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Ultra-Wideband Patch Antenna for K-Band Applications

Umair Rafique*, **Syed Ahsan Ali**
Department of Electronic Engineering, Mohammad Ali Jinnah University,
Islamabad Expressway, Near Kaakpul, Zone V, Sihala, Islammabad, 44000, Pakistan
*Corresponding author, e-mail: umair-rafique@hotmail.com

Abstract

An ultra-wideband patch antenna is presented for K-band communication. The antenna is designed by employing stacked geometry and aperture-coupled technique. The rectangular patch shape and coaxial fed configuration is used for particular design. The ultra-wideband characteristics are achieved by applying a specific surface resistance of 75Ω/square to the upper rectangular patch and it is excited through a rectangular slot made on the lower patch element (made of copper). The proposed patch antenna is able to operate in the frequency range of 12-27.3 GHz which is used in radar and satellite communication, commonly named as K-band. By employing a technique of thicker substrate and by applying a specific surface resistance to the upper patch element, an impedance bandwidth of 77.8% is achieved having VSWR ≤ 2. It is noted that the gain of proposed antenna is linearly increased in the frequency range of 12-26 GHz and after that the gain is decreased up to 6 dBi. Simulation results are presented to demonstrate the performance of proposed ultra-wideband microstrip patch antenna.

Keywords: *ultra-wideband, aperture-coupled, K-Band, surface resistance, thicker substrate*

1. Introduction

Since many years, microstrip patch antennas are popular because of their small and compact size, low profile, light weight, cost effectiveness, easy to fabricate and easy to install in many portable devices [1]. These small miniature devices are increasingly becoming popular for a number of medical applications. They can be used in devices to monitor patient health remotely and provide them help in the emergency situations. Therefore, the research in smaller size patch antennas with high bandwidth and good efficiency has gained a lot of interest. However, reducing the size of patch antenna has lots of challenges. For example, one major limitation of simple structured patch antenna is that it provides narrow bandwidth and low gain. This restricts the use of patch antennas in many interesting applications. Most of the communication systems require the antennas which are small in size and provide largest bandwidth. Both of these design requirements, in most of the cases, are contradicting. However, wideband and ultra-wideband (UWB) communication systems are becoming popular for short range and high bandwidth (≥50%) applications, the use of patch antennas is also increasing day-by-day. Many researchers presented and proposed different types of patch antennas for high bandwidth.

In [2], a microstrip patch antenna which fed through a microstrip line was presented for ultra-wideband communication. The authors used modified ground plane which tends to radiation loss which is not useful for the performance of patch antenna. Also, such kind of configuration is related to monopole antenna design. Abolfazl Azari proposed a fractal shape microstrip antenna for wideband applications [3]. An iterative octagon shape was designed to achieve a large bandwidth. According to the results and 8 dB bandwidth criteria, the presented design was able to operate in the frequency range of 10-50 GHz. But 8 dB bandwidth criteria lead to a power loss greater than 10%. Also, the gain of an antenna is less than 5 dBi at higher frequencies. In [4, 5], an ultra-wideband antenna designs were presented for wireless communications. An average impedance bandwidth of 98% was achieved through the designs. But, these designs suffer from difficult fabrication by the use of shorting walls and folded patch feed.

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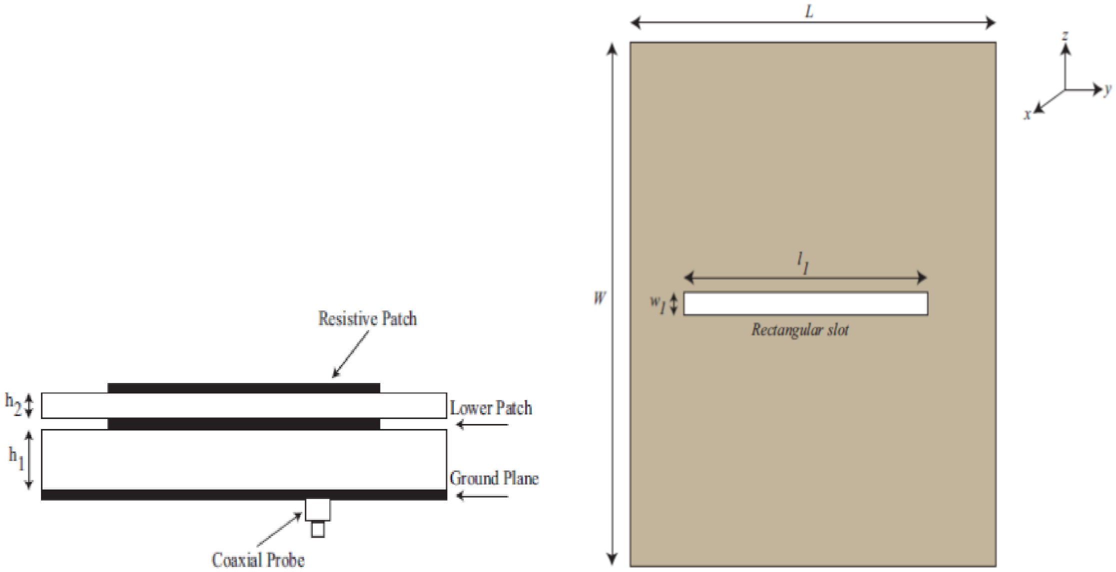

Figure 1. (a) Geometry of the proposed ultra-wideband microstrip patch antenna; (b) Dimensions of the lower patch and rectangular slot

A microstrip patch antenna which was made by using inverted L-slot edge (ILSE) structure was presented for wireless communication [6]. The main advantage of the antenna was, with the increase in frequency, the gain of an antenna is linearly increased which is very useful at higher microwave frequencies. In [7], a reconfigurable microstrip patch antenna was presented for wideband applications. The antenna was designed by using PIN diodes which was useful for reconfigurable applications. The presented antenna was able to operate in two frequency bands, i.e., 7.5-12 GHz and 9-15 GHz, respectively.

In this paper, we present an ultra-wideband microstrip patch antenna for K-band applications. The center frequency (f_0) of the proposed antenna is 16 GHz. A modification is made to the previously presented design [8]. The proposed design consists of a stacked geometry and slot-coupled feed. The resistive material which is made of copper is used to increase the bandwidth of proposed antenna. Also we have used optimized values of h_1 and h_2 to broaden the bandwidth of the proposed design. Recently, resistive materials are used to design Frequency Selective Surface (FSS) absorbers for WLAN security applications [9, 10]. The resistive material allows the movement of electric charge on conducting surface. So, by applying a specific surface resistance to the rectangular patch element, an impedance bandwidth of 77.8% is achieved in the frequency range of 12-27.3 GHz. This bandwidth is greater than the previously presented data in [8], therefore, we used a particular surface resistance for the proposed design. Also, it is noted that the gain of proposed antenna has linearly increased in the whole band of interest. This makes our proposed design further useable in many applications.

The rest of the paper is organized as follows. Section II presents design and configuration of the proposed ultra-wideband patch antenna. Section III presents simulated results and discussion on the results. Finally, Section IV concludes the paper.

2. Design and Configuration of Patch Antenna

The design and configuration of proposed patch antenna is shown in Figure 1. The antenna geometry consists of two dielectric layers, two patch elements and a coaxial probe which is connected to the lower patch element to provide excitation as shown in Figure 1(a). The lower substrate having dimensions 50_50 mm^2 consists of a rectangular patch whose dimensions are 38_34 mm^2 and a rectangular slot is etched from it which is shown in Figure 1(b). The dimensions of the slot are l_1 = 18 mm (along y-axis) and w_1 = 2 mm (along x-axis), respectively. The dielectric used for the lower patch design is Rogers RT/duroid 5870 having relative permittivity (ε_{r1}) 2.33 and thickness (h_1) 1.57 mm. The upper patch with same dimensions is placed on the upper substrate which has a specific surface resistance. The substrate used for the upper patch design is FR-4 having relative permittivity (ε_{r2}) and thickness (h_2) 0.8 mm. This design configuration follows the principle of aperture/slot-coupled technique [1]. By using resistive material and slot-coupled technique, one can obtain ultra-wide bandwidth and high gain of patch antenna. The dimensions of rectangular patch can be calculated by using the design equations given in [1].

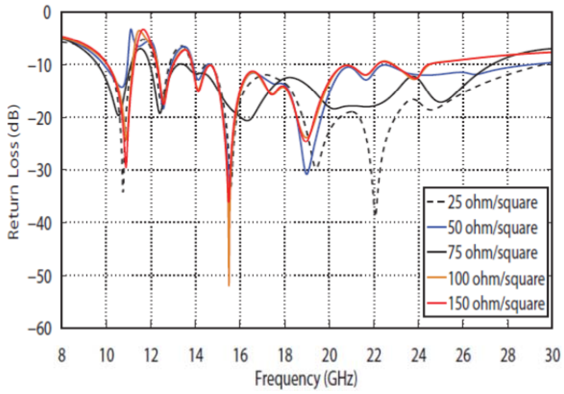

Figure 2. Return loss of UWB patch antenna for different values of surface resistance

One thing is to be noted that the relative permittivity (ε_{r1}) and thickness (h_1) is used for the design purpose. The proposed patch antenna is fed through a coaxial probe. The position of the probe is maintained at X_f = 8 mm and Y_f = 0 to get maximum impedance matching, i.e., to match the input impedance (Z_{in}) to the characteristics impedance (Z_o) and it can be calculated by using the design equations given in [1, 8].

3. Results and Discussion

This section describes the simulation results of the proposed patch antenna. Firstly, a parametric study is taken from the design by changing the surface resistance of the upper patch. Figure 2 shows the input return loss results for different values of surface resistance. It is noted that for lower values of surface resistance, i.e., 25Ω/square, 50Ω/square and 75Ω/square the proposed design gives largest bandwidth. As the surface resistance increased, the bandwidth of the antenna gradually decreases. This is because of the fact that most of the input signal is reflected back at the input terminals increasing the power loss. This is not a desired case as in most of the applications, one likes to transmit the maximum amount of the power in the desired direction. From Figure 2, an optimized value of surface resistance is chosen which gives high bandwidth and gain, i.e., 75Ω/square. The study demonstrated that the bandwidth of an antenna can be maximized by using lower values of surface resistance.

Figure 3 shows input return loss of the proposed UWB patch antenna. An impedance bandwidth of 77.8% is obtained in the frequency range of 11.96-27.3 GHz. Four resonances occurred in the whole band at 12.5 GHz, 16.3 GHz, 20-22 GHz and 25 GHz, respectively. From Figure 3, it is clear evident that the use of resistive material should increase the bandwidth of a patch antenna. The bandwidth of the antenna is calculated as:

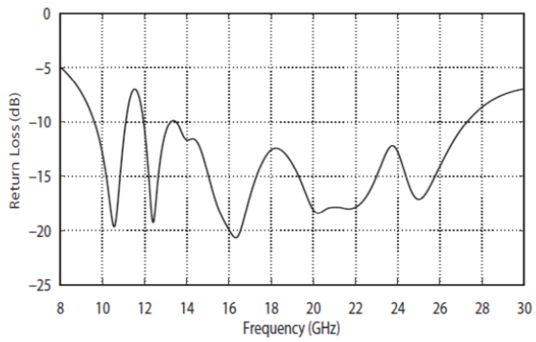

Figure 3. Input return loss of the proposed UWB patch antenna.

$$B.W = \frac{2(f_h - f_l)}{f_h + f_l} \quad (1)$$

Where, f_h and f_l are the highest and lowest frequencies of the band. It is essential to know the VSWR of an antenna so that an optimized input power loss can be achieved. The VSWR can be calculated as follows:

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \quad (2)$$

Where, $|\Gamma|$ is the absolute value of reflection coefficient at the input terminals. It is evident that the ideal patch with no reflections at the input provides maximum power transfer which can be used in many important applications. However, in practical designs there is always some power loss at the input terminals of the pact antenna. The power loss at the input terminals can be calculated as:

$$Power\ Loss\ (dB) = -20\log|\Gamma| \quad (3)$$

In patch antenna design, VSWR is considered based on two criterions of bandwidth. According to 10 dB bandwidth criteria, the VSWR is less than 2 which means a 10% input power loss. If we want less input power loss, we have to calculate the bandwidth according to 15 dB bandwidth criteria. The VSWR according to the 15 dB bandwidth criteria must be ≥ 1.5. But, if we want largest bandwidth, so we have to make a trade-off between power loss and bandwidth. Also, the power loss can be altered or maintained by applying a high power signal at the input port.

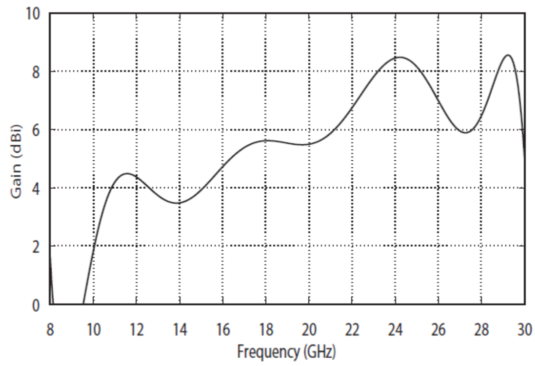

Figure 4. Gain of the proposed UWB patch antenna

Figure 4 shows the simulated results for the gain of the proposed antenna. It is noted that the gain linearly increases from 11.96-27.3 GHz and after that the gain is slightly decreased up to 6 dBi. Also, the minimum gain noted for the proposed antenna is 4 dBi in the frequency range of 12-14 GHz. It is clear from Figure 4 that the gain of the proposed patch antenna is related to the input return loss. It is also concluded from this result that the gain of the antenna is inversely proportional to the input return loss and surface resistance of the antenna. As surface resistance increases the gain decreases but the bandwidth increases. So there is a trade-off between the increased bandwidth and the achieved gain.

4. Conclusion

An ultra-wideband microstrip patch antenna is designed and presented for K-band communications. A simple and novel design is made to enhance the bandwidth of a microstrip patch antenna. By the use of slot-coupled technique and by applying the surface resistance to the patch element, an impedance bandwidth of 77.8% (11.96-27.3 GHz) is achieved at 10 dB return loss with a VSWR less than 2. The gain of the antenna is linearly increased and it is noted that, at higher K-band frequencies, the average gain is 8 dBi. Also, the design is demonstrated that the use of stacked patch configuration with resistive material is useful to increase the bandwidth and gain of patch antenna. Presented results demonstrated that the proposed design is suitable for radar and satellite communication.

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