Systems Engineering

Electromagnetic Compatibility

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Source: A significant part is from Tim Williams' *The Circuit Designer's Companion*

Electromagnetic compatibility

- Electronic gadgets
  - Generate electromagnetic interference
  - Are susceptible to electromagnetic interference
- Acceptable levels of interference are getting lower
  - Solid-state more susceptible than vacuum-tube devices
  - Many devices in close distance
  - Plastic cases
- Military: high-power pulse equipment near sensitive devices in same vehicle
- Walkie-talkies, mobile phones, WiFi-enable devices

Importance of EMC

- Poor EMC performance when device is deployed becomes costly
  - Damaged Reputation
  - Difficult and expensive to repair
- EMC testing is important even if no legislation is available
- Device able to operate in hostile environment: immunity
- Device does not cause unreliable operation to others: emissions

Immunity / Emissions

Immunity

- Mains voltage drop-outs, dips, surges and distortion
- Transients and radio frequency interference (RFI) conducted into the equipment via the mains supply
- Radiated transient or RFI, picked up and conducted into the equipment via signal leads
- RFI picked up directly by the equipment circuitry
- Electrostatic discharge

Emissions

- mains distortion, transients or RFI generated within the equipment and conducted out via the mains supply
- transient or RFI, generated within the equipment and conducted out via signal leads
- RFI radiated directly from the equipment circuitry, enclosure and cables

Immunity: RF

- Electromagnetic environment very variable
- Fields dependent on the distance. $E \propto 1/d$ for $d > \lambda/2\pi$

$$E = \sqrt{30\mathrm{EIRP}}/d \qquad (1)$$

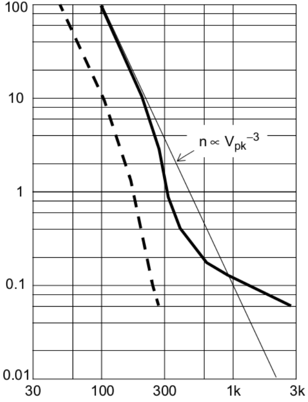
- Radio transmitters.
  - AM 100-500 kW. Far from equipment. E ∼1–10 V/m
  - FM, TV 10 kW. May be close to offices or industries. E ∼1 V/m after building attenuation. Difficult to shield: λ is small
  - Walie-talkies, cellphones. Close to equipment. 1 W gives 5 V/m at 0.5 m distance
- Radars
  - 1–10 GHz, near airports. 50 V/m at 3 km
  - Pulses: hazardous for microprocessors
- 10 V/m immunity (or 3 V/m) from 10 MHz to 1 GHz

Immunity: Mains conducted transients

- Conducted transients: digital devices are more susceptible to them

Area	Transients/hour
Industrial	17.5
Business	2.8
Domestic	0.6
Laboratory	2.3

- Rate of rise, $\sim \sqrt{V_{peak}}$. 10 V/s for 2 kV pulses
- Microprocessor equipment: whithstand pulses up to 2 kV



Relative number of trasients vs. maximum transient amplitude

Solid: mains lines (> 100 V)

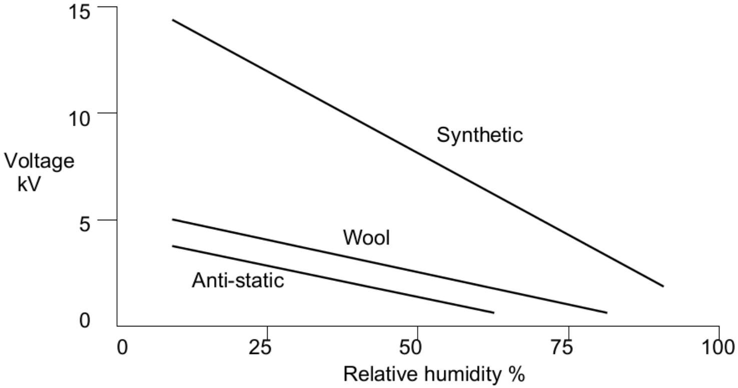
Dashed: telecomm lines (> 50 V)

Other conducted transients

- Telecommunications lines
- Lightning
  - 100 lightning strikes per second worldwide
- Automotive 12 V supply
  - Changes in alternator load
  - Switching of inductive loads

Electrostatic Discharge ESD

- Person charged to high potential
- Equivalent model: 150 pF in series with 150 Ω
- Fast pulses (sub–ns) of high current (10 A)
- Effects of ESD may be subtle or fatal



Emissions

- Generated by switching transients
  - Pulses at mains frequency
  - Switching power supply
- Digital clock or data signals
  - Digital equipment with square wave clocks: noise up to 1 GHz
  - System clock frequency and harmonics: narrow spikes
  - Wideband noise from data
  - $f < 30$ MHz: conducted via mains leads
  - $F > 30$ MHz: radiated
- Regulations assume some separation between transmitter and receiver

The EMC directive

Essential requirements

The apparatus shall be so constructed that:

- Equipment shall not generate electromagnetic disturbances exceeding a level allowing radio and telecommunications equipment and other apparatus to operate as intended
- Equipment shall have an adequate level of intrinsic immunity from electromagnetic disturbances

Standards

- Comply with standards $\Rightarrow$ comply essential requirements
- CENELEC : European standards body
- Most standards based on IEC

Conduced measurements

- LISN: Line Stabilization Network

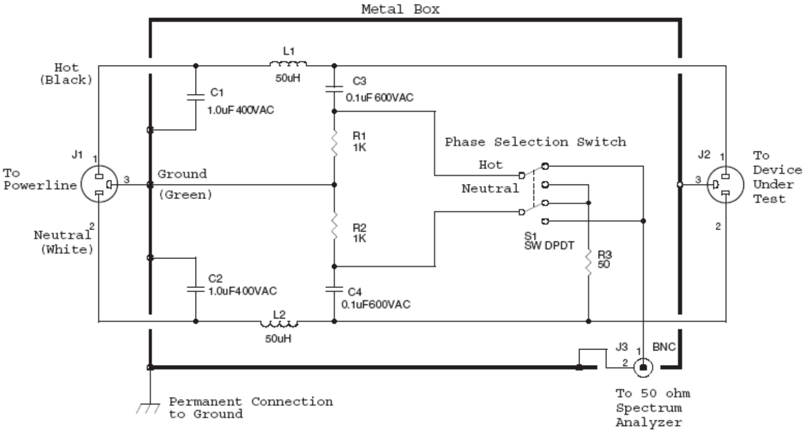


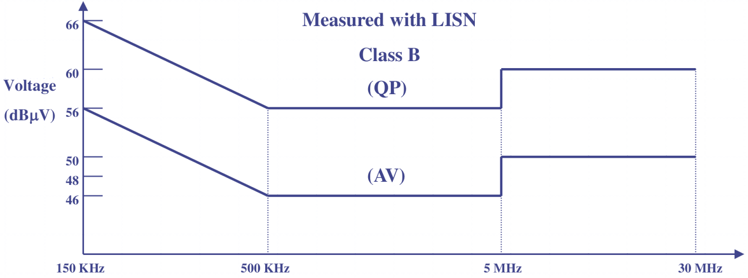
Figure 4.16 A 50 Ω/50 μH LISN as defined by standard CISPR16-1. This circuit provides a 50-Ω output impedance for measurement of RF emissions produced by the device under test. Conducted emission measurements are carried out from 150 kHz to 30 MHz.

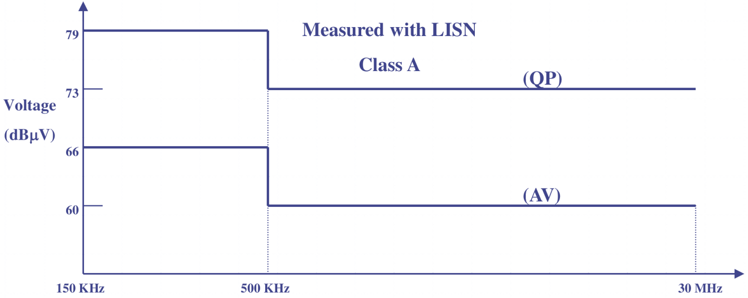
Radiated measurements

- Open Area Test Site or anechoic chamber

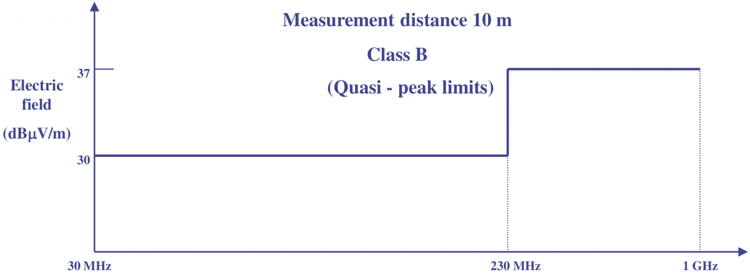
- Measurement
  - Quasi-Peak
  - Average

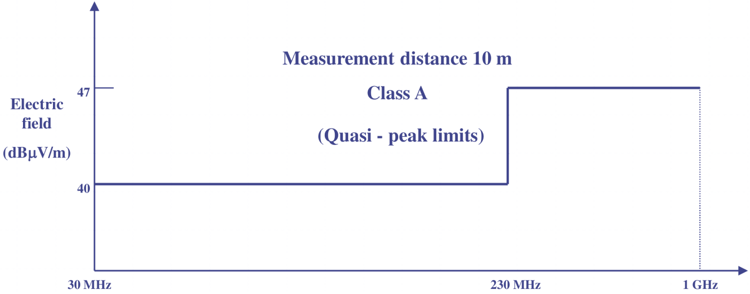
Mains conducted limits



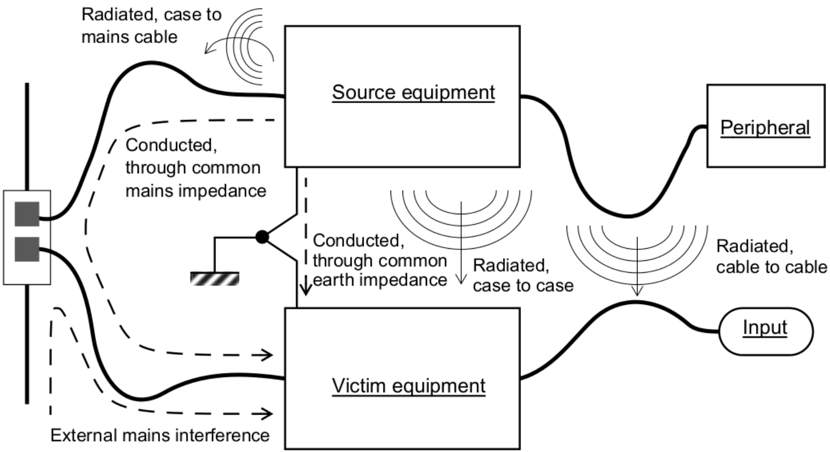


Radiated limits

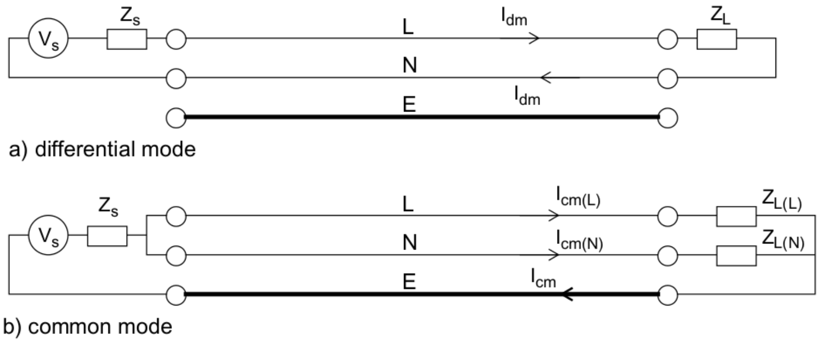




Interference coupling mechanisms



Common and differential mode propagation

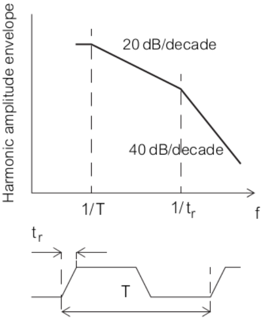


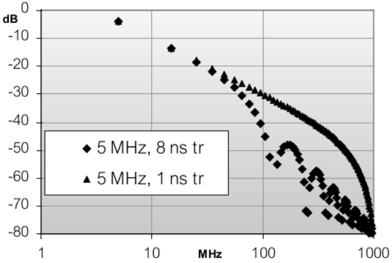
Design guidelines

- Shielding and filtering costs money
- Circuit design doesn't!
- Short tracks with nearby ground return or differential signaling

Digital

- Use slowest logic family





- Use lowest clock frequency
- (Clock dithering)

Design guidelines 2

Analog

- Watch out for RF oscillations (or overshots)
- Minimise signal bandwidth. RC or ferrites
- High signal level
- Balanced signals
- Galvanic isolation
- Keep the circuit linear (avoid intermodulation distortion). Filtering cleans everything up

Design guidelines 3

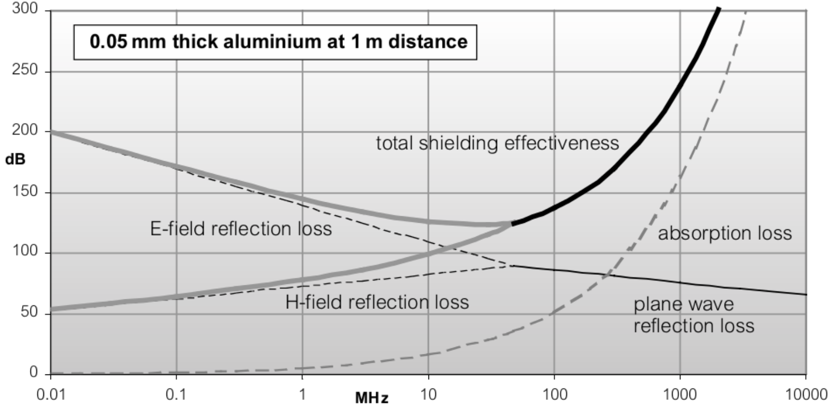
Software

- Watchdog timer
- Check range of input data. Reject if outside valid range
- Oversample and average data
- Parity check
- Implement error detecting and/or correcting codes
- Rely on levels rather than on edges
- Re-initialise programmable peripherials: they *will* lose their configuration

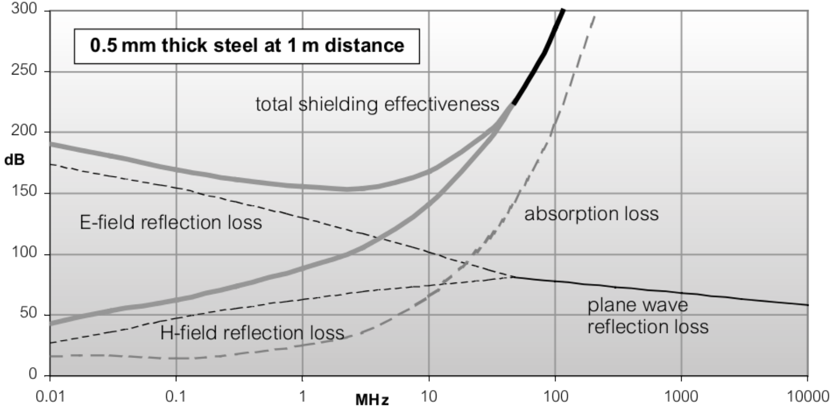
Shielding

- Conductive surface around critical parts
- Atenuation by reflection and absorption
- All-metal (for low f) or only a conductive coating on plastic
- Typical shielding effectivity: 20–80 dB is average. > 120‘ dB is unachievable
- Perfect shield: seamles box of zero-resistance material with no apertures. The Faraday cage
- Practical shields
  - Are not made of perfect conductors
  - Have apertures

Shielding. Aluminium

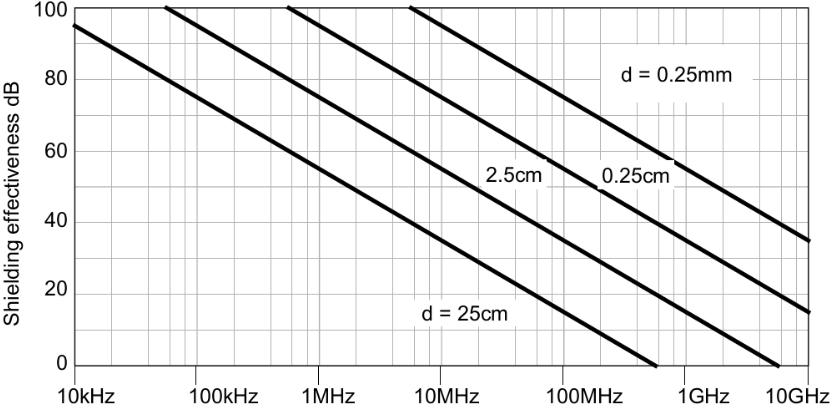


Shielding. Steel



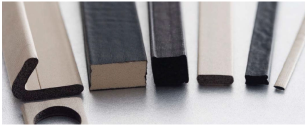
Apertures

- Practical shielding effectiveness is limited by apertures and discontinuities in shielding.
- Apertures: ventilation, indicators, ...
- Leakage depends on the longest dimension d and the minimum wavelength λ. No shielding if $\lambda < 2d$

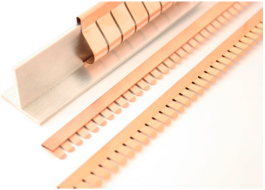


Seams

- Imperfect joints: distortion, painting, anodising, corrosion...
- Overlap: capacitor. Path for higher frequencies
- Place screws or rivets no farther than $\lambda/20$
- Conductive gasket: knitted wire mesh, conductive fabric over foam, ...



- Beryllium copper fingers

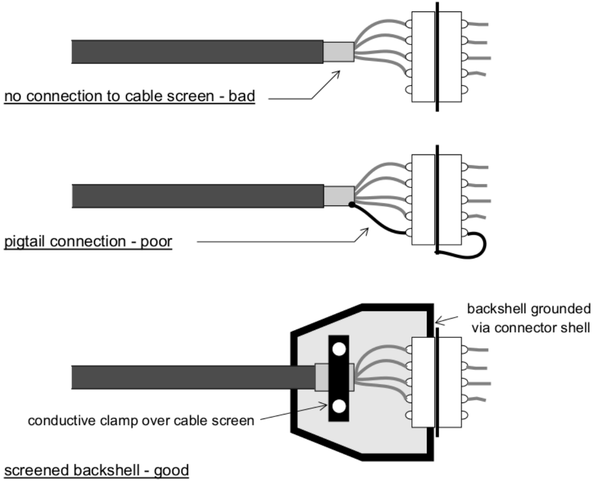


Filtering

- Low-pass filters
  - Single inductor. Works well if Z_G and Z_L are low.
  - Single capacitor. Works well if Z_G and Z_L are high.
  - LC, CL, CLC... Analysed using conventional techniques. But: source and load impedances are not exactly known!
- Provide low-inductance ground path
- Ready-made mains filters

Cables and connectors

- Cable shield to minimize the creation of external fields
- Shield has to be properly terminated. 360°contact is desirable (such as in BNC).
- Screened connector shell



EMC checklist

Components

- use slow and/or high-immunity logic
- use good RF decoupling of power supplies
- minimise signal bandwidths with RC filtering, maximise levels
- use resistor buffering on long clock or data lines
- incorporate a watchdog circuit on every microprocessor

PCB layout

- keep interference paths segregated from sensitive circuits
- minimise ground inductance with an unbroken ground plane or ground grid
- minimise loop areas in high-current or sensitive circuits
- minimise track and component leadout lengths

EMC checklist 2

Cables

- avoid parallel runs of signal and power cables
- make sure that screens are 360 °bonded through properly designed connectors
- use twisted pair for high-speed data or high-current switching
- run internal cables away from apertures in shielded enclosures
- use multiple ground wires or planes in ribbon or flexi cables

Grounding

- ensure adequate bonding of screens, connectors, filters, cabinets etc.
- ensure that bonding methods will not deteriorate in adverse environments
- mask paint from any intended conductive areas
- keep earth straps short and wide: aim for a length/width ratio less than 3:1
- route conductors to avoid common ground impedances

EMC checklist 3

Filters

- apply a mains filter for both emissions and immuity: check required current rating
- use correct components and filter conf. for I/O lines
- ensure good interface ground return / each filter group
- ensure filter input and output terminal wiring is kept separate
- apply filtering to interference sources, such as switches or motors

Shielding

- determine the type and extent of shielding required from the frequency range of interest
- enclose particularly sensitive or noisy areas with extra internal shielding
- avoid large or resonant apertures in the shield, or take measures to mitigate them
- use conductive gaskets where long $(> \lambda/20)$ gaps or seams are unavoidable