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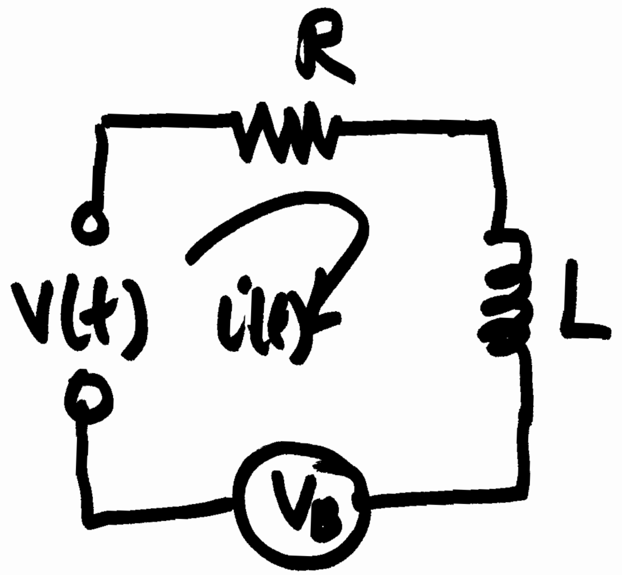
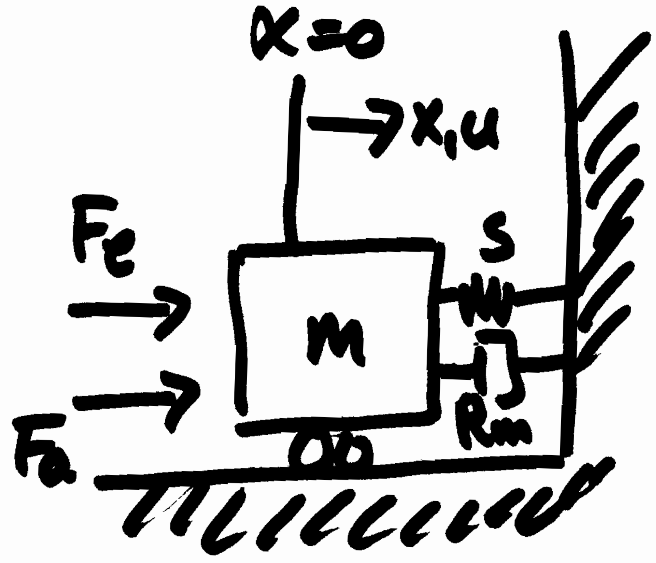
Electromagnetic Loudspeaker Driver





R = DC Voice coil resistance, Ω

L = Inductance of voice coil, H

V_B = Back emf voltage.

F_e = Electromagnetic force of magnet on voice coil

F_a = Force of air on voice coil

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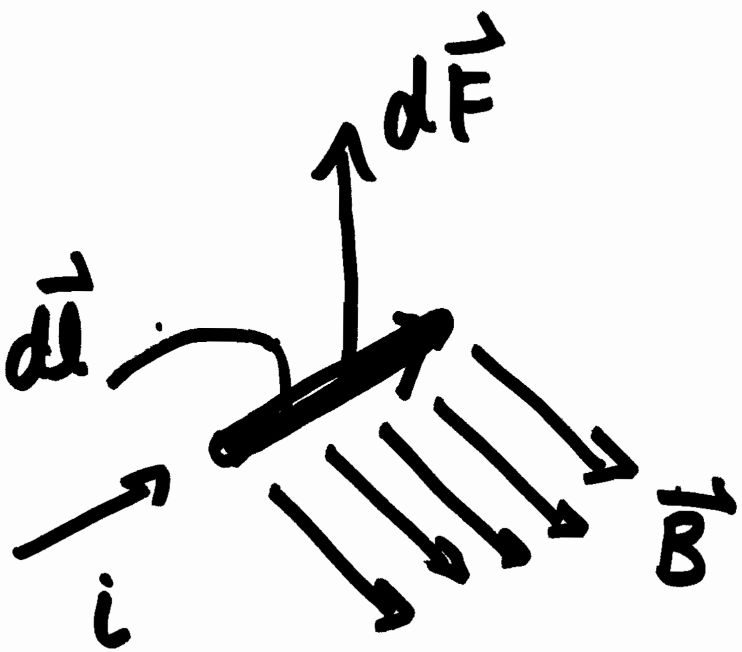
F_e: Force exerted on a current carrying wire located in a magnetic field.



$$d\vec{F} = i\left(d\vec{l} \times \vec{B}\right)$$

In practice, for a given coil ~~of magnet~~ magnet geometry

$$F \propto i$$

For a loudspeaker $F_e \approx B \cdot l \cdot i = (Bl)\, i$

Bl = Force coeff $\frac{N}{A}$

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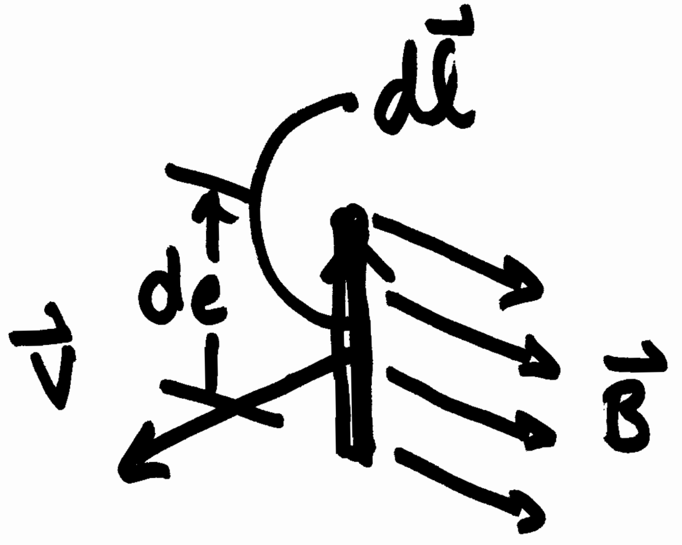
Back emf V_a: Moving conductor in a magnetic field generates a voltage.



de = Back emf

$de = (\vec{v} \times \vec{B}) \cdot d\vec{l}$

Again, for a given or coil/magnet geometry

$V_B \propto$ velocity

Because of reciprocity: $V_B = (Bl)v$

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Newton's law for the voice coil is:

$$F_e + F_a - sx - R_m\dot{x} = m\ddot{x} \quad , \quad F_e = (Bl)i$$

The circuit law for the voice coil is

$$V(t) = Ri + L\frac{di}{dt} + (Bl)\dot{x}$$

Lets also neglect F_a, inductance L

$$(Bl)i = sx + R_m\dot{x} + m\ddot{x}$$

$$V(t) = Ri + (Bl)\dot{x}$$

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Then the model becomes

$$(Bl)\hat{I} = \frac{S}{j\omega}\hat{U} + R_m\hat{U} + (j\omega)m\hat{U}$$

$$\hat{V} = R\hat{I} + (Bl)\hat{U}$$

Use one equation to eliminate $\hat{I}$, and solve for $\hat{U}$

$$\hat{U} = \frac{Bl}{R}\,\frac{1}{(j\omega)m + \left[R_m + \frac{Bl^2}{R}\right] + S/j\omega}\,\hat{V}$$

Now, ~~swith~~ switch from displacement to ~~velocity~~ voice coil velocity as the dependent variable

$$x = \int u\,dt$$

Then the model reduces to:

$$\left.\begin{aligned} (Bl)i &= s\int u\,dt + R_m u + m\dot{u} \\ V(t) &= Ri + (Bl)u \end{aligned}\right\} \begin{array}{l} \text{Input: } V(t) \\ \text{two unknowns: } u, i \\ \text{two equations} \end{array}$$

Now, use complex variables to solve

$$V(t) \rightarrow \hat{V}e^{j\omega t},\ \hat{V} = V + 0j,\ i(t) \rightarrow \hat{I}e^{j\omega t},\ u(t) \rightarrow \hat{U}e^{j\omega t}$$

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Then the model becomes

$$(Bl)\hat{I} = \frac{s}{j\omega}\hat{U} + R_m\hat{U} + (j\omega)m\hat{U}$$

$$\hat{V} = R\hat{I} + (Bl)\hat{U}$$

Use one equation to eliminate $\hat{I}$, and solve for $\hat{U}$

$$\hat{U} = \frac{Bl}{R}\,\frac{1}{(j\omega)m + \left[R_m + \frac{Bl^2}{R}\right] + s/j\omega}\,\hat{V}$$

Then, the velocity amplitude $\hat{u}$ becomes

$$\hat{u} = \frac{Bl\,\omega_n}{Rs} \frac{1}{j\left(\frac{\omega}{\omega_n}\right) + \left(\frac{1}{Q_m} + \frac{1}{Q_e}\right) + \left(\frac{\omega_n}{j\omega}\right)} \hat{V}$$

$$u(t) = \frac{Bl}{R} V \frac{Q_t}{m\omega_n} \frac{1}{\sqrt{1 + Q_t^2\left(\frac{\omega}{\omega_n} - \frac{\omega_n}{\omega}\right)^2}} \cos\left(\omega t + \arg \hat{u}\right)$$