Sandia National Laboratories

END TO END - MODELING, CONTROLLER OPTIMIZATION, AND TESTING OF SWITCHED MODE POWER SUPPLIES

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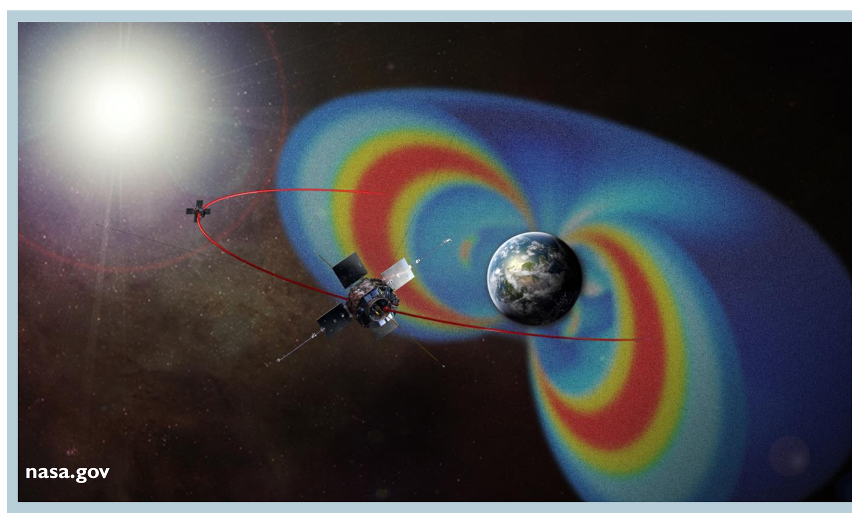
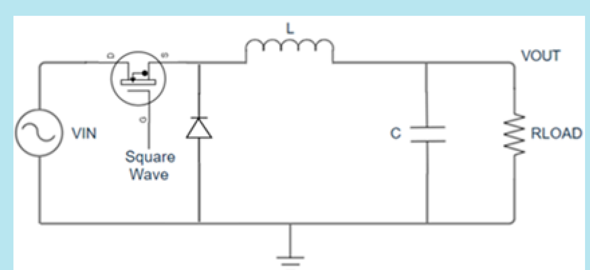
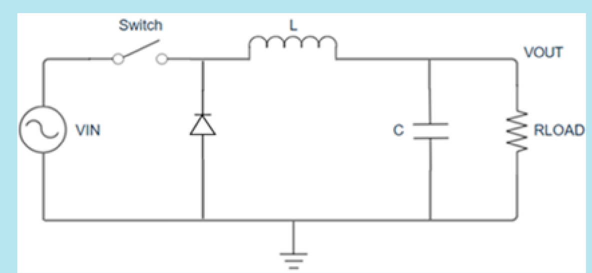
BACKGROUND / SUPPORTING MISSION

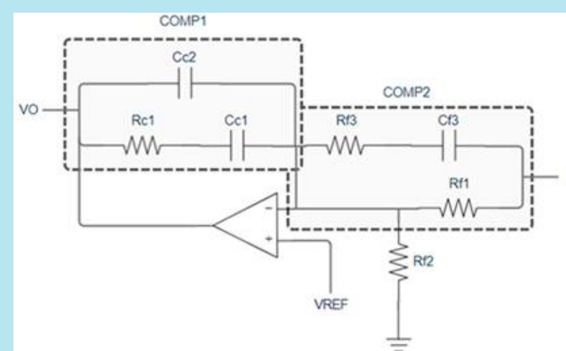


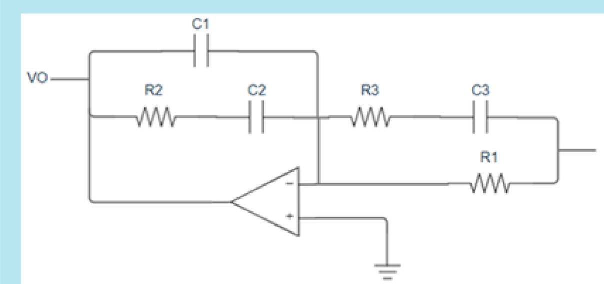
- Broadening the understanding of, and optimizing, Switch Mode Power Converters (SMPCs) and DC-to-DC feedback-controlled conversion, like a Buck Converter with a Type Three (III) Compensator system, the focus of this project, and its analysis is key to the future implementation and development of radiation hardened/resilient systems and technology for use in space missions and nuclear disaster response

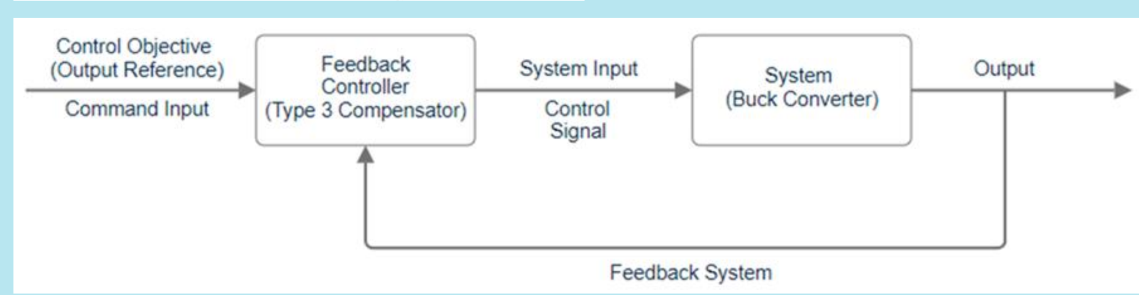
BUCK CONVERTER & TYPE 3 COMPENSATOR





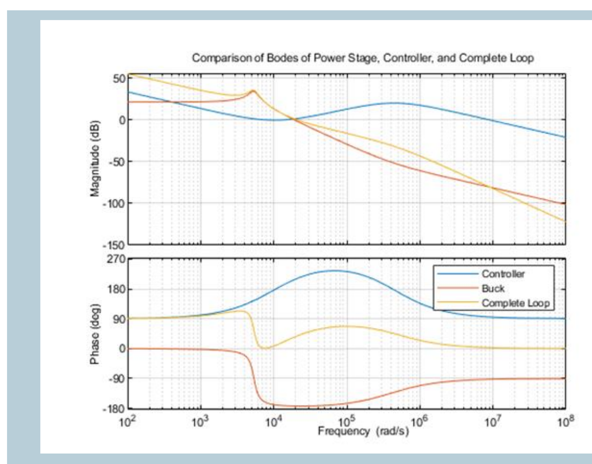


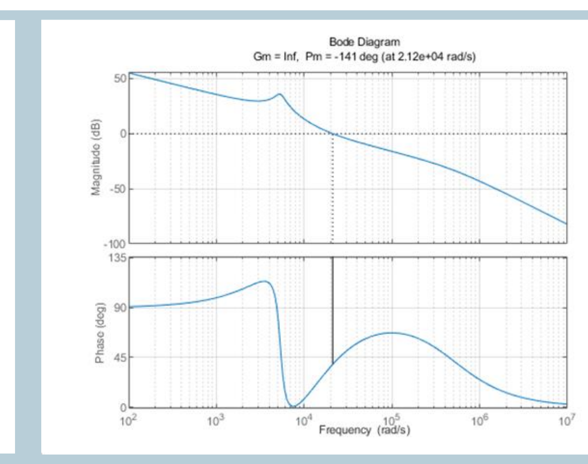




- Research Objectives
  - Create a method to obtain the bode plot of a live DC-to-DC feedback-controlled Switch Mode Power Converter (SMPC) with a Tektronix Mixed Signal Oscilloscope
  - Specifically focus on a Buck (step-down) Converter with a Type Three (III) Compensator
  - Compare its results with Simulink and MATLAB simulations for accuracy

BODE PLOTS FROM MATLAB SIMULATIONS



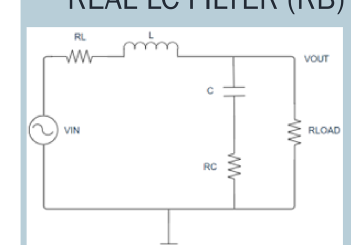


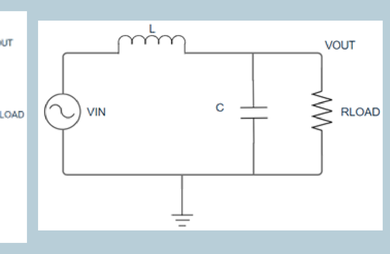
$$H(s)_{RB} = \frac{V_{out}}{V_{in}} = \frac{1 + (C * RC) * s}{1 + \frac{RL}{R} + \left(\frac{L}{R} + RC * C + RL * C + \frac{RL * RC * C}{R}\right) * s + \left(\frac{R + RC}{R}\right) * L * C * s^2}$$

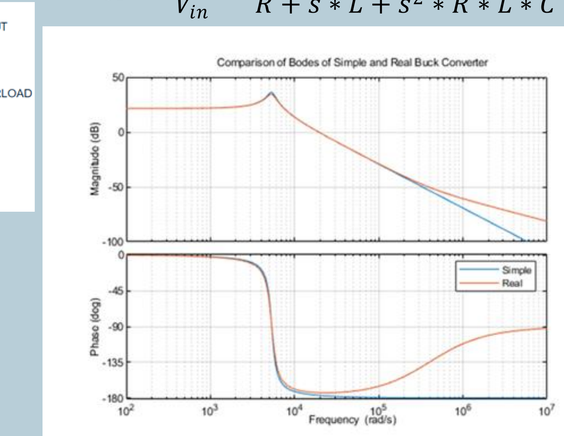
SIMPLE LC FILTER (SB)

REAL LC FILTER (RB) - Parasitic Resistance

$$H(s)_{SB} = \frac{V_{out}}{V_{in}} = \frac{R}{R + s * L + s^2 * R * L * C}$$





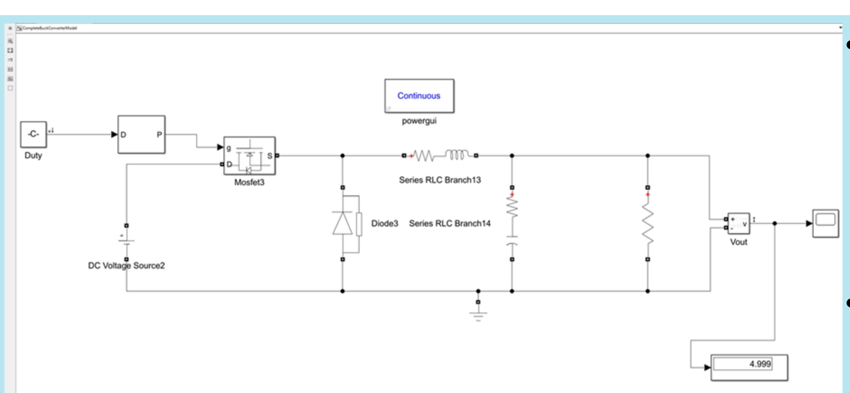


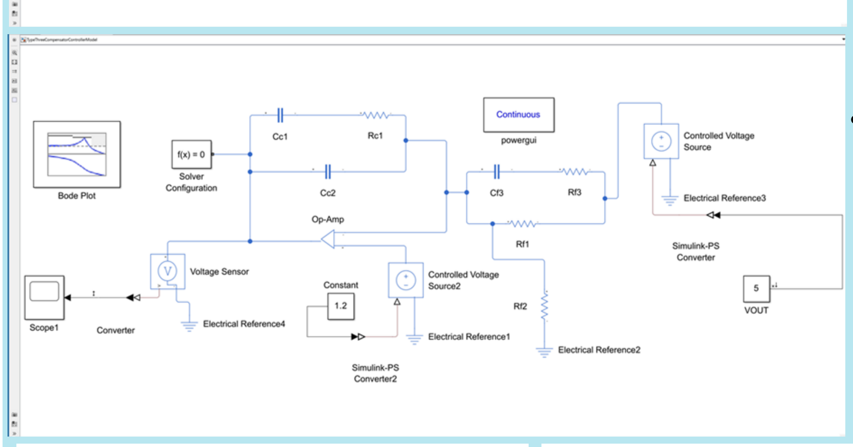
- $H(s)_{COMP+}$ represents the transfer function, that was made in MATLAB, with Reference Voltage, Voltage Divider, and Specific Op-Amp Implementations (Both transfer functions produced the same bode plot seen above)

$$H(s)_{SYSTEM} = H(s)_{RB} * H(s)_{COMP} = H(s)_{RB} * H(s)_{COMP+}$$

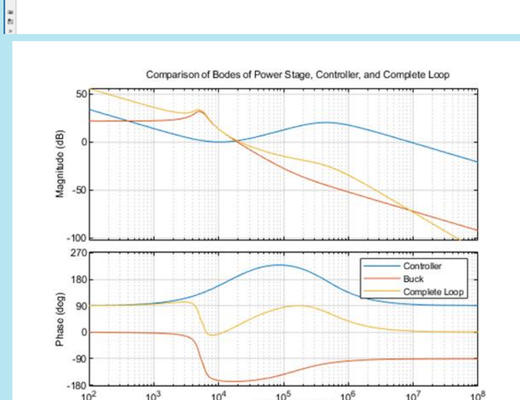
$$H(s)_{COMP} = \frac{V_{out}}{V_{in}} = -\frac{(s * C3 * (R1 + R3) + 1) * (s * C2 * R2 + 1)}{(s * R1 * (C1 + C2)) * (s * C3 * R3 + 1) * \left(s * \left(\frac{C1 * C2}{C1 + C2}\right) * R2 + 1\right)}$$

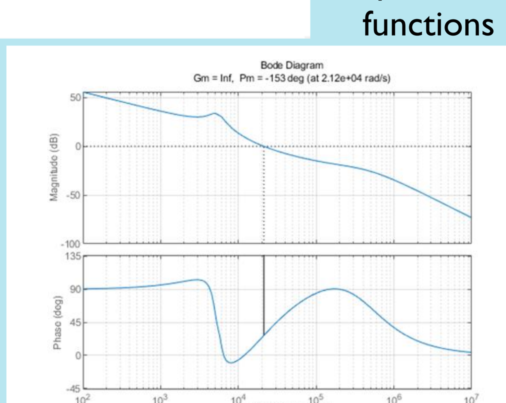
BODE PLOTS FROM SIMULINK SIMULATIONS





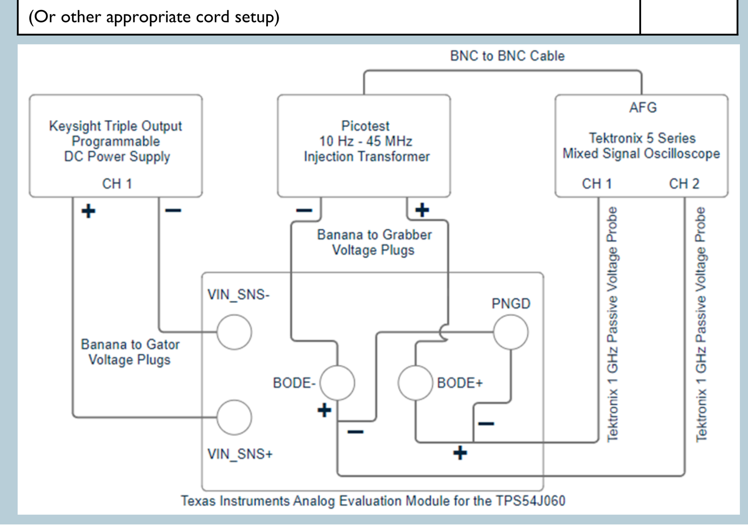
- Created Simulink models and configured them with appropriate components and values to operate correctly
- Changed the values to match the values used in the previous derived transfer function testing
- Found way to get a transfer function to represent the simulation that could be used in MATLAB to create bode plots using the specialized MATLAB functions

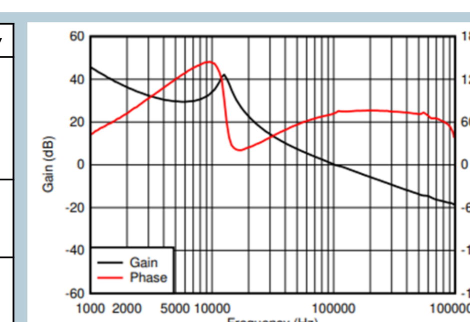


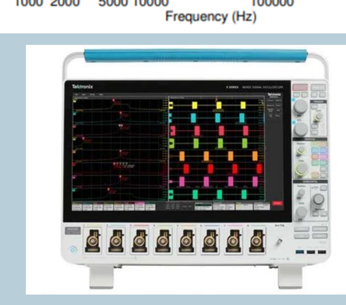


HARDWARE TOOLSET & TEST PROCEDURE

System or Part	Quantity
Tektronix 5 Series Mixed Signal Oscilloscope (MSO58B) (2 GHz) * (Or other appropriate Tektronix Mixed Signal Oscilloscope) *Must have SUP5-PWR and SUP5-AFG licenses.	1
Picotest 10 Hz - 45 MHz Injection Transformer (J2101A) (Or other appropriate Injection Transformer)	1
Texas Instruments Analog Evaluation Module for the TPS54J060 (TPS54J060EVM-067) (Or other DC-to-DC Feedback-Controlled Converter that fits requirements)	1
Tektronix TPP1000 1 GHz Passive Voltage Probe (Or other appropriate Voltage Probe)	2
Keysight Triple Output Programmable DC Power Supply (E36313A) (Or other appropriate DC Power Supply)	1
Banana to Grabber Voltage Plugs (Or other appropriate cord setup)	1
Banana to Gator Voltage Plugs (Or other appropriate cord setup)	1
BNC to BNC Cable (Or other appropriate cord setup)	1







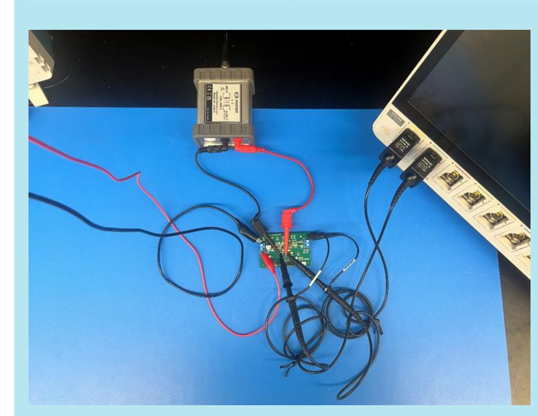
- The results of the test confirmed that the hardware tool set and test procedure will produce the correct bode plot of a DC-to-DC converter

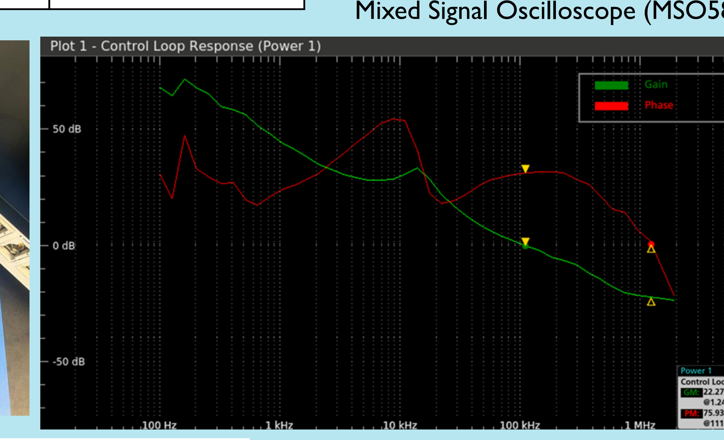
BODE PLOTS FROM HARDWARE

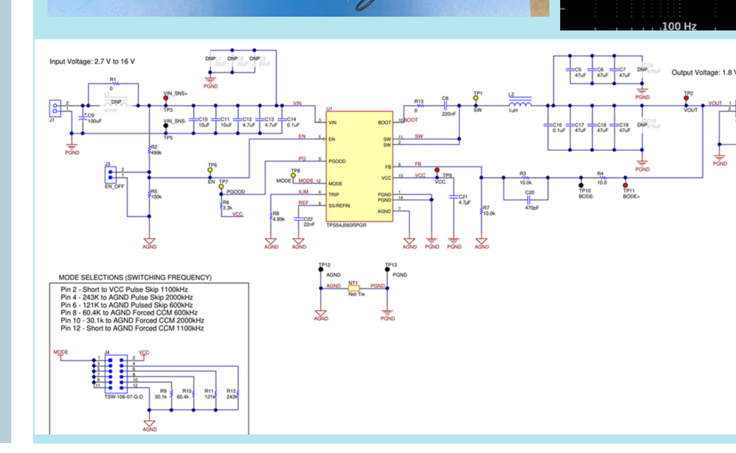
Program Name: Bode Plot	**Test Item:** TI Analog Eval Module for TPS54J060	**Test Plan (TK):** Test Plan is in sub-section 4.3.5
Test Location: George H. W. Bush Combat Development Complex 717 RELLIS Parkway Bryan, TX 77807	**Test Start:** Time: 1030 Date: 06/21/2024	**Test End:** Time: 1045 Date: 06/21/2024
Program Lead: Matthew McDonough	**Test Lead:** Kyle Rex	

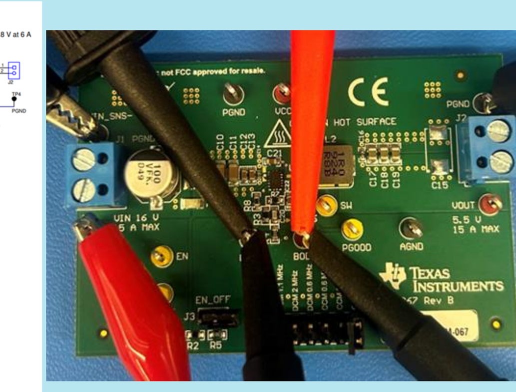
- TPS54J060EVM-067 Eval Board

- Bode Plot from Tektronix 5 Series Mixed Signal Oscilloscope (MSO58B)

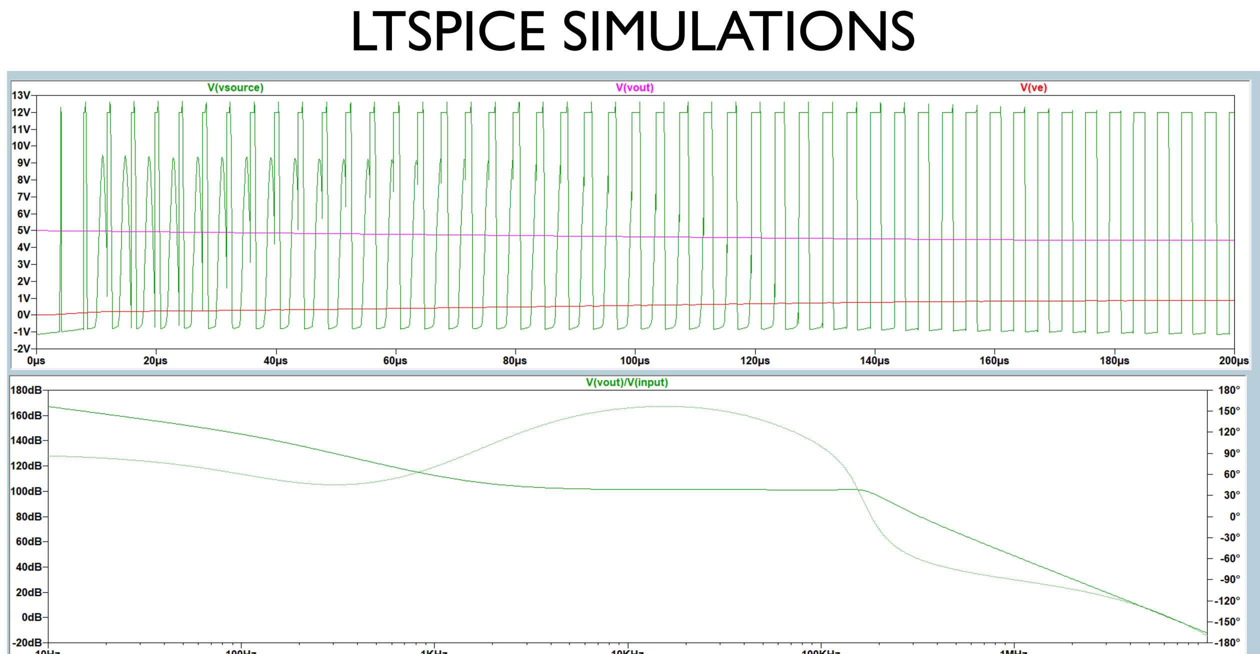




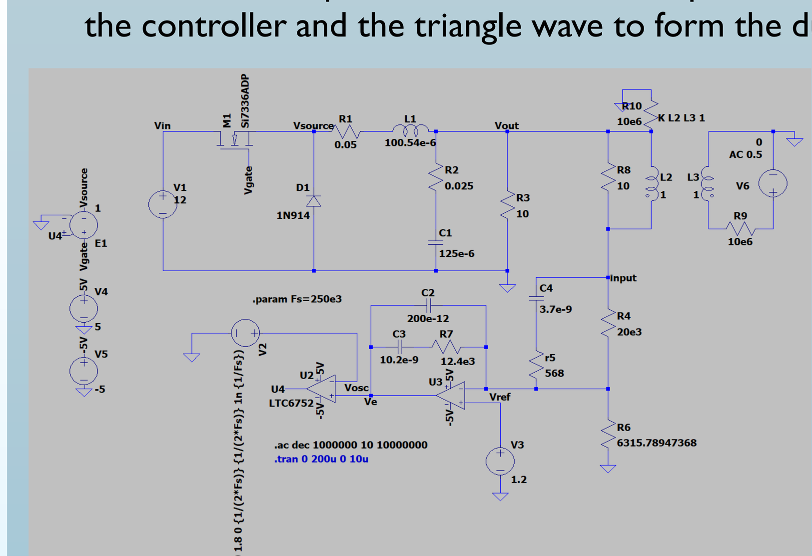




LTSPICE SIMULATIONS

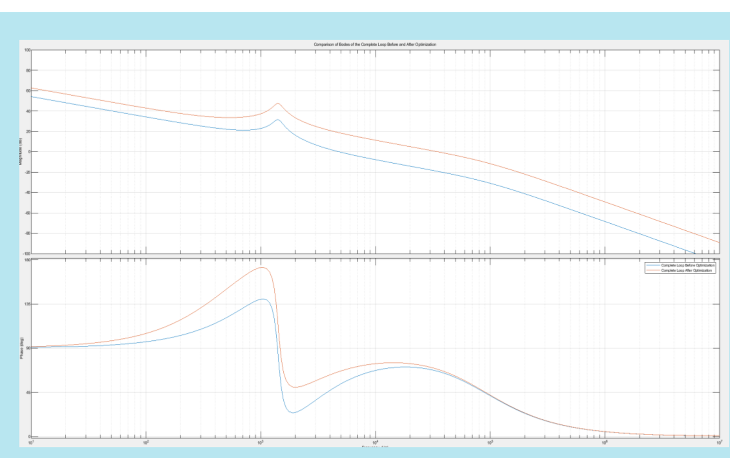


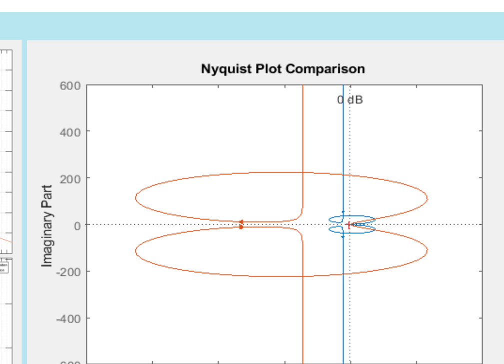
- LTspice simulations of a Type-III Compensator controlled Buck Converter were taken to evaluate the accuracy of the Bode Plots derived from MATLAB
- A LTC6752 comparator was used to compare the voltage error output from the controller and the triangle wave to form the duty cycle

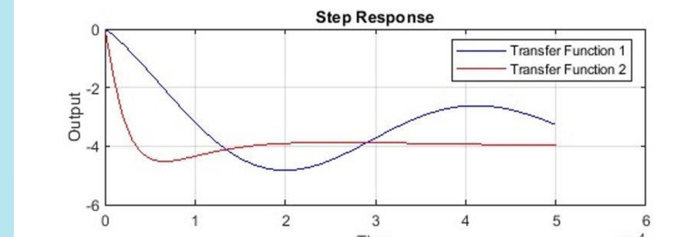


- A Si7336ADP MOSFET acted as the switch for the system
- The voltage of the Source terminal of the MOSFET should be switching from ground to the input voltage
- The output voltage is 5V
- The implementation of the diode makes Buck Converter unsynchronous

CONTROLLER OPTIMIZATION METHOD



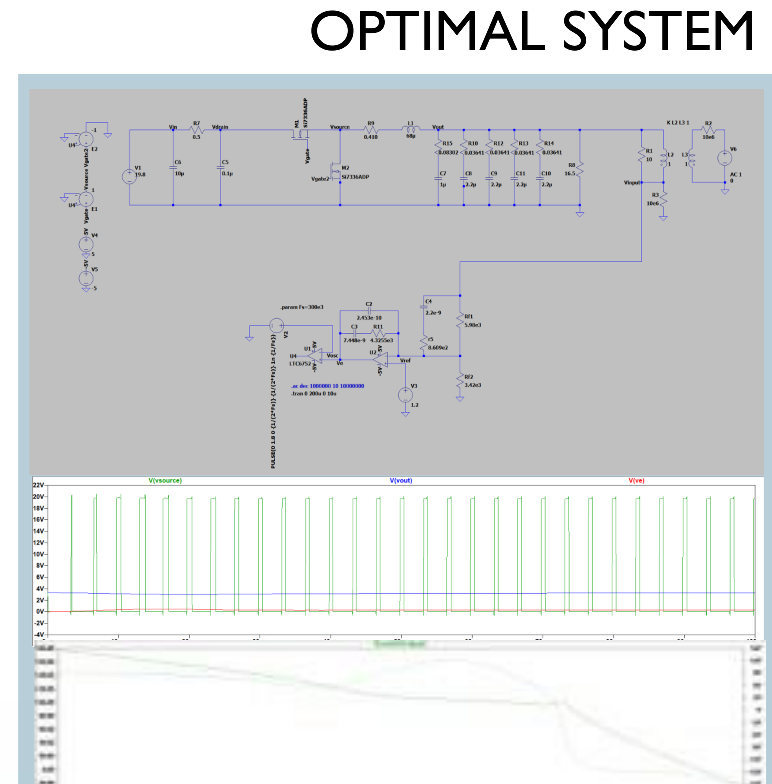




- Next, we built an optimization routine for the system in MATLAB
- We used a nonlinear equation solver tool in MATLAB called fmincon

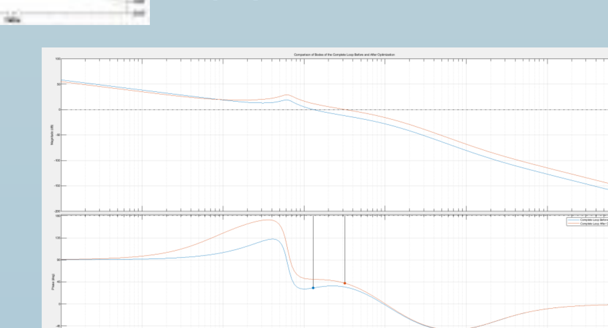
- For stability, we wanted the Gain Margin, Phase Margin, and Crossover Frequencies within optimum ranges
- We also wanted to make sure that when the gain was greater than 0dB, the phase was larger than –135 degrees
- For the transient response, we looked at the steady-state error, overflow, rise-time, and settling-time
- The code was written to keep overflow at a maximum of 10% while minimizing the other parameters
- The output poles and zeroes of the function were used to calculate the optimum component values through the transfer function equations

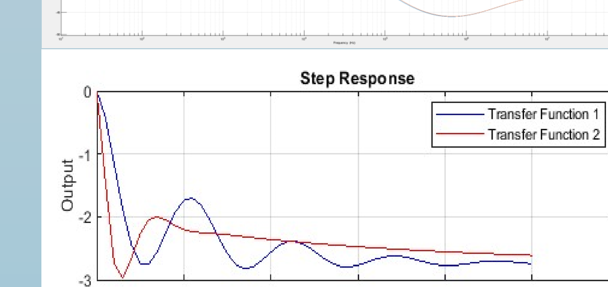
OPTIMAL SYSTEM DESIGN



- To test these methods, we were given the task to optimize the controller values for an actual Buck Converter under development for another program
- The parasitic resistance values were taken from the datasheet of the specific capacitors and inductors in the physical circuit

- The LTspice model was changed to be synchronous
- The MATLAB code was changed to account for the system's positive phase shift
- The optimization routine was able to reduce oscillation at the step-response of the closed-loop system





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