MODELLING-Choosing a model

Model categories

When using a model to help in the design process, it is important that the right type of model is used. Using the wrong type of model can waste computing power and time, and either provide too little detail or far too much.

In a pure black box model the internal workings of a device are not described, and the model simply solves a numerical problem without reference to any underlying physics. This usually takes the form of a set of transfer parameters or empirical rules that relate the output of the model to a set of inputs.

For example, a standard current gain transistor model is a form of black box model where the internal workings of the transistor are 'hidden'. In such a model, the output current is related to the input current at the transistor base by a linear current gain.

In a grey box model, some or all of the mechanisms describing the behaviour of a device are known, but are not all fully represented in the model. In a grey box model, certain elements within the model can be approximated by rules.

If we continue our transistor model analogy, then a grey box model of a transistor would be more complex, and would model some of the internal transistor operation. For example, the Ebers-Moll transistor model is more 'grey' than the basic current gain model because it begins to describe and breakdown the operation of the transistor into several elements. However, there are still some approximations in this type of model.

A white box model contains as much detail as the simulation model can provide and no approximations are made using any bulk parameters. Such detail in a model is only used in situations where the simulation results must closely match those produced in reality and often consume large amounts of computing power. A pure white box model cannot exist as it is essentially a copy of reality!

Although a pure white box transistor model does not exist, 'whiter' models than our Ebers-Moll does exist. For example, transistor models have been devised that actually model the movement of electrons and holes through the p and n-type silicon materials in that make up the transistor.

The choice between these three types of model will depend upon the level of detail we require in the model. This is ultimately dependant upon how closely we wish the models behaviour to match that of the real system.

Discussion of black box models

A black box model is used where the response of a system is not broken down into its underlying mechanisms, and is represented by an empirical description or set of transfer parameters that do not describe any internal physics. Compared with grey and white box models, black box models have advantages and disadvantages:

Advantages of black box models:

Fast running: Because black box models usually consist of a set of rules and equations, they are easy to optimise and can run very rapidly. For example, determining the area under a curve using a least-squares fit could give you a useful answer, but does not rely on any real understanding of the problem.

Minimal required computing power: Because a black box model is relatively simple, it does not require a great deal of computing power.

Disadvantages of black box models.

Lack of flexibility: The major disadvantage of a black box model is its lack of flexibility. If the model needs to be changed to describe something physically only slightly different, it can mean a lot of work to determine any new rules or bulk parameters. A black box model is not appropriate for any form of sensitivity analysis.

Non-physical: Another restriction of a black box model is in its lack of any form of physical meaning. This makes it hard to relate the model to the actual device being modelled.

Good examples of black box models are any form of parametric model, where transfer parameters are used to relate model outputs to model inputs.

Example of a simple black box model.

A resistor’s final steady state temperature is governed by the equation:

$$T = \frac{0.4P}{A^{0.7}} + T_0 \qquad \text{. . . . . Eqn.1}$$

where P is the power applied to the resistor, and A is the resistor’s area and T0 is the ambient temperature.

This is a type of black box model, with three inputs, P, A and T0, and one output, T. We see that a model based on Equation 1 has the following properties.

The model only gives us steady state information.

The model does not have much physical meaning. What determines the values 0.4 and 0.7 in equation 1?

The model is not flexible. For example, what happens if we want to find the effect on the temperature of the resistor when we place another one nearby?

Other general examples of black box models include:

Statistical models that use correlation or interpolation to predict system behaviour.

Rule-based models, such as those based on neural networks.

Models based on purely numerical calculations, such as curve fitting processes like cubic-spline fits.

None of these types of model attempt to model by low-level application of the physics of the problem, they just try to get the right answer by using a high-level process.

Applications for a black box model

Black box models are useful when an answer to a specific problem is required and the flexibility to change aspects of a model and see the effect is not. The required flexibility of a model depends upon its long-term objectives as part of the design process. If the purpose of the model is only to provide quick, approximate answers, based on a pre-determined set of input parameters, then a black box model is appropriate. In such a case, flexibility is not required, as the overall design has already been fixed. For example, the maximum power handling capability of a component could be related to its dimensions, material thermal properties and electrical properties. A rule-based black box model could be set up to determine a component's power handling based on these parameters. However, such a model is not flexible, and if a different answer is required, or new parameters are added, it usually means re-designing the model from scratch rather than just modifying the existing rule.

Discussion of grey box models

The majority of simulation models are grey box models. A grey box model provides a physical representation, but some of the physics is approximated. For example, in a PCB thermal model, convection at the board surfaces is often represented by a convective heat transfer coefficient. Though this represents the amount of power escaping from the board in terms of physical parameters, it hides the underlying process of air flow across the PCB surface, laminar or turbulent. It is a high-level model of a low-level process. This is typical of a grey box model.

Other typical approximations that are made in a grey box thermal model:

Non-linear parameters or processes are often approximated by linear ones.

Areas of physical detail are often simplified by averaging the localised properties. For example, multi-layer structures can be approximated by a single layer, the single layer having the average properties of all of the layers involved.

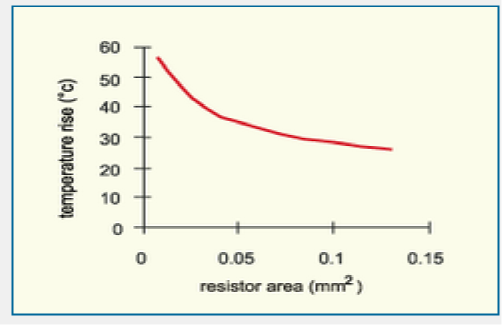
Contact between one part of a model and another is sometimes considered perfect, when in reality it is not. For example, the thermal contact between a surface-mount component and a PCB.

Applications for a grey box model

In cases where flexibility is required, we need a more generic model, that can be adapted to model variations in a design. A grey box model provides more flexibility, and enables us to use modelling to optimise a design, rather than just tell us answers based on a fixed design. This includes determining the effects of variations in device geometry, right through to a change in material parameters. Grey box models can be used for design sensitivity analysis, where we want to see how sensitive a design is to a particular design aspect, such as how component temperature is related to the position of components on a PCB. The flexibility of a grey box model also allows us to extract rules that describe the behaviour of a device. In this sense, a grey box model can be used to form a black box model that could be used as a design tool itself. For example, we could use a grey box thermal model of a PCB to obtain a relationship between the area of a resistor and its temperature rise for the same component power dissipation. Figure 1 shows a curve that could have been generated from a grey box model.

Figure 1: Graph of temperature rise against resistor area

Graph of temperature rise against resistor area



The results shown in Figure 1 could then be extracted and used in the form of a table lookup as part of a black box rule-based model.

Discussion of white box models

A white box model is the most detailed type of model, and is as close as possible to a full description of the real device. The physical processes are described at as low a level as possible, with no approximations or bulk parameters used. So the PCB thermal simulation would model the actual laminar flow of air across the PCB surface, instead of using a heat transfer coefficient to describe the heat loss through convection. In this sense, it would no longer be a pure thermal model, as we would also require an air-flow model as well.

Advantages of white box models:

Extremely flexible: Because everything is modelled on a low level, the behaviour of a white box model can be changed in minute detail, in line with the actual physics.

Realistic: White box models provide the closest match to the real device, and models the behaviour of a real device extremely closely to its actual behaviour.

Disadvantages of white box models:

Complexity: Because white box models contain no or few approximations, they are the most complex types of model to set up and implement. This also renders them the slowest running type of model.

Large computing overheads: The complexity of a white box model means it requires fast computers and large amounts of memory.

A white box model is only really necessary where we need the flexibility of a grey box model plus a high level of detail in the physical processes. If we need to determine the sensitivity of a design to the smallest of details, then we may need a white box model. In every other sense, a white box model can be used for the same applications as a grey box model, but provides greater realism.

Choice of model type for purpose

The question of which model type to use for a specific modelling task can be answered by considering the requirements of a model.

Required level of flexibility: Will the model need to be flexible, to predict how changes in the design of a system will affect certain aspects of its behaviour?

Long term aims: Will the model be used over several years or several weeks? A model designed to assist in a long term design project needs to be flexible so it can keep up with any unexpected design changes.

The available resources: Sometimes, the type of model used is limited by the available computing power. In such a case, a model must be simplified or broken down. For example, a white box model could be broken down into a set of several grey box models.

The number of approximations that can safely be made: Making several appropriate approximations can greatly increase the efficiency of a model. This is acceptable, provided the applied approximations do not significantly reduce model accuracy. A white box model is reduced to a grey box model by making such approximations.

Author: Martin Tarr

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