dsPIC33CH512MP506 Digital Power Plug-In Module (PIM) User's Guide

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dsPIC33CH512MP506 DIGITAL POWER PIM USER'S GUIDE

Table of Contents

NOTES:

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Preface

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For the most up-to-date information on development tools, see the MPLAB® IDE online help. Select the Help menu, and then Topics to open a list of available online help files.

INTRODUCTION

This chapter contains general information that will be useful to know before using the dsPIC33CH512MP506 Digital Power Plug-In Module (PIM). Items discussed in this chapter include:

- Document Layout
- Conventions Used in this Guide
- Recommended Reading
- The Microchip Website
- Product Change Notification Service
- Customer Support
- Document Revision History

DOCUMENT LAYOUT

This document provides an overview of the dsPIC33CH512MP506 Digital Power PIM. The document is organized as follows:

- **Chapter 1. "Overview"** — This chapter introduces the dsPIC33CH512MP506 Digital Power PIM and provides a brief overview of its various features.
- **Appendix A. "Board Layout and Schematics"** — This appendix presents the schematics and the board layouts for the dsPIC33CH512MP506 Digital Power PIM.
- **Appendix B. "Bill of Materials (BOM)"** — This appendix presents the Bill of Materials for the dsPIC33CH512MP506 Digital Power PIM.
- **Appendix C. "Characterization Data"** — This appendix provides characterization data and guidance on sub-circuits of the dsPIC33CH512MP506 Digital Power PIM.

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CONVENTIONS USED IN THIS GUIDE

This manual uses the following documentation conventions:

DOCUMENTATION CONVENTIONS

<table>
<tr><th>Description</th><th>Represents</th><th>Examples</th></tr>
<tr><td colspan="3">Arial font:</td></tr>
<tr><td rowspan="2">Italic characters</td><td>Referenced books</td><td>MPLAB® IDE User's Guide</td></tr>
<tr><td>Emphasized text</td><td>...is the only compiler...</td></tr>
<tr><td rowspan="3">Initial caps</td><td>A window</td><td>the Output window</td></tr>
<tr><td>A dialog</td><td>the Settings dialog</td></tr>
<tr><td>A menu selection</td><td>select Enable Programmer</td></tr>
<tr><td>Quotes</td><td>A field name in a window or dialog</td><td>"Save project before build"</td></tr>
<tr><td>Underlined, italic text with right angle bracket</td><td>A menu path</td><td><u>File>Save</u></td></tr>
<tr><td rowspan="2">Bold characters</td><td>A dialog button</td><td>Click OK</td></tr>
<tr><td>A tab</td><td>Click the Power tab</td></tr>
<tr><td>N'Rnnnn</td><td>A number in verilog format, where N is the total number of digits, R is the radix and n is a digit.</td><td>4'b0010, 2'hF1</td></tr>
<tr><td>Text in angle brackets < ></td><td>A key on the keyboard</td><td>Press <Enter>, <F1></td></tr>
<tr><td colspan="3">Courier New font:</td></tr>
<tr><td rowspan="7">Plain Courier New</td><td>Sample source code</td><td><code>#define START</code></td></tr>
<tr><td>Filenames</td><td><code>autoexec.bat</code></td></tr>
<tr><td>File paths</td><td><code>c:\mcc18\h</code></td></tr>
<tr><td>Keywords</td><td><code>_asm, _endasm, static</code></td></tr>
<tr><td>Command-line options</td><td><code>-Opa+, -Opa-</code></td></tr>
<tr><td>Bit values</td><td><code>0, 1</code></td></tr>
<tr><td>Constants</td><td><code>0xFF, 'A'</code></td></tr>
<tr><td>Italic Courier New</td><td>A variable argument</td><td><code>file</code><code>.o</code>, where <code>file</code> can be any valid filename</td></tr>
<tr><td>Square brackets [ ]</td><td>Optional arguments</td><td><code>mcc18 [options] file [options]</code></td></tr>
<tr><td>Curly brackets and pipe character: { | }</td><td>Choice of mutually exclusive arguments; an OR selection</td><td><code>errorlevel {0|1}</code></td></tr>
<tr><td rowspan="2">Ellipses...</td><td>Replaces repeated text</td><td><code>var_name [, var_name...]</code></td></tr>
<tr><td>Represents code supplied by user</td><td><code>void main (void)
{ ...
}</code></td></tr>
</table>

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RECOMMENDED READING

This user's guide describes how to use the dsPIC33CH512MP506 Digital Power PIM. Other useful document(s) are listed below. The following Microchip document is available and recommended as a supplemental reference resource:

- ***"dsPIC33CH128MP508 Family Data Sheet"*** (DS70005319)
  Refer to this document for detailed information on the dsPIC33CH Dual Core Digital Signal Controllers (DSCs). Reference information found in this data sheet includes:
  - Device memory maps
  - Device pinout and packaging details
  - Device electrical specifications
  - List of peripherals included on the devices

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DOCUMENT REVISION HISTORY

Revision A (April 2019)

This is the initial version of this document.

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Chapter 1. Overview

1.1 INTRODUCTION

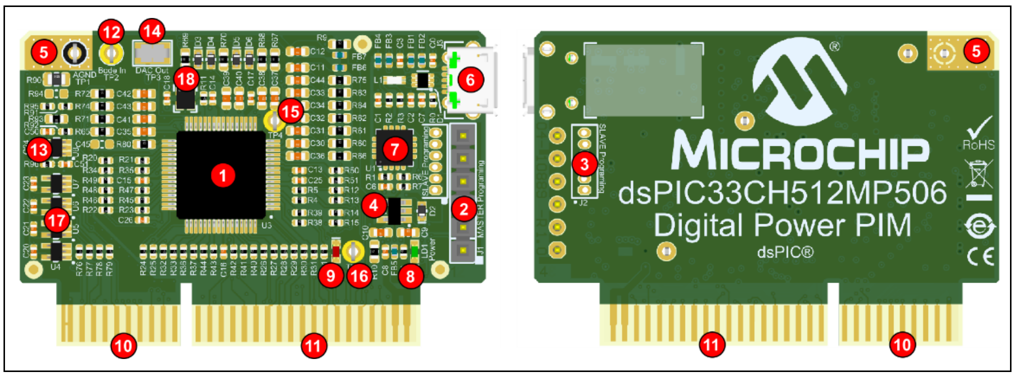
The dsPIC33CH512MP506 Digital Power Plug-In Module (DP PIM) is a demonstration board that, in conjunction with different power boards, showcases the Microchip dsPIC33CH512MP506 16-Bit Digital Signal Controller (DSC) features. The DP PIM provides access to the dsPIC33CH512MP506 analog inputs, the Digital-to-Analog Converter (DAC) output, the Pulse-Width Modulation (PWM) outputs and the General Purpose Input and Output (GPIO) ports.

The series of Microchip DP PIMs feature different device families, from dsPIC33E to dsPIC33CK and dsPIC33CH. These devices have different CPU performance levels as well as peripheral features and functions. However, even if the features and performance levels are different, all DP PIMs have the same functional card edge connector pinout to support seamless migration between device families.

1.2 FEATURES

The dsPIC33CH512MP506 DP PIM has the following features, as shown in Figure 1-1.

FIGURE 1-1: dsPIC33CH512MP506 DP PIM



1. Microchip dsPIC33CH512MP506 16-Bit DSC (64-pin TQFP package).
2. ICSP™ programming header for the Master core (6-pin, 2.54 mm header).
3. ICSP programming header for the Slave core (6-pin, 1.27 mm header – not populated).

> **Note:** Both cores can be programmed and debugged through one ICSP interface.

4. On-board LDO with Power Good (PG) function.
5. Solder pad for ground connection.
6. Micro-USB connector.
7. MCP2221A USB to UART/I^2C serial converter.
8. Power indicator LED (Green).
9. User LED (Red).
10. Board edge connection interface for analog inputs/outputs.
11. Board edge connection interface for PWM outputs, digital peripherals and GPIO ports.

12. Analog input with op amp buffer via test point loop connector; can be used for Bode plot measurements.
13. Op amp buffer for Bode input.
14. Test point loop for DAC output.
15. Test point to access RD13 (also available on card edge connector pin 12).
16. Test point to access RD15 (also available on card edge connector pin 8).
17. Op amp buffers for medium speed ADC inputs.
18. MEMS oscillator.

Board dimensions are: 51 mm (length) x 38.5 mm (width).

1.2.1 Test Points

Table 1-1 lists the test points available on the dsPIC33CH512MP506 DP PIM.

TABLE 1-1: TEST POINTS

Test Point Name	Function/Description
TP1, TP2	Bode Measurement Signal Injection Point
TP3	RB2_DAC1_OUT: Digital-to-Analog Converter Output
TP4	Test Point for Debugging: Access to RD13 through 270Ω Resistor
TP5	General Purpose Test Point Connected to RD15 along with LD2 (Red LED)

1.2.2 Electrical Characteristics

Table 1-2 shows the electrical characteristics of the dsPIC33CH512MP506 DP PIM.

TABLE 1-2: ELECTRICAL CHARACTERISTICS

Parameter	Value
Input Voltage Range	3.6 VDC to 10 VDC, Absolute Maximum 16 VDC
Current Consumption	Minimum 82 mA, Typical 108 mA, Absolute Maximum 200 mA
Power Dissipation	Minimum 295 mW, Typical 414 mW, Maximum 1100 mW
Operating Temperature Range	-40°C to +85°C

Note: Typical Test Conditions: Ambient Temperature +25°C, Master core running at 90 MIPS, Slave core running at 100 MIPS, all peripherals powered but not enabled, power-on LED, LD1, active, no USB device or debugger connected.

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1.2.3 Analog and Digital Signals

The dsPIC33CH512MP506 DP PIM ensures good signal integrity and provides all signals needed to control a power train. These signals are divided into two main sections: Analog and Digital.

1. **Analog Section**
   The analog section is located at the short segment of the edge connector.
   It consists of 17 signals, all referenced to the analog ground. These lines are split into the following subsections:
   - High-Speed Comparator Inputs: RC filtered with corner frequency of 10 MHz and maximum signal rise/fall time of 33 ns. These lines are designed to be used with on-chip comparators for signal tracking tasks, such as peak, valley or zero-cross detections.
   - High-Speed ADC Inputs: RC filtered with corner frequency of 2 MHz and maximum signal rise/fall time of 180 ns. These lines are connected to the Track-and-Hold (T&H) circuitry of the dedicated ADC inputs and to the Sample-and-Hold (S&H) circuitry of the shared ADC inputs.
   - Medium Speed ADC Inputs: Buffered input lines, RC filtered with corner frequency of 1 MHz and maximum signal rise/fall time of 360 ns.
   - Low-Speed ADC Inputs: RC filtered with corner frequency of 190 kHz and maximum signal rise/fall time of 1.8 µs.
   - 12-Bit DAC Output with Optional On-Board RC Filtering.

> **Note:** RC filtering and series resistance are needed for good signal integrity, and for reducing EMI issues. Hence, the board can be used for development purposes under frequent plug-in/out cycles. This decoupling also increases robustness in case of accidental shorts and EMC issues.

2. **Digital Section**
   The digital section is located at the long segment of the edge connector.
   It consists of 31 signals, all referenced to digital ground. These lines are split into four subsections:
   - High-Speed PWM Outputs: Each line has a 75Ω series resistance.
   - Medium Speed GPIO: Each line has a 270Ω series resistance.
   - Programing/Debugging Lines: Each line has a 100Ω series resistance.
   - Communication Lines (SPI): Each line has a 75Ω series resistance.

> **Note:** The range of the digital I/Os allows access to other peripheral functions of the populated DSC, such as communication interfaces like I^2C, SPI, UART, Single-Edge Nibble Transmission (SENT), Controller Area Network (CAN), input capture, output compare, Combinatorial Logic Cells (CLC) and more. Please refer to the device data sheet for further information on available functions.

1.2.4 dsPIC33CH512MP506 DP PIM – PCB Edge Connector

The dsPIC33CH512MP506 DP PIM has an edge connector compatible with any application board that provides a mating socket.

The mating socket type is Samtec, Inc.: MECF-30-01-L-DV-WT.

1.3 UART COMMUNICATION

The on-board USB to UART serial bridge enables easy serial connection to PCs. The USB port can provide power to the Digital Power PIM and allows the user to communicate with the dsPIC® Digital Signal Controller (DSC).

The USB driver package and software tool support of the MCP2221A serial converter also offers free terminal software for I^{2}C Master and Slave emulation, as well as generic API drivers for custom software development. Please visit the MCP2221A product web page for more details (www.microchip.com).

1.4 LOW-FREQUENCY BODE PLOT MEASUREMENTS

The dsPIC33CH512MP506 device, along with an additional on-board circuitry, allows Bode plot measurements to be performed without the need for an isolation transformer. The transformer might still be required if the injected signal tends to be at a very low frequency (for instance, in case of Power Factor Correction (PFC) applications).

Perform the following steps:

1. Solder the 150Ω resistor from position R74 to R94. Make sure that the RD10_S1AN13_IN line is not driven by any other low-impedance source.
2. Run the power stage in Open-Loop mode with a fixed duty cycle.
3. Connect the Bode 100 AC output to TP1 and TP2. The on-board operational amplifier will add a $V_{DD}/2$ (1.65V) offset. In this case, no injection transformer is needed.
4. Connect RB2_DAC1_OUT to CH2 of the Bode 100.
5. Use the S1AN13 input to sample the signal from Bode 100 in every PWM cycle at Frequency Switching (f_{SW}) (action in firmware is needed).
6. Remove the $V_{DD}/2$ offset to regain a signal with no DC value (action in firmware is needed).
7. Add sampled AC signal to the nominal duty cycle (PDCx) (action in firmware is needed).
8. Use a second dedicated ADC core input (ANx) to sample the output of the plant at FSW. The output can be:
   - Output voltage.
   - Average coil current sampled at $T_{ON}/2$, where T_{ON} is the switch-on time.
9. Duty cycle input and plant output are converted into an analog signal using RB2_DAC1_OUT.

The measured transfer function is the plant (power stage and digital modulator), after scaling and ADC sampling, versus digital duty cycle input (PDCx).

Note:	Due to run-time delays of Sample-and-Hold circuits and conversion time of ADC and DAC, this measurement is only recommended for low-frequency measurements: a maximum two decades below sampling frequency.

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Figure 1-2 and Figure 1-3 show examples of schemes of plant and closed-loop measurements, respectively.

FIGURE 1-2: SCHEME OF PLANT MEASUREMENT

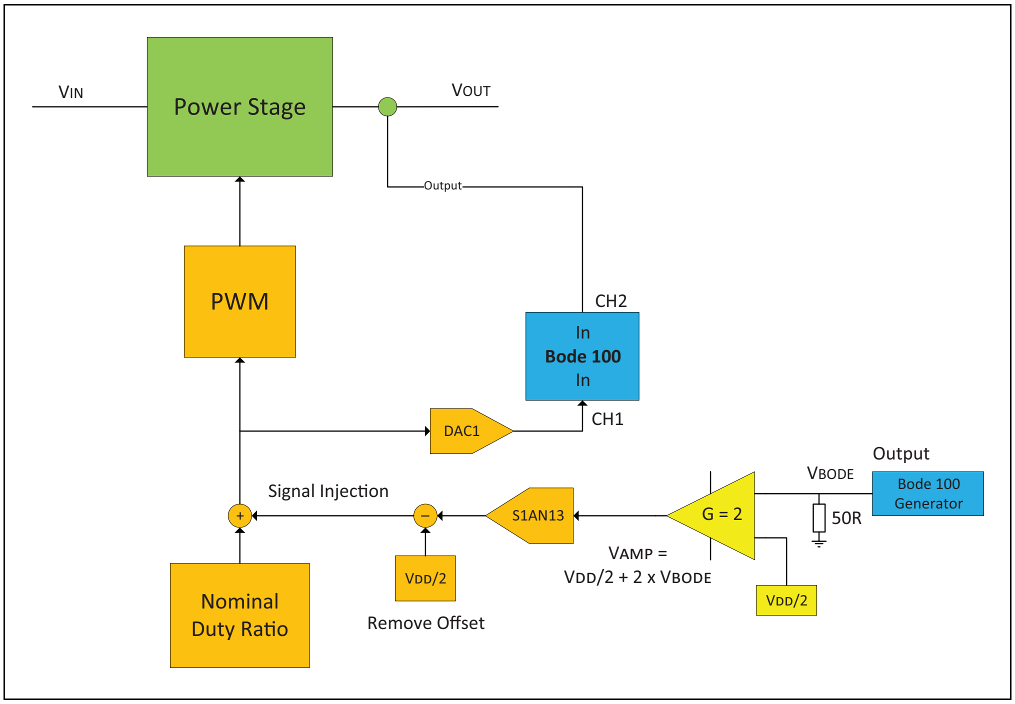
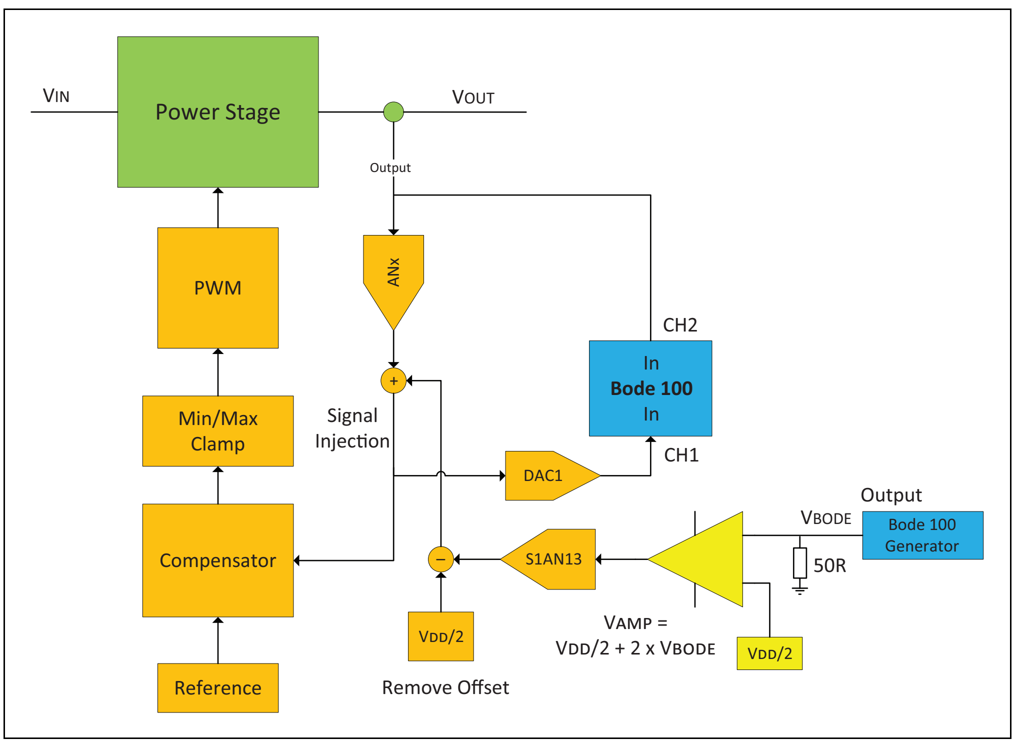


FIGURE 1-3: SCHEME OF CLOSED-LOOP MEASUREMENT



NOTES:

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Appendix A. Board Layout and Schematics

This appendix contains the pinout, the schematics and the board layouts for the dsPIC33CH512MP506 DP PIM.

- Pinout
- Board Schematics
- PCB Layout

A.1 PINOUT

Pinout and electrical parameters are shown in Table A-1.

TABLE A-1: PINOUT AND ELECTRICAL PARAMETERS

Name	Edge Connector Pin	Device Pin	Function/Description	Remarks
GND_A	1	20	Analog Ground	—
GND_A	2	20	Analog Ground	—
RB2_DAC1_OUT	3	33	DAC Output, Optional RC Filter	560R Series Resistance
RC7_AN15_IN	4	32	Analog Input, RC Filtered	F_C = 190 kHz, tr = 1.8 µs
RC0_S1AN10_IN	5	13	Analog Input, RC Filtered	F_C = 1 MHz, tr = 360 ns – Buffered
RC2_S1ANA0_IN	6	23	Analog Input, RC Filtered	F_C = 1 MHz, tr = 360 ns – Buffered
—	7	—	—	—
RC3_S1CMP3B_IN	8	27	Analog Input, RC Filtered	F_C = 10 MHz, tr = 33 ns
RD11_S1AN17_IN	9	30	Analog Input, RC Filtered	F_C = 1 MHz, tr = 360 ns – Buffered
RC1_S1ANA1_IN	10	22	Analog Input, RC Filtered	F_C = 1 MHz, tr = 360 ns – Buffered
RA2_S1AN16_IN	11	16	Analog Input, RC Filtered	F_C = 190 kHz, tr = 1.8 µs
RA3_S1AN0_IN	12	17	Analog Input, RC Filtered	F_C = 1.9 MHz, tr = 180 ns
RA1_AN1_IN	13	15	Analog Input, RC Filtered	F_C = 1.9 MHz, tr = 180 ns
RA4_S1AN1_IN	14	18	Analog Input, RC Filtered	F_C = 1.9 MHz, tr = 180 ns
RA0_AN0_IN	15	14	Analog Input, RC Filtered	F_C = 1.9 MHz, tr = 180 ns
RD10_S1AN13_IN	16	31	Analog Input, RC Filtered	F_C = 190 kHz, tr = 1.8 µs
RD12_S1AN14_IN	17	21	Analog Input, RC Filtered	F_C = 190 kHz, tr = 1.8 µs
RC6_S1CMP1B_IN	18	24	Analog Input, RC Filtered	F_C = 10 MHz, tr = 33 ns
—	19	—	—	—
RB1_S1AN4_IN	20	29	Analog Input, RC Filtered	F_C = 190 kHz, tr = 1.8 µs
Slot	21	Slot	Slot	Slot
Slot	22	Slot	Slot	Slot
—	23	—	—	—
RC8_RP56_ASDA1	24	36	Digital General Purpose	75R Series Resistance
RB12_RP44	25	63	Digital General Purpose	270R Series Resistance
RD14	26	11	Digital General Purpose	270R Series Resistance
RB13_RP45	27	64	Digital General Purpose	270R Series Resistance

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TABLE A-1: PINOUT AND ELECTRICAL PARAMETERS (CONTINUED)

Name	Edge Connector Pin	Device Pin	Function/Description	Remarks
RD9	28	38	Digital General Purpose	270R Series Resistance
—	29	—	—	—
—	30	—	—	—
RD6_S1PWM6H	31	43	PWM Output	75R Series Resistance
RC9_ASCL1	32	37	Digital General Purpose	75R Series Resistance
RD5_S1PWM6L	33	44	PWM Output	75R Series Resistance
RB11	34	62	Digital General Purpose	270R Series Resistance
RB14_S1RP46	35	1	Digital General Purpose	270R Series Resistance
RB10	36	61	Digital General Purpose	270R Series Resistance
RD4_S1PWM3H	37	54	PWM Output	75R Series Resistance
RB15_S1RP47	38	2	Digital General Purpose	270R Series Resistance
RD2_RP66	39	58	Digital General Purpose	270R Series Resistance
RC5_S1PWM2L	40	51	PWM Output	75R Series Resistance
RD3_S1PWM3L	41	55	PWM Output	75R Series Resistance
RC4_S1PWM2H	42	50	PWM Output	75R Series Resistance
RD1_S1PWM4H	43	59	PWM Output	75R Series Resistance
RD0_S1PWM4L	44	60	PWM Output	75R Series Resistance
RC10_S1PWM1H	45	52	PWM Output	75R Series Resistance
RC12_S1RC12	46	3	Digital General Purpose	270R Series Resistance
RC11_S1PWM1L	47	53	PWM Output	75R Series Resistance
RC13_RP61	48	4	Digital General Purpose	270R Series Resistance
MCLR_IN	49	7	Device Reset	100R Series Resistance
RD7	50	42	Digital General Purpose	270R Series Resistance
RB4_PGC2	51	35	Programing/Debugging	100R Series Resistance
RD8	52	39	Digital General Purpose	270R Series Resistance
RB6_SCL2	53	46	Digital General Purpose	75R Series Resistance
RD13	54	12	Digital General Purpose	270R Series Resistance
RB5_SDA2	55	45	Digital General Purpose	75R Series Resistance
RB3_PGD2	56	34	Programing/Debugging	100R Series Resistance
VDD	57	LDO	VDD Rail	6.3V max, 70 mA max
GND_D	58	9,26,40,56	Digital Ground	—
VDD	59	LDO	VDD Rail	6.3V max, 70 mA max
GND_D	60	9,26,40,56	Digital Ground	—

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A.2 BOARD SCHEMATICS

Figure A-1 and Figure A-2 show the board schematics.

FIGURE A-1: dsPIC33CH512MP506 DIGITAL POWER PIM SCHEMATIC REV. 1.0 (PAGE 1 OF 2)

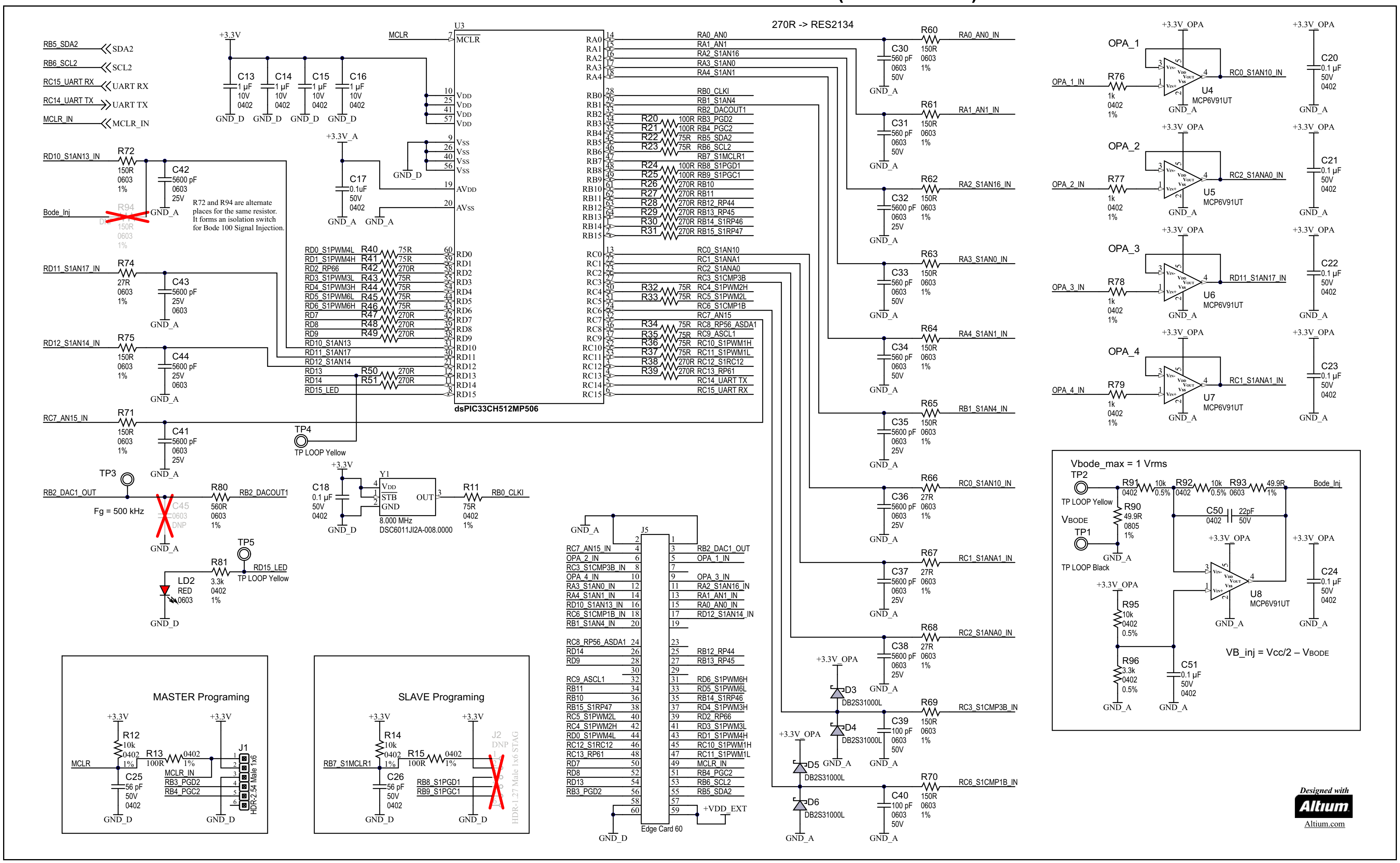
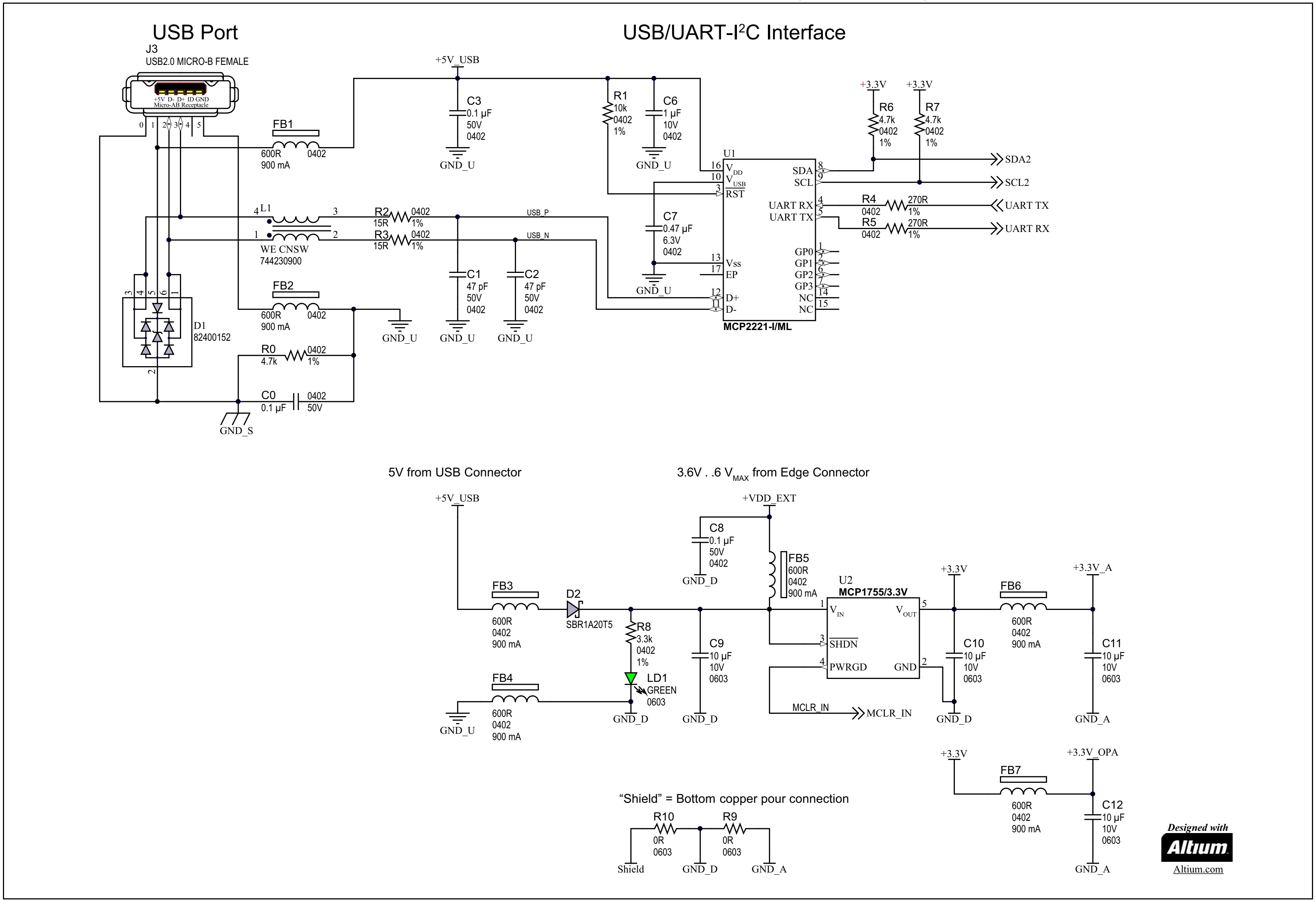


FIGURE A-2: dsPIC33CH512MP506 DIGITAL POWER PIM SCHEMATIC REV. 1.0 (PAGE 2 OF 2)



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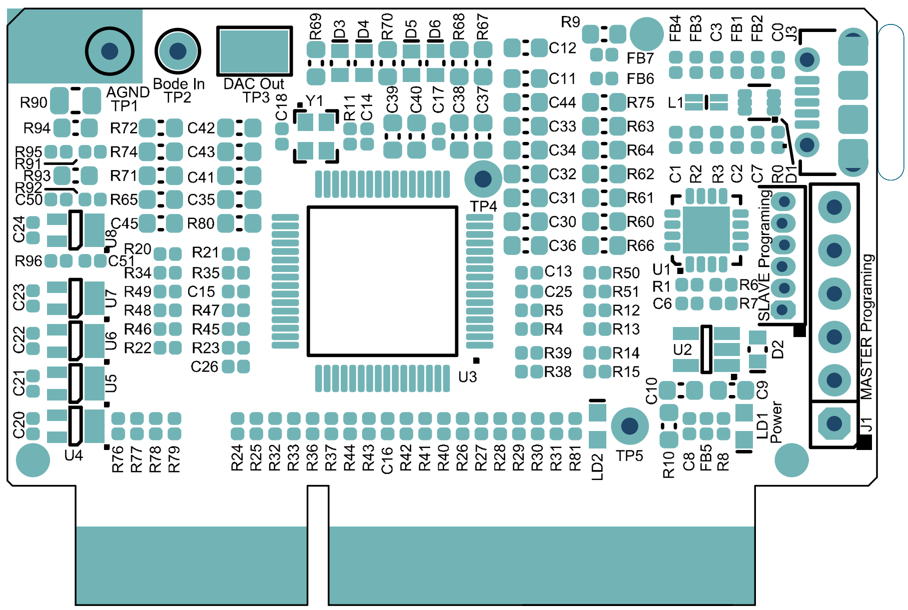
A.3 PCB LAYOUT

The dsPIC33CH512MP506 DP PIM is a four-layer FR4, 1.55 mm, Plated-Through-Hole (PTH) PCB construction. Figure A-3 through Figure A-5 illustrate the PCB layers and Figure A-6 shows the assembly drawings of the dsPIC33CH512MP506 DP PIM.

FIGURE A-3: dsPIC33CH512MP506 DIGITAL POWER PIM TOP SILKSCREEN AND TOP COPPER

Top Silkscreen



Top Copper

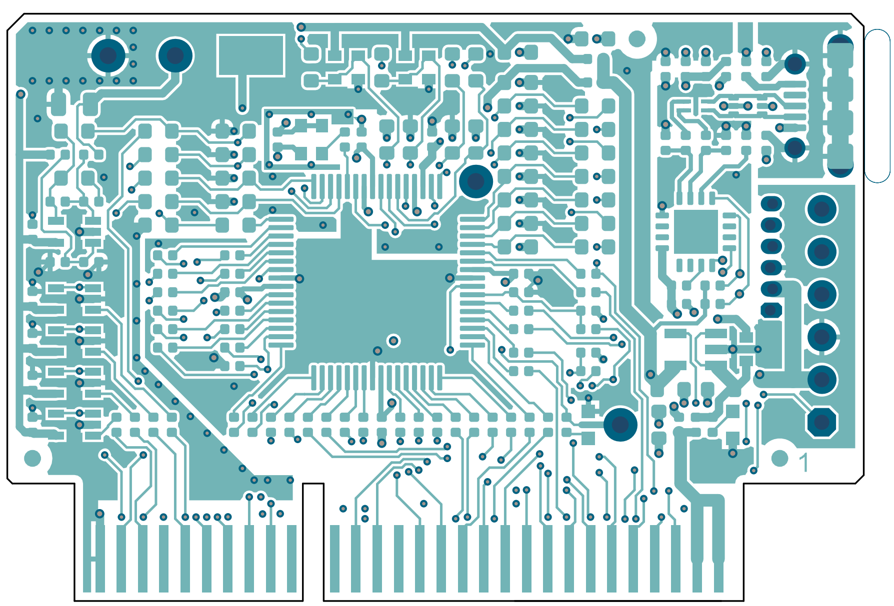
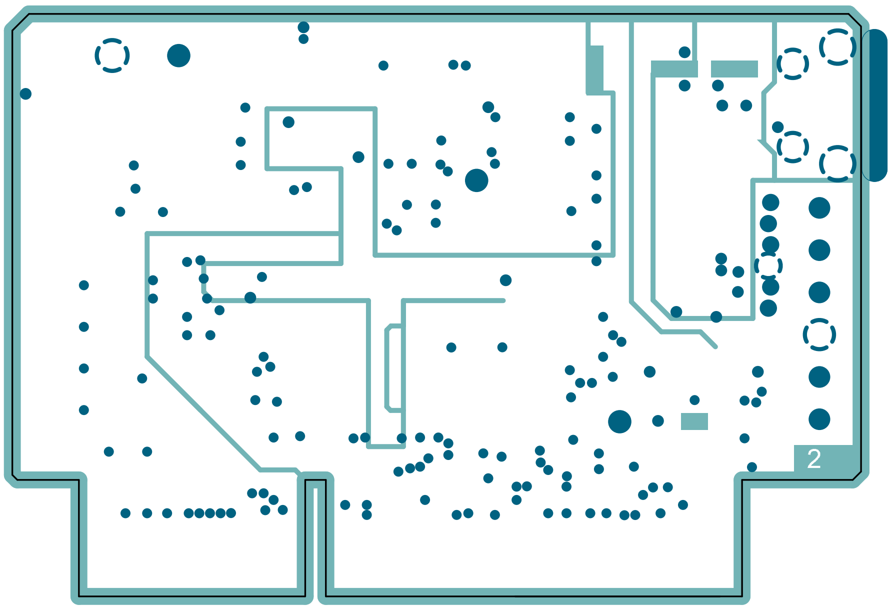


FIGURE A-4: dsPIC33CH512MP506 DIGITAL POWER PIM MID1 AND MID2 INNER COPPER (BOTTOM VIEW)

Mid1 Inner Copper



Mid2 Inner Copper

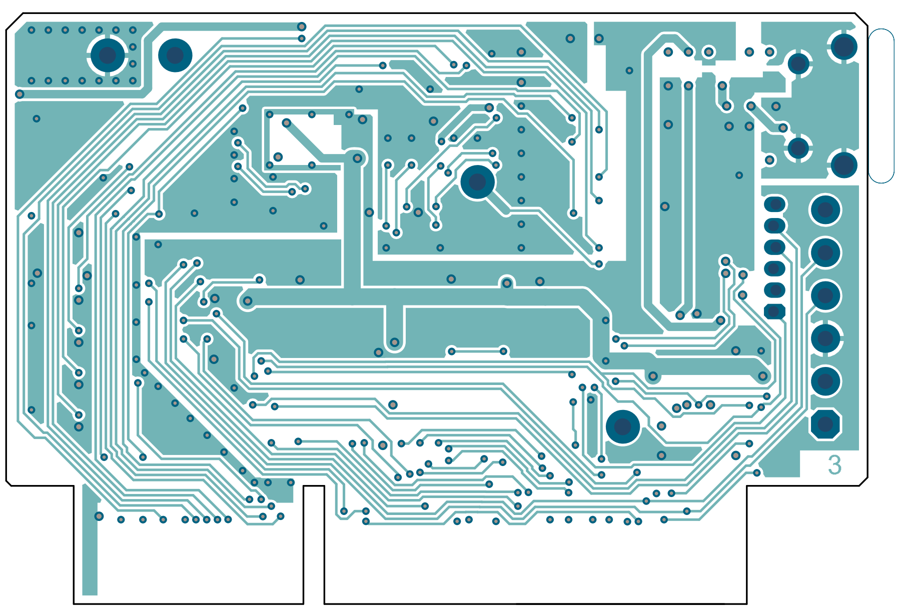


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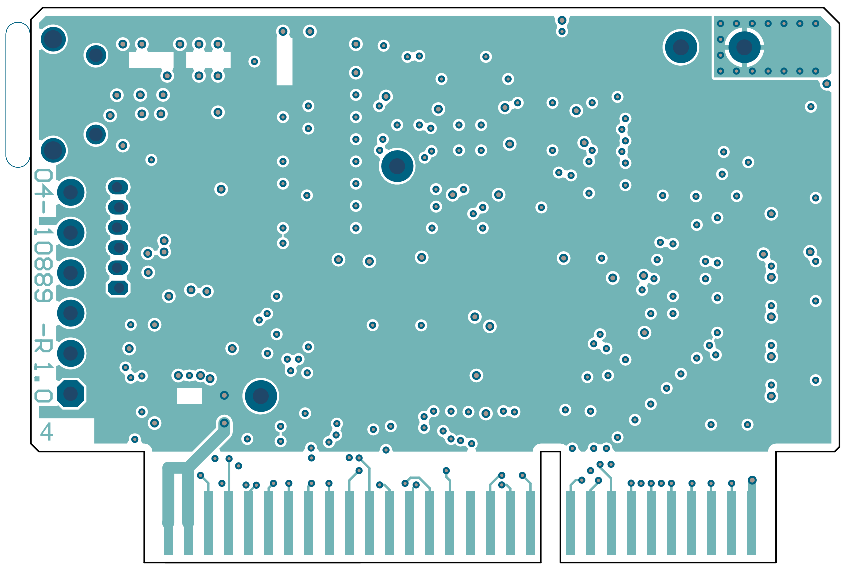
FIGURE A-5: dsPIC33CH512MP506 DIGITAL POWER PIM BOTTOM COPPER AND BOTTOM SILKSCREEN (BOTTOM VIEW)

Bottom Copper



Bottom Silkscreen

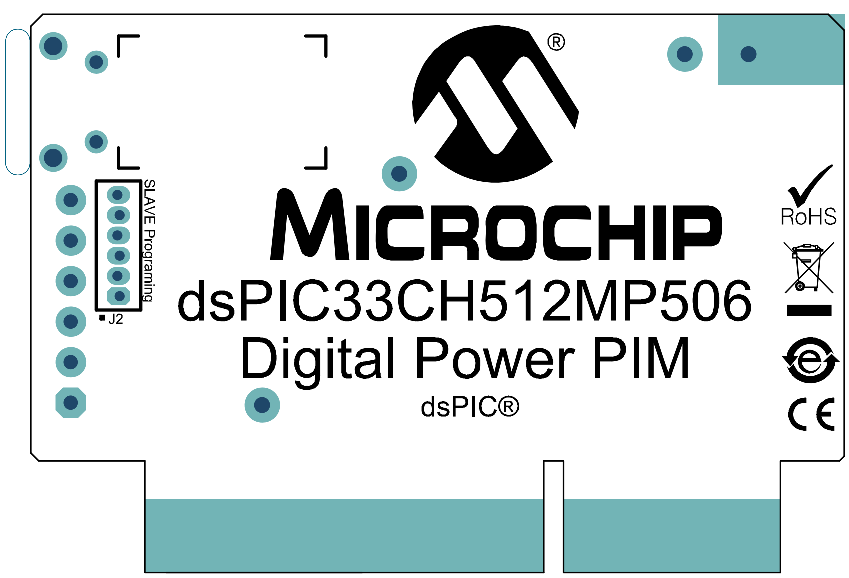
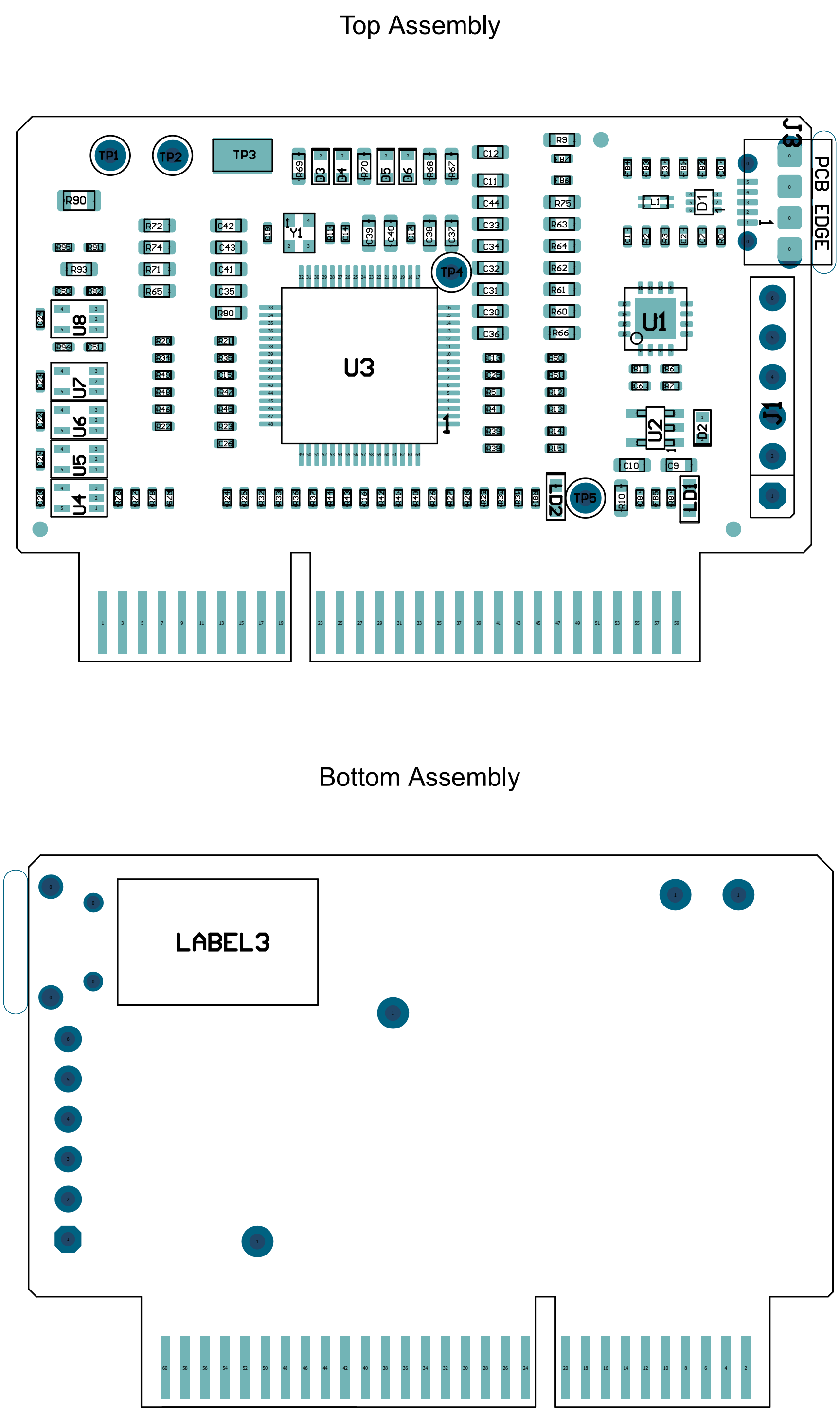


FIGURE A-6: dsPIC33CH512MP506 DIGITAL POWER PIM TOP AND BOTTOM ASSEMBLY



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Appendix B. Bill of Materials (BOM)

This appendix contains the Bill of Materials (BOM) for the dsPIC33CH512MP506 Digital Power PIM.

- Bill of Materials

B.1 BILL OF MATERIALS

Table B-1 shows the Bill of Materials for the dsPIC33CH512MP506.

TABLE B-1: dsPIC33CH512MP506 DIGITAL POWER PIM BILL OF MATERIALS (BOM)

Qty	Designator	Description	Manufacturer	Manufacturer Part Number
11	C0, C3, C8, C17, C18, C20, C21, C22, C23, C24, C51	Capacitor, Ceramic, 0.1 µF, 50V, 10%, X7R, SMD, 0402	TDK Corporation	C1005X7R1H104K050BB
2	C1, C2	Capacitor, Ceramic, 47 pF, 50V, 5%, NP0, SMD, 0402	Murata Electronics®	GRM1555C1H470JA01D
5	C6, C13, C14, C15, C16	Capacitor, Ceramic, 1 µF, 10V, 10%, X7S, SMD, 0402	TDK Corporation	C1005X7S1A105K050BC
1	C7	Capacitor, Ceramic, 0.47 µF, 6.3V, 10%, X5R, SMD, 0402	Murata Electronics	GRM155R60J474KE19D
4	C9, C10, C11, C12	Capacitor, Ceramic, 10 µF, 10V, 20%, X5R, SMD, 0603	Samsung Group	CL10A106MP8NNNC
2	C25, C26	Capacitor, Ceramic, 56 pF, 50V, 5%, C0G, SMD, 0402	TDK Corporation	C1005C0G1H560J050BA
4	C30, C31, C33, C34	Capacitor, Ceramic, 560 pF, 50V, 5%, C0G, NP0, SMD, 0603	KEMET	C0603C561J5GACTU
9	C32, C35, C36, C37, C38, C41, C42, C43, C44	Capacitor, Ceramic, 5600 pF, 25V, 5%, C0G, SMD, 0603	TDK Corporation	C1608C0G1E562J080AA
2	C39, C40	Capacitor, Ceramic, 100 pF, 50V, 5%, NP0, SMD, 0603	AVX Corporation	GMC10CG101J50NT
1	C50	Capacitor, HiQ, 22 pF, 50V, 5%, NP0, 1.95 GHz, SMD, 0402	Johanson Technology Inc.	500R07S220JV4T
1	D1	Diode, TVS Array, 82400152, 5V, USB 2.0, SMD, SOT-563	Wurth Elektronik	82400152
1	D2	Diode, Schottky, SBR1A20T5-7, 520 mV, 1A, 20V, SOD-523	Diodes Incorporated®	SBR1A20T5-7
4	D3, D4, D5, D6	Diode, Schottky, DB2S31000L, 470 mV, 200 mA, 30V, SMD, SOD-523	Panasonic® - ECG	DB2S31000L
7	FB1, FB2, FB3, FB4, FB5, FB6, FB7	Ferrite, 600R at 100 MHz, 0.23R, 900 mA, SMD, 0402	Murata Electronics	BLM15PX601SN1D
1	J1	Connector Header-2.54, Male, 1x6 Gold, 5.84 MH TH, Vertical	FCI	68000-106HLF
1	J3	Connector, USB 2.0, Micro-B, Female, TH/SMD, R/A	FCI	10118194-0001LF

TABLE B-1: dsPIC33CH512MP506 DIGITAL POWER PIM BILL OF MATERIALS (BOM) (CONTINUED)

Qty	Designator	Description	Manufacturer	Manufacturer Part Number
1	L1	Common-mode Choke, 90R, 100 MHz, 0.145R, 550 mA, SMD, 0603	Wurth Elektronik	744230900
1	LD1	Diode LED Green, 2V, 30 mA, 35 mcd, Clear, SMD, 0603	Lite-On®, Inc.	LTST-C190KGKT
1	LD2	Diode LED Red, 1.8V, 40 mA, 10 mcd, Clear, SMD, 0603	Lite-On, Inc.	LTST-C190KRKT
3	R0, R6, R7	Resistor TKF, 4.7k, 5%, 1/10W, SMD, 0402	Panasonic® - ECG	ERJ-2GEJ472X
3	R1, R12, R14	Resistor TKF, 10k, 1%, 1/10W, SMD, 0402	Panasonic - ECG	ERJ-2RKF1002X
2	R2, R3	Resistor TKF, 15R, 1%, 1/10W, SMD 0402	Panasonic - ECG	ERJ-2RKF15R0X
16	R4, R5, R26, R27, R28, R29, R30, R31, R38, R39, R42, R47, R48, R49, R50, R51	Resistor TKF, 270R, 5%, 1/10W, SMD 0402	Panasonic - ECG	ERJ-2GEJ271X
2	R8, R81	Resistor TKF, 3.3k, 5%, 1/10W, SMD, 0402	Panasonic - ECG	ERJ-2GEJ332X
2	R9, R10	Resistor TKF, 0R, 1/10W, SMD, 0603	Yageo Corporation	RC0603JR-070RL
15	R11, R22, R23, R32, R33, R34, R35, R36, R37, R40, R41, R43, R44, R45, R46	Resistor TKF, 75R, 1%, 1/16W, SMD, 0402	Yageo Corporation	RC0402FR-0775RL
6	R13, R15, R20, R21, R24, R25	Resistor TKF, 100R, 1%, 1/10W, SMD, 0402	Panasonic - ECG	ERJ-2RKF1000X
11	R60, R61, R62, R63, R64, R65, R69, R70, R71, R72, R75	Resistor TKF, 150R, 1%, 1/10W, SMD, 0603	Stackpole Electronics, Inc.	RMCF0603FT150R
4	R66, R67, R68, R74	Resistor TKF, 27R, 1%, 1/10W, SMD, 0603	Yageo Corporation	RC0603FR-0727RL
4	R76, R77, R78, R79	Resistor TKF, 1k, 1%, 1/10W, SMD, 0402	Panasonic - ECG	ERJ-2RKF1001X
1	R80	Resistor TKF, 560R, 1%, 1/10W, SMD, 0603	Yageo Corporation	RC0603FR-07560RL
1	R90	Resistor TKF, 49.9R, 1%, 1/8W, SMD, 0805	Panasonic - ECG	ERJ-6ENF49R9V
3	R91, R92, R95	Resistor TF, 10k, 0.5%, 1/16W, SMD, 0402	Susumu Co., LTD.	RR0510P-103-D
1	R93	Resistor TKF, 49.9R, 1%, 1/10W, SMD, 0603	Panasonic - ECG	ERJ-3EKF49R9V
1	R96	Resistor TKF, 3.3k, 0.5%, 1/16W, SMD, 0402	Panasonic - ECG	ERA-2AED332X
1	TP1	Misc. Test Point, Multipurpose, Mini, Black	Keystone Electronics Corp.	5001
1	TP2	Misc. Test Point, PC, Mini, 0.040", D, Yellow	Keystone Electronics Corp.	5004
1	TP3	Connector, Test Point, TAB, Silver Mini, 3.8x2.03, SMD	Keystone Electronics Corp.	5019

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TABLE B-1: dsPIC33CH512MP506 DIGITAL POWER PIM BILL OF MATERIALS (BOM) (CONTINUED)

Qty	Designator	Description	Manufacturer	Manufacturer Part Number
2	TP4, TP5	Misc. Test Point, PC, Mini, 0.040", D, Yellow	Keystone Electronics Corp.	5004
1	U1	Microchip Interface, USB, I^2C/UART, MCP2221A-I/ML, QFN-16	Microchip Technology Inc.	MCP2221A-I/ML
1	U2	Microchip Analog LDO, 3.3V, MCP1755T-3302E/OT, SOT-23-5	Microchip Technology Inc.	MCP1755T-3302E/OT
1	U3	Microchip MCU, 16-Bit, 180/200 MHz, 512/72 kB, 48/16 kB, dsPIC33CH512MP506-I/PT, TQFP-64	Microchip Technology Inc.	dsPIC33CH512MP506-I/PT
5	U4, U5, U6, U7, U8	Microchip Analog Op Amp, 1-Ch, 10 MHz, MCP6V91UT-E/LTYCT-ND, SC-70-5	Microchip Technology Inc.	MCP6V91UT-E/LTY
1	Y1	Microchip Clock Oscillator, Single, 8.000 MHz, DSC6011JI2A-008.0000, VDFN-4	Microchip Technology Inc.	DSC6011JI2A-008.0000

NOTES:

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Appendix C. Characterization Data

This chapter provides some characterization data and further guidance on sub-circuits of this Digital Power PIM to allow engineers to gain a better understanding of technical limitations, as well as enable users to solve design trade-offs in additional circuits on custom boards, such as signal conditioning or auxiliary power supplies.

Note: The graphs and tables provided following this note are a statistical summary based on a limited number of samples and are provided for informational purposes only. The performance characteristics listed herein are not tested or guaranteed. In some graphs or tables, the data presented may be outside the specified operating range (e.g., outside specified power supply range), and therefore, outside the warranted range.

C.1 MEASUREMENT ACCURACY IMPACTS

C.1.1 High-Speed Analog Signal Tracking Considerations

Each of the four groups of the analog inputs, high-speed ADC, mid-speed ADC, low-speed ADC and high-speed comparator inputs have been equipped with RC low-pass filters to prevent corruption of sampling results, such as alias-frequencies being injected into a series of ADC sampling results, and to ensure proper operation of the high-speed comparators in noisy environments. These deliberate bandwidth limitations, however, may affect the accuracy of the ADC results when tracking high-speed signals.

C.1.1.1 FILTER BANDWIDTH IMPACTS

This section discusses the influence of the RC low-pass filter bandwidth limits versus the expected sampling error to allow designers to identify the maximum signal slew rate, which can be tracked with a certain known accuracy.

The cutoff frequency, f_c, of an RC low-pass filter defines the frequency at which its output signal magnitude is reduced by -3dB.

The first-order RC filter cutoff frequency is defined by Equation C-1.

EQUATION C-1:

$$f_c = \frac{1}{2\pi(R_{Filt}C_{Filt})}$$

When using high-speed ADCs with sampling times of 10 ns to 50 ns or less, tracking signal transients at this frequency will also show a 3 dB offset in ADC results in accordance to the damped signal gain. To allow a more accurate analysis of the tracking error, with regards to the transient frequency, we need to look at the total gain characteristic over frequency.

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The transfer function of a first-order RC low-pass filter is defined by Equation C-2 through Equation C-4.

EQUATION C-2:

$$H(s) = \frac{1}{1 + \frac{s}{\omega_c}}$$

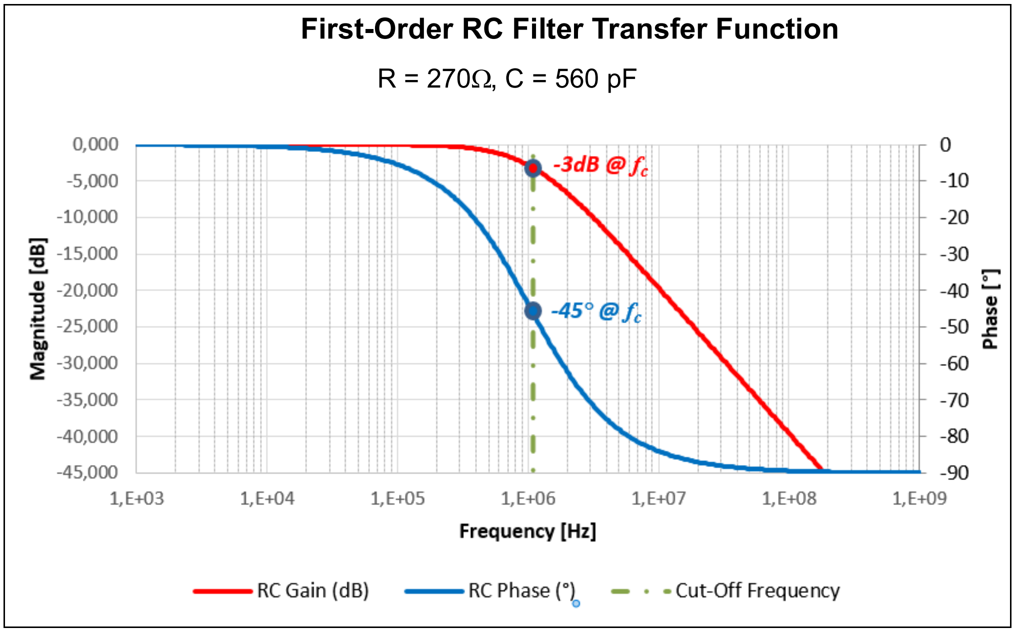
EQUATION C-3:

$$\omega_c = 2\pi f_c = \frac{1}{R_{Filt}C_{Filt}}$$

EQUATION C-4:

$$H(s) = \frac{1}{1 + sR_{Filt}C_{Filt}}$$

FIGURE C-1: FIRST-ORDER RC LOW-PASS FILTER TRANSFER FUNCTION



By plotting the frequency domain transfer function of the RC filter, it is shown that the output voltage of the RC filter network at the cutoff frequency, f_c, is not only damped in amplitude, but also shifted in time. While the amplitude reduction is absolute, the phase delay may require a relocation of the ADC sample trigger to achieve accurate results.

As both magnitude and phase of the RC filter output signal do not change instantly, but over frequency with varying degree, the deviation from the unfiltered feedback signal, and thus, the related ADC result deviation, may have to be considered.

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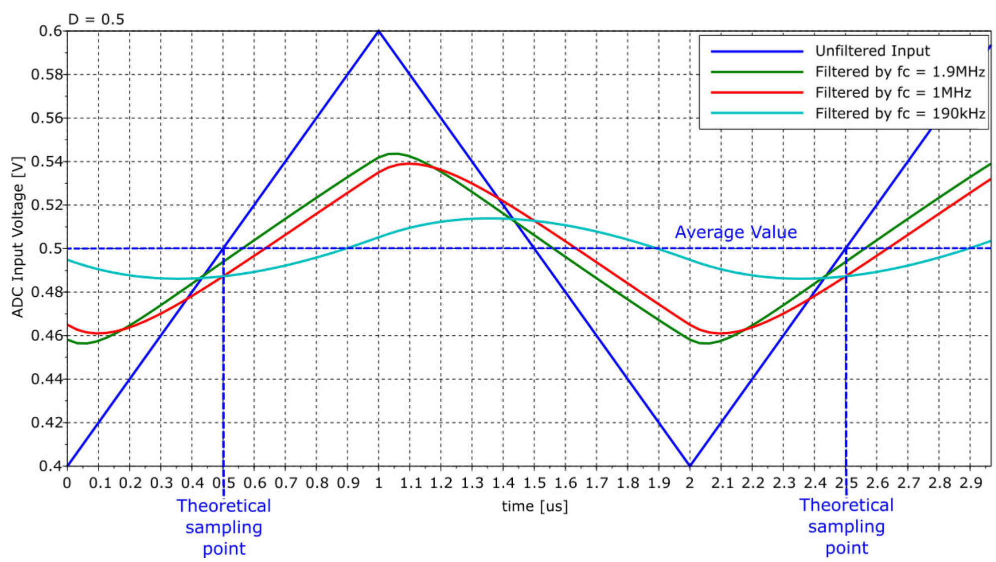
C.1.2 Example

In order to demonstrate the impact of the on-board RC filtering, the following example shows the impact when tracking the average value of a 500 kHz at 50% duty cycle current feedback signal with minimum sampling error.

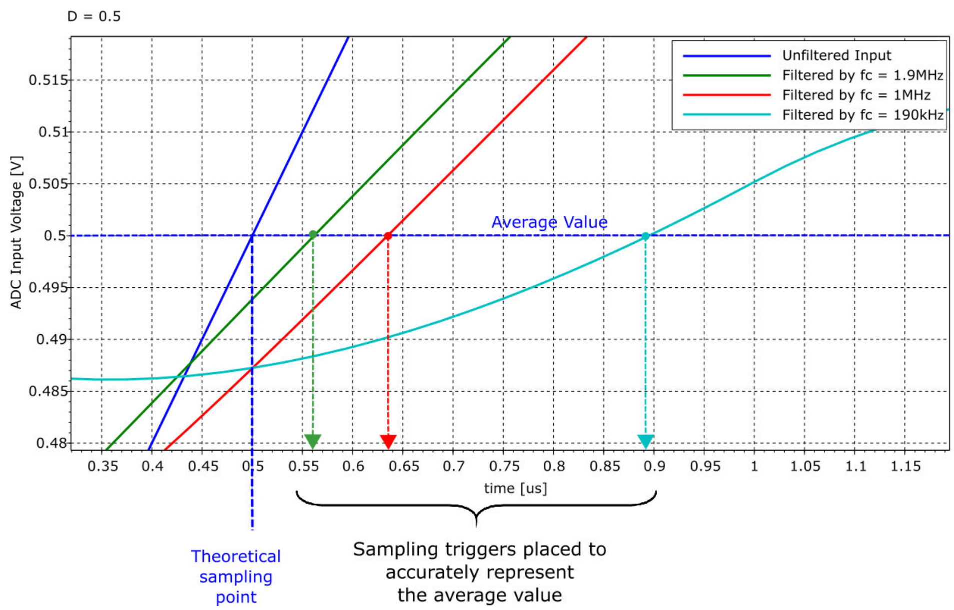
Let the average value be 500 mV and the peak-to-peak voltage 200 mV, following ideal current-to-voltage conversion. Figure C-2 shows the unfiltered ideal signal along with the waveforms obtained after this signal is passed through any of the on-board RC filters. Note that the filtering does not alter the average value along (ADC Input Voltage = 0.5) any of the filtered signals. The mid-points of each filtered AC signals, however, have been shifted in time with respect to the phase delay of the RC filter. When this phase delay is not properly considered, the ADC trigger may be displaced from the desired average point of the oversampled signal, resulting in a significant measurement error.

FIGURE C-2: UNFILTERED AND FILTERED TRIANGULAR WAVEFORMS



Depending on the application, in order to obtain the average value with the required accuracy, a time delay in the sampling trigger of the ADC might need to be introduced. In our specific case, in order to take the sample with the best accuracy, the trigger should be offset by approximately 60, 135 and 390 ns, as shown in Figure C-3.

FIGURE C-3: SAMPLING TRIGGER PLACEMENT FOR BEST ACCURACY



C.1.2.1 STEP RESPONSE DELAY ESTIMATION

Deriving from Equation C-1, the time constant of the first-order RC filter is defined by Equation C-5, which is generally used to characterize the response of a first-order RC filter to a step input, as shown in Equation C-6.

EQUATION C-5:

$$\tau = R_{Filt} \cdot C_{Filt}$$

EQUATION C-6:

$$V_{OUT}(t) = V_{IN}(t) \cdot (1 - e^{-t/\tau})$$

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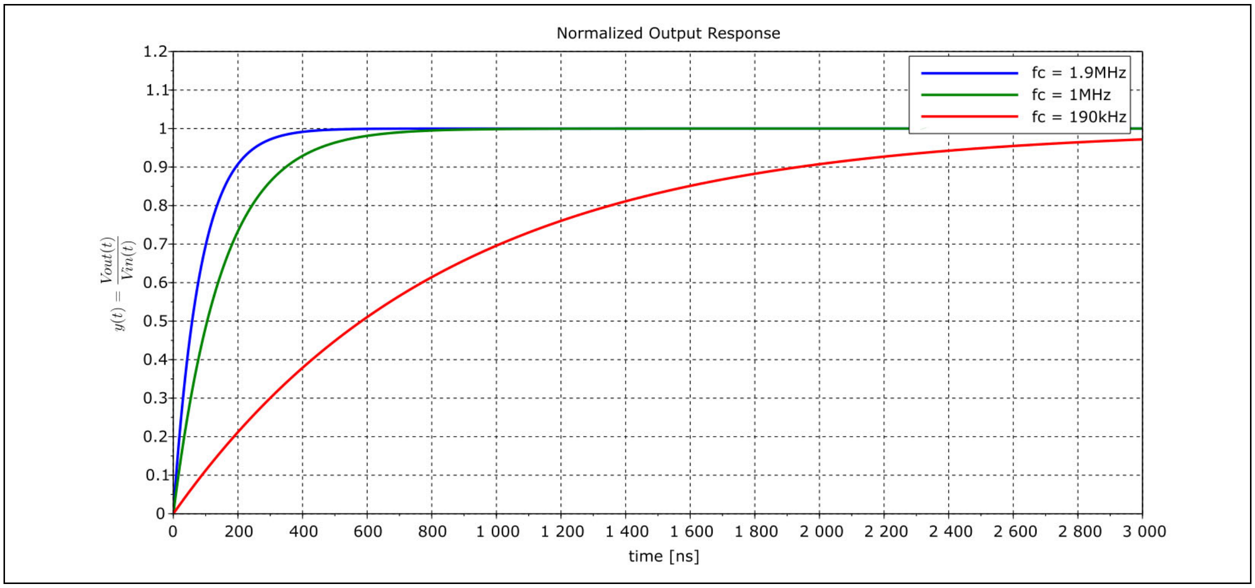
Figure C-4 shows the calculated step responses of the on-board filters normalized to the input voltage.

FIGURE C-4: NORMALIZED STEP RESPONSE



In case a sample is taken at the filter output time, t, after the step input was applied, the percentage error with respect to the settled value can be calculated by using Equation C-7 and Equation C-8 (substituting Equation C-6).

EQUATION C-7:

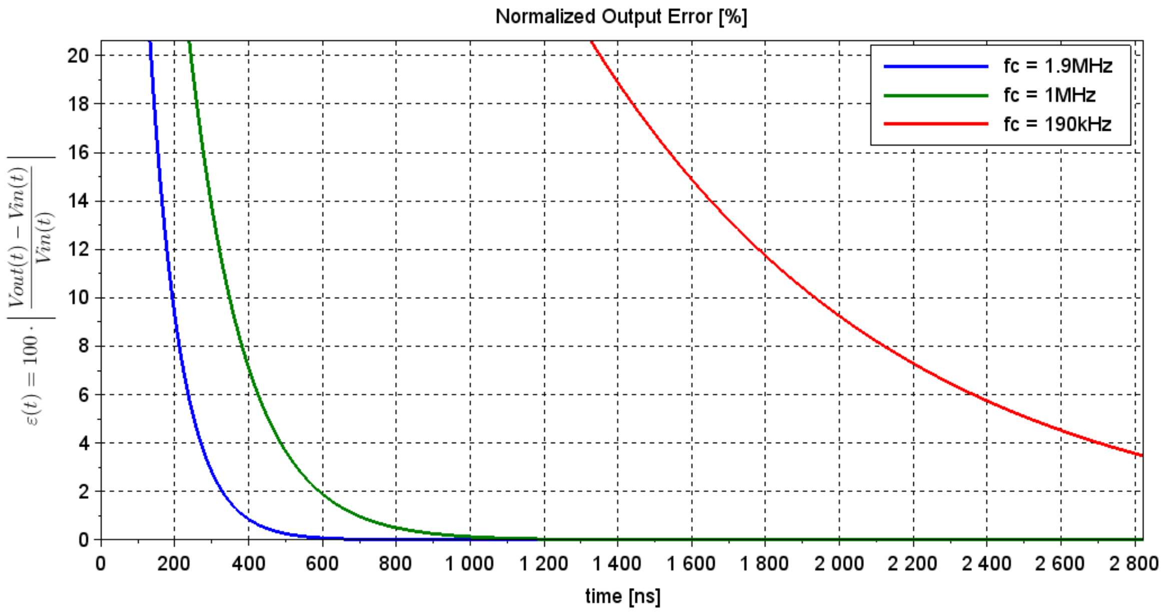
$$\varepsilon(t) = 100 \cdot \left|\frac{V_{OUT}(t) - V_{IN}(t)}{V_{IN}(t)}\right|$$

EQUATION C-8:

$$\varepsilon(t) = 100 \cdot e^{-t/\tau}$$

Figure C-5 depicts the remaining percentage error with respect to the sampling time.

FIGURE C-5: NORMALIZED OUTPUT ERROR



On the other hand, if a maximum tolerable percentage error, ε_{max}, is defined in advance, the earliest time the sample should be taken can be calculated by using Equation C-9, which is obtained from Equation C-8 by expressing t.

EQUATION C-9:

$$t_s = -\tau \cdot \ln\left(\frac{\varepsilon_{max}}{100}\right)$$

Filter capacitors on the board are either 560 pF or 5600 pF, whereas the on-chip hold capacitance is around 5 pF. Due to the large ratio of the on-board versus on-chip capacities, and for the sake of simplicity, the loading effect of the Sample-and-Hold (S&H) circuitry has been neglected here.

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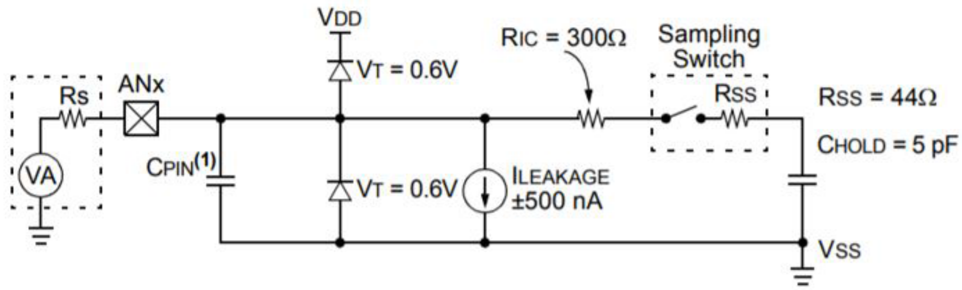
Demanding applications, however, might need to consider the loading effect of the S&H capacitance as well. The electrical model shown in Figure C-6 can be used to make more elaborate calculations.

FIGURE C-6:



Legend:

C_{PIN}	=	Input Capacitance	V_T	=	Threshold Voltage
R_{SS}	=	Sampling Switch Resistance	R_{IC}	=	Interconnect Resistance
R_S	=	Source Resistance	C_{HOLD}	=	Sample-and-Hold Capacitance
$I_{LEAKAGE}$	=	Leakage Current at the Pin due to Various Junctions			

Note 1: The C_{PIN} value depends on the device package and is not tested. The effect of the C_{PIN} is negligible if $R_S \leq 5\ k\Omega$.

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