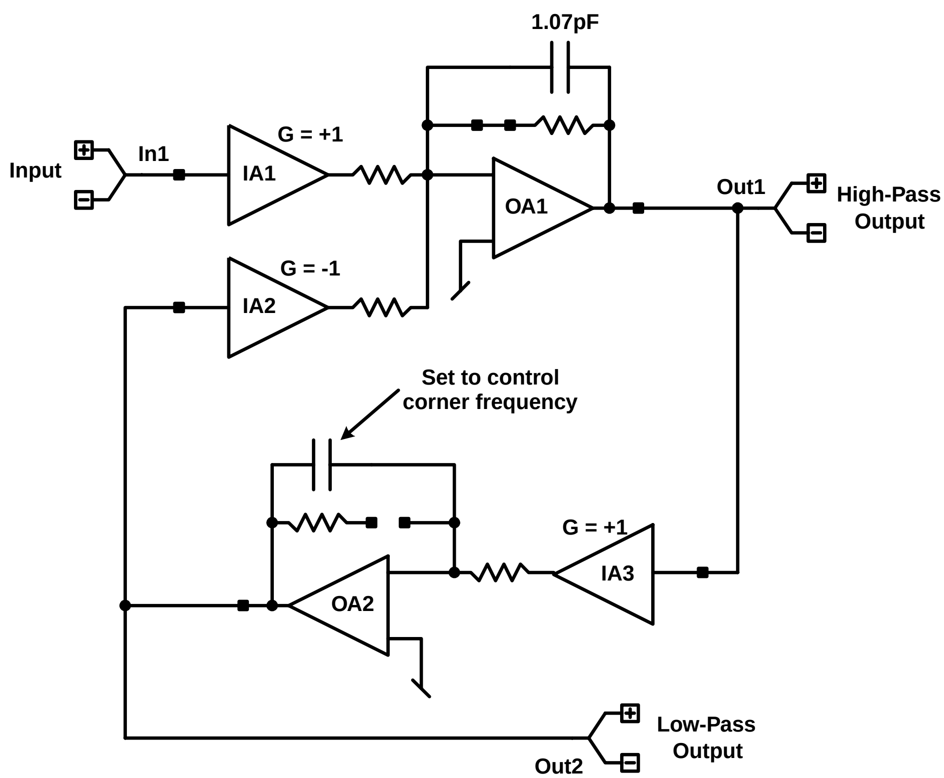
Combo High-Pass/Low-Pass Filter

February 2001 **Circuit Solution**

Because ispPAC® PACblocks feature a programmable first-order low-pass filter section, it is very easy to use them as first-order filters over the frequency range of 10kHz-500kHz. How to implement a high-pass filter, however, is not as obvious. While one can take the output from a low-pass section and subtract it from the original signal (using a second PACblock), the results of this approach are not entirely satisfactory. Because of gain mismatches between amplifiers, it is difficult to get a DC response much lower than -40dB when using this approach. A better method is to use a closed-loop feedback arrangement such as that shown in Figure 1. This filter uses two PACblocks, so one of these filters can be implemented in an ispPAC20 and two of them can be implemented with a single ispPAC10.

Figure 1. Filter with Both High-pass and Low-pass Outputs

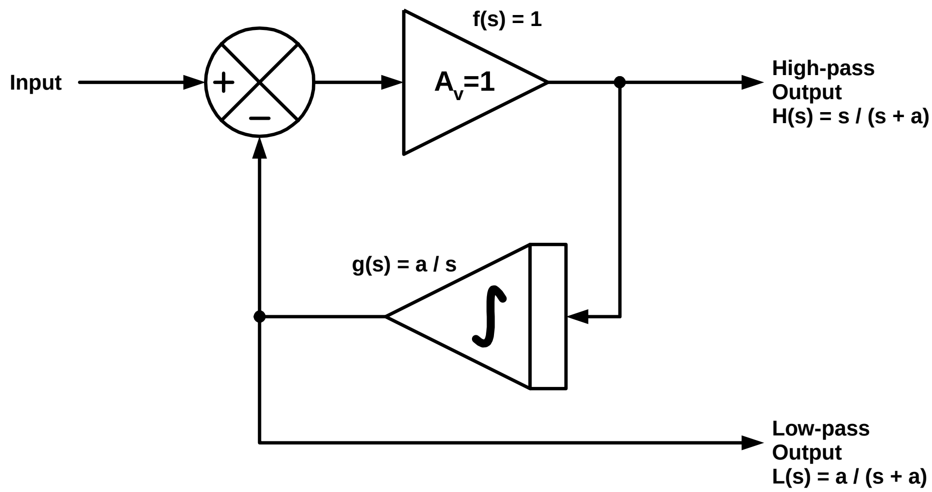


To understand how this circuit obtains a high-pass response requires a small amount of analysis of the feedback loop. To do this we will used a simplified model, which ignores the dynamics of the amplifiers, and the additional high-frequency pole resulting from OA1's feedback capacitor. Figure 2 shows the feed-forward function g(s), and the feedback function h(s).

For a general linear feedback loop, the overall transfer function is given by equation 1:

$$H(s) = \frac{f(s)}{1 + f(s)g(s)} \tag{1}$$

Figure 2. Filter Block Diagram



For this particular loop, g(s)=1, and h(s)=a/s, a/s representing an integrator with a gain of 'a.' This results in the transfer function given by equation 2:

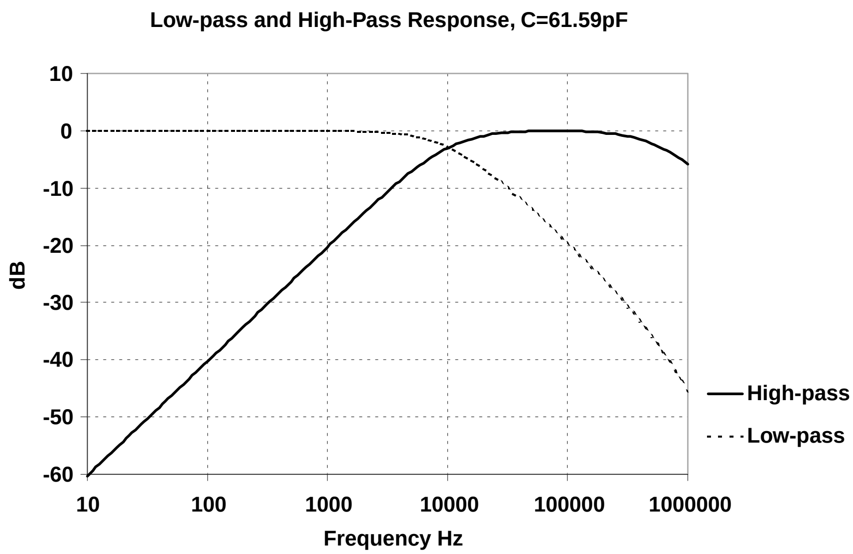
$$H(s) = \frac{1}{1 + a/s} = \frac{s}{s+a} \quad (2)$$

This transfer function describes a filter with a DC (s=0) gain of zero, in which the gain will approach unity as the frequency increases toward infinity ($s \to \infty$). This is the transfer function for a high-pass filter with a single pole located at -a and a zero located at the origin (zero frequency). A low-pass function can be obtained at the output of the integrator. This corresponds to multiplying by the integrator's gain of a/s. This yields the transfer function given in equation 3.

$$L(s) = \frac{a}{s+a} \quad (3)$$

This is the transfer function of a low-pass filter with a single pole at -a and unity gain at DC. Because both filter functions have the same pole location, they theoretically have identical corner frequencies. In practice, because of the finite bandwidth of OA1, the corner frequencies for the low-pass and high-pass functions will be slightly different. The corner frequency can be adjusted by varying OA2's feedback capacitor. The actual corner frequency for both filter functions will vary slightly from that listed for the capacitor value in PAC-Designer®, also because of finite bandwidth issues. Another effect of the PACblock's finite bandwidth is that the 'highpass' response curve will begin to roll off around 500kHz, in actuality being a band-pass filter with an adjustable lower limit. The low-pass and high-pass responses of this filter are shown in Figure 3.

Figure 3. Magnitude Response of Filter Outputs



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