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A MODELING OF NEGATIVE RESISTANCE MOSFET FOR METAMATERIALS LOW LOSS OSCILLATORS FOR NANOTECHNOLOGY APPLICATIONS

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ABSTRACT

This paper presents analysis of the Metamaterials parameters and its dependence on its nanostructure and have linear electric permittivity and magnetic permeability. These parameters affect functionally the energy propagation and losses. It also investigates that these materials need to employ a controllable negative resistance to control the above mentioned parameters and compensate for the nanometric oscillator losses. A new nonnumeric negative resistance MOSFET (NR-MOSFET) has been proposed, designed and examined for this reason. These losses results from metallic sub wavelength Split-Ring Resonator (SRR) and the metamaterial itself is constructed of arrays of these SRR cells. The basic idea of the negative resistance MOSFET depends on contracting the channel width proportionally as increasing the drain voltage. The new device is expected to have a speed of response which is higher than any of the known traditional techniques, a very low power consumption and a wide dynamic range of resistance variation . This good performance serve to have the desired functionality of the metamaterial.

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I. INTRODUCTION

Metamaterials are nanostructure materials fabricated from repetition of dielectric and / or metallic elements to produce the desired electromagnetic behavior and they are characterized by negative electric permittivity $-\epsilon$ and magnetic permeability $-\mu$ which makes it to have negative refractive index n and energy propagating in the opposite direction of the phase velocity [1-2] as shown in Figure (1) .

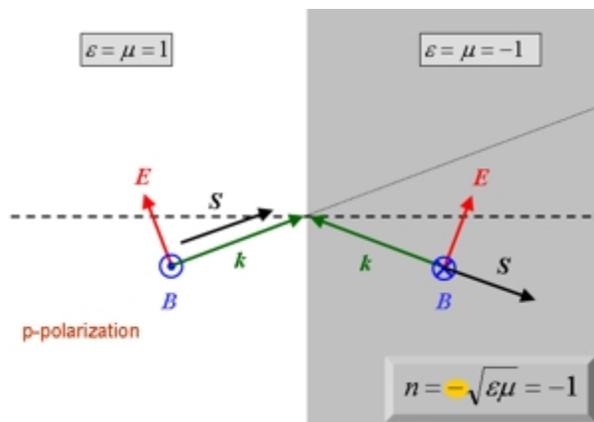


Figure (1) Negative refraction at the interface between vacuum and metamaterial .

The idea of metamaterials is based on an array of metallic sub-wavelength split-ring resonator (SRR). Each of the SRR mimics an LC-Oscillator consisting of a magnetic coil with inductance L and a capacitor with capacitance C as shown in Figure (2) .

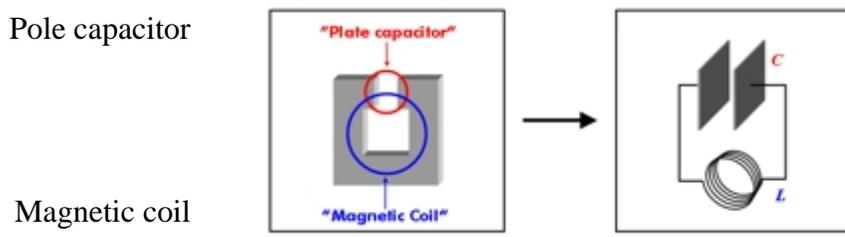


Figure (2). The basic physics of a SRR simulated as an LC oscillator

If the frequency of the incident light lies within a spectral band slightly above the LC-resonance frequency, the effective magnetic permeability of the SRR array can indeed be negative. These cells act as electric dipoles whose electric response can lead to a negative permittivity. As is well known, in order to obtain a magnetic response from a metal nanostructure the incident light has to excite local currents circulating in loops (solenoid currents). These currents in turn give rise to a magnetic dipole-moment. By properly designing the metal nanostructure, one can obtain a resonant enhancement of

the local currents leading to strong magnetic response, and if a current is excited and circulated in monomolecular loops, it gives rise to a magnetic dipole moment, which in turn gives a current which circulates in the same direction as that creating the magnetic dipole moment. This latter current enhances by the same manner the magnetic dipole moment and so on, leading to strong magnetic response with negative permeability and does the same w.r.t. the electric response and gives rise to negative permittivity [3]. As shown in Figure (3), I^{\prime} meta assists I and B^{\prime} meta assists B .

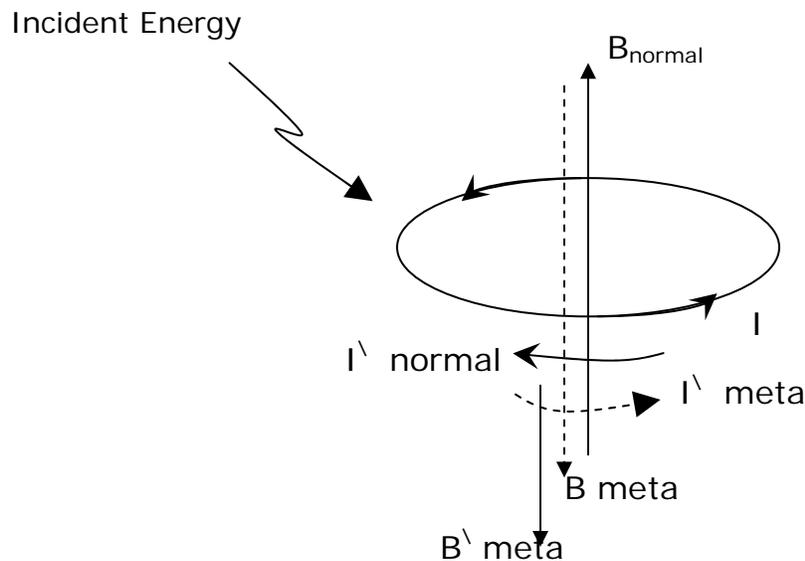


Figure (3) The circulated currents and the magnetic dipole moments.

This property is very needed in many applications such as antenna where the radiation is noticeably increased and Several advantages of such nanostructure materials are gained. Size reeducation, high directivity, increased power radiability and novel functionalities are examples of these advantages.

This meatmaterial oscillator has a power loss due to the series resistance of the coil. Work presented by M. Abdalla et al [4] for compensating the resistance with an active negative CMOS resistance and the idea is to reduce the losses not to eliminate it as the limitations of the Kramers-Krongig relations for lossless particles is considered in this paper [5]. Our model for negative resistance has advantages of frequency dependent which is compatible with metamaterial, where the metamaterials are dispersive. Hence the positive resistance is function of frequency. Therefore our model to compensate this positive dependent frequency resistance is also frequency dependent and almost the same functional form [4].

Section II illustrates the Electric / magnetic response enhancement, negative resistance MOSFET (NR-MOSFET) is presented in section III, theory and modeling in section IV , and measurement technique is presented in section V. The conclusions of this work are given in section 6.

ii. ELECTRIC/MAGNETIC RESPOSE ENHANCEMENT

Knowing that an array of metmaterial SRR can be modeled or equivalent to a series of array of LC sections (see figure (4)), then the enhancement of the electric and magnetic response can be further enhanced by decreasing the nanostructure resonator losses, which can be fulfilled by inserting a nano structure negative resistance element such as a nanometer negative resistance MOSFET(NR-MOSFET) in series with each array element of SRR [6] .

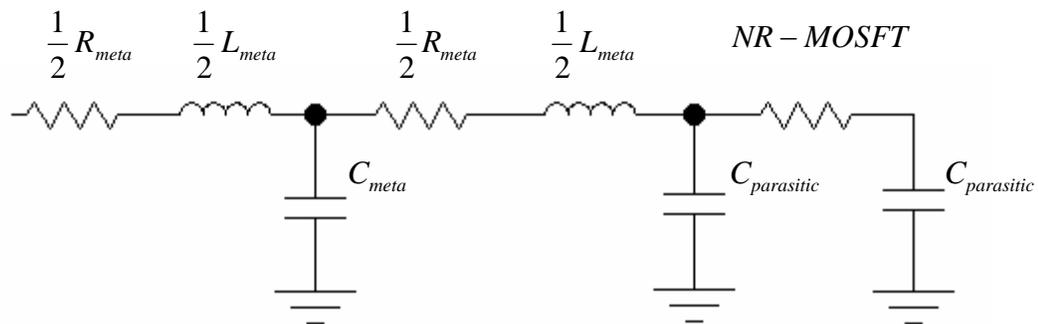


Figure (4) The proposed equivalent circuit for an array of SRR and compensated negative resistance

Where $\frac{1}{2} R_{meta}$, $\frac{1}{2} L_{meta}$ and C_{meta} are metamaterial equivalent circuit and $NR - MOSFT$, $C_{parasitic}$ are the negative resistance compensation.

III. NEGATIVE RESISTANCE MOSFET

The idea and construction of the proposed voltage controlled negative resistance MOSFET (NR-MOSFET) is shown in figure (5). It is realized using the polysilicon gate N-channel MOSFET technology. It consists of a MOSFET (T_{NR}) with channel length L_N , width Z_N and oxide thickeners h_{ON} , the channel width contraction is achieved using two additional P⁺ lateral diffusions whose potential is maintained negative with respect to the channel well potential and its amplitude kept varying proportionally with the drain voltage V_{Ds} . To carry out this requirements a MOSFET operational amplifier are designed so as to perform the desired amount of channel contraction. This operational amplifier is biased between $+V_R$ and $-V_R$ with V_R being the control voltage [7-8] .

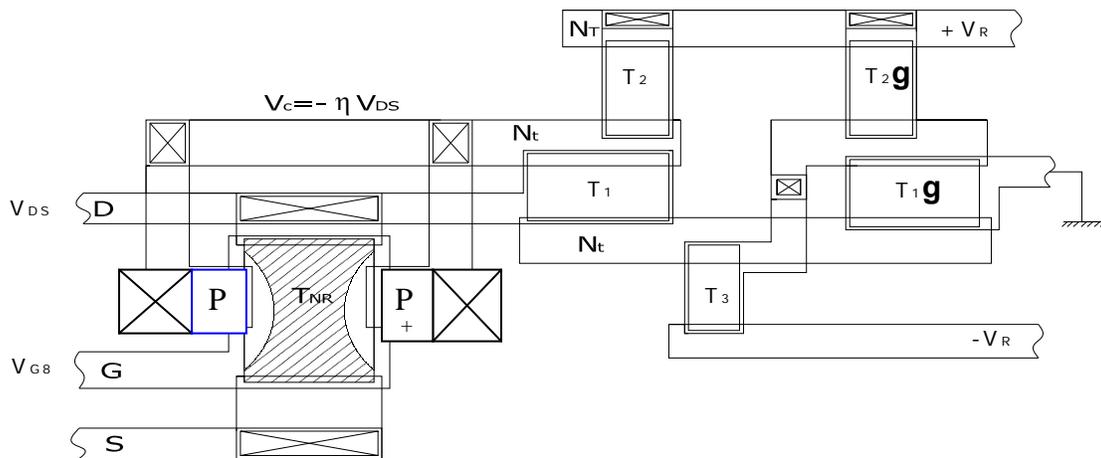


Figure (5) The construction of the proposed voltage controlled negative resistance

A MOSFET operational amplifier is designed so as to reverse the polarity and have the desired amplitude needed to elaborate the wanted contraction and it is biased between the control voltages $+V_R$, $-V_R$. The equivalent circuit of the controlled negative resistance is shown in Figure (6) .

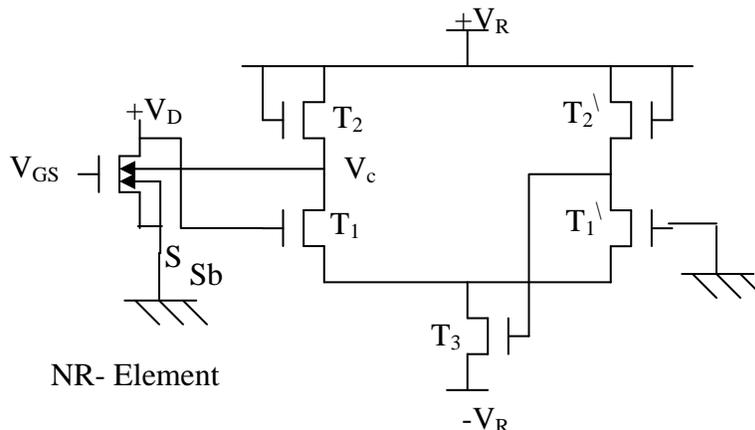


Figure 6. NR - MOSFET equivalent circuit

The op amp is designed so as the control voltage V_c obeys the behavior shown in figure (7), and goes negative as V_{DS} goes positive. Since the channel well potential is always negative this design guarantees a strong depletion of the N^+ version layer of the channel well. This leads to a depletion layer width W which increases steeply as V_{DS} increases, thus controlled decrease of the channel width and consequently channel current I_{DS} decreases as V_{DS} increases; we notice that the decrease of I_{DS} becomes more noticeable in the saturation region where I_{DS} should remain constant and cause more observable negative resistance behavior.

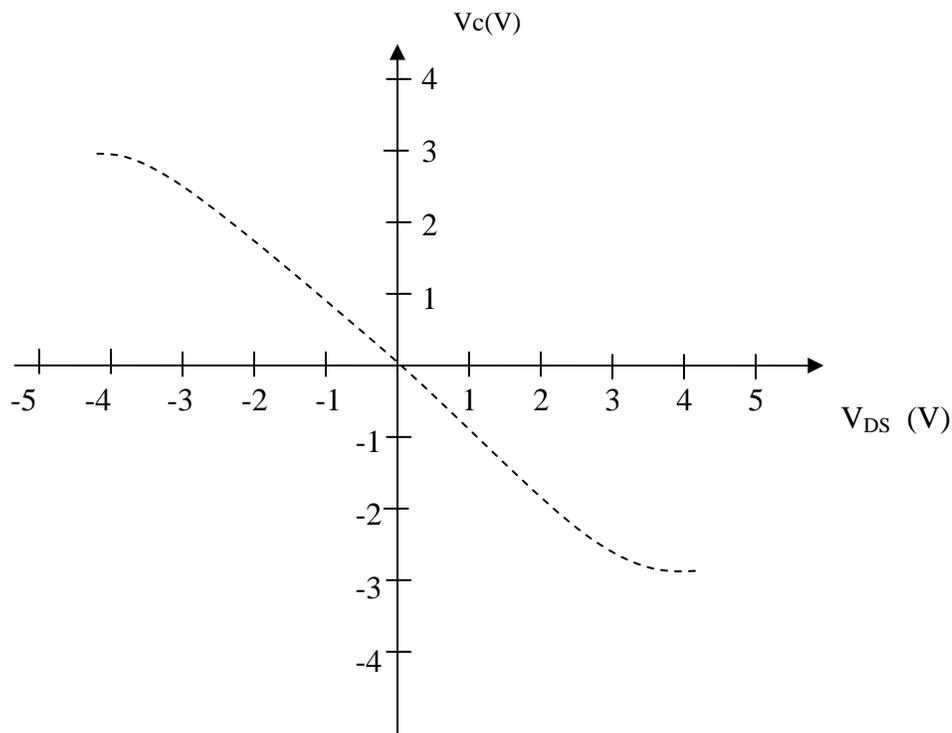


Fig.(7) Variation of V_c with V_{DS} (the working are is in the linear region only from +3V to -3V)

IV. THEORY AND MODELING

In this section we evaluate and model the depletion layer width, the effective channel width and the frequency and voltage controlled negative resistance.

IV. A. EVALUATION OF THE CHANNEL CONTRACTION DUE TO DRAIN AND GATE VOLTAGES

The variation of the channel width W and its dependence on the drain and gate voltages in saturation region. Referring to figure (8) which shows the energy band diagram of the proposed negative resistance NR-MOSFET[10-12].

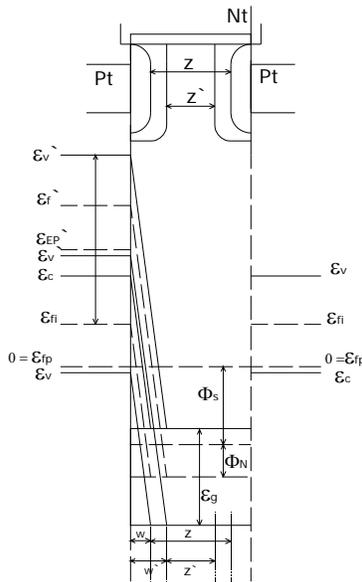


Figure 8. the energy band diagram for NR - MOSFET

The variation of the potential V_Z with distance, when the Al Languge potential is made zero is given by:

$$V_Z = V_C + \frac{C_{ox}}{2d_o \epsilon_s} (V_{GS} - V_T - V_x) Z^2 \dots\dots\dots(1)$$

where V_c is the control voltage

$$V_c = -\eta V_{DS}, \quad \eta = \frac{\sqrt{Z_1/L_1}}{\sqrt{Z_2/L_2}} \dots\dots\dots(2)$$

Z is the channel width, and Z_1, Z_2, L_1 and L_2 are the channel width and length of opamp MOSFET T_1 and T_2

d_o the MOSFET channel depth ($\sim 100\text{\AA}$),

C_{ox} is the oxide thickness

V_T the threshold voltage ($\sim 0.5V$),

V_x the channel potential taken, longitudinally, at postion X (V).

The amount of channel contraction can be calculated by equating the channel voltage to the surface potential, one can find:

$$W = \sqrt{\frac{2d_0\epsilon_s (V_s + \eta V_{DS})}{C_{ox} (V_{GS} - V_T - V_X)}} \dots\dots\dots(3)$$

The effective channel width can be expressed in terms of position X in the channel from the source and the biasing voltages V_{DS} and V_{GS} as follows:

$$Z_{effective} = Z - 2W \dots\dots\dots(4)$$

IV. B. NEGATIVE RESISTANCE MOSFET

The modified drain current equation in the saturation region is therefore:

$$I_{DS} = \beta \frac{1}{2} [V_{GS} - V_T - V_{DS} \frac{X}{L}]^2 \dots\dots\dots(5)$$

where $\beta = \mu C_{ox} \frac{Z_{effective}}{L}$,(6)

The Resistance equivalent

$$R_N = \frac{dV_{DS}}{dI_{DS}} \dots\dots\dots(7)$$

$$R_N = - \frac{L^2}{\mu C_{ox} (Z - 2W) (V_{GS} - V_T - V_{DS} \frac{X}{L})} \dots\dots\dots(8)$$

This indicates that the NR-MOSFET acquire a negative resistance in saturation region of operation. Controlling the geometrical ratio of the NR controls this resistance. To realize a nano geometric NR-MOSFET advanced fabrication process based on ion implantation will be used instead of the traditionally known photolithographic technique to implement all drain, source and gate regions [9-10].

We can see as the negative resistance can be controlled by the frequency and the contraction of the channel width until we reach to the low loss of the metamaterials cell.

V. MEASUREMENT TECHNIQUE

Experimental test MOSFETs have been prepared by Thomson microelectronics DRD of Grenoble / France. The source channel-width $Z = 10$ micron, the drain channel-width Z' ranges from 5 to 10 micron, channel length $L = 5$ micron and oxide thickness h_o are 40 \AA and 1200 \AA . Measurements are performed on these test specimens to obtain the value of the effective MOSFET geometrical ratio $\left(\frac{Z}{L}\right)_{eff}$ and its dependence on the device geometry (Z, L, β) and biasing (V_{DS}, V_{GS}). Measurement and characterization are achieved using the experiential set up shown in Figure 9. Hundreds of measurements have been performed to specify the device parameters .

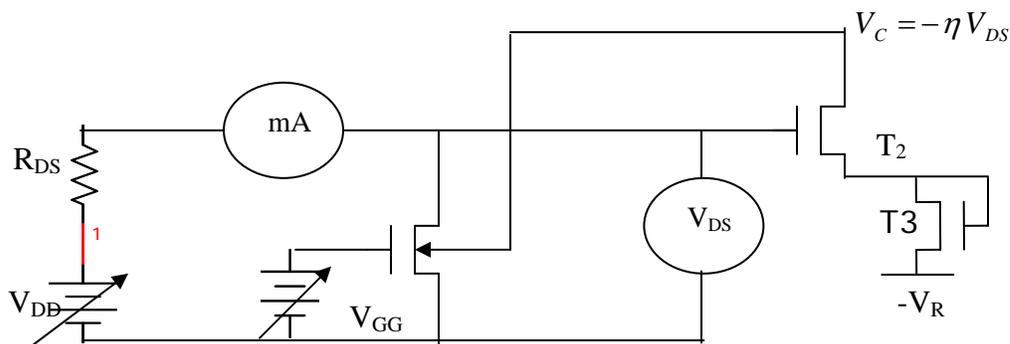


Figure 9. Experimental Setup.

Figure (10) shows the dependence of the $I_{DS}-V_{DS}$ characteristics on the value of the parameter η and geometries. We observe that I_{DS} still increasing proportionally in the ohmic region with V_{DS} but at smaller rate. Then I_{DS} begins to decrease as increasing V_{DS} in the saturation region. The rate of decreases becomes more important at greater

values of η . This behavior is attributed to the increase of the depletion region width with V_{DS} . It becomes more noticeable of at greater values of V_{GS} .

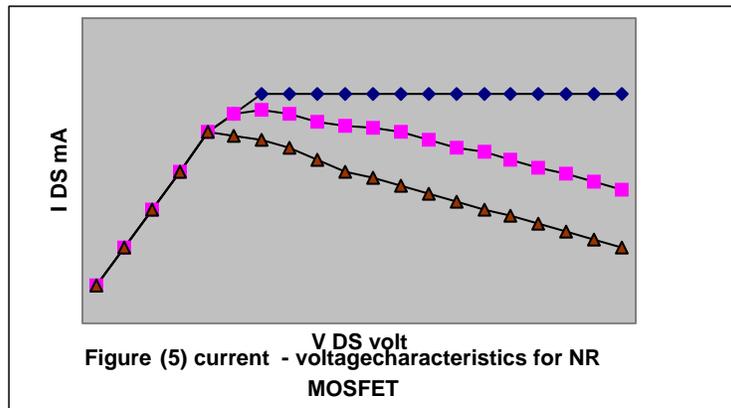


Figure 10. Current –Voltage characteristics for NR-MOSFET

VI. CONCLUSIONS

This paper gives a simple analytical model for frequency dependent, voltage controlled, low loss oscillator metamaterial cell which is composed of SRR cell and a nanometer negative resistance NR-MOSFET. Although the cell always remains causal, the limitations like the Kramers-Kronig relation (for lossless particles) can be overcome in this design. This is achieved where a power generated can be realized by active loads which clearly violates the Kramers-Kronig relation, which required besides causality the system be linear and memory effects decay in time [11-12].

We can finally conclude that the paper presents a general approach to the design of an effective class of metamaterials. We hope that the model of this paper clearly demonstrates the power of the metamaterial concept that allows a great flexibility in the design and applications of nanotechnology.

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