A tube-based phono preamplifier – Marcel van de Gevel

This article in Vol 4 contains a sidebar under the heading 'Phono preamplifier with a +1 term', starting on page 128. In that section, some notations about time constants did not survive the layout process unscathed. Following is the complete section, corrected. My apologies to Mr. van de Gevel. – ed.

Phono amplifier with a +1 term

Many phono amplifiers have a gain defined by an impedance ratio plus one. See Figure 13 for a typical example.

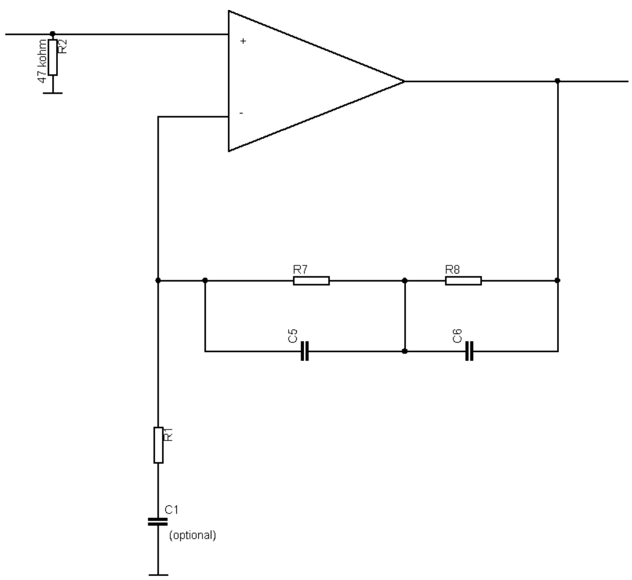

Figure 13 Typical phono amplifier with a +1 term

The mid-band gain of a phono amplifier for moving-magnet cartridges is typically about 100, so the +1 term only introduces an error of about 1 %. At the upper edge of the audio band, the intended gain drops to about 10, but it is almost 90 degrees out of phase with the +1 term. As a result, the error in the magnitude of the transfer remains small.

Assume that the op-amp, the resistors and the capacitors are all ideal. It is clear from inspection of the circuit that the feedback disappears and the transfer tends to infinity at $s=-1/(R_7C_5)$, at $s=-1/(R_8C_6)$ and at $s=-1/(R_1C_1)$. That is, the poles stay where they should be and are not affected by the +1 term. This is logical: when you add one to an infinite gain, you still have an infinite gain.

The situation is more complicated for the zeroes. The gain at ultrasonic frequencies drops to one rather than zero, which means that there is an extra zero introduced whose corner frequency is somewhere in the ultrasonic range. The desired zero with 500 Hz corner frequency shifts a bit, which can be corrected by changing the ratio of R_7 to R_8.

To keep the equations simple, the time constants of the RIAA correction poles will be called τ_{p1} and τ_{p2}, the time constant of the subsonic filter will be called τ_{p0} and the time constant of the zero of the impedance of R7, C5, R8 and C6 will be called τ_n. The ratio of $R_7 + R_8$ to R_1 will be called K. That is,

$$\tau_{p2} = R_8C_6$$
$$\tau_{p1} = R_7C_5$$
$$\tau_{p0} = R_1C_1$$
$$\tau_n = R_7R_8(C_5+C_6)/(R_7+R_8)$$
$$K = \frac{R_7+R_8}{R_1}$$

The transfer of the circuit of Figure 13 is:

$$H(s) = K\frac{s\tau_{p0}}{s\tau_{p0}+1}\frac{s\tau_n+1}{(s\tau_{p1}+1)(s\tau_{p2}+1)}+1 = \frac{s\tau_{p0}}{s\tau_{p0}+1}\left(K\frac{s\tau_n+1}{(s\tau_{p1}+1)(s\tau_{p2}+1)}+1+\frac{1}{s\tau_{p0}}\right)$$

The last term on the right side, $1/s\tau_{p0}$, will at frequencies around 500 Hz ($s=j\omega=1000\ \pi j$ rad/s) be small compared to unity. For example, with a 20 Hz cut-off frequency of the subsonic filter, it will be -0.04*j*. As the error due to the +1 term is already small, the error due to the $1/s\tau_{p0}$ term will normally be negligible. We will therefore neglect the effect of the optional subsonic filter on the RIAA correction zero. Without subsonic filter, the transfer simplifies to:

$$H(s)=K\frac{s\tau_n+1}{(s\tau_{p1}+1)(s\tau_{p2}+1)}+1=\frac{sK\tau_n+K+s^2\tau_{p1}\tau_{p2}+s(\tau_{p1}+\tau_{p2})+1}{(s\tau_{p1}+1)(s\tau_{p2}+1)}=$$
$$\frac{s^2\tau_{p1}\tau_{p2}+s(K\tau_n+\tau_{p1}+\tau_{p2})+K+1}{(s\tau_{p1}+1)(s\tau_{p2}+1)}$$

Calculating the zeroes by equating the numerator to zero:

$$z=\frac{-(K\tau_n+\tau_{p1}+\tau_{p2})\pm\sqrt{(K\tau_n+\tau_{p1}+\tau_{p2})^2-4\tau_{p1}\tau_{p2}(K+1)}}{2\tau_{p1}\tau_{p2}}$$

The solution with the minus sign is the extra ultrasonic zero; the solution with the plus sign is the RIAA correction zero. Denoting the RIAA correction zero as z_{RIAA}:

$$2\tau_{p1}\tau_{p2}z_{RIAA}+K\tau_n+\tau_{p1}+\tau_{p2}=\sqrt{(K\tau_n+\tau_{p1}+\tau_{p2})^2-4\tau_{p1}\tau_{p2}(K+1)}\Rightarrow$$
$$(2\tau_{p1}\tau_{p2}z_{RIAA}+K\tau_n+\tau_{p1}+\tau_{p2})^2=(K\tau_n+\tau_{p1}+\tau_{p2})^2-4\tau_{p1}\tau_{p2}(K+1)\Leftrightarrow$$
$$K^2\tau_n{}^2+2K\tau_n(2\tau_{p1}\tau_{p2}z_{RIAA}+\tau_{p1}+\tau_{p2})+(2\tau_{p1}\tau_{p2}z_{RIAA}+\tau_{p1}+\tau_{p2})^2=$$
$$K^2\tau_n{}^2+2K\tau_n(\tau_{p1}+\tau_{p2})+(\tau_{p1}+\tau_{p2})^2-4\tau_{p1}\tau_{p2}(K+1)$$

This can be simplified to:

$$\tau_n=\frac{(\tau_{p1}+\tau_{p2})^2-4\tau_{p1}\tau_{p2}(K+1)-(2\tau_{p1}\tau_{p2}z_{RIAA}+\tau_{p1}+\tau_{p2})^2}{4K\tau_{p1}\tau_{p2}z_{RIAA}}$$

The zero of the impedance of the network R7, C5, R8 and C6 is -1/τ_n. Using this to rewrite the equation for the ratio of R_8 to R_7 found in the previous section:

$$R_8 = \frac{1-\frac{\tau_{p2}}{\tau_n}}{\frac{\tau_{p1}}{\tau_n}-1} R_7$$

As a typical example, take an amplifier with K=1000 (DC gain without C1 of 1001). With τ_{p1}=1/(100 π) seconds, τ_{p2}=75 µs, z_{RIAA}=-1000 π rad/s, one finds:

$\tau_n \approx$ 316.12 µs
$R_8 \approx 0.0841025\ R_7$

For an amplifier with K=300 (DC gain of 301):

$\tau_n \approx$ 311.011 µs
$R_8 \approx 0.0821739\ R_7$