# A Compact MMIC 90° Coupler for ISM Applications

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## ABSTRACT

In this paper, a new GaAs MMIC quadrature hybrid is described which is based on a lumped element approach. The MMIC makes use of interleaved spiral inductors in a transformer-like configuration and MIM capacitors. A design technique is proposed. The resulting 90° coupler is characterised by a reduced size (500 μm X 500 μm). An analytical derivation of the hybrid design parameters is discussed and results are compared with experiments.

## INTRODUCTION

Directional couplers are key components in the design of many microwave and millimeter wave systems. Several compact structures, mainly based on a distributed component approach, have been proposed [1]. These solutions, while extremely efficient for MIC design, are not suitable for single chip MMIC implementation.
This paper introduces a GaAs MMIC 90° coupler operating in the 2.4 GHz ISM band. The coupler design is based on an original technique which takes advantage of the coupling between integrated spiral inductors [2]. The structure proposed is analyzed and the design formulae in a closed-form are reported. Sample prototypes have been designed and tested using GEC Marconi F20 process. Experimental results, showing a fairly good agreement with theory, are reported and discussed.

## LUMPED ELEMENT APPROACH

The ideal 3dB directional coupler is described in terms of S parameters by the symmetrical matrix S shown in (1).

$$S = \frac{e^{j\alpha}}{\sqrt{2}} \begin{bmatrix} 0 & 1 & 0 & j \\ 1 & 0 & j & 0 \\ 0 & j & 0 & 1 \\ j & 0 & 1 & 0 \end{bmatrix} \qquad (1)$$

The matrix can be implemented on a lumped element basis, according to [3], which is suitable for MMIC design. The structures proposed in [3] are generally based on two or more inductances and do not provide a satisfactory chip area occupation. Furthermore, many structures found in the literature do not take advantage of any symmetry in the circuit topology which may be extremely useful in terms of design.
On the other hand, the use of spiral inductors introduces a strong coupling effect if a close spacing between inductors is chosen in order to optimize chip area occupation.
These effects can be either considered as parasitic or taken into account in the design procedure by using proper circuital solutions [4,5]. In particular, the approach proposed in [4] allows a close spacing between inductors (which can be even concentric), taking into account mutual inductance (Fig.1b). This mutual inductance becames a design parameter that should be carefully evaluated either by measurements or full-wave analysis or by

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extracting a proper model of the structure.
This paper is based on a modelling technique reported in [2] which was extended to concentrical structures whose model is depicted in Fig.1a.

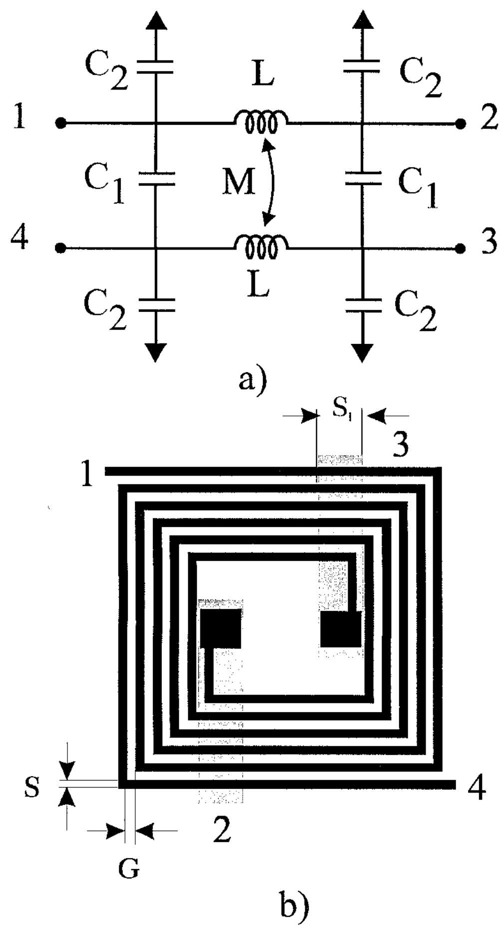


Fig.1) Concentrical spiral inductors; a) Circuit model; b) MMIC implementation.

Fig.2 shows the variation of the components L and K=M/L, obtained for the structure depicted in Fig.1b where S=10μm, $S_I$=40μm. These parametrs are the most relevant in determining the concentric spiral inductors model fitness.
The component variation is reported as a function of the number of turns, N, for different values of the conductor spacing G. It is worth to note that for N ranging form 3.75 to 5, K is fairly constant while L is linearly variable.

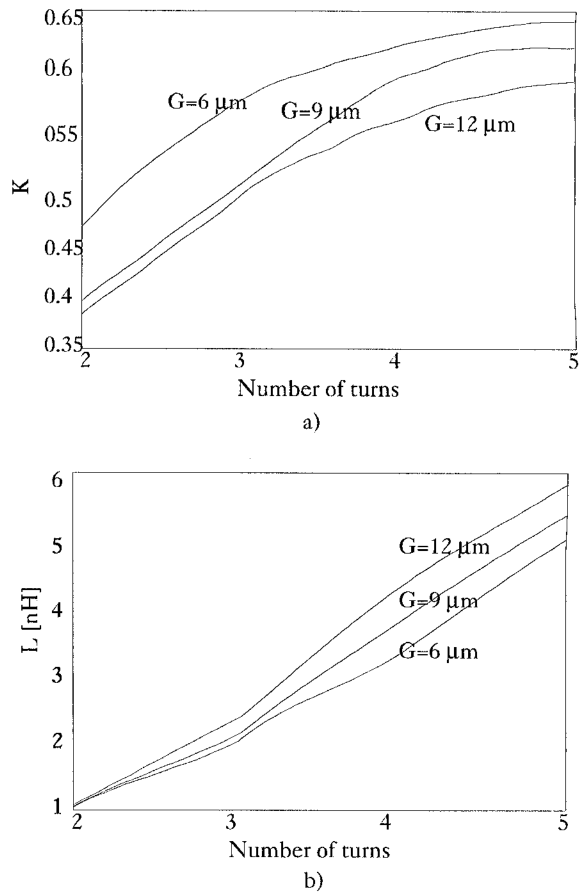


Fig.2) Concentric spiral inductors parametric model; a) Coupling factor K; b) Autoinductance L.

The topology in Fig.1a can also be an implementation of the 90° coupler, as proposed in [4] where an analytical procedure is described to extract the element values. This synthesis procedure allows to evaluate the proper capacitance values to be added to the structure in Fig.1b. In this case, ports 1 and 3 became respectively the Σ and Δ coupler ports.
The main disadvantage of this approach is represented by the fact that input ports (and, then, output ports) are placed on opposite sides of the coupler. This circumstance is particularly undesirable when laying out the coupler on GaAs. In fact, the insertion of the capacitances C1 of Fig.1a, requires long interconnection paths to be placed around the spiral inductor. These introduce unpredicted couplings and

losses and, above all, unbalancing in the coupler.

In order to circumvent these problems a new coupler topology can be assumed in which the above interconnections are not required. This topology (depicted in Fig.3) is characterised by the fact that the Σ and Δ inputs lay on one edge and the output ports on the other edge. As a consequence, the coupler is both geometrically and electrically symmetrical.

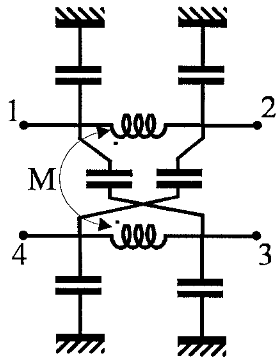


Fig.3) Lumped element coupler topology

The components in Fig.3 are evaluated by using the procedure described in [2], which relates the single components of the model to the symbolical $\underline{Y}$ matrix elements.

The components are expressed as a function of the α parameter of equation (1) by the relations:

$$C_1 = -\frac{1}{\omega Z_0}\left[\frac{1-\sqrt{2}\cos(\alpha)}{\cos(2\alpha)}\right]$$

$$C_2 = \frac{1}{\omega Z_0}\left[-\frac{\sin(4\alpha)}{1+\cos(4\alpha)}+\frac{1+\sqrt{2}(\sin(\alpha)-\cos(\alpha))}{\cos(2\alpha)}\right]$$

$$K = -\cot(\alpha)$$

$$L = -\frac{1}{\omega}\frac{Z_0\sin(\alpha)}{\sqrt{2}}$$

Assuming $Z_0$ equal to 50 Ω, the design is based on a right choice of α which in turn univocally determines L and M.

The curves reported in Fig.2 were used to define the geometrical parameters of the two coupled spiral inductors. As was pointed out, a large number of turns allows to obtain the proper value of K by choosing a proper value of G; as a consequence, L depends only from N.

This procedure allows to optimize with standard CAD tools the choice of the α parameter and, thus, circuit performance.

The capacitances which must be effectively layed out are determined starting from the parasitic capacitances associated with the resulting coupler.

## EXPERIMENTS

A 2.4GHz ISM band prototype of the proposed coupler has been implemented in order to validate the design procedure. The MMIC was designed using GEC Marconi F20 process.

Fig.4b shows the S parameters ($S_{11}$, $S_{12}$, $S_{13}$ and $S_{14}$ ) and the phase shift between I and Q port, showing a good agreement with respect to the ideal behaviour.

## CONCLUSION

An analytical approach to the design of a lumped element MMIC 90° coupler has been described. Each component value has been given in closed form in terms of characteristic impedance and frequency. A design procedure has also been presented to determine the geometry of the interleaved spiral inductors, as reported in the corresponding curves. Finally, measurements carried out on a protopype designed and realized by using the GEC-Marconi F20 process, are reported

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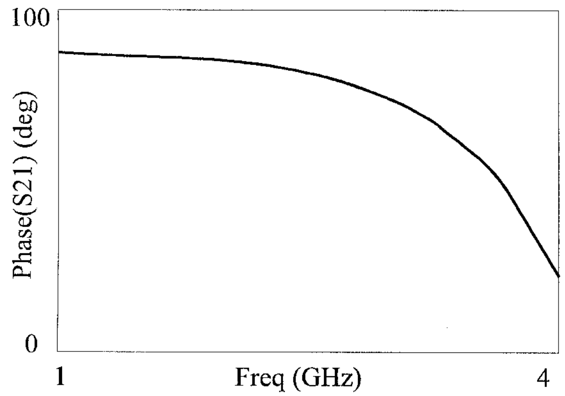
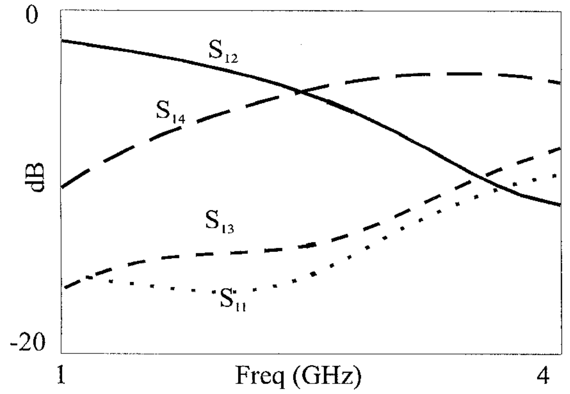



a)




b)

Fig.4) Coupler Measured data;
a) S21 phase; b) scattering parameters.

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