When the dual 412 device is used for A_1, the circuit of Fig. 5-30 is suited for high-performance applications at frequencies up to 20 kHz. For higher-frequency use, a 318 device can be substituted for the two amplifiers, with a general lowering of resistances values. Both amplifiers should have good common-mode rejection. For less critical applications, a dual device, such as the 4558, can be used for both A_1 and A_2. In such cases, it is best to keep R_3 in the range of 100 kΩ or less and the signal levels at 2 V rms or less.

5.3.7 All-Pass Circuits

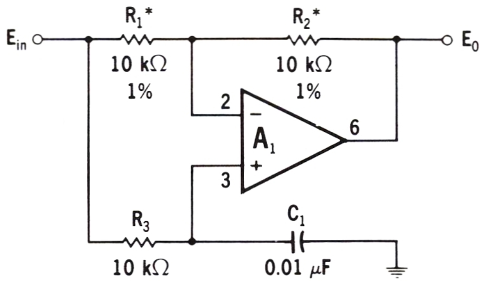
Using op-amp techniques, it is possible to alter the phase/frequency and amplitude characteristics of audio signals in a very precise and predictable manner. Phase-shifted and controlled stages are very useful tools when used in combination with other op-amp circuits. A class of active filters called ***all-pass filters,*** are useful for this and they exhibit a constant amplitude versus frequency characteristic.

Two circuits that exemplify the simplicity of op-amp techniques in phase manipulation are shown in Fig. 5-31. These circuits are identical except for the positions of R_3 and C_1, which determine the lag or lead characteristics. The circuit of Fig. 5-31A operates as follows; R_3 and C_1 form a simple lag circuit with the output across C_1 applied to the reference input of A_1. The voltage across C_1 will lag E_{in} by 45° when $X_{c_1} = R_3$, or when

$$f = \frac{1}{2\pi R_3 C_1} \qquad \text{(Eq. 5-18)}$$

Because of zero differential-input voltage, the voltage across C_1 must also appear at the summing point through feedback. If $R_1 = R_2$, the phase angle of the output signal will be −90°, or twice the phase angle of the signal at the summing point, with an amplitude equal to E_{in}.

The general ability of the circuit to alter output phase for different frequencies can be appreciated by considering the relative reactances of R_3 and C_1 for different conditions. For instance, when $X_{c_1} \gg R_3$, the circuit behaves as a follower and the phase is that of the input. When X_{c_1} is $\ll R_3$, the circuit behaves as an inverter and the output phase is −180°. These general conditions are described in the circuit notes, and the phase shift of the circuit is generally described as



* $R_1 = R_2$, output phase angle = θ

$\theta = -2 \tan^{-1} 2\pi f R_3 C_1,$

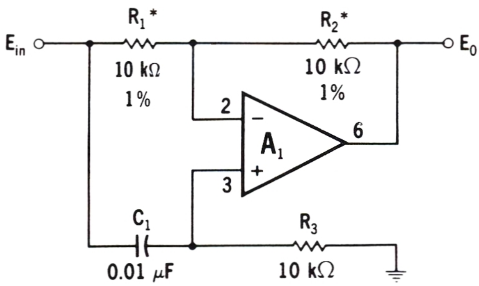
$\theta \simeq 0° @ f << \frac{1}{2\pi R_3 C_1}$

$= -90° @ f = \frac{1}{2\pi R_3 C_1}$

approaches $-180° @ f >> \frac{1}{2\pi R_3 C_1}$

as shown, $\theta = -90°$ @ 1590 Hz

(A) Constant-amplitude lag circuit.



* $R_1 = R_2$, output phase angle = θ

$\theta = -180° - 2 \tan^{-1} 2\pi f R_3 C_1$

$\theta \simeq -180° @ f << \frac{1}{2\pi R_3 C_1}$

$= -270° @ f = \frac{1}{2\pi R_3 C_1}$

approaches $-360° @ f >> \frac{1}{2\pi R_3 C_1}$

as shown, $\theta = -270°$ @ 1590 Hz

(B) Constant-amplitude lead circuit.

Fig. 5-31. Constant-amplitude, phase lead/lag circuits.

$$\theta = -2 \tan^{-1} 2\pi f R_3 C_1 \qquad \text{(Eq. 5-19)}$$

The companion circuit of Fig. 5-31B is achieved by interchanging C_1 and R_3. This circuit has the same amplitude properties as the circuit of Fig. 5-31A but, in this case, the phase shift is described as

$$\theta = -180° - 2 \tan^{-1} 2\pi f R_3 C_1 \qquad \text{(Eq. 5-20)}$$

As can be seen from the notes, this circuit behaves as an inverter at low frequencies and as a follower at very high frequencies, again due the relative reactances of C_1 and R_3.

Perhaps the most useful function for these circuits is the generation of 90° leading or lagging signals for phase detectors and similar circuits. The networks are easily adjustable by varying either R_3 or C_1, and the constant amplitude output can be a great convenience. Op amps compensated for unity gain will work in this circuit, but a low input-current, high input-resistance type, such as the 34081 (or other similar FET-input unit), will allow the widest range of R_3/C_1 values. The R_1-R_2 values are not critical but should be matched, so 10-kΩ, 1% values are suggested.

5.4 REFERENCES

1. Allen, P. E. "Practical Considerations of Active Filter Design." *Journal of the AES,* Vol. 22 #10, December 1974.
2. Al-Nassar, F. "Tables Shorten Design Time for Active Filters." *Electronics,* October 23, 1972.
3. ______. "Tables Speed Design of Low-Pass Active Filters." *EDN,* March 15, 1971.
4. Ashley, J R. and Kaminsky, A. L. "Active and Passive Filters as Loudspeaker Crossover Networks." *Journal of the AES,* Vol. 19 #6, June 1971.
5. Brokaw, A. P. "Simplify 3-Pole Active Filter Design." *EDN,* December 15, 1970.
6. Dobkin, R C. "High Q Notch Filter." *National Semiconductor LB-5,* April 1967, National Semiconductor Corp., Santa Clara, CA.
7. Doyle, N. P. "Swift, Sure Design of Active Bandpass Filters." *EDN,* January 15, 1970.
8. *Data Sheet AF100,* "Universal Active Filter." National Semiconductor Corp., 1976.
9. Estep, G. J. "The State Variable Filter Handbook."
10. ______. "Universal Active Filter Theory and Applications." Kinetic Technology, Santa Clara, CA, 1971.
11. Geffe, P. R. "Designer's Guide to Active Bandpass Filters, Parts 1–5." *EDN,* Febuary 5, 1974; March 5, 1974; April 5, 1974; May 5, 1974; June 5, 1974.
12. Hilburn, J. L. and Johnson, D. E. *Manũal of Active Filter Design.* McGraw Hill, NY, 1973.
13. *IEEE Transactions on Circuits and System*—"A continuing dialogue on active filter realizations." (IEEE, New York).