MMICs for K band low noise receivers

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Abstract

The two basic parts of a receiver operating in K band: a low noise amplifier and a mixer, have been designed and fabricated using Philips Microwave Limeil process D02AH. The circuits presented in this paper show very interesting results. For the low noise amplifier three stages were used obtaining good noise figures and gain results. The first two stages employ series feedback, and the last one uses parallel feedback. For the mixer, a recently proposed scheme, based on drain mixing was applied. On wafer measurements for both circuits are shown. The results show a reasonable performance and address weak points in modelling and technology for the design of enhanced prototypes.

Introduction

High quality satellite receivers and digital microwave radio systems operating in the band 20-30 GHz are increasingly in demand. The required noise figures are below 5 dB. HEMT transistor technology allows the achievement of these necessities.

Two basic components of a receiver, a low noise amplifier and a mixer have been developed. The conversion is done in K band, with an intermediate frequency of 1 GHz. The D02AH technology of Philips Microwave Limeil [1] has been employed, which uses 0.2 µm gate length HEMTs. A non linear model, wich includes the noise sources, provided by the foundry has been used. The circuits have been measured on wafer showing reasonable and promising behaviour. These results allow the evaluating the model used and the design methods.

The low noise amplifier uses three stages to get sufficient gain in order to decrease the noise contribution of the mixer to the global receiver noise.

For the mixer a drain LO injection is adopted. This topology has been chosen because the RF and LO frequency bands are very close and the use of filters to provide a good RF and LO signal isolation would not be possible. In this paper we have done an analysis of the mixer when the drain bias is changed, and an optimum bias point has been found. This mixer can operate even when the drain voltage is not applied, which can be very useful when the power consumption needs to be small.

1.Low noise amplifier

1.1 Design

HEMT transistors have demonstrated good performances in low noise amplification at high frequencies. The design and performance of a K band low noise amplifier fabricated with the D02AH process of Philips Microwave Limeil is described. The transistors employed have 0.2 µm gate length and a total gate width of 90 µm. The noise of the transistor can be reduced using several short fingers. On the other hand, the Rn noise parameter decreases with the increase of the number of fingers. It results in a lower sensitivity of the device with respect to the noise mismatch.

The amplifier has a 3-stage configuration to achieve the necessary gain in order to reduce the noise contribution of the mixer to the global noise of the converter chain. The first two stages use an inductive series feedback to approach the noise and impedance matching aims, however the excess of feedback can degrade the gain. The last stage has been designed using series inductive and shunt resistive feedback to guarantee the stability of the amplifier and to flatten the gain. The interstage and matching circuits use transmission lines and capacitors. The design of these passive circuits has been made to match and bias simultaneously using the minimum number of elements. Figure 1 shows the photograph of the chip containing the low noise amplifier and two devices for testing purposes. The chip size is 2x1.5 mm .

1.2 Measurements

On-wafer coplanar probes have been used to determine the low noise amplifier performances. The test set-up included the Cascade Microtech on-wafer probe station, HP8510 network analyzer and HP8970B noise figure meter. The amplifier exhibits gains over 17 dB across the 20-26 GHz frequency band (figure 2) with typical matching values for these applications. The noise figure is less than 2.75 dB in the 22-25 GHz band (figure 4) with a gain over 14 dB (figure 3).

2.Mixer

2.1 Behaviour of a drain LO mixer

The most important nonlinealities in a FET equivalent circuit are: the transconductance g_m and the drain resistance R_{ds}[5]. In a FET transistor, the mixing occurs when small signal elements are changed at a periodic rate by a large local oscillator signal applied between a pair of the device terminals. Usually these two terminals are gate and source, and in this kind of mixers the most important nonlineality is the transconductance g_m in the mixing process. There is another kind of mixers, called "drain mixers", in which the LO signal is injected between the drain and source terminals. In these mixers the drain resistance becomes a very nonlinear element, so it is not correct to use its time average value, as it is used in gate mixers [7]. When a LO signal is applied between the drain and source terminals, the transconductance and the drain resistance are modulated by the local oscillator. The rest of the elements of the FET equivalent circuit can be considered almost constant. The drain mixer makes use of the nonlineality of the drain resistance. In Fig.6 the time dependence of the drain resistance is shown when a large LO signal is applied to the drain. When the drain bias voltage is changed, the nonlineality effect is also changed. In Fig. 6(a) the time dependence of R_d is shown for a saturate drain current. In Fig. 6 (c) the time dependence of R_d is shown for an unsaturated drain current. And in Fig 6(b), the drain resistance R_d varies between a high value (A), and a low value (C). Throughout the LO cycle, saturated and unsaturated current levels are overtaken, so R_d will vary from a maximum to a minimum value. If the LO signal is large enough, a R_d variation can be expected similar to (b) case, even the drain bias voltage is zero. For this reason, this kind of mixer can operate even with the drain bias voltage is zero. Depending on the LO power and the bias voltage the nonlineality will be bigger or smaller. In this paper the optimum conditions of the gate and drain bias voltage are shown, obtained from the measurements of the designed mixer.

2.2 Design of the mixer

The RF port impedance matching is a three elements network (two inductances and one capacitor). A D.C. block capacitor and an inductance to bias the gate HEMT were added to the input network. In order to increase the RF/FI isolation, the IF signal is short-circuited at the gate. To inject the LO signal and to get the IF, a diplexer has been used. The LO signal is applied through a high pass filter, and the FI signal is extracted though a low pass filter. The design has been done with a non linear model, supplied by the foundry. The HEMT used has a 90 μm gate width. The M.D.S. (Microwave Design System) simulator of Hewlett Packard has been used in the design.

2.3 Measurements

In Fig. 7 the conversion losses (simulated and measured) are shown versus the drain bias voltage, with -0.2 V. gate bias voltage and for 5 dBm LO power. The optimum point has been found for 0.3 V. drain bias voltage. The mixer has been measured in the RF band (17-24 GHz) (Fig. 7). The 1 dB compression point occurs for +7 dBm input RF power with +10 dBm LO power. The IF output power and the 3rd-order intermodulation (IM3) output level versus RF power have been measured. The intercept point is about 11 dBm. A photograph of the mixer is shown in Fig. 5. In Fig. 8 conversion losses versus LO power are shown, with minimum conversion losses of 3 dB.

Conclusions

A low noise amplifier and a drain mixer have been design and measured using MMIC technology with HEMT transistors in the K band. The two circuits are basic blocks in low noise receivers at these frequencies. The low noise amplifier has three stages in order to obtain sufficient gain to minimize the noise contribution of the mixer to the total converter noise. The measurements show a gain up to 18 dB. The noise figure obtained is less than 2.7 dB in the band of interest. For the mixer, the analysis done shows that an optimum bias exists point for minimum conversion losses. This mixer can operate even with zero bias drain voltage, which is very important when the D.C. power consumption is a critical point. The results allow these circuits to be considered as demonstrators of the HEMT MMIC technology at low noise specifications for high frequency receivers.

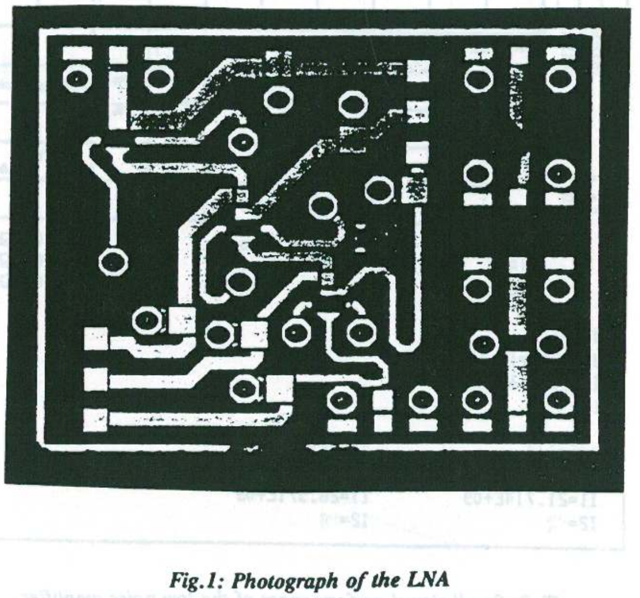

Fig.1: Photograph of the LNA

Acknowledgment

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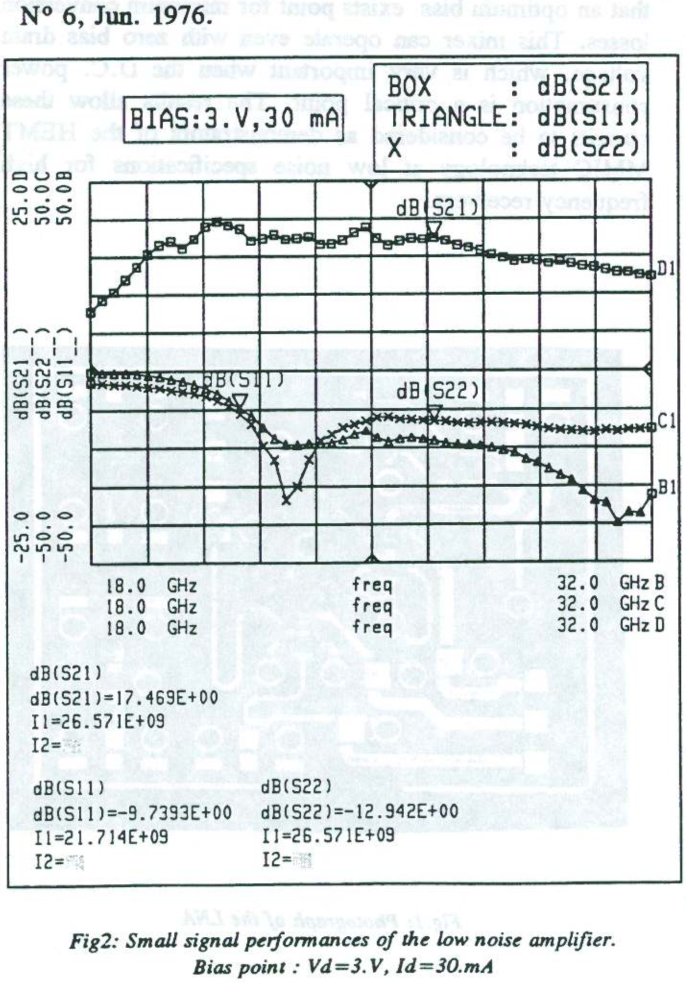


Fig2: Small signal performances of the low noise amplifier. Bias point : Vd=3.V, Id=30.mA

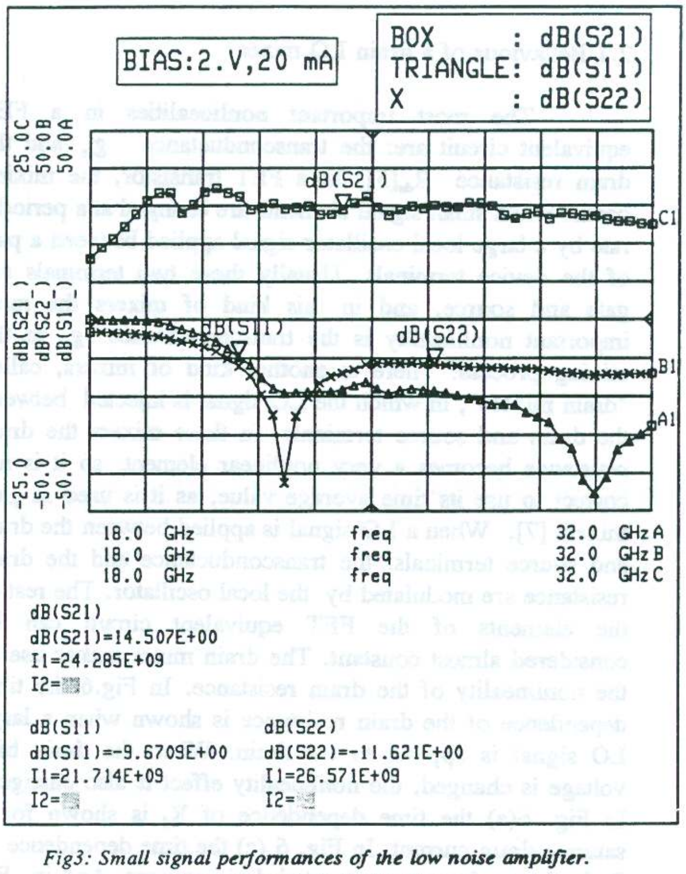


Fig3: Small signal performances of the low noise amplifier. Bias point: Vd=2.V, Id=20.mA

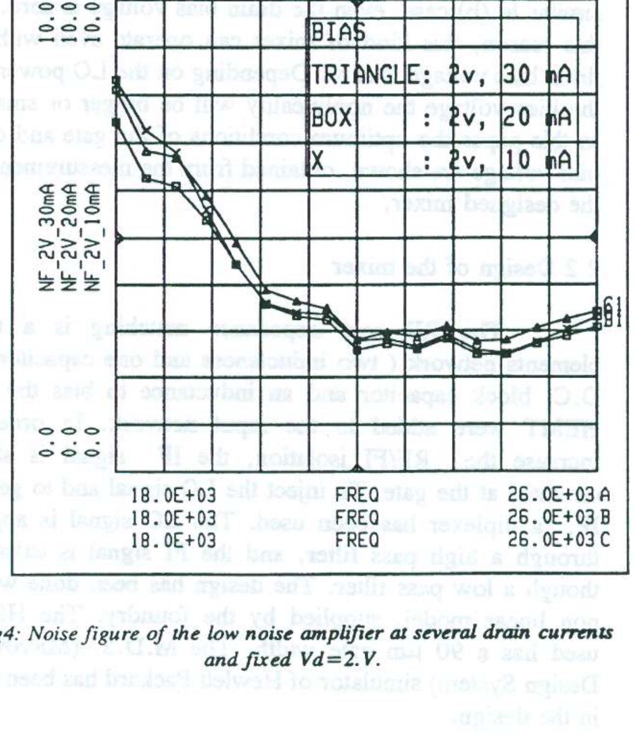


Fig4: Noise figure of the low noise amplifier at several drain currents and fixed Vd=2.V.

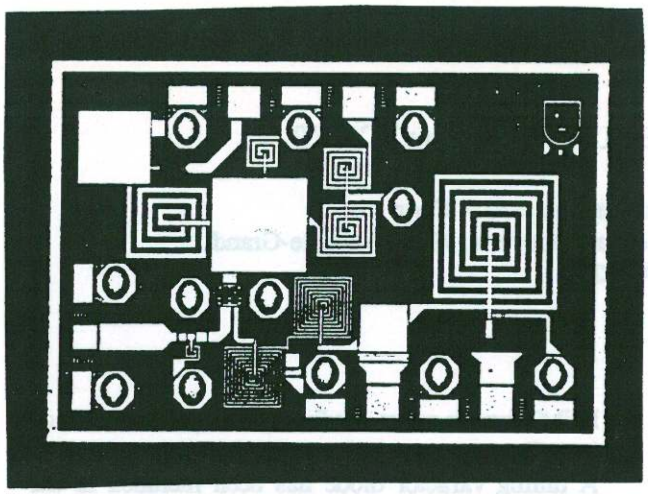
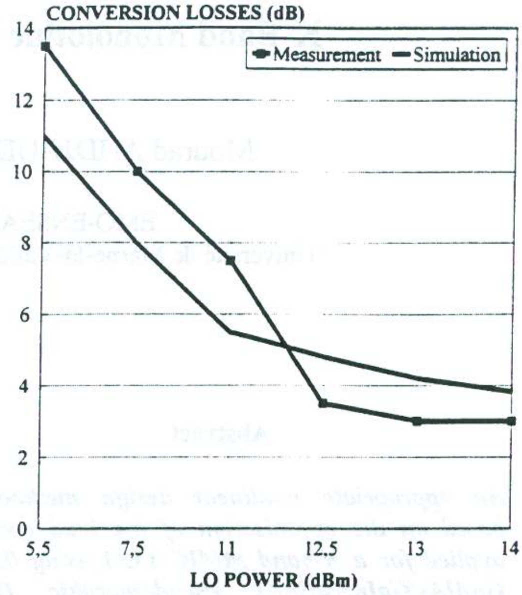


Fig5: Photograph of the Drain Mixer



RF=20 GHz
OL=21 GHz

Fig8: Conversion losses of the mixer versus LO power

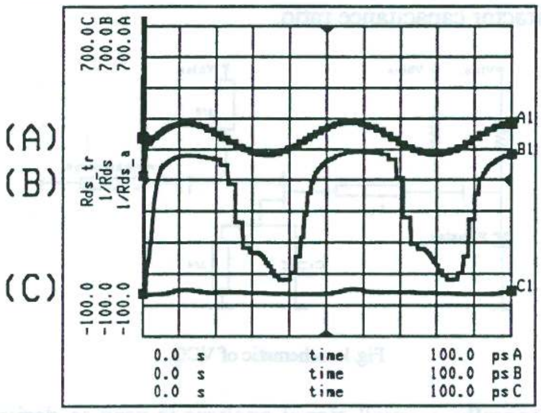
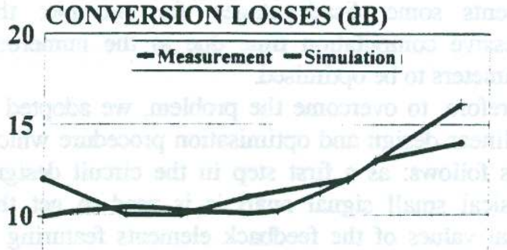


Fig 6: R_d modulation with the LO signal for three values of V_{ds}: (a) 5V, (b): 0.3V, (c): -0.3V



OL:22 GHz, 5 dBm
RF:21 GHz
Vgs: -0.2 V

Fig 7: Conversion losses of the mixer versus V_{ds}