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CAENels

Gear for Science

Company Presentation

2019

Member of DPG

Member of MicroTCA Technology Lab

Overview

CAENels
Gear For Science

- The CAEN Group
- CAEN, CAEN RFID and CAEN SyS
- History of CAEN ELS
- Custom Made Projects
- Product Lines
- Outlook New Developments
- References
- Distribution Network

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Company Profile

The CAEN Group

- **CAEN S.p.A.** (Costruzioni Apparecchiature Elettroniche Nucleari, Società per Azioni) seated in Viareggio/Italy was founded in 1979 from Marcello Givoletti, Piero Salvadori and Luigi Pardini, who were former employees at the INFN (Istituto Nazionale di Fisica Nucleare) in Pisa.
- Initiator of the founding was **CERN**, which cooperates closely with the INFN. Hence CERN was the first customer of CAEN and up to today CERN is still the biggest customer of the CAEN group with thousands of installed electronic boards.
- The CAEN Group has **nearly 10.000 customers** in more than 50 countries in public research as well as in private organizations.
- Locations and **distributors in more than 30 countries.**
- More than 140 employees generated a **direct turnover** of **25 M€** in 2018.
- CAEN and its spin-offs are **100% self-financed.**
- Core Areas: High Energy Physics, Astrophysics, Neutrino Physics, Dark Matter Research, Nuclear Physics, Particle Physics , Radio Frequency Identification, Nuclear Security and Safety, Didactics, Material Sciences, Medical Applications, Industrial Applications, Calibration Technologies.

CAEN Company Network

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Company Profile

Trieste - Italy

CAENels
Gear For Science

CAEN
Tools for Discovery

CAEN SyS
Systems and Spectroscopy Solutions

CAENRFID
THE ART OF IDENTIFICATION

Viareggio - Italy

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Locations

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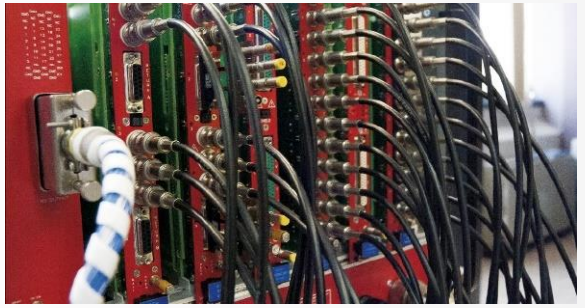
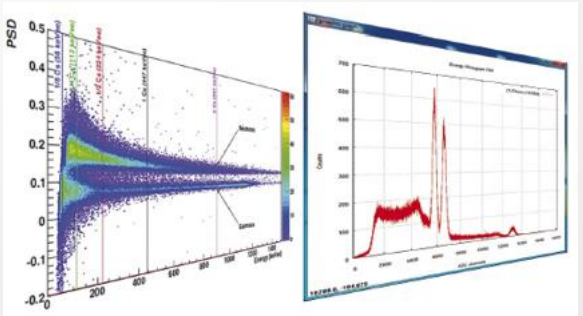
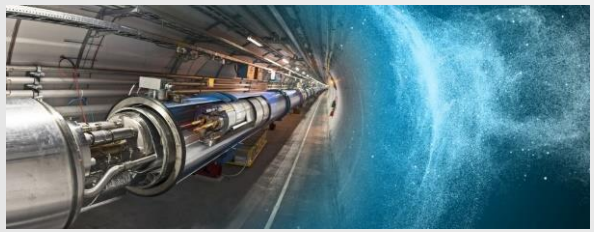
CAEN

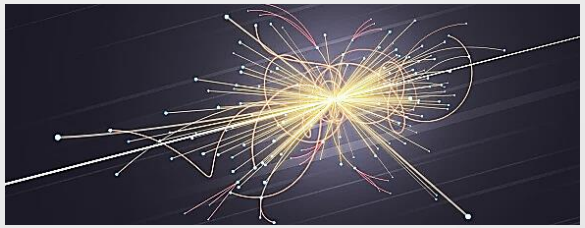
CAEN
Tools for Discovery

- **CAEN** is the world leader with the most advanced electronic instrumentation for any **particle, radiation and low light detectors**.
- Nearly all **world major research laboratories and institutes** are using **the high end products of CAEN** for the detection and data acquisition in **particle physics experiments**.
- R&D division of **50 high level Physicists and Engineers**.
- High Voltage and Low Voltage Power Supplies
- Signal Conditioning, Read Out Electronics and Emulation
- Acquisition Systems
- Spectroscopy Solutions
- Powered Crates and Chassis
- Educational Kits









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CAEN RFID

CAENRFID
THE ART OF IDENTIFICATION

- **CAEN RFID** was founded in 2006 and is a **key player in the European RFID Market** with **worldwide customers** in manufacturing, logistics, transport, healthcare, fashion, retail...
- **Radio frequency identification (RFID) is a form of wireless communication** that uses radio waves to identify and track objects.
- RFID takes the barcoding concept and digitizes it for the modern world
- **UHF RFID Readers, Loggers, Custom Products, Integration**
- Uniquely identify an individual item beyond just its product type
- Identify items without direct line-of-sight
- Identify many items simultaneously
- Identify items within a vicinity of between a few centimeters to several meters

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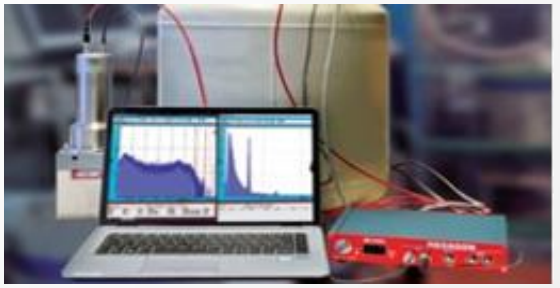
CAEN SyS

CAEN SyS
Systems and Spectroscopy Solutions

- **CAEN SyS** provides nuclear measurement solutions and technical expertise for **Nuclear Safety, Nuclear Security and Laboratories**.
- Health Physics , Spectroscopy and Radiation Measurements Systems
- Custom Nuclear Measurement Systems, Nuclear Waste
- Identification of gamma and neutron sources
- Networking of radiation detectors and robotics
- Safeguard and security products for non-proliferation and threats
- Fuel cycle process monitoring characterization Fresh & Spent Fuel Burn-up solutions
- Nuclear emergency preparedness
- Site remediation studies, products and solutions for mitigation plans



Location

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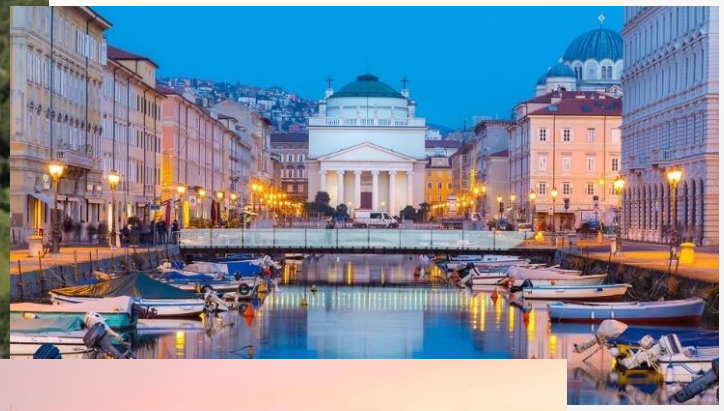


- Founded 2009 as a spin-off from CAEN S.p.A.
- Developer and manufacturer of high-performance digital bipolar and monopolar power sources, high-precision current transducers and current measurement systems, electronic components for beamlines in accelerators and FMC and MicroTCA equipment
- **Headquarters** in Basovizza, **Trieste - Italy** at the location of Elettra-Sincrotrone Trieste S.C.p.A.

History

CAENels - from foundation to today...

2009: CAEN acquires three leading developers (Denis Molaro, Enrico Braidotti, Mitja Guštin) from Elettra Sincrotrone in Trieste/Italy who are dedicated in custom specific power sources and electronic instrumentation. **Founding of** the spin-off **CAEN ELS** with the target of providing institutes in the accelerator technology (e.g. CERN, DESY) with high-end electronic equipment.

2011: **First turnovers** with worldwide partners inside the accelerator technology developing and selling custom specific digital bipolar power sources.

2013: Development of the high precision **o-FLUCS-Current-Transducer** series (accuracy < 30 ppm/FS).

2014: Development of **new bipolar and monopolar** standard power sources for reactive (inductive and capacitive) loads with **digital control loop** – currently from few W up to 10-kW for all kinds of high-end applications.

Entering the high-end industrial, automotive, battery, medical markets and further.

2015: Founding of the US American Branch Office in New York City (at **CAEN Technologies, Inc.**)

2016: Founding of the **German Branch Office** near Karlsruhe.

Entering the calibration market.

2019 ff.: Continuous development of further custom-made solutions as well as standard sources and electronic instrumentation with state-of-the-art technology.

Where it started

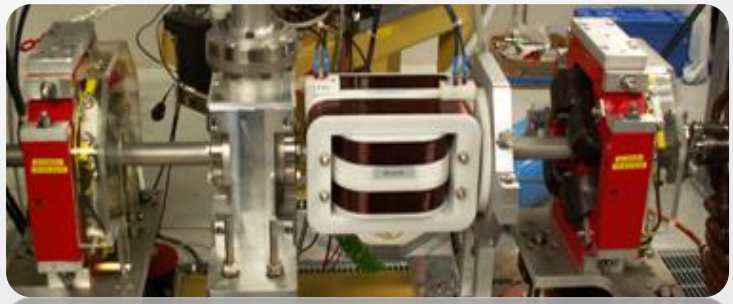
FERMI@Elettra

- Linear accelerator – FEL (400 meters length)
- about 400 magnets of **5 A** up to **750 A**
- 24 hours/day – 365 days/year
- Reliability and Efficiency

FERMI basic installations

X-FEL requirements for the power sources:

- 180 power sources of ±20A @ ±20V (A2620BS)
- 210 power sources of ±5A @ ±10V (A2605BS)
- Correction and Quadrupole Magnets



Customer Projects

Custom Design Example

Tsukuba - Japan

- Custom specific **bipolar linear** power sources rated at **±5 A** and **±60 V**
- Start of design in December, delivery and installation after **4 months** in March

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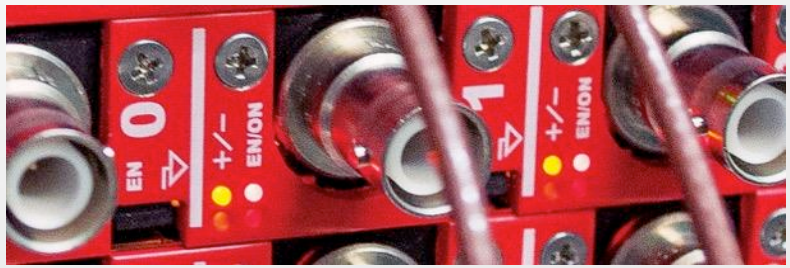
Product Lines

Power Supply Systems

Precision Current Measurements

Beamline Electronic Instrumentation

FMC MicroTCA



Power Supply Systems

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Power Supply Systems

Catalogue
Power Supply
Series

CAENels Power Sources - A New State-Of-The-Art

Unite The Advantages – **Eliminate** The Disadvantages – **Add** New Features

Linear Analog Controlled Sources
Simple platform, low complexity
Easy to use
High Reliability
Low ripple, low noise
Low Cost
Analog Input
Fast transient response
Only low power possible
Big Size
High Weight
High Heat Loss
Low Efficiency
Need for additional hardware depending on load

Switched Digitally Controlled Sources
High Power possible
Step up (boost) and step down (buck) possible
Small Size
Low Weight
High Efficiency
Low Heat Loss
Load easily adaptable by software PiD regulation
Digital Input
Easy integration in main control systems
Complex platform, many parts
High cost due to many parts
High ripple high noise - switching transformer

The challenge was, to combine the positive aspects of the both worlds "linear" and "switched" along with eliminating or optimizing the negative aspects.

CAENels Power Sources - A New State-Of-The-Art

Unite The Advantages – **Eliminate** The Disadvantages – **Add** New Features

Linear Analog Controlled Sources
Simple platform, low complexity
Easy to use
High Reliability
Low ripple, low noise
Low Cost
Analog Input
Fast transient response
Only low power possible
Only step down (buck) possible
Big size
High Weight
High Heat Loss
Low Efficiency
Need for additional hardware depending on load

Switched Digitally Controlled Sources
High Power possible
Step up (boost) and step down (buck) possible
Small Size
Low Weight
High Efficiency
Low Heat Loss
Load easily adaptable by software PID regulation
Digital Input
Easy integration in main control systems
Complex platform, many parts
High cost due to many parts
High ripple high noise switching transformer

CAENels Power Sources - A New State-Of-The-Art

Unite The Advantages – **Eliminate** The Disadvantages – **Add** New Features

Switched Digitally Controlled Sources - The New High-End-State-Of-The-Art

Easy to use	High Power possible
High Reliability	Step up (boost) and step down (buck) possible
Low ripple, low noise	Small Size
Low Cost	Low Weight
Analog Input	High Efficiency
Fast transient response	Low Heat Loss
Additional High Speed Optical Input	Load easily adaptable by software PID regulation
High Resolution Digital Inputs and Outputs	Digital Input
High Accuracy at ppm Ranges	Easy integration in main control systems
	Complex platform, many parts

The highly ambitional, two years lasting effort in research and development finally succeeded in power sources that combine the advantages of both technologies and that are unique in the world.

CAENels Power Sources – A novel digital magnet power supply approach

ABSTRACT

Programmable logic and integrated technologies, as **SoC, FPGA and DSP**, have became mature enough to be employed in **high performance magnet power supply applications**.

The use of a configurable **mixed current and voltage digital control**, combined with adaptable complex algorithms for protections (e.g. **quench** in superconducting magnets) and auxiliary integration (e.g. transverse flux density in a dipole gap) allows obtaining the **perfect fit for each specific magnet application**.

An entire series of power supplies, coming from a background of particle accelerator applications, has been developed for both **bipolar and monopolar operation with high bandwidth** (fast fields as in corrector magnets and steerers) and high adaptability with a **user-friendly interface** and an **embedded Linux OS** that allows users to implement their own applications directly on the power supply.

The use of **24-bit ADCs and state-of-the-art PWM generation** (with possible application of dithering techniques to reach **65-ps resolution**) enables to obtain fields **actuations in the ppm-level range**.

Some of the CAENels power converters, for specific applications (usually dipoles or superconducting), are equipped with our **closed-loop zero flux transducers** that feed their signals to temperature-stabilized electronics to reach **current temperature coefficient values of lower than 1 ppm/K**.

CAENels Power Sources – A novel digital magnet power supply approach

Control Board

Digital Control Board including:

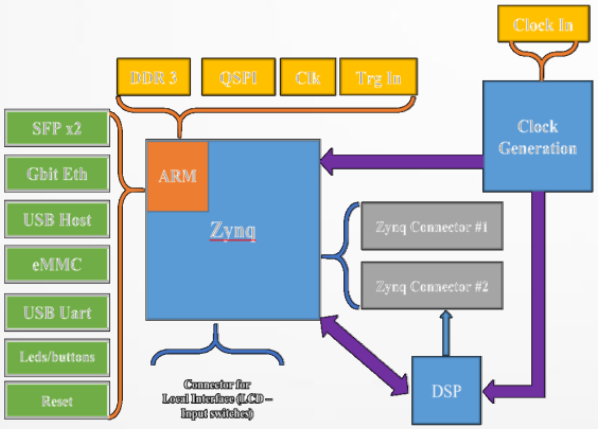
- **FPGA (Zynq)**
- **DSP (Texas Instruments)**

Interfaces included are the following:

- **10/100/1000 Ethernet**
- **2 x SFP+ (6.5 Gbps/channel)**
- **USB Host**
- **eMMC**
- **display and encoder control**

FPGA is used for digital output control algorithms and **DSP for High-Resolution PWM generation.**

Linux OS (Yocto Project) is embedded in the **ARM**.



Carrier Board

The **Digital Control Board** is plugged onto the **Carrier Board** with two 100-pin high-speed FCI connectors. The Carrier Board is provided with:

- **2 x 24-bit@100 ksps ADCs** for current and voltage readout (Temperature-stabilized)
- **DC-Link, Temperature and Auxiliary analog readings (16-bit@100 ksps)**
- **I/O signals** for interfacing with external protections (e.g. **quench**)
- **interlocks** and **status signals**
- connector for future expansions.

The Carrier Board also embeds the power section to supply the **active CAENels DCCT transducer** with low-noise power at ±15V in order to have a direct, accurate, stable and precise current readout.

CAENels Power Sources – A novel digital magnet power supply approach

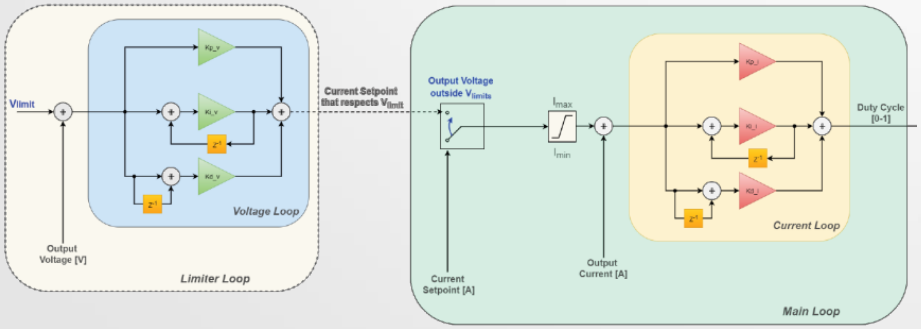
Output Control Loop

The on-board programmable logic allows for complex algorithms to be performed on the current and voltage output values.

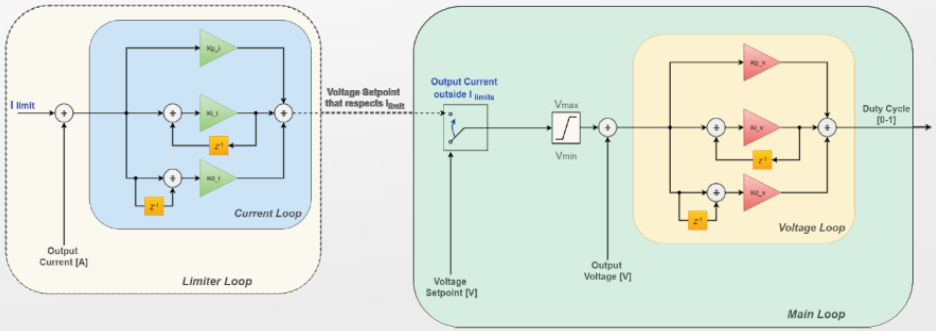
A lot of different feedback control loops have been implemented but standard ones are modified versions of **Proportional Integral Derivative (PID).**

Two examples are hereafter shown:

Constant Current (CC) Output Control



Constant Voltage (CV) Output Control



Application Example: a user can implement a slower closed loop directly on the Linux OS by using the readings of the magnetic field from a Hall probe fed to the auxiliary input of the carrier board.

CAENels Power Sources – A novel digital magnet power supply approach

Power Stage Control

The **on-board FPGA** performs all the **control loop algorithms at a hardware-level** to maximize speed and computing power.

The **DSP** is used as a **multi-channel PWM generator** with a **65-ps PWM resolution**. For bipolar stages **(H-Bridge topologies)**, this resolution can be halved.

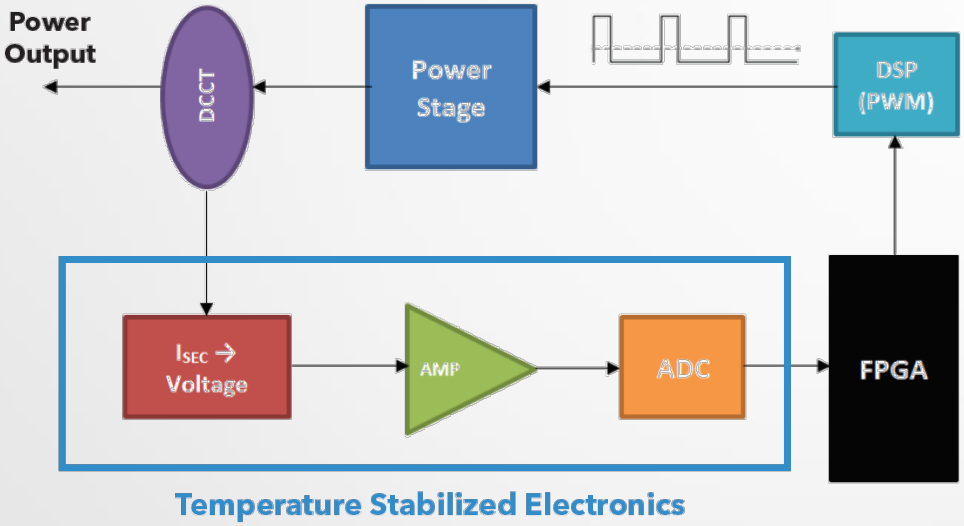
The equivalent setting resolution for a **15-kHz switching monopolar power stage** can be computed as:

$$Resolution = log_2\left(\frac{1}{T_{PWM} \cdot f_S}\right) = log_2\left(\frac{1}{65 \cdot 10^{-12} \cdot 15 \cdot 10^3}\right) \cong 20\ bit$$

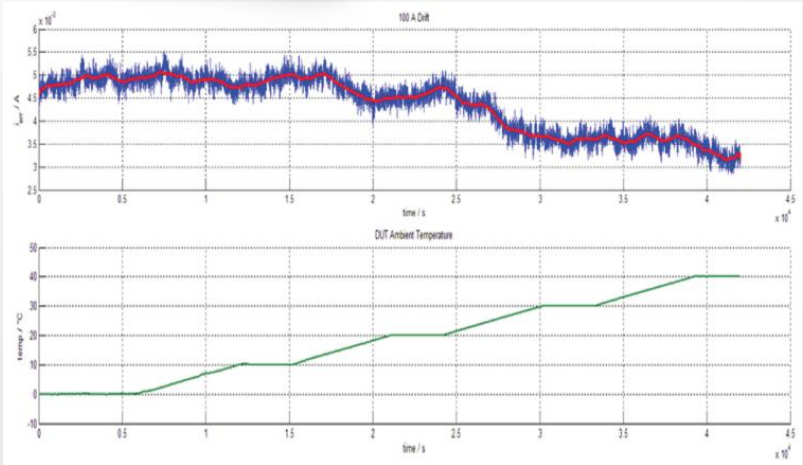
This resolution can be increased to 21 bit for bipolar stages.

CAENels Power Sources – A novel digital magnet power supply approach

Current Sensing



CAENels o-FLUCS DC Current Transformer

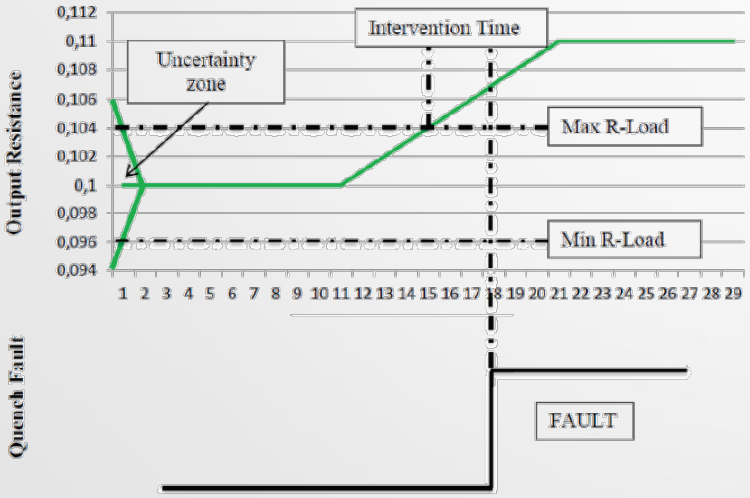


The current sensing is made using a proprietary closed-loop **Zero Flux DCCT** (DC Current Transformer) and fed **to the ADC via a temperature-stabilized signal** conditioning section to reach a **TC < 1 ppm/°C.**

CAENels Power Sources – A novel digital magnet power supply approach

Quench Detection

A **quench protection procedure is running on the FPGA** and it is configurable.



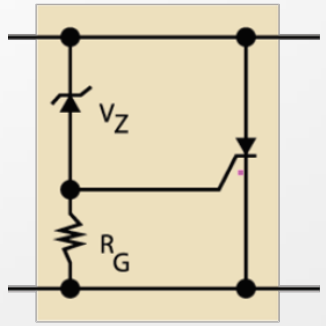
Auxiliary Inputs

External analog control input (e.g. to use the power supply **as an amplifier**) is provided by using another **ADC at 16-bit 100 ksps.**

An external input can also be used **to read**, for example, **the magnetic field** generated by the magnet - e.g. Hall probe. A slow loop can be closed on the field value.

Crowbar

Active circuits to protect against back-energy are designed for monopolar and bipolar power supplies.

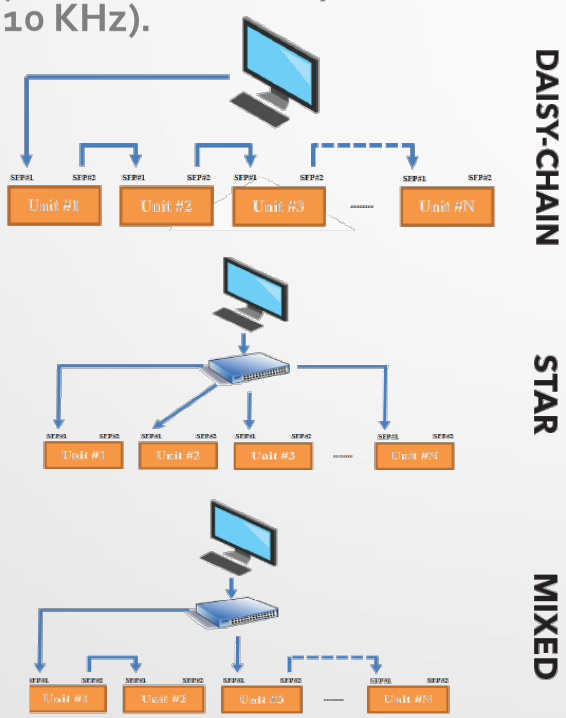


A specific circuit that **remains active for > 10 min after an AC mains failure** has been integrated also for superconducting magnets.

CAENels Power Sources – A novel digital magnet power supply approach

Fast Connections

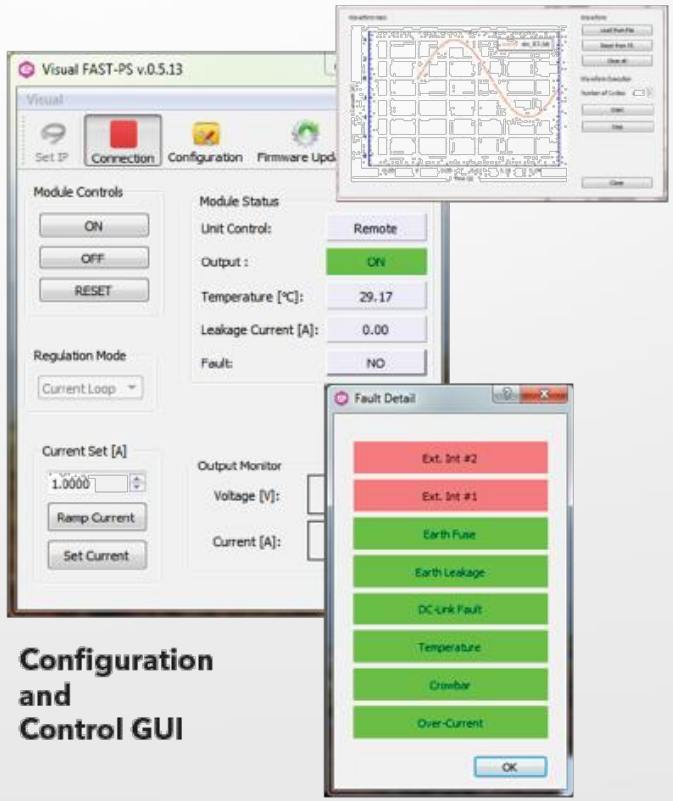
Two 6.5 Gbps SFP+ links are provided for **fast update rates (> 10 KHz).**



Paralleling is also performed using the **SFP+.**

Remote Configuration

Interlocks and protections can be configured remotely to match the application.



Configuration and Control GUI

CAENels Power Sources – A novel digital magnet power supply approach

CONCLUSIONS

- Control of different types of power topologies - i.e. **different magnet types** with different requirements
- **Remote optimization of the current dynamic behaviour** using the digital control loop - no oscillations or slow response
- **Fast connectivity** (Gigabit Ethernet + SFP/SFP+): optimized for single module or for large installations
- **Extreme high-stability at 1 ppm/°C** with matched o-FLUCS DCCTs + temperature stabilization
- **Easy software development**/integration directly on the power unit using the embedded **Linux OS** - Yocto Project
- **Paralleling of modules** via SFP/SFP+ optical links
- **Remote configuration of waveforms, triggers, interlocks and protections configurations** for the specific application
- Implementation of **different control schemes** - e.g. IIR filters, adaptive algorithms, etc.

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Power Supply Systems

Easy-Driver

Compact Digital Bipolar Power Supply

- 19" – 1U stand-alone crate
- **±5A@±20V** and **±10A@±20V**
- 10/100 Mbit Ethernet interface
- Digital Current regulation loop
- Low noise
- Internal protections and
- Auxiliary Readbacks
- External Interlock and Status Signal
- Extended input range (90-260VAC)
- Local display for monitoring
- "VISUAL" free software available

	"0520" Model	"1020" Model
Output current range	± 5 A	± 10 A
Output voltage range	± 20 V	
Maximum output power	100 W	200 W
Topology	Bipolar	
Current setting resolution	160 µA	320 µA
Output current readback	20 bit	
Output voltage readback	20 bit	
Output current ripple*	< 40 ppm / FS	
Output current stability	< 40 ppm / FS	
Output Current TC	< 40 ppm / °C	
Switching Frequency	> 100 kHz	
Closed Loop Bandwidth	> 1 kHz	
Efficiency	up to 84 %	
External Interlocks/Status	1 Input: External Fault 1 Output: Power Supply Status	
Internal Interlocks	DC Link Under-Voltage MOSFETs Over-Temperature Shunt Over-Temperature	
Hardware Protections	Input Fuses Passive Crowbar (Over-Voltage)	
Cooling	Forced Air Convection – Front-to-Rear	
Control System Drivers	EPICS IOC	
Connectivity	Ethernet 10/100 Mbit TCP-IP	
Extra-Features	User-settable Slew Rate Value Firmware Remote Update	
Mechanical Dimensions	19" × 1U × 264 mm 19" × 1U × 295 mm - *with output connectors*	
Input Ratings	90/260 VAC) 47-63 Hz	

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Power Supply Systems

FAST-PS

High-Performance Bipolar Power Supply

- 19" – 1U stand-alone crate
- Different current and voltage ratings
- 10/100/1000 Ethernet
- 2x Fast SFP interface (10 kHz update)
- Current or Voltage regulation
- High analog bandwidth
- Analog control and Trigger Input - optional
- Low noise
- Configurable Digital control loop
- Internal protections and auxiliary readbacks
- Local display and control

Regulation Type	Current- or Voltage- Control
Output current range	± 5 A, ± 10 A, ± 20 A, ± 30 A
Output voltage range	± 20 V, ± 40 V, ± 80 V
Maximum output power	up to 600 W
Setting resolution	18 bit
Output readbacks	20 bit
Output current ripple*	30 ppm / FS
Output current stability	< 50 ppm / FS
Output voltage stability	< 50 ppm / FS
Switching Frequency	100 kHz
Max Current/Voltage update rate	10 kHz
Accuracy	0.05%
External Interlocks/States	2 Inputs: user-configurable "dry" contacts 1 Outputs: relay (2 magnetic contacts)
Internal Interlocks	DC Link Under-Voltage MOSFETs Over-Temperature Over-Current and Over-Voltage Earth Fault Current Regulation Fault and Excessive Current Ripple
Hardware protections	Input Fuses Earth Fuse Over-Voltage
Auxiliary ADC Read-Backs	DC Link Voltage Ground Leakage Current Temperature
Cooling	On-Module Self-Regulated Fans
Control System Drivers	EPICS
Connection	1 x Ethernet 10/100/100 2 x SFP ports
Extra-Features	Point-by-Point Current Waveform Loading User-definable interlock thresholds, active levels and timings Firmware Remote Updates
Input Voltage	90/260 V(AC) (47-63 Hz)
Efficiency	up to 84 %
Power Factor	> 0.95

Easy-Driver and FAST-PS

Comparison

	Easy - Driver	FAST-PS
Output Current	up to ±10 A	up to ±30 A
Output Voltage	up to ±20 V	up to ±80 V
Ouput Power	up to 200 W	up to 600 W
Local Display	✔	✔
Local Control	✗	✔
Control Loop Type	Digital	Digital
Control Loops	Current	Current Voltage
External Interlocks	1	2
Status Signals	1 solid state relay	1 solid state relay 1 magnetic relay
Remote Sensing	No	Yes
Remote Interface	10/100 Ethernet	10/100/1000 Ethernet SFP Fast Interface
Remote Update Rate	250 Hz	1 kHz - Ethernet 10 kHz - SFP Fast Interface
Other Features	Firmware Remote Update Configurable Thresholds/Limits Internal Protections	Firmware Remote Update Waveform loading and execution Configurable Thresholds/Limits Internal Protections Embedded Linux OS USB host External Trigger - *option* Analog Control Input - *option*

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Power Supply Systems

FAST-PS-M

High-Performance Monopolar Power Supply

- 19" – 1U stand-alone crate
- **100A-6V, 75A-8V, 60A-10V** ratings
- 10/100/1000 Ethernet
- 2x Fast SFP interface (10 kHz update)
- Current or Voltage regulation
- High switching frequency – 300 kHz equivalent
- Analog control and Trigger Input - optional
- High-stability and low TC
- Configurable Digital control loop
- Internal protections and auxiliary readbacks
- Local display and control

Regulation Type	Current- or Voltage- Control		
Output current range	60 A	75 A	100 A
Output voltage range	10 V	8 V	6 V
Maximum output power	up to 600 W		
Setting resolution	> 18 bit		
Output readback	24 bit		
Output current ripple*	30 ppm / FS		
Output current stability	50 ppm / FS		
Output voltage stability	50 ppm / FS		
Switching Frequency	300 kHz (equivalent)		
Max Current/Voltage update rate	10 kHz		
Accuracy	< 0.05%		
External Interlocks/States	2 Inputs: user-configurable "dry" contacts 1 Outputs: relay (2 magnetic contacts)		
Internal Interlocks	DC Link Under-Voltage Over-Temperature Over-Current & Over-Voltage Earth Fault Current Regulation Fault & Excessive Current Ripple DCCT OK		
Hardware protections	Input Fuses Earth Fuse Over-Voltage		
Auxiliary ADC Read-Backs	DC Link Voltage Ground Leakage Current Temperature		
Cooling	On-Module Self-Regulated Fans		
Connection	1 x Ethernet 10/100/100 2 x SFP ports		
Extra-Features	Point-by-Point Current Waveform Loading User-definable interlock thresholds, active levels and timings Firmware Remote Updates		
Dimensions	19"– 1U – 365 mm (W x H x D)		
Input Voltage	90/260 V(AC) (47-63 Hz)		
Efficiency	up to 85 %		
Power Factor	> 0.95		

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Power Supply Systems

FAST-PS-IK5

1.5-kW High-Stability Bipolar Power Supply

- 19" – 2 U stand-alone unit
- Models **up to ±100 A** and **up to ±100 V**
- Configurable digital control loop
- 10/100/1000 Ethernet interface
- Current or Voltage regulation
- Low noise and Ripple
- < 1 ppm/K temperature dependence
- Excellent long-term stability
- Quench protection for SC magnets
- External Analog Control, Trigger and
- Configurable ADC Inputs
- Fast SFP interface (10 kHz update)

	15-100	30-50	50-30	100-15
Output Current	±15 A	±30 A	±50 A	±100 A
Output Voltage	±95 V	±50 V	±30 V	±15 V
Maximum Output Power	1.500 W			
Topology	Bipolar			
Control Mode	Current (CC) and Voltage (CV) Control			
Floating Output	Up to 200 V			
Remote Sensing	Up to 0.5 V			
Current Sensing	High-Precision Current Transducers			
Analog Control Input	Yes			
Current Setting Resolution	150 µA	250 µA	400 µA	800 µA
Voltage Setting Resolution	1 mV	500 µV	300 µV	150 µV
Output Readback Resolution	24-bit			
Noise + Ripple (RMS)	< 0.01 % on resistive load < 0.005 % on 1 mH load			
Temperature Coefficient	< 0.0002 % / K (CC mode) < 0.005 % / K (CV mode)			
Long Term Stability (8 h)	< 0.0005 % / K (CC mode) < 0.005 % / K (CV mode)			
Analog Bandwidth (-3 dB)	> 2 kHz			
Control/Communication Interface	Ethernet TCP-IP SFP/SFP+			
Local Control	Colour display with multi-function navigation switch			
External Signals	2 External Interlocks 2 Status signals – 1 magnetic relay and 1 solid state Trigger Input Analog Control Input Additional Configurable ADC Input			
Extra Features	Waveform execution Quench Protection Remote Firmware Update Linux OS on-board			
Mechanical Dimensions (L x W x H)	19" x 2U x 550 cm			
Operating Temperature	0 ... 45 °C			

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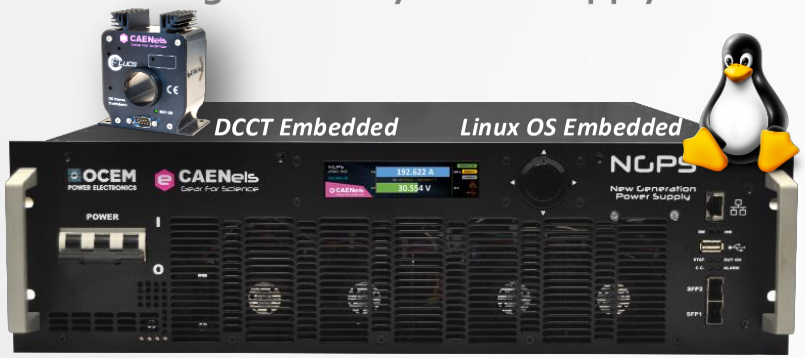
NGPS

10-kW High-Stability Power Supply



- 19" – 3U stand-alone unit
- Different current and voltage ratings
- Versions: **200A/50V, 100A/100V (both 10 kW) + 140A/50V (7kW)**
- 10/100/1000 Ethernet interface
- 2x Fast SFP interface (10 kHz update)
- Current or Voltage regulation
- Low noise and Ripple
- 1 ppm/K grade ("HS" version)
- High temperature and long-term stability
- Configurable digital control loop
- Internal protections and auxiliary readbacks
- Local display and control

powered by OCEM POWER ELECTRONICS

NGPS Information and Data

Input Ratings	208 VAC ('E') Three-phase 50/60 Hz 400 VAC ('A') Three-phase 50/60 Hz	
Regulation Type	Current-control (C.C.) or Voltage-control (C.V.)	
Output current range	NGPS 120-50 NGPS 200-50	120 A 200 A
Maximum output voltage	50 V	
Maximum output power	up to 10 kW	
Output Isolation	500 V	
Power Factor	> 0.9	
Efficiency	> 90 %	
Current and Voltage Setting	18 bit	
Current and Voltage Readback	20 bit	
Max Current/Voltage update rate	10 kHz *(over SFP)*	
Closed-loop Bandwidth	C.C. mode C.V. mode	> 100 Hz > 200 Hz
Accuracy	C.C. mode C.V. mode	< 0.01 % (0.005% *upon request*) < 0.05 %
Line Regulation	±5 ppm/FS	
Load Regulation	±5 ppm/FS	
Remote Sensing Compensation	up to 2 V	
Cooling	Forced Air Convection (front-to-rear)	
Temperature Stability	C.C. mode C.V. mode	5 ppm/K (1 ppm/K – *"HS" version*) 50 ppm/K
Interfaces	10/100/1000 TCP-IP Ethernet Two (2) SFP *other interfaces available upon request*	
Internal Interlocks/Protections	Over-Temperature MOV Input Over-Voltage Main circuit-breaker for Over-Current Output Free-wheeling diodes Output Over-current and Over-Voltage Earth current leakage Input Phase-Loss	
External Interlocks/States	user-configurable "dry" contacts relay (magnetic contacts, NO and NC)	
Other Features	Firmware remote update Interlock configurabilty Adaptable thresholds for trips and interlocks	
Modularity	Parallel connection Series connection	up to 4 up to 2
Mechanical Dimensions	19" x 3 U x 600 mm *including connectors*	
Weight	28 kg	
Operating Temperature	0 ... 50 °C	

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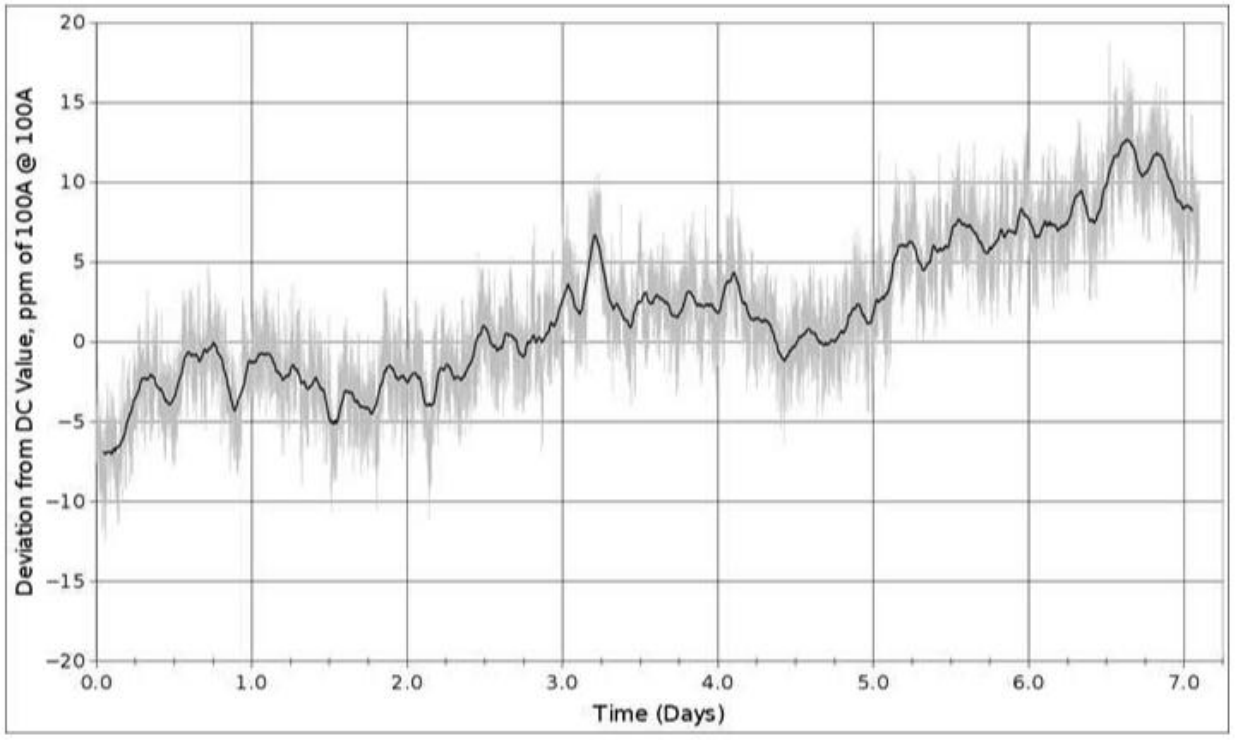
NGPS Long Term Stability

NGPS

Accuracy Performance over 7 days – tested from one of our customers



- Measured at 100A CC
- Guaranteed accuracy in the datasheet: 100 ppm
- Measured Long Term Stability – **Maximum Deviation in 7 days: 13 ppm (0,0013%)**
- Measured Long Term Stability – **Maximum deviation in 1 day: 6 ppm (0,0006%)**

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Polarity Inverters

200A, 400A, 600A

- 19" – 6U crate
- Current ratings up to 630A
- Perfect fit for the NGPS, both in single or paralleled configurations
- Controlled via the NGPS (no separate control needed)
- Adaptable to further sources from the market

	200 A	400 A	600 A
Rated Current	200 A	420 A	630 A
Rated Voltage	250 V	250 V	250 V
Auxiliary Input Voltage	100 – 240 V_{AC} @ 50 – 60 Hz		
Auxiliary Input Power	350 W		
DC Input/Output Connection	Phoenix Contact HDFKW-95-F/7	Phoenix Contact HKH240F	Bus-bars
Max Interlock Rating (pin 6 – 7)	240 V – 16 A		
Max Enable Rating (pin 8, 9 & 10)	240 V – 10 A		
Total weight	28 kg	35 kg	
Dimensions	19" × 6U × 550 mm *w/out output connections*		
Input Fuses Mains 230 V	2 x IW 1421002 2 A – 500 V (38 x 10.3 mm)		
Input Fuses Mains 24 V	2 x IW 1421010 10 A – 500 V (38 x 10.3 mm)		

Precision Current Measurements

Precision Current Measurements

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Precision Current Measurements

High-Precision Current Measurement System

Comparison of Current Measurement Technologies

The **ZERO-FLUCS** principle was already discovered in the 1930 years and is up to today the most complex and overall most precise, most stable and most versatile current measuring method.

Characteristics/Capability	Shunt	Hall Effect Sensor	Current Transformer	Rogowski Coil	CAENels ZERO FLUCS DCCT
DC Currents	Yes	Yes	No	No	Yes
Bandwidth	Medium	Very poor	High	Very high	High
Insulation	No	Yes	Yes	Yes	Yes
Linearity	Medium	Very poor	Poor	Medium	Very high
Accuracy	Medium	Medium	Medium	Medium	Very high
Offset	Yes	Yes	No	No	No
High Currents	No	Medium	Medium	High	Very high
Magnetical Saturation	No	Yes	Yes	No	No
Temperature Stability	Medium	Poor	High	Very high	Very high
Power Consumption	High	Low	Low	Low	Medium
Dimension	Very small	Small	Small	Medium	Medium
Long Term Stability	Poor	Poor	Poor	Very good	Very good
Automotive Interface Ability	Difficult	Possible	Difficult	Possible	Possible

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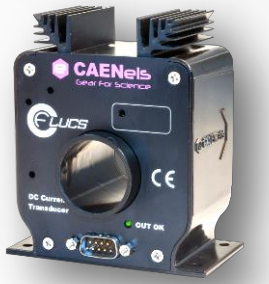
FLUCS
DCCT SERIES

Precision Current Measurements

CT-13 CT-26 CT-52
(PCB Mountable)

CT-100 CT-150



CT-200 CT-300 CT-400
CT-600 CT-1000

System CT-BOX plus CT

The Features

- **AC- and DC-** measurements separately or combined
- Standard Accuracy: **< 100 ppm (< 0,01%) FS** / High-Accuracy Calibrated System: **< 50 ppm (< 0,005%) FS**
- **Voltage Output Versions:** Standard Accuracy: **< 2.500 ppm (< 0,25%) FS**, Optional Accuracy: **< 500 ppm (0,05%) FS**
- Temperature Coefficient: **< 1 ppm/K FS**
- High-Linearity: **< 3 ppm/FS**
- Input Noise: **< 1.5 ppm at 200 Hz, < 10 ppm at 50 kHz**
- Excellent AC-Amplitude and Phase response **up to 500 kHz**
- **24-bit @ 100 kSPS** sampling
- Current Transformer Ratio: I_S/I_P **from 1:250 up to 1:2000** as standards
- Display: **7 1/2 Digits**

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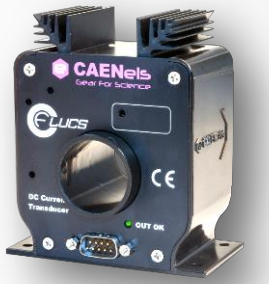
FLUCS
DCCT SERIES

Precision Current Measurements

CT-13 CT-26 CT-52
(PCB Mountable)

CT-100 CT-150



CT-200 CT-300 CT-400
CT-600 CT-1000

System CT-BOX plus CT

The Features

- Galvanic Insulation Primary to Secondary
- External Temperature Sensors (for temperature monitoring)
- Fanless
- **microSD** for data storage (also for long-term measurements)
- Analog Monitoring (±10 V)
- **CT-Viewer Software** free and included
- Trigger Input/Output and Alarm Output
- Interfaces: **Ethernet 10/100 Mbps TCP-IP, USB 2.0, RS-232**
- All Cables **included**

PS1215 bipolar power source for DCCTs available!

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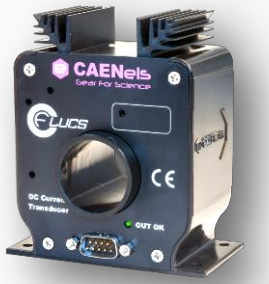
FLUCS
DCCT SERIES

Precision Current Measurements

CT-13 CT-26 CT-52
(PCB Mountable)

CT-100 CT-150



CT-200 CT-300 CT-400
CT-600 CT-1000

System CT-BOX plus CT

Customization Services - *higher quantities or additional charge*:

- Custom Specific Transformer Ratios, i.e. 1:423 (primary current = 42.3 A / secondary current = 100 mA)
- Custom Specific Current Values > 1 kA: up to 30 kA
- Expansion of primary hole diameter up to 80 mm
- Up to 150 A PCB-mountable versions possible

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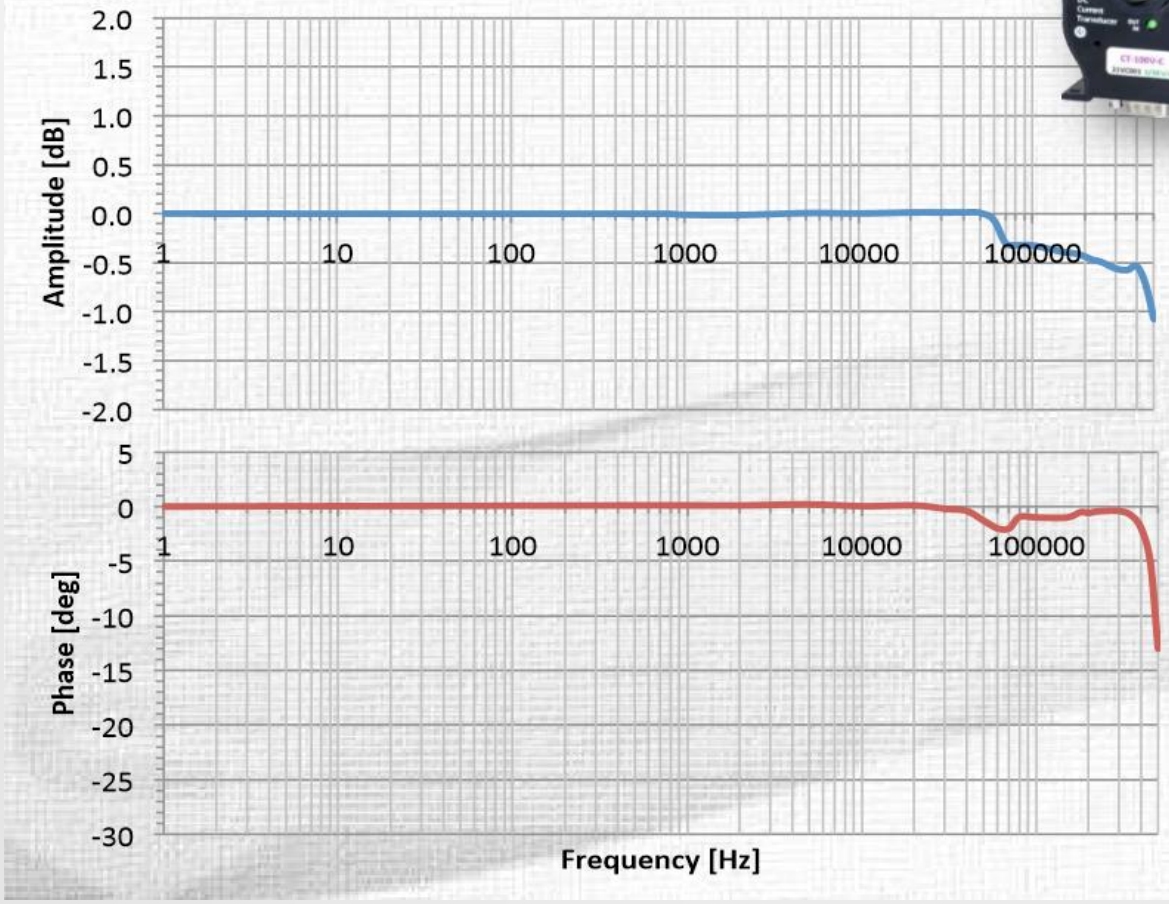
FLUCS
DCCT SERIES

Precision Current Measurements

AC Performance

- CT-150 Amplitude and Phase Response



Amplitude Response

Frequency	Amplitude
DC ... 50 kHz	< 0.02 dB
50 ... 200 kHz	< 0.5 dB
200 ... 400 kHz	< 1 dB

Phase Response

Frequency	Phase Shift
DC ... 2 kHz	< 0.1°
2 Hz ... 40 kHz	< 0.5°
40 ... 400 kHz	< 2°

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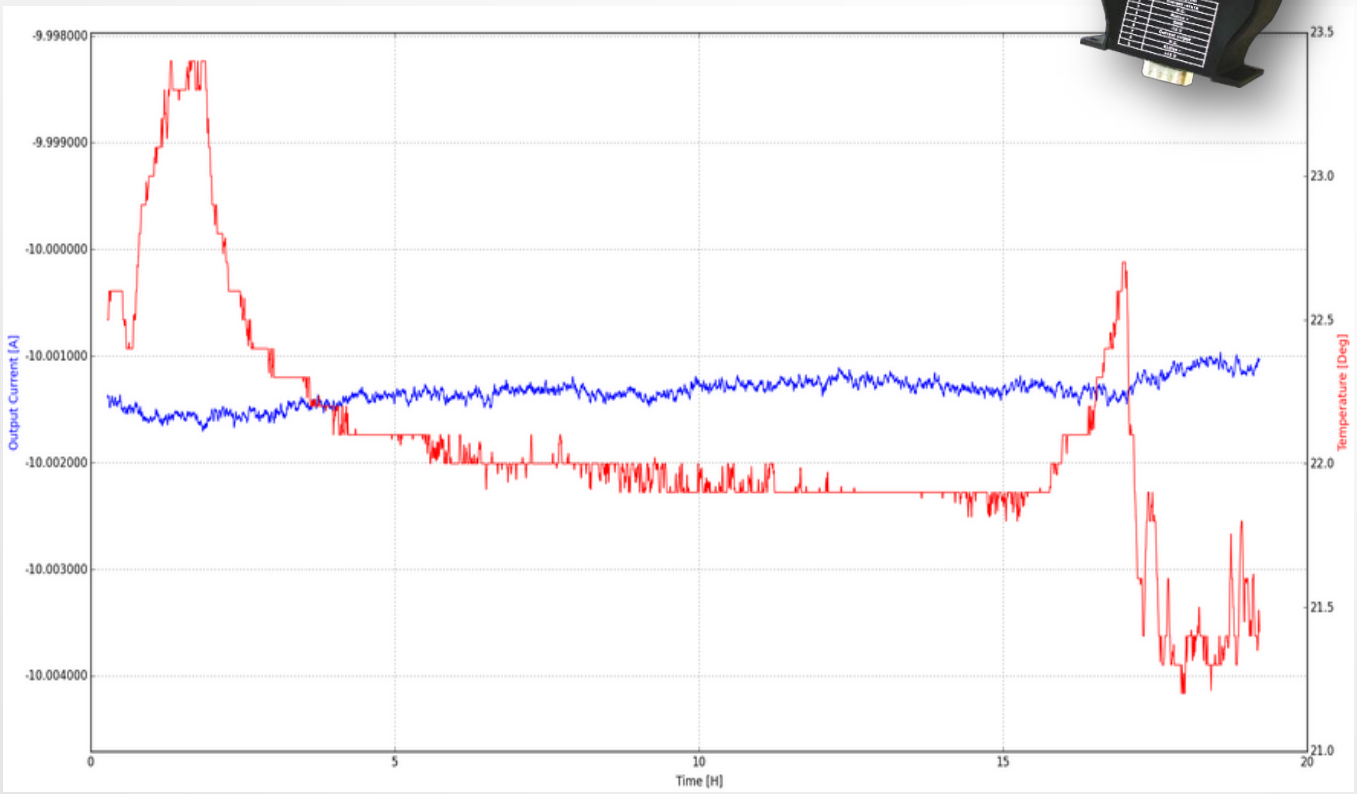
Precision Current Measurements

Temperature Stability (Example):



Temperature Stability over 19 hours:

Temperature
21.2 °C to 23.4 °C

Current Measurement
-10.0023A to -10.0030A

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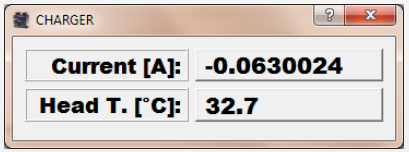
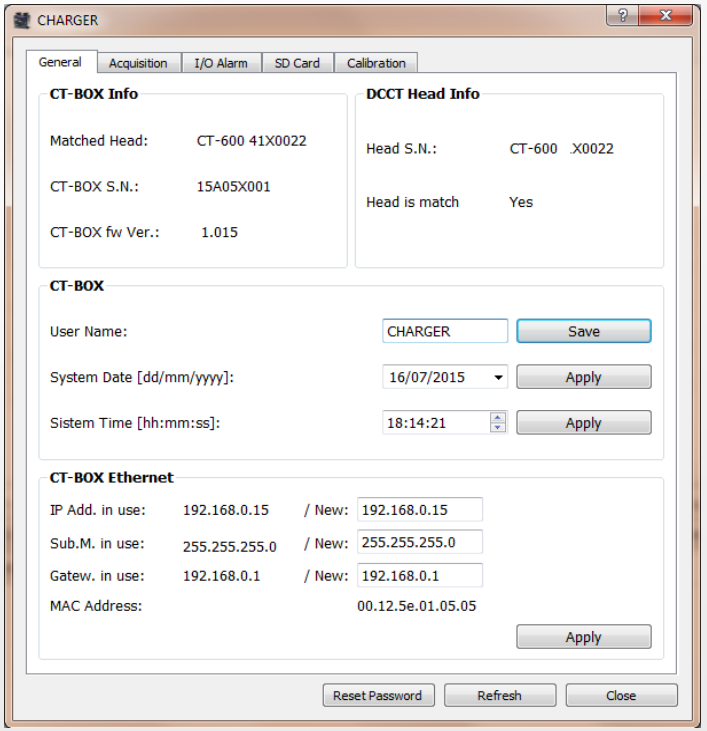
FLUCS
DCCT SERIES

Precision Current Measurements

CT-BOX

CT-Viewer Software





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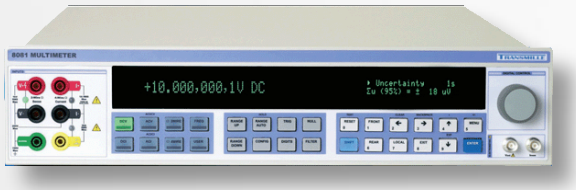
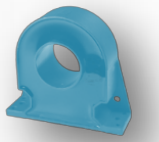
FLUCS DCCT SERIES

Innovation

Usual Measuring System

Digital Multimeter (7,5 digits or higher) + DCCT





- ✗ several times higher costs
- ✗ non-calibrated system – imprecise measurements
- ✗ high quality cables must be purchased separately
- ✗ lower frequencies up to max. 100kHz possible
- ✗ no data storage possible
- ✗ no easy transportation
- ✗ no easy installation
- ✗ no specific software solution

CT-BOX System

- ✓ lower costs
- ✓ system calibrated
- ✓ cables included
- ✓ frequencies up to 500 kHz
- ✓ data storage via SD (included)
- ✓ compact system
- ✓ 19"- rack mount available
- ✓ monitoring software inclusive

Beamline Electronic Instrumentation

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Beamline Electronic Instrumentation

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Beamline Electronic Instrumentation

AH401D

4-channel Charge Integration Picoammeter

Photon BPM applications:

- *Quad-diode BPM´s*
- *Diamond detectors readout*
- *ion chambers*
- *blade gap monitors*
- *radiation monitors*

- 7 different ranges – from 50 pC to 2 nC (monopolar)
- settable integration time: from 1ms to 1s
- 20 bit + low-noise
- Ethernet connectivity
- User-friendly software for photon BPM applications provided
- TTL trigger/gate input signal and output conversion signal → external events

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Beamline Electronic Instrumentation

AH501D

4-channel Bipolar Picoammeter with Bias Voltage Source

Photon BPM applications:

- *Quad-diode BPM´s*
- *Diamond detectors readout*
- *ion chambers*
- *blade gap monitors*
- *radiation monitors*

- 3 different ranges - ±2.5 mA , ±2.5 µA, ±2.5 nA
- sampling frequency – up to 26 kHz (1 channel @ 16-bit)
- 16- or 24-bit resolution
- Ethernet connectivity
- Bias up to 30V (sub-mV RMS noise)
- User-friendly software for photon BPM applications
- TTL gate input signal and output conversion signal → external events

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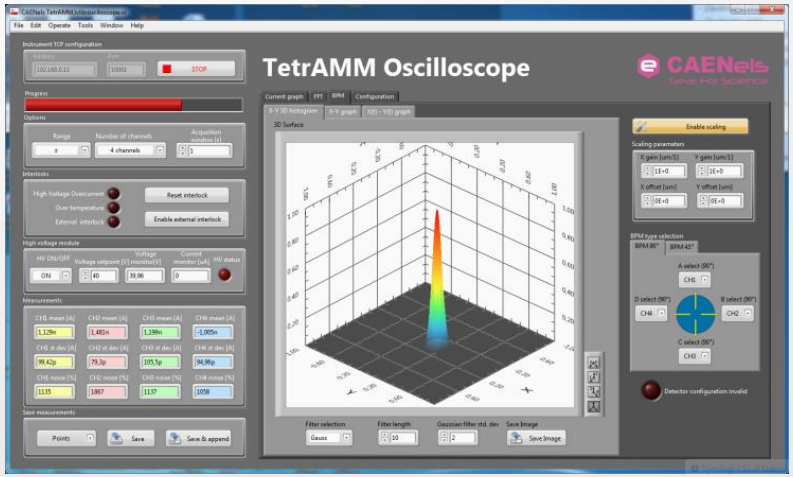
Beamline Electronic Instrumentation

TetrAMM

4-channel Fast-Interface Bipolar Picoammeter with Integrated HV

- 2 different full-scale ranges: ±120 µA and ±120 nA (configurable)
- Internal sampling: 100 kHz@24 bit
- Firmware Remote Update
- Configurable Sampling Frequency
- Automatic independent ranging
- Gigabit Ethernet connectivity
- 500V standard HV bias (up to 4 kV)
- Factory calibration
- FPGA and soft-processor computations
- User-friendly software for photon BPM applications
- Different trigger/gate and configuration → external events



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Power Supply Systems

TetrAMM and AH501D

Comparison

	TetrAMM	AH501D
Standard Ranges	±120 nA to ±120 µA (standardly)	±2.5 nA, ±2.5 µA ±2.5 mA (fixed)
Resolution	24 bit: 15 fA to 15 pA (standardly)	14 bit: 300aA, 300fA, 300pA (fixed)
Ranges customizable	✓	X
Independent Ranging	✓	X
Auto Ranging	✓	X
Sampling Frequency	up to 100 kHz (configurable)	up to 26 kHz **(configurable???)**
Analog Bandwidth	5 kHz	?????
Monitoring	Digital, Plug & Play GUI	Voltage Analog Monitoring (±5V)
BIAS Voltage	Optional: up to 6kV	0 to 30V (integrated)
BIAS Voltage RMS Noise	<2ppm ???	<30ppm
Communication Interface	10/100/1000 Ethernet, SFP	10/100 Ethernet TCP/IP and UDP
Temperature Coefficient	RNG0: <10ppm, RNG1: <20ppm	???
External Signals	Configurable Trigger/Gate, Trigger Output, External Interlock	Trigger/Gate input, CONV output

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Beamline Electronic Instrumentation

TetrAMM-CI

4-channel Fast-Interface Charge-Integration Electrometer (Integrated HV)

- 8 different full-scale ranges: from 50 pC to 2 nC
- Internal sampling: 1 ms – 50 µs
- Firmware Remote Update
- Configurable Integration Period
- Gigabit Ethernet connectivity
- 500V standard HV bias (up to 4 kV)
- Factory calibration
- FPGA and soft-processor computations
- User-friendly software for photon BPM applications
- Different trigger/gate and configuration → external events

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Beamline Electronic Instrumentation

HV-ADAPTOS: High-Voltage ADAPTive Optics PS System

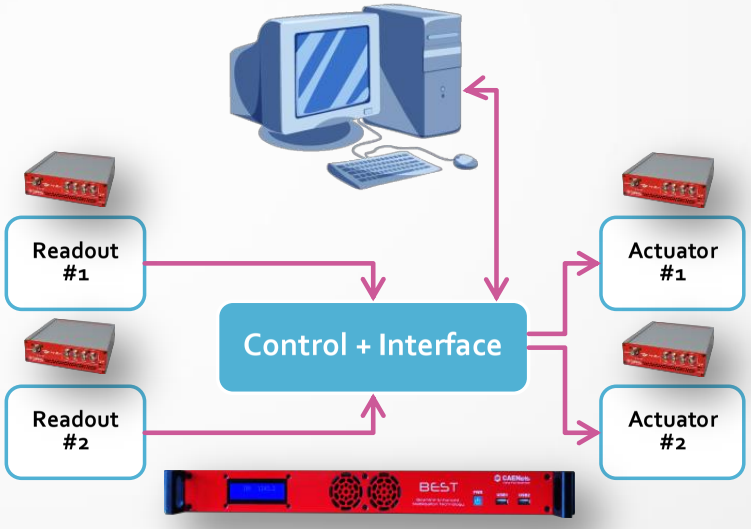
Multi-channel HV PS System:

- *Designed for bimorph mirrors operation*
- *Dedicated integrated control software*

- can control up to 2 mirrors (and up to 48 HV channels)
- bipolar channels rated at ±2kV@±0.5mA
- proprietary creep and hysteresis control and minimization routines
- Web Server application with mirror dedicated software
- standard 10/100/1000 TCP-IP Ethernet connectivity - EPICS IOC

BEST

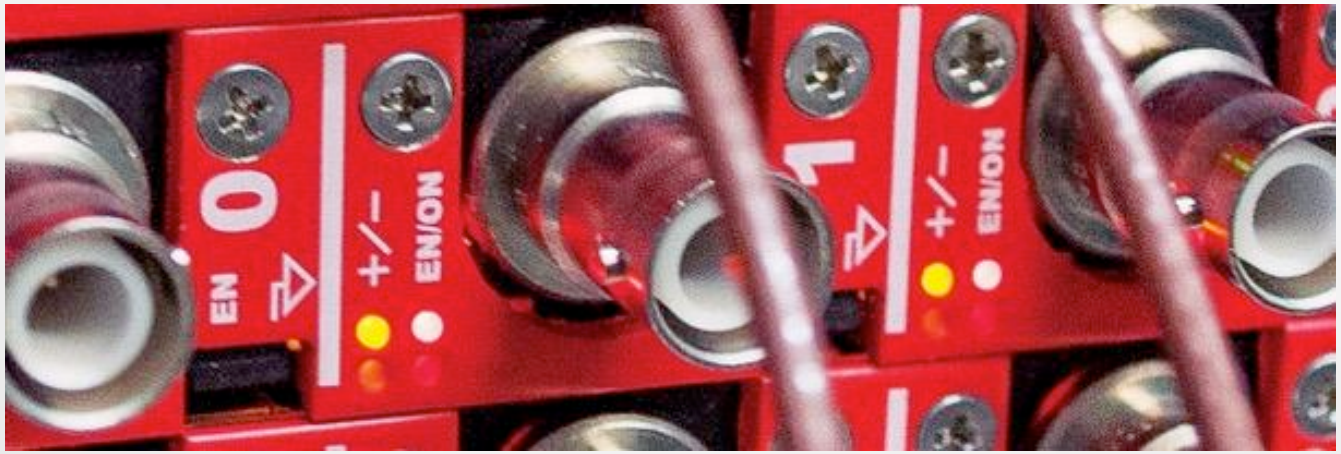
Beamline Enhanced Stabilization Technology



- Powerful **Instrumentation and Software Suite** for stabilization and optimization of photon beam (X, Y, Io)
- System composed by three main building blocks:
- readout block - **TetrAMM**
- control and interface block – **BEST** Central Unit
- actuator block – **PreDAC**
- Expandability → up to two phBPMs and two piezoelectric actuators (monochromators)
- Low-latency and high speed guarantees higher frequency compensation respect to "standard" local feedback implementations (software based)

FMC and MicroTCA

MicroTCA.4 for Physics



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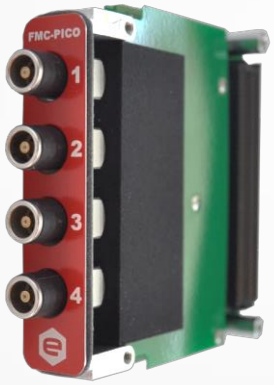
FMC and MicroTCA



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FMC and MicroTCA

What is FMC and MicroTCA?

FMC (FPGA Mezzanine Card) is an **ANSI/VITA standard** that defines **I/O mezzanine modules** with connection to an **FPGA** or other device with re-configurable I/O capability. **It specifies a low profile connector and compact board size** for compatibility with several **industry standard** slot card, blade, low profile motherboard and mezzanine form factors.

MicroTCA or **µTCA** is an environment originated from the development of telecommunications hardware architectures.

It is a standard describing **a new class of modular computer systems** that is **more energy-efficient, compact and economical** than the **ATCA (Advanced TCA)**.

MicroTCA was developed exploiting many of the advantages of ATCA/AMC and was designed with maximum re-usability, so that **many AMC boards originally developed for ATCA can also be used in MicroTCA systems**.

The system uses serial high-speed connections (e.g. PCIe protocol, Gigabit Ethernet), system monitoring and efficient cooling as well as redundancy concepts, representing **the highest-performance solution for applications in telecommunication, industry, medical and military technology**.

ATCA

Innovation

MicroTCA

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FMC and MicroTCA

MicroTCA TECHNOLOGY LAB
A HELMHOLTZ INNOVATION LAB

driven by DESY

Development, Manufacturing and Distribution Partners:

CAENels Gear For Science

elspec group GmbH

N.A.T.

struck innovative systeme

PENTAIR

powerBridge Computer

ROHDE&SCHWARZ

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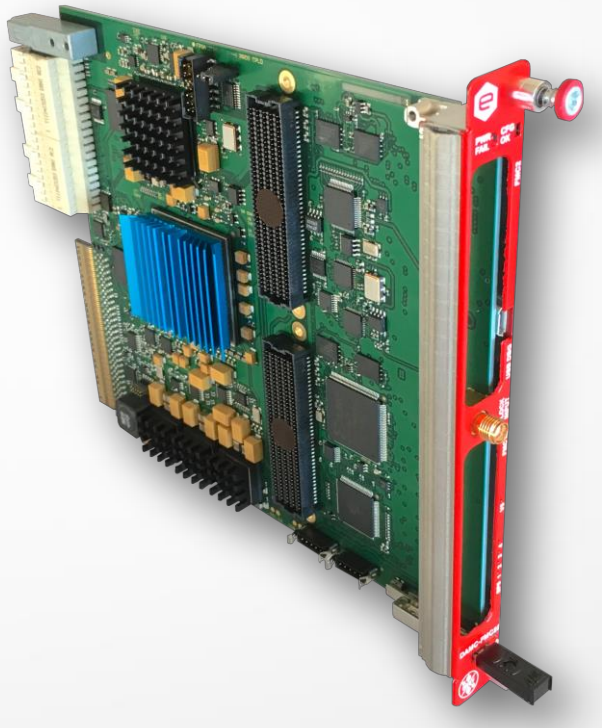
FMC and MicroTCA

DAMC-FMC25

AMC Dual High-Pin Count FMC Carrier Board

- Double width AMC board – MTCA.4 carrier
- Two HPC FMC slots
- Data processing on Virtex-5 FPGA
- Board management on Spartan-6 FPGA
- RTM D1.1 connectivity
- DDR2 memories on both FPGAs
- External clock input on front panel SMA connector
- 6.5 Gbps ("-2") transceiver board options



DESY

µTCA® Turnkey solution with dual 4-channel (8-channel) floating picoammeter AVAILABLE!

License Agreement LV75 between DESY and CAEN ELS

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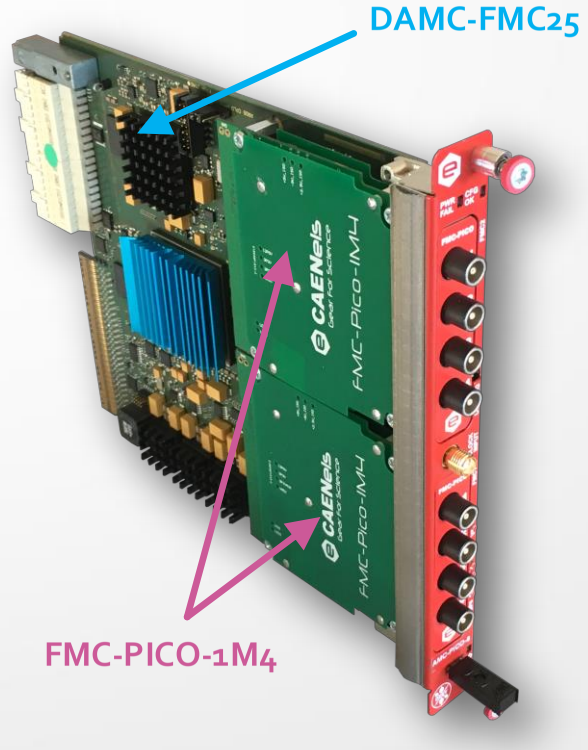
FMC and MicroTCA

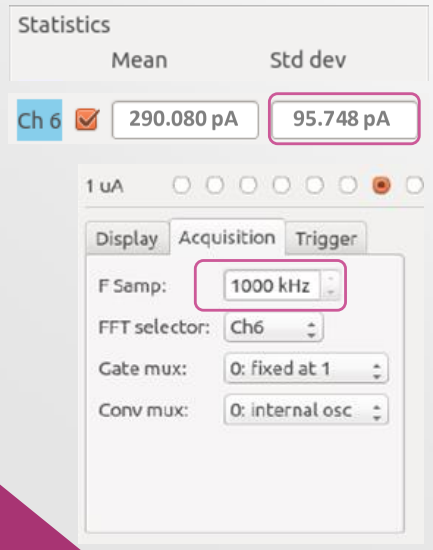
AMC-PICO-8

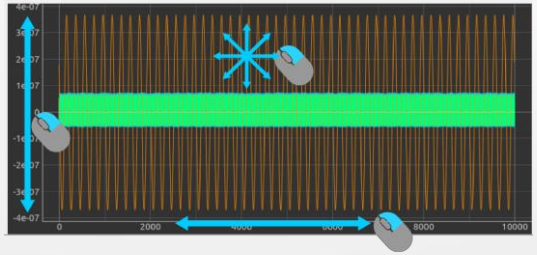
8-channel 20-bit 1 MSPS bipolar current-input AMC picoammeter

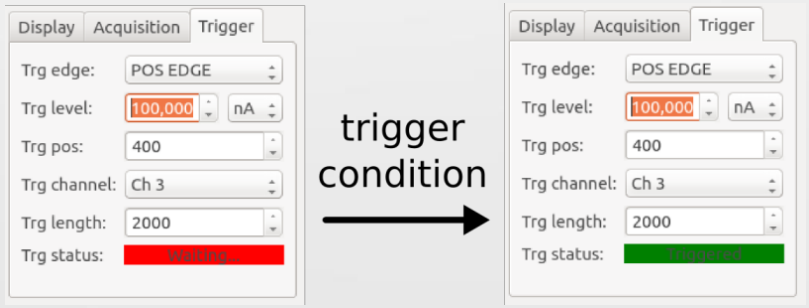
- 1 MSPS 20-bit simultaneous sampling (8-channels)
- Inputs floating up to 300 V
- Trigger/Oscilloscope functionality
- Based on the DAMC-FMC25 carrier designed by DESY
- 2 picoammeter FMC-Pico-1M4 supported
- BSP, GUI and drivers available



Avoids ground loops if two different detectors are connected
to the same DAMC-FMC25 - e.g. quadrature detectors







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FMC and MicroTCA

HV-PANDA

HV Positive And Negative Double-width AMC

- Double-Width AMC Board – Full Size
- MTCA.4 carrier
- Four High-Voltage channels
- Output ratings:
  - 500 V @ 1.5 W
  - 4 kV @ 7 W
  - 6 kV @ 6 W
- Polarity selectable
- Provides infrastructure for management of optional Rear Transition Module (RTM) boards – class D1.1
- DDR3 On-board Memory (up to 4 Gbit)
- Separate Interlock for each channel and global one
- Stand-by voltage, Ramping, Current Monitoring and Current Limit

Cooperation with DESY in the Helmholtz Validation Fond Project «MTCA.4 for Industry» (**HVF-0016**)

FMC-PICO-1M4

4-channel 20-bit 1 MSPS bipolar FMC picoammeter

- Standard FMC - Vita 57.1
- Bipolar current-input stage
- **Two standard measuring ranges** (±1 mA and ±1 µA)
- **CUSTOMIZATION of ranges** upon request
- 20-bit resolution
- Up to 1 MSPS
- **Floating up to ±300 V**
- Extremely low unbalance between channels (by analog design)
- I2C EEPROM calibration

FMC-Pico-1M4-20

Equivalent Input Noise		
	RNG0: ±1 mA	**RNG1: ±1 µA**
F_S = 2 ksps	1 ppm/FS -120 dB	2.5 ppm/FS -112 dB
F_S = 20 ksps	2 ppm/FS -114 dB	7 ppm/FS -103 dB
F_S = 200 ksps	5 ppm/FS -107 dB	10 ppm/FS -100 dB
F_S = 1 Msps	8 ppm/FS -102 dB	15 ppm/FS -96 dB

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FMC and MicroTCA

FMC-SFP+

Dual- and Quad-channel SFP/SFP+ FMC Adapter

- Dual-channel and Quad-channel versions
  - **FMC-2SFP+**
  - **FMC-4SFP+** (w/out FMC bezel)
- Wide I/O operating range: VADJ can vary from 1.5V to 3.3V
- Tested **up to 10 Gbps / channel**
- True level conversion of all SFP+ module pins including I2C lines
- I2C-controlled Oscillator (10-280 MHz)
- Compatible with the DAMC-FMC25 carrier board
- Produced and supported by CAEN ELS
- Designed by DESY

2-channel version

4-channel version

License Agreement LV75
between DESY and CAEN ELS

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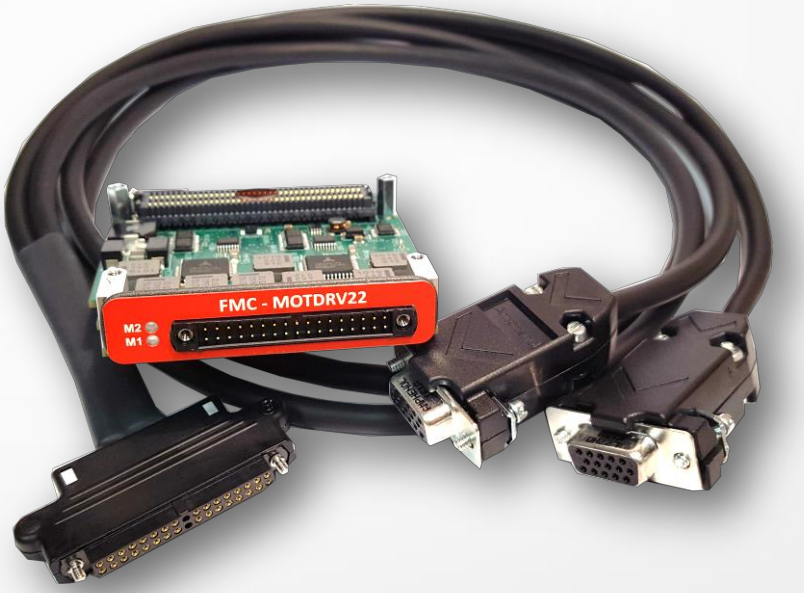
FMC and MicroTCA

FMC-MOTDRV22

Dual-channel FMC Stepper Motor Driver

- Dual-channel stepper motor driver
- Supports up to **1.8 A motor coil current**
- Three different versions
  - 12-V internal supply
  - 12-V external supply
  - 24-V external supply
- Compatible with the DAMC-FMC25 carrier board
- Produced and supported by CAEN ELS
- Designed by DESY



FMC-MOTDRV22 and cable

License Agreement LV75
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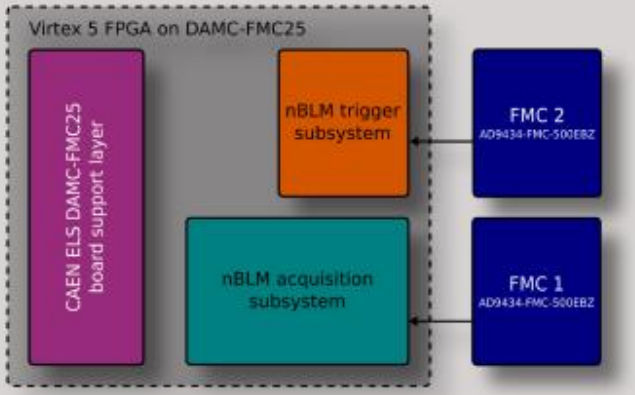
Custom Developments - Examples

DAMC-FMC25 with AD9434-FMC-500EBZ boards



The two AD9434-FMC-500EBZ boards provide two analog inputs sampled at 500 MS/s and 12-bit resolution.
A custom FPGA application was developed to identify and capture specific events.

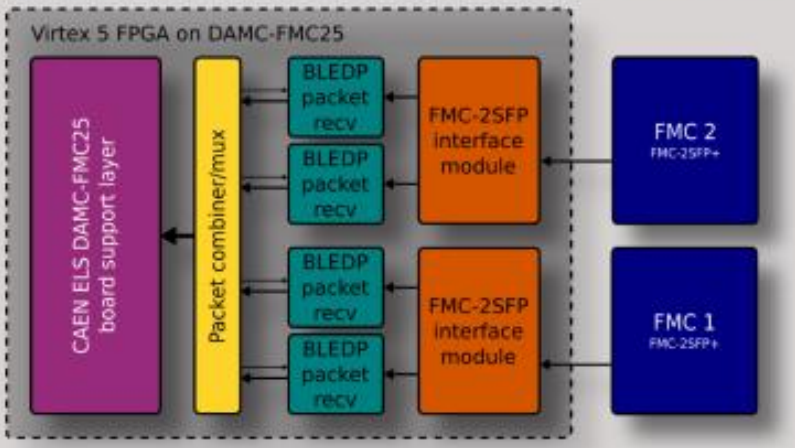
DAMC-FMC25 with 16-channel 125 MS/s ADC and GPIO boards

The 16-channel 125 MS/s ADc board with 14-bit precision can be used to monitor the status of the system, while the GPIO board can be used as an interface to various external devices.

Combined with the advanced processing power of the FPGA, this system can be used in all applications where a fast response time of entire system is needed.

Custom Developments - Examples

DAMC-FMC25 with FMC-2SFP+ boards



The two FMC-2SFP+ boards allow communication with up to four (4) fast links at 6.25 Gbps on the DAMC-FMC25. These links can be used to develop a data aggregation board together with post-processing on the FPGA.

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Newest Developments

Water cooled modules up to 200A up to 60V (based on the NGPS architecture). Realized in 2018.

Water cooled systems at 420A with polarity inverter switch (bipolar architecture, based on the NGPS). Realized in 2018.

Paralleling of up to 4 Fast-PS-1K5. Available since 2018.

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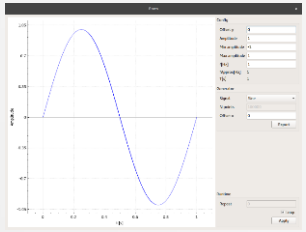
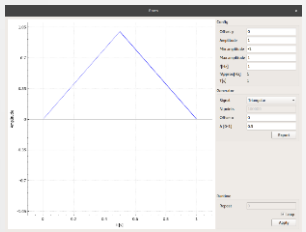
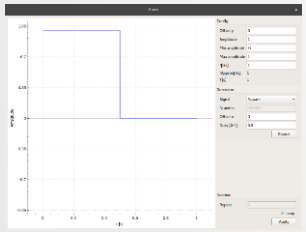
Developments 2018/2019

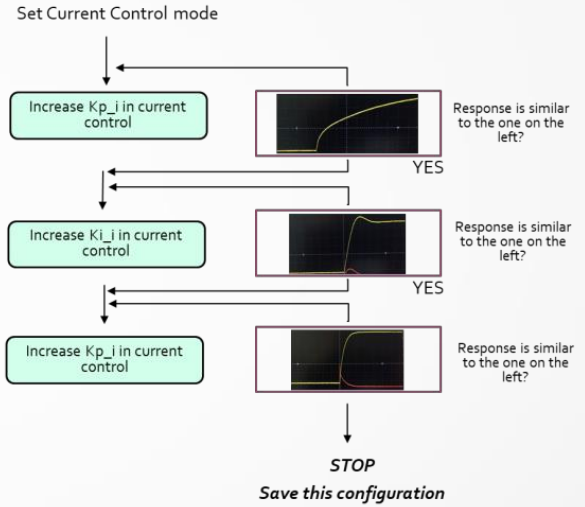




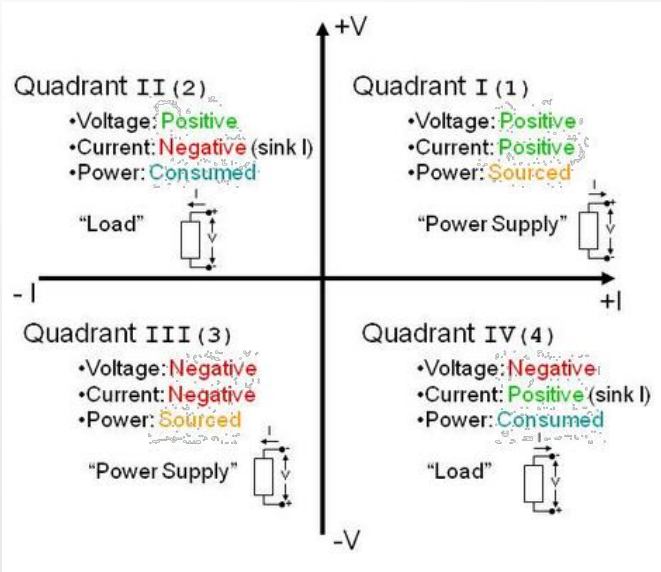


Arbitrary Waveform Generator + Embedded Oscilloscope for the Fast-PS family and NGPS. Available since 2018.

Autotuning function for the Fast-PS family and NGPS. Planned for summer 2019.



Regenerative Full-4-Quadrant Source based on Fast-PS-1K5. Planned for summer 2019.



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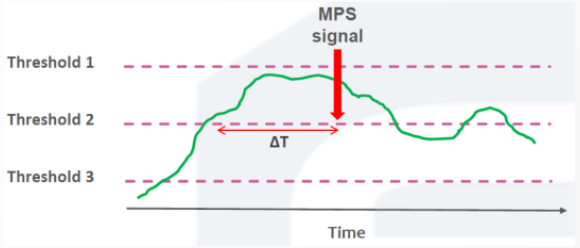
Newest Developments

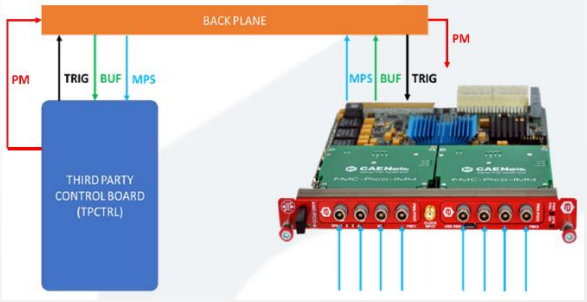
1 HU Full 4-Quadrant Control Board – for the adaption to and control of any power stage.

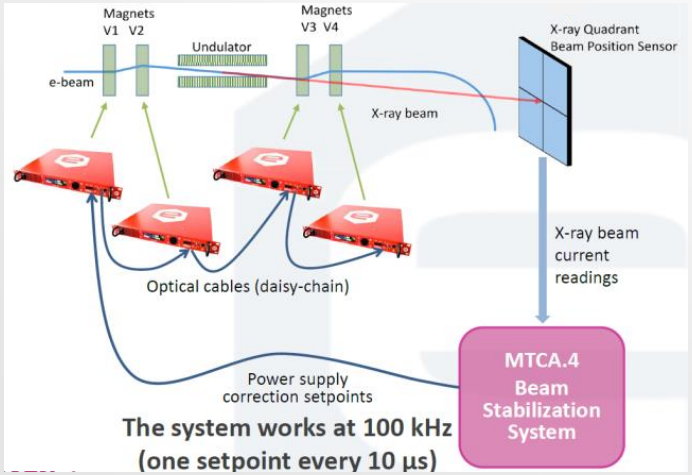
Planned for summer 2019.



Beamline Machine Protection System based on MicroTCA technology.

Planned for end of 2019.





Beamline Stabilization System based on MicroTCA technology in combination with Fast-PS .

Already under test at Diamond Light Source.

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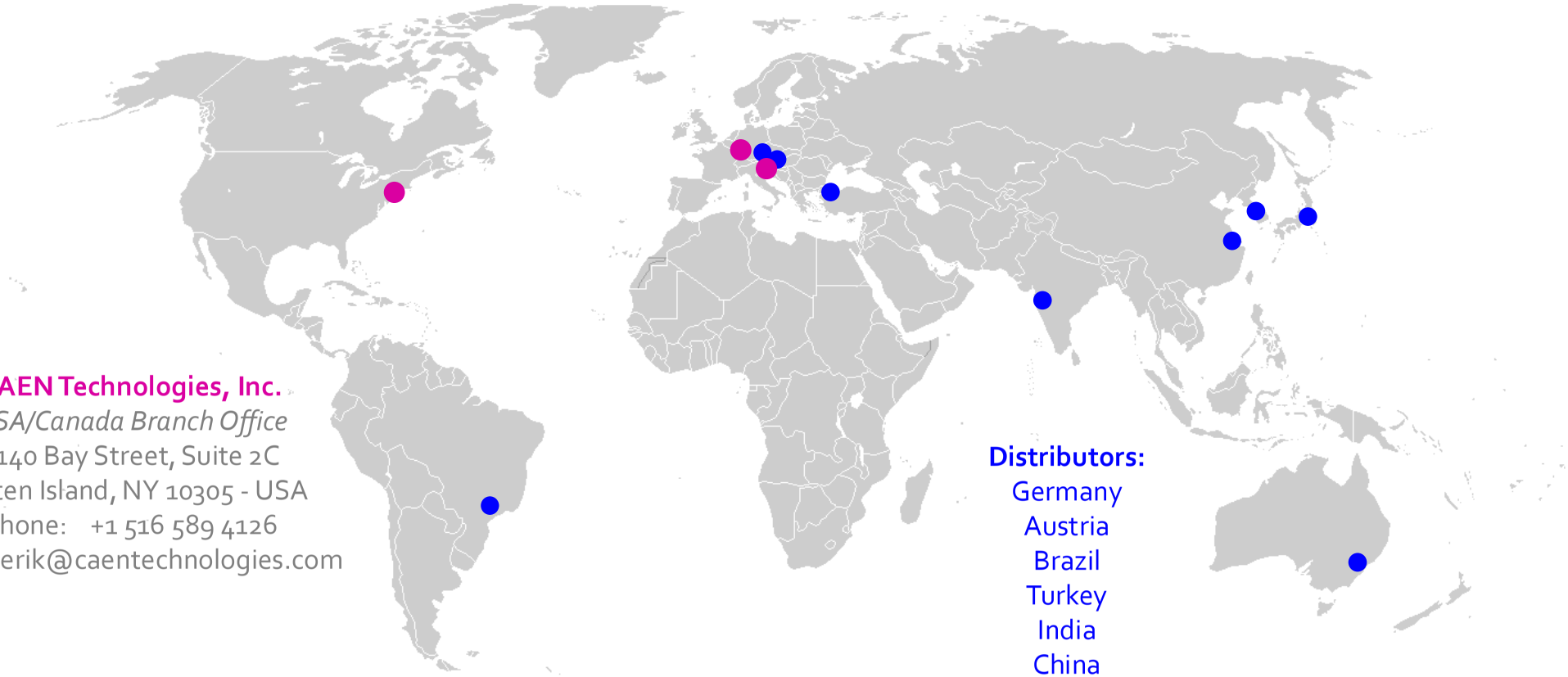

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