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EBG Structured Metamaterial Inspired Wideband MIMO Antenna for Mutual Coupling Reduction

Antena MIMO de banda ancha inspirada en metamaterial estructurado EBG para reducción de acoplamiento mutuo

EBG Estruturado Metamaterial Inspirado Antena MIMO de Banda Larga para Redução de Acoplamento Mútuo

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Astrac

In this article, metamaterial inspired wideband MIMO antenna using EBG (Electromagnetic Band Gap) structure is presented. Designed MIMO antenna geometry consists of two square shaped monopole radiators with defected ground structure for proper impedance matching. The proposed antenna is fabricated on 1.6 mm thick, low cost FR4 substrate of dielectric constant 4.4 possessing an overall size of 22mm×36mm. The antenna shows simulated and measured-10 dB impedance bandwidths and the EBG structure exhibits single stop band and suppresses E-plane coupling over these bands. Isolation better than -15 dB is achieved over the complete impedance bandwidth. Radiation efficiency and peak gain of the antenna varies from 72%-86% and 2.8 dB to 5.6 dB respectively. Envelope correlation coefficient, diversity gain and channel capacity loss document the antennas behaviour. The antenna was fabricated and measured. Measurement validated the simulation and showed that the designed antenna can be well applied in wideband MIMO systems.

Keywords: Defected Ground Structure (DGS), Electromagnetic Band Gap (EBG), Metamaterial, Multiple Input Multiple Output (MIMO), Split Ring Resonator (SRR).

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Resumen

En este artículo, se presenta una antena MIMO de banda ancha inspirada en metamateriales que usa la estructura EBG (Gap de Banda Electromagnética). La geometría de antena MIMO diseñada consta de dos radiadores monopolares de forma cuadrada con una estructura de tierra defectuosa para una adaptación de impedancia adecuada. La antena propuesta se fabrica con un sustrato FR4 de bajo costo de 1,6 mm de espesor y constante dieléctrica 4.4 que posee un tamaño total de 22 mm × 36 mm. La antena muestra anchuras de banda de impedancia simuladas y medidas de 10 dB y la estructura EBG exhibe una banda de parada única y suprime el acoplamiento del plano E sobre estas bandas. Se logra un aislamiento mejor que -15 dB en todo el ancho de banda de impedancia. La eficiencia de radiación y la ganancia máxima de la antena varían del 72% al 86% y de 2,8 dB a 5,6 dB respectivamente. El coeficiente de correlación de envolvente, la ganancia de diversidad y la pérdida de capacidad del canal documentan el comportamiento de las antenas. La antena fue fabricada y medida. La medición validó la simulación y mostró que la antena diseñada se puede aplicar bien en sistemas MIMO de banda ancha.

Palabras clave: Estructura de Tierra Degradada (DGS), Hueco de Banda Electromagnética (EBG), Metamaterial, Salida Múltiple de Entrada Múltiple (MIMO), Resonador de Anillo Partido (SRR).

Resumo

Neste artigo, é apresentada uma antena MIMO wideband inspirada em metamateriais usando a estrutura EBG (Electromagnetic Band Gap). A geometria da antena MIMO projetada consiste em dois radiadores monopolares com estrutura de terra defeituosa para correspondência de impedância adequada. A antena proposta é fabricada em substrato FR4 de baixo custo com 1,6 mm de espessura de constante dielétrica 4,4, possuindo um tamanho total de 22 mm x 36 mm. A antena mostra amplitudes de banda de impedância simuladas e medidas em 10 dB e a estrutura EBG exibe uma única banda de parada e suprime o acoplamento do plano E nessas bandas. O isolamento melhor do que -15 dB é alcançado através da largura de banda de impedância completa. A eficiência de radiação e o ganho de pico da antena variam de 72% -86% e 2,8 dB a 5,6 dB, respectivamente. Coeficiente de correlação de envelope, ganho de diversidade e perda de capacidade de canal documentam o comportamento das antenas. A antena foi fabricada e medida. A medição validou a simulação e mostrou que a antena projetada pode ser bem aplicada em sistemas MIMO de banda larga.

Palavras-chave: Estrutura Terrestre Defeituosa (DGS), Banda Eletromagnética (EBG), Metamaterial, Múltipla Saída Múltipla de Entrada (MIMO), Ressonador de Anel Dividido (SRR).

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Introducción

Introduction: The exceptionally high bandwidth of wideband antennas can be technically utilized by placing MIMO antennas to enhance the system capacity. MIMO antennas provide multiple antennas at transmitter and receiver side to reduce the effects of multipath fading. It also improves the link reliability and spectral efficiency of the system. MIMO antennas transmit power by using multiple antennas at the transmitter, there by supporting high data rate and increased channel capacity without sacrificing additional power. Various configurations for realizing MIMO antennas have been proposed in the literature [1-5]

The design of compact MIMO antennas with low signal correlation is very important for portable devices. The main problem is that the antenna elements must be located very closely to save space, and at the same time high isolation between their elements must be kept. MIMO antenna elements are close to each other, hence energy radiated from one element can couple to another element through near field coupling [6-8].

Coupling affects the system performance significantly, especially in lower wideband band. The inter-element spacing of the antenna elements is to be kept optimum to reduce the effects of coupling, thereby posing a minimum limit on the antenna size [9-10]. To maintain optimum performance and reduce the inter-element spacing, decoupling structures are desired between the radiators. Several ways how to increase the isolation between antenna elements has been proposed by the researchers with DGS and EBG structures [11-12].

Introducción

A largura de banda excepcionalmente alta de antenas de banda larga pode ser tecnicamente utilizada colocando antenas MIMO para aumentar a capacidade do sistema. As antenas MIMO fornecem várias antenas no lado do transmissor e do receptor para reduzir os efeitos do desvanecimento de vários caminhos. Também melhora a confiabilidade do link e a eficiência espectral do sistema. As antenas MIMO transmitem energia usando múltiplas antenas no transmissor, suportando alta taxa de dados e aumentando a capacidade do canal sem sacrificar a energia adicional. Várias configurações para a realização de antenas MIMO foram propostas na literatura [1-5].

O design de antenas MIMO compactas com baixa correlação de sinal é muito importante para dispositivos portáteis. O principal problema é que os elementos da antena devem estar localizados muito próximos para economizar espaço e, ao mesmo tempo, um alto isolamento entre seus elementos deve ser mantido. Os elementos de antena MIMO estão próximos uns dos outros, portanto a energia irradiada de um elemento pode ser acoplada a outro elemento através do acoplamento de campo próximo [6-8]. O acoplamento afeta significativamente o desempenho do sistema, especialmente na banda de banda larga inferior. O espaçamento entre elementos dos elementos da antena deve ser mantido ideal para reduzir os efeitos do acoplamento, colocando assim um limite mínimo no tamanho da antena [9-10]. Para manter o desempenho ideal e reduzir o espaçamento entre elementos, são desejadas estruturas de desacoplamento entre os radiadores. Diversas maneiras de

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2. Antenna Geometry:

The geometry of the basic MIMO antenna structure to the proposed MIMO antenna model iterations are shown in Fig1. The basic structure consists of square shaped radiating elements placed on FR4 substrate and pencil point shaped feed line is modelled in such way to attain 50 Ω impedance. The resonant frequency can be calculated from the equation

$$fr = \frac{144}{Lg+P_l+Pg+\frac{A1}{2\Pi Lg\sqrt{\varepsilon r\,eff}}+\frac{A2}{2\Pi P_l\sqrt{\varepsilon reff}}} \text{ ---- (1)}$$

'Lg' denotes length of ground plane, 'PL' represents length of the patch and 'Pg' represents gap between them. Here 'A1' is ground plane area and 'A2' is patch area. εreff is the effective dielectric constant and εreff = (εr+1)/2. The L-shaped stub consists of long slot on the structure to provide better isolation between the ports. To attain notching at WLAN band, two strips are added on the ground plane, which behaves like λ/4 resonators at notch frequency.

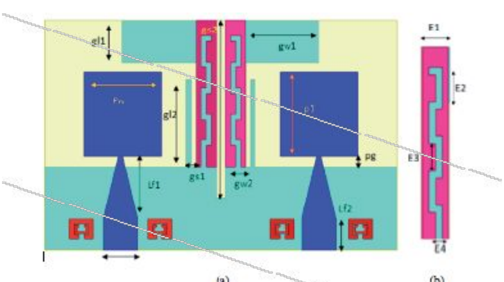

Fig 1. Proposed EBG Structured MIMO Antenna, (a) Antenna Geometry, (b) EBG Geometry

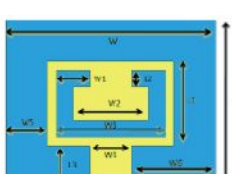

Fig 2. Split Ring Resonator Dimensions

Table 1. Antenna Parameters

S. No	Parameter	Dimension in mm	Parameter	Dimension in mm
1	L	22	P.	1
2	W.	36	L.	2
3	gL	4	W	2.4
4	gL	8.3	L	1
5	ga	0.5	L	0.2
6	ga	18	L	0.5
7	gw.	9.5	W.	0.4
8	gw.	2	W.	0.9
9	P.	8	W.	1.3
10	P!	8.3	W.	0.5
11	L	6	W.	0.5
12	L.	3	W.	1
13	Lg	8	W.	2.6
14	E1	2	E3	2
15	E2	2.5	E4	1

The structure and the dimensions of the proposed antenna are presented in Fig 3 and Table 1. The antenna is occupying very compact size of 36 X 22mm2. The split ring resonator dimensions are presented in Fig 2.

3. Results and Discussion:

A. S-parameters

The designed antenna was simulated using HFSS and the prototyped model results are measured with vector network analyser (VNA) and antenna measurement setup being in anechoic chamber. When return loss was measured with VNA, a good agreement observed between simulated and measured results

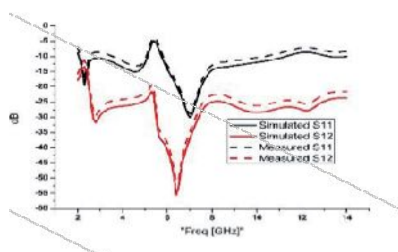

Fig 3. Frequency Vs Reflection Coefficient and Transmission Coefficient of the Proposed Antenna

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The FR4 substrate with relative permittivity 4.4, 1.6 mm in thickness, and loss tangent equal to 0.025 was used in the fabrication of the proposed notch band MIMO antenna, see photograph in Fig. 1. Measured and simulated return and insertion loss are plotted in Fig. 3. It shows that the antenna operates at frequency band from 2.1 to 5 GHz and 6 to 12 GHz with return loss lower than -10 dB. Mutual coupling is better than -20 dB within the frequency band from 2.1 to 5 GHz and from 6 to 12 GHz it reaches value better than -25 dB. A good consistency can also be noticed between the measured and simulated results. However, measured and calculated resonance frequencies are slightly shifted. This is due to the mismatch of the feeding setup and the accuracy of fabrication process.

B. Effect of Split ring resonator dimensions

The effect of width of the inner split ring resonator is presented here in the Fig 4. When width is 2.4 mm the optimum performance can be observed from the parametric analysis. When width is 2.6, the operating band shifted to 0.2 GHz towards upper frequency and with the width of 2.8 mm, it is further shifted to 0.3 GHz as shown in Fig 4.

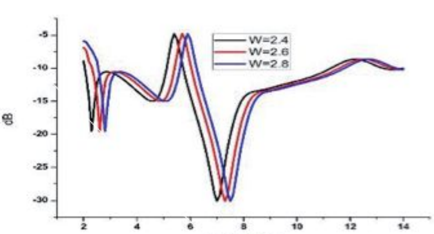

Fig 4. Parametric Analysis of width of inner SRR

C. Gain and efficiency

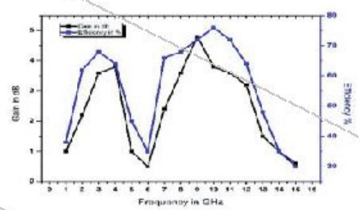

Fig 5.1 2D-Gain and Efficiency of the Antenna

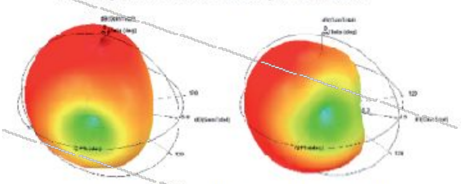

Fig 5.2 3D-Gain of the antenna at (a) 2.4 GHz, (b) 8 GHz

Fig 5.1 shows the gain and efficiency plot with respect to the operating band. A peak realized gain of 4.8 dB and efficiency of 75% is attained from the current model. A minimum gain of 0.6 dB and efficiency less than 40% is observed in the notch band of 5-6 GHz. Fig 5.2 is showing the three-dimensional view of the gain at 2.4 GHz and 8 GHz respectively.

D. Radiation Patterns

Simulated and measured 2-D radiation patterns for the proposed MIMO antenna at 2.4 GHz, 6GHz, 7.5GHz, 12.5GHz and 16GHz in xz-, yz-, and xy- planes are demonstrated in Fig. 6. Radiation pattern shape is omni-directional and resembles to that of monopole antenna. The measured results are near the simulated results. Variation between simulated and measured results may be attributed to fabrication errors, measurement uncertainty, and high loss tangent of substrate.

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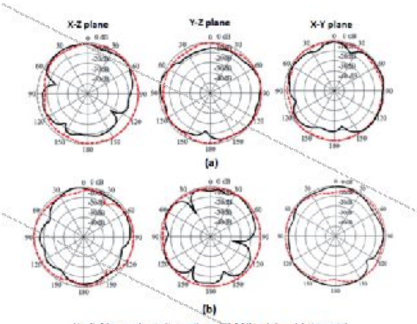
Fig 5. Measured radiation pattern at 2.4 GHz, (a) port 1 (b) port 2

E. Envelope correlation coefficient and Diversity gain

Envelope correlation coefficient (ECC) is the parameter to evaluate the diversity performance of the MIMO antenna. The equation to determine the ECC from S-parameters is presented in this section. The overlapping between the two radiation patterns can be reduced for the lesser ECC values of the antenna model. The measured ECC values are plotted in Fig 7. The ECC value of 0.5 is set as acceptable value and in our case except at notch bands the average ECC obtained in the operating band is around 0.02.

$$Ecc = \frac{|S_{11}S_{12} + S_{21}S_{22}|}{(1-(|S_{11}|^2+|S_{21}|^2))(1-(|S_{22}|^2+|S_{12}|^2))} \text{ --- (1)}$$

Diversity Gain = 10√1-ECC --- (2)

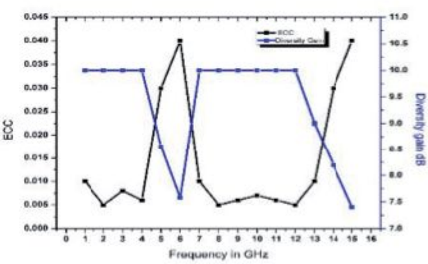

Fig 7. ECC and Diversity Gain of the Antenna

F. Group Delay

By exciting two identical antennas with placement of face to face orientation in far field, group delay was noted and presented in Fig 8. In this case when port 1 was excited then port 2 was terminated with 50-ohm impedance and when port 2 was excited then port 1 was terminated with 50-ohm impedance. It is being observed that the measured group delay is flat in the operating band. At notch bands sharp edges are obtained for group delay.

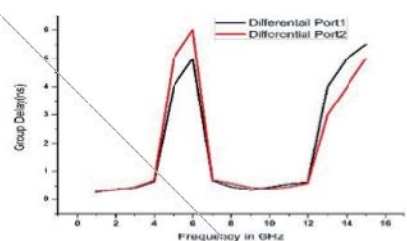

Fig 8. Group Delay of the Antenna

G. Prototype Measurements

The prototyped antenna on FR4 substrate has been shown in Fig 9. The measured reflection coefficient and transmission coefficient along with simulation results are presented in Fig 10. It is being observed that the measured results are providing excellent correlation with the simulation results.


Fig 9. Antenna prototype on FR4 substrate

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Table 2. Antenna Model comparison with Literature

Antenna dimensions	Gain (dB)	Notch bands	Ref Paper No
32X32	4.3	-	[1]
55X26	4	-	[2]
40X30	4.6	2	[3]
60X30	3.6	3	[4]
80X80	4.2	-	[5]
55X85.5	3.8	1	[6]
50X40	4.2	-	[7]
22X36	4.8	1	This work

Conclusion: In this article, mutual coupling reduction between elements of MIMO antenna using EBG structure exhibiting notch band is presented. EBG configuration is inserted between the radiating elements. EBG forbids the propagation of surface waves over its stop band, thus providing isolation. Proposed antenna shows good impedance bandwidth and Isolation better than -15 dB over the complete impedance bandwidth. Radiation efficiency and peak gain of the antenna varies from 72%-86% and 2.8 dB to 4.8 dB respectively. The antenna exhibits extremely low envelope correlation coefficient with a maximum value of 0.04 over the impedance bandwidth and diversity gain near to 10 is achieved.

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