Air gap aperture coupled stacked patch antenna for dual-band

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Abstract-Microstrip antennas (MAS) are very useful antenna where low profile antennas are required. They are most popular due to their small size, low cost, light weight. The first aperture coupled microstrip antenna was introduced in 1985 by D M Pozar. Aperture coupled antenna is a particular antenna with high gain and wide bandwidth. This paper presents aperture coupled stacked patch antenna using air gap variation. The variation of air gap [2mm to 6mm] has been done between single patch antenna and an aperture coupled antenna. The main advantage of this antenna to increase the band width of the antenna as compared with single layered patch antenna. The resonant frequencies changes with air gap variations. The feed can be done either a conventional coaxial probe or through a coupling aperture in the ground plane as we done. This antenna works well in the frequency range (2.9 GHz to 6.0 GHz). The measured return loss exhibit an impedance bandwidth of 35%. The input impedance and VSWR return loss have been measured with the help of Network analyzer. [Agilent E8363B A.04.06] From the measured result it is found that the value of VSWR corresponding lower resonance frequencies increases from 14 to 2.2 with increasing air gap variation where as at the upper resonance frequencies is also increased from 1.8 to 2.3.

Key words: Aperture coupled microstrip antenna, Dual-band antenna, Network analyzer, Microstrip line feed

I INTRODUCTION

In recent year the use of microstrip antenna has become quit popular because of their properties such as low profile, light weight, compact and conformable is structure and easy to fabricate[1]. The aperture coupled microstrip antenna first proposed by Pozar [2] in 1985 has a number of advantages over other feeding method involving galvanic contact between the antenna and feed line. The aperture is usually centered with respect to the patch where the patch has its maximum magnetic field. A simple technique for changing the resonant frequencies with out resulting to a new antenna [3-4]. The idea is introduce an air gap variation between the single patch and aperture coupled microstrip antenna. The air gap variations affect the resonant frequencies. The resonant frequencies can therefore be tuned by the variation of air gap. The band width will also increases particularly due to the increases in the height of the dielectric medium. A number of experiment and theoretical structure have been carried out to analyze and design aperture coupled microstrip antenna. Full wave analysis using the method of moments has been used to determine the various antenna parameters [5-8]. A transmission line [9] and cavity model [10] have been proposed as efficiently analysis and design method. Recently an effect of the different shapes aperture coupled microstrip slot antenna [11] and circularly polarized aperture coupled microstrip antenna with resonant slot and a screen was proposed [12]. Optimum design of an aperture coupled microstrip patch antenna describe in details [13]. An Introduction of aperture coupled microstrip slot antenna with microstrip line feed has been discussed [14]. In this paper a simple but accurate design method from air gap aperture microstrip antenna is presented. The dual-band operation of air gap aperture coupled microstrip antenna are useful in many application such as dual-band transmit receive models for space vehicles.

II ANTENNA DESIGN

The proposed air gap aperture coupled microstrip antenna is shown in Fig.1 (a). In this figure there are two antennas.
1. Upper patch (single patch)
2. Aperture coupled patch with microstrip line

The single patch is design by using 3.0GHz and the aperture coupled patch is design at 2.5GHz. The side view of the air gap aperture coupled microstrip antenna is shown in Fig.1 (b). The radiating microstrip patch element is printed on the top of the substrate and the microstrip feed line is printed on the bottom of the feed substrate. The first thing to design of the patch is choosing a suitable substrate of suitable thickness. Taking low dielectric substrate to increases the band width and radiation efficiency of the antenna. A microstrip antenna in its simplest form consists of a radiating patch on one side of dielectric substrate and a ground plane on the
other side. Transmission line model is used for analyzing the patch antenna for rectangular shapes. A simple patch antenna can be designed for the given dielectric constant.

2.1 Length and width of single patch: To design the rectangular patch width of the antenna is given by

$$W_u = \frac{c}{2 \cdot f_r \left( \frac{\varepsilon_r + 1}{2} \right)^{\frac{1}{2}}}$$  \hspace{1cm} (1)

where $C =$ velocity of light
$W =$ width of the microstrip patch
$\varepsilon_r =$ Dielectric constant of the substrate

Length of the resonant element is given by

$$L_{\text{eff}} = \frac{c}{2 \cdot f_r \sqrt{\varepsilon_{\text{eff}}}} - 2A$$  \hspace{1cm} (2)

where $\varepsilon_{\text{eff}} =$ Effective dielectric constant of the substrate
$\Delta l =$ Line extension
$\varepsilon_{\text{eff}}$ and $\Delta l$ can be expressed as

$$\varepsilon_{\text{eff}} = \left( \frac{\varepsilon_r + 1}{2} \right) + \left( \frac{\varepsilon_r - 1}{2} \right) \cdot \left( 1 + \frac{10 \cdot h}{W_u} \right)^{-0.5}$$  \hspace{1cm} (3)

$$\Delta l = 0.412h \left[ \frac{0.262 + \frac{W_u}{h}}{0.813 + \frac{W_u}{h}} \right] \left[ \varepsilon_{\text{eff}} + 0.3 \right] - \frac{\varepsilon_{\text{eff}} - 0.258}{\varepsilon_{\text{eff}} - 0.258}$$  \hspace{1cm} (4)

where, h is the thickness of the substrate.

Finally the actual length of the single patch antenna is obtained as $L_u = L_{\text{eff}} - 2\Delta l$. The single patches were designed to operate at a resonant frequency of 3.0 GHz, their length and width were calculated to be $L_u = 23.01$ mm and width $W_u = 30.01$ mm respectively.

2.2 Length and width of aperture coupled patch: The dimension of aperture coupled microstrip antenna can also calculated by using above transmission equations. The dimension of aperture coupled microstrip antenna remaining was designed at a resonant frequency of 2.5 GHz, their length and width were calculated to be $L_p = 27.78$ mm and width $W_p = 36.18$ mm respectively.

2.3 Slot width: The width of slot affect coupling level from the feed lines to the patch. Generally the ration of the slot length to the slot width is kept typically as 10:1. In this paper the width of the slot is taken $W_s = 1.0$ mm.

2.4 Slot length: The coupling level is primarily decided by the slot length. There are two types of the slot are used in aperture coupled microstrip antenna design they are resonate and non resonate type based on the length of length slot. If the slot length is comparable to the half of the wave length of the antenna it is called as the resonant slot. If small length slot are used it is non resonant.

2.5 Feed line width: The physical size of the antenna derived from microstrip transmission line, the microstrip antenna is modeled as a length of transmission line of characteristics [15-16] impedance given by (5) (6)
\[ A = \sqrt{\left( \frac{14 + \frac{8}{\varepsilon_r}}{11} \right) \left( \frac{4h}{W} \right) + \frac{1 + \frac{1}{\varepsilon_r}}{2} \pi^2} \tag{6} \]

Where \( W' = W_p + \Delta W \) and

\[ \Delta W = \Delta W = W_p \left( \frac{1 + \frac{1}{\varepsilon_r}}{2} \right) \tag{7} \]

\[ \frac{\Delta W}{t} = \frac{1}{\pi} \ln \left( \frac{4e}{\left( \frac{t}{h} \right)^2 + \left( \frac{1}{\varepsilon_r} \right) \left( \frac{w}{t} + 1.11 \right)^2} \right) \tag{8} \]

If we replace \( \varepsilon_r \) with \( \varepsilon_{eff} \)

\[ Z_0 = \frac{60}{\sqrt{\varepsilon_{eff}}} \ln \left( \frac{8h}{W_p} + \frac{W_p}{4h} \right) \Omega \text{if } \frac{W_p}{h} < 1 \tag{9} \]

Otherwise

\[ Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{eff}}} \left( \frac{W_p}{h} + 1.393 + 0.677 \text{Im}\left( \frac{W_p}{h} + 1.449 \right) \right) \Omega \tag{10} \]

\( \varepsilon_{eff} \) is expressed as follow

\[ \varepsilon_{eff} = \frac{\varepsilon_r}{1 + \frac{12h}{W_p}} + 0.04 \left( 1 - \frac{W_p}{h} \right)^2 \text{if } \frac{W_p}{h} < 1 \tag{11} \]

Otherwise

\[ \varepsilon_{eff} = \left( \frac{\varepsilon_r + 1 + \varepsilon_r - 1}{2} \right) \left[ \frac{1}{1 + \frac{12h}{W_p}} \right] \]

Characteristics impedance evaluation of microstrip is important to determine the width of the feeding line calculated using equation (6). The width of a \( Z_0 = 50 \) \( \Omega \) line \( w=3.0 \) mm

2.5 Feed line position with respect slot: For maximum coupling the feed line must be placed positioned to the centre of slot. Skewing the feed line from the slot will reduce the coupling as will positioning the feed line toward the edge of slot.

2.6 Position of the patch with respect to slot: For the maximum coupling the patch should be centered over the slot, moving the slot in H-field direction little effect on the antenna performance. But if it is moved in E-field leads to reduction in coupling

2.7 Length of tuning stub: The length stub is used to turn the excess reactance of the slot could antenna.

He stub is typically slightly less than \( \frac{\lambda_g}{4} \) in length.

III EXPERIMENTAL MEASUREMENTS

The air gap aperture coupled microstrip antenna was measured using network analyzer [Agilent E8363B A.04.06] for obtaining the desired dual-frequency behavior. The aim of air gap variation to see the how the resonant frequencies are shifting. The input impedance is easily matched by the variation of air gap. The variation of upper and lower resonant frequencies and their ration with air gap variation is shown in Table 1. In order to study the performance of designed air gap aperture coupled microstrip antenna return loss and band width were measured experimentally with air gap variation are shown in Table 2. The band width is achieved about 35% with air gap variations.

<table>
<thead>
<tr>
<th>Air Gap Variation (mm)</th>
<th>Lower resonant frequency ( (f_1) ) in GHz</th>
<th>Upper resonant frequency ( (f_2) ) in GHz</th>
<th>Ratio of resonant frequencies ( (f_2/f_1) ) in GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>2.9</td>
<td>6.10</td>
<td>2.10</td>
</tr>
<tr>
<td>4.0</td>
<td>3.5</td>
<td>5.9</td>
<td>1.68</td>
</tr>
<tr>
<td>6.0</td>
<td>3.6</td>
<td>6.0</td>
<td>1.65</td>
</tr>
</tbody>
</table>

Table1-Variation of upper and lower resonant frequencies and their ration with air gap variations
Table 2-Variation resonant frequencies, return loss and band width with the variations of air gap

<table>
<thead>
<tr>
<th>Lower resonance frequency $f_1$ (GHz)</th>
<th>Upper resonance frequency $f_2$ (GHz)</th>
<th>Return loss (dB) for $f_1$</th>
<th>Return loss (dB) for $f_2$</th>
<th>Band width in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.9</td>
<td>6.10</td>
<td>-14</td>
<td>-10</td>
<td>35</td>
</tr>
<tr>
<td>3.5</td>
<td>5.9</td>
<td>-11</td>
<td>-7.8</td>
<td>25</td>
</tr>
<tr>
<td>3.6</td>
<td>6.0</td>
<td>-8.5</td>
<td>-7.5</td>
<td>24</td>
</tr>
</tbody>
</table>

IV DESIGN PARAMETERS
For designing the air gap aperture coupled microstrip antenna following parameter was used.
Substrate material used Glass Epoxy
Thickness of the dielectric substrate $h = 1.6$ mm
Relative permittivity of the substrate $\varepsilon_r = 4.5$
Frequency for single patch antenna $f_1 = 3.0$ GHz
Frequency for ACM antenna $f_1 = 2.5$ GHz
Thickness of the patch $t = 0.0018$ cm
Permittivity constant $\varepsilon_0 = 8.85 \times 10^{-12}$ F/m

Calculated using the standard equations, which are given below.
Dimensions of single patch $= 23.01 x 30.15$ mm
Dimension of ACM antenna $= 27.78 x 36.18$ mm
Dimensions of the slot $(L_s W_s) = 1.0 x 20.0$ m
Length of the microstrip line $L_f = 14.70$ mm
Width of the microstrip line $W_f = 3.0$ mm

V DISCUSSION OF RESULT
1. The variation of input impedance with frequency for aperture coupled microstrip antenna with air gap variation as shown in Fig 2. [(a)-(c)]. It is observed that when we are increasing the air gap [20-6 mm] variation between the single patch and aperture coupled microstrip antenna shows dual resonance in which lower resonance frequency increases where as upper resonance frequency is almost constant with increasing air gap.
2. The variation of VSWR with frequency for aperture coupled microstrip antenna with air gap variation as shown in Fig 3. [(a)-(c)]. It is observed that the value of VSWR corresponding to lower resonance frequency is increases from 1.4 to 2.2 with increasing the air gap [20-6 mm] variation between the single patch and aperture coupled microstrip. Where as at the upper resonance frequency the value of VSWR is also increased from 1.8 to 2.3
3. The variation of resonance frequencies with return loss is shown in Fig 4. [(a)-(c)]. It is observed that the value of return loss corresponding lower resonance frequency decreases from -14 dB to -8.5 dB with increases the air gap. Where as at upper resonance frequency is also decreases from -10 dB to -7.5 dB with increases the air gap.
4. The variation of resonance frequency ratio $f_2/f_1$ with increases the air gap between the single patch and aperture coupled microstrip antenna are decreases. It is shown in Fig 5

VI CONCLUSIONS
This paper has investigated air gap between single patch antenna and aperture coupled microstrip antenna. By using air gap variation between single patch antenna and aperture coupled microstrip antenna is obtain dual-band operation. It is observed from experimental results good impedance matching at both resonant frequencies. The overall band width is also achieved 35% of the aperture coupled microstrip antenna. The ratio of resonance frequency is found decreasing (2.1 to 1.6 GHz) with increasing the air gap variation. Therefore the proposed antenna can be used for dual sim mobile application

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REFERENCES
Fig. 3 (b) The variation of VSWR with frequency for aperture coupled microstrip antenna with air gap variation = 4.0mm

Fig. 3 (c) The variation of VSWR with frequency for aperture coupled microstrip antenna with air gap variation = 6.0mm

Fig. 4 (a) The variation of return loss with frequency for aperture coupled microstrip antenna with air gap variation = 2.0mm

Fig. 4 (b) The variation of return loss with frequency for aperture coupled microstrip antenna with air gap variation = 4.0mm

Fig. 4 (c) The variation of return loss with frequency for aperture coupled microstrip antenna with air gap variation = 6.0mm

Fig. 5 The variation resonance frequency ratio for aperture coupled microstrip antenna with air gap