BROADBAND 0.3 - 7 GHz MESFET AMPLIFIER WITH LOW NOISE FIGURE UP TO $f_T/2$ OF THE ACTIVE DEVICE

U. Lott, W. Baumberger

ETH Zürich, Laboratory for Electromagnetic Fields and Microwave Electronics,
Gloriastr. 35, CH-8092 Zürich, Switzerland, Fax + 41 1 261 10 26

Abstract

A broadband amplifier has been designed with a low noise figure up to 7 GHz using a standard 0.8 µm GaAs MESFET process ($f_T \approx 13$ GHz). An active match common gate input stage, a common source output stage and a combination of resistive and reactive loads give a gain of 10 +/- 1 dB and a noise figure below 5 dB over the 0.3 to 7 GHz frequency range.

Introduction

When designing broadband amplifiers, there are certain specifications that need to be met: bandwidth, gain, port impedances (ie. input and output match), noise and stability. As the bandwidth gets closer to the frequency limit of the active devices (ie. f_T or f_{max}), fulfilling all the specs becomes increasingly difficult.

In general, the decreasing gain and the increasing parasitics of the transistors must be compensated. There are at least three possibilities for designing a broadband low-noise amplifier:

(i) the amplifier with feedback,

(ii) the distributed amplifier,

(iii) the active match amplifier.

Feedback amplifiers, when properly designed, provide good stability against process, temperature and supply voltage variations. They offer the possibility to exchange gain versus bandwidth and to set port impedances freely. Several types of feedback amplifiers are commonly used:

Resistive feedback amplifiers can provide good port match and tend to be rather stable. However, their noise performance is degraded by the added noise of the feedback resistors. The degradation is particularly significant if strong feedback for getting a large bandwidth is applied.

Reactive feedback toplogies that are very attractive in hybrid designs [1] do not have this drawback; large bandwidths can be obtained without compromising dynamic range. The required multi-winding transformers can be realised monolithically [2], but suffer from their low Q's and a limited inductance range.

Active feedback amplifiers [3] are well suited for monolithic integration and do not exhibit impaired noise properties. They are promising canditates for moderate bandwidths. If a large bandwidth and therefore a strong feedback is required, the excessive phase shift usually causes stability problems. Additionally, good port matching is difficult to achieve.

Distributed amplifiers are not limited to the gain-bandwidth compromise, which is typical for the feedback type. Their bandwidth is limited by f_{max}, not f_T, which is an advantage if FETs are used as active devices. Therefore, the distributed amplifier provides the best low-noise broadband amplifier at millimeter-wave frequencies [4]. In the form of matrix amplifiers, a high gain and better noise figure can be achieved than with cascaded distributed amplifiers [5]. In the lower GHz range the required inductors get rather large and lossy, and the gain per stage of a MESFET distributed amplifier is restricted by the finite transconductance of the FETs and the port impedances. Exchanging bandwidth versus gain is not possible with this type of amplifier.

Active match amplifiers [6,7] offer good port matching over a relatively large frequency range without introducing explicit feedback and without noisy resistors. Through the use of a small number of inductors, their bandwidth can be extended over the usual $f_T/4$-limit without impairing the low frequency performance. In the frequency range which cannot be covered with feedback amplifiers for stability or noise reasons, but which is too low for an efficient distributed solution, active match amplifiers with additional reactive tuning are considered successful candidates for monolithic broadband low noise amplifiers in the frequency range up to $f_T/2$.

Design of the active match low-noise amplifier circuit

The circuit presented in this paper (Fig. 1) belongs to the active match category, using a common gate input stage and a common source output stage.

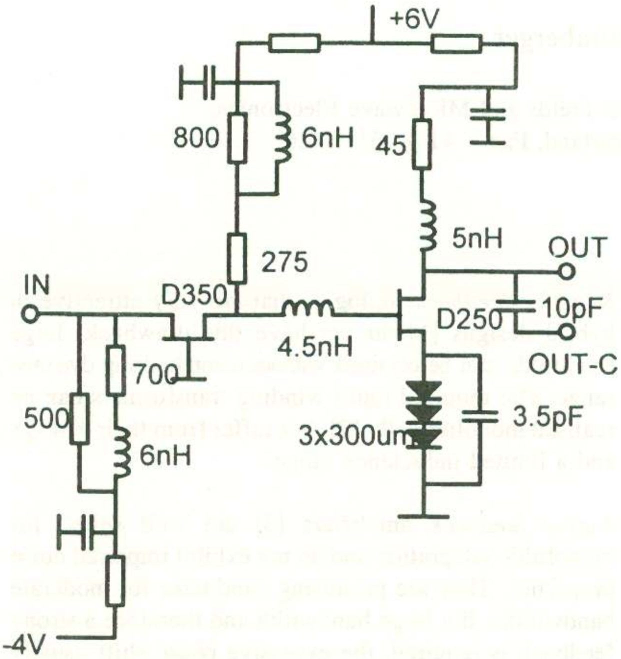

Fig. 1: Schematic diagram of the broadband low-noise amplifier

With the combined resistive/reactive loads the noise contribution of the resistors at frequencies above 2 GHz is minimised. The width of the input FET in a common gate active match stage is usually chosen so that $Z_{in} = 1/g_m = 50\ \Omega$. In this amplifier a compromise between optimum noise performance and optimum matching to $50\ \Omega$ has been made (w = 350µm). The capacitor across the level shifting diodes in the second stage helps to keep the high frequency gain at the same level as the low frequency gain.

The low frequency response is only limited by the input and output coupling capacitors because the two FETs are DC coupled. A 10 pF coupling capacitor has been integrated at the output, allowing for direct cascading of chips without external components (visible in the upper right corner of the chip, see the layout in Fig. 2)

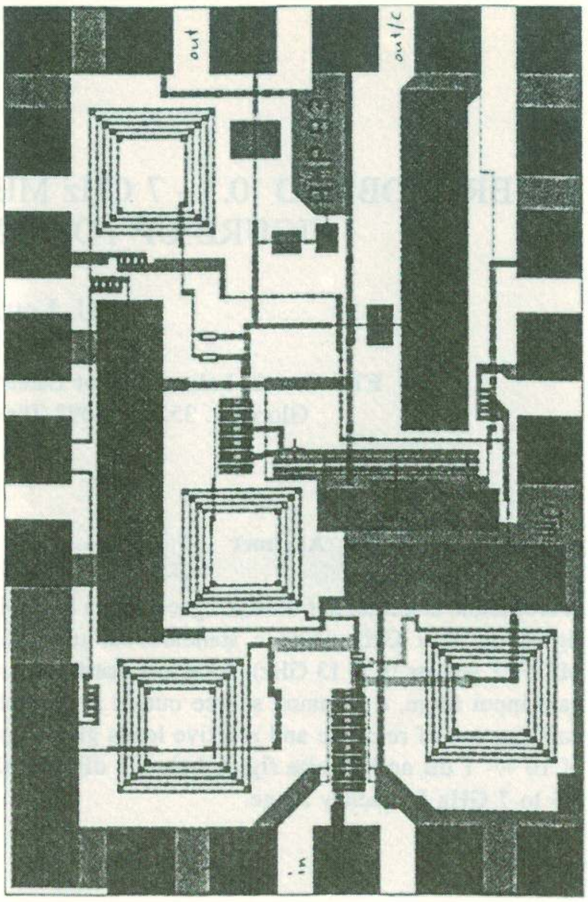

Fig. 2: Layout plot (actual size 0.9mm x 1.35 mm)

A second output can be used for applications down to DC or together with larger off-chip coupling capacitors. The length of the bond wires has also been taken into account in the simulation (approximated by L_B = 1 nH/mm).

Measured results

The circuit has been fabricated using a commercial enhancement/depletion process (Triquint QED/A) with 0.8 µm gate length MESFETs. At V_{GS} = 0V ($I_D = I_{Dss}$) the depletion FETs have an f_T of about 13 GHz and a minimum noise figure F_{min} of 0.9 dB at 2 GHz and 2 dB at 8 GHz. The overall die size is 1 x 1.5 mm (Fig. 3).

The gain of a single chip is 10+/-1.5 dB with a noise figure of 4.5+/-0.5 dB. The input and output reflection coefficients are less than 0.5. Thus, the noise penalty of the broadband circuit compared to the F_{min} of the FET is only about 2 dB at 7 GHz. This result validates the design approach used for this amplifier even compared to designs using the very advanced PHEMT technology [9]. The results also compare favorably with results of a broadband active match amplifier published recently [10]. The total DC power consumption (2 chips) from the +6V and -4V supplies is 470mW.

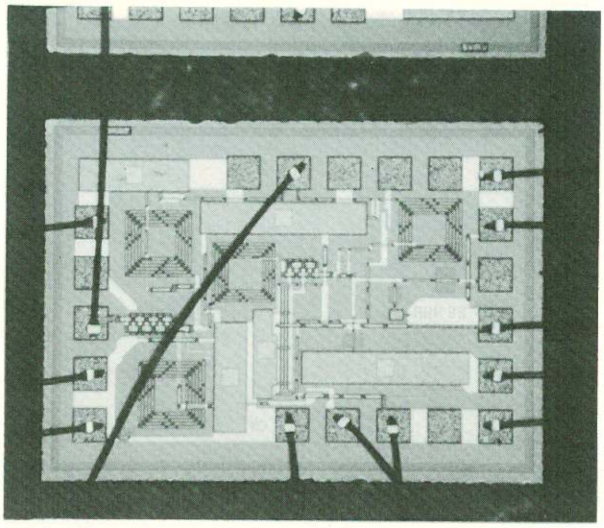

Fig. 3: Photograph of one chip bonded into the package (second of two cascaded chips)

Fig. 4 shows the measured gain and noise of two cascaded chips mounted in a standard ceramic package (Triquint MLC20/8L). The measured noise figure includes the loss of the package and the test fixture (ETF 9000). The estimated fixture loss is less than 0.5 dB per side [8] at 7 GHz.

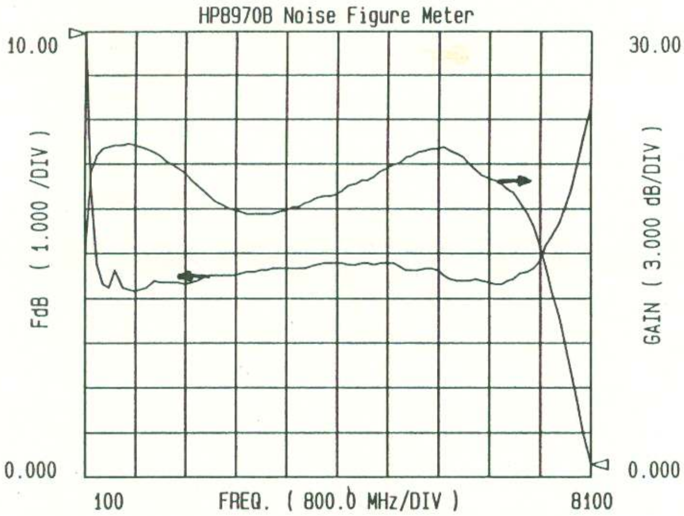

Fig. 4: Measured noise and gain of two cascaded chips from 0.1 to 8.1 GHz

A gain of 20+/-3 dB and a noise figure below 5 dB over the frequency range of 300 MHz to 7 GHz have been measured on the HP 8970B noise figure meter.

Conclusions

An active match broadband amplifier with a bandwidth up to 7 GHz fabricated using a commercial MESFET process has been presented. A combination of reactive and resistive loads provides a low noise figure up to $f_T/2$ of the MESFET. The noise figure of one amplifier chip is 4.5+/-0.5 dB with a gain of 10+/-1.5 dB. On chip coupling capacitors facilitate the direct cascading of chips, yielding broadband performance from 0.3 to 7 GHz with 10 dB gain per stage. Possible applications include preamplifiers in broadband instrumentation and optical communications as well as microwave links.

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