MMIC QUASI-CIRCULATOR WITH LOW NOISE AND MEDIUM POWER

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ABSTRACT

This paper presents the design and the measured performances of a narrow band quasi-circulator module. Its design implements active divider and combiner. The device demonstrates a noise figure of 5.5dB and an output power of 18dBm with associated gains of 4dB and 7.6dB for the receive and transmit path, respectively.

INTRODUCTION

A quasi-circulator is a three-port network that allows to transmit power from port (1) to port (2) and from port (2) to port (3) [1,2,3]. At present, there are no published results concerning an active device allowing to transport simultaneously a high power signal from transmitter to antenna and a weak power signal from antenna to receiver. This problem has been studied by P.Katzin [2], but his paper describes successively the performances of two different circulators. One presents a noise figure greater than 8.5dB and an insertion loss of 2dB, the other allows to obtain an output power of 1W but with a 12dB noise figure in the receive-path.

In this paper, we propose a circuit allowing to optimize simultaneously the noise figure and the available output power of an active quasi-circulator. The analyzed frequency band is 3.8-4.2GHz.

QUASI-CIRCULATOR MODULE

Figure 1 shows the block diagram of the quasi-circulator module (QCM). The device is realized by connecting the output ports of the in-phase

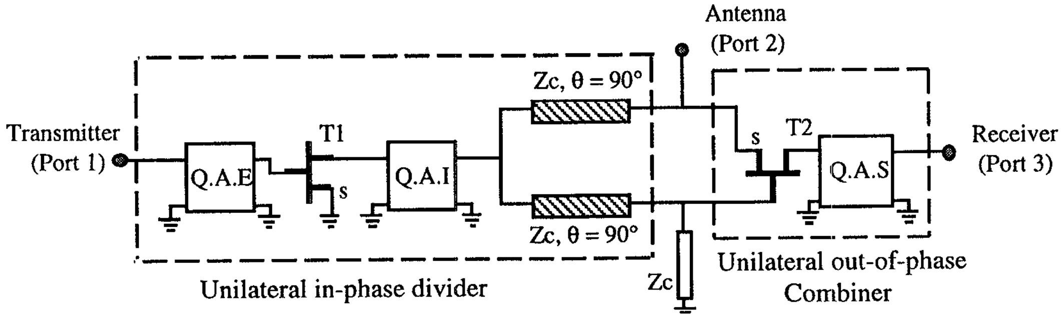

Figure 1: Block diagram of the quasi-circulator module.

divider to the input ports of the out-of-phase combiner. Port (2) of the QCM is branched from one of the connected lines while a shunt impedance Z_c is connected to the other one. The value of Z_c is equal to the reference impedance value in order to preserve the symmetry.

The operating principle of this circuit has been described in [1,3]. The isolation between the ports is obtained by the non-reciprocity of the transistors and by connecting the in-phase divider to the out-of-phase combiner. The divider is achieved by using a common source transistor T1, a matching two-port (Q.A.E) at port (1), an interstage matching two-port (Q.A.I) and a junction constituted of two 90°phase shifters. The combiner consists of a transistor T2 and a matching two-port (Q.A.S) at port (3).

THE NOISE FIGURE CALCULATION

Before optimizing the noise figure F_{23} between ports (2) and (3), it is necessary to know its minimum value if the transistor T2 is a noiseless three-port. For this purpose, we have used a simple model in which the transistor T2 is represented by its transconductance g_m. Similarly, the noise behavior of the circuit constituted of the impedance Z_c (the load 50Ω at port (1)), the transistor T1 and the two-port Q.A.I has been modelized by an output equivalent impedance Z_l and a noise current source i_l (figure 2). Moreover, the circuit (figure 2) is constituted of two other impedances:

-The load impedance Z_c at port (2) which is at the standard temperature T_0 (290°K).

-The shunt impedance Z_c between the divider and combiner which is at the room temperature T_a (300°K).

These three impedances generate three noise current sources i_1, i_{c1}, and i_{c2}, respectively. It is straightforward to calculate the noise current i_s at the output impedance Z' :

$$i_s = \frac{g_m Z_c}{1 + g_m Z_c}(i_{c1} - i_{c2}) \qquad (1)$$

This result shows that the noise generated by the transistor T1 has no influence on the receive-path, because i_s is independent of the noise source i_1 and is independent of the impedance Z1. By definition of a two-port noise figure, the noise figure F_{23} of the quasi-circulator will be simply expressed as:

$$F_{23} = \frac{T_0 + T_a}{T_0} \qquad (2)$$

This equation shows that the QCM noise figure will be greater than 3.1dB even if the QCM is realized with a noiseless transistor T2. In the actual case, T2 is a transistor of F20 technology of GMT foundry with 0.5x350μm^2 gate dimensions. The noise figure F_{23} of the QCM is calculated by simulation and is equal to 5.3dB.

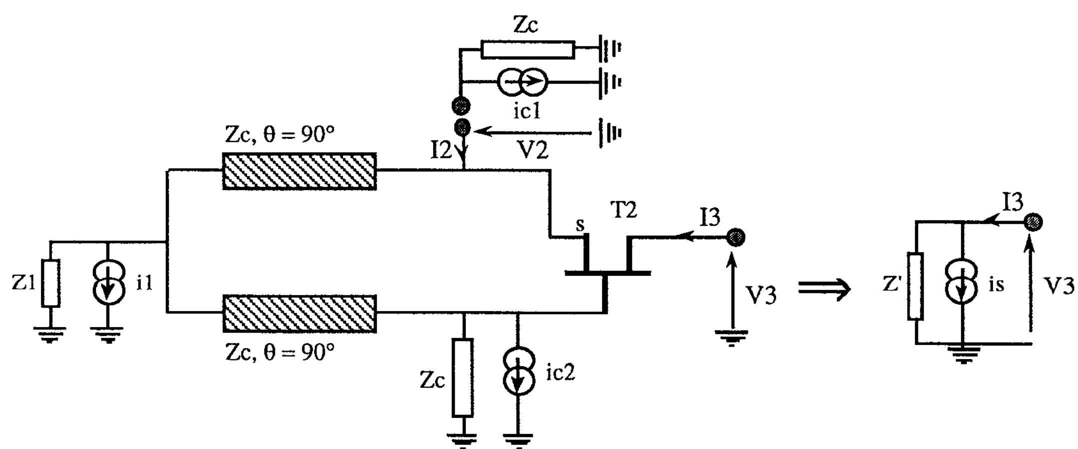

Figure 2: Simplified circuit configuration to calculate the noise figure F_{23}.

THE POWER OPTIMISATION

The transistor T1 is a common source MESFET, with a gate area of 0.5x700µm^2. By using the Curtice nonlinear model, we have obtained the optimum load impedance value of T1 that gives the maximum output power. Then, the elements of the two-port network Q.A.I (figure 1) have been calculated so that the transistor T1 is terminated by its optimum load impedance. In this case, the output power at port (2) of the QCM is 20dBm at 1 dB compression point.

MEASUREMENT RESULTS AND COMMENTS

The layout drawing of the QCM is shown in figure 3. Its overall size is about 5mm^2. Figure 4 shows the measurement results of the QCM. For a frequency of 4GHz, the circuit presents gain values of 7.6dB and 4dB between the transmitter-antenna ports and the antenna-receiver ports, respectively, and an isolation of 22dB in the transmit-receive path. The minimum isolation of 13dB in the receiver-antenna path is in most cases sufficient because the receiver is generally well matched. It can be noticed that the best return losses are obtained at 4.1GHz instead of 4GHz and are greater than 14 dB. This small frequency shift can be due to the coupling between elements, which was not taken into account during the simulation.

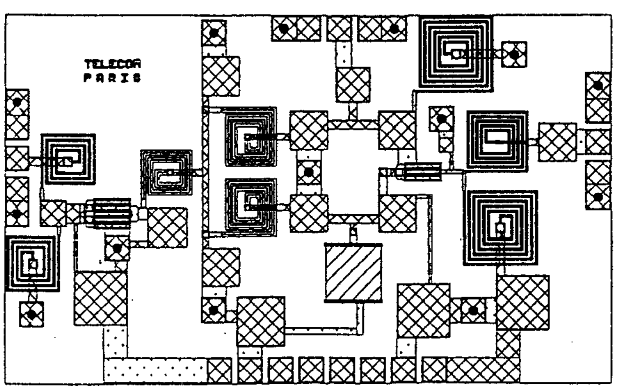

Figure 3: Layout of the quasi-circulator module.

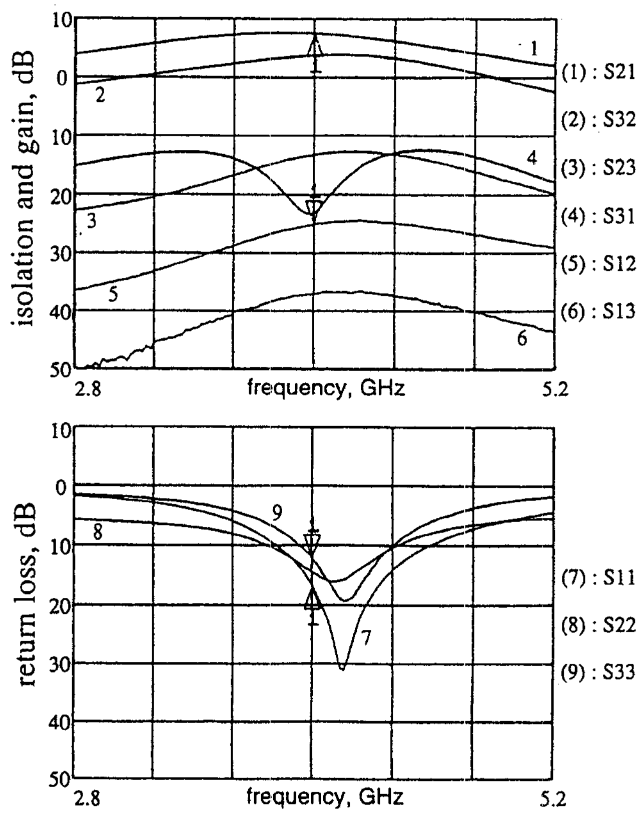

Figure 4: Measured frequency characteristics of the quasi-circulator.

Figure 5 shows the input-output characteristics of the fabricated quasi-circulator. The circuit

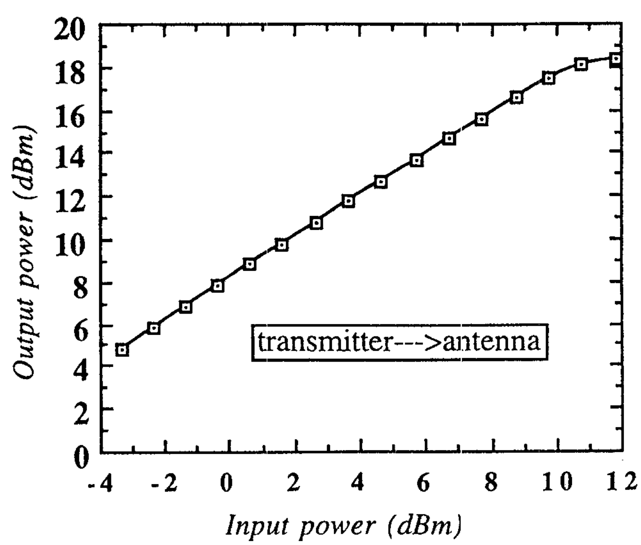

Figure 5: Handling power characteristics of the quasi-circulator.

presents 18dBm output power at 1dBcompression point. The measured noise figure F_{23} between port (2) and port (3) is 5.5dB.

Finally, it is important to note that this circuit can handle very high power between ports (1) and (2) by simply increasing the width of the transistor T1. The noise figure F_{23} will always have the same value because it is independent of the noise generated by T1.

REFERENCES

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