High-speed Serial Interface

Lect. 6 – TX Driver and Equalizer
Block diagram

• Where are we today?
Classic output driver

- An inverter can be used as voltage-mode output driver

TTL output buffer

CMOS output buffer
Classic output driver

- It is difficult to use inverter-style output driver in high-speed applications
  - Full-swing logic is speed-limited because of slow switching time of inverter-style driver
  - Impedance matching is not easy
    - Transistors have variable output resistances during output voltage transients
Single-ended signaling

- Signal is transferred via single channel
- Simple but …
- Threshold should be generated in RX side.
  - Logic levels in TX may not be same as in RX side
    - Supply and ground levels are different for RX and RX sides
- Poor noise immunity
  - Noises are added while signals travel through channel
Differential signaling

- Differential signals are transferred via two adjacent channels
  - Each signal has opposite logic level
  - Ex) twisted pair, differential PCB lines
Differential signaling

• Larger signal swing and self-reference
  – Signal = (positive signal – negative signal)
  ➔ Decision margin enhanced
  – threshold = (positive signal + negative signal)/2

• Common-mode noise rejection
  – Noise usually affects both positive and negative channels
  – Subtraction rejects common-mode noise
Current-mode driver

• Reduced switching time
  – Current-steering: Switching current path while source current is kept constant.
  – Switching time is reduced since current source is not turned-off

• Disadvantage
  – Differential signaling is required.
  – Static current causes static power consumption
  – Usually larger power consumption than voltage-mode
50-Ω termination

• Why 50Ω?
  – Historical issue

  • In early microwave systems, it was known that
    – 33Ω shows best performance in power transfer
    – 75Ω shows best performance in signaling
    – For convenience, 50 Ω was selected instead of medium value, 54 Ω

  • Nowadays, almost all high-speed instruments are 50Ω-based
    → Significant for high-speed serial interface
    – In CATV systems, 75-Ω termination is still used
50-Ω termination

- **Tx-side termination topology**
  - Voltage-mode driver has small output impedance
    → Series termination
  - Current-mode driver has large output impedance
    → Parallel termination
DC- and AC-coupling

- AC coupling with a series capacitor
  - Both TX and RX are possible
  - Common-mode voltage can be separately controlled in both side
  - Coupling capacitor can cause low-frequency loss
    → Capacitance $> 100\text{nF}$ is generally used.
DC- and AC-coupling

- AC coupling cannot be used if consecutive identical bits are transmitted
  $\Rightarrow$ 8B/10B coding for many standards
Push-pull driver

- 2 current sources
  - Current path switching
  - Upper and lower pairs
  - Same rising and falling time for each differential signal
  - Upper PMOS pair can be replaced by NMOS pair to enhance switching time
  - Head room problem in low-voltage technologies
  - Used in Low-Voltage Differential Signals (LVDS) standard
  - TX termination?
CML (Current-Mode Logic) driver

- Loaded by 50ohm resistor
  - Current steering
  - Both side are terminated by 50Ω
  - Output voltage can be both DC, AC-coupled
  - Used in most high-performance serial link
TX equalization

- Channel causes ISI on received signal.
  - High-frequency loss in channel $\rightarrow$ eye-diagram closed
TX equalization

- TX driver can be also channel equalizer
  - TX driver can enhance high-frequency components before traveling through channel.
How to reject ISI?

- **FIR filtering**
  - Forcing cursors to 0 can be implemented by FIR filtering.
  - ISI can be removed since we know input data in TX-side.
  - Tx-side FIR filtering can include pre-cursor.
Feedforward vs Feedback

- DFE
Pre-/De-Emphasis

- Tx FIR is often called Pre-/De-Emphasis
  - De-emphasis: to reduce low-frequency components
  - Pre-emphasis: to enhance high-frequency components

- High-frequency component is transition bits
Circuit implementation

- Current-mode drivers can be easily used for pre-/de-emphasis
  - It is very easy to modify drivers into current-mode adder including controllable gain

![Circuit diagram](image-url)
Circuit implementation

• Simultaneous implementation of pre-/de-emphasis
  - $D_1 = D_0 \rightarrow V_{\text{out,diff}} = \pm 50 \times (C_0 - C_1) \Rightarrow \text{De-emphasis}$
  - $D_1 \neq D_0 \rightarrow V_{\text{out,diff}} = \pm 50 \times (C_0 + C_1) \Rightarrow \text{Pre-emphasis}$
  - Level difference is defined as sum and subtract

![Circuit Diagram]
Tx- vs. Rx- equalization

• **Tx equalization**
  – Consumes large power
  – Enlarged output signal improves SNR at Rx side
  – Easy implementation

• **Rx equalization**
  – Relatively low power consumption
  – More complex implementation (especially DFE)
  – For best performance, LE and DFE combination
Design example

“4-Channel 3.2/6.4-Gbps Dual-rate Transmitter”
김두호, 최우영
대한전자공학회 논문지 2010
4ch transmitter with 1-tap pre-emphasis
Dual-rate (3.2/6.4 Gbps)
130nm CMOS technology / COB package
600mW dissipation @1.2V power supply
Design example

- 4-channel transmitter sharing a clock generator
  - 2:1 serializer function is included in pre-emphasis circuit
  - Displayport application
Design example

• Clock generator performance
  – PLL jitter is main performance metric of transmitter evaluation.
Design example

- De-emphasis waveform

$V_{\text{swing}}=600 \text{mV}_{\text{diff}}$ / De-emphasis=$1/3$

$V_{\text{swing}}=600 \text{mV}_{\text{diff}}$ / De-emphasis=$1/2$

$V_{\text{swing}}=600 \text{mV}_{\text{diff}}$ / De-emphasis=$2/3$

$V_{\text{swing}}=600 \text{mV}_{\text{diff}}$ / De-emphasis=$1$

3.2Gb/s
Design example

- De-emphasis waveform

V_{swing}=600mV_{diff} / De-emphasis=1/3

V_{swing}=600mV_{diff} / De-emphasis=1/2

V_{swing}=600mV_{diff} / De-emphasis=2/3

V_{swing}=600mV_{diff} / De-emphasis=1