Design of Microstrip Patch Antenna for Ku-Band Satellite Communication Applications

Settapong Malisuwan, Jesada Sivaraks, Navneet Madan, and Nattakit Suriyakrai

***Abstract*—A rectangular microstrip patch antenna is presented in this paper for Ku-band satellite communication applications. The proposed E-shaped patch antenna is designed to cover various applications such as broadcasting, remote sensing and space communication. To include the effect of high frequency in the procedure, the concept of microstrip-based Cole-Cole diagram is adopted to create a frequency-dependent (lossy) characteristic impedance. The simple method proposed in this research is compatible with Computer Aided Design (CAD) and hence, design of microstrip antenna for Ku Band satellite from this research will be fast and easy to implement.**

***Index Terms*—Microstrip antenna, ku-band, e-shaped, frequency-dependent, CAD.**

I. Introduction

In the recent years, demand for small antennas for wireless communication has increased tremendously hence, resulting extensive research on compact microstrip antenna design among microwave and RF engineers. A compact microstrip antenna such as VSAT systems is one of the most suitable applications to support high mobility satellite communication devices. Ku-band (12-18 GHz) is one of the most preferred choices in VSAT systems. VSAT can be adopted for satellite television broadcast and satellite television [1]-[3]. Moreover, VSAT is a one of the best emergency communication backup system during disasters.

Microstrip patch antenna is a two dimensional planner antenna configuration having all the advantages of a printed circuit board which include but are not limited to easy to design, easy to manufacture and low cost. Though these antenna structures possess several advantages over other methods it also has some severe disadvantages which are low bandwidth, low gain, and low efficiency. There are many researches in progress in overcoming these disadvantages in order to make full use of advantages such as ease in design, ease in manufacturing and low cost in manufacturing these compact microstrip antennas.

The performances of these antennas are dependent upon their physical configuration. Various methods to improve the performance of antenna on their physical configuration are suggested by the researchers. Microstrip patch antennas are fed by methods that are categorized into contacting and non-contacting. In contacting methods, RF power is fed directly to the radiating patch using the connecting link which is the microstrip line [4]. While non-contacting, electromagnetic field coupling is conducted via transmission of power from microstrip line and radiating patch. "The four most popular feed techniques used are the microstrip line, coaxial probe (both contacting schemes), aperture coupling and proximity coupling (both non-contacting schemes)" [5].

In this paper, an E-shaped antenna structure is designed by cutting a notch in a rectangular microstrip patch antenna. Moreover, in this research, we consider the effect of very high operating frequency in GHz range which increases chances calculation error in the model. The proposed antenna in this paper can be used for broadcasting, remote sensing, aeronautical radio navigation and mobile satellite applications.

II. Antenna Design Methodology

To achieve the design objective in this research, first a rectangular microstrip patch antenna is constructed based on the standard designing procedure. For efficient radiation, a practical width of the rectangular patch element is [6]

$$\mathrm{w} = \frac{1}{2\mathrm{f_r}\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_\mathrm{r}+1}} \tag{1}$$

And the length of the antenna becomes [7], [8]

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

where,

$$\Delta L = 0.41h\frac{\varepsilon_{eff}+0.3}{\varepsilon_{eff}-0.258}\frac{\left(\frac{w}{h}+0.264\right)}{\left(\frac{w}{h}+0.8\right)} \tag{3}$$

And

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+10\frac{h}{w}\right)^{-B} \tag{4}$$

where B is given by:

$$B = 0.564\left\{1+\frac{1}{49}\ln\left(\frac{\left({}^{w}/_{h}\right)^4+\left({}^{w}/_{52h}\right)^2}{\left({}^{w}/_{h}\right)^4+.432}\right)+\frac{1}{18.7}\ln\left[1+\left(\frac{w}{18.1h}\right)^3\right]\right\}\left(\frac{\varepsilon_r-0.9}{\varepsilon_r+3}\right)^{0.053} \tag{5}$$

"where, λ is the wave length, f_r (in Hz) is the resonant frequency, L and W are the length and width of the patch element, in cm, respectively and ε_r is the relative dielectric constant." [6]

Prior to analyzing the frequency-dependent variables, the capacitance parameter in microstrip-line system should be analyzed. The capacitance per unit length of the classical

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parallel-plate capacitor is [7]:

$$C = \varepsilon \frac{w}{h} \tag{6}$$

A simple frequency-dependent capacitance of the parallel-plate capacitor can be expressed in any frequency-dependent attributes of ε which is

$$C(\omega) = \varepsilon_0 \varepsilon^*(\omega) \frac{w}{h} \tag{7}$$

where $\varepsilon^*(\omega)$ is a complex permittivity is expressed as $\varepsilon'(\omega) - j\varepsilon''(\omega)$. Therefore,

$$C(\omega) = \varepsilon_0 \varepsilon'(\omega) \frac{w}{h} - j\varepsilon_0 \varepsilon''(\omega) \frac{w}{h} \tag{8}$$

Referring to the equivalent Cole-Cole diagram deduced for a parallel-plate microstrip line in [8] is substitute into (8). Hence,

$$C(\omega) = C\left(\frac{1}{1+Q(\omega)}\left[Q(\omega) + \frac{\varepsilon_{eff}}{\varepsilon_r}\right]\right) - j\frac{C}{\varepsilon_r}\left[\varepsilon''_u(\omega) + \varepsilon''_c(\omega) + \varepsilon''_d(\omega)\right] \tag{9}$$

where $C = \varepsilon_0 \varepsilon_r (w/h)$.

For simplicity, the coefficients of (9) are defined as follows:

$$A(\omega) = \frac{1}{1+Q(\omega)}\left[Q(\omega) + \frac{\varepsilon_{eff}}{\varepsilon_r}\right] \tag{10}$$

$$B(\omega) = \frac{1}{\varepsilon_r}\left[\varepsilon''_u(\omega) + \varepsilon''_c(\omega) + \varepsilon''_d(\omega)\right] \tag{11}$$

In general, the characteristic impedance of a transmission line is given by

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \tag{12}$$

where R, L, G, C are per unit length quantities defined as follows:

R = resistance per unit length in Ω/m.
L = inductance per unit length in H/m.
G = conductance per unit length in S/m.
C = capacitance per unit length in F/m. [9]

If G and C are neglected, the characteristic impedance can be written as:

$$Z_0 = \sqrt{\frac{L}{C}} \tag{13}$$

To achieve frequency-dependent characteristic impedance $(Z_0'(\omega))$, the frequency-dependent capacitance $(C(\omega))$of (9) is replaced into the capacitance (C) in (13). Therefore, frequency-dependent characteristic impedance is [9]

$$Z_0'(\omega) = \sqrt{\frac{L}{C[A(\omega) - jB(\omega)]}} = \frac{Z_0}{\sqrt{A(\omega) - jB(\omega)}} \tag{14}$$

Now, the frequency-dependent (lossy) Smith-chart can be derived through input of $Z_0'(\omega)$ in (14) into the normalized terminal impedance expression as done in traditional Smith-chart model [9]. Therefore the normalized terminal impedance Z_L' is

$$Z_L' = \frac{Z_L}{Z_0'(\omega)} = br + jbx \quad (Dimensionless) \tag{15}$$

As r and x are the normalized resistance and normalized reactance, and $b = \sqrt{A(\omega) - jb(\omega)}$.

The voltage reflection coefficient of present Smith chart is

$$\Gamma' = \Gamma_r' + j\Gamma_i' = \frac{Z_L' - 1}{Z_L' + 1} \tag{16}$$

or

$$Z_L' = \frac{Z_L}{Z_0'(\omega)} = br + jbx = \frac{(1+\Gamma_r') + j\Gamma_i'}{(1-\Gamma_r') - j\Gamma_i'} \tag{17}$$

The procedure and formulas described above are used to construct an in-house MATLAB program. The calculated parameters are transferred to the software for simulation.

A rectangular microstrip patch antenna and ground plane dimensions of WxL and $W_g x L_g$ respectively, as shown in Fig. 1. It is designed on a substrate with dielectric constant (ε_r) and thickness (h).

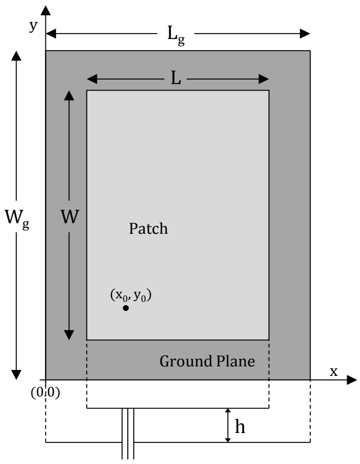

Fig. 1. Basic structure of a rectangular microstrip patch antenna.

Fig. 2 illustrates the E-shaped microstrip patch antenna by using cutting a notch technique to perturb the surface current patch and introducing local inductive effect [10]. By using this technique, it can create a multiband antenna [7], [11], [12].

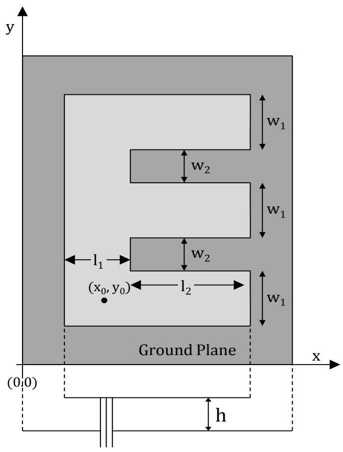

Fig. 2. Geometry of proposed antenna.

III. Results and Discussions

In this research, the design of simple rectangular microstrip antenna structure uses the cutting a notch to make it E-shapedas mentioned in Section II. This structure is further fed by using probe feed method. The simulation and analysis of the proposed antenna is done over in-house MATLAB program software.

The calculated parameters are transferred to the software for simulation. The proposed antenna is designed on FR4 substrate with dielectric constant of 4.2. According to the formulas, the antenna characteristics are shown in Table I.

TABLE I: E-Shaped Microstrip Patch Antenna Characteristics

Parameters	Value (mm)
(x_0, y_0)	(15.35, 18.95)
h	1.5
l_1	6.5
l_2	9.45
w_1	5.75
w_2	2.95
L_g	26.5
W_g	32.85
L	16.5
W	22.75

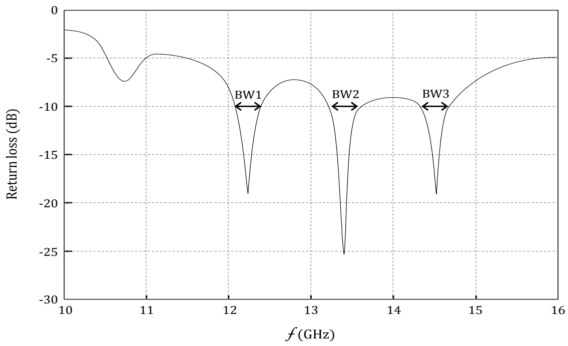

Fig. 3. Return loss of the proposed antenna.

From the Fig. 3, it is observed that the proposed antenna operates at the frequencies of 12.25GHz, 13.4GHz and 14.5GHz with return loss of -17.5dB, -26dB and -15.5dB respectively.

The bandwidth can be observed and calculated from the return loss at -10dB. The results are shown in Table II.

TABLE II: Bandwidth (BW) of the Proposed Antenna

Parameters	Value
BW1 at 12.25GHz	200MHz
BW2 at 13.4GHz	250MHz
BW3 at 14.5GHz	150MHz

As indicated in the results, the operating frequencies of the proposed antenna comply with the Ku-band. The Ku-band is typically in the downlink frequencies of 10.7GHz to 12.75GHz and uplink frequencies of 13.75GHz to 14.5GHz.

IV. Conclusions

A compact E-shaped microstrip patch antenna is designed for Ku-band satellite communication applications. The operating frequencies of the proposed antenna are at 12.25GHz, 13.4GHz and 14.5GHz which cover the Ku-band and provide good results in terms of bandwidth. The procedure proposed in this paper can be applied in CAD applications thus; practical implementation will be simple and effortless.

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