EMC Crosstalk between PCB Traces

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Outline

1. Electromagnetic fields and crosstalk
2. Inductive and capacitive coupling
3. Circuit model
4. Circuit analysis
5. PCB measurements
6. Conclusions and design implications
**PCB Crosstalk**

*Crosstalk* - unintended electromagnetic coupling between PCB traces.

Voltage (or current) from one circuit, called the *generator or aggressor circuit*, induces voltage (or current) at the terminals of another circuit, called the *receptor or victim circuit*.

*Important EMC concern:* design the product that does not interfere with itself.
PCB Geometry and Fields Coupling

PCB Geometry

Magnetic field coupling

Electric field coupling

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Fields Coupling vs. Inductive and Capacitive Coupling

Magnetic field coupling:
\[ I_G \]

Inductive coupling:
\[ V_R = \frac{d\Psi_R}{dt} = L_m \frac{dI_G}{dt} \]

Electric field coupling:
\[ q_G \]

Capacitive coupling:
\[ I_R = \frac{dq_G}{dt} = C_m \frac{dV_G}{dt} \]
EMC problem to solve:

Given: $V_S(t), R_S, R_L, R_{NE}, R_{FE}$

Determine: $V_{NE}(t), V_{FE}(t)$
Crosstalk Model in Receptor Circuit

Generator and Receptor Circuit Model

Crosstalk Model in Receptor Circuit
Principle of Superposition

Receptor circuit with both sources present
Partial Induced Voltages

\[ V_{NE}(t) = \frac{R_{NE}}{R_{NE} + R_{FE}} L_m \frac{dI_G}{dt} \]

\[ V_{FE}(t) = -\frac{R_{FE}}{R_{NE} + R_{FE}} L_m \frac{dI_G}{dt} \]

\[ V_{NE}(t) = \frac{R_{NE}R_{FE}}{R_{NE} + R_{FE}} C_m \frac{dV_G}{dt} \]

\[ V_{FE}(t) = \frac{R_{NE}R_{FE}}{R_{NE} + R_{FE}} C_m \frac{dV_G}{dt} \]
Total Induced Voltages

**Receptor circuit**

\[ V_{NE}(t) = \frac{R_{NE}}{R_{NE} + R_{FE}} L \frac{dI_G}{dt} + \frac{R_{NE} R_{FE}}{R_{NE} + R_{FE}} C \frac{dV_G}{dt} \]

**Total induced voltage at near end.**

\[ V_{FE}(t) = -\frac{R_{FE}}{R_{NE} + R_{FE}} L \frac{dI_G}{dt} + \frac{R_{NE} R_{FE}}{R_{NE} + R_{FE}} C \frac{dV_G}{dt} \]

**Total induced voltage at far end.**
Total Induced Voltages

Relationship between the generator signals and the source signals, valid for electrically short traces:

\[
V_G(t) \approx \frac{R_L}{R_S + R_L} V_S(t)
\]

\[
I_G(t) \approx \frac{1}{R_S + R_L} V_S(t)
\]

**Total induced voltage at near end.**

\[
V_{NE}(t) = \left[ \frac{R_{NE}}{R_{NE} + R_{FE}} L_m \left( \frac{1}{R_S + R_L} \right) \right] + \left[ \frac{R_{NE} R_{FE}}{R_{NE} + R_{FE}} C_m \frac{R_L}{R_S + R_L} \right] \frac{dV_S(t)}{dt}
\]

**Total induced voltage at far end.**

\[
V_{FE}(t) = \left[ -\frac{R_{FE}}{R_{NE} + R_{FE}} L_m \left( \frac{1}{R_S + R_L} \right) \right] + \left[ \frac{R_{NE} R_{FE}}{R_{NE} + R_{FE}} C_m \frac{R_L}{R_S + R_L} \right] \frac{dV_S(t)}{dt}
\]
PCB Board
PCB Board Layout
Experimental Set-Up
Case 1

![Diagram showing Aggressor Signal with rise time = 100 ns and fall time = 200 ns. Victim Line - Near End showing 1.54 mV and 760 µV. Victim Line - Far End showing 260 µV and 560 µV.]

- Aggressor Signal
- Rise time = 100 ns
- Fall time = 200 ns
- 1V_{PP}
- 25 mils
- 54.8 mils
- Case 1
- 1.54 mV
- 760 µV
- 260 µV
- 560 µV
Case 2
Case 3
Design Implications

Induced crosstalk voltage is proportional to \( \frac{dV}{dt} \) and board geometry.

To reduce crosstalk:

- Increase the rise and fall times
- Move ground plane closer to the signal plane
- Move signal traces in the signal plane farther apart
Crosstalk in Frequency Domain

\[ \hat{V}_{NE} = \frac{R_{NE}}{R_{NE} + R_{FE}} j\omega L_m \frac{1}{R_S + R_L} \hat{V}_S + \frac{R_{NE} R_{FE}}{R_{NE} + R_{FE}} j\omega C_m \frac{R_L}{R_S + R_L} \hat{V}_S \]

\[ \hat{V}_{FE} = -\frac{R_{FE}}{R_{NE} + R_{FE}} j\omega L_m \frac{1}{R_S + R_L} \hat{V}_S + \frac{R_{NE} R_{FE}}{R_{NE} + R_{FE}} j\omega C_m \frac{R_L}{R_S + R_L} \hat{V}_S \]
Transfer Function Response

\[
\hat{V}_{NE} = \frac{R_{NE}}{R_{NE} + R_{FE}} j\omega L_m \frac{1}{R_s + R_L} \hat{V}_S + \frac{R_{NE} R_{FE}}{R_{NE} + R_{FE}} j\omega C_m \frac{R_L}{R_s + R_L} \hat{V}_S
\]

\[
\text{inductive coupling}
\]

\[
\hat{V}_{FE} = -\frac{R_{FE}}{R_{NE} + R_{FE}} j\omega L_m \frac{1}{R_s + R_L} \hat{V}_S + \frac{R_{NE} R_{FE}}{R_{NE} + R_{FE}} j\omega C_m \frac{R_L}{R_s + R_L} \hat{V}_S
\]

\[
\text{capacitive coupling}
\]

\[
\frac{\hat{V}_{NE}}{\hat{V}_S} = j\omega (M_{IND}^{NE} + M_{CAP}^{NE}) = j\omega M_{NE}
\]

\[
\frac{\hat{V}_{FE}}{\hat{V}_S} = j\omega (M_{IND}^{FE} + M_{CAP}^{FE}) = j\omega M_{FE}
\]

Crosstalk increases 20 dB/decade.
Crosstalk at 1 MHz – NE – Case 1
Crosstalk at 10 MHz – NE – Case 1
References and Acknowledgements

B. Adamczyk, J. Teune “EMC Hardware Demonstration – PCB Crosstalk” – 2008 IEEE International EMC Symposium, Detroit, MI

Bill Spence and Pete Vander Wel, Gentex Corp. – Board Design


B. Adamczyk, Lecture Notes, GVSU, 2008-2013
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The Impact of Cables and Connectors on Radio Frequency and Microwave Measurement Uncertainties

More details at: http://www.westmichigan-emc.org/