Unit 5:
Additional Topics

Lecture 5.6:
A Second Look at Compact Circuit Models

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Type 1 Compact Models

In Lecture 1.5, we discussed two types of “compact models.”

1) **Compact physical models**

   These models aim to describe a device in terms of a few parameters with strong physical significance. These kinds of models are useful for device characterization, process monitoring, and for the conceptual understanding that guides device research.

Our focus in this course has been on this type of compact model.

Type 2 Compact Models

2) Compact device models for circuit simulation

These models accurately describe the electrical behavior of a device **in a form suitable for use in numerical circuit simulation programs**. To describe everything relevant to a circuit, these models are more complex and semi-empirical, but the core of the model is usually a compact physics model.

These kinds of compact models interface semiconductor technology to circuit design.

Compact models for circuit simulation

1) **Table based**
   Tables of measured or simulated data. The model then interpolates (smoothly) to describe a device across a range of biases.

2) **Physics based**
   Analytical or simple numerical expressions that describe a device across a range of biases, layout geometries, and temperatures.

Why physics-based?

+ Physics-based model relate the needs of designers to the manufacturing process.

+ Generally results in the fewest number of model parameters and simplifies model calibration.

+ These models provide the best basis for statistical and mismatch modeling.

+ As manufacturing processes evolve, these models can quickly adapt.

- Development time

MVS for circuit simulation

Versions of the MVS model for circuit simulation exist and are useful for technology development.

But the MVS model is not an industry-strength model for digital circuit simulation because it:

- doesn't smoothly go from short to long channels
- doesn't treat a number of second and third order effects
- doesn't treat noise
- doesn't treat layout dependencies
- etc.

Source referenced models

Square Law Model

$$V_{GS} > V_T \qquad V_{DS} < V_{GS} - V_T \qquad I_D = \mu_n C_{ox} \frac{W}{L}\left[\left(V_{GS} - V_T\right)V_{DS} - \frac{V_{DS}^2}{2}\right]$$

$$V_{GS} > V_T \qquad V_{DS} > V_{GS} - V_T \qquad I_D = \mu_n C_{ox} \frac{W}{2L}\left(V_{GS} - V_T\right)^2$$

Problems occur when V_{DS} changes sign.

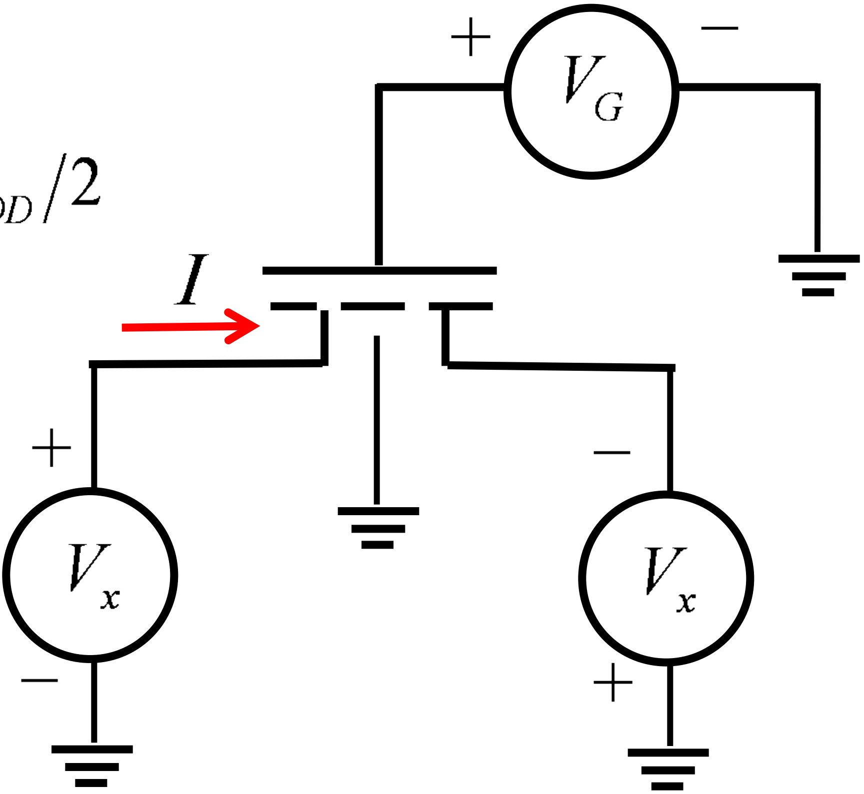
For an early example that is not source referenced, see:

H. Shichman and D.A. Hodges, "Modeling and simulation of insulated gate field-effect transistor switching circuits," *IEEE J. Solid State Circuits*, **SC-3**, 285-289, 1968.

“Gummel symmetry test”

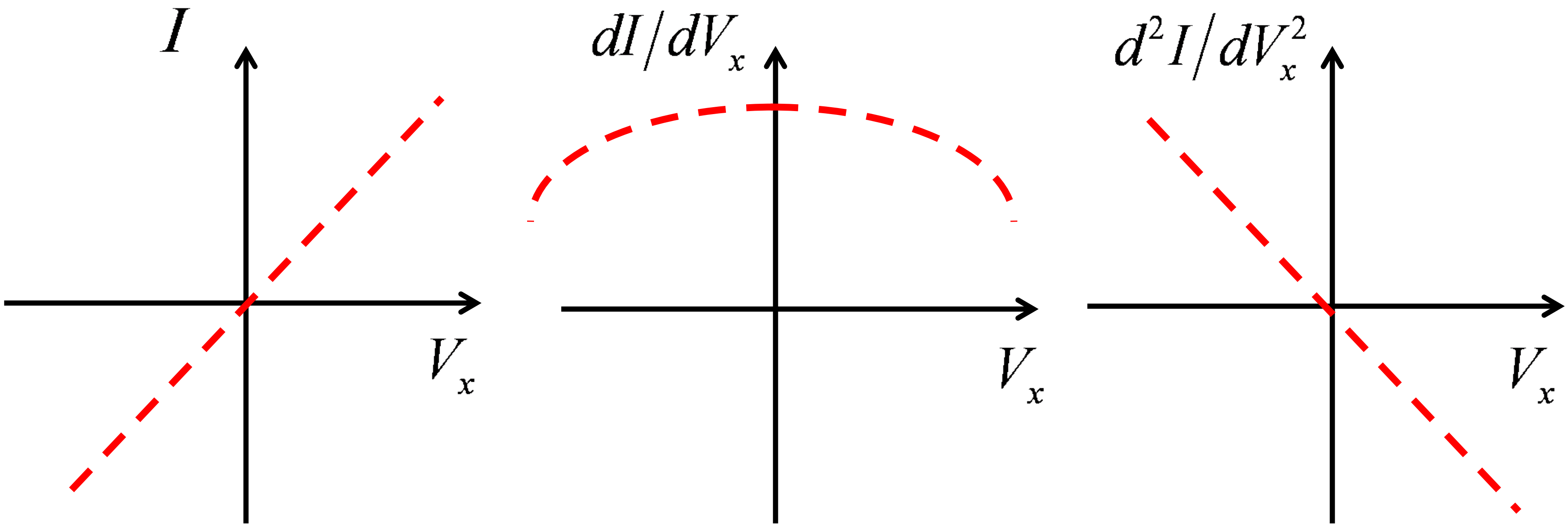
$$-V_{DD}/2 \leq V_x \leq +V_{DD}/2$$

$$V_{DS} = 2V_x$$



Many models had problems near the origin where V_{DS} = 0.

Gummel Symmetry Test



Designers need robust, well-behaved models, but for early stage R&D, simpler models are still useful.

Device research

"The principal applications of any sufficiently new and innovative technology always have been – and will continue to be – applications created by that technology." – Herbert Kroemer, 2001 Noble Lecture

But today, electronics is mature, many devices are available, and materials and device research is more and more driven by applications.

Compact circuit models allow materials and device researchers to explore impact on applications at an early stage.

Finding compact models

Device researchers and developers may be able to locate and suitably modify a model for their purposes. (Some open source models can be found at the **NEEDS** site: needs.nanoHUB.org.)

Designers need industrial strength compact models. The **Compact Model Coalition** provides members with industry-standard models (http://www.si2.org/cmc/)

BSIM: An industry standard MOSFET model

BSIM (Berkeley Short Channel IGFET Model) was first introduced in 1987. Since that time, BSIM has been continually enhanced, updated, and extended and now refers to a family of models. (https://en.wikipedia.org/wiki/BSIM)

BSIM is one of the models selected by the Compact Model Coalition as an industry standard. (http://www.si2.org/cmc/)

BSIM is supported by all commercial circuit simulation platforms.

Writing your own compact model

Verilog-A is an industry standard modeling language for analog systems. It can also be used to write compact circuit models that can be used by all commercial circuit simulators and by some open source simulators.

A good starting point is:

Geoffrey Coram, “Writing Your First Verilog-A Compact Model,” https://nanohub.org/resources/20579

Additional tutorial information is available at: www.needs.nanoHUB.org

Writing your own compact models

MAPP (Model and Algorithm Prototyping Platform) is a MATLAB-based, open-source, environment for developing, testing, experimentally validating compact models and for inserting them in open SPICE-compatible simulation platforms. MAPP is also useful in developing and debugging high-quality Verilog-A compact models.

Additional information and a pointer to the github repository are available at: www.needs.nanoUB.org

Before writing your own compact model

Familiarize yourself with the many lessons learned over the decades in developing compact circuit models for MOSFETs.

Start by searching "Colin C. McAndrew"

Summary

1) Compact circuit models link semiconductor manufacturing and circuit design.

2) Compact circuit models also link device and materials R&D to circuit design and applications.

3) Developing compact circuit models requires a good understanding of the device physics, what goes on inside the circuit simulator, and the intended application.

4) Many of the lessons learned in developing compact circuit models for MOSFETs can be transferred to other devices.

Next topic

We've covered several different topics in Unit 5. In the next lecture, I'll review the main points.