Design and Implementation of Mosfet Model Equations on MATLAB Simulink Library

Nishant Goyal
M.tech Student
BGIET Sangrur,
Punjab,India

Sushil Kakkar
Assistant Professor
BGIET Sangrur,
Punjab,India

Shweta Rani
Associate Professor
BGIET Sangrur,
Punjab,India

ABSTRACT
The Complexity and Simulation time of MOSFET equations are major problems in VLSI applications and these problems should be resolved using different methods which are capable to conquer these limitations. The method of block designing for all the MOSFET equations like current, voltage, capacitance characteristics, flat band capacitance, threshold voltage, oxide capacitance etc., can be a better solution for this problem. This methodology provides a simple procedure for handling complex VLSI circuit, because every parameter present in MOSFET has their individual equation and it may not be an easy task to memorize each equation at all time. Blocks provide an easy and simple way for many operations like scaling, reduction of multipart circuits, error free, and reduction of time. This paper determines the controllability and observability in MATLAB/Simulink, which is an easy way for handling complex MOSFET equations. The methodologies for implementation of different equations of MOSFET that are based on VLSI applications have been designed on the MATLAB Simulink.

Keywords
FET, MOSFET, FINFET

1. INTRODUCTION
The metal oxide semiconductor field-effect or MOSFET transistors are a type of transistor used for amplifying or switching electronic signals. The process for controlling and saving the electric current with the help of transistors is fulfilled by passing the field from semiconductor material which was first invented on 1930 by Lilien-feld and gives the basic concept of MOSFET. The two-terminal devices can be invited at past that can use for describing the current voltage relation between two terminal i.e. The MOSFET applications includes the digital integrated circuits such as microprocessors and memory devices which contains thousands to millions of integrated MOSFET transistors on each device, providing the basic switching functions required to implement logic gates and data storage [1]. The circuit designers need to develop new models for the use of circuit simulation which is further used for accuracy, continuity, scalability and simulation of different MOSFET models performances requirements for each model of MOSFET models [2].This is because of the scaling of the transistor for decrease in circuit size with high performance and advancement in technology with running days.

The MOS structure was formed by several layers of conduction, insulation and transistor formation of material on a single plate and its fabrication step by step structure consist of level that are diffusion, poly-silicon layering, metal layering which are then separated by insulating layers [3].

MATLAB simulink provides a platform for designing of methodologies and for the implementation of different equations of MOSFET that are based on VLSI applications. MOSFET is used mostly as transistor in both digital and analog circuits. The main advantage of a MOSFET over a regular transistor is that it requires very little current to turn on. As identified in VLSI, there are number of different MOSFET models which have their own different kind of priorities with parameters like

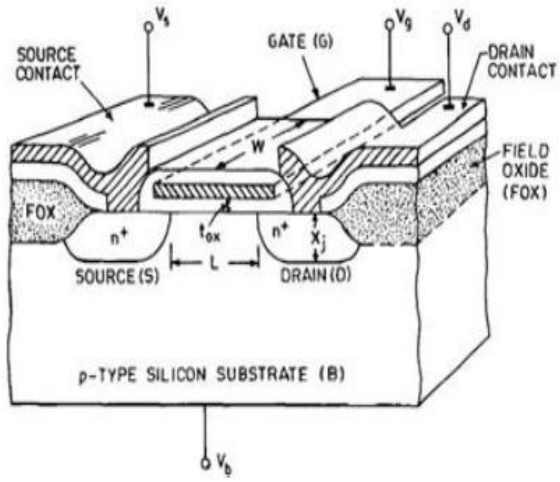

Fig 1: Schematic diagram of MOSFET

potential, oxide capacitance, flat band voltage and other. Similarly for Dual gate and FINFET, drain current equation with compact and impact model, blocks are utilized in MATLAB simulink.

This paper is divided into four sections section I review some relevant studies on the previous work done in this field. In section II the detailed procedure of design and implementation of MOSFET equations in simulink library is elaborated. Finally section III concludes an analysis and implementation of the present work and a comparison has been done with practical results and theoretical results.

1.1 MOSFET design & its various Parameters
MOSFET (metal-oxide semiconductor field-effect transistor) is a special type of field-effect transistor (FET) that works by electronically varying the width of a channel along which charge carriers (electrons and holes) flow. The wider the channel, the better the device conducts. The charge carriers enter the channel at the source and exit via the drain. [4]

Oxide Capacitance The capacitance of oxide per unit area in the MOSFET channel is known to be oxide capacitance [5].

$$C_{ox} = E_{ox}/t_{ox}$$

Threshold Voltage The voltage at which an adequate amount of mobile electrons gather to form a conducting channel in the channel formation region between drain and source is called threshold voltage. Mostly it lies between 0.5v to 1.0v in case of n MOS [6].

Capacitance Voltage Characteristics The MOSFET capacitor is the main point of MOSFET as it is a heart of MOSFET which gives the main information about the MOS device and then obtained the Capacitance Voltage characteristics with the interface of oxide semiconductor. The capacitance of the device can be defined as

$$C = dQ/dK$$

Work function difference Work function can be defined as potential that is required to inject an electron from metal to conduction band of oxide [7].

$$\Phi_{ms} = ['\Phi'_m - \left(\chi' + \frac{Eg}{2e} + \Phi_{fp}\right)]$$

MOSFET capacitance model

In a MOSFET, the capacitive coupling between the gate electrode and the semiconductor is distributed, making the channel act as an RC transmission line. But because of short gate length and limited bandwidth of MOSFET makes the thin capacitance of intrinsic device terminals that are known to be lumped capacitance model, having capacitive elements between various intrinsic terminals [1]

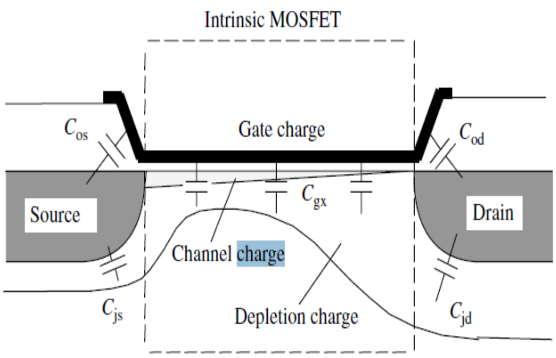

Fig 2: MOSFET model of capacitance [8]

Flat band capacitance
Flat band capacitance is a function of oxide thickness and semiconductor doping. Flat band capacitance is defined as the difference between the accumulator and depletion condition. The capacitance at flat band is given by

$$C'_{fb} = E_{ox}/\{t_{ox} + (E_{ox}/\varepsilon_s)\sqrt{(kT/e)(\varepsilon_s/\varepsilon_0)N_a)}\}$$

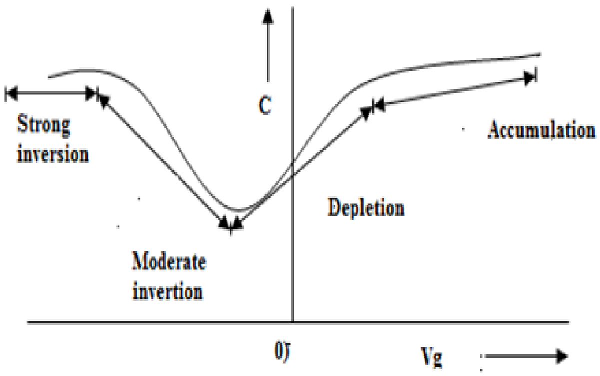

Fig 3: C-V graph for low frequency MOSFET [8]

In [9] Cheng et al. presented the new and creative, physical and continues model for current and voltage for short channel characteristics for circuit simulation and to describe the main non ideal effects of MOSFET. G.Paillongy et al. has done the study of MOSFET with high frequency and noise for down scaling process. Under this work performance of transistor to make accuracy of power and low noise characteristics of MOSFET was done [10]. Adam Milik and Andrzej Pulka has explained the methodology for the implementation of active HDL and MATLAB environment and the testing of circuit. The designed and implemented co-simulation environment was dedicated to testing of model's hardware in mathematical modeling system developed with MATLAB and Simulink [11]. A Siligarie et al. described an empirical nonlinear model which was used to change conservation of charge for MOS transistor and useful for large signal RF circuits [12].

Hariharan et al. represented the work on drain current of dual gate for MOSFET which were symmetric means the gates used here were having the same symmetry between two dependent gate with the light doping of material on that gates [13]. Darko Kirovski et al. has described the method used for new block creation which was based on the complete cut based approach. In this work emphasis was given on, to have advantages of simulation and deigns of new blocks [14]. Niraj K. Jha et al. has designed the BSIM which defines two types of model that were CMG and IMG with a number of gates which can be same or not. The compact and impact models were designed for the simulation of multi-gate by using long channel description of planar MOSFET, and were developed to simulate the dual triple and multi-gate FINFET [15]. Wei wang et al. presented the current voltage characteristics model for double gate MOSFET for continues current equation. Author derived this with the help of Poisson equation and current continuous equation [16].

In [3] Gurinder Pal Singh has determined that controllability and observability in MATLAB/SIMULINK, which was very easy way for handling complex VLSI circuits. As the complexity of VLSI circuits was increasing, calculations for controllability and observability by mathematical formulas was becoming tedious job for each and every gate in a complex circuit, and further if circuit was sequential then additional mathematical calculations for flip flops were required. Balwinder Singh has proposed a new approach for VLSI testing in MATLAB and implemented. In this technique, a user library for simulink by using 2-D logic array block, for D-algorithm and SPODEM is designed. This environment is useful for VLSI testing to make understand the concept of testing to students and can be used as teaching tool [8].

2. PRESENT WORK

In the design and implementation of new system the first step is to handle the complexity level of mathematical equations and utilization of different MOSFET model equations in MATLAB. As it is known that the complex calculations of equations for different parameters are done by using different data sheets for transistor. But the complexity level of transistor increases with increase in number of transistors, thus it has become tedious job to calculate the different parameters for each transistor [8].

Secondly, the aim is to design the system in MATLAB, in order to reduce each parameter calculation for different equations and the utilization of MOSFET equations in block form. In the MATLAB/SIMULINK library, there is an inbuilt block for MOSFET but there is no as such block available which can represent different non ideal and ideal equations of MOSFET for different models like n-MOSFET, p-MOSFET, dual gate and FINFET[17]. So this work involves the designing of blocks for different MOS ideal and non-ideal parametric equations which are used for MOSFET from different models. But the main target is to represent that designed blocks in such a way so that if anyone interested to calculate the result for each parameter can use directly for calculation and these blocks are further targeted to be used for new circuit implementation [18].

Thus, the idea behind the development of MATLAB simulink library for different MOSFET equations and steps required to design that environment is totally dependent upon the mathematical blocks already present in simulink library. After the solution of the above problem, all the blocks will be designed in such a way so that all the internal blocks and relative calculation inside the block will be hidden from the end users and the designed block will be permanently saved in MATLAB simulink library. In second phase the blocks of MOSFET parameters in dual gate and FINFET will be designed in MATLAB simulink by taking a particular circuit as an example. As maximum number of equations of MOSFET are dependent on each other, thus no need to design that parameter block again and again.

The major objective of the proposed work is to handle the complexity level of mathematical equations and implementation of different MOSFET model equations in MATLAB simulink library. The focus is to represent the designed blocks in such a way that if anyone interested to calculate the result for each parameter, can use blocks directly for calculations and these blocks are further targeted to be used for reducing complexity and saving of time.

2.1 Integration of Designed system in simulink Library

- Now user has to save that block permanently in simulink library.
- For the fulfillment of this purpose, the blocks are first convert from the model window to library window with ".lib" then these designed cells are added to "library new model" for designing them as a library and are saved in the MATLAB directory in the single folder named "Mos1" [19].
- By doing so, simulink library is modified and the designed model or system can be used directly.

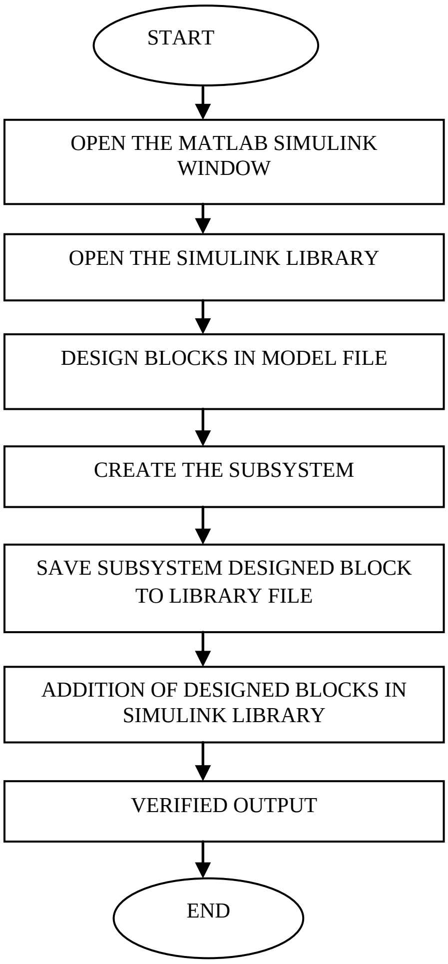

Fig 4: Procedure to make design in simulink library

3. RESULT AND DISCUSSION

The use of complete design for different blocks for the analysis and calculation of different-different parameters is presented here. By following the approach as mentioned above blocks are also added into the simulink library browser [20]. From simulink library user can directly pick the block of equation that are required and directly put the value of input parameters to get the final result of that equation. We can attach a display with the output so that to see the output directly in the display block.

Example can be represented with the simulation result of C_{ox} equation in figure 5 and calculating result of C_{ox} equation rather than to theoretically implement every time. MATLAB SIMULINK gives direct results by applying input to the block.

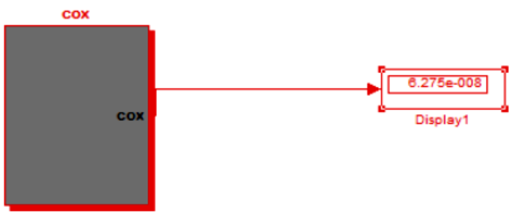

Fig 5: Result of C_{ox} equation

3.1 Current-Voltage Characteristics

The following plot shows the effect of the gate-to-source voltage and the drain-to-source voltage upon the drain current [21]

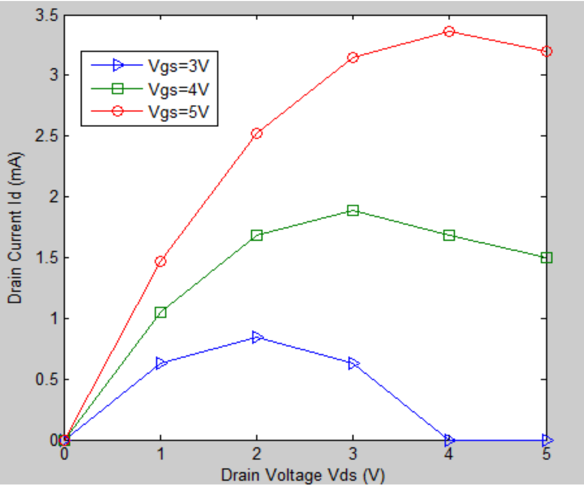

Fig 6: MOSFET Current-Voltage characteristics graph

In this plot I_d varies as a function of V_{ds} , for different values of V_{gs}.

Let $Q_I(y)$ be the total mobile electron charge in the surface inversion layer. This charge can be expressed as a function of the gate-to-source voltage v_{gs} and of the channel voltage V_c (y) as follows: [21]

$$Q_I(y) = -C_{ox}.[V_{gs} - V_c(y) - V_t] \qquad (6.1)$$

The integrated drain current equation along the channel i.e. from y=0 to y=L [21]

$$\int_0^L I_d\, dy = -w\mu_n \int_0^{vds} Q_I(y).dV_c \qquad (6.2)$$

Put the value of $Q_I(y)$ in equation (1)

$$\int_0^L I_d\, dy = C_{ox} w\mu_n \int_0^{vds} (V_{gs} - V_c - V_t)\, dV_c \qquad (6.3)$$

Assuming that the channel voltage V_c is the only variable in equation (3) that depends on the position of y, the drain current is found as follows[21]

$$I_d = \frac{W\mu n\, C_{ox}}{2L}\left[2(V_{gs} - V_t)V_{ds} - V_{ds}{}^2\right] \qquad (6.4)$$

This current equation can also be written as:[21]

$$I_d = \frac{\beta}{2}\left[2(V_{gs} - V_t)V_{ds} - V_{ds}{}^2\right] \qquad (6.5)$$

$$Id = 0.21 mA/V^2 [2(V_{gs} - V)v_{ds} - V_{ds}{}^2] \qquad (6.6)$$

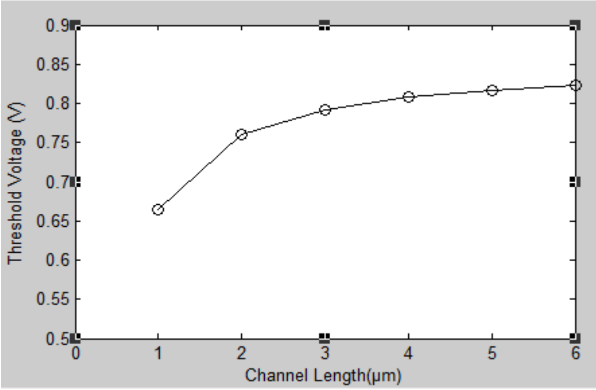

Fig 7: Variation of Threshold Voltage with the Channel Length

3.2 Threshold voltage with channel length

It can be visualized from the graph how the channel length vary with voltage and it clearly justify the MOSFET property.

$$V_{TO} = 0.855\ V - 0.19\ V\ \frac{1}{L[\mu m]} \qquad (6.7)$$

The threshold voltage decreases by as much as 50% for channel length in the submicron range, while it approaches the value of 0.8V for larger channel length.[21]

It can be evaluated from the figure 7 that the threshold voltage rapidly increases with increase in channel length. But in case of the increment in channel length is more then the increment in threshold voltage is slow and less even for maximum.

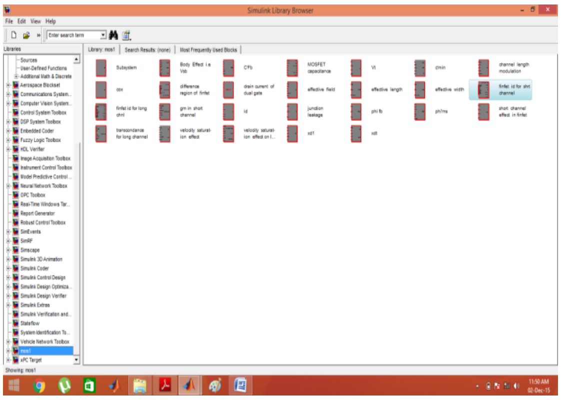

Fig 8: Updated Simulink Library with MOSFET

Using a circuit as shown in figure 9, is taken for verification of the user-designed library. In this the blocks are directly loaded into workspace from simulink browser, in which our newly designed library exists as shown in figure 8.

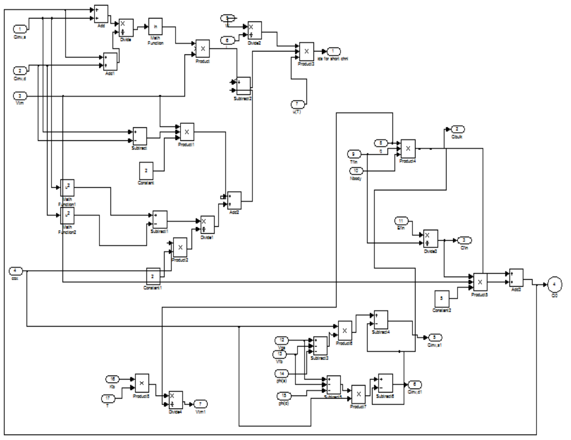

Fig 9: Simulink Block Model of FINFET Drain Current for Short Channel

As shown in above figure by taking FINFET drain current as an example a simulink model is designed for controllability and observability. This model is designed in MATLAB/simulink by using the blocks, add block, min/max block. In similar manner the model for all other parameters are designed.

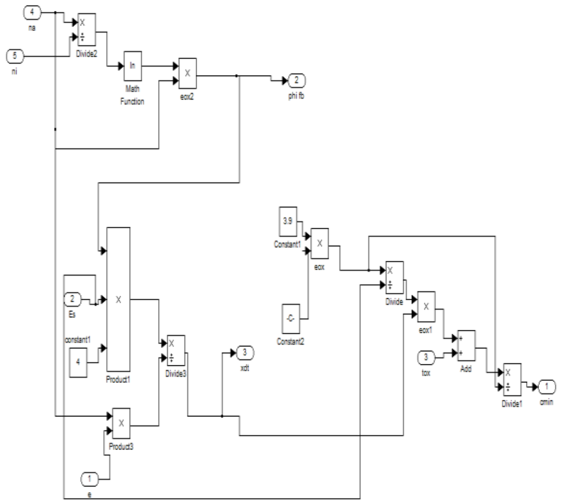

Fig 10: Simulink Block Model of (C'_{min}) C-V Characteristics

4. RESULT FOR DESIGNED BLOCKS:

A number of parameters are involved in these equations and the Values of these parameters equations are given in below table 1.

Table 1. Different Values of Parameters in MOSFET

Sr. No.	Parameter	Values
1	X_{dt}	E_{s}=(11.7)(8.85*10^{-14}) e= 1.6* 10^{-19}V
2	(work function) Φ'_{ms}	Eg =1.11v,e=1.6*10^{-19}v, χ = 3.25 v,Φ'm =3.20
3	(potential equation) Φ_{fb}	n_i=1.5*10^{10}, N_a=10^{10}, V_t=0.0259v
4	(C-V characteristics) $C'min$	2.23*10^{8} f/cm^{-2}
5	(oxide capacitance) C_{ox}	E_{ox}=(3.9)(8.85*10^{14})F and T_{OX}=500*10A
6	(flat band capacitance)$C'fb$	k=Boltzmann constant= 8.6*10^{-5}ev/k and t=300k
7	**(Current Voltage Characteristic)** I_d	μ_n=600cm^2,C_{ox}=7.10^-8F/cm^2, L=2µm, V_t=1.0V, W=20µm, V_{gs}=2.0V

The parameters which are involved in design of MOSFET are displayed in table 1. These values are given to the designed blocks in MATLAB Simulink as input and then the output of the display block is compared with the theoretical results. The results so obtain are approximately equal [7].

Table 2. Comparison between the Theoretical and Practically Calculated Values in Simulink

Sr. No	Para-meters	Applied Equation	Theoretical Result	Practical Result
01	X_{dt}	$x_{DT} = \left(\frac{4\epsilon s\Phi fb}{ena}\right)^{1/2}$	0.30*10^{-14} µm	2.39$e^{-0.12}$ µm
02	Φ'_{ms}	$\Phi'_{ms} = [\Phi'm - \left(\chi' + \frac{Eg}{2e} + \Phi fb\right)]$	0.83*10^{19}V	8.39$e^{=0.18}$V

03	Φ_{fb}	$\Phi_{fb} = V_t \ln\{N_a/n_i\}$	0.347 V	0.34373V
04	$C'min$	$C'min = \frac{E_{ox}}{t_{ox} + (\frac{E_{ox}}{\varepsilon s})xDT}$	$6.95*10^{13}$ f/cm^{-2}	$3.695e^{+0.14}$ f/cm^{-2}
05	C_{ox}	$C_{ox} = E_{ox}/t_{ox}$	$6.28*10^{8}$V	$6.278e^{0.08}$V
06	$C'fb$	$C'_{fb} = E_{ox}/\{t_{ox} + (E_{ox}/\varepsilon_s)\sqrt{(k}$ $\varepsilon_0)N_a)\}$	$5.03*10^{12}$F	$4.853e^{+0.14}$F
07	I_d	$I_d = \frac{W\mu_n C_{ox}}{2L}\left[(V_{gs} - V_t)^2\right]$	$0.021*10^{-10}$A	$2.1e^{-0.12}$A

It has been clearly verified that the practical results are much better than the theoretical [22]. It is clear that level of complexity has been decreased during the calculation of controllability and observability. The reason includes the use custom libraries instead of using the formulas for these parameters that make the calculations easier. The results are shown in tabular form in table 1 and 2.

5. CONCLUSION

In this paper a new technique is described for testing and calculation of different MOSFET equation's for different transistor technologies. By using inbuilt functions and modules of MATLAB/simulink, the different MOSFET equations are designed. So that for further work done on MOSFET, the designed blocks will be helpful for directly getting results of each equation rather than to learn different parameter equation's every time. Here, simulink gave direct results by applying input to parameters at designed blocks. By using the designed library models as represented, the level of calculation and complexity for each MOSFET equation is reduced to large extent. By implementing blocks of different MOSFET equations for different models in simulink library makes the matlab environment more attractive, easy and user friendly by using the designed testing library model based on MOSFET.

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