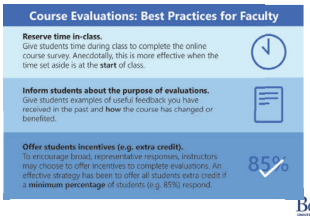
inst.eecs.berkeley.edu/~eecs251b

EECS251B : Advanced Digital Circuits and Systems

Lecture 25 – Supplies and Clocks

Borivoje Nikolić, Vladimir Stojanović, Sophia Shao

Time for course surveys!



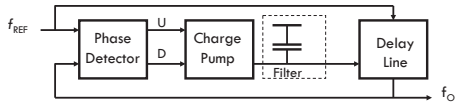
Recap

- Basics of phase-locked loops
- Digital PLLs

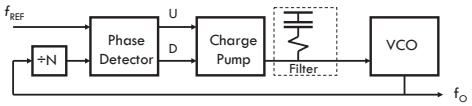
Delay-Locked Loops

Clock Generation

Delay-Locked Loop (Delay Line Based)

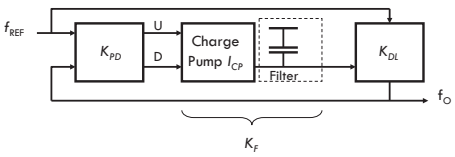


Phase-Locked Loop (VCO/DCO-Based)

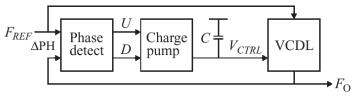


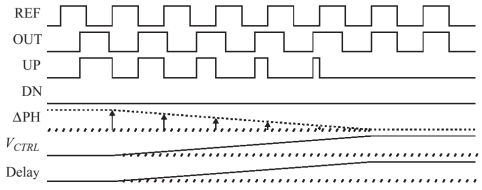
Delay-Locked Loop

- First order loop: inherently stable
- No filtering of input jitter
- Constant frequency (no synthesis)
- No phase error accumulation



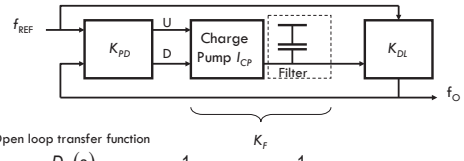
DLL Locking





Courtesy of IEEE Press, New York. © 2000

Delay-Locked Loop



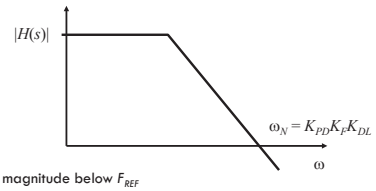
› Open loop transfer function

$$\frac{D_O(s)}{D_I(s)-D_O(s)} = K_{PD}\frac{1}{sC}I_{CP}K_{DL}F_{REF} = \frac{1}{s}K_{PD}K_FK_{DL}$$

› Closed loop transfer function

$$H(s) = \frac{D_O(s)}{D_I(s)} = \frac{K_{PD}K_FK_{DL}}{s + K_{PD}K_FK_{DL}}$$

Delay-Locked Loop



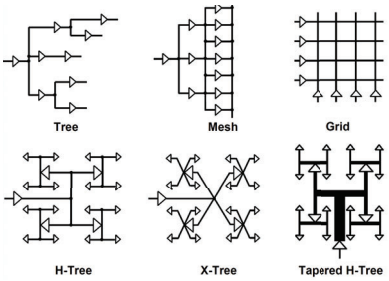
- ω_N > an order of magnitude below F_{REF}
- Use of DLLs requires low-jitter input
- VCDL must span adequate delay range + reset to min delay
- Noise sources:
  - Delay line (Supply sensitivity)
  - Clock buffers that follow
  - Device noise (small)

Announcements

- Final is in-class 4/28
  - 80min, 9:40am-11am
- Project presentations 5/5
  - 9am – 12:30pm
  - BWRC
  - 12min + 3min Q&A

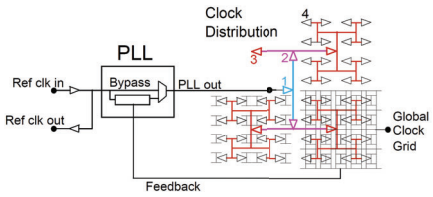
Clock Distribution

Clock Distribution



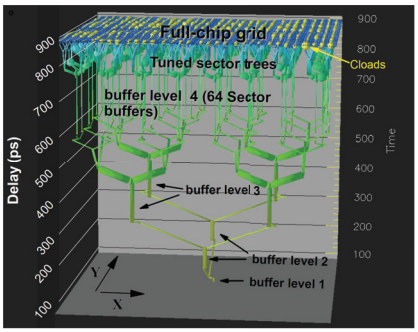
Example (Older) Clock System

- IBM Power 4

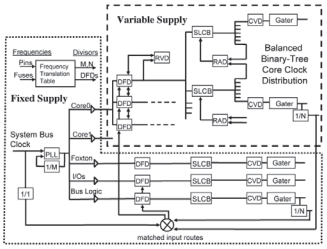


Restle, ISSCC'02

Clock Grid

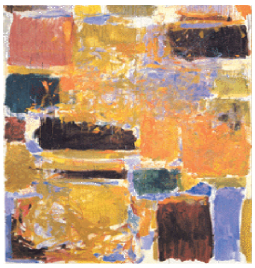


One PLL with multiple DLLs



- Single PLL, and two cores vary frequency through digital frequency dividers (DFDs) and DLLs
  - SLCB: Second-Level Clock Buffer
  - CVD: Clock Vernier Device – fine (static) delay tuning

Fischer, JSSC 1/06

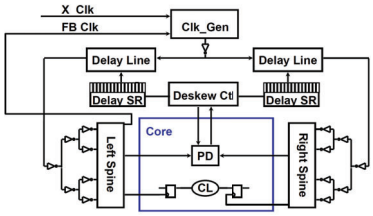


Deskewing and Synchronization

Clock Domain Synchronization

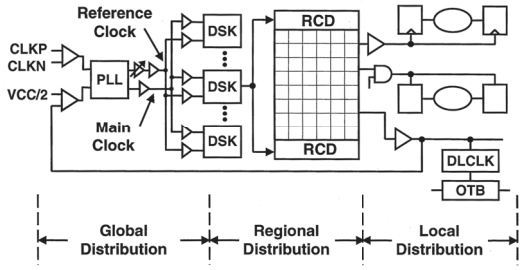
Type	Frequency	Phase
Synchronous	Same	Same
Mesochronous	Same	Constant offset
Plesiochronous	Small difference	Slowly varying
Asynchronous	Different	Arbitrary

Deskew System (Mesochronous)



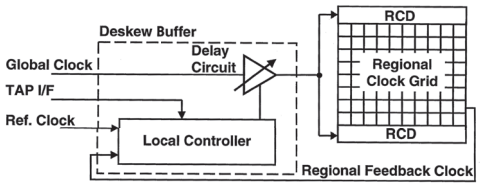
Geannopoulos, ISSCC'98

Deskew System



- Rusu, ISSCC'00

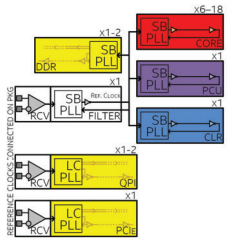
Deskew Buffer



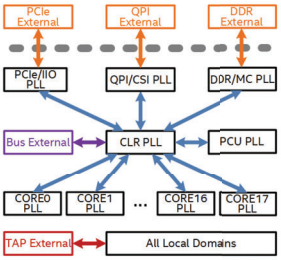
- Essentially a DLL to align regional clock with ref. clock

Clock Subsystem

- Intel Xeon – Bowhill, ISSCC'15
  - Independent clocks for 4-18 cores
- Self-biased (SB) and LC PLLs

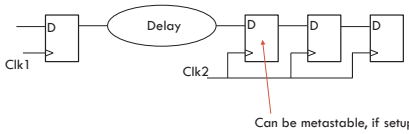


Clock Domain Crossings



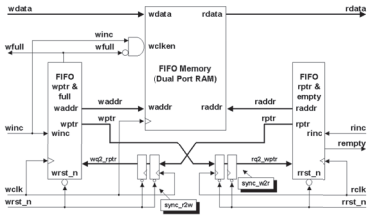
- Bowhill, ISSCC'15

Brute-Force Synchronizer



- Cascaded flip-flops reduce the probability of metastability

Clock Crossing FIFOs



- FIFO for clock crossings

http://www.sunburst-design.com/papers/CummingsSNUG2002SJ_FIFO1.pdf

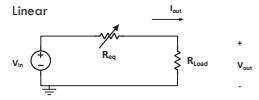
Supply Generation

Supply Generation

- Linear
  - Series or shunt
  - Linear regulation
  - Quiet
  - Inefficient (unless Vin-Vout is small)
- Switching (Capacitive)
  - Limited efficiency
  - Poor regulation
  - Voltage ripples
- Switching (Magnetic)
  - Efficient
  - Require external components
  - Noisy

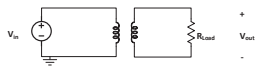
Linear vs. Switching Regulators

Linear

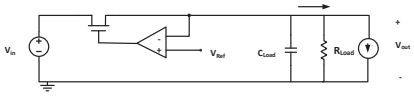


Efficiency η < Vout/Vin

Switching



Linear Voltage Regulator

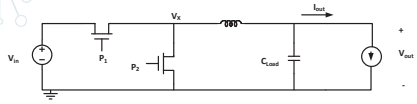


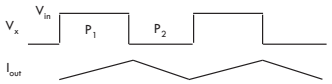
Negative feedback sets low supply resistance
Voltage regulated to desired level

E.g. IBM Power7 has 48 linear regulators

Switching Supply

- Buck Converter

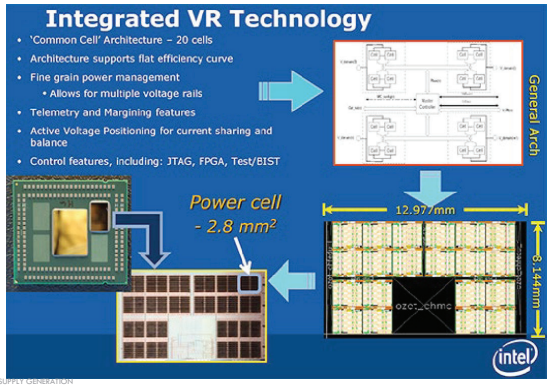




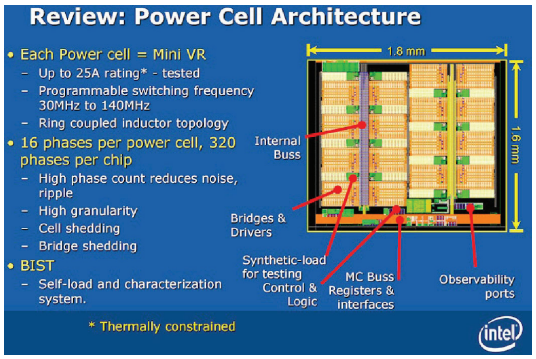
Pulse-Width Modulation (PWM) regulates V_{out}

High switching frequency, interleaving reduce ripple

Inside Haswell

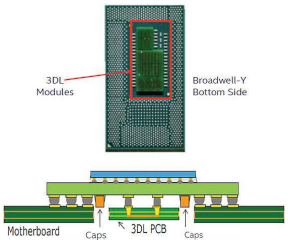


Inside Haswell

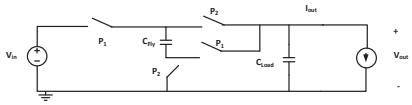


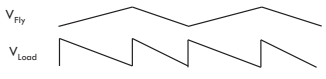
Intel Broadwell

- Inductors moved to a small PCB



Switched-Capacitor Supply

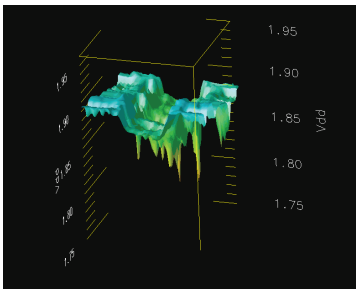




Interleaving reduces ripple, but lowers efficiency

What happens with supply when load changes?

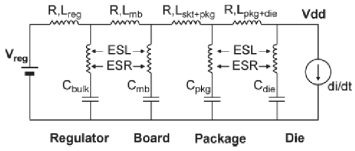
http://www.research.ibm.com/people/r/restle/Animations/DAC01top.html

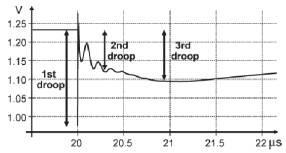


Phillip Restle, IBM

Power Delivery

- Typical model





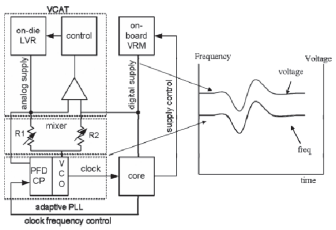
Wong, JSSC'06

Supply Resonances

- First droop
  - Package L + on-die C
- Second droop
  - Motherboard + package decoupling
- Third droop
  - Board capacitors

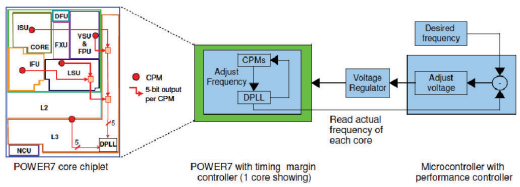
Clock and Supply

- Large digital systems can have large voltage transients
  - Can we filter impact of voltage on a clock generator?



Kurd, JSSC'09

Clock and Supply

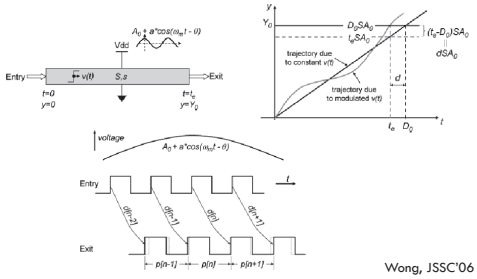


- IBM Power7, with one PLL per core

Lefurgy, MICRO'11

How to model

- Abstracted delay line

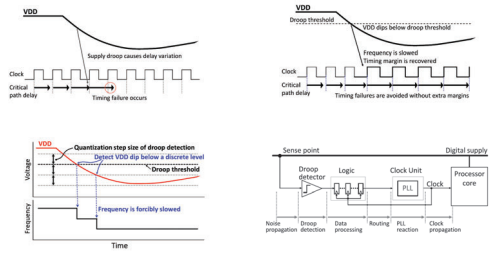


Wong, JSSC'06

Period modulation from successive modulated delays

Droop Detection

- Hashimoto, JSSC 4/18



Summary

- DLLs are used for phase alignment, deskewing
- Modern SoCs are globally asynchronous, locally synchronous
- Supply regulators
- Clock and supply interact

Next Lecture

- Wrap-up