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Optimization of Antenna Design in Millimeter Wave Band and 15 GHz Band for Wireless Communications

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Abstract: Square patch antenna fed by strip line with meta-phi cell printed on the ground plane is proposed here. Meta-cell technique is very powerful way to shift operating band to lower frequencies. According to the propagation characteristics of radio signals, rapid attenuation of signals occurs in millimeter wave spectrum when it penetrates buildings. This is limited this area of spectrum to short range (indoor) communications. Embedding meta-cell in antenna structure make the operating frequency of antenna shifted from 30 GHz to 15 GHz. This will keep the physical dimension unchanged and it will be applicable in long range (outdoor) communications.

Key words: Millimeter wave, phi-cell metamaterial, square patch antenna, wireless communication systems, frequency, Iraq

INTRODUCTION

A lot of efforts and big interest both in academia and in industry are focused in millimeter wave spectrum to measure and model their channels and to estimate its potentialfor future wireless systems (Akdeniz *et al*., 2014; Ghosh *et al*., 2014; Rappaport *et al*., 2015; Anonymous, 2016). The growing need to high speed datatransmission and video distributionfor both indoor and outdoor applications and multimedia services like HDMI and HDTV which requires high channel capacity face many researches towards this part of spectrum (Qiao *et al*., 2016; Rappaport *et al*., 2013, 2015).

When someone decide to use this frequency range, there is some limitations must be take into account. The signals at lower frequencies can propagate for a long distance and penetrate through buildings while millimeter wave signals can travel just few kilometers and do not penetrate through solid materials very well. Buildings are consists of different materials. Some old one is coated by metal for better thermal insulation. This coating introduces signal losses reach to 40 dB (Rodriguez *et al*., 2014). Other materials like concrete and bricks have losses that increase with frequency. Different solutions were proposed in literatures to overcome this problem (Larsson *et al*., 2014), gain enhancement of antenna using metamaterial cover is one of these solutions (Shaalan and Shareef, 2014).

In this research, a metamaterial technique is applied to square millimeter wave antenna design to produce a second frequency band without affecting its physical size. The proposed antenna has dual frequency bands lies at 30 and 15 GHz. The principal frequency (30 GHz) can be used for indoor communication applications while the second band (15 GHz) can be used for outdoor communications. The proposed antenna has fair gain and directivity and suitable far field shape for wireless communication.

MATERIALS AND METHODS

Antenna and metamaterial cell design: The proposed antenna is a square its dimensions are optimized to operate at 30 GHz band. It is fed by line strip as shown in Fig. 1. The dimensions of the antenna and substrate are

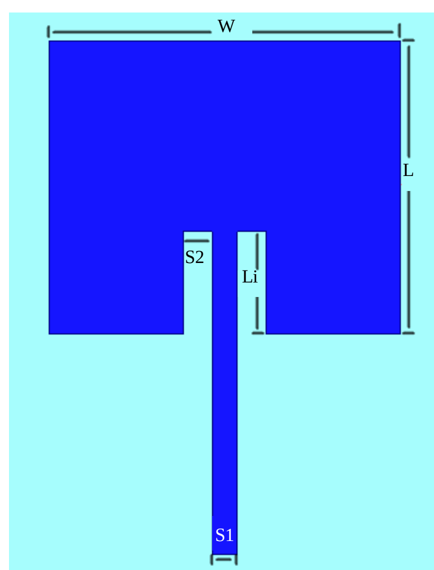

Fig. 1: Square antenna model fed by strip line

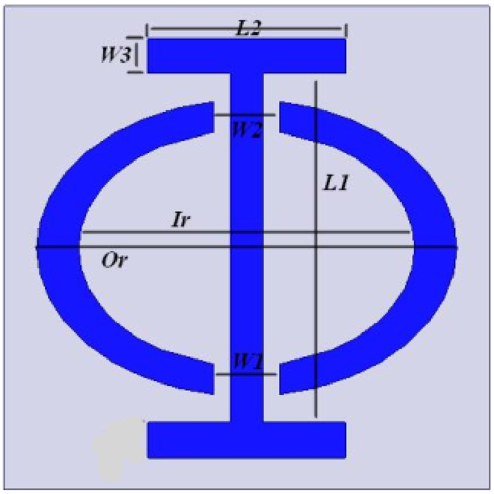

Fig. 2: Meta-phi cell model

Table 1: Square antenna parameters

Antenna dimensions	
Parametres	Values
W	2.4 mm
L	2 mm
Li	0.7 mm
S1	0.168 mm
S2	0.2 mm
Substrate dimensions	7*7*0.15 mm
Substrate type	Rogeres RO3006™
Relative permittivity	6.15
Relative permeability	1
Dielectric loss tangent	0.0025

Table 2: Meta-phi cell parameters

MTM Cell dimensions	
Parameters	Values
Outer radius (Or)	1.5 mm
Inner radius (Ir)	1.2 mm
W1 = W2	0.23 mm
W3	0.13 mm
L1	1.3 mm
L2	0.7 mm
Substrate type	Rogeres RO3006™
Relative permittivity	6.15
Relative permeability	1
Dielectric loss tangent	0.0025
Substrate thickness	0.2 mm

listed in Table 1. The substrate is a dielectric material named Rogeres Ro3006, its relative permittivity is 6.15 and has dielectric loss tangent equal to 0.0025.

Phi cell is printed on the ground plane of the antenna to achieve metamaterial behavior and generate second frequency band. Shape of phi cell is shown in Fig. 2 and its dimensions are listed in Table 2. Final model shape of antenna and the printed meta-cell on the ground plane is shown in Fig. 3.

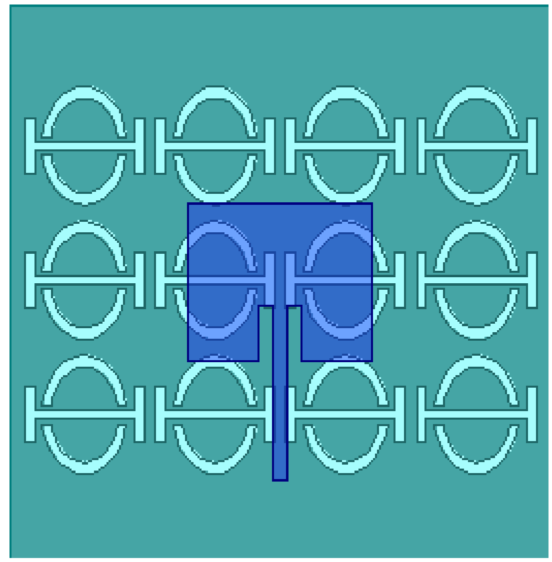

Fig. 3: Square antenna with meta-phi cell printed on ground plane

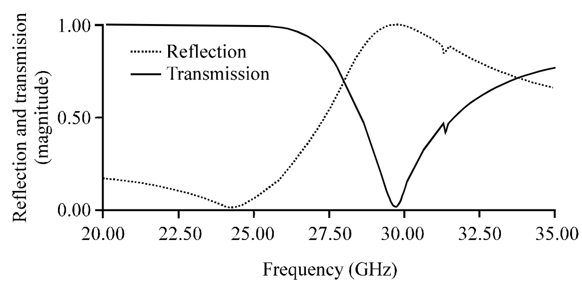

Fig. 4: Transmission and reflection parameters of phi-cell

RESULTS AND DISCUSSION

Simulation of meta-phi cell is done with HPHFSS code, results of the cell are shown in Fig. 4-7. From these Fig. 4-7, it is obvious that, this model of phi-cell has negative refractive index at the same frequency band of its resonance. The dispersion diagram illustrates the backward radiation behavior. Negative slope and negative refractive index lies at the same frequency. We can say that this cell behave as metamaterial at this frequency band. Antenna parameters without meta-cell and after print it on the ground plane of the antenna are shown in Fig. 8-10.

From these figures, we notice that, the antenna has very good matching points lies at 15 and 30 GHz with input impedance 50 Ω (Fig. 11-13). From the figures of far field and gain, we see that, this model has fair gain and directivity and pattern shape suitable for short and long range communications.

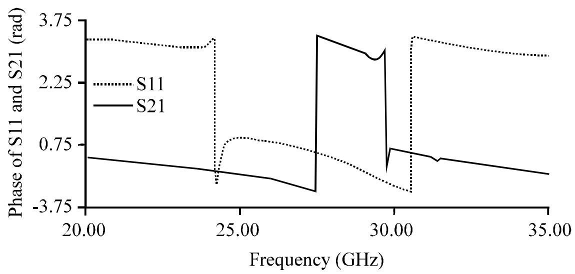

Fig. 5: Phase shift of transmission and reflection parameters of phi-cell

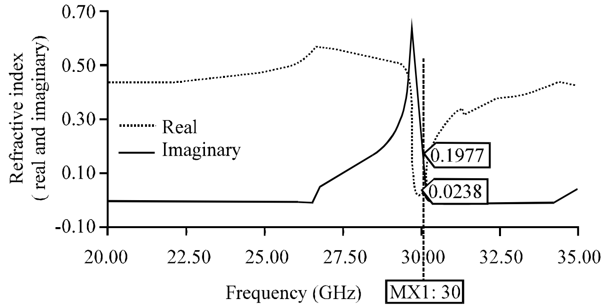

Fig. 6: Refractive index

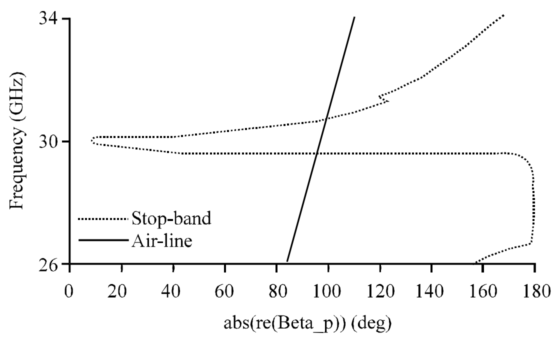

Fig. 7: Dispersion diagram of phi-cell

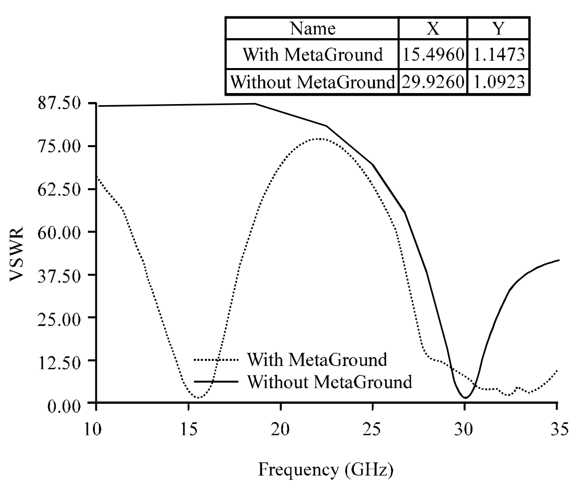

Fig. 8: Voltage standing wave ratio of antenna model

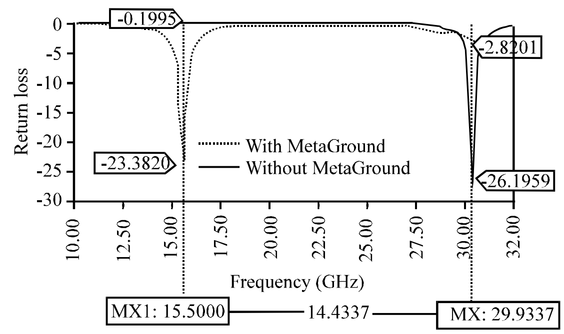

Fig. 9: S-parameters of antenna model

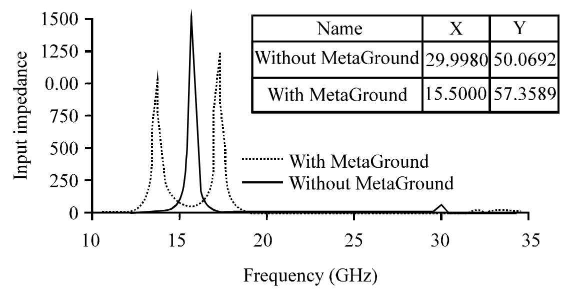

Fig. 10: Input impedance at resonant frequencies

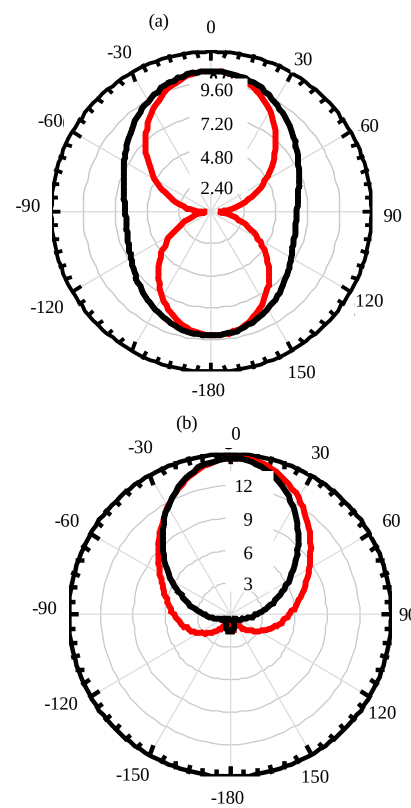

Fig. 11: Far field pattern of the antenna at resonant frequencies: a) Frequency = 15.5 GHz and b) Frequency = 30 GHz

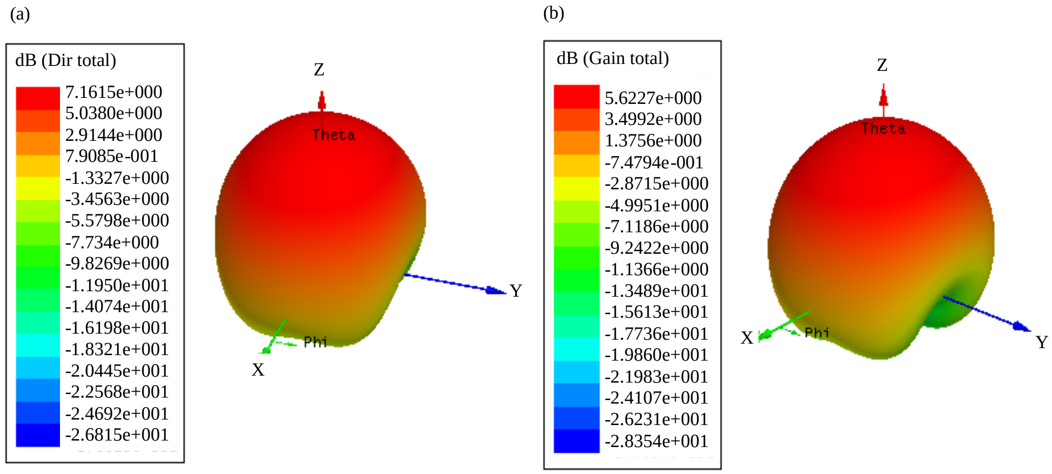

Fig. 12: Gain and directivity of the antenna at 30 GHz

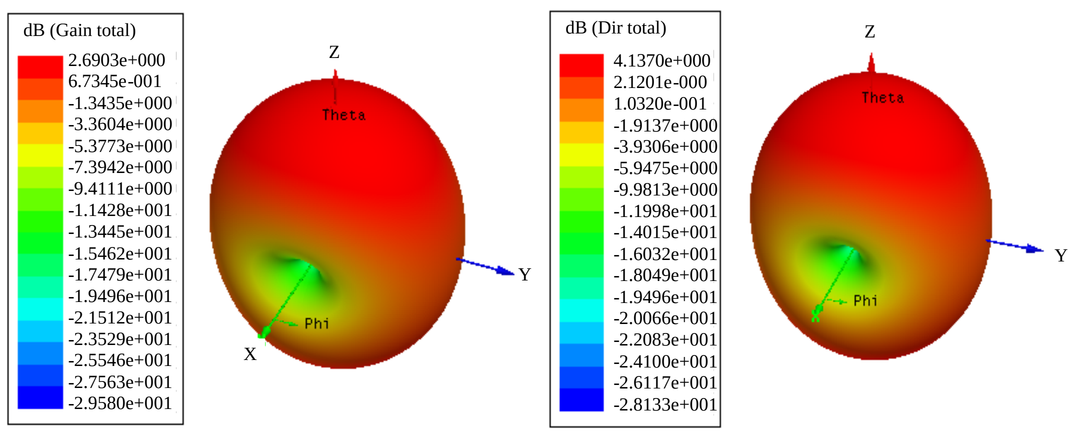

Fig. 13: Gain and directivity of the antenna at 15 GHz

CONCLUSION

Millimeter wave bands regards as very low noisy part of the spectrum. A lot of applications can benefit from this property. Even though, this part of frequencies has less noise but it suffers from attenuation. Signals are attenuated rapidly when penetrating buildings which make it not suitable for long range communications. To this end, meta-cell is printed on the ground plane of square antenna to shift the operating frequency from 30-15 GHz. Results shows good characteristics for this model. It has fair gain and directivity while kept its physical dimensions unchanged.

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