CDCM HD White Paper

• What is CDCM HD technology？

CDCM HD (Comprehensive Dynamic Circuit Modeling HD) is next generation modeling technology from Hotone's in-house research team.

Like Hotone's previous generation CDCM modeling, CDCM HD technology models every component of the original device, building a model that tracks the dynamic variations of the instrument's input signal. This technology maximizes the capability for the reproduction of the exact sound characteristics of the modeled object.

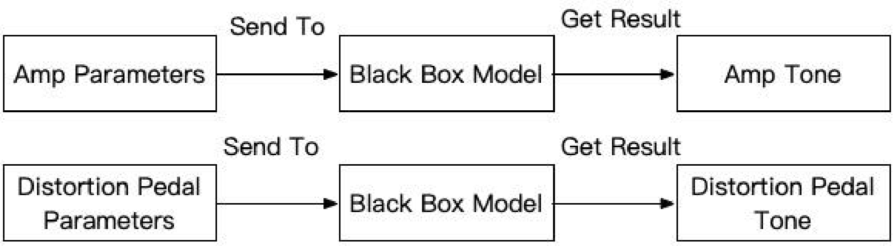
In a quest to push the modeling algorithm sound quality even higher and create an even more realistic user experience, Hotone's research and development team has further improved and updated the modeling technology and methods that served as the cumulative foundation for the successful XTOMP, Binary, and VStomp product series. The result was the birth of CDCM HD. Compared to the previous generation CDCM, CDCM HD modeling technology even more accurately reflects the real sound characteristics of the device and the sound variation caused by changes in component states. The control parameters are also more precise and deliver more dynamic, deep, in-the-moment tonal feel. International professional musicians who have embraced this technology are enamored by how live play becomes so unbelievably realistic.

Current mainstream modeling technologies can be divided into two categories: Black Box Modeling and White Box Modeling. What are the advantages and disadvantages of each of these two modeling technologies? How is CDCM HD modeling unique? We'll explore these questions next.

• Pros and Cons of Black Box Modeling Technology

<u>Definition</u>

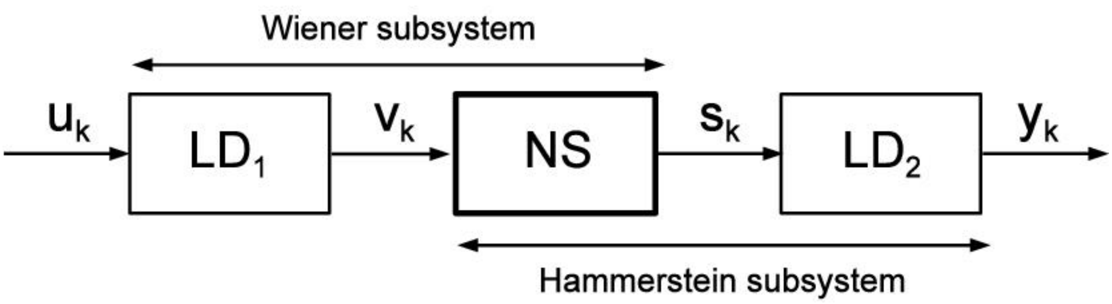
Black box theory explains a system viewed in terms of inputs and outputs without any knowledge of internal workings. Between the input and output is an opaque (black) implementation. The black box modeling method refers to the use of a common model to represent a type of distortion circuit. This distortion circuit may be a stompbox or an amplifier. This universal model is able to receive different parameters from different targeted modeled objects and sort the corresponding data through an optimized algorithm. The goal is matching the sound characteristics of a certain device or multiple devices.



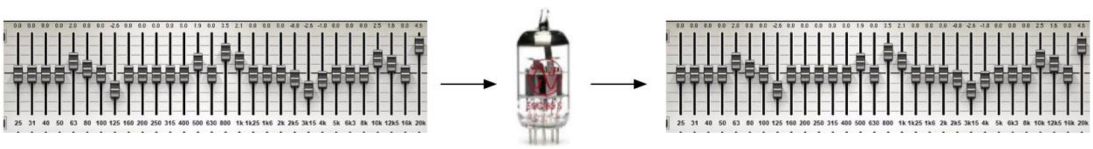
Model Selection

The most important part of black box modeling is the selection of black box models. This has an enormous impact on the final result. Overly simple models will not match as many different types of distortion circuits as possible. On the other hand, overly complex models result in complicated algorithms with excessive calculations too difficult for the processor to handle. For this reason there are always trade-offs in this process.

The most commonly used black box model is the Wiener-Hammerstein model, shown below：



The Wiener-Hammerstein model is composed of the Wiener subsystem and the Hammerstein subsystem. Among them, LD1 and LD2 represent the linear part, which can be simply understood as EQ, which will modify the frequency response of the input signal. NS represents the non-linear part. It is understood as a non-linear device (such as a diode or a vacuum tube), which will change the shape of the input signal waveform, resulting in clipping distortion.



The Wiener-Hammerstein model can be widely used because it is able to easily and efficiently represent the module functions of most distorted circuits (although it cannot represent its circuit topology).

Model Implementation

Here is how the Wiener-Hammerstein model is used in sound modeling:

(1) Use digital filters to achieve modeling of linear systems (LD1, LD2)

(2) Use a certain method (such as Map Function) to achieve modeling of non-linear systems (NS)

The preliminary tone of the model is obtained by solving the parameters of the model above. However, the sound needs to be further dynamically adjusted. At this point it must:

(3) Use modeled objects for comparison.

After repeated comparisons and optimal results are obtained, the modeling is finally completed.

Advantages and disadvantages of black box modeling technology

The advantages of black box modeling are obvious:

1. The modeling process is completely automatic. By simply measuring the input and output signals, it can automatically match the appropriate parameters to emulate the sound of the device through the optimization algorithm. In the modeling process, no circuit diagram of the device is needed, and no relevant knowledge of analog circuitry is required.

2. Black box modeling algorithms have a certain universality. A set of mature black box algorithms can build many different device models, which greatly saves on algorithm development and maintenance costs.

However, the current level of black box modeling has some inherent problems:

1. Model complexity and algorithm complexity

Take the common Wiener-Hammerstein model for example. It can only perform black box modeling on a single part of the circuit, and complex circuits cannot be simply expressed by this model. The pre- and post stages of amplifier head circuits, for example, create non-linearity. If a complex model is used, the number of parameters rises, and the calculation burden for solving the optimal value sharply increases. Because of this, there is a forced compromise between model complexity and algorithm complexity: when the model is too simple, the resulting sound is not ideal; when the model is too complicated, the process of solving parameters becomes virtually impossible.

2. Problems with variable circuit components

As can be seen from the modeling process shown above, black box modeling actually only recreates the tone of a certain device under a specific setting. As a knob is adjusted, the state of the modeled object changes. This means that the model also needs to change even though it is using the same input signal. When this happens, new parameters need to be solved again, which is basically equivalent to starting the modeling process again. It's like taking a picture of a continuous action with a camera: it captures the transient action at a certain moment, but it cannot show the whole image of the entire action.

What if multiple values are measured and processed? Let's use our example of the action photograph. We could take a series of pictures, arrange them in order, and create a flipbook to approximate the entire action, but this would require many, many pictures to be convincing. If we only took a few pictures, the flipbook would be far from recreating an expression of the continuous action. The same is true for black box modeling. If you test different positions of the knob (most black box modeling products do not even do this), you end up with an enormous amount of measurement data, and even then the final result is a sorry approximation. Black box modeling only allows the approximate effect of the knob to be simulated, and the changes in the frequency response and phase response caused by the change of the knob can not be accurately calculated.

3. The problem of circuit topology

Consider amplifier presence knob mechanisms. Some rely on independent filters to attenuate high frequencies (often known as Cut knobs), some interact with the Tone Stack EQ part, and some (on most amps, actually) depend on adjusting the amount of negative feedback in the post stage. Because of this versatility, black box modeling cannot accurately reflect the topology of the circuit, and it simply cannot accurately embody the effect of the sound various presence knob designs will have. This results in the user feeling there is no real difference when making adjustments. There is no way to accurately recreate the true characteristics of the modeled object.

<u>Summary</u>

- Current level black box modeling is suitable for emulating fixed sounds.
- Current level black box modeling has difficultly accurately reproducing circuits containing variable circuit elements.
- Current level black box modeling has difficulty recreating the difference in tone caused by the differences in various circuit structures.

- # Pros and Cons of White Box Modeling Technology

Definition

White box modeling is the opposite of black box modeling. In black box modeling, the internal structure of the system is unknown, so necessary information is extracted only from the relationship between input and output signals. White box modeling requires that all the information about the internal structure of the system be known, including circuit structure, component characteristics, and other design details. For this reason, white box modeling is also called circuit-based simulation technology.

Model Selection

In white box modeling, the model selects the circuit of the object being modeled. Generally, the modeling process begins with dividing the circuit structure. It splits a complex system into multiple simpler subsystems and completes the modeling separately before piecing them back together in order.

Model Implementation

1. Linear part

White box modeling can perform accurate symbolic analysis on the linear parts of a circuit (such as the Gain, EQ, and Master knobs), and calculate the corresponding digital filter coefficients to recreate the circuit's frequency and phase response.

As for the nonlinear part, the DK-method, Wave Digital Filters, and other methods can be used to solve the nonlinear part numerically.

Advantages and disadvantages of white box modeling technology

The advantages of white box modeling are obvious:

1. White box modeling can reflect differences in devices. White box modeling completely follows the device circuit structure and can, to the greatest extent, reflect the difference in tonal color between different devices due to differences in circuit structure.

2. White box modeling results are freely customizable. Because white box modeling is a simulation of the circuit itself, the modeled circuit can be modified to a certain degree (for example, defining the value of custom circuit components) simply by following the circuit logic. This allows better sound quality to be achieved.

3. White box modeling is more concise and accurate. Compared with the complex models of black box modeling, the white box modeling method is much simpler when handling circuits containing variable components. The frequency and phase response of any adjustment knob is also more accurate.

Still, the current level of white box modeling has some inherent problems:

1. Over-reliance on circuit diagrams

White box modeling must have all the circuit information, which has led those who use this modeling method to rely heavily on circuit drawings. If the complete circuit diagram of the device being modeled cannot be obtained, it becomes very difficult to produce a decent modeling result.

2. Burdensome modeling process

As mentioned above, if the circuit diagram of the modeled device cannot be obtained, it becomes necessary to disassemble the device and study its circuitry. This is both tedious and time consuming. Secondly, because the circuit structure and components of each device is different, there is no universal method to complete the modeling, which means that the modeling of different kinds of devices must be done one at a time.

3. Difficulty solving the nonlinear part in real time

The non-linear part of the white box model is difficult to solve in real time because of its high computational complexity and variable computational complexity. Trade-offs must be made in terms of time complexity or space complexity. One solution is to store an approximate solution value in the memory of the DSP in the form of a look-up table. However, this process requires an immense amount of memory space, and it often places a heavy burden on the entire digital platform.

Summary

- The white-box modeling process is complicated.
- White box modeling can better reflect the characteristics of different circuits.

- White-box modeling can accurately emulate linear circuits, but the calculation of non-linear parts is too large to be solved in real time.

• CDCM HD Modeling Technology

Having briefly explained the advantages and disadvantages of traditional black box and white box modeling techniques, let's look at how CDCM HD modeling overcomes the methodical challenges.

CDCM HD modeling technology is a combination of white box modeling and black box modeling:

1. For the linear part of the circuit to be modeled (including the part with variable components), we use white box modeling technology to accurately recreate the circuit response and the circuit response change caused by adjustments of the knob. This allows the model to match the circuit structure and knob behavior of the modeled object to the largest possible degree.

2. For the non-linear part of the circuit, we designed a unique dynamic non-linear black box model. While guaranteeing the match of the non-linear characteristics of the device, we also reduce the burden to the digital processor. We deeply optimized the model's own computational complexity so that the model recreates to the highest degree the characteristic circuitry of the modeled device's non-linear system.

3. As we compare the final modeling results with the actual piece of equipment, we further employ proprietary black box modeling technology to make fine adjustments to model parameters in order to repair errors in the modeling process.

Recreating linear parts using white box modeling

In reality, the knob control effects of most analog devices are highly interactive. As a knob performs its specified function, it may also be accompanied by expected or unexpected "side effects." As mentioned above, these irregularities are impossible for black box modeling to replicate. Below are some examples to illustrate the characteristics of analog equipment, and we'll explain the uniqueness of CDCM HD technology in capturing them.

Case study 1: Amplifier Gain Knob
Under normal circumstances, an amp will take the guitar signal through a first stage of amplification before entering the circuit related to the gain knob. The gain control circuit often uses an attenuated circuit design* to control the amplitude of the gain, and thus the amount of distortion. However, some devices will add bright cap capacitors to the gain circuit to achieve the effect of changing the frequency response as the gain is adjusted. This affects the amp in such a way that the lower the gain, the brighter the tone, and the higher the gain, the darker

the tone. This allows different types of guitars to get as similar a tone as possible. Some modern high-gain speakers feature two gain knobs to thicken the sound. These amps have one gain knob to control only the gain amplitude and another to control both the gain amplitude and the frequency response.

*(Attenuation means that when the Gain knob is at the maximum position, no processing is performed on the input signal of the previous stage, and turning the Gain knob down will attenuate the previous stage signal.)

In the CDCM HD modeling process, our engineers use white box modeling technology to make different models of the different gain circuit designs of various amplifiers to accurately recreate the changes in circuit response during gain adjustment. They also take into account the actual design features of different brands of amplifiers and use employ our proprietary black box technology to adjust errors and supplement tonal variations.

Case Study 2: Amplifier EQ Knob Curve

To a certain extent, the type of potentiometer knob an amplifier uses will determine its overall sound characteristics. For example, some people believe that the sound of a certain brand of amplifiers is darker than another brand, even though they share the same Tone Stack EQ circuit design. Among all the other components that make up a great amplifier, including the cabinet and speakers, the potentiometer is a critical factor. At the 12 o'clock position, linear potentiometers and logarithmic potentiometers will have a different resistance, and adjusting them in either direction will yield very different tonal results.

In the CDCM HD modeling process, our engineers customize the knob curve mapping function one by one for different types of potentiometer knobs found on various amplifiers. Then they manually adjust the knob velocity of each model to recreate the behavior of the knobs on the actual amps.

Matching Nonlinear Parts with Dynamic Non-linear Black Box Modeling

As mentioned earlier, for the non-linear part, black box modeling cannot accurately reflect the dynamic changes of the device being modeled, and the calculation volume of white box modeling is too great. The unique dynamic non-linear black box modeling method of CDCM HD combines the characteristics of black box and white box modeling while further refining and developing traditional modeling techniques.

On the one hand, CDCM HD can adjust the model parameters dynamically in real time in response to a hard or soft playing style, so as to recreate the amp's electrical feedback. This is accomplished by our dynamic non-linear black box modeling in a way not too computationally intensive, thus overcoming the challenge of traditional white box modeling. On the other hand, our process adjusts the model parameters to accurately match the harmonic components produced by real equipment due to non-linearity. This allows the final modeling result to be extremely close to the equipment being modeled.

Final fine-tuning: frequency response error modification

There will always be a certain deviation between the model and the real device. There are several possible reasons for this difference. One common cause is circuit diagram limitations. As mentioned earlier, over-dependence on circuit diagrams is one of the disadvantages of white box modeling. Many prototypes of modeled devices are often very difficult to obtain. Even if by some good fortune an original prototype can be found, the existing circuitry may not be accessible for accurate study. There is also the possibility that original prototype components were changed out for different parts. This would cause variation in the sound.

Another challenge has to do with the Miller effect. When two components with different voltages are close to each other, the electric field between them will cause the charge to be stored on the component, which is equivalent to introducing a parasitic capacitance. This will cause the component behavior to deviate from how it was ideally designed in the circuit map. In an amplifier, for example, the parasitic capacitance between the grid and the triode plate will affect the high frequency to some extent. The Miller effect has a smaller effect on amp heads that are routed using PCBs, but it has a larger effect on old point-to-point amp heads.

There is another possible reason for tonal disparity, this one related to the cabinet. When speakers with different impedances are matched, the frequency response of the amp head output signal will change the impedance curve of the speakers. Although this is made up for by the negative feedback design found in many modern amplifiers, this deviation still exists, and of course even more in amplifiers which do not have negative feedback circuitry.

In the final stage of the CDCM HD modeling process, a unique black box modeling algorithm is employed to correct the frequency response for the possible errors mentioned above. This algorithm is specially tailored to address the subtle differences between the model and the original device as a final step in the modeling process.

CDCM HD technology is unique in the industry because it recreates in intense detail the sound and behavior of amps and effects without overly taxing digital processors. It’s for this reason that Hotone products like Ampero can feature so many hi-def models in a small platform.