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Influence of the Integration of Ferrite Films in the Substrate, On Resonant Frequency of the Patch Antenna

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ABSTRACT
Improving the performance of communication systems often results in an increase of their operating frequencies and the need to reduce the dimensions of the electronic equipment to ensure the portability of these systems, which requires the use of anisotropic materials such as ferrites, The work we have performed was applied to the design of a patch antenna for UMTS applications.

This antenna is etched on a substrate of glass-epoxy of permittivity $\varepsilon_r = 4.32$ and is fed by a micro-strip line matched to 50Ω. In order To study the influence of ferrite on the resonance frequency of the antenna, and its bandwidth. We varied the substrate characteristics while incorporating ferrite films $Ni_{0.23}Co_{0.13}Fe_{2.64}O_4$ characterized by the permittivity $\varepsilon_r = 13$ and permeability $\mu_r = 10$ between the patch and the ground without making changes to the geometry of the antenna used. The results obtained by the simulator CST, show that the studied antenna performance, are improved through ferrite films loaded in the glass-epoxy substrate, which we noticed also has a decrease in resonance frequency and this lower frequency depends on the thickness of the ferrite films and their location in the antenna structure. We conclude at the end that the combination of dielectric substrate with ferrite films enables us to design miniature antennas with high performance in the gigahertz range.

***Keywords* -** Multilayer patch antenna, anisotropic materials, ferrite, permeability tensor, miniaturization of antennas.

I. INTRODUCTION

Telecommunication has known a lot of improvement, thanks to their wide use in our daily lives, a large amount of thought was directed towards the development of systems of wireless communication, to improve their flexibility and speed of information transfer. The antennas are important elements in the chain of transmission. And it is thanks to the micro-strip antennas known by their small size, ease of fabrication, and integrability with other mobile devices, that these systems have experienced a real revolution. Hence the need for miniaturization of antennas. Indeed there are different techniques to ensure this miniaturization such as the use of parasitic elements, capacitive loading, and realization of slots. But due to the antenna performance degradation when using these different methods, we find that the current technology is moving towards the integration of anisotropic materials with high permeability and permittivity.

The films of ferrites are used in the structure of micro-strip antennas because their magnetic field, the high permeability and permittivity can change the performance of antennas. In this paper we will introduce ferrite films to adjust the resonance frequency of an antenna for UMTS applications.

II. FERRITES AND THEIR EFFECT ON THE FREQUENCY RESONANCE.

1. Ferrites

Ferrites are magnetic materials widely used in industry. They are used in radar applications, information storage, as well as in the field of telecommunications. And it is thanks to their particularity (also noticed in ferromagnets) that resides in the presence of remanent magnetization (translated by the existence of magnetization total non-zero magnetization to the excitation of an external magnetic field zero). Also the use of these anisotropic materials is due to their low conductivity that encourages electromagnetic wave interaction where the resistivity of these materials is between 102 and 109 Ω / cm, the non reciprocal property which means that no signal amplification takes place, so the dependence of the permeability is on their polarization states.

The permeability tensor of a sphere uniformly magnetized with the magnetization directed along Z is given by:

$$\left[\hat{\mu}\right] = \begin{bmatrix} \mu & jk & 0 \\ jk & \mu & 0 \\ 0 & 0 & \mu_0 \end{bmatrix}$$

Or

$$\mu = \mu_0 \left[1 + \frac{\omega_0 \omega_m}{\omega_0^2 - \omega^2} \right]$$

$$K = \mu_0 \frac{\omega \omega_m}{\omega_0^2 - \omega^2}$$

$$\omega_0 = \mu_0 \gamma H_{net}$$

$$\omega_m = \mu_0 \gamma M_s$$

- γ: the gyromagnetic ratio
- H_{net}: the magnetic field along the Z direction
- $\mu_0 M_s$: the saturation magnetization

2. THE INFLUENCE OF FERRITE ON THE RESONANCE FREQUENCY, AND OTHER ANTENNA PERFORMANCE

The frequency of operation of microwave devices is fixed by the magnetization saturation ($4\Pi M_s$) of the ferrite introduced. The reduction of magnetization allows increasing the power level bearable by the material without generating non-linear effects; it leads also to the reduction of insertion loss of the device at a frequency lower than the resonant gyro-magnetic frequency of the material.

III. PATCH ANTENNA DESIGN

Antennas are very important links in the chain of transmission; it can receive and transmit radio waves by the transformation of energy guided at radiated energy and vice versa. This device has several roles of which the main ones are the following:

Ensure the matching between the propagation medium, and the radio-electric equipment.

Ensure the transmission or reception of energy in preferred directions.

There are several antenna manufacturing technologies to meet the needs of telecommunications. In this document we worked on patch antennas, and we chose the means of reducing the size of antenna by introducing films of ferrites in antenna substrate used. Generally this technique allows the fabrication of antennas self-polarized, resonant at frequencies above 1GHz.

1. TECHNIQUES OF MINIATURIZATION ANTENNA.

The integration of several electronic components in the same mobile terminal always leads to miniaturization of its components. It is also known that the reduction in size of an antenna leads to a significant reduction of bandwidth, and a decrease of radiation efficiency. Also reducing of the antenna dimensions leads to an increase of the intensity of electromagnetic fields in the vicinity of the structure. The resonance phenomena likely occur leading to a high coefficient quality, which makes antenna matching and obtaining large bandwidths tricky.

The different techniques are used to reduce the size of antennas. The most popular of these methods is the use of high dielectrique permittivity substrate; this method allows us to concentrate the field lines under the antenna, this concentration led to the weakening of the efficiency, and therefore decrease gain and increase losses in the material in the substrate, which leads to an increase in the quality factor of the antenna and decrease its bandwidth. For this reason, the use of this method is useful in cases where the intended applications demand low bandwidth, and low gain. Obtaining an antenna with small size, can be made using the slots which induce inductive and capacitive effects, and consequently the increase of surface currents, the cross-polarization radiated, and the lowering of the resonance frequency, as well as degradation of the bandwidth and the gain. Also for miniaturizing the antenna dimensions, metamaterials with metallic circuits are used but the losses are still too high, in addition to the difficulty of the implementation of its circuits. In recent years we notice that the miniaturization of antennas was oriented towards action on the substrate of the antenna, and especially the introduction of the substrates made by self-polarized magnetic materials, where no external bias field was applied. But because of the limits of miniaturization Snoek this technique was blocked for lower frequencies at 600MHz. To solve this problem, the integration of ferrite films is necessary; since these thin magnetic films are characterized by a high magnetization field, that produces self-bias at high resonance frequency (up to GHz).

2. MULTILAYER PATCH ANTENNA.

For Micro-strip antenna, the length and width (has a very important effect on the antenna input impedance and the bandwidth) of the radiating patch and the effective permittivity of the micro-strip structure are calculated by the use of following formulas:

Length of the patch: the length of patch determines the resonance frequency a resonator. And above all, do not forget to subtract the length ΔL corresponding to the extensions of fields.

$$L = \frac{\lambda_{diel}}{2} - 2\Delta L$$

$$\lambda_{diel} = \frac{C}{f_r \sqrt{\varepsilon_r}}$$

$$\Delta L = 0.412h \frac{\left(\varepsilon_{r_{eff}} + 0.03\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{r_{eff}} - 0.258\right)\left(\frac{W}{h} + 0.8\right)}$$

$$\varepsilon_{r_{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12h}{W}\right)^{-\frac{1}{2}}$$

Width of the patch: The patch width has a minor effect on the resonance frequencies, and on the radiation pattern of the resonator. On the other hand, it plays an important role for the input impedance of the resonator, and bandwidth. To assure proper performance of the resonator, the width W is:

$$W = \frac{C}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

I. ANTENNA DESIGN

The patch antenna (shown in **Fig.1**) designed to operate at a resonance frequency of 2.1GHz. It consists of a rectangular patch, with two symmetrical notches relative to micro-strip line supply adapted to 50Ω. The patch and the ground are made of copper of thickness, 35µm and they are separated by a substrate of glass-epoxy of dielectric permittivity $\varepsilon_r = 4.32$, and of relative permeability $\mu_r = 1$.

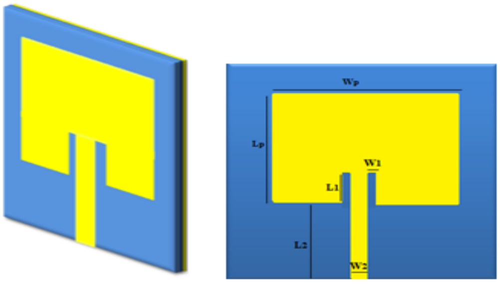

Fig 1: Patch antenna dielectric substrate of glass-epoxy

The Different antenna parameters are detailed in Table 1.

Table 1. Dimension of antenna structure

Basic configuration	Variable	Dimension (mm)
Copper Patch	W_p	***42.79***
	h_p	***0.035***
	L_p	***32.6***
Notch	W_1	2
	L_1	10
Glass-epoxy Substrate	L_{sub}	80
	W_{sub}	80
	h_{sub}	2
Feeding Line	L_1+L_2	26.6
	W_2	4
	H	0.035
Copper ground	L_g	80
	h_g	0.035
	W_g	80

To study the effects of loading ferrite films, as well as the influence of their locations, we proceeded as follow.

The second antenna designed, is loaded with a single film of ferrite $\mathbf{Ni_{0.23}Co_{0.13}Fe_{2.64}O_4}$ 2µm thick, the latter is integrated between the ground and the substrate (**Fig. 2 (a)**). For a third design, we integrated the ferrite film between the substrate and the patch (**Fig.2 (b)**).

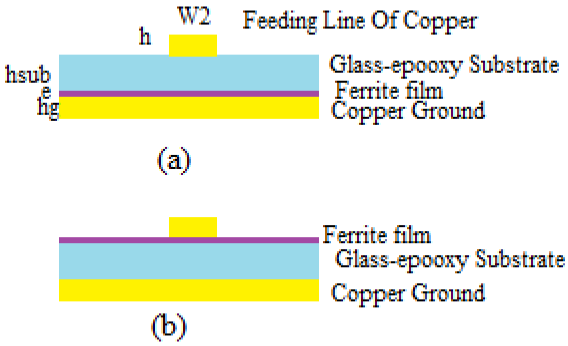

Fig 2: Antenna patch loaded with a ferrite film

(a) : the ferrite film between ground and the substrate.
(b) : the ferrite film between the patch and the substrate.

In a second step to evaluate the influence of the thickness of the ferrite films on the resonance frequency, and other performances of antenna, we designed antennas presented in **Fig.3**.

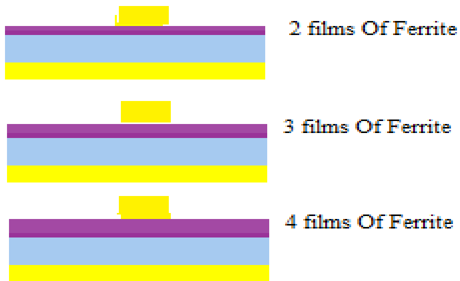

Fig 3: Change in thickness of film loaded in the ferrite antenna

The results obtained of these several designs are made by using electromagnetic simulation software. This software allows making the optimization of various parameters of antenna, knowing that this step can be costly in terms of time and resources. In our design methodologies, we used the solver CST Microwave Studio which implements the method of finite integrals associated with the boundary conditions to solve an electromagnetic problem.

IV. RESULT

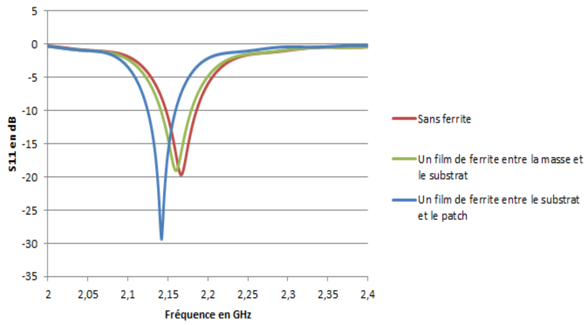

Fig 4: Simulation results of patch antenna with and without ferrite.

Table 2. THE Mesurs of the RESONANCE FREQUENCY AND BANDWIDTH of the PATCH ANTENNA, WITH AND WITHOUT FERRITE

	the Resonance frequency (GHz)	The bandwidth -3dB in MHz	The bandwidth -10dB in MHz
without ferrites	2.166	106,809	38.003
A ferrite film between the mass and the substrate	2.16	107.534	37.876
A ferrite film between the substrate and the patch	2.142	93.135	34.837

The results show that the introduction of ferrite in the substrate results in a decrease of the resonance frequency. We noticed that the location of these films (**Fig. 4**) plays a very important role in the reduction of the resonance frequency and the antenna matching.

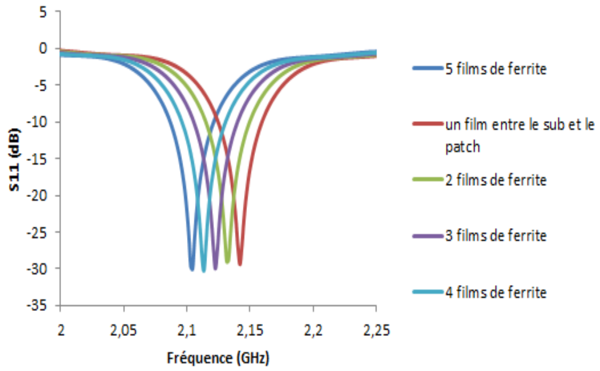

Fig 5: Simulation results the patch antenna with ferrite at different thickness

Table 3. The measures of the frequency resonance and bandwidth of patch antenna with different thickness of ferrite.

the film Ferrite thickness	the Resonance frequency (GHz)	The bandwidth -3dB in MHz	The bandwidth -10dB in MHz
2µm	2.142	93.135	34.837
4 µm	2.131	92.896	34.761
6 µm	2.122	92.734	34.700
8 µm	2.113	92.528	34.611
10 µm	2.104	92.234	34.139

The results shown in (**Fig. 5**) and summarized in (**table.3**). Show that the increase of the thickness of the ferrite films, leads to the improvement of the matching of the patch antenna, and the correction of the resonance frequency thereof without adversely the changes at its dimensions. As against this, we note that the integration of the ferrite substrate limits the bandwidth.

V. CONCLUSION

The self-polarized ferrite films introduced into the structure of the patch antenna leads to a correction of the resonance frequency thereof to a frequency close to 2.1 GHz, as a result it was concluded that this method of antenna design enables the miniaturization of antennas.

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