New Design of Single Band Elliptical Microstrip Antenna for Satellite Communication

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Abstract. An elliptical microstrip antenna with a special slot pattern on the patch was designed covering a bandwidth of 9.8701 GHz to 10.535 GHz, with gain of 3.1 dBi to 3.49 dBi with a voltage standing wave (VSWR) of less than two and reflection coefficient (S 11) of -63.4 dB. Computer simulation technology (CST) was used to obtain simulation results, while a vector network analyser (VNA) was used to obtain practical results. The proposed antenna is intended for radiolocation and satellite communications, with dimensions of (19 x 23 x 1.6)mm$^3$, making it smaller than most UWB antennas, manufactured on a substrate with a relative dielectric constant ($\varepsilon_r$) of 4.3 and loss tangent (tan $\delta$) of 0.025. Reasonable agreement was found between the practical and simulation results.

1. Introduction

There is a growing need for high-speed wireless communications, and many solutions have been presented to address this issue. One of these solutions is ultra-wideband (UWB) technology, the communication technology used in wireless networking to achieve high bandwidth links with low spectral densities of power. This has attracted a tremendous amount attention because of various features such as low power, high data rates, reductions in the multipath fading effect, and high degrees of reliability and accuracy [1][2]. Despite UWB's benefits, however, the downside is the potential interference between UWB and narrowband communication networks in the 3.4 GHz to 3.69 GHz and 5.15 GHz to 5.825 GHz ranges [3][4][5]. In 2002, the Federal Communications Commission (FCC) provided a 7.5 GHz wide unlicensed band at 3.1GHz to 10.6 GHz with effective isotropic radiated power below -41.3 dBm/MHz for communication applications such as radiolocation, amateur-satellite work, and so on [6][7][8]. Microstrip antennae are becoming increasingly popular in these ranges because of various appealing features such as low profile, low cost, lightweight, ease of manufacturing, and compatibility with printed circuit boards. However, these also have disadvantages such as low gain, low performance, and narrow bandwidths [2][9]. The feeding methods in microstrip antenna can be classified into contacting and non-contacting methods, with contacting methods further classified into microstrip line feeds and coaxial feeds, and non-contacting methods further classified into aperture coupled feeds, proximity coupled feeds, and co-planar waveguide feeds. Radiofrequency (RF) power supplies the radiation patch directly through the connector in contacting methods, while electromagnetic coupling is used to transfer power between the patch and the feed line in non-contacting techniques [2]. In this paper, a microstrip line feed was utilised.

Several researchers have made suggestions for the design of a UWB microstrip antenna. In 2019, Yang et al. constructed a circular patch microstrip antenna with a partial ground and a compact bandpass filter;
the proposed design provided a 116.8% passband bandwidth ranging from 3 GHz to 11 GHz [10]. In 2019, Ul Islam et al. designed a circular patch antenna with a U-shaped slot to give a band notch characteristic across 5 GHz to 6 GHz; the antenna operated for the band at 3 GHz to 12 GHz with a gain of 4 dBi to 6 dBi [11]. In 2011, Nasser-Moghadasi and Koohestani designed a rectangular microstrip antenna to cover the frequency range 1.82 GHz to 12.59 GHz with a gain of 2.8 dBi to 6.3 dBi [12], while in 2010, Hassanien and Hamad, designed a partially grounded rectangular patch microstrip antenna with a U-shaped slot in the patch operating within the frequency range 3.6 GHz to 15 GHz [13].

An elliptical patch antenna was adopted in this paper because it has a wider operating frequency band than the circular patch [14], covering the band 9.8 GHz to 10.5 GHz. The elliptical microstrip antenna was designed for radiolocation and satellite communications, with dimensions of (19 x 23 x 1.6)mm³, which is smaller than most UWB antennas. Computer simulation technology (CST) was used to design the antenna and to develop simulation results, and the antenna was constructed and tested using a vector network analyser (VNA), so that a comparison could be made between the outcomes of the simulation and the measured results. The required design equations are outlined below [2]:

\[
e_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[1 + 12 \frac{h}{w}\right]^{-1/2} \quad (1)
\]

where \(e_{\text{eff}}\) is the effective relative dielectric constant, \(\varepsilon_r\) is the relative dielectric constant, \(w\) is the width of the patch, and \(h\) is the thickness of the substrate.

\[
L_g = L + 6h \quad (2)
\]

where \(L_g\) the length of the ground and \(L\) is the length of the patch.

\[
W_g = w + 6h \quad (3)
\]

where \(W_g\) is the ground width.

\[
\lambda = \frac{c}{f} \quad (4)
\]

where \(\lambda\) is the wavelength, \(f\) is the frequency, and \(c\) is the speed of light in vacuum.

\[
\lambda_g = \frac{\lambda}{\sqrt{e_{\text{eff}}}} \quad (5)
\]

\[
L_f = \frac{\lambda_g}{4} \quad (6)
\]

where \(L_f\) is the length of the feed line.

2. The proposed antenna
The suggested antenna substrate consisted of FR-4 with a dielectric constant ($\varepsilon_r$) of 4.3, a loss tangent ($\tan \delta$) of 0.025, and a thickness of 1.6 mm. The antenna patch and ground were of annealed copper with a thickness of 0.035 mm. Figure 1 shows diagrams of the suggested antenna.

![Figure 1. The suggested antenna (a) frontal view (b) posterior view](image)

3. **Parametric study**

A parametric study was conducted on the effect of variations of different parameters on the reflection coefficient response ($S_{11}$) in order to determine the best parameter value with the most negative $S_{11}$ value.

3.1. **Feeder length ($L_f$)**

The effect of changing the $L_f$ on $S_{11}$ is illustrated in figure 2; as shown, when $L_f$ equals 6 mm, the $S_{11}$ has the most negative value ($S_{11} = -48.16 \text{ dB}$).

![Figure 2. The effect of $L_f$ on $S_{11}$](image)
The effect of changes in the $W_f$ on $S_{11}$ is demonstrated in figure 3; as shown, when $W_f$ is equal to 1.75mm, the $S_{11}$ takes a more negative value ($S_{11} = -48.16\, dB$).

![Figure 3. The effect of $W_f$ on $S_{11}$](image)

**Figure 3.** The effect of $W_f$ on $S_{11}$

3.3. **Semi-major axis (b)**

The effect of changing in the semi-major axis (b) on $S_{11}$ is illustrated in figure 4; as shown, when b is equal to 7 mm, the $S_{11}$ has a more negative value ($S_{11} = -48.16\, dB$), with a single band characteristic at 10.1 GHz.

![Figure 4. The effect of b on $S_{11}$](image)

**Figure 4.** The effect of b on $S_{11}$

3.4. **Semi-minor axis (a)**

The effect of changes in the semi-minor axis (a) on $S_{11}$ is illustrated in figure 5; as shown, when a is equal to 5 mm, the $S_{11}$ takes a more negative value ($S_{11} = -48.16\, dB$) with a single band characteristic at (10.1) GHz.
3.5. Ground width ($W_g$)

The effect of any change in $W_g$ on $S_{11}$ is illustrated in figure 6; as shown, when $W_g$ is equal to 23 mm the $S_{11}$ takes a more negative value ($S_{11} = -48.16 \, dB$).

3.6. Ground length ($L_g$)

The effect of change in the $L_g$ on $S_{11}$ is demonstrated in figure 7; as shown, when $L_g$ is equal to 19 mm, the $S_{11}$ takes a more negative value ($S_{11} = -42.62 \, dB$).
Table 1 illustrates the best parameters for the proposed antenna based on the parametric study.

**Table 1. Antenna parameters (best values)**

| Parameter          | Value (mm) |
|--------------------|------------|
| h                  | 1.6        |
| t                  | 0.035      |
| $L_f$              | 6          |
| $W_f$              | 1.75       |
| $L_g$              | 19         |
| $W_g$              | 23         |
| Substrate length   | 19         |
| Substrate width    | 23         |
| b                  | 7          |
| a                  | 5          |

4. Characteristics of the proposed antenna

A comparison between the simulation results and the measured results for the $S_{11}$ is shown in figure 8. The differences between the simulation and practical results are most likely due to manufacturing error and the fact that in the simulation the $\varepsilon_r$ is constant, while in practice, this changes with the frequency, creating differences between the practical and simulated results. As compared to other research studies, however, antenna generally has a better $S$-parameter, with a more negative value.

![Figure 8. $S_{11}$ for the simulated antenna and practical antenna.](image)

The voltage standing wave (VSWR) is $< 2$ is in the band 9.8701 GHz to 10.535 GHz, and the change of gain with frequency, shown in figure 9. The gain thus has a minimum value of 3.12 dBi and a maximum value of 3.49 dBi in the specified band.
Figure 9. Gain VS frequency for the suggested antenna.

The surface current distribution at a frequency of 10.186 GHz for the antenna, where the maximum current is $122\ A/m$, is illustrated in figure 10.

Figure 10. Surface current distribution for the proposed antenna.

The far-field (H-field and E-field) for the suggested antenna at the frequency of 10.186 GHz is illustrated in figure 11.

Figure 11. Far-field (a) E-field (b) H-field
The 3D radiation pattern for the suggested antenna, with a max directivity of 6.19 dBi at a frequency of 10.186 GHz, is illustrated in figure 12, while the manufactured antenna is illustrated in figure 13. The vector network analyser (VNA) and the room where the antenna was tested are illustrated in figure 14.

![Figure 12. The 3D radiation pattern for the suggested antenna](image)

![Figure 13. The manufactured antenna (a) frontal view (b) posterior view.](image)

![Figure 13. Equipment used for antenna testing.](image)

Table 2 illustrates the comparison between the designed antenna and relevant previous work as noted in the literature survey.
Table 2. Comparison between research work

| Antenna design                  | Dimensions in mm | Patch shape | Antenna bands | Gain in dBi | S 11 in dB |
|---------------------------------|------------------|-------------|---------------|-------------|------------|
| Yang et al [10]                 | 32x25            | Circular    | Single band (3-11) GHz | 3           | -40        |
| Ul Islam, et al [11]            | 30x30            | Circular    | single band-reject (5-6) GHz | 3 - 4.5     | ---        |
| Nasser-Moghadas [12]            | 70x60            | Rectangular | Single band (1.82-12.59) GHz | 2.8-6.3     | -47        |
| Hassanien [13]                  | 30x30            | Rectangular | Single band (3.6-15) GHz | 1 - 5.5     | -27        |
| The proposed antenna in the current work | 19x23            | Elliptical  | Single band (9.8-10.5) GHz | 3.1 - 3.49  | -63.4      |

From the table above, the designed antenna is clearly more compact than the others, and as the proposed antenna covers a bandwidth of 9.8 to 10.5 GHz there is no potential for interference between the UWB and the narrowband communication network in the 3.4 GHz to 3.69 GHz and 5.15 GHz to 5.825 GHz ranges. The designed antenna also offers better S 11 performance in the 9.8 GHz to 10.5 GHz band.

5. Conclusions

An elliptical microstrip antenna was designed for radiolocation and satellite communications and tested practically using a vector network analyser (VNA). The antenna dimensions were (19 x 23 x 1.6) mm³ on an epoxy substrate with \( \varepsilon_r = 4.3 \) and tan \( \delta = 0.025 \). The antenna works at a band of 9.8701GHz to 10.535 GHz with an S 11 equal to -63.4 dB and a gain of 3.1 dBi to 3.49 dBi. Reasonable agreement between the simulation and practical results emerged, with the slight difference attributable to manufacturing error and variations in the relative dielectric constant with frequency. In future work, modification of the antenna to cover more bands could be considered to make it compatible with additional applications.

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6. References

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