



FilterLab[®] 2.0

User's Guide

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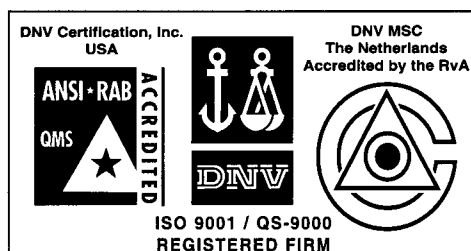
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General Information

INTRODUCTION

FilterLab® 2.0 is an innovative software tool that simplifies active filter design. Available at no cost from Microchip's web site (www.microchip.com), the FilterLab 2.0 active filter software design tool provides full schematic diagrams of the filter circuit with recommended component values and displays the frequency response.

FilterLab 2.0 allows the design of low-pass filters up to an 8th order filter with Chebyshev, Bessel or Butterworth responses from frequencies of 0.1 Hz to 1 MHz. FilterLab 2.0 also can be used to design band-pass and high-pass filters with Chebyshev and Butterworth responses. The circuit topologies supported by FilterLab 2.0 are the Sallen Key and Multiple Feedback (MFB). The low-pass filters can use either the Sallen Key or MFB, the band-pass is available with the MFB and the high-pass uses the Sallen Key.

Users can select a flat pass band or sharp transition from pass band to stopband. Options (such as minimum ripple factor, sharp transition and linear phase delay) are available. Once the filter response has been identified, FilterLab 2.0 generates the frequency response and the circuit. For maximum design flexibility, changes in capacitor values can be implemented to fit the demands of the application. FilterLab 2.0 will recalculate all values to meet the desired response, allowing real-world values to be substituted or changed as part of the design process.

FilterLab 2.0 also generates a SPICE model of the designed filter. Extraction of this model will allow time domain analysis in SPICE simulations, streamlining the design process.

Further consideration is given to designs used in conjunction with an Analog-to-Digital Converter (ADC). A suggested filter can be generated by simply inputting the bit resolution and sample rate via the Anti-Aliasing Wizard. This eliminates erroneous signals folded back into the digital data due to the aliasing effect.

This section also covers the following topics:

- About This Guide
- The Microchip Internet Web Site
- Customer Support

ABOUT THIS GUIDE

Document Layout

The User's Guide layout is as follows:

- **General Information** – this section describes how to use the FilterLab® 2.0 User's Guide.
- **Chapter 1: Dialog Boxes** – this section describes the dialog boxes and their uses.
- **Chapter 2: Wizards** – this section describes the Filter Selection Wizard and helps you design a filter.
- **Chapter 3: Toolbars** – this section describes the toolbars and their functions.
- **Chapter 4: Menus** – this section describes the menus and their functions.
- **Chapter 5: Window Views** – this section describes the window views and how they are used.
- **Worldwide Sales and Service** – this section gives the address, telephone and fax number for Microchip Technology Inc. sales and service locations throughout the world.

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FilterLab® 2.0 User's Guide

NOTES:

Chapter 1. Dialog Boxes

1.1 DIALOG BOXES

1.1.1 Filter Design Dialog

The *Filter Design* dialog enables the user to create a filter by specifying all aspects of the filter.

1.1.2 Filter Specification Tab

The *Filter Specification* tab enables the user to specify the approximation type, the selectivity and the gain. Select any approximation, the selectivity for the approximation and the overall filter gain. The maximum allowed gain is 10 V/V. After specifying the approximation, selectivity and gain, select *OK* or the *Filter Parameters* tab.

Note: *Bessel* approximations only support low-pass selectivities. Therefore, when the *Bessel* approximation is selected, the only available selectivity will be low-pass.

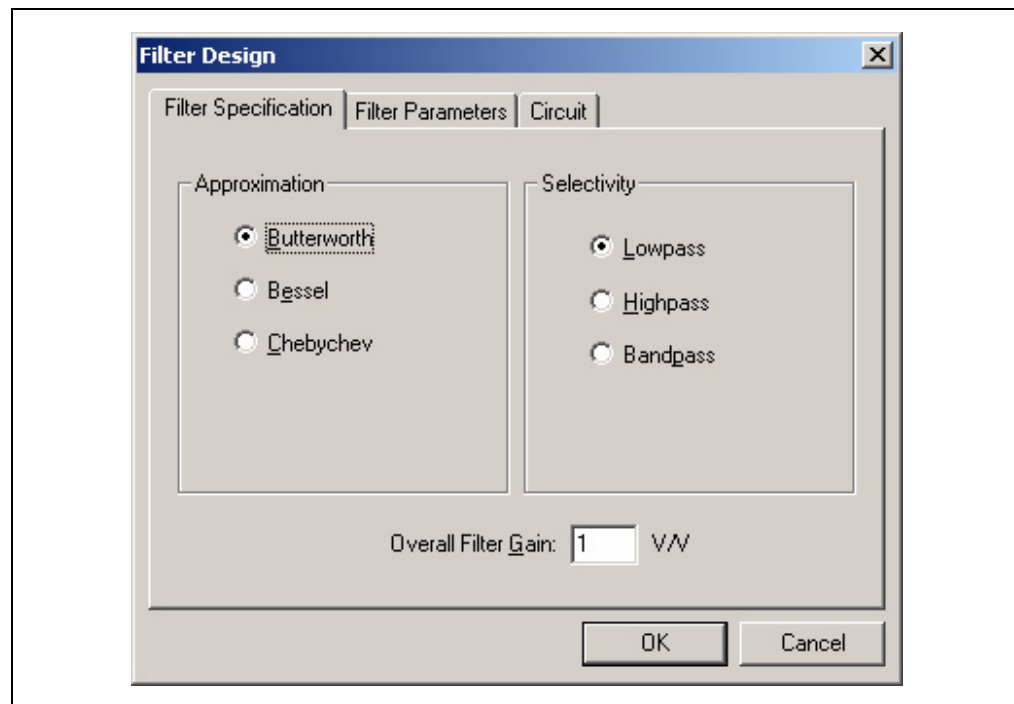


FIGURE 1-1: *Filter Specification Tab*

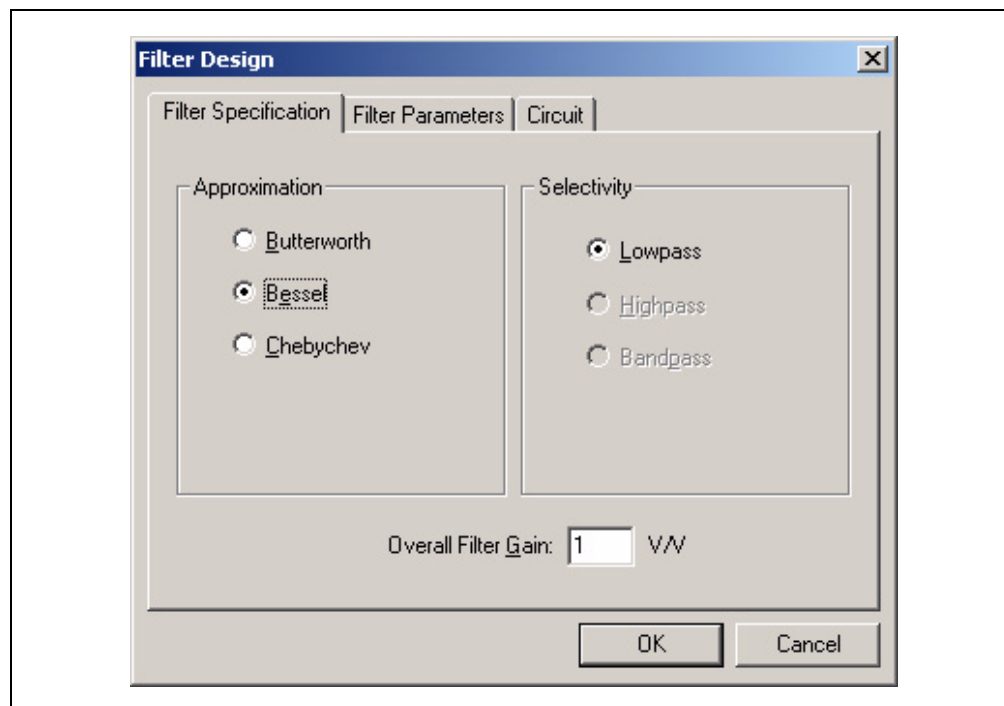


FIGURE 1-2: Filter Specification Tab with Bessel Selected

1.1.3 Filter Parameters Tab

Figures 1-4, 1-5 and 1-6 demonstrate the location of the pass band and stop band upper and lower frequencies. For all selectivities, a_{pass} and a_{stop} represent the pass band and stop band attenuations. For low-pass selectivities (Figure 1-4), f_{pass} and f_{stop} represent the pass band and stop band frequencies. For high-pass selectivities (Figure 1-5), f_{pass} and f_{stop} represent the pass band and stop band frequencies. For low-pass selectivities (Figure 1-6), f_{pass} upper and f_{pass} lower represent the pass band and upper and lower frequencies, while f_{stop} upper and f_{stop} lower represent the stop band and upper and lower frequencies.

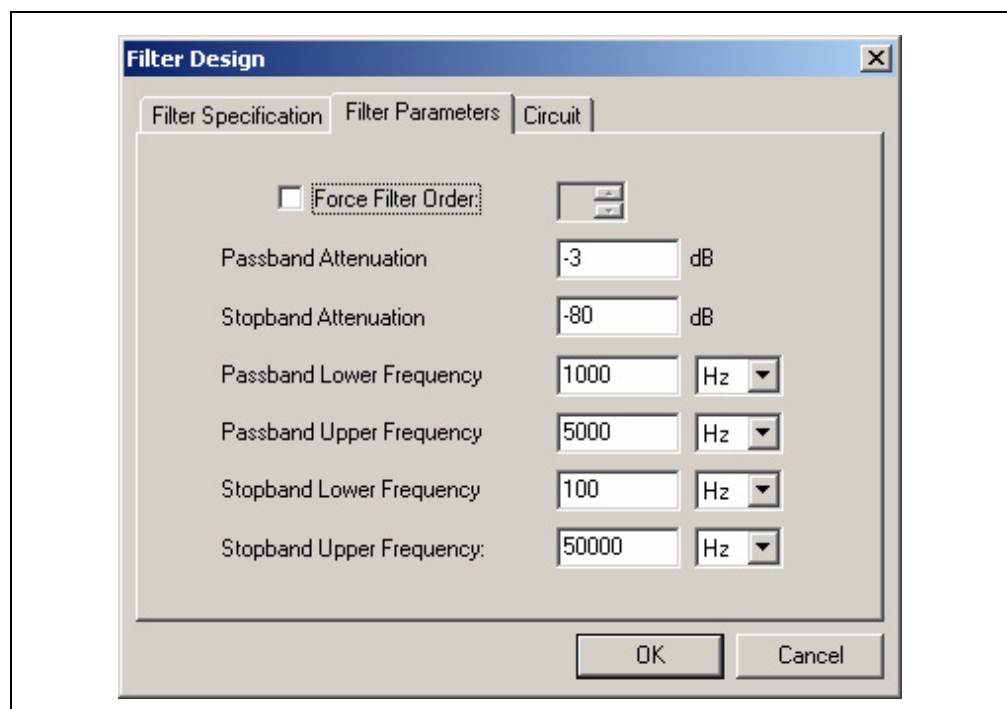


FIGURE 1-3: Filter Parameters Tab

The *Filter Parameters* tab enables the user to modify the filter's parameters. Figures 1-4, 1-5 and 1-6 provide a simplified representation of the filter specification parameters. A detailed discussion of the filter specification is provided in **Appendix B, "Filter Magnitude Templates"**.

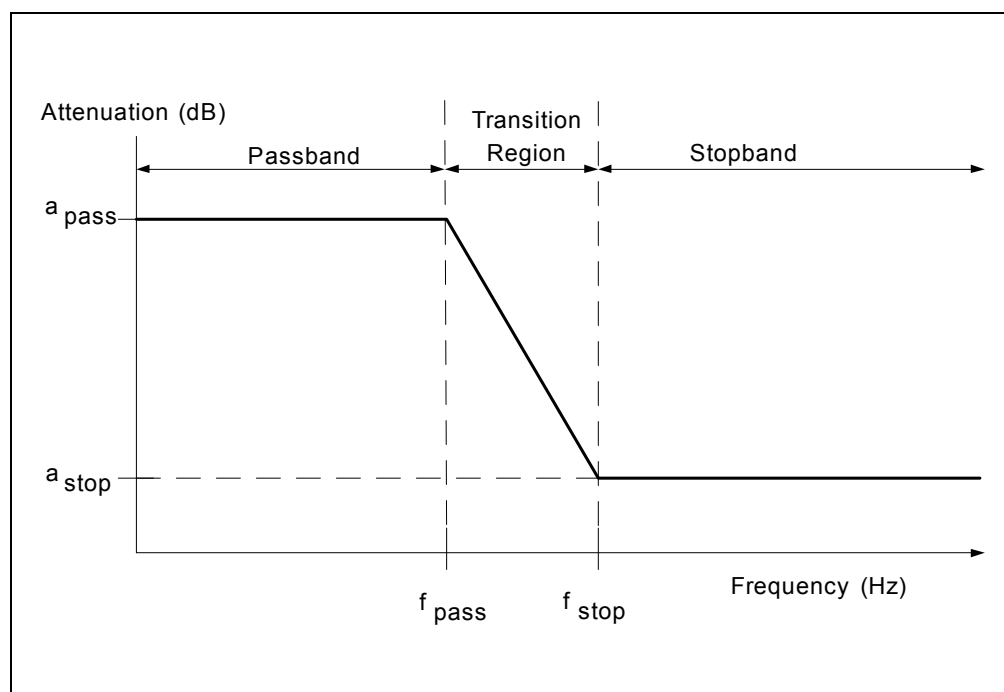


FIGURE 1-4: Parameter Definitions for Low-pass Selectivity

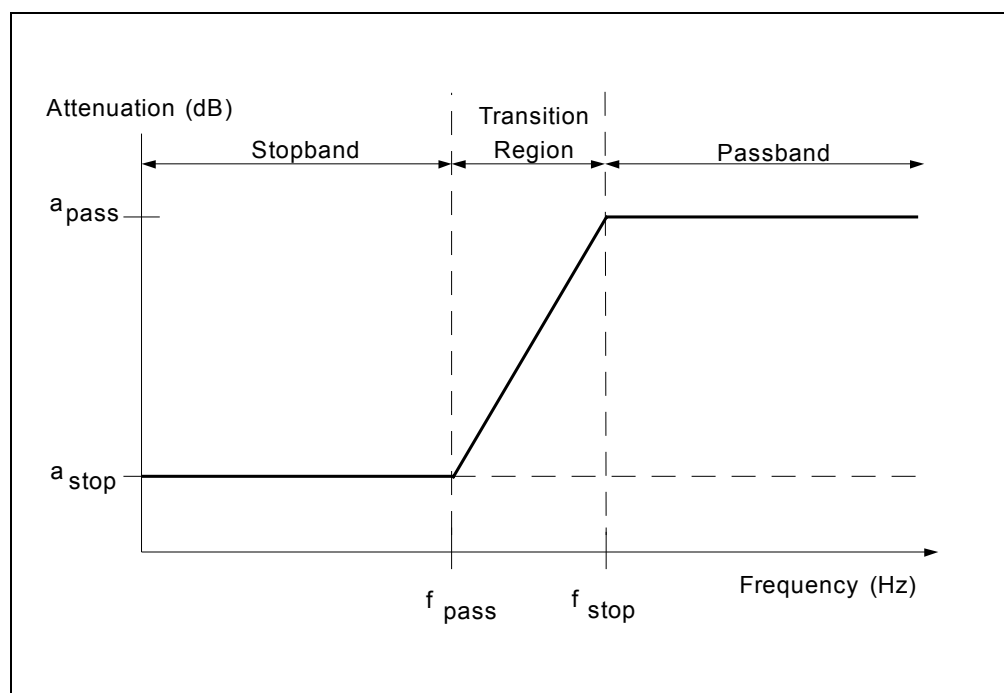


FIGURE 1-5: Parameter Definitions for High-pass Selectivity

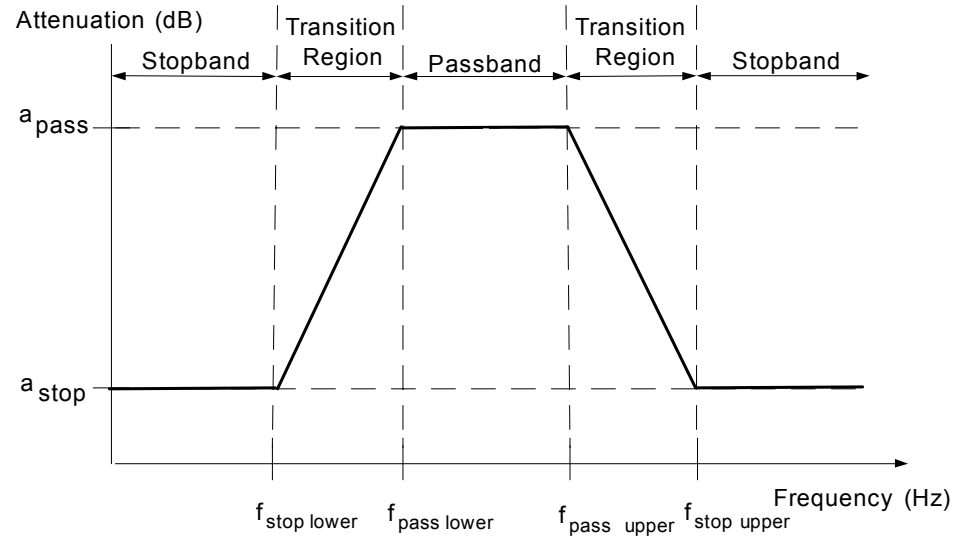


FIGURE 1-6: Parameter Definitions for Band-pass Selectivity

1.1.3.1 FILTER ORDER

The *Force Filter Order* option enables the user to specify the filter order or have the program calculate the filter order based on the dialog entries. To force the filter order, select the *Force Filter Order* checkbox. When the checkbox is selected, the user specifies the *Pass Band Attenuation* and the *Pass Band* frequencies. FilterLab 2.0 then calculates the *Stop Band Attenuation* and *Stop Band* frequencies based on the order. When the checkbox is not selected, the user specifies the attenuation and all frequency values. FilterLab 2.0 then calculates the order based on the attenuation and frequency values.

Note: Bessel approximations only support forced filter orders. When the Bessel approximation is selected, the Force Filter Order checkbox will be checked and disabled.

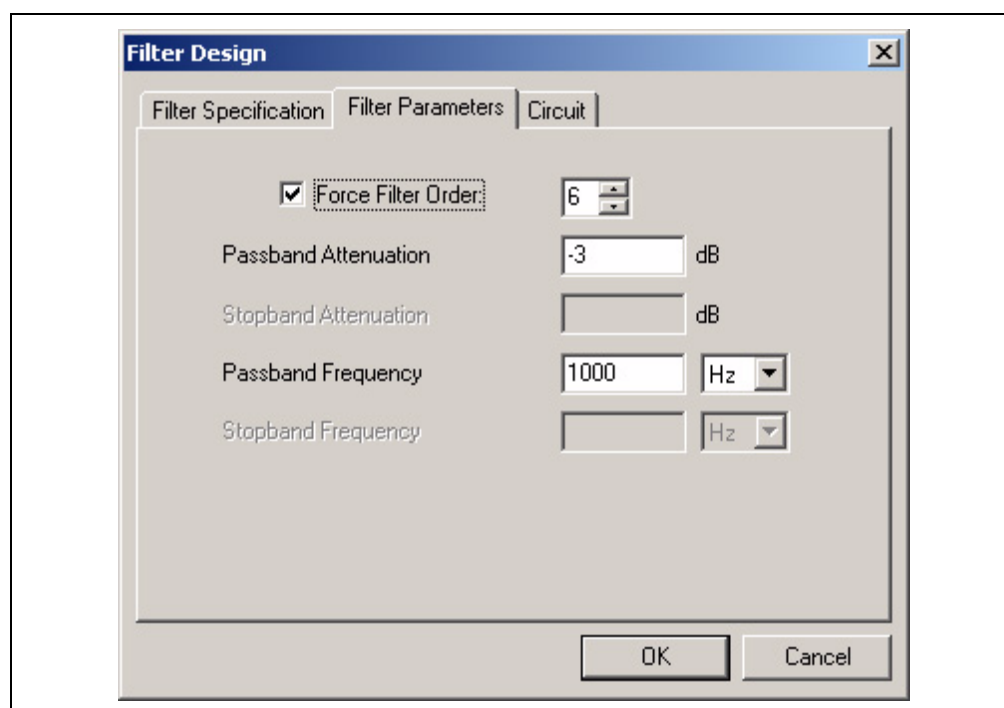


FIGURE 1-7: Filter Parameters Tab with Force Filter Order Selected

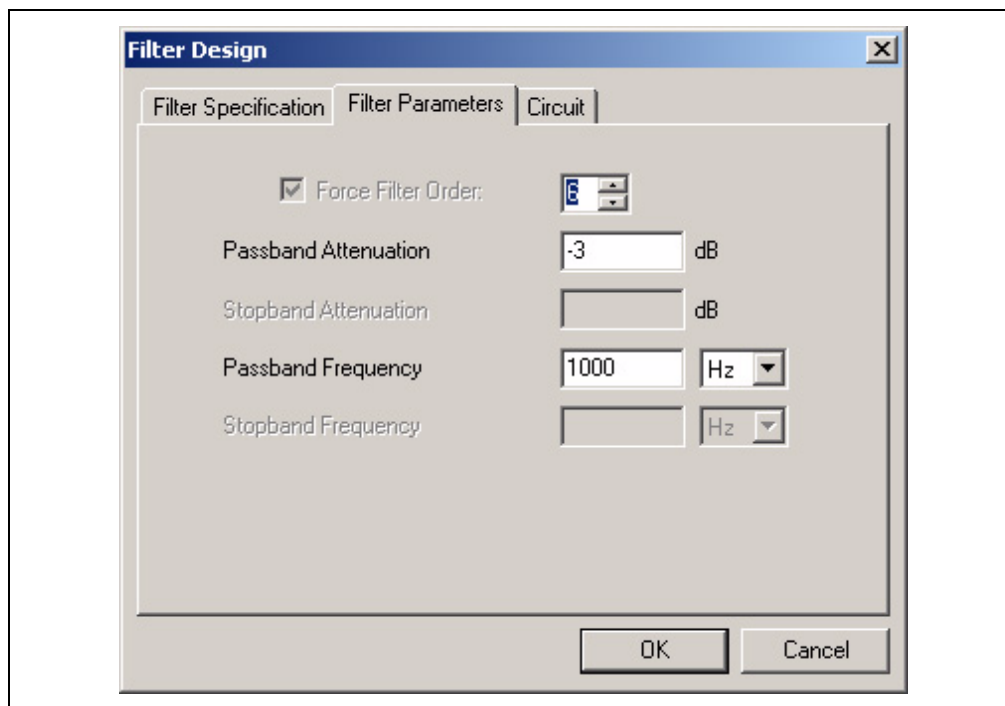


FIGURE 1-8: Filter Parameters Tab with Bessel Approximation Selected

1.1.3.2 PASS BAND ATTENUATION

The *Pass Band Attenuation* is the change in magnitude of the frequencies in the pass band. The *Pass Band Attenuation* for each selectivity (low-pass, high-pass, band-pass) is shown in Figures 1-4, 1-5 and 1-6. The allowable range is -0.01 dB to -3 dB. If a value beyond this range is entered in the *Filter Parameters* tab, the error message shown in Figure 1-9 will appear.

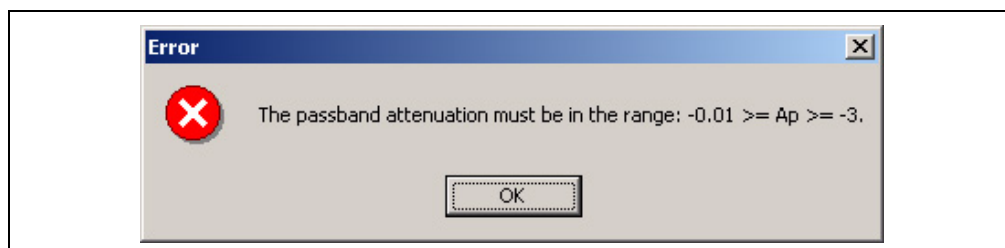


FIGURE 1-9: Error Message

1.1.3.3 STOP BAND ATTENUATION

The *Stop Band Attenuation* is the minimum reduction in magnitude of the frequencies in the stop band relative to the pass band. The *Stop Band Attenuation* for each selectivity is shown in Figures 1-4, 1-5 and 1-6. The allowable range is -10 dB to -100 dB. If a value beyond this range is entered in the *Filter Parameters* tab, the error message shown in Figure 1-10 will appear.

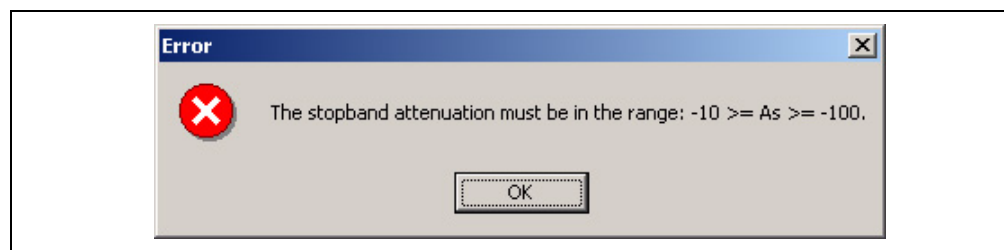


FIGURE 1-10: Error Message

1.1.3.4 PASS BAND FREQUENCY

The *Pass Band Frequency* is the starting point of the pass band, as shown in Figures 1-4, 1-5 and 1-6. The allowable range is 0.1 Hz to 1,000,000 Hz. If a value beyond this range is entered in the *Filter Parameters* tab, the error message shown in Figure 1-11 will appear.

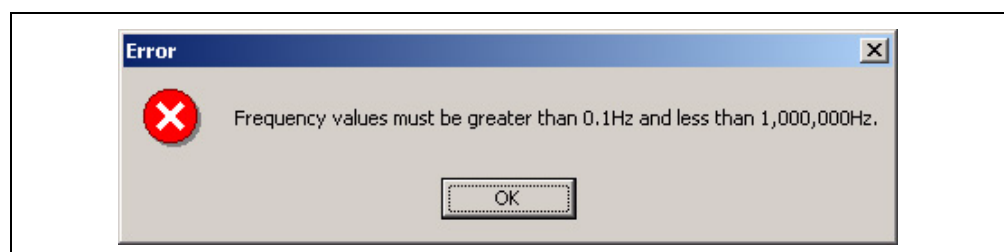


FIGURE 1-11: Error Message

1.1.3.4.1 Low-pass

The *Pass Band Frequency* must be lower than the *Stop Band Frequency* for low-pass filters. If a value is entered in the *Filter Parameters* tab which is larger than the *Stop Band Frequency*, the error message shown in Figure 1-12 will appear.

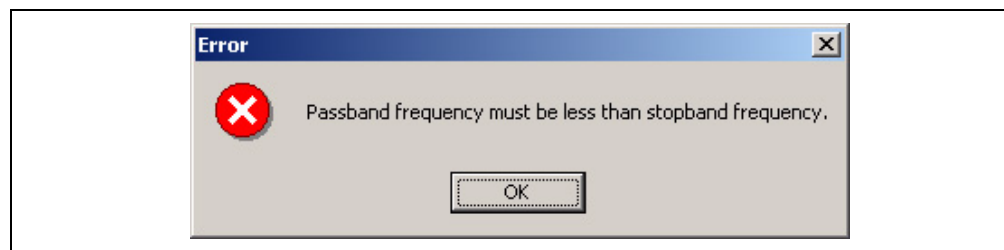


FIGURE 1-12: Error Message

1.1.3.4.2 High-pass

The *Pass Band Frequency* must be greater than the *Stop Band Frequency* for high-pass selectivities. If a value is entered in the *Filter Parameters* tab that is smaller than the *Stop Band Frequency*, the error message shown in Figure 1-13 will appear.

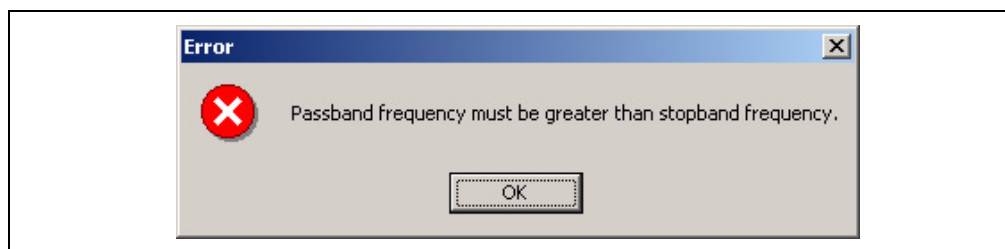


FIGURE 1-13: Error Message

1.1.3.4.3 Band-pass

The *Pass Band Lower Frequency* must be lower than the *Pass Band Upper Frequency* and both *Stop Band Frequencies* for band-pass selectivities. If a value is entered in the *Filter Parameters* tab that is greater than the *Stop Band Frequency* or *Pass Band Upper Frequency*, the error message shown in Figures 1-14 and 1-15 will appear.

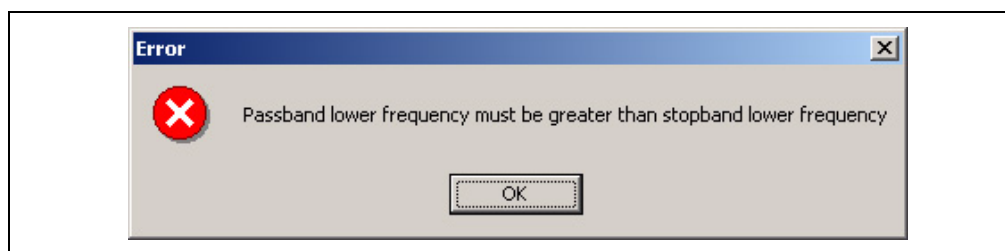


FIGURE 1-14: Error Message

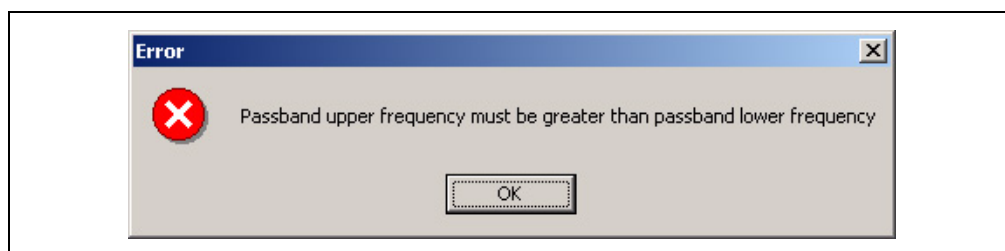


FIGURE 1-15: Error Message

1.1.3.5 STOP BAND FREQUENCY

The *Stop Band Frequency* is the starting point of the stop band, as shown in Figures 1-4, 1-5 and 1-6. The allowable range is 0.1 Hz to 1,000,000 Hz. If a value beyond this range is entered in the *Filter Parameters* tab, the error message shown in Figure 1-16 will appear.

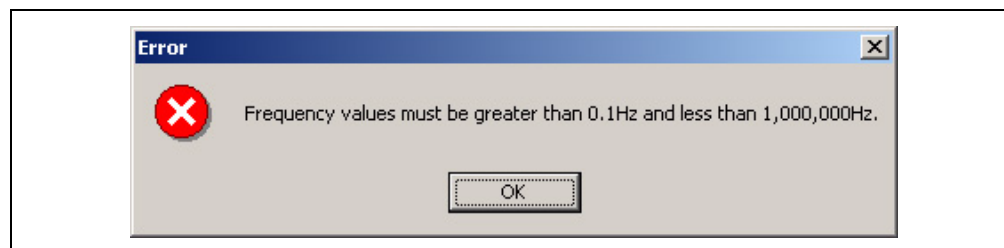


FIGURE 1-16: Error Message

1.1.3.5.4 Low-pass

The *Stop Band Frequency* must be greater than the *Pass Band Frequency* for low-pass selectivities. If a value is entered in the *Filter Parameters* tab that is smaller than the *Pass Band Frequency*, the error message shown in Figure 1-17 will appear.

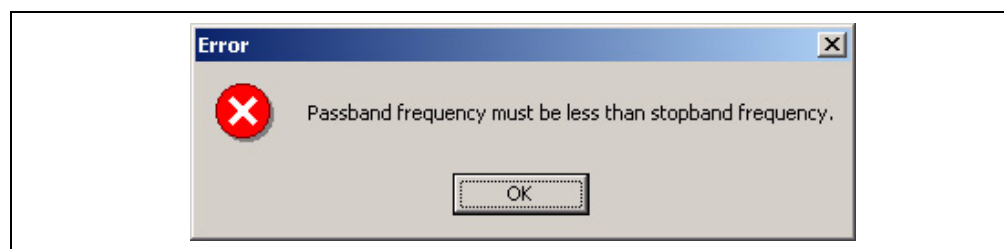


FIGURE 1-17: Error Message

1.1.3.5.5 High-pass

The *Pass Band Frequency* must be greater than the *Stop Band Frequency* for *High-pass* selectivities. If a value is entered in the *Filter Parameters* tab that is smaller than the *Stop Band Frequency*, the error message shown in Figure 1-18 will appear.

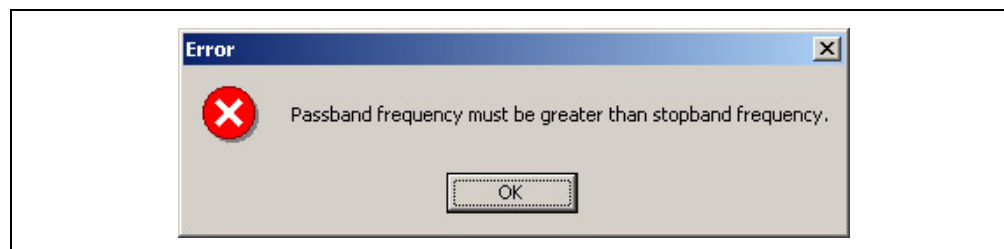


FIGURE 1-18: Error Message

1.1.3.5.6 Band-pass

The *Pass Band Lower Frequency* must be lower than the *Pass Band Upper Frequency* and both *Stop Band Frequencies* for band-pass selectivities. If a value is entered in the *Filter Parameters* tab that is greater than the *Stop Band Frequency* or *Pass Band Upper Frequency*, the error message shown in Figures 1-19 and 1-20 will appear.

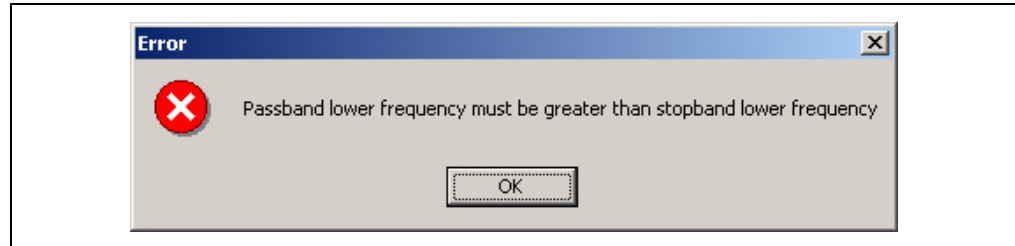


FIGURE 1-19: Error Message

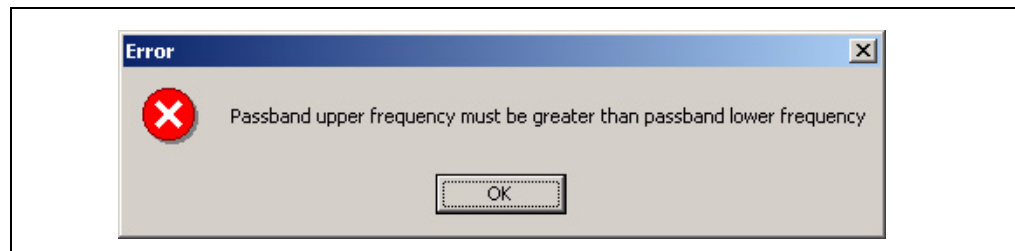


FIGURE 1-20: Error Message

1.1.4 Circuit Tab

The *Circuit* tab enables the user to modify the circuit topology and component values.

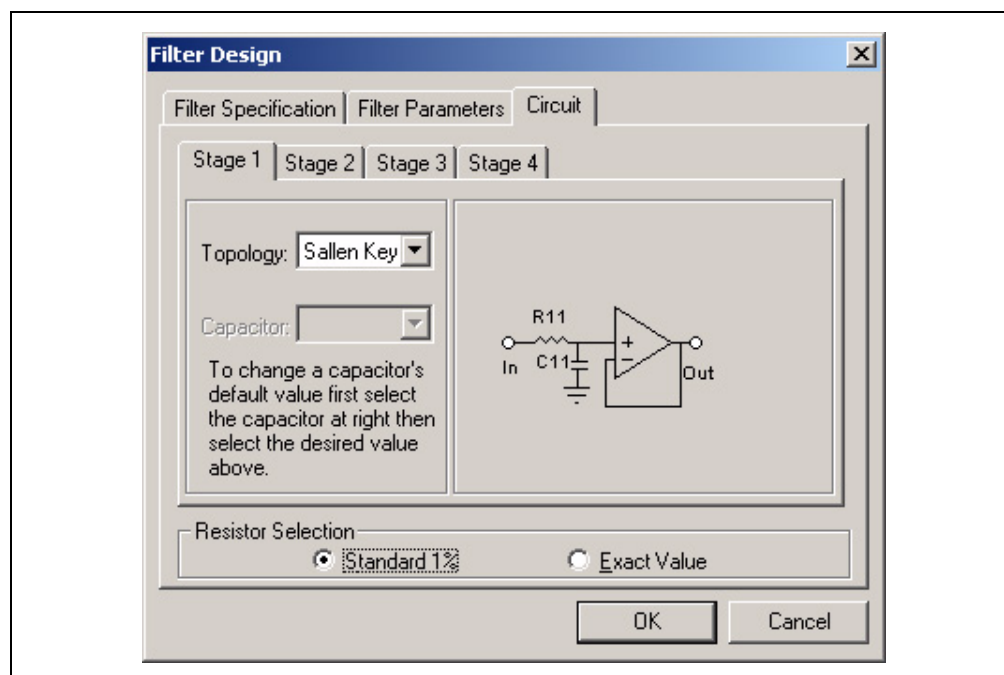


FIGURE 1-21: Circuit Tab

1.1.4.1 RESISTOR SELECTION

The *Resistor Selection* enables the user to change from standard 1% resistors to the exact calculated value. Changing the *Resistor Selection* affects all stages.

1.1.4.2 TOPOLOGY SELECTION

The *Topology Selection* enables the user to change the topology for *Low-pass* selectivities.

Note: Band-pass selectivities only support Multiple Feedback (MFB) topologies, while the high-pass selectivities only support Sallen Key topologies. Changing the topology only affects the stage for the active tab.

1.1.4.3 CAPACITOR SELECTION

The *Capacitor Selection* enables the user to change the value of a capacitor from the default value calculated by FilterLab 2.0. FilterLab 2.0 automatically scales the other resistors and capacitors of the filter section to maintain the desired filter specifications. Changing the capacitor value only affects the capacitor that is selected. The capacitor combo box is disabled unless a capacitor has been selected (Figure 1-21). To modify a capacitor's value, select the appropriate stage tab, then select the capacitor to be modified by left-clicking it with the mouse. When a capacitor is selected, it will be highlighted and the capacitor combo box will be enabled (Figure 1-22). Select "Automatic" from the combo box to automatically calculate the capacitor value. Select a value to force the capacitor to that value.

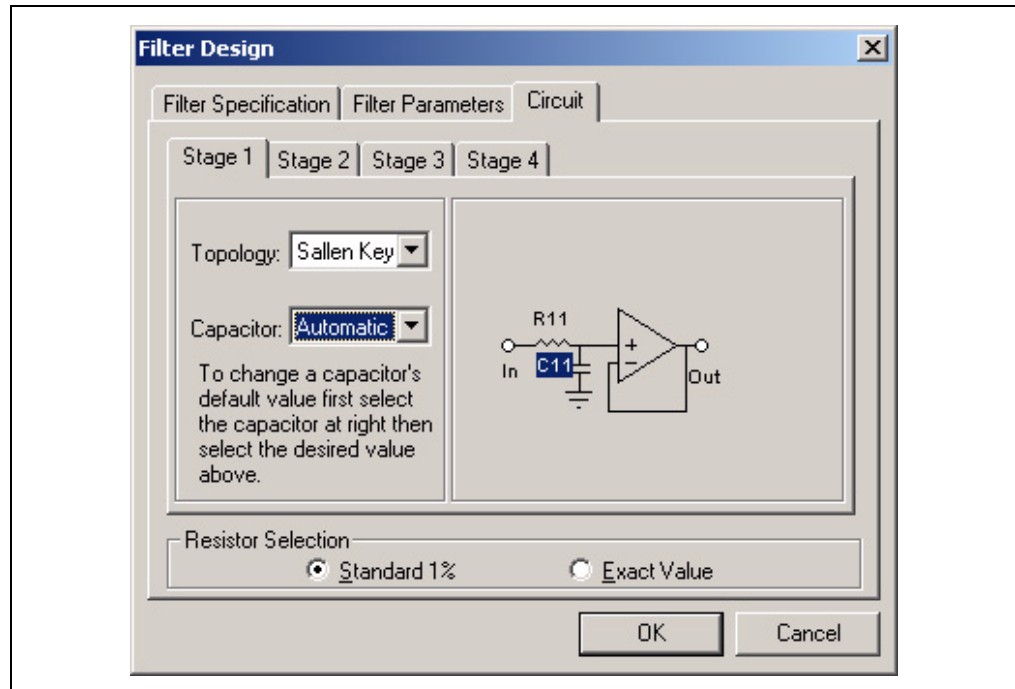


FIGURE 1-22: Capacitor Selected

1.1.5 Cancel

To cancel changes made to the *Specification*, *Parameters* or *Circuit* tabs, select *Cancel*.

1.1.6 OK

To implement changes made to the *Specification*, *Parameters* or *Circuit* tabs, select *OK*.

FilterLab® 2.0 User's Guide

NOTES:

Chapter 2. Wizards

2.1 ANTI-ALIASING WIZARD

The *Anti-Aliasing Wizard* assists the user in designing a low-pass filter used with an A/D converter. The wizard prompts the user for the bandwidth, the sampling frequency, the resolution and the signal-to-noise ratio of the A/D converter.



FIGURE 2-1: *Anti-Aliasing Wizard*

2.1.1 Anti-Aliasing Wizard Filter Bandwidth Page

The *Cut-off Frequency* (Figure 2-2) determines the bandwidth of the anti-aliasing filter. The frequency range is limited to values from 0.1 Hz to 1 MHz. If a value outside this range is entered, the error message shown in Figure 2-3 will appear.

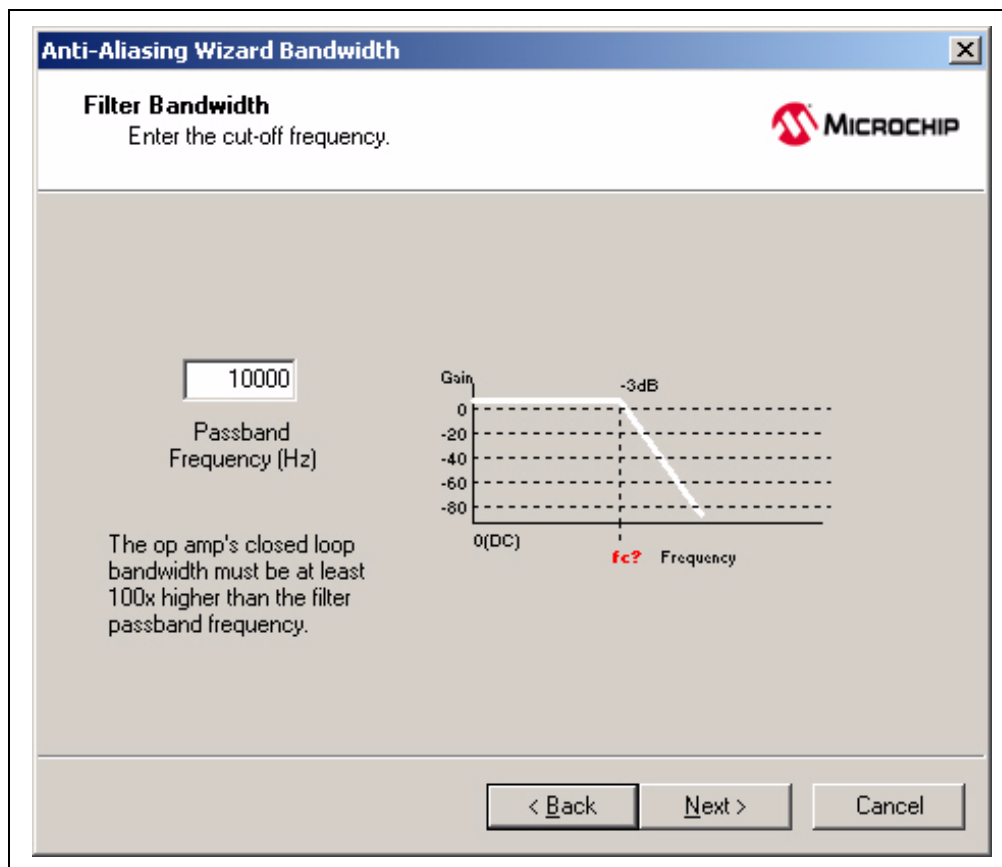


FIGURE 2-2: Filter Bandwidth

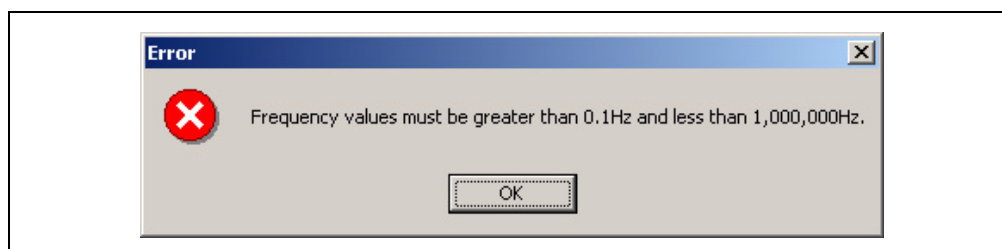


FIGURE 2-3: Error Message

2.1.2 Anti-Aliasing Wizard Sampling Frequency Page

Enter the *Sampling Frequency* of the A/D converter. The *Sampling Frequency* must be greater than $2 * \text{cut-off frequency}$. If a value which is less than $2 * \text{cut-off frequency}$ is entered, the error message shown in Figure 2-5 will appear.

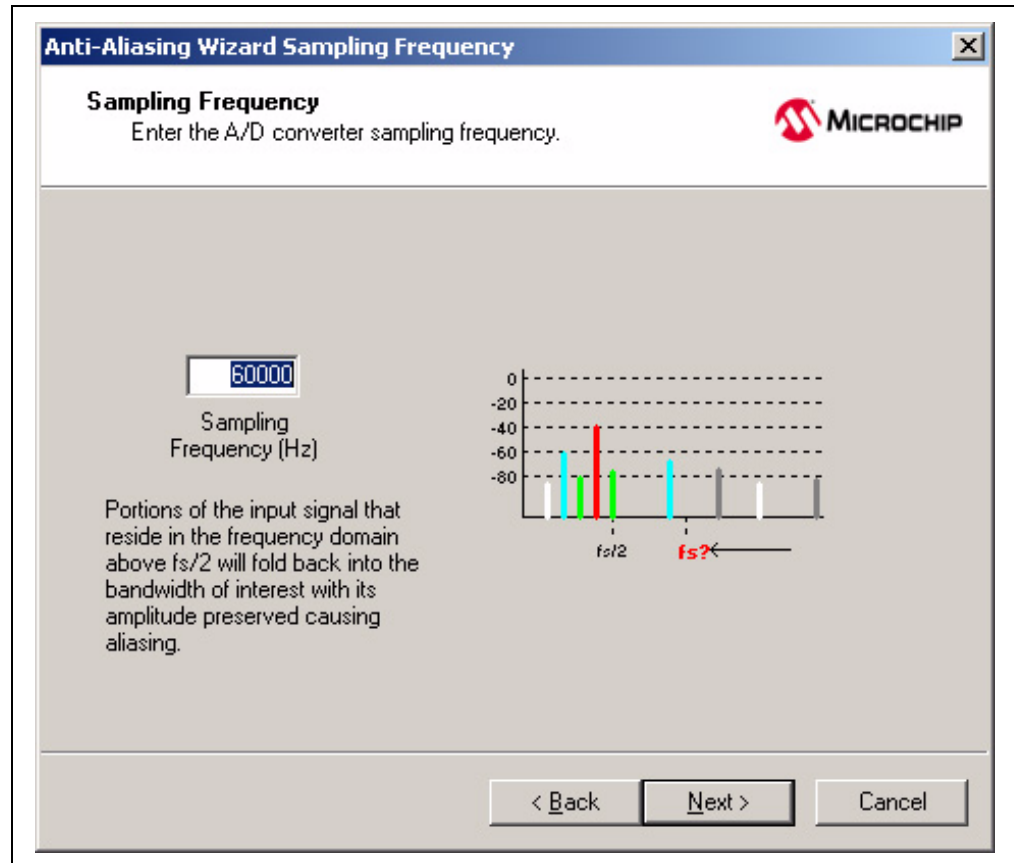


FIGURE 2-4: Sampling Frequency

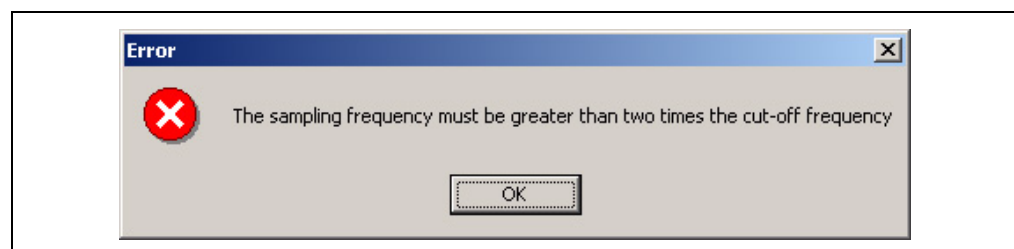


FIGURE 2-5: Error Message

2.1.3 Anti-Aliasing Wizard Resolution Page

Enter the *Resolution* of the A/D converter. The *Resolution* must be between 8 and 24 bits. If a value outside this range is entered, the error message shown in Figure 2-7 will appear.

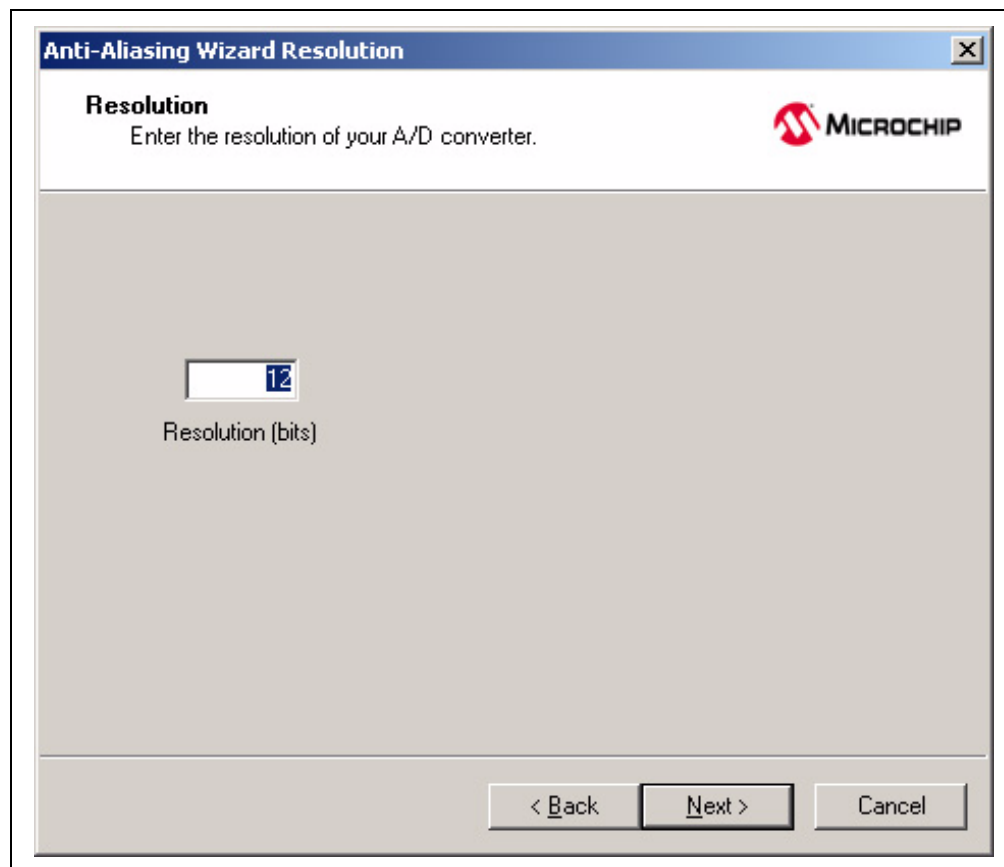
The image shows a Windows-style dialog box titled "Anti-Aliasing Wizard Resolution". The title bar is blue with a close button (X) on the right. The main area has a white background. At the top, the word "Resolution" is in bold, followed by the instruction "Enter the resolution of your A/D converter." in a smaller font. The Microchip logo is in the top right corner. In the center, there is a text input field containing the number "12". Below the input field, the text "Resolution (bits)" is displayed. At the bottom of the dialog, there are three buttons: "< Back", "Next >", and "Cancel".

FIGURE 2-6: Resolution



FIGURE 2-7: Error Message

2.1.4 Anti-Aliasing Wizard Signal-to-Noise Page

Enter the desired *Signal to Noise Ratio*. The default value is $6.02 * \text{bits} + 1.76$. Decreasing the value will decrease the order of the filter, while increasing the value will increase the filter order.

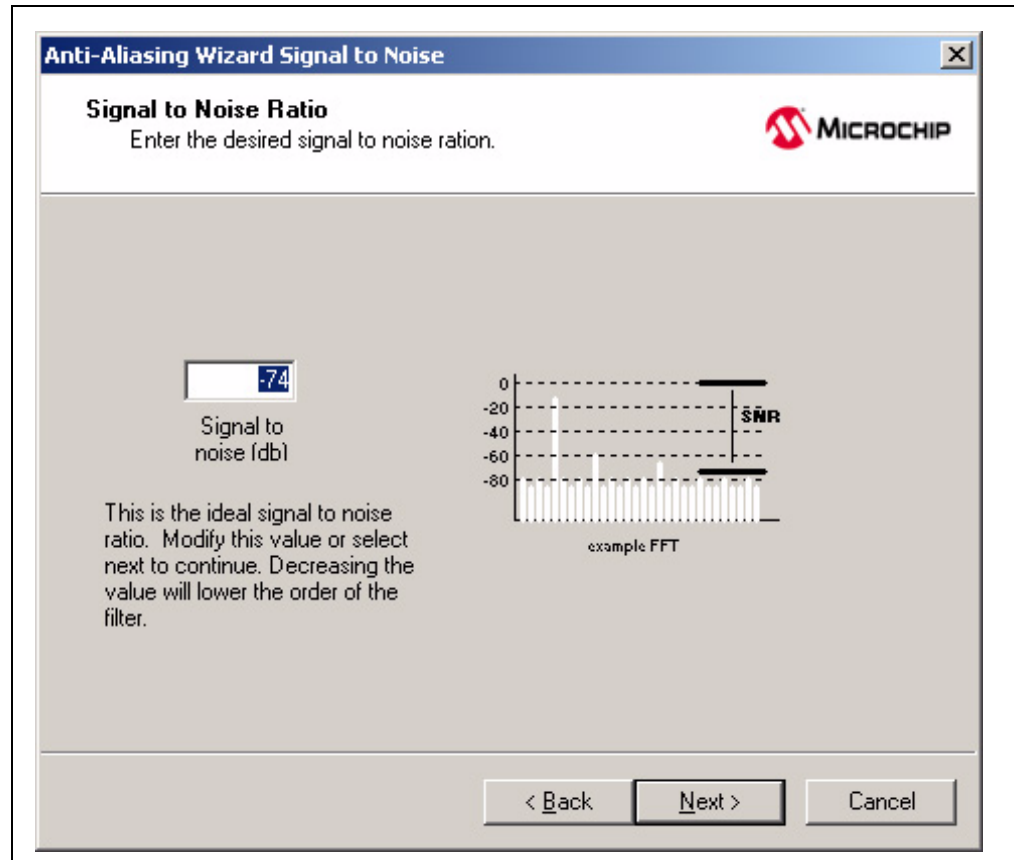


FIGURE 2-8: Signal to Noise Ratio

2.1.5 Anti-Aliasing Wizard Completion Page

The completion page summarizes the selections and presents the filter options. If the previous settings cause a filter to have a higher order than allowed by the program, the radio button for that option will be disabled.

Note: Filters with an order greater than 8 typically are not practical. If the calculated filter order is greater than 8, the user should evaluate increasing the sampling rate.

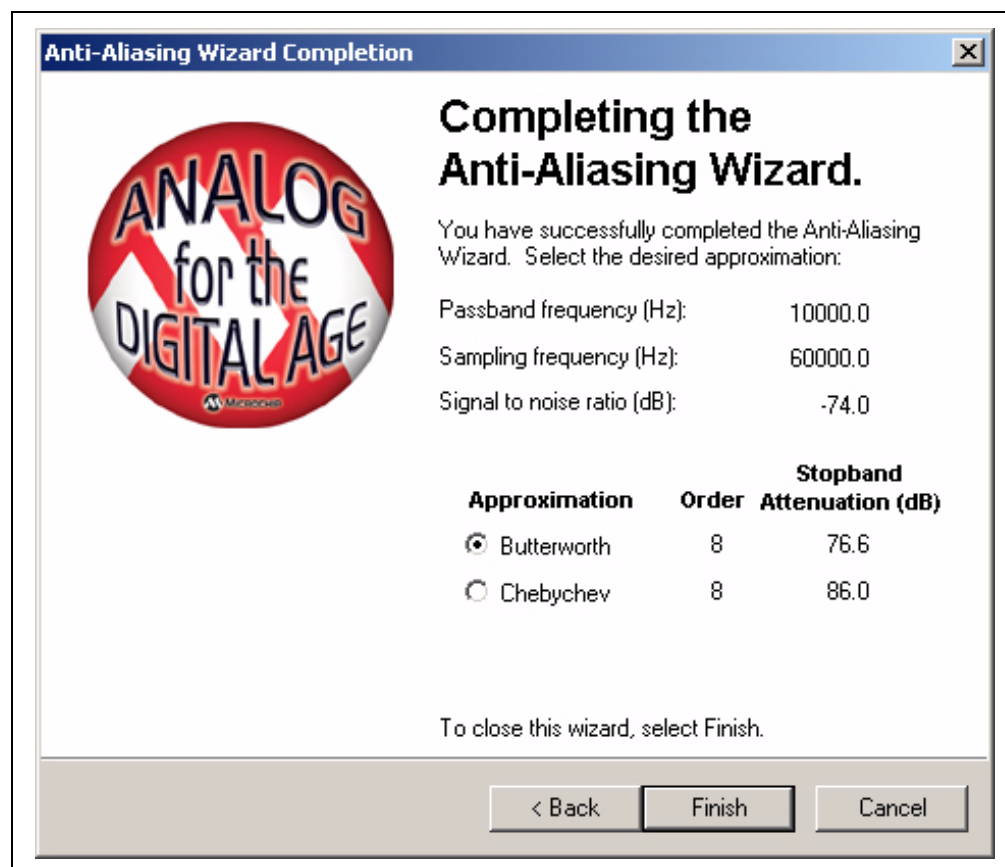


FIGURE 2-9: Completion Page

2.2 FILTER SELECTION WIZARD

The *Filter Selection Wizard* allows the specification of the selectivity, attenuation and frequencies, then presents a table of data showing the order, frequencies and attenuations for each approximation.



FIGURE 2-10: *Filter Selection Wizard*

2.2.1 Filter Selection Wizard Selectivity Page

The *Filter Selectivity* page allows the modification of the selectivity. The response of the selected selectivity is displayed in the property page.

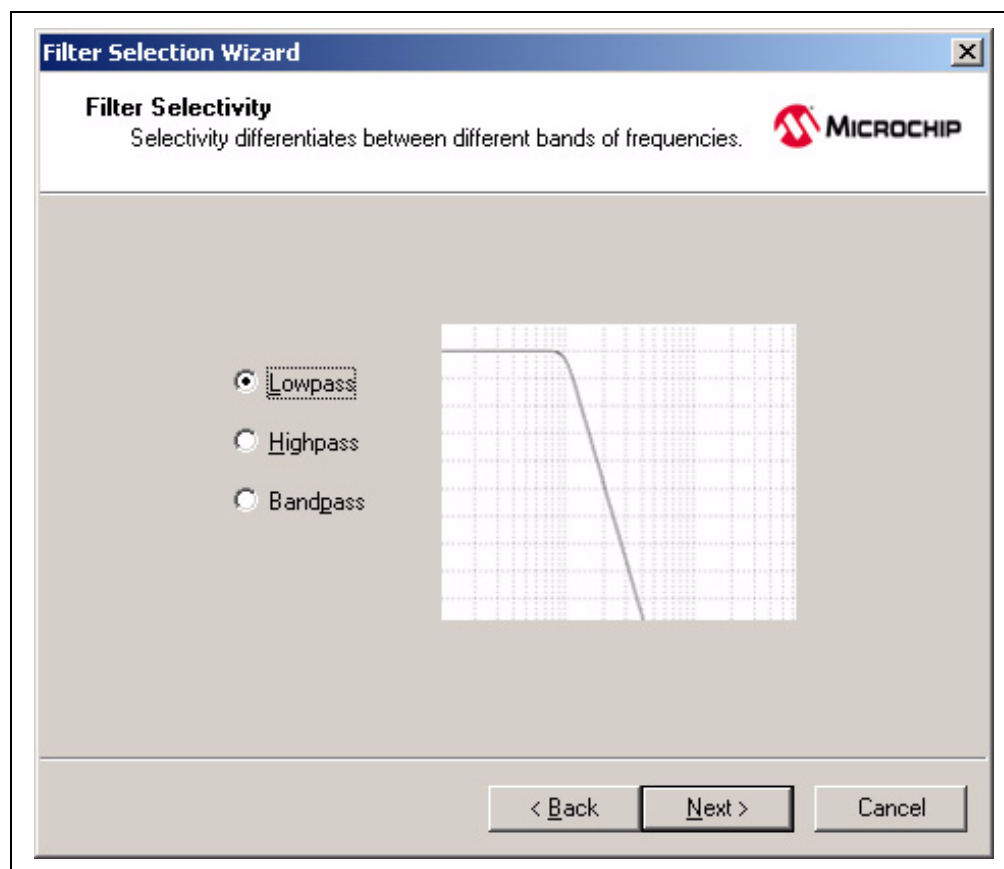


FIGURE 2-11: *Filter Selectivity*

2.2.2 Filter Selection Wizard Specification Page

The *Filter Specification* page allows the modification of the filter parameters, attenuations and frequencies. The values are defined in Figures 1-4, 1-5 and 1-6. The response of the selectivity is displayed in the property page.

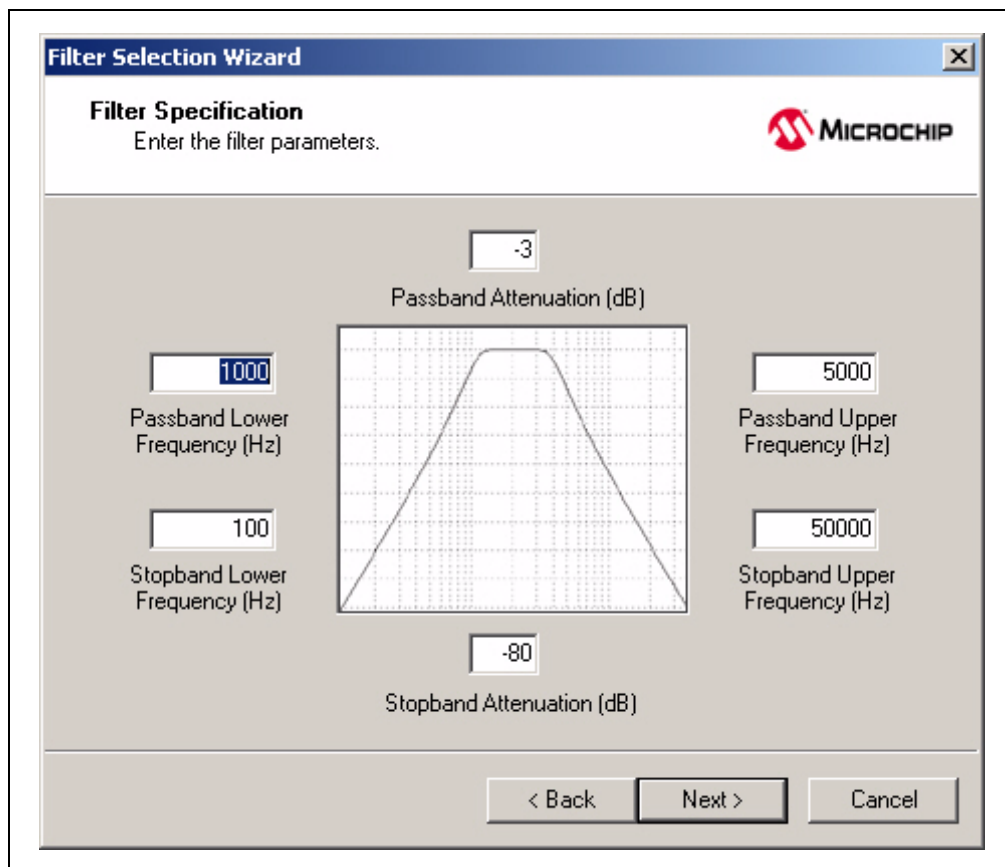


FIGURE 2-12: Filter Specification – Filter Parameters

2.2.2.1 PASS BAND ATTENUATION

The *Pass Band Attenuation* is the change in magnitude of the frequencies in the pass band. The *Pass Band Attenuation* for each selectivity is shown in Figures 1-4, 1-5 and 1-6. The allowable range is -0.01 dB to -3 dB. If a value beyond this range is entered, the error message shown in Figure 2-13 will appear.



FIGURE 2-13: Error Message

2.2.2.2 STOP BAND ATTENUATION

The *Stop Band Attenuation* is the change in magnitude of the frequencies in the stop band. The *Stop Band Attenuation* for each selectivity is shown in Figures 1-4, 1-5 and 1-6. The allowable range is -10 dB to -100 dB. If a value beyond this range is entered, the error message shown in Figure 2-14 will appear.



FIGURE 2-14: Error Message

2.2.2.3 PASS BAND FREQUENCY

The *Pass Band Frequency* is the starting point of the pass band, as shown in Figures 1-4, 1-5 and 1-6. The allowable range is 0.1 Hz to 1,000,000 Hz. If a value beyond this range is entered, the error message shown in Figure 2-15 will appear.

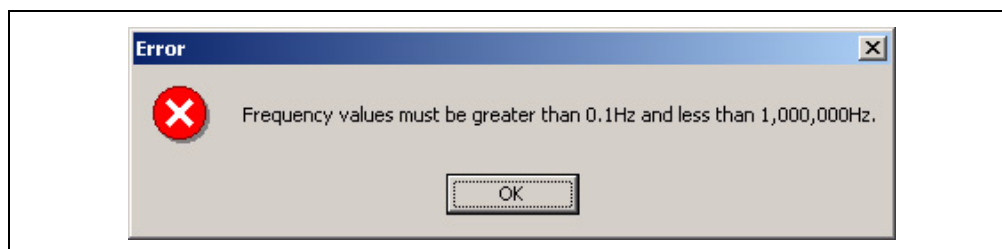


FIGURE 2-15: Error Message

2.2.2.3.1 Low-pass

The *Pass Band Frequency* must be lower than the *Stop Band Frequency* for low-pass selectivities. If a value is entered which is larger than the *Stop Band Frequency*, the error message shown in Figure 2-16 will appear.

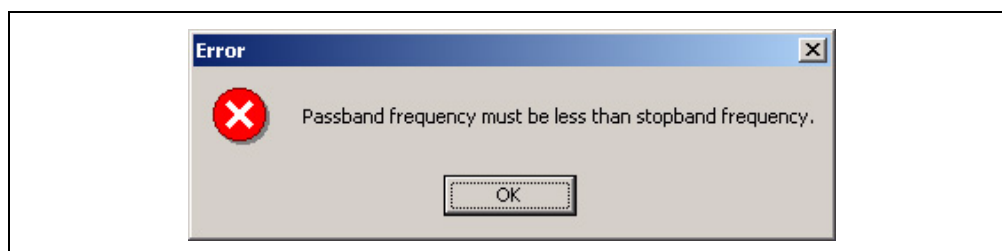


FIGURE 2-16: Error Message

2.2.2.3.2 High-pass

The *Pass Band Frequency* must be greater than the *Stop Band Frequency* for high-pass selectivities. If a value is entered that is smaller than the *Stop Band Frequency*, the error message shown in Figure 2-17 will appear.

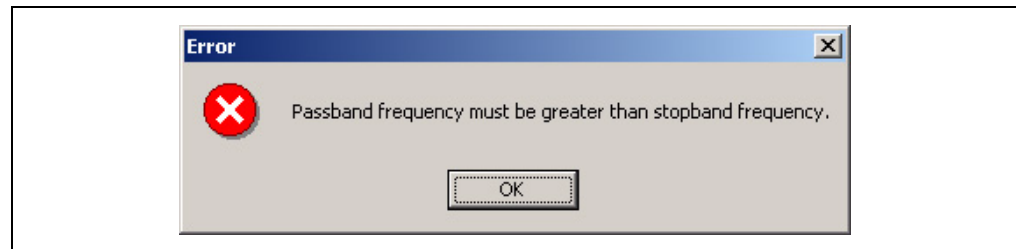


FIGURE 2-17: Error Message

2.2.2.3.3 Band-pass

The *Pass Band Lower Frequency* must be lower than the *Pass Band Upper Frequency* and both *Stop Band Frequencies* for band-pass selectivities. If a value is entered that is greater than the *Stop Band Frequency* or *Pass Band Upper Frequency*, the error message shown in Figures 2-18 and 2-19 will appear.

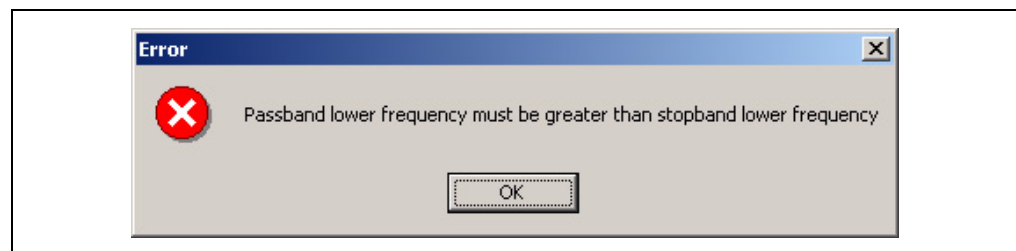


FIGURE 2-18: Error Message

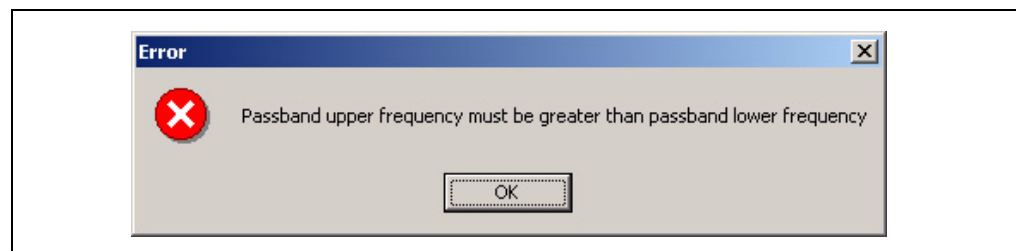


FIGURE 2-19: Error Message

2.2.2.4 STOP BAND FREQUENCY

The *Stop Band Frequency* is the starting point of the stop band, as shown in Figures 1-4, 1-5 and 1-6. The allowable range is 0.1 Hz to 1,000,000 Hz. If a value beyond this range is entered, the error message shown in Figure 2-20 will appear.

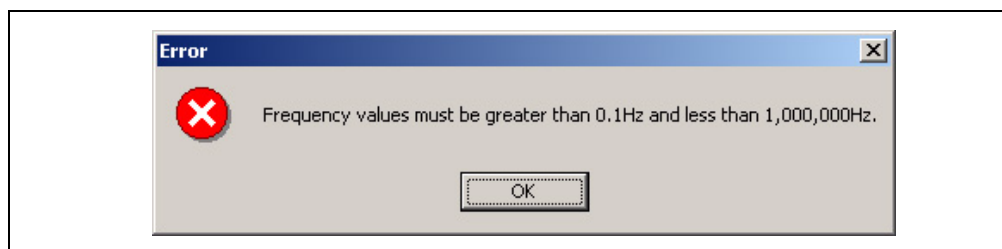


FIGURE 2-20: Error Message

2.2.2.4.4 Low-pass

The *Stop Band Frequency* must be greater than the *Pass Band Frequency* for low-pass selectivities. If a value is entered that is smaller than the *Pass Band Frequency*, the error message shown in Figure 2-21 will appear.

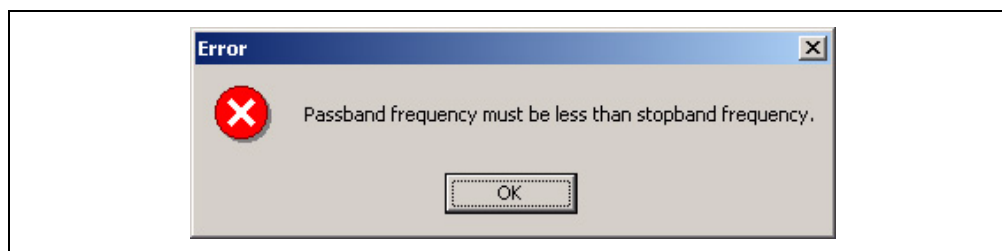


FIGURE 2-21: Error Message

2.2.2.4.5 High-pass

The *Pass Band Frequency* must be greater than the *Stop Band Frequency* for high-pass selectivities. If a value is entered that is smaller than the *Stop Band Frequency*, the error message shown in Figure 2-22 will appear.

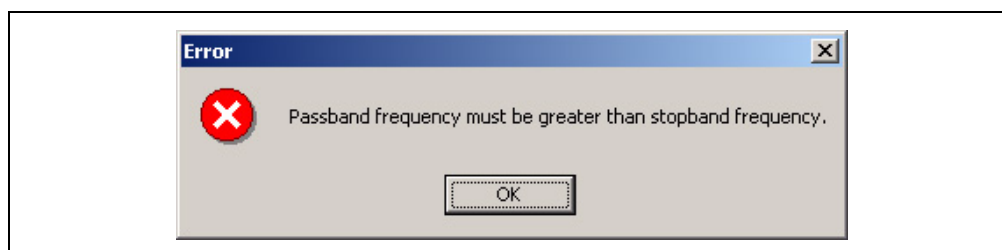


FIGURE 2-22: Error Message

2.2.2.4.6 Band-pass

The *Pass Band Lower Frequency* must be lower than the *Pass Band Upper Frequency* and both *Stop Band Frequencies* for band-pass selectivities. If a value is entered that is greater than the *Stop Band Frequency* or *Pass Band Upper Frequency*, the error message shown in Figures 2-23 and 2-24 will appear.

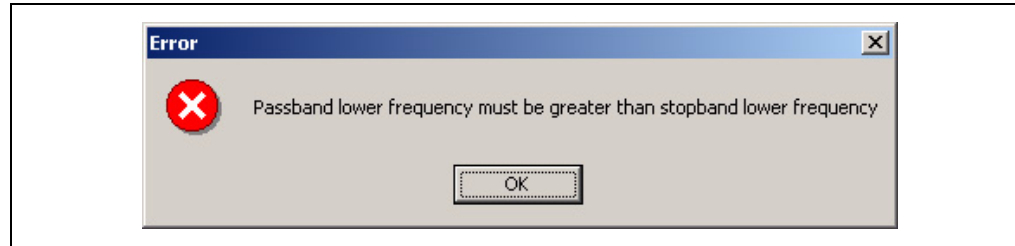


FIGURE 2-23: Error Message

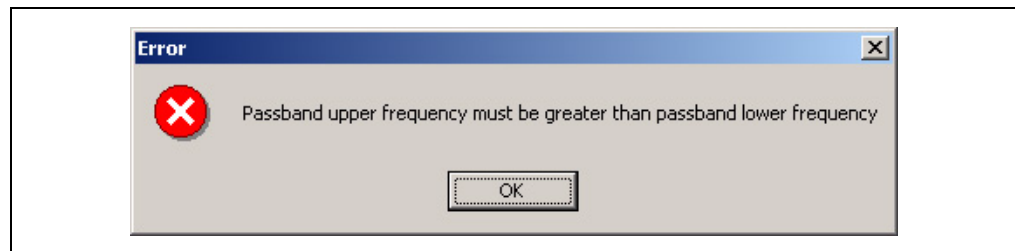


FIGURE 2-24: Error Message

2.2.3 Filter Selection Wizard Approximation Page

The *Filter Approximation* page summarizes the filter settings and lists the calculated *Order* and *Stop Band Attenuation* for each approximation.

Note: If the calculated order for either approximation exceeds 8, the approximation will be disabled. The user should consider modifying either the pass band or stop band frequencies so that a more practical filter can be produced.

Approximation	Order	Passband Attenuation (dB)	Actual Stopband Attenuation (dB)
<input checked="" type="radio"/> Butterworth	8	-3.0	-87.7
<input type="radio"/> Chebyshev	8	-3.0	-105.7

FIGURE 2-25: Filter Approximation

2.2.4 Filter Selection Wizard Completion Page

The *Filter Completion* page summarizes all selections made. To implement the filter, click the *Finish* button.

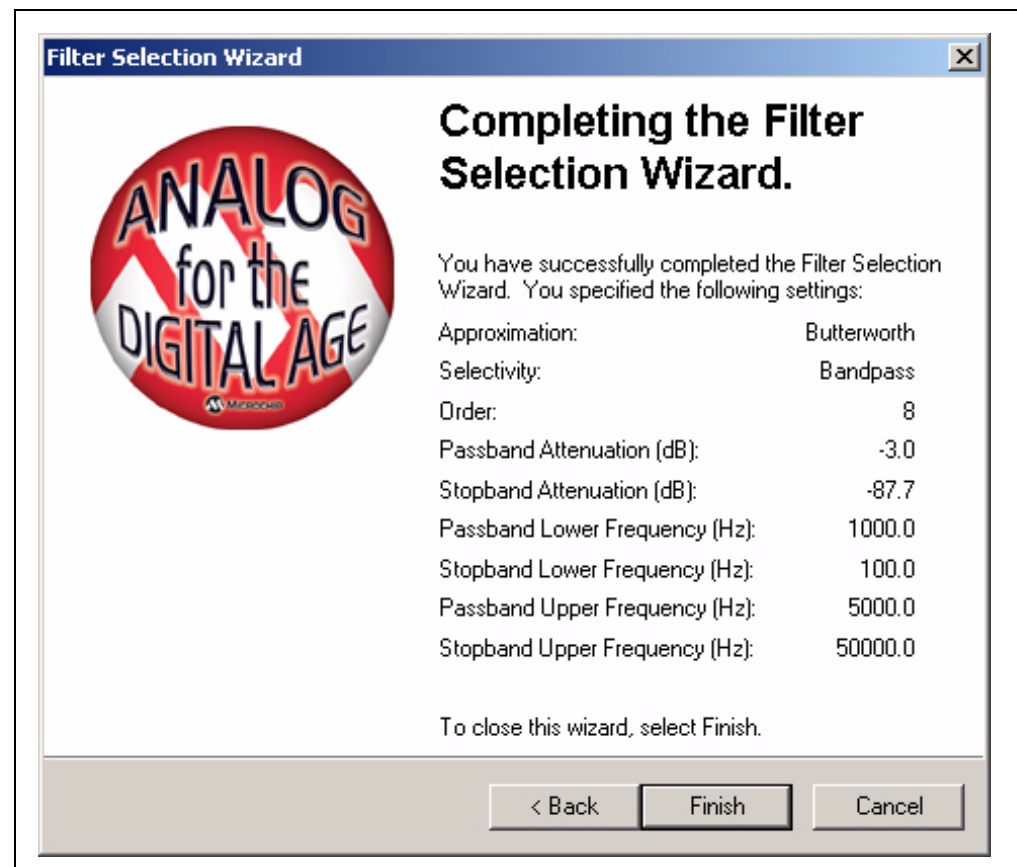


FIGURE 2-26: Completion Page

FilterLab® 2.0 User's Guide

NOTES:

Chapter 3. Toolbar

3.1 TOOLBAR

The toolbar provides a shortcut to FilterLab 2.0 program settings. Options available on the toolbar can also be accessed from the menus or dialog boxes.

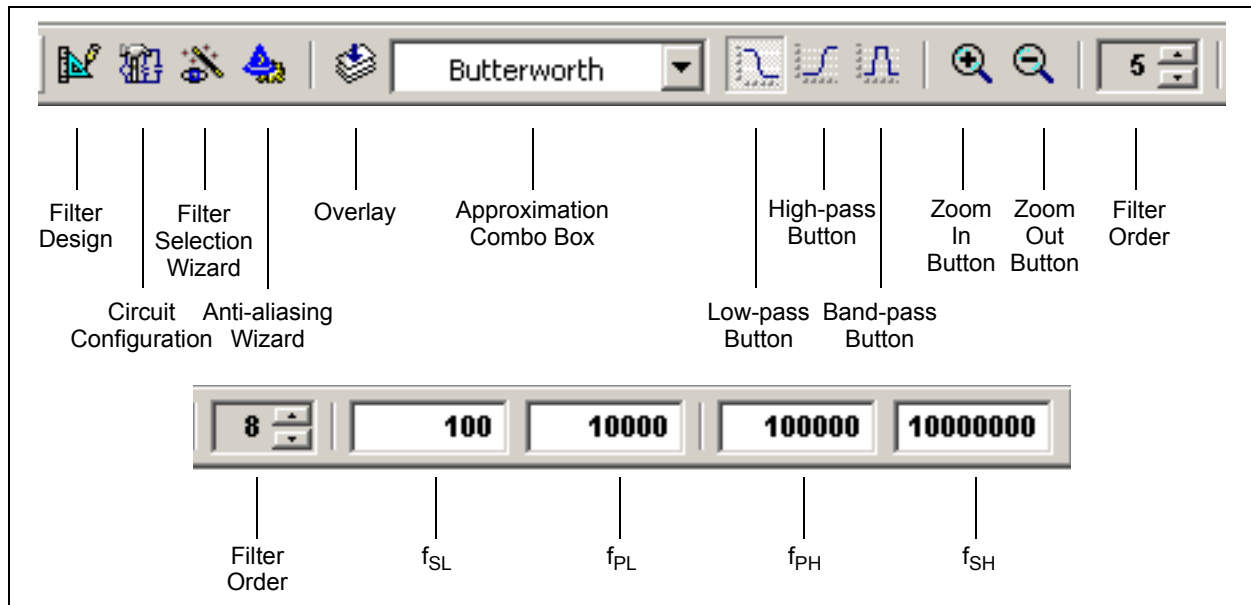


FIGURE 3-1: Toolbar

3.2 BUTTONS

3.2.1 Filter Design

The *Filter Design* toolbar button (Figure 3-2) opens the *Filter Design* dialog box.



FIGURE 3-2: Filter Design Button

3.2.2 Circuit Configuration

The *Circuit Configuration* toolbar button (Figure 3-3) opens the *Filter Design* dialog with the *Circuit* tab active.



FIGURE 3-3: Circuit Configuration Button

3.2.3 Overlay

The *Overlay* button (Figure 3-4) enables the overlay feature. The overlay feature overlays approximations selected from the toolbar's approximation combo box (Figure 3-5) in the response view. The overlay button functions as a radio button. When the overlay feature is enabled, the overlay button will be depressed. To overlay approximations in the response view, select the first approximation to overlay from the toolbar's approximation combo box. After the first approximation has been selected, select the overlay button. Once the overlay button has been selected, any approximations selected from the toolbar's approximation combo box will be overlaid with the original approximation. A checkmark will appear next to all approximations that have been selected to be overlaid. To disable the overlay feature, select the overlay toolbar button.

Note: Bessel approximations cannot be overlaid. Therefore, if you select the Bessel approximation from the toolbar's approximation combo box, it will not be overlaid with the other approximations.

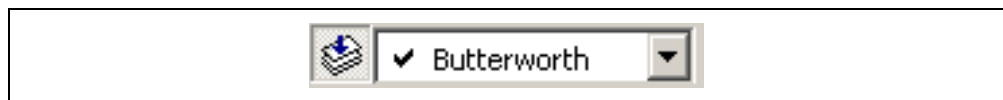


FIGURE 3-4: Overlay Button

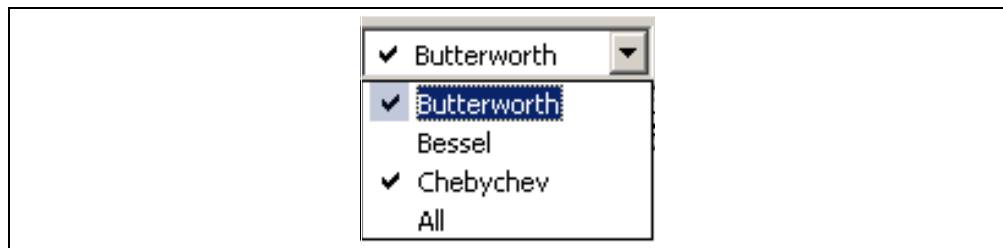


FIGURE 3-5: Approximation Combo Box

3.2.4 Low-pass

The *Low-pass* toolbar button (Figure 3-6) changes the selectivity to low-pass and the frequencies to the default values with a pass band frequency of 1,000 Hz and a stop band frequency of 10,000 Hz.



FIGURE 3-6: Low-pass Button

3.2.5 High-pass

The *High-pass* toolbar button (Figure 3-7) changes the selectivity to high-pass and the frequencies to the default values with a pass band frequency of 10,000 Hz and a stop band frequency of 1,000 Hz. The *High-pass* toolbar button is disabled for Bessel approximations.



FIGURE 3-7: *High-pass Button*

Note: Bessel approximations only support low-pass selectivities. The *High-pass* toolbar button will be disabled when Bessel approximations are selected.

3.2.6 Band-pass

The *Band-pass* toolbar button (Figure 3-8) changes the selectivity to band-pass and the frequencies to the default values with a lower pass band frequency of 1,000 Hz, an upper pass band frequency of 5,000 Hz, a lower stop band frequency of 100 Hz and an upper stop band frequency of 50,000 Hz. The *Band-pass* toolbar button is disabled for Bessel approximations.



FIGURE 3-8: *Band-pass Button*

Note: Bessel approximations only support low-pass selectivities. The *Band-pass* toolbar button will be disabled when Bessel approximations are selected.

3.2.7 Zoom-In

The *Zoom-In* button (Figure 3-9) zooms the response view towards the center of the response. The zoom button has no effect on the *Circuit* or the *SPICE* views.



FIGURE 3-9: *Zoom-In Button*

3.2.8 Zoom-Out

The *Zoom-Out* button (Figure 3-10) zooms the response view out from the center of the response. The *Zoom-Out* button has no effect unless the response has been previously zoomed with the *Zoom-In* button (Figure 3-9). The zoom button has no effect on the *Circuit* or the *SPICE* views.



FIGURE 3-10: *Zoom-Out Button*

3.2.9 Filter Order

The *Filter Order* button (Figure 3-11) displays the filter's order and modifies that order. Selecting the *Filter Order* arrow buttons will increase or decrease the order of the filter. When the minimum or maximum order of the program is reached, the order will automatically roll over. If the current design filter had the order automatically calculated and one of the *Filter Order* arrow buttons is selected, the program automatically sets the *Force Filter Order* flag (Figure 1-7) and forces the filter order to the value in the *Force Filter Order* text box. Band-pass selectivities only have even order selectivities. Therefore, the order will increment by two when a band-pass selectivity is selected.



FIGURE 3-11: *Filter Order*

3.3 APPROXIMATION COMBO BOX

The *Approximation* combo box (Figure 3-12) changes the filter approximation. Selecting *All* will enable the overlay feature and overlay all approximations, excluding the Bessel approximation. The Bessel approximation is only available for low-pass selectivities and forced filter orders. Therefore, when the Bessel approximation is selected, the selectivity will be changed to low-pass and the *Force Filter Order* flag will be enabled.

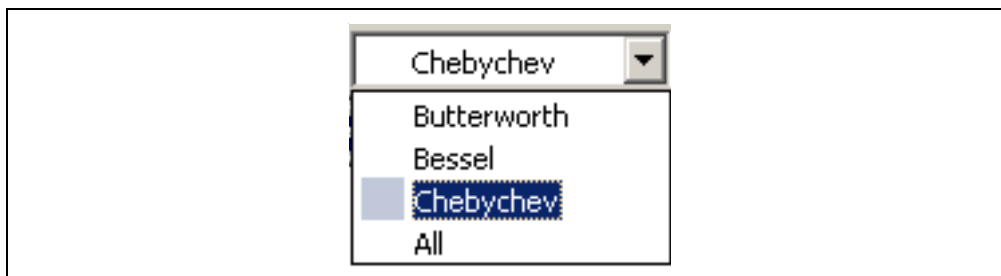


FIGURE 3-12: *Filter Approximation*

Note: Bessel approximations only support low-pass selectivities. Choosing a selectivity other than low-pass changes the selectivity to low-pass and resets the frequency values.

3.4 FREQUENCY TEXT BOXES

The frequency text boxes provide a shortcut for modifying the pass band and stop band frequencies. The range of values is limited to 0.1 Hz to 1,000,000 Hz.

The text boxes are enabled and disabled depending on the currently specified selectivity and whether the filter order is forced or calculated by the program. If the frequency order is forced, there is only one frequency value that can be adjusted for low-pass and high-pass selectivities and only two frequencies that can be adjusted for band-pass selectivities. Therefore, only one text box will be enabled for low-pass and high-pass selectivities and two text boxes will be enabled for band-pass selectivities.

3.4.1 Low-pass

When the *Low-pass* selectivity is specified, the left-most enabled text box represents the filter's pass band frequency and the rightmost enabled text box represents the filter's stop band frequency (Figure 3-13). When the filter order is forced only, the filter's pass band frequency can be modified. Therefore, only the left most text box is enabled (Figure 3-14).



FIGURE 3-13: *Frequency Text Boxes - Order Unforced*



FIGURE 3-14: *Frequency Text Boxes - Order Forced*

3.4.2 High-pass

When the *High-pass* selectivity is specified, the leftmost enabled text box represents the filter's stop band frequency and the right most enabled text box represents the filter's pass band frequency (Figure 3-15). When the filter order is forced only, the filter's pass band frequency can be modified. Therefore, only the right most text box is enabled (Figure 3-16).



FIGURE 3-15: *Frequency Text Boxes - Order Unforced*



FIGURE 3-16: *Frequency Text Boxes - Order Forced*

3.4.3 Band-pass

When the band-pass selectivity is specified, the left most text box represents the filter's lower stop band frequency. The second textbox represents the filter's lower pass band, while the third text box represents the filter's upper pass band. The right most text box represents the filter's pass band frequency (Figure 3-17). When the filter order is forced, only the filter's lower and upper pass band frequencies can be modified. Therefore, only the center text boxes are enabled (Figure 3-18).



	100	1000	10000	100000
--	-----	------	-------	--------

FIGURE 3-17: *Frequency Text Boxes - Order Unforced*



	1100	3900	
--	------	------	--

FIGURE 3-18: *Frequency Text Boxes - Order Forced*

Chapter 4. Menus

4.1 MENUS



FIGURE 4-1: Menu Bar

4.2 FILE

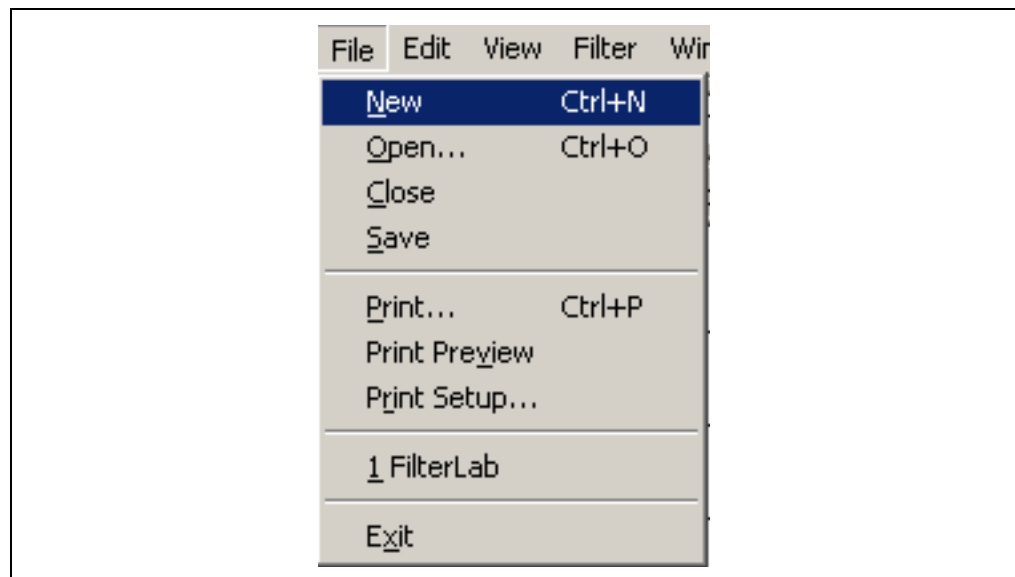


FIGURE 4-2: File Menu

4.2.1 New

The *New* menu item (Figure 4-2) creates a new project with filter properties that are independent of the original project. When selected, a new window will open for the new project.

4.2.2 Open

The *Open* menu item (Figure 4-2) opens a saved project. Select *Open*, then select the previously saved project in the *Open Project* dialog box (Figure 4-3).

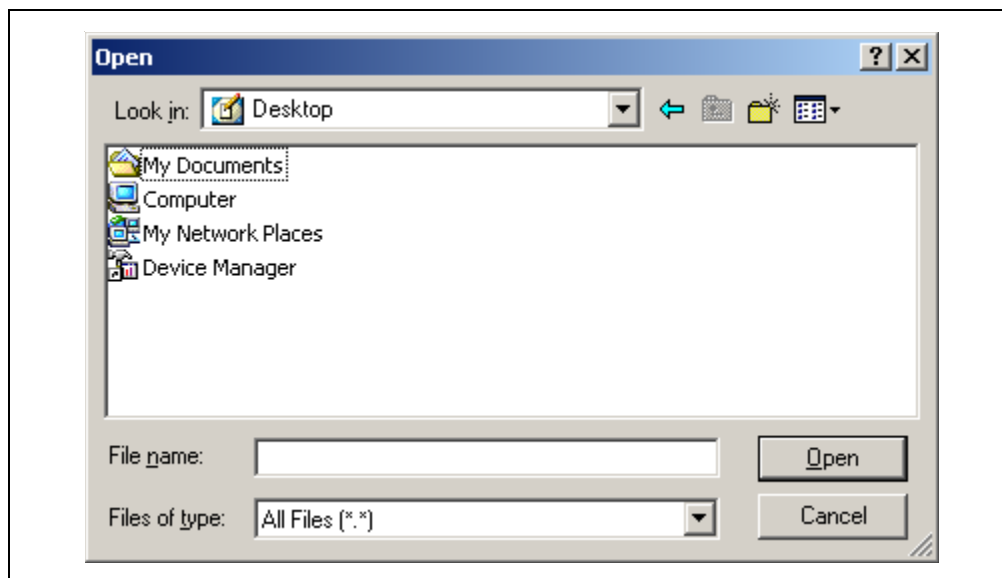


FIGURE 4-3: Open Project Dialog

4.2.3 Close

The *Close* menu item (Figure 4-2) closes the currently active project.

4.2.4 Save

The *Save* menu item (Figure 4-2) saves the currently active project and changes the title bar's file name (Figure 4-5) and spice listing's macro-model title (Figure 4-6), to the specified file name in the *Save File* dialog box (Figure 4-4).

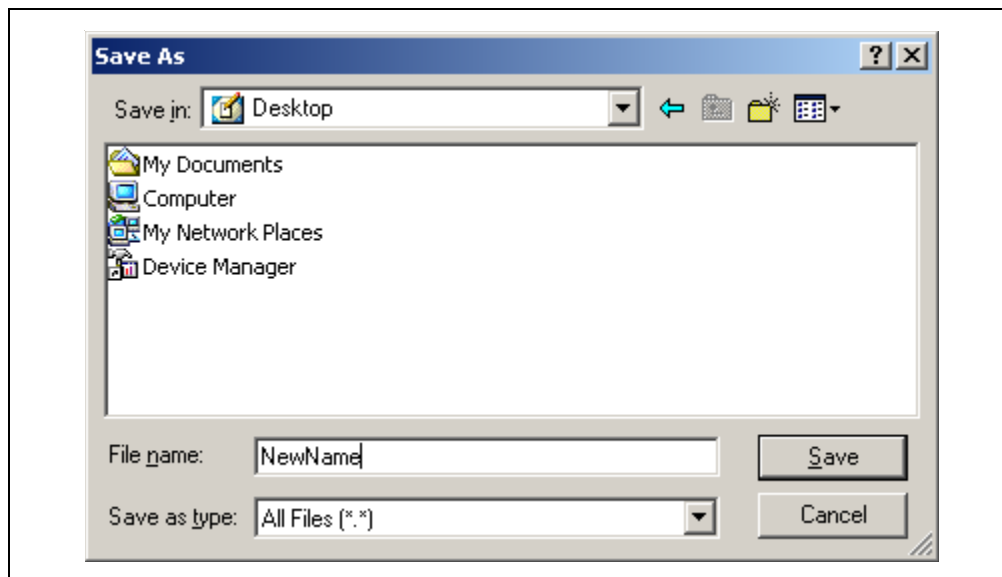


FIGURE 4-4: Save Project Dialog



FIGURE 4-5: Title Bar Filename

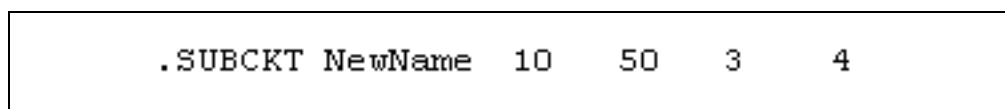


FIGURE 4-6: SPICE Listing Model Title

4.2.5 Print

The *Print* menu item (Figure 4-2) prints the active view.

4.2.6 Print Preview

The *Print Preview* menu item (Figure 4-2) previews the active view.

4.2.7 Print Setup

The *Print Setup* menu item (Figure 4-2) opens the *Print Setup* dialog box (Figure 4-7).

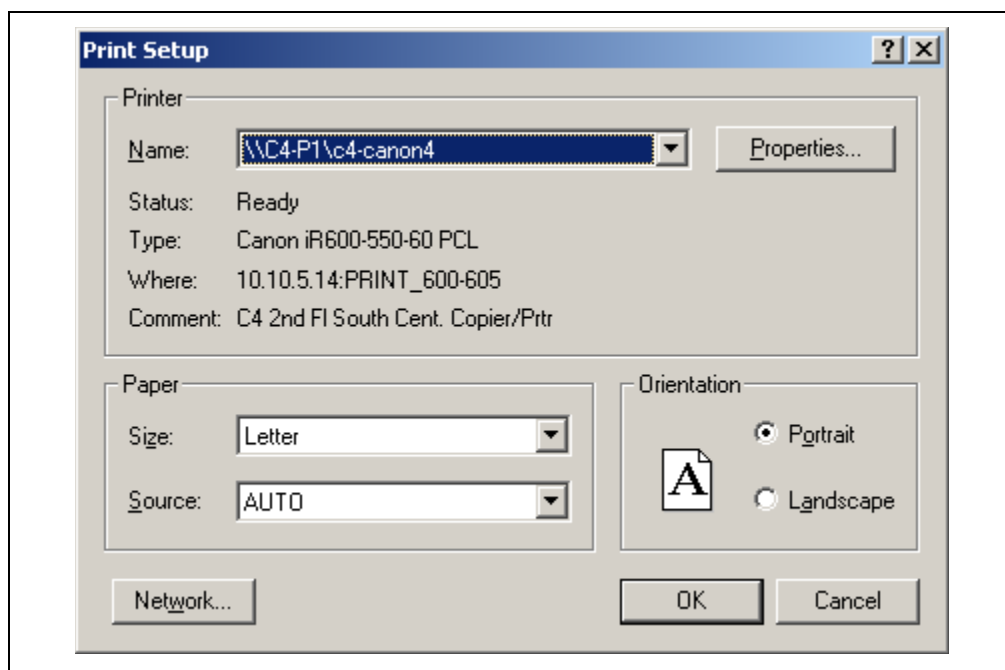


FIGURE 4-7: Print Setup Dialog

4.2.8 Exit

The *Exit* menu item (Figure 4-2) exits the program.

4.3 EDIT

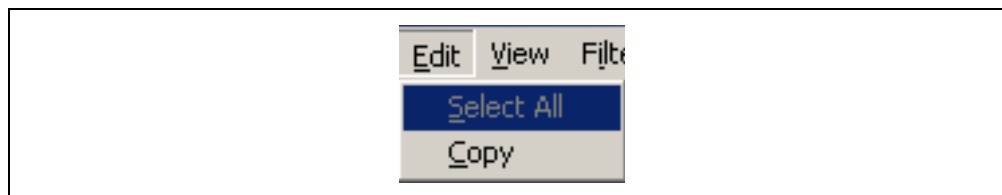


FIGURE 4-8: Edit Menu

4.3.1 Select All

The *Select All* menu item (Figure 4-8) selects the text in the SPICE listing for copying and pasting. The *Select All* menu item is only available when the *SPICE* view has focus.

4.3.2 Copy

The *Copy* menu item (Figure 4-8) copies the active view or SPICE listing to the clipboard. It is enabled for the *Response* and *Circuit* views and is disabled for the *SPICE* view unless text has been selected.

4.4 VIEW

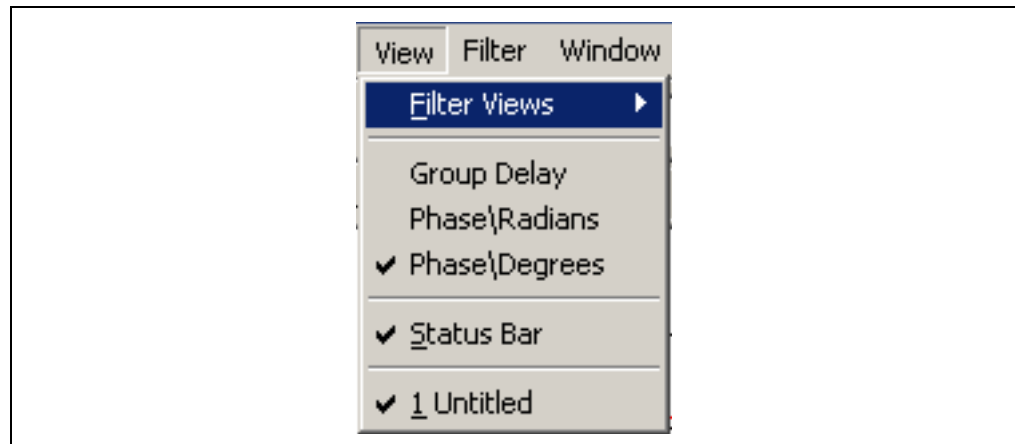


FIGURE 4-9: View Menu

4.4.1 Filter Views

The *Filter View* menu items (Figures 4-9 and 4-10) change the current view.

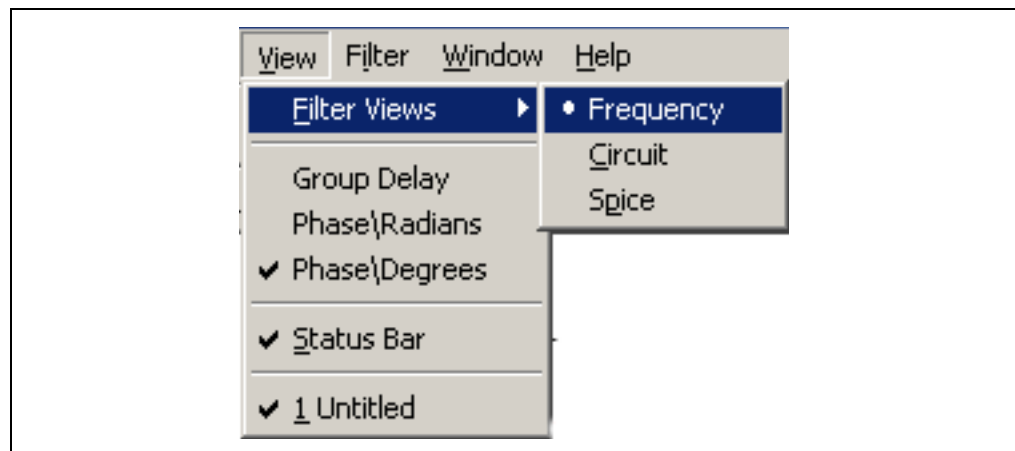


FIGURE 4-10: Filter View Menu

4.4.2 Group Delay

The *Group Delay* menu item (Figure 4-9) changes the *Response* view's auxiliary data to group delay. The *Group Delay* menu item is enabled only when the *Response* view has focus.

4.4.3 Phase\Radians

The *Phase\Radians* menu item (Figure 4-9) changes the *Response* view's auxiliary data to radians. The *Phase\Radians* menu item is enabled only when the *Response* view has focus.

4.4.4 Phase\Degrees

The *Phase\Degrees* menu item (Figure 4-9) changes the *Response* view's auxiliary data to phase. The *Phase\Degrees* menu item is enabled only when the *Response* view has focus.

4.5 FILTER



FIGURE 4-11: Filter Menu

4.5.1 Design

The *Design* menu item (Figure 4-11) opens the *Filter Design* dialog box (Figure 1-1) with the *Filter Specification* tab active.

4.5.2 Filter Selection Wizard

The *Filter Selection Wizard* menu item (Figure 4-11) opens the *Filter Selection Wizard* dialog box (Figure 2-10).

4.5.3 Anti-Aliasing Wizard

The *Anti-Aliasing Wizard* menu item (Figure 4-11) opens the *Anti-Aliasing Wizard* dialog box (Figure 2-1).

4.5.4 Overlay

The *Overlay* menu item is used to display both the frequency and phase or group delay response of the filter.

4.6 WINDOW

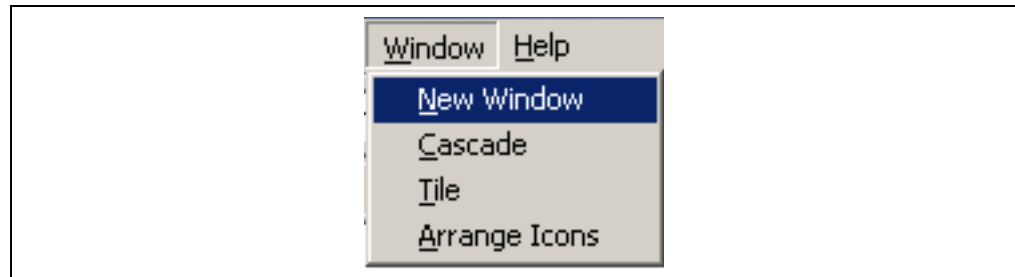


FIGURE 4-12: Window Menu

4.6.1 New Window

The *New Window* menu item (Figure 4-12) creates a new window for the current project and changes to the filter design are represented in both windows. When a new window is created, the title bar will change to *[ProjectName]:[Window Number]*. The view listing in the *View* menu will have a new listing in the form *[Project Name]:[Window Number]*.

4.6.2 Cascade

The *Cascade* menu item (Figure 4-12) cascades all windows.

4.6.3 Tile

The *Tile* menu item tiles all windows.

4.6.4 Arrange Icons

The *Arrange Icons* menu item (Figure 4-12) arranges the minimized window icons at the bottom of the main window.

4.7 HELP

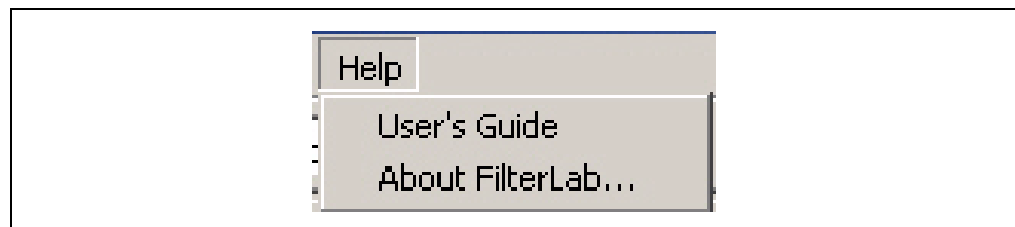


FIGURE 4-13: Help Menu

4.7.1 About

The *About FilterLab* menu item (Figure 4-13) opens the *About* dialog box.

FilterLab® 2.0 User's Guide

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Chapter 5. Window Views

5.1 FREQUENCY VIEW

The *Frequency View* displays the filter response.

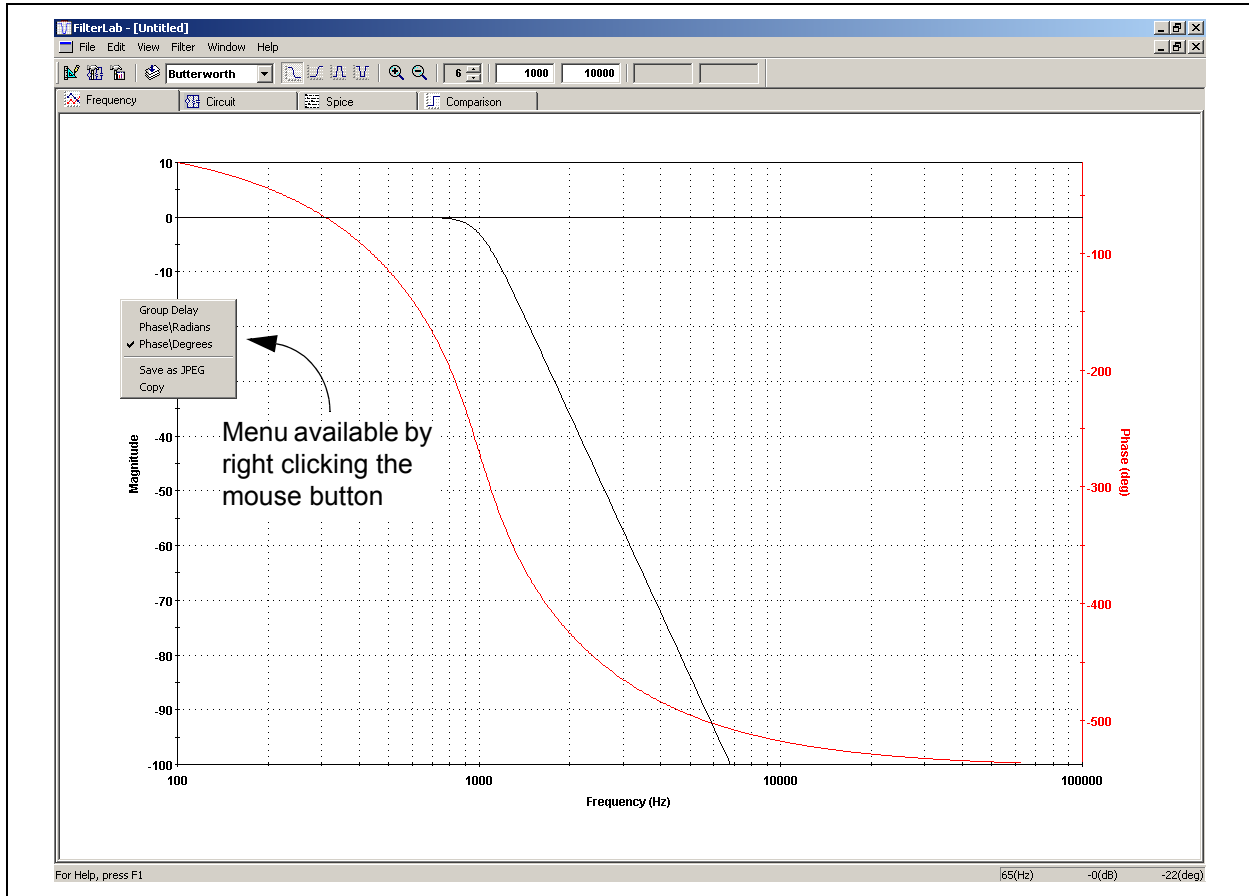


FIGURE 5-1: *Frequency View*

5.1.1 Axes

The left axis displays the attenuation of the filter. The default left axis scale is +10 dB to -80 dB. The right axis displays either the phase in degrees or radians, or the group delay. The frequency range is automatically set to three decades when the filter order is forced.

5.1.2 Pop-up Menu

5.1.2.1 PHASE/GROUP DELAY

The *Phase/Group Delay* pop-up menu item (Figure 5-1) changes the right axis to one of the three right axis options. These options are:

- Group Delay
- Phase/Radians
- Phase/Degrees

5.1.2.2 SAVE AS JPEG

The *Save as JPEG* pop-up menu item (Figure 5-1) saves the *Response* view as a JPEG file.

5.1.2.3 COPY

The *Save as JPEG* pop-up menu item (Figure 5-1) copies the *Response* view image to the clipboard.

5.2 CIRCUIT VIEW

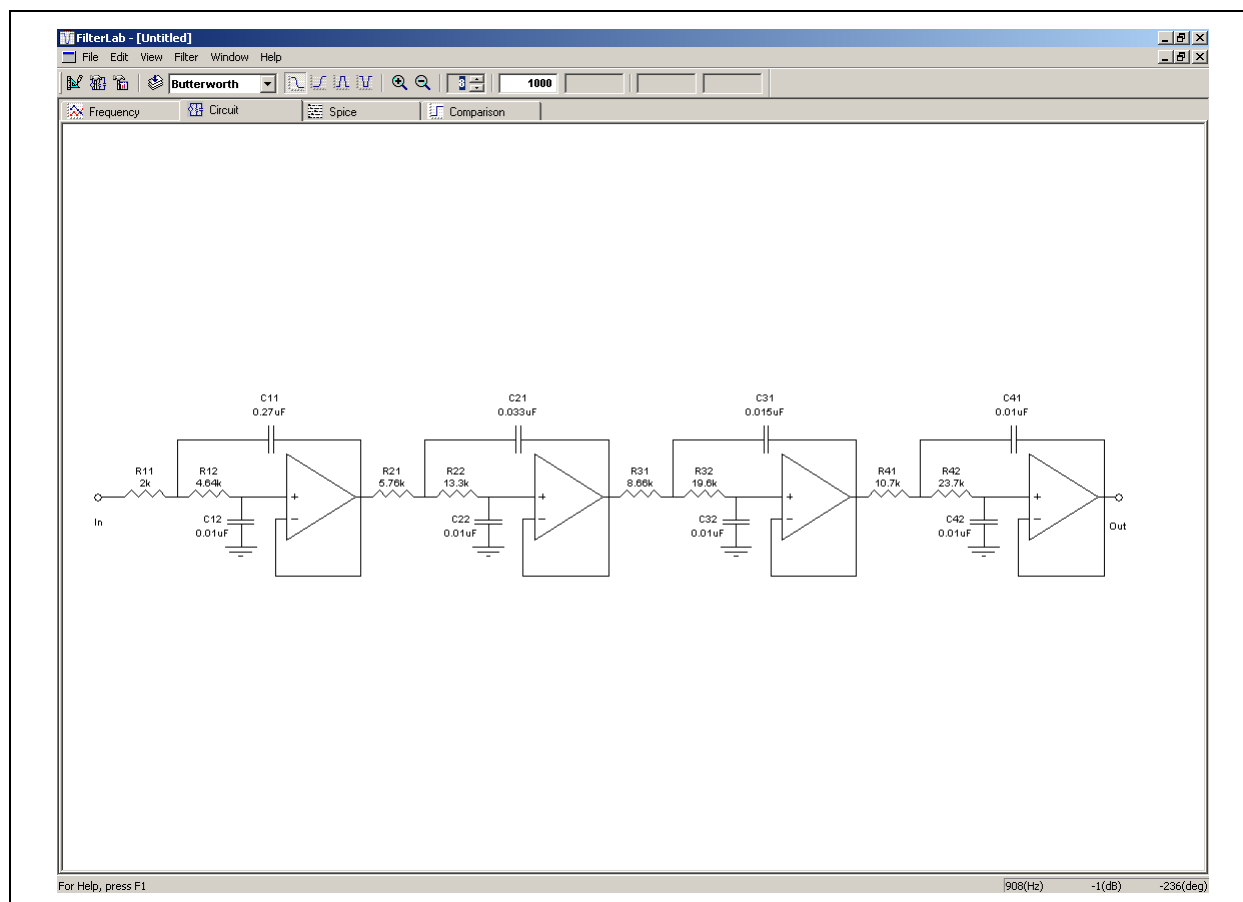


FIGURE 5-2: Circuit View

5.2.1 Circuit Display

The *Circuit View* (Figure 5-2) displays the current circuit for the specified filter.

FilterLab® 2.0 User's Guide

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Appendix A. FilterLab 2.0 to SPICE Interface

A.1 INTRODUCTION AND HIGHLIGHTS

FilterLab 2.0 provides a net list of the filter circuit that can be imported to a SPICE simulator. The SPICE output of FilterLab 2.0 and the Microchip operational amplifiers macromodels are designed to be compatible with PSPICE™ or other SPICE 2G6 circuit simulators. Other simulators may require translation.

The FilterLab 2.0 to PSPICE interface consists of a three-step procedure. First, the filter is defined using either the *Filter Design* dialog box or the *Filter Selection Wizard*.

The second step consists of reviewing the frequency response and schematic of the filter design. The last step consists of copying the net list filter that is provided in the SPICE view to the SPICE simulator.

FilterLab 2.0 SPICE Design Example

```
*****
*****
*1 KHz Low-pass Filter
*2nd Order Butterworth Approximation
*Sallen-Key Circuit Topology
*MPC6001 Operational Amplifier PSPICE Macromodel
*****
*****
* AC Response Test
* Node 10 functions as the input to the filter network
V_IN 10 0 AC 1V
*
*           N#pts Start/Stop Freq.
.AC DEC 100      1 10MEG
*
* OP-AMP Power (pin 3 = V+, pin 4 = V-)
V_PWR_PLUS 3 0 2.5V
V_PWR_NEG 4 0 -2.5V

*CALL FILTER_DEMO CIRCUIT
*CONNECTIONS:
*   INPUT
*   |   OUTPUT
*   |   |
*   |   |   POSITIVE POWER SUPPLY
*   |   |   NEGATIVE POWER SUPPLY
*   |   |
*   |   |
*   1   2   3   4
X1    10  20  3   4 FilterLab1

.PROBE
```

DS51419A-page 54 © 2003 Microchip Technology Inc.

```
*****
**
*
* Macromodel for the MCP6001/2/4 op amp family:
*   MCP6001 (single)
*   MCP6002 (dual)
*   MCP6004 (quad)
*
* Revision History:
*   REV A: 21-Jun-02, KEB (created model)
*   REV B: 16-Jul-02, KEB (improved output stage)
*   REV C: 03-Jan-03, KEB (added MCP6001)
*
* Recommendations:
*   Use PSPICE (or SPICE 2G6; other simulators may require translation)
*   For a quick, effective design, use a combination of: data sheet
*   specs, bench testing, and simulations with this macromodel
*   For high impedance circuits, set GMIN=100F in the .OPTIONS
*   statement
*
* Supported:
*   Typical performance at room temperature (25 degrees C)
*   DC, AC, Transient, and Noise analyses.
*   Most specs, including: offsets, DC PSRR, DC CMRR, input impedance,
*   open loop gain, voltage ranges, supply current, ... , etc.
*
* Not Supported:
*   Variation in specs vs. Power Supply Voltage
*   Distortion (detailed non-linear behavior)
*   Temperature analysis
*   Process variation
*   Behavior outside normal operating region
*
* Input Stage
V10  3 10 -300M
R10  10 11 6.90K
R11  10 12 6.90K
C11  11 12 115E-15
C12  1  0 6.00P
E12  1 14 POLY(4) 20 0 21 0 26 0 27 0   1.00M 20.1 20.1 1 1
I12  14  0 1.50P
M12  11 14 15 15 NMI L=2.00U W=42.0U
C13  14  2 3.00P
M14  12  2 15 15 NMI L=2.00U W=42.0U
I14  2  0 500E-15
C14  2  0 6.00P
I15  15  4 50.0U
V16  16  4 300M
D16  16 15 DL
V13  3 13 50M
D13  14 13 DL
*
* Noise, PSRR, and CMRR
I20  21 20 423U
D20  20  0 DN1
D21  0 21 DN1
G26  0 26 POLY(1) 3 4   110U -20.0U
R26  26  0 1
G27  0 27 POLY(2) 1 3 2 4   -440U 80.0U 80.0U
R27  27  0 1
*
* Open Loop Gain, Slew Rate
G30  0 30 POLY(1) 12 11   0 1.00K
R30  30  0 1
E31  31  0 POLY(1) 3 4   104 -2.33
D31  30 31 DL
```

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```
E32  0 32 POLY(1) 3 4   140 -6.07
D32 32 30 DL
G33  0 33 POLY(1) 30 0   0 447
R33 33  0 1
C33 33  0 77.1M
G34  0 34 POLY(1) 33 0   0 1.00
R34 34  0 1.00
C34 34  0 50.2N
G35  0 35 POLY(2) 34 0 33 34   0 1.00 3.00
R35 35  0 1.00
*
* Output Stage
G50  0 50 POLY(1) 57 5   0 2.00
D51 50 51 DL
R51 51  0 1K
D52 52 50 DL
R52 52  0 1K
G53  3  0 POLY(1) 51 0   50.0U 1M
G54  0  4 POLY(1) 52 0   50.0U -1M
E55 55  0 POLY(2) 3 0 51 0   -10M 1 -40.0M
D55 57 55 DLS
E56 56  0 POLY(2) 4 0 52 0   10M 1 -40.0M
D56 56 57 DLS
G57  0 57 POLY(3) 3 0 4 0 35 0   0 1.00M 1.00M 2.00M
R57 57  0 500
R58 57  5 500M
C58  5  0 2.00P
*
* Models
.MODEL NMI NMOS
.MODEL DL  D   N=1   IS=1F
.MODEL DLS D   N=10M IS=1F
.MODEL DN1 D   IS=1F KF=146E-18 AF=1
*
.ENDS MCP6001

.END
```

Appendix B. Filter Magnitude Templates

B.1 INTRODUCTION

B.1.1 LOW-PASS FILTER MAGNITUDE RESPONSE

The magnitude response of low-pass filters is shown in Figure B-1.

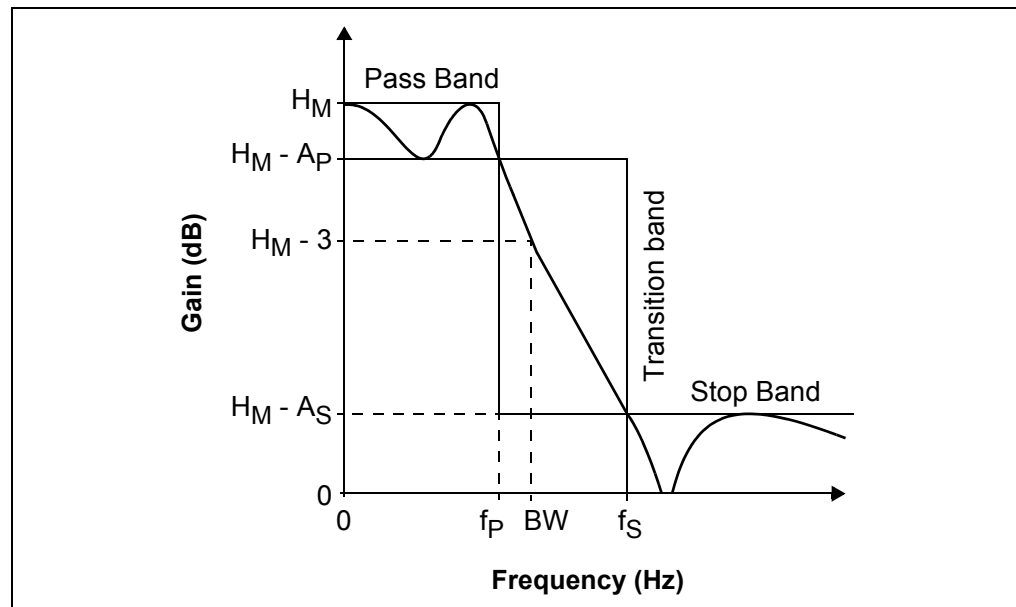


FIGURE B-1: Low-pass Filter Template.

The nominal filter response is required to stay within the three regions shown (pass band, transition band and stop band). The relevant parameters for the three regions and the controlling inequalities are:

- Pass Band

- H_M = Maximum Pass Band Gain (dB)
- A = Attenuation (relative to H_M) (dB)
- A_P^* = Pass Band Ripple/Max. Attenuation (dB)
- f_P^* = Pass Band Frequency (Hz)
- BW = -3 dB Bandwidth
- $0 \leq f \leq f_P$
- $0 \leq A \leq A_P$

* sometimes referred to as cut-off

- Transition Band

- $f_P \leq f \leq f_S$
- $A_P \leq A \leq A_S$

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- Stop Band

f_S = Stop Band Edge Frequency (Hz)

A_S = Minimum Stop Band Attenuation (dB)

$f_S \leq f$

$A_S \leq A$

The gain parameter in FilterLab (G) corresponds to the DC gain (for good sensitivity performance). Thus,

$G = H_M$; Bessel, Butterworth and Chebychev ($n = 1, 3, 5, 7$)

$G = H_M - A_P$; Chebychev ($n = 2, 4, 6, 8$)

Note: The *Frequency Response* plot in FilterLab 2.0 does not show even order Chebychev responses correctly.

The limits that FilterLab 2.0 enforces on these low-pass parameters are:

$0.1 \text{ Hz} \leq f_P < f_S \leq 1.0 \text{ MHz}$

$A_P = 3.0 \text{ dB}$, Bessel Filters

$0.01 \text{ dB} \leq A_P \leq 3.0 \text{ dB}$, Butterworth and Chebychev

$10 \text{ dB} \leq A_S \leq 100 \text{ dB}$

$1V/V \leq G \leq 10V/V$, (0 dB to 20 dB)

B.1.2 BAND-PASS FILTER MAGNITUDE RESPONSE

The magnitude response of band-pass filters is shown in Figure B-2.

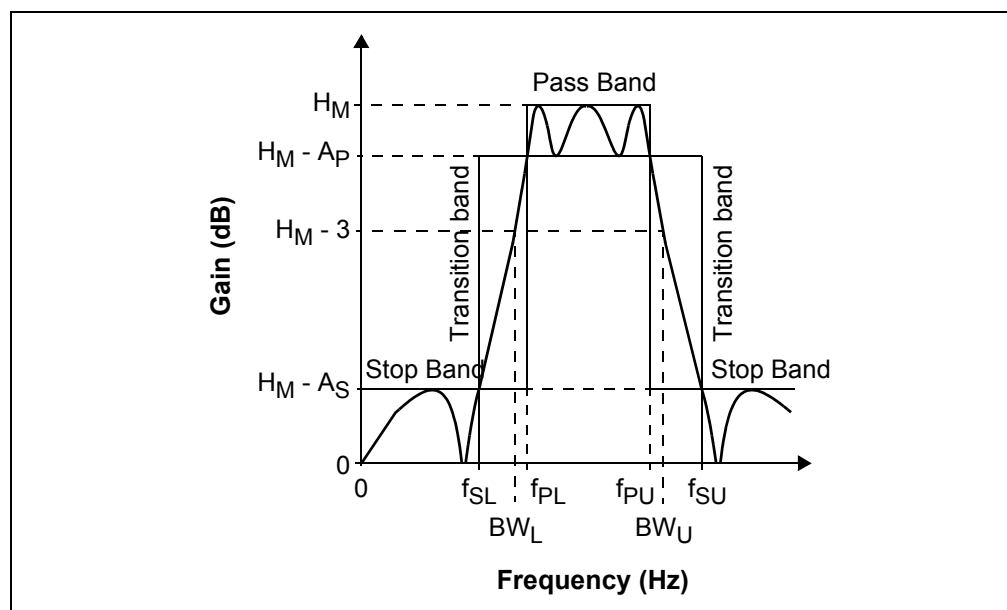


FIGURE B-2: Band-pass Filter Template.

The nominal filter response is required to stay within the five regions shown (pass band, two transition bands and two stop bands). The relevant parameters for the three regions and the controlling inequalities are:

- Lower Stop Band

f_{SL} = Lower Stop Band Edge Frequency (Hz)

A_S = Min. Stop Band Attenuation (dB)

$f \leq f_S$

$A_S \leq A$

- Lower Transition Band

$f_{SL} < f < f_{PL}$

$A_P < A < A_S$

- Pass Band

f_{PL}^* = Lower Pass Band Frequency (Hz)

f_{PU}^* = Upper Pass Band Frequency (Hz)

BW_L = Lower -3 dB Bandwidth

BW_U = Upper -3 dB Bandwidth

H_M = Maximum Pass Band Gain (dB)

A = Attenuation (relative to H_M) (dB)

A_P^* = Pass Band Ripple/Max. Attenuation (dB)

$f_{PL} \leq f \leq f_{PU}$

$0 \leq A \leq A_P$

* sometimes referred to as cut-off

- Upper Transition Band

$$f_{PU} < f < f_{SU}$$

$$A_P < A < A_S$$

- Upper Stop Band

$$f_{SU} = \text{Upper Stop Band Edge Frequency (Hz)}$$

$$A_S = \text{Min. Stop Band Attenuation (dB)}$$

$$f_{SU} \leq f$$

$$A_S \leq A$$

The gain parameter in FilterLab 2.0 (G) corresponds to the midband gain (for ease of implementation), where:

$$f_0 = \text{Midband Frequency}$$

$$= (f_{PL} f_{PU})^{1/2}$$

Thus,

$$G = H_M; \quad \text{Bessel, Butterworth and Chebychev (n = 2, 6)}$$

$$G = H_M - A_P; \quad \text{Chebychev (n = 4, 8)}$$

Note: The *Frequency Response* plot in FilterLab 2.0 does not show Chebychev response correctly for orders 4 and 8.

The limits that FilterLab 2.0 enforces on these band-pass parameters are:

$$0.1 \text{ Hz} \leq f_{SL} < f_{PL} < f_{PU} < f_{SU} \leq 1.0 \text{ MHz}$$

$$1.2210 \leq f_{PU}/f_{PL} \leq 5.8284$$

$$0.01 \text{ dB} \leq A_P \leq 3.0 \text{ dB}$$

$$10 \text{ dB} \leq A_S \leq 100 \text{ dB}$$

$$1 \text{ V/V} \leq G \leq 10 \text{ V/V, (0 dB to 20 dB)}$$

If the ratio f_{PU}/f_{PL} is larger than 5.8284, the wider pass band can be designed by cascading a low-pass and high-pass filter. If the ratio f_{PU}/f_{PL} is smaller than 1.2210, the narrow pass band cannot be implemented with this version of FilterLab 2.0.

B.1.3 HIGH-PASS FILTER MAGNITUDE RESPONSE

The magnitude response of high-pass filters is shown in Figure B-3.

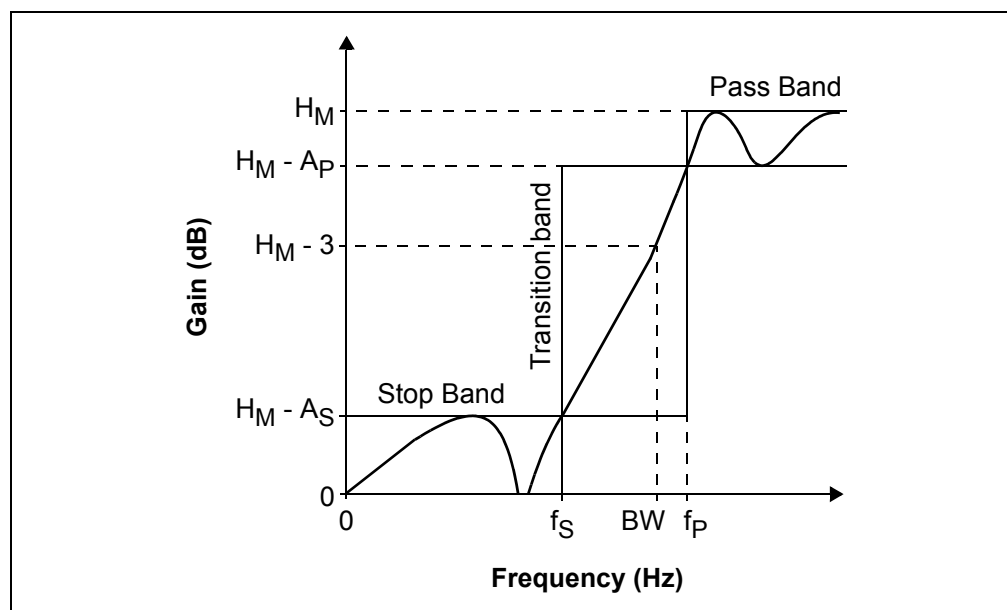


FIGURE B-3: High-pass Filter Template.

The nominal filter response is required to stay within the three regions shown (pass band, transition band and stop band). The relevant parameters for the three regions and the controlling inequalities are:

- Pass Band

- f_P^* = Pass Band Frequency (Hz)
- BW = -3 dB Bandwidth
- H_M = Maximum Pass Band Gain (dB)
- A = Attenuation (relative to H_M) (dB)
- A_P^* = Pass Band Ripple/Max. Attenuation (dB)
- $f_P \leq f$
- $0 \leq A \leq A_P$
- * sometimes referred to as cutoff

- Transition Band

- $f_S < f < f_P$
- $A_P < A < A_S$

- Stop Band

- f_S = Stop Band Edge Frequency (Hz)
- A_S = Min. Stop Band Attenuation (dB)
- $f \leq f_S$
- $A_S \leq A$

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The gain parameter in FilterLab 2.0 (G) corresponds to the high-frequency gain (at "infinity" for good sensitivity performance). Thus,

$$G = H_M; \quad \text{Bessel, Butterworth and Chebychev (n = 1, 3, 5, 7)}$$

$$G = H_M - A_P; \quad \text{Chebychev (n = 2, 4, 6, 8)}$$

Note: The *Frequency Response* plot in FilterLab 2.0 does not show even order Chebychev responses correctly.

The limits that FilterLab 2.0 enforces on these high-pass parameters are:

$$0.1 \text{ Hz} \leq f_S < f_P \leq 1.0 \text{ MHz}$$

$$0.01 \text{ dB} \leq A_P \leq 3.0 \text{ dB}$$

$$10 \text{ dB} \leq A_S \leq 100 \text{ dB}$$

$$1 \text{ V/V} \leq G \leq 10 \text{ V/V, (0 dB to 20 dB)}$$

Appendix C. Group Delay

C.1 INTRODUCTION

Group delay is a measure of time domain response. It focuses on the relative delay among sine waves of nearly equal frequency. Its usual definition is:

$$\begin{aligned}\Omega &= \text{Radian Frequency (rad/s)} \\ \phi(\omega) &= \text{Phase Response (rad)} \\ &= \text{atan}(\text{Im}\{G\}/\text{Re}\{G\}) \\ \tau_{gd}(\omega) &= \text{group delay (s)} \\ &= -d\phi(\omega)/d\omega\end{aligned}$$

An equivalent definition, when frequency is in Hz and phase is in degrees, is:

$$\begin{aligned}f &= \text{Frequency (Hz = cycles/s)} \\ \phi(f) &= \text{Phase Response (}^\circ\text{)} \\ &= \text{atan}(\text{Im}\{G\}/\text{Re}\{G\}) \\ \tau_{gd}(f) &= \text{group delay (s)} \\ &= (1 \text{ cycle}/360^\circ) (-d\phi(f) / df)\end{aligned}$$

Figure C-1 and Figure C-2 illustrate phase and group delay.

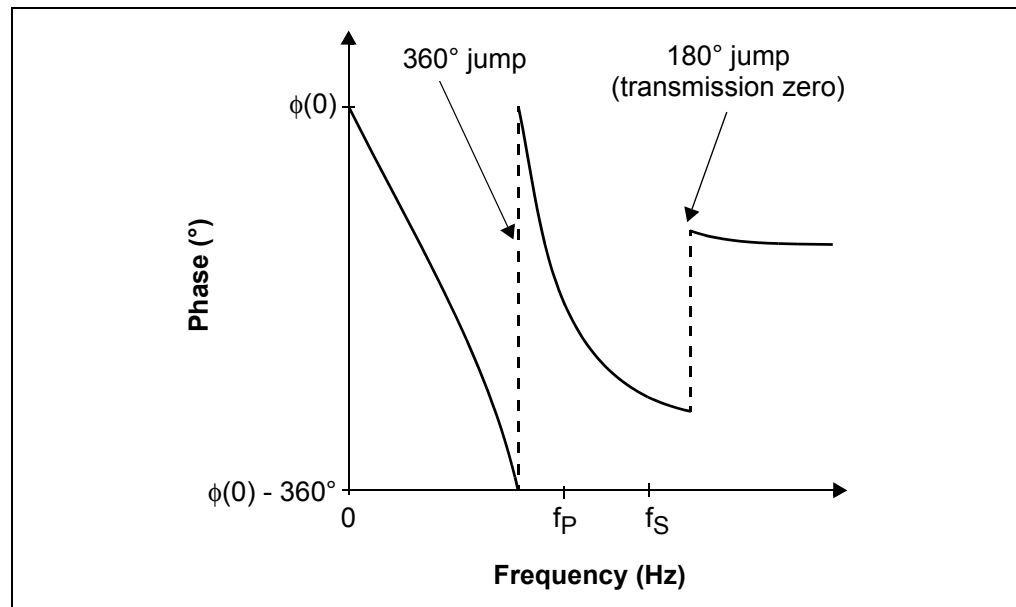


FIGURE C-1: Low-pass Phase Response.

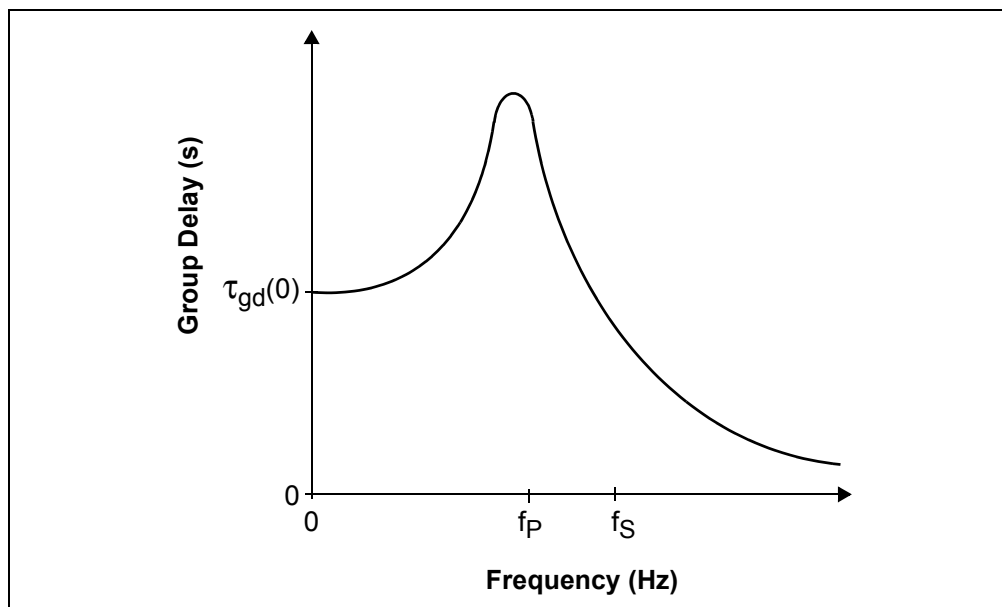


FIGURE C-2: Low-pass Group Delay.

Some reasons that group delay has been traditionally used for filter work are:

- It is easier to manipulate mathematically (no arc-tangent functions)
- Group delay is easier to optimize
 - Its jump discontinuities are only at transmission zeros on the $j\omega$ -axis (gain is zero)
 - It is a non-negative function for low-pass filters
- It applies directly to AM modulated signals
 - The information is delayed by the group delay (also known as envelope delay)
 - It maps directly to group delay at baseband
 - The carrier is delayed by a different time (total phase shift divided by carrier frequency)
- It is a good indicator of low-pass step response quality
 - Constant group delay in the pass band, and well into the transition band ($A < 10$ dB to 20 dB), indicates a very good step response
 - Group delay with peaking (usually near f_P) indicates overshoot and ringing

Appendix D. FilterLab 2.0 Filter Response

D.1 INTRODUCTION

Bessel (low-pass) filters are mainly used for applications that need excellent step response. The emphasis is on phase and group delay; the frequency selectivity is poor compared to the other classical filter response functions (e.g., Butterworth). Some typical applications are: PWM communications channels, instrumentation and simple anti-aliasing filters for ADCs.

Figure D-1 and Figure D-2 show the normalized frequency response. Increasing the filter order does not provide a significant improvement in the stop band rejection. Figure D-3 shows the normalized group delay, Figure D-4 shows the normalized step response. The step response overshoot is minimal.

FilterLab 2.0 does not allow the user to select Bessel filters based on their frequency response. Use Figure D-3 and Figure D-4 to choose the order based on group delay and step response.

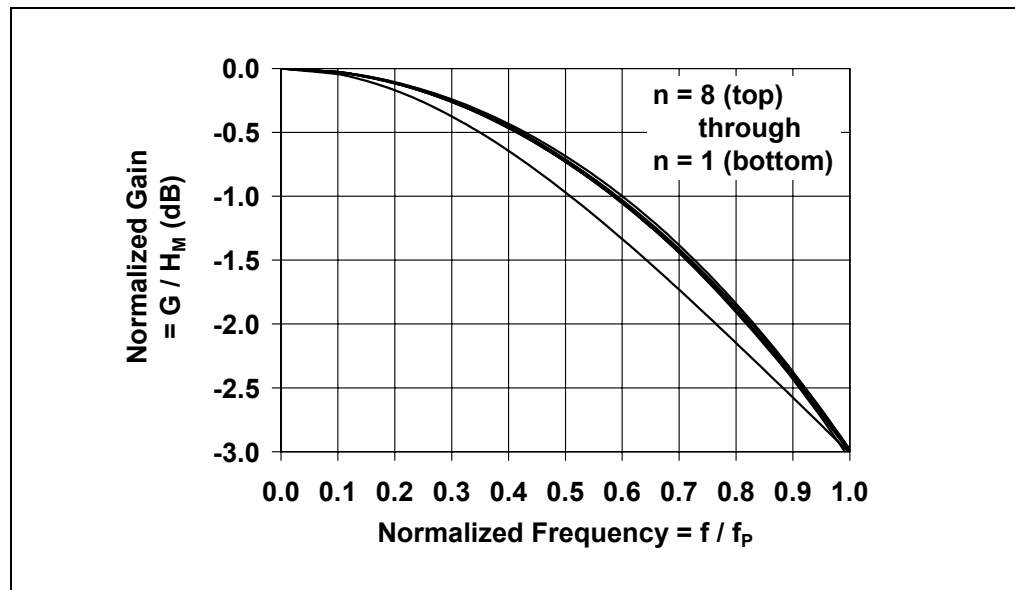


FIGURE D-1: Normalized Bessel frequency response in the pass band.

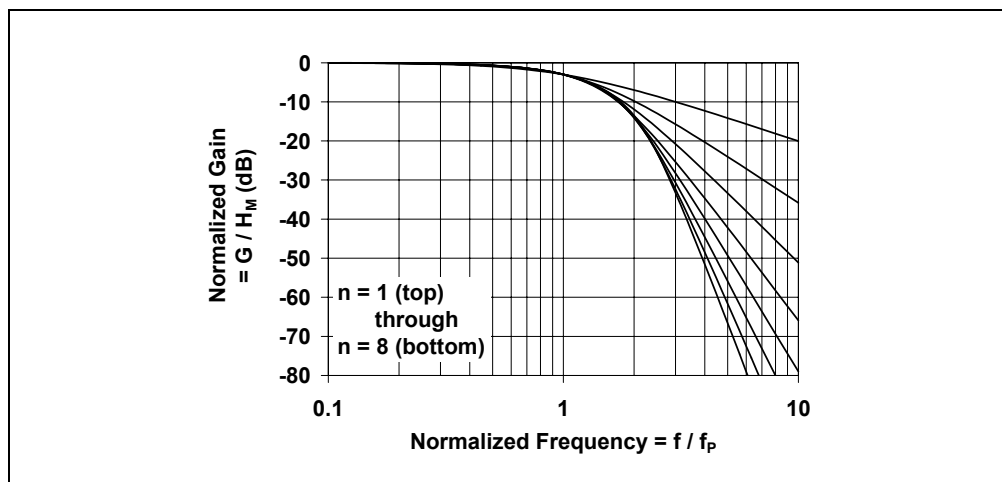


FIGURE D-2: Normalized Bessel frequency response in the stop band.

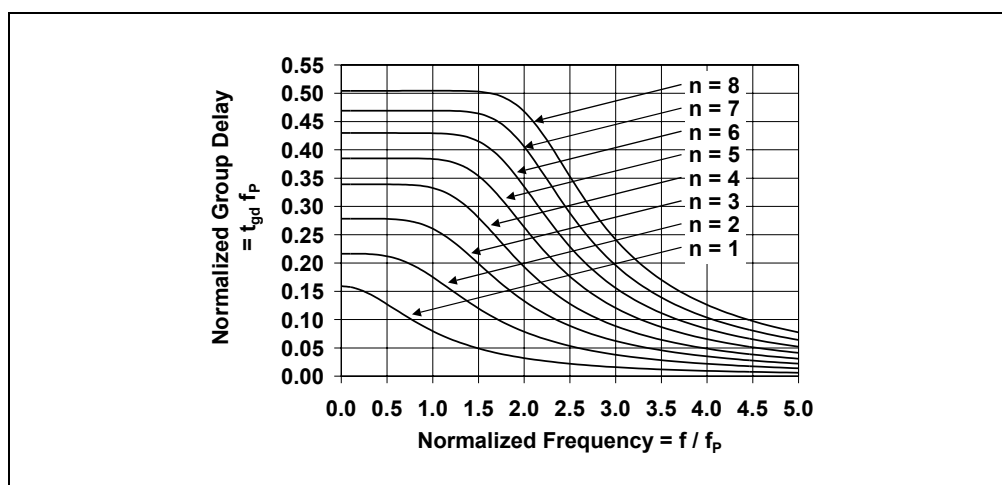


FIGURE D-3: Normalized Bessel group delay.

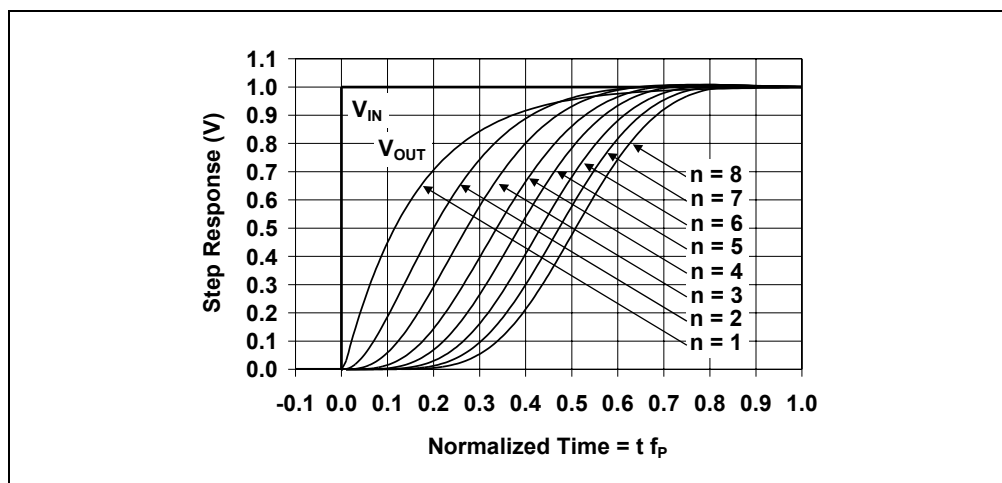


FIGURE D-4: Normalized Bessel step response.

Appendix E. Op Amp Selection

E.1 INTRODUCTION

E.1.1 OP AMP SMALL SIGNAL BANDWIDTH

The op amps you select for your filter need to be fast enough to avoid problems with non-linear distortion and filter response distortion. A crude estimate of the op amp GBWP (Gain Bandwidth Product) that you need for a filter section is:

$$\begin{aligned} \text{GBWP} &= K \cdot 100 \cdot f_p \quad \text{low-pass} \\ &= K \cdot Q \cdot 100 \cdot f_{PU} \quad \text{band-pass} \\ &= K \cdot \max \{100 \cdot f_p, f_{\max}\} \quad \text{high-pass} \end{aligned}$$

Where:

$$\begin{aligned} K &= \text{Filter section's gain (V/V)} \\ f_p &= \text{Low-pass and high-pass filters' pass band frequency (Hz)} \\ f_{PU} &= \text{Band-pass filter's upper pass band frequency (Hz)} \\ Q &= \text{Band-pass filter's overall Q-factor} \\ &= 1 / \text{"fractional bandwidth"} \\ &= (f_{PL} \cdot f_{PU})^{1/2} / (f_{PU} - f_{PL}) \\ f_{\max} &= \text{Maximum pass band/signal frequency for high-pass response } \gg f_p \end{aligned}$$

Try op amps with different GBWPs to see what you require. Small signal frequency response (typically $V_{OUT} < 100 \text{ mV}_{P-P}$) starts to peak as the GBWP goes too low. Harmonic distortion also grows as the GBWP goes lower.

E.1.2 OP AMP FULL-POWER BANDWIDTH

The op amps also need to handle large signals. The SR (Slew Rate) specified in our op amp data sheets is related to the full-power bandwidth as follows.

$$\begin{aligned} f_{FPBW} &= \text{SR} / (\pi \cdot V_{OUT_P-P}) \text{ (Hz)} \\ \text{Where:} \\ V_{OUT_P-P} &= \text{Filter section's maximum output voltage swing (V}_{P-P}\text{)} \\ &< V_{DD} - V_{SS} \\ \text{SR} &= \text{Slew rate (V/s); data sheets usually give units of V/}\mu\text{s} \\ &\quad (1 \text{ V/}\mu\text{s} = 1,000,000 \text{ V/s)} \\ f_{FPBW} &= \text{op amp full-power bandwidth (Hz)} \end{aligned}$$

Sine waves faster than f_{FPBW} will not be faithfully reproduced because their derivative (slew rate) is too high.

In order to keep harmonic (non-linear) distortion to a minimum, the recommended minimum SR for all op amps in the filter is:

$$\begin{aligned} \text{SR} &= X_{\text{FF}} \pi V_{\text{OUT_P-P}} f_p, \text{ low-pass} \\ &= X_{\text{FF}} \pi V_{\text{OUT_P-P}} f_{\text{PU}}, \text{ band-pass} \\ &= X_{\text{FF}} \pi V_{\text{OUT_P-P}} f_{\text{max}}, \text{ high-pass} \end{aligned}$$

Where:

$$\begin{aligned} f_p &= \text{Low-pass and high-pass filters' pass band frequency (Hz)} \\ f_{\text{PU}} &= \text{Band-pass filter's upper pass band frequency (Hz)} \\ f_{\text{max}} &= \text{Maximum pass band/signal frequency for high-pass response } \gg f_p \\ X_{\text{FF}} &= \text{rough fudge factor for distortion performance (relative to fundamental)} \\ &\approx 2, \quad \text{THD}_{\text{SR}} = -60 \text{ dBc} \\ &\approx 4, \quad \text{THD}_{\text{SR}} = -72 \text{ dBc} \\ &\approx 8, \quad \text{THD}_{\text{SR}} = -84 \text{ dBc} \\ &\approx 16, \quad \text{THD}_{\text{SR}} = -96 \text{ dBc} \\ \text{THD}_{\text{SR}} &= \text{Slew Rate induced distortion level (dBc)} \end{aligned}$$

Note that non-linear distortion may include a DC offset term.

E.1.3 OP AMP OUTPUT LOADING

Choose the resistance values in your filter so that the op amp is not overloaded. A compromise among loading, noise and parasitic RC time constants needs to be made. To scale the resistor values, change the capacitor values in the *Filter Design* dialog box within FilterLab 2.0.

E.1.4 MINIMUM GAIN

Most op amps are unity gain stable ($G \geq +1 \text{ V/V}$). A few op amps need to be set at higher gains to remain stable (e.g., $G \geq +10 \text{ V/V}$ for the MCP6141). If you need gain in your filter, this kind of part can give you the bandwidth and gain you need for less quiescent current. Note that inverting gains, used in Multiple Feedback (MFB) sections, have an equivalent "noise gain" that is used to determine stability. It is calculated as: $1 + |G|$ (e.g., a signal gain of -1 V/V gives a noise gain of $+2 \text{ V/V}$).

E.1.5 CURRENT MICROCHIP OP AMPS

The following table shows the Microchip op amps recommended for new designs as of October 1, 2003. See our web site (www.microchip.com) for the latest information.

TABLE E-1: MICROCHIP OP AMPS

Op Amp Family	# Amplifiers	GBWP (Hz)	SR (V/μs)	Rail to Rail Input/Output	Supply Voltage (V)	Comments
MCP6041	1, 2, 4	14k	0.003	I/O	1.4-5.5	
TC1034	1, 2, 4	90k	0.035	I/O	1.8-5.5	Also TC1026, TC1029, TC1030, TC1035
MCP6141	1, 2, 4	100k	0.024	I/O	1.4-5.5	Gain ≥ 10 V/V
MCP606	1, 2, 4	155k	0.08	O	2.5-5.5	
MCP616	1, 2, 4	190k	0.08	O	2.3-5.5	Bipolar (PNP) input
TC7652	1	400k	1.0	O	6.5-16.0	Chopper Stabilized ($V_{OS} \leq \pm 5 \mu V$)
MCP6001	1, 2, 4	1.0M	0.6	I/O	1.8-5.5	
TC913	2	1.5M	2.5	—	6.5-16.0	Chopper Stabilized ($V_{OS} \leq \pm 15 \mu V$)
TC7650	1	2.0M	2.5	O	6.5-16.0	Chopper Stabilized ($V_{OS} \leq \pm 5 \mu V$)
MCP6271	1, 2, 4	2.0M	0.9	I/O	2.0-5.5	
MCP601	1, 2, 4	2.8M	2.3	O	2.7-5.5	
MCP6281	1, 2, 4	5.0M	2.5	I/O	2.2-5.5	
MCP6291	1, 2, 4	10.0M	7.0	I/O	2.4-5.5	
MCP6021	1, 2, 4	10.0M	7.0	I/O	2.5-5.5	

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NOTES:

Appendix F. Selected References

F.1 INTRODUCTION

F.1.1 FILTER TEXTBOOKS AND CLASSIC REFERENCES

- [1] Arthur B. Williams and Fred J. Taylor, *Electronic Filter Design Handbook*, 3rd ed., McGraw-Hill, 1995.
- [2] Rolf Schaumann, M.S. Ghausi, and Kenneth R. Laker, *Design of Analog Filters: Passive, Active RC, and Switched Capacitor*, Prentice Hall, 1990.
- [3] Andreas Antoniou, *Digital Filters: Analysis and Design*, McGraw-Hill, 1979.
- [4] Anatol I. Zverev, *Handbook of Filter Synthesis*, Wiley, John & Sons, 1967.
- [5] Rolf Schaumann, Mac E. Van Valkenburg, and Mac Van Valkenburg, *Design of Analog Filters*, 2nd ed., Oxford University Press, 2001.

F.1.2 APPLICATION NOTES

- [1] Bonnie Baker, *Anti-Aliasing, Analog Filters for Data Acquisition Systems*, Application Note 699, DS00699, Microchip Technology Inc., 1999.



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