Seminar in delavnica
Načrtovanje elektronike za EMC
Elektromagnetna združljivost (EMC)
M. Jankovec
Zakaj EMC?

http://www.compliance-club.com/archive/old_archive/Bananaskins.htm
Banana skin #1

A (CE marked) portable PC carried up the stairs in a domestic household whilst operating, reliably caused the "power shower" in the bathroom to turn itself off if it was in use at the time. (Personal communication in 1997)
When a piezo-electric cigarette lighter was lit near the cabinet of a car park barrier control box, the radiated pulse caused the barrier to open and drivers were able to park free of charge.
Excessive mains harmonics in the London area, due mainly to the rapidly increasing use of personal computers, are causing overheating problem in AC power cables (including those that run under the Thames). In the offices where the computers are, it is increasingly common for the power-factor correction capacitors normally fitted to fluorescent lamps to blow (the electricians usually just remove the blown capacitors). Damaged and overheated neutrals, and damaged electrical switchgear is increasingly seen as a result of harmonic mains pollution. In the US, fire insurance companies are being urged not to take on any new policies unless they have had the size of the neutral cables in the company concerned checked for their adequacy for the heating effects of harmonic currents.  (Personal communications, January 1996)
Banana skin #4

Catastrophe with H.M.S. Sheffield during the Falkland crisis. An Exocet missile hit this frigate because its search radar was switched off (so its anti-missile guns couldn’t be used – Editor) It was switched off because it was known that the satellite communication system was interfered with by this radar.
Osnovna delitev EMC področja

Motnja/emisija
- Prevodna (Conducted)
- Sevalna (Radiated)

Odpornost/imunost
- Prevodna (Conducted)
- Sevalna (Radiated)
Standardi s področja EMC

• **Osnovni standardi**
  ▫ IEC 61000-1-1: Definicije izrazov
  ▫ IEC 61000-2-x: Definicije okolij
  ▫ IEC 61000-3-x: Omejitve emisij
  ▫ IEC 61000-4-x: Imunost na sevanja in razelektritve
  ▫ IEC 61000-5-x: Priporočila za povezovanje in ozemljevanje

• **Generični standardi za posamezna okolja uporabe**
  ▫ **Imunost**
    • IEC 61000-6-1 (domača, komercialna, lažja industrijska)
    • IEC 61000-6-2 (industrijska)
  ▫ **Emisije**
    • IEC 61000-6-1 (domača, komercialna, lažja industrijska)
    • IEC 61000-6-2 (industrijska)
EMC razredi naprav

<table>
<thead>
<tr>
<th>Razred A</th>
<th>Razred B</th>
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</thead>
<tbody>
<tr>
<td>• Uporaba</td>
<td>• Uporaba</td>
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<tr>
<td>▫ industrijsko okolje</td>
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<td>• Nadziran dostop</td>
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<tr>
<td>• Časovno omejena izpostavljenost uporabnikom</td>
<td>▫ Lažja industrija</td>
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<tr>
<td>• Kvalificirani uporabniki</td>
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<td>• Večje razdalje med napravami</td>
<td>• Nekvalificirani uporabniki</td>
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<tr>
<td>• Dopustno sevanje je večje</td>
<td>▫ Široka potrošnja</td>
</tr>
<tr>
<td>▫ + 10 dB glede na razred B</td>
<td>• Ostrejše zahteve za sevanje</td>
</tr>
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Omejitve prevodnih RF motenj (< 30 MHz)
Omejitve sevalnih RF motenj (> 30 MHz)

Tim Wiliams, EMC for product designers
Doseganje EMC

![Diagram showing the relationship between solution availability and price during development and testing phases.](image-url)
Model EMC

- Model, s katerim se prikaže elektromagnetne motnje, ima tri osnovne gradnike:
  - **izvor** sevanja (motenj),
  - **sprejemnik**,
  - **povezava** med izvorom in sprejemnikom.

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**Izvor**
- Naravni
- Umetni
  - Namerni
  - Nenamerni

**Povezava**
- Prevodne
- Električno polje
- Magnetno polje
- Elektromagnetno polje

**Žrtev**
- Biološke
- Umetne
Izvori motenj

VF potenciali

VF tokovne zanke
Izvori motenj

- Vprašanja:
  - Kje teče tok?
  - Kje so napetostna nihanja?
  - Kakšna je frekvenčna vsebina toka, napetosti?

\[ t_r \]

\[ T_{ON} \]

\[ T \]

\[ \frac{1}{T} \]

\[ \frac{1}{\pi T_{ON}} \]

\[ \frac{1}{\pi t_r} \]

\[ 20 \text{ dB/dek} \]

\[ 40 \text{ dB/dek} \]
Povezava - mehanizmi sklapljanja motenj

Tim Wiliams, EMC for product designers
EMC razdelitev glede na vire in sklope

**Emisije**
- Sevalne
- Prevodne
- NF magnetna polja

**Imunost**
- Hitri prehodni pojavi (FTB)
- Prenapetosti (Surge)
- Elektrostatične izpraznitve (ESD)
- Sevalne motnje
- Prevodne motnje
- NF magnetna polja
Kapacitivni prenos motenj (prek $E$ polja)

$$U_2 = C_{12} \frac{dU_1}{dt} Z_{in}$$

Diagram:

- **Agresor**
- **Žrtev**
- $U_1$ and $U_2$
- $C_{12}$
- $Z_{in}$
Induktivni prenos motenj (prek $H$ polja)

$\begin{align*}
I_2 &= -L_{12} \frac{dI_1}{dt} \frac{1}{Z_{in}}
\end{align*}$
EMC meritve sevalnih emisij v bližnjem polju
Antene za bližnje E polje (precompliance)
Antene za bližnje H polje (precompliance)

Osnovna zanka  
Bližnje H polje

Oklopljena zanka

Oklopljena zanka z režo

Gjorgji Nusev, Diplomsko delo, 2014
EM scan / Detectus
Detectus
Detectus
Primer nizkih emisij
Prenos motnje preko EM polja

E-field

H-field

Near field

Far field

Radiating source

Electromagnetic wave

Tim Williams, EMC for product designers
Prenos motnje preko EM polja

Agresor

Žrtev
Prevodno-sevalni prenos motenj

Napajanje

Električni tok z motnjami

Agresor

Žrtev
Diferencialni in sofazni signali

\[ I_1 = I_{dm} + I_{cm} \]
\[ I_2 = I_{dm} - I_{cm} \]
\[ I_{dm} = \frac{I_1 + I_2}{2} \]
\[ I_{cm} = \frac{I_1 - I_2}{2} \]
Diferencialne in sofazne motnje

\[ E_{dm_{max}}(f) = 1,31 \cdot 10^{-14} \frac{I_{dm}(f)f^2Ld}{R} \text{ V/m} \]

\[ E_{cm_{max}}(f) = 2,63 \cdot 10^{-14} \frac{I_{cm}(f)f^2Ld}{R} \text{ V/m} \]

\[ E_{cm_{max}}(f) = \pi \cdot 10^{-7} \frac{I_{cm}(f)fL}{R} \text{ V/m} \]

Primer vira diferencialne motnje na TIV

Radiated emission

Current $I_S$

Loop of area $A$, formed by signal and return tracks

Tim Wiliams, EMC for product designers
Primer vira sofazne motnje na TIV

Tim Wiliams, EMC for product designers
Primeriava diferencialne in sofazne motnje

Intel AP-711, EMI Design Techniques

- Signali na PCB
  - Majhne tokovne zanke \((A)\)
  - Protifazni zančni tokovi \((I)\)
    \[ E_{dm} = 2,63 \cdot 10^{-14} \frac{I_{dm} A f^2}{R} \]
  - \(I = 1 \, mA, f = 100 \, MHz, A = 1 \, cm^2\)
  - \(E = 26 \frac{\mu V}{m} @ 1 \, m\)

- Signali na povezovalnem kablu
  - Velike dipolne antene (dolžine \(L\))
  - Sofazni tokovi \((I)\)
    \[ E_{cm} = \pi \cdot 10^{-7} \frac{I_{cm} f L}{R} \]
  - \(I = 0.8 \, \mu A, f = 100 MHz, L = 1 m\)
  - \(E = 26 \frac{\mu V}{m} @ 1 \, m\)

\[
26 \frac{\mu V}{m} = 20 \cdot \log \left( \frac{26}{1} \right) = 28 \, \text{dB} \mu V / m
\]
Feritni obroček

Diferencionalni (koristni) signali

Sofazni (motilni) signali

$I_{cm}$
Kitajska tablica z dvomljivim CE znakom
Meritve sevalnih emisij - komora

Antena

Višina antene 1-4m. Obe polarizaciji

3 ali 10 metrov

Lesena miza

DUT

Kovinska tla

Vrtljiva mizica

80cm
Meritve sevalnih emisij – neodbojna komora
Meritve sevalnih emisij - GTEM celica
Meritve sevalnih emisij - GTEM celica
Prevodni prenos motenj preko skupne mase

\[ U_{GND} = R_{GND} \times (I_1 + I_2) \]
Prevodni prenos motenj iz napajalnih linij

Napajanje

\[ I_1 + I_2 \]
\[ R \]
\[ U \]
\[ U - 2R(I_1 + I_2) \]

Agresor

\[ I_1 \]
\[ R \]
\[ I_1 + I_2 \]
\[ I_1 \]
\[ I_2 \]

Žrtev

\[ I_2 \]
Primer prevodnihih motenj

Figure 5.14 Coupling paths for conducted emissions

Tim Williams, EMC for product designers
Meritve prevodnih emisij - LISN
Meritve prevodnih emisij - LISN

Slikano na SIQ pri meritvi emisij vezij iz EMC delavnice
Meritve prevodnih motenj- domača izdelava
Odpornost

Sevalna

- VF EM polja
- Elektrostaticna izpraznitev (ESD)
- NF magnetna polja

Prevodna

- Prehodni pojavi
  - Hitri prehodni pojavi (FTB)
  - Prenapetost (surge)
  - Elektrostaticna izpraznitev (ESD)
- Pojavi v omrežni napetosti
Odpornost na sevalne motnje – (recipročnost)

Field coupling to cable induces common-mode current at input to circuit

Field coupling with internal wiring and components

Possible standing wave in enclosure

Tim Wiliams, EMC for product designers
Hitri prehodni pojavi (Fast Transient Bursts FTB)

- Hitri signali, vlaki impulzov
- Vklopi/izklopi
  - Preklapljanje stikal v bližini
- Induktivna bremenja
  - Motorji in releji
  - Balasti fluorescenčnih sijalk
- V šopih kablov se ob preklopih motnje kapacitivno prenašajo z vodnikov, ki napajajo močne porabnike na ostale
- Posredni udarci strele, mnogokratni odboji na povezovalnih linijah

Prenapetost

• Nizkofrekvenčni močnostni impulzi.
  ▫ Preklopi v omrežju
  ▫ Izolacijski problem omrežju
  ▫ Vklopi/izklopi močnih porabnikov
  ▫ Pregorevanje varovalk
  ▫ Udarci strele
• Moč in energija pulzov je dovoljšna, da povzroči eksplozije elementov v napravi
• AC vtičnica v stanovanju
  ▫ 3 x 6kV prenapetostnih pulzov na leto!

Elektrostaticčne izpraznitve

- Air
- Human Skin
- Glass
- Human Hair
- Wool
- Fur
- Paper
- Cotton
- Wood
- Hard Rubber
- Acetate Rayon
- Polyester
- Polyurethane
- PVC
- PTFE

Voltage kV

Relative humidity %

Synthetic
Wool
Anti-static

Figure 3P The standard EN 61000-4-2 current waveshape

Tim Williams, EMC for product designers
Elektrostatics

Coupling plane

Direct discharge

Electrostatic charging

Transient current paths

Tim Williams, EMC for product designers
Sekundarne izpразnitvene poti
Elektrostatične izpraznitve (ESD)

Ostale težave z odpornostjo naprav

**NF magnetna polja**
- Indukcija v sklenjenih zankah
  - Transformatorji
  - Stikalni napajalniki (transformatorji)
  - Najpogostejše pri 50 Hz
- Zaščita
  - Oklopi iz visoko permabilnih materialov

**Težave v omrežni napetosti**
- Višji harmoniki
- Nihanje napetosti, kratki in daljši izpadi in prekinitve napetosti
- Neuravnoteženost trifaznega sistema
- Komunikacije prek napetostnega omrežja
- Spremembe frekvence omrežne napetosti
"Some of the worst printed circuit boards we've seen were designed by engineers who were trying to comply with a list of EMC design rules."

Todd Hubing
Na koncu?

http://lpvo.fe.uni-lj.si/izobrazevanje/seminarji/nacrtovanje-elektronike-za-emc/