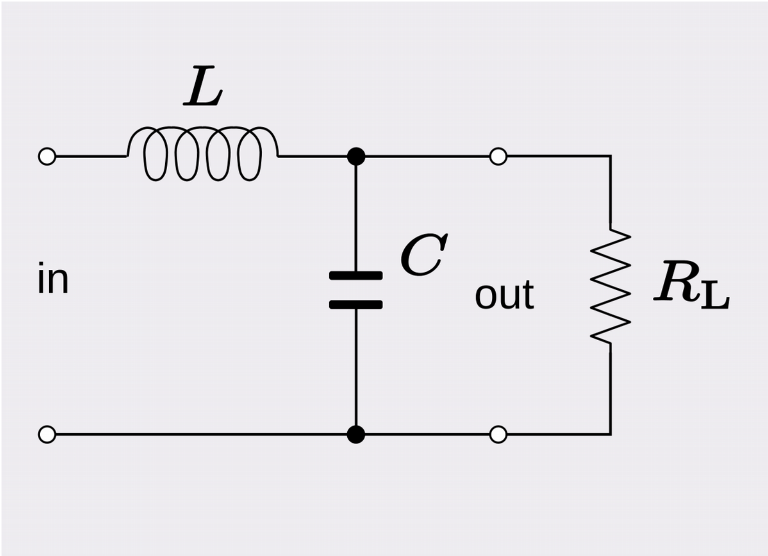

Generic RLC high-pass filter as simple geophone model.

$$Transfer\ function = \frac{V_{out}}{V_{¿}} = \frac{s^2}{s^2 + \frac{1}{R_L C} s + \frac{1}{LC}} = \frac{s^2}{s^2 + 2\xi\omega_n s + \omega_n^2}$$

$$\omega_n = \frac{1}{\sqrt{LC}}$$

$$2\xi\omega_n = \frac{1}{R_L C} \Rightarrow \xi = \frac{1}{2R_L}\sqrt{\frac{L}{C}}$$

From Encyclopedia of Petroleum Science & Engineering V3
Geophone equivalent circuit values:

$$B = geophone\ open-circuit\ physical\ damping \left[\frac{dyne}{cm/s}\right]$$

$$K = geophone\ spring\ constant \left[\frac{dyne}{cm}\right]$$

$$M = geophone\ mass\ [Kg]$$

$$G = geophone\ sensitivity \left[\frac{V}{cm/s}\right]$$

$$F_0 = geophone\ natural\ frequency\ [Hz]$$

$$D = geophone\ open-circuit\ damping\ ratio\ versus\ critical\ damping$$

$$R_C = geophone\ coil\ resistance\ [\Omega]$$

$$L_C = geophone\ coil\ inductance\ [H]$$

M, G, F_0, D, R_C *are usually provided by geophone datasheet*

Since K and B are usually not provided on geophone spec. sheets we must calculate them from other parameters which are available.

$$2\pi F_0 = \sqrt{\frac{K}{M}} \Rightarrow K = \frac{M}{(2\pi F_0)^2}$$

$$B = 2\omega_0 M D = 4\pi F_0 M D$$

$$R_{eqv} = \frac{G^2}{4\pi F_0 MD} \left[\Omega\right]$$

$$L_{eqv} = \frac{G^2}{4\pi^2 F_0^2 M} \left[H\right]$$

$$C_{eqv} = \frac{M}{G^2} \left[F\right]$$

Geophone PS-4.5B datasheet:

Natural frequency [Hz] = 4.5 ±10%
Typical open-circuit damping = 0.6
Coil resistance [Ω] = 375 ±5%
Moving mass [g] = 11.3
Sensitivity [V/cm/s] = 28.8

$$K = \frac{11.3\text{e-}03}{(2\pi 4.5)^2} = 14.1349\text{e-}06 \left[\frac{dyne}{cm}\right]$$

$$B = 2\omega_0 M D = 4\cdot\pi\cdot 4.5\cdot 11.3\text{e-}03\cdot 0.6 = 38.34\text{e-}02 \left[\frac{dyne}{cm/s}\right]$$

$$R_{eqv} = 2163.38 \left[\Omega\right]$$

$$L_{eqv} = 91.82 \left[H\right]$$

$$C_{eqv} = 13.62\text{e-}06 \left[F\right]$$

Now, let’s take a look to SM-24 geophone:

Natural frequency [Hz] = 10.0 ±2.5%
Typical open-circuit damping = 0.25
Coil resistance [Ω] = 375 ±2.5%
Moving mass [g] = 11
Sensitivity [V/cm/s] = 28.8 ±2.5%
Typical damping (@R_s = 1339Ω) = 0.60
Typical damping (@R_s = 1000Ω) = 0.69

In open-circuit we got following parameters:

$$K = 2.786\text{e-}06 \left[\frac{dyne}{cm}\right]$$

$$B = 34.558\text{e-}02 \left[\frac{dyne}{cm/s}\right]$$

$$R_{eqv} = 2400\,[\Omega]$$

$$L_{eqv} = 19.1\,[H]$$

$$C_{eqv} = 13.26\text{e-}06\,[F]$$

$$G = still\ 28.8 \left[\frac{V}{cm/s}\right]$$

Transfer function becomes:

$$\xi = \frac{1}{2R_{eqv}}\sqrt{\frac{L_{eqv}}{C_{eqv}}} = 0.25 \quad \text{(obviously)}$$

$$\omega_n = \frac{1}{\sqrt{L_{eqv} \cdot C_{eqv}}} = 62.832 \left[\frac{rad}{s}\right]$$

$$Out(s) = \frac{28.8\,s^2}{s^2 + 31.42 \cdot s + 3947.84} \quad \text{(no shunt resistor)}$$

Ok, geophone response changes upon shunt resistor so let’s take care of shunt resistor (in this case we don’t take care of coil’s inductance):

$R_{load} = R_{coil} + R_{shunt}$ this resistor is in parallel to $L_{eqv}' = 19.1\,[H]$

$$R_{eqv}' = R_{eqv} \| R_{load} = \frac{R_{eqv} \cdot R_{load}}{R_{eqv} + R_{load}}$$

That’s why we get different damping value for different shunt resistors.

Since shunt resistor acts as resistive partitor, it changes also sensitivity:

$$G' = G \frac{R_{shunt}}{R_{coil} + R_{shunt}}$$

Then we have new equivalent system:

$$Out(s) = \frac{22.5\,s^2}{s^2 + 79.18 \cdot s + 3947.84} \quad (R_{shunt} = 1339)$$

$$Out(s) = \frac{20.9\,s^2}{s^2 + 90.02 \cdot s + 3947.84} \quad (R_{shunt} = 1000)$$

Geophone SM-24 response curve (shunt resistor – damping)