# On the stability of MMIC's using transistors with inductive source feedback

F.E. van Vliet, A. de Boer

TNO Physics and Electronics Laboratory,
P.O. Box 96864, 2509 JG The Hague, The Netherlands,
Email: vanvliet@fel.tno.nl

*Abstract* — **This paper describes potential stability problems occurring in transistor stages with inductive source feedback. These problems occur at very high frequencies, where modelling of passive components is far from trivial. Due to the increase in maximum operating frequency of submicron pHEMT transistors, this problem is recently attracting attention. After comprehensively showing the problem, a simulation strategy is suggested for a timely recognition of the problem. The effectiveness is proven for an MMIC example.**

*Index Terms* — **MMIC's, LNA's, pHEMT, integrated circuits, stability analysis.**

## 1. Introduction

Microwave low-noise amplifiers (LNA's) are increasingly relying on the use of III-V pHEMT devices with shorter and shorter gatelengths. The performance of these devices is ever increasing, with lower noise figures and higher $f_T$'s and $f_{max}$'s for successive process generations. This allows for operation at higher frequencies, but also allows devices at lower frequencies to benefit from the noise figure advantage. In the latter case, the devices operate far below their maximum frequency of oscillation, and extra care must be taken.

## 2. Problem

For the class of amplifiers described, the LNA design uses a device that has excessive gain as compared to devices with longer gatelengths.

This elevated gain level introduces a reduced sensitivity for noise introduced in later stages, but does involve a larger risk of instabilities.

Series feedback, often referred to as source feedback for unipolar devices, is commonly applied as it can be used to move the optimum input impedance to a desired value. In particular inductive source feedback is often found, since the input impedance for optimum matching and the input impedance for highest gain may move closer together. Further, a lossless series feedback leaves the minimum noise figure unchanged.

Using devices at a much lower fraction of the $f_{max}$ indicates that the stability of the devices must be checked up to much higher frequencies. This would have been a trivial remark except for the frequencies concerned. For 0.15 μm pHEMT processes, the $f_{max}$ may be well above 100 GHz. The general methodology adopted for Microwave Monolithic Integrated Circuit (MMIC) design includes the use of common-source transistor modelled data combined with passive element models and planar EM simulations. Actually, all these three elements generally do not satisfy the accuracy requirements up to the maximum oscillation frequency of the transistor.

As a result, the transistor may encounter unexpected impedances at frequencies well exceeding the frequency for which the design was made. This may express itself in unexpected S-parameters or as unexpected stability problems. Potentially, the stability problems can occur up to the $f_{max}$ of the transistor used. As it is virtually impossible to model everything correctly up to $f_{max,}$, the only solution is to ensure the unconditional stability for these frequencies, and accept possible deviations in the scattering parameters as they will generally not affect the system performance.

## 3. Example

As an illustration to the problem, consider the first stage of an X-Band LNA. This first stage consists of a 0.25 μm pHEMT common-source transistor with inductive source feedback. A photograph of this stage is shown in figure 1.

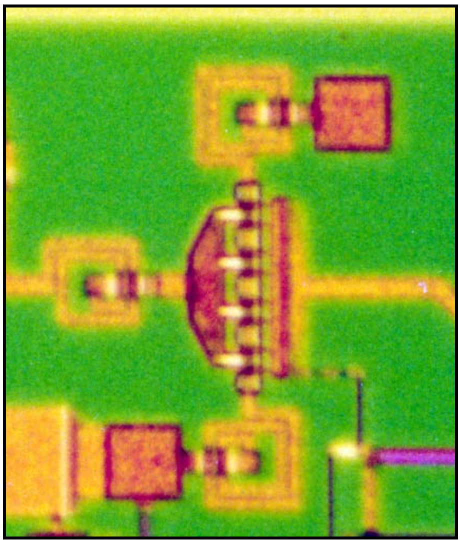

*Figure 1: First stage of an X-Band LNA. The input and output are on the right and left side, respectively. Source inductors are shown on top and bottom of the picture, corresponding to both grounded source contacts. The darker squares top right and bottom left are via holes, connecting the sources to the ground plane. Both source inductances are 0.44 nH in value.*

Upon measurement of the device, minor deviations of the $S_{11}$ were noticed, but for all the rest the amplifier was working correctly. Measurements were performed up to 50 GHz with both a network and a spectrum analyzer.
Surprising results were only noted when the noise figure was measured, which was far worse than the 2 dB that was expected.
After elaborate investigations, no modelling errors or process deviations were observed, and the only remaining possibility was an oscillation outside our measurement frequency range, below the spectrum analyser noise floor, or masked by the encapsulating circuitry.
With unconventional simulation methods, details to be found in the next section, we were able to show that this was indeed a valid possibility and a redesign on the source feedback was performed. The result complied fully with the noise performance expected and is shown in Figure 2.

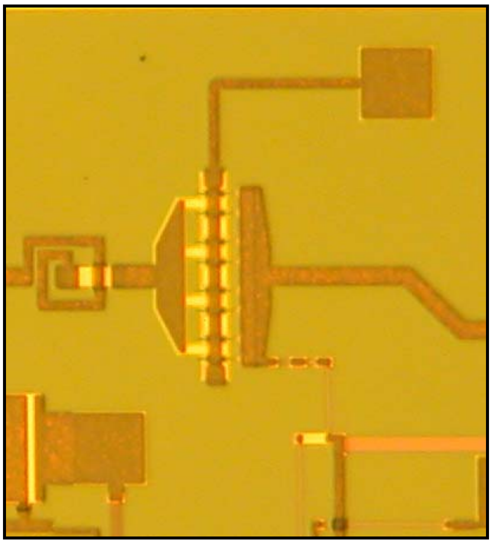

*Figure 2: First stage of the updated LNA. Notice a single-sided source inductance, which was here laid out as a microstrip line. Photographs are made with different camera set-ups.*

## 4. Simulation approach and Solution

The simulation of such LNA input stages is generally performed based on a compact model or on measured S-parameter data for the transistor used.
For the 8-finger transistor used in the example, the input and output stability circles are shown below [1].

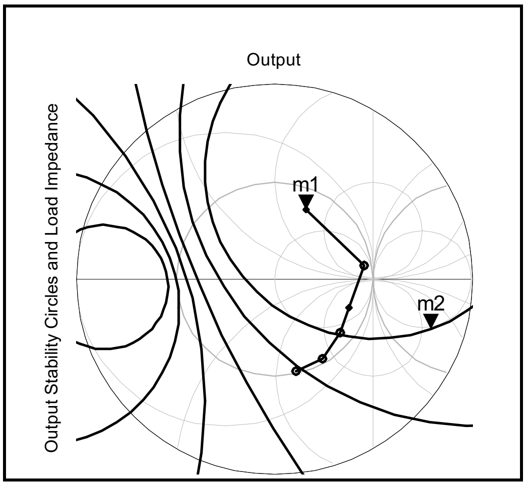


*Figure 3 Output stability circles simulated using a compact transistor model. Stability circles are shown from 50 to 100 GHz, with 10 GHz step size. Markers m1 and m2 indicate 50 GHz. As can be clearly seen, the device should be unconditionally stable.*

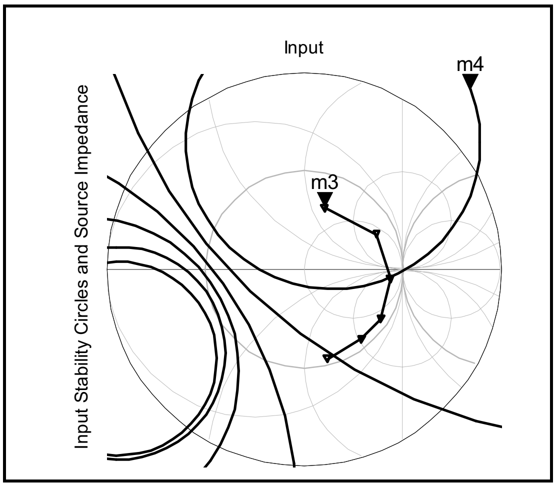


*Figure 4: Input stability circles simulated using a compact transistor model. Stability circles are shown from 50 to 100 GHz, with 10 GHz step size. Markers m3 and m4 indicate 50 GHz. As can be clearly seen, the device should be unconditionally stable.*

Any instability occurring inside this transistor can however not be simulated. In order to take effects inside the transistor into account, the first thing necessary is to split the transistor in fingers. The simplified equivalent circuit is shown in Figure 5. The equivalent circuit shows four parallel transistors, whereas eight were used for the real simulations, as an 8-finger transistor was employed.

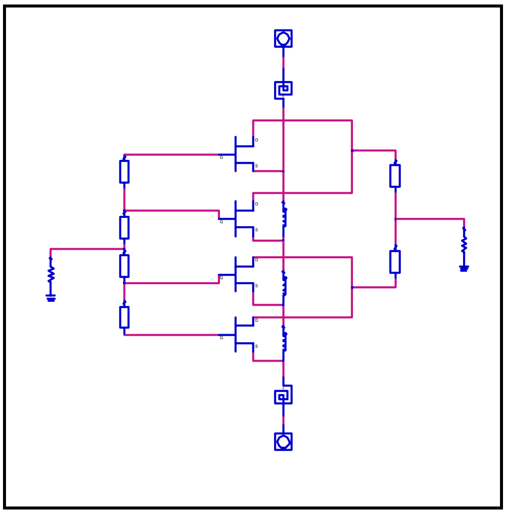

*Figure 5: Equivalent circuit for the active device. Segments of the transistor are interconnected at gate and drain with transmission lines. The sources of the transistor segments are mutually connected with inductances. The resistors shown at in- and output model the port impedances.*

By doing so, odd-mode type of oscillations can be found by observing the open-loop gain for loops inside the transistor [2].
Potential instabilities were instantly recognised by observing the open-loop gain, as is shown in Figure 6.

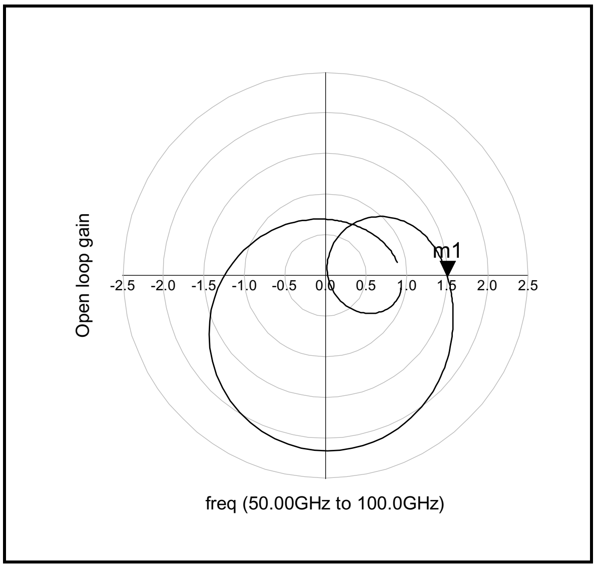


*Figure 6: Open-loop gain between 50 and 100 GHz for one of the loops. The 1 is enclosed and the real axis is crossed at approximately 75 GHz (marker m1). Potential instabilities for the equivalent circuit are hence proven.*

This simulation method holds for a number of instability problems, including intrinsic technology problems.

For the particular example presented before, a further analysis indicated that mainly the parasitic capacitances associated with the source of the gate fingers and the source feedback inductors were problematic.
Effectively, a 0.22 nH source inductor was formed by two parallel 0.44 nH inductors. As a single 0.22 nH inductor has fewer parasitics, one of the source inductors was removed.
In general, the asymmetry would be thought to stimulate odd modes, but in this case, the stability of the transistor was greatly enhanced. To further increase the safety margin, the inductor was laid out as a microstrip line, see Figure 2. The resulting open-loop gain is shown in Figure 7.

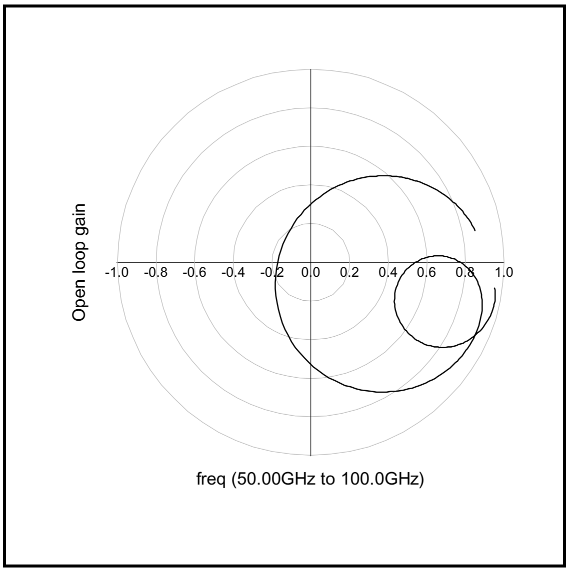


*Figure 7: Open-loop gain between 50 and 100 GHz after correction for one of the loops. The 1 is not enclosed no potential instabilities are indicated.*

The measures clearly show to be effective, this was confirmed by the measurements on the MMIC's themselves later.

A final remark regarding the number of fingers should be made. Normally, the first stage transistor gate width is determined by the combination of bias point for lowest noise performance and required 1-dB compression point. The number of fingers is then maximised to minimise the contribution of the gate resistance to the noise figure.

It is this latter step, which gives a relatively small benefit in the minimum noise performance, that significantly increases the risk on oscillations. The source-to-source inductances introduced in Figure 5 increase in absolute value and increase the imbalance.

## 5. Conclusion

In conclusion, it has been shown that great care is required when applying source feedback to modern submicron technology transistors for LNA's. As these transistors still provide gain at frequencies where the accuracy of passive components is clearly insufficient to provide accurate load values, the device must be unconditionally stable at these frequencies. Ensuring this for transistors with source feedback forces the designer to segment a multi-finger transistor model. The necessity of open-loop analysis for the segmented transistor model was clearly demonstrated.

## References

[1] J. M. Rollett, "Stability and Power-Gain Invariants of Linear Twoports,", *IRE Transactions on Circuit Theory*, March 1962.

[2] ] M.Ohtomo, "Stability Analysis and Numerical Simulation of Multidevice Amplifiers, " IEEE Transactions on MTT, June/July 1993, vol. 41, pp. 983-991.