TWO-DIMENSIONAL DISTRIBUTED THEORY FOR A MICROWAVE SCHOTTKY BARRIER FIELD EFFECT TRANSISTOR

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ABSTRACT

A small signal equivalent circuit for a SBFET derived from the basic transport equations is extended to include the effects of finite propagation velocities along the contact metallizations. Resonances are shown to occur in the device y parameters due to distributed effects along these contacts.

INTRODUCTION

In previous work[1] we have, using numerical methods, deduced the static and dynamic properties of a Schottky barrier field effect transistor (SBFET), including distributed effects parallel to the channel. The silicon device with a 1 micron wide gate which we analyzed showed an f_{max} of 42 GHz when fabricated on an insulating substrate and 18 GHz when fabricated on a high resistivity substrate, neglecting the effects of contact metallizations in both cases. These results are in good agreement with experiment.[2] The inherent high frequency performance of such devices suggests that distributed effects perpendicular to the channel may very well play an important role in their operation. For bipolar devices it has been found both experimentally and theoretically that indeed distributed effects are important at microwave frequencies.[3,4] In this paper we describe an analysis of a distributed SBFET that includes both the effects of finite signal velocity along the gate and drain contact structures and in the channel perpendicular to these contacts. Using the results of the analysis, we have carried through the numerical computations to show the distributed character of the performance of the device whose lumped properties were derived in Reference 1. The results of our analysis show the dependence of SBFET performance upon distributed effects and include all parasitics associated with the basic device. We believe that the design information implicit in our analysis is required if the device is to be optimized for use above X band.

THEORETICAL MODEL

The device we propose to analyze is sketched in Figure 1. We consider the structure to be a distributed parameter circuit and extend the results of Murray[5] to include active as well as passive coupling between two transmission lines. An equivalent circuit for the distributed device of length Δz in the z-direction is shown in figure 2. The elements Z_G and Z_D are the series combination of the resistance per unit length of the gate and drain contact structures respectively. The resistances may be obtained from a knowledge of the sheet resistance and width of the contact structures, while the inductances may be obtained by treating the gate and drain lines as coupled microstrip lines using a TEM approximation. The parallel elements, Y_G, Y_{GD}, Y_D and G_m involve the per unit length admittance parameters of the lumped device and the admittances per unit length associated with the contact structure capacitances, gate-to-source, gate-to-drain and drain-to-source. For the specific SBFET which we treat as an example, the active device admittance are obtained from the common-source admittance parameters previously calculated[1] and the resistance, capacitances and inductances are calculated using the known properties of the contact lines.

The differential equations which describe the distributed device are

$$\frac{d^2\overline{V}}{dz^2} = \overline{Z}\ \overline{Y}\ \overline{V} = \overline{\Gamma}_1^{\,2}\ \overline{V} \qquad (1)$$

$$\frac{d^2\overline{I}}{dz^2} = \overline{Y}\ \overline{Z}\ \overline{I} = \overline{\Gamma}_2^{\,2}\ \overline{I} \qquad (2)$$

in which $\overline{I}$ and $\overline{V}$ are the two element column matrices composed of the gate and drain current and voltage, $\overline{Y}$ is the 2 by 2 admittance matrix for the parallel elements in Figure 2 and $\overline{Z}$ is the 2 by 2 impedance matrix of the series elements Z_G and Z_D.

From equations (1) and (2), we see that the propagation matrices $\overline{\Gamma}_1$ and $\overline{\Gamma}_2$ for $\overline{V}$ and $\overline{I}$ are not identical. This is due to the fact that the drain and gate lines are, in general, different and to the fact that active coupling is included by way of g_m in the admittance matrix $\overline{Y}$.

The solutions of the matrix equations (1) and (2) yield the gate and drain voltages and currents at any point on the respective lines. The complex constants of integration are determined from the boundary conditions at each of the four ports. Thus knowing the impedances terminating each of the lines, the ratios of current and voltage are known and from these the constants of integration may be found.

Having obtained $\overline{V}$ and $\overline{I}$, the four port ABCD matrix defined below then fully describes the linear behavior of the device

$$\begin{bmatrix} \overline{V}_i \\ \overline{I}_i \end{bmatrix} = \begin{bmatrix} \overline{A} & \overline{B} \\ \overline{C} & \overline{D} \end{bmatrix} \begin{bmatrix} \overline{V}_o \\ \overline{I}_o \end{bmatrix} \qquad (3)$$

in which $\overline{V}_i$, $\overline{I}_i$, $\overline{V}_o$, $\overline{I}_o$ are the vectors formed from the input and output voltages and currents. The elements of the ABCD matrix are themselves 2 by 2 matrices which have been found in terms of components of the circuit illustrated in figure 2, that is from the admittance parameters of the lumped device and the properties of the gate and drain contact lines. For a specific structure the former can be found as described in Reference 1 and the latter can be found from the properties of the contacts and their environment.

$$\overline{A} = \cosh \overline{\Gamma}_1 \, \ell \qquad (4)$$

$$\overline{B} = \sinh \overline{\Gamma}_1 \, \ell * \overline{Z}_o \qquad (5)$$

$$\overline{C} = \overline{Y}_o * \sinh \overline{\Gamma}_1 \, \ell \qquad (6)$$

$$\overline{D} = \overline{Y}_o * \cosh \overline{\Gamma}_1 \, \ell * \overline{Z}_o \qquad (7)$$

where,

$$\overline{Y}_o = \overline{Z}_o^{-1} = \overline{Z}^{-1} \sqrt{\overline{ZY}} \quad . \qquad (8)$$

Having the elements of the transmission matrix, the performance of the distributed device at any given frequency has been investigated using equation (3). In particular, we can find the two port admittance matrix and the maximum available gain of the distributed device for any particular set of terminations on the remaining two ports.

NUMERICAL RESULTS

The analysis described above has been used to determine the behavior of a specific device of the type sketched in figure 1 and described in detail in (1). Using the admittance parameters derived for the lumped device and the conductive properties of the device, we have calculated the composite two port y parameters and the maximum available gain of this distributed device and have found that for the device studied resonances due to distributed effects occur in the y parameters for a gate length-frequency product of 10^7 meters x Hz. Calculated values for Y_{11}, Y_{21} and the maximum available gain are shown in figures 3-5 for a common source device with a 1 micron wide and 1000 micron long gate fabricated on a high resistivity substrate. In each case the curves are given both with and without the distributed effects in the z direction. The extension of the analysis to other SBFET configurations will be discussed.

REFERENCES

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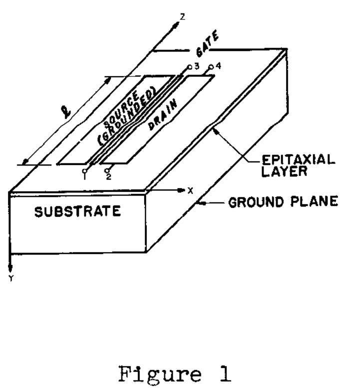

Figure 1

Schottky barrier field effect transistor, SBFET

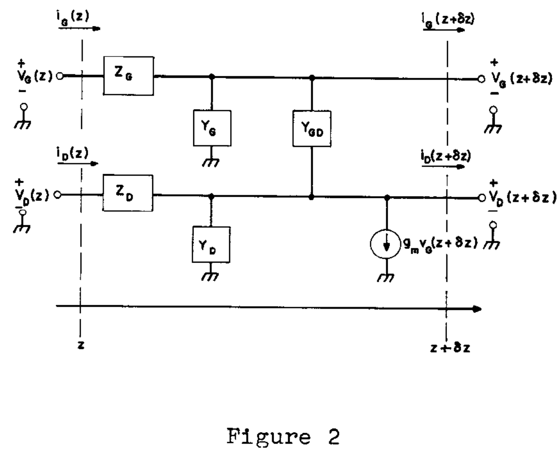

Figure 2

Equivalent circuit for distributed SBFET of length Δz

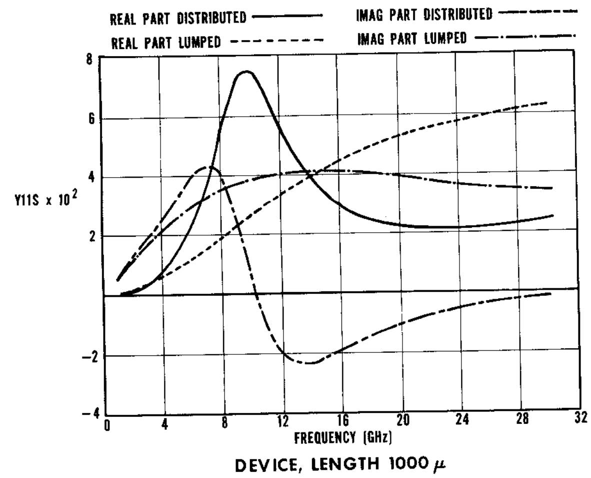

Figure 3

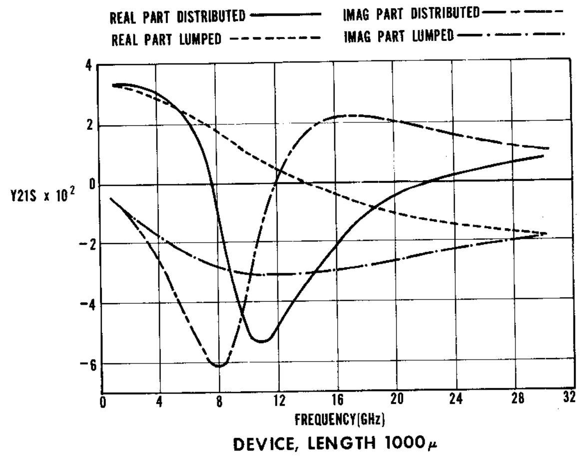

Figure 4

Calculated real and imaginary parts of y_{11} and y_{21} for a common source silicon SBFET with a 1-micron wide gate and a 0.2-micron thick epitaxial layer with an impurity concentration of 10^{17} cm^{-3}. V_{GS}=0 volts and V_{DS}=5 volts. Curves for the distributed device were calculated with ports 2 and 3 open circuited.

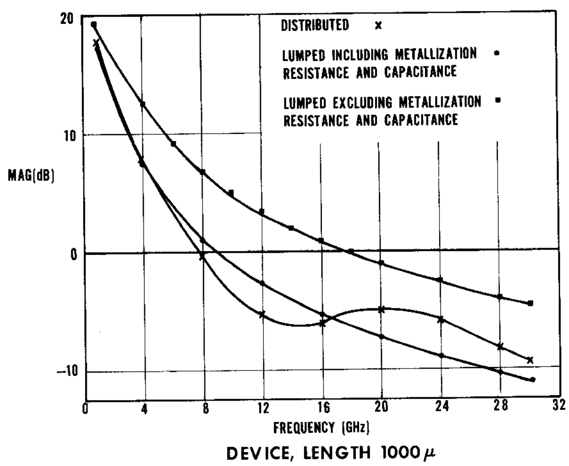

Figure 5

Calculated maximum available gain for a silicon SBFET with a 1-micron wide and 1000-micron long gate and an epitaxial layer thickness of 0.2 micron ($N_D=10^{17}cm^{-3}$). The impurity concentration in the substrate was 1.5×10^{13} cm^{-3}. V_{GS}=0 volts and V_{DS}=5 volts. The curve for the distributed device was calculated with ports 2 and 3 open circuited.