AN1541

Using the MCP19111 Design Tools

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INTRODUCTION TO THE MCP19111

The MCP19111 is a stand-alone, mixed-signal, synchronous buck pulse-width modulator (PWM) controller for many step-down converter applications. The device combines high-voltage capability with precise analog technology and a PIC® microcontroller core to develop flexible step-down DC-DC converter applications. Common applications include Point-of-Load (POL) converters, intelligent LED drivers and programmable battery chargers. The device is capable of efficiently converting 4.5V-32V input voltage down to an output voltage of 0.5V-3.6V. The 2A drive strength allows POL converters to be designed for high output current applications, such as servers, networking equipment, set-top boxes (STBs), telecommunication equipment and graphic cards. Using a simple resistor divider enables the device to step high-input voltages down to output voltages greater than 3.6V, while adding a current-sense resistor enables the device to become a regulated current source.

This application note provides a walk through on the design example using the MCP19111 as a buck POL converter with supporting tools developed specifically for this device and application.

The MCP19111 is packaged into a 28-lead 5 mm x 5 mm QFN. It provides several GPIO pins and supports program debugging. Many of these applications require a high level of integration to minimize cost and circuit board area. By using the advanced digital and analog features of the Microchip proprietary process, many of the desired customizable attributes of POL converters are integrated into the MCP19111. Solutions that exist today require external resistors and capacitors to set switching frequency, current limit, control system compensation and delay time between power MOSFET switch control. By using the latest enhanced PIC core, the MCP19111 uses the digital attributes of the Microchip proprietary process to make these features user programmable through a simple graphical user interface (GUI).

The ability for system designers to configure application-specific features allows the MCP19111 to be offered in a smaller package than the currently available POL devices. The GPIO of the MCP19111 can be used to develop proprietary features or configured to offer a power good output, device enable, switching frequency synchronization input/output, output voltage margining or even a device status or "heartbeat". This flexibility allows the MCP19111 package and complete solution to be smaller, thereby saving size and cost of the system printed circuit board.

Several software tools have been developed to assist in managing the flexibility of the MCP19111, including a Microsoft® Office Excel®-based design analyzer, as well as a graphical user interface. A full introduction of these tools and their strengths are included later in this application note.

DEVELOPING STEP-DOWN DC-DC CONVERTER SOLUTIONS USING MCP19111

Similar to any power management circuit design, the application must be well defined to begin the design process. Several tools were developed to expedite the design and validation process for MCP19111 step-down DC-DC converter applications. The steps required for the design are outlined in the following sections.

DESIGN INPUTS

Input Voltage (Minimum and Maximum steady-state voltages are needed)

The input voltage range is typically well known for most systems. In some cases, there may be distribution voltage drops in the system that lowers the V_{INMIN}. The maximum steady state V_{IN} is used for worst case power dissipation, while the maximum peak transient voltage should be considered for robustness.

Output Voltage (Minimum and Maximum steady state voltage are needed if V_{OUT} is variable)

Typically, V_{OUT} is a fixed value, but in some applications, the DC-DC converter output voltage can be programmed to match certain load requirements or for margining the system.

Output Current Range

It is very important to know the maximum load current for developing the DC-DC converter. If the load is significantly higher than what the power supply is designed for, changes to the footprint of the external MOSFET, switches or to the inductor physical size may be necessary.

Design Goals

Typically, the system design goals are identified early in the design process. Trade-offs between efficiency, size and dynamic response must be made. High efficiency is expected, but size and cost are also considered when developing non-isolated step-down DC-DC converters.

Higher switching frequency generally results in lower efficiency, but leads to a smaller, faster responding design. Typically, a balance between these two is accomplished. Using Microchip's MCP19111 device and supporting design tools help optimize the solution with the first pass hardware.

Power Train Calculations

- **Switching Frequency Selection** (based on design goals)

  Switching frequency selection is based on many variables. For high-voltage input, hard switching step-down DC-DC converters, switching losses are appreciable as shown in the MCP19111 Design Analyzer. Optimizing switching frequency is critical to meet the design efficiency and size targets.

- **MOSFET Technology Selection** (Cost vs. Efficiency vs. Size)

  New MOSFET technology is available to increase the design efficiency. Microchip Technology Inc. introduced a new generation of low-resistance, low-capacitance MOSFET devices that reduce the switching time by lowering the switch capacitance for an equivalent on resistance. This technology results in lower switching losses for similar conduction losses.

- **Inductor Technology Selection**

  Several inductor types are available for step-down DC-DC converters. Typically, the core losses are low for the ferrite or composite magnetic core. The inductor's DC resistance also plays an important role in converter efficiency, and is taken into consideration in the MCP19111 Design Analyzer tool.

- **Capacitance Technology Selection**

  Low equivalent series resistance (ESR) capacitors are recommended for both input and output use in high-frequency DC-DC converter design. The input capacitor ripple current is discontinuous, leading to high input ripple voltage. The MCP19111 Design Analyzer takes the maximum ripple current into account when calculating efficiency and input capacitance value.

  Even though the buck output current is continuous, many of today's designs use low-inductance values, resulting in high-ripple current. Using low ESR capacitors reduces the output ripple voltage. The MCP19111 Design Analyzer uses input voltage, output voltage, output capacitance and output capacitance ESR to calculate the system efficiency and control system bode plot.

Control System Design

- **Stability vs. Performance Design**

  Adjustable integrated peak current mode control is used in the MCP19111 device. The peak current control system design is forgiving, making the converter easy to stabilize. When optimizing the control system for speed, this stability can be compromised. Careful evaluation of the control system and measurements should be taken to ensure the design is stable over the entire range of operation.

- The MCP19111 Design Analyzer is a good way to quickly evaluate the control system. There is a good correlation between the analyzer and lab results.
- Testing is the last step in the design of the control system. Two test methods are used: step load performance and bode plot analysis. The step load testing consists of load-stepping the output of the step-down DC-DC converter and measuring the output voltage perturbation. Sinusoidal output ringing indicates a low-phase margin system; output voltage oscillation indicates an unstable system. The bode measurement analysis requires special equipment to inject an isolated AC signal into the control system and measure the system response. A network analyzer is required for this type of testing.

INTRODUCTION TO THE DESIGN TOOLS

The following additional documents and tools are available to help users in their designs:

- MCP19111 Data Sheet – *"Digitally Enhanced Power Analog Controller with Integrated Sync Driver"* (DS22331). This document includes all of the necessary specifications and information required to develop a DC-DC solution using the MCP19111.
- MCP19111 Design Analyzer. This tool is used to input application variables while it computes the desired external components (e.g. switches, inductor and capacitors) and assists in setting the internal configuration of the part, including defining the control loop and protection thresholds.
- MCP19111 MPLAB® X Integrated Development Environment Plug-in. This plug-in is used to interface the MPLAB X IDE with the MCP19111. Many of the device's capabilities can be demonstrated using the GUI. For more information, see *"MCP19111 MPLAB® X Integrated Development Environment Plug-in User's Guide"* (DS52113).
- MCP19111 Evaluation Board (ADM00397). The evaluation board can be used to become familiar with the MCP19111 device while controlling two switches in a step-down DC-DC topology. See *"MCP19111 Evaluation Board User's Guide"* (DS52109) for information on how to install and operate the board.

Starting the Design

To get started, use the values in Example 1:

EXAMPLE 1:

V_{IN}	=	12V (10V to 13.2V)
V_{OUT}	=	1.8V
I_{OUT}	=	0A to 20A (no airflow); 0A to 30A (1.52 m/s airflow)
Design Goal	–	Efficiency > 90% @ 25A (most common operating point).

Starting with the MCP19111 Design Analyzer Tool

A Microsoft Office Excel-based design spreadsheet is used to input variables and component values to assist in the design process. The spreadsheet is used to optimize the POL synchronous step-down or Buck converter design.

For specific input and extraction or calculation of data, the tool includes the following sheets:

- Input Parameters
- Components
- Efficiency
- Frequency Analysis
- GUI

INPUT PARAMETERS SHEET

This sheet is used during the design phase as a guide. All operating corners of the design can be analyzed by using multiple iterations of the design parameter entry cells (shaded yellow). To do this, enter the parameters into the table and evaluate the results for several operating conditions, including worst case corners.

Enter the input voltage, output voltage and output current of interest:

- The Switching Frequency of the converter determines the efficiency, transient response, size and cost of the design. The switching frequency should be evaluated carefully to optimize the design to the performance goals.
- The Input Voltage Ripple defines how much input capacitance and its equivalent series resistance (ESR) is necessary to meet the specified input ripple requirement.
- The Minimum Input Voltage is used to calculate the undervoltage lockout setting for the system.
- The Step Load Parameters are used to define the dynamic performance of the system and indicate the amount of output capacitance needed to achieve the desired transient response. The MCP19111 control system uses an analog peak current mode control. The load step is defined as the load current step from a High Output Current to the Low Output Current. The next step is entering the size of the overshoot desired for this load step. Larger load current steps and smaller output voltage overshoot result in larger output capacitance and lower ESR to minimize the overshoot leading to a higher system cost.

The spreadsheet calculates the system operating parameters, estimates and graphs the system efficiency and plots the closed loop response of the system using a calculated bode plot. The equations used to plot the estimated efficiency and bode response are detailed in **Appendix A: "MCP19111 Design Analyzer Tool"**.

FIGURE 1: MCP19111 DESIGN ANALYZER – INPUT PARAMETER PAGE

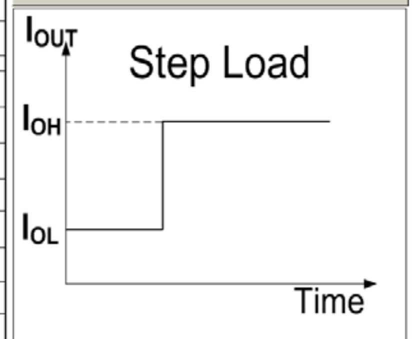
MICROCHIP

MCP19111 DESIGN ANALYZER

Input Parameters for Design

Parameter	Designator	Value	Units	Notes
Input Voltage	V_{IN}	12	V	$4.5 \le V_{IN} \le 30$
Output Voltage	V_{OUT}	1.8	V	$0.6 \le V_{OUT} \le 3.6$
Output Current	I_{OUT}	30	A	$0 \le I_{OUT} \le 30$
Switching Frequency	Fs	300	kHz	$100 \le Fs \le 1200$
Input Voltage Ripple	V_{RIN}	100	mV	
Minimum Input Voltage	V_{IN_MIN}	12	V	$4.5 \le V_{IN\_MIN} \le V_{IN}$
Step Load Parameters				
High Output Current	I_{OH}	7.5	A	
Low Output Current	I_{OL}	2.5	A	
Output Voltage Overshoot		100	mV	

Use Default EVAL Board Components and Compensation



Use Recommended Components and Compensation

SYSTEM COMPONENTS

The next step in the design process is to select the power train components by entering their basic parameters into the design spreadsheet. Remember that all cells shaded yellow should be selected by the designer.

In the **System Components** table as displayed in Figure 2, the calculated results are shown in the cells shaded green. They represent component values that meet the design goals.

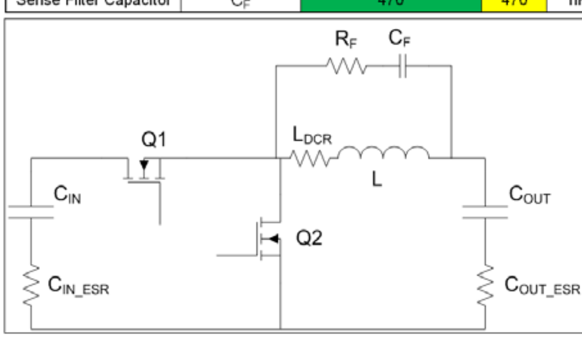
The cells shaded yellow are used by the designer to input the actual values. These cells are used for the estimated efficiency and control system plots. The inductance, output capacitance, input capacitance and current sense filter are selected from this side of the sheet.

The **Power Train Component Parameters** table on the right is for the MOSFET parameters and parasitic values of the passive components.

FIGURE 2: MCP19111 DESIGN ANALYZER – COMPONENTS SHEET FOR DEFAULT EVALUATION BOARD SETTINGS

System Components

Component	Designator	Calculated Value	Value	Units
Inductance	L	0.85	1	µH
Output Capacitor	C_{OUT}	135.135	400	µF
Input Capacitor	C_{IN}	127.5	132	µF
Sense Filter Resitor	R_F	0.213	0.22	kΩ
Sense Filter Capacitor	C_F	470	470	nF



Power Train Component Parameters

Component Parameter	Designator	Value	Units
High side MOSFET	**Q1**		
$R_{DS(ON)}$	$R_{DS(ON)HS}$	5	mΩ
Total gate charge	Q_{GATEHS}	12.5	nC
Low side MOSFET	**Q2**		
$R_{DS(ON)}$	$R_{DS(ON)LS}$	1.8	mΩ
Total gate charge	Q_{GATELS}	40	nC
Total Conduction Time for the Body Diode	t_{BD}	16	ns
Reverse Recovery Charge of the Body Diode	Q_{RR}	39	nC
Inductor DC Resistance	L_{DCR}	1	mΩ
C_{IN} ESR	C_{IN_ESR}	2	mΩ
C_{OUT} ESR	C_{OUT_ESR}	2	mΩ

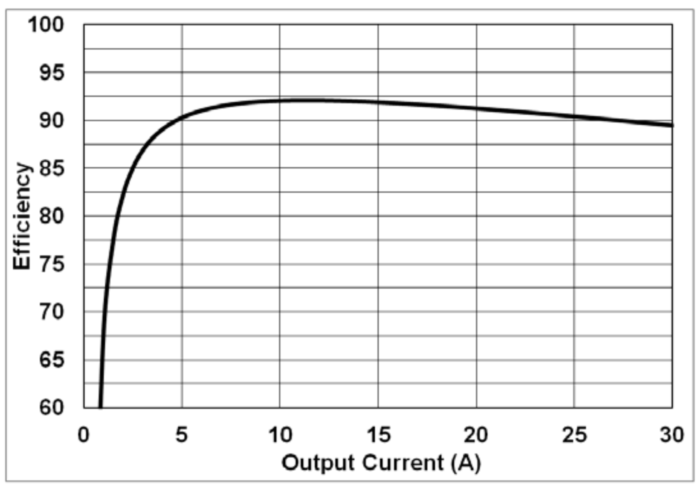
Microchip's MCP87050 and MCP87018 MOSFETs were used for the high-side and low-side switches. The MOSFET's ON resistance (R_{DSON}) and gate charge are both critical parameters for design analysis. The low-side MOSFET body diode characteristics are also a key parameter for estimating the efficiency of the converter. Refer to the MOSFET's data sheet for more information. The diode conduction time is the estimated amount of time when the current is flowing through the low-side switch body diode. This time can be adjusted by using the MCP19111 dead time adjust setting. The inductor DC resistance and ESR of the input and output capacitors are also used for efficiency and control system calculations. Refer to the component data sheet for more information on these values.

EFFICIENCY SHEET

The efficiency tab represents the calculated efficiency using the component parameters. A good idea is to vary the critical values to see the effect on the system efficiency. For example, increasing the switching frequency results in a lower efficiency. Optimizing the high-side MOSFET results in higher efficiency for specific operating conditions. Lower resistance high-side MOSFETs do not always result in the highest efficiency. If the switching losses are much larger than the conduction losses for the high-side MOSFET, a MOSFET with higher R_{DSON} and lower gate charge or capacitance may be a better choice for the operating conditions of interest.

FIGURE 3: MCP19111 DESIGN ANALYZER – EFFICIENCY SHEET FOR DEFAULT EVALUATION BOARD SETTINGS

Estimated System Losses at Full Load		
High side MOSFET losses		
Conduction losses	0.7	W
Switching losses	1.384615385	W
Total losses	2.084615385	W
Low Side MOSFET losses		
Conduction losses	1.4	W
Body diode conduction losses	0.103384615	W
Body diode reverse recovery losses	0.0702	W
Total losses	1.573584615	W
Controller losses	0.3	W
Inductor conduction losses	0.9	W
C_{OUT} losses	0.024	W
C_{IN} losses	0.64	W
Current Sense Loss	0.185885117	W
Total losses	5.708085117	W
Estimated Efficiency at Full Load	89.43	%

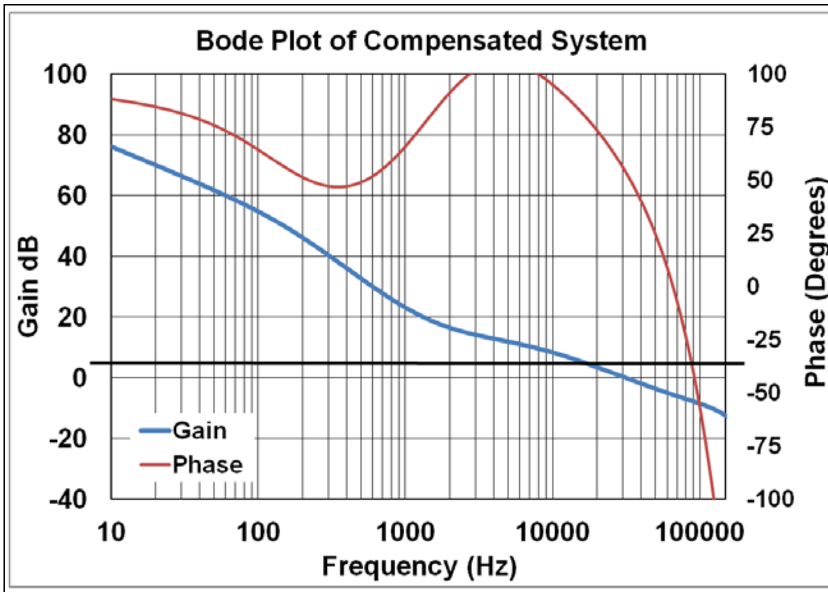


FREQUENCY ANALYSIS SHEET

This sheet shows the tools/elements that are used to design the system's analog control loop. The cells shaded green are the calculated values while those shaded yellow are filled in by the designer. The Gain and Zero Frequency cells from the Compensation section set the position of the zero used to compensate the control system. Changes in the system dynamic performance result from changing the location of the system zero and gain. The next rows show the slope compensation needed for peak current mode control. Adding more slope compensation makes the system appear more voltage mode and can lead to instability (output voltage oscillation). The last two cells are used to set the gain of the current sense signal.

The calculated system crossover frequency and phase margin are also displayed. The higher the crossover frequency, the faster the system responds to transients. Higher switching frequency and lower inductance enable a higher crossover frequency while sacrificing efficiency. Phase margin greater than 45 degrees is recommended.

FIGURE 4: MCP19111 DESIGN ANALYZER – CALCULATED BODE PLOT FOR DEFAULT EVALUATION BOARD SETTINGS



Compensation			
Gain	4.61	4.61	dB
Zero Frequency	1500	1500	Hz
Slope dV/dT	0.04	0.04	V pk-pk
Slope Gain	2		

Current Sense Configuration			
Current Sense Gain	7	7	dB
Current Sense DC Gain	19.5	19.5	dB

Crossover	31000	Hz
Phase Margin	54.67	Degrees
Gain Margin	5.62	dB

SPECIAL MACROS

There are two automated features in the MCP19111 Design Analyzer that require the use of macros. The **Use Default Evaluation Board Compensation and Components** feature sets the designer cells (shaded yellow) to the default values that are standard on the MCP19111 Evaluation Board (ADM00397). This feature is used as a reset to restore the analyzer back to the original evaluation board component values.

The **Use Recommended Components and Compensation** feature automatically fills in the designer input cells (shaded yellow) with the calculated values. This feature is used to evaluate changes in key parameters quickly (such as switching frequency, inductance, output capacitance and ESR, MOSFET parameters, etc.). Once the design goals are met, the designer can enter values in the input cells to further optimize the size, efficiency and dynamic performance.

To access and use the macros, select “Developer” item from the main menu/ribbon in Excel. In the “Code” sub-menu, click on the “Macros” icon. From the dialog window, select one of the available macros.

GUI SHEET

The last step in the design phase is to review the calculated GUI values in the design analyzer and enter this data into the MCP19111 MPLAB® X Integrated Development Environment Plug-In. These values are programmed into the device.

FIGURE 5: MCP19111 DESIGN ANALYZER – GUI INPUTS FOR DEFAULT EVALUATION BOARD SETTINGS

Parameter Tab		
Output Voltage		
Set Coarse Value	1785.4	mV
Set Fine Value	1799.8	mV
Multi-phase Configuration		
Device Configuration	stand alone unit	
SM Error Signal Input Gain		
Switching Frequency		
Generated Frequency	308	kHz
Phase Delay	0	
Max Duty Cycle	76	%
Dead Time Delay		
High Side	15	ns
Low Side	16	ns
Startup Behavior		
Soft Start Duration	200	ms
Use Startup Pin	Use pin GPB7	

Protection Tab		
Output Voltage Protection		
Enable Output Under Voltage	1769.6	mV
Enable Output Over Voltage	1848.6	mV
Output Over Current		
High-Side RDS-on Value	5	mΩ
Leading Edge Blanking Time	780	ns
Set Value	50	A
Input Under Voltage Lockout		
Enable VIN Under Voltage Lockout	11080	mV
Enable VIN ON	11080	mV

Compensation Tab		
Compensation		
Gain	4.61	dB
Zero Frequency	1500	Hz
Slope Amplitude	0.04	V pk-pk
Slope dV/dT	2	
Current Sense Configuration		
Current Sense Gain	7	dB
Current Sense DC Gain	19.5	dB

Figure 5 shows three tables: **Parameter**, **Protection** and **Compensation**. The **Parameter** table is used to set the output voltage and the mode of operation (single converter running stand alone, multi-output converter or multi-phase). The switching frequency, phase delay and maximum duty cycle define the pulse-width modulator (PWM) fixed frequency oscillator. The Dead Time Delay settings are used to adapt the delay between the high-side switch and low-side switch turning on and off. The value of 24 ns is set for the Microchip MOSFETs. The settings used for the dead time depend on the size and speed of the selected MOSFETs. Microchip MOSFETs offer very low capacitance, resulting in faster switching times. By using a lower value delay, the system efficiency can be increased using the Microchip MOSFETs. When using trench or MOSFETs with large gate capacitance, care should be taken to ensure there is enough dead time. The last parameter in this tab specifies the rise time of the output voltage and the use of a GPIO pin for enable.

The **Protection** table is used for setting the output overvoltage and undervoltage values. The MCP19111 can detect if the output is ever outside of the expected range. The response options are provided in the GUI. In addition to the output overvoltage and undervoltage settings, the input undervoltage lockout, startup voltage and high-side switch peak current limit can be adjusted to protect the power supply from abnormal operating conditions.

The **Compensation** table is used to enter the calculated parameters used to stabilize the system:

- Gain represents the amount of error amplifier gain added
- Zero Frequency is the location of where the control system Zero is placed
- Slope Amplitude and Slope dV/dT represent the amount of slope compensation added to the system (actually subtracted from the output of the error amplifier).

In the Current Sense Configuration section, there are two gain settings used to amplify the current sense signal:

- Current Sense Gain - for AC
- Current Sense DC Gain - for DC

WORKING WITH MCP19111 MPLAB® X IDE PLUG-IN

The next step in the design is to start the MPLAB® X IDE and run the MCP19111 plug-in. See *"MCP19111 MPLAB® X Integrated Development Environment Plug-in User's Guide"* for step-by-step instructions on installing and running the MCP19111 graphical user interface (GUI).

Entering the Parameters into the MPLAB® X GUI Plug-In

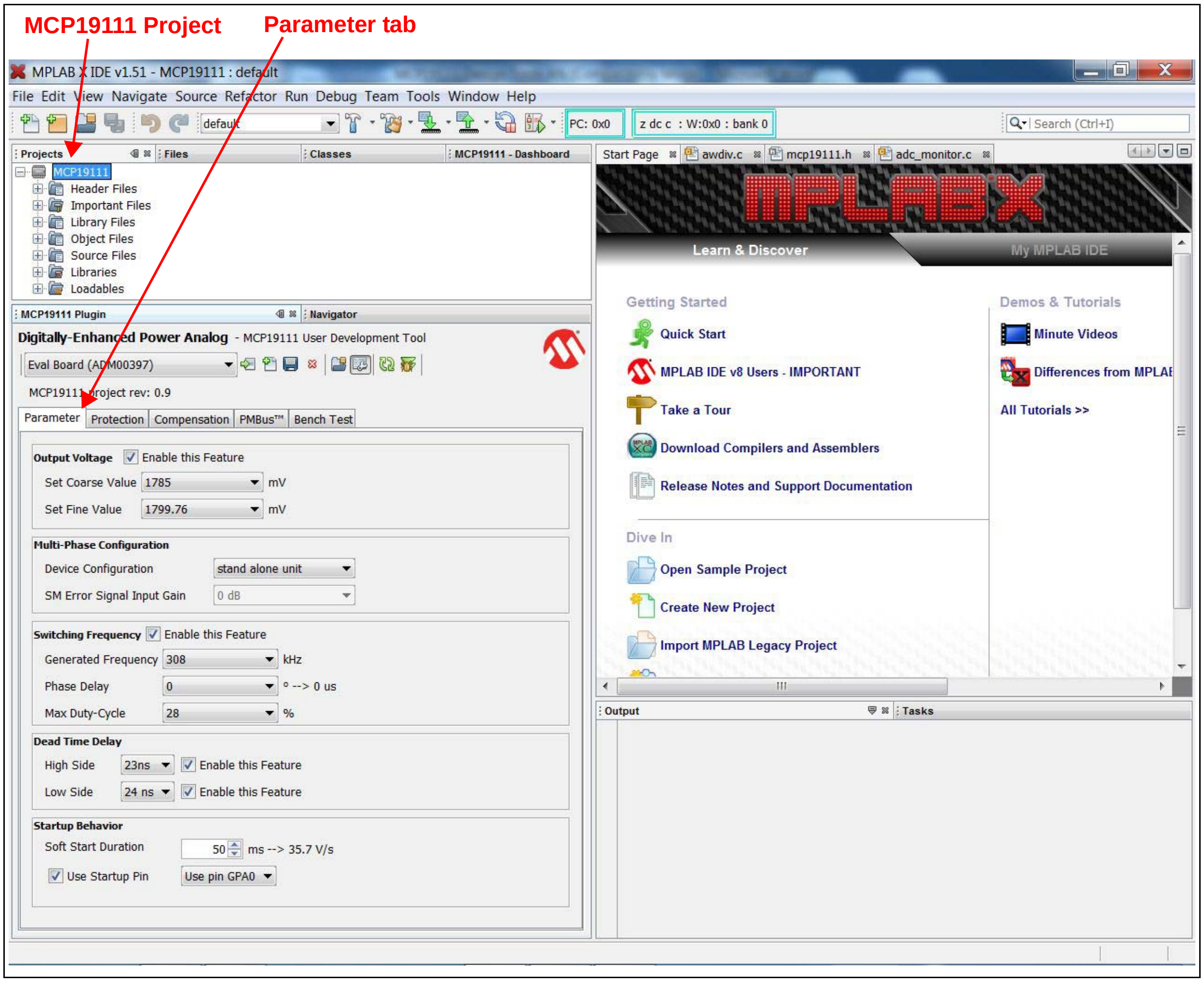
The MCP19111 MPLAB X Integrated Development Environment Plug-In is used with the MPLAB X IDE to program the device for proper setup.

Figure 6 shows the MPLAB X IDE window. Once the MCP19111 Project is opened and the plug-in installed, the MPLAB X shows the plug-in panel under the project window. The project tabs inputs (**Parameter**, **Protection** and **Compensation**) match the MCP19111 Design Analyzer's GUI sheet. The output values from the analyzer are manually entered into the MPLAB X GUI.

PARAMETER TAB

Figure 6 depicts the **Parameter** tab with the parameter values filled in from the design analyzer spreadsheet GUI page.

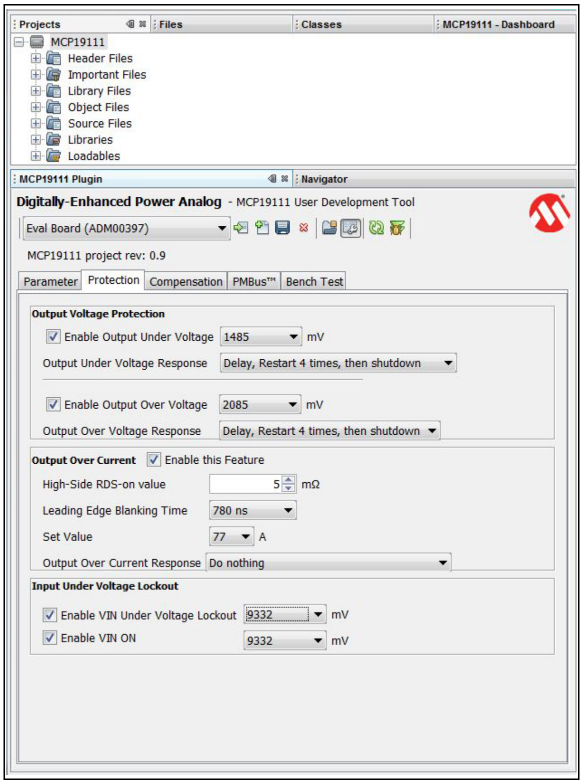
FIGURE 6: MPLAB® X IDE – PARAMETER TAB WITH DEFAULT EVALUATION BOARD SETTINGS COMPLETED



PROTECTION TAB

Figure 7 shows the **Protection** tab filled in with the values from the MCP19111 Design Analyzer.

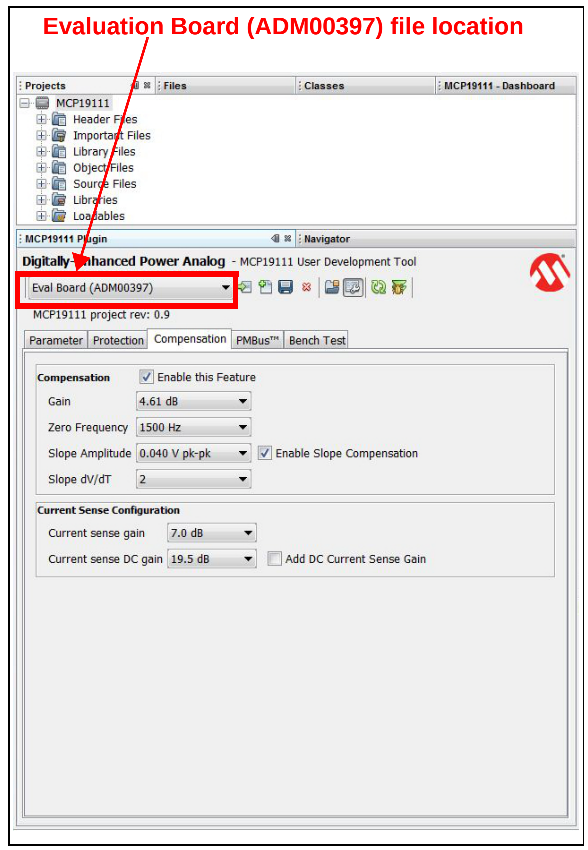
FIGURE 7: MPLAB® X IDE – PROTECTION TAB WITH DEFAULT EVALUATION BOARD SETTINGS COMPLETED



COMPENSATION TAB

Figure 8 shows the **Compensation** tab filled in with the values from the MCP19111 Design Analyzer, completing the preliminary design process. The MCP19111 can be reprogrammed to optimize the switching frequency, output set point value, protection or compensation. After loading all the parameters, a new design parameter profile can be created using the MPLAB X IDE Plug-in. The evaluation board design parameters are stored under the Evaluation Board (ADM00397) file and can be reloaded any time to bring the evaluation board back to factory settings.

FIGURE 8: MPLAB® X IDE – COMPENSATION TAB WITH DEFAULT EVALUATION BOARD SETTINGS COMPLETED



At this step, by pressing the MPLAB X IDE's **Make and Program Device Main Project** button ( ) from the main toolbar, the device is programmed to the new parameters, the output voltage is set to the desired value and all the critical internal registers should be set.

MCP19111 EVALUATION BOARD (ADM00397) MEASUREMENTS

Figure 9 through Figure 13 represents the actual data taken from a standard MCP19111 Evaluation Board (ADM00397) while using the default settings (ADM00397) from the GUI sheet.

Figure 9 shows the efficiency of the Evaluation Board while operating with the chosen optimized dead time vs. non-optimized dead time.

FIGURE 9: EFFICIENCY VS. OUTPUT CURRENT AT 12V INPUT, 1.8V OUTPUT

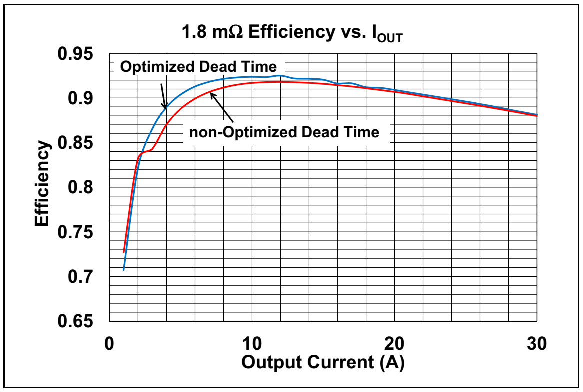


Figure 10 represents the system efficiency vs. load, using the selected 1.8 mΩ low-side FET compared to a 2.2 mΩ low-side FET.

FIGURE 10: EFFICIENCY VS. OUTPUT CURRENT AT 12V INPUT, 1.8V OUTPUT

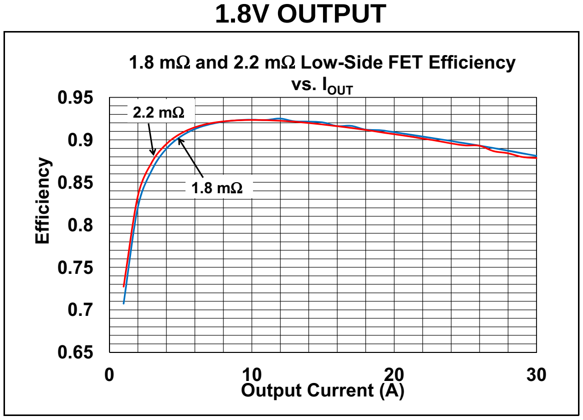


Figure 11 represents the *measured* system bode plot in comparison to the *calculated* system bode plot when using the calculated values.

FIGURE 11: MEASURED BODE PLOT PERFORMANCE

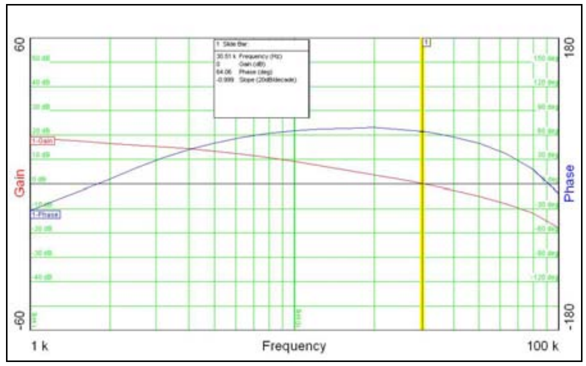


Figure 12 shows the system response to a load step, top traces representing a high-to-low load step, while the bottom traces represent a low-to-high step.

FIGURE 12: STEP LOAD RESPONSE

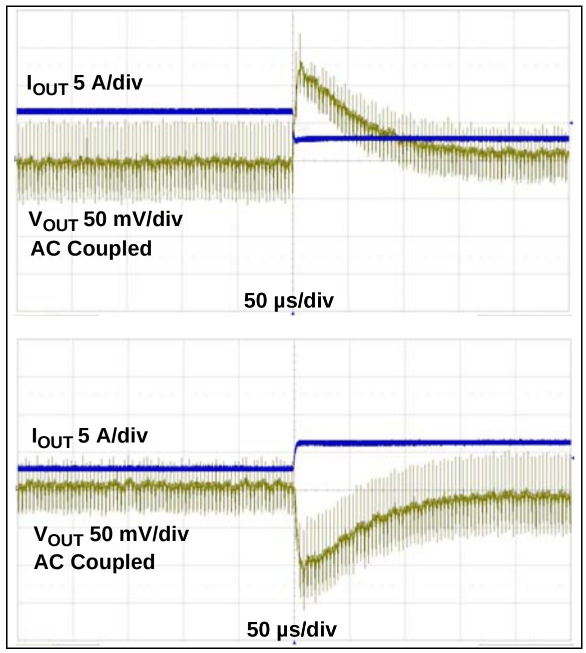
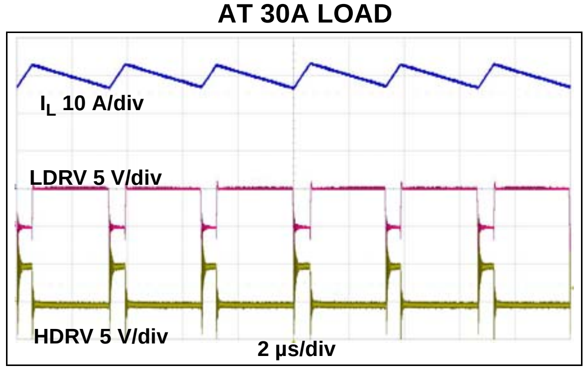


Figure 13 shows steady state waveforms with a 20A load. The top trace displays the inductor current, while the bottom two traces show the gate drive outputs from the MCP19111.

FIGURE 13: SWITCHING WAVEFORMS AT 30A LOAD



CONCLUSION

The MCP19111 device integrates a PIC microcontroller, flash memory, high voltage, high current half-bridge driver and precise analog technology into one monolithic device. This application note covered the design tools used to quickly scale a Point-of-Load design. The MCP19111 can be used for developing power systems to drive LEDs, charge batteries or produce general purpose DC-DC converters. The integrated analog control system allows the designer to adapt and adjust the dynamic performance without printed circuit board changes while only consuming 5 mA of the input current. Special features for increasing efficiency, dynamic performance and the ability to communicate make the MCP19111 a good choice for many new applications and designs.

APPENDIX A: MCP19111 DESIGN ANALYZER TOOL

This appendix reviews some of the design tool's characteristics and shows the equations used to plot the estimated efficiency and bode response.

TABLE A-1: RECOMMENDED PARAMETERS CALCULATION - INPUT PARAMETERS SHEET

Parameter	Equation
• All values are user input.	
• The user must enter values within the specified range given in the “Notes” column. An error occurs if a value outside of this range is used.	

TABLE A-2: RECOMMENDED PARAMETERS CALCULATION - COMPONENTS SHEET

Parameter	Equation
Recommended Inductance	$L = (V_{IN} - V_{OUT}) \times \frac{V_{OUT}}{V_{IN}} \times T \times \frac{1}{0.2 \times I_{OUT}}$ This is calculated based on a 20% ripple current.
Recommended Output Capacitance	$C_{OUT} = \frac{L \times \left\|I_{OH}^2 - I_{OL}^2\right\|}{\left\|(V_{OUT} + V_{OVERSHOOT})^2 - V_{OUT}^2\right\|}$
Recommended Input Capacitance	$C_{IN} = \frac{I_{OUT} \times D \times (1 - D)}{f_{SW} \times (V_{RIPPLE} - (D \times I_{OUT} \times C_{IN_{ESR}}))}$
Recommended Sense Filter Resistor	$R_f = \frac{L}{10 \times L_{DCR} \times C_f}$
Recommended Sense Filter Capacitor	This value is fixed at 100 nF
Power Train Components	All parameters are selected by user

TABLE A-3: RECOMMENDED PARAMETERS CALCULATION - EFFICIENCY SHEET

Device Type	Parameter	Equation
High-Side MOSFET	Conduction Losses	$P_{COND_{HS}} = I^2_{RMS_{HS}} \times R_{DS_{HS}}$
	Switching Losses	$P_{SW_{HS}} = V_{IN} \times I_{OUT} \times Q_{GATEHS} \times f_{SW}$
Low-Side MOSFET	Conduction Losses	$P_{COND_{LS}} = I^2_{RMS_{LS}} \times R_{DS_{LS}}$
	Body Diode Conduction Losses	$P_{LOSS_{BD}} = I_{OUT} \times V_f \times t_{BD} \times f_{SW}$
	Body Diode Reverse Recovery Losses	$P_{LOSS_{RR}} = \frac{Q_{RR} \times V_{IN} \times f_{SW}}{2}$
	Controller Losses	$P_{LOSS_{CONT}} = V_{IN} \times (5mA + f_{SW} \times (Q_{GATE_{LOW}} + Q_{GATE_{HIGH}}))$
	Inductor Conduction Losses	$P_{LOSS_{IND}} = I^2_{LRMS} \times L_{DCR}$
	C_{OUT} Losses	$P_{LOSS_{OUT}} = C_{OUT_{ESR}} \times 0.2 \times \frac{I_{OUT}}{3}$
	C_{IN} Losses	$P_{LOSS_{CIN}} = C_{IN_{ESR}} \times \left(I_{RMS_{HS}} - \frac{V_{OUT} \times I_{OUT}}{V_{IN}}\right)^2$

TABLE A-4: RECOMMENDED PARAMETERS CALCULATION - FREQUENCY ANALYSIS SHEET

<table>
<tr><th>Parameter</th><th>Conditions</th><th>Equation</th></tr>
<tr><td>Recommended Gain</td><td>• Based on the bode plot of power train only.
• Uses a desired crossover of $\frac{f_{SW}}{2 \times \pi}$
• Looks up the desired crossover and figures out how much gain must be added to obtain that crossover frequency.</td><td>Example: f_{SW} = 300 kHz
Desired Crossover = 48 kHz
Frequency | Gain
48 | -18.75
Chosen value is 19.1 dB.</td></tr>
<tr><td>Recommended Zero</td><td></td><td>$F_{zero} = 1500 \times \log\left(\frac{\omega_p}{2 \times \pi \times 1500}\right)$
This places the zero at approximately one decade below the loop pole (ω_p=$R_{OUT}C_{OUT}$), but is limited between 1500 and 35300.</td></tr>
<tr><td>Recommended Slope Compensation</td><td>The SLPG and SLPS values are selected to match the down slope of the current sense signal.</td><td>$Slope = \frac{V_{OUT}}{2 \times L} \times T \times L_{DCR} \times Gain_{CS}$
Where $Gain_{CS}$ is the combination of the R_f, C_f current sense gain and CSGSCON.</td></tr>
<tr><td>Recommended Current Sense Gain</td><td colspan="2">

$$CSGSCON = \frac{20 \times \log\left(\frac{0.5}{L_{DCR} \times I_{pk} \times \frac{\left(1 + 2 \times \pi \times f_{SW} \times \frac{L}{L_{DCR}}\right)}{(1 + 2 \times \pi \times f_{SW} \times R_f \times C_f)}}\right)}{1.5}$$

Final Bode Plot Transfer Function

$$G_{CL} = G_{PWR}(S) \times G_{EA}(S)$$

$$G_{PWR}(S) = \frac{R_{OUT}}{R_i(S)} \times \frac{1}{1 + \frac{R_{OUT} \times T_S}{L}[m_c \times D' - 0.5]} \times F_p(S) \times F_h(S)$$

Where: $R_i(S) = CSGSCON \times \frac{L_{DCR} + sL}{1 + sR_fC_f}$

$$F_p(S) = \frac{1 + sC_{OUT}C_{OUT_{ESR}}}{1 + \frac{s}{\omega_p}}$$

$$\omega_p = \frac{1}{C_{OUT}R_{OUT}} + \frac{T_S}{LC_{OUT}}(m_cD' - 0.5)$$

$m_c = 1 + \frac{S_e}{S_n}$ (where S_e is slope of compensation ramp, S_n is the inductor current slope)

$F_h(S) = \frac{1}{1 + \frac{s}{\omega_n Q} + \frac{s^2}{\omega_n^2}}$, where $\omega_n = \frac{\pi}{T_s}$ and $Q = \frac{1}{\pi(m_cD' - 0.5)}$

$G_{EA}(S) = \frac{K_{COMP}(S)}{1 + \frac{1 + K_{COMP}(S)}{K_{COMP}(S)}}$, where $K_{COMP}(S) = EAG \times \left(1 + \frac{2 \times \pi \times EAZ}{S}\right)$

$K_{AV}(S) = \frac{10^{\frac{AV}{20}}}{\left(1 + \frac{S}{\omega_{p1}}\right) \times \left(1 + \frac{S}{\omega_{p2}}\right)}$, where $\omega_{p1} = \frac{2 \times \pi \times GBW}{10^{\frac{AV}{20}}}$

$$\omega_{p2} = 3 \times \pi \times GBW$$

</td></tr>
</table>

TABLE A-5: RECOMMENDED PARAMETERS CALCULATION - GUI SHEET

Parameter	Condition
Parameter Tab	
Output Voltage	The fine value and coarse value are chosen to be as close to the user input/output voltage as possible
Multi-Phase Configuration	Fixed at Stand Alone Unit
Switching Frequency	**Generated Frequency:** Closest attainable value to the user input switching frequency
	Phase Delay: Fixed at 0
	Maximum Duty Cycle: Set to be twice the expected duty cycle
Dead Time Delay	Both high-side and low-side are fixed to 48 ns
Startup Behavior	**Soft Start Duration:** Fixed at 500 ms
	Use Startup Pin: Fixed at Use pin GPA0
Protection Tab	
Output Voltage Protection	**Output Undervoltage:** Set to approximately V_{OUT} - 300 mV
	Output Overvoltage: Set to approximately V_{OUT} + 300 mV
Output Overcurrent	**High-Side RDS-ON value:** Gets value from user input
	Leading Edge Blanking Time: Fixed at 800 ns
	Set Value: Approximately Double the Maximum Load
Input Undervoltage Lockout	Approximately 1V less than the given minimum input voltage
Compensation Tab	
Compensation	**Gain:** User input frequency analysis tab
	Zero Frequency: User input frequency analysis tab
	Slope dV/dT: User input frequency analysis tab
	Slope Gain: Calculated based on SLPCRON
Current Sense Configuration	**Current Sense Gain:** User input frequency analysis tab
	Current Sense DC Gain: Fixed at 0 dB

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