*Semiconductor Physics, Quantum Electronics & Optoelectronics, 2006. V. 9, N 3. P. 44-48.*

PACS 84.37.+q, 85.30. Tv

# Active inductances controlled in GaAs MESFET technology

**M.S. Benbouza, C. Kenzai-Azizi, N. Merabtine, Y. Saidi, S. Amourache**
*Physical laboratory of the Thin Layers and Interfaces, University of Constantine, Algeria*
*Electromagnetism and telecommunication laboratory, Electronics department, University of Constantine*
*E-mail: na_merabtine@hotmail.com; Benb5506@yahoo.fr; aziziche@yahoo.fr*

**Abstract.** Two new structures of active inductance which implement MESFET transistors are proposed in this article. The technological parameters of the components of "inductances" are those of 0.8 µm MESFET technology. We expose the advantages of these new structures such as the adjustable character of the value of the active inductance like their limitation, and we compare them to those of the literature.

**Keywords:** active inductance, GaAs MESFET, quality factor, silicon bipolar technology, RF applications.

Manuscript received 24.02.06; accepted for publication 23.10.06.

## 1. Introduction

The studies of RF inductances are justified by the keen demand of the applications in telecommunication such as filtering in continuous time, the controlled oscillators and decoupling. These basic elements of analog electronics are certainly essential.

Integrated passive inductances are limited by their low quality coefficient [1], the reproducibility of their values and the large area of silicon surface necessary for their synthesis for the RF applications, frequency of which is a few gigahertz. It is moreover to note that this problem of size involves an additional difficulty of characterization of the couplings existing between the various tracks that constitute the inductance. Some techniques were introduced to palliate or to lessen the impact of these defects [2, 3]. These improvements were obtained with the detriment of the facility of design and require a high number of used metal layers, as well as lead to the inductance modelling.

The wire bonding was also explored in order to synthesize a passive inductance [4]. However, this option does not present a strong integration and poses also the problem of the reproducibility of the inductance value. Thus it remains held for certain applications.

For a few years, another approach is known as a renewal of attention on behalf of the analogious originators: the "active inductance". This revival is mainly due to better performances of the transistors, which result from the technological improvements of the integrated circuit manufacturing processes. In addition to the adjustable aspect of the active inductance, we can note the possibility of obtaining the good quality factors ($Q > 5$), a broader frequency range, as well as the independence between the inductance value and the circuit size.

As we will point out, achievements were presented in GaAs technology for the high frequencies; others were presented in silicon bipolar technology for RF applications in the gigahertz frequency band around. We propose two new GaAs MESFET structures and compare their characteristics to those of other MESFET and bipolar structures from the literature.

## 2. Active inductances in GaAs technology

The first active inductances elaborated in the gigahertz frequency range were in GaAs technology. Fig. 1 represents the basic topology presented by Hara and its characteristics according to the frequency [5]. This configuration implements MESFET transistors. It has an inductance of the order of 13 nH and a series resistance about hundred ohms at 1 GHz frequency. The approximated expressions of the coil and synthesized series resistance are given by:

$$L \approx \frac{C_{gs} R_{\text{ext}}}{g_m} \text{ and } R \approx \frac{1}{g_m}, \qquad (2.1)$$

where $C_{gs}$ is the gate-source capacity of the MESFET component, $g_m$ is its transconductance, and $R_{\text{ext}}$ is the negative feedback resistance connected between the drain of the input transistor and the gate of the second transistor. The transistors are supposed to be identical. The surface area occupies 400×500 µm. Then improvements were made to this structure in order to reduce the value of series resistance. Fig. 2 represents an evolution of the circuit of Fig. 1, transistors in feedback

*© 2006, V. Lashkaryov Institute of Semiconductor Physics, National Academy of Sciences of Ukraine*

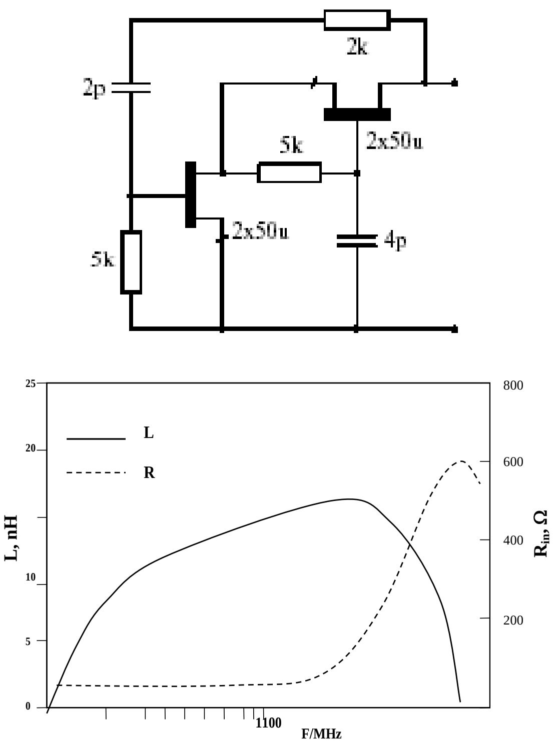


**Fig. 1.** Basic topology of the active inductance [5].

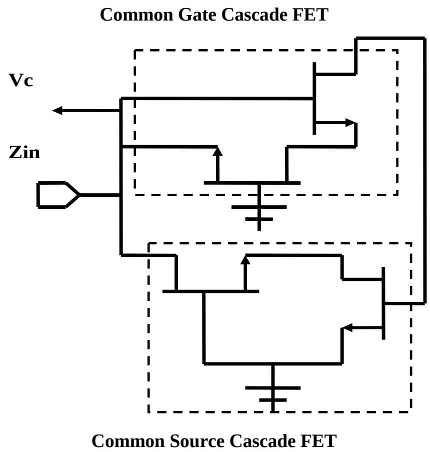


**Fig. 2.** The circuit “Cascade FET feedback active inductor”.

are called “Cascade FET feedback active inductor” [6]. Using a control voltage $V_c$, an inductance is adjustable from 2 to 3 nH. This structure has a 8 Ohm series resistance and the quality coefficient 5 at 1 GHz frequency.

Finally, we present the Zhang configuration [7] that is made up of three transistors of the MESFET type (Fig. 3).

In a similar way, via the control voltage provided by the polarization, the value $L$ of the inductance can vary around 7 nH and the series resistance $R$ around 5 Ohm at 1 GHz frequency. The values of $L$ and $R$ are given by:

$$L \approx \frac{C_{gs}}{g_m g_{m3}} \left( 2 + \frac{1}{2} \left( \frac{f}{f_T} \right)^2 \right)$$

$$\text{and} \quad R \approx \left( g_{m3} \left( 1 - \frac{1}{f / f_T} \right) \right)^{-1} \qquad (2.2)$$

where $f_T$ is the transition frequency of the transistors, $g_m$ is the transconductance of the transistor 1 or 2 and $g_{m3}$ is the transconductance of the transistor 3. The maximum used frequency reaches approximately 8 GHz.

## 3. Active inductances in silicon bipolar technology

### *3.1. Generalities*

The surface occupied by the integrated circuits in bipolar technology is important because of many passive elements (inductance, capacity and resistance) and active of polarization.

The various studies undertaken on the active inductances conceived starting from transistors of the bipolar type showed that their quality coefficient is proportional to the transistor parameters according to the formula:

$$Q = \frac{g_m}{g_{\text{out}}}, \qquad (3.1)$$

where $g_{\text{out}}$ is the output conductance of the transistor and $g_m$ is its transconductance.

Thus the bipolar transistor presents interesting possibilities for the synthesis of active inductances taking into account its strong transconductance compared to that of MESFETs. Moreover, in the frequency range near gigahertz, the inductance values used are more important than those met at the higher frequencies. Then the output transconductance of the bipolar transistor contributes to the necessary increase in the inductance value.

Moreover, other advantages result from it:

- The advantage over the transconductance will lead to a less power consumption.
- The size of the bipolar transistors being lower, the saving in space compared to the GaAs configurations is interesting.

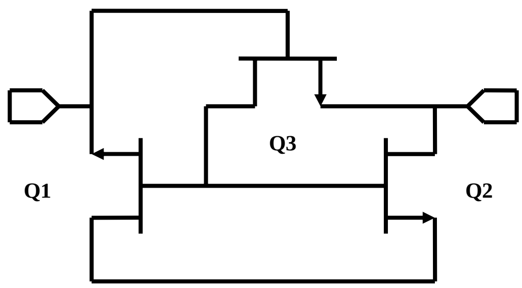


**Fig. 3.** Circuit of the active inductance presented by Zhang [7].

© 2006, V. Lashkaryov Institute of Semiconductor Physics, National Academy of Sciences of Ukraine

- Silicon BiCMOS technology used to carry out active inductance opens the possibility of integration of analog and digital functions. Their various circuits that we will consider in bipolar technology are those of an inductance connected to the ground.

*3.2. R. Kaunisto model*

In the circuit presented by R. Kaunisto [8], used was a configuration with two *n-p-n* transistors given in Fig. 4.

Using the HF2CMOS technology parameters, during the AC simulations of this structure revealed was an average inductance of about 3.5 nH and a resistance of approximately 1 Ohm with a notable reduction in the value of the series resistance from 850 MHz (Fig. 5).

Then the best quality factor is obtained at the frequency for which the series resistance is minimal, $Q$ is equal 20 at a 1 GHz frequency.

## 4. Proposed models

In this part of the study, we propose two MESFET based models to determine active inductances.

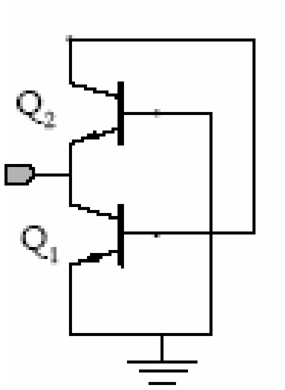


**Fig. 4.** Electric diagram of the active inductance [8].

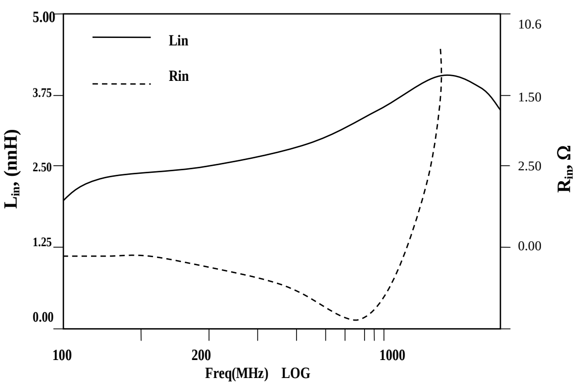


**Fig. 5.** AC Simulation of the active inductance and the associated series resistance.

*4.1. The first suggested inductance*

The first structure that we propose comprises two *n*-type MESFET transistors, transition frequency of which is of the order of 9 GHz under the used polarization conditions. Its small signal equivalent electric diagram is shown in Fig. 6.

The AC simulations (Figs 7-9) of this configuration results in 1 GHz with an adjustable inductance of about 7 nH and a resistance series of about 2 Ohm. The obtained inductance is proportional to the MESFET parameters.

This dependence clarifies the adjustable character of the inductance by the means of the polarization current. Indeed, the intrinsic parameters of the model such as $C_{gs}$, $C_{ds}$, $C_{dg}$, and $g_m$ depend on the transistors polarization current [9].

Compared to the performances of the circuit in Fig. 6, this structure must be modified in order to reduce the ohmic loss and increase the quality factor.

*4.2. The second suggested inductance*

The second suggested structure is shown in Fig. 10 to reduce the series resistance. This circuit adopts a configuration with three *n*-type MESFET transistors ($f_T$ ~ 9 GHz). The simulations (Figs 11-13) show that this circuit satisfies our criteria: the value of the variable inductance obtained is about 12.5 nH and the series resistance remains lower than 1.3 Ohm at 1 GHz frequency.

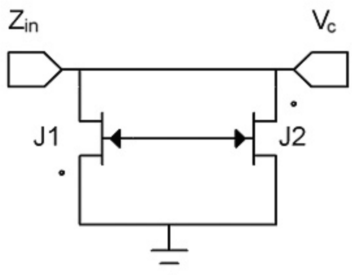


**Fig. 6.** Electric diagram of the first suggested active inductance.

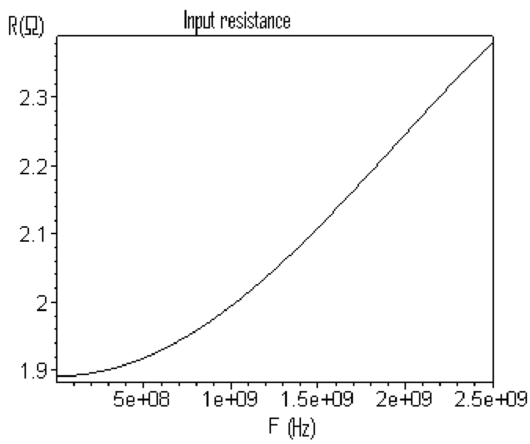


**Fig. 7.** AC simulation of the series resistance associated with the inductance.

*© 2006, V. Lashkaryov Institute of Semiconductor Physics, National Academy of Sciences of Ukraine*

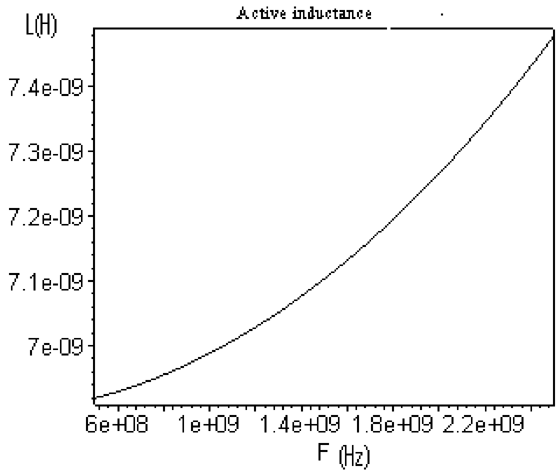


**Fig. 8.** Frequency variation of the inductance.

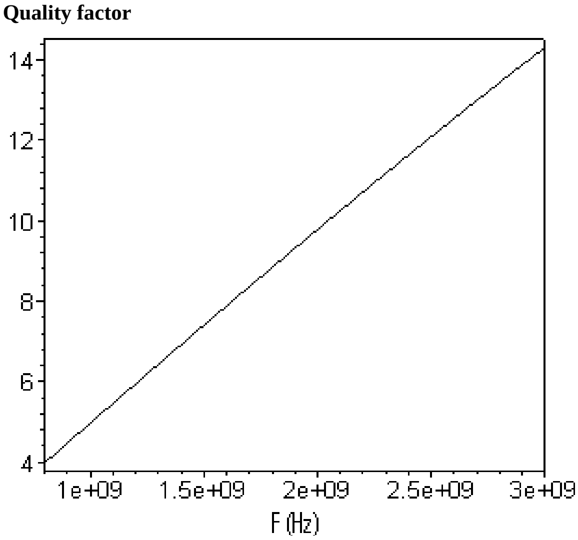


**Fig. 9.** Frequency variation of the value of the inductance quality coefficient.

*4.3. Conclusion and comparison between these two configurations*

It should be noted for the configurations of Figs 6 and 10 that the polarization conditions were determined to obtain a good quality factor. These polarization conditions can also be sources of instabilities, which result from the influence of polarization on the series resistance of the inductance; however, the series resistance can indeed become negative under certain conditions.

**Table. Comparison of the various presented configurations.**

| Parameter | Circuit | | | | |
|---|---|---|---|---|---|
| | Fig. 2 | Fig. 3 | Fig. 4 | Fig. 6 | Fig. 10 |
| *L* (nH) | 2 | 6 | 3.5 | 7 | 12.5 |
| *R* (Ohm) | 8 | 5 | 1 | 2 | 1.3 |
| *Q* | 5 | – | 20 | 5 | 8 |
| Consumption (mW) | – | – | – | 10 | 20 |

Table illustrates well the evolution of the inductance *L* and the resistance *R* among the topologies of Figs 2, 3, 4, 6, and 10 from a value and power consumption point of view.

The circuit of Fig. 10 is that shows the best characteristics. Moreover, it proposes a value of the inductance higher than the circuit of the Fig. 6 configuration for a less power consumption. This inductance value and that of the associated series resistance are adapted to the RF applications of the filtering type and oscillators at 1 GHz frequency.

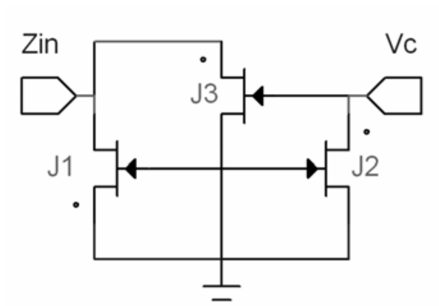


**Fig. 10.** Electric diagram of the second suggested active inductance.

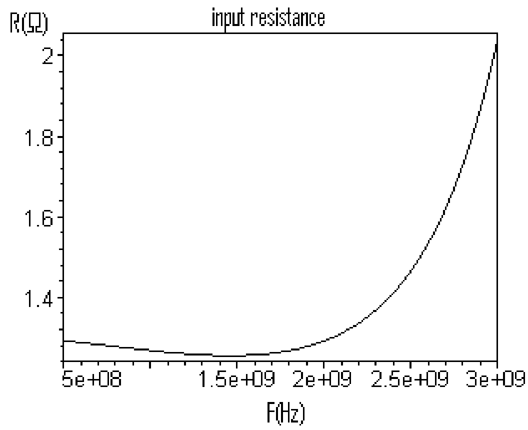


**Fig. 11.** AC simulation of the circuit inductance.

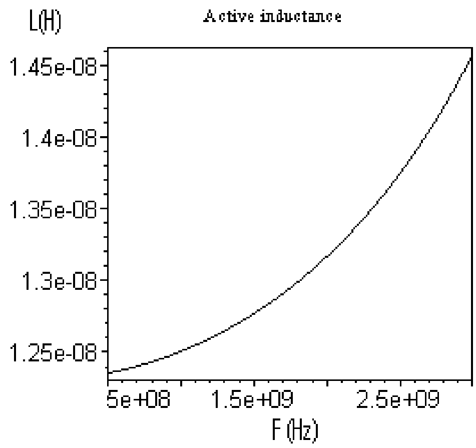


**Fig. 12.** AC simulation of the series resistance associated with the inductance.

*© 2006, V. Lashkaryov Institute of Semiconductor Physics, National Academy of Sciences of Ukraine*

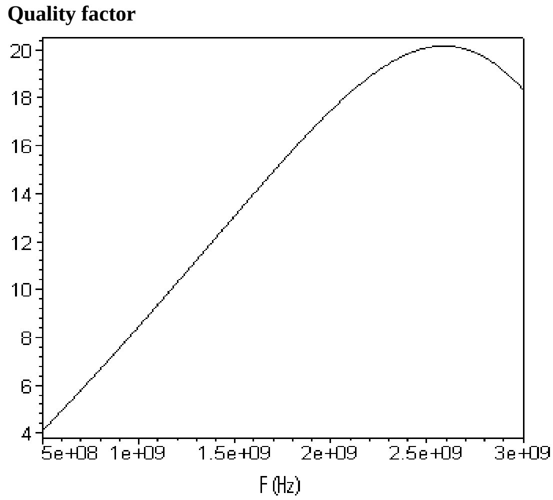


**Fig. 13.** Frequency variation of the quality coefficient value.

*References*


1. J.N. Burghartz, D.C. Edelstein, Mr. Soyuer, H.A. Ainspan, and K.A. Jenkins, RF circuit design aspects of spiral inductors one silicon // *IEEE Newspaper of Solid-State Circuits* **33**, No 12 (Dec. 1998).
2. C.P. Yue and S.S. Wong, Spiral one-chip inductors with patterned ground shields for if-based RF IC' S // *Ibid.* **33**, No 5 (May 1998).
3. J.N. Burghartz, Mr. Soyuer, H.A. Ainspan, and K.A. Jenkins // Integrated RF and microwave components in BiCMOS technology // *IEEE Transactions One-Electron Devices* **43**, No 9 (Sept. 1996).
4. F. Svelto, S. Deantoni, and C. Castello, A 1.3 GHz low-phase noise fully tunable CMOS LLC VCO // *IEEE Newspaper of Solid-State Circuits* **35**, No 3 (Mar. 2000).
5. S. Hara, T. Tokumitsu, Mr. Aikawa, Lossless broadband monolithic microwave activate inductors // *IEEE Transactions on Microwave Theory and Techniques* **37**, No 12, p. 1979-1984 (Dec. 1989).
6. S. Hara, T. Tokumitsu, T. Tanaka, Mr. Aikawa, Broad-band monolithic microwave activates inductor and its application to miniaturized wide-band amplifiers // *Ibid.* **36,** No 12, p. 1920-1924 (Dec. 1988).
7. G.F. Zhang, Mr.L. Villegas, C.S. Ripoll, and J.L. Gautier, New broadband tunable monolithic microwave floating activate inductor // *Electronics Lett*. **28**, No 1 (Jan. 1992).
8. R. Kaunisto, P. Alinikula, and K. Stadius, Activate inductors for GaAs and bipolar technologies // *AICSP* **7** (1995).
9. B. Tiallet-Guy, Z. Ouarche, M. Prigent, R. Quere, and J. Obregon, Direct extraction of a distributed nonlinear fet model from pulsed // *IEEE Microwave and Guided Wave Letters* **8**, No 2 (Feb. 1998).


*© 2006, V. Lashkaryov Institute of Semiconductor Physics, National Academy of Sciences of Ukraine*