LEFT HANDED ELECTROMAGNETIC MEDIA BASED ON METAMATERIALS

T. Crépin, X. Mélique, A. Marteau, E. Lheurette, T. Decoopman, O. Vanbésien and D. Lippens

Institut d'Electronique de Microélectronique et de Nanotechnologie
Université de Lille1, Avenue Poincaré, BP 60069, 59652 Villeneuve D'Ascq Cedex, France
Didier.Lippens@iemn.univ-lille1.fr

ABSTRACT :

We report on the experimental assessment of left-handed electromagnetic media which are fabricated from metamaterial-based transmission lines. Two kinds of micro-and nano-structured lines were fabricated namely (i) a novel scheme of finline-based technology, which operates at microwave and (ii) a coplanar strip (CPS) scheme which operates at Terahertz frequency. Experimental assessment is achieved for the finline technology in the Frequency domain via the sign of the phase offset between two lines of various lengths while the C-L-type CPS line was experimentally assessed using electro-optic sampling with direct evidence of a phase advance in the time domain

INTRODUCTION

Left handed material systems are now attracting much interest after the demonstration of a pass band when the propagation medium exhibits negative permittivity and permeability simultaneously [1]. This was possible owing to the proposal of Pendry of using non magnetic double Split Ring Resonators (SRR's) [2] for negative permeability and thin wire for negative permittivity. Under these conditions, it is expected that the phase and Poynting vectors are anti-parallel. These media were termed Left handed materials (LHM's) by Veselago about two decades ago [3]. So far, most of the studies devoted to this topic addressed free space prototypes constituted of arrays of thin wires and SSR's highlighting thus the bulk material properties by de-embedding notably the permittivity and permeability values from the transmission and reflection coefficients [4]. Also negative refraction experiment have been conducted showing experimentally the double negative media exhibit a refraction angle in the same half plane as the incident one.

On the other side, a number of works have focused on transmission lines either in a planar technology or a waveguide scheme [5-6]. While the former approach was suitable for near field probing and can be probed using wafer probing techniques, the latter present a key advantage to prevent any radiation losses. At least two complementary routes for the synthesis of the double negative media have been followed. The first one is to couple split ring resonator to a transmission line. This can be done in a number of technology including microstrip, Coplanar waveguide or CPS schemes. The second solution is to use the dual version of a conventional low-pass L-C type transmission line. This is simply obtained loading a transmission line by series capacitance and shunt inductance namely a C-L type rather the conventional L-C distributed element.

In this paper, we report on the experimental assessment of (i) a left handed waveguides using SRR's operating at microwave and (ii) a C-L CPS transmission line which operates at Terahertz frequency. In both case special attention are paid on the experimental demonstration of left handedness and on the losses.

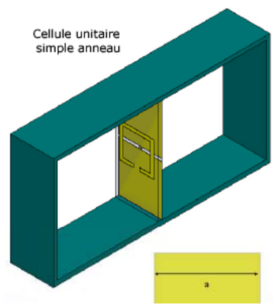

Fig. 1: Finline based prototype

Fig. 2: Optical view of the finline-based prototype

FINLINE MICROWAVE TRANSMISSSION LINE

The finline waveguide consists of a uniplanar finline loaded, on the upper side, by narrow wires shunting periodically the two metal plates and on the back side by single Split Ring Resonators (Fig. 1). Details of the design of the tapering section [7] for avoiding standing wave and of the numerical evidence of the left handed character can be found in [8-9].

Measurement of scattering parameters was conducted on a HP 8510 network analyzer by Agilent. A calibrating procedure was established including the coaxial-waveguide transitions necessary to rf probe the structure. Excellent agreement between modeling and experiment was obtained for the magnitude of the measured and calculated scattering parameters in the left handed window (not shown here) particularly for the frequency band This permits us to have confidence in the derivation of the frequency dependence of the loss term which are of prime importance for any potential application. The origin of the loss has to be further clarified and to this aim we plotted in Fig. 8 the loss contribution which can be computed from the equation $L= 1 -S_{21}^2-S_{11}^2$. It can be noticed that the loss peaks close to the low frequency of the transmission window. This frequency correspond to the resonance frequency of the SRR's and an increase of losses around this resonant is in agreement with an increase in the imaginary part of the effective permeability

Some indirect evidence of left-handedness can be obtained via the comparison of band structure and of transmission spectrum but a direct experimental verification is still lacking. An elegant means to shows a reversal in the k vector direction is to use the phase offset between two lines of different lengths. Under this condition, in the frequency window where the EM waves can propagate, the phase offset is positive if the propagation is backward and negative for conventional lines. Fig.4 gives the phase offset between two lines respectively of 3 and 2 unit cells as a function of frequency. It can be seen that ΔΦ is positive in the frequency band where the permittivity and permeability are negative simultaneously, while it is negative or vanishing elsewhere.

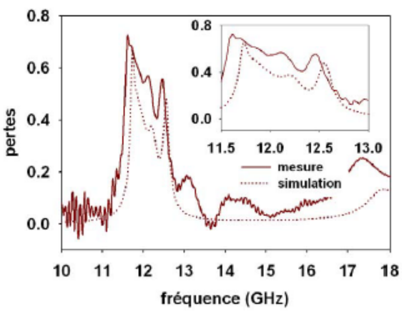

Fig 3: Estimation of losses between 10 and 18 GHz for the finline prototype

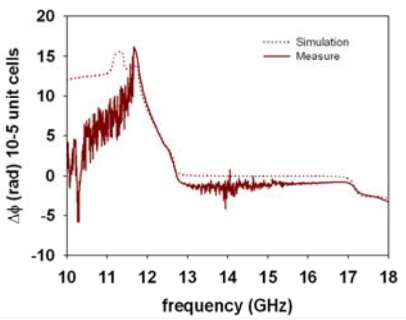

Fig 4. : Phase difference for two different lengths of the finline prototype.

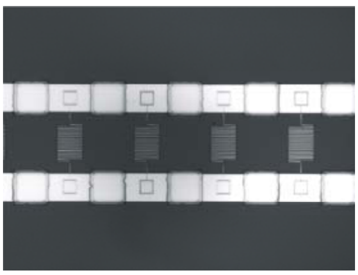

Fig 5 : View of the C-L terahertz transmission line

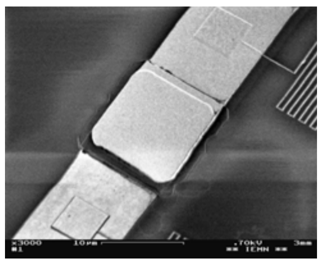

Fig 6 : Zoom view on the capacitance area of the C-L prototype

CPS TERAHERTZ TRANSMISSION LINES

Fig. 5 gives a general view of a C-L transmission line aimed to operate at THz frequency whereas Fif. 6 is a zoomed view of a completed circuit under polarized light. As shown in Fig. 7, a left-handed band is expected to appear from 150 GHz up to 380 GHz. Owing to edge current effects along the planar strips and to minimize radiation losses, their width was limited to 10 µm for a slot of 25µm. Periodically with a pitch of 30 µm, the

lines integrate 10x10 μm^2 parallel plate capacitance in a series configuration. They are fabricated using a Si_3N_4 thin film technique (layer thickness of 500 nm) by plasma enhanced chemical vapor deposition. This corresponds to a unit capacitance for a basic cell around 15 fF. The shunt inductances which interconnect the two conductors strips consist of a folded strip (section 0.2x 0.2 μm^2) patterned by e-beam lithography**.** For the time dependence measurement of the transmitted and reflected wave we have used, in the present experiment, a detection techniques based on Franz Keldysh effect. Further details about this technique can be found in [10]. In practice, for the implementation of semiconductor epilayers necessary for feeding and probing the propagating wave along the lines, we used thin films (typically 2 μm thick) of lifted-off Low temperature GaAs and AlGaAs patches bounded by Van de Waals force onto the transmission line.
Figure 8 illustrates how the patches are grafted on overlapping two CPS transmission lines with GaAs and AlGaAs patches, the latter being bonded in the input and in the output sections. Since the observation of Franz-Keldysh effect needs high field magnitude, a dc bias of 60 V was applied in the access region dc isolated in a natural fashion from the transmission lines by the end series capacitance. Moreover the bias allows the generation of the feeding pulse

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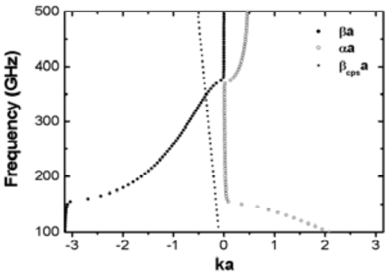

Fig. 7 Evidence Left handed behaviour via phase offset

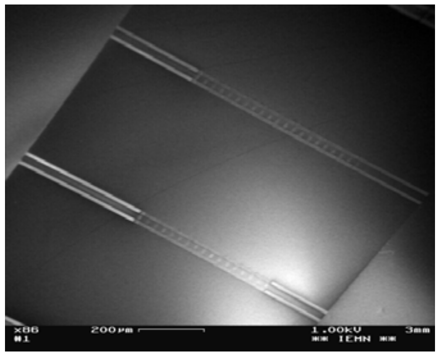

Fig. 8: Scanning Electron Micrograph of the devices under test

Figure 9 displays the variations versus time of the electro-absorption recorded for the AlGaAs patch of the output (transmitted wave) for a 21 cell transmission line . The signal is rapidly varying with an oscillating form on a time scale of a few picoseconds (~3 ps). Around 30 ps of delay and hence well above the time window of interest, the detector records a first echo due to a, spurious reflection at the open-end of the line. The Fourier transform of the time variation of the transmitted signal between 0 and 20 ps is displayed in the inset of Figure 4. A well-defined pass-band is apparent starting from 250 GHz up to 380 GHz in agreement with a left handed dispersion branch in this frequency range. Quantitatively the low cut-off frequency is shifted to higher frequency. It is believed that uncertainties in the material parameter at Terahertz frequencies along with imperfect in the fabrication of prototype can explained such a discrepancy. Outside the band, the signal is reflected by the structure as it could be assessed from the time dependence of reflected wave (not shown here).

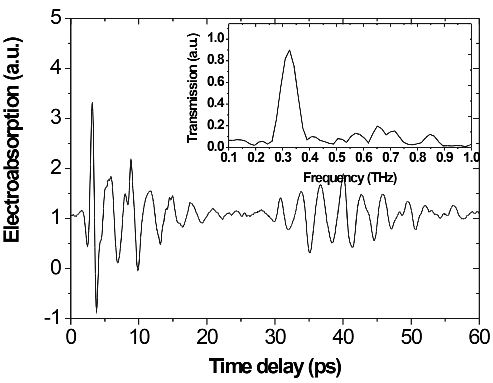

Fig 9.: Electro-absortpion measured on the prototype shown in Fig. 8. Insert gives the Fourier spectrum associated.

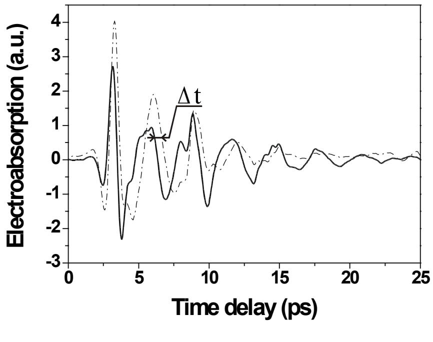

Fig 10: Comparison of time response between two transmission ines of different lengths.

Direct evidence that the wave is backward during the propagation in the left handed section can be done using the comparison between the time dependence of the transmitted signal between lines of various lengths. Fig. 10 shows such a comparison for 21 (solid line) and 17 cells (dashed line) respectively. It can be seen that the ultra-short time component, which correspond to the very high frequency of the investigated spectrum may be used to give a time reference. Under this condition, it can be shown the signal corresponding to 21 cells shows a phase advance. Fig. 6 shows the phase offset ΔΦ between the two lines. In the stop band the signal fluctuates round zero while in the left handed dispersion branch ΔΦ is positive in agreement with the arguments developed in introduction.

CONCLUSION

Left-handedness was experimentally assessed on two kinds of metamaterial based transmission lines. The double negative media were synthesized on one hand via slit ring resonator designed for an operation around 10 GHz and on the other hand by means of lumped reactive elements circuits aimed at resonating in the Terahertz region The characterization techniques have also been different with a continuous wave probing in the first case while the second prototype was assessed under pulse experiment. Beyond the left handed character special attention of the losses has been paid and we have shown that they are particularly high close to the resonance frequency in agreement with the resonance effect in the effective permeability . Extensions to SRR or C-L type surface (Figs. 11 and 12) are currently under progress .

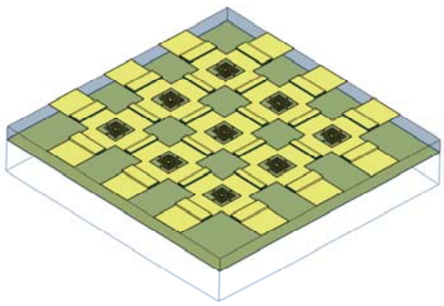

Fig. 11 : Artist view of a C-L type surface

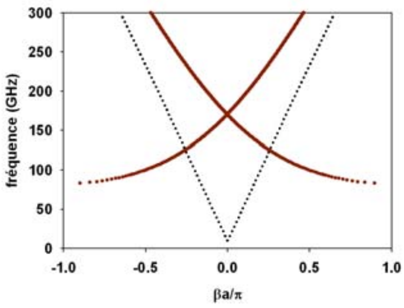

Fig 12 : Dispersion curve associated to the C-L surface

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