Converter Technology

A power electronic converter is machine for converting electric energy (current, voltage, frequency), by applying one or more power semiconductors, magnetic components, capacitors, control electronics, and other essential supplementary components.

SINTEF Energy Research

Know-how:

- ✓ Power Semiconductors
- ✓ Circuit Topologies
- ✓ Magnetic Components
- ✓ Motor Drives
- ✓ Simulation
- ✓ Control Electronics
- ✓ Control Engineering
- ✓ EMC
- ✓ Energy Storage

Products:

- ✓ **Analysis & Verifications**
  - Components
  - Converter Topologies
  - Converters in Power Systems
  - Converter related EMC
- ✓ **Prototypes**
  - Design support
  - Complete units
- ✓ **Special products**
  - Subsea Equipment
  - Electric Propulsion

This presentation

- Generally about Power Electronics at SINTEF
- Some products and research activities
- A review of problems and challenges related to high power subsea power electronics
- Possible exploitation from the research project: ”Development of technologies for design of integrated power electronic converters”

Power Electronics at SINTEF

- 5-6 specialists on power electronics
- Supporting power electronic industry with development of new products
  - All from assistance with basic studies to development of prototypes ready for production
  - Power supplies and converters employing switching power transistors (IGBT, MOSFET, etc)
  - Converters in the power range 100 W to 5 MW
- Assisting industry and utilities with problems related to application of power electronics
  - Evaluation and recommendations of installations containing converters
  - Evaluation of new converter applications in power systems
  - Operating problems involving converters and motors
  - Development of application specific converters

Power Electronics at SINTEF cont.

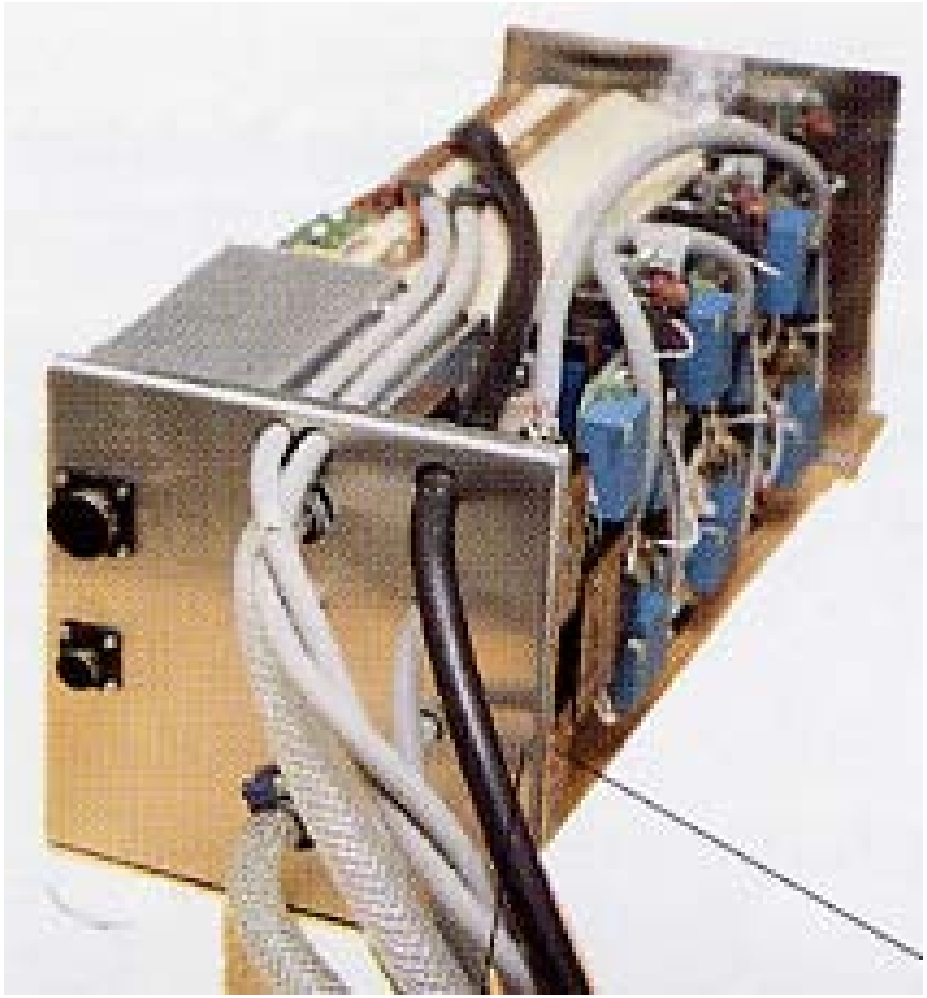
- Power semiconductor switching devices
  - Understanding physics of most types of modern switching devices like IGBTs, MOSFETs and bipolar transistors
  - Limitations and possibilities regarding power, high frequency characteristics, short circuit protections etc.
  - Characteristics of semiconductor modules
  - Optimal selection of components for various applications
- Power electronic circuit technology
  - Detailed understanding of most types of converter topologies
  - Power electronic circuit analysis by numerical simulations (E.g. PSCAD, MATLAB)
  - Snubbers and other protecting circuits
  - Optimising and adaptation of driver circuits
  - Control of distortion and harmonics
  - Optimal selection of topologies for various applications

Power Electronics at SINTEF cont.

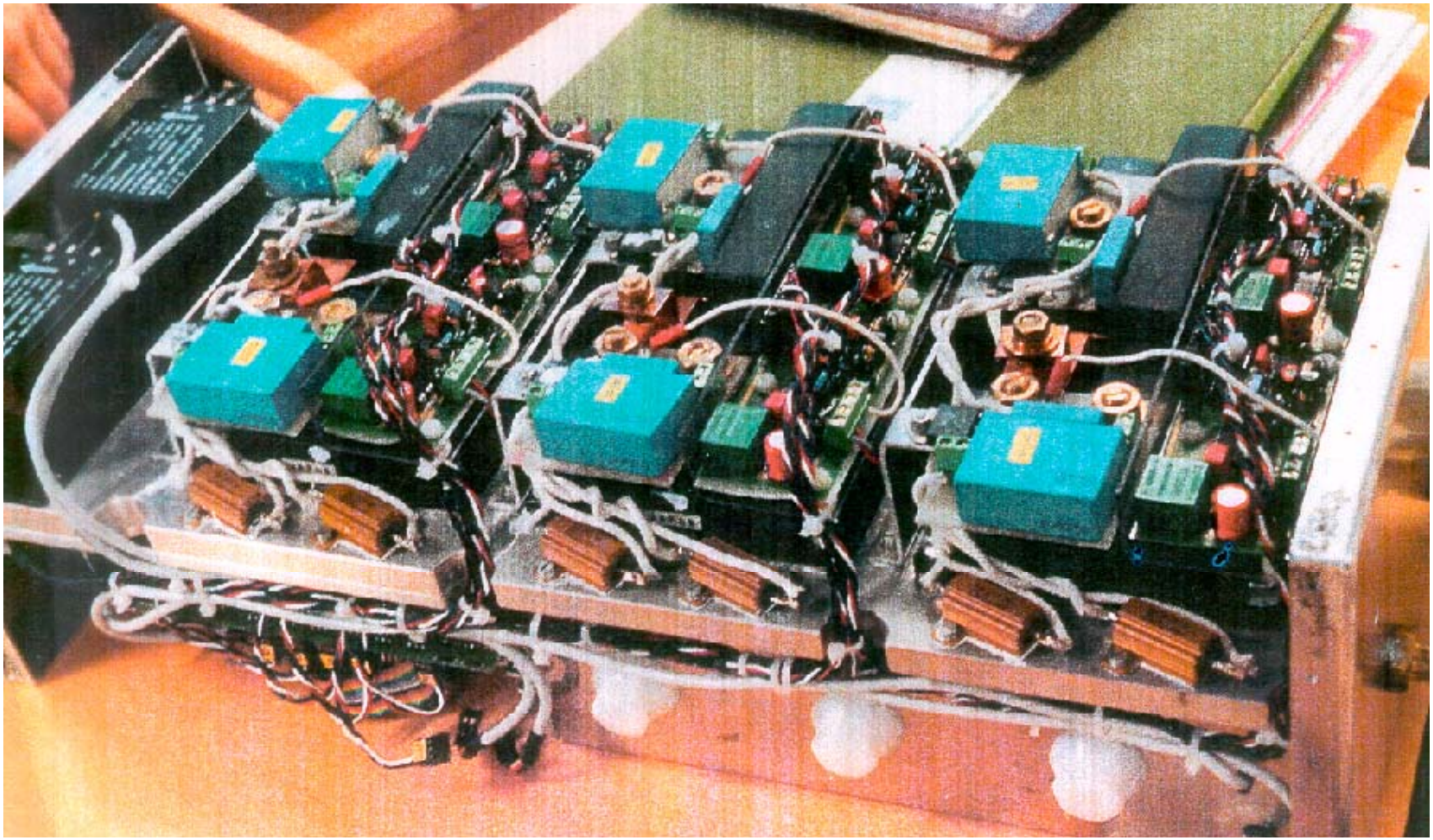
- Design of prototypes
  - Power components and power circuits
  - Magnetic components for high frequency converters
  - Cooling and packaging
  - EMC design considerations
- Control electronics
  - Control schemes for current and voltage control of converters
  - Optimization of control loops
  - Optimization of electronics for state monitoring and self-protection
  - Digital control with dedicated microelectronics
- Converters in power systems
  - Analysis of power systems with integrated converters
    - HVDC and FACTS-components
    - VSDs and other converter loads
  - Power quality issues - UPS, PLC, active filters etc.
  - New technologies for maritime power distribution
  - New technologies for subsea applications
- Well equipped laboratories

Compact converter for motor drive (developed by SINTEF for Volvo / ABB)

- 100 kW
- 17 kg
- 17,7 litre
- Liquid cooled

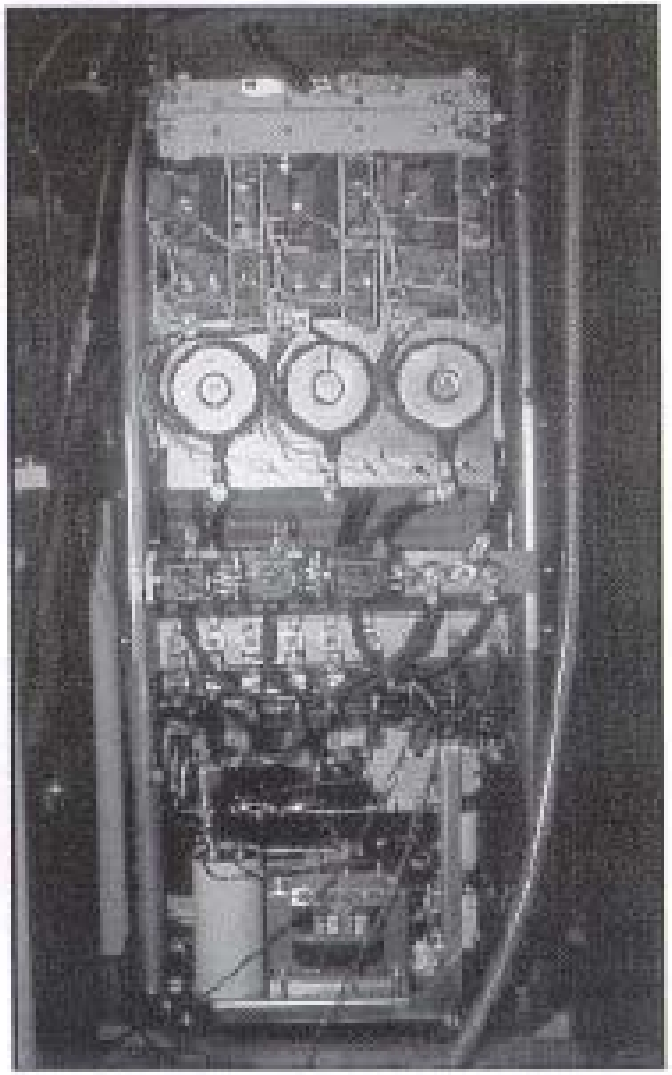


Compact converter for motor drive
Power Module



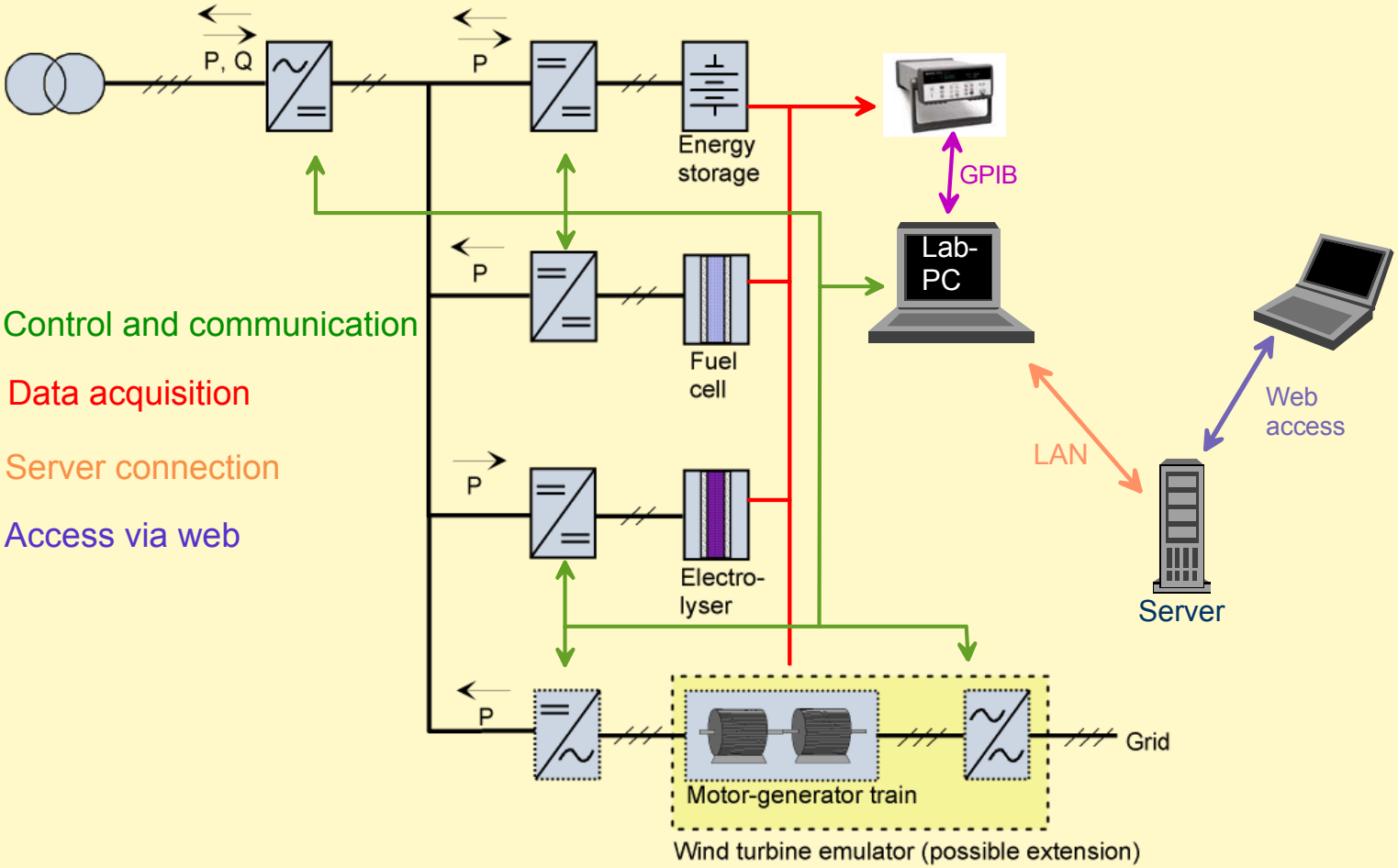
Special converter for hyperbaric welding (developed by SINTEF for industry clients)

- Down to 400 m seabed
- Heatsinks for power semiconductors prepared for seawater cooling
- Cooling tubes of steel, moulded into aluminium heatsink
- Reliable operation in 15 years



The Energy Laboratory at SINTEF

- Evaluation of power electronic converters in off- or on-grid systems (Multidisciplinary co-operation: Power electronics, electrochemical, wind…)
- Testing new technologies for production, storage and conversion of electric energy
- Pre-testing of control systems for real systems and plants



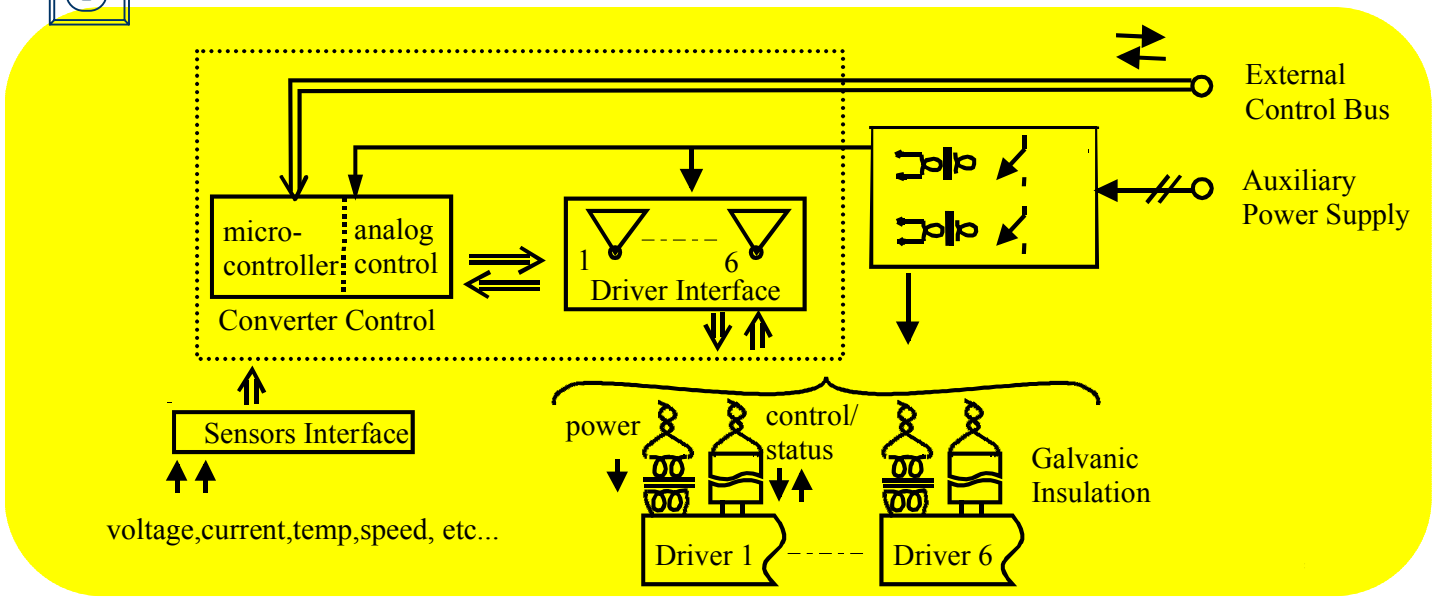
Evaluation of risk for interaction between components in power grids with high a percentage of converter loads

- ✓ Clarification of possible network interaction between turbine-generator train and converters in the power network at VISUND – Accomplished project for Norsk Hydro
  - Technical report: TR F5451
  - ”Investigation of Possible Network Interaction between Turbine-Generator Trains and Converters in the Power Grid at the Oil Platform Visund” - Paper presented on PCC-Osaka 2002:
- ✓ "Clarification of possible interactions between generator train and converter at GRANE” – Accomplished project for Kvaerner Oil and Gas
  - Technical report TR F5477
- ✓ Simulation of possible VSD and Gas Turbine-Generator interaction at the HAMMERFEST LNG-plant – Ongoing project for Linde AG
  - A project in cooperation with: Ødegaard & Danneskiold-Samsøe A/S (ØDS)
  - 5 generators with detailed modelling of electrical and mechanical dynamics
  - 4 large compressor drives with detailed modelling of electrical and mechanical dynamics
  - Underlying grid with i.a. several direct coupled asynchronous motors
  - Cables and lines to external grid (Hammerfest, Skaidi)

Reference list for offshore related studies/projects within Power Electronics at SINTEF

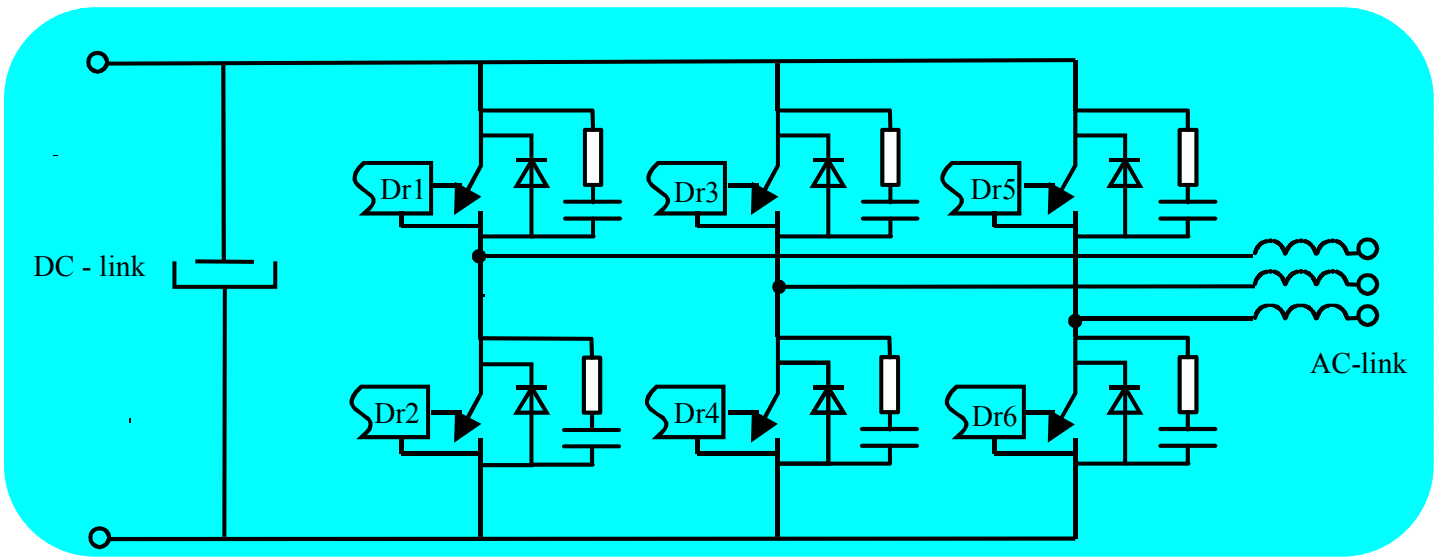
- A study of Motor Drives/ Controllers – Statoil - Confidential report 1985
- Power Transmission and Bottomside Distribution for Oseberg Hyperbaric Welding System – Norsk Hydro - Confidential note 1985.
- Verification of Hyperbaric Welding Machines for Oseberg Transportation Project - Norsk Hydro - Several documents 1986, 1987
- A study of Inductive Couplers – Statoil - Confidential report 1986.
- Inductive Power Couplers – BENNEX - Design, Testing, Computer Aided Simulation - Confidential notes and report 1986, 1987.
- Performance Analysis of Uninterruptible Power Supply on Gullfaks A – STATOIL - Computer aided simulation - Confidential report 1986
- Development of new Hyperbaric Welding Machine for PRS (Pipeline Repair System) - Norsk Hydro, Statoil et al - Working unit in operation since 1996, without any operating problems
- Clarification of possible network interactions between turbine-generator train and converters in the power network at Visund – Norsk Hydro - Confidential report 2001
- Clarification of possible interactions between generator train and converter loads at Grane - Kvaerner Oil and Gas - Confidential report 2001
- Simulation of possible VSD and Gas Turbine Generator Interaction at the Hammerfest LNG-plant – Linde AG - Ongoing project (2003)
- Smaller studies and measurements for various clients
  Examples: Cable Pumps, Valve Controllers, DC-transmission for ROV, Downhole welding converter, Electrical gear for heave compensator drive system - Mainly confidential reports
- Several smaller problem-solving projects for various clients
  Examples: Mud-pump converter problems, emergency power problems, separator power supply problems
  Mainly confidential reports

3-phase IGBT Converter with Power Circuit and Control Electronics



Control Electronics

- Converter Control
- Measurements
- Driver Interface
- Aux. Power Supply
- External Control



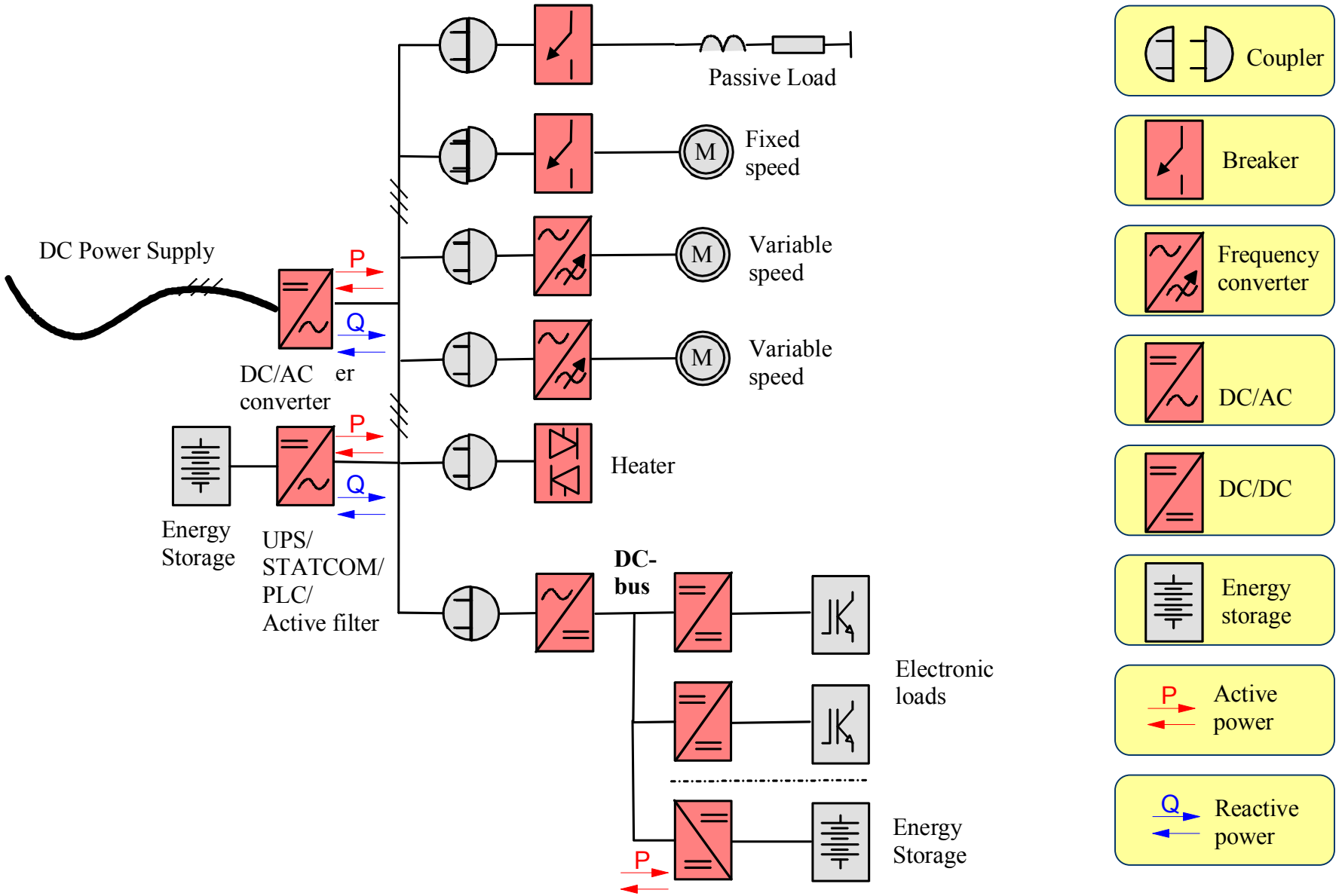
Power Circuit

- Current Valve
- IGBT & FWD
- Snubber Circuit
- Gate Driver
- Output Filter

Possible future subsea and downhole applications involving power electronic converters

- Motor drives for valve actuators, pumps, compressors, etc.
- Power supplies for monitoring equipment (reservoir mapping etc.)
- Inductive power couplers (to and between subsea modules)
- Solid state power breakers
- Downhole tools for assembling and repair (welding etc.)
- Well stimulation (vibrators, etc)
- Converters for interfacing local (subsea, downhole) power production- and energy storage-devices

Subsea Power System with Converter Control



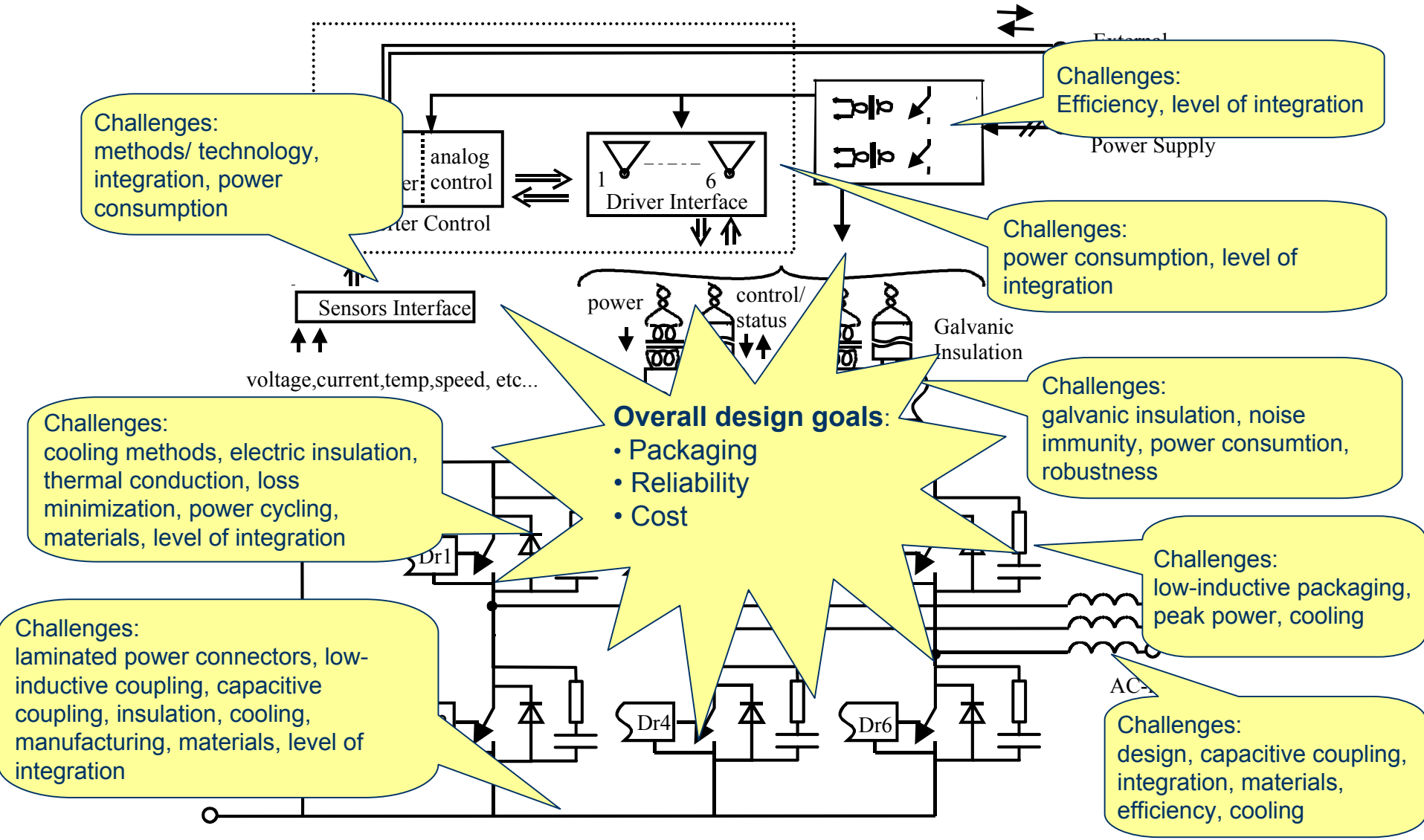
Future subsea applications demand for new solutions

- Satisfactory operating reliability in harsh environments
- Satisfactory accessibility for condition control and repair
- Satisfactory solutions for high-pressure environment
- Satisfactory solutions for high ambient temperatures (downhole)
- Adaptation to space limitations (downhole)
- Acceptable costs

Challenges when searching for converter solutions subsea

- Exploitation of advances in power semiconductor development:
  - Voltage and current rating
  - Switching characteristics
  - Temperature and losses
  - Electrical, thermal and mechanical robustness)
- Evaluation and testing of techniques for heat removal from hot spots
- Exploitation of advances in application of new materials
- Joining methods for electric connectors
- Integrated bus bars, magnetic components, semiconductors etc.
- Compacting methods
- Finding optimal control strategies (normal operation, overload, fault recovery, etc)
- Develop adequate test methods

Challenges to integrated Design



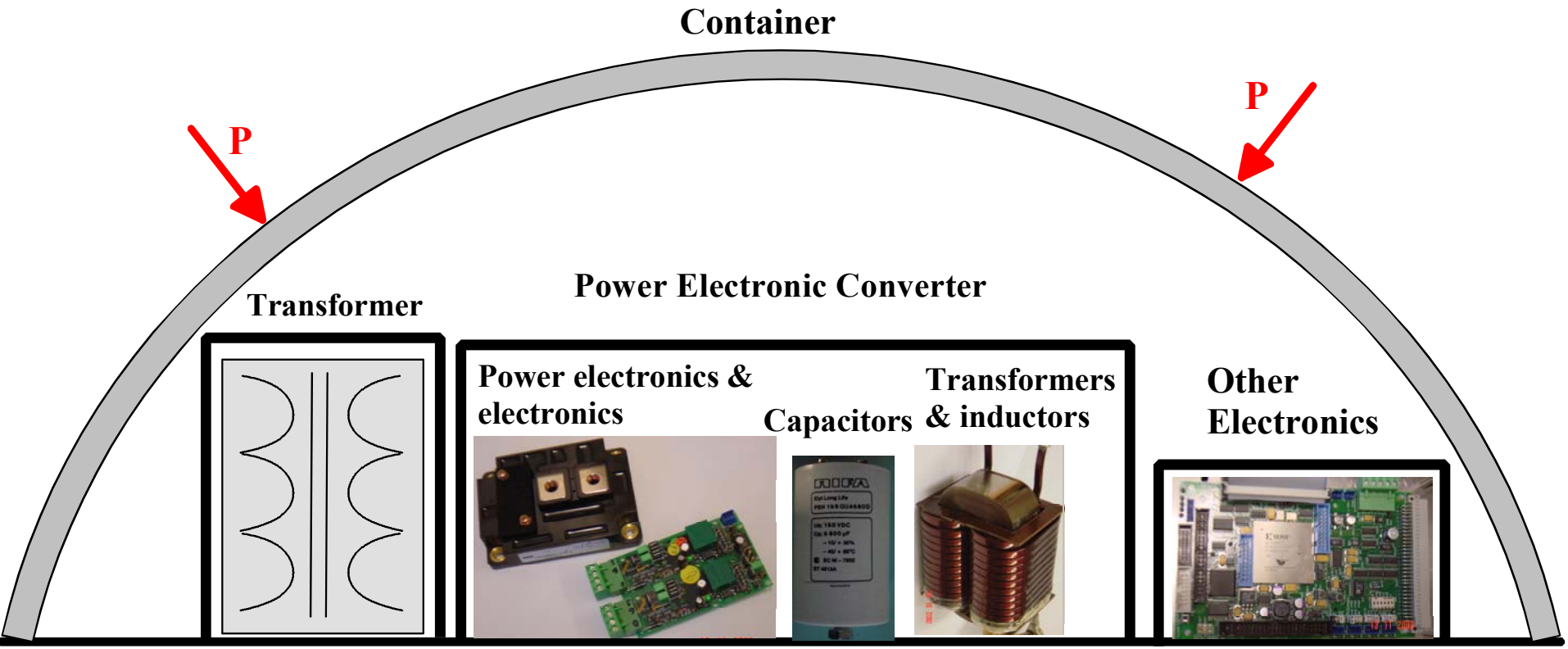
Reliability issues

- Testing and selection of materials
  - Electrical parameters
  - Mechanical parameters
  - Thermal parameters
  - Ageing effects
  - Compatibility between materials
  - Other application specific
- Design specific
  - Over all design methodology
  - Specifications
  - Reliability studies (FMECA-analysis etc.)
  - Inbuilt robustness
    - Power circuit topology selection
    - Power component derating factors (Voltage, current, temperature, etc)
    - Control strategies:
      - state monitoring
      - local and remote fault handling
      - self protection

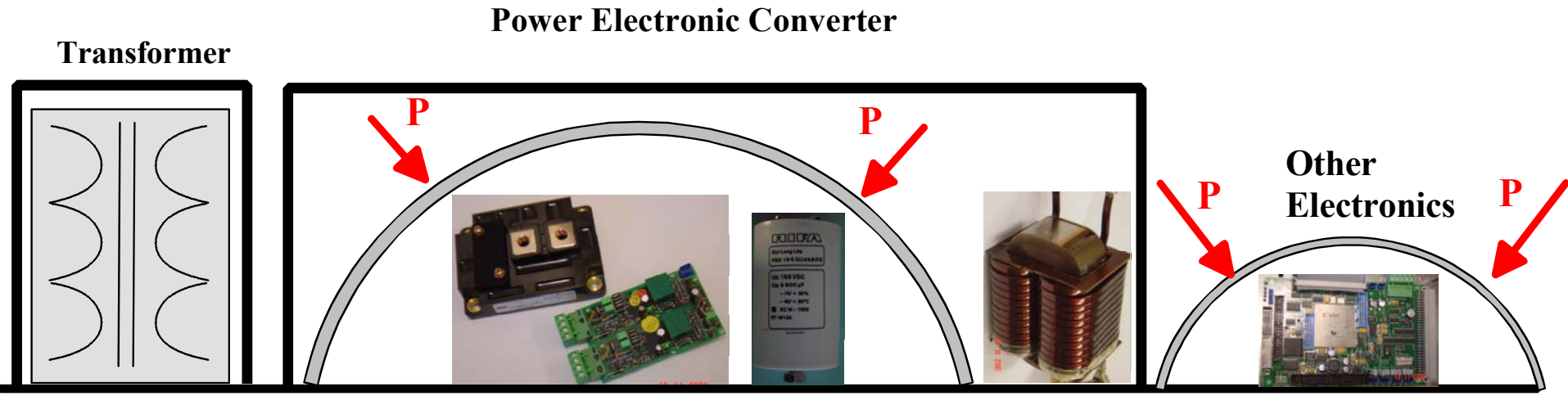
Traditional converter design is not sufficient

- E.g. commercial available transistor and capacitor encapsulations will experience pressure problems
- If traditional encapsulations are replaced with special solutions, these components can probably be exposed to ambient pressure
- This involves the need for cooperation with manufacturers of such components
- New design solutions and methods need to be evaluated
- Prototypes must be developed and tested

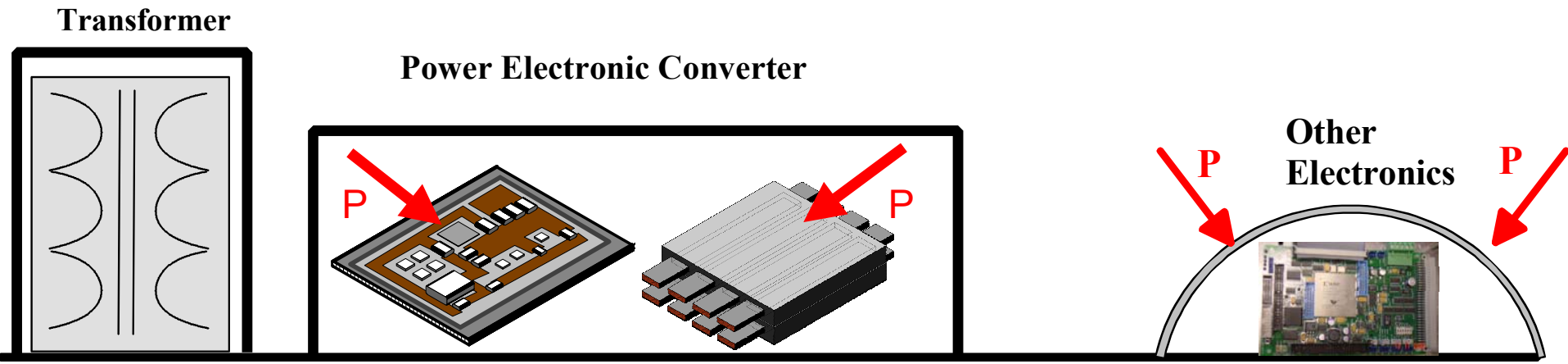
Alternative levels for pressure barriers



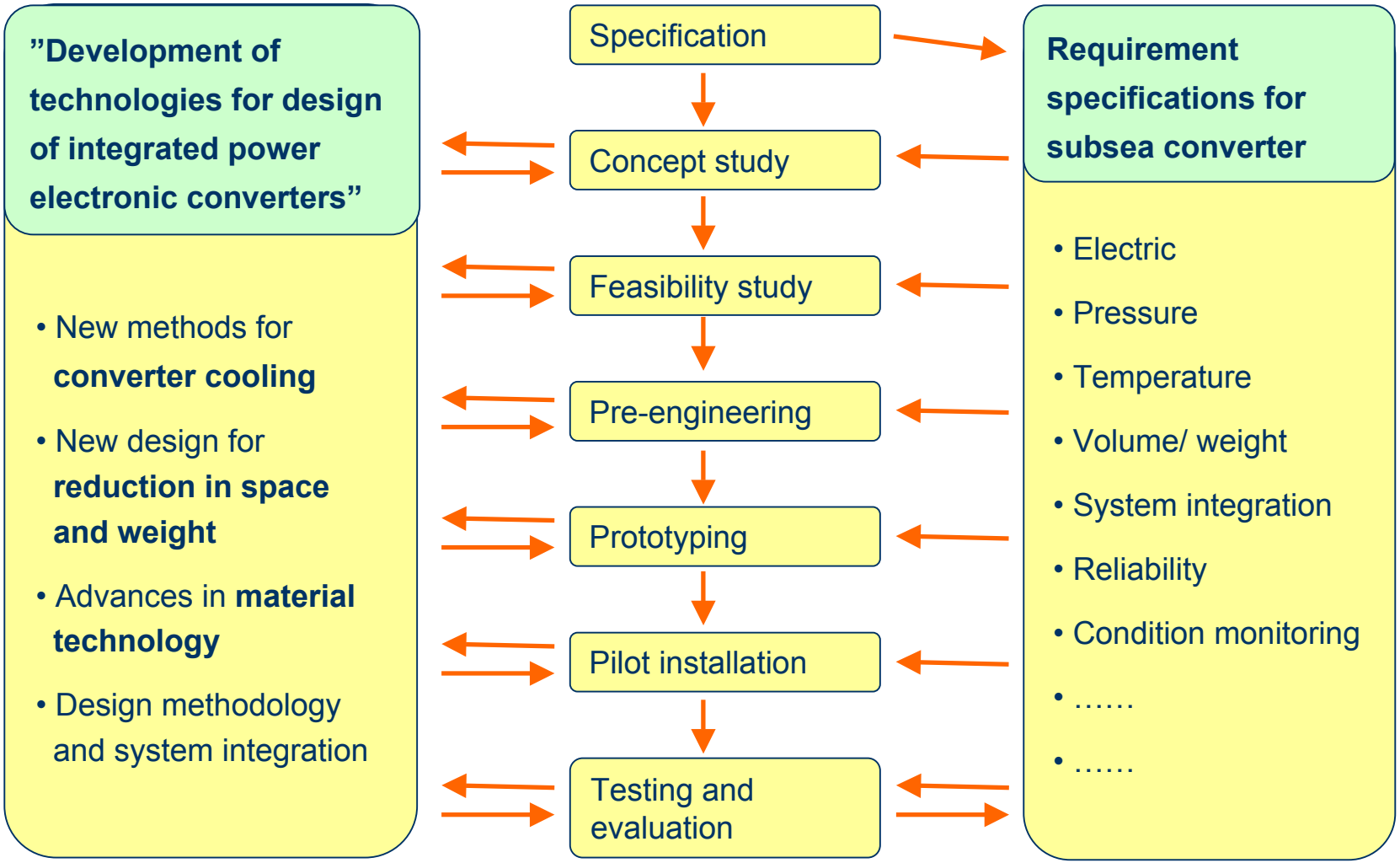
Alternative levels for pressure barriers



Alternative levels for pressure barriers



Accomplishment of a specific subsea application



Execution of a specific subsea or downhole application

- Generic research project on integrated compact converter design, especially emphasizing high degree of integration, and efficient cooling of power semiconductors, power circuits and magnetic components
- Project on power circuit topologies for a specific application
- Project on investigation of specific converter and power system behaviour

Generic project on integrated compact converter design for subsea and/or downhole applications

- **Objective**:
  To obtain reliable, technical solutions for integrated and compact converter design, especially emphasizing high integration and efficient cooling of power semiconductors, power circuits and magnetic components
- **Typical activities:**
  - Obtain **requirement specification** for the application, including worst-case ambient conditions, requirements as regards reliability, maintenance and repair, etc.
  - Preparation of **test criteria and test procedures**
  - **Specify electrical ratings** for critical components, especially the switching devices (IGBTs and FWDs)
  - **Surveying the availability** of switching devices, capacitors and other vulnerable components from relevant manufacturers, and the **possibility for custom design** and compliance for cooperation to produce special solutions for marinization
  - Surveying the open and patent literature for identification and evaluation of **compact and reliable cooling strategies.**
  - Identification of possible **heat transport working fluids** with respect to subsea pressure conditions and material compatibility.
  - Preparation of **design alternatives**. This includes mechanical layout of switching devices, snubber circuit, bus bars and DC-link capacitors. It also includes evaluation of cooling methods, i.e. heat transfer from component hotspots to ambient, and layout of cooling lines
  - Planning and building **prototypes.** Several types of prototype approaches are assumed to be necessary, both as regards electric and thermal functionality, extent of completion, and completion date
  - Building **test bench**, including pressure chambers
  - Carry out **tests according to test program**
  - Reporting with **evaluations and recommendations**

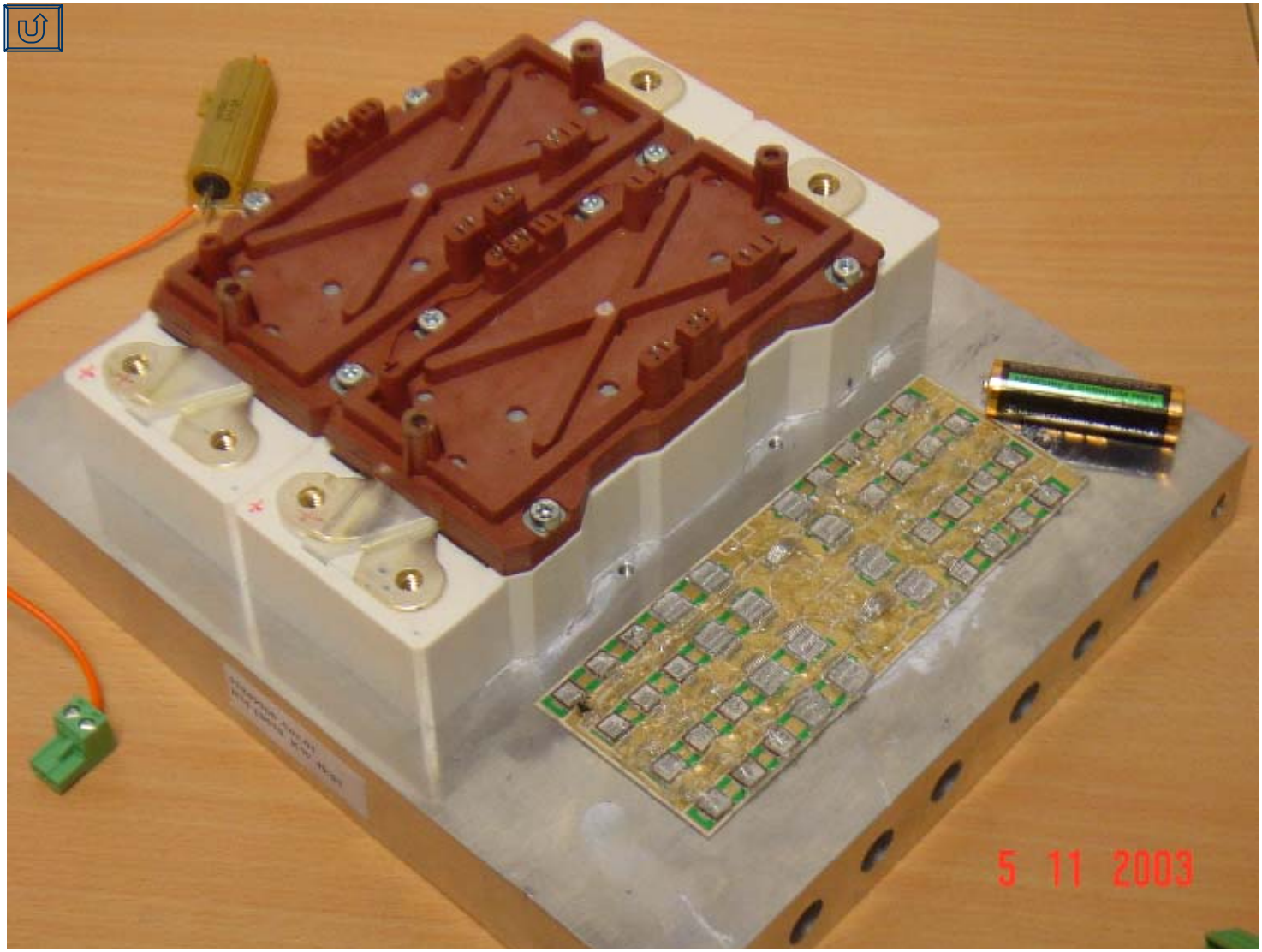
Specific project on power circuit topologies specific subsea or downhole converter

- **Objective**:
  To evaluate and recommend power circuit topologies for specific converter, with a special attention to voltage and current limitations, and to derating requirement for switching power semiconductors.
- **Typical activities:**
  - Evaluation and selection of **power circuit topology candidates**
  - Clarification of **worst case voltage, current and temperature stress** of the components for power circuit topologies of current interest. This will be done both in normal operation modes as well as under fault conditions
  - **Rating of individual components** (switching devices, magnetic component etc.), snubber circuits and other protecting circuit
  - **Simulations in order to obtain requirements** to gate drivers, auxiliary power supply and other auxiliary components
  - Obtaining **design support for control electronics** by investigations of converter and load dynamics
  - Analysis and search for **adequate control methods** for the specific application

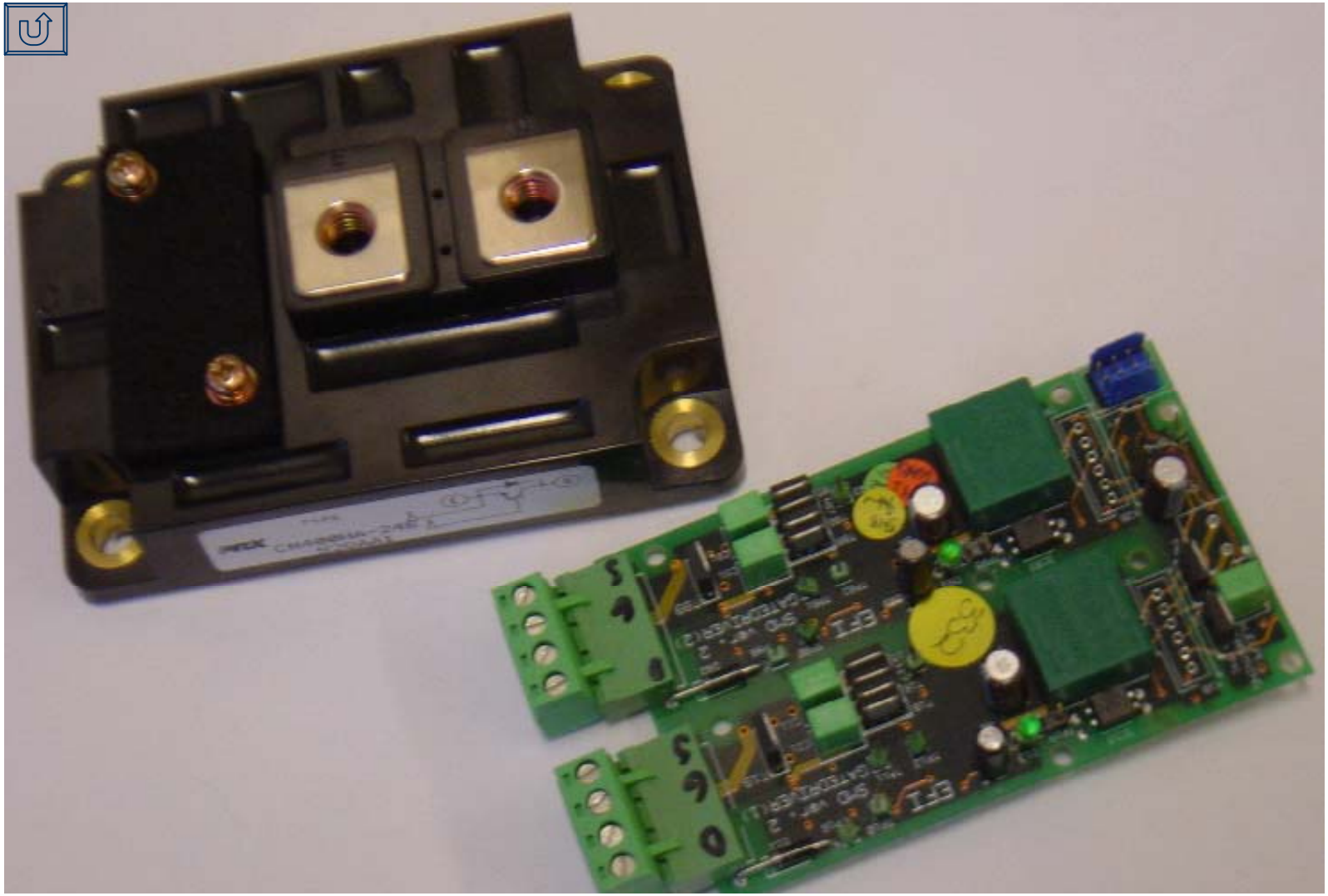
Specific project on investigation of converter and power system behaviour

- **Objective**:
  Investigate converter stress (voltage, current, temperature) converter control, and system behaviour (system dynamics, line transients etc.) in normal and abnormal operating conditions, by detailed numerical simulation of converter, cables and other vital components.
- **Typical activities:**
  - **Worst case converter stress and demand to converter** control during various transient incidents, and for various lengths of supply lines, ac- or dc-transmission etc.
  - Support for selecting the **most appropriate system solutions**, with a special view to remote power transmission (cable length, ac- versus dc-transmission, etc)
  - Support for selecting proper **protective measures (**control electronics, self-protection, condition monitoring, etc) in order to obtain satisfactory reliability
  - Clarification of **effect of various failures**, thereby giving support for doing corrective modifications of system and components, and selecting alternative countermeasures, in the operating phase.

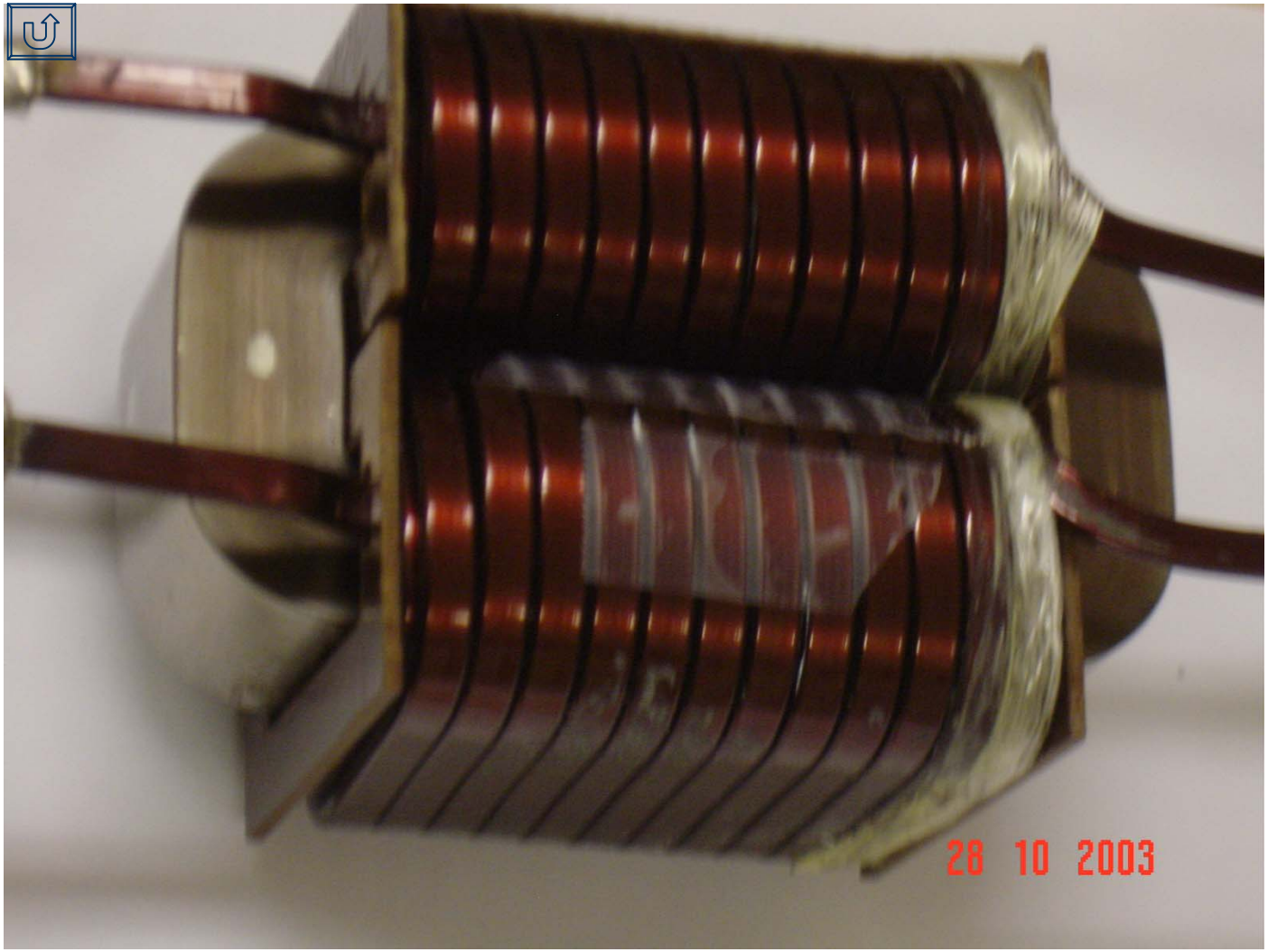
IGBT module for 1.5 MW motor converter



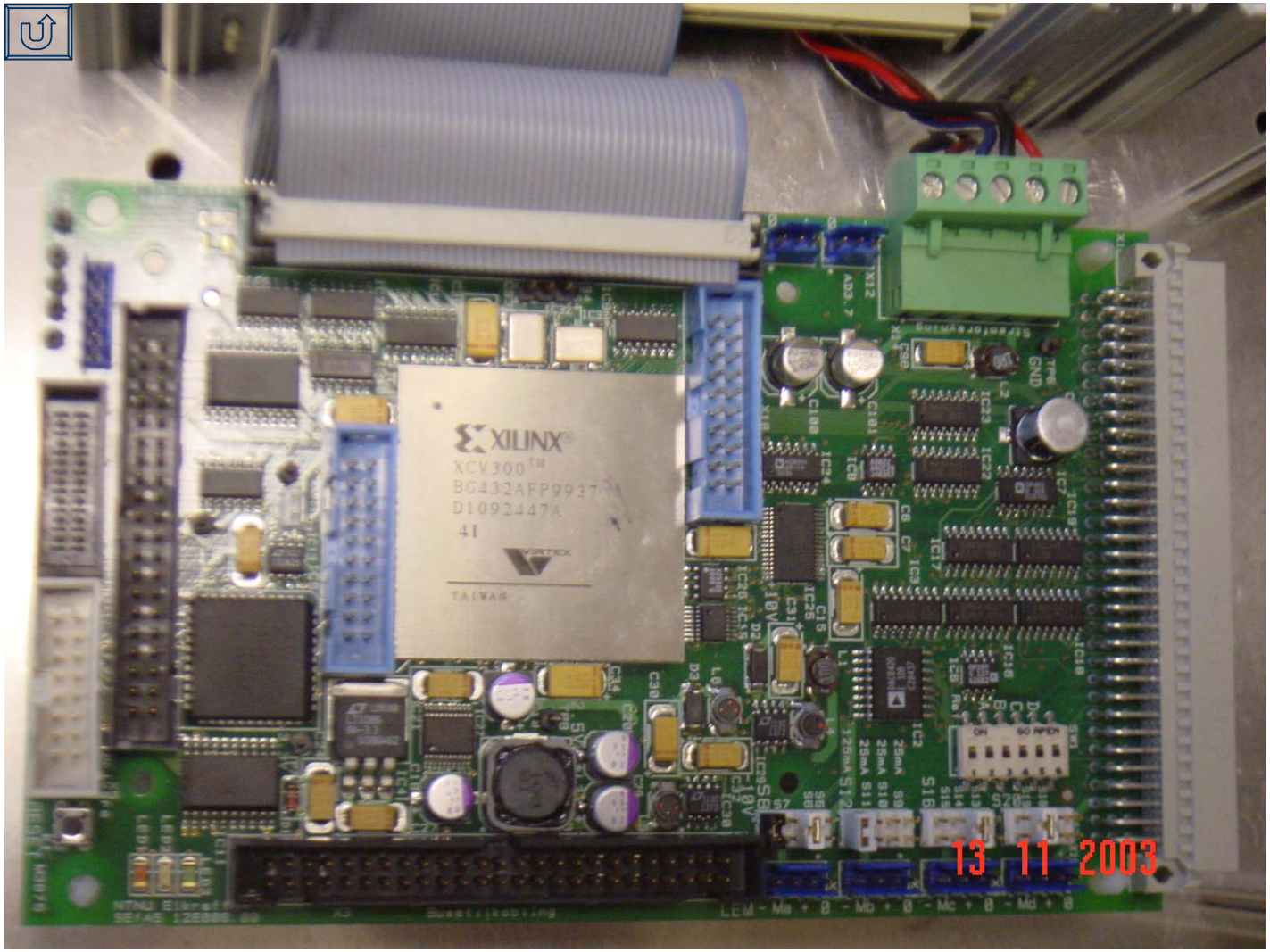
1200V/400A IGBT-module and Driver (Driver developed at SINTEF)



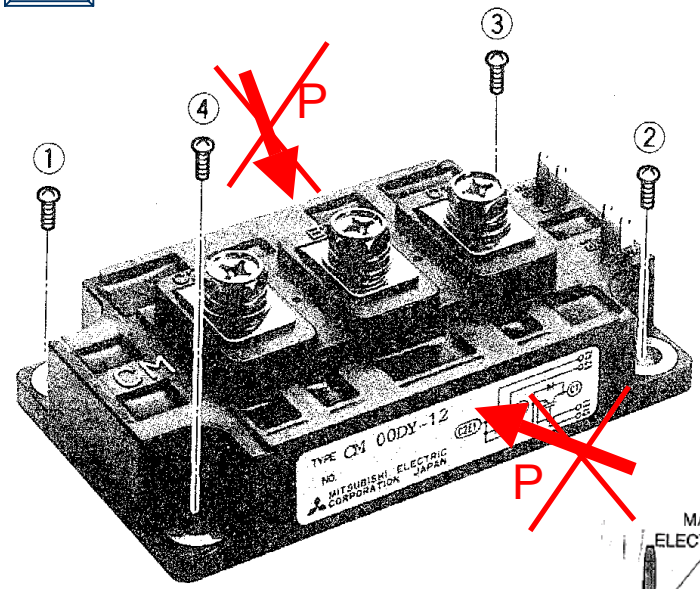
Filter Coil for PWM Converter
Standard design



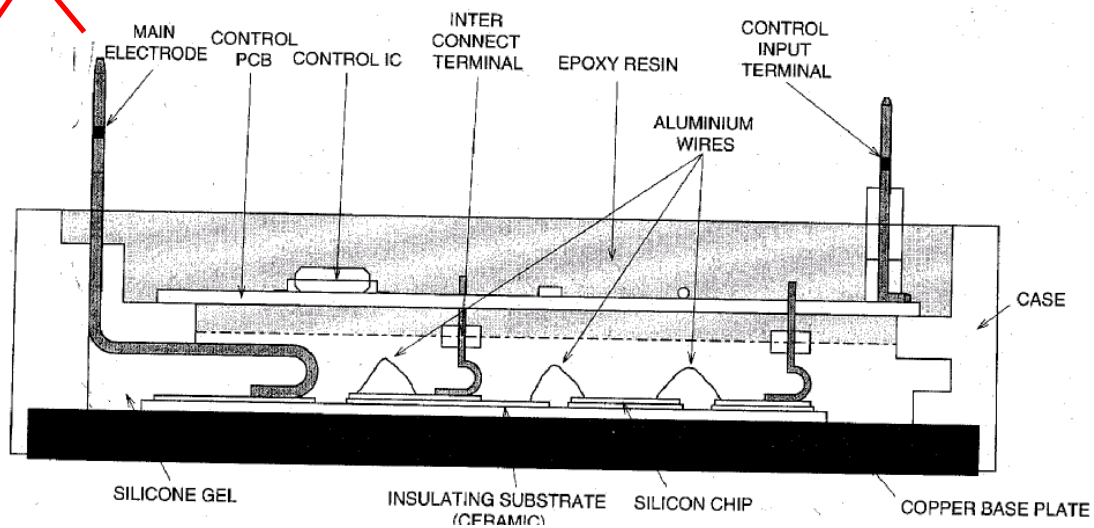
Digital Control Board with FPGA- chip (Board developed by SINTEF)



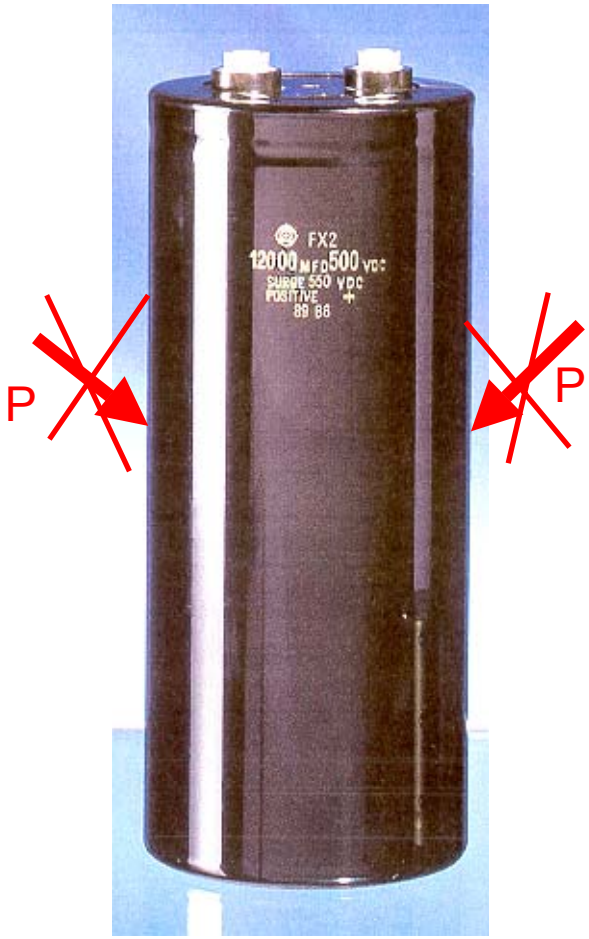
Typical structure of IGBT Power Module

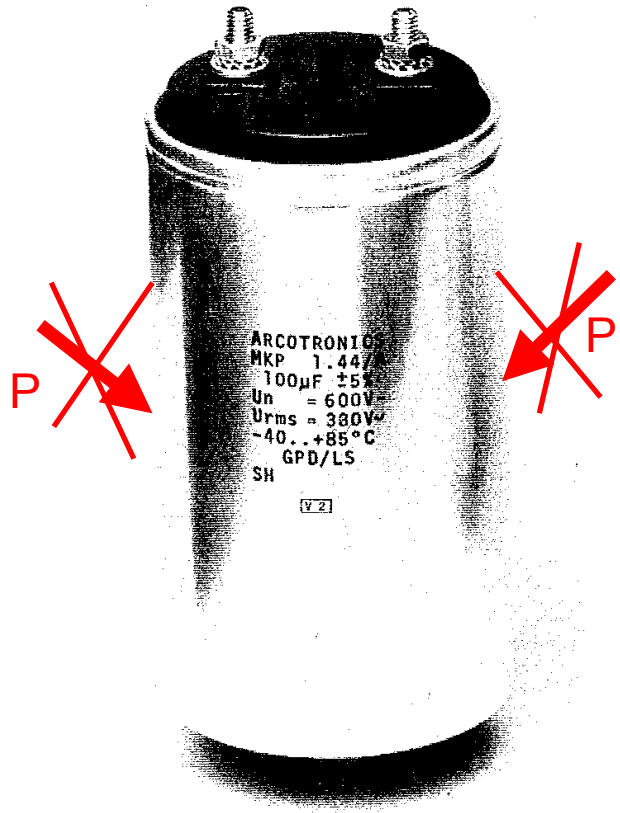


(b) Four-screw tightening module

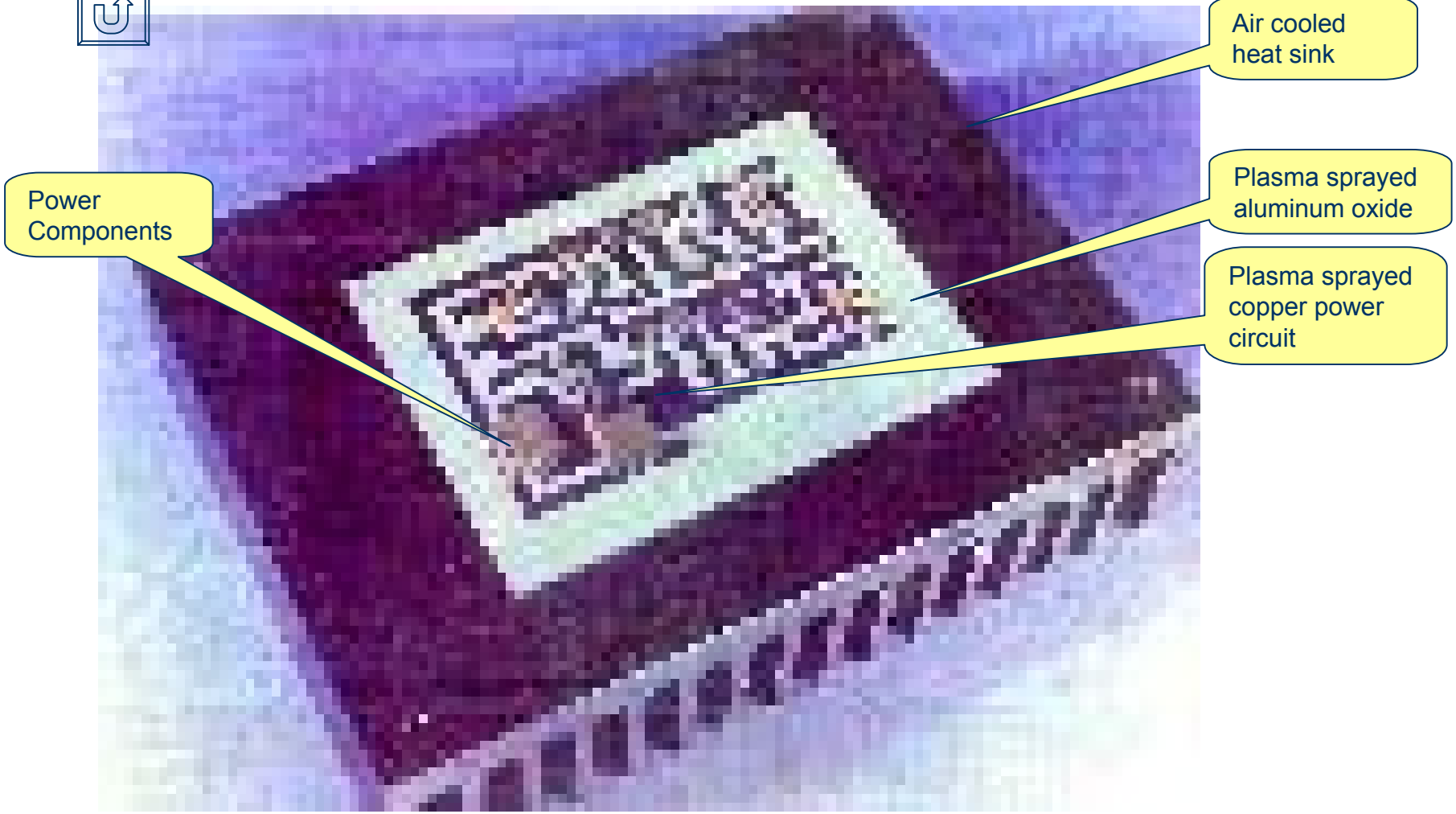


Typical structure of Power Capacitors

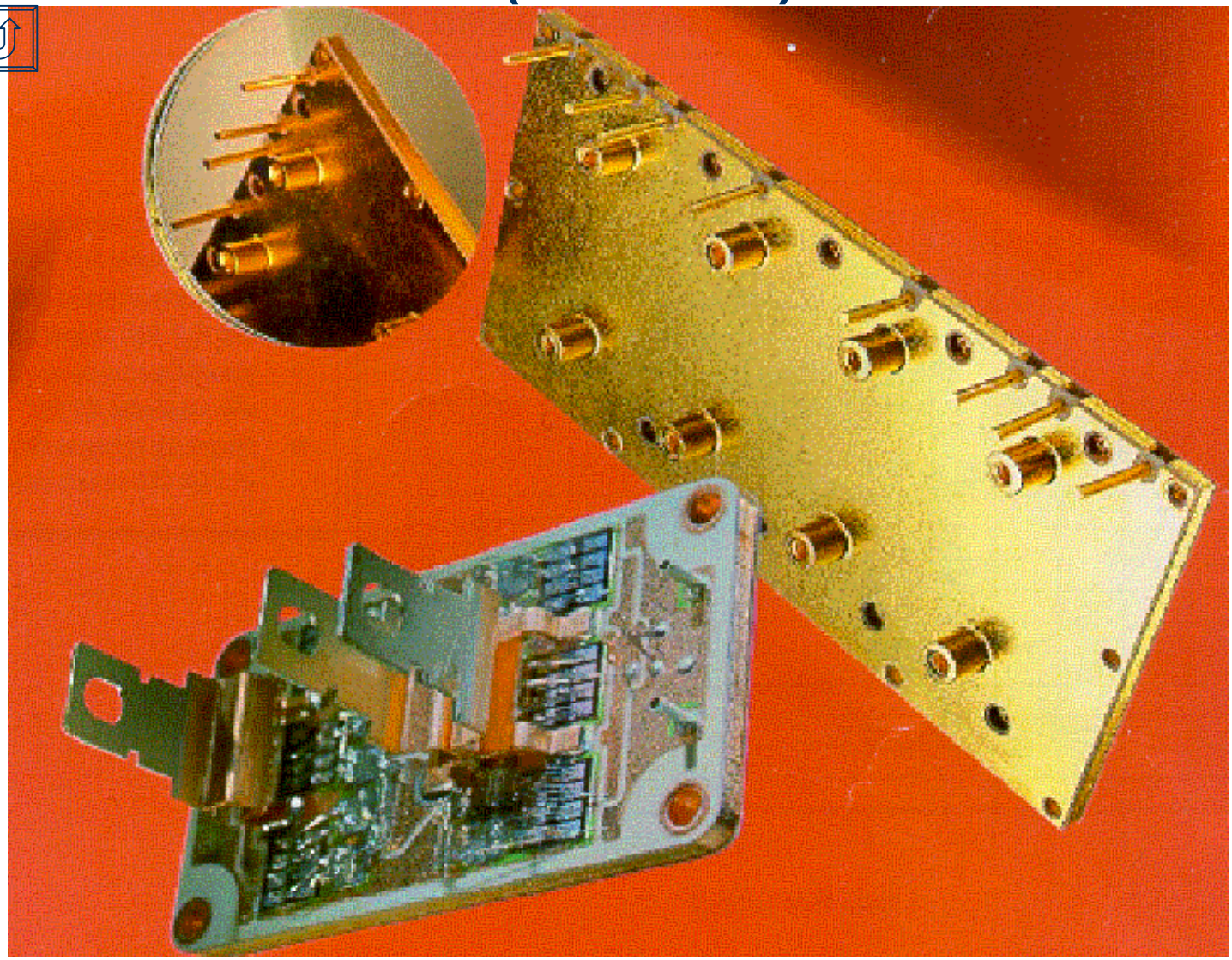




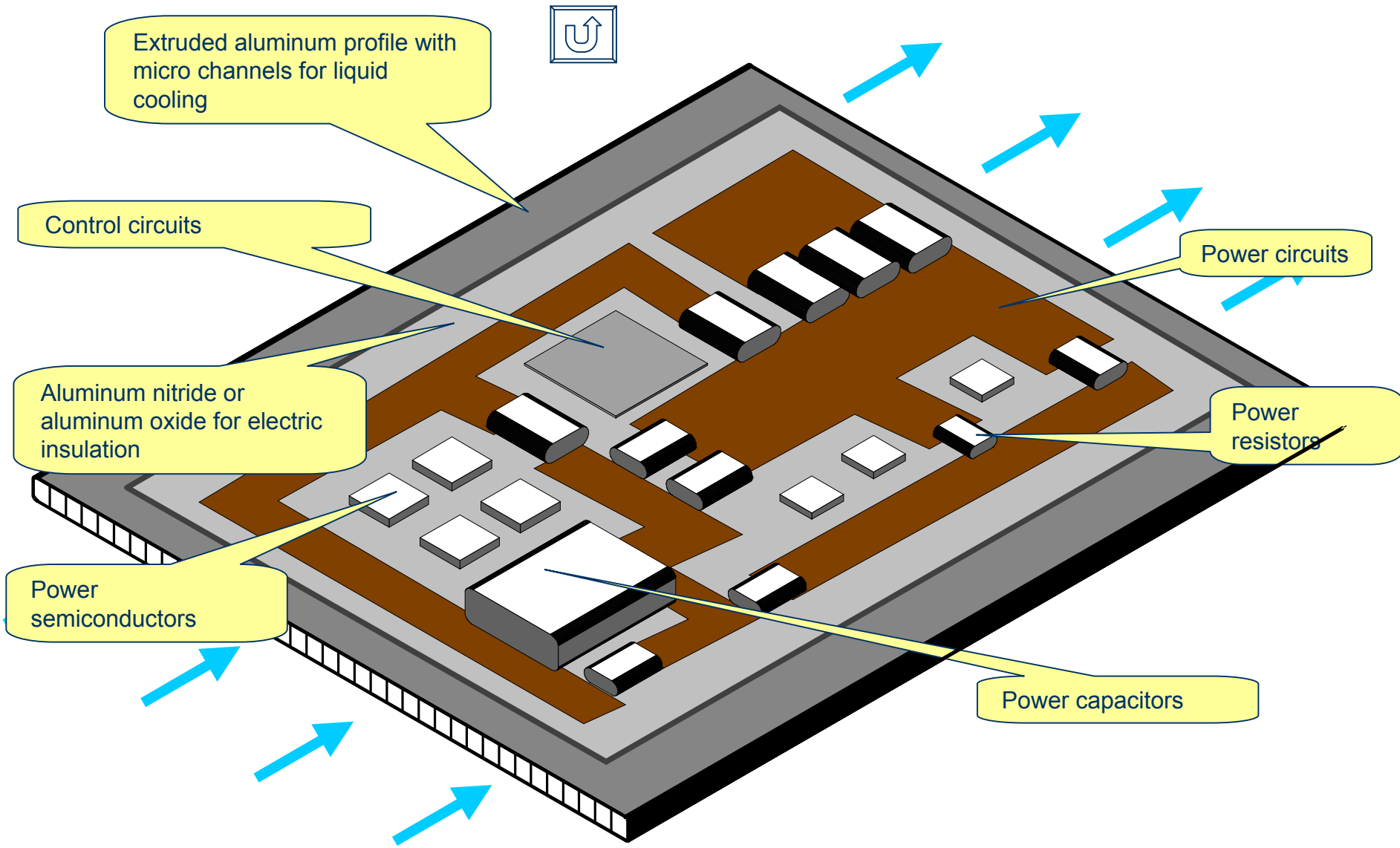
Plasma sprayed Power Circut from CPC (Norwegian company – 1992)



Power Circuit on Fluid Cooled DBC Substrate (Curamik)



Possible ”Intelligent” Integrated Power Module



Planar Design of Inductive Component