Inverting amplifier flips filter's response curve

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The voltage-controlled bandpass filter so popular in music synthesizers and useful in remote-tuned receivers can be also made to work in the band-reject mode by placing an inverting operational amplifier stage in the existing filter's input/output feedback loop. In that way, a controlled notch, which is often equally valuable in the aforementioned applications, may be put together at low cost.

The transfer function of the typical VCF is given by:

$$H(s) = (s/\omega_o)/[(s/\omega_o)^2 + 2k(s/\omega_o) + 1]$$

where ω_o is the voltage-controlled resonant frequency and k is the damping factor, which is usually adjusted with a potentiometer. It is seen that when k is at its maximum, the response approaches that of a wideband filter. As k decreases, the filter's Q increases, and the bandwidth therefore decreases. At the limit, for a value of k that is slightly negative, the system oscillates at ω_o.

By adding the operational amplifier and its gain-controlling resistors to the feedback loop of the VCF as shown in (a), the output voltage generated is:

$$V_o(s) = -V_o(s)H(s) - V_i(s)$$

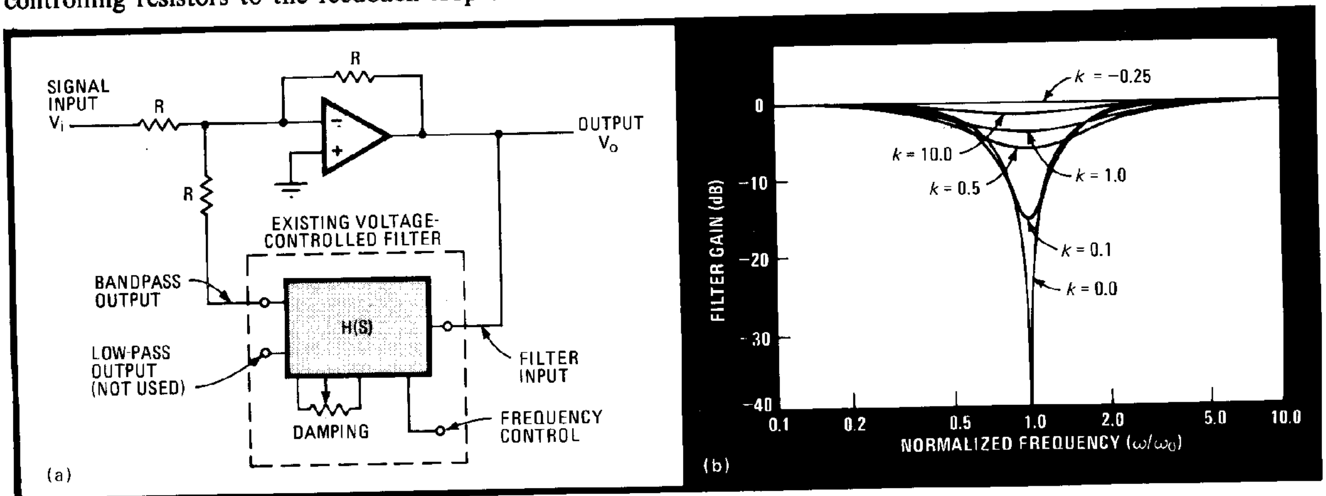
This expression leads to the transfer function:

$$H'(s) = \frac{V_o(s)}{V_i(s)} = \frac{(s/\omega_o)^2 + 2k(s/\omega_o) + 1}{(s/\omega_o)^2 + (2k+1)(s/\omega_o) + 1}$$

This function has two zeros and two correspondingly equal poles. But although the absolute value of both pairs is the same, for $k > -0.25$ the poles will be more damped than the zeros, and thus the filter's frequency response will be mainly determined by the zeros. Therefore, the system will operate as a band-reject filter (b).

The deepest null is attained at $k = 0$, and a theoretically infinite attenuation is thereby achieved at $\omega = \omega_o$. Thus the filter can be tuned to null the fundamental frequency of any synthesized signal, leaving only its harmonics. If the frequency control is simultaneously fed with a low-frequency sine or triangle wave, the so-called phaser sound used for special effects is obtained.

As k is increased toward infinity, the null becomes less sharp and the filter offers almost no attenuation at any frequency, thereby behaving as a quasi–all-pass network. Note that as k increases beyond $k = 10$, the filter response approaches that of $k = -0.25$. Clearly, k should not be less than -0.25, because the poles of the function will again become prominent and the system will once more behave as a bandpass filter. At $k < -0.50$, the system will oscillate. □



Double duty. Adding inverting op-amp stage into feedback loop of music synthesizer voltage-controlled bandpass filter (a) adapts it for band-rejection duties. Notch depth (b), selected by filter's damping potentiometer, may be adjusted for a maximum value of −60 dB.