Microstrip Patch Antenna Array Design for C-Band Electromagnetic Fence Applications

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Abstract

Electromagnetic fence designs have potential to provide border security especially for military tasks. In this paper, design, simulation and experimental results of a microstrip patch antenna array which may be suitable for an electromagnetic fence application at C-band are presented. Moreover, an experimental demonstration of the effect of a person on the signal propagation between the transmitter and the receiver is presented basically.

1. Introduction

Electronic warfare concept and its applications have been taking the place of classical military aspects for the last decade. Especially, providing the security of any border by using tools of this concept may be considered one of the most comprehensive and challenging problems. However, an electromagnetic fence, which is illustrated in Fig.1, may be a good candidate to detect intruders and prevent smuggling while reducing the defence costs and demand for human resources. The idea of the electromagnetic fence basically depends on the detection of the received signal fluctuations because of an obstacle moving between the transmitter and receiver antennas. Obviously, this concept must provide some requirements like mobility, low-cost and artificial concealment. Thus, it is important to minimize the components of the electromagnetic fence, especially the antennas.

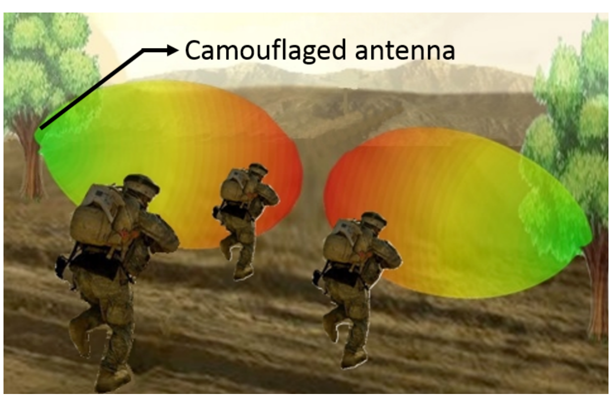

Figure 1. Illustration of an electromagnetic fence behind concealment

Microstrip antenna concept was proposed by Descamp in 1953 [1] but its practical applications were developed by Munson [2] and Howel [3] in 1970s. Microstrip antennas became very popular for wide-band [4] or multi-band [5] wireless communication, satellites, radars, cell phones etc. because of their simple and cheap fabrication process [6]. Besides having these advantages, they also have several disadvantages, such as low efficiency, narrow bandwidth, and low gain. But, these drawbacks can be overcome by using multiple patch elements in different configurations called microstrip arrays.

In this paper, design steps of a microstrip patch antenna array with simulation results are presented in Section 2. Experimental results of the fabricated antenna and a simple demonstration of the signal propagation between transmitter and receiver arrays are given in Section 3. Conclusion and the future study plans are mentioned in Section 4.

2. Design, Simulation and Fabrication of the Array Antenna

2.1. Design of the single array element

A microstrip antenna may have any shape or size for a desired application. But rectangular shape of a conductive patch allows to use empiric mathematical model in the early steps of design. With this mathematical model, one can calculate the width (W), length (L), effective dielectric constant (ϵ_{eff}) and characteristic impedance (Z) of the patch approximately by using the equations given below [2, 6]

$$W = \frac{c}{2\pi f}\sqrt{\frac{2}{\epsilon_r + 1}} \tag{1}$$

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left(1 + 12\frac{h}{W}\right)^{-1/2} \tag{2}$$

$$\Delta L = 0.412\frac{h\left(\epsilon_{eff} + 0.3\right)\left(W/h + 0.264\right)}{\left(\epsilon_{eff} - 0.258\right)\left(W/h + 0.8\right)} \tag{3}$$

$$L_{eff} = L + 2\Delta L \tag{4}$$

$$Z = \frac{120\pi}{\sqrt{\epsilon_{eff}}\left[\frac{W_0}{h} + 1.393 + 0.667ln\left(\frac{W_0}{h} + 1.444\right)\right]} \tag{5}$$

where f is resonant frequency of the antenna, W_0 is width of the microstrip line, c is speed of the electromagnetic wave in vacuum, ϵ_r is relative permittivity of the dielectric substrate, h is the total height of the antenna, L_{eff} is effective length of the patch illustrated in Fig.2.

After determining the dimensions of the rectangular patch, one should consider the feeder type. As it is well known, microstrip line, coaxial probe, aperture coupling and proximity coupling are popular feeding methods for patch antennas

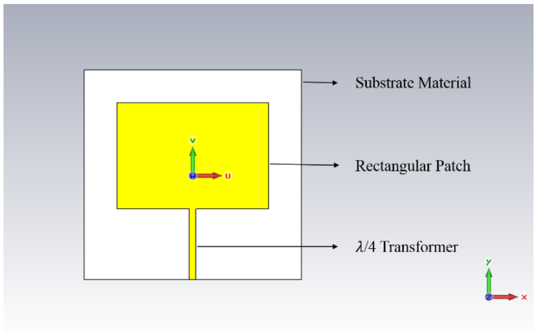

Figure 2. Rectangular patch antenna

[6]. Here, microstrip line method with corporate-feed network model is selected as a feeding method because it is easy to fabricate and control the feeding position. Optimized design parameters of the proposed microstrip antenna element are given in Table 1.

Table 1. Design parameters of the rectangular patch element

Center frequency	4 GHz
Substrate	FR-4
Copper thickness	0.035 mm
Substrate height	1.6 mm
Loss tangent	0.025
Dielectric constant	4.3
Length of the substrate	33 mm
Width of the substrate	32 mm
Length of the patch	16.2 mm
Width of the patch	23 mm
Length of the feeder	10.8 mm
Width of the feeder	1.0 mm

By using the aforementioned parameters, it is possible to simulate S-parameters and even the three dimensional (3D) directivity pattern of the single element patch via CST Microwave Studio. Simulation results for S_{11} values and 3D directivity pattern are illustrated in Fig. 3 and Fig. 4, respectively.

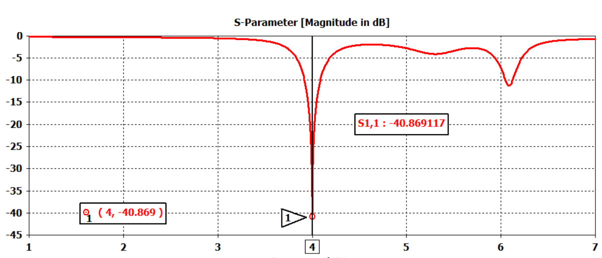

Figure 3. Return loss of the single element antenna

Even if the S_{11} values show resonance at 4 GHz, half-power beam width (HPBW) of the radiation pattern is predicted as 93.9 degree in θ-plane and obviously it is too wide for an electromagnetic fence applications. Thus, to achieve narrower HPBW, higher gain values and lower side lobe levels, an 1x4 array antenna is designed and the procedure is given in the next subsection.

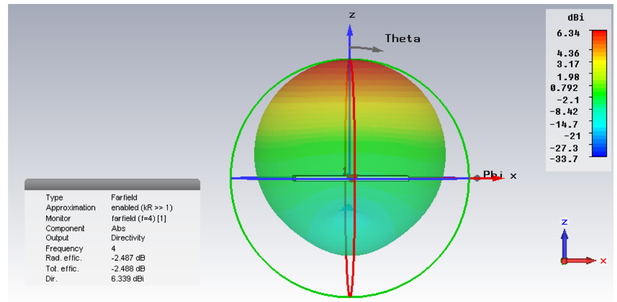

Figure 4. Directivity pattern of the single element antenna

2.2. Design of the 1x4 array

The 1x4 antenna array system is composed of two identical 1x2 array systems and its feeding network is seen in Fig. 5. Optimized design parameters of the array are given in Table 2. Note that, quarter-wave transformer (QWT) technique is used to provide impedance matching for different type of microstrip lines which produce the feeding network. The impedance of the QWT can be given as

$$Z_{QWT} = \sqrt{Z_i \cdot Z_o} \tag{6}$$

where Z_i and Z_o are impedance values of any microstrip lines that are connected to each other with the QWT. The distances between the patches are 0.75 λ.

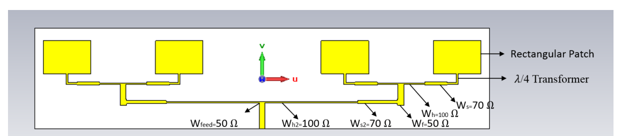

Figure 5. Illustration of 1x4 microstrip patch array antenna

By using the design parameters, 3D directivity pattern of the array is predicted by using CST Microwave Studio as seen in Fig. 6.

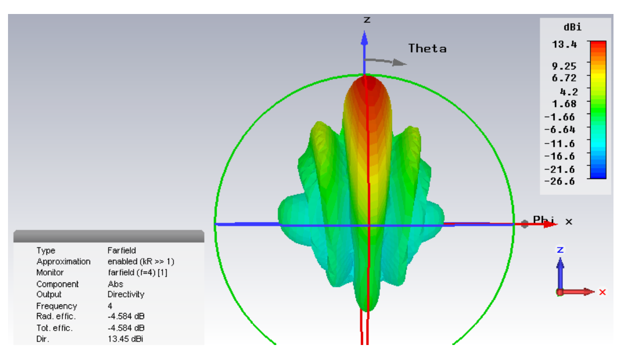

Figure 6. Directivity pattern of the 1x4 microstrip patch array antenna

It should be noted that different array antennas (such as 1x2, 2x4 etc.) are designed at the initial phases of this study. However, none of them yield desired radiation pattern.

Table 2. Design specifications of the 1x4 array

Center frequency	4.07 GHz
Substrate	FR-4
Copper thickness	0.035 mm
Substrate height	1.6 mm
Loss tangent	0.025
Dielectric constant	3.85
Length of the substrate	50 mm
Width of the substrate	228 mm
Length of the patch	16.5 mm
Width of the patch	23.8 mm
Width of the $\lambda/4$ transformer	1.0 mm
Length of the $\lambda/4$ transformer	9.9 mm
Width of the W_s	1.6 mm
Length of the W_s	11.2 mm
Width of the W_h	0.72 mm
Length of the W_h	0.72 mm
Width of the W_f	3.0 mm
Length of the W_f	10.7 mm
Width of the W_{s2}	1.6 mm
Length of the W_{s2}	19.8 mm
Width of the W_{h2}	0.72 mm
Length of the W_{h2}	48.0 mm
Width of the W_{feed}	3.0 mm
Length of W_{feed}	13.0 mm

3. Experimental Results

Depending on the simulation results of the 1x4 array antenna, 13.45 dBi directivity, -9.4 dB side lobe level, 15.1 degree HPBW in θ-plane and 80.2 degree HPBW in ϕ-plane are obtained. It is possible to increase the directivity and decrease the HPBW in θ-plane by designing the array with more elements but it is obvious that this needs larger antenna dimensions which may not be suitable for an electromagnetic fence requirements. Thus, the 1x4 array which has 22.79 cm length and 4.52 cm height, is fabricated as shown in Fig. 7 and its S_{11} values are investigated experimentally. Measurement and simulation results of the S_{11} values are presented in Fig. 8.

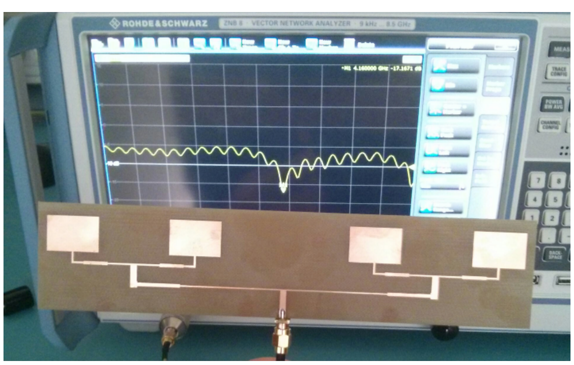

Figure 7. Fabricated array antenna and its S_{11} measurement

As a basic demonstration of the effect of a person on the signal propagation between the antennas, an experimental setup is prepared. In this setup, as shown in Fig. 9, a Rohde & Schwarz ZNB 8, 9 kHz-8.5 GHz vector network analyzer and a FSP 9 kHz-7 GHz spectrum analyzer are used as transmitter and receiver, respectively. Distance between the transmitter and the receiver antennas is set to 1.25 meter.

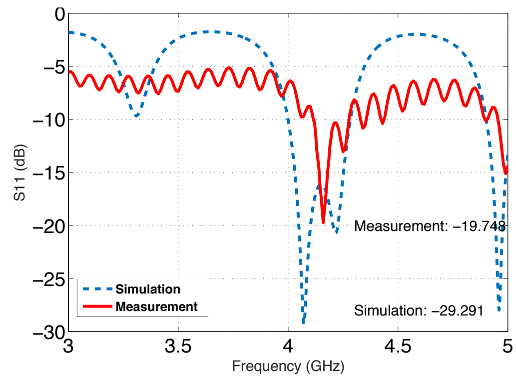

Figure 8. Measured and simulated return loss of the array antenna

Figure 9. Experimental setup for the electromagnetic fence prototype

The aim of the experiment is to observe signal distortion for different scenarios. In the first scenario, only the receiver antenna connected to the spectrum analyzer and noise is measured. The average noise level is obtained -68 dBm. In the second scenario, transmitter antenna connected to the network analyzer while receiver antenna is still connected to the spectrum analyzer. When there is no obstacle between the transmitter and the receiver antenna, approximately 24 dBm signal level is observed over the noise level. The peak level of the received signal is detected as -44 dBm at the resonant frequency of the array antenna. In third scenario, the received signal is recorded while someone is passing between the antennas. In this scenario, the received signal has a peak at -54 dBm level which is 10 dBm lower than the second scenario. Power spectrum of the measured signals for these scenarios is drawn in Fig. 10.

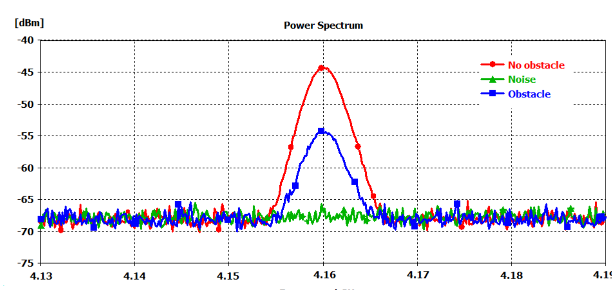

Figure 10. Power spectrum of the measured signals

4. Conclusion

In this paper, a microstrip patch antenna array which may be suitable for electromagnetic fence applications is proposed. Moreover, the experimental demonstration of the effect of a person on the signal propagation between the transmitter and the receiver is presented basically. Higher frequencies may be more suitable for the proposed task but because of the limited experimental resources, C-band is preferred to work. However, depending on the obtained results, it is possible to say that proposed array antenna may fulfil the requirements such as mobility, low-cost and artificial concealment for military tasks. As future work, the antenna array is going to connect to an universal software radio peripheral (USRP) transceiver. Thus, producing different types of signals such as FM or AM modulated, pulse or chirp would be possible and that gives an opportunity for analysing received signals by using signal processing techniques to detect and classify the obstacles.

5. Acknowledgement

Authors would like to thank Associate Professor Dr. Elif Uray AYDIN and Atilim University staff for their contributions to fabrication process of the antennas.

6. References

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