Letters

Comments on "An Analytical Two-Dimensional Perturbation Method to Model Submicron GaAs MESFET's"

Nirupama Kukreja and R. S. Gupta

Using a two-dimensional perturbation method for GaAs MESFET's, the authors of the above paper [1] conclude that in the perturbed case, there is an increase in channel potential with channel position (along x-axis) by around 70 percent towards the drain end of the channel as compared to unperturbed case. However, their contention is contradicted by the relation in their paper which shows that at $x = 0$ and $x = Lg$, the potential for the perturbed and unperturbed case is the same. Also, the model is valid till the linear regime and not in the saturation regime, as has been pointed out in the following text.

In the above paper [1] Donkor and Jain have developed a two-dimensional analytical model for the potential distribution in submicron GaAs MESFET's by solving the Poisson's equation with non-rectangular boundary conditions using perturbation method. They have used this expression to derive the current-voltage relationship and have pointed out that the model is applicable in the linear, the saturation and the subthreshold regimes. While the overall analysis is rigorous, we have found some serious discrepancies, particularly in the potential expression and the equation governing the current-voltage characteristics of GaAs MESFET. Moreover, it is also found that the model is valid till the linear regime and not in the saturation regime.

The authors have reported that the channel potential is given by

$$\begin{aligned}\Phi(x,y) =& V_{\rm bi} + Vg + qN_d y[2h(x) - y]/(2\epsilon)\\ &+ \Sigma[A_n \sinh((2n+1)\pi x/(2h_s))\\ &+ B_n \sinh((2n+1)\pi(Lg - x)/(2h_s))]\\ &\cdot \sin((2n+1)\pi y/(2h_s))\\ &+ \lambda\Sigma C_n[\sin((2n+1)\pi x/Lg)]\\ &\cdot [\sinh((2n+1)\pi y/Lg)] \qquad (1)\end{aligned}$$

where

$$\begin{aligned}A_n \equiv& 4[V_d - Vbi - Vg - 4qN_d h_s h_d/(\pi^2 \in (2n+1)^2)]/\\ &((2n+1)\pi \sinh((2n+1)\pi L_g/(2h_s))).\end{aligned}$$

$$\begin{aligned}B_n \equiv& -4[V_{\rm bi} + Vg + 4qN_d h_s^2/(\epsilon\pi^2(2n+1)^2)]\\ &((2n+1)\pi \sinh((2n+1)\pi L_g/(2h_s))) \quad \text{and}\end{aligned}$$

$$\begin{aligned}C_n \equiv& 2(A_n - B_n)m_o \sinh((2n+1)\pi L_g/\\ &(2h_s))/(L_g \cosh((2n+1)\pi h_s/L_g)\\ &(1 + 4h_s^2/L_g^2)) -\\ &8(A_n - B_n)m_1 h_s \cosh((2n+1)\pi L_g/(2h_s))\\ &/(L_g \cosh((2n+1)\pi h_s/(L_g))\\ &(1 + 4h_s^2/L_g^2)^2) + 2A_n m_1 \sinh((2n+1)\pi L_g/(2h_s))\\ &/(\cosh((2n+1)\pi h_s/L_g)\\ &(1 + 4h_s^2/L_g^2)^2)\end{aligned}$$

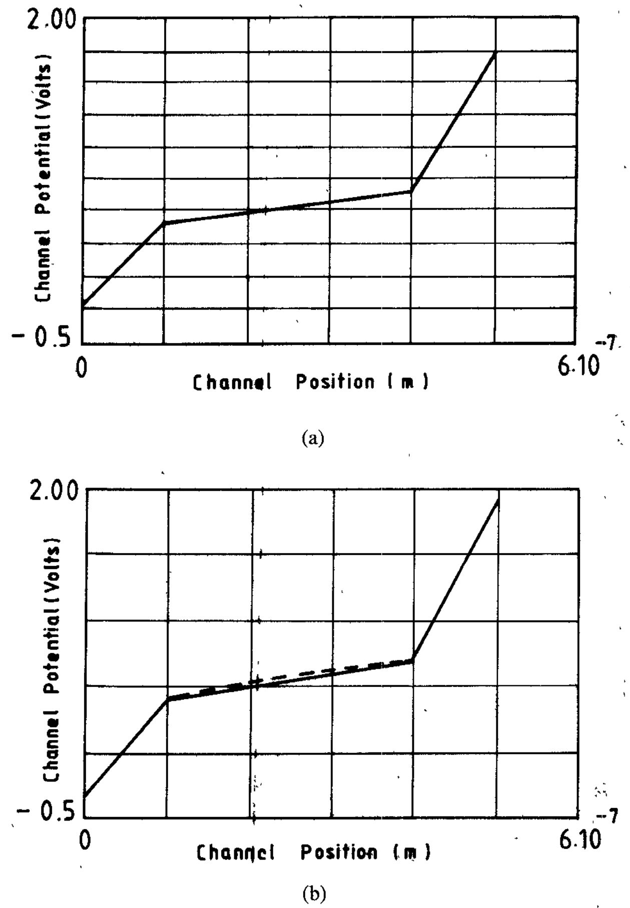

Fig. 1. (a) Variation of channel potential with channel position (without perturbation), [1]. (b) Variation of channel potential with channel position. (——): without perturbation. (— —): with perturbation).

Here, we have solved the Poisson's equation under the same boundary conditions and found that the values of the constants are different from the one's given by the authors. The correct values of the constants are given below:

$$\begin{aligned}A_n \equiv& 4(V_d - V_{\rm bi} - Vg - qNd((-1)^n(h_d - 2h_s)/k + 2/k^2)/(2\epsilon))/\\ &((2n+1)\pi \sinh((2n+1)\pi L_g/(2h_s))),\end{aligned}$$

$$\begin{aligned}B_n \equiv& -4(V_{\rm bi} + Vg + qN_d((-1)^{n+1} h_s/k + 2/k^2)/(2\epsilon))/\\ &((2n+1)\pi \sinh((2n+1)\pi L_g/(2h_s)))\end{aligned}$$

where

$$k = (2n+1)\pi/(2h_s)$$

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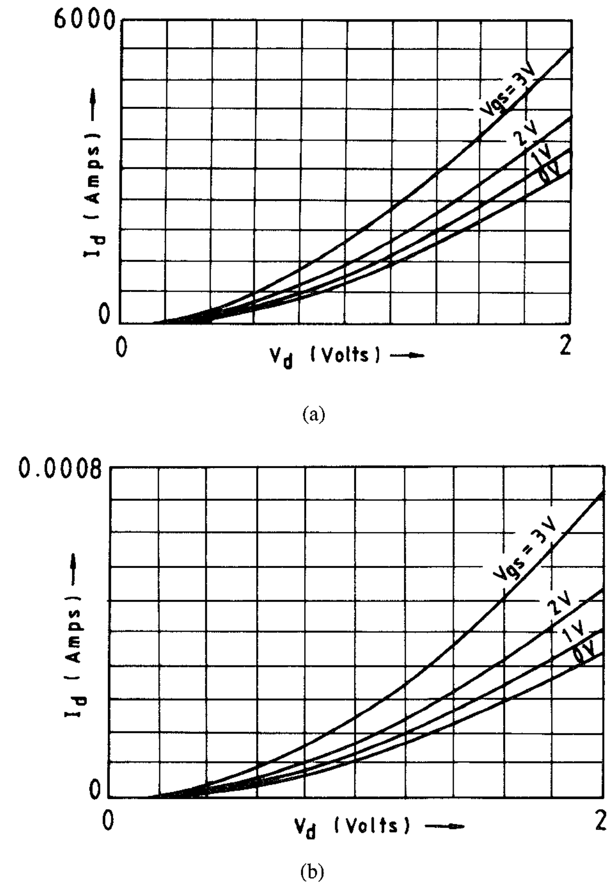

Fig. 2. (a) Variation of drain current with drain voltage, [1]. (b) Variation of drain current with drain voltage.

and

$$C_n \equiv (-1)^n(2n+1)\pi(A_nI_1+B_nI_2)/(2h_s\cosh((2n+1)\pi h_s/L_g))$$

where

$$I_1 \equiv 4h_s^2\sinh((2n+1)\pi L_g/(2h_s))/(L_g(2n+1)\pi(1+4h_s^2/L_g^2))$$

and

$$I_2 \equiv -I_1$$

Fig. 1(a) shows a plot showing variation of channel potential with channel position for the unperturbed case taking the values of constants as obtained by the authors and Fig. 1(b) shows the same for perturbed and unperturbed cases considering the values of constants obtained by us. It is seen that the graph obtained in Fig. 1(a) is different from the one given in their paper. Moreover, the perturbed case cannot be drawn for the authors' case because they have not mentioned the values of m_o and m_1. The plot of Fig. 1(b) shows that there is a variation in channel potential with channel position only between $x = 0$ and $x = L_g$ (gate length) and at $x = 0$ and $x = Lg$, the perturbed and unperturbed cases coincide which, in fact, approves the potential equation while it is not true with the authors' case. From (1), it can be seen that at $x = 0$ and $x = Lg$, the term containing the perturbation parameter $\lambda(0 < \lambda < 1)$ reduces to zero which implies that the potential for the perturbed and unperturbed cases remains the same.

The authors have made a mistake while calculating the value of field E. The correct equation for E is given below.

$$\begin{aligned}E_{1c_o} &= \Sigma((2n+1)\pi/(2h_s))(A_n\cosh((2n+1)\pi x/(2h_s)) \\ &\quad - B_n\cosh((2n+1)\pi \\ &\quad (Lg-x)/(2h_s))) \\ &\quad + \lambda\Sigma((2n+1)\pi C_n\sinh((2n+1)\pi h_s/Lg) \\ &\quad \cdot\cos((2n+1)\pi x/Lg)/Lg).\end{aligned}$$

Also, the equation showing the $I_d - V_d$ relation in their paper is dimensionally incorrect. The equation obtained by us taking into account all the approximations considered by the authors is given below and is dimensionally correct:

$$\begin{aligned}I_d &\equiv qaN_d\mu_nW/Lg(((V_d+Vg+V_{\rm bi})/Vp)^{.5} \\ &\quad - ((V_g+V_{\rm bi})/Vp)^{.5}) \\ &\quad \cdot\Sigma(-1)^n4Vp/((2n+1)\pi)[V_d/Vp+2(-1)^{n+1}/ \\ &\quad ((2n+1)\pi)((V_{\rm bi}+V_g)/Vp)^{.5} \\ &\quad \cdot[((V_d+V_{\rm bi}+V_g)/Vp)^{.5} - ((V_g+V_{\rm bi})/Vp)^{.5}]]\end{aligned}$$

Fig. 2(a) shows a plot depicting variation of drain current with drain voltage in their case. The range of current is 0–6000 amperes which proves that the equation is dimensionally incorrect thereby giving wrong results. Fig. 2(b) shows the $I_d - V_d$ characteristics, as obtained by our relation where the range of current thus obtained tallies with the one obtained from standard $I_d - V_d$ equation for MESFET's. It is very clear from Fig. 2(b) that the model is valid till the linear regime and not in the saturation regime as has been reported by the authors.

References

[1] E. Donkor and F. C. Jain, "An analytical two-dimensional perturbation method to model submicron GaAs MESFET's," *IEEE Trans. Microwave Theory Tech.*, vol. 37, no. 9, pp. 1484–1487, Sept. 1989.

Reply to "Comments on 'An Analytical Two-Dimensional Perturbation Method To Model Submicron GaAs MESFET's'"

E. Donkor and F. C. Jain

***Abstract*—This paper replies to the suggestions, corrections and comments of Kukreja and Gupta, reported in this issue, on our paper [1]. Their main observation concerns a) constants A_n, B_n and C_n; in that they obtained different expressions from what we reported, b) the dimensionality and range of applicability of the current-voltage relation, c) details about parameters m_o, and m_1.**

I. Parameters m_o, m_1

These two parameters were first used [2] (see also ref. [14] cited in [1]) in order to emphasize the linear approximation we made to the

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depletion-edge boundary (Fig. 1 of ref [1]). The slope of the line is m_1 and m_o represents the y-intercept. These parameters have been defined in terms L_g, h_d and h_s, and are given by

$$m_1 = \frac{h_d - h_s}{L_g} \tag{1}$$

$$m_o = h_s. \tag{2}$$

II. Evaluation of A_n, B_n, C_n

A detailed derivation of the constants, A_n, B_n and C_n has been reported [2]. We have reviewed our procedure for deriving these constants in [2] and feel that our results are correct as stated. However, the procedure followed by Kujreja and Gupta in deriving those constants is not available to us. We are therefore unable to draw conclusion on the accuracy of the results obtained by them

Kukreja and Gupta [3] have however given a plot of channel potential vs channel position in Fig. 1 of their paper. Their plots show three line segments connected together with discontinuities at channel positions 0.1 μm and 0.4 μm. It is not clear how they obtained linear plots since the potential expression (eq. (1) of their paper) shows hyperbolic dependence. Secondly they failed to give reasons for the discontinuities in the plots. We, however, agree that the x-axis of Fig. 2 in our paper should be labelled channel position rather than channel length.

III. I-V Equation

One of the objection raised by Kukreja and Gupta is the dimensionality of our current-voltage relation (eq. (27) of [1] reproduced below for convenience). In this equation "a" is a product term and not the subscript of "W." Thus the current-voltage relation in [1] and [3] should have similar dimensionality:

$$I_D = \frac{qN_D\mu_s W_a}{L_g}\left[\sqrt{\frac{V_D + V_{bi} + V_g}{V_p}} - \sqrt{\frac{V_{bi} + V_g}{V_p}}\right. \cdot \sum_{n=0}^{\infty} \frac{4V_p}{(2n+1)\pi} \cdot \left[\frac{V_D}{V_p} - \frac{2}{\pi^2(2n+1)^2}\sqrt{\frac{V_{bi}+V_g}{V_P}} \cdot \left\{\sqrt{\frac{V_D + V_{bi} + V_g}{V_P}} - \sqrt{\frac{V_{bi} + V_g}{V_P}}\right\}\right]. \tag{3}$$

For simulating the current-voltage characteristics, we used the field dependent mobility relation given in ref. [10] of [1]. For a given drain voltage we determined the value of the electric field at the drain end using eq. (24) of [1]. The corresponding value for the mobility at that field strength was then deduced. By this iterative process we were able to obtained a good agreement in the linear as well as the saturation region of operation.

We would like to correct a typographical error in our paper. In the last term of eq. (24), representing the electric field, in our paper [1], the denominator "$2h_s$" should be "L_g." This follows since eq. (24) was obtained by differentiating the potential expression eq. (19) of our paper. The corrected form of the equation should be:

$$E = \left.\frac{\partial\phi}{\partial x}\right|_{C_0} = \sum_{n=0}^{\infty} \frac{(2n+1)\pi}{2h_s} \cdot \left[A_n \cosh\frac{(2n+1)\pi x}{2h_s} - B_n \cosh\frac{(2n+1)\pi(L_g - x)}{2h_s}\right] + \lambda \sum_{n=0}^{\infty}\left[\frac{(2n+1)\pi C_n}{L_g}\sinh\frac{(2n+1)\pi h_s}{L_g}\cos\frac{\pi(2n+1)x}{L_g}\right]. \tag{4}$$

This error however does not affect the validity of the current equation because the perturbation term in the electric field vanishes after evaluation of the definite integral in eq. (25) of [1].

IV. Conclusion

In conclusion we stand by our expression for the potential distribution and the current-voltage equation as reported. The dimension of the current-voltage relation is correct as reported.

References

[1] E. Donkor and F. C. Jain, "An analytical two-dimensional perturbation method to model submicron GaAs MESFET's," *IEEE Trans. Microwave Theory Tech.*, vol. 37, no. 9, pp. 1484–1487, Sept. 1989.

[2] E. Donkor, "Design and modeling of submicron GaAs FET's," Ph.D. dissertation, University of Connecticut, 1988.

[3] N. Kukreja and R. S. Gupta, "Comments on analytical two-dimensional perturbation method to model submicron GaAs MESFET's," *IEEE Trans. Microwave Theory Tech.*, this issue.