A PRACTICAL MMIC NEGATIVE RESISTANCE STRUCTURE FOR X AND Ku BAND APPLICATIONS

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ABSTRACT

This paper presents the mathematical analysis and measured results of a novel practical MMIC negative resistance structure. This structure operates at X and Ku bands. The measured results show a negative resistance (down to -50 Ω) over a 6 GHz bandwidth centered at 11 GHz.

INTRODUCTION

Design and synthesis of high Q microwave active filters and broadband amplifiers require the use of negative resistance. In the case of filters, the negative resistance compensates the parasitic losses associates with filter passive elements and enhances the filter Q factor [1-3]. In the amplifier case, the negative resistance is required to enhance the gain and bandwidth of a type of amplifier, namely distributed amplifier by reducing the detrimental effect of resistive losses at high frequency [4,5]. Negative resistance is also the main part of microwave negative resistance oscillators.

Producing the required negative resistance at the specified center frequency with required bandwidth is the underlying selection criteria for a suitable circuit configuration. The available negative resistance structures which are commonly used usually consist of a common gate or common drain MESFET with a reactive load which functions as a feedback element. These types of structures result in negative resistance over a narrow bandwidth at lower microwave frequency region. Their negative resistance is accompanied by a large value reactive part which have detrimental effect in many applications. Often it is possible to trade off between reducing the reactive part at the expense of extra circuit complexity and loss of bandwidth.

In this paper the mathematical analysis and measured results of a novel practical MMIC negative resistance structure is presented. This structure which is a modified version of a previously proposed negative resistance circuit by the authors [6] extends the frequencies of operation to X and Ku bands.

CIRCUIT STRUCTURE AND ANALYSIS

In Figure 1 a conventional negative resistance structure is shown. As can be seen the feedback element here is a capacitor which is used as the load of a common drain configuration transistor.

The input impedance of this structure is given by:

$$Z_{in} = g_m Z_1^2 + 2 Z_1 \quad (1)$$

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where $Z_1 = 1/(j\omega C_{gs})$ and g_m is the transistor transconductance. In this calculation for simplicity and clarity the transistor is modeled by its equivalent input capacitance and the output current generator. It is assumed that the load capacitance is equal to the capacitance of the gate to source capacitor of the transistor.

Equation 1 shows that the real part which is the negative resistance, $g_m Z_1^2$ is accompanied by a large reactive part, $2Z_1$ (small capacitance). These two terms are plotted in Figure 2. The typical value of the negative resistance which can be achieved by this structure in MMIC design is too high at low frequency and it is strongly frequency dependent. Its rapid reduction with frequency as shown in Figure 2 seriously limits its usefulness to a narrow bandwidth of operation. In order to alleviate the above mentioned difficulties and considerably improve the response of the negative resistance one needs to shape the circuit configuration. In Figure 3 an alternative structure which employs two MESFETs in a novel configuration is shown. The input impedance of this structure is given by:

$$Z_{in} = \frac{2g_m Z_1^2}{1 - g_m^2 Z_1^2} + \frac{2Z_1}{1 - g_m^2 Z_1^2} \qquad (2)$$

The real and imaginary part of the above equation for a typical microwave transistor is plotted in Figure 4. The objective of the new configuration with two MESFETs is to significantly scale down the undesired electrical behavior embedded in Equation 1 and enhance the bandwidth and flatness of the negative resistance. This is achieved by the introduction of suitable corrective factor for the real and imaginary parts as is evident from a comparison of Equations 1 and 2. The corrective factors which the negative resistance and reactive parts are divided by, are given by

$$\text{RE\_COFF} = \frac{1 - g_m^2 Z_1^2}{2} \text{ and}$$

$$\text{IM\_COFF} = 1 - g_m^2 Z_1^2 \text{ respectively.}$$

Figure 5 shows a plot of the corresponding corrective factors as a function of frequency. The correction mechanism utilized here can be explained in the following steps:

1- The high value of the real part corrective factor at low frequency reduces the negative resistance value to a useful range while the reduction of this factor with frequency insures flatness within the bandwidth.

2- The corrective factor of the imaginary part is twice of the corrective factor for the real part, resulting in an effective reduction of the unwanted reactive part.

3- At high frequency where the negative resistance begins to decrease to an undesirable low value, the corrective factor of the real part falls below unity thereby maintaining the negative resistance for even higher bandwidth of operation. In fact the relative magnitude of the corrective factors for the real and imaginary parts insures that reactive part is scaled down by a factor less than 1 at high frequency while negative resistance is scaled up by a factor greater than 1, thus enforcing flatness at higher frequencies.

In order to flatten the response further and to compensate the effect of the transistor elements which were not taken to account in the above discussion, two of the structures of Figure 3 may be connected together as shown in Figure 6. Any remaining capacitive imaginary part can also be canceled out by a suitable inductor as shown in the figure.

Based on the structure shown in Figure 6 an MMIC negative resistance circuit was designed. Design and simulation process were optimized in order to extend the bandwidth to cover most of X and Ku bands. The MMIC layout of the circuit is shown in Figure 7. The circuit was implemented within an area of 1 x 2 mm^2 using the GEC F20 GaAs process.

PRACTICAL RESULTS

The on wafer measurement technique were used to measure the response of the implemented circuit. The measured results are shown in Figure 8. As the measured results show the circuit produces negative resistance from 8.1 to 15.5 GHz. The lowest value measured is -50 Ω at 11 GHz. Even though the measured imaginary part of the circuit was more than the predicted value, it was small enough to be ignored over more than 70 % of the measured bandwidth.

CONCLUSIONS

It has been shown that it is possible to produce negative resistance over a broad range of frequency centered at 11 GHz. The measured results of an implemented MMIC negative resistance suggest that the negative resistance structure can be employed in active filter design due to low imaginary value of its input impedance. Its broad-bandwidth makes this negative resistance structure suitable for loss compensation in distributed amplifiers. The structure could also be employed in a negative resistance oscillators.

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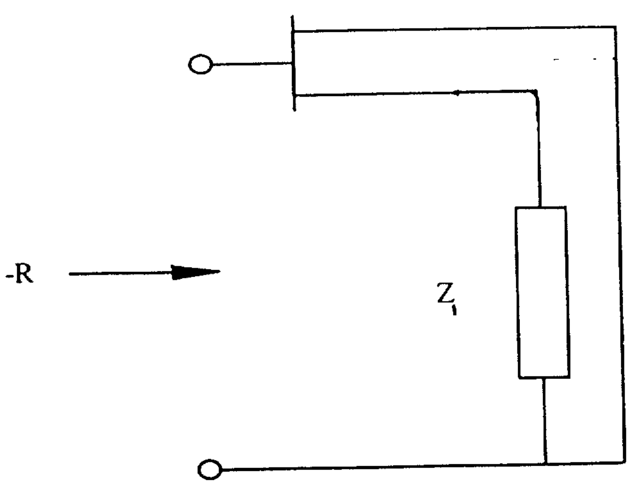

Fig. 1 A common drain MESFET with a capacitive load producing negative resistance.

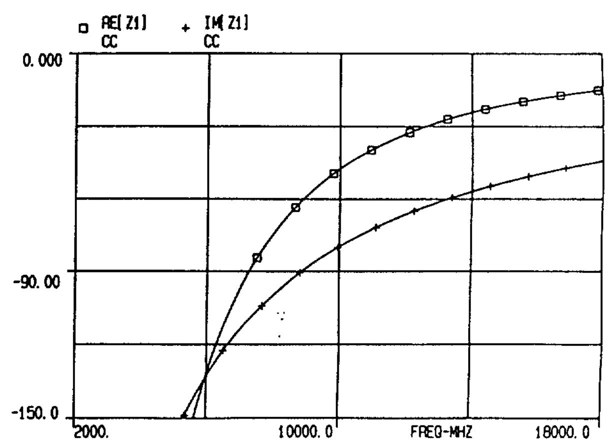

Fig. 2 Real and imaginary parts of the input impedance of Fig. 1 as functions of frequency.

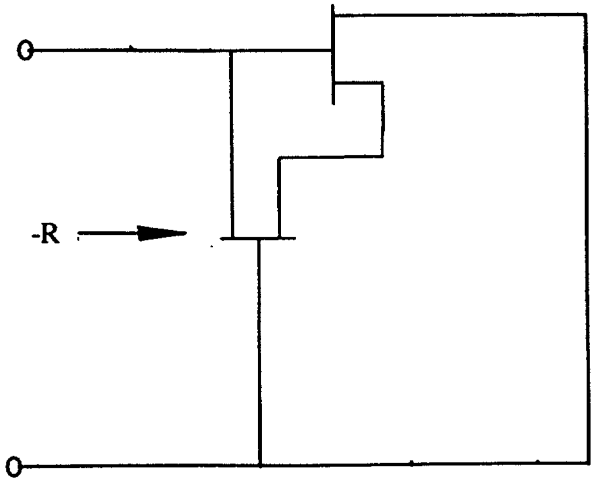

Fig. 3 A common drain and a common gate MESFET used as negative resistance.

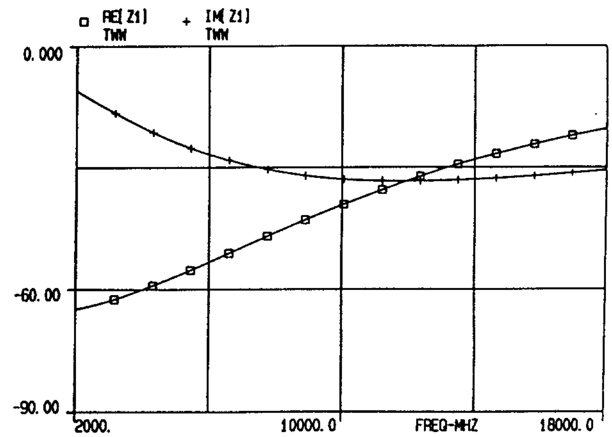

Fig. 4 Real and imaginary parts of the input impedance of Fig. 3 as functions of frequency

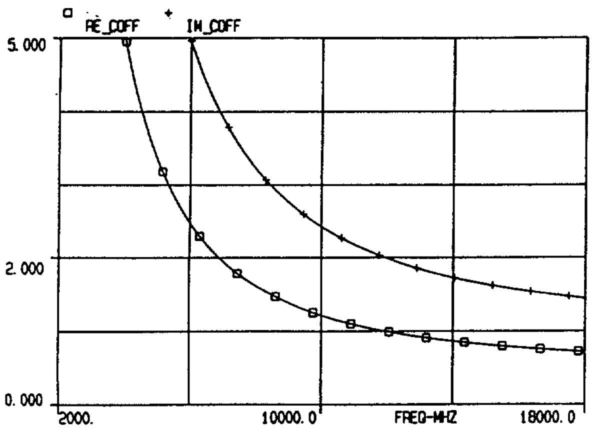

Fig. 5 Real and imaginary part Corrective Factors as functions of frequency.

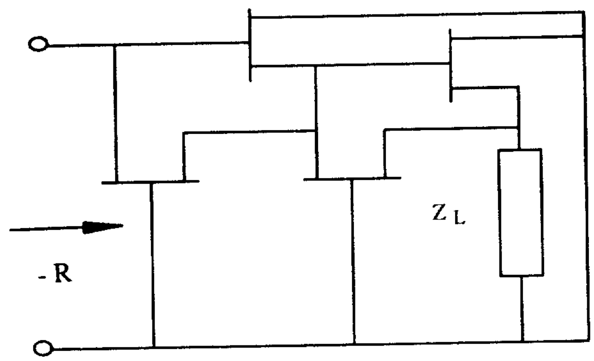

Fig. 6 The Practical circuit.

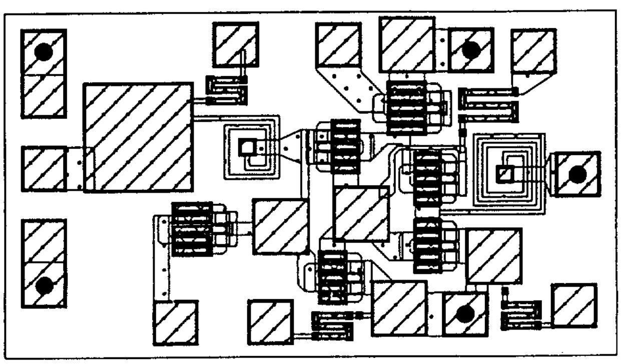

Fig. 7 The MMIC Layout of the implemented circuit.

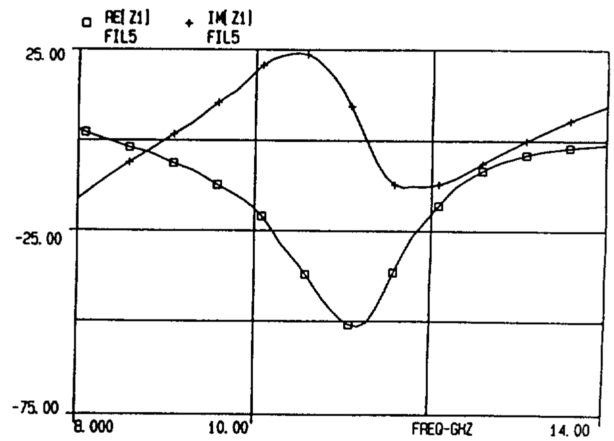

Fig. 8 The measured real and imaginary parts ot the implemented negative resistance structure.