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Design of Ku-Band Microstrip Patch Antenna in Dual-Band by Utilizing U-Slot and Slits

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Abstract – In this paper, the Ku-band rectangular microstrip patch antenna (RMPA) is intended to operate in the dual-band for satellite communication (SATCOM). The antenna which is obtained for dual-band by utilizing a U-slot and vertical slits on RMPA is fed with a microstrip feed-line for the input impedance of 50 ohms. Arlon AD 300 which is used as the dielectric substrate for the antenna has the permittivity value of 3, the loss tangent value of 0.003 and the thickness of 1.524 mm. The antenna has the return loss of -30.078 dB at 12.25 GHz (the first resonance center frequency) and -31.214 dB at 14.24 GHz (the second resonance center frequency). Voltage standing wave ratio is 1.0647 at 12.25 GHz and 1.0566 at 14.24 GHz. The results reveal that the bandwidths (BW) of 836 MHz (11.894 to 12.73 GHz) at 12.25 GHz for downlink and 703 MHz (13.823 to 14.526 GHz) at 14.24 GHz for uplink are achieved. The Ku-band RMPA which is designed and simulated via Computer Simulation Technology Microwave Studio (CST MWS) is convenient for dual-band SATCOM systems.

Keywords – RMPA, microstrip feed-line, Ku-band, slot, slit, dual-band

I. Introduction

The IEEE standard specifies antennas as an element of propagating or collecting electromagnetic waves [1]. Antennas are the principal components in satellite communication systems [2].

Microstrip patch antennas (MPA) in Ku-band (Kurtz-under the band) are mainly used to transmit or receive audio, data, video in SATCOM. Ku band supplies reliable high-speed connectivity. This band is divided into multiple segments for geographical regions. The International Telecommunication Union (ITU) decides those segments in the frequency bands. The Ku band which is a section of the electromagnetic spectrum works between 12 GHz and 18 GHz [3], [4], [5].

Dual-band antennas provide electromagnetic wave radiation and its collection via the same antenna [6]. By the way, using two different single-band antennas could be averted. There are some techniques to obtain dual or multi-band antennas [7] such as etching slits [8], loading slots on the patch [9], two feeding ports method [10], truncating on patch. Besides, there are some particular geometries to get dual-band operations [11].

In this study, the Ku-band RMPA is designed in dual-band for SATCOM. The antenna unit is fed by 50 Ω microstrip feed-line with center feed technique for impedance matching. Here, using a single antenna, different resonance frequencies are achieved. The size of the dielectric substrate is the same size as the ground plane, 17.8 x 14 (Width x Length). The patch size is 8.9 x 7. The optimization is obtained to operate at 12.25 GHz (836 MHz BW, 11.894 to 12.73 GHz) for downlink and at 14.24 GHz (703 MHz BW, 13.823 to 14.526 GHz) for uplink. The considered antenna has been simulated via CST MWS.

II. Materials and Method

An MPA is consist of a conductor element, dielectric substrate and ground plane. Radiating patch and ground plane are conductors such as copper, silver, etc. There are many dielectric substrates which have dielectric constant (ε_r) values in the range of $2.2 \leq \varepsilon_r \leq 12$.

Here, U-slot on the lower part of patch provides to radiate at 12.25 GHz as first operating center frequency and two vertical slits on the upper part of the patch provide to radiate at 14.24 GHz which is the second operating center frequency. Both of these frequencies are involved in Ku-band. Two vertical slits next to feed-line provides impedance matching as shown in Fig. 1. Arlon AD 300 which is used as the dielectric substrate for the antenna has the permittivity value of 3, the loss tangent value of 0.003 and the thickness of 1.524 mm. The patch and the ground plane have a thickness value of 0.035 mm.

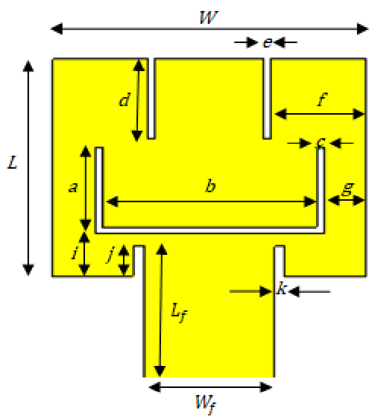

Fig. 1 The Ku-band RMPA with U-slot and slits in dual-band

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On the patch surface, to etch two vertical slits on the upper part of the patch and to load U-slot on the lower part of the patch will cause the gap-coupling of the current. Thus, RMPA has a dual-band resonance frequency.

The antenna is fed with 50 ohms (input impedance) center microstrip line feed technique on the RMPA. That means reference impedance (Z_0) must be equal to 50 ohms. The first values of the patch are found by the basic formulas as follows [12]-[15].

Step 1: Computation of patch width (W)

$$W = \frac{c}{2 f_0 \sqrt{(\varepsilon_r + 1)/2}} \tag{1}$$

c is free space light velocity, f_o is the operation frequency in GHz, ε_r is dielectric substrate constant kept at 3 for Arlon AD 300.

Step 2: Computation of effective dielectric constant (ε_{reff})

$$\varepsilon_{reff} = \frac{(\varepsilon_r+1)}{2} + \frac{(\varepsilon_r-1)}{2} [1 + 12\frac{h}{w}]^{-1/2} \tag{2}$$

h is thickness of the substrate given as 1.524 mm.

Step 3: Computation of the extension length (ΔL)

$$\frac{\Delta L}{h} = 0.412 \frac{(\varepsilon_{reff}+0.3)(\frac{w}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{w}{h}+0.8)} \tag{3}$$

Step 4: Computation of the patch length (L)

$$L = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} - 2\Delta L \tag{4}$$

Step 5: The equation for the reference Z_0 is given by;

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{reff}}[\frac{W_f}{h}+1.393+0.667ln(\frac{W_f}{h}+1.444)]} ; \frac{W_f}{h} \geq 1 \tag{5}$$

Z_0 for 50 ohms, W_f can be calculated. The performance of the antenna is related to the impedance matching. If there is a mismatch, maximum power is not transferred to the antenna from the source. The input impedance can be reduced if the microstrip feed line is closer to the center. Because voltage is maximum at the edge of RMPA, on the other hand, the current is maximum at the center of RMPA [12].

Here, dual-band frequency in Ku band can be obtained by slits and slot in antenna patch [16]. Loading U-slot on the lower side of antenna controls lower operating frequency, etching two vertical slits which are etched as symmetric to x-axis on the upper side of the antenna control higher operating frequency. Two vertical slits next to feed line are for input impedance matching.

U-Slot and two slits on the RMPA, they alter the effective antenna width and length. Dimensions of U-slot and two slits should be improved and changed shapes for the desired frequencies.

The substrate width and length is taken two times bigger than the patch size. The dimension of the ground plane is the same as the size of the dielectric substrate. The patch is center of the dielectric substrate surface.

The RMPA parameters are given in Table 1.

Table 1. The parameters of the RMPA

Parameters	**Dimensions**	**Unit**
Dielectric Constant (ε_r)	3	-
Loss Tangent ($tan\partial$)	0.003	-
Thickness (h)	1.524	mm
Frequency (f_o)	12.25 and 14.24	GHz
Length (L)	7	mm
Width (W)	8.9	mm
Length of Ground (L_g)	14	mm
Width of Ground (W_g)	17.8	mm
Length of Feed (L_f)	4.58	mm
Width of Feed (W_f)	3.6	mm
U-slot (a)	3.01	mm
U-slot (b)	6.1	mm
U-slot (c)	0.2	mm
Length of Slits (d)	2.58	mm
Width of Slits (e)	0.2	mm
f	2.8	mm
g	1.2	mm
i	1.43	mm
j	1.08	mm
k	0.3	mm

III. Results and Discussion

In this paper, the RMPA fed with microstrip line has been accomplished in the dual-band for Ku band. This feed method has some advantages. For instance, this feeding can be inserted on the substrate surface like a piece of the patch to maintain the planar shape and also match can be provided without any other additional component [17], [18]. The U-slot size is improved to obtain the desired lower frequency band. Moreover, the etching two vertical slits on the upper part of the patch make the antenna to get the upper-frequency band. In Ku band, 10.7-12.75 GHz for downlink and 14-14.5 GHz for uplink can be used for direct broadcast SATCOM service. The designed antenna can be operated both these frequencies range.

The antenna is designed by using CST MWS software. The simulated antenna bandwidth and return loss are shown in

Fig. 2. This figure indicates two resonance center frequencies as 12.25 GHz and 14.24 GHz. The reflection coefficients of the antenna are -30.078 dB and -31.214 dB, respectively. It is accepted that the antenna starts to radiate when the reflection coefficient is less than -10 dB. So the bandwidth is 836 MHz at lower frequency band and 703 MHz at higher frequency band.

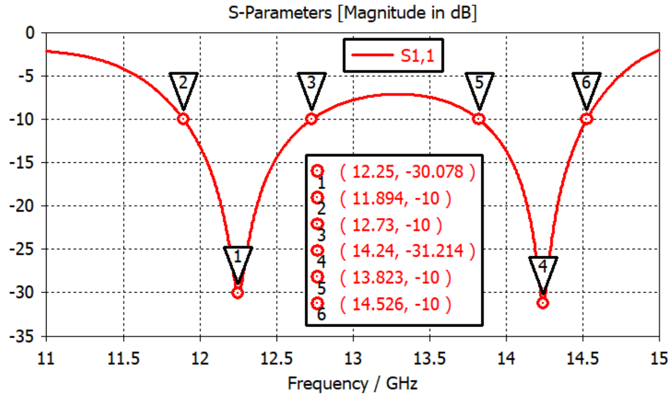

Fig. 2 The reflection coefficients of the Ku-band RMPA

The VSWR of the RMPA is shown in Fig. 3. It is 1.0647 at 12.25 GHz and 1.0566 at 14.24 GHz. The ratio is in the desirable range between 1 and 2. It shows that there is a good matching.

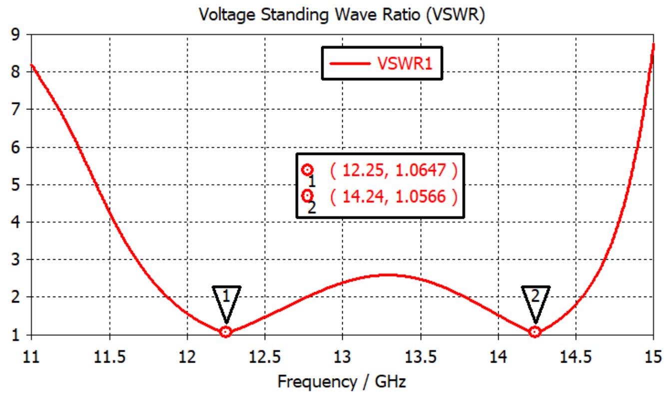

Fig. 3 The voltage standing wave ratio of the Ku-band RMPA

The input impedance (Z_i) is 47.865 Ω at 12.25 GHz and 53.822 Ω at 14.24 GHz as shown in Fig. 4. It is almost 50 Ω for both center operation frequencies.

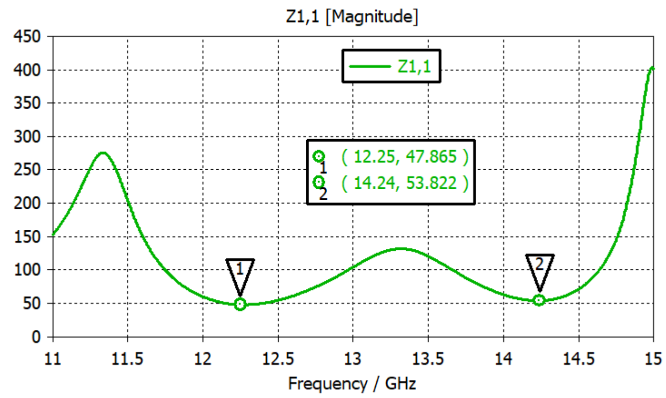

Fig. 4 The impedance graphic for the designed antenna

The efficiency is corresponded to the ratio between gain and directivity. In addition to this, the efficiency is so related to VSWR and impedance matching. Efficiency of the designed antenna as shown in Fig. 5.

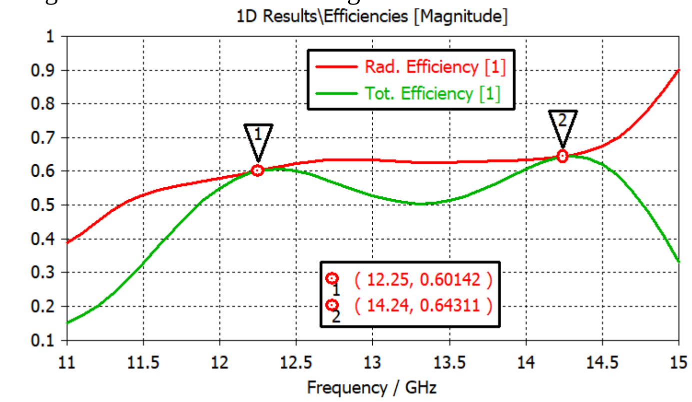

Fig. 5 The effiency of the Ku-band RMPA

Directivity is a measure of how strong the radiation in a selected direction. It is a ratio of radiating power in a selected direction to the same power radiating equally in all directions. Fig. 6 shows the E field and H field radiation pattern in the low resonance center frequency 12.25 GHz.

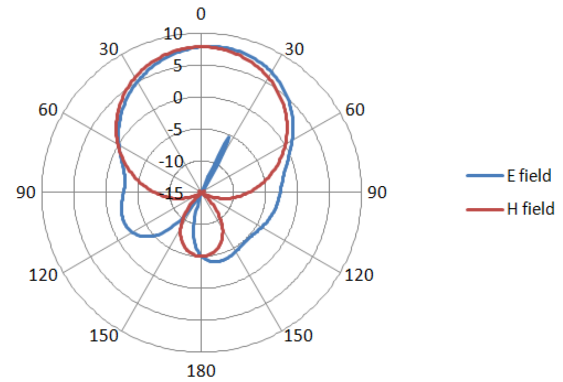

Fig. 6 The directivity of the Ku-band RMPA at 12.25 GHz

Fig. 7 shows the E field and H field radiation pattern in the high resonance center frequency 14.24 GHz.

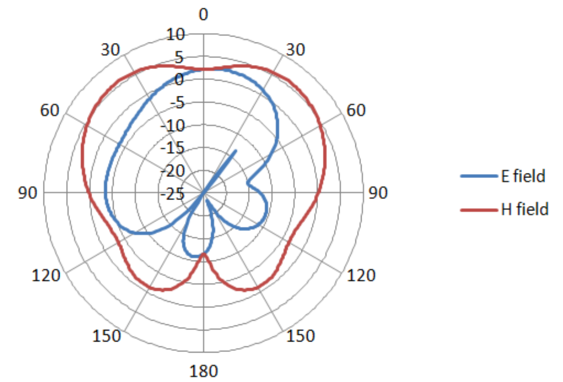

Fig. 7 The directivity of the Ku-band RMPA at 14.24 GHz

Gain is the antenna parameter associated with directivity and efficiency parameters. If the efficiency of the antenna is 100%, that means the gain and directivity is equal [12].

Table 2. The dual-band RMPA for Ku-band far-field results

Frequency	Directivity	Gain	Bandwidth
12.25 GHz	8.003 dBi	5.795 dB	836 MHz
14.24 GHz	6.268 dBi	4.351 dB	703 MHz

IV. CONCLUSION

In this study, the Ku-band RMPA in dual-band is designed and simulated via CST MWS. Investigations have been made on variables such as return loss, VSWR, directivity, gain, far-field radiation patterns. From the results of the simulation, it has been monitored effects of parameters such as the thickness of the dielectric substrate, the size of the patch, the size of microstrip feed-line, the sizes of the slits/slot and their position. An RMPA which has been purposed to radiate in the dual-band at Ku frequencies can be easily designed by using two vertical slits and U-slot. Dual-band is achieved and the antenna is operated at 12.25 GHz (the low-frequency resonance center) and 14.24 GHz (the high-frequency resonance center) as the resonance center frequencies. The VSWR is 1.0647 at 12.25 GHz and 1.0566 at 14.24 GHz. The antenna has been a BW of 836 MHz which defines 6.82% at 12.25 GHz and 703 MHz representing a BW of 4.94% at 14.24 GHz. The antenna with a good return loss, directivity and gain values can be utilized for Ku band applications such as satellite communication, military systems, and radar applications.

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