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# **Active Filter Demo Board Kit User's Guide**

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# ACTIVE FILTER DEMO BOARD KIT USER'S GUIDE

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## Preface

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### NOTICE TO CUSTOMERS

All documentation becomes dated, and this manual is no exception. Microchip tools and documentation are constantly evolving to meet customer needs, so some actual dialogs and/or tool descriptions may differ from those in this document. Please refer to our web site ([www.microchip.com](http://www.microchip.com)) to obtain the latest documentation available.

Documents are identified with a "DS" number. This number is located on the bottom of each page, in front of the page number. The numbering convention for the DS number is "DSXXXXA", where "XXXX" is the document number and "A" is the revision level of the document.

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

## INTRODUCTION

This chapter contains general information that will be useful to know before using the Active Filter Demo Board Kit. Items discussed in this chapter include:

- Document Layout
- Conventions Used in this Guide
- Recommended Reading
- The Microchip Web Site
- Customer Support
- Document Revision History

## DOCUMENT LAYOUT

This document describes how to use the Active Filter Demo Board Kit. The manual layout is as follows:

- **Chapter 1. "Product Overview"** - Important information about the Active Filter Demo Board Kit.
- **Chapter 2. "Setup and Installation"** – Covers the initial set-up of the Active Filter Demo Board Kit. It lists the required tools, shows how to connect the boards and demonstrates how to verify the set-up.
- **Chapter 3. "Building the Filter Supplied in the Kit"** – Discusses the filter supplied in the kit (loose parts in a separate bag). Its design, component placement, and testing are discussed.
- **Chapter 4. "Common Filter Modifications"** – Covers modifications that are easy to do with these boards. It also discusses common filter limitations.
- **Appendix A. "Schematics and Layouts"** – Shows the schematic and board layouts for the Active Filter Demo Board Kit.
- **Appendix B. "Bill Of Materials (BOM)"** – Lists the parts used to build the sub-assemblies in the Active Filter Demo Board Kit.

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## CONVENTIONS USED IN THIS GUIDE

This manual uses the following documentation conventions:

### DOCUMENTATION CONVENTIONS

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

## RECOMMENDED READING

This user's guide describes how to use Active Filter Demo Board Kit. Other useful documents are listed below. The following Microchip documents are available and recommended as supplemental reference resources.

### **MCP6271 Data Sheet (DS21810)**

Gives detailed information on the op amps that are included in the Active Filter Demo Board Kit Accessory Bag.

### **FilterLab® 2.0 User's Guide (DS51419)**

Covers the functionality of Microchip's active filter design software. The appendices include information on filter terminology, design parameters, selecting an op amp, and selected references to the analog filter literature.

## THE MICROCHIP WEB SITE

Microchip provides online support via our web site at [www.microchip.com](http://www.microchip.com). This web site is used as a means to make files and information easily available to customers. Accessible by using your favorite Internet browser, the web site contains the following information:

- **Product Support** – Data sheets and errata, application notes and sample programs, design resources, user's guides and hardware support documents, latest software releases and archived software
- **General Technical Support** – Frequently Asked Questions (FAQs), technical support requests, online discussion groups, Microchip consultant program member listing
- **Business of Microchip** – Product selector and ordering guides, latest Microchip press releases, listing of seminars and events, listings of Microchip sales offices, distributors and factory representatives

## CUSTOMER SUPPORT

Users of Microchip products can receive assistance through several channels:

- Distributor or Representative
- Local Sales Office
- Field Application Engineer (FAE)
- Technical Support
- Development Systems Information Line

Customers should contact their distributor, representative or field application engineer for support. Local sales offices are also available to help customers. A listing of sales offices and locations is included in the back of this document.

Technical support is available through the web site at: <http://support.microchip.com>

## DOCUMENT REVISION HISTORY

### **Revision A (June 2006)**

- Initial Release of this Document.

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NOTES:



## Chapter 1. Product Overview

### 1.1 INTRODUCTION

The Active Filter Demo Board Kit is described by the following:

- Assembly # : 114-00097R1
- Order # : MCP6XXXDM-FLTR
- Name: Active Filter Demo Board Kit

Items discussed in this chapter include:

- Kit Contents
- Intended Use of the Active Filter Demo Board Kit
- Active Filter Demo Board Kit Description
- Sub-Assemblies
- Associated Tools

### 1.2 KIT CONTENTS

- $V_{DD}/2$  Filter Section Board - One partially assembled board
- Active Filter Section – Four partially assembled boards
- Important Information “Read First”
- Accessory Bag - contains loose parts for populating sockets on boards
- Analog and Interface Products Demonstration Boards CD-ROM (DS21912) – This CD-ROM contains the files and literature mentioned in this user's guide



**FIGURE 1-1:** Active Filter Demo Board Kit Contents.

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## 1.3 INTENDED USE OF THE ACTIVE FILTER DEMO BOARD KIT

This kit is intended to support active filters designed by FilterLab® V2.0 (see **Section 1.6 “Associated Tools”**). These filters are all pole and are built by cascading first and second order sections.

Higher frequency filters (e.g., a low-pass filter with cutoff at 1 MHz) can have their design initially verified on these boards; see **Section 4.5 “Higher Frequency Filters”**.

## 1.4 ACTIVE FILTER DEMO BOARD KIT DESCRIPTION

The Printed Circuit Boards (PCB) in the Active Filter Demo Board Kit have the following features:

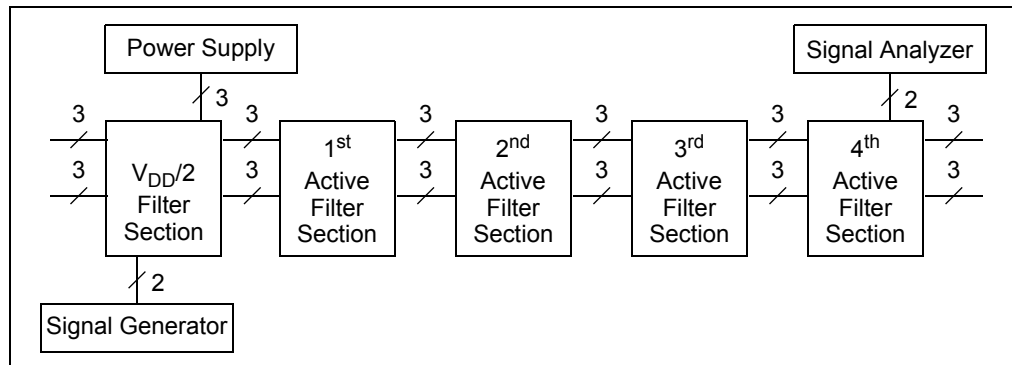
- All filter resistors and capacitors are socketed
- Supports all Microchip single op amps
  - PDIP-8 package (e.g., MCP6271) are socketed
  - SOIC-8 package can be accommodated; see **Section 4.6 “Using 8-Pin SOIC Op Amps”**
- Test points for connecting lab equipment
- Single supply configuration
- Modularized connection scheme

## 1.5 SUB-ASSEMBLIES

The Active Filter Demo Board Kit is comprised of three sub-assemblies:

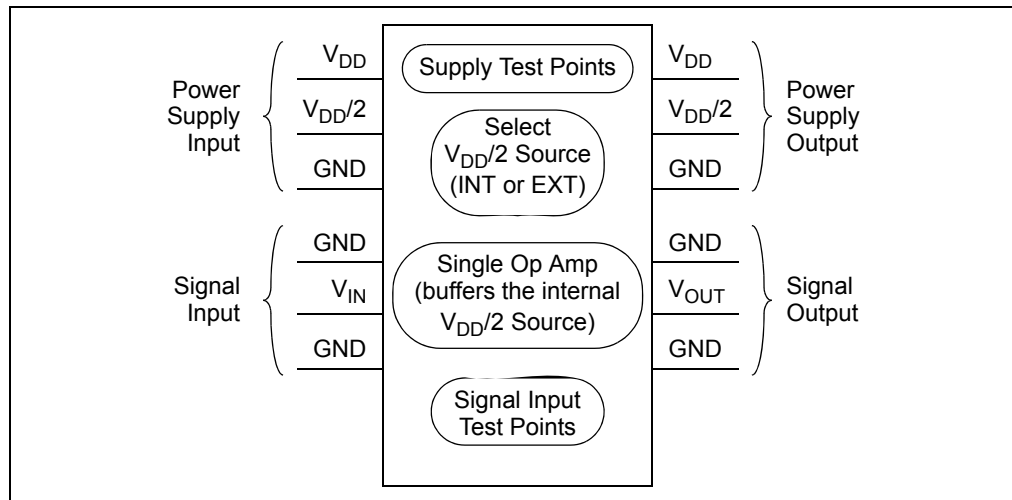
- $V_{DD}/2$  Filter Section
  - Sub-Assembly # : 102-00098R1
  - One PCB designed to provide mid-supply biasing to the other PCBs
  - Provides power supply test points for a lab power supply
  - Provides input test points for a lab signal generator
- Active Filter Sections
  - Sub-Assembly # : 102-00097R1
  - Four PCBs designed to be cascaded
  - Support filter orders between  $n = 1$  and  $n = 8$
  - Provide output test points for lab equipment
- Accessory Bag
  - Sub-Assembly # : 110-00097R1
  - Kit of resistors, capacitors, and op amps that can be used to build the filter circuit in Figure 2-8

Figure 1-2 shows the Active Filter Demo Board Kit's five PCBs; one  $V_{DD}/2$  Filter Section PCB and four Active Filter Section PCB's. It shows how these boards are cascaded (using board connectors), and how lab equipment can be attached (via test points) to measure the filter response.

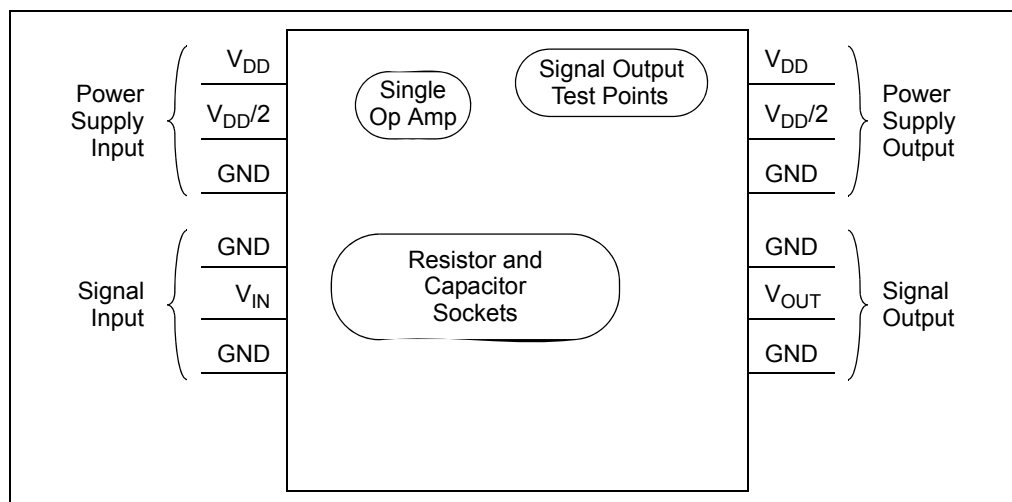


**FIGURE 1-2:** Measurement Setup Block Diagram.

Figure 1-3 shows the block diagram of the  $V_{DD}/2$  Filter Section, and Figure 1-4 shows the block diagram of the Active Filter Sections.



**FIGURE 1-3:**  $V_{DD}/2$  Filter Section Block Diagram.



**FIGURE 1-4:** Active Filter Section (4 each) Block Diagram.

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## 1.6 ASSOCIATED TOOLS

FilterLab 2.0<sup>®</sup> is an innovative software tool that simplifies active (op amp) filter design. Available at no cost from Microchip's web site ([www.microchip.com](http://www.microchip.com)), the FilterLab 2.0 active filter software design tool provides full schematic diagrams of the filter circuit with component values, displays the frequency response, and gives a SPICE listing for further simulations. Users can select a low-pass, band-pass or high-pass response. Available functions are Bessel, Butterworth, and Chebyshev, with order between  $n = 1$  and 8.

## Chapter 2. Setup and Installation

### 2.1 INTRODUCTION

This chapter shows how to set up the Active Filter Demo Board Kit. Items discussed in this chapter include:

- Required Tools
- Connecting the PCBs
- $V_{DD}/2$  Filter Section Set-up
- Active Filter Section Set-up
- Set-up Verification

### 2.2 REQUIRED TOOLS

- Lab power supply
- Lab signal source (e.g., function generator)
- Lab measurement equipment (e.g., oscilloscope)

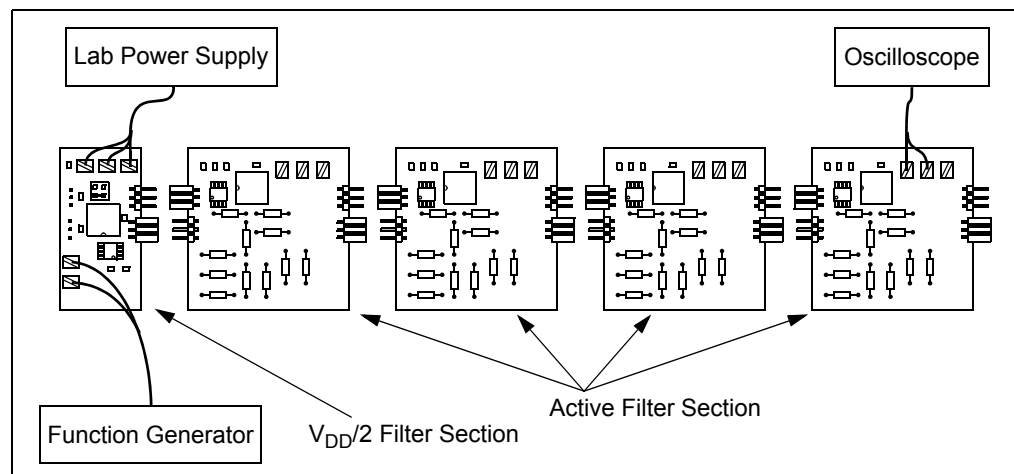
### 2.3 CONNECTING THE PCBs

This section discusses the primary method for setting up the Active Filter Demo Board Kit. An exploded view of how the different boards connect is shown in Figure 2-1 (see also Figure 1-2).

The filter order will determine how many of the Active Filter Section boards need to be cascaded (one board when  $n = 1$  or 2, two boards when  $n = 3$  or 4, ...).

The board edge connectors are slid together to make good electrical connection between boards.

The (surface mount) test points allow lab equipment to be connected to these boards. The user provides the input signal and power to the  $V_{DD}/2$  Filter Section, and measures the output signal at the last Active Filter Section.



**FIGURE 2-1:** Board Connections for the Active Filter Demo Board Kit.

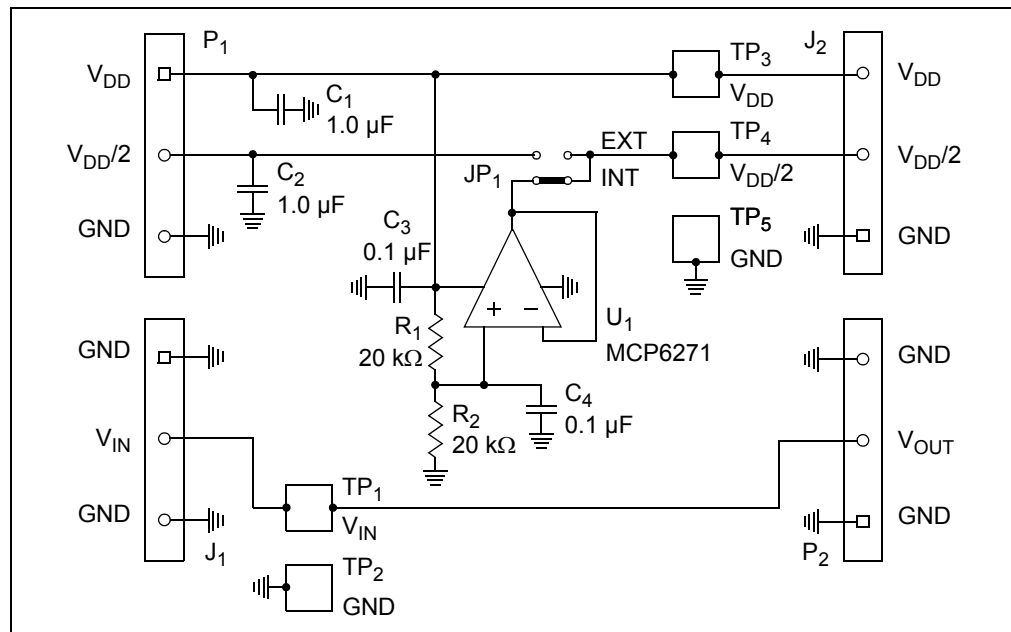
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The user provides the supply voltages, which need to be in the allowed range for the installed op amps. Any of Microchip's op amps that operate below 5.5V can be used; higher voltage parts can be accommodated (see **Section 4.2 "Power Supplies"**). Five MCP6271 op amps are included in the accessory bag for convenience.

The power lines are bypassed by 1.0  $\mu\text{F}$  capacitors at each board input. The op amps also have 0.1  $\mu\text{F}$  local bypass capacitors.

## 2.4 $V_{DD}/2$ FILTER SECTION SET-UP

Figure 2-2 gives the circuit diagram for the  $V_{DD}/2$  Filter Section. It allows the mid-supply voltage ( $V_{DD}/2$ ) to be set by an external power supply (JP<sub>1</sub> at EXT), or internally (JP<sub>1</sub> at INT) by the on-board op amp (U<sub>1</sub>). The headers and test points allow the user flexibility in setting up a filter circuit.



**FIGURE 2-2:**  $V_{DD}/2$  Filter Section Circuit.

The  $V_{DD}/2$  Filter Section PCB is shown in Figure 2-3. The single op amp U1 can have either a PDIP-8 or SOIC-8 package:

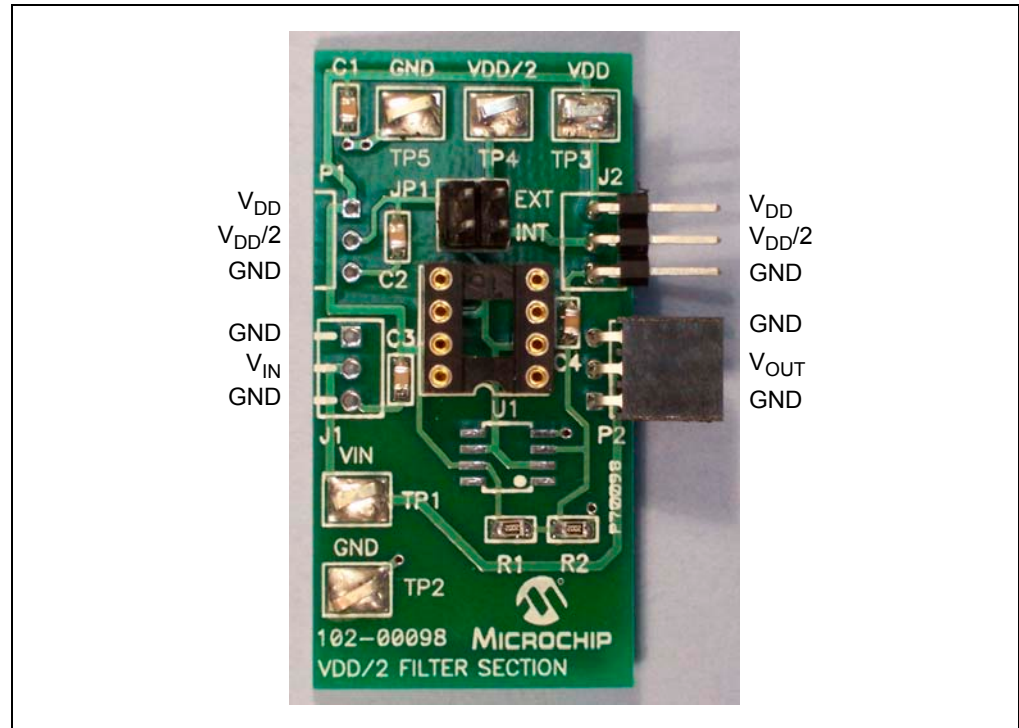
- PDIP-8 packages are inserted into the DIP-8 socket above the U1 label
- SOIC-8 packages can be accommodated; see **Section 4.6 "Using 8-Pin SOIC Op Amps"**
- Only one op amp can be connected at a time

Select the mid-supply power source by setting jumper JP1 to (see Figure 2-3):

- Internal  $V_{DD}/2$  (INT on bottom)
  - Op amp U1 drives the  $V_{DD}/2$  line on all of the PCBs
  - The  $V_{DD}/2$  line must be disconnected from any power supply (at P1 or TP4)
- External  $V_{DD}/2$  (EXT on top, as shown)
  - Op amp U1 has no load
  - The  $V_{DD}/2$  line must be connected to an external supply voltage (at P1 or TP4)

The headers P1 and J1 on the left of the board are unpopulated (see Figure 2-3):

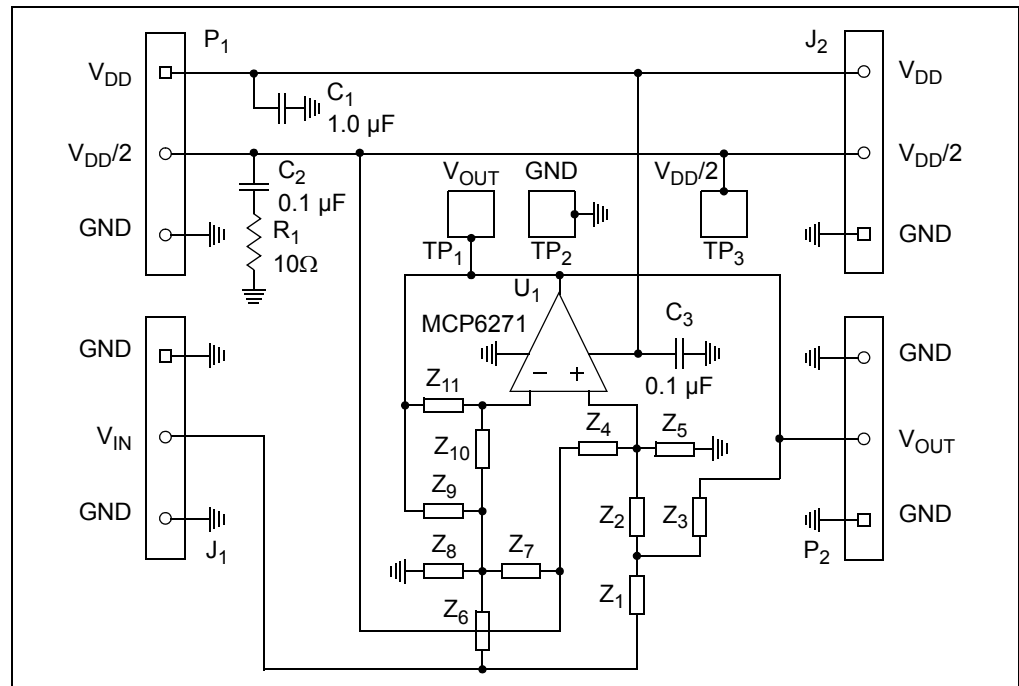
- The test points TP1 through TP5 provide connections for the same voltages
- P1 and J1 can be populated by the user, if desired, to connect to another (user provided) board on the left



**FIGURE 2-3:** *V<sub>DD</sub>/2 Filter Section Top View.*

## 2.5 ACTIVE FILTER SECTION SET-UP

The filter sections designed by FilterLab V2.0 have several topologies. This section details the conversion of these topologies to the Active Filter Demo Board Kit. Figure 2-4 shows the circuit diagram for the Active Filter Section.



**FIGURE 2-4:** *Active Filter Section Circuit.*

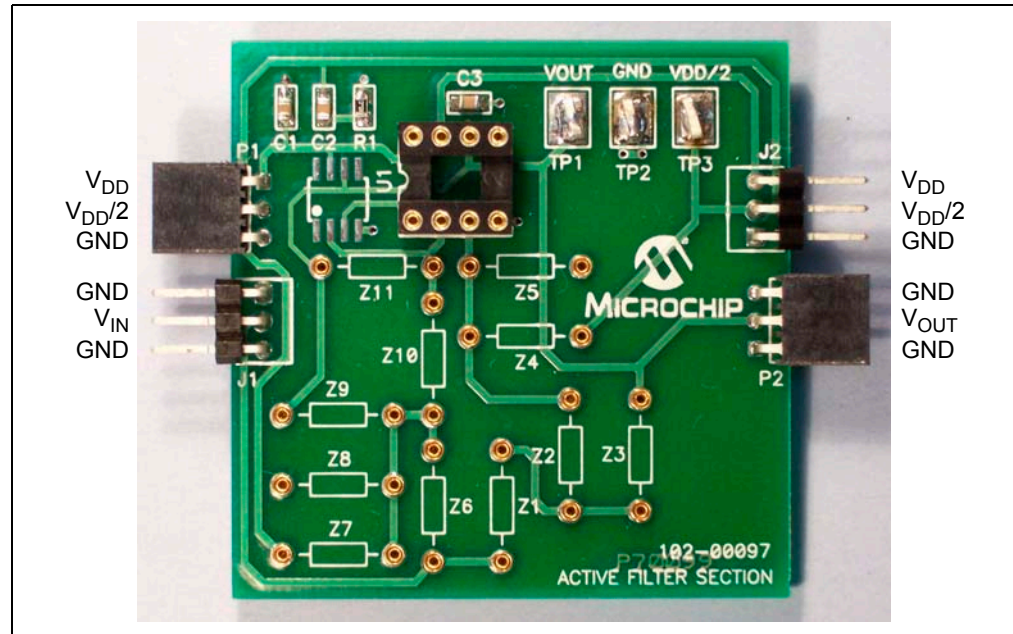
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The Active Filter Section is shown in Figure 2-5. The single op amp U1 can have either a PDIP-8 or SOIC-8 package:

- PDIP-8 packages are inserted into the DIP-8 socket to the right of the U1 label
- SOIC-8 packages can be accommodated; see **Section 4.6 “Using 8-Pin SOIC Op Amps”**

The resistors and capacitors that are part of a filter section are placed in pin sockets (see Figure 2-5):

- The socket pairs are labeled Z1 through Z12
- The following sub-sections detail how the resistors and capacitors are chosen and populated



**FIGURE 2-5:** Active Filter Section Top View.



## 2.5.1 FilterLab Circuit Topology vs. PCB Reference Designators

FilterLab V2.0 labels the capacitors and resistors in its circuit diagram as follows:

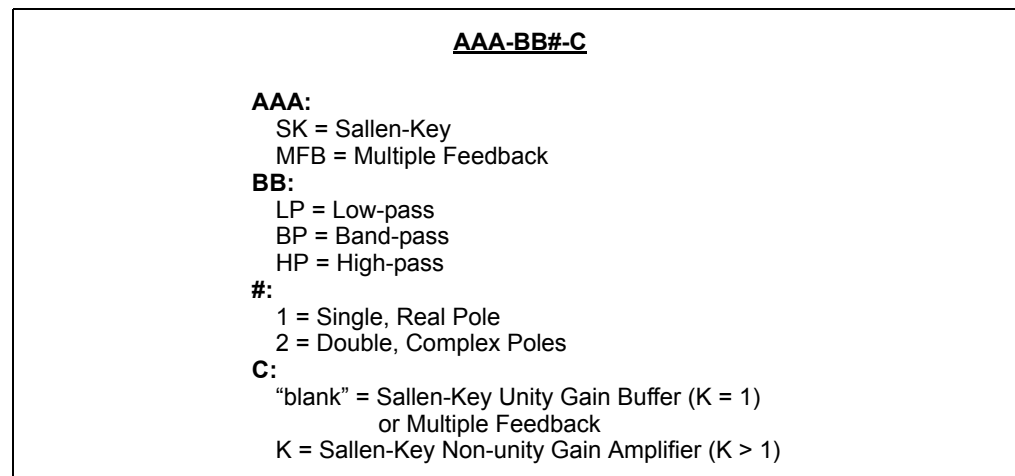
- R12 = Resistor, Section # 1, Resistor # 2 in that section
- C31 = Capacitor, Section # 3, Capacitor # 1 in that section
- Ra = Gain setting resistor for op amp in Sallen-Key Section # 1 (open, and not labeled, when in unity gain)
- Rb = Feedback resistor for op amp in Sallen-Key Section # 1 (0Ω, and not labeled, when in unity gain)

The resistor and capacitor reference designators on the Active Filter Section board (Z1 - Z11) need to be filled according to FilterLab's design. The following sub-sections show how to convert from FilterLab's circuit diagram to the PCB.

In the following, the PCBs are given section numbers 0 to 4:

- Section # 0 – for  $V_{DD}/2$  Filter Section
- Section # 1 to # 4 – for cascaded Active Filter Section

The different circuit topologies referred to in **Section 2.5.2 “Sallen-Key, Low-pass Filter Sections”**, **Section 2.5.3 “Sallen-Key, High-pass Filter Sections”**, and **Section 2.5.4 “Multiple Feedback, Low-pass and Band-pass Filter Sections”** will be labeled as shown in Figure 2-6.



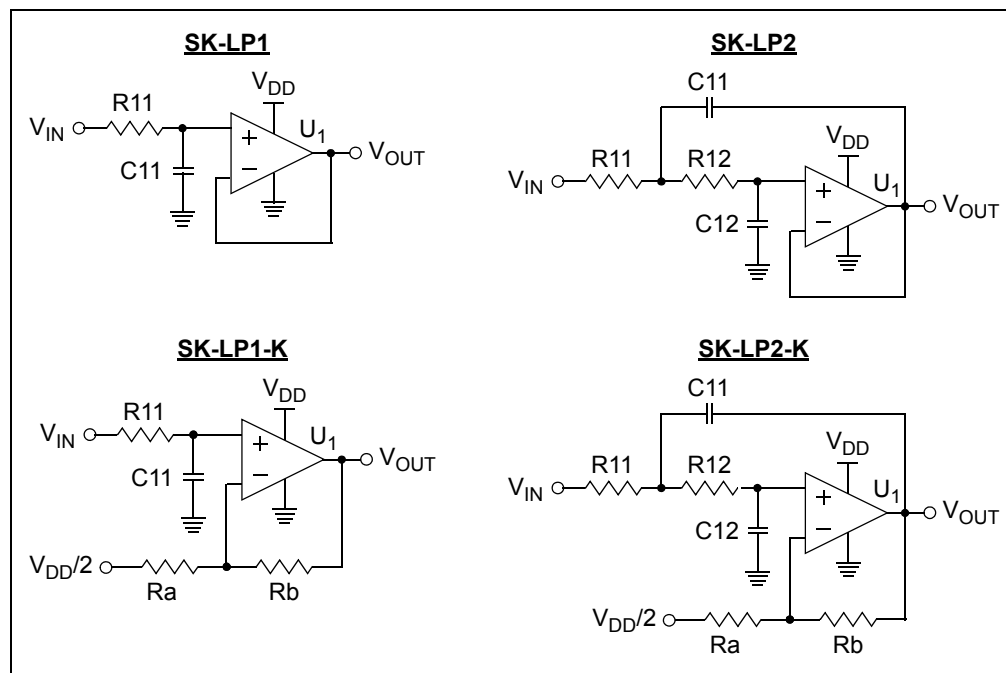
**FIGURE 2-6:** Filter Section Labels.

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## 2.5.2 Sallen-Key, Low-pass Filter Sections

**TABLE 2-1: IMPEDANCES FOR SALLEN-KEY, LOW-PASS FILTER SECTIONS**

Topology	SK-LP1	SK-LP2	SK-LP1-K	SK-LP2-K
$Z_1$	$0\Omega$	R11	$0\Omega$	R11
$Z_2$	R11	R12	R11	R12
$Z_3$	—	C11	—	C11
$Z_4$	—	—	—	—
$Z_5$	C11	C12	C11	C12
$Z_6$	—	—	—	—
$Z_7$	—	—	$0\Omega$	$0\Omega$
$Z_8$	—	—	—	—
$Z_9$	—	—	—	—
$Z_{10}$	—	—	Ra	Ra
$Z_{11}$	$0\Omega$	$0\Omega$	Rb	Rb

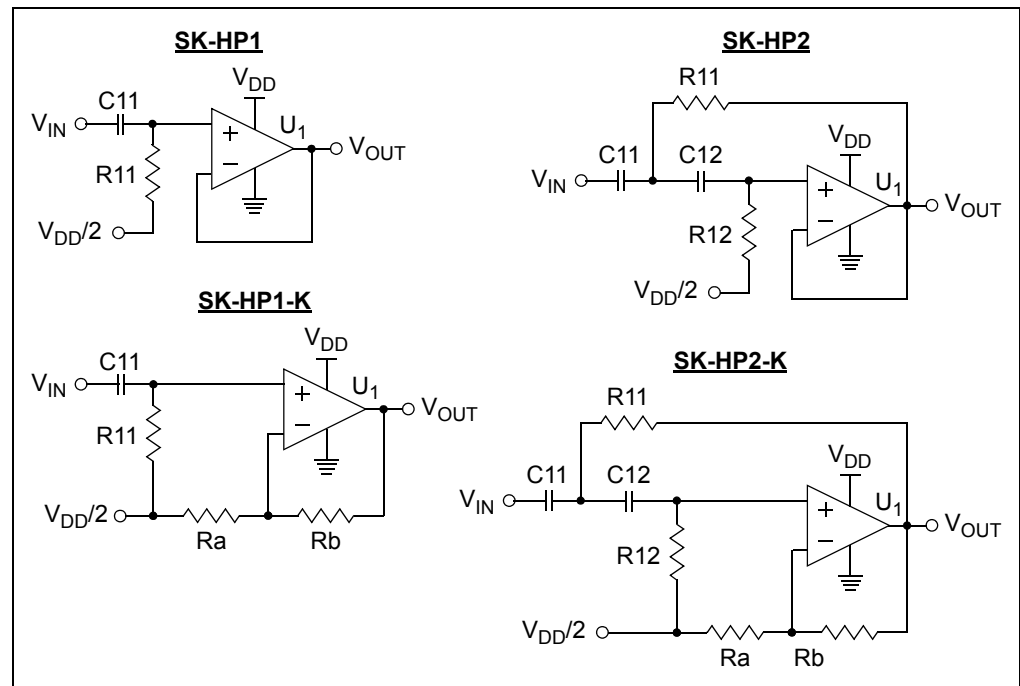


**FIGURE 2-7:** Sallen-Key, Low-pass (modified) Filter Topologies.

## 2.5.3 Sallen-Key, High-pass Filter Sections

**TABLE 2-2: IMPEDANCES FOR SALLEN-KEY, HIGH-PASS FILTER SECTIONS**

Topology	SK-HP1	SK-HP2	SK-HP1-K	SK-HP2-K
Z <sub>1</sub>	0Ω	C11	0Ω	C11
Z <sub>2</sub>	C11	C12	C11	C12
Z <sub>3</sub>	—	R11	—	R11
Z <sub>4</sub>	R11	R12	R11	R12
Z <sub>5</sub>	—	—	—	—
Z <sub>6</sub>	—	—	—	—
Z <sub>7</sub>	—	—	0Ω	0Ω
Z <sub>8</sub>	—	—	—	—
Z <sub>9</sub>	—	—	—	—
Z <sub>10</sub>	—	—	Ra	Ra
Z <sub>11</sub>	0Ω	0Ω	Rb	Rb



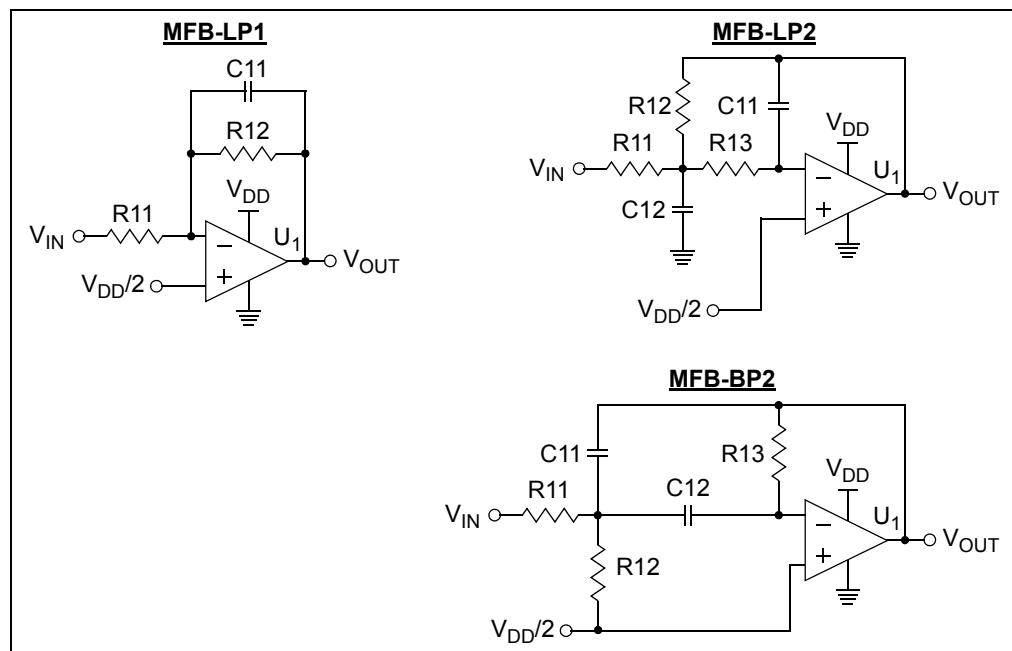
**FIGURE 2-8:** Sallen-Key, High-pass (modified) Filter Topologies.

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## 2.5.4 Multiple Feedback, Low-pass and Band-pass Filter Sections

**TABLE 2-3: IMPEDANCES FOR MULTIPLE FEEDBACK, LOW-PASS AND BAND-PASS FILTER SECTIONS**

Topology	MFB-LP1	MFB-LP2	MFB-BP2
$Z_1$	—	—	—
$Z_2$	—	—	—
$Z_3$	—	—	—
$Z_4$	$0\Omega$	$0\Omega$	$0\Omega$
$Z_5$	—	—	—
$Z_6$	R11	R11	R11
$Z_7$	—	—	R12
$Z_8$	—	C12	—
$Z_9$	R12	R12	C11
$Z_{10}$	$0\Omega$	R13	C12
$Z_{11}$	C11	C11	R13



**FIGURE 2-9:** Multiple Feedback, Low-pass and Band-pass (modified) Filter Topologies.

## 2.6 SET-UP VERIFICATION

1. Install components (resistors, capacitors, and op amps) for a filter design (e.g., the filter described in **Section 3.2 “The Filter Design”** and **Section 3.3 “Putting the Filter Together”**).
2. Verify the power supply voltages, including  $V_{DD}/2$ , for all of the boards.
3. Test the filter response as described in **Section 3.4 “Testing the Filter”**.

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NOTES:

## Chapter 3. Building the Filter Supplied in the Kit

### 3.1 INTRODUCTION

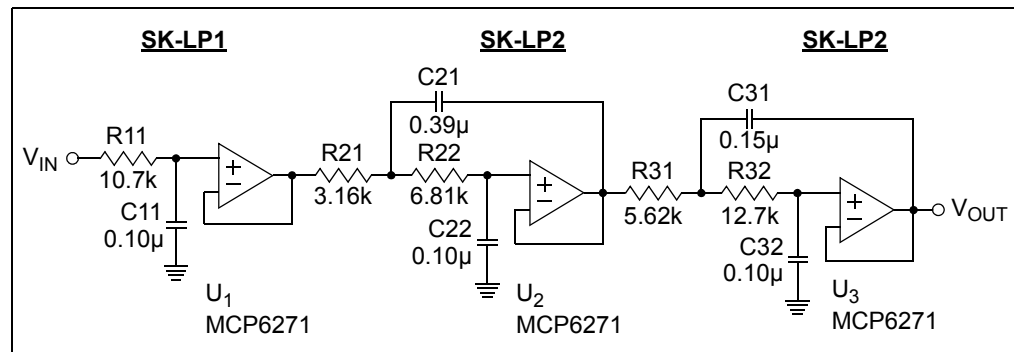
The accessory bag that comes with this kit makes it quick and easy to evaluate the filter described below; it was designed in FilterLab V2.0. Items discussed in this chapter include:

- The Filter Design
- Putting the Filter Together
- Testing the Filter

### 3.2 THE FILTER DESIGN

See Figure 3-1 for the circuit diagram supported by the accessory bag. This filter is described as follows:

- Bessel Low-pass
- $n = 5$ , (filter order)
- $f_C = 100$  Hz, (cut-off frequency)
- Gain = 1 V/V
- Sallen-Key sections
- Single Supply



**FIGURE 3-1:** 5th Order, Bessel, Low-pass Filter Supported by the Active Filter Demo Board Kit.

This filter was built, and its frequency response was measured; the result is shown in Figure 3-2. MCP601 op amps were used, instead of MCP6271 op amps, because they are slower. Notice how close the measured and simulated data are; this happened because the MCP601 op amp is much faster than the filter, and because 1% resistors and 5% capacitors were used.

# Active Filter Demo Board Kit User's Guide

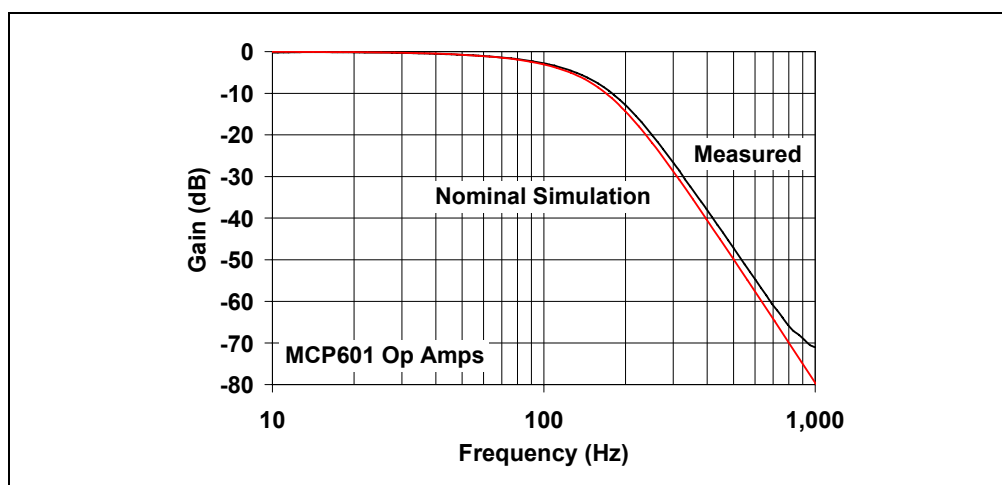


FIGURE 3-2: Filter Frequency Response.

## 3.3 PUTTING THE FILTER TOGETHER

Each of the components in Figure 3-1 that needs to be inserted in a socket is listed in Table 3-1 (see Table B-5). This table gives the section number (see **Section 2.5 “Active Filter Section Set-up”**) and the PCB reference designators (e.g., Z5). Since this design is of 5<sup>th</sup> order, there are no components for Section # 4.

TABLE 3-1: ACCESSORY BAG PARTS LIST

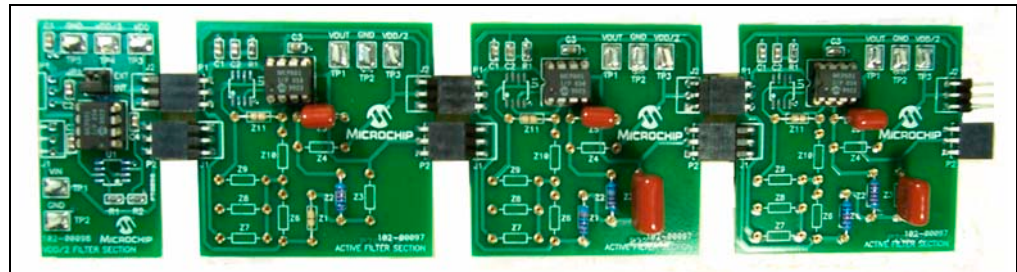
Component Values	Qty	Section	Reference	PCB Label
100 nF	1	1	C11	Z5
	1	2	C22	Z5
	1	3	C32	Z5
150 nF	1	3	C31	Z3
390 nF	1	2	C21	Z3
Jumper Wire (0Ω) (Note 1)	2	1	—	Z1, Z11
	1	2	—	Z11
	1	3	—	Z11
3.16 kΩ	1	2	R21	Z1
5.62 kΩ	1	3	R31	Z1
6.81 kΩ	1	2	R22	Z2
10.7 kΩ	1	1	R11	Z2
12.7 kΩ	1	3	R32	Z2
MCP6271, Single Op Amp, 2 MHz, PDIP-8, Microchip Technology Inc. (Note 1)	1	0	U <sub>1</sub>	U1
	1	1	U <sub>1</sub>	U1
	1	2	U <sub>2</sub>	U1
	1	3	U <sub>3</sub>	U1

**Note 1:** The other 6 jumpers and 1 op amp in the accessory bag are for convenience in building other filters.



# Building the Filter Supplied in the Kit

Figure 3-3 is a picture of the fully assembled filter shown in Figure 3-1. Note that the board on the left ( $V_{DD}/2$  Filter Section) provides an easy way to connect the input signal source and power supply to the filter. JP1 on this board may be connected to INT or EXT in this case.

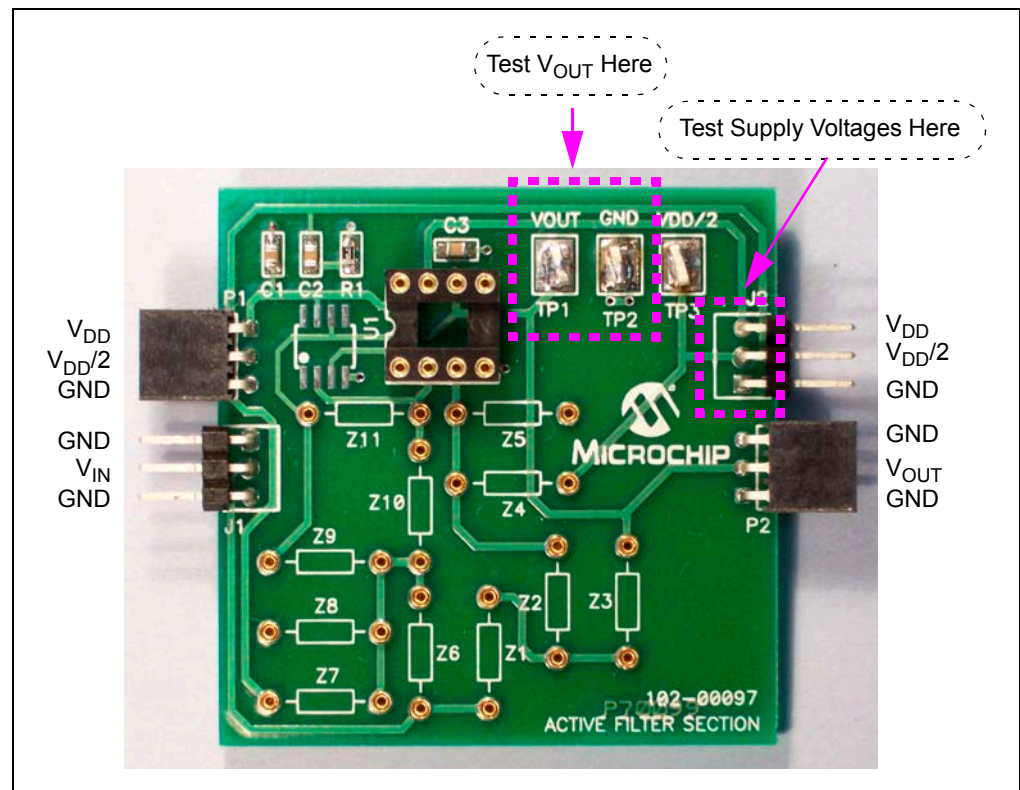


**FIGURE 3-3:** Picture of the Filter Supported by the Active Filter Demo Board Kit.

## 3.4 TESTING THE FILTER

### 3.4.1 DC Bias

Figure 3-4 shows the most important DC bias voltages to check.

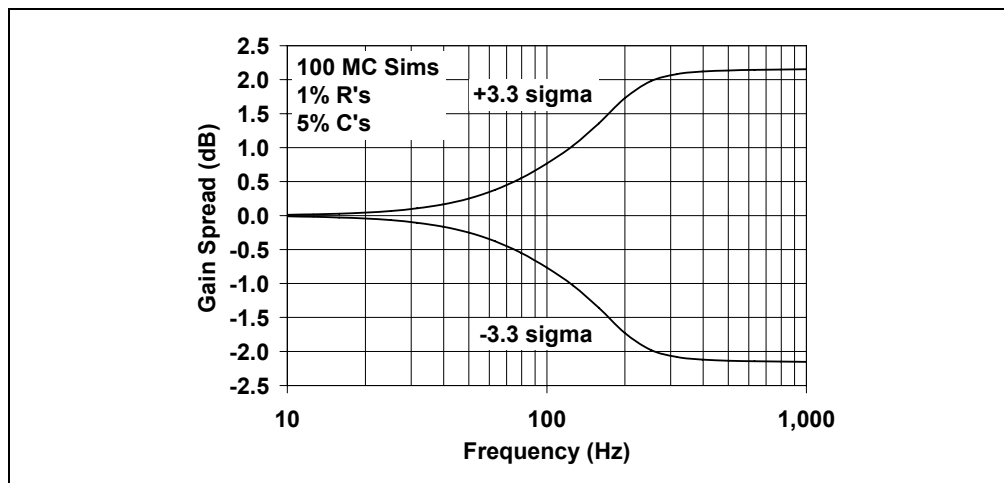


**FIGURE 3-4:** Points to check DC Bias.

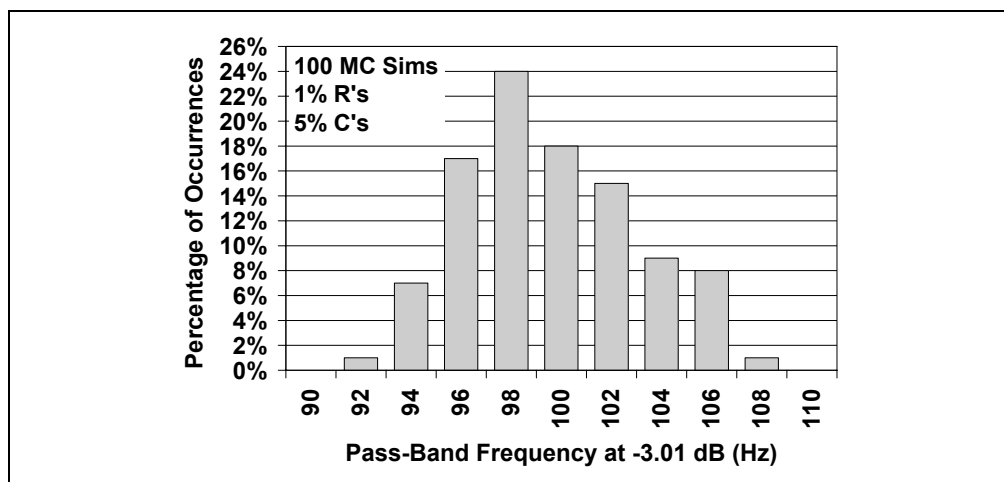
### 3.4.2 Response Variability

Resistors and capacitors with tighter tolerances will reduce the variability of the filters response over process and, sometimes, temperature. Figure 3-5 shows the simulated  $\pm 3.3$  sigma gain error (in dB) for each frequency (based on a uniform random distribution). Figure 3-6 shows a histogram of the pass-band frequency ( $f_p$ ) from the same simulation.

# Active Filter Demo Board Kit User's Guide



**FIGURE 3-5:** Gain Error (Monte Carlo simulation) vs. Frequency.



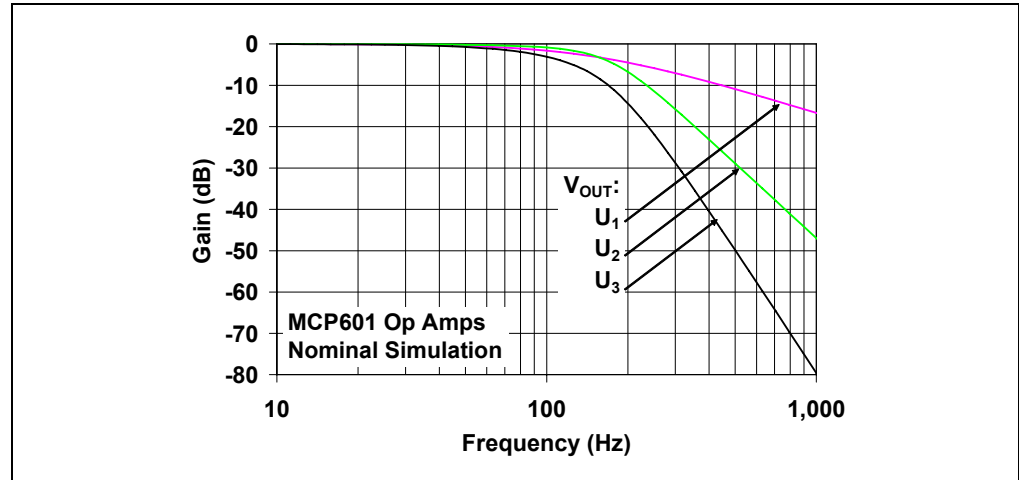
**FIGURE 3-6:** Pass-Band Frequency (Monte Carlo simulation) Histogram.

Using components with tighter tolerances (e.g., 2% capacitors) will improve the variability of the filter response. This is especially important for filters with a sharp cutoff characteristic (i.e., Chebyshev).

### 3.4.3 Checking Output Headroom

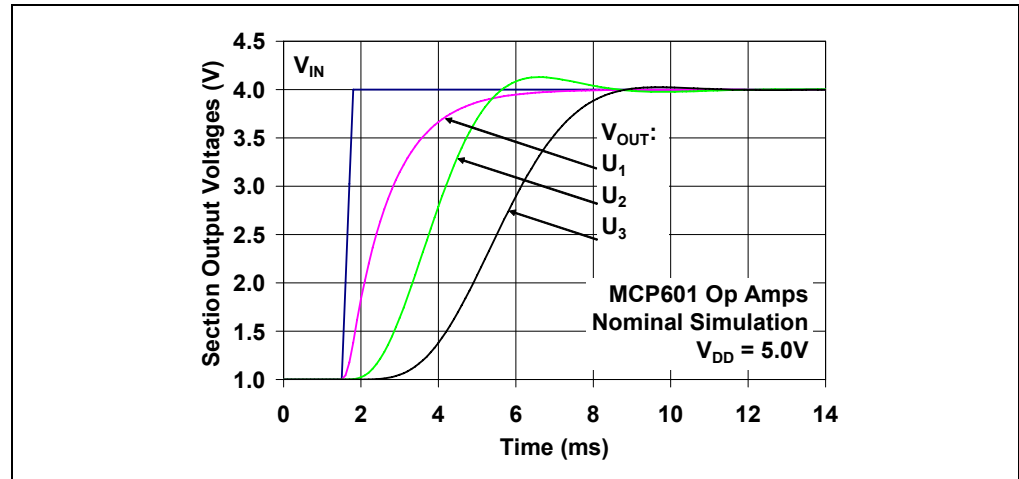
It is also possible to check op amp overdrive issues by testing the output of all of the op amps (every Active Filter Section). The worst-case signal(s) needs to be applied at the first input. Figure 3-7 shows the frequency response of the filter in Figure 3-1. None of the traces goes above 0 dB, so this filter should not have output voltage range issues when the input is a sinewave.

# Building the Filter Supplied in the Kit



**FIGURE 3-7:** Frequency Response for All Outputs.

Figure 3-8 shows the step response of the filter in Figure 3-1. The output of U<sub>2</sub> (the second op amp) shows the largest overshoot, so it limits the output voltage range of the filter. The nominal overshoot is 6.1% (0.18V for a 3.0V step).



**FIGURE 3-8:** Step Response for All Outputs.

Many SPICE simulators support Monte Carlo simulations. Using this capability on your design will help determine what tolerances are needed on your design. The same results can be obtained by measuring many filters (i.e., 30 to 10,000), but at a greater cost.

# Active Filter Demo Board Kit User's Guide

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NOTES:

## Chapter 4. Common Filter Modifications

### 4.1 INTRODUCTION

The modifications described in this chapter include:

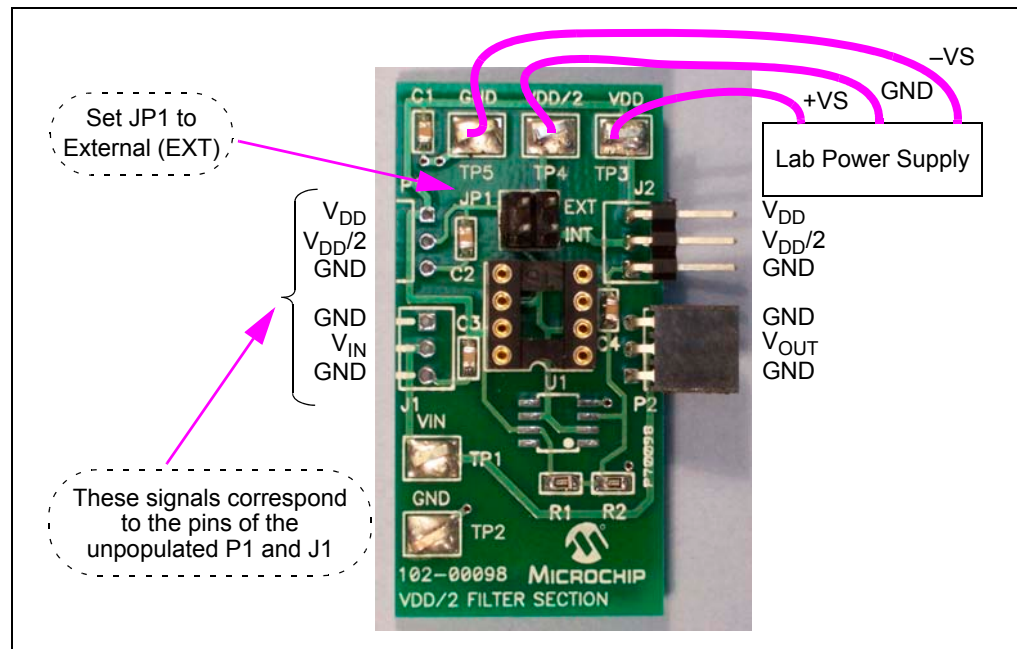
- Power Supplies
- Filter Section Ordering for Noise and Headroom
- Combining Low-pass and High-pass Sections
- Higher Frequency Filters
- Using 8-Pin SOIC Op Amps

### 4.2 POWER SUPPLIES

#### 4.2.1 Dual Power Supplies

To implement dual supplies, change the  $V_{DD/2}$  Filter Section (see Figure 4-1) setup:

- The boards' bypass capacitors (C1 and C3) need to be removed and replaced
  - Connect one set from  $-V_S$  (board GND) to GND (board  $V_{DD/2}$ )
  - Connect the other set from  $+V_S$  (board VDD) to GND (board  $V_{DD/2}$ ).
- Remove R1 and R2, and then replace R2 with a short
- Set JP1 to External  $V_{DD/2}$  (EXT, as shown)
- Connect the Lab Power Supply
  - Voltage  $+V_S$  to the board's  $V_{DD}$  input (TP3)
  - Voltage GND to the  $V_{DD/2}$  input (TP4)
  - Voltage  $-V_S$  to the board's GND input (TP5)



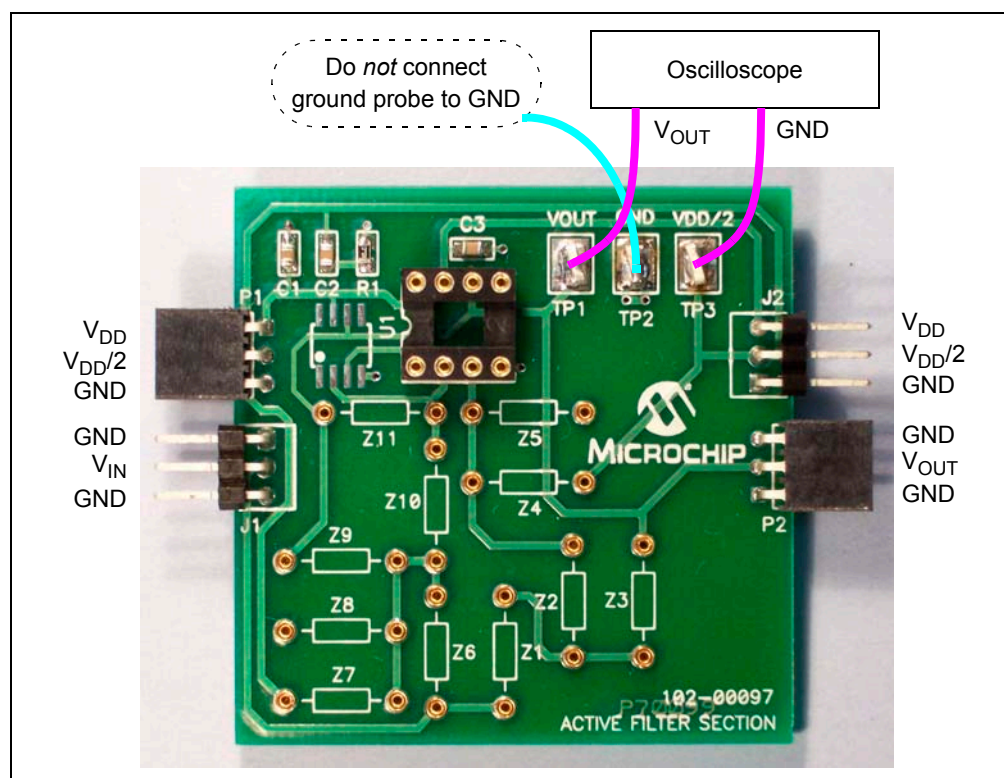
**FIGURE 4-1:** Setting up  $V_{DD/2}$  Filter Section for dual supplies.

# Active Filter Demo Board Kit User's Guide

To implement dual supplies, it is also necessary to change the Active Filter Section (see Figure 4-2) set-up:

- The boards' bypass capacitors (C1 and C3) need to be removed and replaced
  - Connect one set from  $-V_S$  (board GND) to GND (board VDD/2)
  - Connect the other set from  $+V_S$  (board VDD) to GND (board VDD/2).
- If desired, R1 and C1 can be removed
- Connect the Oscilloscope as follows
  - Oscilloscope signal probe to VOUT (TP1)
  - Oscilloscope GND probe to VDD/2 (TP3)

**Note:** Do not connect the oscilloscope GND probe to board GND (TP2) when set up for dual supplies; *this may cause a ground conflict between lab equipment.*



**FIGURE 4-2:** Setting up Active Filter Section for dual supplies.

Using dual supplies may not work well for high frequency designs.  $-V_S$  will be connected to the ground plane, instead of GND, causing greater radiation of supply noise and more crosstalk.

## 4.2.2 Increased Power Supply Voltages

The total voltage across the power supplies should not exceed the op amp's specification (5.5V for the MCP6271). The large bypass capacitors on each board are rated at 16V, which also limits the possible supply voltage.

If necessary, op amps with higher supply voltage can be accommodated. The boards' bypass capacitors must be removed and replaced with other bypass capacitors with a higher voltage rating.

## 4.3 FILTER SECTION ORDERING FOR NOISE AND HEADROOM

FilterLab V2.0 orders the filter sections for good dynamic range performance. Its default selections are:

- Section pole quality factors ( $Q_P$ ) are ordered from lowest to highest (from Section # 1 to Section # 4)
  - In other words, section damping factors ( $\zeta = 0.5/Q_P$ ) go from highest to lowest (from Section # 1 to Section # 4)
- Gains greater than unity are placed in Section # 1 (for best component sensitivities)

Some applications may need to alter the default section ordering for special requirements. To compare different section orderings:

- Check the output headroom of each section's output ( $V_{OUT}$ ) using the worst-case input signal; examples include:
  - Minimum and maximum DC levels
  - Swept frequency sine wave with maximum magnitude
  - Voltage step with maximum step size
- Measure the noise performance
  - Measure the output with a DC input signal (i.e., at mid-supply), an oscilloscope, and a high gain low noise amplifier
  - Calculate the standard deviation of the output; this is the integrated noise in  $V_{RMS}$
  - The noise can be improved by scaling the resistors, or by changing the op amps
- Re-connect the sections in a different order
  - Usually it is best to leave the high gain section at the front of the filter
  - Re-check output headroom and noise

## 4.4 COMBINING LOW-PASS AND HIGH-PASS SECTIONS

Some band-pass and band reject filters can be implemented using cascaded low-pass and high-pass filter sections. These filters have their pass-band frequencies ( $f_{PL}$  and  $f_{PH}$ ) far apart (e.g.,  $f_{PH}/f_{PL} > 5.8$ ). The low-pass and high-pass filters are usually designed separately, then cascaded together.

The Active Filter Demo Board Kit allows the user to try out these filters on the bench with little effort. They also help debug this type of design.

## 4.5 HIGHER FREQUENCY FILTERS

Higher frequency filters (e.g., a low-pass filter with pass band edge at 1 MHz) can have their design initially verified on these boards. Simply scale either the resistors or capacitors to a lower frequency design:

- Increase resistors (or capacitors) by a power of 10
- Choose an op amp that is slower by the same power of 10
- Evaluate response:
  - All frequency parameters are divided by the same power of 10
  - All time parameters are multiplied by the same power of 10

For example, a low-pass filter with a pass-band frequency of 1 MHz could be scaled back to 10 kHz.

The final design must be evaluated on a board capable of supporting higher frequency signals.



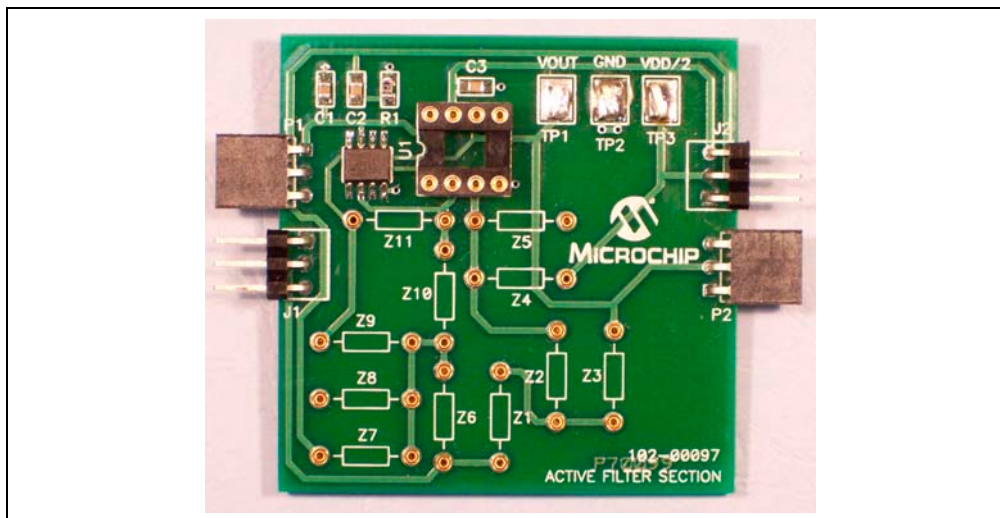
# Active Filter Demo Board Kit User's Guide

## 4.6 USING 8-PIN SOIC OP AMPS

There are two options available when using single op amps in SOIC-8 packages (150 mil wide); soldering onto the  $V_{DD}/2$  Filter Section and/or Active Filter Section board(s) or soldering it onto a separate board which is connected to the DIP-8 socket.

**Note:** The DIP-8 socket must be empty; only one op amp can be used at a time.

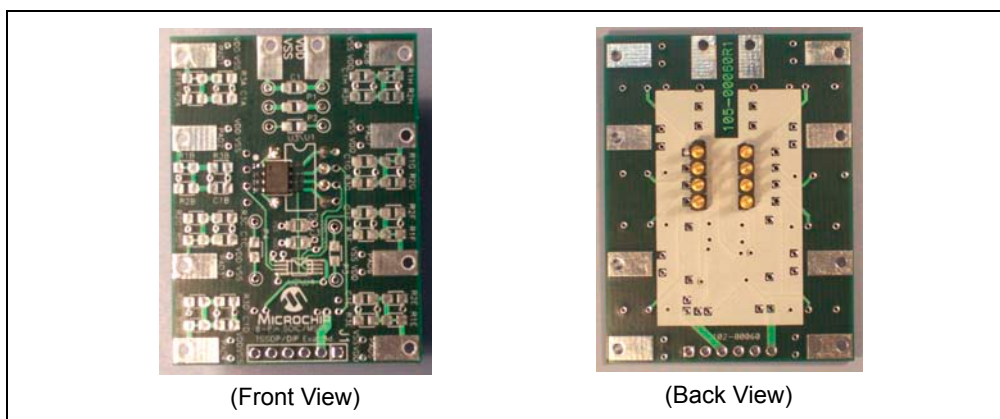
Figure 4-3 shows a SOIC-8 op amp soldered onto the Active Filter Section Board.



**FIGURE 4-3:** Op Amp in SOIC-8 package soldered onto Active Filter Section Board.

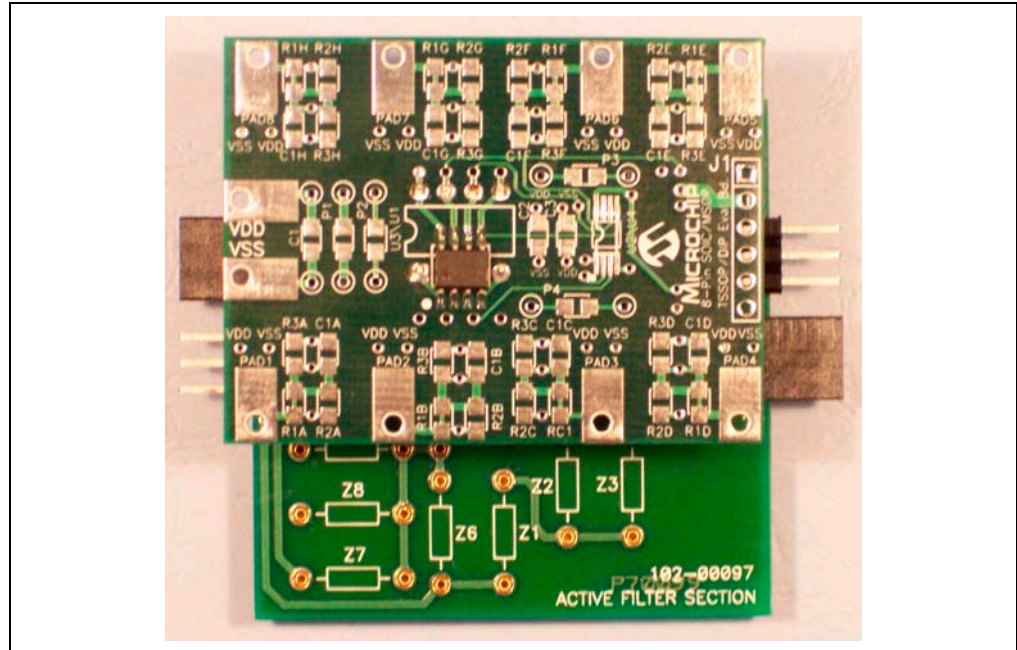
Figure 4-4 shows a SOIC-8 op amp and a DIP-8 socket, soldered onto the 8-Pin SOIC/MSOP/TSSOP/DIP Evaluation Board available from Microchip Technology Inc (order # SOIC8EV). The two interconnect strips on the bottom are Samtec part # BBS-14-T-B or equivalent and are soldered into the through holes for the DIP-8 socket. Figure 4-5 shows this board plugged into the Active Filter Section Board.

**Note:** Insert the interconnect strips into the DIP-8 socket on the  $V_{DD}/2$  Filter Section or Active Filter Section board. Place the SOIC8EV board on the top of the interconnect strips with the same pin orientation. Now solder the strips to the top board; this procedure ensures correct alignment of the strips. Clip the pins flush with the top surface of the SOIC8EV board, then solder the SOIC-8 op amp on the top.



**FIGURE 4-4:** Op Amp in SOIC-8 package soldered to a separate board.





**FIGURE 4-5:** Connecting Adaptor Board onto Active Filter Section.

# Active Filter Demo Board Kit User's Guide

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NOTES:

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## Appendix A. Schematics and Layouts

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### A.1 INTRODUCTION

This appendix contains the schematics and layouts for the different pieces of the Active Filter Demo Board Kit Sub-assemblies:

- $V_{DD}/2$  Filter Section (Sub-Assembly #: 102-00098R1)
- Active Filter Section (Sub-Assembly #: 102-00097R1)
- Accessory Bag (Sub-Assembly #: 110-00097R1)

### A.2 $V_{DD}/2$ FILTER SECTION (SUB-ASSEMBLY #: 102-00098R1)

#### A.2.1 Circuit

See Figure A-1 for the  $V_{DD}/2$  Filter Section circuit diagram. The input and output headers (J1, J2, P1, and P2) allow the PCBs to be cascaded as needed. The filter order will determine how many of the Active Filter Section boards need to be cascaded.

R1, R2, and C3 produce a  $V_{DD}/2$  reference voltage. The op amp U1 buffers this reference voltage, and is set to unity gain. U1 must drive the impedances connected to it on all of the Active Filter Section. Op amp U1 is usually a single, PDIP-8 part inserted into the DIP-8 socket; it can be a SOIC-8 that is soldered to the board (see U1A in Figure A-1).

C1 and C2 are bypass capacitors for  $V_{DD}$ .

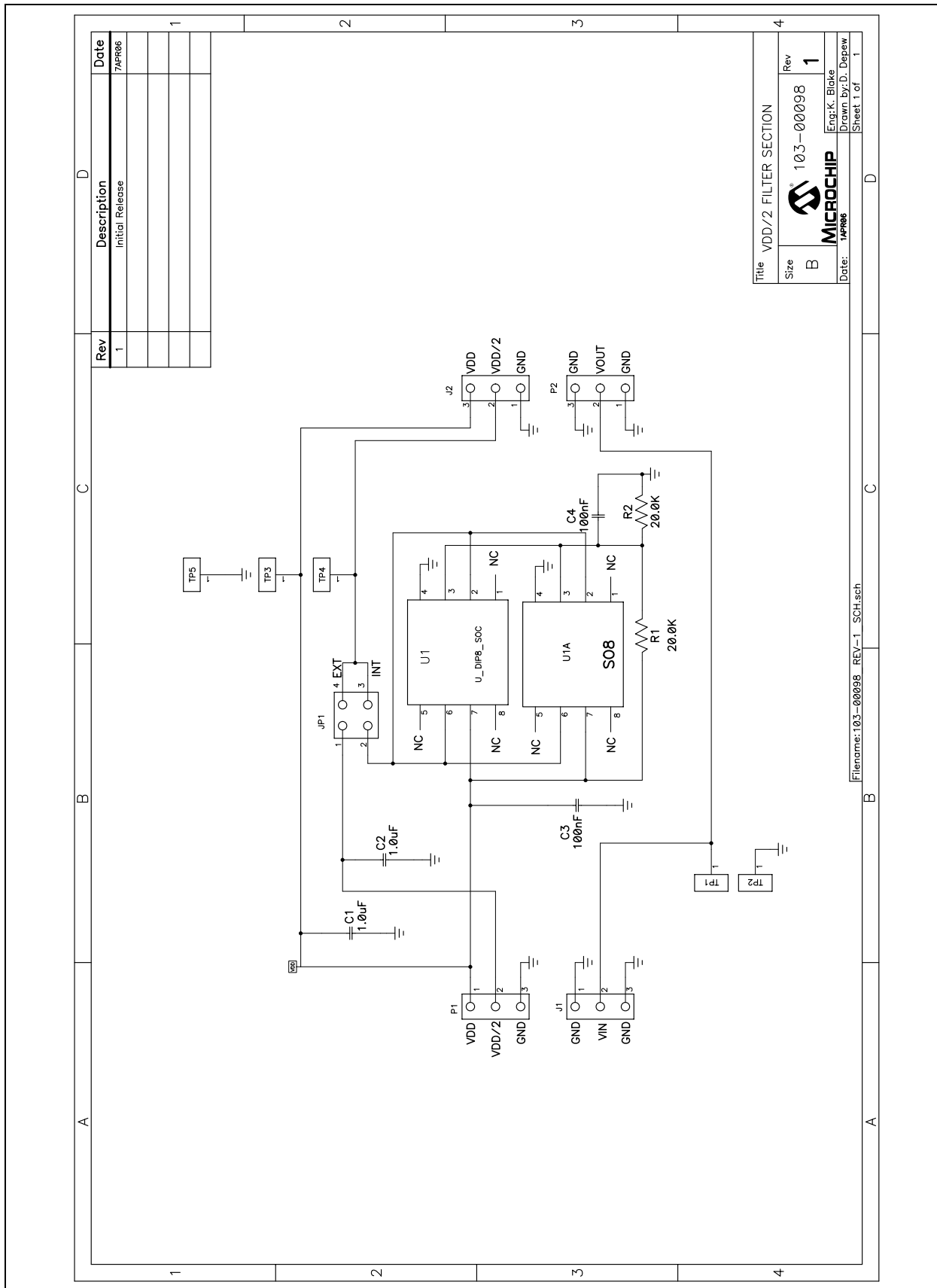
The demonstration board includes five test points for convenience on the bench. TP1 and TP2 make it possible to connect a function generator to the filter input; this signal is passed on to the other boards. TP3 through TP5 provide connections for external power supplies, which are also passed on to the other boards.

JP1 allows the user to choose the  $V_{DD}/2$  reference voltage source:

- A lab supply (EXT = External  $V_{DD}/2$  source)
- Op amp U1's output (INT = Internal  $V_{DD}/2$  source)

See **Section B.1 “ $V_{DD}/2$  Filter Section BOMs”** for the Bill of Material for this kit.

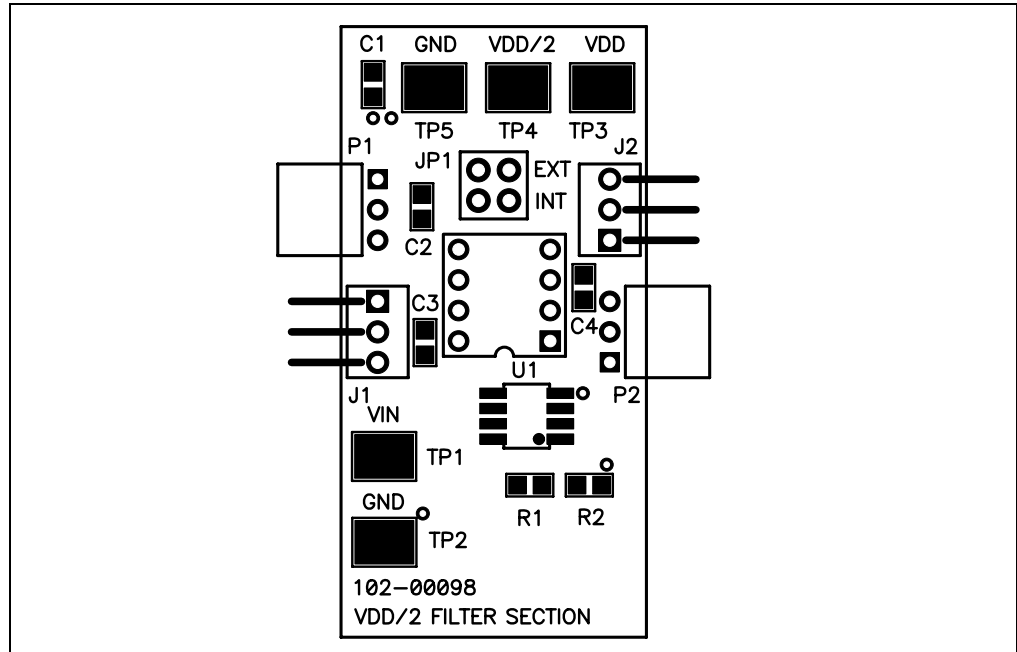
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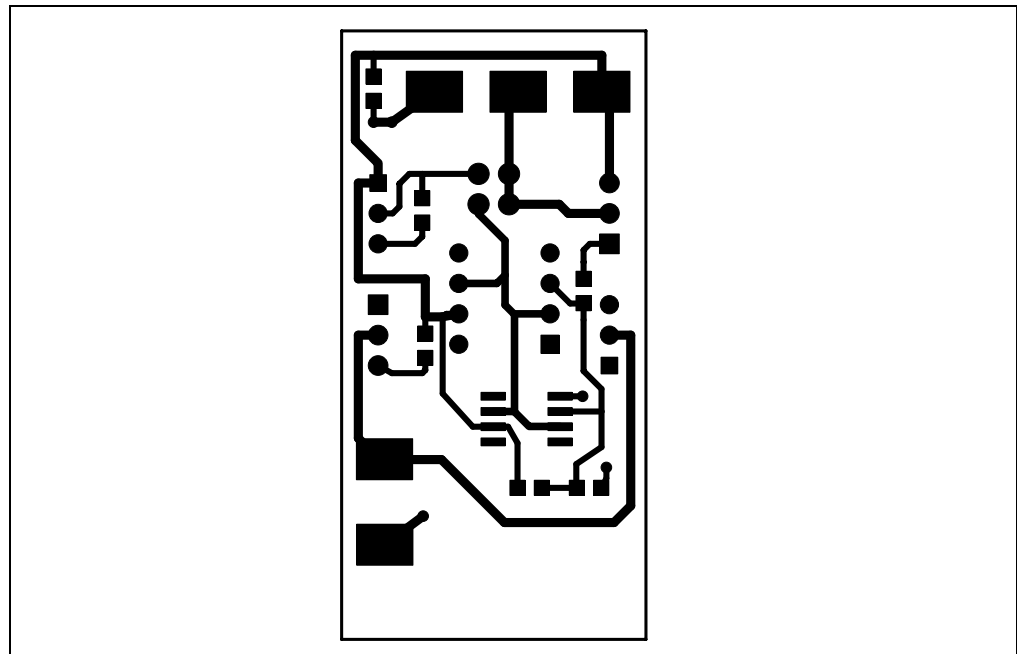
**FIGURE A-1:** V<sub>DD</sub>/2 Filter Section – Schematic.

## A.2.2 Board Plots

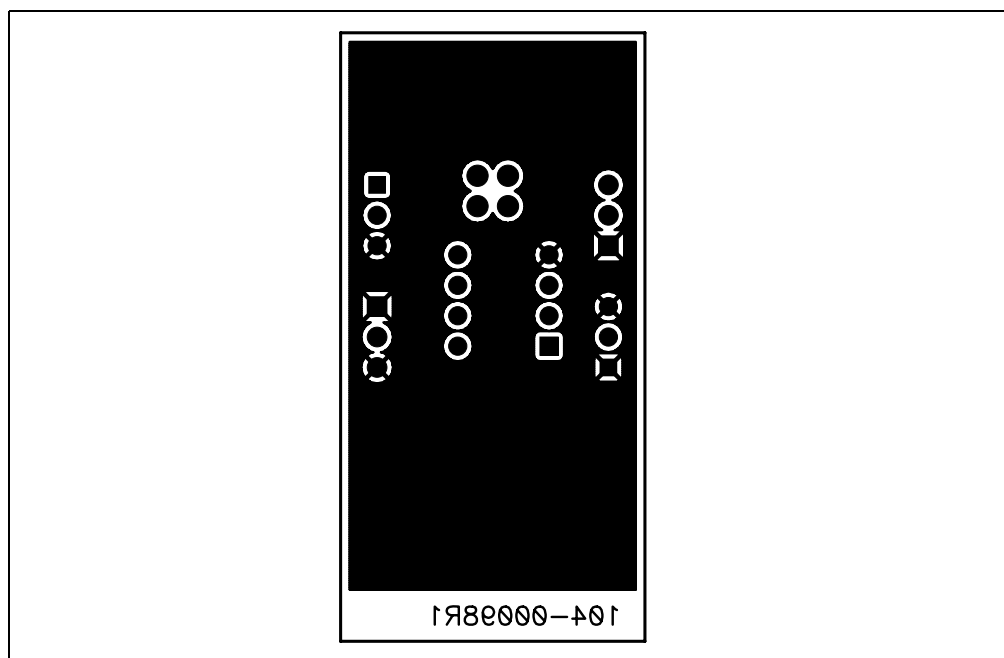
The Gerber files for this board are available on the Microchip website ([www.microchip.com](http://www.microchip.com)) and are contained in the zip file "00098R1 Gerbers.zip".



**FIGURE A-2:**  $V_{DD/2}$  Filter Section – Top Silk Screen.



**FIGURE A-3:**  $V_{DD/2}$  Filter Section – Top Metal Layer.



**FIGURE A-4:**  $V_{DD}/2$  Filter Section – Bottom Metal Layer.

## A.3 ACTIVE FILTER SECTION (SUB-ASSEMBLY #: 102-00097R1)

### A.3.1 Circuit

See Figure A-5 for the  $V_{DD}/2$  Filter Sections circuit diagram. The input and output headers (J1, J2, P1, and P2) allow the PCBs to be cascaded as needed. The filter order will determine how many of these boards need to be cascaded.

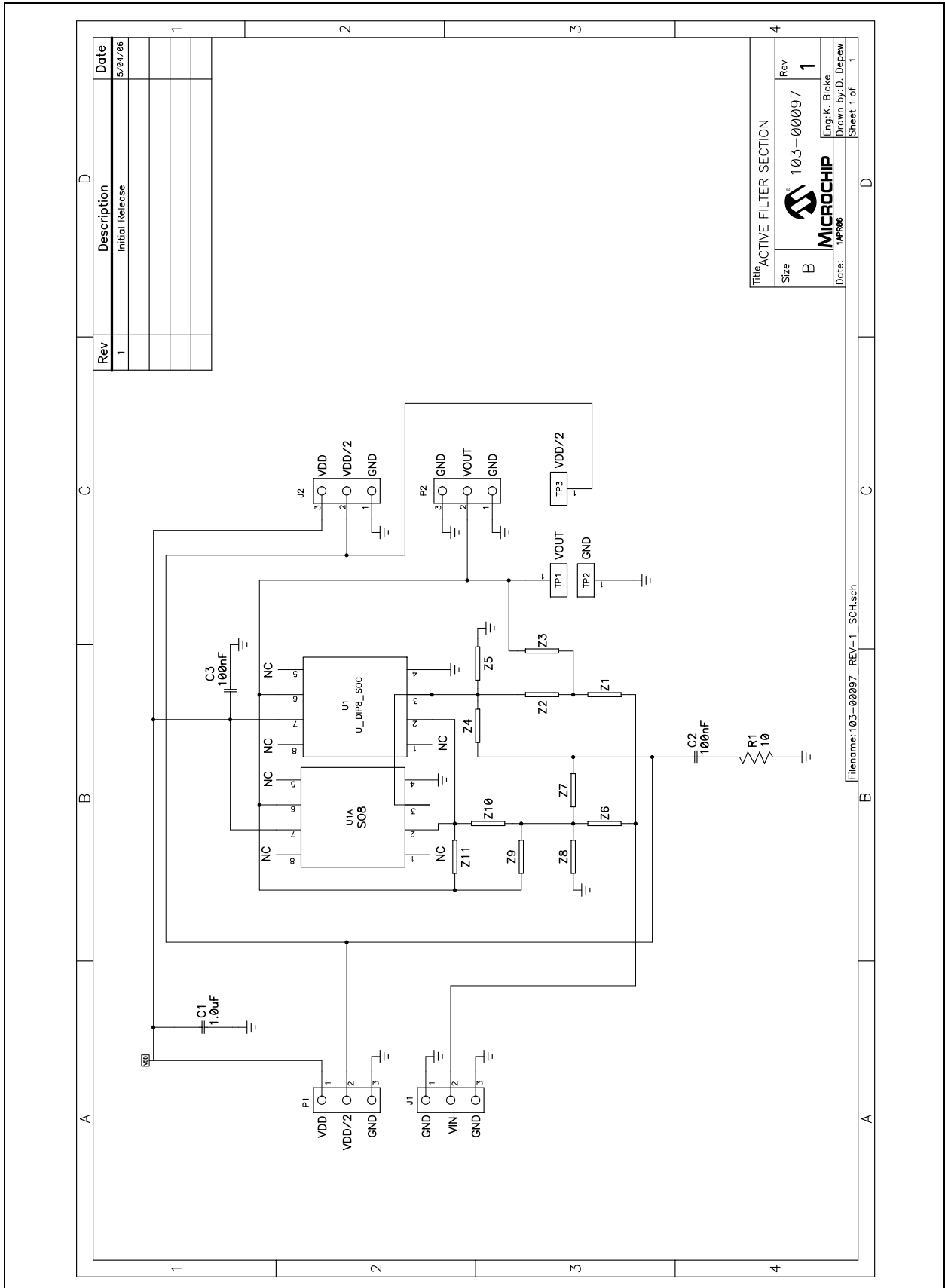
The impedances Z1 to Z11 are realized as resistors, capacitors, shorts or open circuits, depending on the section topology. These components are placed in pin sockets.

Op amp U1 interacts with the impedances Z1 to Z11 to form an active filter section (one or two pole). Op amp U1 is usually a single, PDIP-8 part inserted into the DIP-8 socket; it can be a SOIC-8 that is soldered to the board (see U1A in Figure A-5).

C1 and C3 are bypass capacitors for  $V_{DD}$ . C2 is a bypass capacitor for  $V_{DD}/2$ , and R1 is a snubber resistor that helps prevent capacitive loading problems for the op amp on the  $V_{DD}/2$  Filter Section.

The demonstration board includes test points for convenience on the bench. TP1 through TP3 make it possible to measure the output voltage of each filter section.

See **Section B.1 “ $V_{DD}/2$  Filter Section BOMs”** for the Bill of Material for this kit.

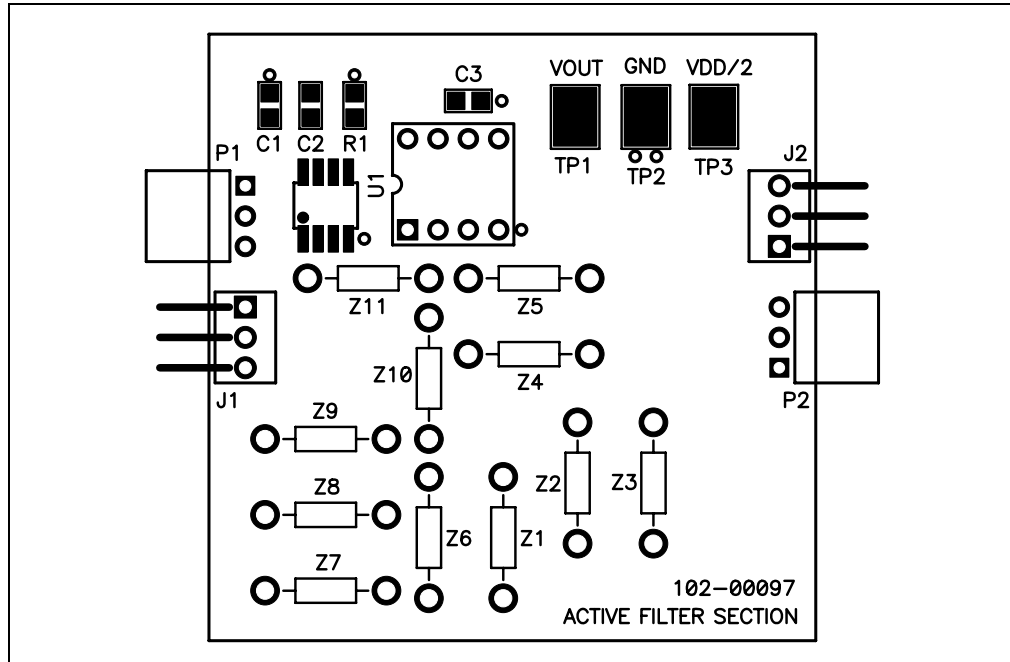


**FIGURE A-5:** Active Filter Section – Schematic.

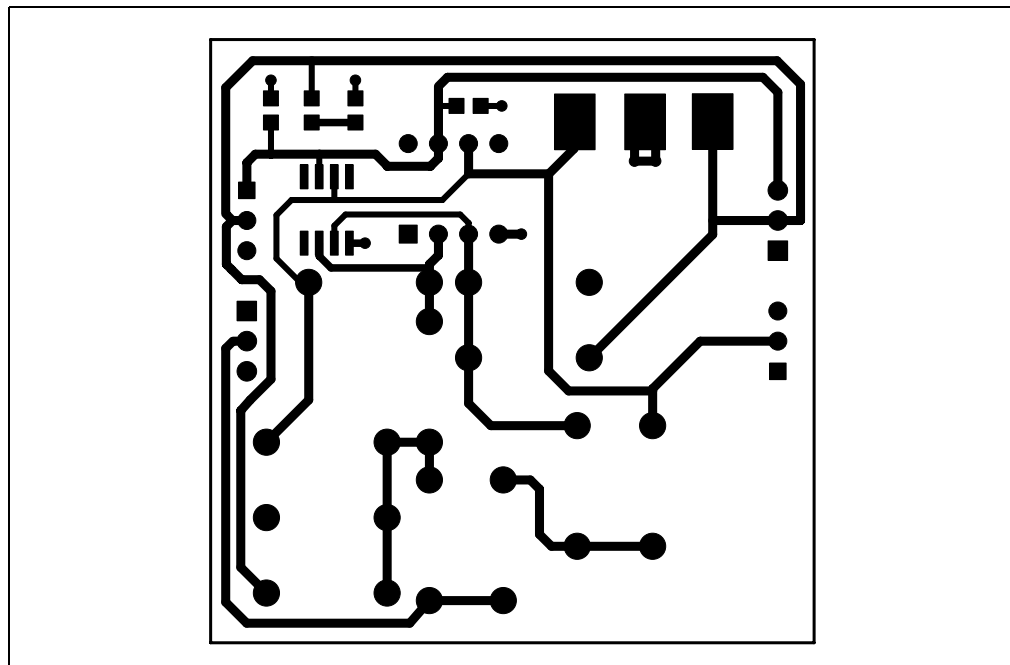
# Active Filter Demo Board Kit User's Guide

## A.3.2 Board Plots

The Gerber files for this board are available on the Microchip website ([www.microchip.com](http://www.microchip.com)) and are contained in the zip file "00097R1 Gerbers.zip".

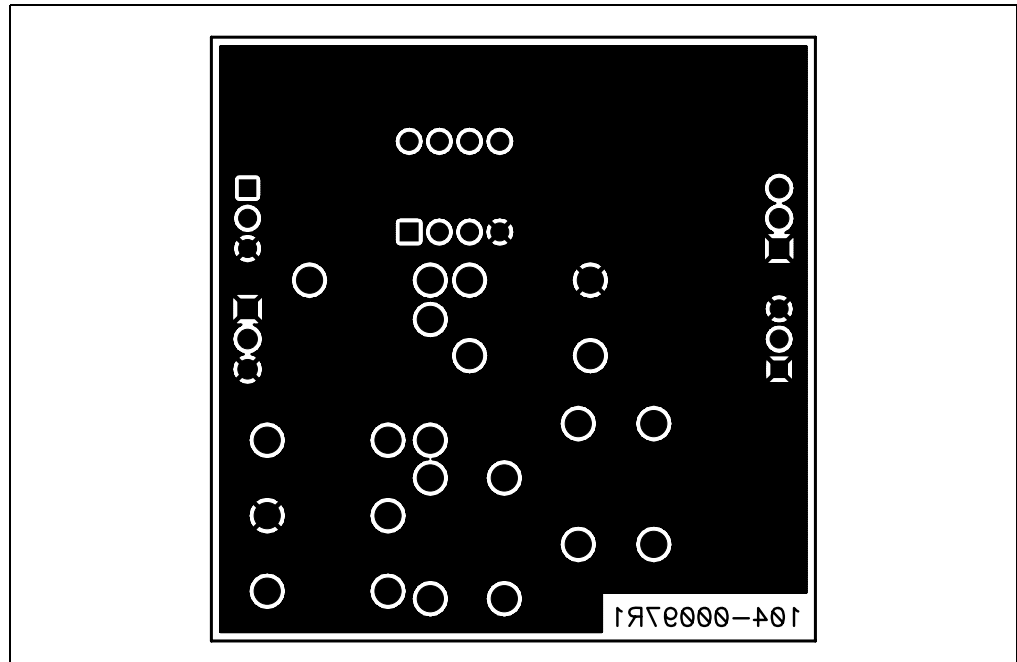


**FIGURE A-6:** Active Filter Section – Top Silk-Screen.



**FIGURE A-7:** Active Filter Section – Top Metal Layer.





**FIGURE A-8:** Active Filter Section – Bottom Metal Layer.

## A.4 ACCESSORY BAG (SUB-ASSEMBLY #: 110-00097R1)

See Figure 3-1 for the circuit diagram supported by this Accessory Bag. This filter is a Bessel low-pass with  $n = 5$ ,  $f_c = 100$  Hz, and Gain = 1 V/V. It uses single supply, Sallen-Key sections.

See **Section B.3 “Accessory Bag BOM”** for the Bill of Material for this filter. These components are placed in an ESD separate ESD bag. The Accessory Bag includes more MCP6271 op amps than needed for Figure 3-1; there are enough to populate all of the DIP-8 sockets in the Active Filter Demo Board Kit. These op amps are included in the accessory bag for ESD protection.

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NOTES:

## Appendix B. Bill Of Materials (BOM)

### B.1 $V_{DD}/2$ FILTER SECTION BOMS

The BOM in Table B-1 corresponds to Figure 2-2. Unpopulated parts are in Table B-2.

**TABLE B-1: BILL OF MATERIALS (102-00098R1)**

Qty	Reference	Description	Manufacturer	Part Number
2	C <sub>3</sub> , C <sub>4</sub>	100 nF, 50V, 10%, X7R, 0805 SMD, Ceramic	Kemet <sup>®</sup> Electronics	C0805C104K5RACTU
2	C <sub>1</sub> , C <sub>2</sub>	1.0 $\mu$ F, 16V, 10%, X7R, 0805 SMD, Ceramic	Kemet Electronics	C0805C105K4RACTU
1	JP <sub>1</sub>	Header, 2 × 2, 0.100" Pitch, Vertical, Gold	Amp <sup>®</sup> /Tyco <sup>®</sup> Electronics	87227-2
1	(for JP <sub>1</sub> )	Shunt, 1 × 2, With Handle, Gold	AMP/Tyco Electronics	881545-2
1	J <sub>2</sub>	Header, Male, 1 × 3, 0.100", R/A, Tin	AMP/Tyco Electronics	640453-3
1	P <sub>2</sub>	Header, Female, 1 × 3, 0.100", R/A, Tin	Mill-Max <sup>®</sup>	801-44-003-20-001000
2	R <sub>1</sub> , R <sub>2</sub>	20.0 k $\Omega$ , 1/8W, 1%, 0805 SMD	Yageo <sup>®</sup> America	RC0805FR-0720KL
5	TP <sub>1</sub> – TP <sub>5</sub>	PC Test Point, Compact, Surface Mount	Keystone Electronics	5016
1	(for U <sub>1</sub> )	IC Socket, 8-pin DIP, Tin, 0.300"	AMP/Tyco Electronics	2-641260-1
1	PCB	RoHS Compliant Bare PCB, $V_{DD}/2$ Filter Section (1.0 in × 2.0 in)	—	104-00098R1

**Note 1:** The components listed in this Bill of Materials are representative of the PCB assembly. The released BOM used in manufacturing uses all RoHS-compliant components.

**TABLE B-2: BILL OF MATERIALS – UNPOPULATED PARTS (102-00098R1)**

Reference	Description	Manufacturer	Part Number
J <sub>1</sub>	Header, Male, 1 × 3, 0.100", R/A, Tin ( <b>Note 1</b> )	AMP/Tyco Electronics	640453-3
P <sub>1</sub>	Header, Female, 1 × 3, 0.100", R/A, Tin ( <b>Note 1</b> )	Mill-Max <sup>®</sup>	801-44-003-20-001000
U <sub>1</sub>	MCP6271, Single Op Amp, 2 MHz, PDIP-8 ( <b>Note 2</b> )	Microchip Technology Inc	MCP6271-E/P
	SOIC-8 ( <b>Note 3</b> )	Microchip Technology Inc	MCP6271-E/SN

**Note 1:** These parts are supplied by the user, if desired.

**2:** This op amp is supplied by Microchip; it is found in the Accessory Bag described in Table B-5. Any other op amp is supplied by the user.

**3:** Op amps in SOIC-8 package are supplied by the user, if desired. See "4.6 Using 8-Pin SOIC Op Amps" for information on using op amps in these packages (150 mil wide).

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## B.2 ACTIVE FILTER SECTION BOM

The BOM in Table B-3 corresponds to the circuit in Figure 2-4, which is repeated four times. Unpopulated parts are in Table B-4.

**TABLE B-3: BILL OF MATERIALS (102-00097R1) (NOTE 3)**

Qty (Note 1)	Reference	Description	Manufacturer	Part Number
8	C <sub>2</sub> , C <sub>3</sub>	100 nF, 50V, 10%, X7R, 0805 SMD, Ceramic	Kemet Electronics	C0805C104K5RACTU
4	C <sub>1</sub>	1.0 µF, 16V, 10%, X7R, 0805 SMD, Ceramic	Kemet Electronics	C0805C105K4RACTU
8	J <sub>1</sub> , J <sub>2</sub>	Header, Male, 1 × 3, 0.100", R/A, Tin	AMP/Tyco Electronics	640453-3
8	P <sub>1</sub> , P <sub>2</sub>	Header, Female, 1 × 3, 0.100", R/A, Tin	Mill-Max <sup>®</sup>	801-44-003-20-001000
4	R <sub>1</sub>	10.0Ω, 1/8W, 1%, 0805 SMD	Yageo America	RC0805FR-0710RL
12	TP <sub>1</sub> – TP <sub>3</sub>	PC Test Point, Compact, Surface Mount	Keystone Electronics	5016
4	(for U <sub>1</sub> )	IC Socket, 8-pin DIP, Tin, 0.300"	AMP/Tyco-Electronics	2-641260-1
88	(for Z <sub>1</sub> to Z <sub>11</sub> )	Pin Recepticle, 0.015" to 0.025" dia., 0.057" hole dia.	Mill-Max <sup>®</sup> (Note 2)	0252-0-15-15-30-27-10-0
4	PCB	RoHS Compliant Bare PCB, Active Filter Section (2.0 in × 2.0 in)	—	104-00097R1

- Note 1:** The quantities per board all have been multiplied by 4 because there are four Active Filter Section PCB's (sub-assembly) in the Active Filter Demo Board Kit (assembly).
- 2:** This part is also found at Digi-Key (ED90069-ND).
- 3:** The components listed in this Bill of Materials are representative of the PCB assembly. The released BOM used in manufacturing uses all RoHS-compliant components.

**TABLE B-4: BILL OF MATERIALS – UNPOPULATED PARTS (102-00097R1)**

Reference	Description	Manufacturer	Part Number
U <sub>1</sub>	MCP6271, Single Op Amp, 2 MHz, PDIP-8 (Note 1)	Microchip Technology Inc	MCP6271-E/P
	SOIC-8 (Note 2)	Microchip Technology Inc	MCP6271-E/SN
Z <sub>1</sub> – Z <sub>11</sub>	Impedances (resistors and capacitors) (Note 3)	—	—

- Note 1:** These op amps are supplied by Microchip; they are found in the Accessory Bag described in Table B-5. Other op amps are supplied by the user.
- 2:** Op amps in SOIC-8 package are supplied by the user, if desired. See "4.6 Using 8-Pin SOIC Op Amps" for information on using op amps in these packages (150 mil wide).
- 3:** The resistors and capacitors represented by Z<sub>1</sub> to Z<sub>11</sub> are provided by the customer. Not all of these will be populated for any given filter. The Accessory Bag described in Table B-5 includes 10 jumpers that can be used to configure different filter circuits.

## B.3 ACCESSORY BAG BOM

The BOM in Table B-5 corresponds to the collection of resistors, capacitors, and MCP6271 op amps that comes in the Accessory Bag which is shipped in the Active Filter Demo Board Kit. It includes enough op amps and jumpers to support any reasonable filter design. It also supports the circuit in "Chapter 3. "Building the Filter Supplied in the Kit". Other filters may need tighter tolerance resistors and capacitors (i.e., 1% or 2%). The customer provides the resistors and capacitors for any other filter circuit.

**TABLE B-5: BILL OF MATERIALS (110-00097R1)**

Qty	Reference	Description	Manufacturer	Part Number
3	C11, C22, C32	100 nF, 50V, 5%, Radial, Polyester Film	Panasonic	ECQ-B1H104JF
1	C31	150 nF, 50V, 5%, Radial, Polyester Film	Panasonic	ECQ-B1H154JF
1	C21	390 nF, 50V, 5%, Radial, Polyester Film	Panasonic	ECQ-B1H394JF
10	—	Jumper Wire, 0 $\Omega$ , Axial 1/8W Resistor" ( <b>Note 1</b> )	Yageo America	ZOR-12-B-52
1	R21	3.16 k $\Omega$ , 1/4W, 1%, Axial, Metal Film	Yageo America	MFR-25FBF-3K16
1	R31	5.62 k $\Omega$ , 1/4W, 1%, Axial, Metal Film	Yageo America	MFR-25FBF-5K62
1	R22	6.81 k $\Omega$ , 1/4W, 1%, Axial, Metal Film	Yageo America	MFR-25FBF-6K81
1	R11	10.7 k $\Omega$ , 1/4W, 1%, Axial, Metal Film	Yageo America	MFR-25FBF-10K7
1	R32	12.7 k $\Omega$ , 1/4W, 1%, Axial, Metal Film	Yageo America	MFR-25FBF-12K7
5	U <sub>1</sub>	MCP6271, Single Op Amp, 2 MHz, PDIP-8 ( <b>Note 2</b> )	Microchip Technology Inc	MCP6271-E/P

**Note 1:** Four of these "resistors" (jumpers) are used for shorting the feedback resistors ( $Z_1$  on 3 PCBs), and for shorting  $Z_{11}$  on the SK-LP1 stage (see Table 3-1), for the filter in "Chapter 3. "Building the Filter Supplied in the Kit". A total of ten is included because this is the maximum that might be needed for any FilterLab design, plus two spares.

**2:** These five op amps are placed in ESD protective "clam shells," which are then put into an ESD protective bag with the resistors and capacitors.



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