Magnetic coupling (electric hum in audio equip., noise becomes audible, similar to transformer's hum)

Faraday law

\[ \oint \vec{E} \cdot d\vec{l} = -\frac{d}{dt} \int \vec{B} \cdot d\vec{A} = -\frac{d\Phi_B}{dt} \]

Ex. \( B \approx \text{mV/m}^2 \) due to 60Hz (in most buildings due to power lines, light fixtures)

with \( R \approx 0.1 \Omega \) wire, in \( \approx 10 \text{mA} \) for 1m\(^2\) loop

- time varying B-field induces voltage around any closed loop

- low freq. B-field is not easily shielded by metals

\[ \delta = \frac{1}{\sqrt{\nu f \mu \sigma}} \]  

- skin depth

\[ \delta \text{ attenu. of } B \text{ in material} \]

\[ \text{magn. permeability} \]

Ex. need 0.43" Al for \( \frac{1}{e} \) attenu. of 60Hz fields

To reduce

- avoid large enclosed conducting paths (e.g. ground loops)

Ex. V_{sensor} \times B

\[ = \Delta V_{mag} \]

Controller

Analog IN

GND

break here
- use coax or twisted pair
  \[ \text{EB} \]
  - reduced fields cancel in successive twists
  - small enclosed area

- use magnetic shielding: Mu-metal (Ni-Fe alloy, \( \mu = 10^5 \mu_0 \))
  - shorts out magn. flux

- use isolation transformers
  - opto-isolators

\[ \text{break ground loops} \]

\[ \text{uses short optical transmission path} \]

4. RF coupling
- wire leads, circuit parts can act as resonant pickups (antennas) \( \Rightarrow \) high freq. noise (VHF 1-10m, FM, TV, UHF 0.1-1m, TV, wireless, SHF 0.01-0.1m, cell-phones)

\[ \frac{\lambda}{4} \text{ antenna or } \frac{\lambda}{4} \text{ antenna} \]
  (near conducting surface)

\( \Rightarrow \) very effective in picking up the RF

To reduce
- use shielding (very effective)
- keep short leads
5 Resistive coupling

- Wires ≠ equipotentials, have finite resistance
  ⇒ Currents flowing thru ground lines can generate voltages in another part of the circuit

Ex.

120 VAC

+5V

CONTROLLER

VA

RB

100m cable

RW4

Rw3

Rw2

I2

I3

Q

Vb

Q = ON: Im ~ 20A when starting ⇒ I1, I3

⇒ Vb - VA ~ 20A * 0.3Ω ~ 6V

Since Vcont - VA < 0.6V, Q goes OFF when motor trying to start

To reduce

- Use low resistance ground wires (copper busbars in extreme cases)
- Separate grounds for low and high level circuit parts