ARTIFICAL INDUCTOR EFFECT ON MOS TRANSISTORS

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1. Introduction and state-of- the-art

Recently the interest to the radio-frequency integrated circuits is sharply increased, connected with the rapid development of mobile communication. The modern integrated technology for RF applications (800 MHz-2.5G Hz) rather easily provides creation of active devices. However, the presence of high-quality passive components represents a serious problem for integrated realization [1, 2]. The high-quality inductor in monolithic performance is the most difficult to realize by methods, which would be compatible to modern planar manufacturing techniques of micro- and nanoscale integrated circuits.

At present a significant progress in integration of monolithic spiral inductors has been achieved [2, 3]. However, for the RF spiral inductors the quality factor, Q, at high frequencies sharply decreases caused by losses of energy in a silicon substrate and metal traces of a spiral. Some approaches have been proposed to address the substrate issues. The increase in the thickness of metal (up to 4 μm) and dielectric (up to 7 μm) layers of inductor design allows one to improve the quality factor till 10-12, and also to weaken the influence of skin effect. Noise coupling via the semiconductor substrate at gigahertz frequency range has been reported [4, 5]. Using of the substrates with high (above 15-20 Ohm·cm) specific resistance partially decreases the level of noise coupling. In many publications [3, 4, 5] it is shown that etching of pits in the silicon substrate under the spiral inductors or using the patterned ground shields between inductor and substrate allow reducing impact of substrate on circuit parameters. However, offered approaches in addition complicate technological process, increase the cost price too, and hence, from the point of view of technology, are not acceptable variants. Thus, new approaches and decisions of a substrate problem are necessary to overcome the increased complexity of process: in particular, for cheap integration monolithic inductors in structure of the chip.

Except for constructive-technological methods of improvement of spiral inductor parameters on chip, the other alternative opportunities of inductive effects are considered. They can be based on different physical principles and schematic solutions [6]. The interesting demonstration of inductive effect is observed in schemes with a feedback. The theoretical analysis [7] for the high-temperature superconducting thin films shows that application in the operational amplifier of a feedback on RC chains can become an effective way of creating synthetic inductance in solid-state circuits.

In the present report a new circuit is offered which can exhibit synthetic inductive effect and the possibilities of realization of the suggested scheme are discussed. Distinctive feature of the offered scheme is based on the opportunity of universality of the MOS transistor to use as a typical circuit element (as an active device, resistor, and capacitor). Moreover, it is very important that the offered variant of integrated synthetic inductance both in technological and schematic aspects is compatible with modern planar MOS technology.

2. Description of the circuit

The electric scheme of realization of synthetic inductive effect and the corresponding equivalent scheme for calculations are shown in Figs. 1 and 2.

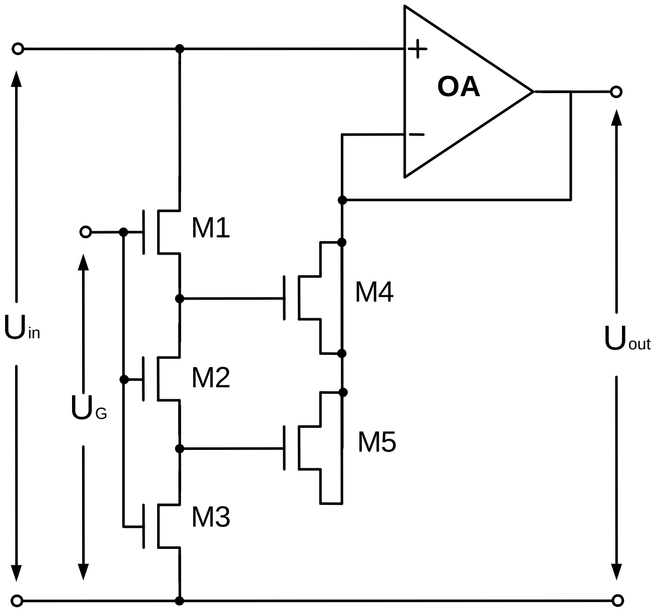


Fig. 1

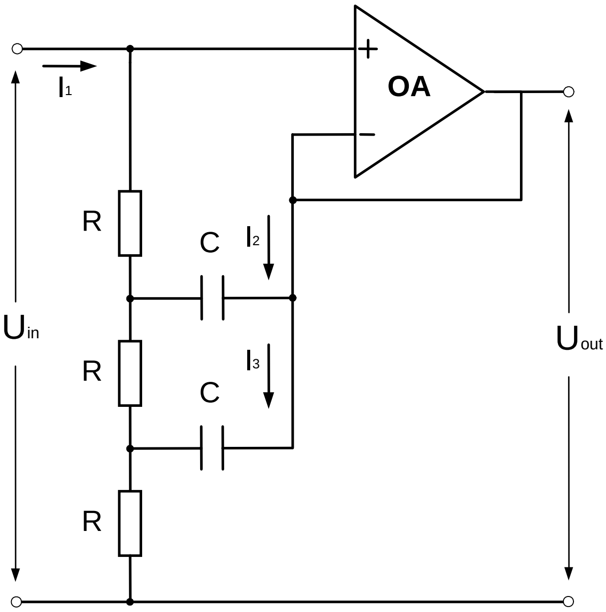


Fig. 2

As resistors and capacitors in a RC feedback chain the MOS transistors are used. They are included in the circuit of realization of passive components the parameters of which can be varied in a wide range. The operational amplifier is also collected on MOS transistors under the scheme of emitter-follower with voltage gain close to unit.

Considering that the input resistance of amplifier is real and also approaches infinity, we can write down the equations for finding the input impedance of the scheme

$$
\begin{aligned}
&R\dot{I}_1 - \frac{\dot{I}_2}{j\omega C} = \dot{U}_{in}(1-K_U), \\
&R\dot{I}_1 + R(\dot{I}_1 + \dot{I}_2) - \frac{\dot{I}_3}{j\omega C} = \dot{U}_{in}(1-K_U), \qquad (1) \\
&R\dot{I}_1 + R(\dot{I}_1 + \dot{I}_2) + R(\dot{I}_1 + \dot{I}_2 + \dot{I}_3) = \dot{U}_{in}.
\end{aligned}
$$

At input sinusoidal signal U and voltage gain K_u=1 for an impedance of a circuit we obtain the expression

$$Z(j\omega) = R_{eq} + jX_{eq} = R_{eq} + j\omega L_{eq}, \tag{2}$$

where R_{eq} and L_{eq} are, accordingly, equivalent to resistance and inductance of a circuit. They are expressed as

$$R_{eq} = R(3 - \omega^2 R^2 C^2), \qquad L \cong 4CR^2. \tag{3}$$

For the circuit's equivalent quality factor the following expression is obtained:

$$Q_{eq} = \frac{4\omega RC}{3 - \omega^2 R^2 C^2}. \tag{4}$$

From equation (2) it is seen that for the offered circuit the equivalent reactive component of impedance has an inductive character. The input impedance, as a first approximation, can be presented in the form of consistently connected equivalent resistance and equivalent inductance. Both components of the impedance and the quality factor, as follows from expressions (3) and (4), depend on the resistance R and capacitance C of the MOS structure.

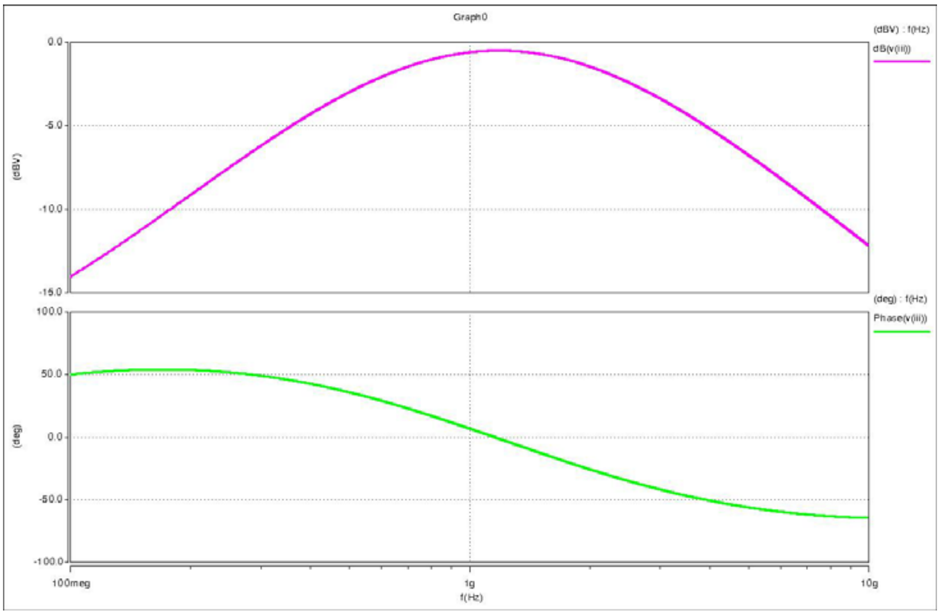
3. Discussion of results

For a qualitative and quantitative substantiation of presence of inductive effect in the offered scheme the circuit frequency characteristics one analyzed by means of program SPICE. Modeling is led for the circuit, in which all MOS structures are realized on modern submicron (90 nm and probably below) technological level. The geometrical sizes of structures will correspond to the micron and submicron range.

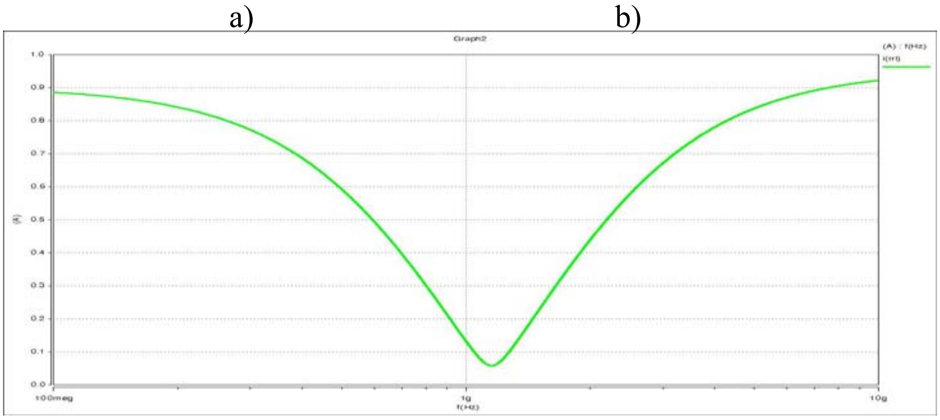
The analysis of circuit inductive nature was investigated by means of resonant characteristics. The amplitude-frequency (Fig. 3a) and phase-frequency characteristics (Fig. 3b), as well as the current resonant characteristic (Fig.3c) of the realized scheme are simulated. The resistance and capacitance parameters of RC feedback chain for the simulated circuits correspond to R=5 Ω and C=100 pF.

Obtained dependences are inherent to a parallel resonance circuit with corresponding equivalent C_{eq}, L_{eq} and R_{eq} parameters. At certain frequencies (in our case ~ 1.2 GHz) the circuit shows self-resonance and at the resonance point the reactive part of the admittance is equal to zero (in Fig. 3b the phase angle is equal to zero). At lower frequencies the inductive character of the circuit is observed. Beyond the self-resonance frequencies equivalent capacitance will dominate and circuit has a capacitive behavior. Thus, the inductive effect has a finite bandwidth. For the practical applications it is necessary to stay well below the self-resonance frequencies. However, the inductive effect, consequently self-resonant frequency of the circuit, will be controlled and adjusted, as evident from (3), by changing the R and C parameters of MOS structures in RC feedback circuit.

One can use the obtained dependences and results for the design of monolithic integrated circuits with synthetic inductance.



a) b)



c)

Fig. 3

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