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Verifying Error Budget Analysis For A Buck Converter—On The Bench

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A previous article[1] looked at hand calculations for buck converter error budgeting and saw how they stacked up against simulations from EE-Sim, Maxim Integrated's online SIMPLIS power supply design and simulation tool. This naturally leads to a deeper question: how closely do the hand calculations and models match bench measurements? Because at the end of the day, it's the physical silicon that matters, and all the calculations and simulations in the world won't help if they don't adequately model your real power supply.

In this article, we go one step further in verifying the output voltage error budget analysis performed on the MAX17242 buck converter design by comparing simulation results with bench measurements on working hardware. We begin by checking the accuracy of the MAX17242 SIMPLIS model in simulating the load step response against measured results.

After observing the close correlation in results, we then explain the steps taken to tweak the IC model to reflect the characteristics of the actual silicon being tested, while also discussing the capabilities and advantages of Maxim's EE-Sim OASIS design tool. We then demonstrate, through further simulation and measurement, how the confidence achieved in developing and testing the model, enables us to accurately simulate the performance of the converter with respect to the voltage droop we set out to determine in the earlier article.

Finally, we sweep specific parameters to understand the range of potential transient responses across component and silicon variation. Nonidealities like capacitor or inductor variations contributed ±10-mV (0.3% of nominal 3.3 V) deviation to the droop voltage, illustrating the need to understand and account for expected physical component variations during simulation.

Load Step Responses—Simulated Vs. Measured

So, how do the models stack up to bench measurements? For the quick answer to that, check out Fig. 1, which compares measured and simulated results for a synchronous buck converter design based on the MAX17242 IC.[2] It shows the MAX17242EVKIT output responding to a load step, and the MAX17242 SIMPLIS model responding to the same load step in Maxim's new OASIS (Offline Analog Simulator Including SIMPLIS) design tool. The correlation, especially with regard to peak surge/sag voltage and recovery time, is remarkable.

Granted, this didn't come from the typical model, and for good reason: each piece of silicon responds a little differently, while each instance of the model is bound to respond identically. Model parameters are correlated to typical silicon parameters, so comparing them to a random IC is bound to introduce discrepancies. In order to establish the accuracy of the models, the model we used to generate the above step response has been tweaked slightly to match the values of the silicon on the bench, a process which we'll explain in detail below.

Determining the necessary adjustments requires a quick trip to the frequency domain for Bode plots. But once we've established that we can trust the model's results, we can use it to show the range of step responses predicted by process and component variation.

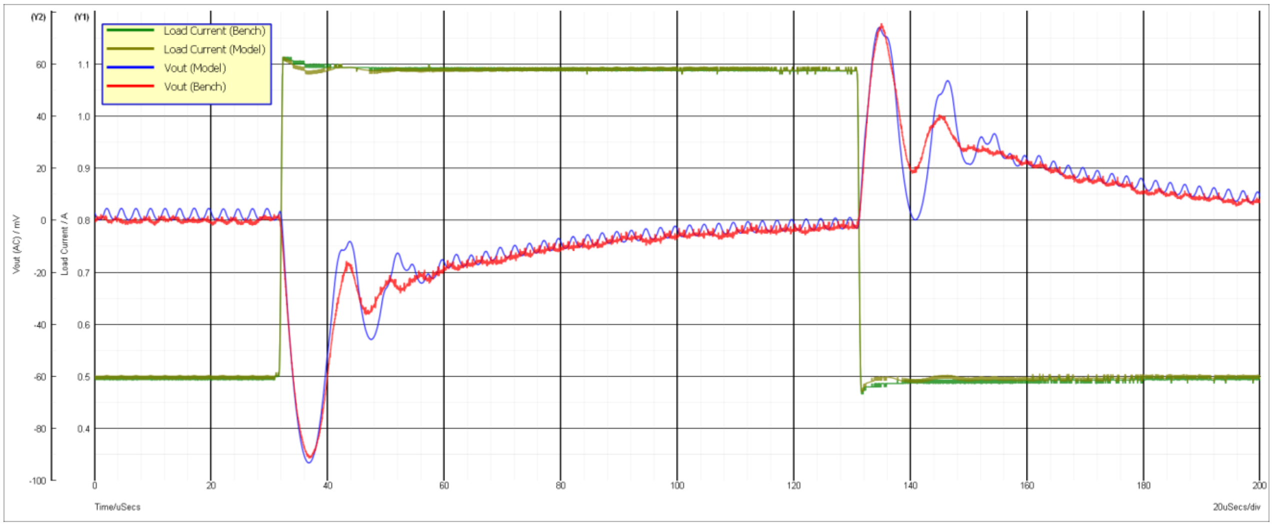


Fig. 1. Comparison of load step responses from a MAX17242EVKIT measured on the lab bench (output current, dark green trace and output voltage, red trace) versus the MAX17242 SIMPLIS model in an EE-Sim OASIS simulation (output current, light green trace and output voltage, blue trace).

Correlation Process

When it comes to diagnosing issues and finding discrepancies in a power supply, there are few tools in a power designer's toolbox more powerful than the Bode plot. The presence of ringing on a transient waveform hints that a problem exists, but it does little to identify the source of the issue. Moving to the frequency domain provides more information about where the issue is coming from and how to fix it.

When it came to correlating the model parameters to the hardware, we worked exclusively in the frequency domain. Once the Bode plots lined up, the time domain correlation displayed in Fig. 1 happened by itself.

Maxim uses SIMPLIS, in part because you can't take a quick trip to the frequency domain with SPICE. You either have to stop and take the additional time to create (and correlate) a linearized average model to run in a SPICE ac simulation or work tediously in the time domain by settling and running the time domain model over and over again with different test signal frequencies in long time-domain SPICE simulations. You would then perform FFT post-processing for each output and finally, manually stitch together the FFT results into Bode plots.

On the other hand, the SIMPLIS simulator included with Maxim’s new EE-Sim OASIS design tool provides a periodic operating point (POP) analysis that quickly settles the time domain model. It includes a proprietary linearizing/averaging algorithm that seamlessly generates Bode plots directly from extracted frequency domain data. Ac and transient data are effectively derived from the same model in a single simulation, speeding up the correlation process by orders of magnitude.

Speaking of speed, in addition to the Bode plot advantages, the switching converter time domain simulation in SIMPLIS is simply faster than in SPICE. Importing the model into Maxim's EE-Sim OASIS design tool provides the ideal environment to rapidly tweak and test the model in both time and frequency domains.

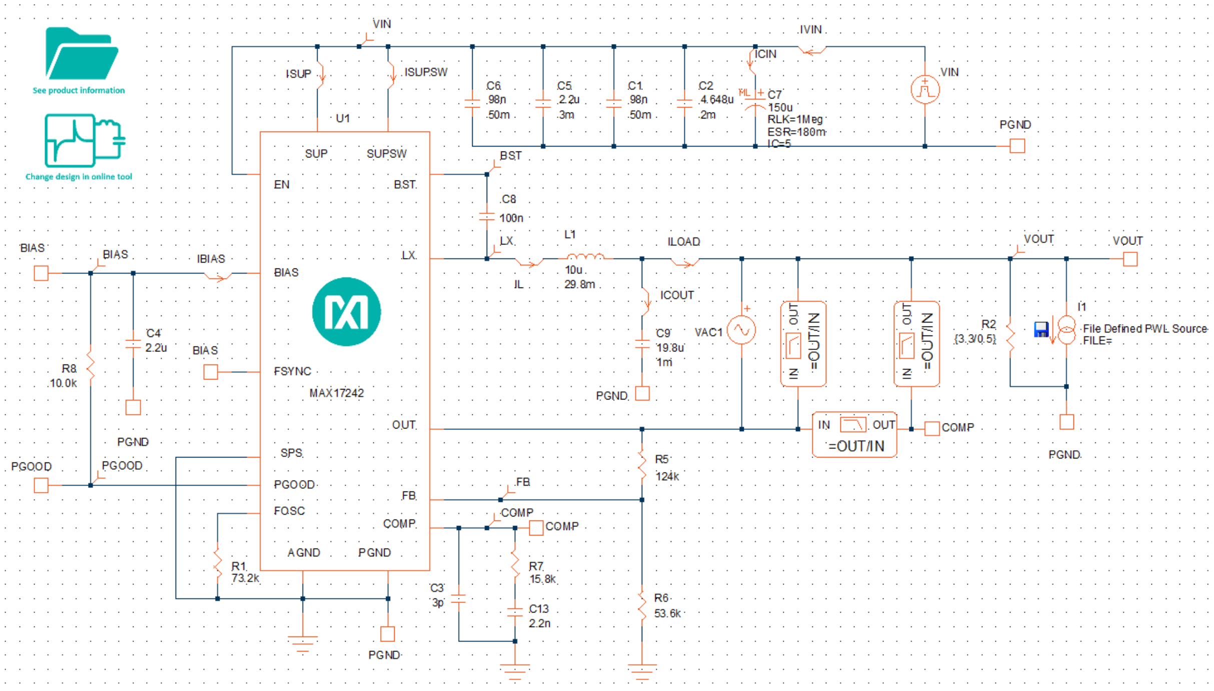


Fig. 2. The schematic used in EE-Sim OASIS to model the MAX17242EVKIT. Input and output capacitors have been derated from schematic values based on dc voltage. Three separate Bode probes allow the measurement of the full loop transfer function, as well as individual power stage and compensator stage transfer functions.

The first thing we did with the MAX17242 evaluation board was to run ac analyses on the control loop, which we compared to the simulations from a typical model placed in an identical circuit (Fig. 2). The first of the three Bode probes in the schematic allows us to capture the full-loop transfer function, while the other two allow us to split it up into the individual compensator (OUT to COMP) and power stage (COMP to OUT) transfer functions. This setup was mimicked in the bench measurements, and the model and bench results are overlaid in Fig. 3. The plots are certainly similar, but there are clear discrepancies with certain poles and gain values.

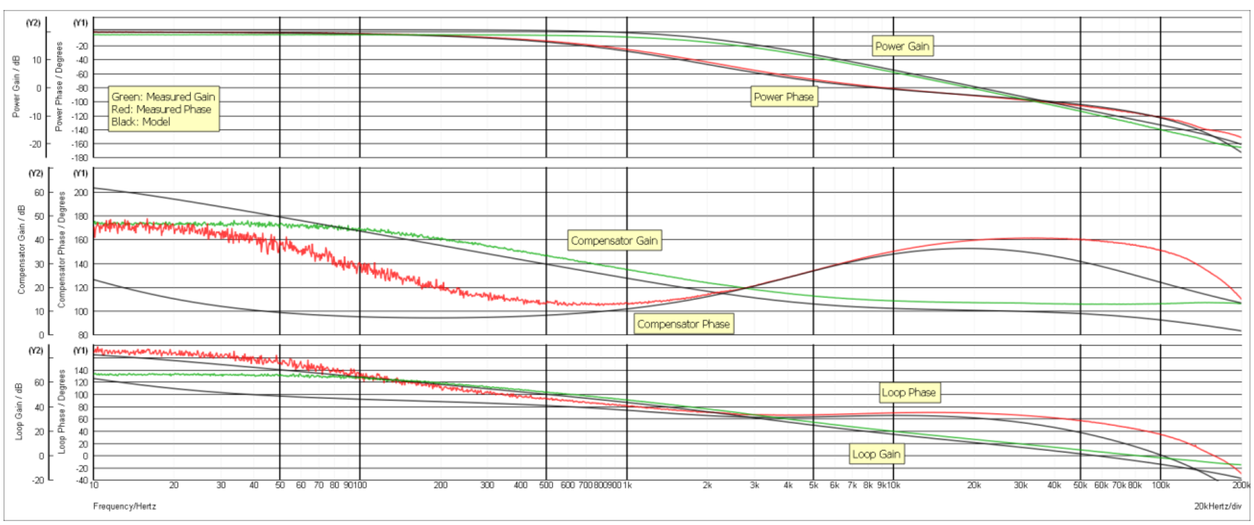


Fig. 3. Bode plots showing gain and phase (top to bottom) for the power stage, compensator stage, and full loop for both the bench measurement and the typical model.

By splitting the control loop, the source of the discrepancies between the model and the hardware becomes obvious. The power stages of the model and the board are almost identical, but in the compensation stages the dc gain of the model is too high, and the first pole happens too early. By pushing the transconductance gain and output resistance of the error amplifier away from their typical values (but still within spec), we can push the model's behavior to mimic what we observe on the bench.

The output resistance and transconductance gain were the only parameters we touched, and the result is shown in Fig. 4. The measurement and the model neatly overlap one another, with gain never deviating by more than 2 dB and phase response typically within 5 degrees or closer through the crossover frequency.

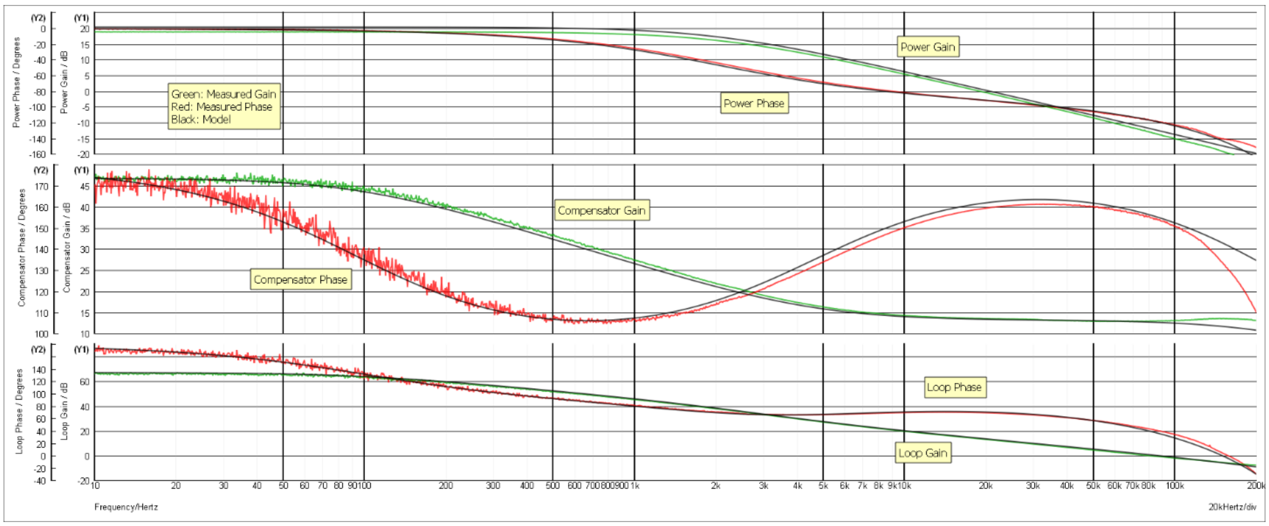


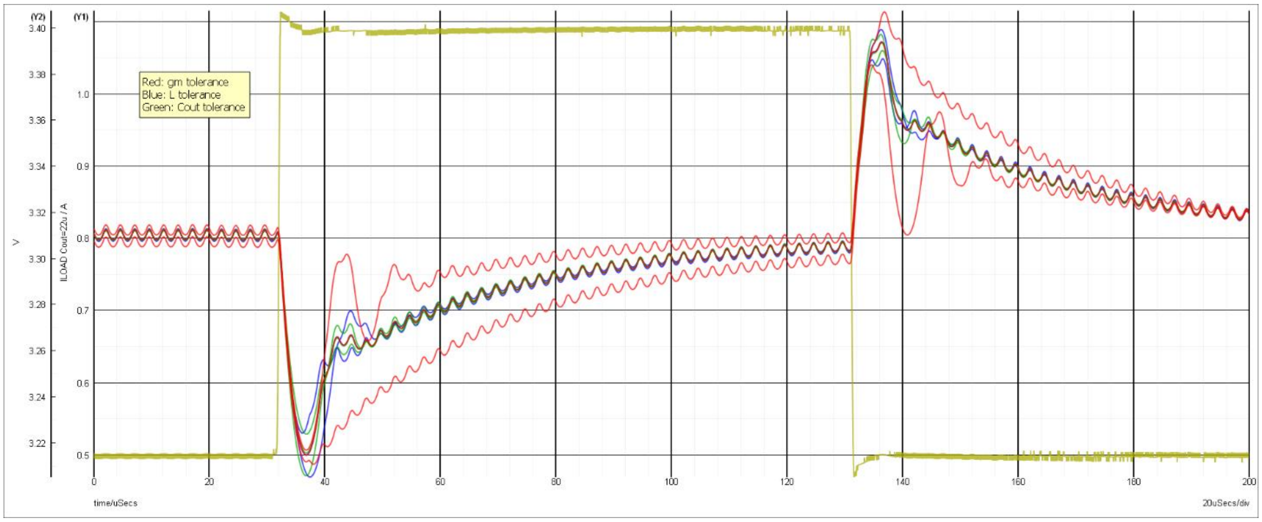
Fig. 4. Bode plots showing gain and phase (top to bottom) for the power stage, compensator stage, and full loop for both the bench measurement and the correlated model.

Once the measured and modeled Bode plots lined up, we moved on to the transient analysis. We began the testing on the hardware, taking careful measurements of both the load current and the output response. To keep the stimulus identical and eliminate as much discrepancy as possible between the model and the bench, we used the measured load current to create a custom current source in the simulation environment. This allowed us to test the model using the same load step that the hardware experienced, rather than an idealized approximation.

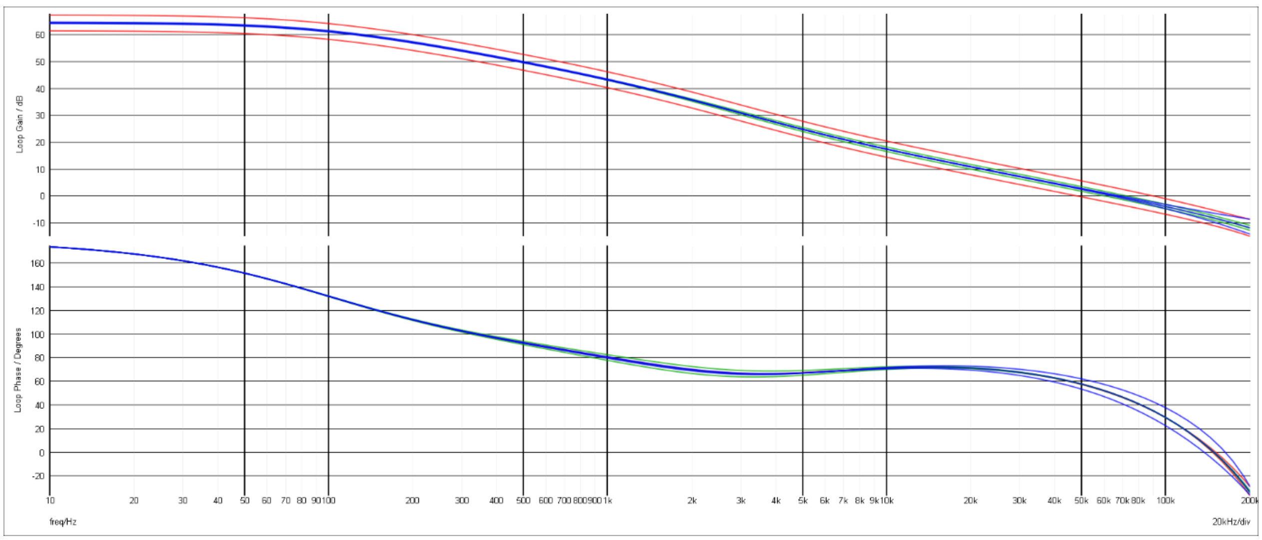
At this point, having correlated the Bode plots and supplied the same stimulus for the physical and modeled circuits, the transient responses lined up without any extra work required. Fig. 1 is evidence that, providing for variation within silicon, the SIMPLIS models used within EE-Sim provide exceptionally accurate responses and EE-Sim is a reliable tool for the design and simulation of real-life power supplies.

Extrapolating Results

Establishing a high level of trust in the model allows us to not only design and simulate typical power supply designs, but also sweep specific parameters to understand the range of potential transient responses across component and silicon variation. Fig. 5 illustrates this, showing the expected load step responses and Bode plots for ±10% tolerance in the load capacitance, ±20% tolerance in the inductor, and ±3-dB variation in error amplifier transconductance.



(a)



(b)

Fig. 5. The expected range of transient responses (a) and frequency responses (b) for typical variations in inductance, output capacitance, and error amplifier transconductance.

These results match up with intuition: increasing the output capacitor or decreasing the inductor value will decrease the magnitude of the voltage droop after the load step, but does little to impact the overall settling time. Increasing the error amplifier transconductance, on the other hand, has little impact on the voltage droop, but gives a quicker recovery to the nominal output at the expense of more ringing during the recovery.

Conclusion

In order to effectively use our design tools, we need to trust them, which requires us to establish when they are accurate and when they are not. When it comes to the SIMPLIS models used in EE-Sim design tools, comparisons to bench data show that we have a high degree of confidence that our simulation results reflect the expected behavior of the part.

The nature of simulation, however, means our models and simulations are confined to typical values, and a more complete picture of our end design requires us to consider potential silicon variations that a model won't account for.

In our situation, the transient droop voltage predicted by the compensated model matched the measurement to within tenths of a millivolt. However, nonidealities like capacitor or inductor variations contributed ±10-mV (0.3% of nominal 3.3 V) deviation to the droop voltage, illustrating the need to understand and account for expected physical component variations during simulation.

References

1. "Online Simulation Validates Output Error Budget Analysis For Buck Converter" by Brooks Leman, Mark Fortunato and Nazzareno (Reno) Rossetti, How2Power Today, January 2018. This article is also posted as a Maxim Design Solutions No. 60, Rev 0; November 2017.

2. MAX17242 3.5-V to 36-V, 2-A synchronous buck converter product page.

About The Author

Benjamin Lampe is an applications engineer at Maxim Integrated. He holds a BSEE degree from Santa Clara University, where he is also pursuing his MSEE.

Brooks Leman is a senior principal member of Technical Staff at Maxim Integrated. Brooks has been developing, applying, and modeling switching power conversion techniques in Silicon Valley for close to 40 years. He holds several patents and has published dozens of technical conference papers, magazine articles, and application notes. He holds BSEE and MSEE degrees from Santa Clara University where he also teaches a power conversion graduate course.

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For further reading on power supply modeling, see the How2Power Design Guide, and locate the Design Area category and select "Modeling and Simulation."