Designing a Microstrip Patch Antenna(with Inset Feed)operating at 3 GHz

(Calculation and visualization of radiation parameters and scrutinization of their use)

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Abstract:

In this contribution, a microstrip patch antenna, with an *inset feed* of desired length, has been designed (using MATLAB), that is allowed to resonate at 3 GHz and resonates, precisely, at*2.74 GHz*. The substrate assigned to the antenna is *Air*. The design and radiation parameters have been discussed, with proper explanations and their utilization in the world of communication systems.

Keywords: microstrip, antenna, feeding, radiation parameters, 5G

a. Introduction:

It wasn't until the 1970s[1],[2]that Microstrip Antennas received a considerable amount of worldwide attention. Conventionally,Microstrip Antennas comprise a pair of parallel conducting layers separated by a dielectric medium, which is referred to as the *substrate* (here, it's air). The patch is a thin conductor and the thickness of the conductor is generally a fraction of a wavelength. It has the resonant behavior and is responsible to achieve the required bandwidth.

The design of the Microstrip Antenna should be done such a way that the maximum radiation can be achieved atthe normal to the patch. This isachieved by proper choice of mode of excitation beneath the patch. Generally, the thickness (t)[3] of the patch should be in the range of (where λ_0 is free space wave length) and the height (h) of dielectric material in the range of:

$$0.003\ \lambda_0 < h < 0.05\ \lambda_0$$

For a rectangular patch, the length (L) of the element is usually[3]in the range of:

$$\lambda_0/3 < L < \lambda_0/2$$

Various substrates can be used for the design of microstrip antenna.

Through the years, feeding methods[4], [5]have proved to be useful for Microstrip Antennas and there exist many configurations for the same. The most popular one is the *Inset Feed* technique, that has been used for the model in this contribution. With the model being ready, the radiation parameters are calculated and the results are vividly discussed.

b. Methods:

Generally, like any other form of antenna, Microstrip Antennas can be designed using the *HFSS(High-Frequency Structure Simulator)* software (by ANSYS) and the *Antenna Design/Simulation Toolbox* of MATLAB- the following model has been created using the later. As mentioned earlier, a Microstrip Antenna primarily consists of a rectangular patch of desired (pre-defined) dimensions, and later on, one of the feeding methods is implemented. *Figure 1* shows the model.

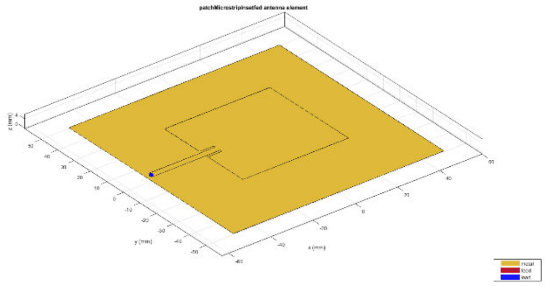

Fig. 1: patchMicrostripInsetFed antenna element

The parameters of the same are given later in *Table 1*.

For the transmission line model of the Microstrip Antenna, initially, the width (w) and length (L) of the rectangular patch are calculated using the following formulae:[6]

$$w = \frac{v_0}{2 f_r}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

$$L = \frac{1}{2 f_r \sqrt{\varepsilon_{eff}}\sqrt{\mu_0 \varepsilon_0}} - 2\Delta L$$

where ΔL is given by:[6]

$$\Delta L = 0.412 \frac{(\varepsilon_{eff} + 0.3)\left(\frac{w}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{w}{h} + 0.8\right)}$$

and ε_{eff} is calculated as:[6]

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{w}\right)^{-0.5}$$

Here, the radiating slots of antenna are identical. Hence $G_1 = G_2$. G_1 can be calculated as follows:[6]

$$G_1 = \frac{1}{90}\left(\frac{w}{\lambda_0}\right)^2, \text{ where } w << \lambda_0$$

$$G_1 = \frac{1}{120}\left(\frac{w}{\lambda_0}\right), \text{ where } w >> \lambda_0$$

Generally, the load impedance is 50 Ω for which, the inset feed length, y_0, is given by:[6]

$$R_{in}(y = y_0) = \frac{1}{2(G_1 \pm G_{12})}\cos^2\left(\frac{\pi}{L} y_0\right)$$

or,

$$R_{in}(y = y_0) = R_{in}(y = 0)\cos^2\left(\frac{\pi}{L} y_0\right)$$

The parameters mentioned above can be calculated by developing a simple MATLAB code as given below:

MATLAB Code:

```
%% Design Parameters
clc; clear all; close all;
er=input('Enter the value of dielectric constant: ');
f=input('Enter the value of operating frequency in GHz: ');
h=input('Enter the value of thickness of substrate in mm: ');
rin0=input('Enter the value of characteristic impedance:');
f1=f*(10^9);
c=3*(10^11);
w=((c/(2*f1))*((2/(er+1))^(0.5)));
w
ereff=((er+1)/2)+(((er-1)/2)*((1+(12*(h/w)))^(-0.5)));
ereff
deltaL=h*0.412*((ereff+0.3)*(((w/h)+0.264))/((ereff-0.258)*((w/h)+0.8)));
deltaL
L=(c/(2*f1*((ereff)^0.5)))-(2*deltaL);
L
lambda0=(c/f1);
```

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```
k=(2*pi)/lambda0;
A=(1/(120*(pi)^2));
F1=0;
for theta=[0:((pi/180)*75):pi]
      z=k*L*sin(theta);
      J=besselj(0,z);
      I=(((sin(((k*w)/2)*cos(theta)))/(
      cos(theta)))^2)*((sin(theta))^3)*
      J;
      F1=I+F1;
end
g12=F1*A
if (w>lambda0)
      g1=((1/120)*(w/lambda0));
      g1
end
if (w<lambda0)
      g1=((1/90)*((w/lambda0)^2));
      g1
end
Rin=(1/(2*(g1+g12)));
Rin
y0=((L/pi)*(acos(sqrt(rin0/Rin))))
```

After entering the required values, the design parameters are obtained, as are given in Table 1.

Parameter	**Value**
ε	1.0 (*Air*)
f	3 GHz
h	1.6 mm
Z_0	50 Ω
w	50mm
L	47.7288mm
ε_{eff}	1
ΔL	1.1356
L	22.4430
g_{12}	-3.2733e-04
g_1	0.0028
R_{in}	204.0442Ω
y_0	15.9968mm

Table 1: Values of Design Parameters

Next, the radiation parameters are calculated and visualized using the Antenna Design/Simulation Tool of MATLAB. A simple MATLAB code can also be used to do the same, which is given below:

MATLAB Code:

```
%% Antenna Properties
% Design antenna at frequency
3000000000Hz
antennaObject =
design(patchMicrostripInsetfed,30000000
00);
% Properties changed
antennaObject.Length = 0.0500000;
antennaObject.Width = 0.0477288;
% Update substrate properties
antennaObject.Substrate.Name = 'Air';
antennaObject.Substrate.EpsilonR =1;
antennaObject.Substrate.LossTangent =
0;
antennaObject.Substrate.Thickness =
0.0016;
% Update load properties
antennaObject.Load.Impedance = 50;

%% Antenna Analysis
% Define plot frequency
plotFrequency = 3000000000;
% Define frequency range
freqRange = (2700:20:3700) * 1e6;
% show for patchMicrostripInsetfed
figure;
show(antennaObject)
% s11 for patchMicrostripInsetfed
figure;
s = sparameters(antennaObject,
freqRange);
rfplot(s)
% current forpatchMicrostripInsetfed
figure;
current(antennaObject, plotFrequency)
% pattern for patchMicrostripInsetfed
figure;
pattern(antennaObject, plotFrequency)
% azimuth for patchMicrostripInsetfed
figure;
patternAzimuth(antennaObject,
plotFrequency)
% elevation for patchMicrostripInsetfed
figure;
patternElevation(antennaObject,
plotFrequency)
% VSWR for patchMicrostripInsetfed
figure;
vswr(antennaObject, freqRange, 50)
```

In the next section, the results from the above calculations have been discussed.

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c. Results:

The Radiation Parameters, that have been obtained using the Design Tool, are given below:

- ***Radiation Pattern*:**

The 3-D Radiation Pattern, shown in Figure 2, gives the **Directivity** of **9.41 dB** at the operating frequency of 3 GHz.

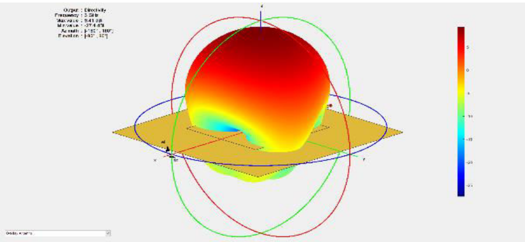

Fig. 2: 3-D Radiation Pattern

- ***Return Loss*:**

It is observed that the Microstrip Antenna resonates at a frequency of 2.74 GHz with a **Return Loss** value of **-8.5669dB**.

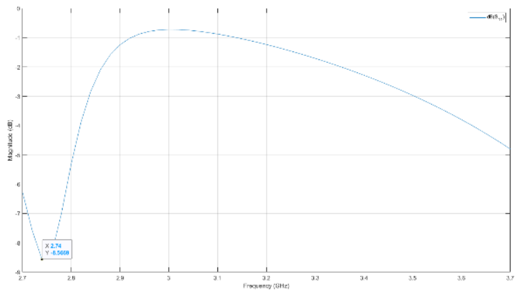

Fig. 3: Plot of Return Loss (dB) vs. Frequency (GHz)

- ***Current Distribution*:**

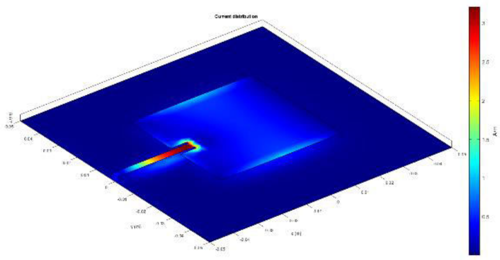

Fig. 4: Current Distribution

- ***Azimuth and Elevation Polar Plots*:**

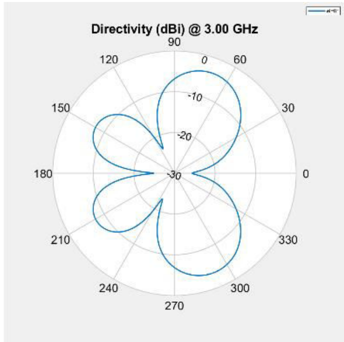

Fig. 5: Azimuth Polar Plot

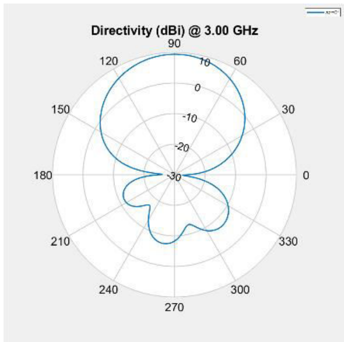

Fig. 6: Elevation Polar Plot

- ***VSWR*:**

For a patch antenna, the VSWR generally lies in between 1 and 2. Ideally, it is 1. Here, the **VSWR** value is **2.1896**.

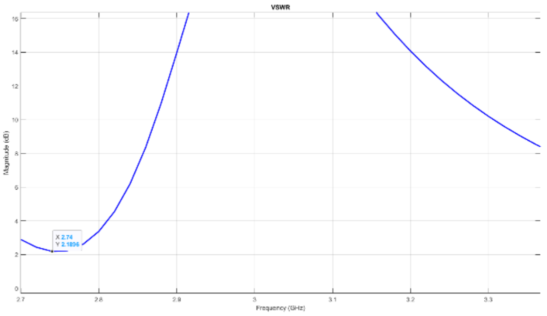

Fig. 7: VSWR plot

d. Conclusion:

The Microstrip Patch Antenna resonates at *2.74 GHz* (operating frequency= 3 GHz) with a *Return Loss* of *-8.5669 dB*. The *VSWR* is *2.1896*whereas, ideally, it is 1, and the Directivity is *9.41 dB*. This antenna can serve its right purpose in 5G mobile communication which requires high bandwidth. Due to its compact size, it is convenient for devices, where the space is a predominant constrain.

References:

[1] G. A. Deschamps, "*Microstrip Microwave Antennas*", Presented at the Third USAF Symposium on Antennas, 1953.

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[3] Constantine A. Balanis, "*Antenna Theory*",Third Edition, 2016.

[4] I. J. Bahl and P. Bhartia, "*Microstrip Antennas*", Artech House, Dedham, MA, 1980.

[5] K. R. Carver and J. W. Mink, "*Microstrip Antenna Technology*", IEEE Trans. Antennas Propagat., Vol. AP-29, No. 1, pp. 25-27, January 1981.

[6] Constantine A. Balanis, "*Antenna Theory*",pp. 669-670, Third Edition, 2016.