Feedback for Multiband Stabilization of CS and CG MESFET Transistors

H. F. Hammad, A. P. Freundorfer, *Member, IEEE*, and Y. M. M. Antar, *Fellow, IEEE*

***Abstract*—A new feedback scheme is used to achieve multiband unconditional stability in common source (CS) and common gate (CG) GaAs MESFET configurations. This technique extends the range of operation of both CG and CS beyond what is currently available. Results based on analytical formulations together with a description of the feedback design procedures are provided. Several CS and CG stabilized transistors were monolithically fabricated and tested.**

***Index Terms*—Feedback, MESFET, stabilization.**

I. Introduction

TRANSISTOR stability is one of the most important issues in amplifier design [1]. Generally, the transistor is designed to be stable for a given load impedance and for a given frequency band. However, this is only valid if the load impedance is well defined at all frequency bands from dc until cutoff. Consequently, if the load impedance (e.g., antennas) is not completely defined at frequencies other than the operating frequency, the transistor could be pushed into instability, and power will be lost in oscillations at other frequencies. Accordingly, when dealing with similar type of load, care must be taken to ensure that the transistor is unconditionally stable over all the needed frequency band. In previous work [1]–[5], stabilization techniques were concerned with unconditional stabilization over narrow frequency range. The commonly employed series or shunt resistive stabilization networks are valid only for pushing the transistor slightly into unconditional stability over a small frequency range [1], [5]. Their use to stabilize the transistor over a large band will result in no achievable gains. On the other hand, resistive-inductive feedback networks [2]–[4] were used either to "neutralize" the transistor, achieve broadband flat gain, or to stabilize the transistor in a specific frequency range, mainly for frequencies below 18 GHz.

A new, effective, and simpler approach, based on the use of a resistive inductive feedback network, to achieve unconditional stabilization of the transistor over a wide frequency band (dc until 40 GHz) is presented. Using the transistor model parameters, an accurate analytical formulation of the frequency behavior of the stability parameters is derived. The formulation was validated by the measured S-parameters of the transistors. A procedure to estimate the exact feedback network parameters needed to achieve the wide band unconditional stability, while maintaining the highest maximum available gain is developed. This could help in reducing the cost of fabrication trails. Furthermore, the technique will be applied to both the common source and the rarely employed common gate. Generally, common gate configuration offers higher gains than common source configurations at high frequencies (K_a-band); however, it is usually avoided, as it is unstable over all frequencies, forcing it to be very challenging to match. Consequently, the stabilization technique developed in here was applied to both configurations achieving gains over 3.5 dB at 30 GHz, which are typical gain values for the type of transistor used in the implementation. Higher gains could be achieved by cascading several cells of the stabilized transistors. A description of the approach and results are provided.

II. Transistor Stability Analysis

When dealing with transistor stability usually two parameters [1] are defined, the stability factor K and the stability measure $B1$. These parameters determine the transistor stability state of being either "unconditionally stable ($K > 1$ & $B1 > 0$)," "conditionally stable ($K < 1$ & $B1 > 0$)," or "unstable ($K < 1$ $B1 < 0$)." Both K and $B1$ are normally defined in terms of the transistor S-parameters and not the transistor model elements; accordingly, such representation does not give a direct indication of the effects of the transistor model elements on the stability performance. Hence, to evaluate the stability parameters in term of the transistor model first the S-parameters are converted to the admittance Y-parameters, yielding new relations for both K and $B1$ given by

$$K = (2\mathrm{Re}(Y_{11})\mathrm{Re}(Y_{22}) - \mathrm{Re}(Y_{12}Y_{21}))/|Y_{12}||Y_{21}| > 1 \quad (1)$$

$$B1 = \mathrm{Re}(Y_{22})(G_o^2 + |Y_{11}|^2) - \mathrm{Re}(Y_{11}\overline{Y}_{12}\overline{Y}_{21}) > 0. \quad (2)$$

The Y-parameters in this case are calculated using the MESFET simplified lumped-element model, as defined in [1]. The lumped model elements values were obtained by curve fitting the Y-parameters derived from the lumped element model to the Y-parameters obtained using the measured S-parameters. Hence, substituting the resulting Y-matrix in terms of the transistor elements in (1) and (2) yield accurate relations for K and $B1$ that are functions of the model elements over the wide frequency range considered. Both the CS and CG configurations were considered, and the results are plotted in Fig. 1 for K and $B1$ calculated using the measured S-parameters. The above relations are used to obtain analytical expressions for K and $B1$ in terms of frequency. Such expressions, which

Manuscript received July 6, 2001; revised January 8, 2002. The review of this letter was arranged by Editor Dr. Samir El-Ghazaly.

H. F. Hammad and A. P. Freundorfer are with the Department of Electrical and Computer Engineering, Queen's University, Kingston, ON, Canada (e-mail: hammadh@ee.queensu.ca; freund@post.queensu.ca).

Y. M. M. Antar is with the Department of Electrical and Computer Engineering, Royal Military College of Canada, Kingston, ON, Canada (e-mail: antar-y@rmc.ca).

Publisher Item Identifier S 1531-1309(02)03964-8.

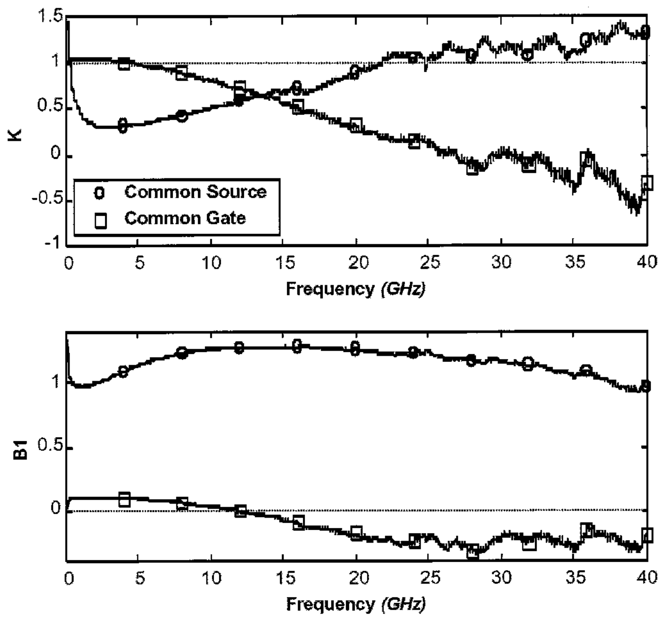

Fig. 1. Measured K and $B1$ for the CS and CG transistor configurations.

give direct indication to how the transistor parameters affect the stability conditions over the frequency range, are given in the next section for both the CS and CG configuration.

III. Common Source

For the CS, the obtained $B1$ relation is found to be always positive, or, in other words, the $B1$ stability condition is always satisfied for any frequency value. In contrast, using the expression for K yields the following relation:

$$\omega > 1 \Big/ \left(T + \frac{2r_g(C_{gs}+C_{gd})^2}{r_{ds}C_{gd}g_{mo}} \right) \tag{3}$$

where ω is the frequency of operation, T is the channel delay time, and the other parameters are as defined in [1]. Equation (3) determines the frequency above which the transistor will become unconditionally stable. For the transistor under consideration, this transition value between unconditional stability and conditional stability is at the measured frequency of 21.5 GHz [compared to a calculated value of 23.4 GHz using (3)]. Equation (3) also illustrates that the range of unconditional stability can be increased by trying to modify the effective values of the transistor parameters. This can be done by lowering the effective C_{gd} value, increasing the effective r_g (commonly known as resistive series stabilization), or lowering the effective value of r_{ds} (commonly known as resistive shunt stabilization). However, the last two methods are valid only for stabilizing the transistor over a very narrow band and their use to stabilize the transistor over a large band will result, as mentioned earlier, in very low or no achievable gains. Hence, lowering the effective C_{gd} by adding an inductance in parallel to it offers the best solution; however, large resistance should be added in series with the inductance to avoid shorting the transistor input/output ports. Hence, the approach provided here, basically using a series combination of a resistive inductive feedback network, would provide the best stabilization performance. The corresponding CPW-based implementation technique employed is shown in Fig. 2. It should be noted that, while a capacitor could be added to the resistive inductive feedback as a dc block [5], this will not allow the all-band unconditional stability, which is the main aim of this work.

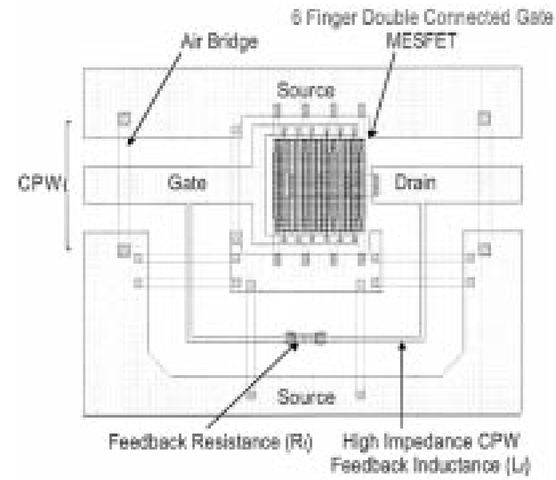

Fig. 2. CPW monolithic implementation of the feedback-stabilizing network.

IV. Common Gate

For the CG configuration, it was found that the expression for K does not satisfy the stability condition at any frequency. On the other hand, the following relation was deduced from the $B1$ expression as shown in (4) at the bottom of the page. Equation (4) demonstrates that beyond a certain frequency value the transistor moves from being "conditionally stable" to being "unstable." For the considered transistor, the transition frequency was measured to be 13.6 GHz [same value as obtained from calculations using (4)].

V. Unconditional Stability Feedback Network Design

A. The Common Source

To examine the effect of the proposed feedback network, its admittance $(Y_f = 1/(R_f + j\omega L_f))$ is incorporated with the transistor Y-parameters, and the values of R_f and L_f that satisfy the unconditional stability were calculated using an approach similar to that in Section II. Fig. 3 shows the value of R_f needed for all-band unconditional stability, and the value of maximum stable gain $G_{\max}$ obtainable, for different values of L_f at 30 GHz. Generally, the higher the value of L_f, the

$$\omega < G_o \Big/ \sqrt{C_{sg}((r_{sd}C_{sd}+T)g_{mo}-C_{sg}) - r_g(C_{dg}+C_{sg})^2((G_o^2 r_g + g_{mo}) + 1/r_{sd})} \tag{4}$$

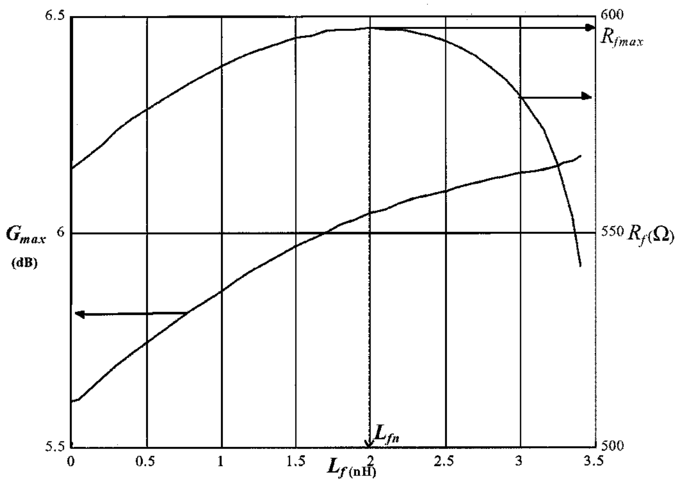

Fig. 3. R_f and $G_{\max}$ for different values of L_f needed for all-band unconditional stability at 30 GHz.

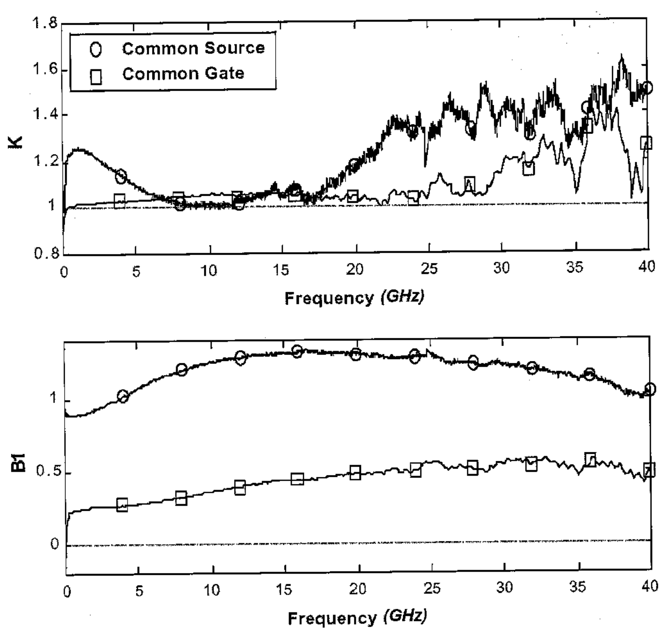

Fig. 4. K and $B1$ values for all-band unconditional stabilized CS and CG transistor configurations.

higher R_f that will be required to reach the unconditional stability boundaries, and, accordingly, the higher will be the obtainable $G_{\max}(|S_{21}|/|S_{12}|)$. However, further increase in L_f value beyond L_{fn}, the value corresponding to $R_{f\max}$ needed for unconditional stability decreases until a point is reached beyond which no stabilization is possible. Moreover, the results demonstrate that the variations in $G_{\max}$ and R_f are insignificant over relatively large inductance range. Consequently, for the lowest dc power dissipation by the feedback network (V_{DG}^2/R_f), feedback should be designed for operation at the maximum value of $R_f(R_{f\max})$. From a practical design point of view, inductors larger than 0.5 nH are bulky and will be difficult to realize, and hence, they are replaced by high impedance coplanar waveguide, as shown in Fig. 2. A different technique for finding the value of R_f was applied to the CG configuration. It provides a check on the accuracy of the previous method; more details can be found in reference [6]. Fig. 4 shows the values of K, and $B1$ with the effect of the chosen feedback stabilization network.

VI. Discussions and Conclusions

For the considered transistor, the feedback networks parameter values were ($L_f = 0.1$ nH and $R_f = 605\ \Omega$), and ($L_f = 0.4$ nH and $R_f = 132\ \Omega$), for the CS and the CG transistor configurations, respectively. Hence, for the CS transistor, more than 80% of the current is fed to the transistor (>40 mA), and only 6.5 mA is used by the feedback network. On the other hand, higher currents are fed to the feedback network in the common gate transistor. However, such feedback stabilization network opens new applications possibilities for the rarely employed common gate configuration. For both configurations measured, unconditional stability from 0 GHz to 40 GHz was obtained with relatively acceptable $G_{\max}$ values at K_a-band (0.5 dB lower than the value before applying the feedback). Hence, the 0.5 dB reduction in $G_{\max}$ is a trade-off between gain and the wideband unconditional stability achieved. The transistor employed is a Nortel Network (NT) process double-connected gate MESFET transistor with six fingers and a total gate width of 300 μm. It has the following process parameters: $V_p = -1.2$ V, $I_{dss} = 120$ A/mm, $f_t = 20$ GHz, and $F_{\min} < 1$ dB up to 5 GHz. Based on this study, two K_a-band MMIC amplifiers were designed, fabricated using coplanar waveguide technology (CPW) [6].

In conclusion, a comprehensive study for unconditionally stabilizing the MESFET transistors was undertaken. Both common source and common gate configurations were considered. The study included an analytical formulation of the stability parameters for both transistor configurations. The use of the transistor model parameters enable the determination of the best feedback network, and, at the same time, achieving the maximum allowable gain. The technique presented here also extends the range of the MESFET transistor beyond its usual operating frequency bands.

References

[1] G. Gonzalez, *Microwave Transistor Amplifiers: Analysis and Design*. Englewood Cliffs, NJ: Prentice Hall, 1997.

[2] F. Perez and V. Ortega, "A graphical method of the design of feedback networks for microwave transistor amplifiers: Theory and applications," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-29, pp. 1019–1027, Oct. 1981.

[3] K. B. Niclas, W. T. Wilser, R. B. Gold, and W. R. Hitchens, "The matched feedback amplifier: Ultrawide-band microwave amplification with GaAs MESFET's," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-28, pp. 285–294, Apr. 1980.

[4] K. B. Niclas and W. T. Wilser, "A 2–12 GHz feedback amplifier on GaAs," *IEEE Trans. Microwave Theory Tech. Symp.*, pp. 356–358, 1981.

[5] I. D. Robertson, *MMIC Design*. New York: IEEE Press, 1995.

[6] H. Hammad, A. P. Freundorfer, and Y. M. M. Antar, "Unconditional stabilization of CS and CG MESFET transistor," in *Eur. Gallium Arsenide and Other Semiconductors Applicat. Symp. (GAAS 2001)*, pp. 295–298.