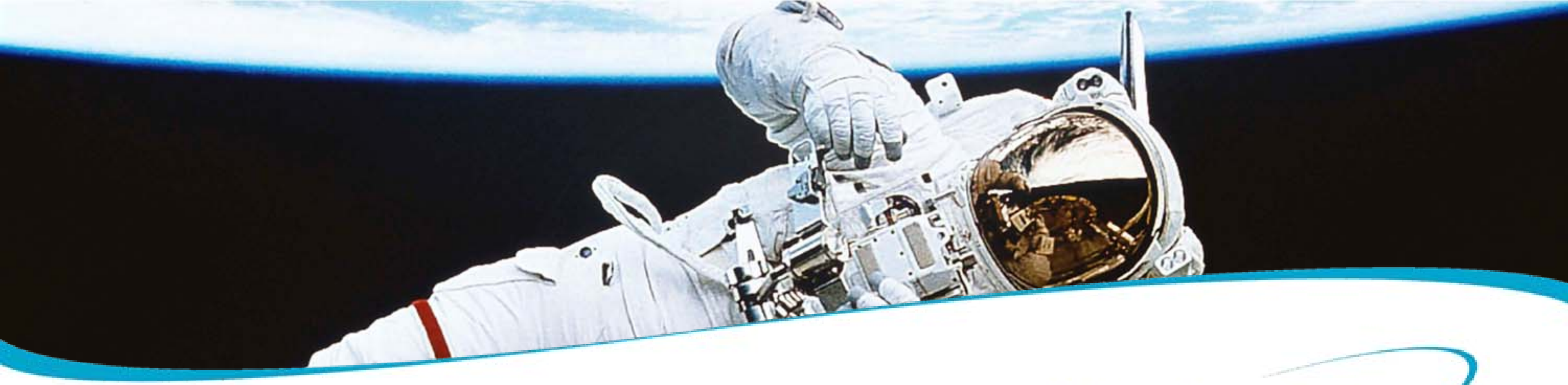

ThalesAlenia
A Thales / Finmeccanica Company Space

The way to future power management

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THALES

Thales Alenia Space ETCA

Ref : ESCCON 2011.
Date : 15 March 2011.

Outline - Introduction

Objective:

Discuss trends in components fields for future space power system

- Evolution for the next 5 years . . .

Remarks:

- Power supply are ubiquitous . . .
- Power supply are very often “mission critical”
- Power supply are considered like a “constraint”

Looking to industrial business can be a source of inspiration

- This field is bourgeoning with innovative solutions
  - improve performances and costs

Lets try to imagine the future power supply . . .

. . . But do not forget the constraints

The main space constraints

Mechanical constraints

- Vibrations and shocks during launch
- Weight constraint on structure

Thermal constraints

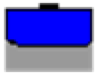
- We are in the vacuum of space . . . No air for cooling

Reliability constraints

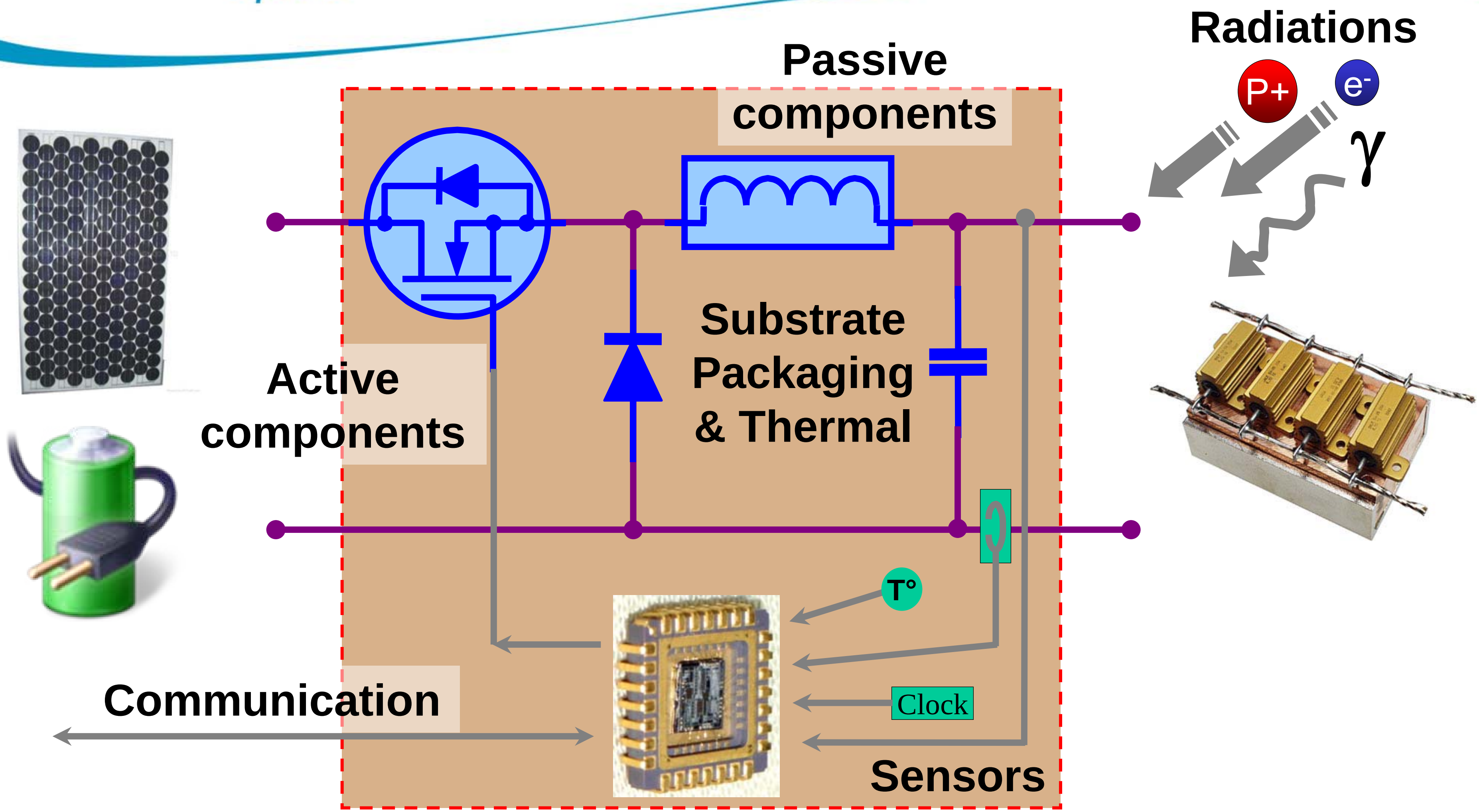
- 15 to 18 years of mission life time – High availability
- No maintenance possible . . . No failure accepted (at system level)
- Reliability and failure mechanisms must be under control

Ionising radiations constraints

- Degradation of physical and electrical parameters
- Corruption of data inside electronic systems - ! Availability impact !
- Use of hardened components is mandatory



Basic components



Low level control

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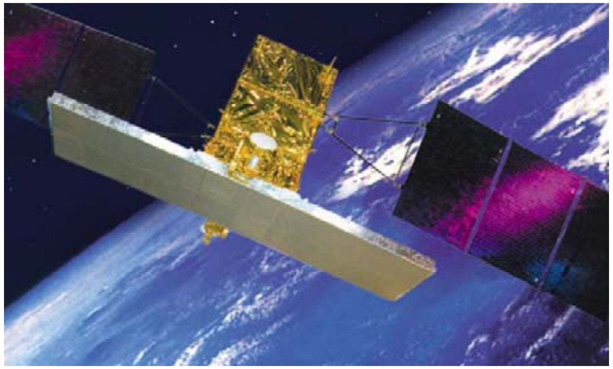
Today, Si based power MOSFET are the unquestionable leader

Looking to industrial market the new device developments are oriented toward WBG (Wide Band Gap)

- Especially GaN for power electronics
  - Push by the electrical vehicle business
  - Push by supply for server business
  - Push by renewable energies
  - Why not by space business ?



Why GaN ?

- Baliga Factor of Merit
  - BFOM = $\varepsilon \mu E_c^3$

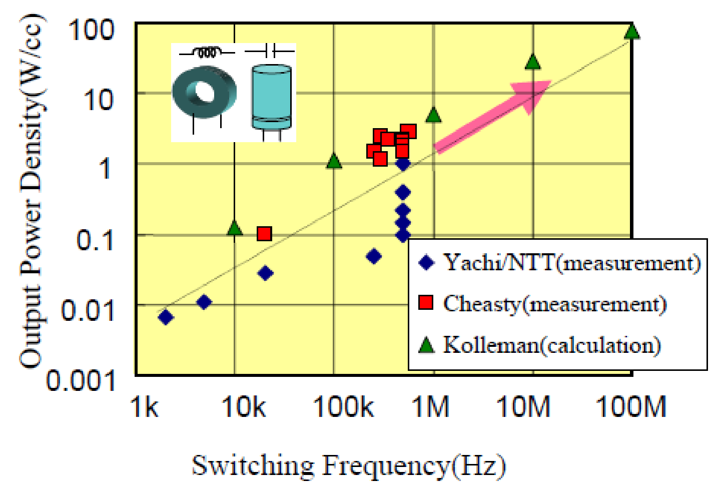
Material	E_g (eV)	ε_s	μ_n (cm^2/Vs)	E_c (MV/cm)	v_{sat} (10^7 cm/s)	n_i (cm^{-3})	BFOM*
Si	1.12	11.8	1350	0.3	1.0	1.5×10^{10}	1
GaAs	1.42	13.1	8500	0.4	2.0	1.8×10^{6}	17
4H-SiC	3.26	10	720	2.0	2.0	8.2×10^{-9}	134
6H-SiC	2.86	9.7	370	2.4	2.0	2.4×10^{-5}	115
2H-GaN	3.44	9.5	900	3.0	2.5	1.0×10^{-10}	537

E_g, bandgap; ε_s, dielectric constant; μ_n, electron mobility; E_c, critical electric field; v_{sat}, saturation velocity; n_i, intrinsic carrier density.
*BM=$\varepsilon \mu E_c^3$, BFOM was normalized by the BM of Si.

Electrical Properties of Wide Bandgap Semiconductors Compared With Si and GaAs

GaN advantages

- Expected improvement 3 to 4 orders of magnitude for Ron.S
- Breakdown voltage BV about 10 times higher
- Robustness (overdrive and radiation)
- GaN Unipolar devices (HEMT)
  with high voltage and
  high frequency operation (x10 vs. Si)
  - Higher Efficiency
  - Compacter modules
  - Lighter modules



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Challenges

- Normally-off devices
  - Needed for correct failure mode management
- High reliability
  - New devices
- Modelling and design
  - New topologies ? !
- Thermal Management and packaging
  - Use of flip-chip ? !
- GaN on Si substrate (for low cost)
  - Not really needed for space ! ?
- Other components "GaN Ready"
  - See here after . . .

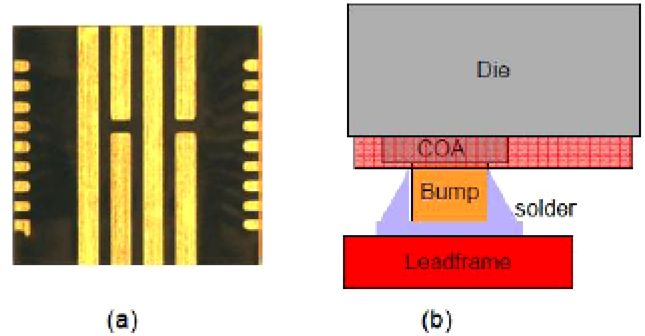


Fig. 10. (a) bottom view of QFN-style package showing board connections. (b) cross-section through plated bump.

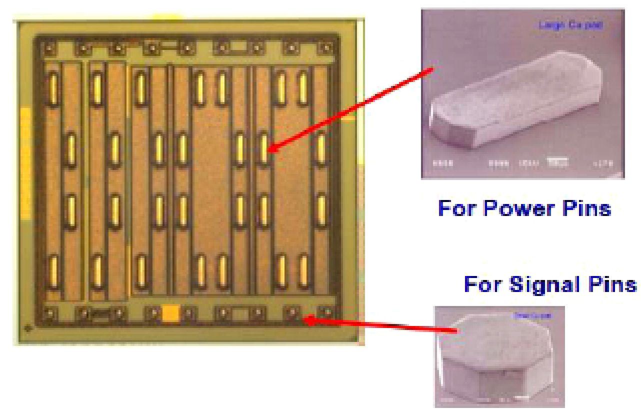


Fig. 11. (left) top view of die. (right) SEM views of plated bump connections.

GaN devices already exist . . . (not exhaustive)

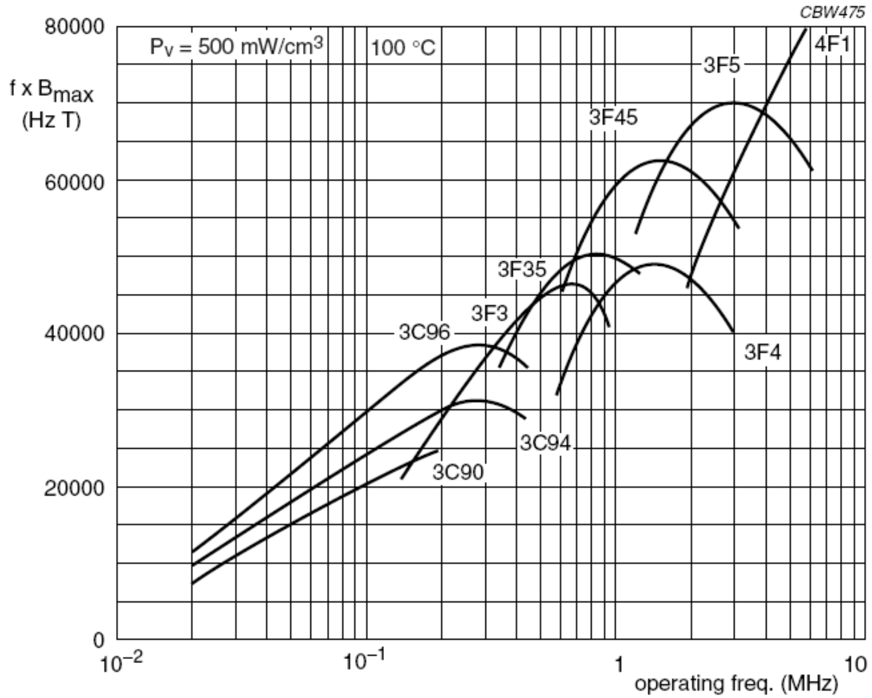
- USA:
  - International Rectifier (AlGaN/GaN HFETs on Si)
  - EPC (Efficient Power Conversion corp.) (AlGaN/GaN HFETs on Si)
  - . . .
- Japan:
  - Sanken Electric co, (20mΩ, 750V, high power, AlGaN/GaN HFETs on Si)
  - Furukawa Electric co, (GaN power transistor, on Si, on Sapphire)
  - Toyota Central R&D Labs inc. (vertical structures with p-type GaN)
  - Sharp (AlGaN/GaN recessed MISgate HFET for power)
  - Panasonic (AlGaN/GaN HFETs on Sapphire)
  - Toshiba (AlGaN/GaN HFETs on SiC or Sapphire)
  - . . .

GaN devices already exist . . . (not exhaustive)

- Europe:
  - IMEC (Interuniversity Micro Electronics Center, Leuven)
    - AlGaN/GaN/AlGaN double hetero struct HFET on Si substrate
  - Ferdinand BRAUN Institute (Berlin) & TESAT Spacecom (Backnang)
    - p-type GaN gate in AlGaN/GaN/AlGaN structure
  - Fraunhoffer Institute (Freiburg)
    - AlGaN/GaN HEMT Id 50A BV 600V (power, only normally on!)
  - LAAS/ CNRS-CRHEA (projet MOreGaN)
  - Alcatel-Lucent - Leti - Thales III-V lab
    - Work today on RF normally_on GaN
  - . . .
- Remark: Today, main activities are done in laboratories.
  We have to look for an industrial supply chain ! ! !

Switching at higher frequency require new ferrite materials

- Merit factor: f x B_{max}
  - Frequency x maximum magnetic flux density
- B.f product of different magnetic materials assuming a maximum value of 500 mW/cm^3 for core losses (source Ferroxcube)



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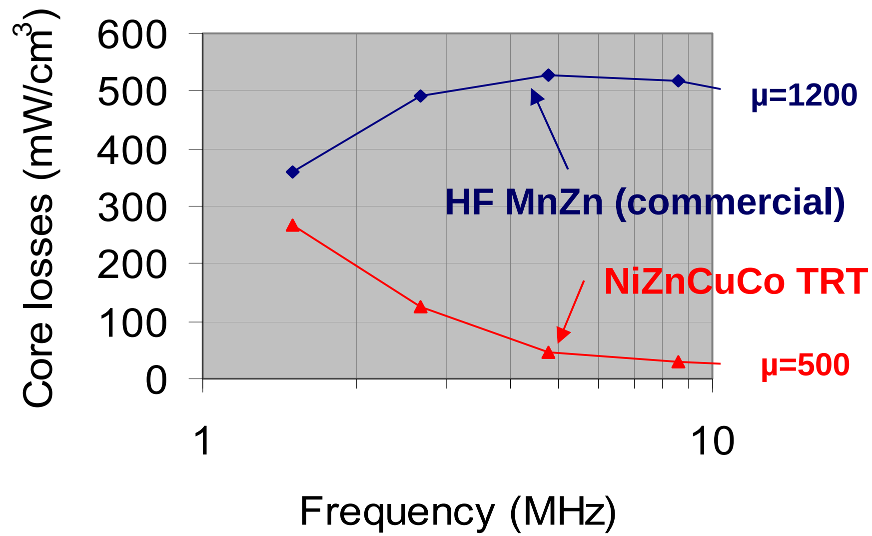
Low core losses at high frequency

- New material developed by TRT
  - NiZnCuCo
  - Can be co-sintered . . .
  - Thales Research & Technology

Ferrite	permeability	Core losses at 3 MHz – 12.5 mT
3F4	900	> 300 mW/cm³
3F45	900	≈ 235 mW/cm³
3F5	650	> 200 mW/cm³
4F1	80	< 300 mW/cm³
TRT ferrites	80 to 500	< 100 mW/cm³

Measured at 37.5 MHz.mT



Best power ferrites at high frequency = NiZnCuCo ferrites

Look out : do not forget skin effect in winding !

High frequency capacitor exist

- Ad hoc dielectric materials are known and used for RF components (like NPO)

But . . .

- Range of values is limited to 100 pF . . . 100 nF
  - Large size => parasitic inductance
- Look out for power losses induced by high current

Solutions

- Use of HF capacitor only in the “converter loop”
- Use of capacitor assemblies
  - With various dielectric materials
  - For wide bandwidth

Drawback

- Cost !

Industrial converter goes to the digital world . . .
. . . Why not the for space applications ?

- A high-growth domain for the past five years on ground
  - 45% growth predicted by 2013 (Darnell – Feb. 2009)

Objectives of the controller:

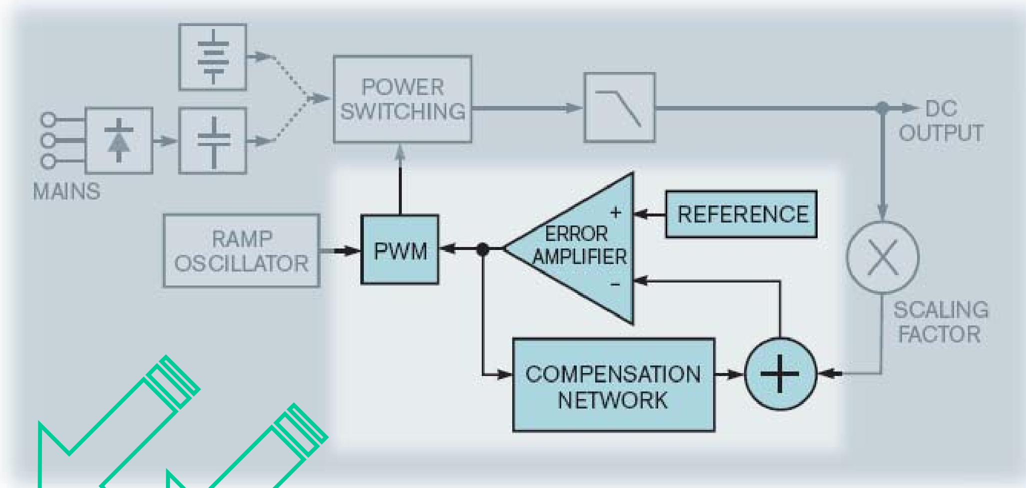
- Management of power devices via digital rather than analogue techniques
- Brings about flexibility and cost reductions

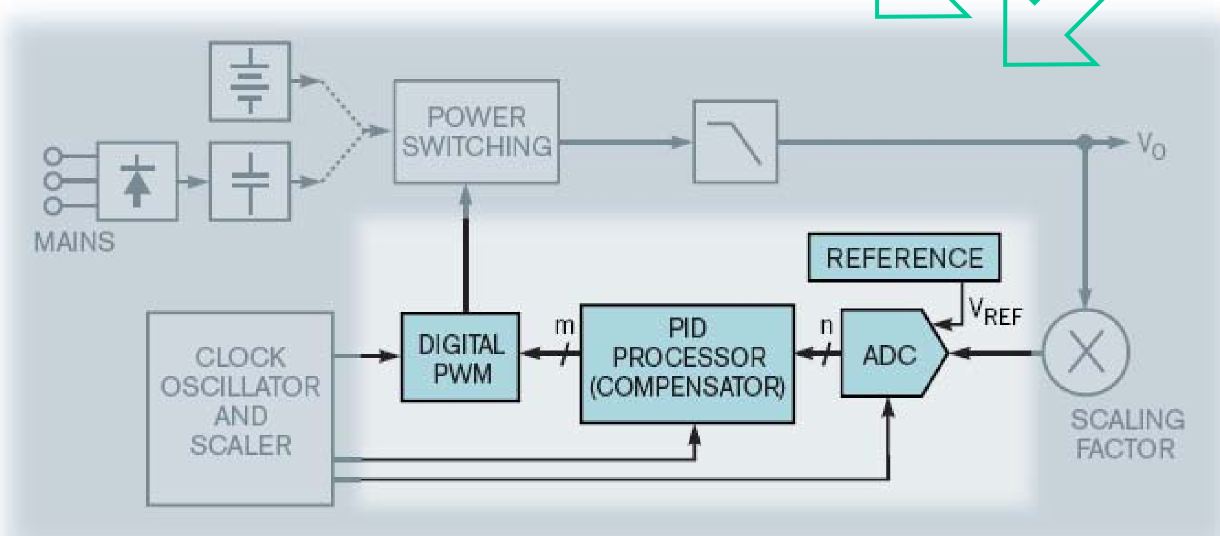
But space constraints must be taken into account . . .

- Radiations
- Reliability and availability

Controllers

An analog SMPS control loop compares a scaled sample of the output voltage with a fixed reference and controls the PWM timing to force the two quantities to match.





A digital SMPS control loop replaces the error amplifier with an ADC. The digital PWM requires a high-speed clock to provide the necessary edge-timing resolution.

A BIT OF POWER digitally controlled power conversion
JULY 21, 2005 | **EDN** 59-66
BY JOSHUA ISRAELSOHN • TECHNICAL EDITOR

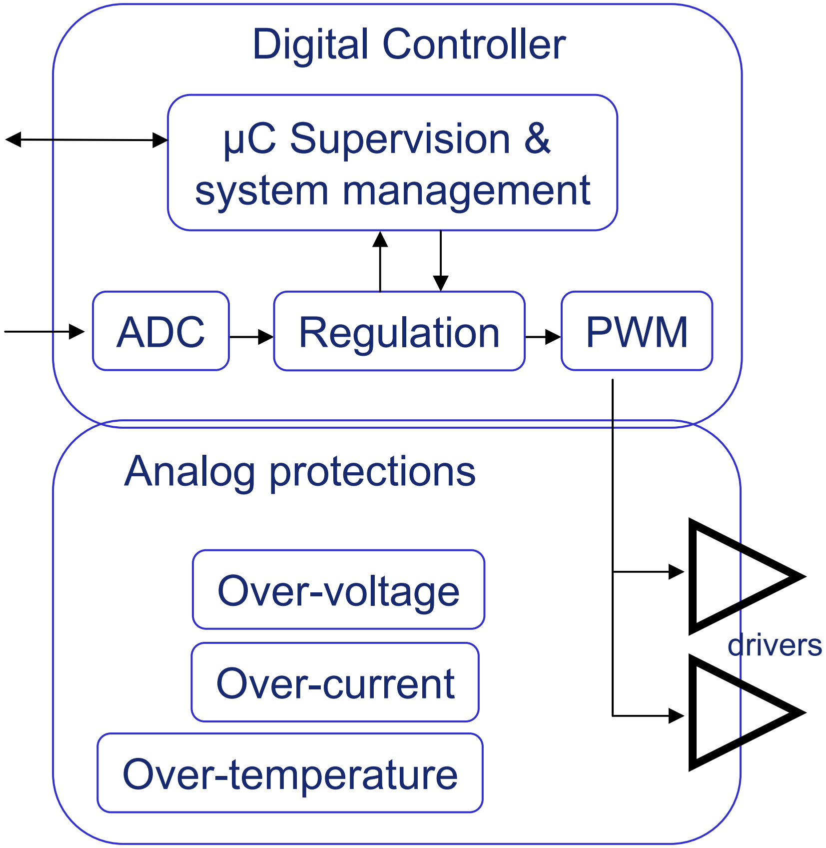
As it is done today on ground digital controllers,
around basic regulation we can easily add:

- Non-linear regulation (fast transient suppression)
- Temperature drifts compensation
- Double regulation on either side of a galvanic barrier
- Complex loop filter with high rejection
- Inrush current limitation
- Alarms & protections: under-voltage, over-voltage, over-current, …
- Multiple outputs with voltage sequencing
- Low output voltage (synchronous rectifier)
- Power-up, power-down control
- Estimate output current without current sensor
- Complex topologies (e.g. resonant converters)

Thank to the flexibility of digital solution

Controller component features => Mixed-mode IC

- Non-volatile memory
- High speed ADC with differential inputs
- DAC
- PLL
- Glue logic
- Serial data communication module
- Digital fast regulation engine
- Digital PWM generator
- Supervision & system management µC
- Timers, watchdog
- Debug functions
- Low pin count



For distributed Power supply : POL

- Key technologies for supplying digital IC (FPGA, mass memory, . . .)
- Good efficiency in small volume and small weight
- More details see ref. 1

POL are already available in IC form

- Linear Technology, intersil
- And some modules

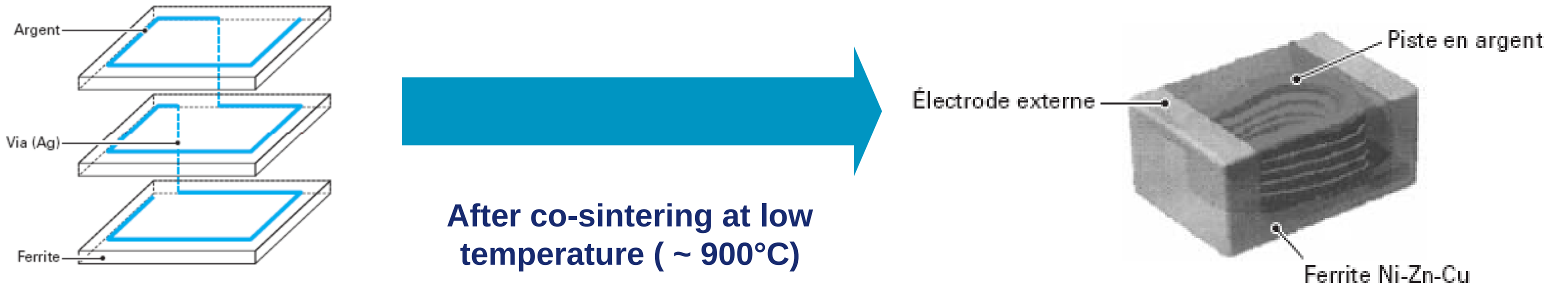
No failure management are included . . .

. . . How can we improve the integration

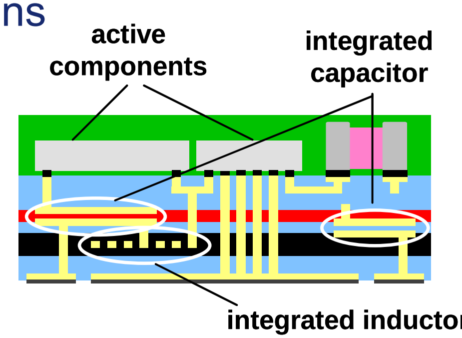
Ref 1: Points of Load Converters and distributed power architecture approach - ESA Technology Innovation Day(s) , Feb 18th, 2010 - F. Tonicello – M. Triggianese - TEC-EPC, ESA-ESTE

Point Of Load future integration . . .

- As frequency increase, the volume of passive components decrease
- Use of the multilayer LTCC technology for magnetic components
  - Low Temperature Co-fired Ceramics



- Objective: co-sintering together different materials for developing complex substrates including both inductive and capacitive functions
- Co-sintering of:
  - magnetic materials (ferrite NiZnCuCo)
  - dielectric materials
  - conductive paths



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Conclusions

We expect a bourgeoning field also in space business

- GaN, ferrites, capacitors and controllers
- All these progress will improve performances and/or cost

As power supply are often “mission critical”

- Innovative solutions must be introduced carefully
- They need costly, lengthy developments and qualifications
- Some improvements imply a “cultural revolution” in system design and industrial practices

We hope that component manufacturers will follow these trends

- A good supply chain is key for the business

To push improvement, we must dream !

- Thank you to have followed me during these few minutes

Thank you for your attention