HyperLynx

Creating VRM models in AC Decoupling Analysis

Updated May 02, 2023

SI/PI Advanced Solvers

https://support Copy

✓ Item Saved

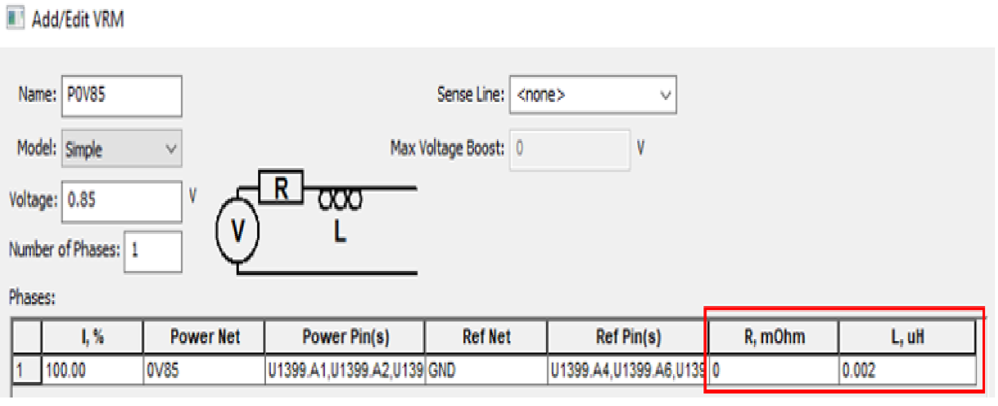
DETAILS

VRM Modeling for PDN Analysis

===

Overview

When running decoupling analysis, it is often desirable to have a model for the voltage regulator module (VRM) that is simple enough to use in a frequency domain simulation. The HyperLynx Advanced Decoupling Wizard allows a VRM model to be included in the analysis. The VRM dialog box is shown in Figure 1.



Name: P0V85

Model: Simple

Voltage: 0.85 V

Number of Phases: 1

Sense Line: <none>

Max Voltage Boost: 0 V

Phases:

	I, %	Power Net	Power Pin(s)	Ref Net	Ref Pin(s)	R, mOhm	L, uH
1	100.00	0V85	U1399.A1,U1399.A2,U139	GND	U1399.A4,U1399.A6,U139	0	0.002

Figure 1 – VRM model assignment in HyperLynx Advanced Decoupling Wizard

This simple model is defined by a resistor and inductor connected in series between a voltage source and the VRM port in the power distribution network (PDN) S-parameter model. This is often referred to as an RL

KB Article ID# MG613540

CONTENTS

ASSOCIATED COMPONENTS

HyperLynx SI/PI

HyperLynx Advanced Solvers

Is this article helpful?

Yes No

Please let us know your feedback about this document

1500 characters remaining

Submit

model, and it is not obvious what values to use for R and L. The purpose of this model is to represent the transient response of the VRM over the bandwidth that the VRM regulates, which is typically below a few hundred KHz. The inductor is used to limit the ability of the VRM model to respond to fast current transients, while the resistor is used to slow the ramping of the inductor current. A slightly more sophisticated model can also be created that includes an additional R and L component in parallel. Adding these components can make the model more closely represent the actual VRM performance.

In this document we will propose a methodology for determining the RL model based on typical current-step response curves available in the VRM datasheet.

Model Creation Methodology

First, find the step response plots in the VRM datasheet. An example is shown in Figure 2. This shows the transient response of the VRM output voltage to a step current load. It is this type of behavior that we are trying to capture in the simplified model. We will use this plot as an example to determine the values for the R and L in the simplified model.

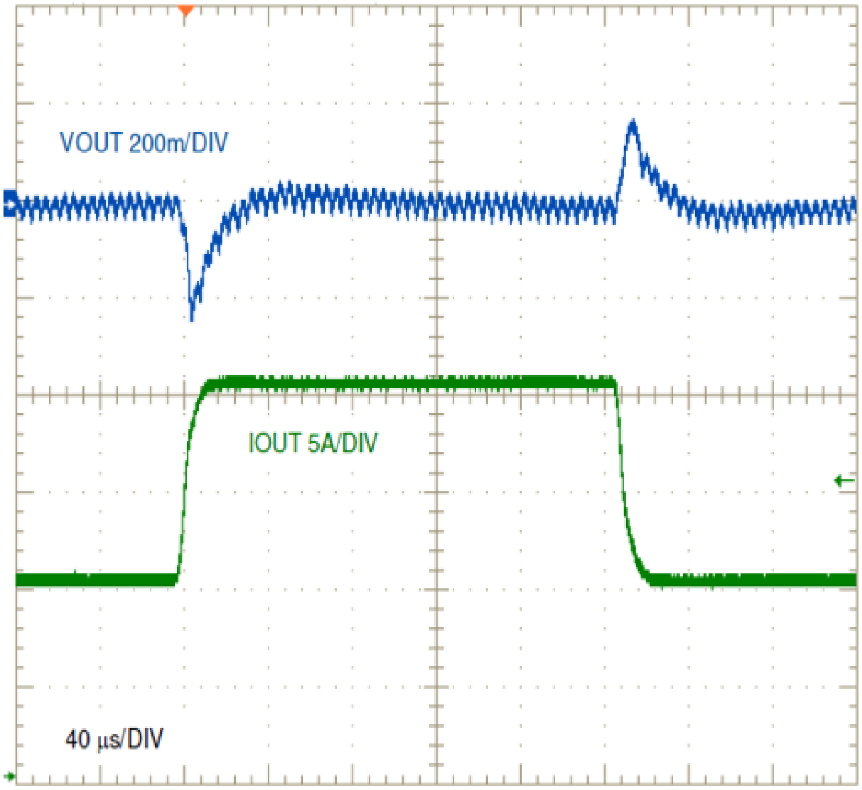


Figure 2 – Step response for LM5145 DC-DC Controller from datasheet

Create a schematic to test the RL model you want to develop. The basic model consists of a single resistor and inductor in series. A slightly more complex model includes another RL in parallel with the basic model. The test circuit is shown in Figure 3 (the calculated values for this example are included).

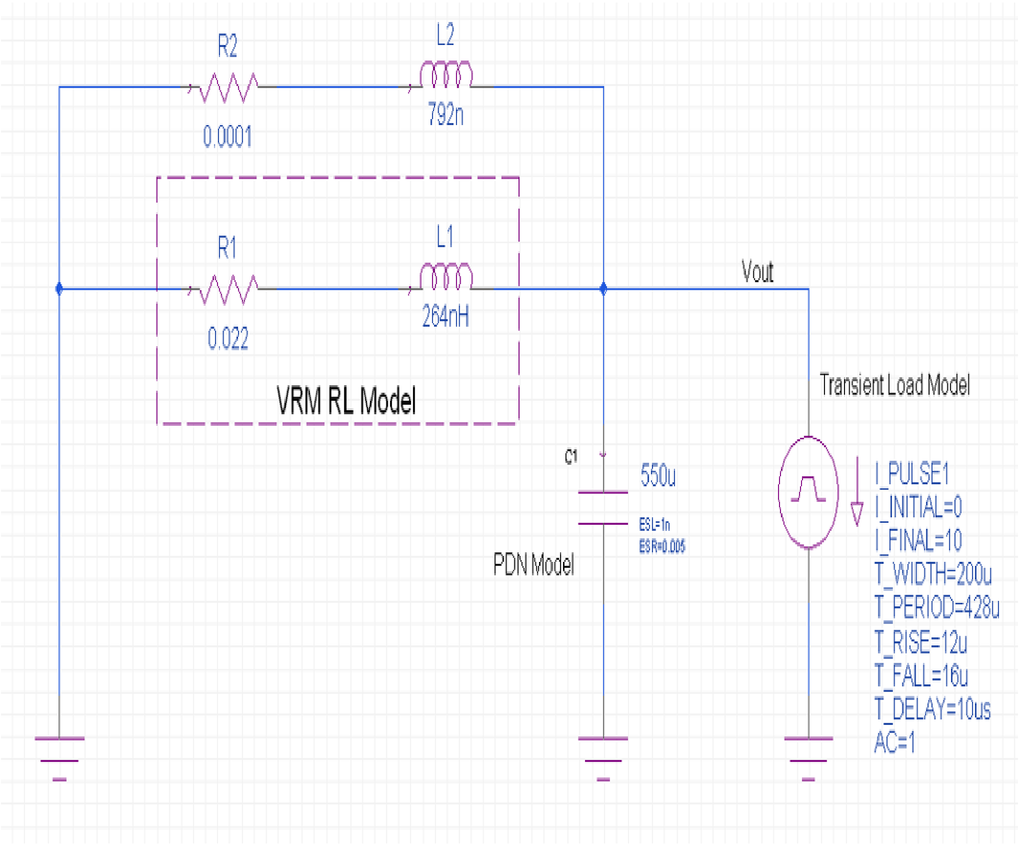


Figure 3 – RL model schematic topology

Steps to determine the RL model:

1. Add capacitor C1 to represent the total decoupling of your PCB. The capacitance should be the capacitance value that was used in the datasheet for the step response curve. Add a small series ESR (5 mOhm) and ESL (1nH). This is not absolutely required but will give better results.
2. Calculate the di/dt of the current step. In this example the current step is 10A, and the fastest edge is the rising edge at 12us. (10A/12us)
3. Measure the induced VOUT voltage for the rising edge from the datasheet. (220 mV)
4. Calculate L = V /(di/dt). (264 nH) (most values will be within tens to a few hundred nH, with higher current regulators having larger inductor values)

5. Calculate the rise time (RT) of the VOUT pulse. (~8 us)
6. Estimate R with this formula: R = L/(1.5*RT). (22 mOhms)

(most values will be in the tens of mOhms)

7. Add these values to the RL circuit for R1 and L1. Leave L2 and R2 out of the circuit for now. Set the current source to have the same pulse as the datasheet current pulse.
8. Observe the VOUT results in time domain, shown in Figure 4. If you are only going to make the RL model, and the magnitude is too high, reduce the value of L. Sweep the value of L if needed to determine an optimal value. This is the minimum RL model, and because the R is needed to dampen the inductor voltage, you will have a DC offset.

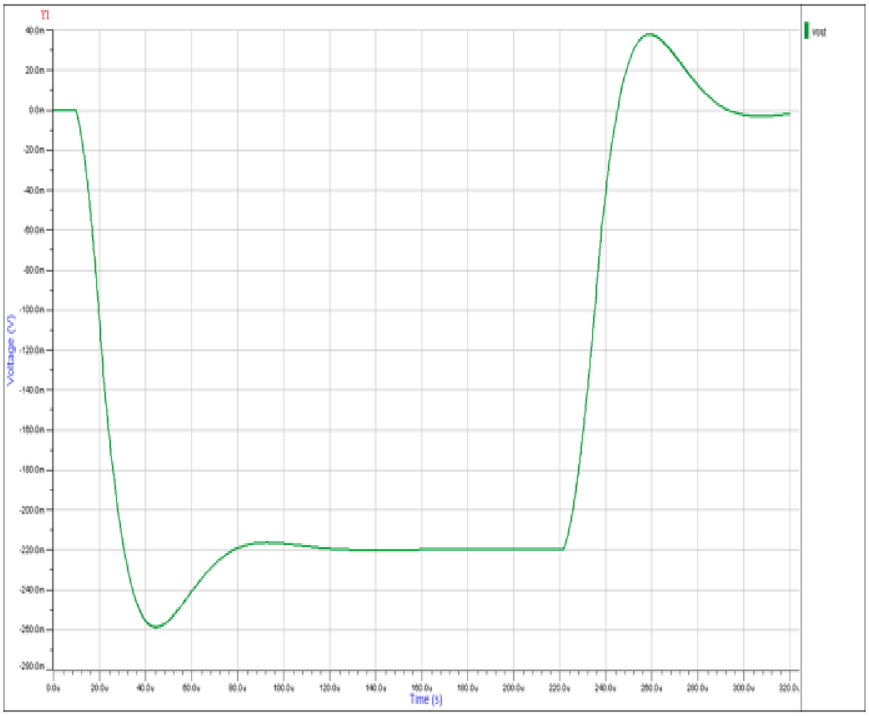


Figure 4 – Single RL model with DC offset

9. If desired, add a value of L2 approximately equal to 3X-6X L1. L2 allows the voltage to return to zero between current pulse edges. R2 can be used to add a DC resistance, or to dampen the effect of L2, but it is not typically needed.
10. Compare your results to the datasheet plot. If the pulse voltage is now too high, reduce the inductor value. You can sweep the L or R values to shape the curve to match the datasheet.
11. Observe the frequency domain results. You should see a peak in the KHz range.

Model Simulation Results

The L2 inductor can be swept to find a reasonable time domain response. In this example, L2 was swept from 600 – 1200 nH. The 3XL1 = 792 nH value is a good selection.

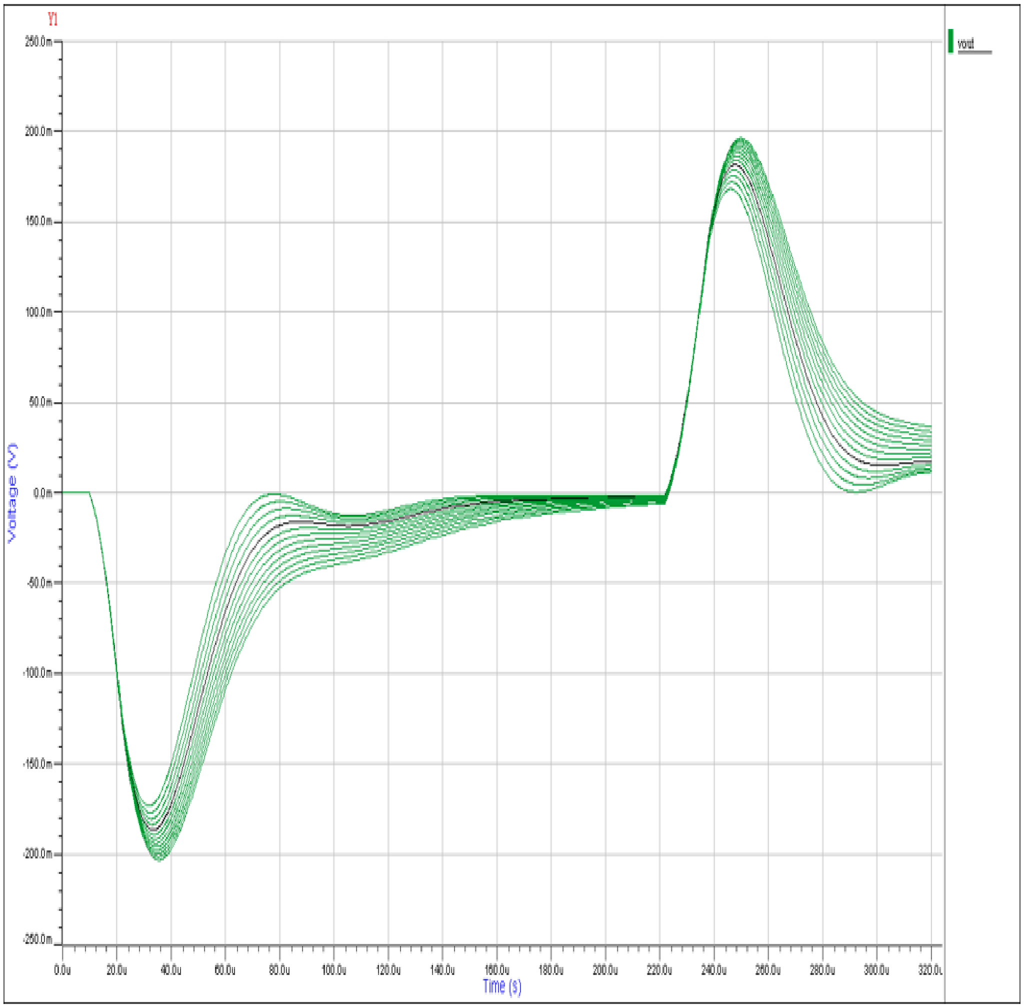


Figure 5 – Sweep of L2 from 600 nH to 1200 nH

Now we will compare a close-up view of the datasheet pulse response to our 2RL model. Figure 6 shows the datasheet plot:

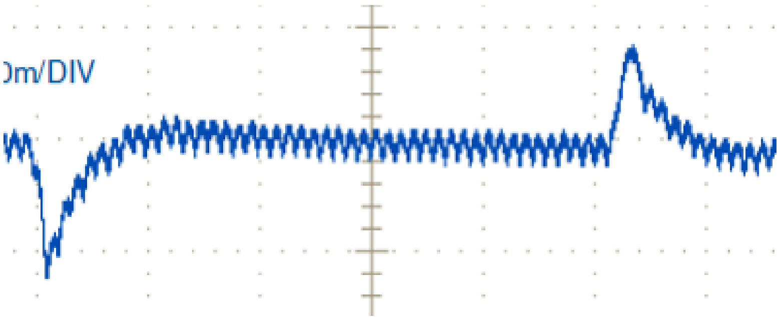


Figure 6 – Close-up view of voltage response of LM5145

Figure 7 shows the time-domain result, and Figure 8 shows the frequency domain results. This VRM model will impact the overall impedance of the PDN (Z-parameters) in the low frequency range.

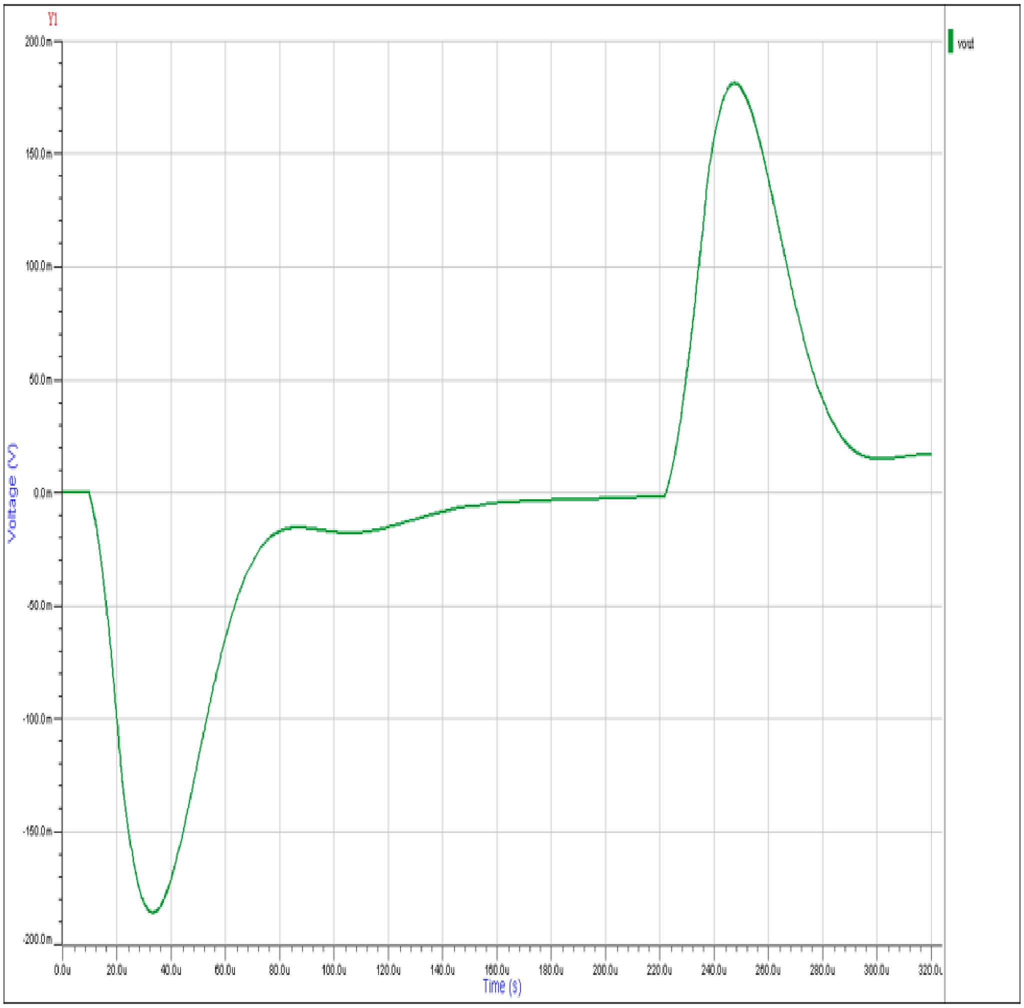


Figure 7 – 2RL model response in time domain

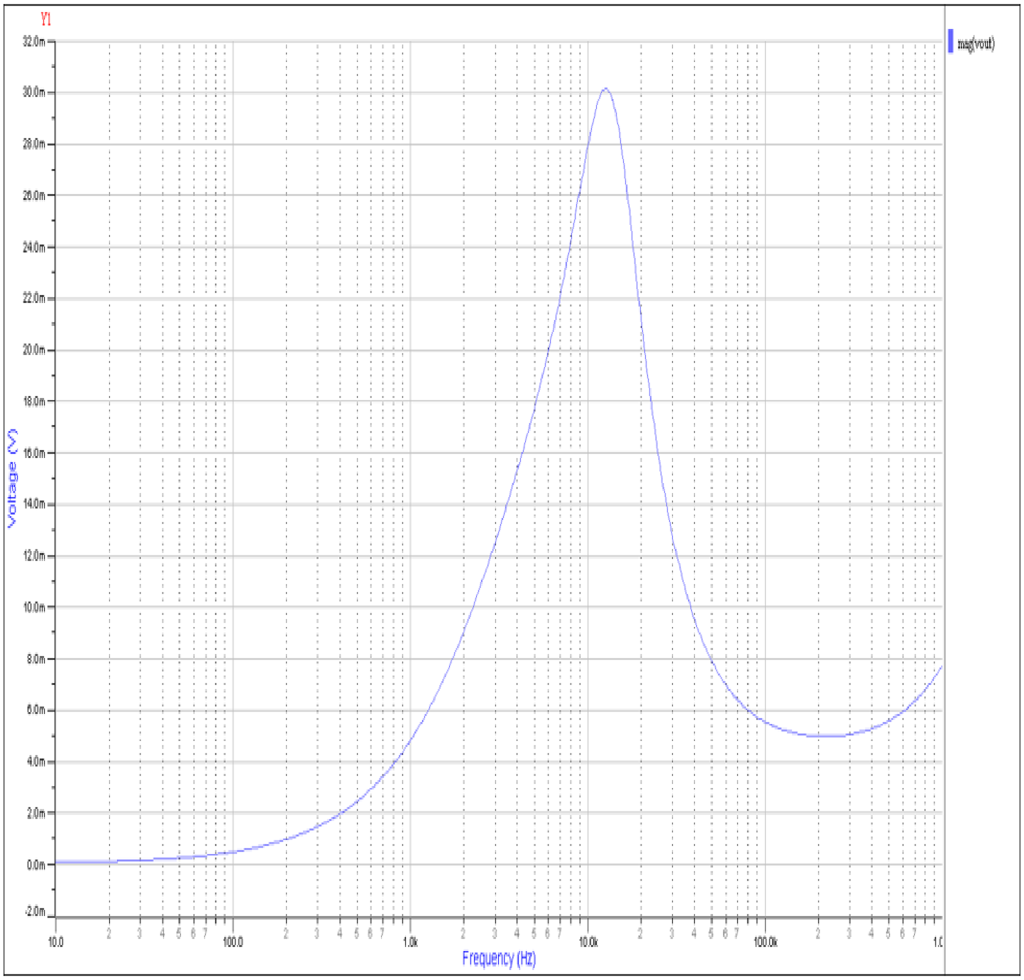


Figure 8 – 2RL model response in frequency domain

Additional VRM Modeling Example

We will follow the same steps from above to create a model from the step response of another VRM. The plot is shown in Figure 9.

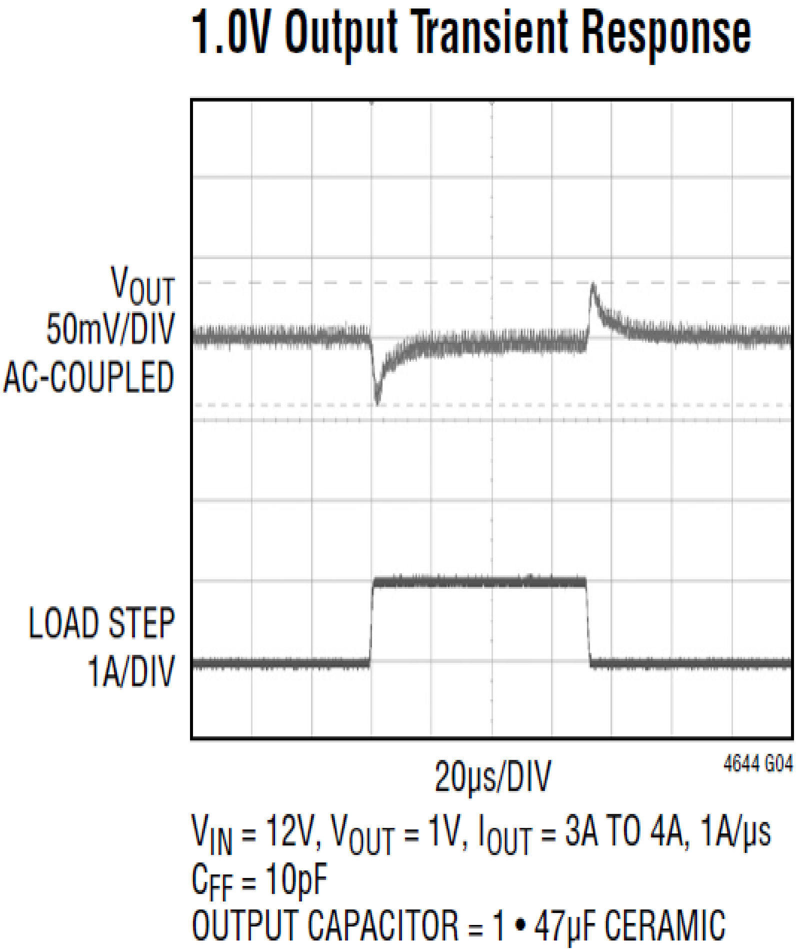


Figure 9 – Datasheet transient response of LTM4644

Steps to determine RL model:

1. C1 = 47 uF
2. ~1A/1us = di/dt of load = 1e6
3. 40 mV induced voltage
4. L = V /(di/dt) = 0.04/1e-6 = 40 nH
5. RT Vout = 2 us
6. R = L/(1.5*RT) = 13.3 mOhms
7. OK
8. OK
9. Add L2 = 6 * 40 nH = 240 nH

Figure 10 shows the completed 2RL model. Figures 11 and 12 show the time and frequency domain simulation results. Note the similarity of the response to the measured response in the datasheet shown in figure 9. While not a perfect model, it is generally accurate enough to use to make design tradeoff decisions.

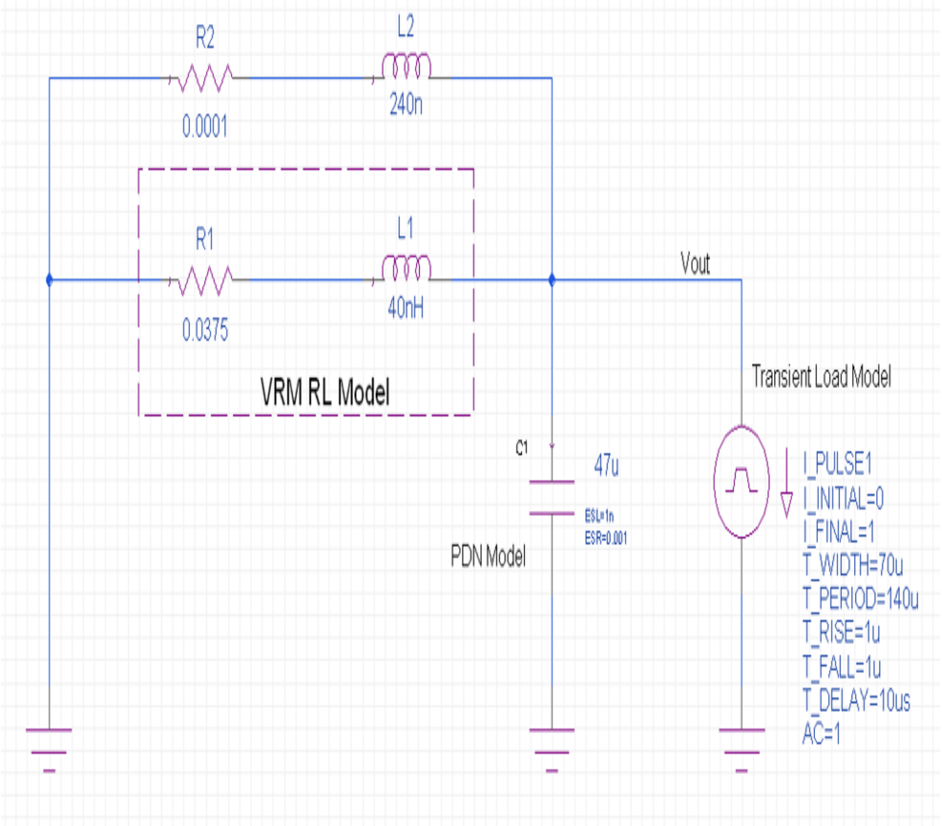


Figure 10 – 2RL model of LTM4644

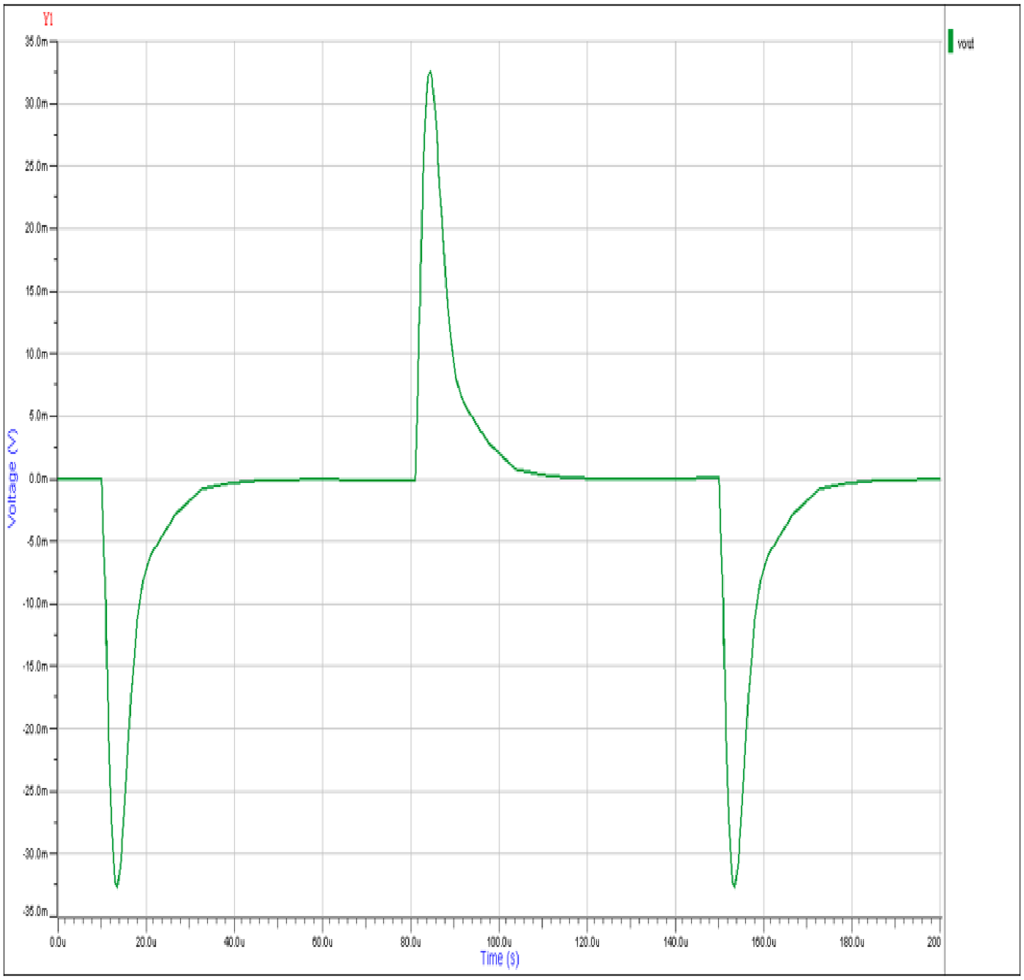


Figure 11 – Time domain response

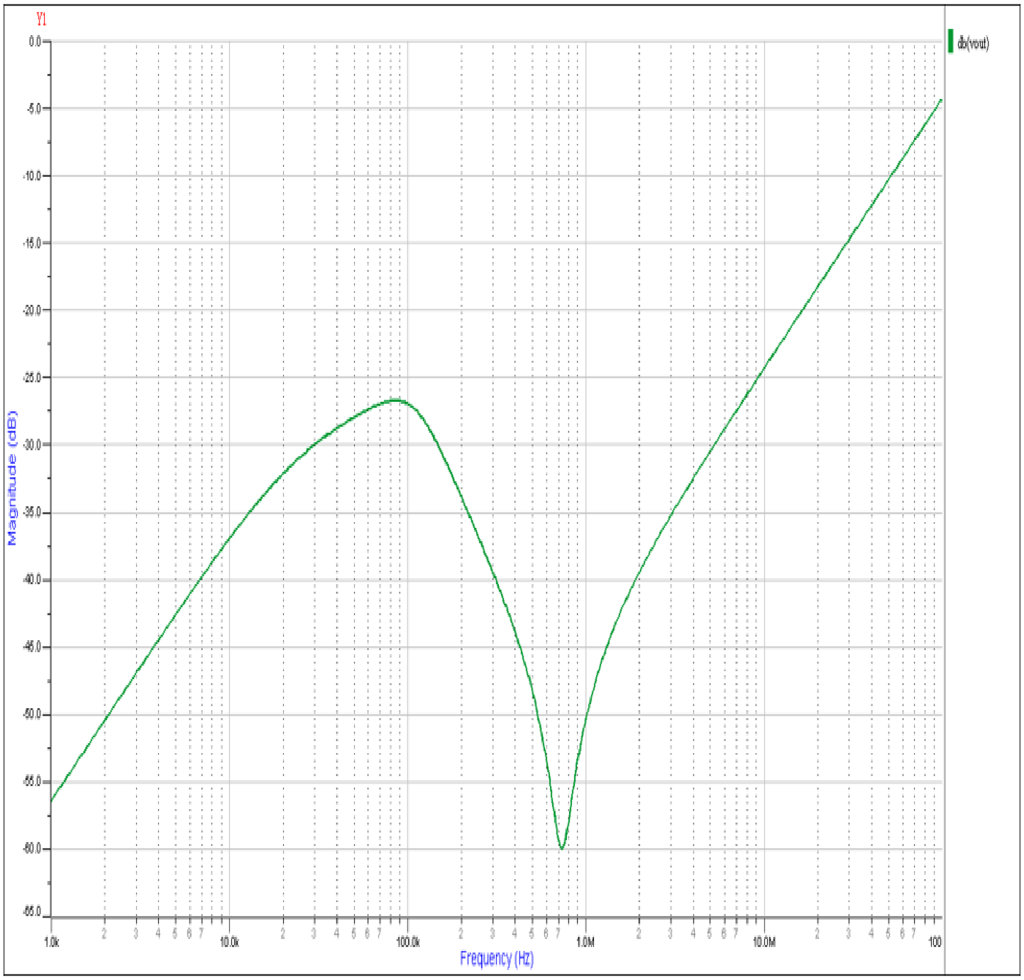


Figure 12 – Frequency domain response

Comparison of RL and 2RL Model

You may be wondering how important it is to include the second RL model to better shape the transient response. Figure 13 shows a comparison of the frequency domain response of the first VRM model in this document with the RL model (Red) and the 2RL model (Blue).

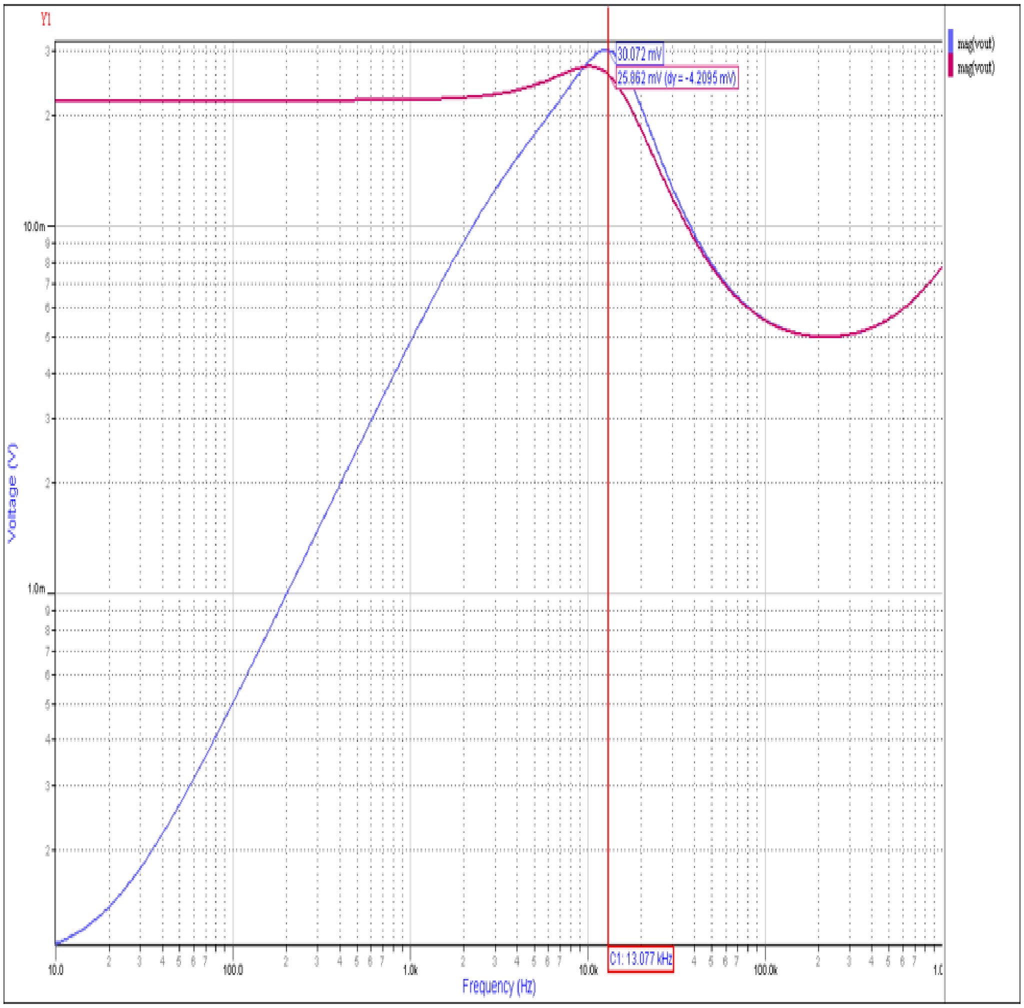


Figure 13 – Frequency domain comparison of RL (red) and 2RL (blue) models

The difference is not that great down to the first resonant peak, so this may be sufficient in many cases, especially if you are focused on designing the PDN in the range where higher-edge-rate transients are the issue. You may be tempted to lower the value of R to reduce the DC voltage, but this will make the resonant peak much higher, which would not accurately model the VRM's transient regulation capabilities.

Further Study

Often the designer would like to simulate the VRM along with the PDN model and also a package and die-capacitance model. These models can all be placed in a simulation tool such as HyperLynx LineSim or Xpedition AMS. Figure 14 shows an example of the second regulator model in this document combined with a PDN S-parameter model and basic package and die model.

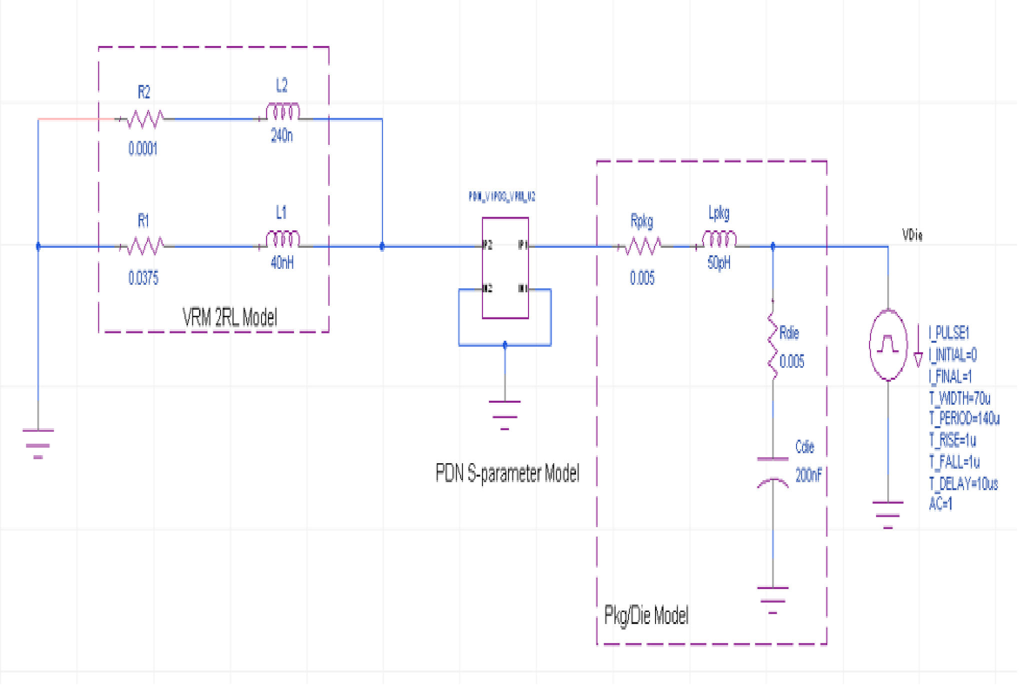


Figure 14 – Full frequency range model of PDN

The frequency domain and time domain results can then be generated, as shown in Figures 15 and 16.

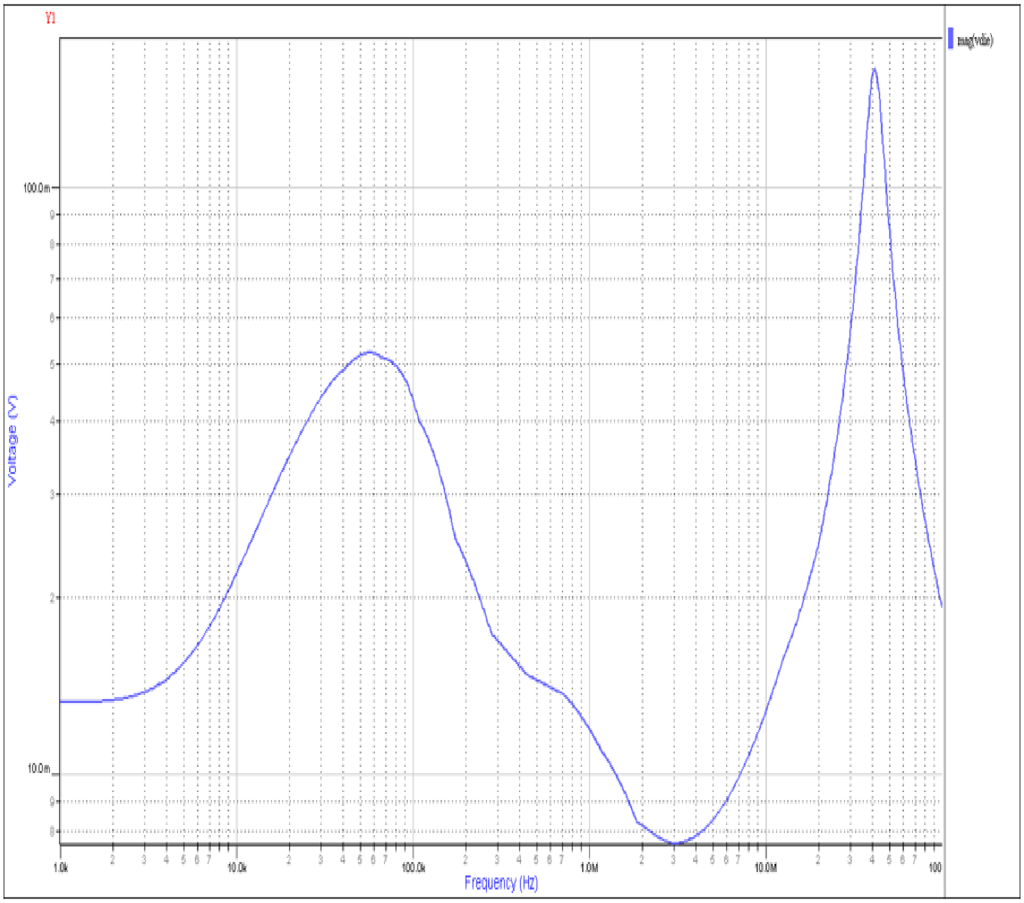


Figure 15 – Frequency domain results of entire PDN model

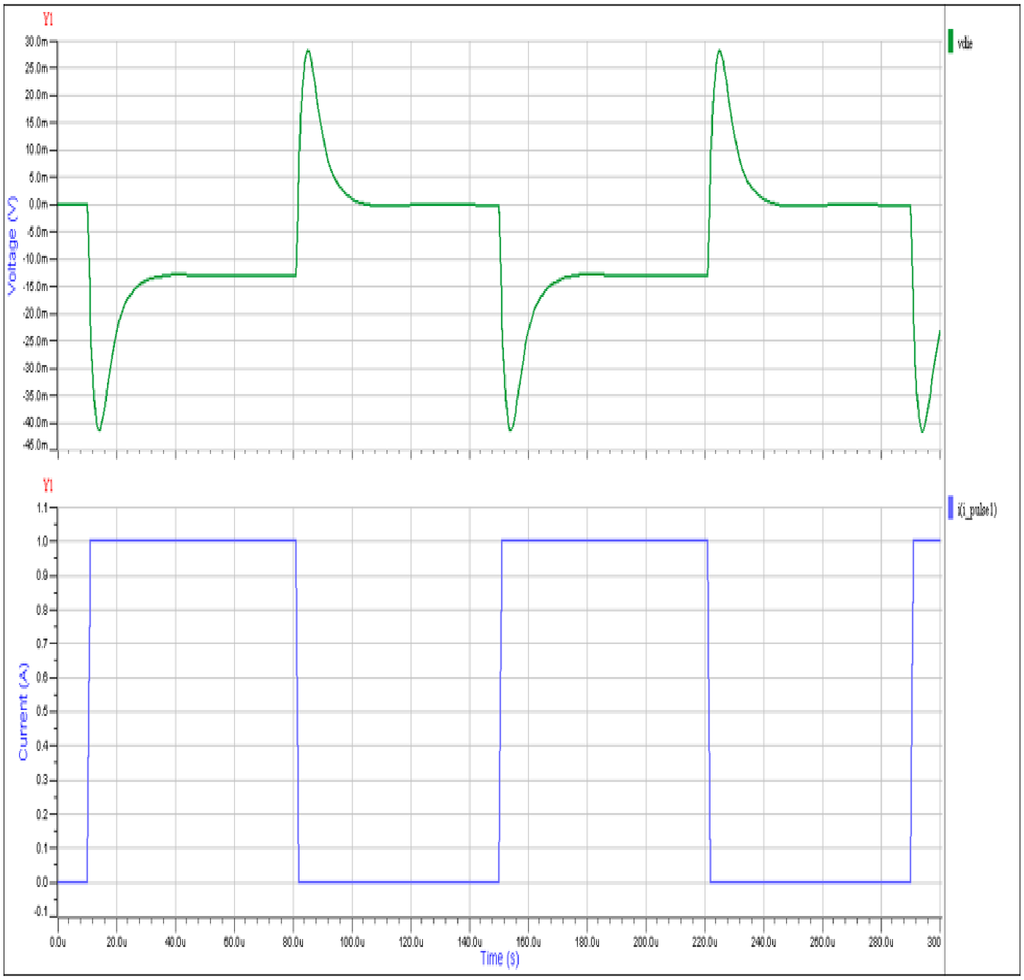


Figure 16 – Time domain results at the die

Summary

Using the step response plots from a voltage regulator datasheet, you can determine a reasonable model for a VRM that can be used in a power distribution network analysis. While not perfect, the model can be useful for exploring design tradeoffs and performance.