Integration Potential of Active Power Delivery Networks

Michael Zelikson - MCD, Intel

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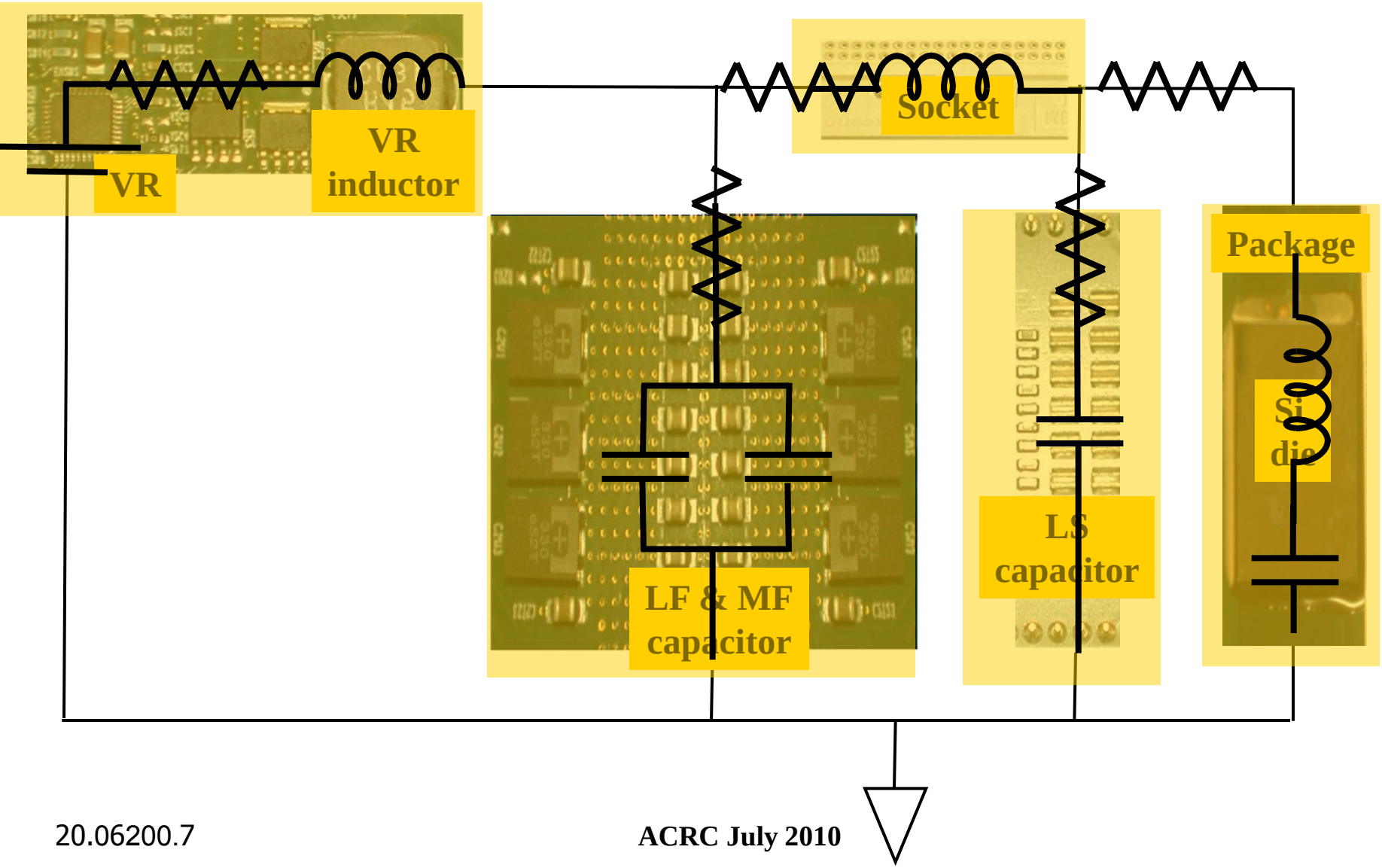
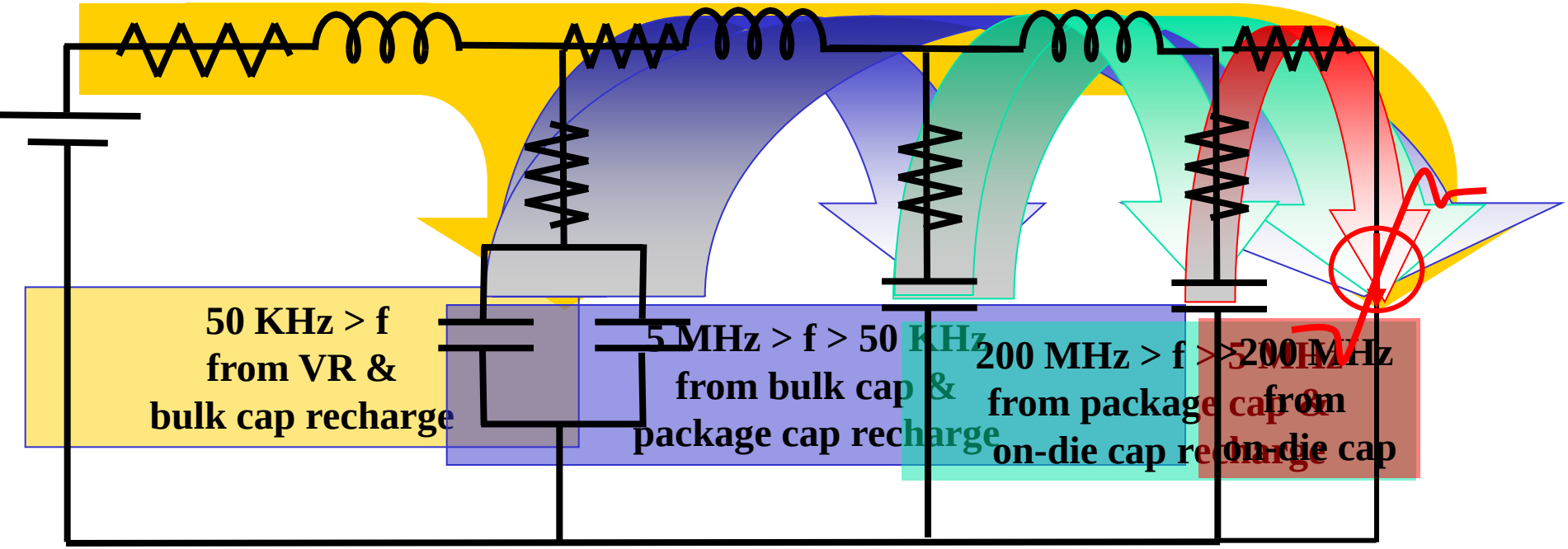
Power Delivery Crisis

- Contradictive requirements from platform power management
  - Support huge power dissipation - 45 W is a typical figure
  - Enable long (24 hours?!) battery time and fast response time
- Increased functionality in smaller dimensions
  - Higher integration level & higher power density
- Unfavorable (for power delivery) technology scaling trends
- Voltage regulators are $\leq$60% of a board area
- Power supply pins may limit package shrink

Equivalent scheme



Current flow in different frequency ranges



Major Power Losses reasons

- Voltage Regulator (VR) and AC brick losses
  - Switching losses
  - Inductors losses
- Joule losses – on-die, package & socket and motherboard (MB) interconnect.
- Overvoltage – via leakage and excessive active power
  - Leakage loss can be higher than active power consumption
  - Functional when not needed
  - Because of guard bands (GB) 

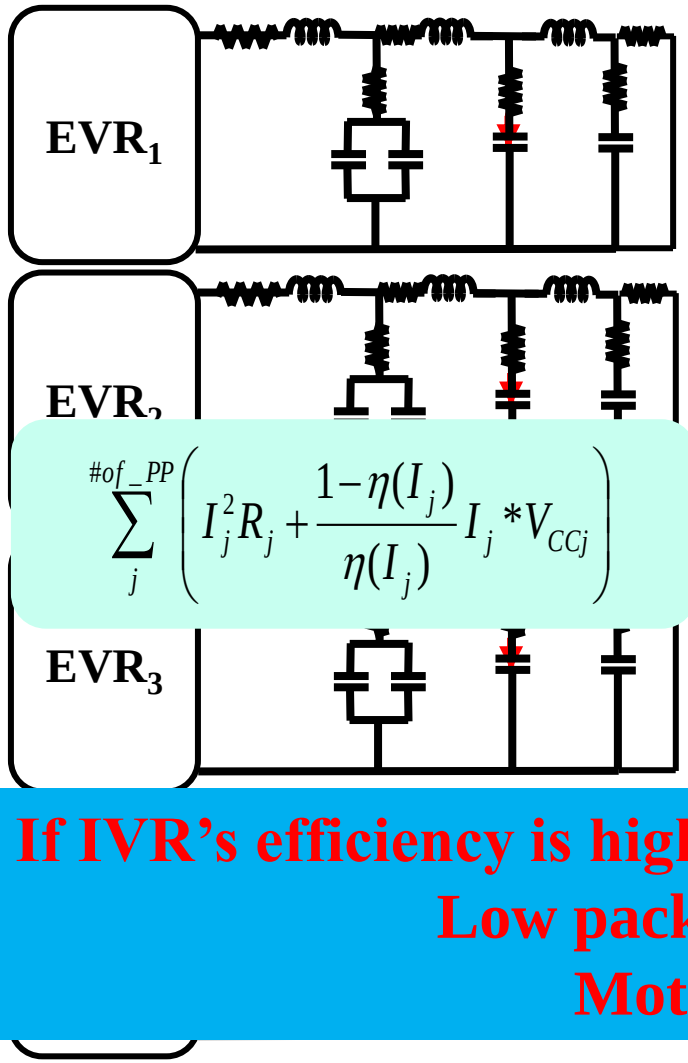
Solution directions

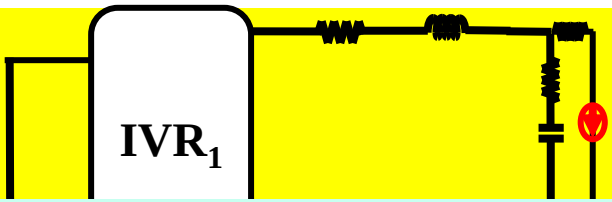
- Smart power management architecture
  - Different power states, allowing tighter voltage control
  - Burst operation when possible, i.e. sleep most of the time
- Active power delivery network
  - Dynamically configurable components
  - Enabling GB reduction
- Selective integration of on-board VRs
  - Consolidation of VRs, MB resources devoted to power supplies
  - Balancing on-board and in-package power dissipation
  - Advanced control approaches

On-die losses reduction

- Dynamically controlled embedded power gates or sleep transistors. p- or nMOS connected in series to core logic.
  - Saves leakage power
  - May be turned on or off, depending on the logic power state
  - Supports retention voltage, when no activity (toggling)
- Interesting research direction:
  - Very low drop-out linear regulator. Enables active power savings through GB reduction.
  - Required features:
    - Very high controllable BW (of order of ~500 MHz)
    - Distributed, variable load. Supports [3A, 25A]
    - Drop-out between ~30 mV to 400 mV

Integrated VRs – board *vs.* die loss balance





$$\sum_{j}^{\#of\_PP}\left(I_j^2 R_j + \frac{1-\eta(I_j)}{\eta(I_j)} I_j * V_{CCj}\right)$$

$$I_{EVR} = \sum_{j}^{\#of\_PP}\left(I_j * \frac{V_{CCj}}{\eta_{IVR_j} V_{EVR}}\right)$$

$$\frac{1-\eta_{EVR_j}}{\eta_{EVR_j}} I_{EVR} * V_{EVR} + I_{EVR}^2 * \frac{R_j}{N} + \sum_{j}^{N}\left(\frac{1-\eta_{IVR_j}}{\eta_{IVR_j}} I_j * V_{CCj}\right)$$

$I_{EVR} \sim 0.55 * \Sigma I_{IVR}$

More favorable current range for EVR

Much lower Joule losses on the board

If IVR's efficiency is high enough, platform level efficiency is higher

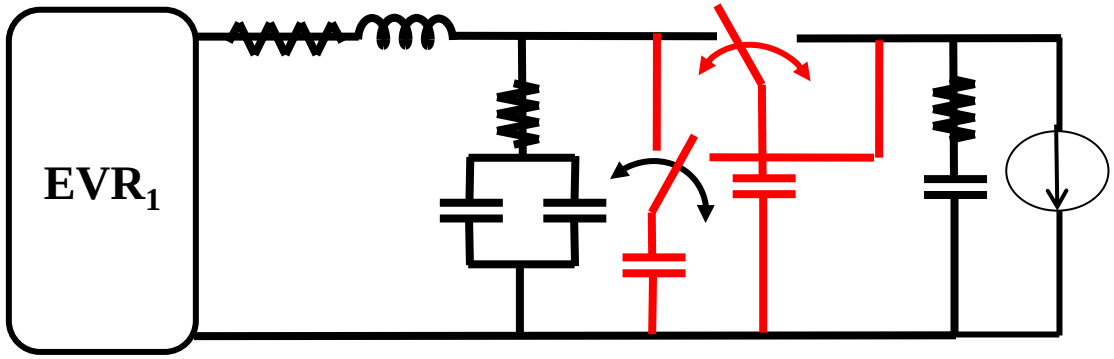
Low package/socket power pin count

Mother board area savings

Integrated Vs should …

- High efficiency (>85% over whole current range)
  - Isn't a burden in light load conditions
- Performance similar to that of EVR
- Low cost adder – compatible with existing process tech
- ~Neutral to process technology scaling
- "Friendly" to logic in the neighborhood
  - Low load injection

Consider Switch Capacitor Design



- Capacitance decreases linearly with process scaling
  - Inductance decreases quadratically
- No EMI, low noise injection
- Need smart design/novel architecture to get sufficient η over ~0.4 V range
- Need ~10 μF on-die – technology is ready but not available

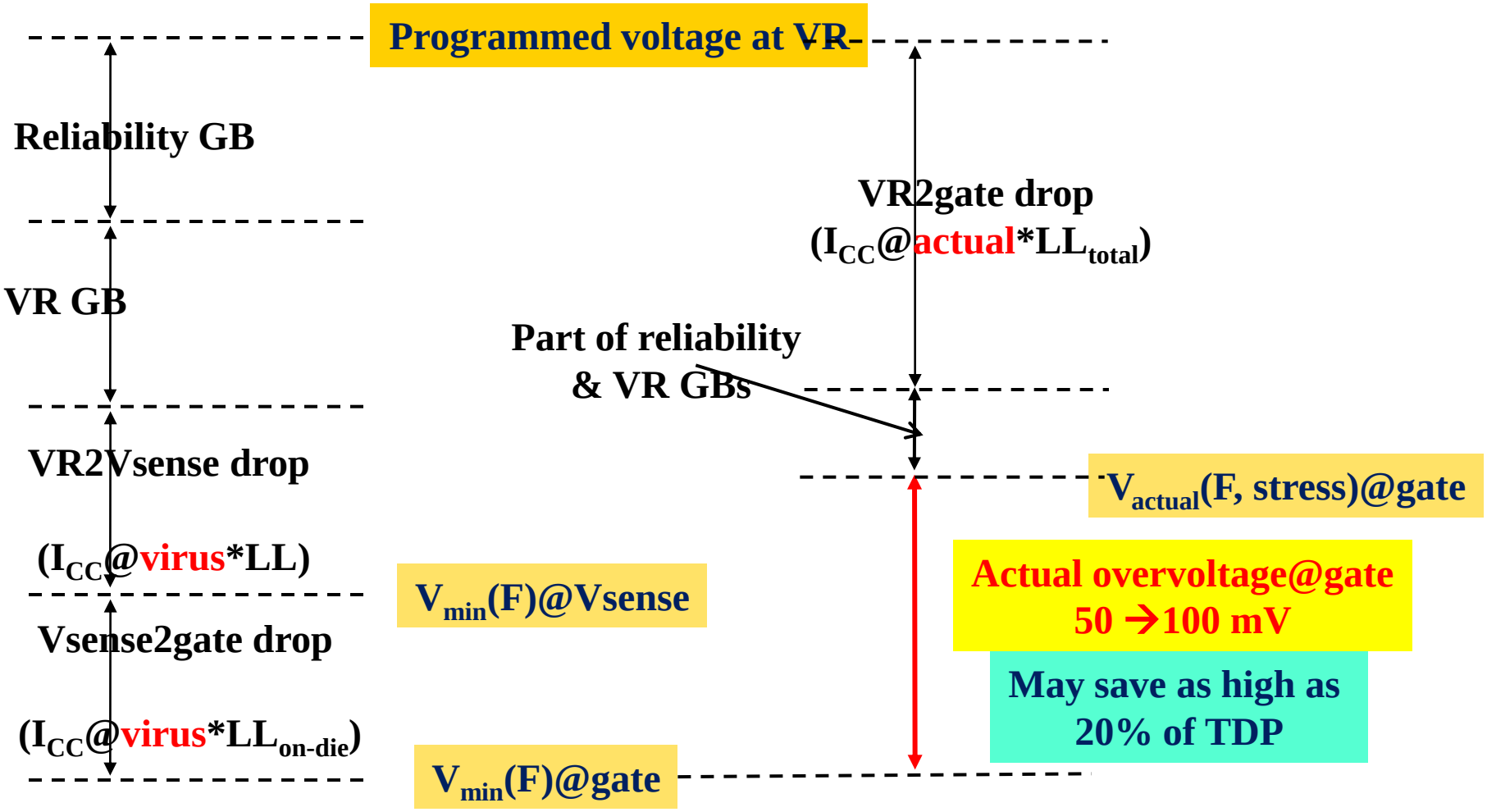
Summary

- If we do nothing, power delivery will be the limiting factor in the development of integrated systems.
- On-die active PDN, i.e. local, dynamic power gating, makes significant contribution system power savings
  - Very low dropout linear regulators can be more efficient, but their design is very challenging
- Integration of VR may help realizing multi-power plane designs, but need to be taken with " a grain of salt"
  - If implemented to early – makes more harm, than good
  - Switch cap VR seems potentially more "integration friendly" than buck convertor

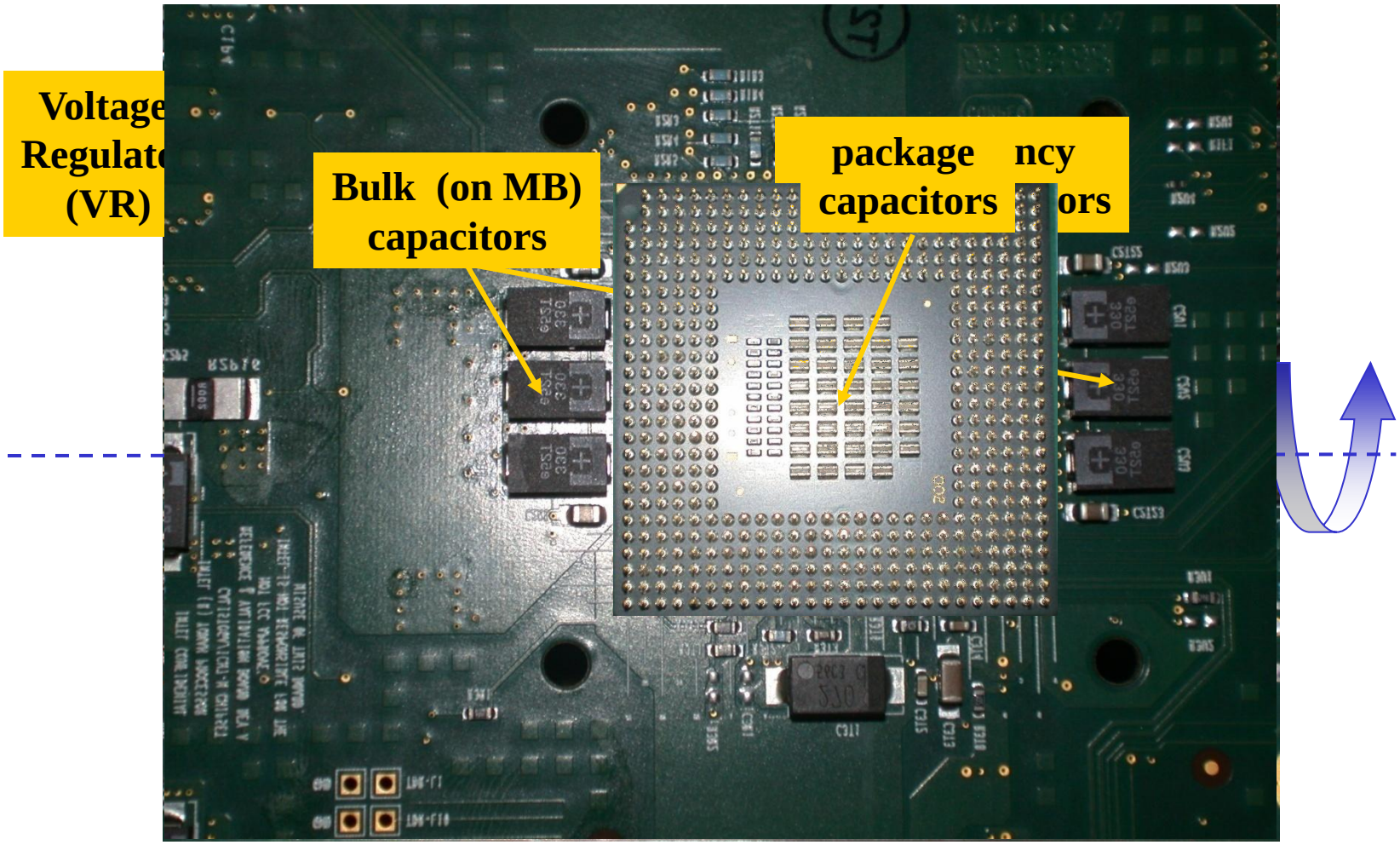
THANK YOU

BACKUP

Voltage budget - breakdown



From voltage regulator to silicon



Energy Efficiency Regulation

Regulation explodes – EU leading