Transmission Line Model of Dual Patch Aperture Coupled Microstrip Antenna

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ABSTRACT

Microstrip antennas have a number of useful properties, but one of the serious limitations of these antennas has been their narrow bandwidth characteristic. Efforts to improve the bandwidth usually result in reduction of radiation efficiency and consequently antenna gain. Moreover, its radiation pattern is normally hemispherical instead of being omni directional, suitable for wire less communication. A novel microstrip antenna is presented here, which is formed by using two aperture coupled rectangular patches fed back to back by a single feed line placed in between with a suitable stub in series. The configuration results in considerable enhancement of bandwidth (about 12% for <2:1 VSWR) without sacrificing the radiation efficiency together with an almost omni directional radiation pattern.

INTRODUCTION

An exploded view of an aperture coupled microstrip antenna [1] is shown in Fig. 1. It consists of a rectangular patch of dimensions a x b printed on a substrate of thickness h and dielectric constant $\varepsilon_{rn}$. The microstrip patch is fed by a microstrip line through an aperture or slot in the common ground plane as shown in the Fig1. The aperture is of dimensions $La \times Wa$ and centered at $(Xo,Yo)$. The width of the microstrip line is W and it is printed on a substrate described by thickness t and dielectric constant $\varepsilon_{rt}$. The characteristic impedance of the microstrip line is denoted by $Z_{om}$ and that of the slot line corresponding to the coupling slot by $Z_{os}$. Coupling of the slot to the dominant mode [2] of the patch and the microstrip line occurs because the slot interrupts the longitudinal current flow in them.

The coupling slot is nearly centered with respect to the patch where the magnetic field of the patch is maximum. This is done on purpose to enhance coupling [3] between the magnetic field of the patch and the equivalent magnetic current near the slot. The coupling amplitude can be determined [4] from the following expression

$$\text{Coupling} \equiv \iiint_{V} M \cdot \vec{H} \, d\tau \equiv \sin \left( \frac{\pi X_0}{La} \right)$$

where $X_0$ is the offset of the slot from the patch edge.

THEORY FOR ANALYSIS

Simplified equivalent circuit of dual patch aperture-coupled microstrip antenna is shown in Figs. 2 and 3. In this equivalent circuit, the patch is characterized by admittance $Y_{patch}$ and the aperture by an admittance $Y_{ap}$. The patch admittance is determined at the centre of the slots.

In this feed configuration the patch antenna appears in series with the feed because of slot coupling. The nonresonant slot is represented as an inductor in series with the R-L-C network representing the patch resonator. The two patches on the both sides of the microstrip feed line are acting as parallel loads. The open circuited microstrip stub of length $L_s$ can be replaced by a shunt capacitor $C_s$ such that $1/\omega C_s = Z_o \cot(\beta L_s)$, where $Z_o$ is the characteristic impedance, and $\beta$ is the propagation constant of the microstrip feed line. As the patches are exited by the same feed line and we took all other microstrip parameters (antenna substrates height and dielectric constant) same, they have the same frequency of operation. In this case patch parameters are exactly the same for the both patches. So we take $n = n', Y_{patch} = Y_{patch}'$, $n_i = n_i'$, $l = l'$ and $Y_{ap} = Y_{ap}'$. The transmission line model for one of the two aperture coupled patches is shown below.

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The coupling of the patch to the aperture is described by an impedance transformer of turns ratio $n_1 = L_2/b$ and $Z_1$ and $Z_2$ are the impedances looking toward the left and right of the aperture. With reference to Fig. 2,

$$Z_{patch} = Z_1 + Z_2 = 1/Y_1 + 2/Y_2$$

$$Y_1 = Y_o \frac{(G_r + j B_{open}) + j Y_o \tan(\beta L_1)}{(Y_o + j (G_r + j B_{open}) \tan(\beta L_1))}$$

$$L_1 = \frac{X_o}{Y_o}$$

$$Y_2 = Y_o \frac{(G_r + j B_{open}) + j Y_o \tan(\beta L_2)}{(Y_o + j (G_r + j B_{open}) \tan(\beta L_2))}$$

$$L_2 = a - L_1$$

Here $(Y_o, \beta)$ characterize the rectangular patch antenna as a microstrip line of width $b$ and $(G_r + j B_{open})$ is the edge admittance of the patch. The value of $Y_{ap}$ can be obtained from the transmission line model of a slot and is given by

$$Y_{ap} = - j 2 Y_o \cot(\beta \frac{L_s}{2})$$

A transformer of turns ratio $n_2$, used to describe the coupling of the patch to the microstrip feed line is modeled from the discontinuity $\Delta V$ in modal voltage of the feed microstrip line, that is
As \( n_2 = \Delta V/V_o \), where \( V_o \) is the slot voltage.

Thus \( n_2 = (J_o(\beta_s W/2) J_o(\beta_m W_a/2) / (\beta_s^2 \beta_m^2)) \)

\((k_2 \cos(k_2 h) + k_2 \sin(k_2 h))\)

where \( J_o(.) \) is the zeroth order Bessel function and

\[ k_1 = k_o(\sqrt{\varepsilon_{res} - \varepsilon_{rem}}) \]

\[ k_2 = k_o(\sqrt{\varepsilon_{res} + \varepsilon_{rem} - 1}) \]

Thus the total input load on the microstrip line is given by

\[ Z_{in} = n_2^2 / (2.(n_1^2 Y_{patch} + Y_{ap})) \]

The expressions for the characteristic impedance and guide wavelength of a slot line on a substrate of low \( \varepsilon_r \) have been obtained [6] by curve-fitting of the numerical results obtained using Galerkin’s method in the Fourier transform domain. These expressions are

\begin{align*}
\lambda_s/\lambda_o &= 1.194 - 0.24 \ln \varepsilon_r - \left( 0.62 - \varepsilon_r^{0.83} \right) / \left( 1.344 + W/h \right) - 0.0617 \left[ 1.91 - \left( \varepsilon_r - 2 \right) / \varepsilon_r \right] \ln \left( h/\lambda_o \right) \\
Z_{os} &= 133 + 10.34 \left( \varepsilon_r - 1.8 \right)^2 + 2.87 \left( 2.96 + (\varepsilon_r - 1.582)^2 \right) \left( W \cos \beta_s L_a + 2.32 \varepsilon_r - 0.56 \left( (35.2 - 6.7 \varepsilon_r) (100 h/\lambda_o)^2 - 1 \right) \right)^{1/2} \left( 684.45 h/\lambda_o \right) \left( \varepsilon_r - 1.35 \right)^2 \left( 13.23 (\varepsilon_r - 1.722) W \cos \beta_s L_a \right)^2 \\
\end{align*}

SIMULATION RESULTS

Investigations have been carried out through computer simulation using the Finite Elements based software IE3D (Zeland Corp., USA) at a frequency band centered around 18 GHz for dual patch aperture coupled rectangular microstrip radiators designed according to the transmission line model developed.
Here both the antenna substrates is of thickness 1/16 inch (=1.5875 mm) and $C_r=2.4$ and corresponding resonant patch length and width are 3.70 mm and 5.60 mm respectively. The feed substrate is 1/32 inch (=0.79375 mm) thick with $C_r=2.4$.

For a 25 ohm feed line the aperture parameters according to our design are chosen as $L_a = 5.234$ mm, $L_s = 2.79$ mm and $W_a = 2.98$ mm.

Simulation results for return loss are shown in Fig. 4. The simulated values indicate good impedance matching at the design frequency (simulation shows a slight shift in resonance frequency as finite substrate effect was not taken into account) and the 2:1 V.S.W.R. bandwidth extending nearly from 16.9 GHz to 18.2 GHz.

The most interesting investigation is the radiation pattern, as shown in Figs. 5 to 7 which show almost omni directional pattern coverage (barring the unavoidable end fire null) with a greater than 30 dB on-axis cross polar discrimination.

**CONCLUSION**

Today’s world goes to more and more digitized wire less communication like mobile, blue-tooth or radio telephony everyone’s need is to multimedia data transfer with high speed and any one have to obtain a wide band width and omni-directional pattern for the antenna used. The dual patch aperture coupled microstrip antenna can fulfill all these criteria unlike other printed radiators.

**REFERENCES**