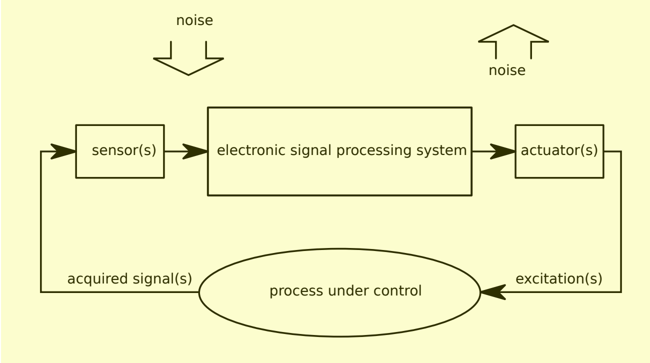
# Electromagnetic Compatibility (EMC)

## Signal processing in noisy environments




### EMC

The ability of an electronic system to function in its intended electromagnetic environment within a defined safety margin and at a specified performance level.

1. The system does not cause interference with other systems
2. The system is not susceptible to interference from other systems
3. The system does not cause interference with itself

### Primary cause of EMC limitation

Finite dimensions of a system that carries electrical signals

### Interference mechanisms

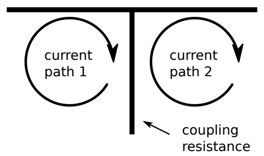
1. Crosstalk (conductive, inductive or capacitive coupling)
2. EM fields (radiative coupling)
3. ESD (electrostatic discharge)

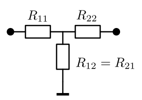
### EMC standards

1. Maximum emission levels for radiated and conducted interference
2. Minimum susceptibility levels for radiated and conducted interference
3. Minimum susceptibility levels for ESD

## Coupling mechanisms

### Conductive coupling




Model resistive network

$$\begin{pmatrix} V_1 \\ V_2 \end{pmatrix} = \begin{pmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{pmatrix} \begin{pmatrix} I_1 \\ I_2 \end{pmatrix}$$

Low resistance: Wide and thick traces

Resistances can often be calculated with PCB layout software.

**Skin effect**

At high frequencies the current migrates towards the surface of the conductor.

Skin-depth: $\delta = \sqrt{\frac{\rho}{f\pi\mu_0}}$

**Proximity effect**

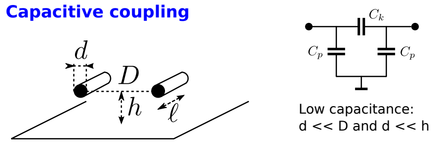
At high frequencies the current migrates towards the surface of the conductor that is facing the return path.

Resistance increases with frequency

**Prevent / minimize conductive coupling**

Avoid / minimize common return paths for different signals

### Capacitive coupling




Model capacitive network

$$\begin{pmatrix} I_1 \\ I_2 \end{pmatrix} = s \begin{pmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \end{pmatrix} \begin{pmatrix} V_1 \\ V_2 \end{pmatrix}$$

Low capacitance: d << D and d << h

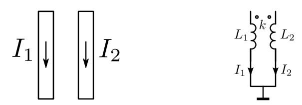
Capacitances can often be calculated with PCB layout software.

**Prevent / minimize capacitive coupling**

Maximize distance between different pairs of signal and return path

Apply a shield between different pairs of signal and return path

### Inductive coupling




Model inductive network:

$$\begin{pmatrix} V_1 \\ V_2 \end{pmatrix} = s \begin{pmatrix} L_{11} & L_{12} \\ L_{21} & L_{22} \end{pmatrix} \begin{pmatrix} I_1 \\ I_2 \end{pmatrix}$$

$$L_{12} = L_{21} = k\sqrt{L_{11}L_{22}}$$

Low inductive coupling:
- Spacial separation of current loops
- Orthogonal current loops

The inductances and mutual inductances can often be calculated with PCB layout software from transmission line impedances using the reciprocity principle.

Relation between capacitive and inductive coupling (symmetrical arrangements above)

$$L_{12} = L_{21} = \frac{C_{21}}{C_{11}} L_{11}$$

$$L_{11} = L_{22}, C_{11} = C_{22}$$

**Prevent / minimize inductive coupling**

Maximize distance between pairs of signal and return path

Minimize loop area formed by the signal wire/trace/plane and its return path wire/trace/place

Apply a shield between pairs of signal and return path, this shield should have a large relative permeability, this reduces the skin depth which increases the shielding effect.

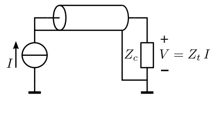
### Transmission lines

Lossless

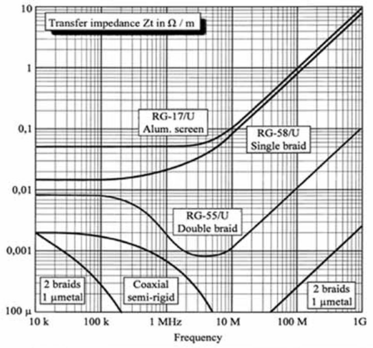
Characteristic impedance: $Z_c = \sqrt{\frac{L}{C}}$

Propagation delay: $\tau_d = \sqrt{LC}$

**Crosstalk via transfer impedance**




Result of shield (or return path) resistance and non-ideal coupling of the two conductors.




**Prevent / minimize transfer impedance crosstalk**

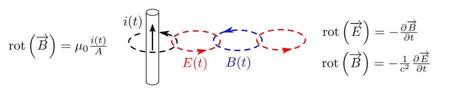
Reduce the noise current by increasing the common-mode impedance

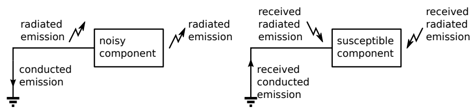
Increase the coupling beween the signal and the return path

Use triaxial cable or a differential signal with a shielded twisted pair

## Emission and reception of EM waves

Wave generation — Wave propagation




**Prevent / minimize radiated emission and susceptibility for it**

Minimize antenna dimensions:
- Loop area signal with its return path
- Length of signal paths

Minimize antenna signals:
- Low voltage and current levels
- Signal bandwidth not larger than necessary

**Prevent / minimize conducted emission and susceptibility for it**

- Minimize radiated emission
- Increase common-mode impedance of cables

### Modeling: lumped versus disrtibuted

Lumped system, near field modeling:
Physical dimensions (very) small with respect to wavelength

Distributed system, far field modeling:
Physical dimensions cannot be ignored with respect to wavelength

## EMC measurement tools

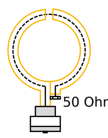
### Conducted emission

Current clamp measurement

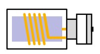
### Radiated emission

**H-Field loop antenna**

Near field measurement with H-field antennas for frequencies below 30 MHz




**H-Field sniffer**

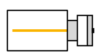


**E-field antennas**

Far field measurement with E-field antennas for frequencies above 30 MHz

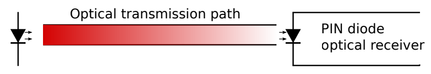
Many types of e-field antennas
- monopole
- dipole
- biconical
- log-periodic
- horn

**E-Field sniffer**



### System level design aspects

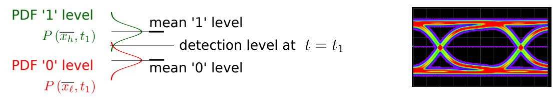
**Electrical or non electrical signals**




Non-electrical signals are not sensitve for 'electrical noise'

**Analog, multi-level digital, or binary signals**

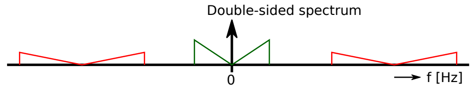
Binary signals have a larger noise immunity than multi-level digital signals
Multi-level digital signals have a larger noise immunity than binary signals




High noise immunity:
- High signal levels
- Maximally limited bandwidth
- Coding: add redundancy + error correction

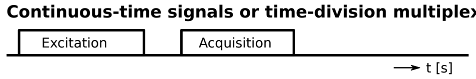
**Baseband or bandpass signals (frequency division multiplexing)**

Baseband signaling: frequencies of interest centered around zero
Bandpass signaling: frequencies of interest centered around a carrier frequency




Increase the noise immunity of the signal:
1. Spread the frequency spectrum of the signal
2. Shift the frequency spectrum of the signal
3. Reduce out-of-band noise with filtering and frequency-selective detection
4. Frequency-division multiplexing: use diferent frequency ranges for different signals

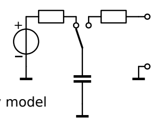
**Continuous-time signals or time-division multiplexed signals**




Use different time slots for excitation of actuators and for read-out of sensors

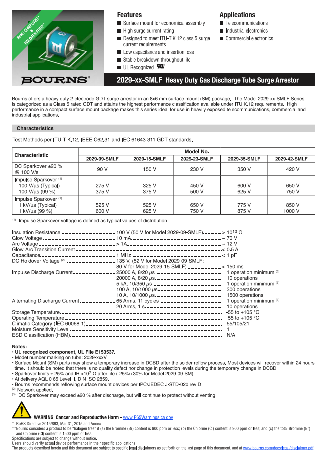
### ESD

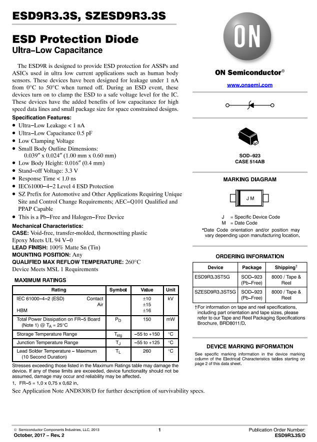
Causes:
- Charge built-up as a result of friction
- Lightning



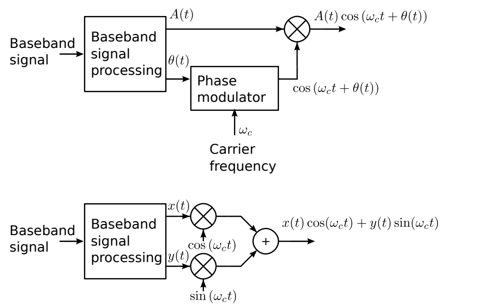

Human body model

ESD protection devices

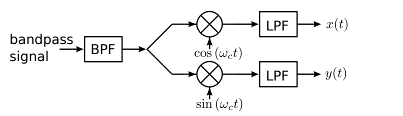



### Generalized transmitter architectures



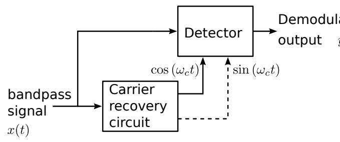

### Generalized receiver architecture (quadrature detector)




Nonlinear behavior may result in unintended modulation or demodulation!

### AM demodulation in noisy environment

Carrier recovery and synchronous detection




Carrier recovery methods:
- Bandpass filter cascaded with a limiter
- Narrow-band PLL

Detection methods:
- Analog balanced mixer with low-pass filter(s)
- Digital 4 samples per period and low-pass filter

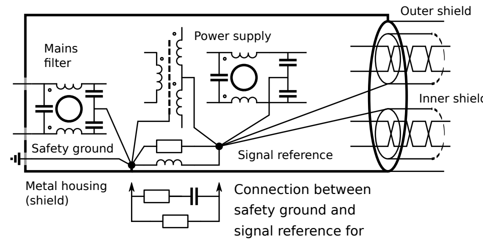
Quadrature detection does not require carrier phase adjustement:

$$y(t) = G\sqrt{x(t)\cos(\omega_c t)^2 + x(t)\sin(\omega_c t)^2}$$

**Lock-in amplifier**

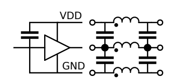
### Physical lay-out

Physical layout with safety groud and shielded twisted pair cables



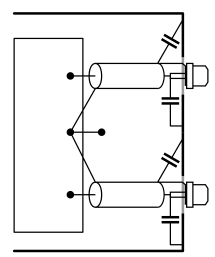

Connection between safety ground and signal reference for connected subsystems

Best connection of a switched output with supply terminals to a multi-pin connector




Equal coupling of output wire to power and ground leads

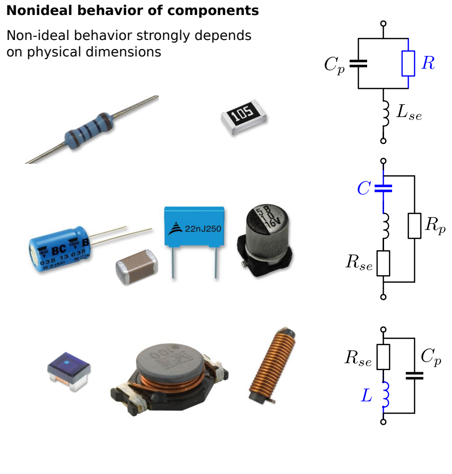
Connection with multiple coaxial cables without safety ground



### Circuit level design aspects

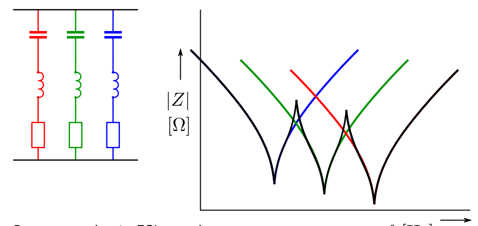
**Nonideal behavior of components**

Non-ideal behavior strongly depends on physical dimensions



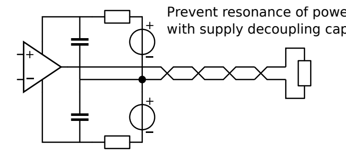

**Power supply decoupling**

- Reduce radiated emission by power traces and planes
- Reduce susceptibility to radiated emission

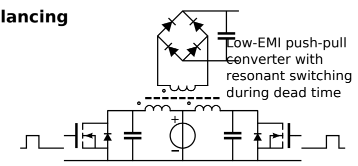



Resonance due to ESL may increase the emission and the susceptibility

Prevent resonance of power supply traces with supply decoupling capacitors



**Balancing**

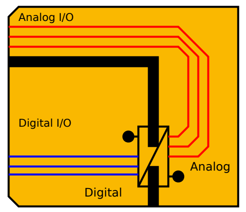



### PCB lay-out design aspects

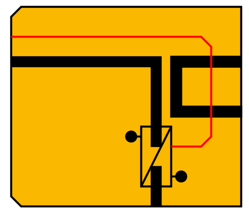
**Main rules:**

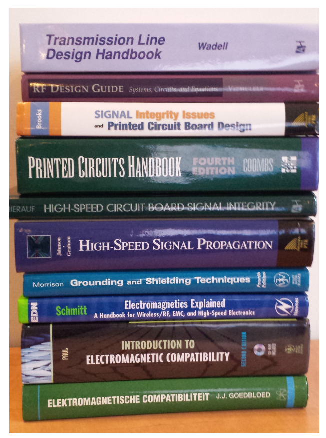
- Minimize noise on power planes
- Maximize coupling between signal and return path (minimize area of high-speed currnet loops)
- Minimize crosstalk between signals

Example of a correct layout with a single ground plane and separation of analog and digital signals

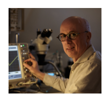



Example of a wrong layout with a signal trace running over an opening in its return path






Some literature related to EMC design and related topics



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