Active Metamaterials to increase absorbing bandwidth

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Abstract

This paper describes circuits designed to improve the absorbing range of metamaterials connected to an active circuit. This circuit's purpose is to behave as a negative inductor. The instability of the previous architecture led us to design a new circuit providing a negative inductor on a wide frequency range. Modifying the voltage applied on the circuit changes the metamaterial behaviour.

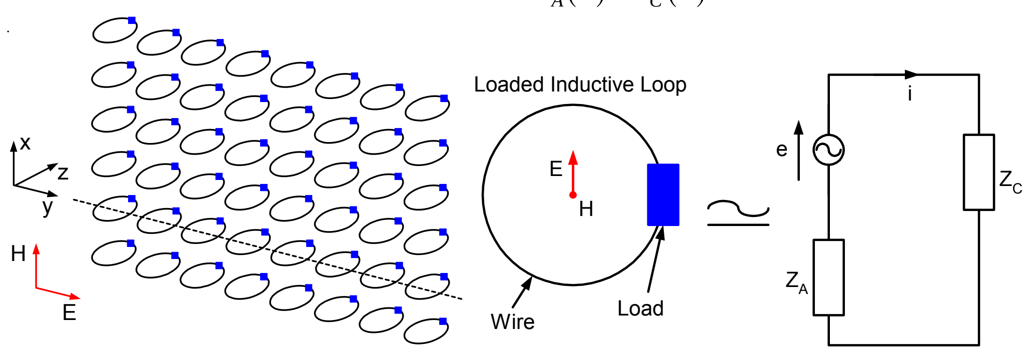
1. Introduction

Metamaterials offer properties that cannot be obtained using classical materials. Most of the metamaterials are "passive metamaterials" relying on the geometry and properties that cannot change after the surface is created. "Active metamaterials" [1] have emerged as a way to adapt the circuit behaviour to take into account the drift resulting from the production and/or to change the frequency response to drive the circuit to a new frequency domain [2]. The other reason to use active metamaterials is to achieve a wider working frequency range. This goal cannot be achieved without facing stability analysis [3]. The first part of this article will describe our previous work and its limitations. It will also enlighten the stability issue encountered while trying to achieve a wider absorbing range. The second part will detail our new architecture. Simulations of this circuit will be described in the third part.

2. Previous work

The metamaterial considered in this paper is composed of loaded small loops, embedded in a host material, with inclusion volume fraction α (Fig. 1a). The antenna loop, of impedance $Z_A = jL\omega$ connected to a capacitive load Z_C, Fig. 1b, is submitted to a sine external field along the loop axis at pulsation ω. The equivalent dipole can be described by its relative permeability [4]:

$$\mu_r(\omega) = \mu_r' - j\mu_r'' = 1 - \alpha \frac{Z_A(\omega)}{Z_A(\omega) + Z_C(\omega)} \quad (1)$$



(a) (b) (c)

Fig. 1. (a) Sketch of magnetic metamaterial, (b) Individual inductive element, (c) Its equivalent model

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The relative permeability is maximized at the resonance pulsation $\omega_r = 1/\sqrt{LC}$. This kind of circuit provides a narrow frequency range. The capacitor is replaced with an active circuit to cancel the denominator of (1) and widen the frequency range. The active circuit previously presented [5] led to results showing no improvement over the use of a capacitor (Fig. 2).

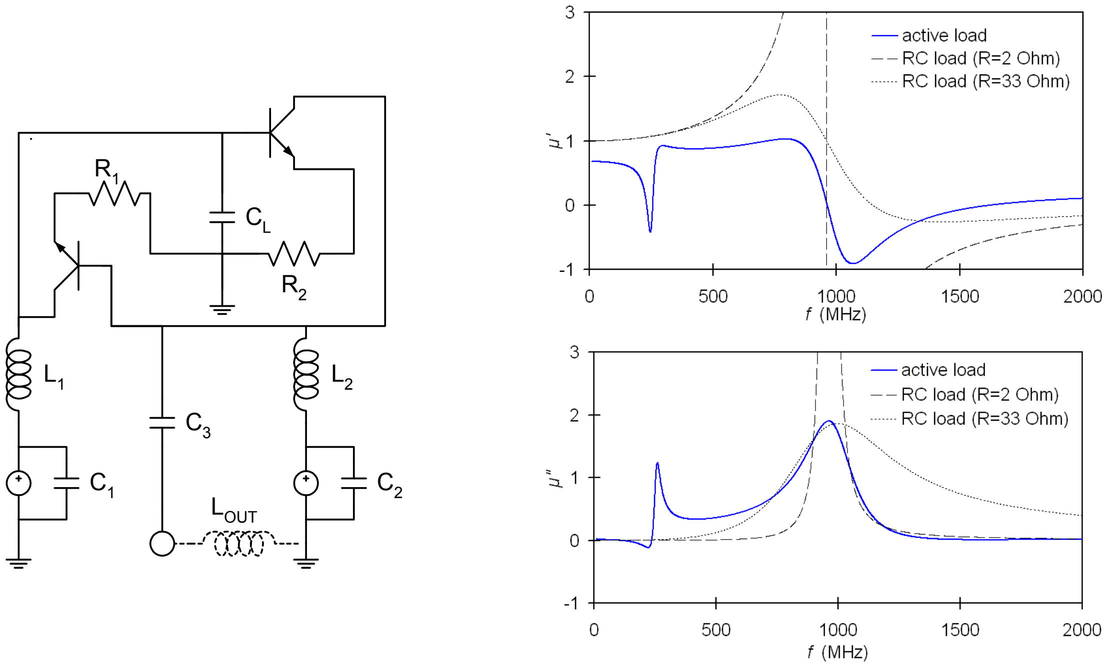

Fig. 2. Active circuit schematic and microwave permeability for a metamaterial made of 10 nH coils connected to various loads: the negative inductor active circuit (full line); a capacitive load with C = 3 pF, R = 2 Ω (dashed line) and R = 33 Ω (dotted line).

Those results are altered by the instability provided by this kind of circuit since this architecture is usually used to compensate the losses in oscillator designs.

3. New architecture

The previous circuit has helped us identify limitations and ways to improve our circuit. The first obvious improvement led us to use an ASIC instead of discrete components to design our next circuit since parasitic losses have to be minimized. A new architecture based on another Negative Impedance Converter [6] was also chosen (Fig.3). This circuit allows using all kind of load to invert and allows a tunable response by adapting the power supply.

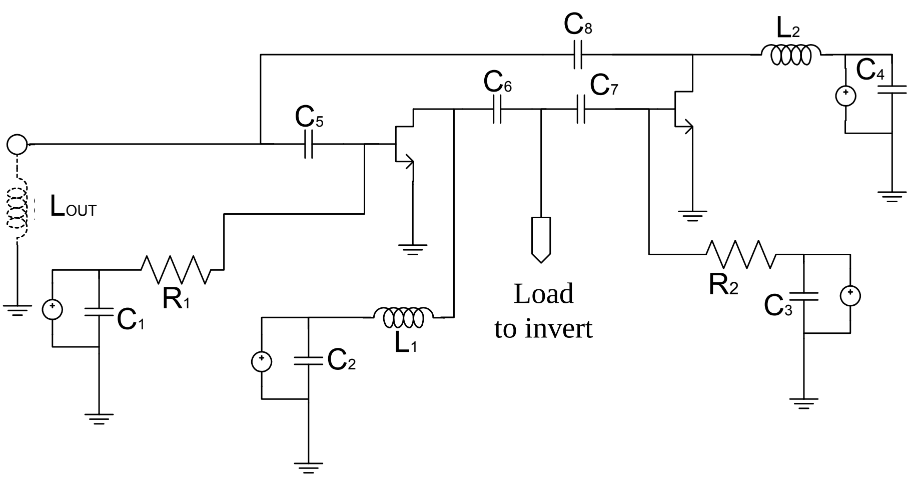

Fig. 3. New proposed active circuit schematic

4. Simulations results

This new architecture has been simulated and tuned to cancel a 22 nH inductor over a frequency range as wide as possible around 200 MHz. Different types of load have been simulated to increase this frequency range.

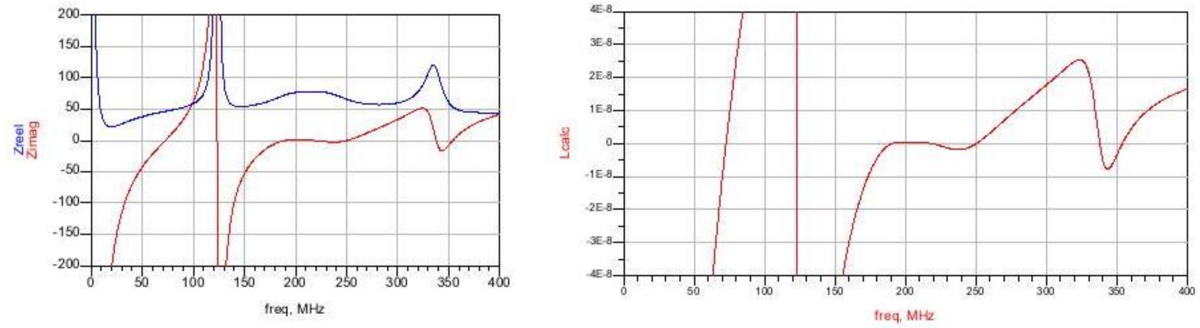

Fig. 4. Simulation results: total impedance on the left and total inductance on the right

These encouraging results have been obtained through simulations. Additional simulations were carried out to make sure it was possible to tune this circuit by modifying the polarisation voltage applied on transistors. It is interesting to note that the frequency range and type of response can also be modified if tunable components and/or a tunable architecture are chosen to design the load to invert.

5. Conclusion

Instability has always been a major issue on Negative Impedance Converters used to design active metamaterials. A new architecture has been proposed to provide a negative inductor on a wide frequency range. This circuit simulation results have to be confirmed through measurement of the ASIC including this architecture. Increasing furthermore the frequency range will lead to more efficient power harvesting circuits.

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