The need for increasing the information transfer rate also demands bandwidth enhancement, without sacrificing the performance. An aperture coupled stacked microstrip antenna is of major importance because of its wider bandwidth and high gain is presented for fulfill the requirement of 5G systems.

Many techniques have been suggested for achieving wide bandwidth [6-10]. In this paper, an aperture coupled microstrip antenna has design at 28 GHz for the above facts to achieve a wide band.

II. MODELING OF APERTURE COUPLED MICROSTRIP ANTENNA

First a model of the aperture coupled feeding is presented. It is shown, which parameters affect the antenna behavior and how they can be used for the development.

Fig.2.1 show the assembly of an aperture coupled patch antenna in detail. The patch of length L and width W is placed on a substrate with height h_2 and relative permittivity ε_{r2}. The lower substrates height h_1 and its permittivity is ε_{r1}. Both substrate are separated by a metallic plane, having a rectangular cutout of edge length L_s and width W_s and its center at the position (x_0,y_0).

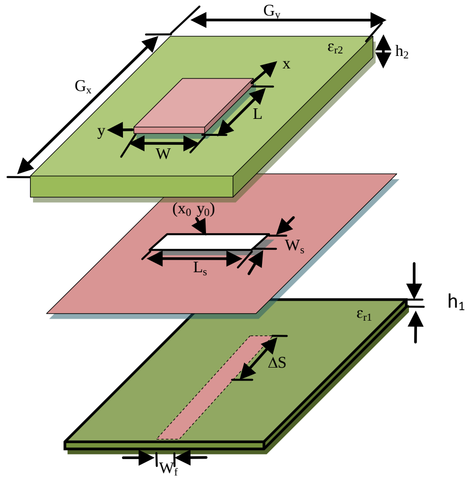


Fig. 2.1: Schematic assembly of an aperture coupled patch antenna

This rectangular cutout is called coupling aperture. The lower edge of the patch is chosen as the point of origin, so ($x_0 = L/2$, $y_0 = W/2$) describes a coupling aperture aligned with the center of the patch. The feeding is realized by an open ended microstrip line of width W_f, overlapping the point x_0 by stub length ΔS. The width of the substrates and the ground plane in x and y direction are named G_x and G_y, respectively.

There are different methods for modeling of this antenna presented [4-5]. In this work transmission line model consider. The equivalent circuit of the transmission line model, derivation and basic concept given by [6].

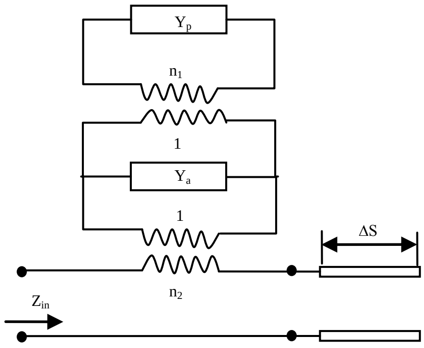


Fig. 2.2: Equivalent circuit of the aperture coupled patch antenna based on the transmission line model

By Fig. 2.2 Z_{in} is characterizes input impedance of the antenna consisting of the serial connection of a transformer and an open ended line. This line corresponds to the end of the microstrip line of stub length ΔS the transformer, with a transfer ratio of n_2: 1, models the coupling between microstrip line and coupling aperture, which can be described by the admittance Y_a. The coupling between the aperture and the patch is modeled by a transformer with the ration of 1: n_1 and the admittance Y_P denote the patch. For the determination of the transfer ratio n_1, assumes that the ratio is approximately equal to the fraction of current flowing through the slot over the total intensity. Hence, give results as in equation (1).

$$n_1 = \frac{L_s}{W_p} \qquad (1)$$

This corresponds to the consideration, that the coupling is reduced for smaller apertures. To get an approximation for the admittance Y_P, the patch is also modeled by electric lines in the transmission line model.

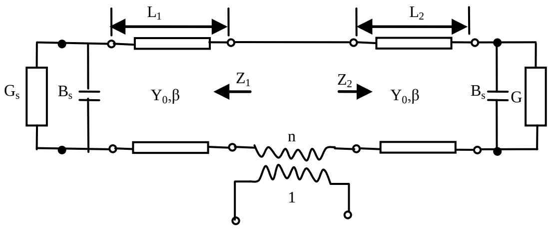


Fig.2.3: equivalent circuit of the patch based on the transmission line model.

Fig.2.3 shows the resulting equivalent circuit for the patch. Two lines are positioned behind the transformer, one with length $L_1 = x_0$ and the other with length $L_2 = L - L_1$.

Together they have the total length of the patch, which is split into two lines at the position x_0 by the transformer. Depending on the resulting input impedances, Z_1 and Z_2, the admittance of the patch results is

$$Y_P = \frac{1}{Z_P} = G_P + jB_P \qquad (2)$$

Where

$$Z_P = Z_1 + Z_2 \qquad (3)$$

The equivalent circuit allows the single input impedances to be determined as

$$Y_i = Y_0 \frac{G_S + jB_S + jY_0 \tan(\beta L_i)}{Y_0 + j(G_S + jB_S)\tan(\beta L_i)} \quad \text{with} \quad i=1,2 \qquad (4)$$

Within the equivalent circuit, Y_0 and β are the transmission line admittance and the phase constant of a microstrip line with width W on a substrate with a relative permittivity of ε_{r1}. The two load admittances $Y_s = G_s + jB_s$ consider the two radiating sides of the patch. Here, G_s depict the radiated power at one slot and B_s depicts the stored energy saved in the field near the slot. The admittance of the coupling aperture Y_a is also determined by the transmission line theory, as the coupling aperture is modeled as a short ended slot line at both ends. Hence, the admittance results is

$$Y_a = -j2Y_{a0}\cot\left(\frac{\beta_S L_a}{2}\right) = jB_a \qquad (5)$$

With Y_{a0} being the characteristic impedance of a slot line, placed on a substrate with the relative permittivity ε_{r2}. Based on this transmission line models, an expression for the input impedance Z_{in} of the aperture coupled patch antenna in the equivalent circuit of fig. 2.3 can be derived to

$$Z_{in} = \frac{n_2^2}{n_1^2 Y_P + Y_a} - jZ_{m0}\cot(\beta_m \Delta S) \qquad (6)$$

Here, Z_{m0} is the transmission line impedance of the feed line and β_m the corresponding phase constant. At this point, an approximation for G_s and B_s as well as for the transfer ratio n_2 has been omitted. For $\cot(\beta_m \Delta S) = 0$ assumed in (6), the following resonance condition is obtained.

$$B_P = \frac{-B_a}{n_1^2} \approx \frac{4Y_{a0}W^2}{\beta_S L_s^3} \qquad (7)$$

Here, β_s describes the phase constant of the slot line. Consider x is small cot(x) ≈ 1/x.
From equation (7) it is clearly visible, that an increasing length L_s results in a decreasing resonance frequency. An increasing length L_s not only results in a decreasing resonance frequency f_r, but also in an increasing resonance resistance R_r, due to the increasing coupling between patch and microstrip line. Hence, the influence of the admittance Y_p is increased, resonance resistance and a decreasing resonance frequency.
Here, a closed loop is formed around the point $Z_{in} = 50\Omega$, which offers a greater bandwidth for the antenna. This effect is knows as mutual resonances shown in fig.5.3. Furthermore, the stronger the coupling can be achieved by a decreased height of feeding substrate. To increase the bandwidth even more, another resonator is require i.e another patch element.

III. APERTURE COUPLED STACKED MICROSTRIP ANTENNA

A successful method to improve the achievable bandwidth of the antenna is the so called multimode technique as per previous research. The stacked patch is a possible realization of such an antenna. Here, the antenna is realized by stacking two patch elements on top of each other. In this part the aperture coupled stacked microstrip antenna with two patch elements is presented. The assembly of this antenna is differing from the reference antenna which is shown in fig.2.1. In this added second patch aligned with the centre of the reference antenna as shown in fig.2.2.The basic concept of this antenna is to create a third resonator, to achieve a greater bandwidth.

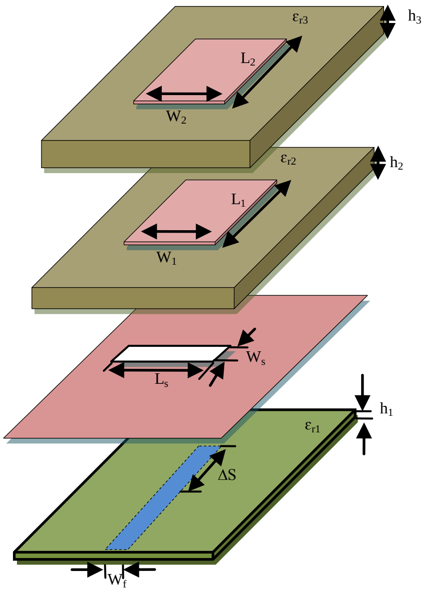


Fig. 2.1: Schematic assembly of stacked antenna

IV. PARAMETER CALCULATION OF PATCH ELEMENT

As per above modeling consider low thickness of feed substrate h_1=0.635 mm with high dielectric constant (ε_{r1}) = 6.15 RT/Duroid 6006 for designing ground plane. In this work consider 28 GHz as a design frequency, thickness of patch substrate height = stacked patch substrate height (h_2= h_3) =1.6 mm with dielectric constant RT/Duroid 5880 (ε_{r2} = ε_{r3}) = 2.2, copper thickness t_c = 0.0175 mm.

TABLE 1. SUMMARY OF BASIC PARAMETER

Antenna Parameter	Values
Design frequency	28 GHz
RT/Duroid 6006 (ε_{r1})	6.15
RT/Duroid 5880 (ε_{r2}= ε_{r3})	2.2
Substrate h_1	0.635 mm
Substrate h_2= h_3	1.6 mm
Copper thickness t_c	0.0175 mm

The width of microstrip line consists of dielectric substrate (ε_{r1}), substrate thickness (h_1) and conductor thickness (t_c). For the calculation of feed line width on the characteristic impedance $Z_0(f)$= 50Ω at central frequency of the proposed antenna, simply put the desired parameter in following equation (8) and find out desire value i.e W_f = 0.9351 mm.

$$W_f = \frac{7.48h}{e\left(z_0\frac{\sqrt{\varepsilon_r+1.41}}{87}\right)} - 1.25t_c \quad (8)$$

The slot length and width can be calculate based on previous research as equation (9-10) where λ_0 is the wave length of central frequency of the proposed antenna and find out the desired value L_a= 2.2 mm and W_a = 0.23 mm.

$$L_a \sim (0.1\text{-}0.2)\lambda_0 \quad (9)$$

$$W_a \sim 0.10\ L_a \quad (10)$$

The stub length L_S is adjusted until the input impedance at the design frequency becomes purely real.

$$Z_{in} = R_{in} + jX_{in} = R + jX - jZ_0\cot\left(2\pi L_{Seff}/\lambda_f\right) \quad (11)$$

Where R is the real part, and X is the imaginary part of the input impedance without stub. The effective stub length can be defined by equation (11) for X_{in} = 0

$$L_{Seff} = \frac{\lambda_0}{2\pi\sqrt{\varepsilon_{rfeff}(f)}}\arctan\left(\frac{X}{Z_0}\right) \quad (12)$$

$$L_S = L_{Seff} - \Delta L_S \quad (13)$$

Where the fringing stub length can be calculated by the following expressions

$$\Delta L_S = h_f g_1 g_2 g_3 g_5 / g_4 \quad (14)$$

$$g_1 = 0.434907\frac{\left[\varepsilon_{rfeff}(f)\right]^{0.81}+0.26}{\left[\varepsilon_{rfeff}(f)\right]^{0.81}-0.189}\left(\frac{\left(W_f/h_f\right)^{0.8544}+0.236}{\left(W_f/h_f\right)^{0.8544}+0.87}\right) \quad (15)$$

$$g_2 = 1 + \frac{\left(W_f/h_f\right)^{0.371}}{2.358\varepsilon_{rf}+1} \quad (16)$$

$$g_3 = 1 + \frac{0.5274\arctan\left[0.084\left(W_f/h_f\right)^{1.9413/g_2}\right]}{\left[\varepsilon_{rfeff}(f)\right]^{0.9236}} \quad (17)$$

$$g_4 = 1 + 0.0377\arctan\left[0.067\left(W_f/h_f\right)^{1.456}\right]\left\{6 - 5\exp\left[0.036\left(1-\varepsilon_{rf}\right)\right]\right\} \quad (18)$$

$$g_5 = 1 - 0.218\exp\left(-7.5\left(W_f/h_f\right)\right) \quad (19)$$

The fringing stub length find out ΔL_S = 0.15 mm at the real value of R.

Now calculate the reference antenna patch length L_1 = 2.4 mm and width W_1 = 4.3 mm and stacked patch length L_2 = 2.6 mm and width W_2 = 4.4 mm at 28 GHz design frequency by using the equation (20-23) given in [11-12].

$$W = \frac{C}{2f_0\sqrt{\frac{(\varepsilon_r+1)}{2}}} \quad (20)$$

$$\varepsilon_{eff} = \frac{(\varepsilon_r+1)}{2} + \frac{(\varepsilon_r+1)}{2}\left[1+12\frac{h}{W}\right]^{-\frac{1}{2}} \quad (21)$$

$$\frac{\Delta L}{h} = 0.412\frac{\left(\varepsilon_{eff}+0.300\right)\left(\frac{W}{h}+0.262\right)}{\left(\varepsilon_{eff}-0.258\right)\left(\frac{W}{h}+0.813\right)} \quad (22)$$

$$L = \frac{c}{2f\sqrt{\varepsilon_{eff}}} - 2\Delta L \quad (23)$$

Finally by using following two equations we can find the dimension of ground and substrate of the antenna are G_x = 12 mm and G_y =14 mm.

$$G_x = L_p + 6h \quad (24)$$

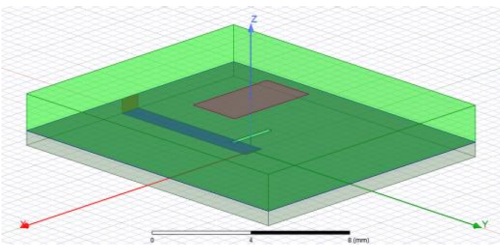
$$G_y = W_p + 6h \quad (25)$$

TABLE 2. ANTENNA DIMENSIONS

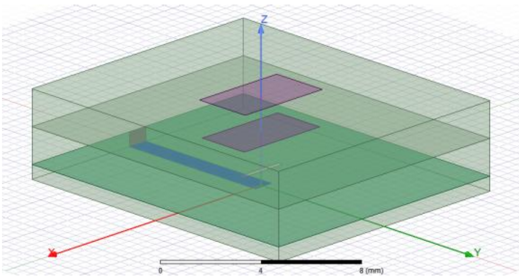
Parameter	Dimension(mm)
Ground Plane & Substrate Length (G_x)	12
Ground Plane& Substrate Width (G_y)	14
Patch Length (L_1)	2.4
Patch Width (W_1)	4.3
Stacked Patch Length (L_2)	2.6
Stacked Patch Width (W_2)	4.4
Width of feedline (W_f)	0.9351
Length of Stub(ΔL_S)	0.15
Length of slot L_a	2.2
Width of slot W_a	0.23

V. DESIGN AND RESULT ANALYSIS

In this paper, ANSYS HFSS 2019R1 was used for simulation work. It is a full wave electromagnetic simulator based on the finite element method. By using the dimensions from table (1-2) design and simulate two antenna. First an aperture coupled microstrip antenna as reference antenna and second aperture coupled stacked microstrip antenna as proposed antenna .After completion of simulation compare the results of reference antenna and proposed antenna in terms of reflection coefficient, impedance characteristics and radiation pattern.



(a) Reference antenna



(b) Proposed antenna

Fig. 5.1 (a) & (b) 3D model of reference and proposed antenna

A Return loss value of -10 dB is taken as the base value which signifies that 10% of incident power is reflected i.e. 90% of the power is accepted by the antenna which is considered excellent for mobile communication. The reference antenna resonates at 28 GHz with a return loss ≤ -10 dB from of -13.8310 dB, impedance bandwidth obtained 2.27 GHz from f_L= 27.07 GHz to f_H= 29.34 GHz while proposed antenna resonate at 28.695 GHz from the f_L= 26.98 GHz to f_H= 30.41 GHz having 3.43 GHz are shown in fig.5.2.

For a microstrip antenna, the VSWR should be between 1 and 2 along the bandwidth of efficiency. The proposed antenna voltage standing wave ratio (VSWR) can be observing 1.5108 at 28 GHz. VSWR value of stacked antenna is between 1 and 2 from lower to upper cut off frequency range.

Fig.5.3 shows the smith chart of the antenna. Reference antenna represent a single loop for single coupling and proposed antenna occur two loops for two coupling.

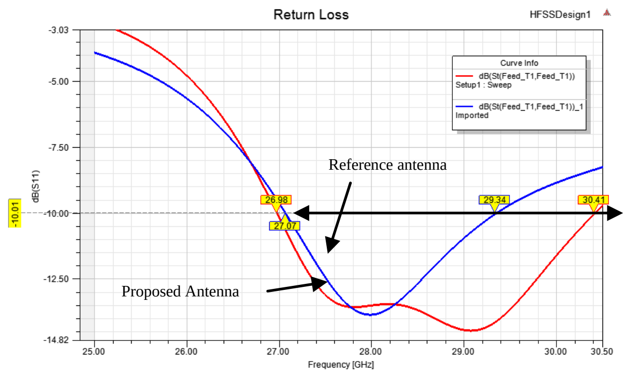


Fig. 5.2 Reflection coefficient of antenna.

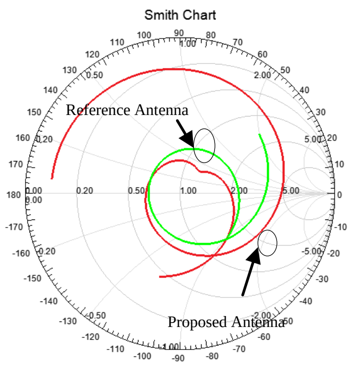


Fig. 5.3 Smith chart of antenna.

The gain of reference antenna is 5.0 dB and 6.36 dB of proposed antenna. 2D and 3D plot of the gain of reference antenna and proposed antenna is shown in fig.5.4 and fig.5.5 respectively.

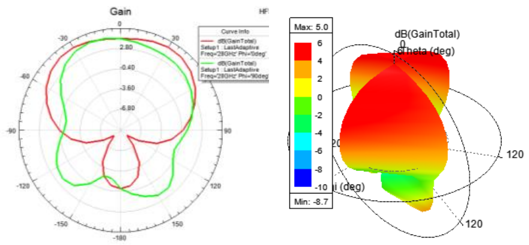


Fig. 5.4 2D & 3D gain plot of reference antenna

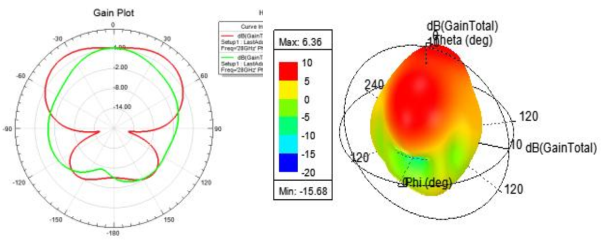


Fig. 5.5 2D & 3D gain plot of proposed antenna

TABLE 3. SUMMARY OF SIMULATED RESULT

Antenna Parameter	**Reference antenna**	**Proposed antenna**
Return loss	-13.83dB	-14.5 dB
VSWR	1.5108	1.4695
Bandwidth	2.27 GHz	3.43 GHz
Gain	5 dB	6.36 dB
Efficiency	99.67%	99.53%

VI. CONCLUSION

An aperture coupled stacked rectangular microstrip antenna has been proposed for 5G application. The antenna has bandwidth of 3.43 GHz which is ≈ 12% wider as compared to reference antenna bandwidth 2.27 GHz. The Gain of proposed antenna is 6.36 dB and reference antenna gain 5.0 dB. Here, it can be observed that the proposed antenna having wide band more than 780 MHz and gain is also high more than 5 dB which are requirements of 5 G application. Therefore, proposed antenna good option for 5G applications.

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