Automotive Discrete Semiconductor MBD Introductory

Description

This document is an application note describing the outline and features of MBD (Model Based Development addressed by Toshiba Devices & Storage Corporation.

Toshiba Electronic Devices & Storage Corporation

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1. Background

1.1. Why MBD are required

In recent years, technological trends called CASE(Connected, Automated/Autonomous, Shared & Service, Electric), shown in Figure. 1.1, have attracted attention as a new trend that is said to be a revolution in the automotive industry once every 100 years. "Connected" refers to IoT(Internet of Things) such as automotives Ethernet and IVI(In-Vehicle Infotainment). "Autonomous" there are technological innovation for automated driving represented by ADAS (Advanced Driving Assistant System). In "Shared", as a next-generation notion called "MaaS"(Mobility as a Service", the vehicle is transformed from the one owned to the new servicing industry. In “Electric”, Electric vehicles equipped with many electronic components, including on-board power semiconductors, are becoming increasingly popular as a solution to the challenges of carbon neutralization.

While there is a technological trends to address environmental issues and enhance automation, convenience, and comfort, the system is becoming large-scale and complex, and huge verification to ensure high levels of safety and reliability is becoming an issue. It is becoming difficult to verify the entire system with limited resources. For example, if a product fails to meet specifications, both the set manufacturer and the parts manufacturer will experience a retreat, leading to an increase in development time and costs. Therefore, In recent years, the automotive industry as a whole has been adopting MBD (Model Based Development) as an efficient development method using models and simulations.

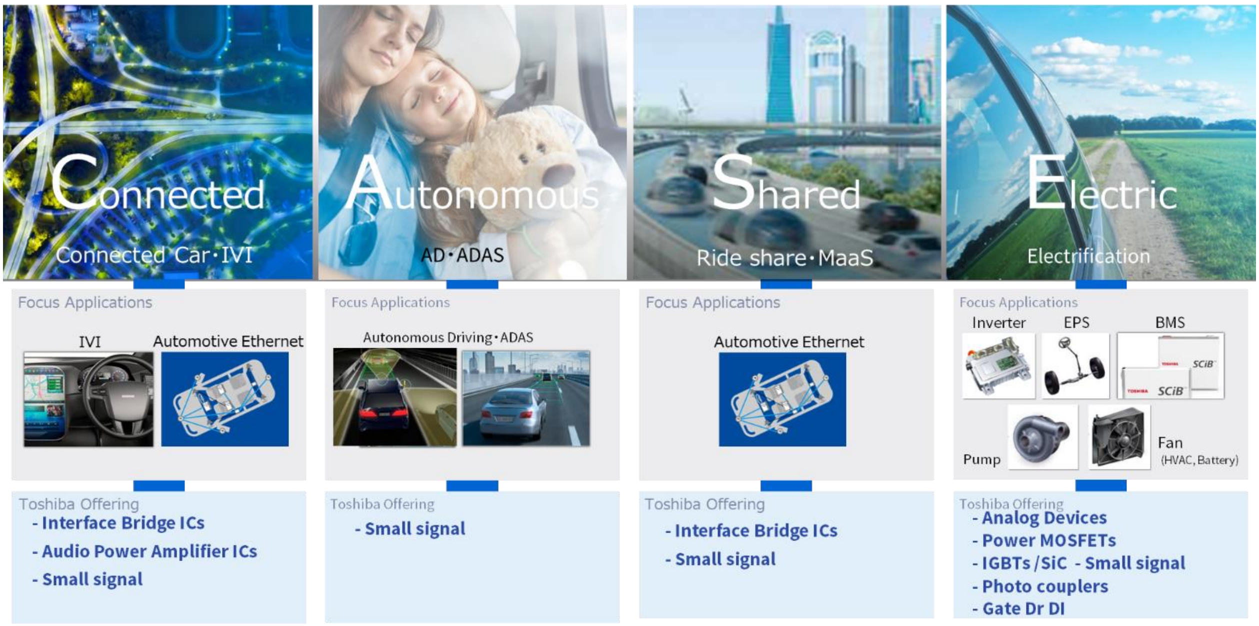


Figure 1.1 “CASE”, the focus them of automotive semiconductors

2. MBD outline

2.1. What is MBD?

MBD(Model Based Development) is a development method that makes use of “model” from the early stages of development.

The three main advantages of introducing MBD are listed below.

(1)Significant backward reduction
(2)To reduce the number of trials
(3)Efficiency through the use of design assets

Figure 2.1 shows the development flow chart of the V-process, which is widely known as the development flow of MBD. In addition to the model-centric design process shown on the left arm and the actual machine-centric verification process shown on the right arm, a verification called front-loading, which is a model-centric simulation, is repeatedly performed at each initial design stage of development. As a result, measures can be taken against discrepancies with specifications at the initial design stage, thereby increasing the degree of completion at the initial development stage for performance targets.

It is possible to reduce the risk of significant setbacks that occur when problems are first discovered in physical verification. In addition, by conducting simulations, the number of prototypes by actual machines can be reduced, which can shorten the development period and expect competitive product development. Also, design assets can be built by MBD. Therefore, even in the development of next-generation products, the use of design assets is expected to further improve efficiency and shorten the development period.

When we consider our roles towards the realization of MBD, First and foremost, We are required to provide a model that operates in the design environment as a "Moving Specifications" to customers. Who are set makers and unit makers.

As a concrete initiative, we provide SPICE models and thermal models as device models compatible with a variety of tools in customer-design environments. Chapter 3 introduces the details.

Discrete semiconductors are often treated as ideal semiconductors in the higher-level designing stage at the system level. There is a gap in terms of model granularity between the MBD (Model-Based Design) conducted by upstream set makers and unit makers, and the MBD of downstream component makers. This is the current situation.

In order to solve this problem, we propose an analysis method using our own degeneration technology that enables thermal designs and EMI noise-verification of in-vehicle powered MOSFET. Chapter 4 introduces initiative.

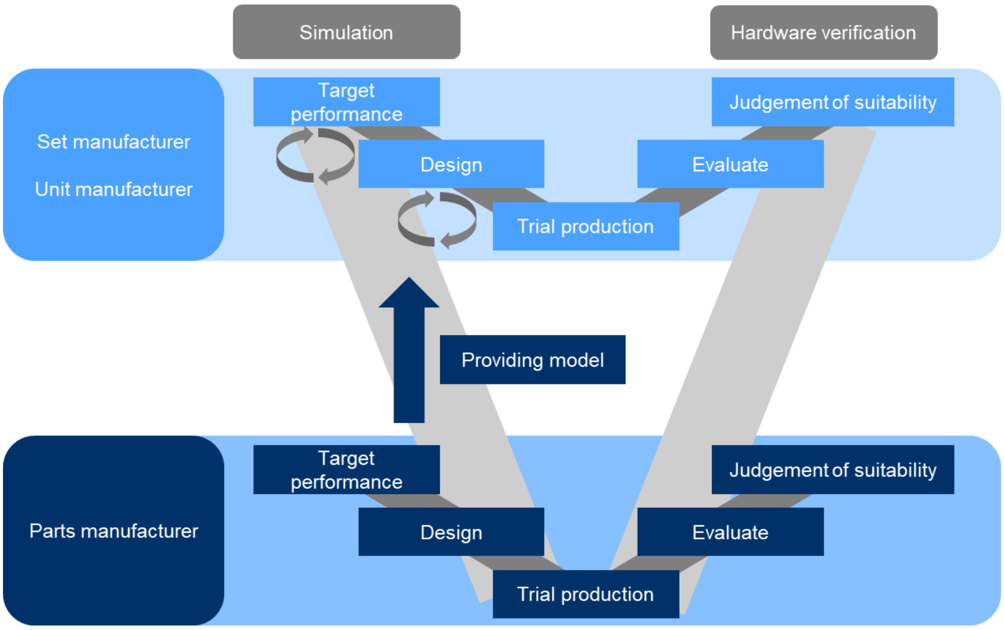


Figure 2.1 Schematic diagram of MBD validation processing

3. Introduction of various models

In this chapter, we present the electrical models, thermal models, and various tools support provided for our in-vehicle discrete semiconductor products.

3.1. Electric model

We prepare two types of Spice models with different grain sizes as electric models for in-vehicle discrete semi-conductor products. One is a G0 that is fast to calculate and is suitable for function checking.

The other one is G2 model (high-precision SPICE model) that we have developed independently for MOSFET products. G2 model is a macro-model based on BSIM3, which expresses the electric properties of the target device by using as few devices as possible and nonlinear devices that use any sequential functions. As a result, the advantages of conventional macro-models are that the convergence of circuit simulation due to the increase in the number of nodes, which is a demerit of conventional macro models, and that the reduction in computation speed is kept as low as possible. In addition, it has excellent reproducibility in the high current range characteristics of I_D-V_{DS} curve and the capacitance characteristics with nonlinearity, enabling high-precision simulations close to actual measurements. The parasitic components of the packages are also considered to enable ringing and EMI analysis that occurs during switching. For more information on G2 models, refer to the application notes below.

“Application Note”
MOSFET SPICE model gradel

We provide SPICE models. These models are compatible with various simulation tools. Specifically, In addition to PSpice®, LTspice®,We have also started web publication of SIMetrix ™ model and ELDO model. Tabel 3.1 shows whether encryption is available depending on our SPICE model grade.

Table 3.1 In-vehicle SPICE Models and Encryption List

Device type	PSpice®	LTspice®	SIMetrix ™	ELDO
MOSFET(G0)	Unencrypted	Encryption	Encryption	Encryption
MOSFET(G2)	Encryption	Encryption	Encryption	Encryption
Diode	Unencrypted	Encryption	Encryption	Encryption
Bipolar	Unencrypted	Encryption	Encryption	Encryption
IPD (Intelligent Power Device)	Encryption	Encryption	—	—

3.2. Thermal model

In discrete power semiconductors, we have begun to disclose WEB on “Simplified CFD Model”(Computational Fluid Dynamics models). These models are suitable for thermal simulations, particularly in MOSFET. By using this simple CFD method, it is possible to visualize the behavior of the flow velocity and the temperature profile in three dimensions. The file format of the model is a STEP format of ISO standard, so it is interchangeable among many 3D CAD tools and can be used with a variety of thermohydrodynamic analysis tools.

By combining the physical properties provided with the product, it is possible to perform thermal simulations when the product is mounted on a PCB board or heat sink.

The following application notes provide detailed information on “Simplified CFD Model”. Also, please contact our sales representatives for models that meet specific requirements for analysis purposes.

“Application Note”
Simplified CFD Model Application Note

4. Features of TOSHIBA's Automotive MBD Initiatives

This section introduces MBD's unique Accu-ROM™(Accurate Reduced-Order Modeling: precision-preserving degenerate modelling) techniques.

Figure 4.1 explains using the example of an automobile’s EPS (Electric Power Steering) system. The left side shows the automobile’s EPS system as a block diagram. Here, each block is represented by a table model defined by equations and tables
As an example of operation, the torque signal is transmitted to the torque assist block in the red frame when the handle is turned, the required motor speed is calculated, and the motor moves. In order to simulate with higher accuracy, MOSFET used is a G2 model instead of the three-phase inverter model (circuit model), which is the actual circuit configuration. This is the right side of Figure4.1.

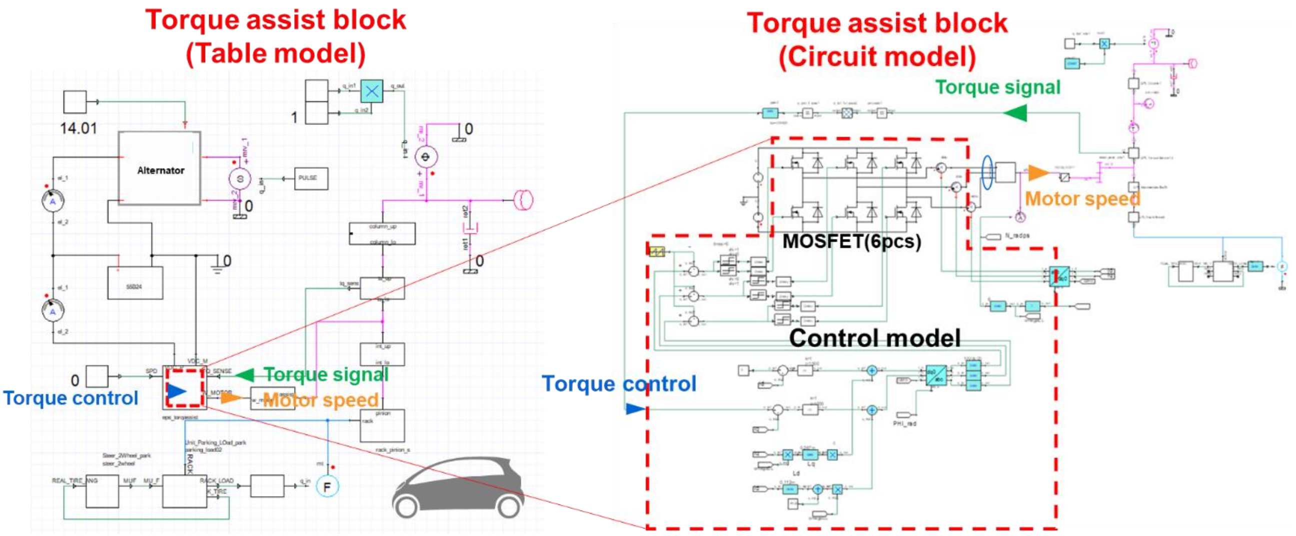


Figure 4.1 EPS plant-model implementation example

Figure 4.2 shows the simulation results for each of these models. The results in Figure 4.2 are the table model on the upper side and the circuit model on the lower side.
Both of them behave in the same way overall, but looking at the output current (motor current) of the inverter shows that in the case of the circuit model, the ripple component is superimposed in accordance with the switching operation of the inverter. If the model is made more detailed in this way, it will be possible to check not only the specifications such as functions and performance, but also the actual operation in more detail.

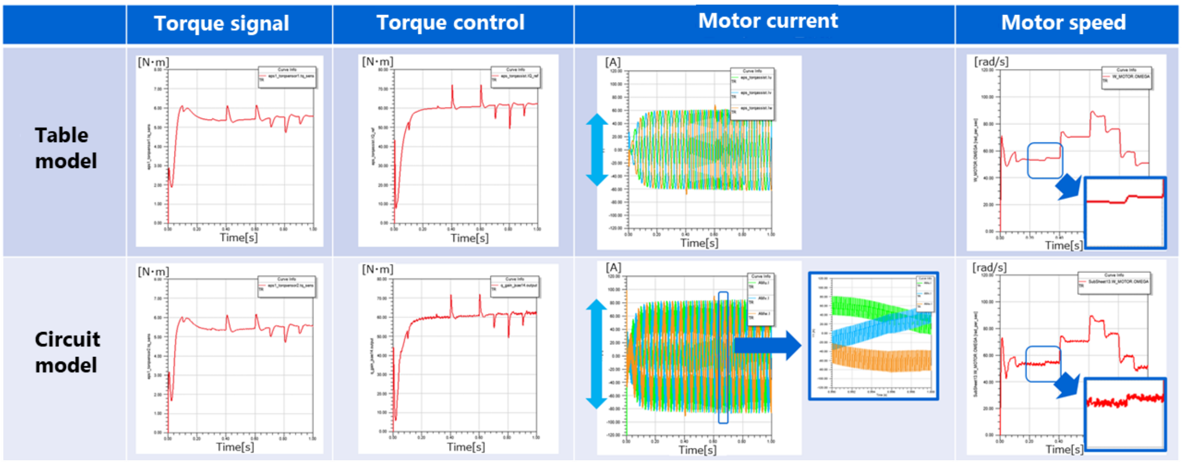


Figure 4.2 Table model and circuit model comparison results

If detailed verification is possible using the circuit-model, the system's thermal feasibility can be verified and observation of EMI noises can be simulated. Figure 4.3 shows an example of a car turning right.

Rotate the handle clockwise for 3 seconds to restore the setting for 3 seconds. Looking at the motor rotation speed, you can see that the motor rotates positively for the first three seconds and oppositely for the second three seconds.

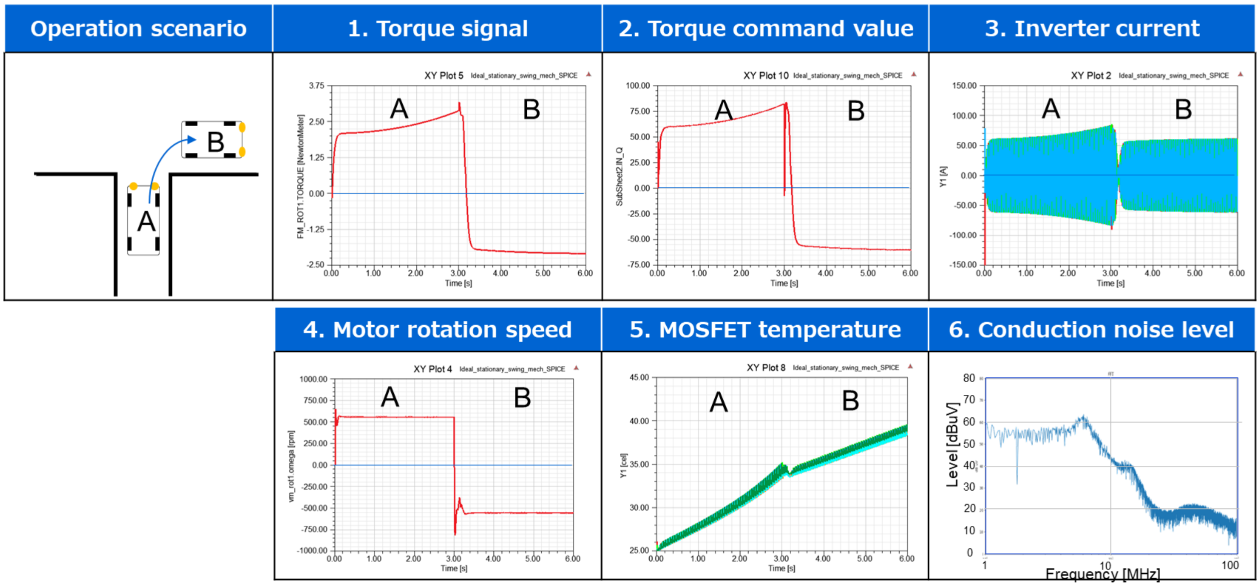
At this time, the junction-temperature of MOSFET continues to rise as it moves. 6. in Figure4.3 shows the conducted EMI noise at the most noisy timing.

The specific method for calculating thermal verification involves calculating the heat generation amount from the current and voltage values flowing through the MOSFET, and adding a peripheral thermal circuit model, which uses the calculated value as the heat source, to the circuit model, thereby enabling thermal verification. Conducted EMI noises are achieved by adding LISN(Line Impedance Stabilization Network specified in CISPR 25 (Note 1) to the circuit model.

In this way, the analysis of thermal verification and conducted EMI noise cannot be represented by a table model. It is realized by adding a LISN circuit based on a circuit model using a high-precision G2 model, which demonstrates the necessity of the circuit model.

However, the problem here is the calculation time. Although it is not possible to verify heat and noise, if the same operation is verified by the table model, it will take 32 hours and 51 minutes by making it a circuit model, although it will end in 3 hours.

Note 1:CISPR 25 (International Radio Interference Special Commission Standard 25)



Operation scenario

1. Torque signal

2. Torque command value

3. Inverter current

4. Motor rotation speed

5. MOSFET temperature

6. Conduction noise level

Figure 4.3 Simulation Results for Automobile Right Turn

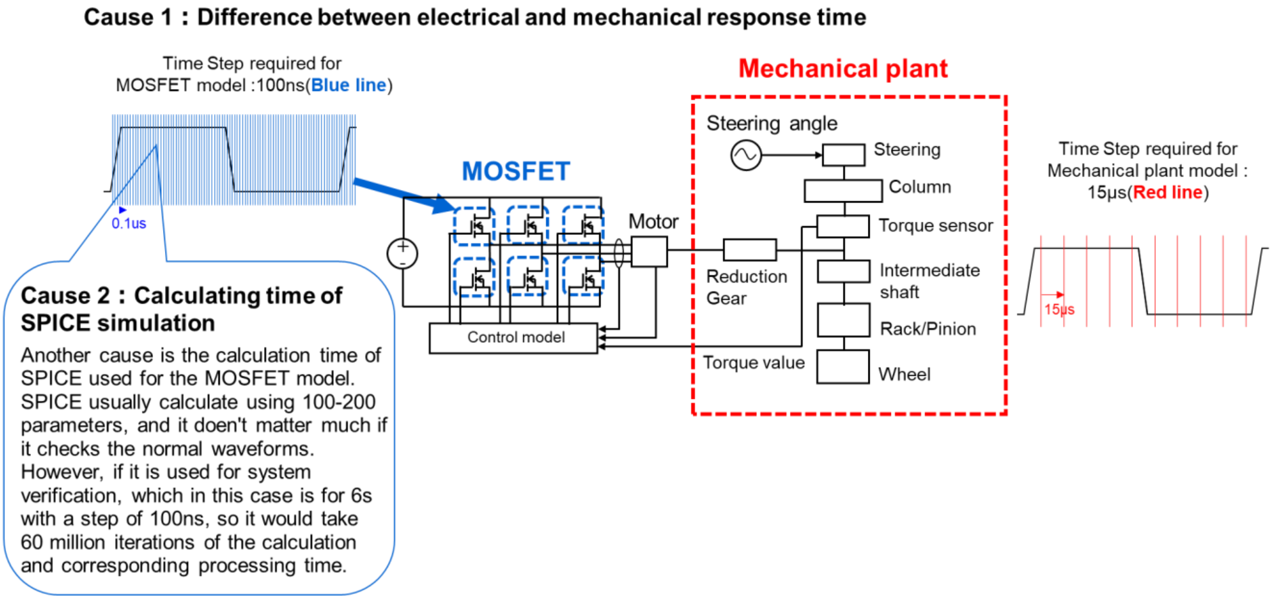
4.1. The Background for the need of Degeneration Techniques

As mentioned earlier, when conducting a characteristic verification of the entire vehicle system, the analysis model becomes large-scale, and it was not realistic to perform a simulation that incorporates heat and noise as it took a long time for analysis. Therefore, when dealing with power MOSFET, it is often treated as an ideal switch. The reasons for the difficulty in analysis include the overall large scale of the circuit, in addition to two other factors that can be considered.

There are two possible causes that make analysis difficult: the overall circuit scale is large.

4.1.1. Cause 1: Difference in time response between electricity and mechanism

The first cause is the difference in the response time of each block. For example, the mecha-plant model shown in Figure 4.4 has a response time on the order of μs, while the torque assist inverter has a response time on the order of ns due to the switching operation of the MOSFET. Therefore, if calculations are performed with a time step that matches the operation of the inverter, the mecha-plant will end up repeating the same calculation except for the switching time.



Cause 2：Calculating time of SPICE simulation

Another cause is the calculation time of SPICE used for the MOSFET model. SPICE usually calculate using 100-200 parameters, and it doen't matter much if it checks the normal waveforms. However, if it is used for system verification, which in this case is for 6s with a step of 100ns, so it would take 60 million iterations of the calculation and corresponding processing time.

Figure 4.4 Cause of longer calculation time

4.1.2. Cause 2: Duration of SPICE simulator

Another cause lies in the calculation time of SPICE used in the MOSFET model. SPICE usually uses 100 to 200 parameters for calculation, which is not a concern for normal waveform verification. However, when used for system verification, in this case, if the operation for 6 seconds is divided into time steps of 100ns, it will repeat calculations 60 million times, which will take time accordingly.

For this reason, in simulations dealing with mecha-plant models, it was often necessary to sacrifice analysis accuracy. This was because G2 models could not be handled from the perspective of simulation time, and they were frequently treated as ideal switches.

4.2. What is Accu-ROM ™?

Toshiba developed a Accu-ROM™(Accurate Reduced-Order Modeling) that enables high-precision and high-speed simulating of thermal properties and EMI noises, which were difficult to achieve in the past.

4.2.1. Accu-ROM^{TM} Technologies

This section describes the analysis content of Accu-ROM™ technology.

Our Accu-ROM™ technology automatically reduces the transient response-characteristics that can be represented by MOSFET's G2 modeling-to automate the simulation-process.

STEP1: Degeneracy of mechanical plant model

First, degenerate the mechanical plant model as shown in Figure 4.5. As mentioned above, there are large differences in the response-times between MOSFET and mechanical plants. Therefore, if you want to observe the behavior of the entire mecha-plant, you don't need the detailed movements of the MOSFET, and it's sufficient to know the state of the switch in terms of time steps. So first, we make the MOSFET model a simple switch model that represents the on and off states of the switch, and calculate with a coarser time step.

Since the switching frequency of the inverter was 6.5kHz (153.85 μs per cycle), the calculation increment is 1/10 of 15 μs. In this way, the characteristics of the entire mechanical plant can be extracted.

All mechanical plant models are then deleted and a torque source is connected to the motor. The torque source connects the required torque fluctuation characteristics to the entire extracted mechanical plant. In addition, the signal that is feedback from the mechanical plant to the control model is connected to the control command value for generating the required torque in the whole mechanical plant. This makes it possible to create models that express the characteristics of the entire mechanical plant.

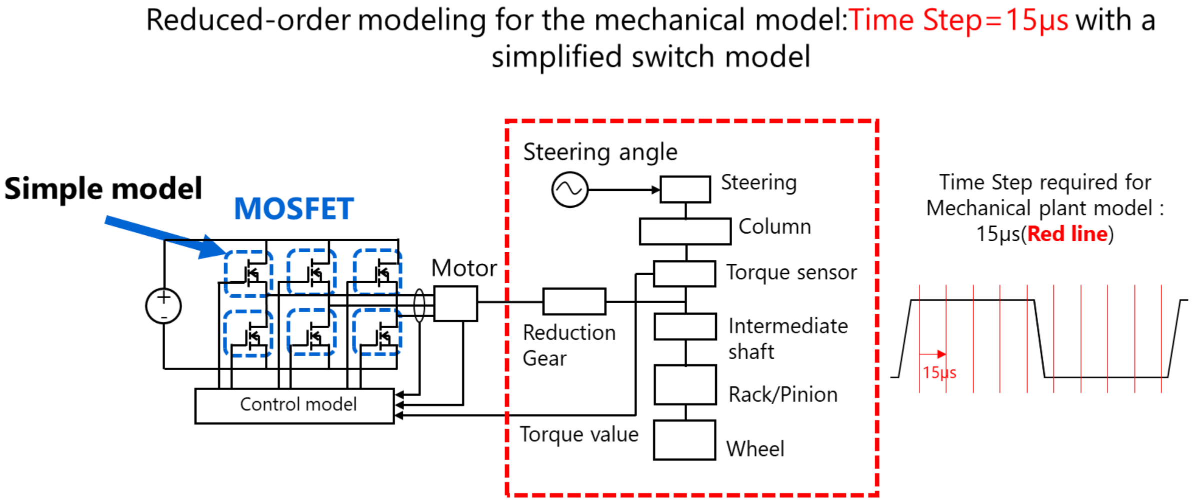

Reduced-order modeling for the mechanical model:Time Step=15μs with a simplified switch model

Figure 4.5 Degraded image diagram of mechanical plant model

STEP2: Degeneracy of MOSFET modeling

Next, as shown in Figure 4.6, we degenerate the MOSFET model. If you want to observe the behavior of the MOSFET, you need to refine the time step. However, if the load torque connected to the motor is the same, it will show the same behavior regardless of the contents of the mecha-plant.

Therefore, a torque source is connected to the motor. MOSFET is modeled as a G2, and the increment is also set to a fine value that matches the switching-characteristics. Using this circuit, the amount of torque is varied within the specification range of the motor, and the amount of switching loss and the amount of noise against the load torque value are obtained in advance. The relation between the load torque and the switching loss is tabulated to create a VHDL-AMS model(Note2). The model is replaced from SPICE model.

Note 2: VHDL-AMS (Very-High Speed IC Hardware Description Language-Analog and Mixed Signal)

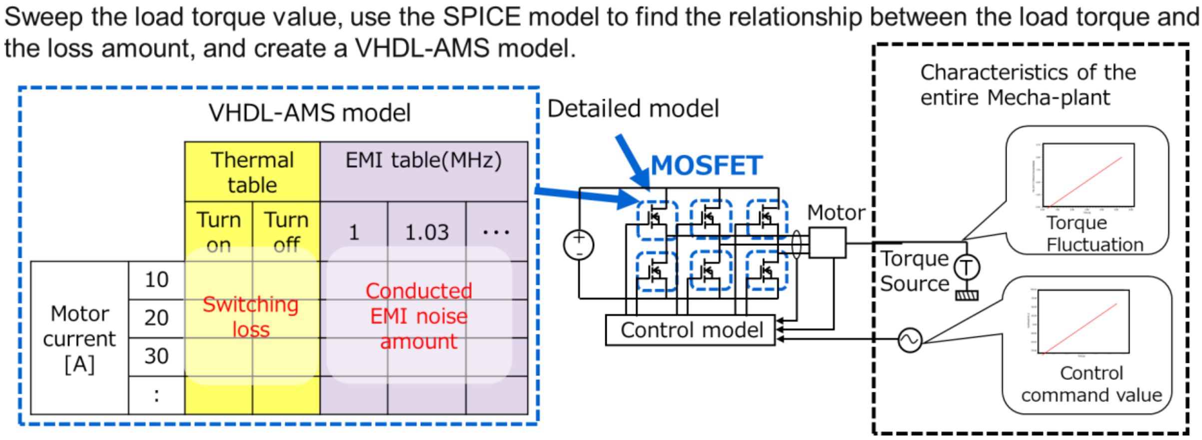

Sweep the load torque value, use the SPICE model to find the relationship between the load torque and the loss amount, and create a VHDL-AMS model.

Figure 4.6 Degeneracy of the graphic MOSFET

STEP3: Simulate using degenerate modeling

Finally, as shown in Figure 4.7, we replace with the degenerate model created in STEP1 and STEP2, finely divide the Time Step, and perform characteristic verification. According to the operating scenario, we look at the load torque value necessary for the entire mecha-plant generated by the system operation, and by referring to the VHDL-AMS model each time, we can omit the calculation of the SPICE model, and it becomes possible to extract switching loss and conducted EMI noise at high speed.

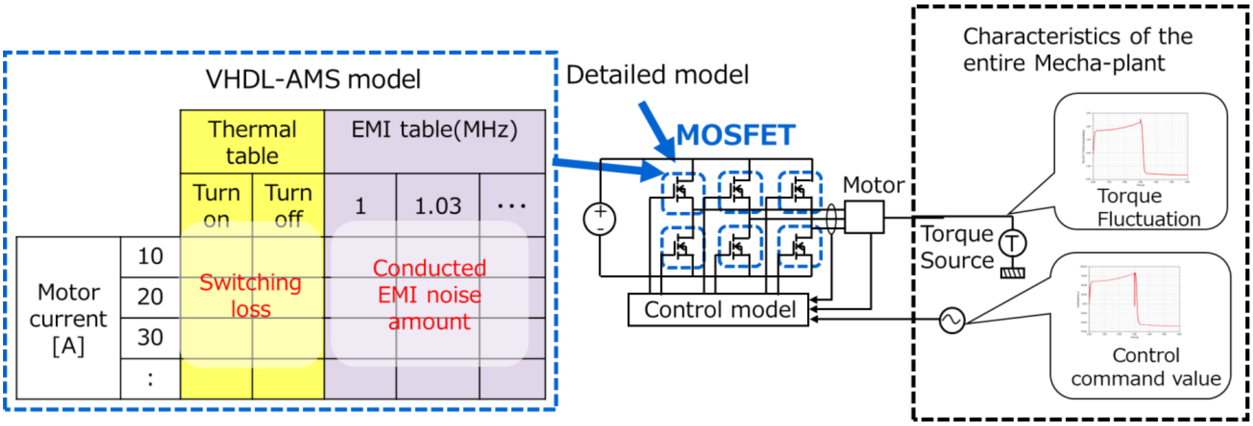


Figure 4.7 Simulation using the degenerate model

4.2.2. Effectiveness of Accu-ROM ™ Techniques in Calculating Times

Figure 4.8 shows the effects of using Accu-ROM™ technology. The analysis accuracy when applying degeneration technology can be almost equally reproduced as before degeneration, and it is second to none. On the other hand, the analysis time, which used to take nearly 32 hours, has been reduced to about 1/10, to 3 hours and 27 minutes, by applying this technology. Accu-ROM™ is a high-precision and high-speed simulation technology that is ideal for heat and noise analysis, and is already built into Ansys® Twin Builder™. If you want to try it now, please access from the link below.

Figure 4.8 Model degeneracy effects

How to install and use Accu-ROM™ on Ansys® Twin Builder™

This paper introduces thermal analysis and conductive EMI noiseanalysis by Accu-ROM^{TM} with EPS as motif.

In the future, we are also considering applying this technology to xEV and other applications.

5. Glossary

Table 5.1 Glossary

Term	Official name	Category	Summary
MBD	Model Based Development	Design technique	A development method that aims to reduce the time and cost involved in prototyping parts and testing by utilizing a 'model' created on a computer during the design process.
SPICE	Simulation Program with Integrated Circuit Emphasis	Circuit simulator	Software that simulates the analog operation of electronic circuits. This is a model language for expressing electronic components and circuits and is a general-purpose circuit analysis program that mainly simulates analog circuits.
PSpice®	-	Commercial SPICE simulator	Cadence's SPICE simulator. Circuit verification is possible.
LTspice®	-	Commercial SPICE simulator	A SPICE simulator provided free of charge by Analog Devices. Circuit verification is possible.
SIMetrix ™	-	Commercial SPICE simulator	SIMetrix Technologies's original SPICE simulator. Circuit verification with good convergence is possible.
ELDO	-	Commercial SPICE simulator	Siemens EDA's proprietary SPICE engine-circuit.
Xpedition AMS	-	System simulator	Siemens EDA's proprietary SPICE engine.
Twin Builder™	-	System simulator	ANSYS's general-purpose system-simulator. Capable of multi-physics analysis that spans multiple physical phenomena such as structure, mechanism, fluid, heat, and electricity.
VHDL-AMS	Very-High Speed IC Hardware Description Language-Analog and Mixed Signal	Model language	A model language that can represent both analog behaviors such as electrical, thermal, and mechanical operations, and digital behaviors such as those of microcontrollers.
Simplified CFD models	Computational Fluid Dynamics	Thermal fluid analysis tool	Simplified CFD models suitable for thermal simulations. This simple CFD models can be used to visualize the three-dimensional behavior of a thermo-hydrodynamic analysis system.

EMI	Electro Magnetic Interference	EMC	Electromagnetic waves generated by the operation of electrical and electronic equipment interfere with the operation of other equipment.

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