Course Introduction

Purpose:
This course discusses techniques that can be applied to reduce problems in embedded control systems caused by electromagnetic noise.

Objectives:
• Gain a basic knowledge about noise that affects embedded systems
• Learn approaches and design methods for minimizing the noise generated by microcontroller based embedded systems
• Get details about techniques chip designers use to decrease the amount of noise a microcontroller produces
• Obtain basic insights for handling noise problems during the system design and development cycle

Content:
19 pages
3 questions

Learning Time:
30 minutes
Noise Can Cause Big Problems

Noise = “Unwanted electrical signals that produce undesirable effects in the circuits of control systems in which they occur.”

Two types of noise:

- Electromagnetic Compatibility (EMC) issues encompass both types
- Noise reduction approaches:
  - Techniques for reducing EMI (Electromagnetic Interference) — Cutting the noise emitted by a specific system, circuit or device that causes other devices/circuits to operate incorrectly
  - Techniques for decreasing EMS (Electromagnetic Susceptibility) — minimizing the effect that external noise has on the operation of a system, circuit or device
- Noise reduction: a goal common to both microcontroller (MCU) designers and the system engineers who apply those devices
Effect of Hidden Impedances

- Many significant Ls and Cs are “hidden” impedances in the circuit.
- Noise is the undesirable result of unintentional interaction due to stray capacitances and inductances.
- Parallel signal paths allow more coupling and interaction, more noise.
  - Capacitance is proportional to the area of electrodes and inversely proportional to the distance between the electrodes.
  - Inductance exists even in straight wires, and mutual inductance between adjacent signal lines causes electromagnetic coupling.
Impedance of Interconnects

- Signal interconnections on a circuit board have resistance
  - Example: Impedance of a copper-foil trace 35µm thick and 0.5mm wide is about 0.01Ω/cm at DC

- Microcontrollers can have fast clock speeds and signals that contain very high frequency components
  - The frequencies in the spectrum of a digital signal increase rapidly as rise and fall times became shorter
  - Example: As the rise time decreases from 10nsec/5V to 2 to 5nsec/5V, a signal will contain frequency components >100MHz

- Interconnection resistance increases as signal frequency components rise
  - Example: Impedance at 100MHz for the trace described above is \( \frac{V_{cc} \times 0.8}{V_{cc} \times 0.2} \approx 4 \) times larger than at DC!

- Design PCBs to handle high frequencies
  - Shorten the wiring traces that connect bypass capacitors to Vcc and ground and make the traces wider, etc.
Impedance of Capacitors

- **Ideal capacitor:**
  \[ Z = \frac{1}{\omega C} \]

  - Example: Impedance of 10pF capacitor at 100MHz is
  \[ Z = \frac{1}{2\pi \times 100 \times 10^6 \times 10 \times 10^{-12}} \approx 170\Omega \]

- **Frequency characteristics of actual capacitors vary by type and capacitance value**
  - Choices for bypass capacitors:

<table>
<thead>
<tr>
<th>Application</th>
<th>Typical Design</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Choice</strong></td>
<td><strong>Typical Design</strong></td>
</tr>
<tr>
<td>Small capacity</td>
<td>Ceramic capacitor</td>
</tr>
<tr>
<td>(0.01 - 0.1μF); install</td>
<td>Small capacitance, but good frequency</td>
</tr>
<tr>
<td>between Vcc/GND of IC response</td>
<td>Tantalum capacitor</td>
</tr>
<tr>
<td>High capacity</td>
<td>Smaller capacitance</td>
</tr>
<tr>
<td>(0.1 - 10μF); install</td>
<td></td>
</tr>
<tr>
<td>than between Vcc/GND</td>
<td>aluminum electrolytic, better frequency</td>
</tr>
<tr>
<td>but of PCB response</td>
<td></td>
</tr>
<tr>
<td>Extra high capacity</td>
<td>Aluminum</td>
</tr>
<tr>
<td>electrolytic (1 - 100μF); install</td>
<td>Poor frequency</td>
</tr>
</tbody>
</table>
Is the following statement true or false? Click Done when you are finished.

“A ceramic capacitor is a good choice for a small-capacity bypass capacitor because it has good frequency response.”

True
False

Done
Typical Causes of Noise

- Signal interference
- Waveform distortion during signal transmission
- Sudden change of power current
- Narrow ground line
- Electromagnetic induction (from power line, power devices)
Review values of components in the clock oscillator circuit
Optimize C1, C2 and R2 to prevent unwanted emission and allow circuit to oscillate at optimum amplitude

Change device package type from a DIP to a QFP
Adopt a package with shorter lead lengths to decrease unwanted emissions from antenna effect

Use a single-chip solution instead of a MCU and external memory
Choose an MCU with on-chip memory to prevent unwanted emissions caused by driving an external bus line
**Techniques for Reducing EMI - 2**

**Reduce power supply voltage**
If possible, reduce Vcc from 5V to 3.3V to reduce the noise level.

![Vcc=5V to Vcc=3.3V comparison](image)

**Use port mode, not bus mode**
Depending on the type of MCU, the signal on a general-purpose port may change voltage much less frequently than the signal on the bus. If this is the case, use the port to reduce the amount of noise generated.

**Typical: Bus-mode**
Activates bus line when accessing peripheral IC and MCU (with on-chip memory + I/O).

**Better: Port-mode**
Activates bus line only when MCU is accessing peripheral IC.

**Use serial damping resistors**
Insert a damping resistor (100 to 150 Ohms) in signal lines to reduce emissions caused by signal reflection. A resistance of about 5kΩ is OK if some signal degradation is acceptable.

![Serial damping resistors](image)
Techniques for Reducing EMI - 3

Revise system timing, if possible
Try to stagger significant signal-driving events, even just slightly, to diffuse the noise generated by switching

Insert L-C filters on each power and ground line
The filters help prevent switching noise from entering the Vcc and GND lines, from which they might otherwise be radiated

Use a multi-layer circuit board and apply best-practice layout methods
Develop effective sheet patterns for the Vcc and GND planes; make interconnect wiring as short as possible; interleave noisy signal lines with GND and Vcc layers to shield the line; etc.
Techniques for Reducing EMI - 4

Use a half-area pattern on the circuit board when whole-area pattern cannot be used
To the greatest extent possible, make symmetrical patterns for Vcc and GND on the facing layers of a double-sided PCB

Select a microcontroller that produces low levels of EMI
Consider the MCUs in the M16C series, devices that were designed from the outset to minimize noise problems in embedded systems
Which statements about reducing EMI in embedded systems are correct? Select all that apply and then click Done.

Choose a microcontroller with on-chip memory to prevent unwanted emissions caused by driving an external bus line.

To reduce emissions caused by signal reflections, insert a serial matching resistor of 100 to 150 Ohms in signal lines.

Use bus mode, not port mode, to reduce the number of voltage changes and, therefore, to reduce the unwanted noise.

If you have a two-sided circuit board, always try to make symmetrical patterns for Vcc and GND on the facing layers.
Designing Low-EMI MCUs - 1

Change the driving capability of the clock oscillation circuit
Use high-drive mode to get oscillator started reliably; low-drive mode to sustain oscillation

Use an optimum output buffer conversion speed (through rate)
Don’t set the speed any higher than necessary

Change the timing of the output buffers
Eliminate the simultaneous switching of all channels, if possible
Designing Low-EMI MCUs - 2

Eliminate pass-through current in output buffer
Change the timing of the N-channel and P-channel transistors to eliminate a source of high-frequency noise

Reduce output amplitude of output buffer
Design circuit to produce a lower amplitude and slower rise time

Optimize output impedance of output buffer
Minimize ringing by matching the buffer’s output impedance to the impedance of the signal wiring, which is about 100 to 150 Ohms
Use an innovative layout, enhanced with added internal capacitance
Add capacitance to reduce the total impedance of the power supply distribution system that’s internal to the microcontroller

Optimize the driving capability of the internal buffer transistors
Design very small transistors with large drive capability; adjust bus wiring, too

Arrange terminals for easy mounting of bypass capacitors across Vcc and GND terminals
Also, use parallel arrangement of signal lines inside package and on the chip to achieve extra filtering
MCUs in the M16C family have an innovative pin layout. Arrangement of pins eases the design of Vcc and GND wiring on the circuit board and aids the placement of bypass capacitors.
Basic Design Insights on Noise

It’s very important to implement noise measures at initial stage of design work

If a problem is discovered in the later stages of the system development process, the noise measures required to solve the problem will end up being far more costly than expected.

Investigations of noise problems take time and are costly

Because it’s difficult to simulate a noise-oriented malfunction, a lot of work will be necessary to identify the root cause of the problem.

Noise problems sometimes require a fundamental solution, such as a re-design

Unless noise measures are taken at the initial design stage, a malfunction that occurs later might be extremely difficult to eliminate using superficial correction methods; a re-design may be necessary to correct the problem.

Attempts to eliminate all possible EMI/EMS problems typically lead to unnecessarily high costs

The optimum design approach is to take pinpoint measures in key areas that require solutions.
Questions

Match each item to the most appropriate MCU design advice by dragging the letters on the left to the correct locations on the right. Click Done when you are finished.

A  Through rate

B  Pass-through current

C  Signal from buffer

D  Vcc and GND terminals

A  Set no higher than necessary

B  Eliminate by changing the timing of the N- and P-channel transistors

C  Reduce amplitude and slow down the rise time

D  Adjust locations to make it easy to install a bypass capacitor

Done  Reset  Show Solution
Course Summary

- Noise problems
- EMI and EMS
- System-level EMI reduction measures
- Techniques for reducing EMI from microcontrollers
- Design insights