Mutual Coupling Reduction using Metamaterial Structure for Closely Spaced Microstrip Antennas

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ABSTRACT

In today's world of miniaturization sensitivity of satellite communication system depends on isolation between transmitting and receiving Microstrip patch antennas which shares common ground plane. Coupling between transmitting and receiving antenna degrades overall system performance. It had been observed that When two patches were separated by the distance equal or greater than λ/10, we can formulate antenna parameters. But the world of miniaturization does demand distance between two patches has to be minimum. Manuscript suggests technique to improve isolation between patches which are separated by distance which is almost λ/24. Such less physical separation between them causes measurable amount of coupling between two patch antennas. The manuscript suggest the technique to improve isolation using Thin Wire (TW) Metamaterial structure which exhibits negative permeability.. Design and characterization of the Metamaterial are presented and it is shown that within a certain frequency band, the material behaves as anisotropic electric plasma, suppressing the mutual coupling. Height of TW is same as substrate height. Array of TW which is inserted between two patches reduces coupling due to surface wave. Also TW had been inserted at the radiating edge of one of the patch where near field just starts which helps to reduce coupling due to radiation in near field. Simulation results using HFSS shows that insertion of TW Metamaterial structure enhances isolation almost by 12 dB without affecting the antenna parameters such as impedance bandwidth gain, directivity and radiation pattern. The only limitation about the same is that band of frequencies over which TW exhibits the negative permittivity is less which can be overcome by placing them at both radiating edges of both patches.

Keywords

Isolation, Microstrip antenna, Metamaterial.

1. Introduction

To meet the essential technical specification of today's satellite communication system, we need very efficient and sophisticated technology. The heart of any advanced and sophisticated satellite communication system is its transmitting and receiving antenna. Today's technology uses microstrip antenna (MA) to meet such crucial requirement. Therefore it is necessary for the system designer that they should meet mechanical and electrical requirement for MA. The various mechanical requirements are its size weight, installation at desired location along with its various aerodynamics conditions, whereas electrical specifications are its electrical size, impedance bandwidth, beam width, gain, directivity and many more. Also to achieve compact system researchers are trying to replace the advance video cameras with the most precisely designed MA. Mainly researchers are trying to design the MA which will have narrow beam width, high direct gain, broad impedance bandwidth as well as less weight and size. To obtain the most efficient and compact satellite system, physical separation between transmitting and receiving antennas has been reduced to very few wavelengths. Also This leads to increased mutual coupling between them. Reduction in isolation between two antennas degraded the system performance. This reduces sensitivity and resolution of the system. Also in case of antenna array, close placement of antenna elements improves mutual coupling which reduces its performance [1, 2]. Thus isolation between two antennas element is very crucial as well as important design parameter.

Researchers had tried various methods to enhance isolation between two closely spaced antennas. These methods were placement of baffle between two antennas. Nowadays researchers were come up with artificial material which is Metamaterial (MTM).The paper suggests technique to improve isolation between closely spaced antenna elements using Thin Wire (TW) Metamaterial (MTM).

1.1 Metamaterial

In 1960's Victor Veselago examined the feasibility of media characterized by a simultaneously negative permittivity (ε) and permeability (μ). He concluded that such media allowed by Maxwell's equations and that plane waves propagating inside them could be described by an electric field intensity vector E, magnetic field intensity vector H and wave vector K, forming left handed triplet, in seeming opposition to wave propagation in conventional media [4]. Obviously such type of material is artificial in nature and known as MTMs. The theoretical speculation by Victor Veselago [4] which is the origin of left handed MTMs has given a new direction to research community. MTM (Meta means "beyond" in Greek) are new artificial material with unusualelectromagnetic property which is not found nature. ***Electromagnetic MTM*** (MTM) are broadly defined as artificial effectively homogeneous electromagnetic structure with unusual properties not readily available in nature[4]. An effectively homogeneous structure is a structure whose structural average cell size 'p' is much small that the guided wavelength λg.

The nature of unit cell decides the nature of consecutive parameters which are permittivity (ε) and permeability μ. ε and μ are related to refractive index ή by

$$ή = \sqrt{\varepsilon\mu}$$

Where $\varepsilon = \varepsilon_o\ \varepsilon_r$ and $\mu = \mu_o\ \mu_r$

When permittivity and permeability both had negative values, refractive index also results in negative value and material is known as MTM.

The Russian physicist Victor Veselago [4] also predicted some phenomenon related to MTM such as Necessary frequency dispersion of consecutive parameters, Reversal of Doppler effect and Negative refraction.

1.2 Types of Metamaterial

MTM are nothing but unit cell of specific shape and material which are periodically arranged at intervals shorter than the specified wavelength .

Since MTMs are generally not available in nature and one has to imposed them, they can be classified as

i) Single negative MTM (SNG)
ii) Double negative MTM (DNG)
iii) Electromagnetic Band-gap MTM (EBG)

Surface waves and radiated wave are the two causes for increased mutual coupling which affect the antenna performance.

Thin Wire (TW), split ring resonator (SRR), omega, mushroom, Fishnet and many more. These structures can be constructed using either metal or any dielectric material. Every homogenous structure results into either into negative ε or negative µ or both. Each structure has its own advantages along with its limitations.

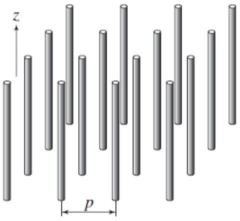

Figure 1TW Structure

1.3 About Thin Wire Structure

TW results into negative ε and positive µ in desired frequency range which is decided by dimensions of TW structure which are described in figure1.If the excitation electric field **E** is parallel to the axis of the wires (**E**_*z*), so as to induce a current along them and generate equivalent electric dipole moments, this MTM exhibits a plasmonic-type permittivity frequency function which is given by equation (2).

$$\varepsilon_r(\omega) = 1 - \frac{{\omega^2}_{\rho e}}{\omega^2 + j\omega\xi} = 1 - \frac{{\omega^2}_{\rho e}}{\omega^2 + \xi^2} + \frac{\xi {\omega^2}_{\rho e}}{\omega\left(\omega^2 + \xi\right)^2} \quad (2)$$

$\omega pe = E$lectric plasma frequency=$\sqrt{2\pi c^2/[\mathrm{p}2}\ \ \ln\left(\frac{\mathrm{p}}{\mathrm{a}}\right)$

C = Speed of light ; a = radius of wire ;p = average cell size

$$\xi = \frac{\varepsilon_0 \left(\frac{\mathrm{p}\omega_{\rho e}}{\mathrm{a}}\right)^2}{\pi\sigma}$$ = Damping factor due to metal losses(3)

σ = Conductivity of metal.

For the same excitation, $\mu = \mu_0$ and since no magnetic material is present, no magnetic dipole moment is generated. But it should be noted that the wires are assumed to be much longer than wavelength (Theoretically infinite) which means that the wires are excited at frequency situated for below their 1st resonance [5].

1.4 Isolation between closely spaced antenna elements

When available space is main constraint in satellite design, the physical separation between transmitting as well as receiving antenna element is very less. As well for antenna array physical separation between two consecutive antenna elements is also less when they share common ground plane.

The results mentioned in [7] conclude that for calculation of S_{12} or S_{21} mainly depends on surface wave formulations. But it had been shown that as the distance between patches increases effect due to surface waves on mutual coupling will reduce. Here radiating field contribute more for mutual coupling. When the patch separation is equal or greater than λ/10 , it had been observed that mutual coupling due to radiating field contributes more in mutual coupling than surface waves. This mutual coupling affects the mutual impedance for antenna. Formulation given in [8] indicates that mutual impedance depends on physical separation between two antenna, plane for them, dielectric constant, and antenna dimensions. When distance between two patches is equal to or greater than λ/10 perfect formulation for antenna behavior is done. Whereas when distance decrease, antenna behavior can’t be predicted. But this decrease in physical separation totally affects the antenna performance which affects the various antenna performance parameters such as impedance bandwidth, radiation pattern. Minimized isolation between them may also change its directivity and beamwidth. Change in direction of the main lobe degrades array performance. Thus it is most essential to introduce some technique to enhance isolation between them without affecting antenna parameters and also it should not make system bulky.

Main highlight of the manuscript is that the patch separation is λ/24 for which antenna behavior is unpredictable. Single patch element was simulated using Ansoft HFSS (High frequency structure simulation), version 11 at 2.4 GHz on Duroid substrate (ε=2.2) .The same design had been repeated for two patch elements with physical separation between them which is less than one wavelength. The structure is shown in figure 2 for physical separation between antenna elements as λ/24 and figure 3 and 4 shows simulated results for the same. Simulated results are tabulated in table-1.

2. PROPOSED DESIGN of CLOSELY SPACED ANTENNA ELEMENTS WITH TW MTM FOR ISOLATION ENHANCEMENT

Initially unit cell for TW MTM structure at 2.4 GHz had been designed with a=0.3mm and p=0.6mm which was simulated .The unit cell had been excited with Electric field parallel and

magnetic field perpendicular to axis of TW. The electromagnetic parameters permittivity (ε) and

Permeability (µ) had been retrieved [6]. These results shows that for certain range of frequencies TW structure possess negative refractive index and due to this only we were going to use them for enhancement of an isolation.An array of such TW structure had been placed between two antenna elements as well as at the radiation edge also and is shown in figure 2. The placement of TW array structure reduces mutual coupling at designed frequency due to its negative refractive index. Array of TW at the center helps to reduce mutual coupling due to surface waves. Array of TW at the radiating edge helps to reduce mutual coupling due to near field radiations. We can also place an array across another radiating edge. But this had not showed measurable difference in resultant isolation.

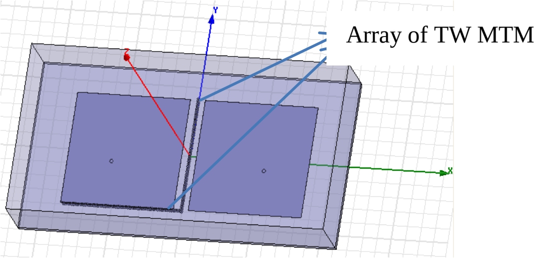

Figure 2: Proposed Technique for Isoaltion Enhancement

Simulations had been carried out for various dimensions of TW and are tabulated in Table2.

The tabulated result shows that nsertion of TW structure not only enhances the isolation but also improves the antenna parameters also.

The same structure had been simulated for various dimensions of TW structure and simulated results are tabulated in Table-3. But not measureable amount of change had been observed at desired frequency.

Table-1: Simulated Results for two antenna elements withoutMTM

Antenna Parameters	Single Patch	For Two Patch Elements for Various Physical Seperationinterms of λ		
Resonant Frequency(GHz)	2.4	2.38	2.38	2.4
Return Loss (S_{11} in dB)	-15	-15	-14	-13.7
Impedance Bandwidth(MHz)	400	360	370	250
Gain(dB)	5	3.5	3.2	1.68
Beamwidth(deg)	80	60	60	--
Isolation(S_{21}in dB)	----	-25	-22	-17.9
Isolation(S_{21}in radians)	----	-4	-1.2	0.22
Isolation(S_{12}in dB)	----	-25	-22	-17.9
Isolation(S_{12}in radians)	----	-4	-1.2	0.22

3. Conclusion

To improve sensitivity of sophisticated satellite system crucial parameter is maximum electrical isolation which can be obtained from minimum physical separation between transmitting and receiving antenna. The manuscript suggests the technique to improve isolation between them using TW MTM. Tabulated results shows appreciable increase in isolation which is sufficient to improve sensitivity of satellite system till 35GHz.Also it is easy to fabricate the same and cheaper also. Simulated results show that insertion of TW had not affected the antenna polarization. TW wire insertion also improves radiation pattern. Also it had increase the gain and made beam sharper. Limitation for the suggested technique is that its narrow band which can be overcome by selecting MTM which will have both negative permittivity as well as negative permeability at desired frequency.

Table 2 : Simulation Results for patches separated by λ/24

Antenna parameters	patch elements separated by distance of λ/24**without TW Structure**	patch elements separated by distance of λ/24 with **TW Structure**
Resonant Frequency(GHz)	2.4	2.39
Return Loss (S_{11} in dB)	-13.7	16
Impedance Bandwidth(MHz)	250	230
Gain(dB)	1.68	4
Beamwidth(deg)	--	65
Isolation(S_{21}in dB)	-17.9	-35.76
Isolation(S_{12}in dB)	-17.9	-35.76

Table-3 Isolation For Various TW Dimensions

Dimensions for TW Structure in mm		S_{21} in dB
a	P	
0.3	0.6	-36
0.5	1	-37
1	2	-27

4.Acknowledgement

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