ScandiNova

# EXCELLENCE IN PULSED POWER

## SOLID STATE MODULATOTS

HG2013

June 6, 2013

# JUNE 6 – SWEDISH NATIONAL DAY

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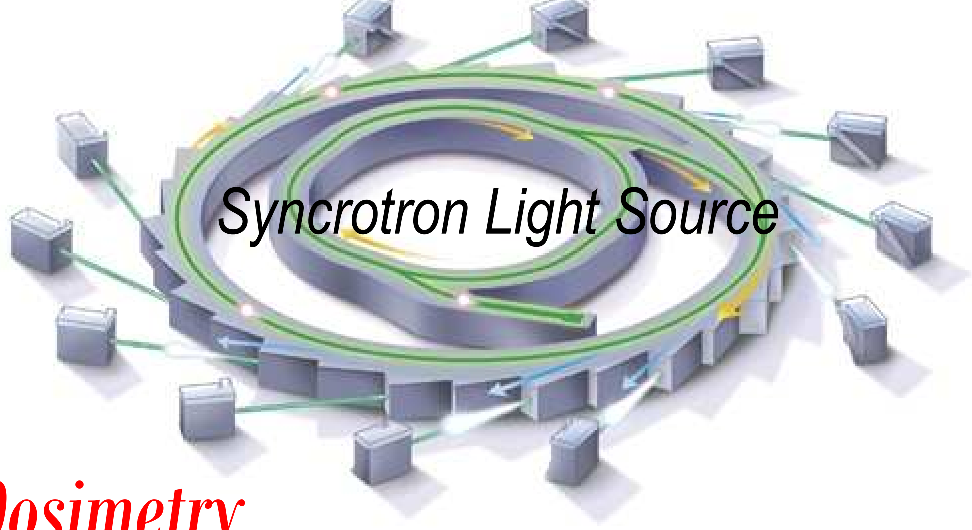
# EXCELLENCE IN PULSED POWER

## INTRODUCTION & BACKGROUND

# BACKGROUND FROM ACCELERATOR SYSTEMS

## Medical


## Science & Research




## Dosimetry

## Industrial



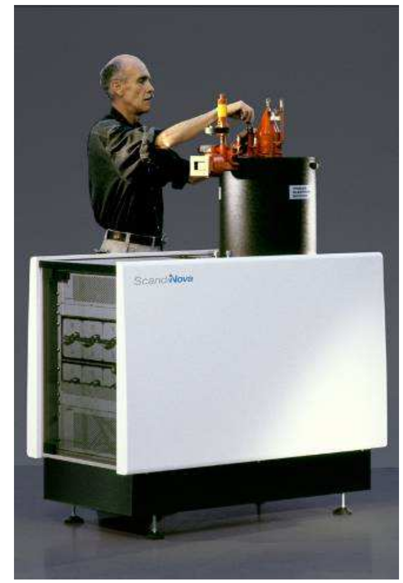
# SOLID STATE TECHNOLOGY EARLY TIME LINE

1996: Proof of Concept

1997: K1 for NCC

1999: K1 for BetaLine

2005: K1 for ECIL



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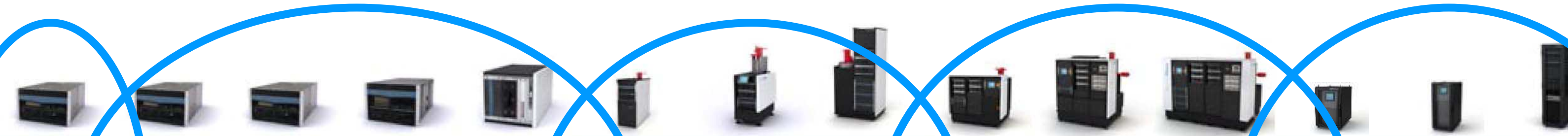
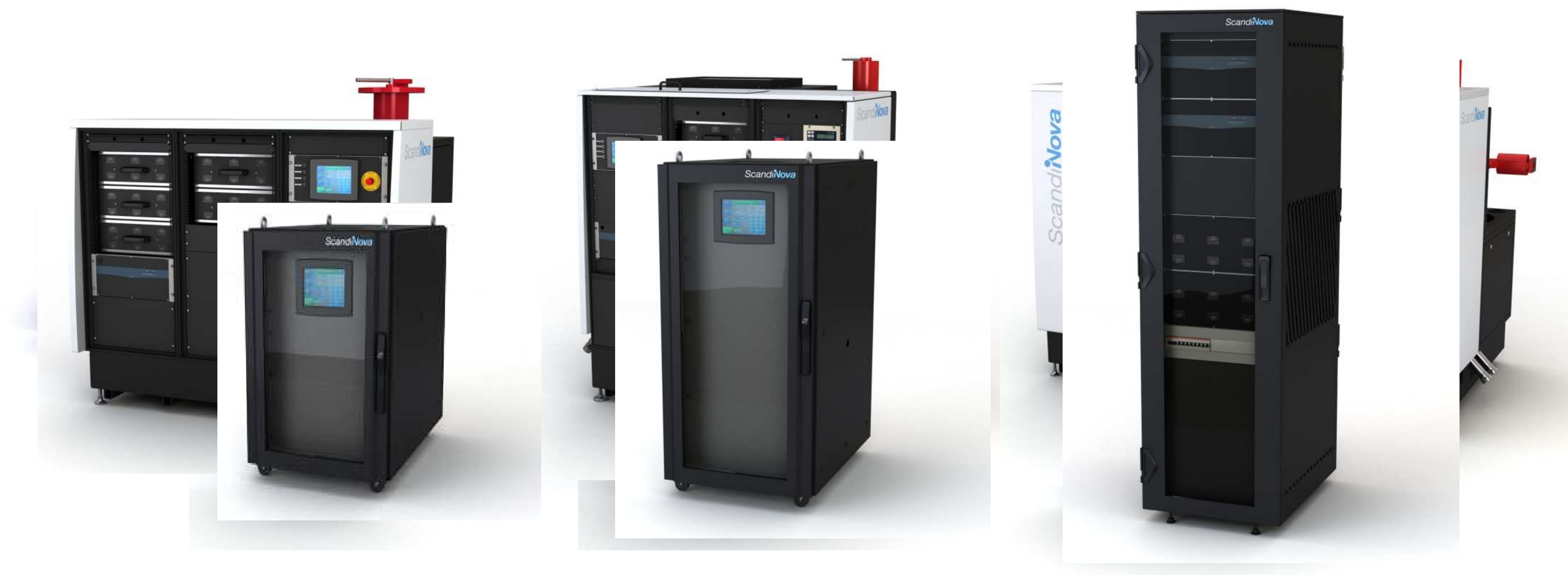
# Product Portfolio

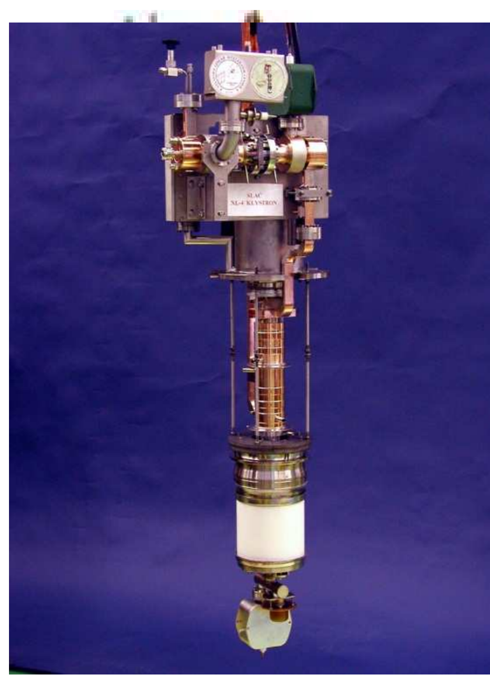


| Parameters | Unit | E1 | M0,5 | M1 | M2 | M3 | K -C | K1 | K1-P | K2-1 | K2-2 | K2-3 | PG-1 | PG-2 | PG-3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RF Peak Power | MW] | | 0,4 - 2 | 1 - 3 | 2,5 - 3,5 | 2,5 - 5 | 3 - 6 | 5 - 7,5 | 6 - 1( | 5 - 30 | 25 - 40 | 30 - 60 | NA | NA | NA |
| Pulse Voltage | [kV] | 10 - 45 | 20 - 40 | 30 - 50 | 40 - 65 | 40 - 75 | 100 - 35 | 130 - 169 | 135 - 190 | 200 - 265 | 250 - 330 | 280 - 450 | 10 - 30 | 20 - 50 | 20 - 50 |
| Pulse Current | [A] | 0,1 - 1,5 | 0 - 100 | 30 -120 | 30 - 120 | 30 - 25 | 60 - 18 | 110 - 124 | 60 - 138 | 180 - 265 | 200 - 350 | 230 - 450 | 100 - 300 | 100 - 600 | 300 - 1000 |
| Modulator Peak Power | [MW] | 0,1 | 4 | 6 | 7,8 | 14 | 14 | 20 | 25 | 74 | 92 | 160 | 6,5 | 14 | 28 |
| Modulator Average Power | [kW] | 0,1 - 0,5 | 0,1 - 1 | 0,1 - 6 | 0,1 - 8 | 0,1 - 16 | 0,5 - 16 | 0,5 - 30 | 0,5 - 46 | 0,5 - 54 | 0,5 - 72 | 0,5 - 100 | 0,1 - 1 | 0,1 - 8 | 5 - 30 |
| Mains: 1-phase / 3-phase | | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 1 | 3 | 3 |
| Cooling | | Air | Air | Water | Water | Water | Water | Water | Water | Water | Water | Water | Air | Water | Water |



# Common Loads in use

| Parameters | [illegible]nit | E1 | M0,5 | M1 | M2 | M3 | K[illegible]-C | K1 | K1-P | K2-1 | K2-2 | K2-3 | PG-[illegible] | PG-2 | PG-3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RF Peak Power | [illegible]MW] | | [illegible],4 - 2 | 1 - 3 | 2,5 - 3,5 | 2,5 - 5 | 3 - [illegible] | 5 - 7,5 | 6 - 1[illegible] | [illegible]5 - 30 | 25 - 40 | 30 - 60 | NA | NA | NA |
| Pulse Voltage | [kV] | 10 - 45 | [illegible]0 - 40 | 30 - 50 | 40 - 65 | 40 - 7[illegible] | 100 - [illegible]35 | 130 - 169 | 135 - 1[illegible]0 | 20[illegible] - 265 | 250 - 330 | 280 - 450 | 10 - 30 | 20 - 50 | 20 - 50 |
| Pulse Current | [A] | 0,1 - 1,5 | [illegible]0 - 100 | 30 -120 | 30 - 120 | 30 - 25[illegible] | 60 - [illegible]18 | 110 - 124 | 60 - 13[illegible] | 1[illegible]0 - 265 | 200 - 350 | 230 - 450 | 100 - 30[illegible] | 100 - 600 | 300 - 1000 |
| Modulator Peak Power | [[illegible]W] | 0,1 | 4 | 6 | 7,8 | 14 | [illegible]4 | 20 | 25 | 74 | 92 | 160 | 6,5 | 14 | 28 |
| Modulator Average Power | [k[illegible]] | 0,1 - 0,5 | 0,1 - 1 | 0,1 - 6 | 0,1 - 8 | 0,1 - 16 | [illegible],5 - 16 | 0,5 - 30 | 0,5 - 46 | 0,5 - 54 | 0,5 - 72 | 0,5 - 100 | 0,[illegible] - 1 | 0,1 - 8 | 5 - 30 |
| Mains: 1-phase / 3-phase | | 1 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 1 | 3 | 3 |
| Cooling | | Air | A[illegible] | Water | Water | Wate[illegible] | Water | Water | Water | [illegible]ater | Water | Water | Air | Water | Water |



# ACHIEVED LEVELS

| Parameter | Range |
|---|---|
| RF Frequency | 1.3 – 140 GHz |
| RF Power | 0.5 - 80 MW |
| Peak Power Mod. | 0.1 - 200 MW |
| Average Power Mod. | 0.05 - 106 kW |
| Pulse Voltage | 10 - 507 kV |
| Pulse Current | 0.2 - 4000 A |
| Pulse length | 0.5 - 25us (3000us) |
| Pulse Repetition Rate | 0.1 - 1000 Hz |
| Rate of Rise | 60 - 392 kV/us |
| Rate of Fall | 60 - 407 kV/us |
| Pulse flatness | ± 0.05% – 3% |
| Pulse to Pulse stability | ± 0.002% – 0.05% |

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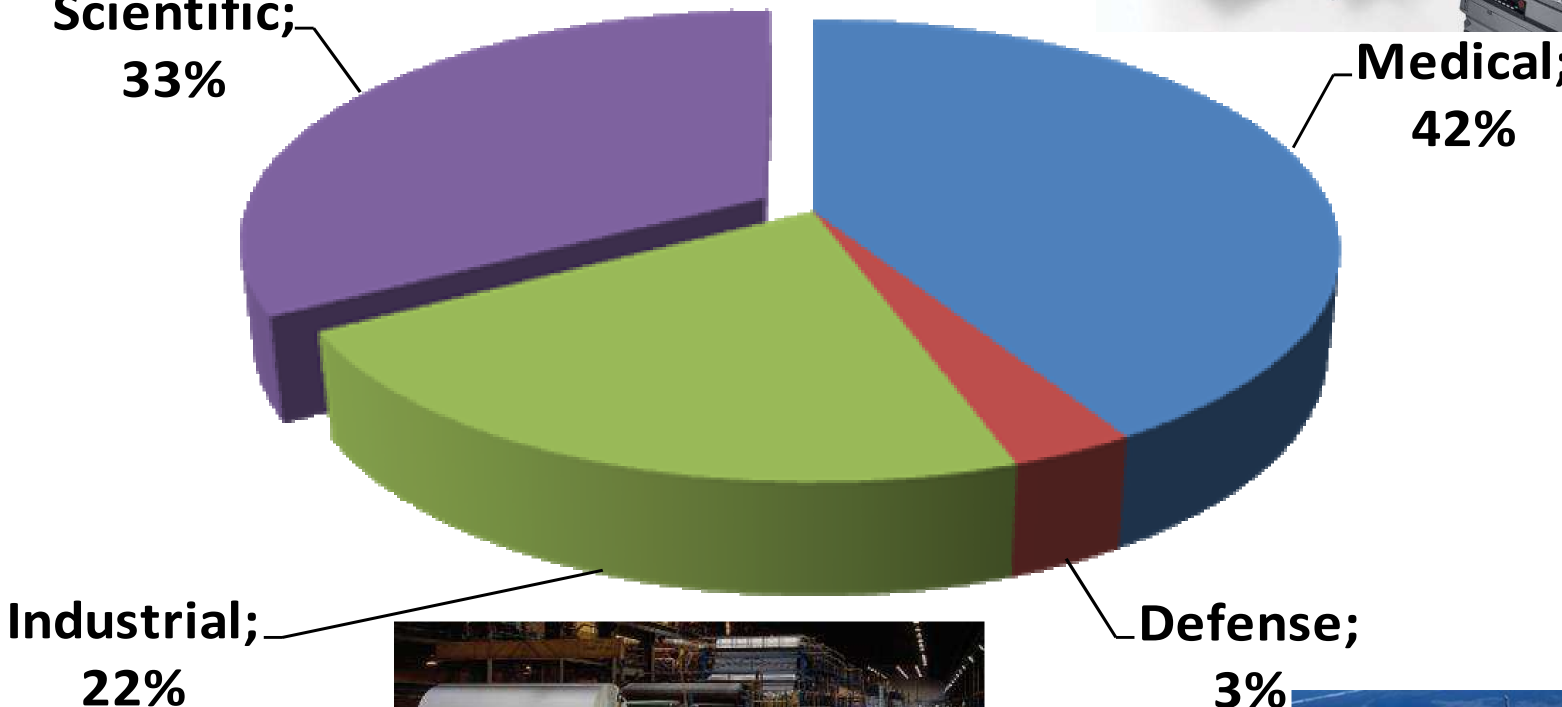
# MAIN APPLICATIONS

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# SOME SCIENTIFIC CUSTOMERS

CERN

PAUL SCHERRER INSTITUT PSI

PAL 포항가속기연구소 Pohang Accelerator Laboratory

MAX-lab

HELMHOLTZ ZENTRUM BERLIN für Materialien und Energie

Australian Synchrotron synchrotron.vic.gov.au

Canadian Light Source Centre canadien de rayonnement synchrotron

DESY

NIU

INFN Istituto Nazionale di Fisica Nucleare

TU Delft Technische Universiteit Delft

CSIR INDIA

CRIC

Fritz-Haber-Institut

UPC

KAERI Korea Atomic Energy Research Institute

cea SACLAY

Argonne NATIONAL LABORATORY

LAWRENCE LIVERMORE NATIONAL LABORATORY

BROOKHAVEN NATIONAL LABORATORY

Los Alamos NATIONAL LABORATORY

JAGIELLONIAN UNIVERSITY IN KRAKOW

Technische Universität Berlin

TU berlin

NRC·CNRC

Science & Technology Facilities Council

NSRRC National Synchrotron Radiation Research Center

UNIVERSITA' DEGLI STUDI DI SALERNO

MIT Massachusetts Institute of Technology

# SYSTEMS DELIVERIES 2012-2013

| CUSTOMER /LOCATION: | Type / RF power / Band | | |
|---|---|---|---|
| CERN | K2 | 50MW | X |
| PSI, Switzerland: | K2 | 50MW | X |
| PSI, Switzerland: | K2 | 50MW | C |
| PAL, Korea | K2 | 80 MW | S |
| MAX-LAB, Sweden | 17x K2 | 37MW | S |
| MAX-LAB, Sweden | K1 | 8 MW | S |
| Jagiellonian University, Poland | 3x K2 | 37MW | S |
| Jagiellonian University, Poland | K1 | 8 MW | S |
| Daresbury, UK | K2 | 10MW | S |
| KAERI, KOREA | K1-P | 10MW | S |
| MIT, USA: | K1 | 3MW 140GHz | |
| MIT / DESY, USA | 2xK1 | 6 MW | X |
| NRC, Canada | K2 | 25MW | S |

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# SOME INDUSTRIAL / MEDICAL CUSTOMERS

INTRAOP
STOPPING CANCER IN ITS TRACKS

HITEC Poland

AS&E

NUCTECH

VARIAN medical systems | SECURITY & INSPECTION PRODUCTS

Advanced Energy Systems, Inc.

Kraft

lyncean TECHNOLOGIES, INC.

GETINGE

DANFYSIK

METAS
Federal Office of Metrology

ADAM

saligus

ETM ELECTROMATIC INCORPORATED

Best Theratronics

research instruments

radiabeam TECHNOLOGIES

Sterigenics

L&W Research Inc.
Precision X-Rays
Since 1987

# SYSTEMS DELIVERIES 2012-2013

| CUSTOMER /LOCATION: | Type / RF power / Band | | |
|---|---|---|---|
| IntraOp, USA | 32x M1 | 1,1MW | X |
| Medical, Europe | 3x M1 | 3MW | S |
| Medical, Asia | 7x(E1+K1) | 3MW | S |
| Medical, Asia | E1+K1 | 4MW | C |
| Medical, USA | 21x M1 | 3MW | S |
| Medical, USA | K1 | 5MW | X |
| Soltan, Poland | 3x M1 | 2,6 MW | S |
| Nuctech, Poland (China) | E1+M1 | 2.6MW | S |
| Radiabeam, USA | 2xM1 | 3MW | S |
| Cargo Scanning, USA | 2xM1 | 1,1MW | X |
| Toriy, Russia | K2 | 4,5 MW | S |
| EVD, Russia | 2x M3 | 4 MW | S |
| RADAR, Europe | M1 | 0,5MW | L |
| RADAR, Europe | M1 | 0,5MW | S |
| CRIC, Spain | PG | 30kV/500A | |
| Radiabeam, USA | E1 | 12kV | |

# EXCELLENCE IN PULSED POWER

## SCANDINOVA TECHNOLOGY

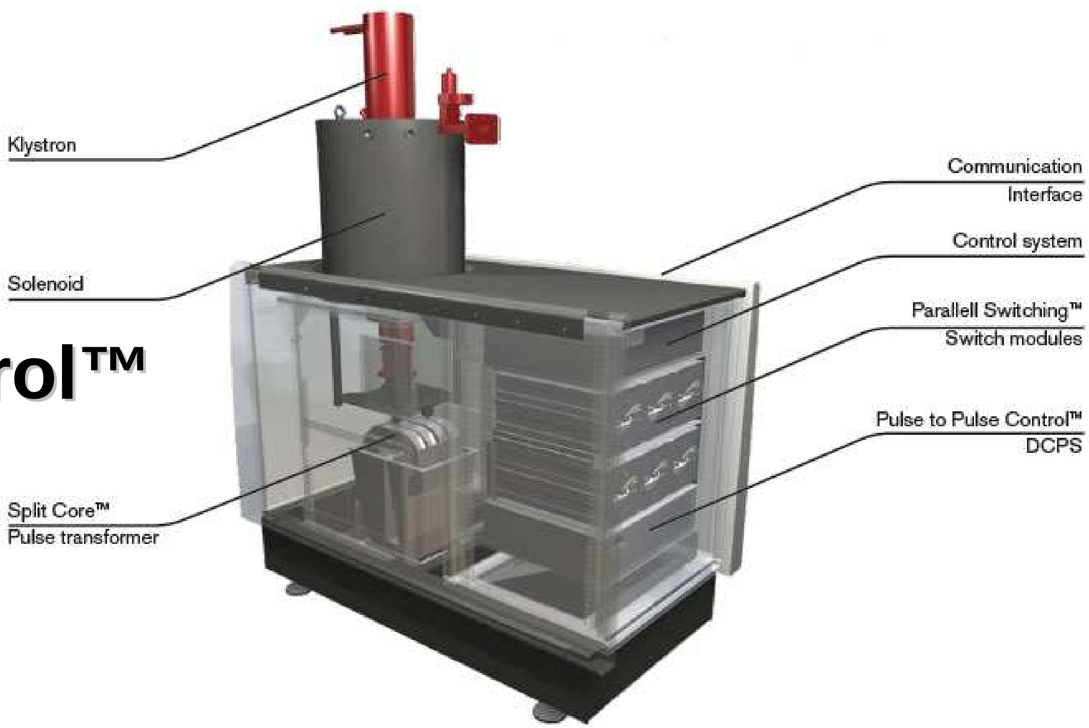
# OUR INVENTION

## Three principal concepts

**Split Core™**

**Parallel Switching™**

**Pulse to Pulse Control™**




**The inventors** of the LCW modulator

Mikael Lindholm, SE

Walter Crewson, USA

David K Woodburn, UK

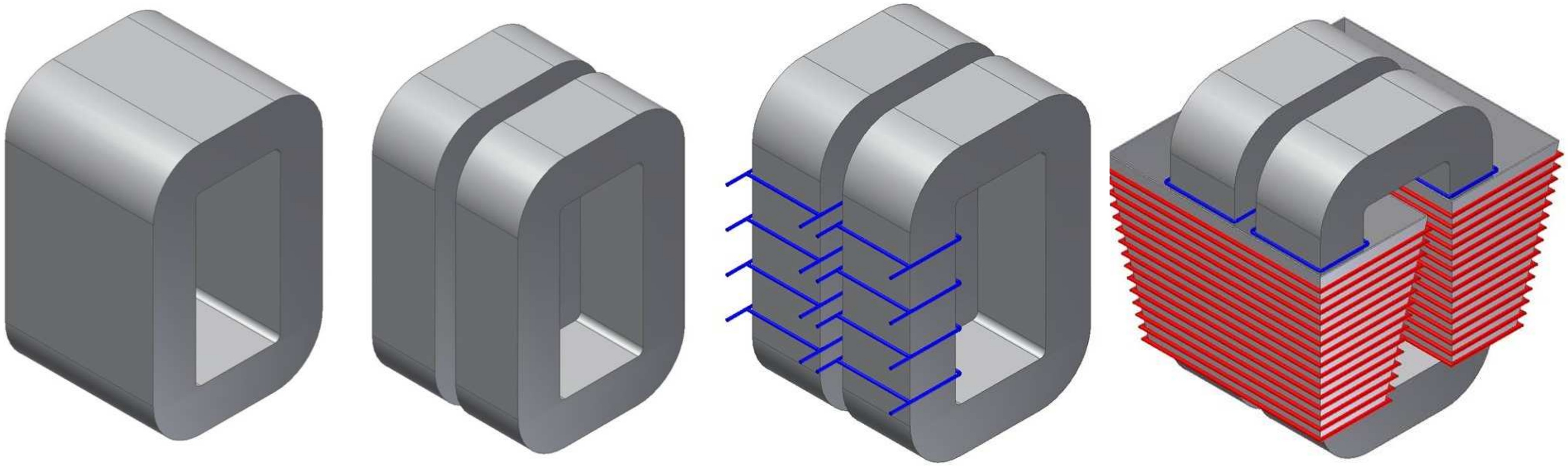
# TECHNOLOGY

- **Split Core™**

**Key component for excellent performance**

## Advantages

- **Low primary voltage level**
- **Enable parallel switching**



Split Core Modulator sc.paper

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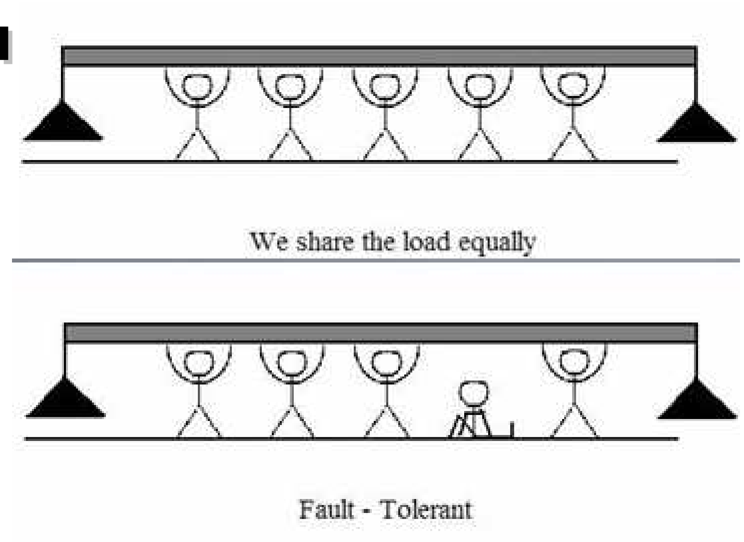
# TECHNOLOGY

## • Parallel Switching™



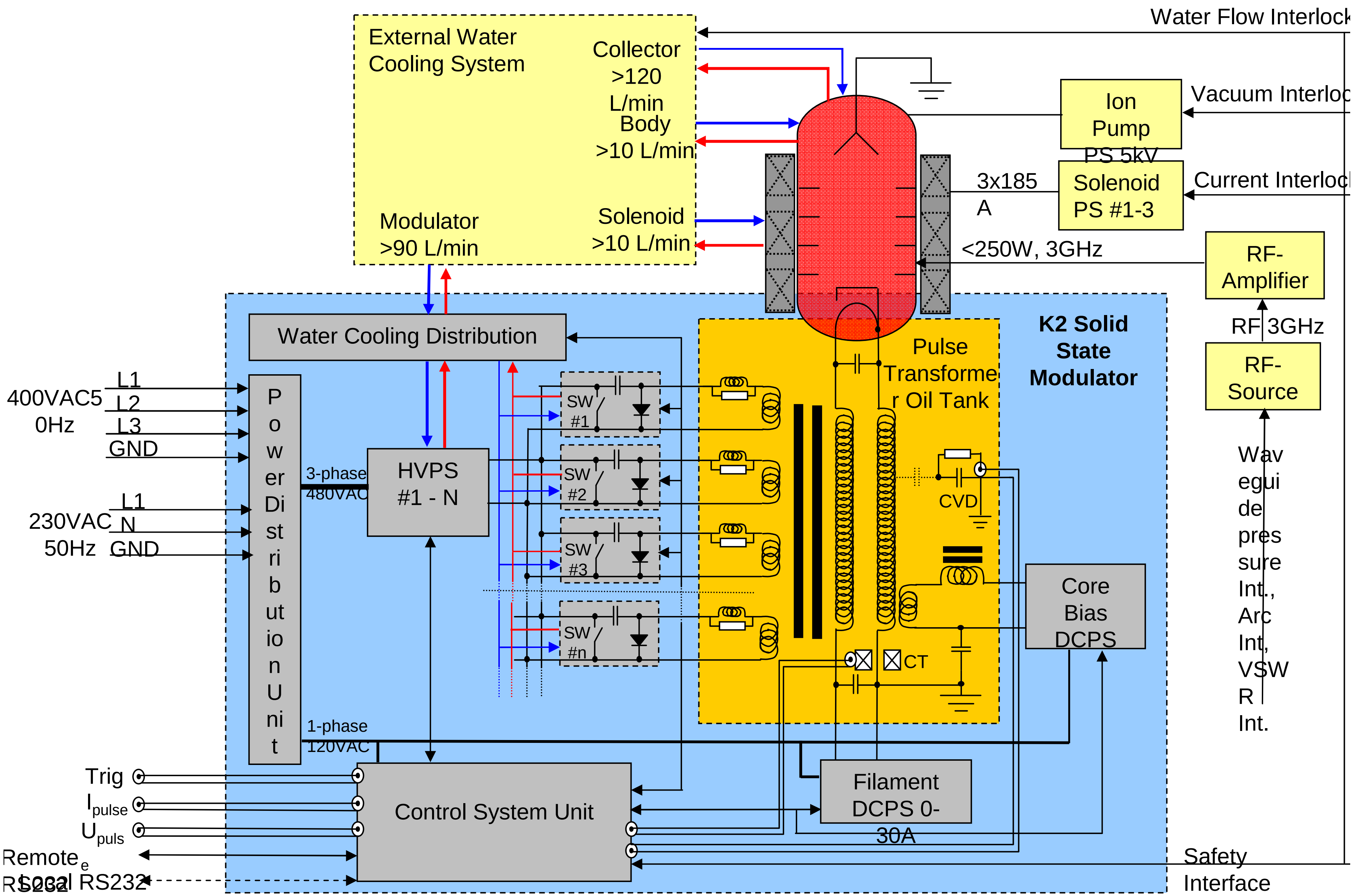

Normal operation – sharing the load

Single switch fault – not critical

## Advantages

- **Improved reliability**
- **Enables better pulse control**

# MODULATOR AND RF SYSTEM, OVERVIEW



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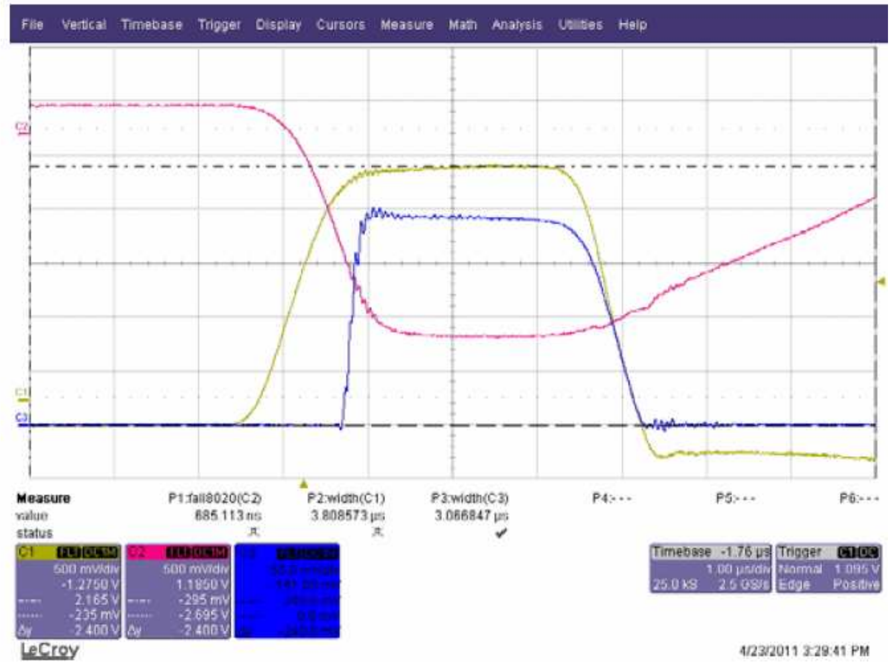
# M0.5 at RF 1.1MW using CTL PMX1100

INTRAOP
STOPPING CANCER IN ITS TRACKS

# M3 at RF 5 MW using e2V MG5028



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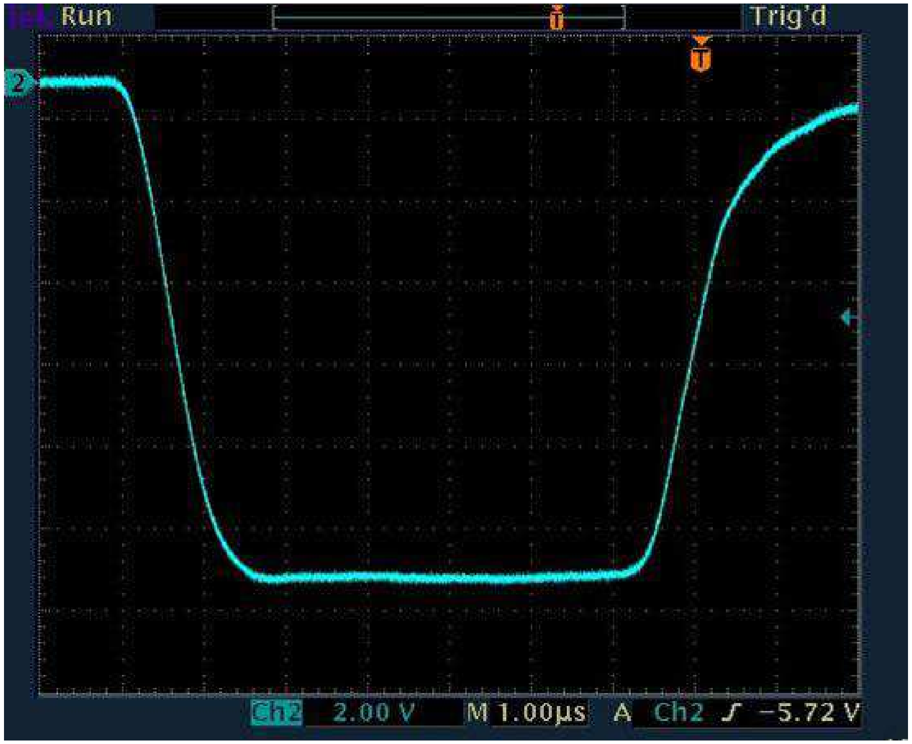
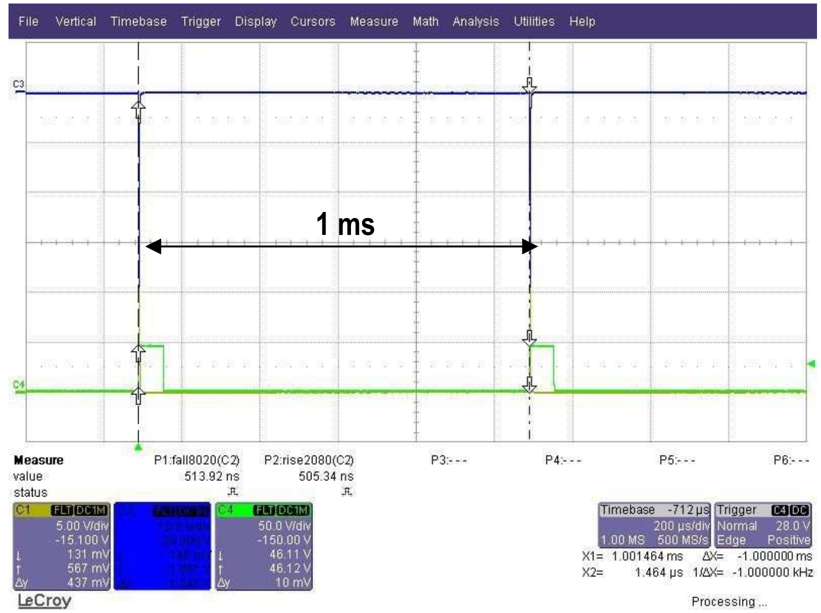
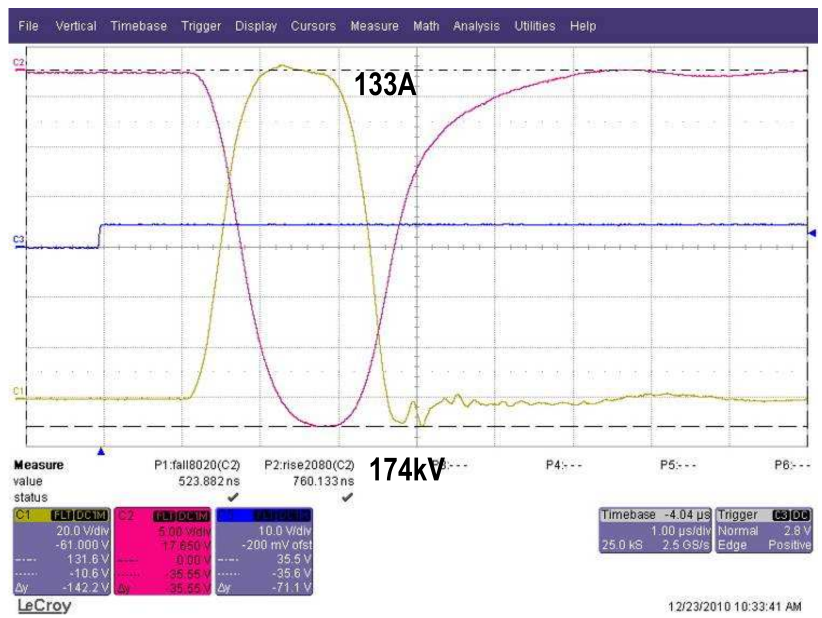
# K1 pulse at RF 6MW using CPI VKS8262S

VARIAN medical systems | SECURITY & INSPECTION PRODUCTS

# K1-P pulse at RF 10MW / 1000Hz using Thales TH2157-A

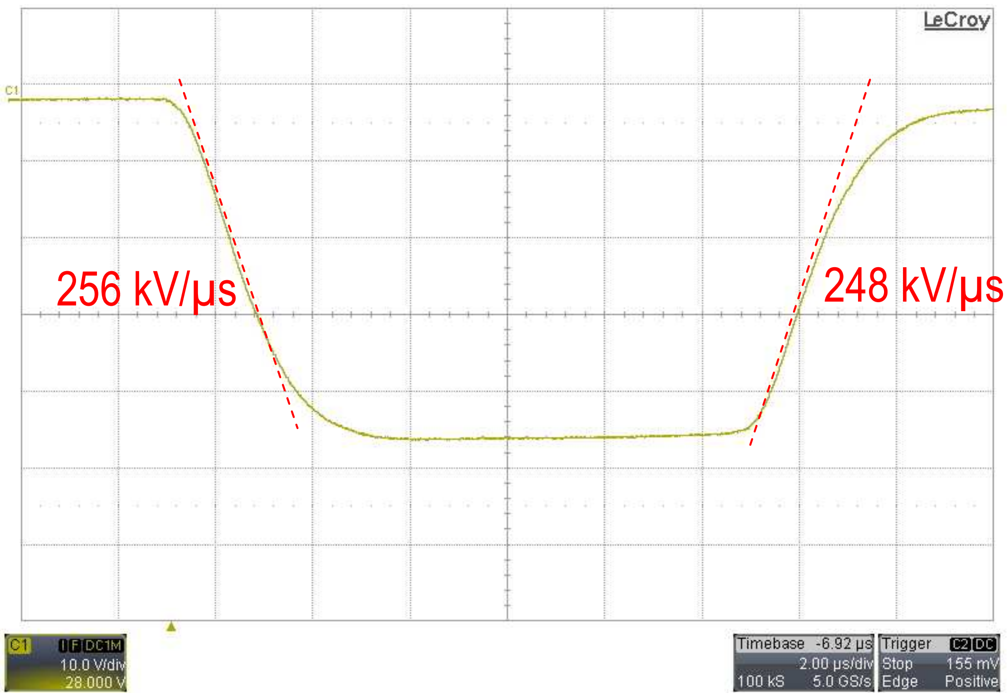


# CLS K2-1 PULSE at 200 kV / 4 µs

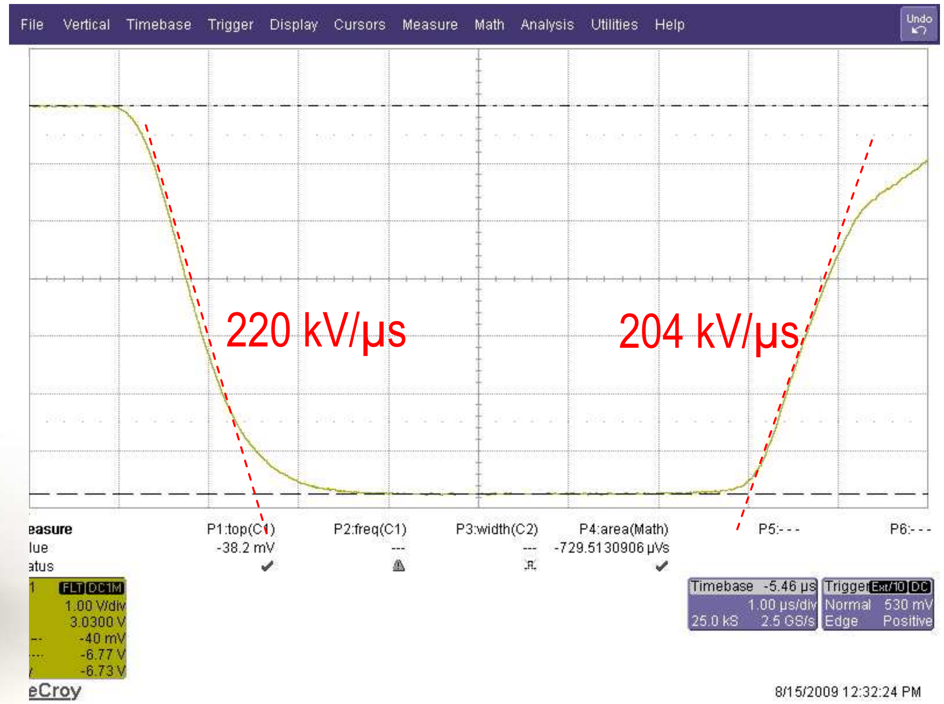
Canadian Light Source
Centre canadien de rayonnement synchrotron


# MAX-LAB K2-2 PULSE 290 kV / 4.5 µs

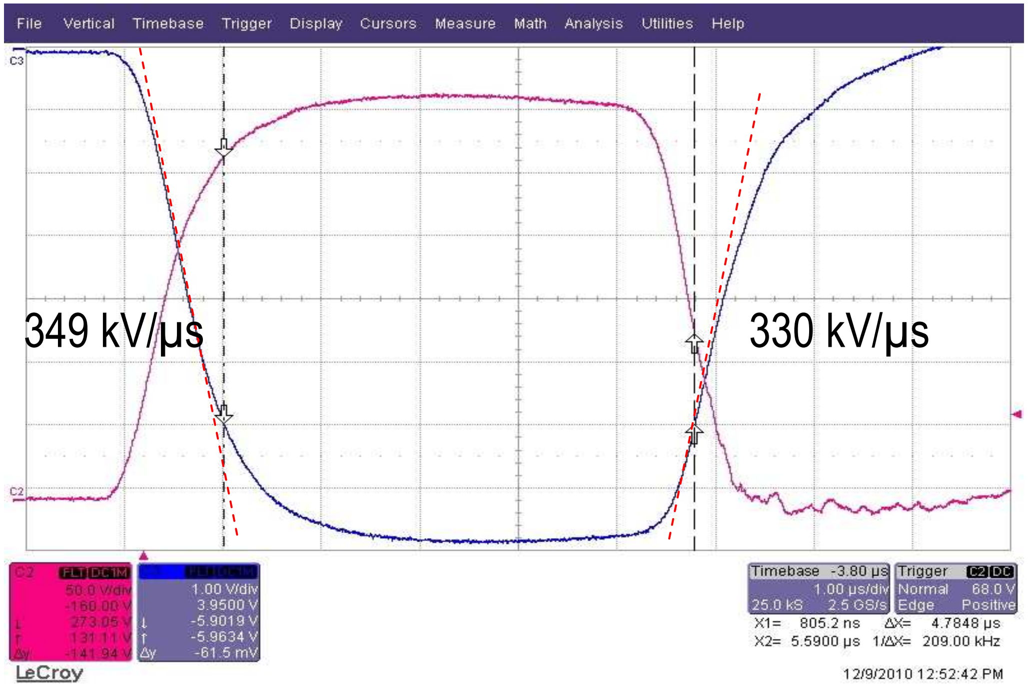


# PSI K2-3 PULSE 265kV / 4 µs

PAUL SCHERRER INSTITUT

# K2-3 FOR C-BAND AT 50 MW-LEVEL, 363kV / 316A / 3µs / 10 Hz

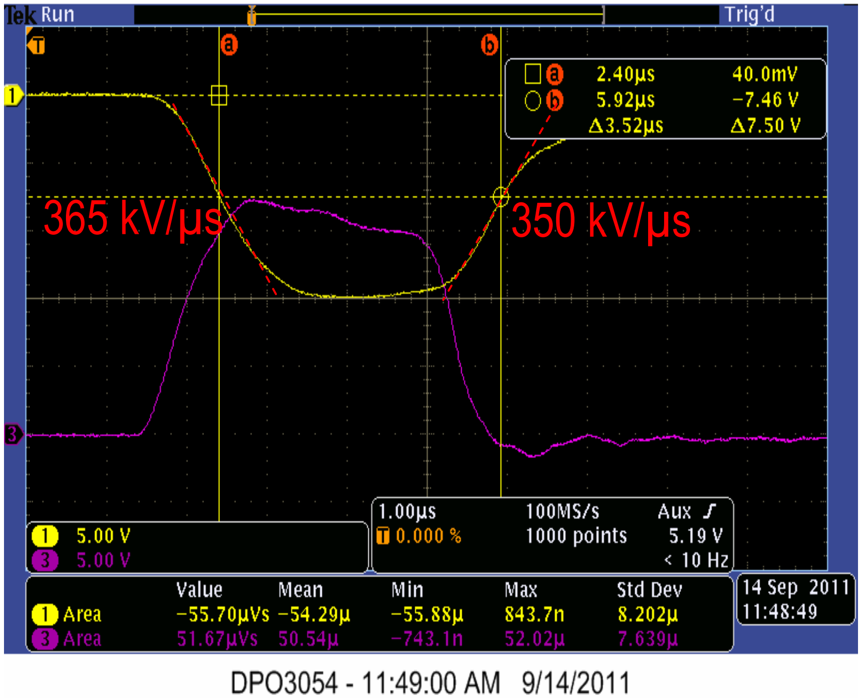




**K2-3 FOR INFN-FRASCATI**

**TOSHIBA E37202 KLYSTRON AT 5712 MHz**

# K2-3 FOR X-BAND AT 50 MW-LEVEL, 420kV / 315A / 1.5µs / 50 Hz

K2-3 FOR CERN / CLIC




PULSE AT SLAC XL5-KLYSTRON

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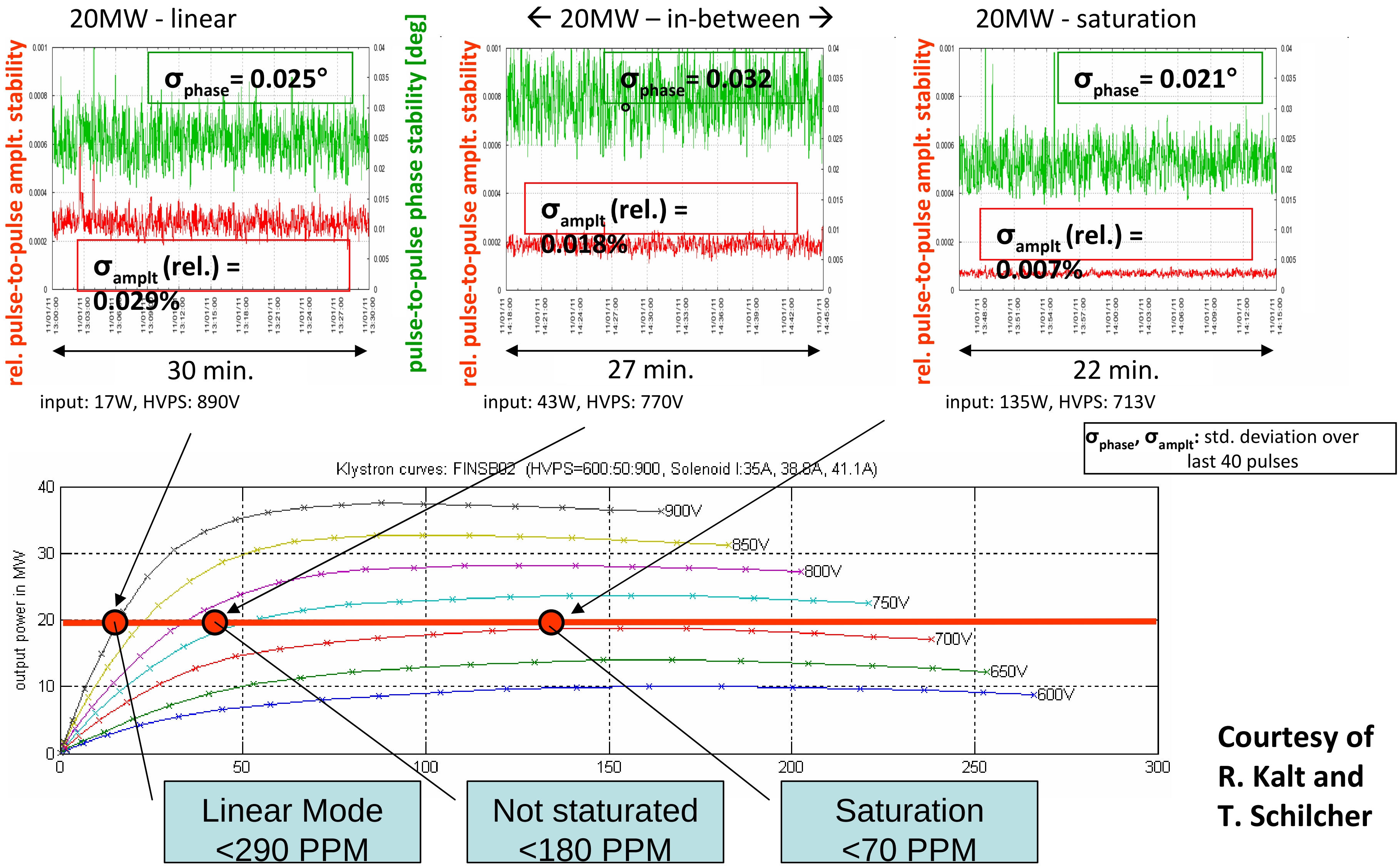
# K2-4 FOR S-BAND AT 80 MW-LEVEL, 400kV / 500A / 4,5µs / 60 Hz

PAL 포항가속기연구소 Pohang Accelerator Laboratory

K2-4 FOR POHANG ACCELEATOR LAB, KOREA


KLYSTRON VOLTAGE AT 400kV, 4.5us

# RF & Modulator Pulse-to-Pulse Stability




**remark:** overall stability < $4 \cdot 10^{-5}$ (rms)

**Courtesy of R. Kalt and T. Schilcher**

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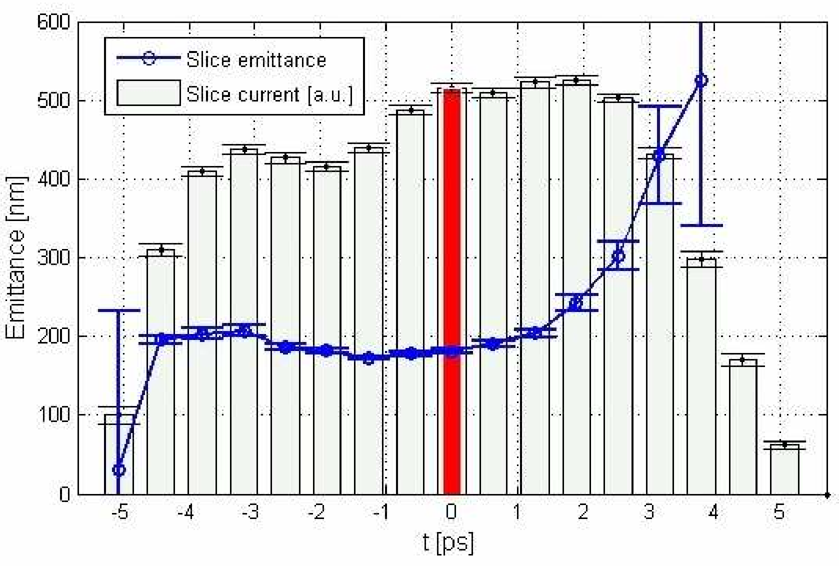
# SUMMARY OF SAMLPING RECORDS

| | | |
|---|---|---|
| Average of the 5th sampling | 57833,32487 | Min value |
| Stdev of the 5th sampling | 1,875198114 | Max value |
| **P to P instability (%)** | 0,003242418 | Min value |

**<0.0033% (33 PPM)**

# Record low emittance at the Swiss FEL Injector Test Facility

The SwissFEL injector test facility at PSI is the principal test bed and demonstration plant for the SwissFEL project. Significant progress has been achieved in the past few months, during which the injector settings were systematically optimized for maximum brightness of the electron beam (low emittance at high beam current).




The result of this optimization is a stable working point for uncompressed electron bunches, which ensures beam transport with minimal emittance dilution. Once the influence of the accelerator itself on the beam emittance is kept at a minimum, subtle effects of the laser generating the electrons at the cathode (via the photo-electric effect) become accessible to beam optics measurements. In this way it was possible, for instance, to demonstrate the effect of the laser photon energy (or wavelength) on the beam emittance. During these studies extremely small emittances were measured, in particular for low bunch charges, where the adverse effects of Coulomb repulsion (space charge) are also smallest. But even at the nominal SwissFEL working point of 200 pC charge and with the standard laser wavelength of 260 nm, which ensures high electron yield, record low emittances well below the SwissFEL requirements have been achieved. At these conditions, global (projected) emittances below 0.35 mm mrad are now obtained routinely, with best values around 0.30 mm mrad. The more relevant **slice emittance**, i.e. the emittance measured for individual slices along the bunch length, which represents a key beam parameter for free-electron lasers, is typically **below 0.20 mm mrad, with a record value of 0.18 mm mrad** (see image).

These promising results were obtained with still uncompressed electron bunches. To reach the high peak currents necessary to drive a free-electron laser, longitudinal bunch compression is essential. The study of compressed electron bunches at the SwissFEL injector test facility is planned for 2013, when a linearizing harmonic cavity will be installed. The new cavity will allow for a more uniform compression of the bunch in the magnetic chicane (the so-called bunch compressor)..

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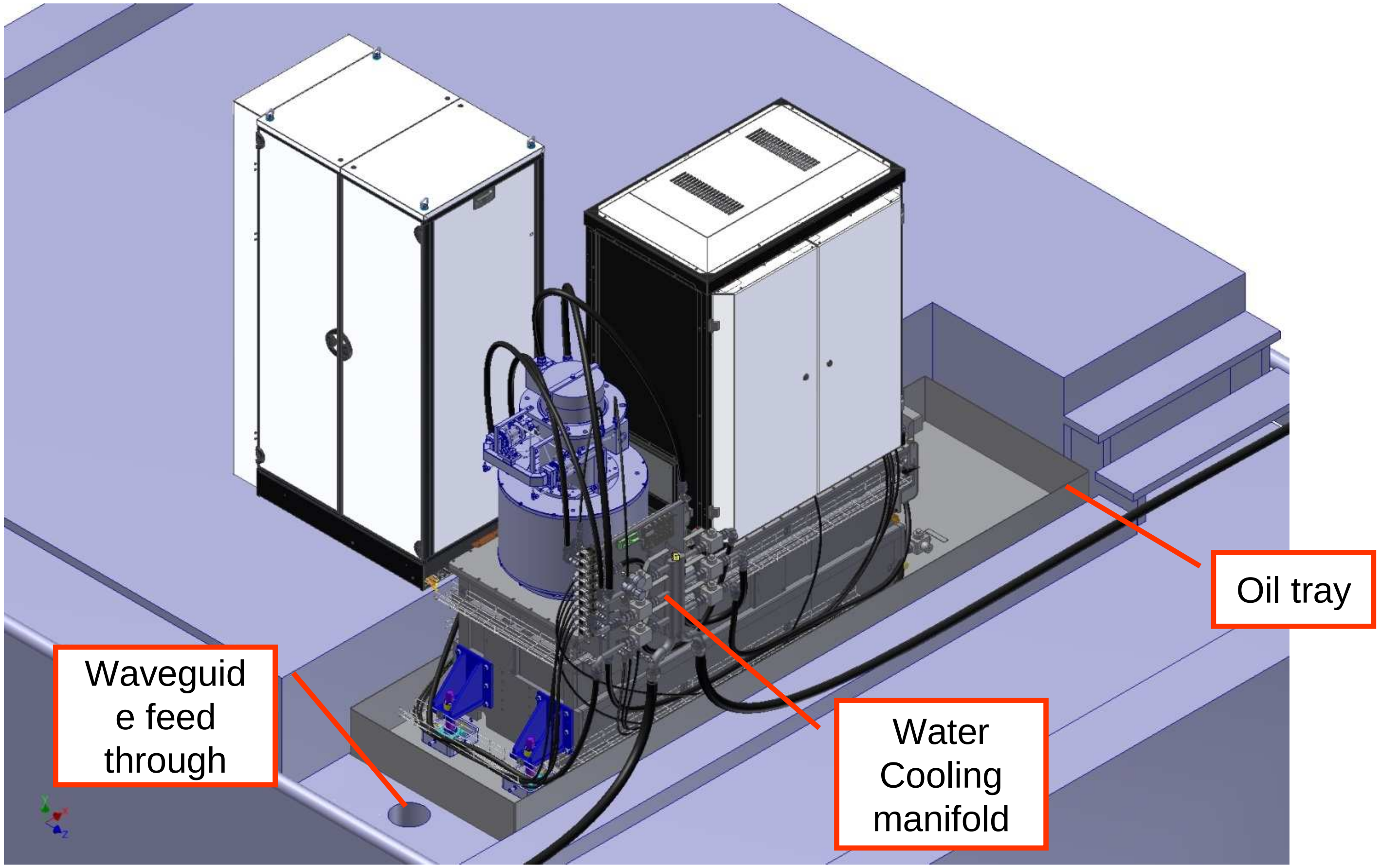
## NEW DEVELOPMENTS

# K2-3 FOR C-BAND AT 50 MW-LEVEL,




## 20 PPM STABILITY

# KLYSTRON MODULATOR - K1

| PARAMETER | UNIT | DATA |
|---|---|---|
| Klystron RF Peak Power (approx) | MW | 5 - 10 |
| Klystron RF Avarage Power (approx) | kW | 10 |
| Modulator Peak Power | MW | 25 |
| Modulator Avarage Power | kW | 0.5 - 30 |
| Pulse Voltage | kV | 110 - 190 |
| Pulse Current | A | 80 - 140 |
| Pulse Repetition Frequency range | Hz | 30 - 1000 |
| Pulse lenght (top) | us | 0.5 - 6 |
| Flatness | % | +/- 1 |
| Amplitude Stability | % | +/- 0.05 |
| Cooling | | Water |

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# K1 FOR X-BAND AT 6 MW-LEVEL, 140kV / 92A / 0,7µs / 1000 Hz

Massachusetts Institute of Technology

DESY

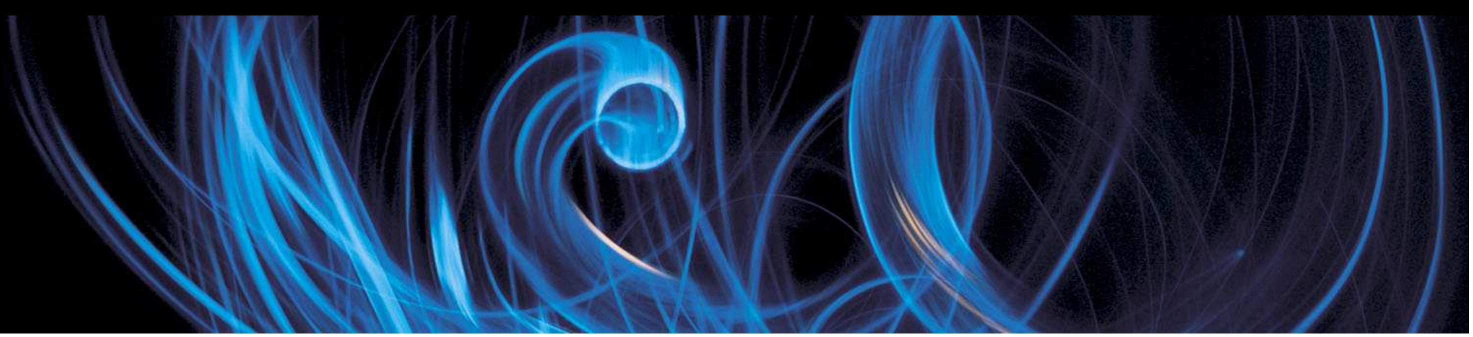
**K1 FOR MIT / DESY X-BAND SYSTEM**
**100 PPM STABILITY**

# KLYSTRON MODULATOR - K1

agenda

# ScandiCAT

## New PLC based control system for ScandiNova modulators



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# Features

- Standard master PLC
- Optically isolated internal high speed communication bus (ethercat)
- Real-time clock (can be synchronized with your system)
- Deterministic behaviour (total control of each pulse up to 1kHz)
- Streaming of pulse data up to 1kHz (a set of vales describing the pulse)
- Digitized wave form streaming
- Separate Trig & Interlock System (~1µs reaction time)
- GUI adapted for mouse & keyboard (more stuff on each page)
- Flexible data interface (EtherCAT, EPICS, OPC, TANGO, Profibus...)

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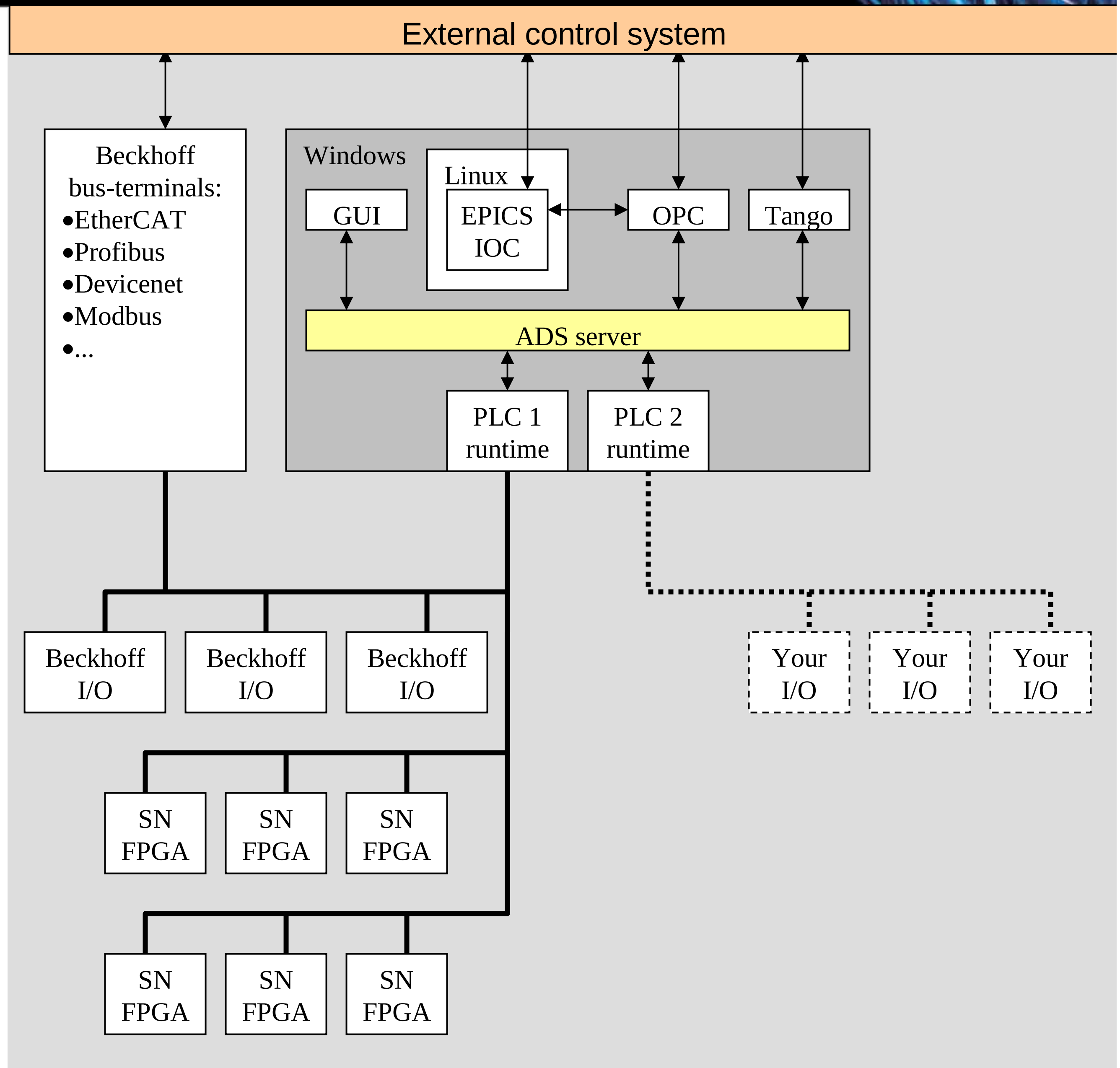
# Adding your own I/O + logic

Since it's based on a standard PLC & bus it will be easy to add new I/O for your specific needs.

You can even have all your code in a separate PLC runtime



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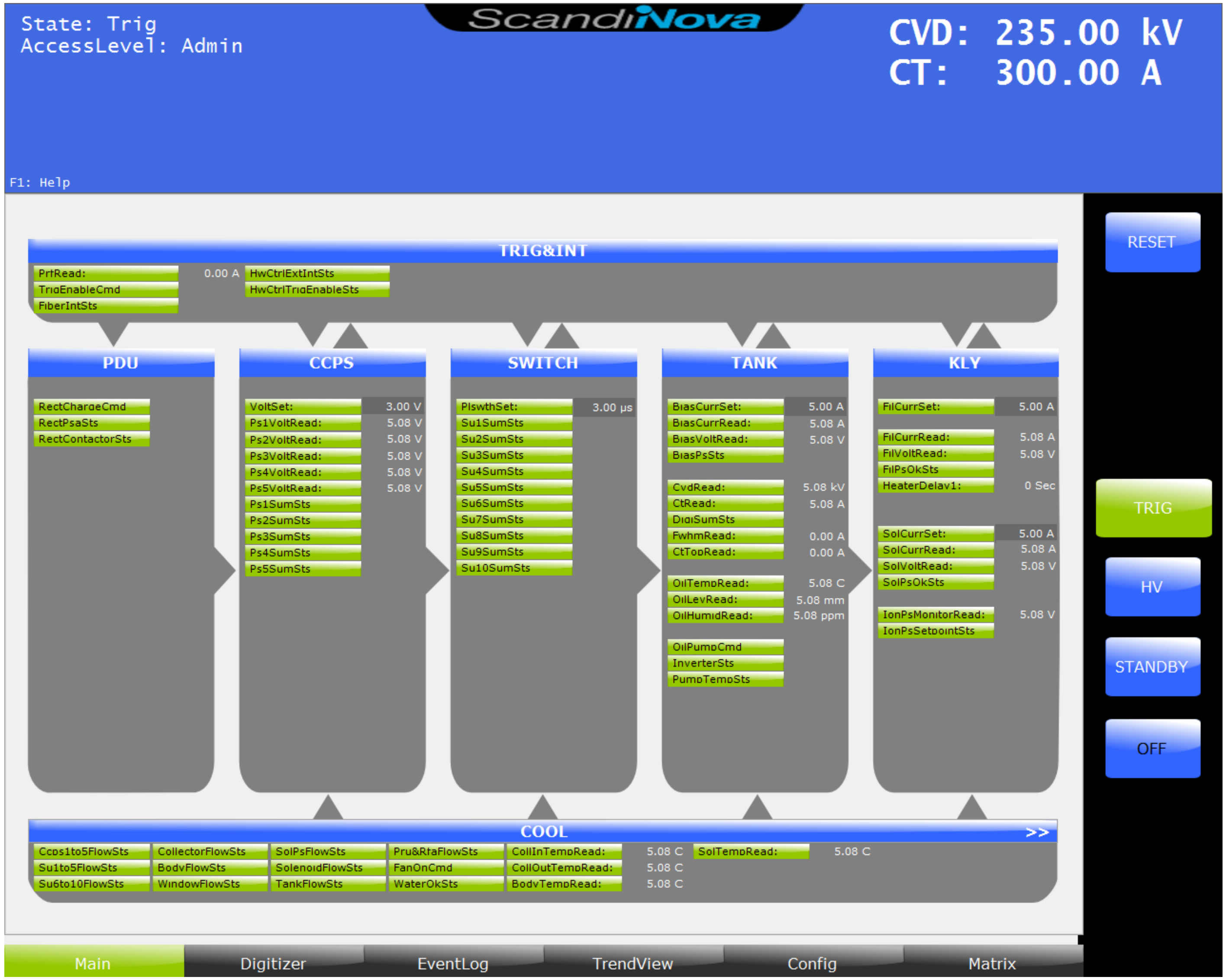
# GUI: Main

This is the “Main” view.

Here you can see the state of all units/interlocks of the modulator by colour code

Set-values needed for every day use are accessible here

This GUI is designed for basic operation via touch-screen (on/off/reset/changing of Tab’s) while more advanced editing requires either keyboard & mouse or a stylus.



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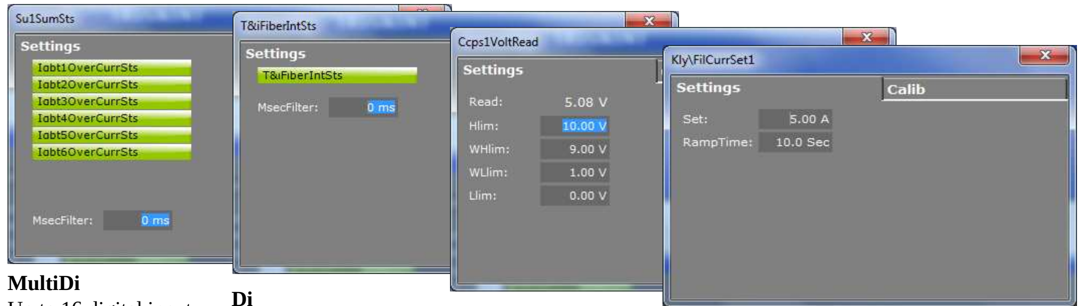
# GUI: Pop-up's

Pressing any of the unit buttons (high-lighted below) open up a pop-up window displaying all relevant parameters

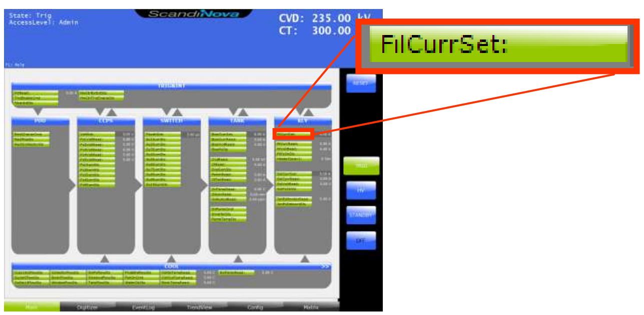


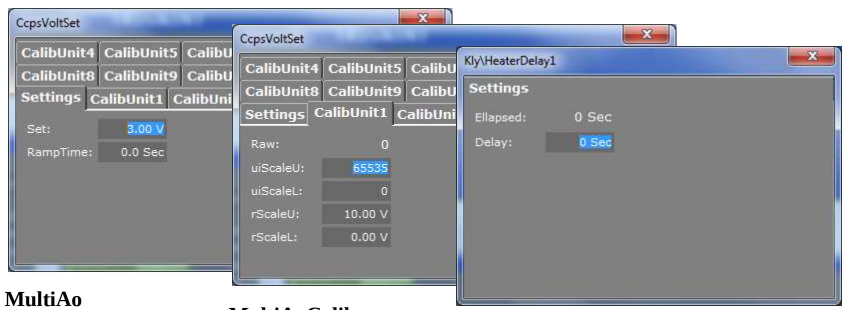

**MultiDi**
Up to 16 digital input status indicators and a common digital filter I/O-field

**Di**
Digital input status indicator and a digital filter I/O-field

**Ai**
Read value + interlock and warning limits. There is also a TAB for calibration (similar to MultiAoCalib example below

**Ao**
Set value + ramp time. There is also a TAB for calibration (similar to MultiAoCalib example below

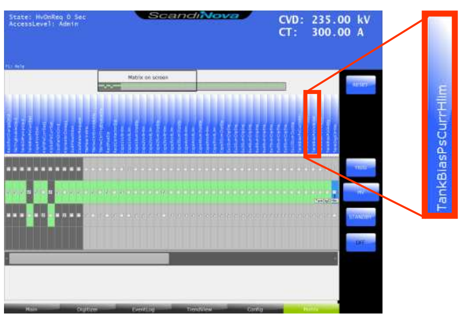



**MultiAo**
Common set & ramp time I/O-field's
Individual calibration Tab's

**MultiAoCalib**
A raw O-field and four I/O-fields with scale factors providing a two-point linear scaling with extrapolation

**Delay**
An elapsed time O-field
And a Delay I/O-field



# Control system overview: Digitizer

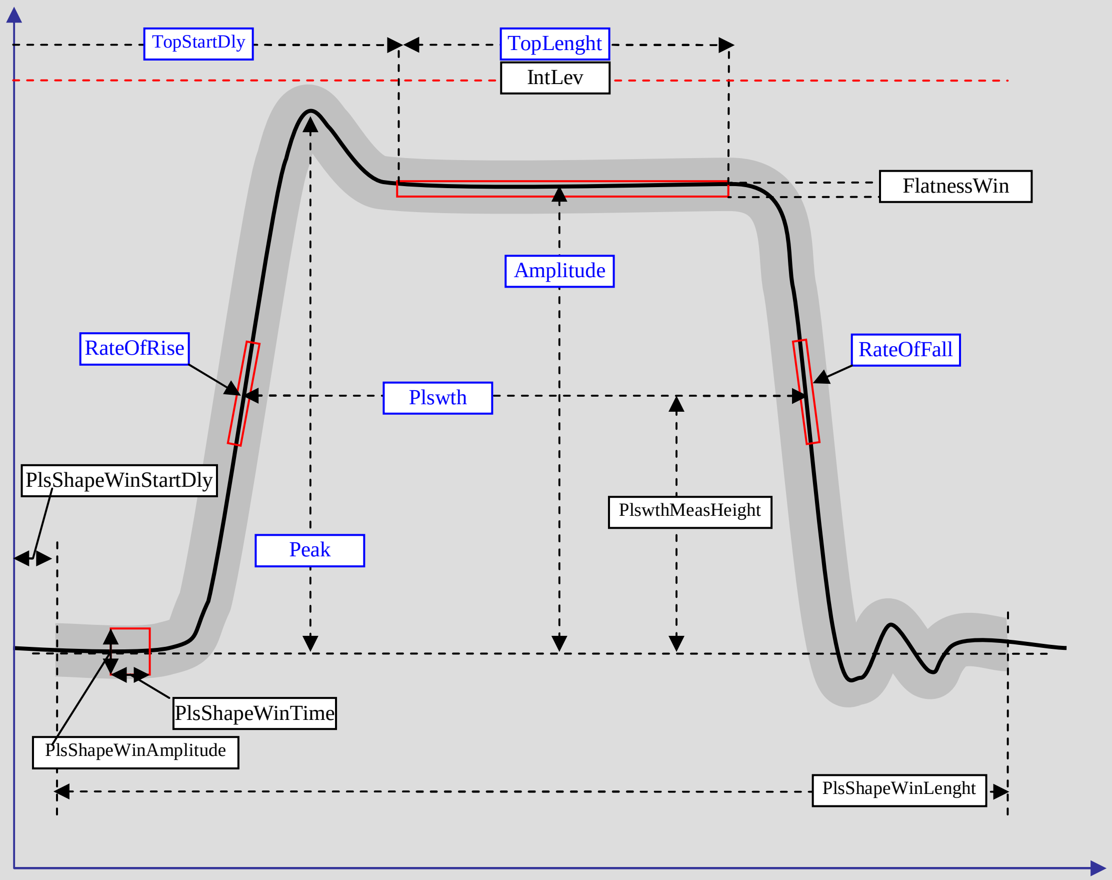
Locally in each Digitizer FPGA many pass/fail test and measurements will be made on each pulse, the reaction of these measurements can be configured (interlock or warning...)

The following measurements are available for each channel:

- Amplitude
- RateOfRise
- RateOfFall
- PulseWidth
- TopLenght
- TopStartDelay
- PeakAmplitude
- Digitized waveform (min 12bit/10Msps)

The following interlocks/warnings are available for each channel:

- AmplitudeExceeded
- WaveformDeviating
- PulseWidth  Hlim/Llim
- Arc



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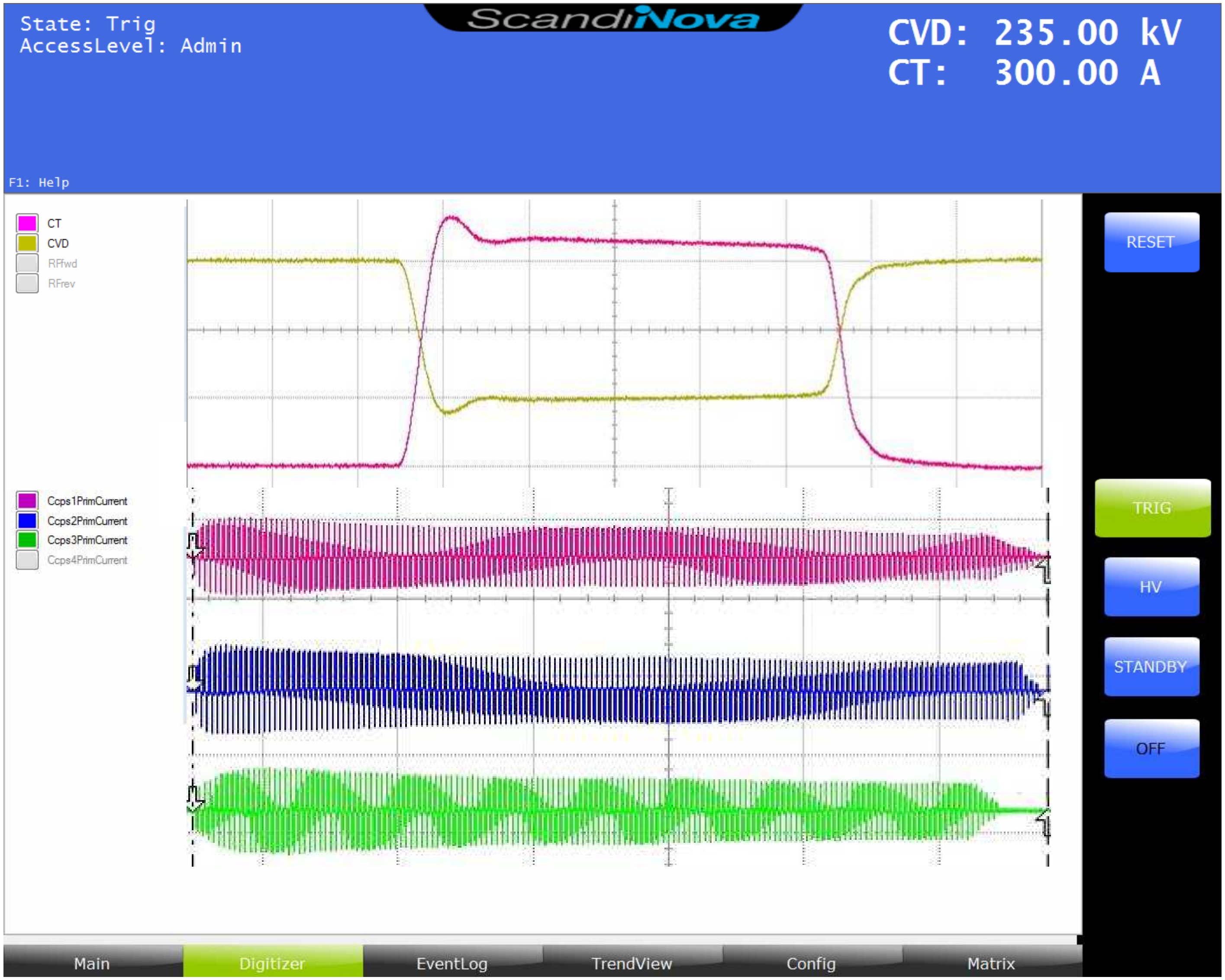
# GUI: Digitizer

A configurable number of waveforms can be displayed here

It will be possible to zoom and save references



# GUI: Trend

A configurable number of trends can be set-up to see behaviour of the last 24hrs

Long term archiving has to be taken care of by your system

# SCANDINOVA SUMMARY




- Unique solid state technology invented 1995
- ScandiNova founded in 2001
- Installations in 24 countries

  (North-South America, Europe, Asia, Australia)
- Ackumulated operational hours >500 000
- Use in 10 applications
- Close collaboration with customers
- Continuous development & improvements

ISO 9001
ISO 14001

# USER MEETING 2011

*June 13-15, Uppsala, Sweden*

# USER MEETING 2012

# USER MEETING 2013


Welcome to …
ScandiNova User Meeting 2014
LUND, SWEDEN
June 11 – 13, 2014

ScandiNova

# Thank you!