A Radiation Pattern Diversity Antenna Operating at the 2.4 GHz ISM Band

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***Abstract*— A novel planar antenna operating in the 2.4 GHz ISM band whose radiation pattern can be switched by changing the frequency channels of the operating band is proposed here. This is achieved by merging the different radiation modes of the antenna together within a single operating band, in contrast to the conventional procedure of covering the whole band with a single radiation mode. Using this method a single antenna can provide radiation pattern diversity across the operating band without an external switching mechanism. This proposal improves the connectivity significantly when the link is dynamic. The channel selection algorithm can be modified accordingly where the channels can be pre-mapped for expected Direction of Arrival (DoA) of specific links. Depending on the standards assumed, a certain number of channels are used for directing the maximum radiation at $\phi = 0^0, \theta = 8^0$, while the rest is suitable for directing the main beam at $\phi = 0^0, \theta = 72^0$.**

***Index Terms*— Antennas, antenna radiation patterns, patch antennas.**

I. Introduction

An antenna is conventionally designed in such a way that the radiation mode does not change over the targeted frequency band of operation. Even if there are multiple resonant modes within the band, a uniform radiation pattern with minimum change is aimed for [1], [2]. On the other hand, radiation pattern diversity is realized using multiple radiators with extra RF circuitry and possibly baseband circuitry [3]. Several examples of antennas achieving radiation pattern diversity by means of a switching mechanism with multiple radiators were reported in the literature [4], [5]. These differ from this proposal by the virtue of the fact that this patch antenna uses a single radiator to generate two different radiation modes. The antenna allows the realisation of these modes within the same frequency band intentionally to achieve radiation pattern diversity by just changing the frequency channels across the operating band.
Two different modes of the patch antenna were merged into 2.4 GHz ISM band. The dimensions of the antenna were optimized in such a way that the two modes were very close to each other in the frequency domain which enable the radiation pattern of the antenna to be switched by changing the channels of the operating frequency band.
A certain number of channels can be allocated for a certain radiation pattern. Therefore, if there is an expected behaviour for an application, the channels achieving the suitable radiation pattern can be pre-allocated for that application.
The unique aspect of this particular work is that it realizes pattern switching with a single antenna with a single layer structure which does not need an external switching mechanism. For both Zigbee and Bluetooth Low Energy standards, 25% of the channels are allocated for one mode of radiation while the rest of the channels are allocated for the other mode of radiation. Note that Zigbee is not a frequency hopping technology therefore two channels from each pool can be assigned for these two different operations. And for Bluetooth Low Energy which uses frequency hopping, the channels can be pre-mapped for Adaptive Frequency Hopping.
The antenna design is detailed in Section II. Section III discusses the results. The radiation pattern diversity is presented in Section IV. Finally, the paper concludes with Section V.

II. Antenna Design

A. Antenna Model

The proposed antenna is a rectangular patch antenna shorted at 4 points and excited with a coaxial feed as seen in Fig. 1. Using HFSS, it was designed on Rogers RT/duroid 6006 with relative permittivity ϵ_r of 6.15 and loss tangent tanδ of 0.0019 [6]. The substrate thickness was chosen to be 4.8 mm in order to cover the whole 2.4 GHz ISM band. The overall dimensions of the antenna is 45 x 14 x 4.8 mm. The patch length (pl) is 39.5 and the patch width (pw) is 9 mm. Radii of the shorting pins are 0.6 mm. The offset of the feed from the centre (fp) is 8 mm. The offset of the longitudinal pins (lpp) and the transverse pins (tpp) are 10.9 mm and 3.55 mm respectively as labelled in Fig. 1a. By shorting the antenna at 4 points, the TM_m mode of the antenna is excited generating a main beam directed at $\theta = 72^0$ [7]. In this paper, this mode is going to be referred as the azimuth mode. The azimuth mode is aimed to be combined with the TM_{01} mode which has a main beam directed at $\theta = 8^0$. This mode is going to be referred as the elevation mode from this point forward.

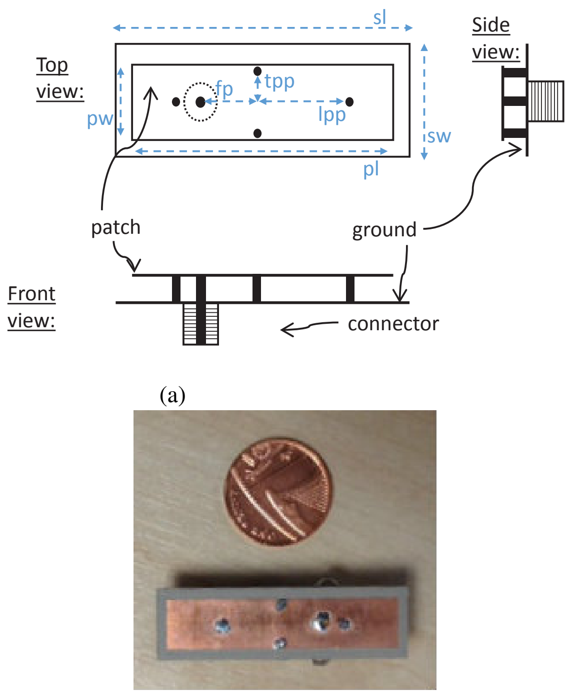


Fig. 1: (a): Antenna model and dimensions, (b): Prototype of the antenna with 1 pence coin

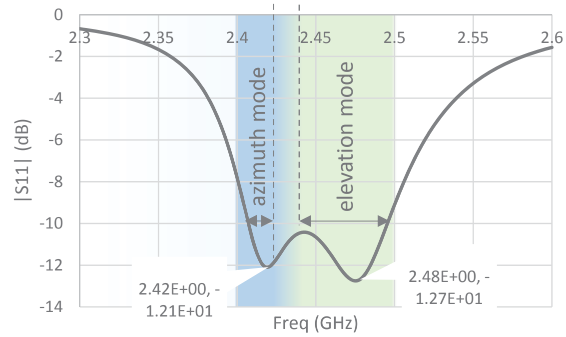


Fig. 2: $|s11|$ vs. frequency: 85 MHz 10 dB bandwidth from 2.395 GHz to 2.48 GHz, centre frequency of the azimuth mode and the elevation mode at 2.42 GHz and 2.48 GHz respectively

B. Design Guidelines

As a starting point, the patch size can be chosen as $0.7\lambda_{guided}$ by $0.2\lambda_{guided}$. Then the structure can be tuned using several parameters such as patch size (pl and pw), positions of the pins (lpp and tpp) and the feed position (fp). Here the effects of these parameters on the frequency response are discussed. Note that the thickness determines the frequency bandwidth.

The shorter edge of the patch radiator is not the resonant edge for the elevation mode therefore it has a stronger effect on the resonant frequency of the azimuth mode. By decreasing the length of short edge (pw), the operating frequency of the omnidirectional mode can be increased toward the elevation mode. The operating frequency of the azimuth mode is dictated by the overall perimeter (pw+ pl). Both longitudinal and the transverse shorting pins are symmetrical to the centre of the antenna. The position of the longitudinal shorting pins (lpp) affects the operating frequency of both modes. Therefore this parameter can be used to tune the whole structure. As the pins are moved away from the centre, each operating frequencies increase. On the other hand, the position of the transverse shorting pins (tpp) does not have any effect on the elevation mode. It affects the matching and the resonant frequency of the azimuth mode. The resonant frequency increases as the pins are moved away from the centre.

The feed point lies between the longitudinal shorting pins. The position of the feed point (fp) should be between the shorting pins and the centre in order to excite both modes. If the feed is central, then the elevation mode cannot be excited. If the feed is closer to the edge than the shorting pins, then the azimuth mode cannot be excited. The optimum position can be found through parametric analysis.

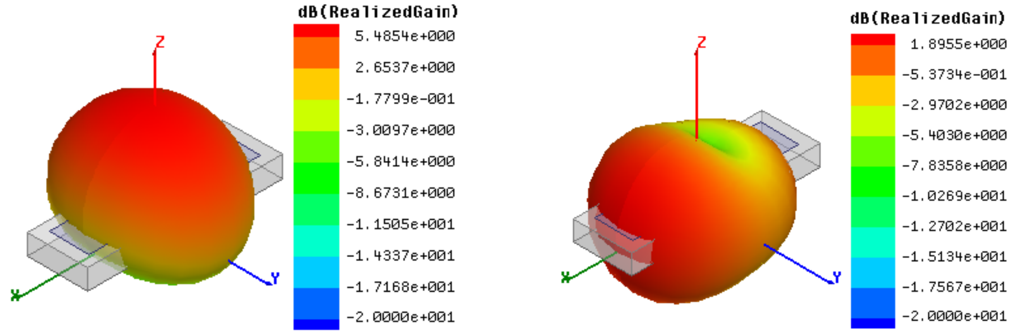
III. RESULTS

The simulated frequency characteristics of the antenna demonstrating the two different modes and their frequency coverage can be seen in Fig. 2. The centre frequencies of the azimuth mode and the elevation mode are at 2.42 GHz and 2.48 GHz respectively as seen in Fig. 2. 3D radiation patterns at two selected frequency points are given in Fig. 3a and Fig. 3b. For the first selected frequency 2.4 GHz, 2.6 dB maximum gain is observed at $\phi = 0^0, \theta = 72^0$. On the other hand, at the second selected frequency 2.48 GHz, 5.8 dB maximum gain is observed at $\phi = 0^0, \theta = 8^0$. According to HFSS simulations, from 2.4 GHz to 2.48 GHz 84% to 91% radiation efficiency is achieved over the band.

IV. PATTERN DIVERSITY

By changing the frequency within the ISM band, the maximum radiation direction is changed. If Bluetooth low energy standards are used, the first 10 channels (Channel 37, Channel 0-8) can be used for the azimuth mode and the remaining 30 channels (Channel 9-39) can be used for the elevation mode. If Zigbee is preferred, Channel 11-14 can be used for the azimuth mode while Channel 15-26 will be more suitable for the elevation mode. Note that the Zigbee channels 1-10 are located in the 915 MHz ISM Band. The number of channels can be adjusted according to the needs of the system by changing the operating frequency of each mode.

The radiation pattern changing from 2.4 GHz to 2.5 GHz



(a) (b)

Fig. 3: (a): 3D Gain pattern of the azimuth mode in linear scale at 2.4GHz corresponding to channel 11 in Zigbee, (b): 3D Gain pattern of the elevation mode in linear scale at 2.48GHz corresponding to channel 26 in Zigbee

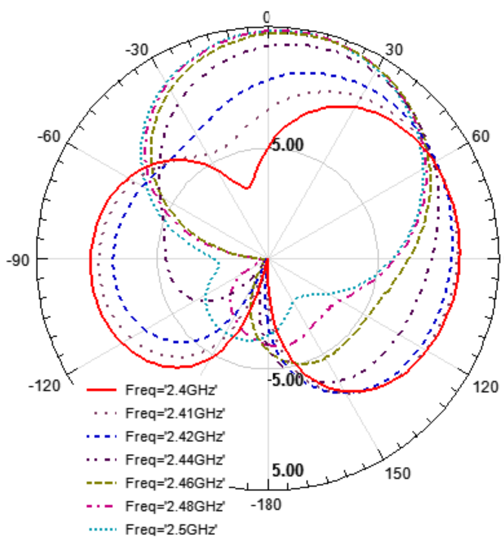


Fig. 4: 2D demonstration of the beam steering: Gain pattern in dB at $\phi = 0^0$ at 6 frequency points

can be seen in Fig. 4 at ϕ=0^0. At 2.4 GHz, the gains in the direction of θ=90^0 and θ=-90^0 are approximately 2 dB and 1 dB respectively as calculated in HFSS simulations. At 2.5 GHz, this pattern completely changed into a more directional shape where the gain in the direction of θ=0^0 is approximately 5 dB.

Looking into interference rejection aspect of the application, approximately 10 dB difference is observed between the modes at θ=0^0. If there is an interferer arriving at the antenna from the z direction, it is going to be attenuated by the antenna. Likewise, approximately 5 dB and 10 dB difference is observed between the modes at θ=90^0 and θ=-90^0 respectively. Note that these numbers are subject to the specific channels chosen.

V. Conclusion

A novel antenna which has the ability to accommodate two different radiation modes has been proposed in this paper. The radiation pattern of the antenna changes over the operating frequency band. At the lower end of the frequency band up to 2.4 GHz, the antenna generates nulls away from the antenna's main axis. On the other hand, for the rest of the band, a directional radiation pattern away from the antenna's main axis is formed. Therefore, by changing the channels of the operating frequency band, the radiation pattern suitable for the type of the link can be chosen. The antenna has 10 dB bandwidth of 85 MHz and the simulated efficiency values are more than 84% throughout the band.

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