Digitally Enhanced Analog Power Control

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Agenda

- **Digital Power Benefits**
- **Paying the Price for Digital Power**
  - Has this limited the growth?
- **Bridging the Gap from Analog to Digital or Digital to Analog?**
- **Introducing Digitally Enhanced Power Analog Solutions "DEPA"**
- **DEPA Applications**
  - POL, LED Lighting, Battery Chargers and Intelligent DC/DC Converters
- **Demo's**

Digital Power Benefits

- **Communication**
- **Flexible Configuration**
  - UVLO, Startup, Shutdown
- **Flexible Fault Handling**
  - Over-Current, Over Voltage, Short Circuit
- **Intelligent**
  - Adapts to Changing Environments
  - Adapts to different Loads
- **Reports Status and Diagnostics**
- **Increases Integration?**

Price of Digital Power

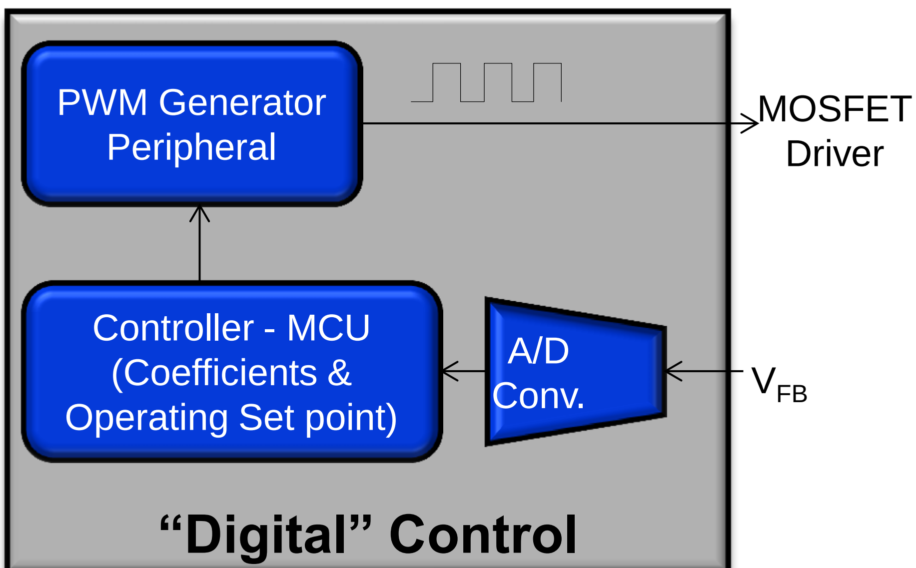
- **What's the cost?**
  - Complexity, Speed and Integration
- **Sense V_{OUT} / I_{PK} / V_{IN}?**
- **Dynamic Performance / Transient Response**
- **A/D Sampling Speed**
- **Hardware PWM Resolution**
  - Example
- **Is Digital Control Digital Power?**
- **Digitally Enhanced Power Analog**
  - Analog Power Drawbacks

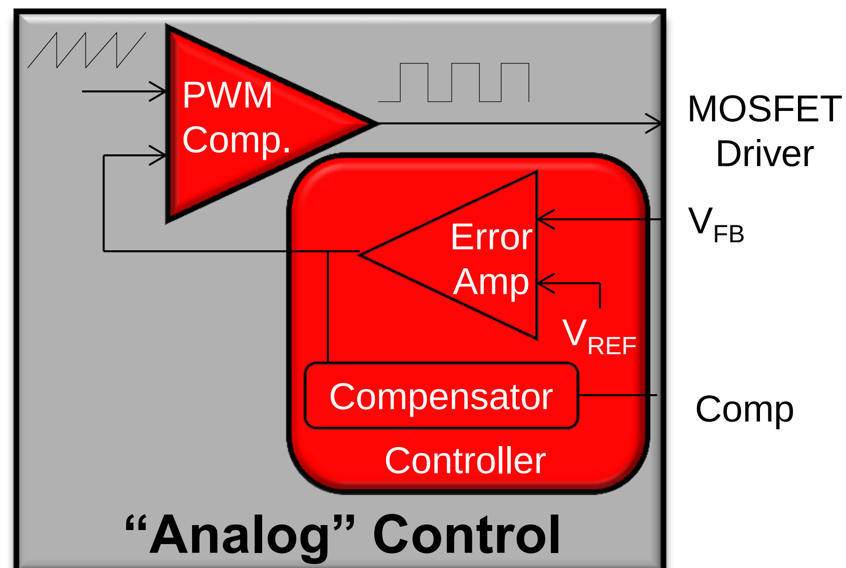
What is Digitally-Enhanced Power Analog?

In Power Conversion Control…

Digital Control
Techniques

Analog Control
Techniques

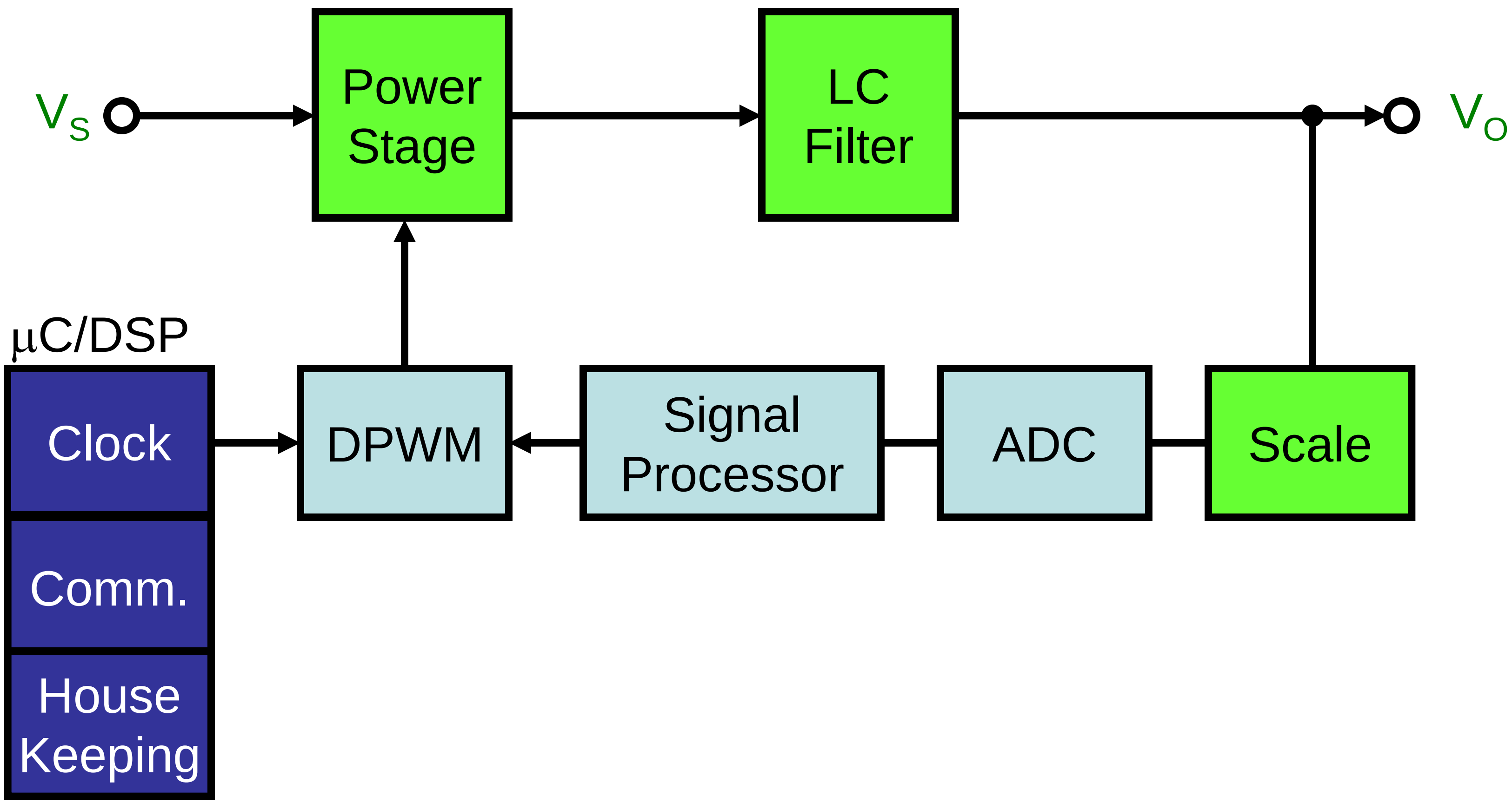




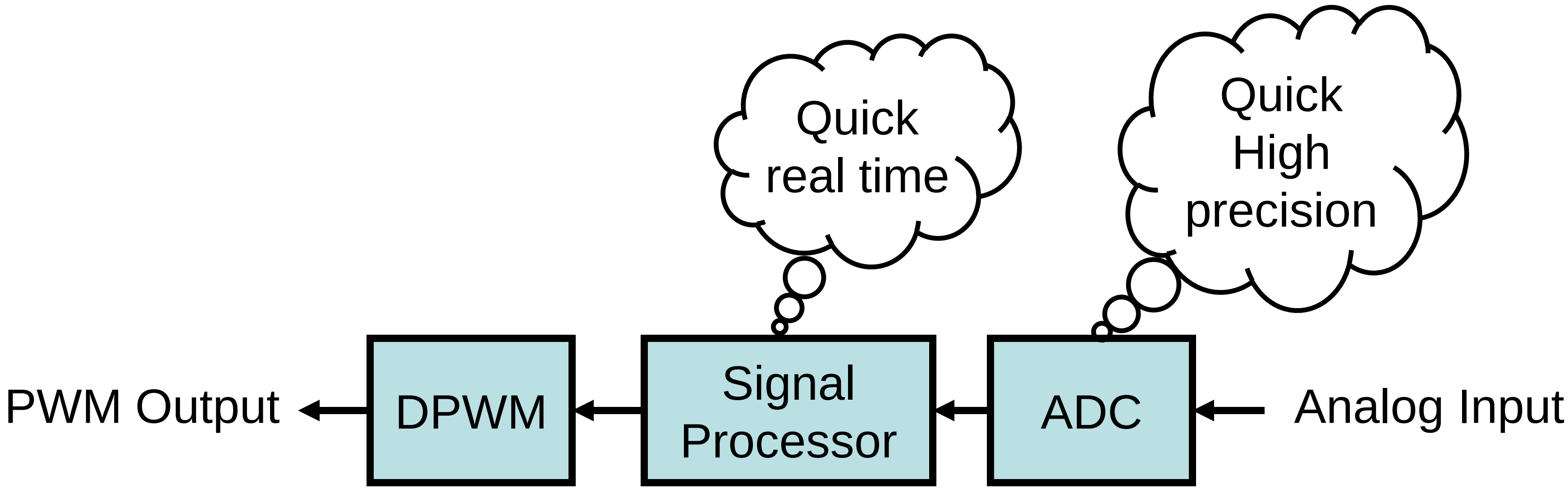
Digital Loop Closure

Digital Loop Closure

- **Digital Control**



Digital Control



Digital Control

- **Analog-to-Digital Converter**
  - Produces digital data that represents output voltage and / or current
  - Resolution and ADC reference voltage set the precision to which the output can be maintained
    - Finite resolution leads to quantization effects

Digital Control

- **Digital Pulse Width Modulator**
  - Performs same drive signal generation as its analog counterpart
  - Does so by "calculating" and then "timing" the desired ON and OFF periods
    - Finite resolution leads to quantization effects

Digital Control

- **Quantization Effects - A digital phenomenon**
  - Analog control provides "infinite" resolution
    - Limited by loop gain, thermal effects, and system noise
  - Digital control provides a finite set of discrete "set points" resulting from the resolution of the "quantizing elements" in the system
    - Two elements in this represented example: ADC and DPWM

Digital Control

Quantization Effects - ADC

- Resolution is defined as the number of states that can be uniquely represented
  - n bit resolution can assume 2^n states
- ADC resolution ensures that the set point tolerance can be met

Example: $V_O = 3.3V$ +/- 1% Required resolution = $\Delta V_O = 1\%$

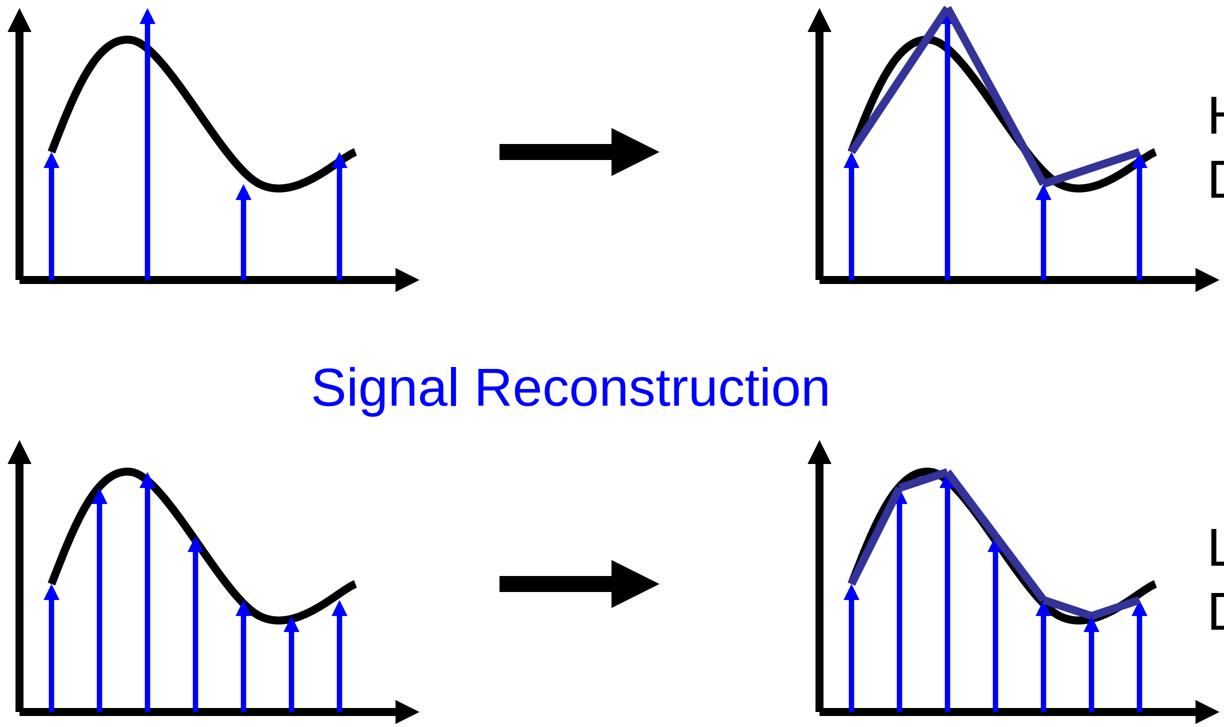
ADC bits required = n $= \text{int}\,[\,\log_2(V_O / \Delta V_O)]$

$= \text{int}\,[\,\log_2(100)] = 7$

● Quantization Effects - ADC

Low ADC Resolution and Speed

High Signal Distortion



High ADC Resolution and Speed

Low Signal Distortion

Digital Control

Quantization Effects - DPWM

- Minimum required number of DPWM states equals 2^{n+1}
  - If less, the system will appear to hunt for a stable output value
- System clock sets the maximum number of bits that can be generated in a fixed time period

Example1: ADC Resolution = 7 Required DPWM resolution = 8
Desired switching frequency = 1MHz
Required system clock = 1MHz * 2^8 = **256MHz** !!

Maximum switching speed = 30MHz / 2^7 = 234kHz

Digital Control

- **"Control" Law Processor**
  - Typically a PI or PID (Proportional Integral Derivative) style
    - Controls dc level and dynamic response characteristics of the control loop
    - Represented as mathematical coefficients; manipulated to adjust system performance
  - Translates digital representation of output voltage into pulse duration (duty cycle) information used by the DPWM
  - Does not affect the resolution of the system

Digital Control

- **Advantages**
  - "Tunable" system on-the-fly
  - Independent of thermal drift, aging, and component tolerance limitations
  - Precise control loop related parameters
- **Disadvantages**
  - Quantization errors
  - Limited system switching frequency

Has Digital Control Slowed the Adoption of Digital Power?

- **“Non-Digital Power Applications”**
  - Point of Load Converters
    - Limited in Power, Size, Cost and Efficiency are highly valued
  - DC/DC LED Drivers
    - Application Drives Feature Set
    - Dimming / Diagnostics / Binning / Temp Comp
  - DC/DC Battery Charging
    - Intelligence, Programmability, Wide Range of Power
  - “Smart DC/DC Converters”

Bridging the Gap

- **What's Wrong with Analog Solutions?**
  - No Flexibility
  - No Adaptability
  - No Communication
- **No Intelligence…**

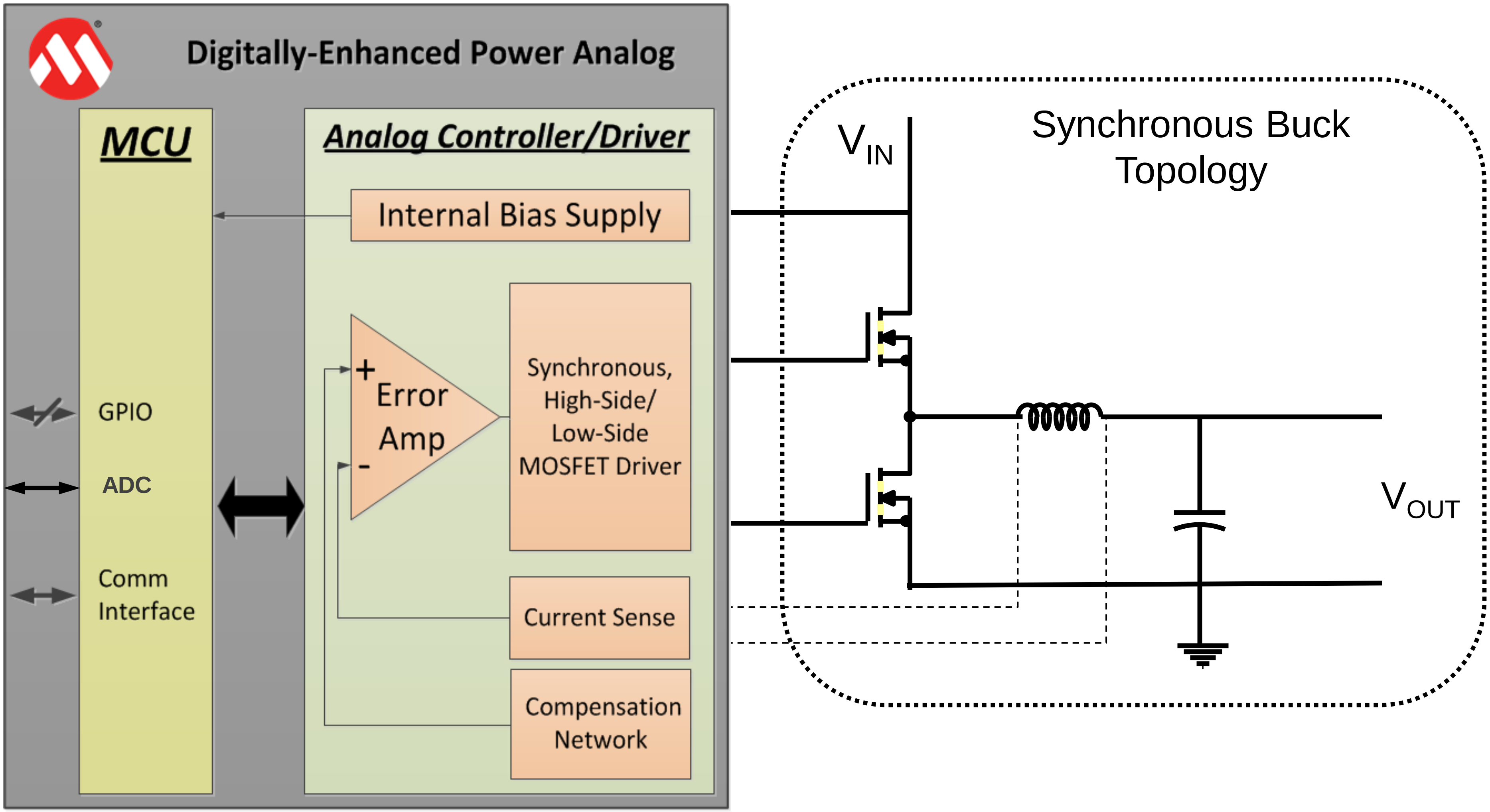
Adding Intelligence to Analog

- **Unique Technology**
- **Design Tools / Programmers**
- **PIC Micro…Mid Range Core Versatility**
- **Add Analog Process**
  - Different than Digital Process
- **Add High Voltage Capability**
- **Add NDMOS for Efficiency**
- **Add Proprietary Integrated Features**

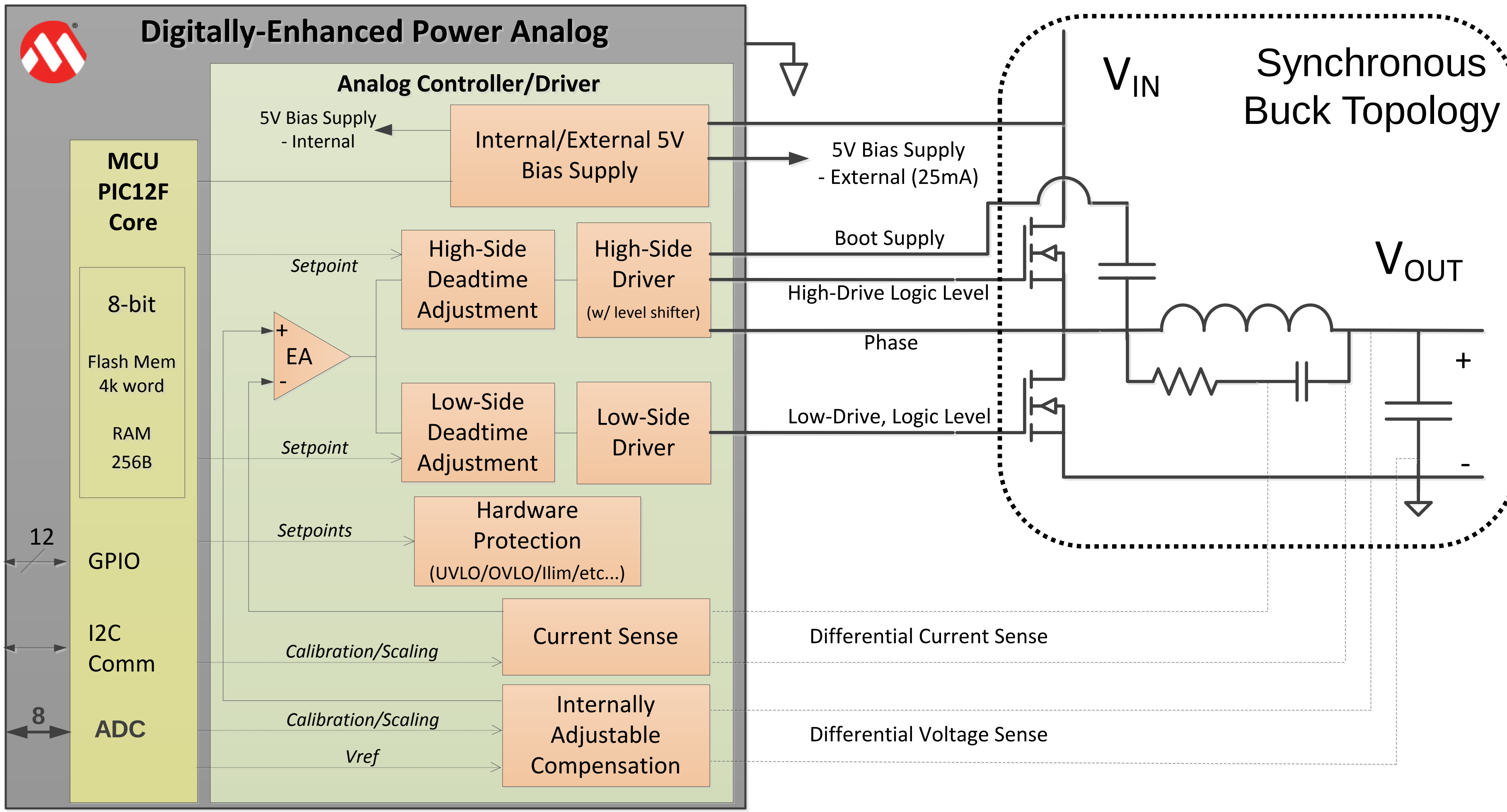
MCP19111

Digitally Enhanced Power Analog Controller with Integrated Synchronous Driver

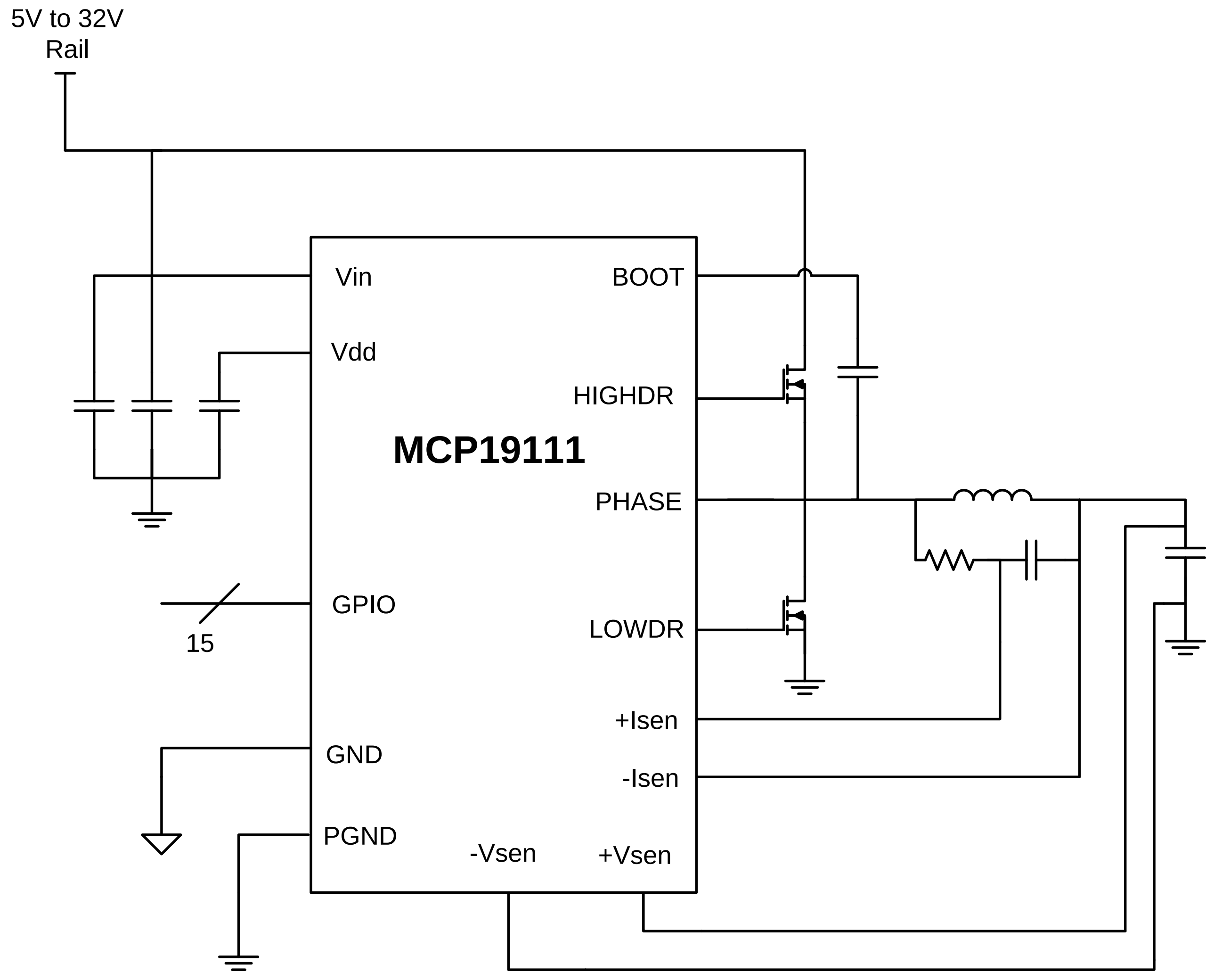
Digitally Enhanced Power Controller
Basic Solution Architecture



MCP19111 Synchronous Buck
High/Low-Side Topology Support



MCP19111
Simplified Schematic

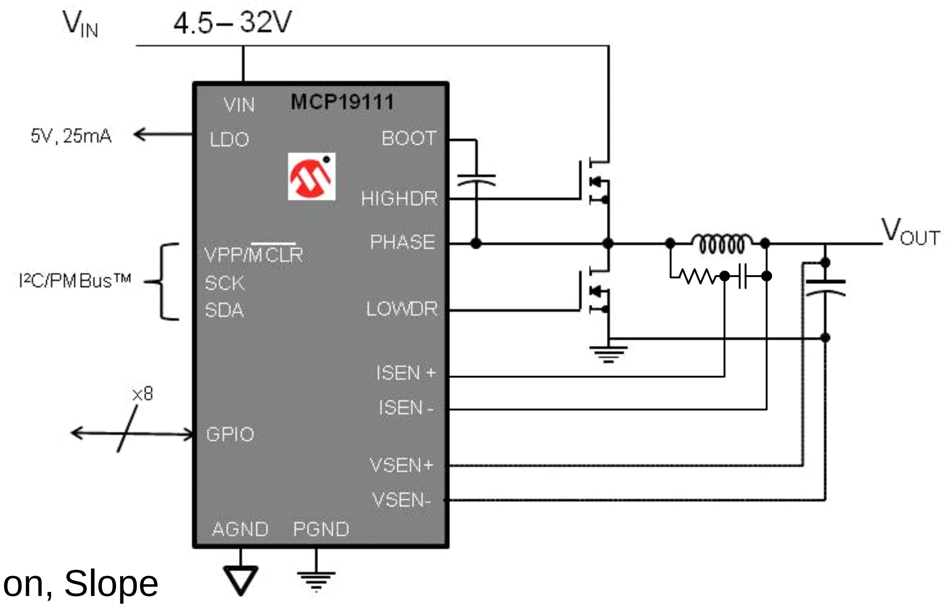


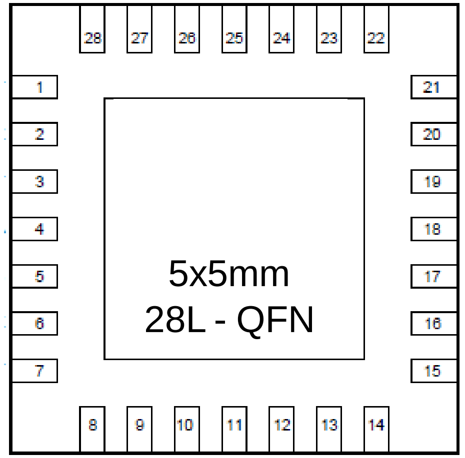
MCP19111

Digitally Enhanced Power Analog Controller

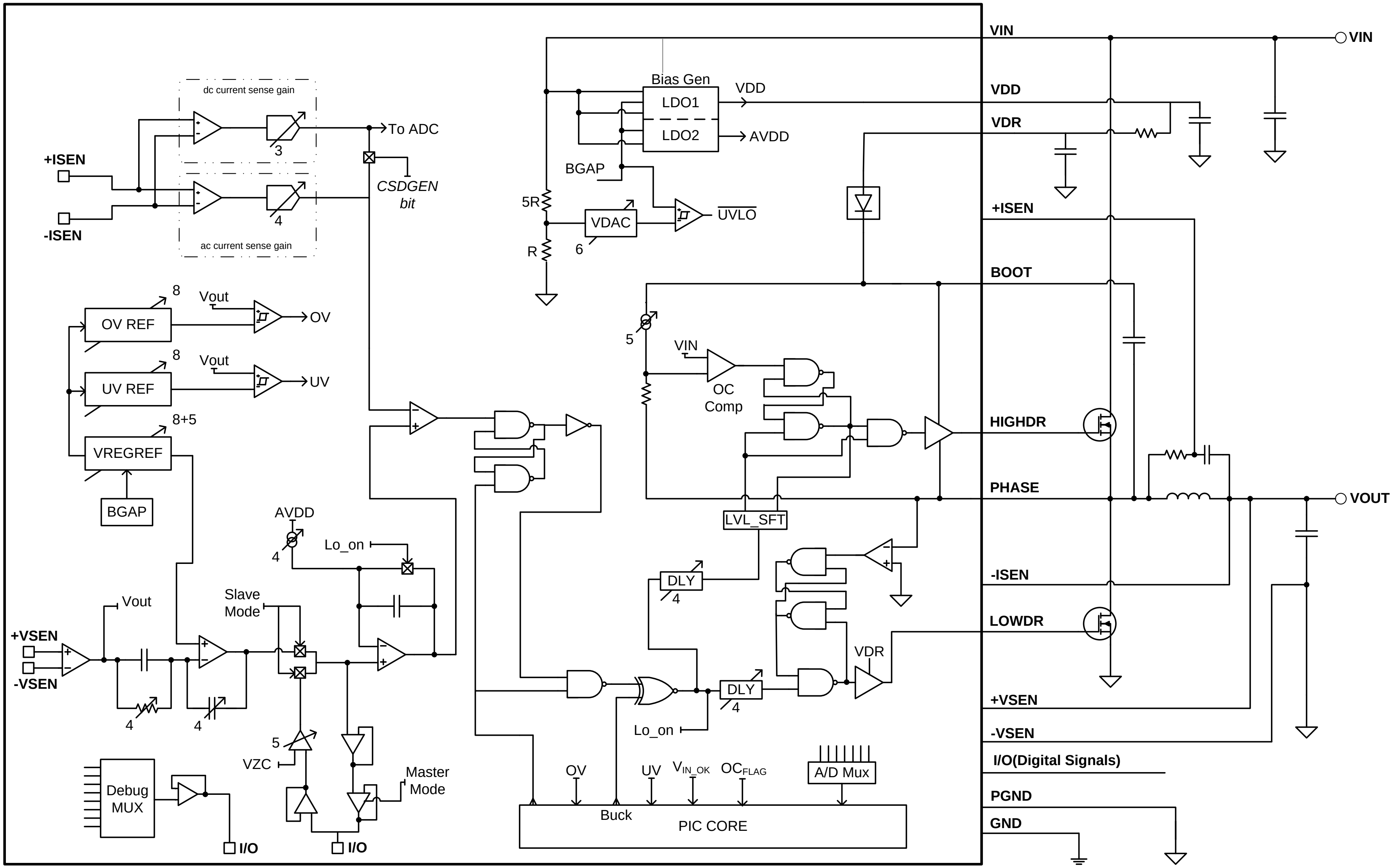
Single Phase Synchronous Buck

- **V_{IN} Range: 4.5V to 32V**
- **V_{OUT} Range: 0.5V to 3.6V**
  - **Greater with output divider**
- **Coarse and Fine V_{REF} DAC**
- **Integrated MOSFET Driver:**
  - Logic-Level Drive (5V)
  - 2A Source/4A Sink Drive Current
- **Programmable Analog Controller:**
  - Switching Freq: 100kHz to 1.6MHz
  - **Analog Control:** Control Loop Compensation, Slope Compensation, Peak Current Limit (Level & LEB Delay), **Gate Drive Deadtime**
  - **Thresholds:** V_{IN} UVLO, I_{OUT} CS Amp Gain, Soft-Start Rate, V_{OUT} Setpoint, V_{OUT} Trim, V_{OUT} OV/UV,
  - **Measure:** V_{IN}, V_{OUT}, Internal Temp + 8 Ext Ch
  - Master/Slave Mode → Multi-phase operation
- **Programmable Digital Core:**
  - Midrange Core (2 MIPS), 4kW Self-Write Flash, 256B RAM
  - (2) 16-bit Timers, (1) 8-bit Timer, (1) PWM, 12 GPIO
  - MSSP w/Enhanced PMBus Support





MCP19111
Block Diagram



Device Communication

MCP19111
Communication

- **I²C™ Communication**
  - Open drain clock and data lines
- **SMBus Alert Pin**
  - GBP4 open drain pin
- **Two address registers**
  - Device specific address register
  - SMBus alert address register
    - When activated, device will respond to either address
- **Have a PMBus stack in the MPLAB X project**

MCP19111 Calibration

Calibration Words

- **16 Calibration words at 2080h-208Fh**
  - Read only, they are not erased with program memory.
  - Contains calibration for amplifier offsets, band gap, temperature measurement, oscillator, output differential amplifier.
  - Calibration words 2080h to 2083h need to be moved to specific SFRs.
    - DOVCAL, OSCCAL, VROCAL, BGRCAL, TTACAL, ZROCAL

Calibration Word Read Example

REGISTER 4-3: CONFIG – CALIBRATION WORD 1 (ADDRESS: 2080h)

U-0	U-0	R/P-1	R/P-1	R/P-1	R/P-1	U-0	R/P-1	R/P-1	R/P-1	R/P-1	R/P-1	R/P-1	R/P-1
—	—	DOV3	DOV2	DOV1	DOV0	—	FCAL6	FCAL5	FCAL4	FCAL3	FCAL2	FCAL1	FCAL0
bit 13													bit 0

V_{OUT} Differential Amp Offset

Oscillator Calibration

	197h
OSCCAL	198h
DOVCAL	199h
TTACAL	19Ah
BGRCAL	19Bh
VROCAL	19Ch
ZROCAL	19Dh
	19Eh

Calibration Word Read Example

```
banksel   PMADRH
movlw     0x20
movwf     PMADRH              ; MS Byte of Program Address to read
movlw     0x80
movwf     PMADRL              ; LS Byte of Program Address to read
bsf       PMCON1, CALSEL
bsf       PMCON1, RD          ; Program Memory read
nop                           ; First instruction after memory read executes
nop                           ; instruction here is ignored as memory is read
                              ; in 2nd cycle after read

movf      PMDATH, W           ; W = MS Byte of Program Memory
banksel   DOVCAL
movwf     DOVCAL              ; Move W to DOVCAL

banksel   PMDATL
movf      PMDATL, W           ; W = LS Byte of Program Memory
banksel   OSCCAL
movwf     OSCCAL              ; Move W to OSCCAL
```

Assisting System Development

MCP19111
Bench Test Mode

- **Ability to look at internal signals**
  - 17 different circuit nodes
  - Multiplexer and buffer
  - BUFFCON register controls signals
  - Alternate GPIO pin function

MCP19111
Virtual Probe Details

bit 4-0 **ANSEL<4:0>:** MUX Control bits

00000 = Voltage proportional to current in the inductor
00001 = Demanded current plus the added slope comp ramp
00010 = Input to current loop, output of the demand mux
00011 = Band gap reference
00100 = Reference voltage for the VREG output
00101 = Internal version of the VREG output
00110 = RE_FRACT_PART
00111 = Analog voltage proportional to internal temperature
01000 = Internal ground of current measurement circuitry
01001 = Reference for over voltage comparator
01010 = Reference for under voltage comparator
01011 = Output of the error amplifier
01100 = Demanded current from remote master
01101 = Demanded current modified by the slave gain amplifier
01110 = 1/12 divided down VIN
01111 = DC Inductor Current
11101 = OC Reference

Minimal Register Configuration

MCP19111
Basic Set-up Code

```
; Configuring the switching frequency
    banksel T2CON
    clrf    T2CON
    clrf    TMR2
    clrf    PWMPHL      ; no phase shift
    movlw   0x13
    movwf   PWMRL       ; max allowed duty cycle ~ 75%
    movlw   0x19
    movwf   PR2         ; switching frequency ~ 300kHz
    bsf     T2CON, 2    ; enable Timer2

; Configuring the device
    banksel PE1
    clrf    PE1
    movlw   b'00001001'
    movwf   ABECON      ; enable current measurement
                        ; & control loop
    banksel VZCCON
    movlw   0x80
    movwf   VZCCON

; Configuring analog SFRs
    banksel VINLVL
    movlw   0x9A
    movwf   VINLVL      ; set UVLO to about 11V
    movlw   0x88
    movwf   DEADCON     ; set driver dead time
    movlw   0x0D
    movwf   CMPZCON     ; set compensation values
    movlw   0x32
    movwf   SLPCRCON    ; set slope compensation
    movlw   0x05
    movwf   CSGSCON     ; set current sense AC gain
    banksel OVCCON
    movlw   0x71        ; set Vout = 1.8V
    movwf   OVCCON
    movlw   0x80        ; enable Vout DAC
    movwf   OVFCON
    banksel ATSTCON
    bcf     ATSTCON, 0  ; enable driver
```

MCP19111 Design Tools

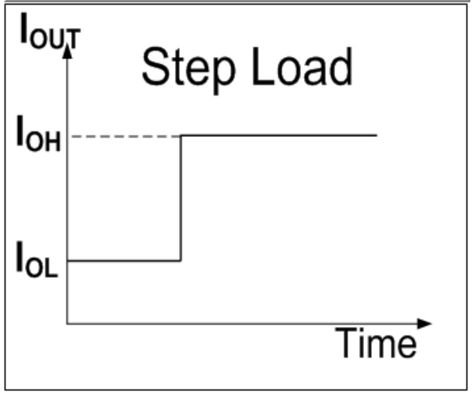
MCP19111 Excel Design Tool

MCP19111 DESIGN ANALYZER

Input Parameters for Design

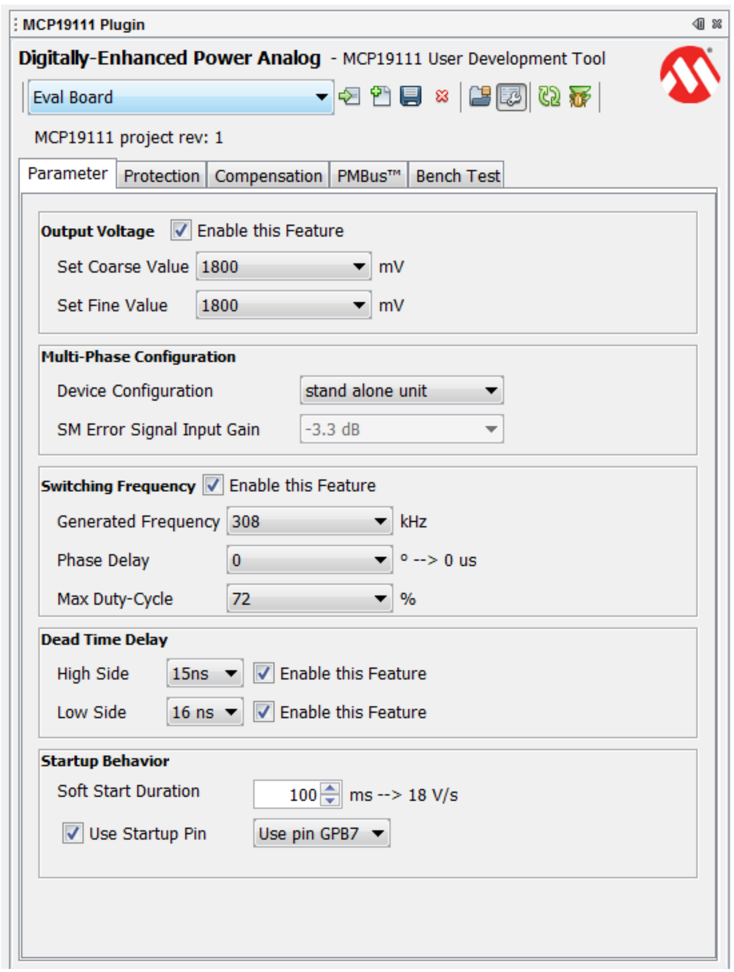
Parameter	Designator	Value	Units	Notes
Input Voltage	V_{IN}	12	V	$4.5 \le V_{IN} \le 30$
Output Voltage	V_{OUT}	1.8	V	$0.6 \le V_{OUT} \le 3.6$
Output Current	I_{OUT}	30	A	$0 \le I_{OUT} \le 30$
Switching Frequency	Fs	300	kHz	$100 \le Fs \le 1200$
Input Voltage Ripple	V_{RIN}	100	mV	
Minimum Input Voltage	V_{IN_MIN}	9	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	

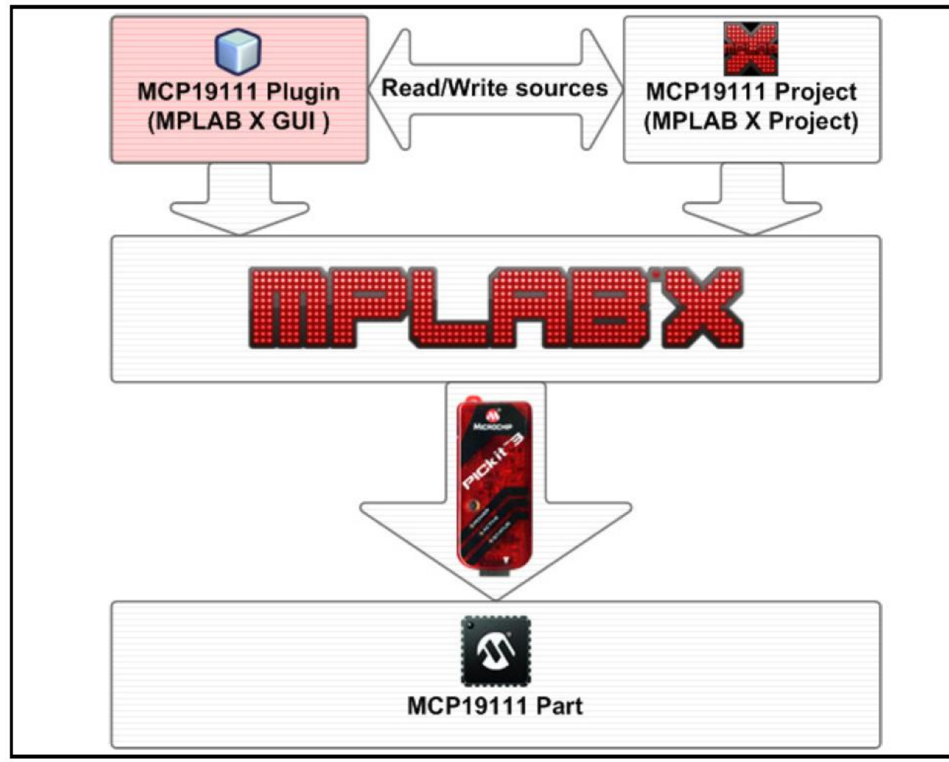
Use Default EVAL Board Components and Compensation



Use Recommended Components and Compensation

MCP19111 Programming GUI



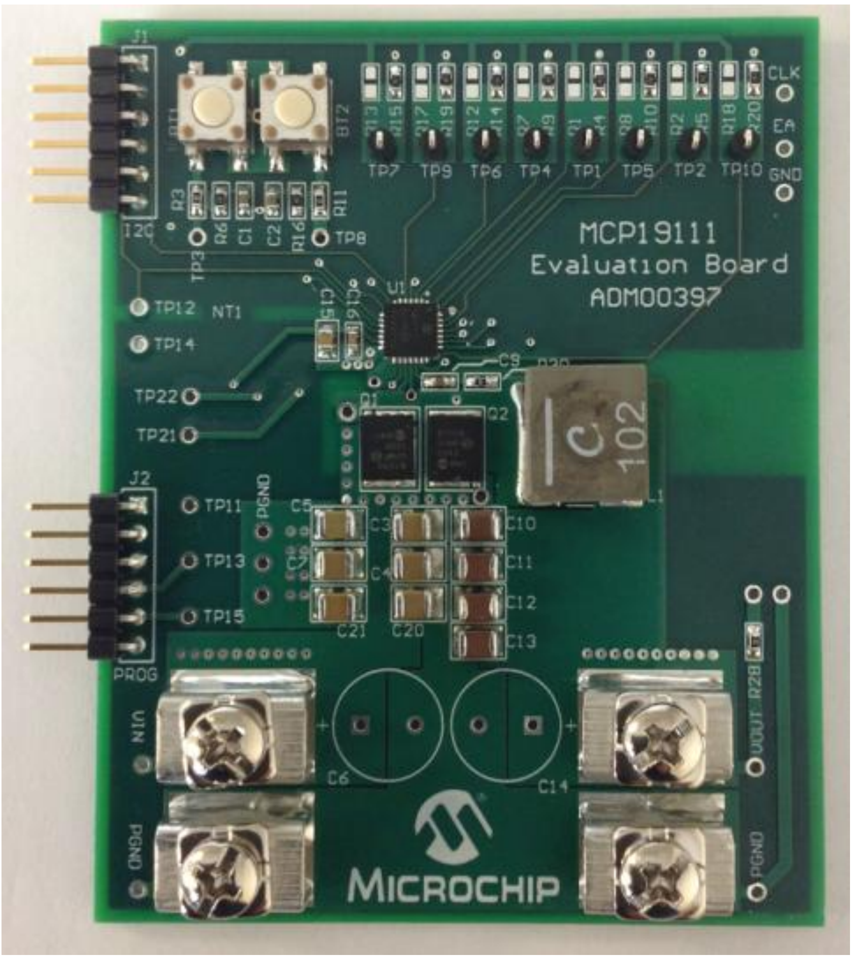


Digitally Enhanced Power Analog Applications

Point of Load or “POL”

- **5V to 24V Inputs**
  - Low V_{OUT}, High I_{OUT} Applications
  - Memory, Processors, FPGA, etc..
  - Small Geometries (sub 1.8V Power)
  - Current from 3A to 30A+

MCP19111 Eval Board and POL Converter Board



- V_{IN} = 6V to 16V
- I_{OUT} = 30A with airflow
- F_{SW} = 100kHz to 1.2MHz
- **Programmable Features**
  - Switching Frequency
  - Output Voltage
    - Fine and Course
  - Dead Time
  - Output OV and UV
  - Over Current Protection
  - Compensation
  - Current Sense Gain

MCP19111 Eval Board and POL Converter Board

- **MCP87XXX Series MOSFETs**
  - MCP87050 HS MOSFET – 5.0mΩ $R_{DS(ON)}$
  - MCP87018 LS MOSFET – 1.8mΩ $R_{DS(ON)}$
- **Optimized PCB Layout**
  - Short, wide traces for all power paths
    - Vin, Pgnd, PHASE, Gate Drive, BOOT, etc.
  - Split ground plane
  - Input/Output ceramic capacitors

MCP19111
Switching Frequency Control

- **Controlled by writing to PR2 register**
  - TMR2 counts up to reach PR2
  - Adjustable from 100kHz to 1.6MHz
    - Larger FETs may require external regulator on V_{DR} at very high switching frequencies.

From the MCP19111 Datasheet

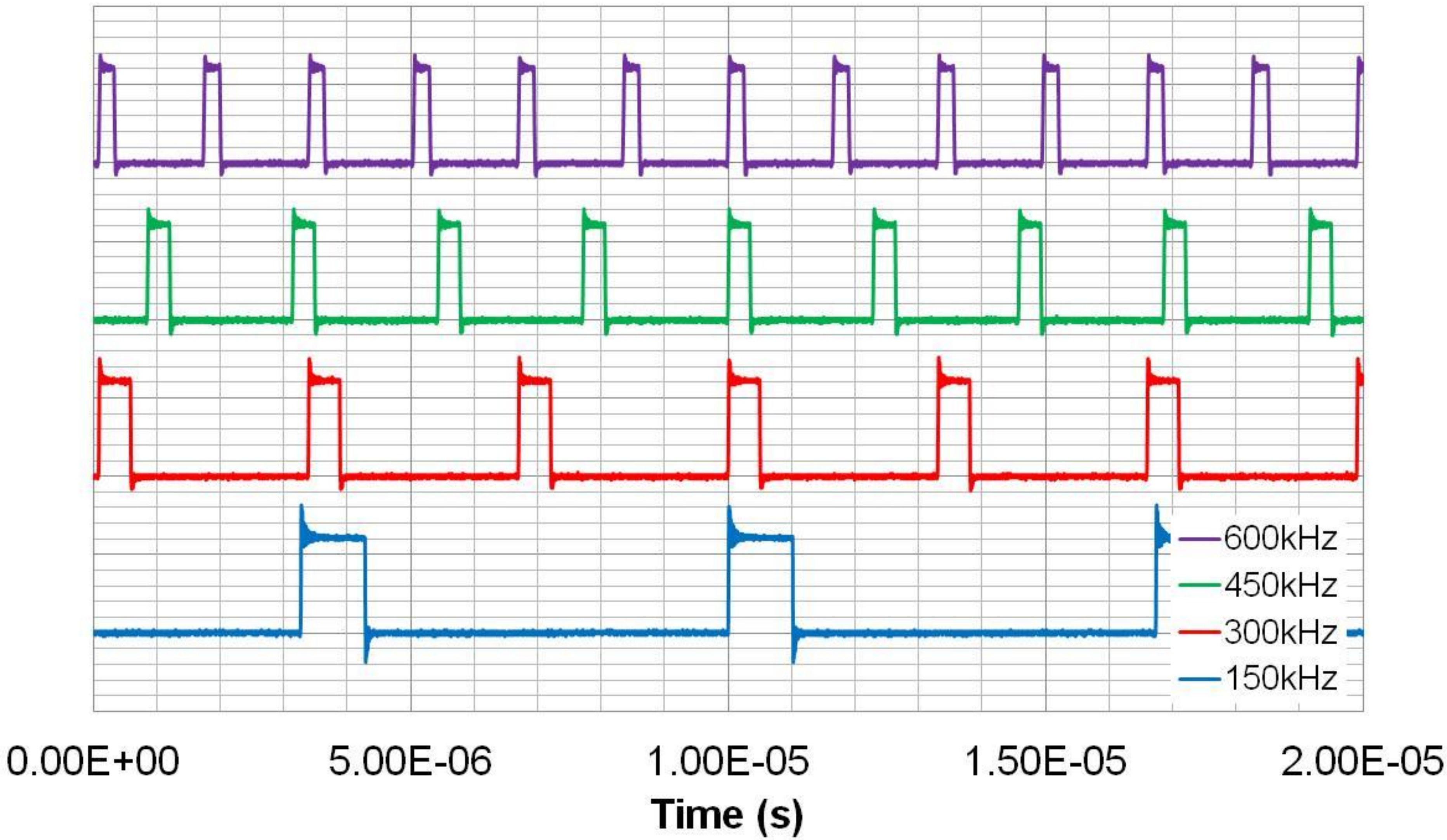
EQUATION 3-2: GATE DRIVE CURRENT

$$I_{DRIVE} = (Q_{gHIGH} + Q_{gLOW}) \times F_{SW}$$

Where:

- I_{DRIVE} is the current required to drive the external MOSFETs
- Q_{gHIGH} is the total gate charge of the high-side MOSFET
- Q_{gLOW} is the total gate charge of the low-side MOSFET
- F_{SW} is the switching frequency

MCP19111 Waveforms
Switching Frequency Control

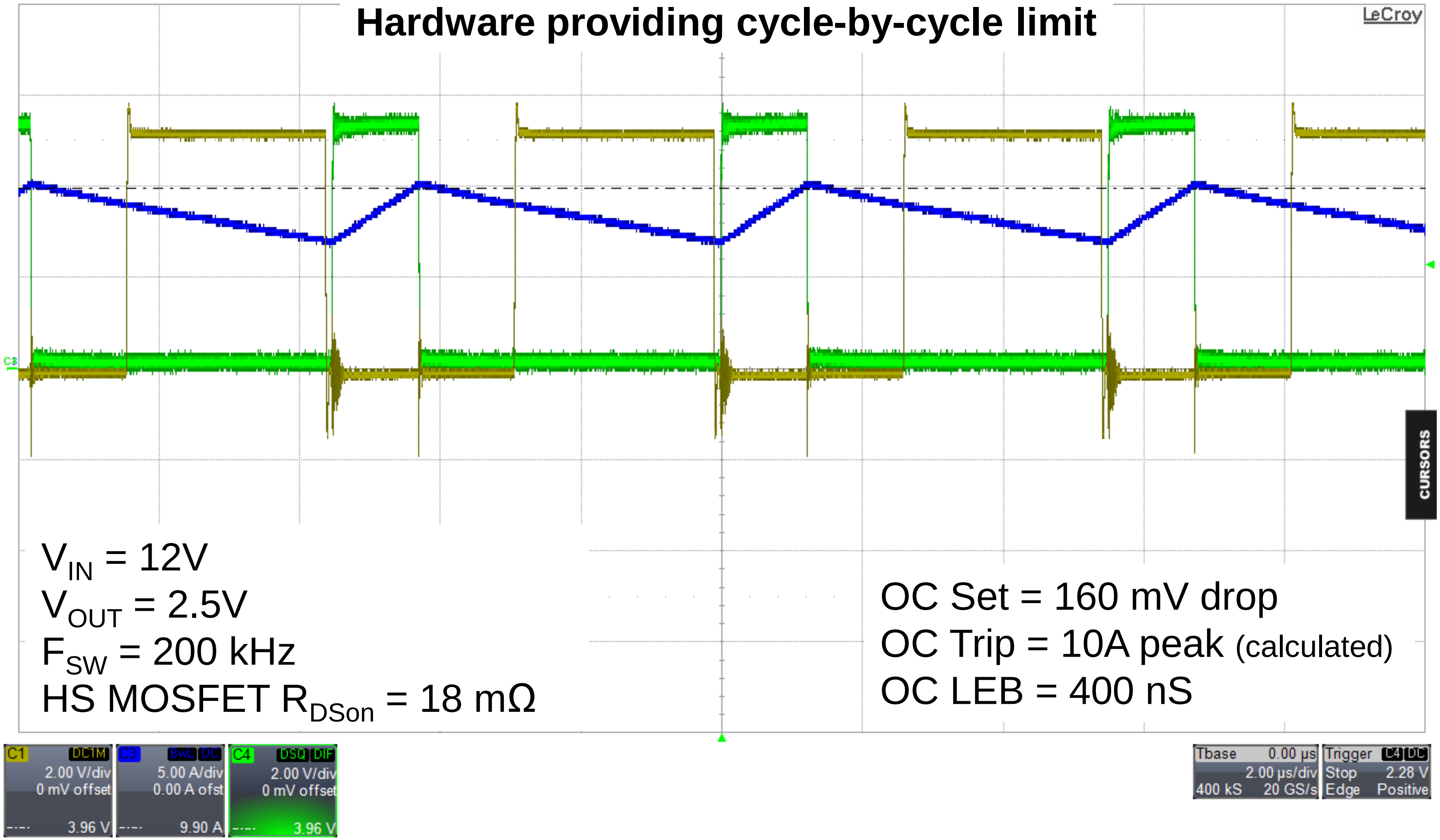


MCP19111
Over Current Protection

- **Voltage drop across high-side MOSFET sensed**
  - Cycle-by-cycle peak current limit
  - Controlled by writing to OCCON register
  - Adjustable range: 160mV to 625mV drop
  - Leading edge blanking of 114nS, 213nS, 400nS, 780nS
  - When OC occurs, OCIF Flag is set, hardware resets
- **Customized fault handling**
  - User’s firmware dictates procedure
    - Ex. Restart 3 times, if fault still exists then shutdown

MCP19111
Cycle by Cycle OC Protection

Hardware providing cycle-by-cycle limit

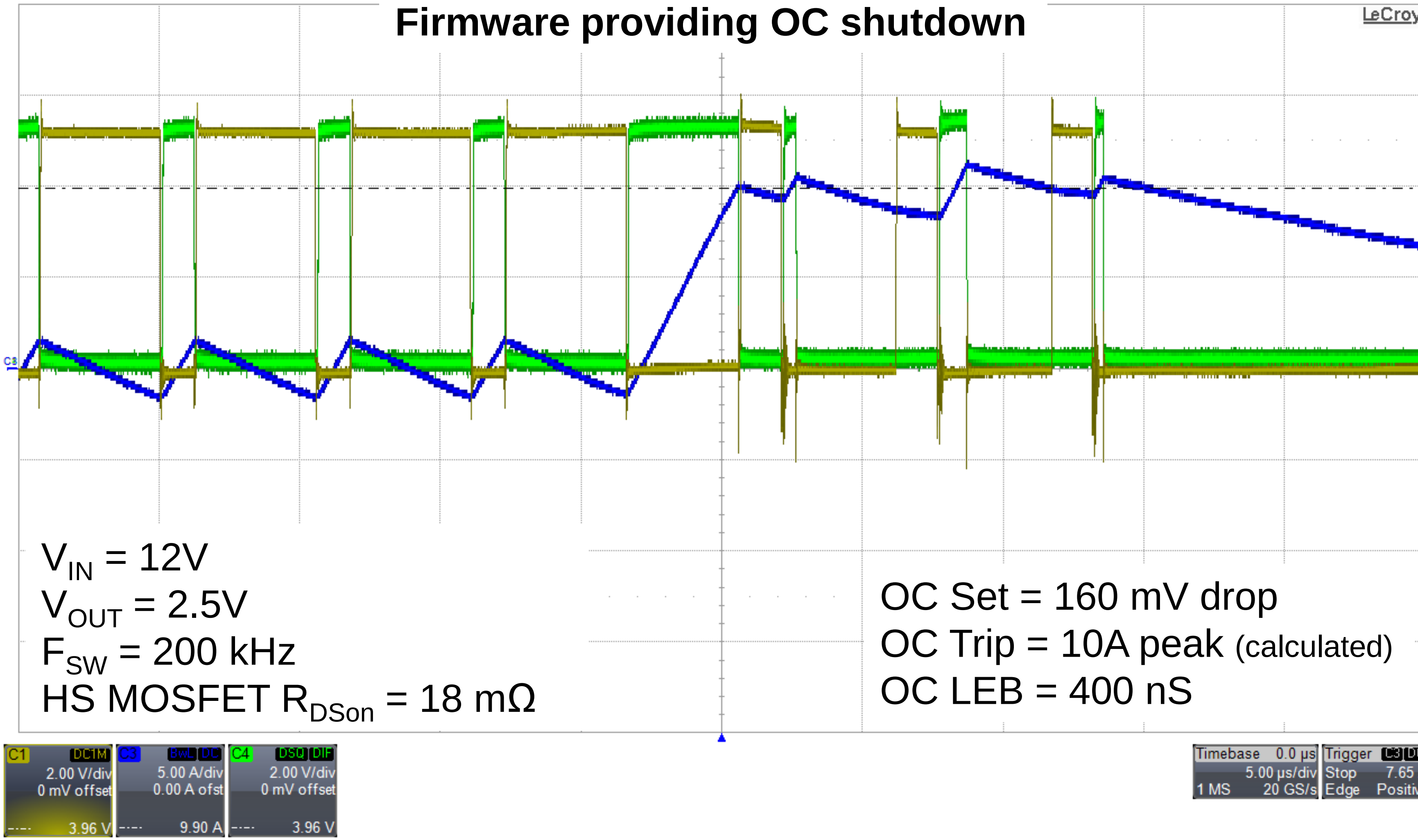


V_{IN} = 12V
V_{OUT} = 2.5V
F_{SW} = 200 kHz
HS MOSFET R_{DSon} = 18 mΩ

OC Set = 160 mV drop
OC Trip = 10A peak (calculated)
OC LEB = 400 nS

MCP19111
Output Short Circuit

Firmware providing OC shutdown



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V_{OUT} = 2.5V
F_{SW} = 200 kHz
HS MOSFET R_{DSon} = 18 mΩ

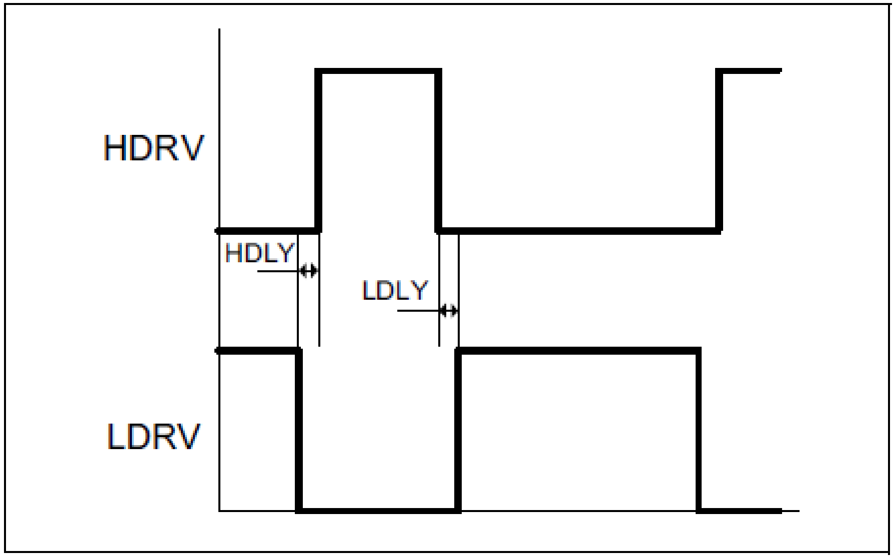
OC Set = 160 mV drop
OC Trip = 10A peak (calculated)
OC LEB = 400 nS

MCP19111
Dead Time Control

- **Controlled by writing to DEADCON register**
  - 4 bits for HDLY, adjustable from 11nS to 71nS
  - 4 bits for LDLY, adjustable from 4nS to 64nS
  - Very important to optimize efficiency, especially with High Speed (Low Parasitic Capacitance) MOSFETs

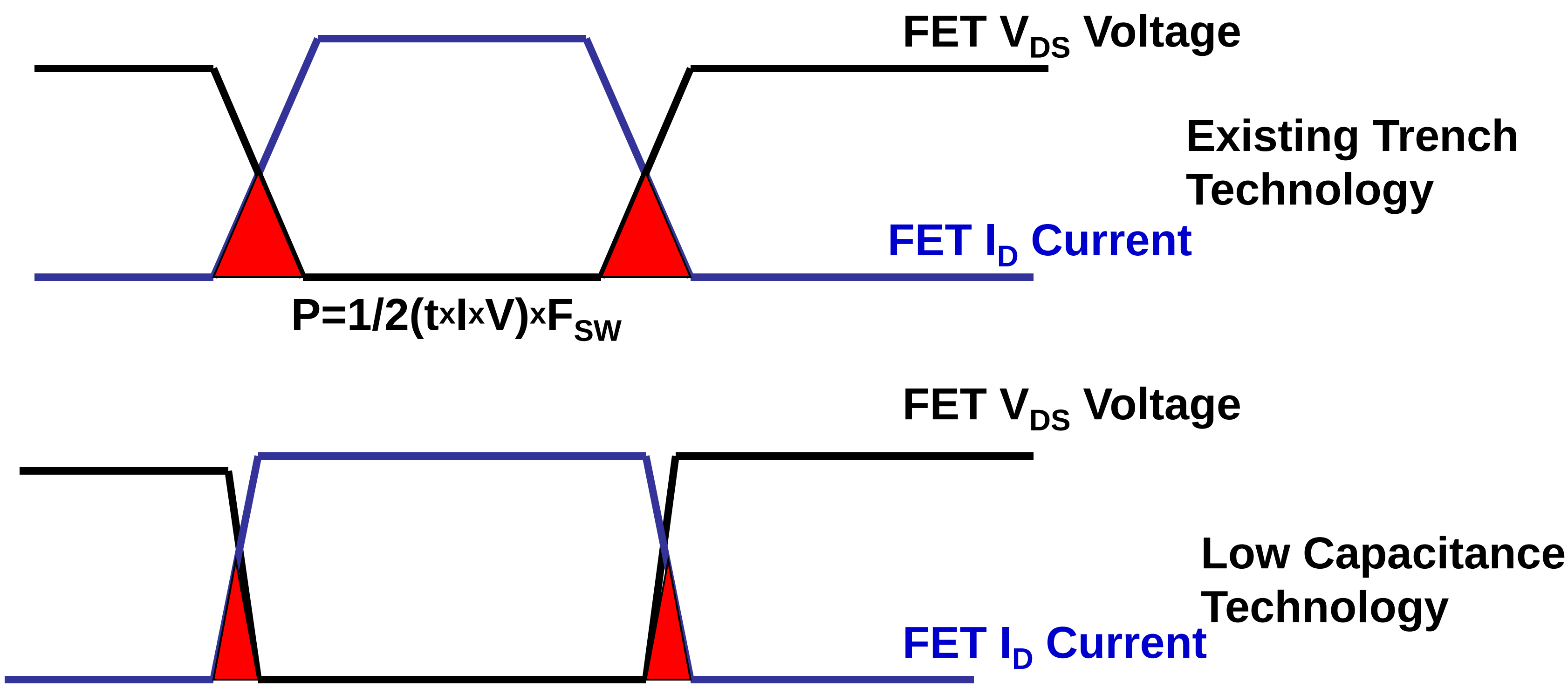
From the MCP19111 Datasheet

FIGURE 6-2: MOSFET DRIVER DEAD TIME



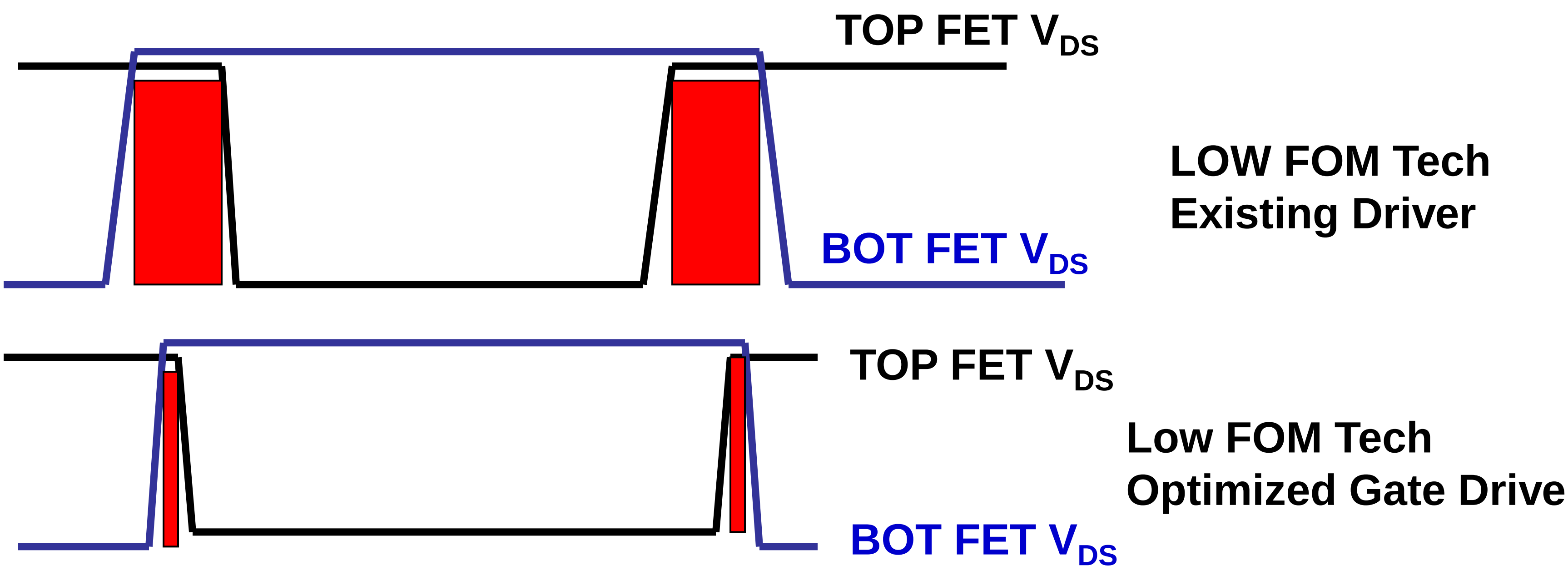
MOSFET Switching Loss

- **MOSFET Low Capacitance Technology**
  - **Lower Switching Losses Increases Efficiency!**

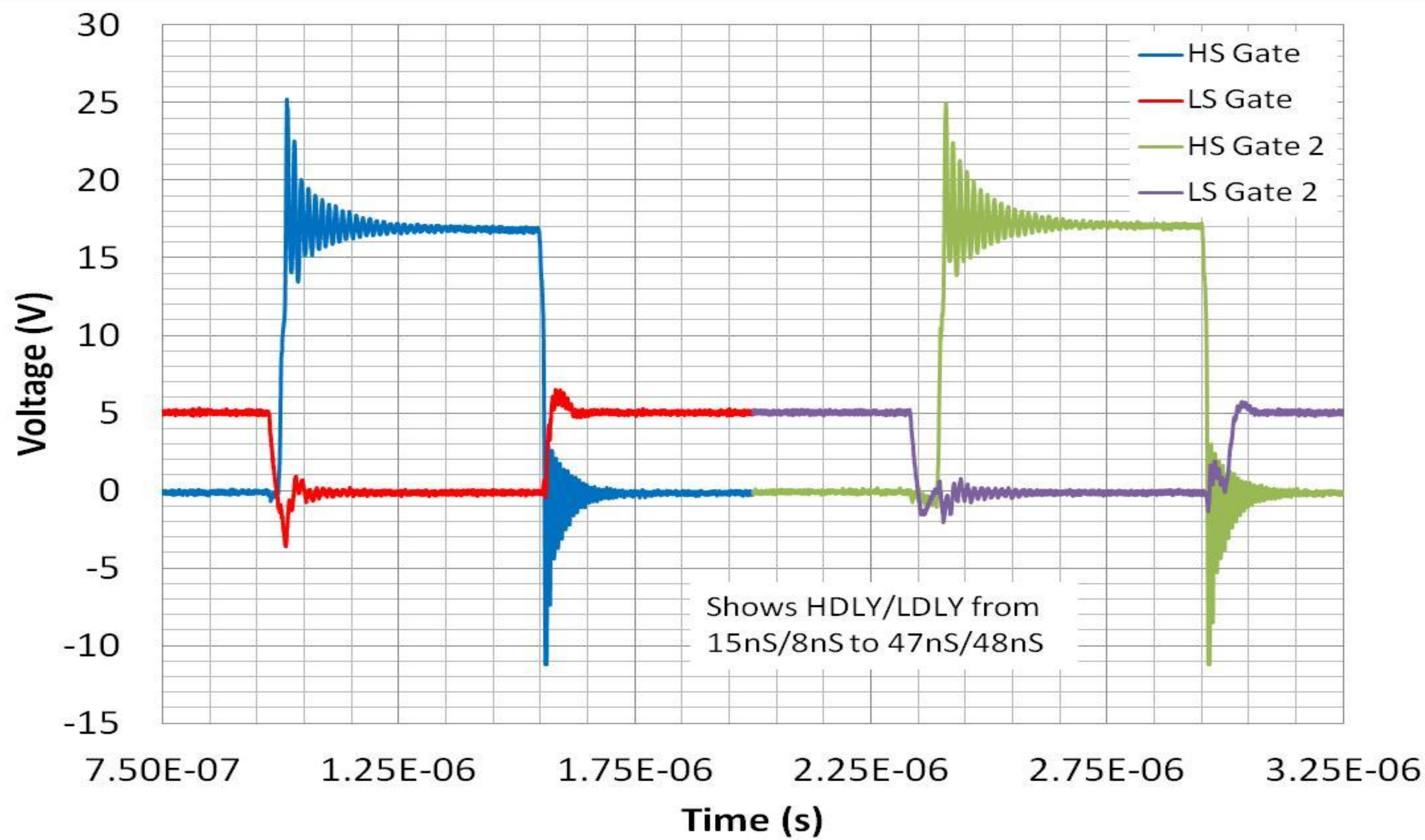


MOSFET Body Diode Loss

- **Optimized Dead Times**
  - **Keeping current out of the diode reduces reverse recovery losses and conduction losses**



MCP19111 Waveforms
Dead Time Control



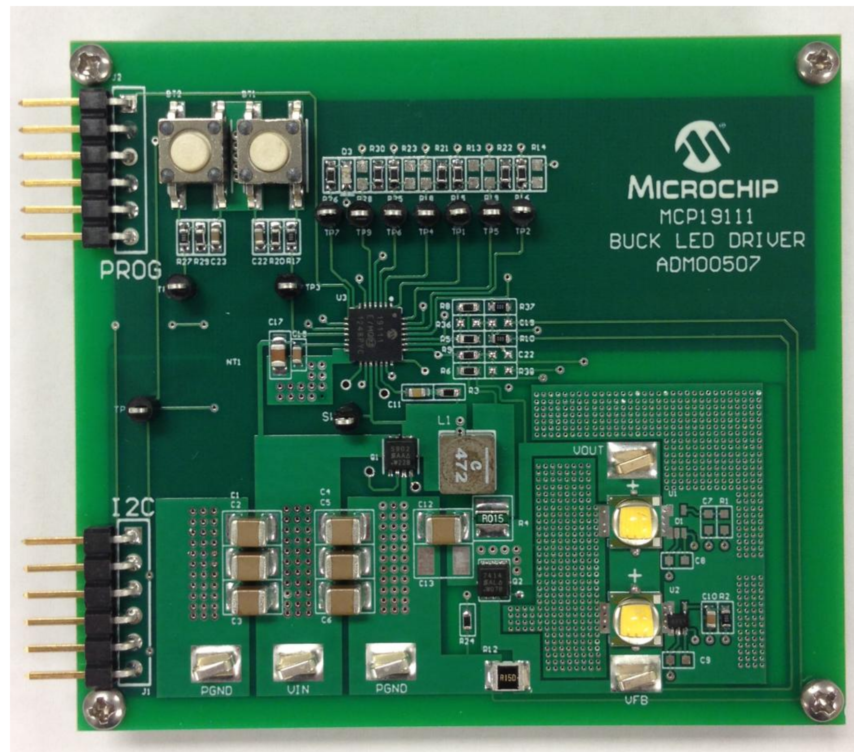
Digitally Enhanced Power Analog Applications Continued

MCP19111 Applications
DC/DC LED Lighting

- **Buck Converter High Power LED Lighting**
- **Applications**
  - Automotive (Optics to Distribute Light)
  - Adaptive Lighting
  - Communicating with LED Lighting
  - Commercial LED Lighting

MCP19111 Applications
DC/DC LED Lighting

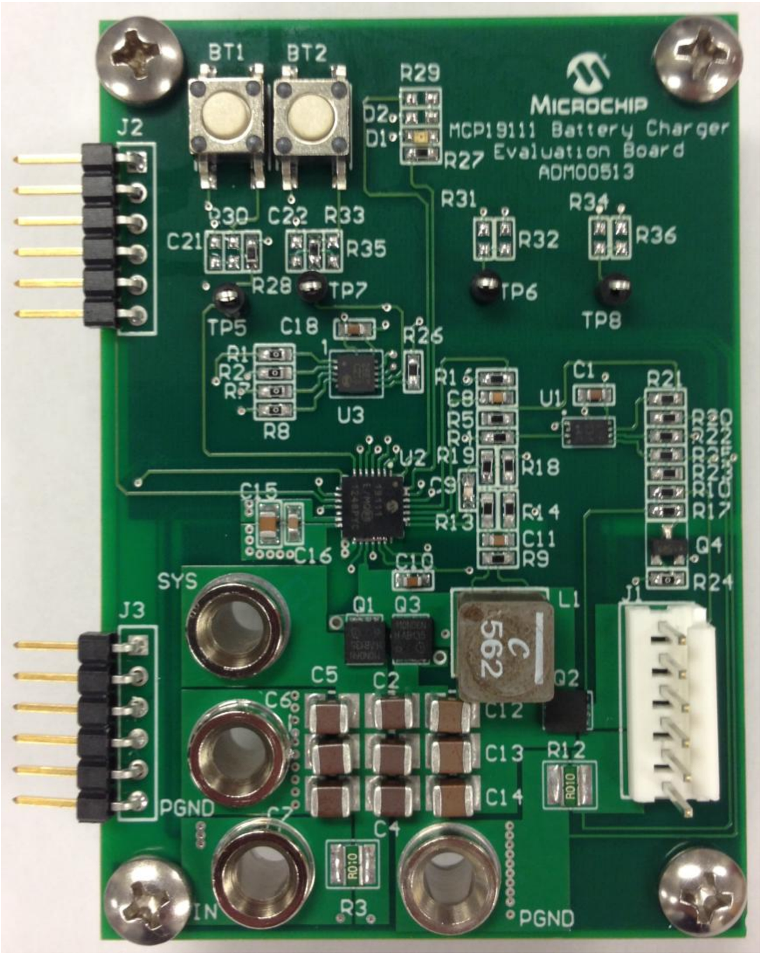
- **Synchronous Buck Converter LED Evaluation Board**
- **V_{IN} = 8V to 32V**
- **Programmable current**
- **Provides current regulation using a sense resistor**
- **Two LEDs in series**
- **Hardware dimming and software dimming**



MCP19111 Applications
Charging Batteries

- **Multi-Chemistry (Programmable Current Source)**
- **Wide I_{OUT} Range**
  - Pre-Charge, Fast Charge, Termination
  - NiMH, Li-Ion, Pb-Acid Battery Profiles

Multi-Chemistry Battery Charger

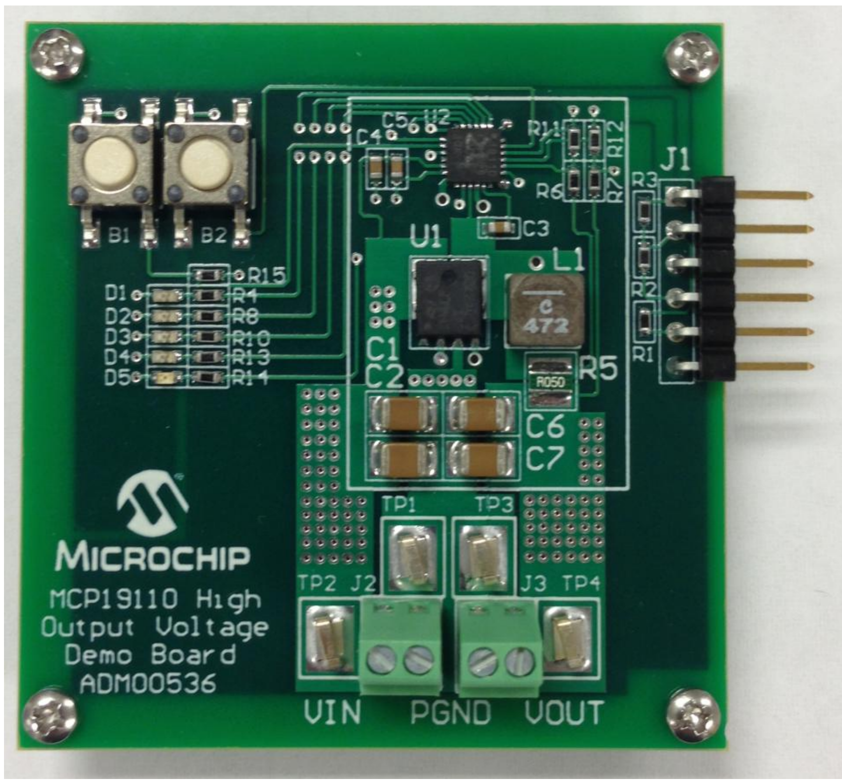


- Sync Buck Multi-Chemistry Battery Charger Evaluation Board
- 1-4 Cell Li-Ion
- NiMH, NiCd, Pb Acid
- V_{IN} = 4.5V to 32V
- Programmable Charging current up to 8A
- PIC core provides ability to design custom charging curves, protections, etc.

MCP19111 Applications
High Output Voltage

- Output of higher than 3.6V are possible with the MCP19111 by connecting the $+V_{SEN}$ pin to a voltage divider
- Care must be taken to ensure voltage rating compliance on all pins

MCP19111 Applications
High Output Voltage



- V_{IN} = 6V to 32V
- I_{OUT} up to 5A
- **Switchable between 4 voltage options using buttons**
  - 3.5V, 5V, 10V, 12V
  - LED Indication
- **Current sensing using resistor**
- **Utilizes MCP19110**
  - Same as MCP19111 in 4x4QFN package, minus 4 pins and debug capability

MCP19111
Output Voltage Control

- **Controlled by writing to OVCCON and OVFCON registers**

REGISTER 6-10: OVCCON: OUTPUT VOLTAGE SET POINT COARSE CONTROL REGISTER

R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
OVC7	OVC6	OVC5	OVC4	OVC3	OVC2	OVC1	OVC0
bit 7							bit 0

bit 7-0 **OVC<7:0>:** Output Voltage Set Point Coarse Configuration bits

OVC<7:0> = $(V_{OUT}/15.8\ mV)+15.8\ mV$

REGISTER 6-11: OVFCON: OUTPUT VOLTAGE SET POINT FINE CONTROL REGISTER

R/W-0	U-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
VOUTEN	—	—	OVF4	OVF3	OVF2	OVF1	OVF0
bit 7							bit 0

bit 7 **VOUTEN:** Output Voltage DAC Enable bit

1 = Output Voltage DAC is enabled

0 = Output Voltage DAC is disabled

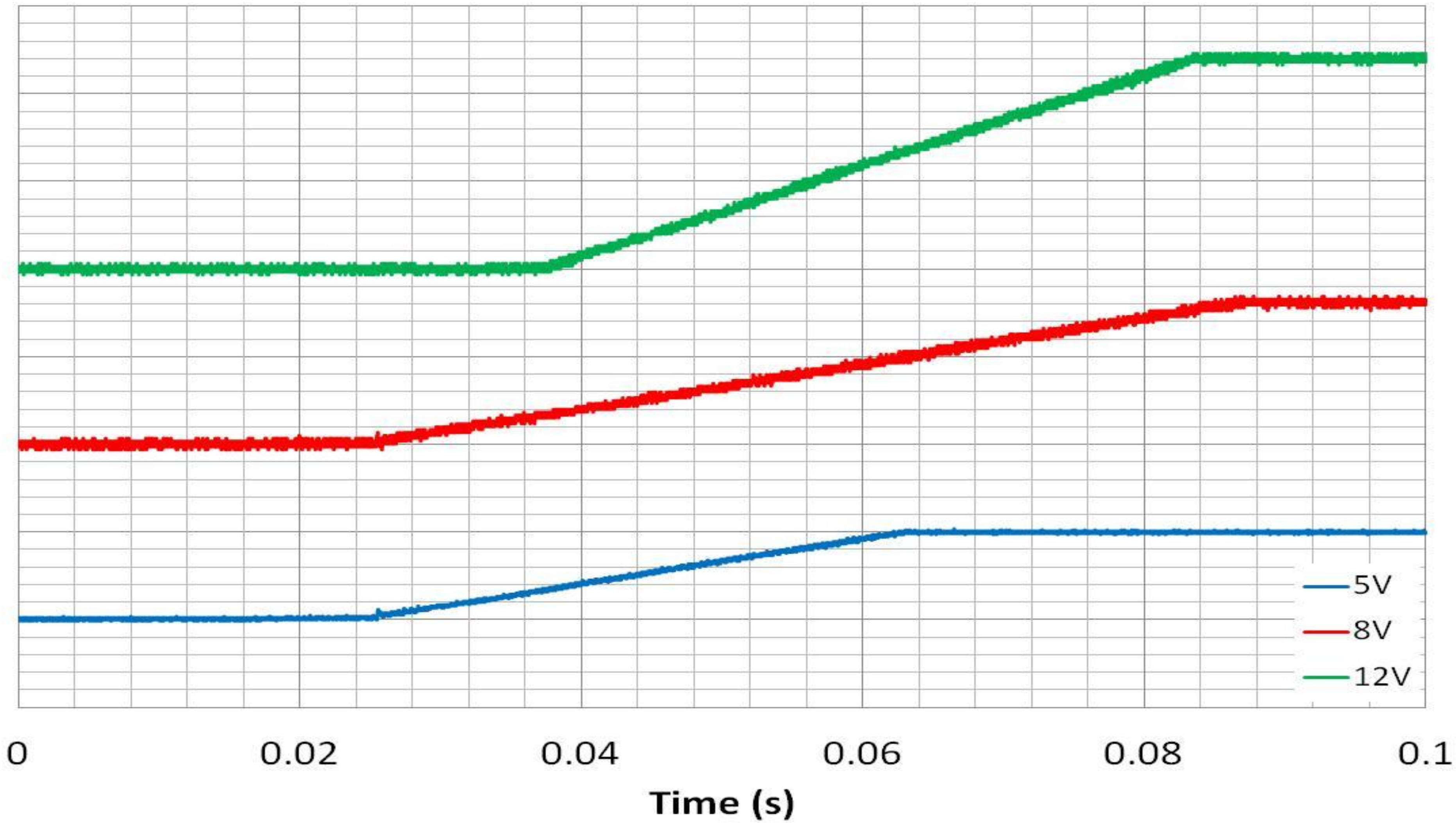
bit 6-5 **Unimplemented:** Read as '0'

bit 4-0 **OVF<4:0>:** Output Voltage Set Point Coarse Configuration bits

OVF<4:0> = $(V_{OUT} - V_{OUT\_COARSE})/0.8\ mV$

Output Voltage can be programmed to < 0.1% accuracy

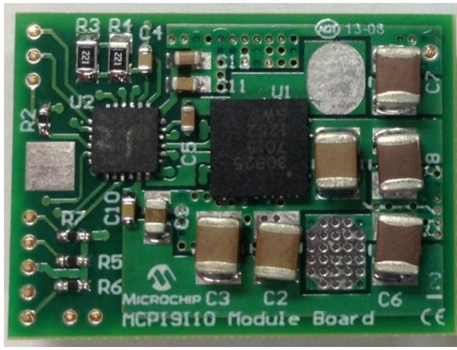
MCP19111 Waveforms
High Output Voltage

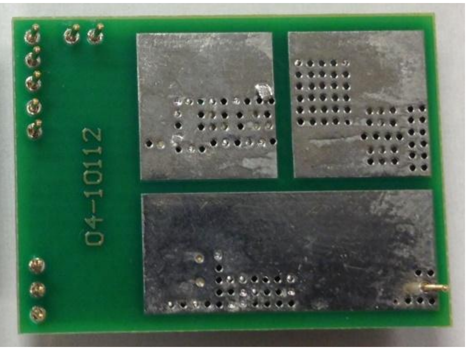


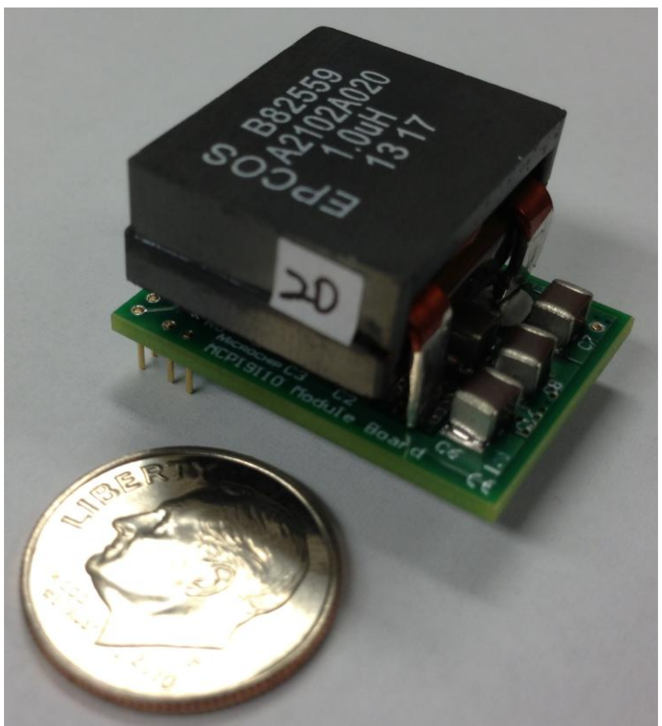
MCP19111 Applications
Power Supply Modules

- **Small footprint lends itself to very high power density applications**
  - MCP19111 – 5x5mm DFN, 28 Leads
  - MCP19110 – 4x4mm DFN, 24 Leads
- **Programmability allows module designer to use the same part number for many different modules**
- **GPIO for communication, P_{GOOD}, Enable, etc**

MCP19111 Applications
Power Supply Modules

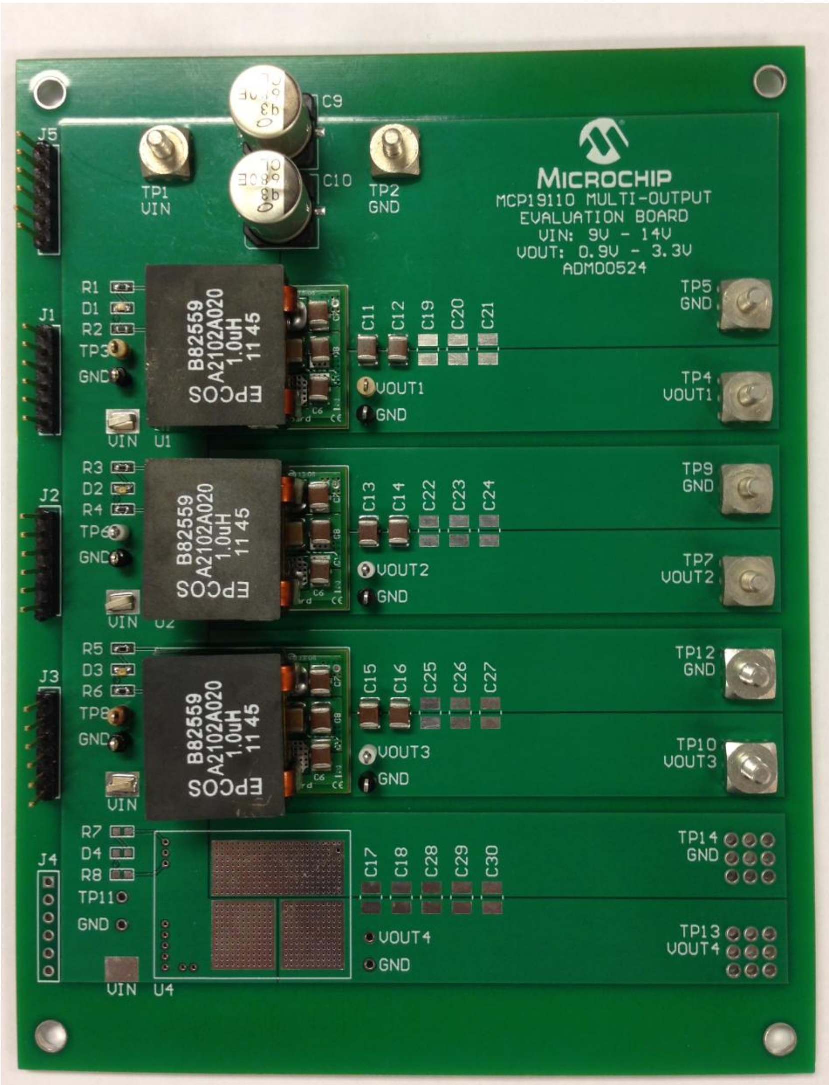






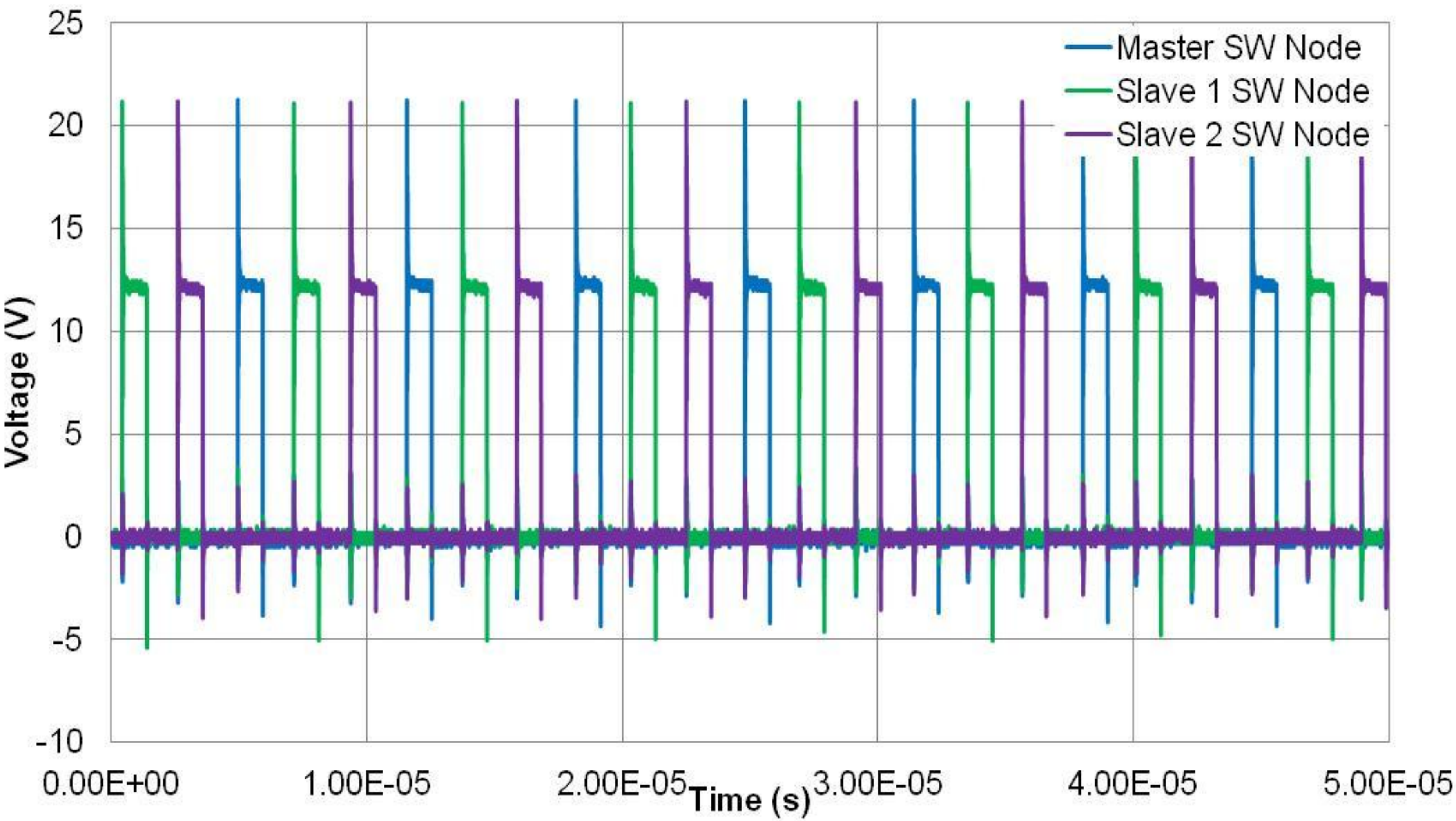
- V_{IN} = 6V to 16V
- V_{OUT} = 0.9 to 3.3V
- I_{OUT} = 30A+
- Utilizes the MCP19110, the GWS30B25 Dual MOSFET, EPCOS inductor
- Inductor “floats” over the PCB
- 66uF input ceramic cap, 300uF output ceramic cap
- 1” x 0.75” PCB
- POWER DENSITY!

MCP19111 Applications
Synchronized Multi-Output



- V_{IN} = 6V to 16V
- I_{OUT} = 30A+ per output
- Utilizes 4x MCP19110 power supply modules
- Switching waveforms synchronized 90° out of phase
  - Simplifies input filtering
- PIC core allows easy control of start-up sequence

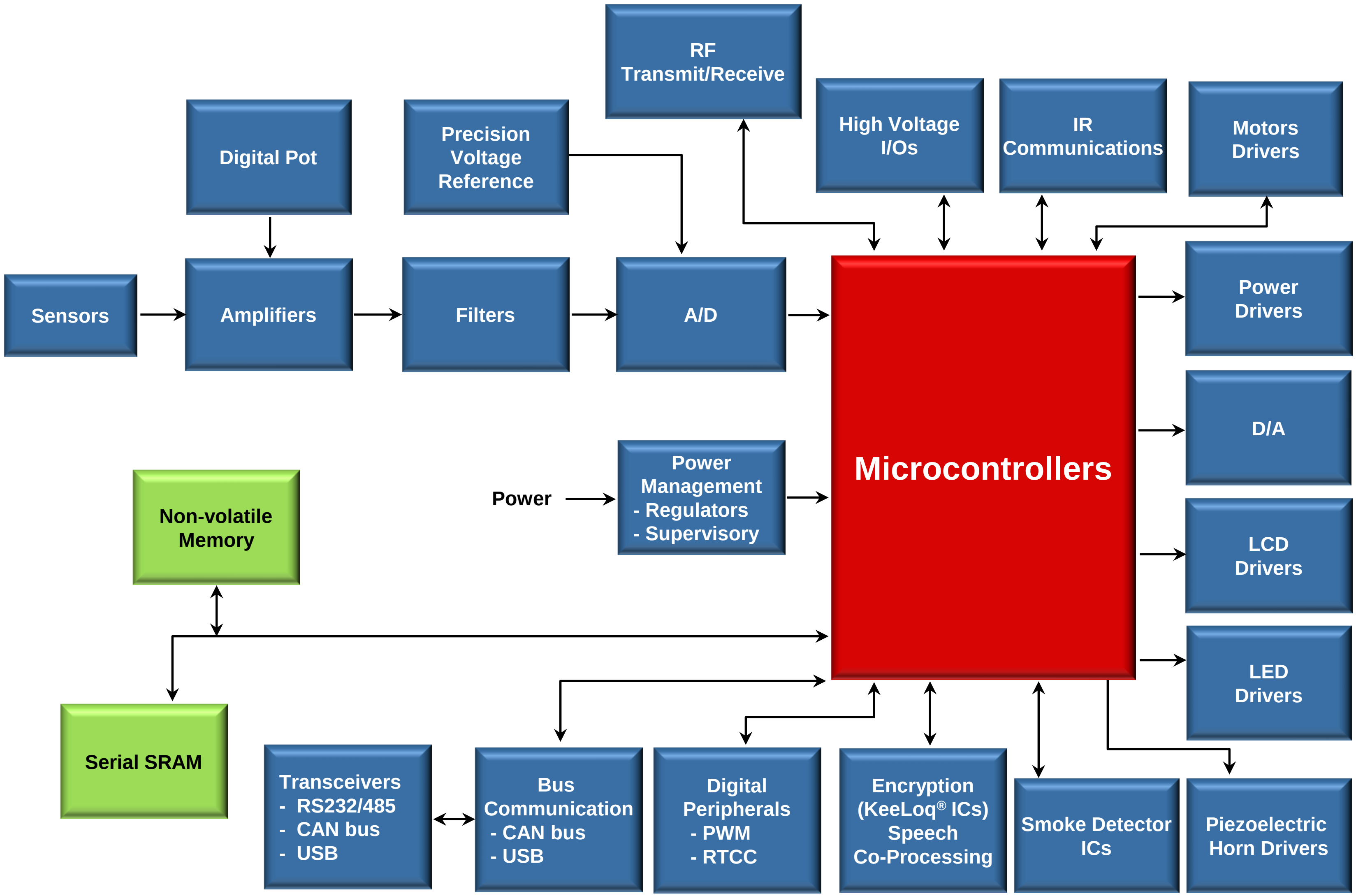
MCP19111 Waveforms Synchronized Multi-Output



MCP19111 RECAP

- **Extremely versatile part**
  - POL, DC-DC LED Lighting, Battery Chargers, Modules, HV Output, Multi-rail, etc
  - PIC core allows the flexibility, fault handling, and communication of a digital solution while offering the speed, resolution, and low quiescent current of an analog solution
  - Flexibility = higher efficiency!
  - Small footprint = high power density!
- **MCP87XXX MOSFETs**
  - FAST, ROBUST

Our Analog & Memory Enables Providing Complete Solutions



Additional Resources

- **Product Landing Page**
- **http://www.microchip.com/wwwproducts/Devices.aspx?dDocName=en560308**