Transistorized Band-Pass Filter

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A simple transistor circuit which can be used as described for band-pass action, or either high-pass or low-pass filters may be used alone. With still further modification, the circuit becomes a crossover network.

With the advent of the stereophonic record, two old problems have once again presented themselves—the extraneous noises at the frequency extremes, caused respectively by turntable rumble and record wear. Rumble is obviously important in stereo, as the stereo pickup is inherently sensitive to vertical motion of the stylus. Similarly, since the signal amplitudes in stereo must be lower than in monophonic reproduction, the high-frequency noises are also more troublesome. A solution to both of these problems is a sharp-cutoff filter for both low and high frequencies, so that the full bandwidth is used only when the program material warrants it. Recent work in active filters has made it possible to accomplish these ends with a simple transistorized filter to be described.

Consider the circuit of *Fig.* 1: it can be shown that the voltage gain is given by

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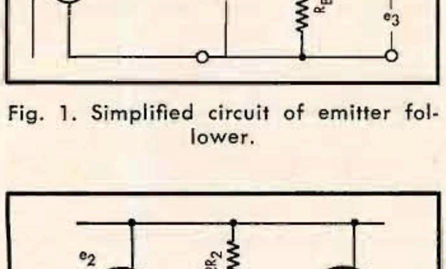


Fig. 1. Simplified circuit of emitter follower.

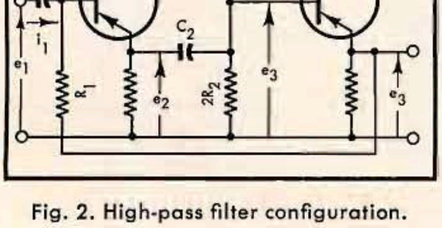


Fig. 2. High-pass filter configuration.

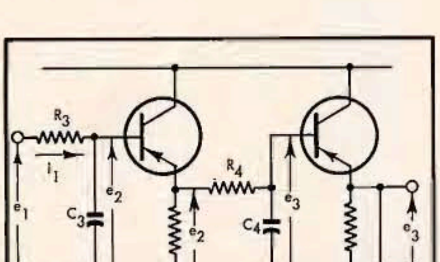


Fig. 3. Low-pass filter configuration.

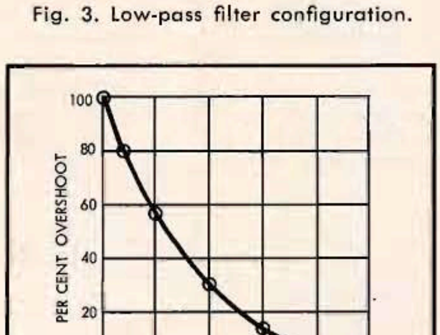


Fig. 4. Plot of overshoot vs. ζ (From "Automatic Feedback Control System Synthesis," J. Truxal, p. 39.)

$$\frac{e_2}{e_1} = \frac{\beta R_E}{\beta R_E + r_{bb} + \dfrac{1}{g_{b'e}}} \qquad (1)$$

and that the input impedance will be

$$\frac{e_2}{i_1} = r_{bb} + \frac{1}{g_{b'e}} + \beta R_E \qquad (2)$$

If we use a 2N109 transistor and make $R_g = 10{,}000$ and $R_e = 4000$, the gain is approximately 0.97 and the input impedance 362K. Thus it is seen that a simple emitter follower can do an excellent job within its frequency and signal handling limitations. In the foregoing analysis, it will be assumed that the gain is exactly unity and the input impedance infinite.

Consider next the circuit of *Fig.* 2, which uses the above approximations. The respective equations will be

$$e_2 = e_1 - i_1\left(\frac{1}{C_1 S}\right) \text{where } S = j2\pi f \qquad (3)$$

$$e_3 = e_2\left(\frac{R_2}{R_2 + \dfrac{1}{C_2 S}}\right) = \frac{e_2 R_2 C_2 S}{1 + R_2 C_2 S} \qquad (4)$$

$$i_1 = \frac{e_1 - e_3}{R_1 + \dfrac{1}{C_1 S}} = \frac{(e_1 - e_3) C_1 S}{1 + R_1 C_1 S} \qquad (5)$$

If we combine these equations and solve for the gain, we have

$$\frac{e_3}{e_1} = \frac{R_1 R_2 C_1 C_2 S^2}{S^2 R_1 R_2 C_1 C_2 + S R_1 C_1 + 1} \qquad (6)$$

This is of the form $\dfrac{S^2}{S^2 + 2\omega_1 \zeta S + \omega_1{}^2}$

where

$$\omega_1 = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}} \text{ and } \zeta = \frac{1}{2}\sqrt{\frac{R_1 C_1}{R_2 C_2}},$$

which can be shown to give a high pass filter of frequency cutoff ω_1 and damping factor ζ.

In a similar way, look at the circuit of *Fig.* 3, which also uses the approximations that an emitter follower has unity gain and infinite input impedance.

$$e_2 = e_1 - i_1 R_3 \qquad (7)$$

$$e_3 = e_2\left(\frac{\dfrac{1}{C_4 S}}{R_4 + \dfrac{1}{C_4 S}}\right) = \frac{e_2}{1 + R_4 C_4 S} \qquad (8)$$

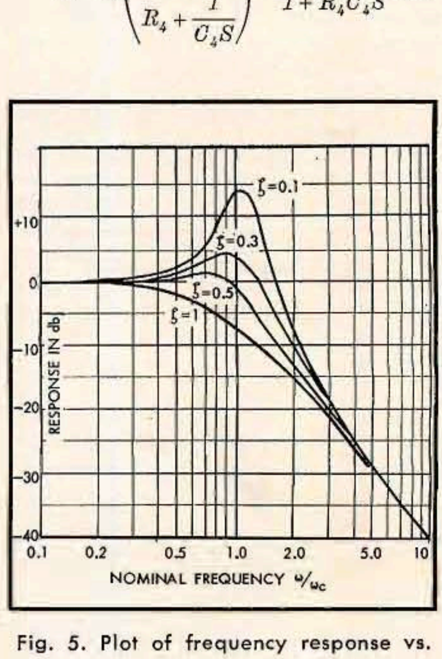
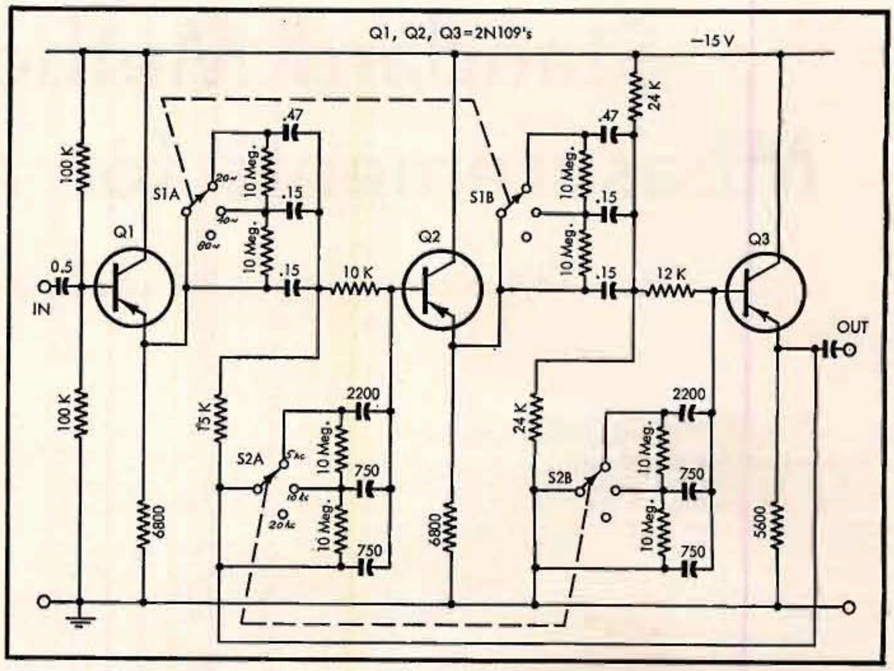


Fig. 5. Plot of frequency response vs.

Fig. 6. Schematic of band-pass filter employing transistors.



$$i_1 = \frac{e_1 - e_3}{R_3 + \frac{1}{C_3 S}} = \frac{(e_1 - e_3)C_3 S}{1 + R_3 C_3 S} \qquad (9)$$

Again if we combine these equations and solve for the gain,

$$\frac{e_3}{e_1} = \frac{1}{S^2 R_3 R_4 C_3 C_4 + R_4 C_4 S + 1} \qquad (10)$$

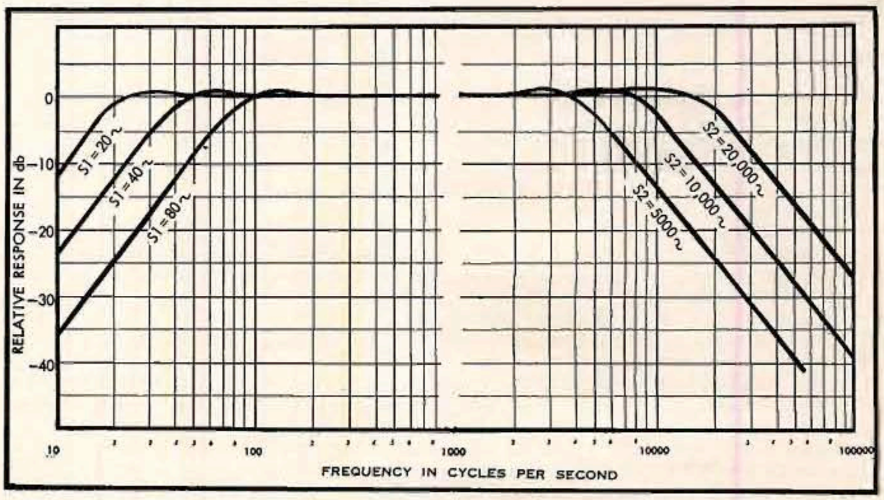
which has the form $\frac{\omega_2^2}{S^2 + 2\zeta\omega_2 S + \omega_2^2}$,

where

$\omega_2 = \frac{1}{\sqrt{R_3 R_4 C_3 C_4}}$ and $\zeta = \frac{1}{2}\sqrt{\frac{R_4 C_4}{R_3 C_3}}$. By the same process, this can be shown to give a low pass filter of frequency cutoff ω_2 and damping factor ζ.

If we plot per cent overshoot to a square-wave input against ζ, we get the curve shown in *Fig.* 4, and if we plot the frequency response for various values of ζ, we get the curves of *Fig.* 5. With the quadratic responses of equations (*6*) and (*10*), it is possible to make any desired compromise between overshoot and performance near the cutoff frequency. The writer has chosen a ζ of 0.55, which gives nearly maximal flatness and also makes the capacitors come out near EIA standard values.

Fig. 7. Frequency response of circuit of Fig. 6.



Combined Circuit

The two circuits mentioned can be combined into a single circuit as shown in *Fig.* 6, with the corresponding response of *Fig.* 7. Measurements showed that for input levels up to 1 volt rms the distortion was negligible and that just below the overload point of 3 volts rms, the distortion was of the order of 0.5 per cent for any frequency within the pass band. Hum and noise are dependent on the supply voltage; with battery operation the noise level will be of the order of 88 db below the 1 volt rms design. One further word of caution—the circuit equations show that the performance will be affected by the driving impedance. That is the reason for the additional emitter follower, Q_1, in *Fig.* 6.

The two original circuits can also be combined in parallel instead of being intermeshed. If the cutoff frequencies are made the same, the circuit of *Fig.* 8 makes an excellent electronic crossover for bi-amplifier operation. Æ

Fig. 8. Circuitry for electronic crossover filter. Cutoff frequencies are the same for both sections.