BROAD BAND MONOLITHIC MICROWAVE ACTIVE INDUCTOR AND APPLICATION TO A MINIATURIZED WIDE BAND AMPLIFIER

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ABSTRACT

A broad band monolithic microwave active inductor is proposed. This active inductor operates in a much higher frequency range than a spiral inductor and its size is independent of the inductance value. A 0.1 – 10GHz miniaturized wide band amplifier is also realized by utilizing the active inductors.

INTRODUCTION

In the MMIC design, spiral inductors are often used to reduce chip size. However, size reduction by use of spiral inductors is limited in wide band MMICs because several spiral inductors and other inductive lines should be combined in the circuit design for higher inductance, or the same effect, and to keep resonant frequencies high[1-3]. Another limitation is the requirement that the spiral inductors should be separated to eliminate cross-talk. Most of the previously reported designs have achieved chip size reduction through neglect of the vicinity effect, as indicated by Pucel[4].

In this paper, a broad band monolithic microwave active inductor composed of two FETs and a resistor is proposed. The most significant innovation of the active inductor is a novel circuit structure which suppress stray capacitance to yield a much higher frequency operating range than a spiral inductor. Furthermore, the inductor is small and independent of the inductance value. The FET oriented configuration allows a denser chip circuitry packing.

CONFIGURATION AND PERFORMANCE

The schematic of the proposed microwave active inductor is shown in Fig.1. The active inductor is composed of a cascode FET and a resistor (R_{ext}) connected between the gate of the 1st FET and the drain of the 2nd FET. C_{gs1} and C_{gs2} are the FET gate-source capacitances. Since, as described later, various inductance values are obtained by changing the values of R_{ext}, the area occupied by the active inductor is independent of the inductance value.

*ATR : *Advanced Telecommunications Research Institute International*

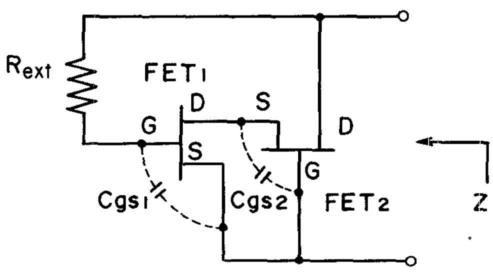

Fig.1 Circuit Configuration of the Active Inductor

The advantages of the active inductor over the spiral inductor are shown clearly in Fig.2. The resonant frequency, which is the maximum inductor operating frequency, is compared in Fig.2(a) to the inductance value at 1GHz. The solid lines show the active inductors utilizing FETs with 20GHz and 40GHz cut-off frequencies. The dashed line shows the spiral inductor of 300μm×300μm size, which is constant, and 10μm line width, where only the line-to-line separation is changed. Those lines are calculated by "Super Compact". As shown in the illustration, the operating frequency range of the active inductor is much wider than that of the spiral inductor, especially in the high inductance region. Furthermore, the operating frequency is extended as the FETs are improved. In Fig.2(b), the area of the active inductor and spiral inductor are compared. The dots show actual inductance areas reported in recent technical papers((1),(2)etc.). In actual wide band MMIC design, the larger the required inductance value, the larger the inductance area necessary. On the other hand, the area of the fabricated active inductor is less than $0.15mm^2$ which can be reduced by using smaller gate width FETs, compact DC bias circuitry, etc.. As shown in figures 2(a),(b), the proposed active inductor performs better than the spiral inductors.

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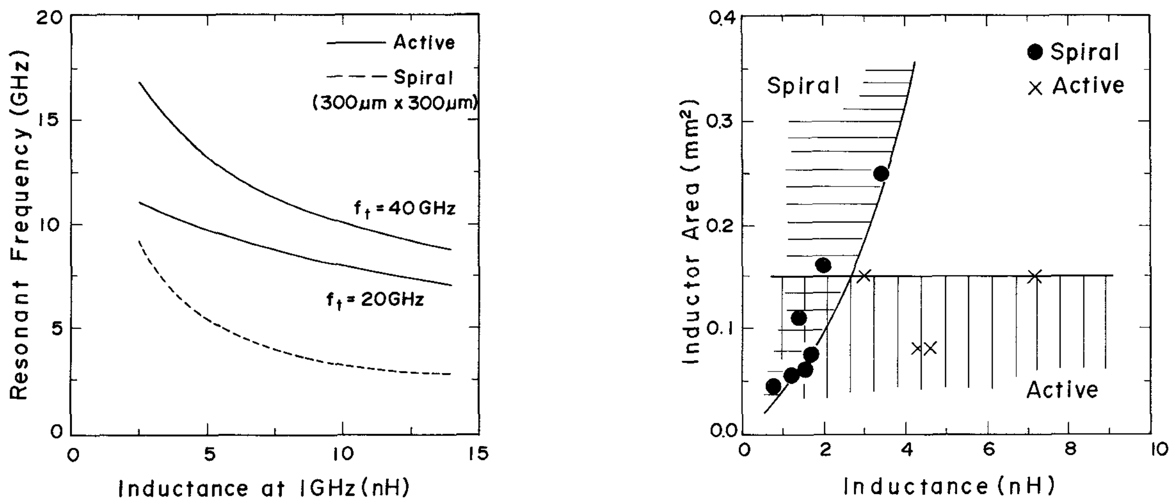


(a) Resonant Frequency Characteristics

(b)Chip Size

Fig.2 Comparisons of Proposed Active Inductor and Conventional Spiral Inductor

MAXIMUM OPERATING FREQUENCY

The broad band characteristics of the active inductor is achieved by suppression of stray capacitances. When the FET is assumed to be the combination of the transconductance g_m and the gate-source capacitance C_{gs} only, the impedance Z of the active inductor is expressed as follows:

$$Z=\frac{1+j\omega C_{gs1}R_{ext}}{g_{m1}+j\omega[C_{gs1}-C_{gs2}+\omega^2C_{gs2}(C_{gs1}C_{gs2}/g_{m1}g_{m2})]} \quad (1)$$

where suffixes 1 and 2 respectively correspond to the 1st FET and the 2nd FET in the cascode FET. When the cascode FET is composed of FETs with the same g_m and C_{gs}, the gate-source capacitances C_{gs1} and C_{gs2} cancel each other. Therefore, equation (1) is rewritten as equation (2).

$$Z=\frac{1+j\omega C_{gs}R_{ext}}{g_m+j\omega C_{gs}(\omega C_{gs}/g_m)^2} \quad (2)$$

The equivalent circuit of this active inductor is approximately represented as in Fig.3. In actual microwave FETs, $\omega C_{gs}(\omega C_{gs}/g_m)^2$ is sufficiently smaller than g_m. Thus the proposed microwave active inductor can operate in the microwave range. From eq.(2) this active inductor can operate under the conditions presented in equation(3).

$$g_m \gg \omega C_{gs}\left(\frac{\omega C_{gs}}{g_m}\right)^2 \quad (3)$$

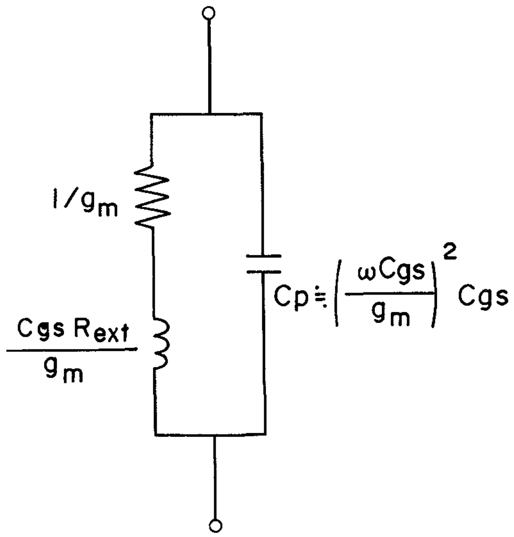
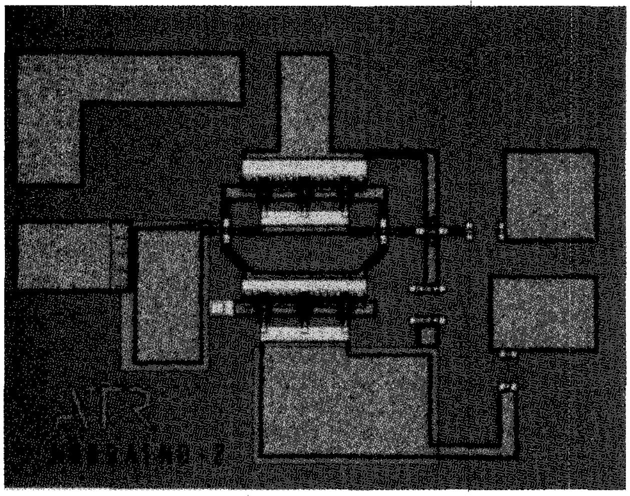


Fig.3 Equivalent Circuit of the Active Inductor

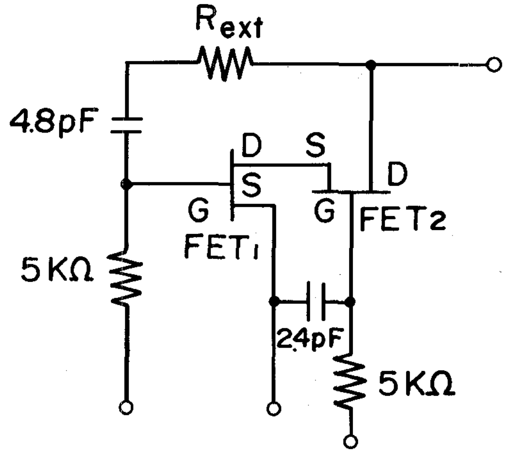
Equation (3) can be rewritten as eq.(4) with the cutoff frequency f_t ($=g_m/2\pi C_{gs}$).

$$(f/f_t)^3 \ll 1 \quad (4)$$

In this equation the maximum operating frequency is about one-half of f_t.



(a) Photograph of the Chip



(b) Circuit Configuration

Fig.4 The Schematics of the Fabricated Active Inductor

EXPERIMENTAL RESULT

A photograph of a fabricated GaAs monolithic active inductor and a circuit configuration diagram are shown in Fig.4. Two 0.3μm×150μm single gate ion implanted FETs with a typical cutoff frequency of 21GHz are employed. The active inductor is located in a 400μm×400μm area with DC-cut capacitors separating the DC biases for each gate. The measured inductances of the active inductor are shown in Fig.5, along with calculated inductances of the spiral inductors. Two kinds of active inductors are fabricated with an external resistance (R_{ext}), 320Ω and 800Ω. The inductances of 3.0nH±0.4nH and 7.7nH±0.9nH are obtained at frequencies ranging up to 7.6GHz and 5.5GHz respectively. As shown in Fig.5, the active inductors have constant inductance over a much wider frequency range compared to the 300μm×300μm spiral inductors.

With regard to the resonant frequency, some differences between measured(Fig.5) and calculated values(Fig.2(a)) can be found. This degradation comes from the distributed lines connecting the inductor's elements. Therefore, it is important to minimize these line lengths in the actual designs.

APPLICATION TO A 0.1-10GHz AMPLIFIER

The schematic of a 0.1-10GHz amplifier utilizing the proposed active inductors is shown in Fig.6. A common gate FET (CGF) with a transconductance of 20mS is used for the input impedance match. A common source FET (CSF) with a transconductance of 40mS is used for the gain stage. Active inductors with

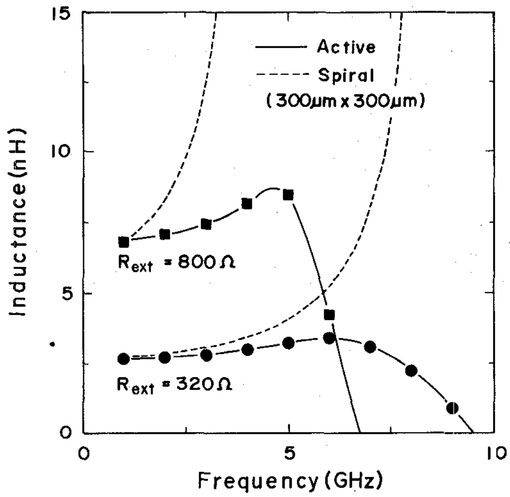


Fig.5 Inductance-frequency Characteristics

low value spiral inductors and resistors are used at the CGF and CSF output ports. The gain and bandwidth are mainly determined by the active inductors. A photograph of this MMIC amplifier is shown in Fig.7. The gain-frequency characteristic can be adjusted by changing the values V_G for the gate of the CSF and V_I for the second FET's gate of the active inductors. The chip size is only 1.0mm×1.3mm. The measured and predicted performance values agree closely and are shown in Fig.8.

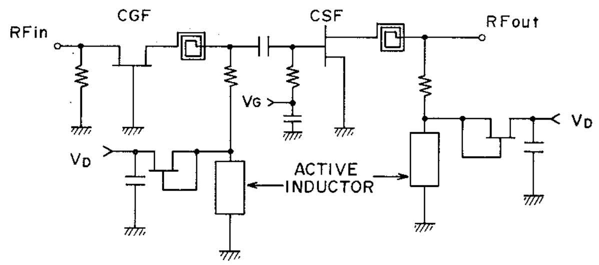


Fig.6 Circuit Configuration of Active Matching Amplifier using Active Inductor

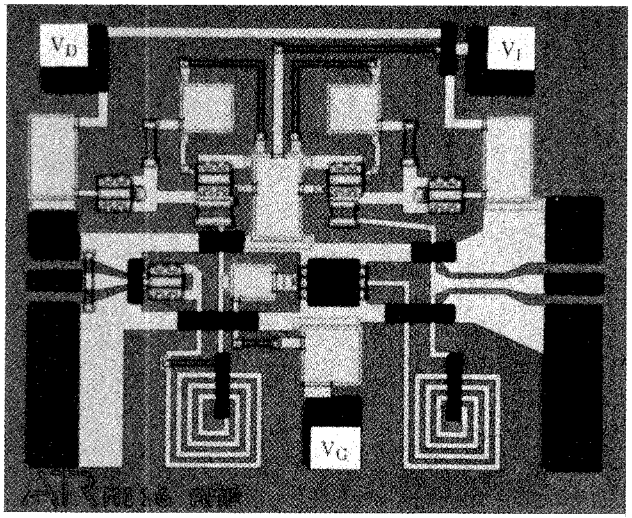


Fig.7 Photograph of Active Matching Amplifier

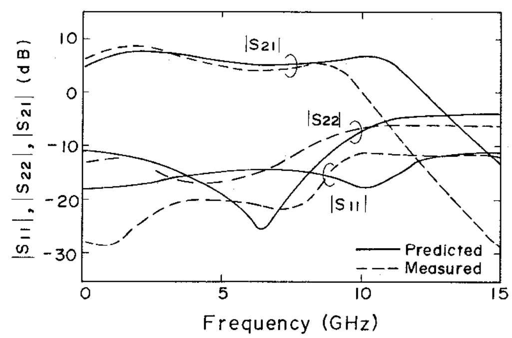


Fig.8 Performance of Fabricated Amplifier

CONCLUSION

A broad band microwave active inductor has been proposed. This active inductor has the following features:

1. Very high frequency operation.
2. Small size independent of the inductance value.

These features were effectively demonstrated in a small fabricated amplifier. This active inductor should prove valuable in designing smaller and more efficient MMICs.

ACKNOWLEDGMENTS

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