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Magnetodielectric Material for VHF Antenna Devices Tunable by a Low DC Magnetic Field

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This study presents the performance of a magneto-dielectric material (MDM) specially developed to enable the tunability of antenna devices operating in the VHF band. The magnetic susceptibility variation of the MDM material is controlled by a current flowing through the sample which creates a DC magnetic field inside the sample with the same symmetry as the magnetic domains. By changing the magnetization state of the MDM with a low DC magnetic field of 740 A/m, a tunability of 40% can be observed. The MDM tunability at VHF frequencies is also verified by microwave measurements for different magnetization states.

Index Terms— ferrimagnetic materials, tunable materials, magnetization state, magnetic susceptibility, tunable VHF device.

I. INTRODUCTION

REDUCING THE size of antennas at VHF band (30-300MHz) is an important issue for airborne systems industry, to reduce the weight of the aircraft and improve its aerodynamic shape. Nevertheless, antennas' integration at VHF band becomes critical since the wavelengths are large at those frequencies and will lead to reduced antenna performances following the fundamental laws [1]. Magneto-dielectric materials (MDM) with a relative permittivity $\epsilon_r > 1$ and relative permeability $\mu_r > 1$ have been used these last few years as a promising solution for antenna miniaturization. Typically, an efficient strategy to miniaturize Inverted F-Antenna loaded by magneto-dielectric material is proposed in [2]. The problem of the tunability of antenna devices controlled by the application of a continuous magnetic field is complicated by the value of the field strength required (>32 kA/m) for their implementation, due to the importance of the shape demagnetizing [3]. To overcome this effect, we propose to use a toroidal material, with the domain walls adopting an approximately orthoradial symmetry. The permeability can then be easily modified by a magnetic field of the same symmetry, without the appearance of demagnetizing shape effects. Our main objective is to vary the magnetic susceptibility value of such a tunable MDM using a DC magnetic field <800 A/m, with the aim of achieving a tunable antenna by currents <10 A.

II. EXPERIMENTS AND RESULTS

A polycrystalline NiZnCoCu ferrite prepared by the Lab-STICC is used. It is obtained from powders synthesized by co-precipitation [4]. The toroidal-shaped samples are obtained by uniaxial pressing, before being subjected to a suitable heat treatment. In the developed MDM material, the domain walls motion mainly controls the magnetization mechanisms. The initial magnetic susceptibility is measured by a laboratory-developed hysteresis meter based on the magnetic transformer method. The primary winding is connected to a low ac voltage to create a low intensity ac magnetic field h in the sample while the secondary winding is connected to an EGG Princeton 5302 lock-in amplifier to measure the ac magnetic flux density b . The initial magnetic susceptibility is then calculated as $\chi = b / (\mu_0 h) - 1$.

In addition, a single control wire running through the toroidal sample allows a DC magnetic field H_{stat} to be superimposed on the ac magnetic field h in the same orthoradial direction. This is a key point of this experiment because it avoids the appearance of demagnetizing shape effects. The DC current I flowing in the control wire can be adjusted to change the magnetization state of the sample and thus modify its susceptibility. According to the characteristics of the experimental setup, the mean static field in the sample is proportional to the current: $H_{\text{stat}} \text{ (A/m)} = 74.1 \times I \text{ (A)}$.

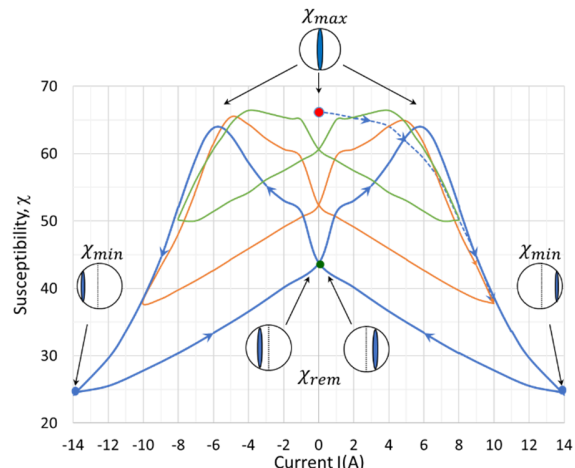


Fig. 1. Initial susceptibility measured at 10 kHz for currents up to 14 (A).

Fig. 1 shows the initial susceptibility measured for a set of control current up to 14 A. Curves obtained with I higher than 4A show hysteretic behaviour. The change in initial susceptibility is closely related to the magnetization state which is set by the control current. Due to the orthoradial symmetry of domains walls, magnetization mechanisms can be represented by the Globus model [5]. The grains are assumed to be spherical with a central domain wall that can vibrate under the action of the dynamic field and move under the action of the static field. In the demagnetized state, the domain wall is located in the middle of the grain (see inset Fig. 1); the susceptibility is equal to its maximum value $\chi_{\text{max}}=66$. First, the susceptibility decreases as the current increases due to the domain wall displacement to a position where its diameter is lower, the susceptibility reaches its minimum value χ_{min} for the maximum

current ($\chi_{\min}=24$ for $I_{\max}=14A$). Then, when the current decreases the domain wall tends to return to its initial position and the susceptibility increases slightly. Due to pinning effects by the grain boundary, the domain wall does not return to its central position and the susceptibility takes a remanent value χ_{rem} for $I=0$ which depends on the maximum current reached before ($\chi_{\text{rem}}=44$ after $I_{\max}=14A$). Continuing, the domain wall moves in the opposite direction when the current reverses. The susceptibility increases until it reaches a value close to the maximum for a central position of the domain wall, which corresponds to a so-called coercive current. Increasing the current, the susceptibility decreases to the same minimum value as in the first branch.

III. TUNABILITY OF THE MAGNETODIELECTRIC MATERIAL

Fig. 2 shows the dependence of the three susceptibilities χ_{\max} , χ_{\min} and χ_{rem} on the static applied current. The deviation of the susceptibility from its maximum value becomes noticeable for currents above 4A and increases significantly up to 14A before showing saturation for high currents. Note that the minimum susceptibility is obtained for a permanent current in the control wire. When the current is established and then stopped, the remanent susceptibility remains. Thus, a fairly good level of tunability can be obtained with this material in the remanent state without maintaining the current. This is a very interesting feature for embedded systems. The tunability of the VHF device is directly related to that of the susceptibility, that is defined by $(\chi_{\max} - \chi_{\min}) / \chi_{\max}$.

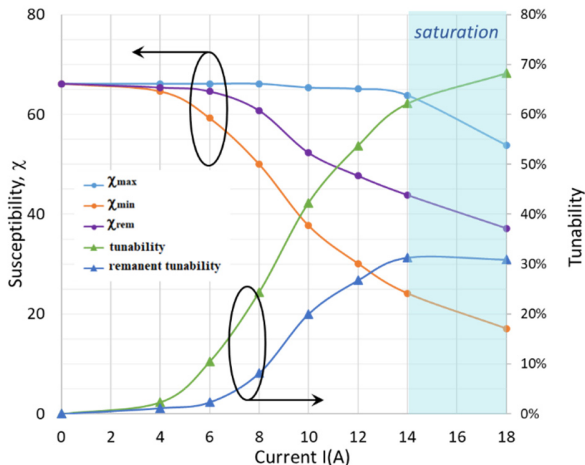


Fig. 2. Initial susceptibility and tunability measured at 10 kHz.

A noticeable MDM tunability can be achieved with moderate currents, up to 40% with $I=10A$ to which corresponds a DC magnetic field $H_{\text{stat}}=740$ A/m. When the sample is briefly polarized (10A) and the current is turned off, the tunability remains at 20%. Higher tunabilities can be achieved at higher currents e.g. 62% and 31% respectively by maintaining and not maintaining the control current of 14A.

IV. MICROWAVE MEASUREMENTS

To control the tunability of the material at the operating frequencies of VHF devices, microwave measurements were

performed using the coaxial transmission line method and Agilent 8753ES network analyzer. However, adding a control current in the transmission line requires the use of bias tees which are usually limited to currents below 5A and also cause severe perturbations in the measured S-parameters. We have therefore chosen to separate the magnetization step and the microwave measurements. The sample is first polarized with the selected current on the permeameter setup, brought into its remanent state and then measured in microwave transmission line without static current.

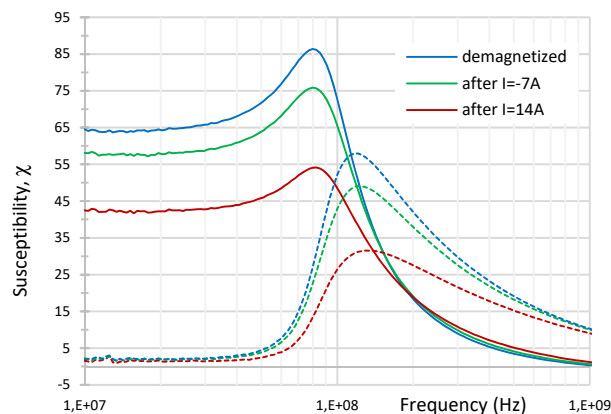


Fig. 3. Microwave susceptibility for three magnetization states. (solid lines : Real part; dashed lines : imaginary part).

Fig. 3 shows the susceptibility spectra measured by transmission line method in the [10MHz-1GHz] frequency band. Magnetic losses remain low in the 10-80 MHz frequency band, making these materials suitable for VHF applications. The MDM tunability is verified: a current control of 14A makes the susceptibility change from 65 to 43, resulting in a remanent tunability of 33% very close to that measured at 10 kHz.

V. CONCLUSION

This work demonstrates the suitability of MDM materials for use in VHF tunable devices. A tunability of the magnetic susceptibility up to 40% can be achieved for currents below 10A. A promising result for further applications is the tunability of the MDM up to 30% that can be reached without holding current when operating in the remanent state.

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