PAUL SCHERRER INSTITUT

PSI

THOMSON

Modern and Crowbarless HVPS

W. Tron, RF power amplifier

Table of Contents

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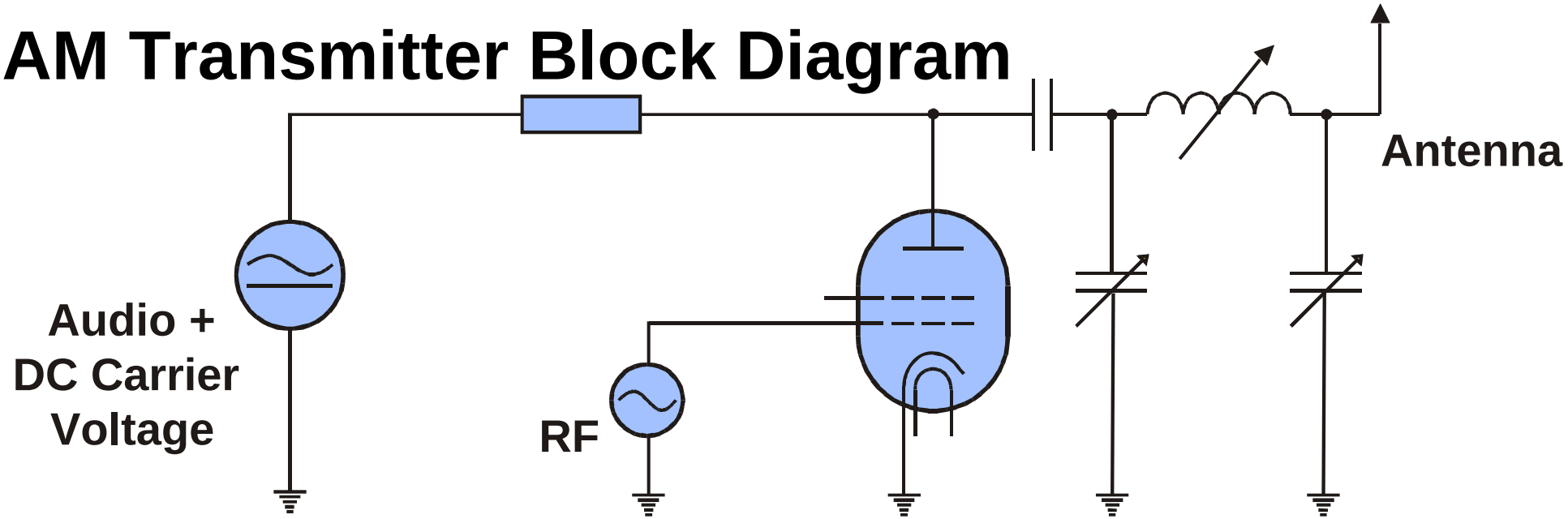
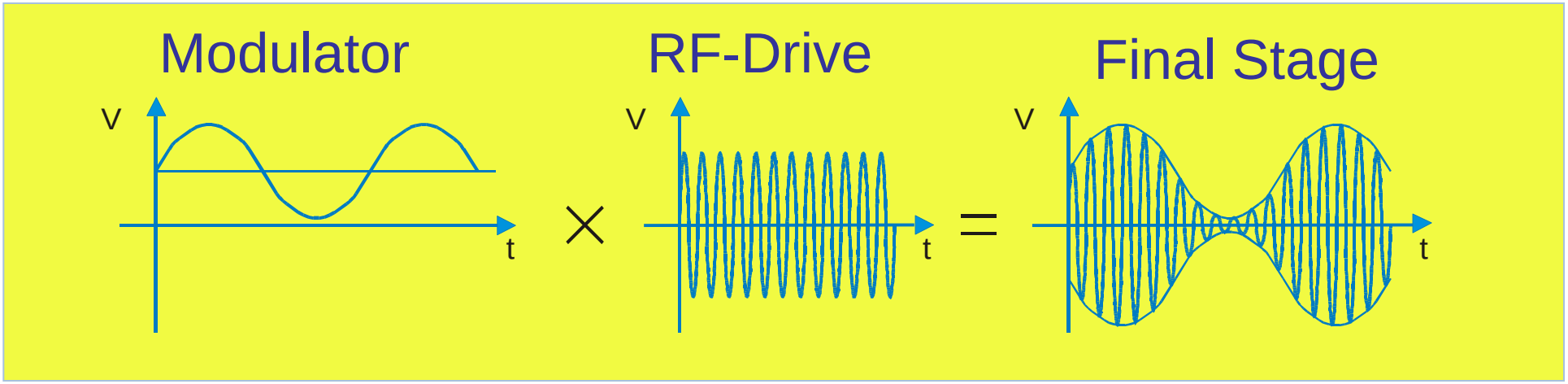
History of PSM

PSM Technological Development

- AM-Transmitter Basic Technology
- B-Modulator Design (Linear System)
- 'Modern' Switched-Mode Systems
  - PDM Modulator
  - Pulse Step Modulator

AM Transmitter Block Diagram

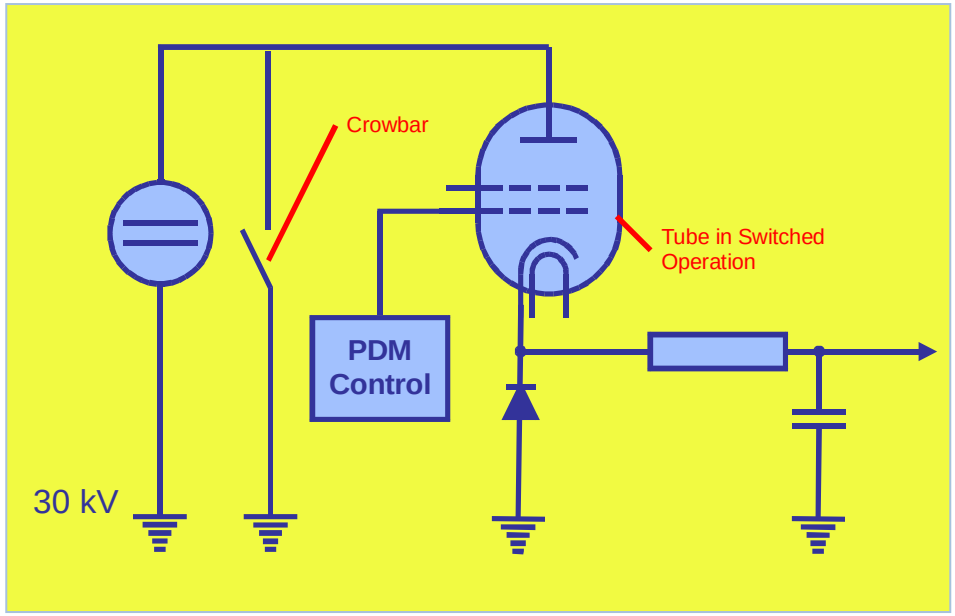


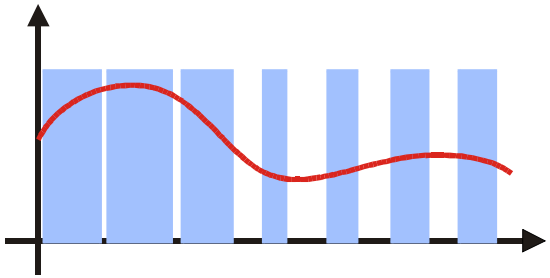


Typical Modulator Specification

- DC-Voltage 14 kV (Carrier Voltage U_C)
- Superimposed audio modulation resulting in output voltage range 0 .. 28 kV
- Continuous output power 1 MW, peak power 2.5 MW
- AF-bandwidth 50 - 7500 Hz
- Signal-to-Noise-Ratio better than 60 dB
- Total Harmonic Distortion < 3 % (THD incl. RF-Part)
- High efficiency > 97 %

PDM Modulator



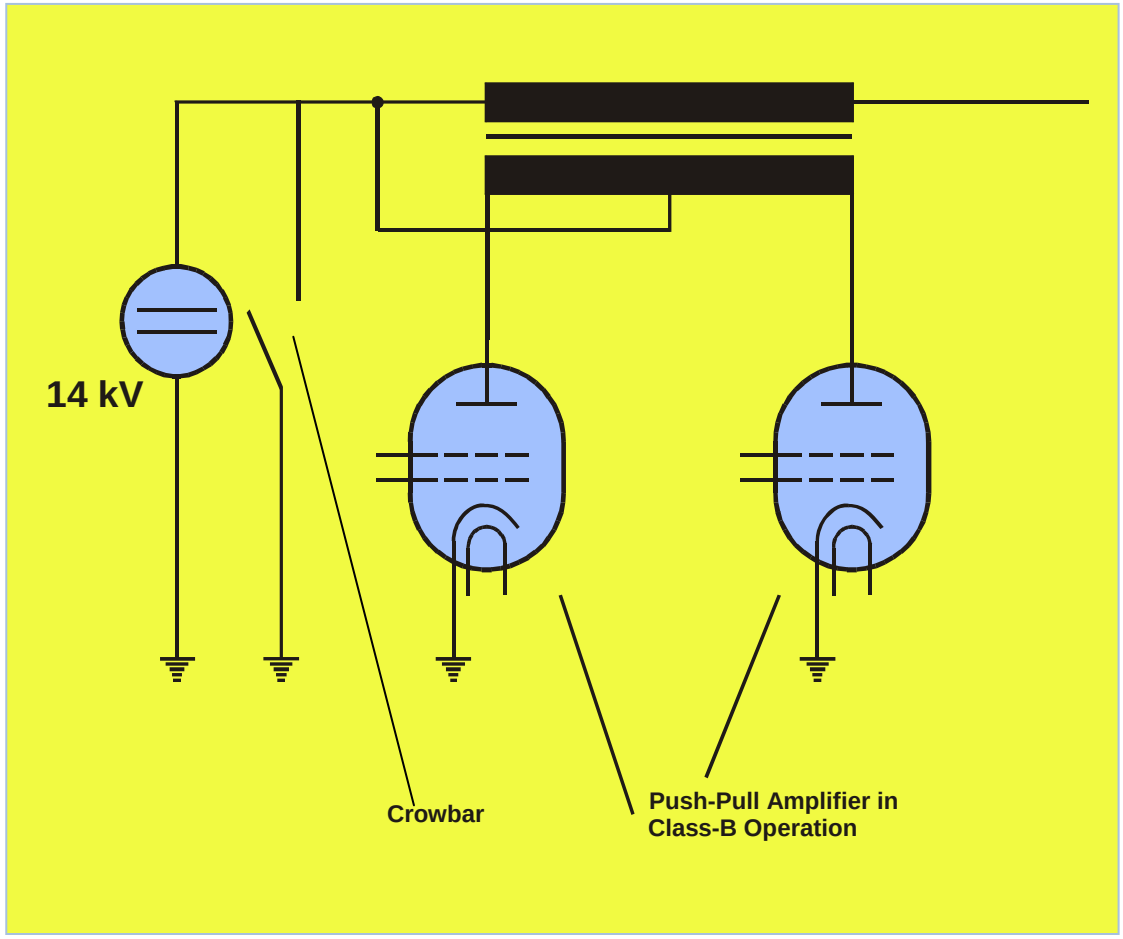


- Switched mode operation
  - Improved efficiency

BUT :

- Tube cathode on high voltage
  - Difficult to control
- Requires very fast high voltage diode
  - Series Connection of Diodes
  - Problems with Stray Inductance
- High switching frequency necessary
  - > 50 kHz
- Output filter network
  - High damping on switching frequency required
- Crowbar system needed

Linear Tube Modulator in Class-B Operation



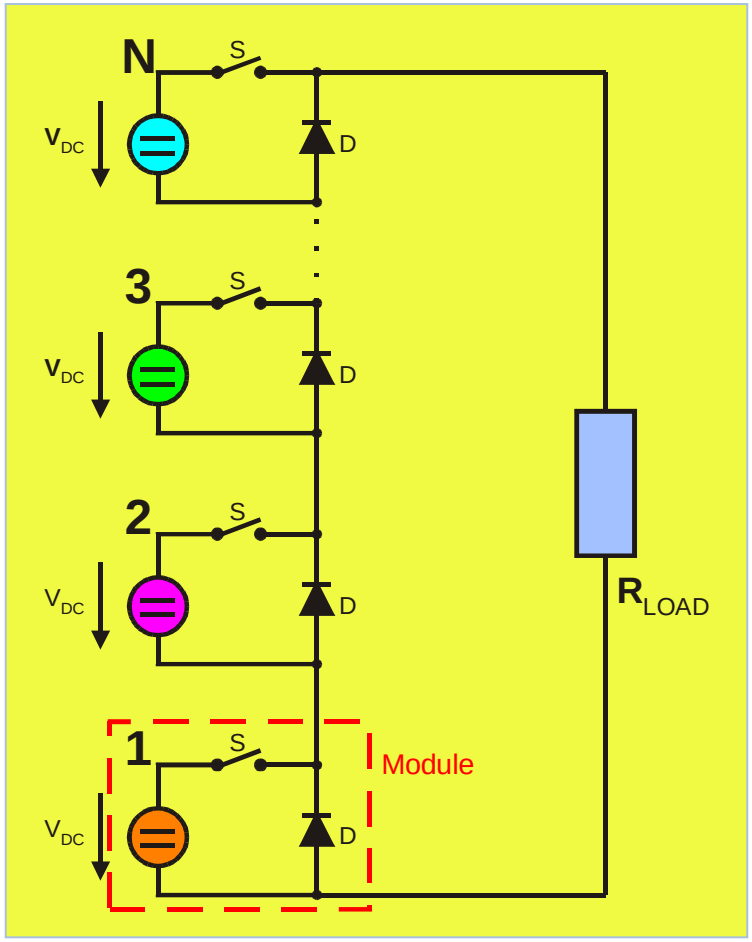
- Requires tubes for operation
  - Expensive devices with limited lifetime
  - High heating power
- Tubes in Class-B operation
  - Low Efficiency (Linear Operation)
- Carrier voltage from DC-source
  - Carrier voltage fixed
  - High stored energy, therefore crowbar system needed

PSM Technology

The Pulse Step Modulation

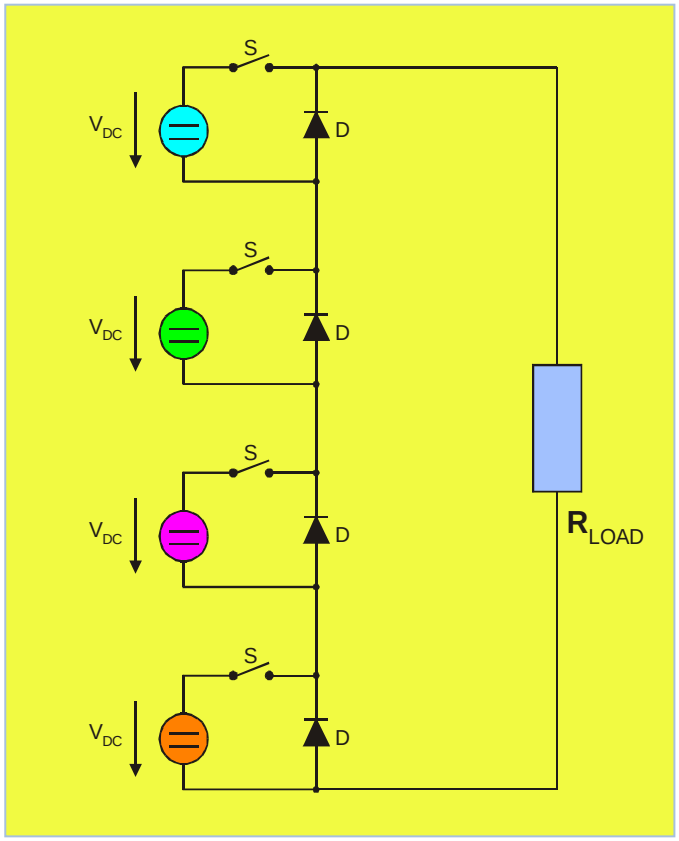
- Introduced by Thomson & Multimedia, Switzerland (formerly BBC / ABB) in 1983
  - Invention keyed by restrictive licensing policy of PDM competition
- Since 1983 continuous improvements of the system
  - IGBT (Insulated Gate Bipolar Transistors) instead of GTO (Gate-turn-off-Thyristor) as switching device
  - Fast Feedforward Regulation
  - Increase in bandwidth from 4.5 kHz to 50 kHz

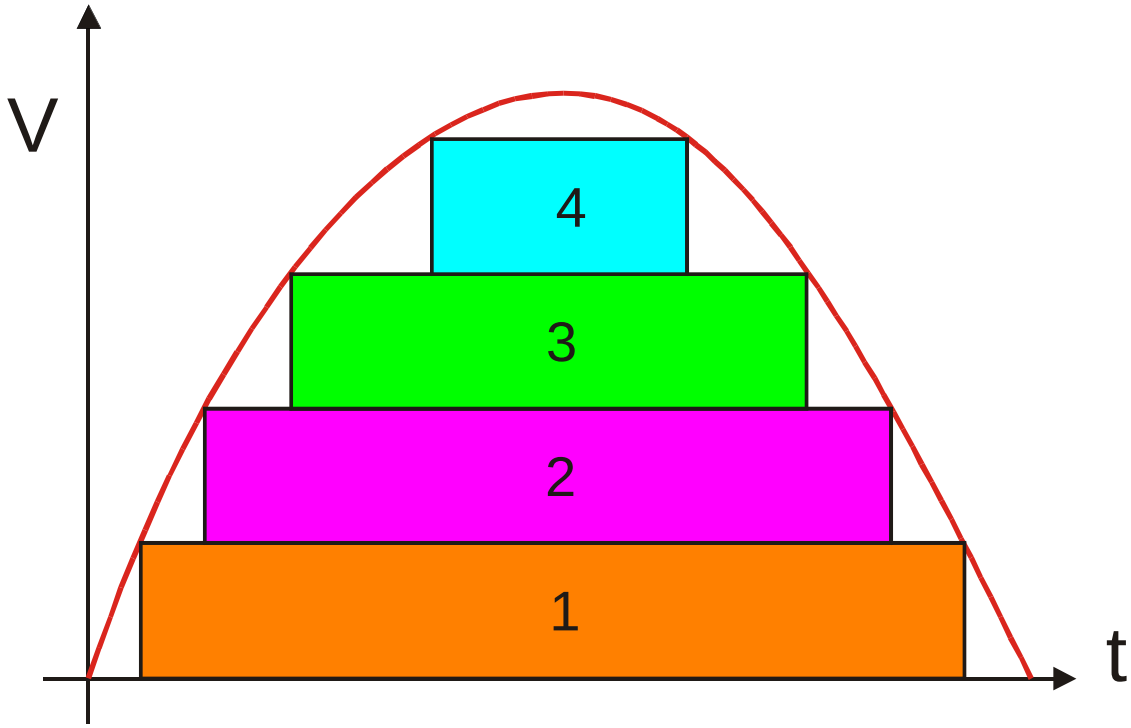
PSM Block Diagram



- The system consists of N series-connected switched mode power supply modules
- Each module consisting of
  - DC voltage source V_{DC}
  - Switching Element S
  - Free-Wheeling Diode D
- The voltage V_{DC} is equal on all modules
- With switch S the voltage V_{DC} can be switched to the output
- If switch S is open, the diode D provides a current path for the output current

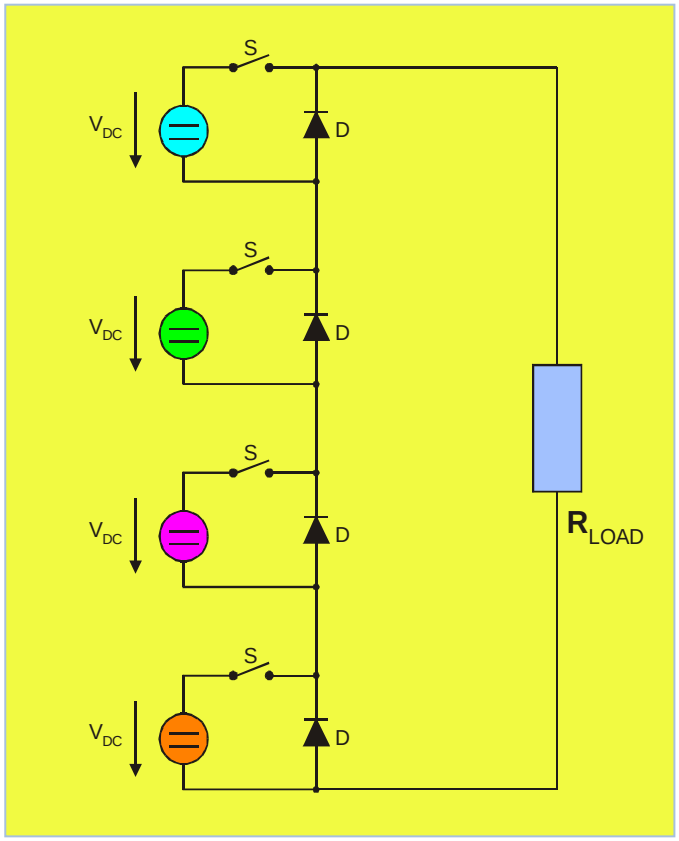
Coarse Step Modulation (CSM)

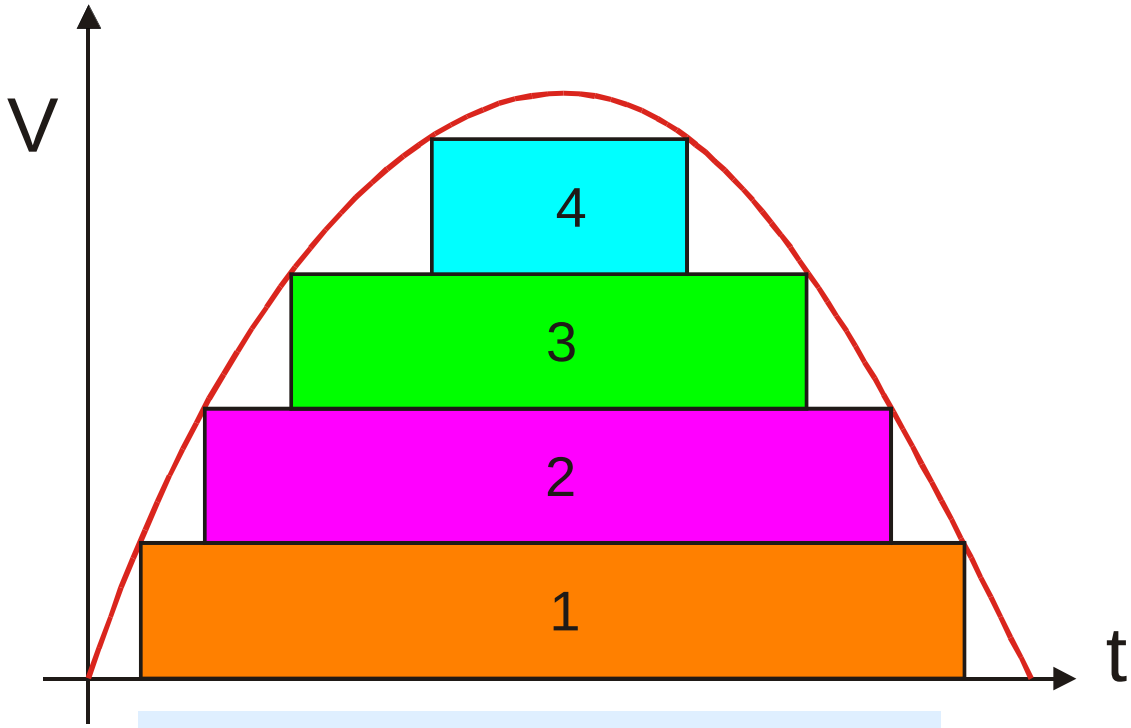




The output voltage can be controlled stepwise to achieve the required level

Coarse Step Modulation (CSM)



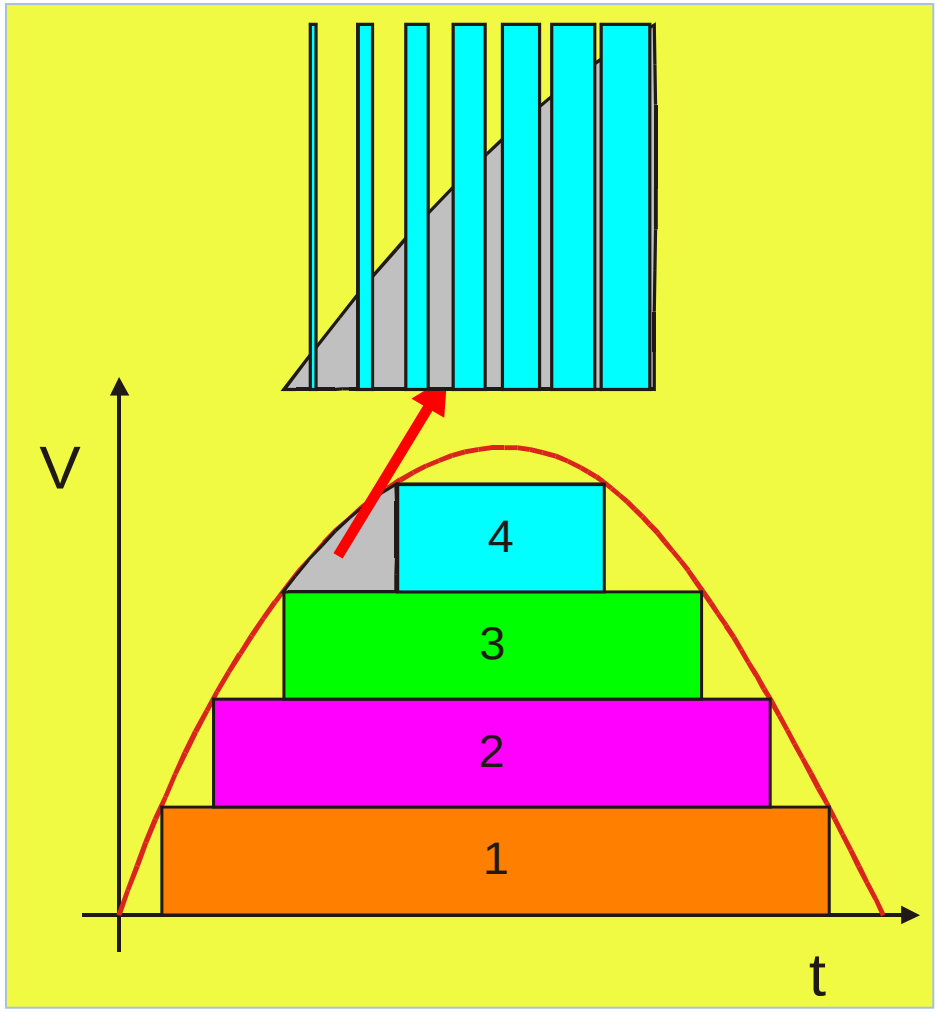


The output voltage can be controlled stepwise to achieve the required level

BUT:

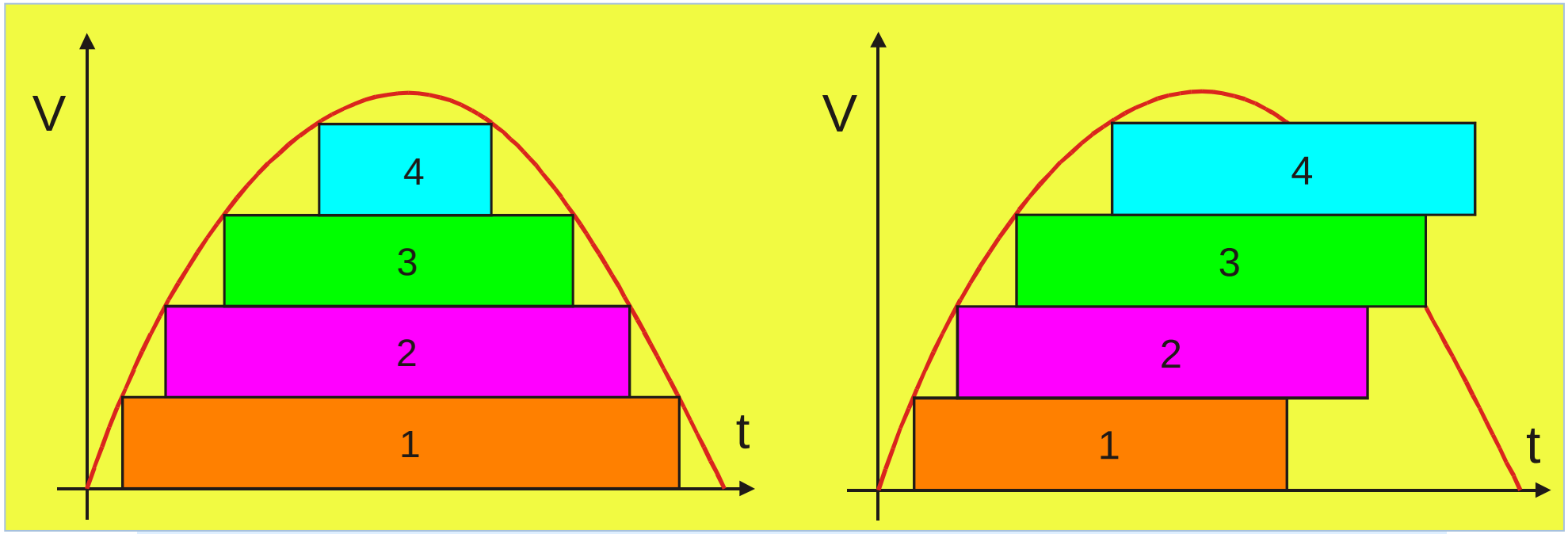
- Ouput level is not accurate
- Modules are unequally loaded

Pulse Width Modulation (PWM)



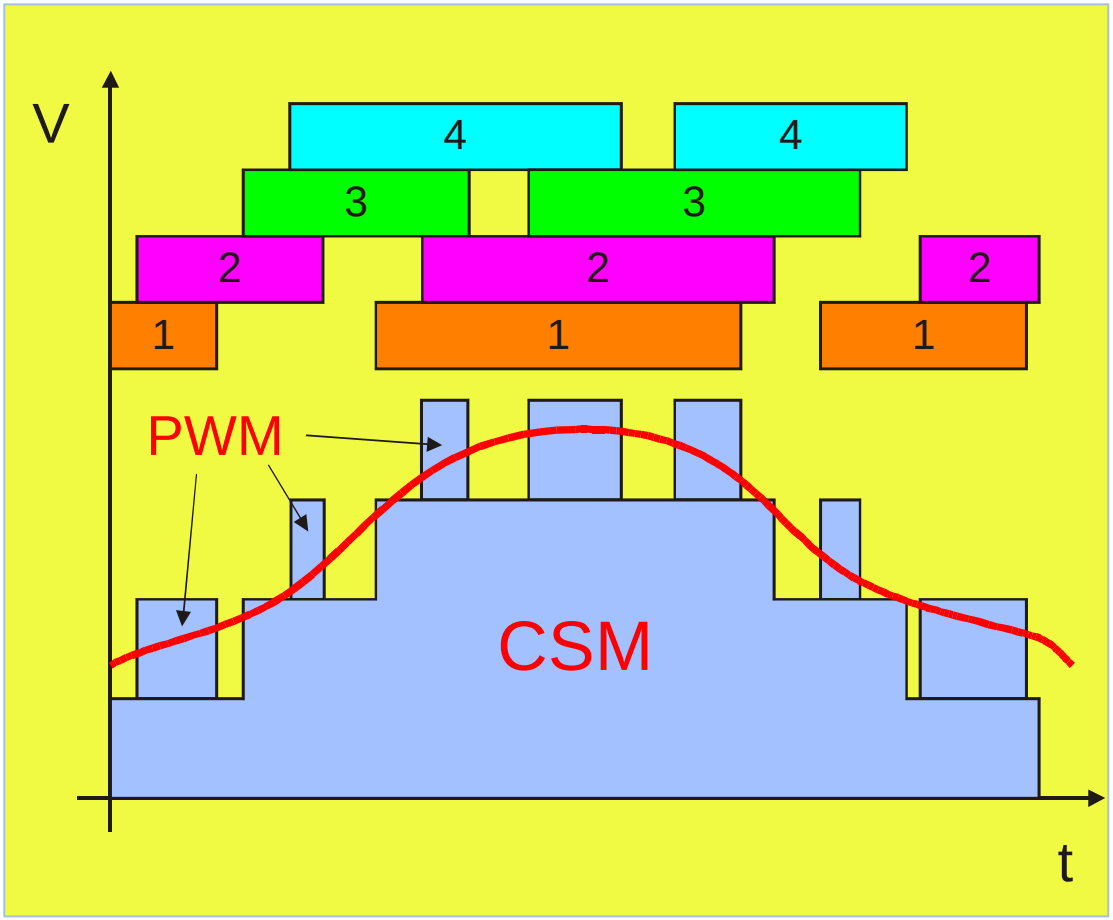
- For accurate voltage control a PWM is superimposed on the switching control
- To eliminate the PWM frequencies, a lowpass filter has to be used in the output circuit
- In this way, PWM allows very accurate voltage regulation

Module Rotation



- The modules are controlled such that:
  - The module switched on the longest time is switched off next (FIFO)
  - The module switched off the longest time is switched on next (FIFO)
- Resulting in equal loading for all modules

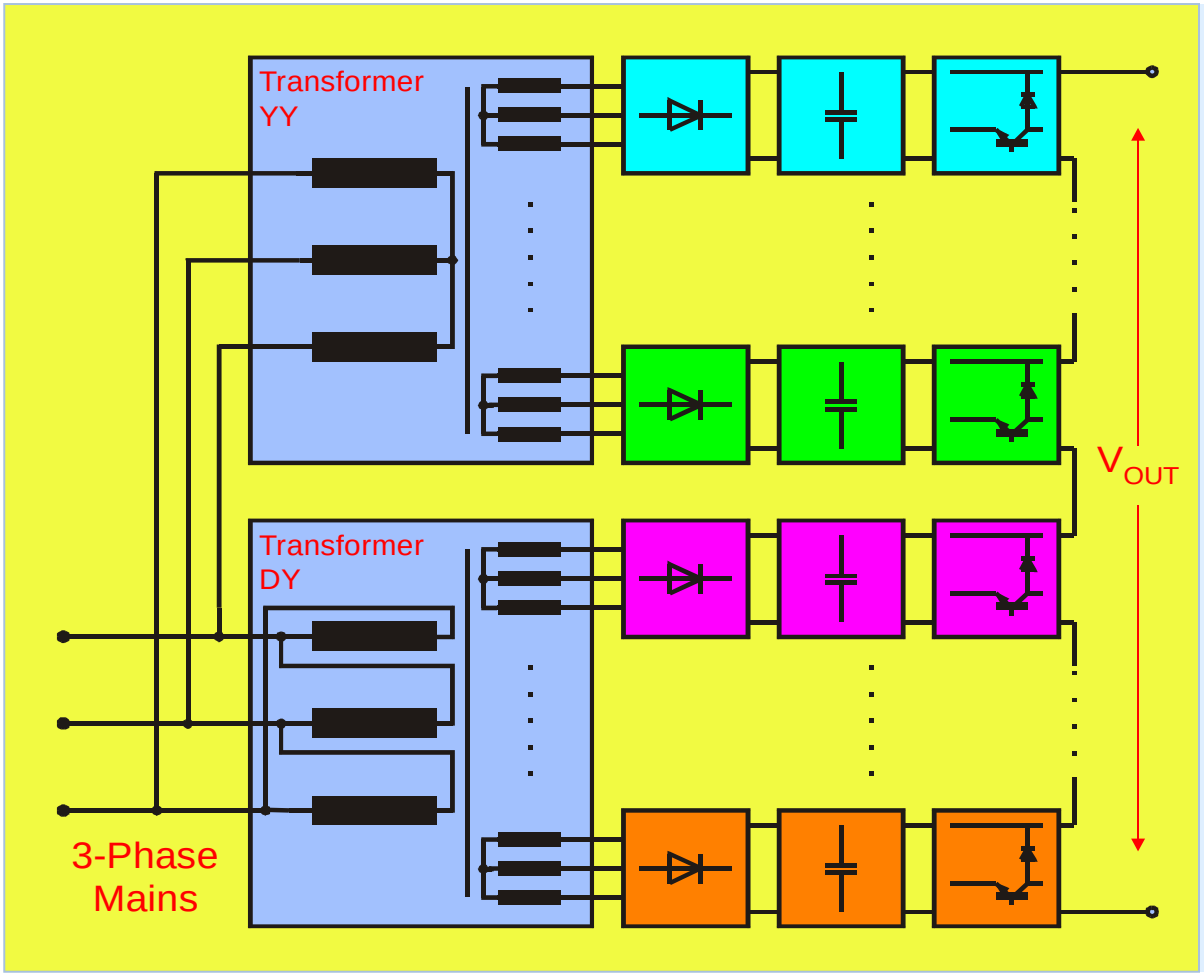
Combination of PWM / CSM and Module Rotation



The final control algorithm achieves:

- Equal loading of all modules
- Lower switching frequency
  allows high PWM frequency
  small switching losses
- Small filter requirements
  Drastic reduction of PWM voltage and stored energy
  High PWM frequency reduces the required filter size

System Block Diagram



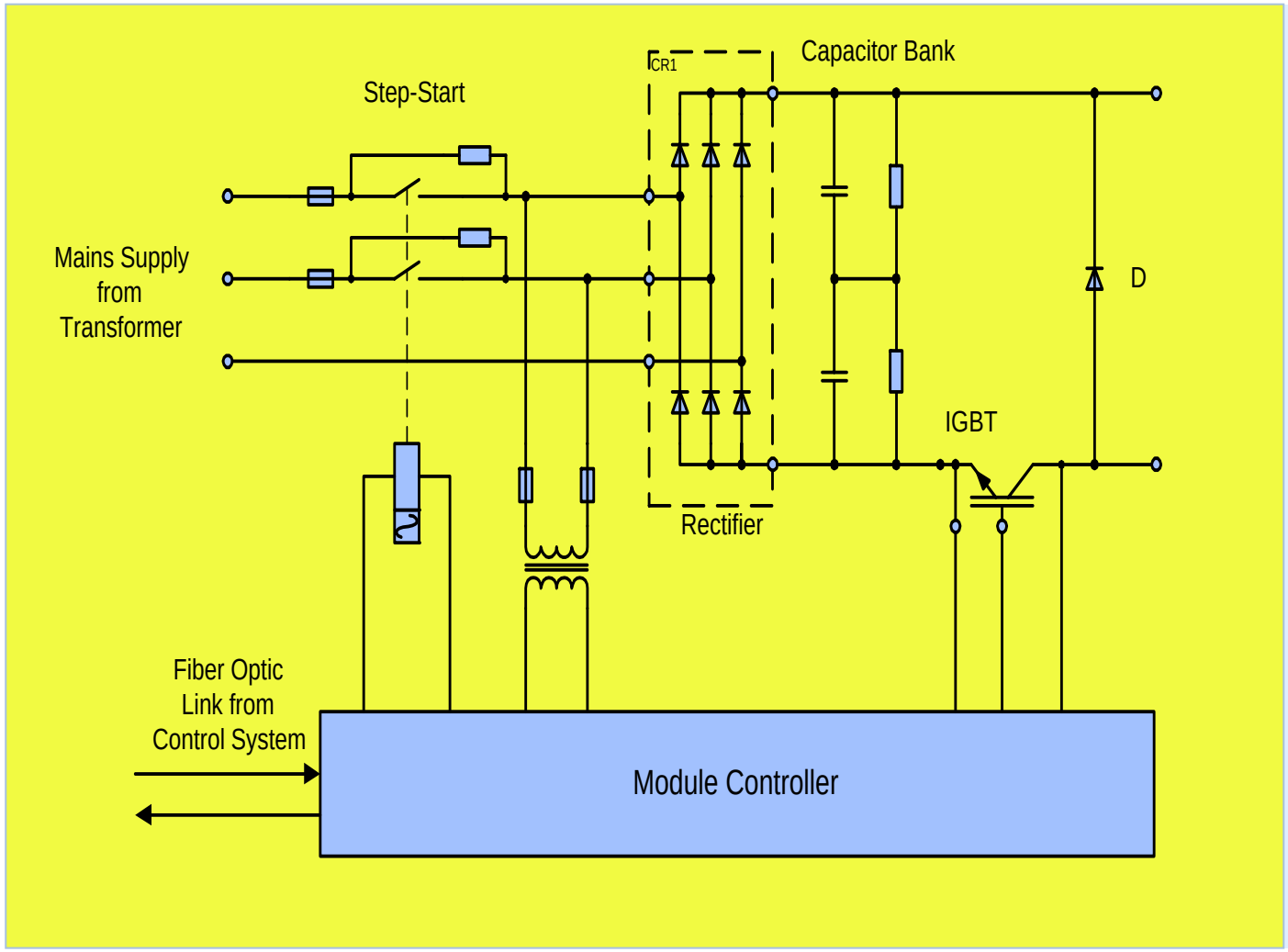
Each Module is supplied from a separate secondary winding of a mains transformer

- Provides Voltage Insulation between the modules
- Transformer is available either with air, cast resin or oil insulation
- Available for mains voltages from 400V to 30 kV

Two different transformers with different phase shifts are used

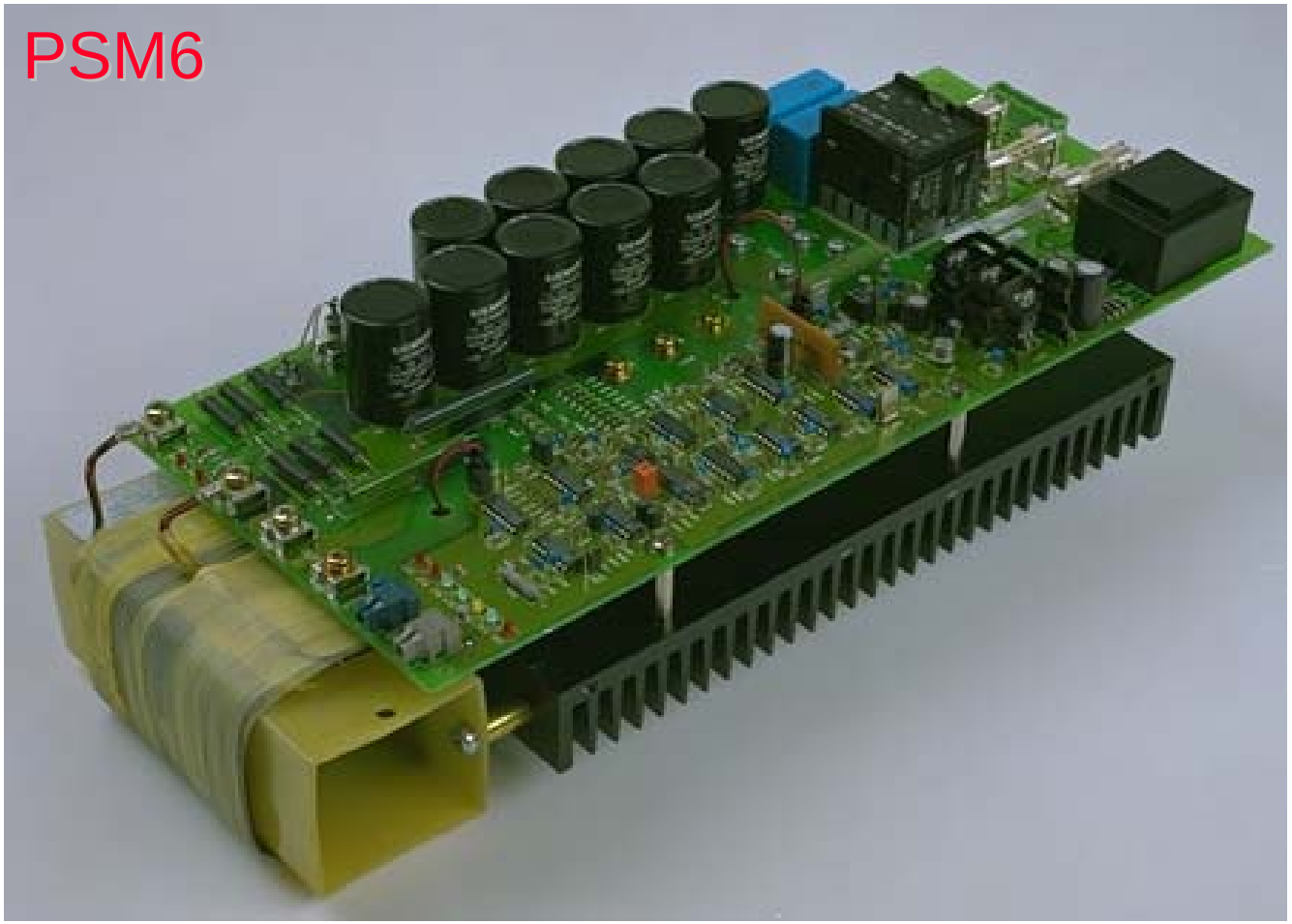
- 12-pulse rectification
- high power factor of > 0.95

Power Module



- Modern IGBT switching devices
- Integrated step-start-system
- Controlled by the PSM control system via fiber optic link
- Integrated safety features
  -Short-Circuit protection
  -IGBT supervision

Module for PSI application



PSM 6 Module

- Air Cooled
- 25 A peak current
- 700 V output level

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PSM for Scientific Applications

HVPS for Scientific Applications 1

- PSM : the ideal solution for various Scientific Applications
  - Large bandwidth in control system, well suited for pulsed systems
    - No limitation for the maximum pulse length
    - Minimum pulse length ~ 10 μ s
  - High efficiency, reduced energy costs for DC loads
    - Typical efficiency better than 97%
- Crowbarless operation, even for very sensitive loads
  - Fast switching-off (< 10 us)
  - Eliminates the need for a crowbar system
  - Typical short circuit energy of less than 5 to 20 J

HVPS for Scientific Applications 2

- Redundancy
  - System remains in operation even with defective modules
  - High reliability and availability
- High power factor of 95% and better due to 12-Pulse rectification
- Fully digital control system, no need for adjustments
- Galvanic separation of control system with fiber optic links
- The first klystron system with PSM was operational since 2000

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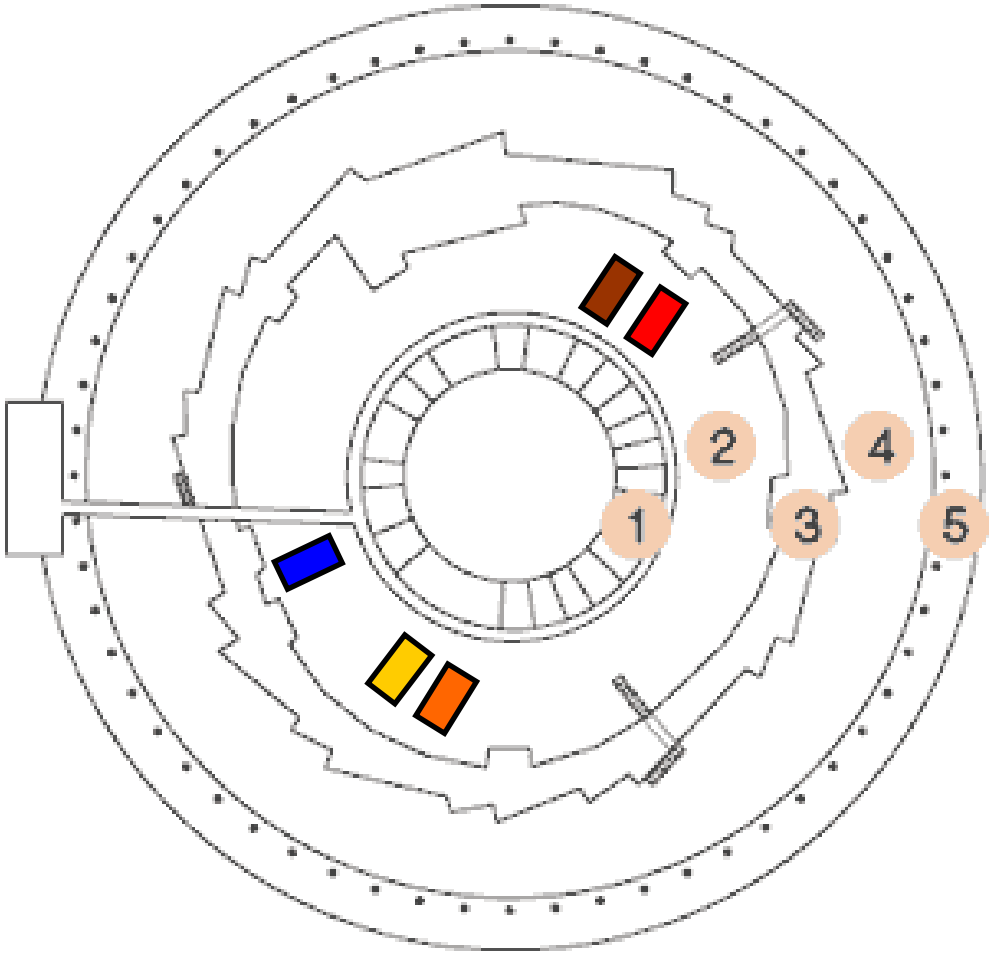
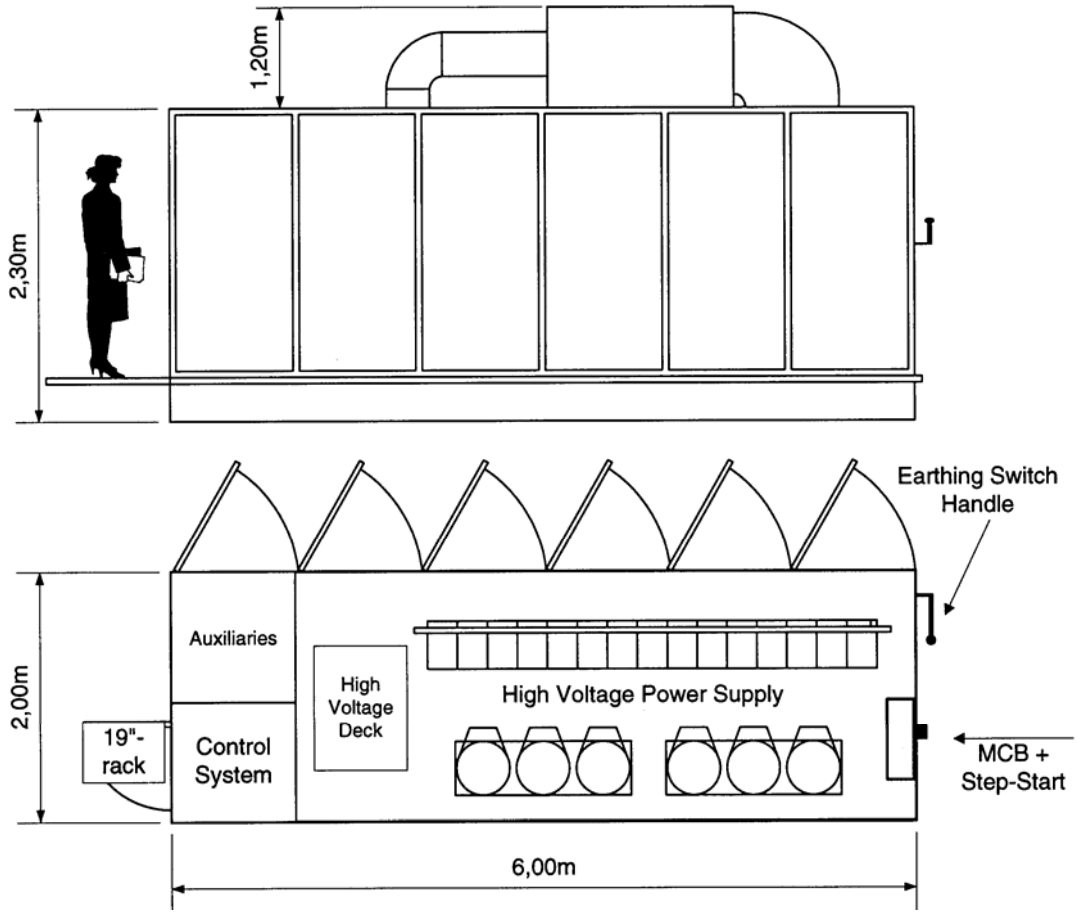
Layout of SLS



Layout of PSI High Voltage Power Supply

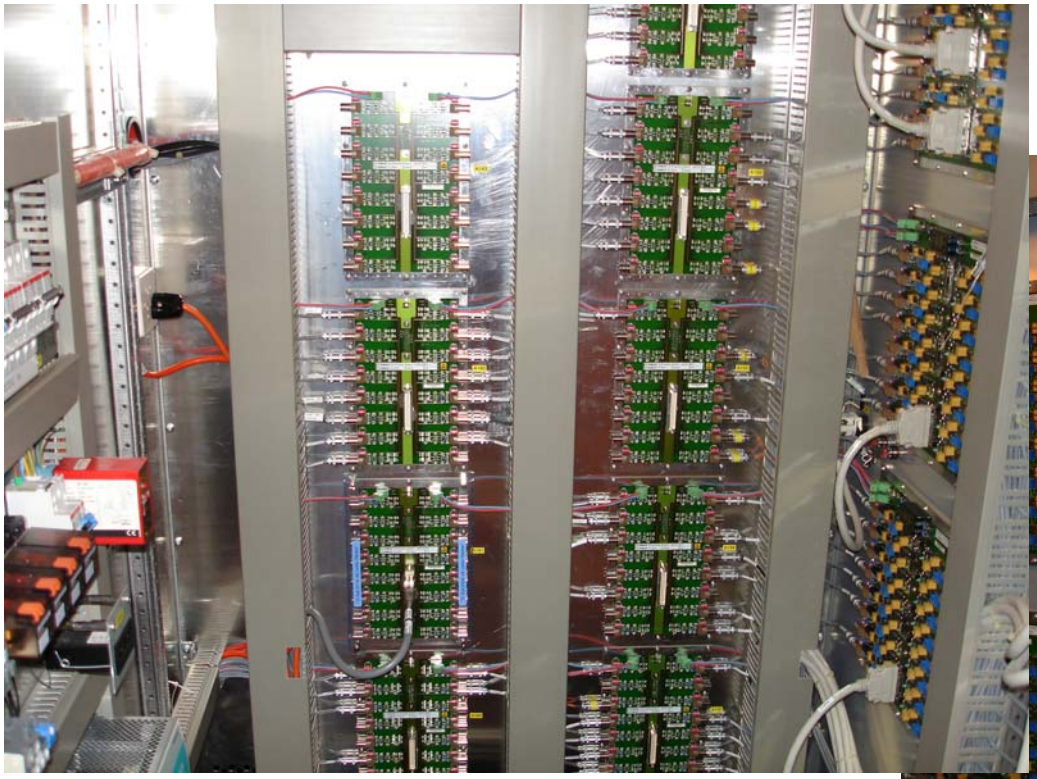


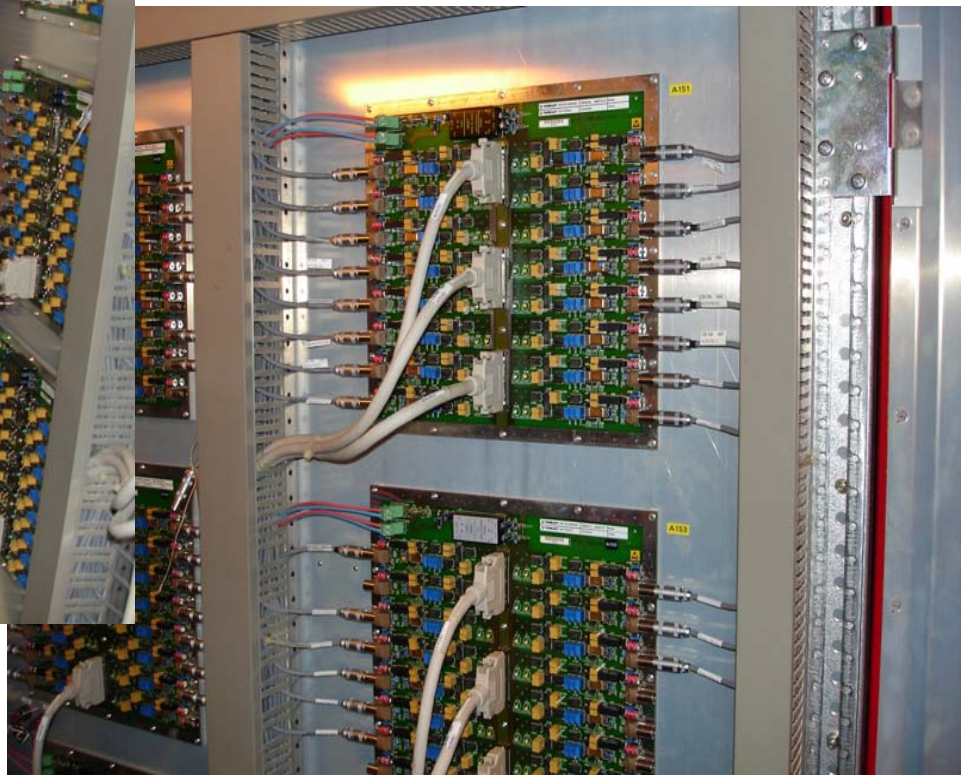
Specification:

Voltage	46kV
Output current	7.5 A
Continuous output power	345kW
Number of modules	68
Number of transformers	2
Efficiency	96%
Power factor	>0.95
Regulation accuracy	<1%
Short circuit energy	<15J

Front view of the HVPS

Digital and Analog I/O





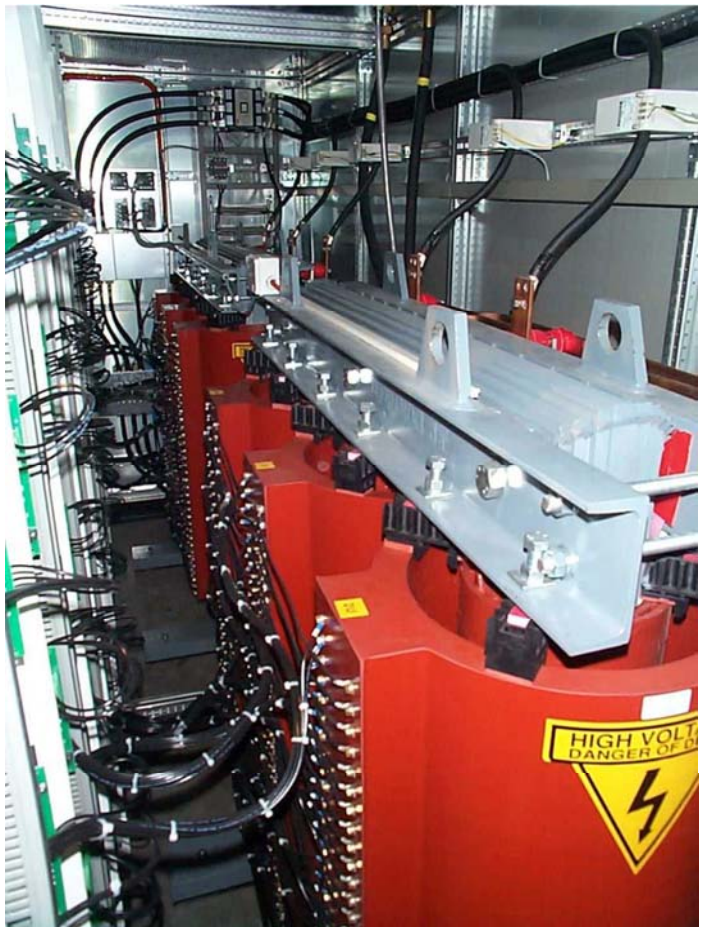
Control Rack

Back and side view of the HVPS

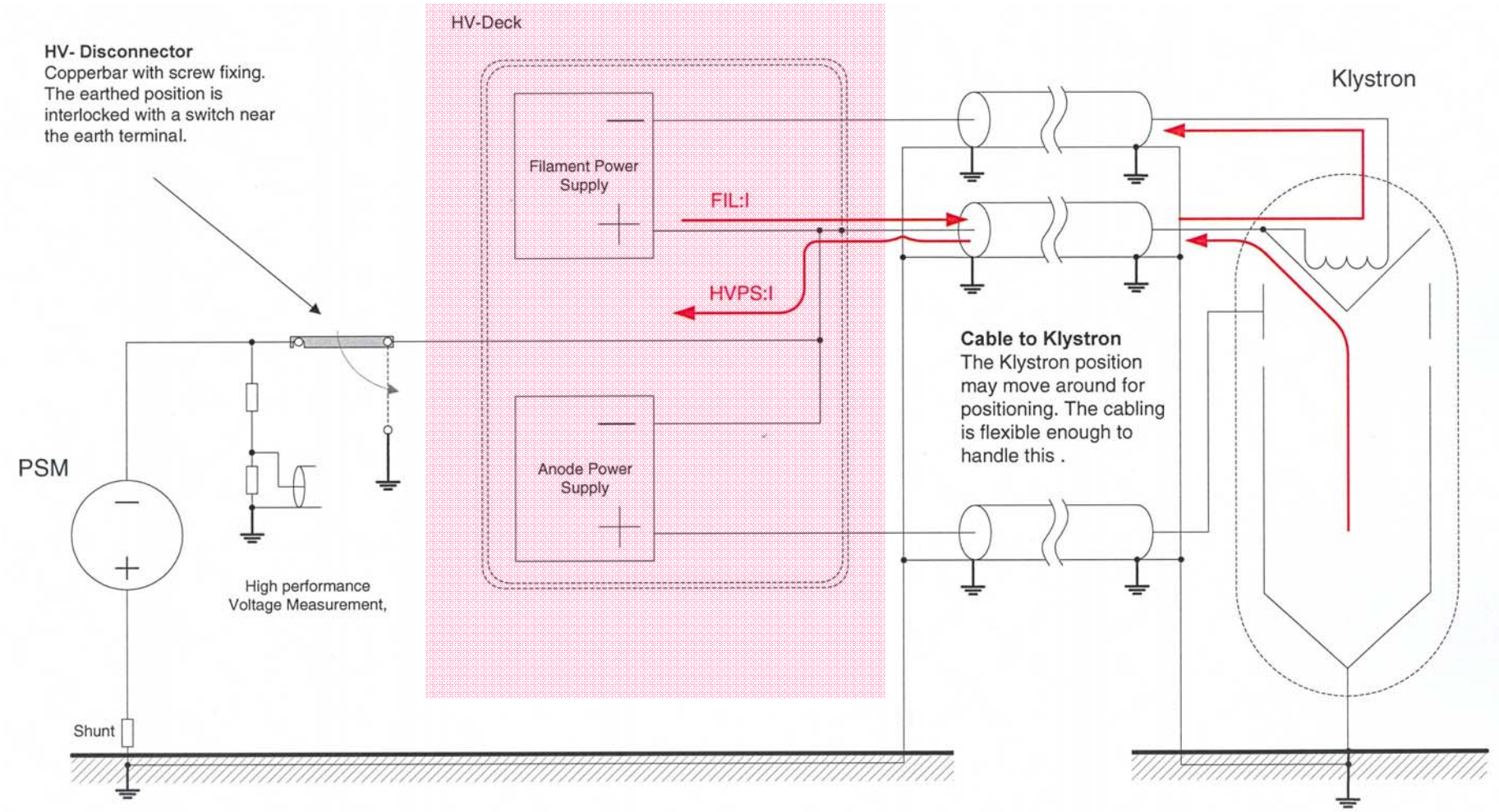
Access to Modules

PSM Module Support

PSM Transformers and HV-Deck



High Voltage Deck



Defective components

Only 2 components were defective from 340 modules after the first year :

- Control Print
- Resistor in Step Start Circuit

Acknowledgement

I would like to thank

Thomson Broadcast & Multimedia AG
Juergen Alex (Juergen.Alex@thomson-bm.ch)
Spinnereistrasse
5300 Turgi / Switzerland
Phone +41 56 299 2455
Fax +41 56 223 5051

For their contribution to this presentation.