TECHNOLOGY DRIVERS AND TRENDS IN POWER SUPPLIES FOR COMPUTER/TELECOM APPLICATIONS

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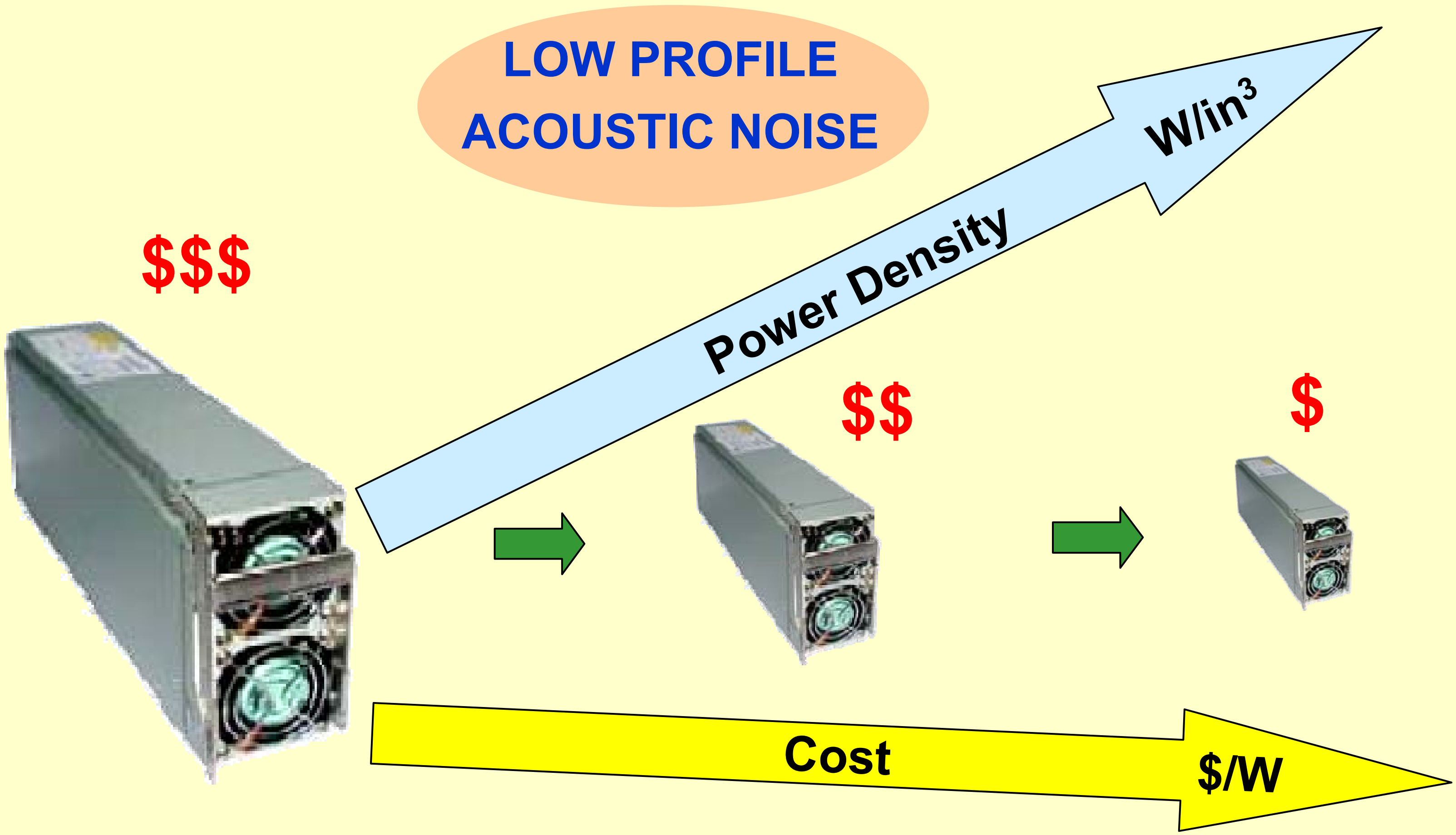
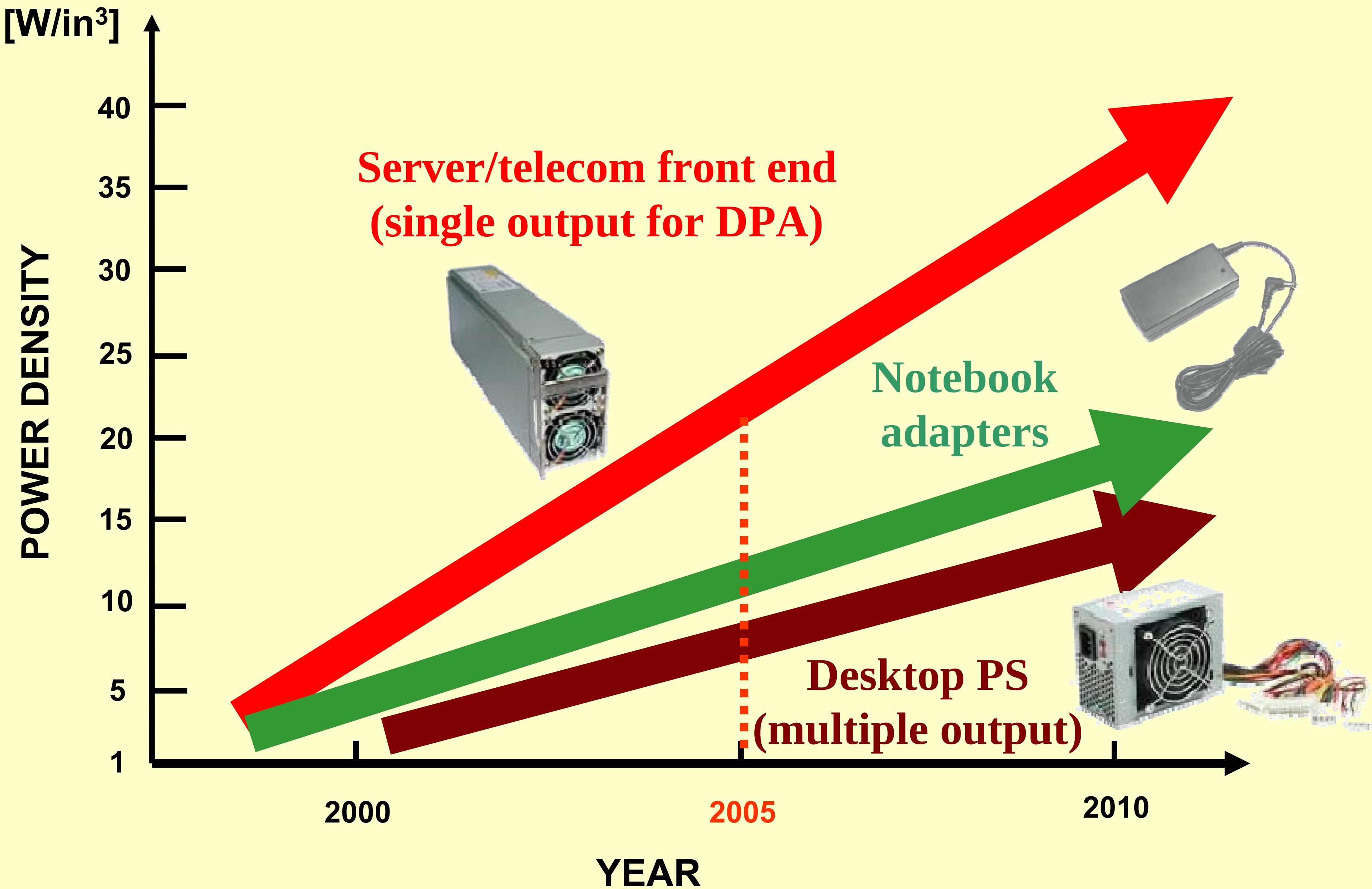
March 20, 2006

PRIMARY TECHNOLOGY DRIVERS

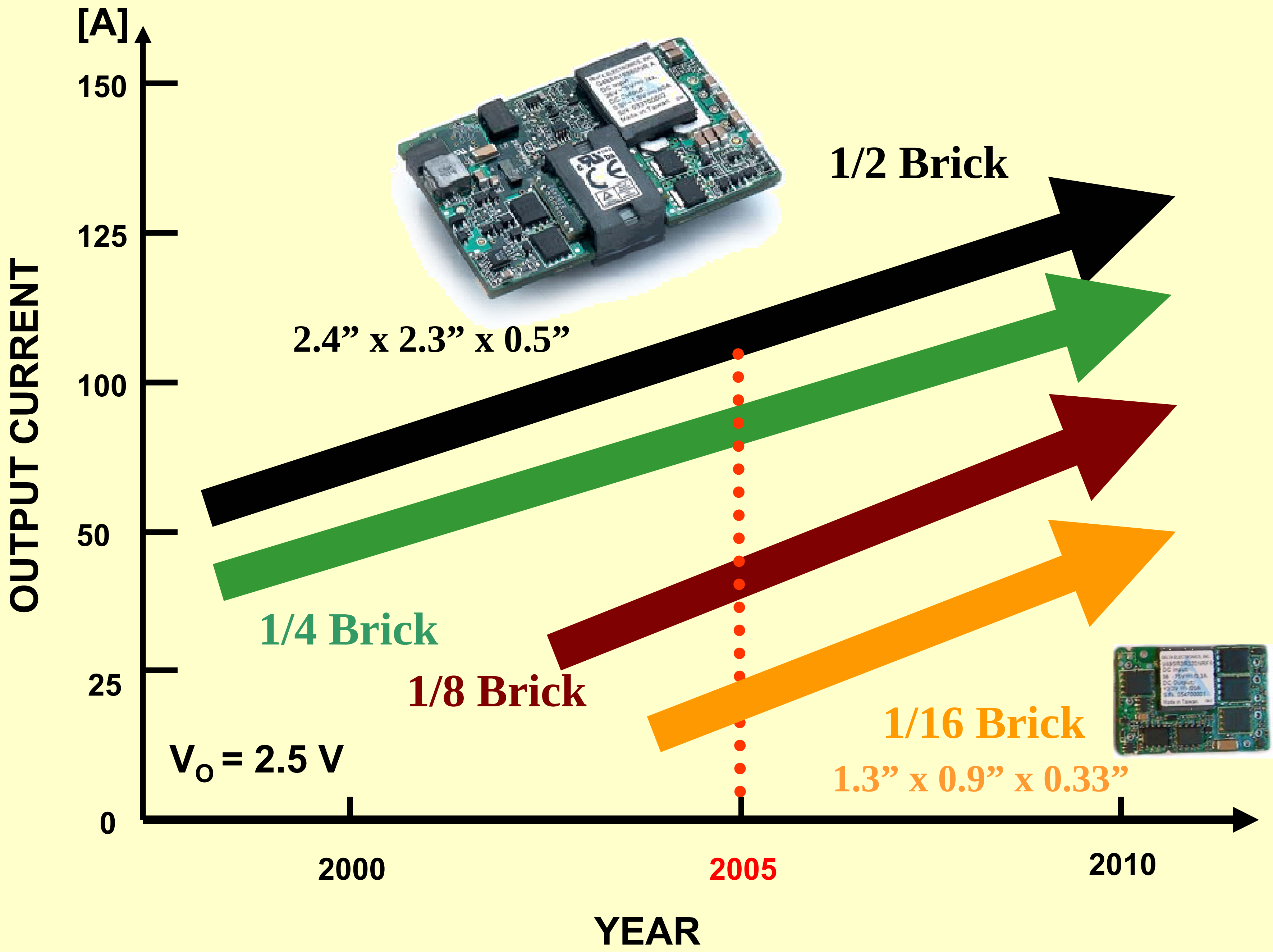


- **Power-supply technology will continue to be primarily driven by extremely challenging power-density requirements that need to be met in cost-effective way**

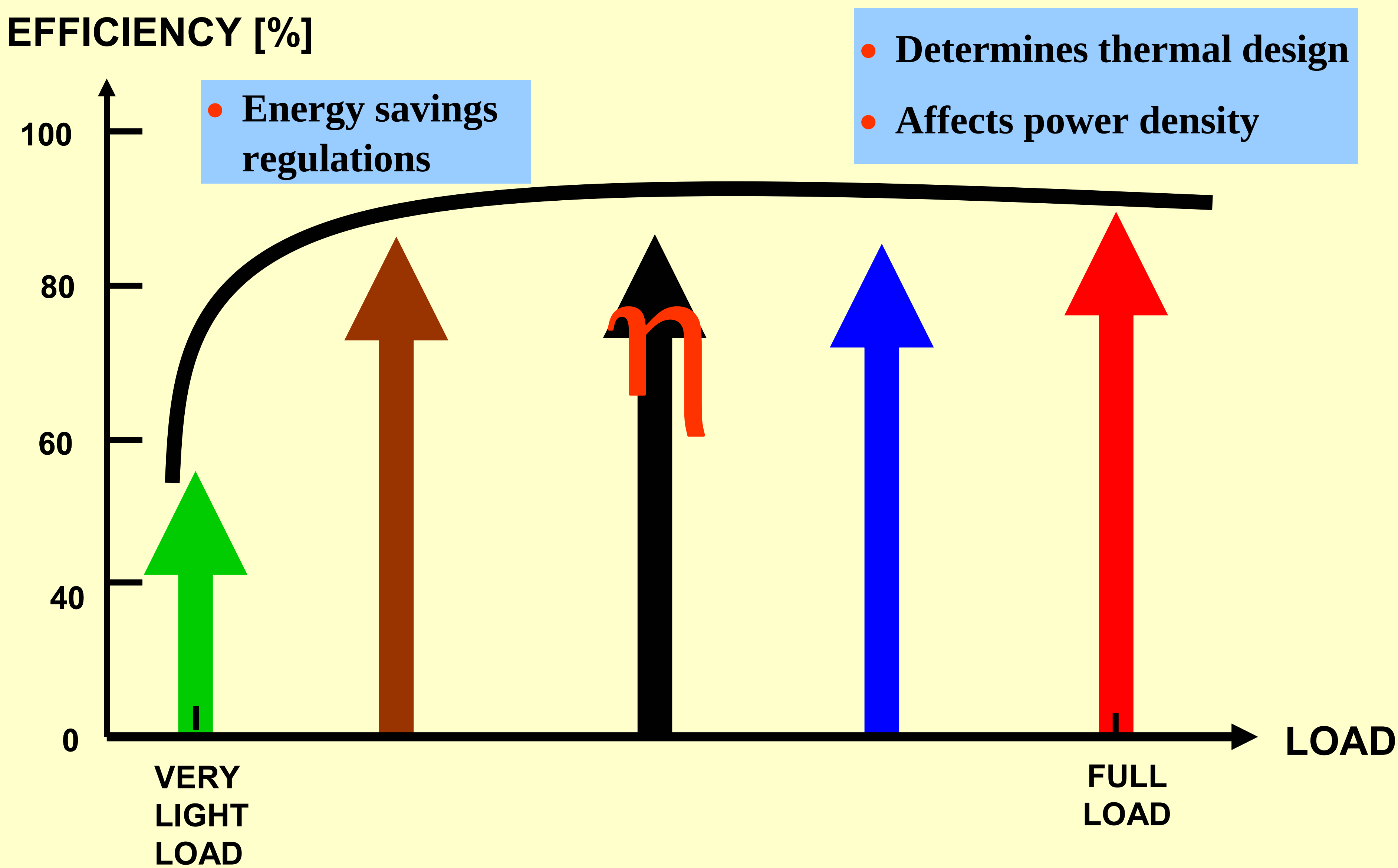
POWER DENSITY TRENDS – AC/DC Power Supplies



POWER DENSITY TRENDS – DC/DC Converters



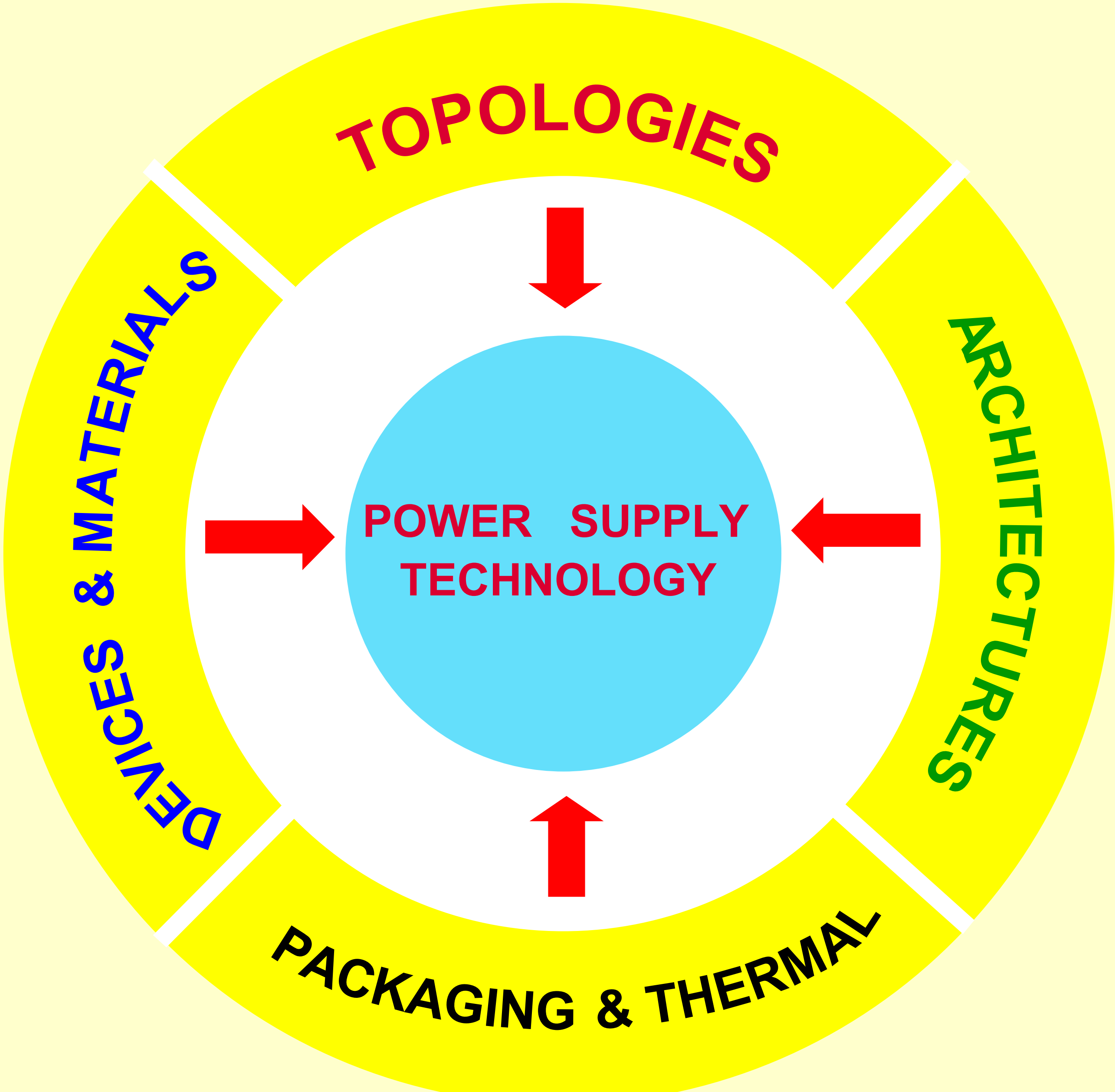
EFFICIENCY AS TECHNOLOGY DRIVER



"DIGITAL POWER" AS TECHNOLOGY DRIVER

- Digital technology has been used in power conversion applications for long time
  - power management
    - UPS, telecom, and server systems
  - digital control
    - motor drives, UPSs, and telecom three-phase SMRs
- Digital control and power management have been recently employed in VRs and POLs
- Single-phase ac/dc front-end server power supplies with digital control are about to become available
- Attractiveness of digital technology stems from its programmability and communication capability
- No doubt that digital technology will be indispensable part of future power supplies

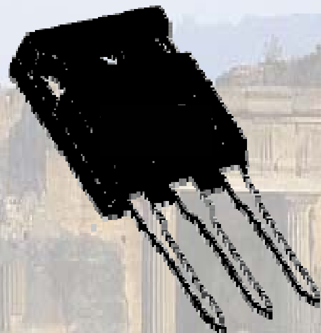
KEY POWER-SUPPLY TECHNOLOGY AREAS



MATERIALS AND COMPONENTS

- **Semiconductor component technology has made impressive advances**

circa 1990



TO-247AC

$V(BR)_{DSS}$= 600 V

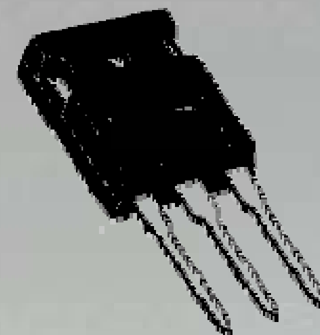
$I_{D(max)}$= 16 A

$R_{DS(on)}$= 0.40 Ω

Q_g= 210 nC

FOM=$R_{DS(on)}$ x Q_g = 84

circa 2005



TO-247AC

$V(BR)_{DSS}$= 600 V

$I_{D(max)}$= 60 A

$R_{DS(on)}$= 45 mΩ — **9X improvement**

Q_g= 150 pF — **1.4X**

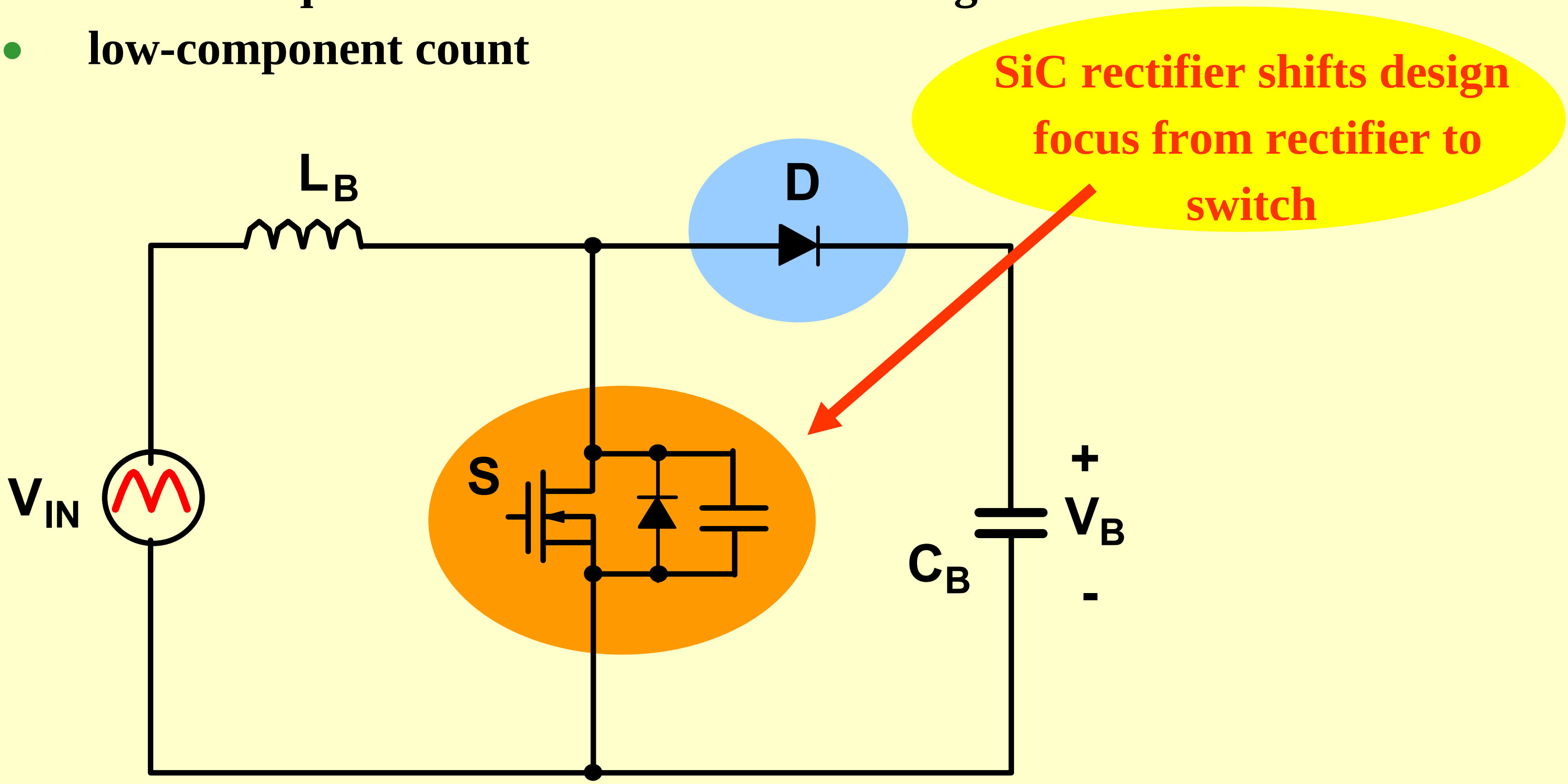
FOM=$R_{DS(on)}$ x Q_g = 6.75 — **12X**

- **Today, low voltage MOSFETS (25 V / 30 V) for synchronous rectifier applications with extremely low resistances are available**

$R_{DS(on)}$=2-3 mΩ

MATERIALS AND COMPONENTS

- Introduction of Silicon Carbide (SiC) rectifiers has enabled operation of PFC circuits at higher switching frequencies
  - no snubber required to control recovered charge of boost rectifier
    - low-component count



- Still majority of PFC with SiC rectifier operate at frequencies below 150 kHz
  - frequency limited by MOSFET performance

MATERIALS AND COMPONENTS

- **Generally, advancements in magnetics and capacitors are lagging far behind advancements in semiconductor components**

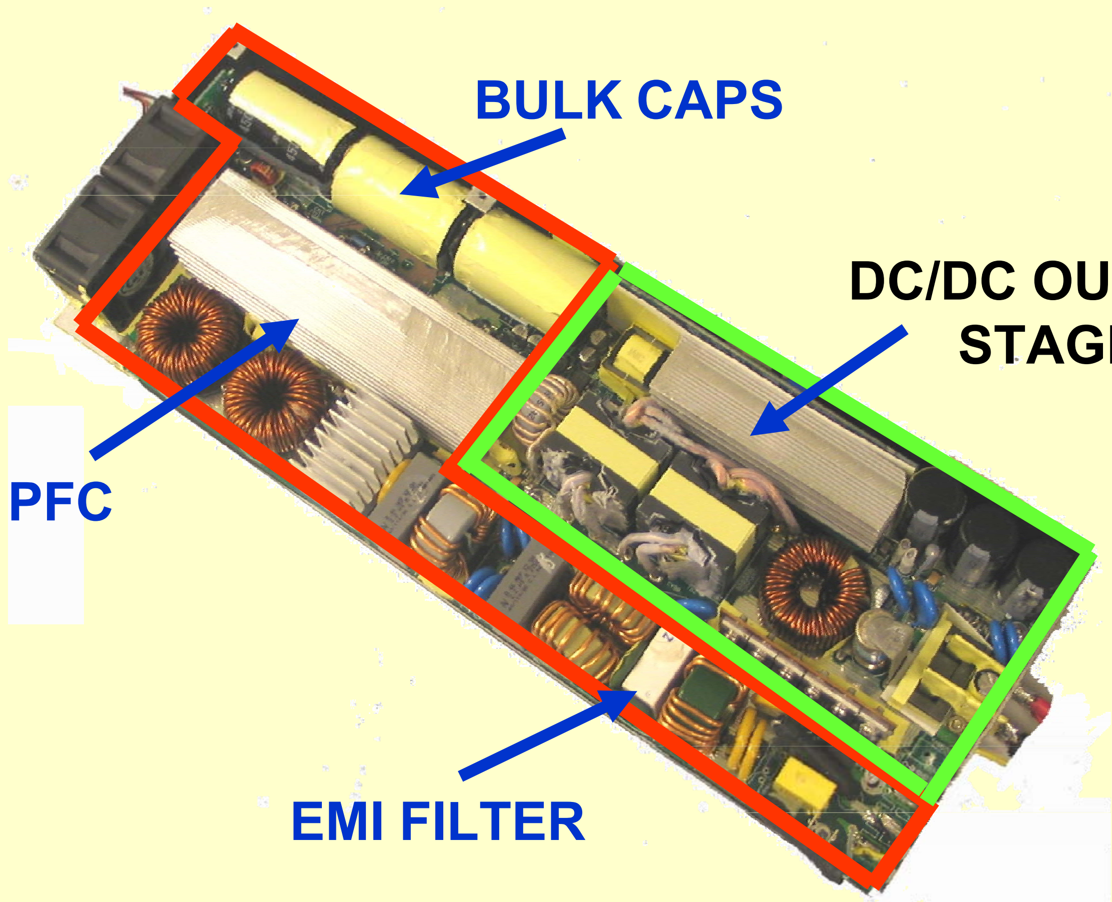
- **Magnetic materials**
  - **no major improvements in core materials for long time**
  - **increased number of available core shapes**
    - **low-profile cores for planar magnetics**

- **Capacitors**
  - **no significant improvements seen in volume reduction of electrolytic capacitors**
    - **size of energy-storage electrolytic capacitors emerging as major obstacle to achieving high-power densities in applications with hold-up time requirements**

HIGH POWER DENSITY AC/DC POWER SUPPLIES

- **In typical high-power-density ac/dc power supply 60-65% of volume is taken by EMI filter, PFC, and bulk capacitors**

3 kW / 48 V
25 W/in^3
1U



- **Decreasing size of front end is key to increasing power density of ac/dc power supplies**

BULK CAPACITOR SIZE CONSIDERATIONS

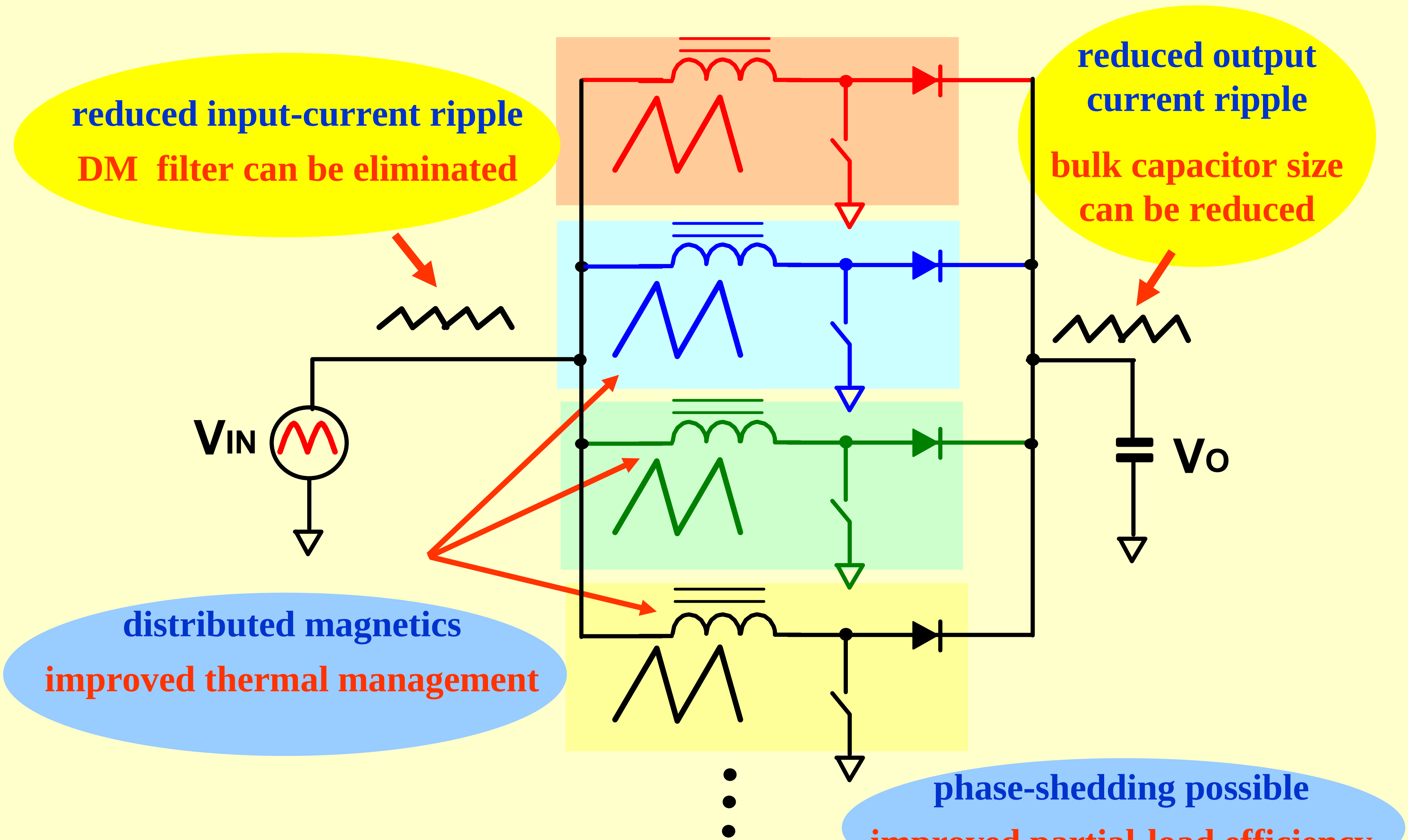
- **Bulk capacitor size / number of caps is limited either by**
  - **life-time (ripple-current) considerations, or**
  - **hold-up time energy requirements**
- **In universal-line (90 – 264 V_{ac}) power supplies with output power rating over 800 W bulk capacitor size is usually limited by life time requirements**

two caps required to meet hold-up time requirement

however, three caps are required to handle ripple current to meet life time specs

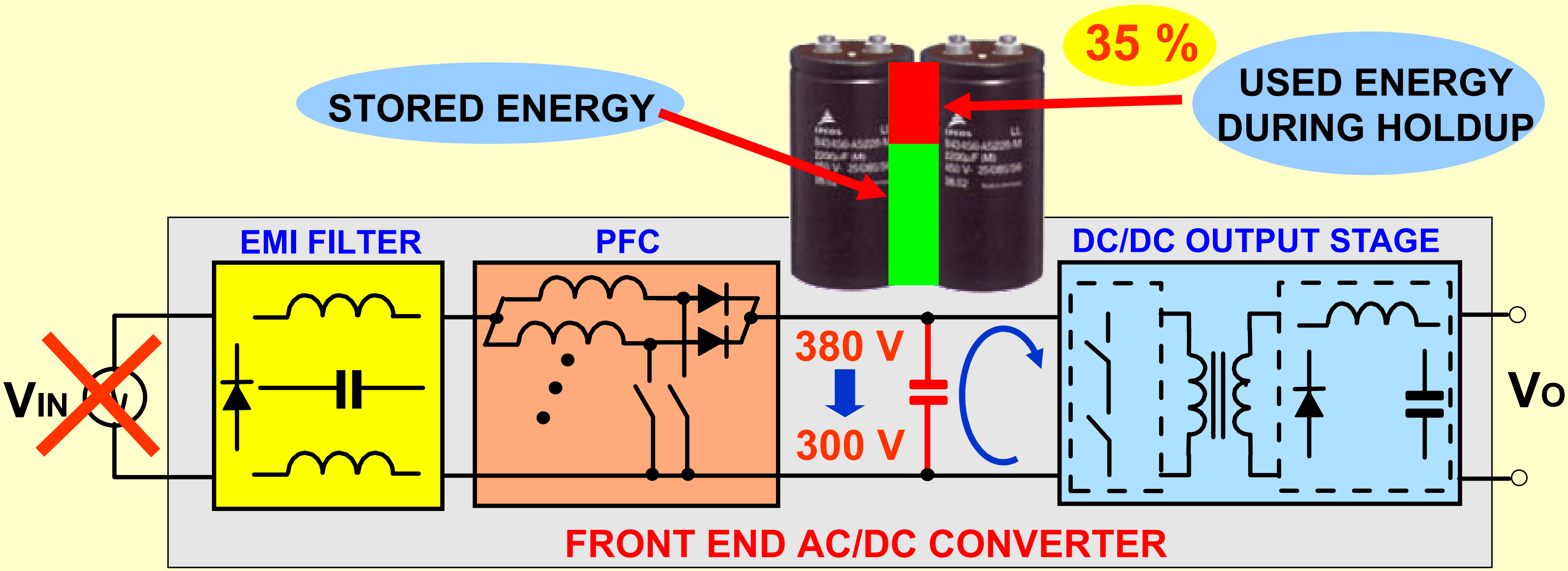
PFC FRONT END CONSIDERATIONS

- **Interleaving technique may help in reducing size of PFC front end**



OPTIMIZATION OF BULK-CAPACITOR ENERGY-STORAGE UTILIZATION

- **Further bulk capacitor volume in applications with hold-up time requirement can be minimized by maximizing stored-energy utilization**

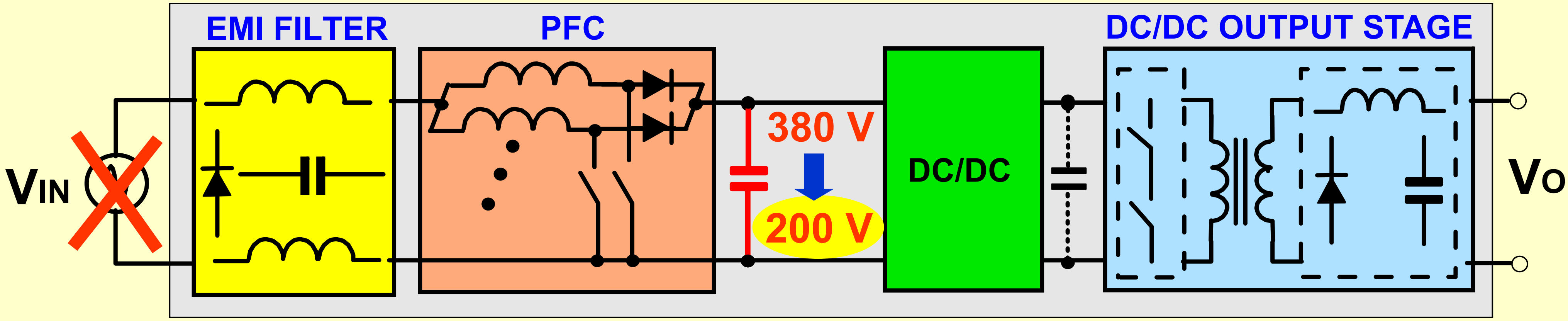


- **Only approximately one-third of energy stored in bulk capacitor(s) is utilized during hold-up time**

POWER ELECTRONICS R & D LABORATORY

POWER-STAGE OPTIMIZATION

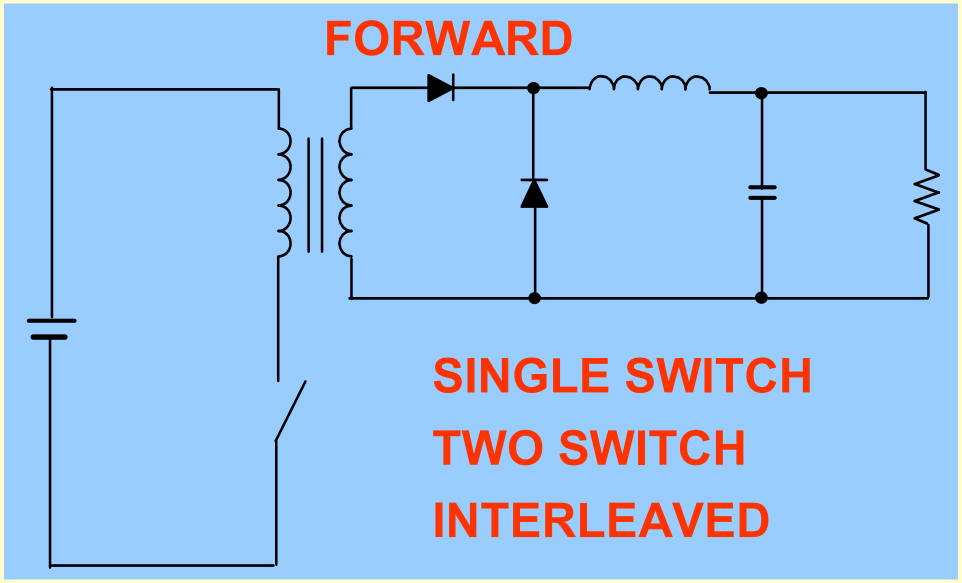
- Three-stage approach can be employed to maximize utilization of bulk-capacitor energy

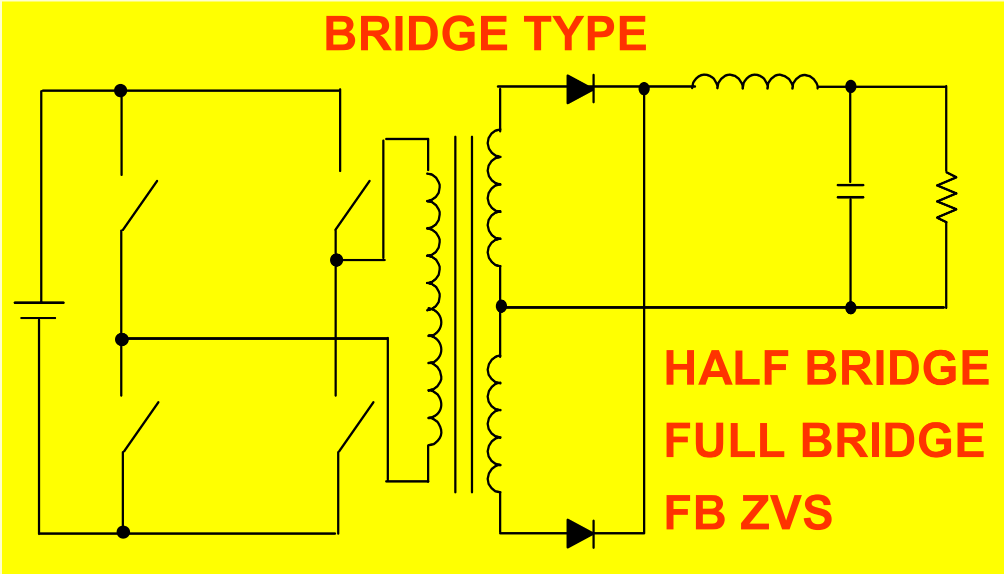


- Three-stage approach may also improve overall performance
  - creates optimal operating conditions for dc/dc output stage
    - constant input voltage operation
      - dc/dc transformer implementation
  - more evenly distributed losses
    - very desirable in low-profile applications, e.g., 1U designs

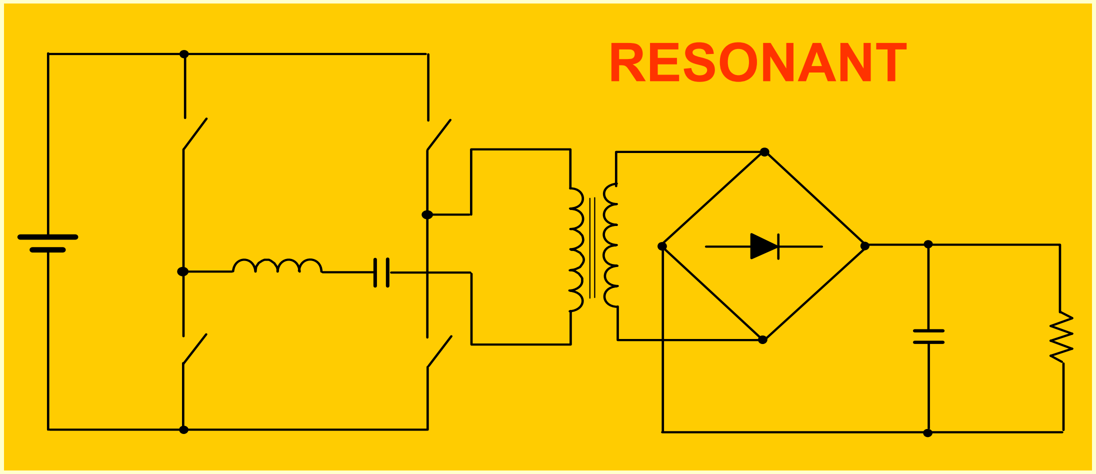
DC/DC TOPOLOGIES

- No panacea topology
  - well known and established PWM topologies will still dominate





- Resonant techniques will be employed more than in the past
  - dc/dc transformer implementations



DELTA POWER ELECTRONICS R & D LABORATORY

PACKAGING & THERMAL CONSIDERATIONS

- **Major future improvements of power densities are expected to come from advancements in**

COMPONENT INTEGRATION

- **active components**
  - **switches, drivers & control**
- **passive components**
  - **magnetics**
  - **capacitors**

PACKAGING TECHNOLOGY

- **component level**
- **board level**
- **box level**
- **system level**

THERMAL MANAGAMENT

- **component level**
- **board level**
- **box level**
- **system level**

DELTA
POWER ELECTRONICS
R & D LABORATORY

PACKAGING & THERMAL MANAGEMENT

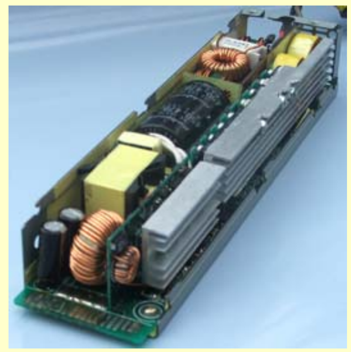
Watts / Sq. Ft.

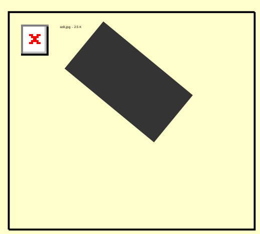
VOLUME UTILIZATION

3D PACKAGING

PACKAGE PARASITICS

PACKAGING





$ /Watts

AIR FLOW / ACOUSTICS

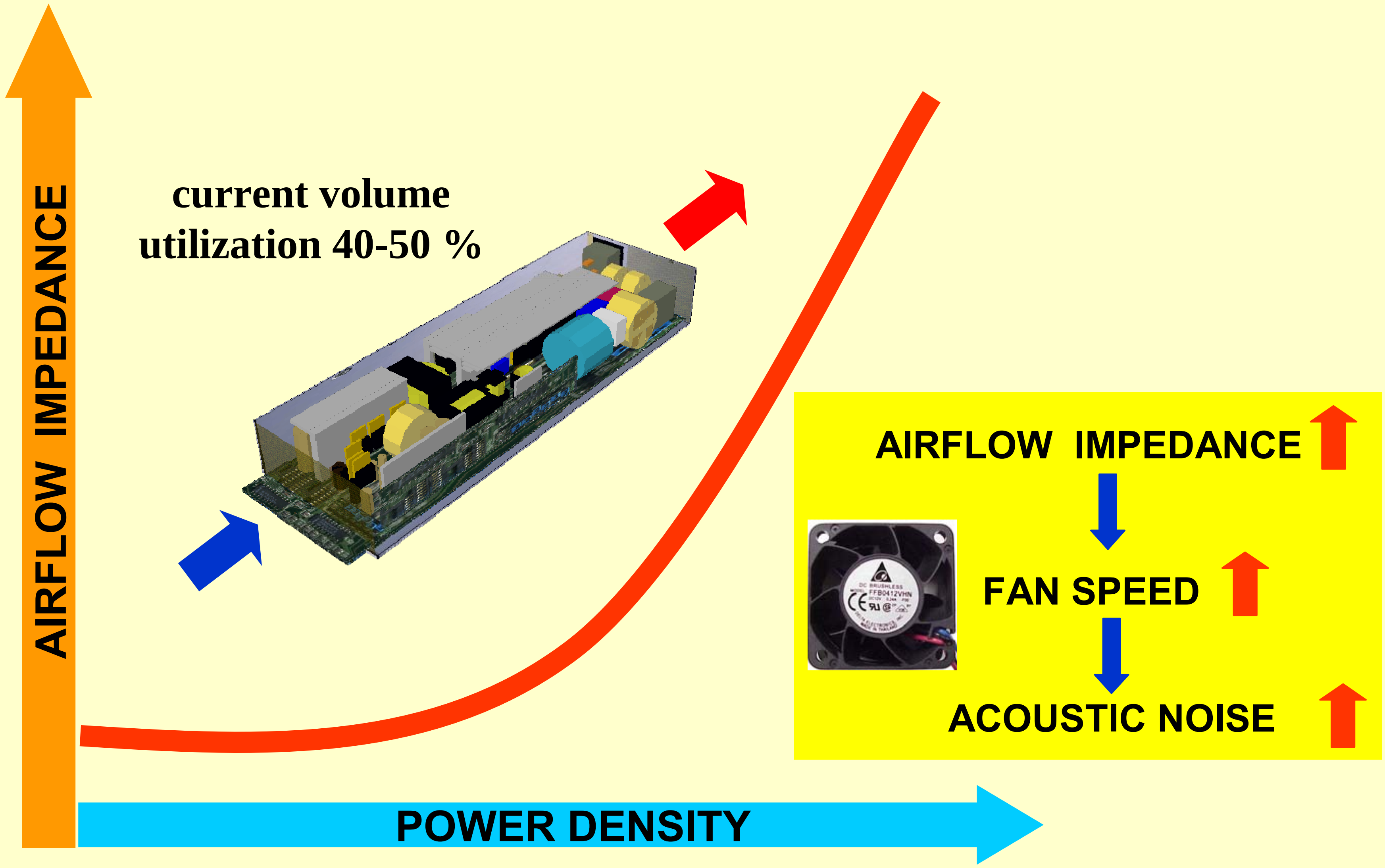
THERMAL VIAS & HEAT SPREADERS

THERMAL IMPEDANCE

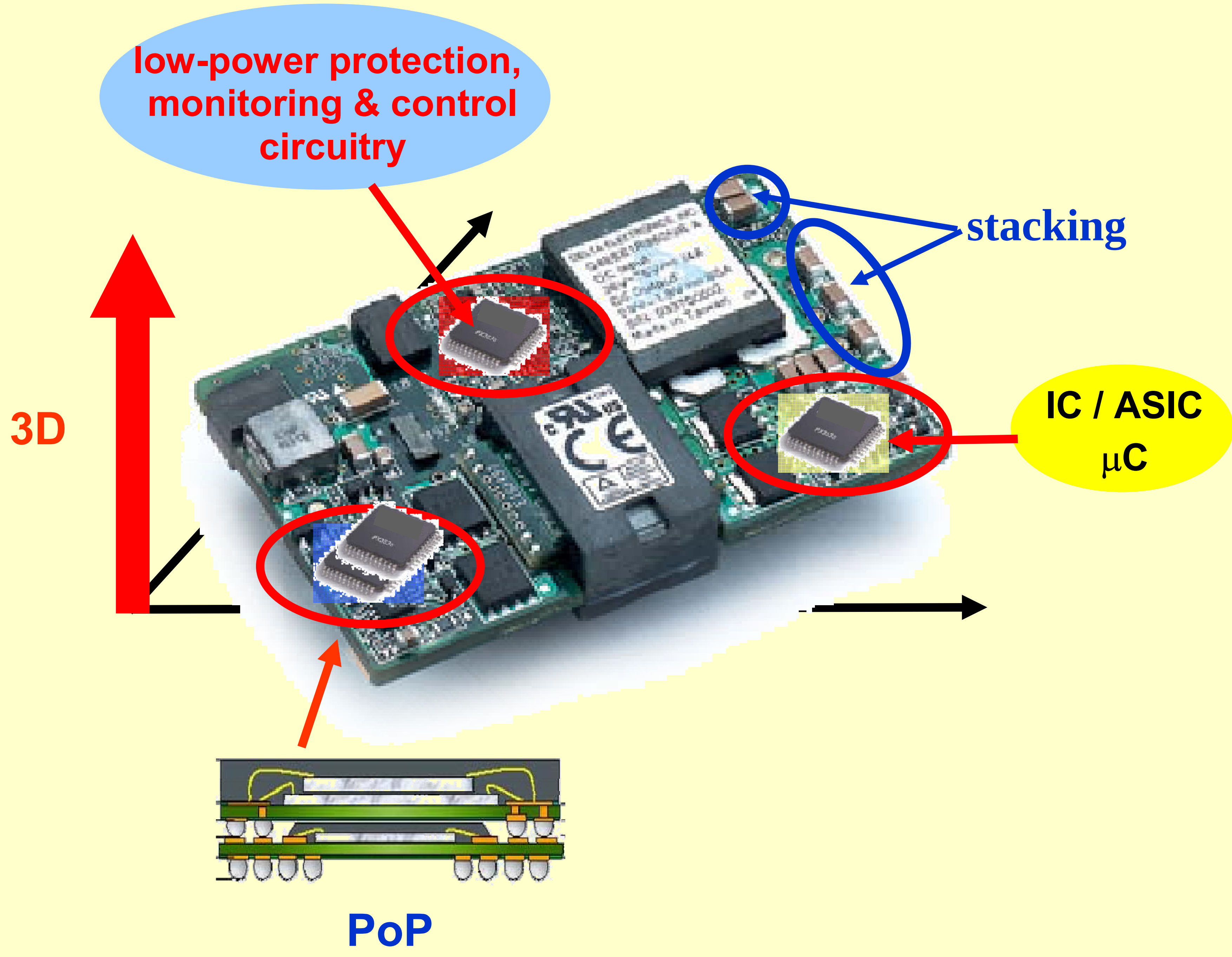
THERMAL

AC/DC PACKAGING & THERMAL CHALLENGES

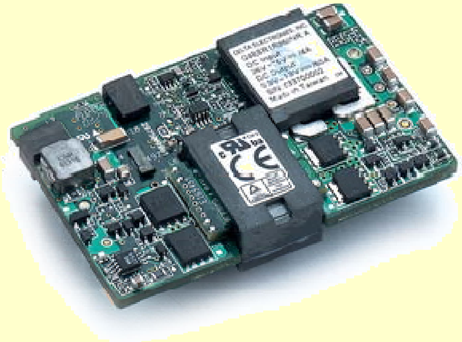
- **Improving cooling efficiency is paramount for further increases of power density of ac/dc power supplies**



DC/DC CONVERTER PACKAGING TRENDS

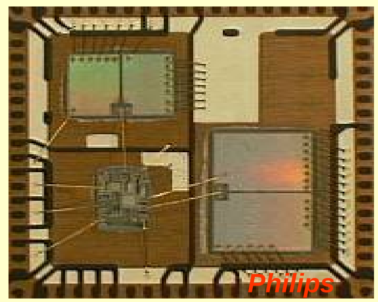


DC/DC CONVERTER PACKAGING TRENDS (cont'd)



Package-on-package (PoP)

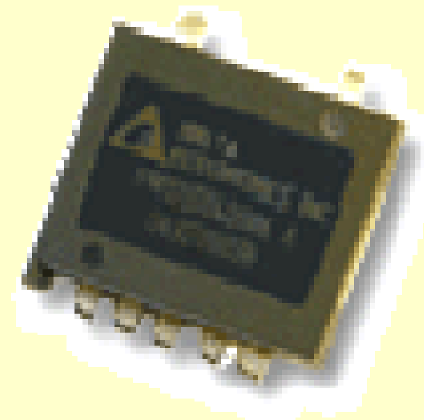
Stacked components



MCM
(Multi Chip Modules)

Monolithic

Power MEMS



POWER LEVEL

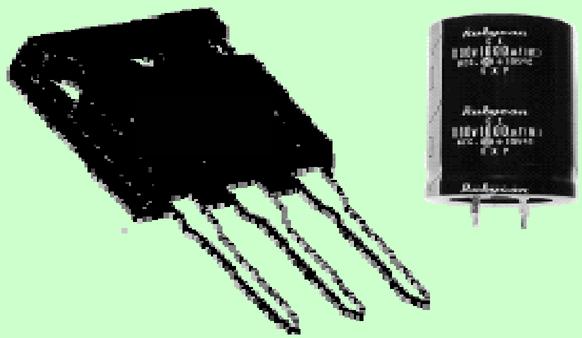
INTEGRATION LEVEL

SUMMARY

- **Future power supply performance improvements will be achieved by incremental gains in**

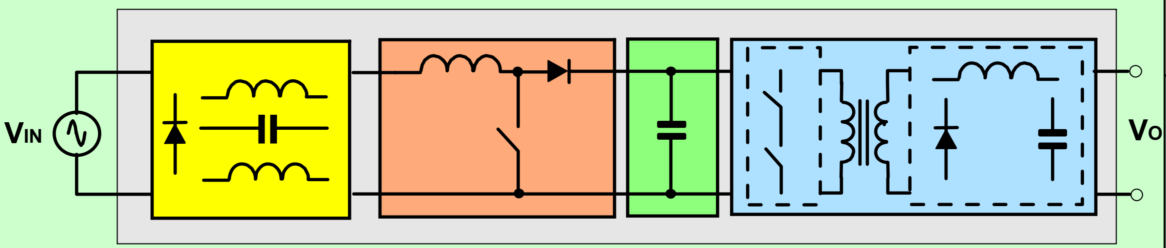
PACKAGING

COMPONENTS

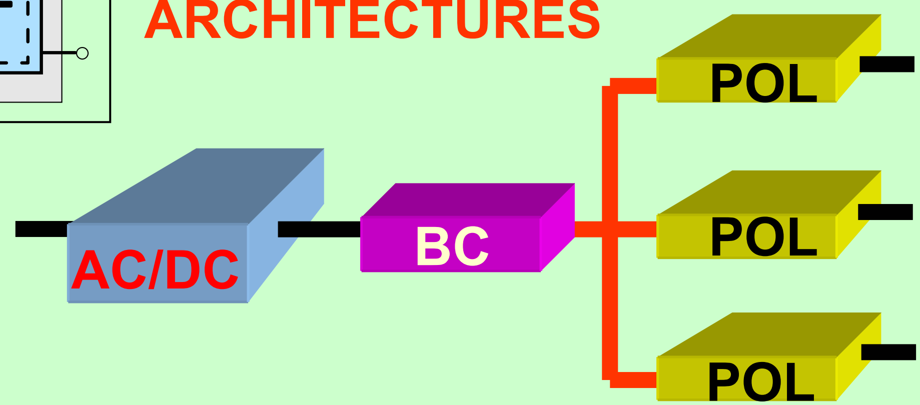


MATERIALS

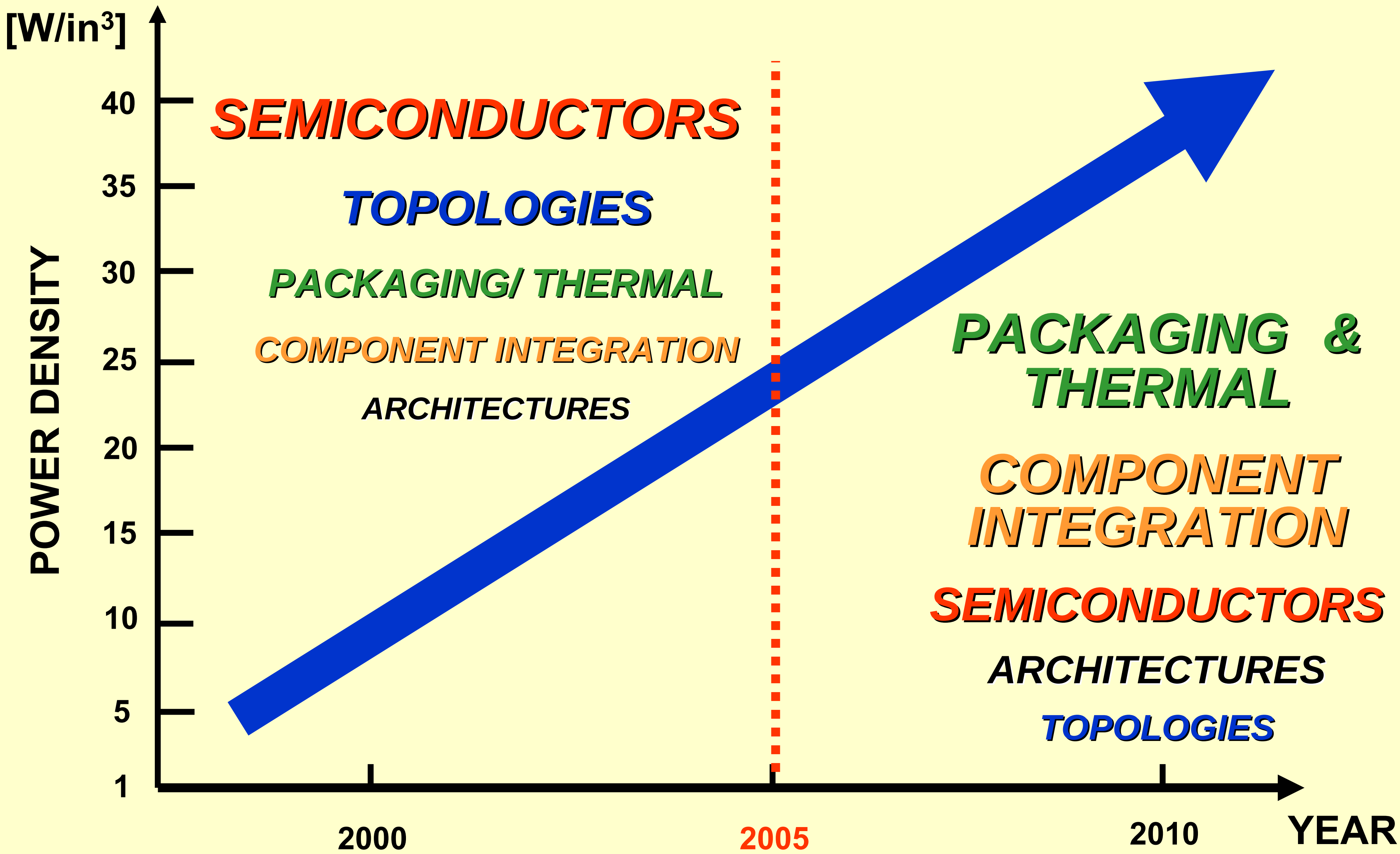
CIRCUIT OPTIMIZATION



ARCHITECTURES



SUMMARY



- **Component integration and packaging/thermal technologies will play major roll in future improvements of power density**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for a better quality of life
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