

# Integrating Controllable DC Power Sources into Modern Industrial Tools and Systems

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# Agenda

- Company Overview
- Controllable Power in Industrial Processes
- Typical Solutions Employed Today
- Modern, Scalable Solutions for Controlled DC Power
- Reliability Assurance
- Accuracy & Precision
- Cooling
- Control Interface
- Summary

# AstrodyneTDI Company Overview



- Privately held company with over 50 years in power industry focused on the Semiconductor, Industrial, Medical, Military & Aerospace Markets
- 500+ employees worldwide, over 10% engineers or technical professionals
- Experts in design and manufacture of innovative High Power, Low Power, and EMI Filter Solutions
- USA and China Engineering design centers
- USA and China wholly-owned Manufacturing
- In-house rigorous testing and agency certifications



# Controllable Power in Industrial Processes



## Many processes depend on control of a DC Power Source to provide their product...

- Controlled Heat derived from Electricity (e.g., Semiconductor Fab, Metal Treatment)
- Controlled Magnetic Field (e.g., Electron Beam Steering in Semi or Medical Treatment)
- Controlled Electric Field (e.g., Chemical Processing, Impressed Current Cathodic Protection)
- Controlled Current Source (e.g., Battery Charging)





# Typical Requirements

- **Significant Amounts of Power**
  - Often as high as 20-100kW, or more
- **Wide Output Control Range**
  - Typically 20-100% of maximum rated voltage, current or power
- **High Degree of Precision and Stability on Delivered Output**
  - Delivered Voltage, Current or Power to 1000ppm, or better, of programmed value
- **High Degree of Precision and Stability on Read-back of critical parameters**
  - Voltage, Current, Power, Temperature to 1000ppm, or better, of actual value
- **Support highly inductive loads or loads which vary significantly with operating conditions (e.g., Resistive Heaters)**

# Typical Requirements

- **Remote Control via Serial Digital Interface**
  - Low latency programming and read-back – as fast as 5-10ms
- **Input Voltage 380-480VAC, 3-phase Delta**
  - Power Factor  $>0.94$  (sometimes  $>0.98$ )
- **High Demand for Reliability in Critical Processes where valuable WIP (\$\$) or Lives (♥♥) are at stake**
  - Delivered MTBF  $> 500,000$  hours
- **Modularity**
  - Scalable solutions with easy installation and maintenance
- **Compact Size**
  - $>1000\text{W/L}$  ( $>16\text{W/in}^3$ )  $\rightarrow$   $>16\text{kW}$  per Rack Unit Power Density

# Typical Solutions

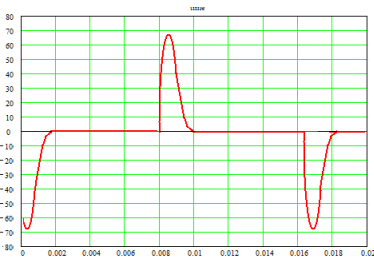
## Non-isolated thyristor or SSR chopper

- Thyristors are controlled by modulating their firing angle back from  $180^\circ$
- Load must be well isolated from ground
- Simplest, Low Cost Strategy

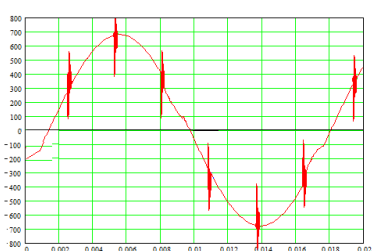
### • Issues

- Extremely low Power Factor and High AC Line Harmonics
  - Cost of electrical power being utilized
- Noise generated by switches connected directly to AC line can cause malfunctions in other connected equipment
  - Dependability of power control function
- Complex delivered voltage waveshape is difficult to quickly and accurately measure RMS value
  - Accuracy and speed of delivered power

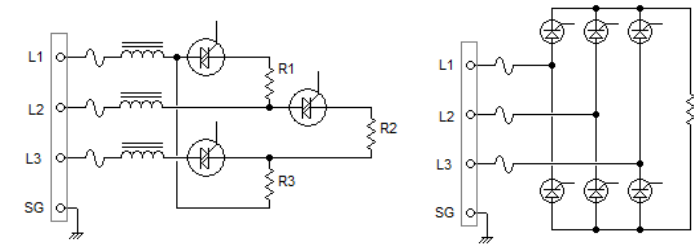
Phase Current:



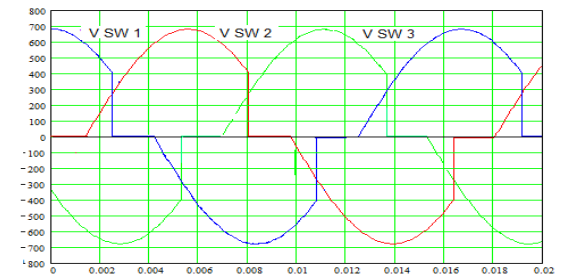
Noise on AC Line:



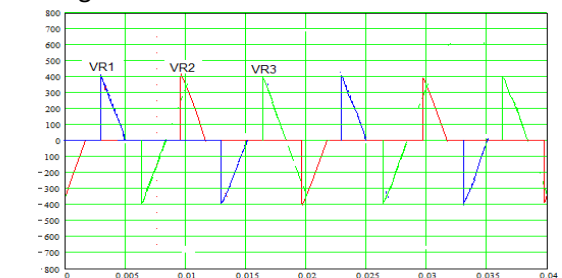
Circuit Examples:



Voltage across Switch:



Voltage Delivered to Load:



# Typical Solutions

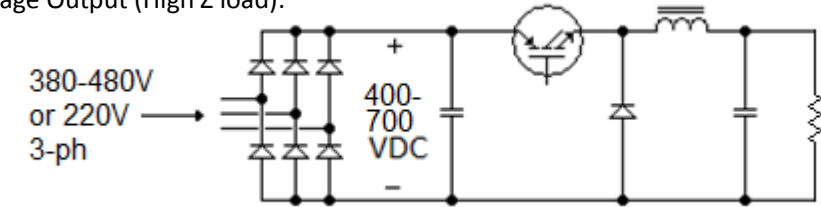
- **Chopper Rectifier**

- 3-ph AC Input to DC Output
- Typically realized with small number of high power semiconductors operating at modest switching frequency ( $\ll 20\text{kHz}$ )
- DC Output easy to control and measure
- Low AC Line Harmonics and high power factor (0.94, or greater) can be realized

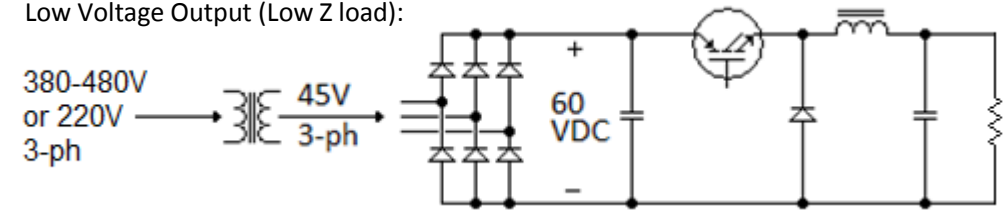
- **Issues**

- Size and cost
  - Typically monolithic with no Granularity or Scalability
  - High MTTR
  - Utility Line Frequency Magnetics are Large and Heavy
  - EMC Management can be Challenging

High Voltage Output (High Z load):



Low Voltage Output (Low Z load):





# Typical Solutions

- **Laboratory-Grade High Frequency Switch Mode (HFSM) Power Supplies**

- Good Adjustability and Precision
- Generally available with 380-480VAC input (PF >0.9)

- **Issues**

- Size & Cost –
  - typically < 300W/liter / >3U High
  - Typically expensive (\$\$\$)
- Implementation and Maintainability
  - Back panels not laid out to easily support multiple units
  - Excessive MTTR if something goes wrong
- Cooling Options
  - Liquid-cooled options to support high power are limited
- Limited Remote Control Options
  - Sometimes limited to analog interface
  - Serial Digital Interfaces may not be in alignment with modern system needs (e.g., EtherCAT)



# Modern, Scalable Solutions for Controlled DC Power

- **Solutions specially designed to address the issues of...**

- Power Conversion System Size / Cost
- Scalability
- Reliability
- Non-common Output Voltages
- Delivered Precision
- Control Interface - Bandwidth/Speed
- AC line harmonics
- AC line noise susceptibility
- Physical Constraints – Cooling
- Maintainability

“Mercury-Flex” AC-DC Power system Air-cooled / 15.2kW in 2U High Space



Modularized, Industrial-Grade Power  
Converters Optimized for Controlled DC Power



“LiquaBlade” AC-DC Power Module - Liquid-cooled / 16.5kW in 1U High Space

# Mercury Flex and LiquaBlade Common Features

- **Cost-Effective, High Reliability Solutions for Demanding Industrial & Semiconductor Applications**
- **Scalable – can be paralleled to support >100kW delivered power**
  - Mechanical Design facilitates stacking of units
- **Wide Range Controllable Output via CV, CC or CP control via High Speed Serial Digital Interface**
- **Wide Selection of Maximum Output Voltages ranging from 28V to 500V**
- **Blind-Mate, Warm-Swap Compatible – low MTTR**
- **Typical Delivered V or I accuracy to 0.1% FS**
- **Full Power Factor Correction for Low AC Line Harmonics (compliant with EN61000-3-2)**
- **380-480VAC/3-ph or 220-240VAC Models Available**
- **Air-Cooled or Liquid-Cooled Solutions**

# Mercury and Mercury Flex

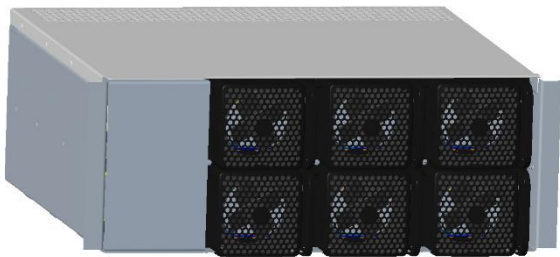
11kW of Delivered Power in 2U Shelf (525W/L) / 230VAC Input (3ph) with Local Touch Pad Control and Metering



Up to 15kW of Delivered Power in 2U Shelf (715W/L) / 230VAC Input (1ph or 3ph)



Up to 22.8kW of Delivered Power in a 4U Shelf / 380-480VAC 3-phase input



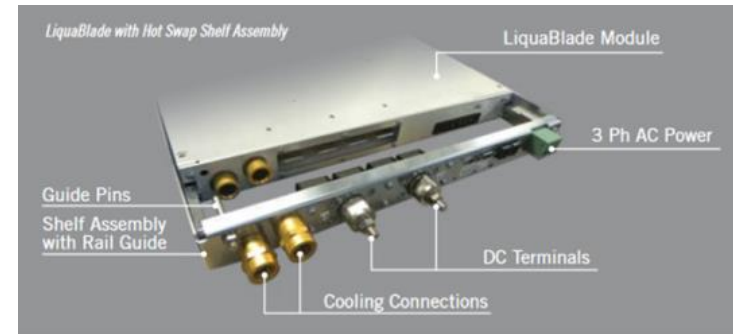
## Latest Generation Air-Cooled AC-DC Power Supply

- Modular / scalable product
- Up to 15kW in 2U Rack-mount Shelf
- Blind-mate / hot plug compatible – Low MTTR
- 190-240VAC or 380-480VAC Nominal Input
- Wide Range 0-28V, 0-56V, 0-125V, 0-250V, 0-450V Models
  - Wide range output provides flexibility to service multiple applications (Constant Voltage, Constant Current or Constant Power)
- Full Power Factor Correction (Low Input Harmonic Currents)
- SEMI F47 Compliant with 20ms Holdup at Full Power
- Rugged Design – Mercury Rectifiers are utilized in numerous High End Industrial and Military Programs where they have been qualified to shock and vibration standards such as MIL-STD-810
- On-board CAN bus and Shelf-Level Ethernet Controller
  - Other Control Interface options available



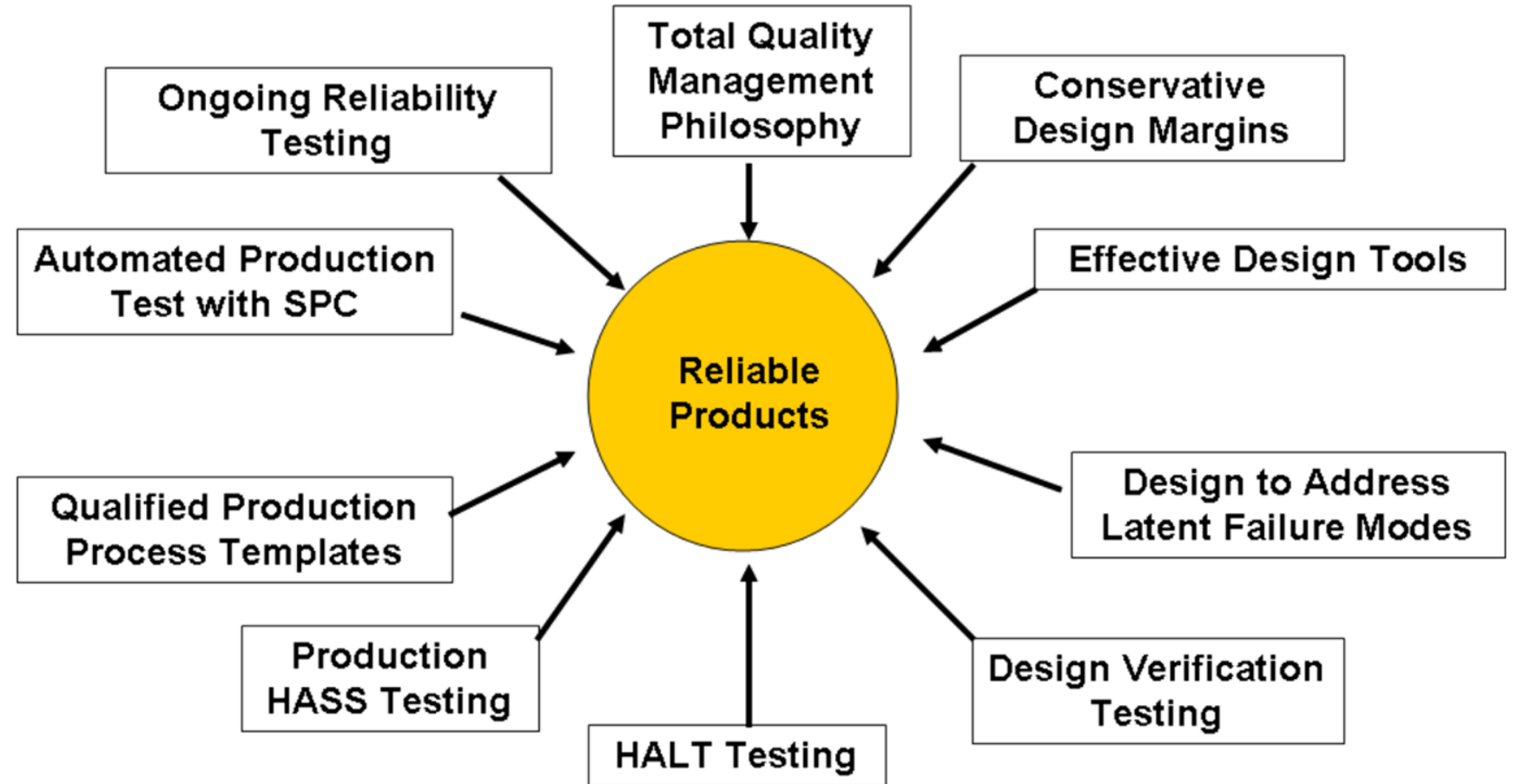
# LiquaBlade™ Liquid-Cooled Power

- **LiquaBlade Liquid-cooled AC-DC Power Supply**
  - Modular / scalable product
  - Patented liquid-cooling technology
  - Blind-mate / hot plug compatible
  - 16.5kW per U of Rack Space (1200W/L)
  - 380-480VAC/3-ph or 200-240VAC/3-ph Models
  - Wide range output suited to process control applications (0-60V, 0-120V, 0-180V, 0-500V)
  - 25-30% of the size and weight of conventional line frequency systems
  - Full power factor correction (Low AC Harmonics)
  - SEMI F47 Compliant
  - Leading Edge Silicon Carbide Mosfet Transistors
  - Proprietary magnetic element design
  - On-board CAN bus and System Level Ethernet Controller



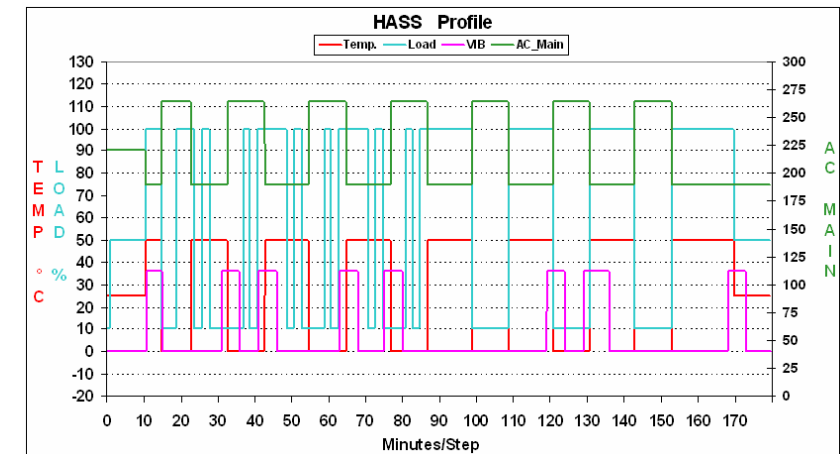
# Product Reliability Assurance

**Product Reliability Assurance provided by Comprehensive Set of Design, Development and Manufacturing Processes within an AS9100 Certified System**



# 100% In-Process HASS Tested

- **100% Automated H.A.S.S. Testing on Each & Every Production Unit with Statistical Yield Analysis**
  - Equivalent to 40-60 Days of Real Life Usage (1-2% of product useful life)
  - Verifies Design Repeatability under extreme conditions
  - Identifies Maverick Component Lots (especially helpful with regard to power semiconductors)
  - Aggressive Thermal Ramps ( $\sim 15^{\circ}\text{C}/\text{minute}$ ) and/or Vibration verify Component Electrical Connection Mechanisms
  - High Temperature Thermal Soak verifies Component Mechanical Connections and Magnetic Component material consistency
  - Input Power Cycling verifies robustness of Inrush Limiting and Power-up Management circuits
  - Output Power Cycling verifies robustness of Output Power and Current Limit circuit

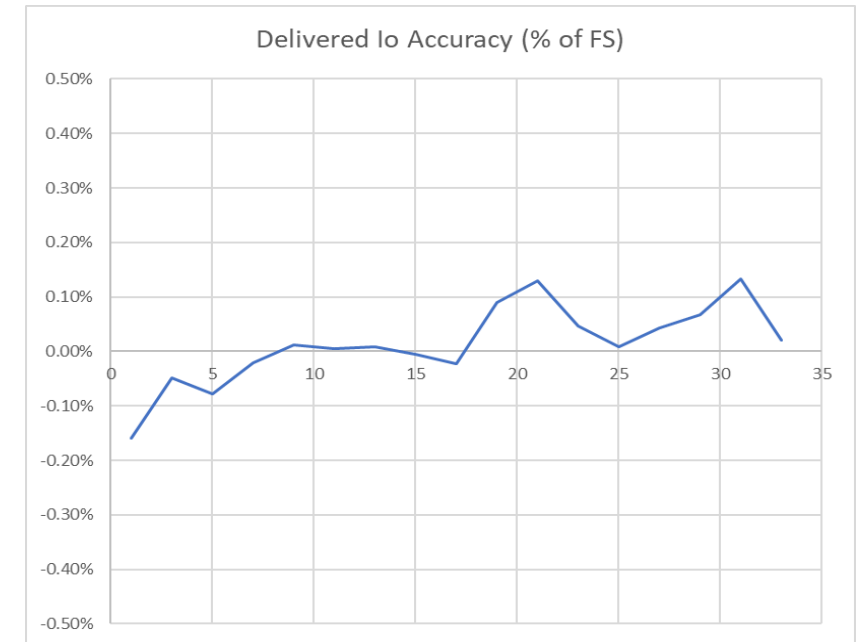
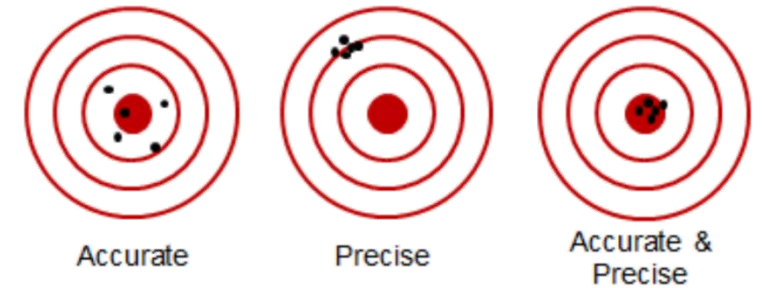




# Accuracy and Precision

- **Parameters to consider**

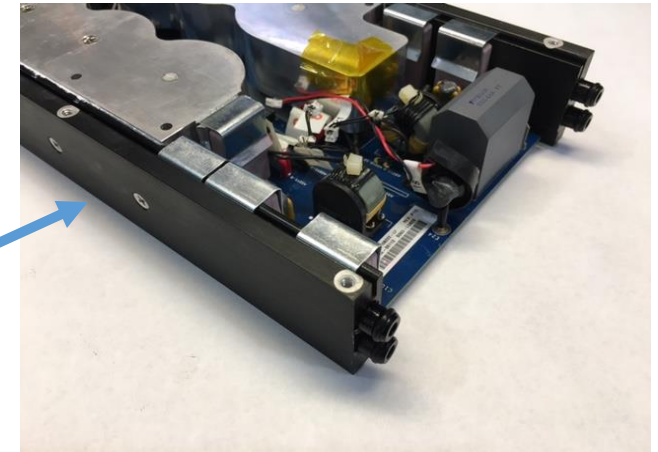
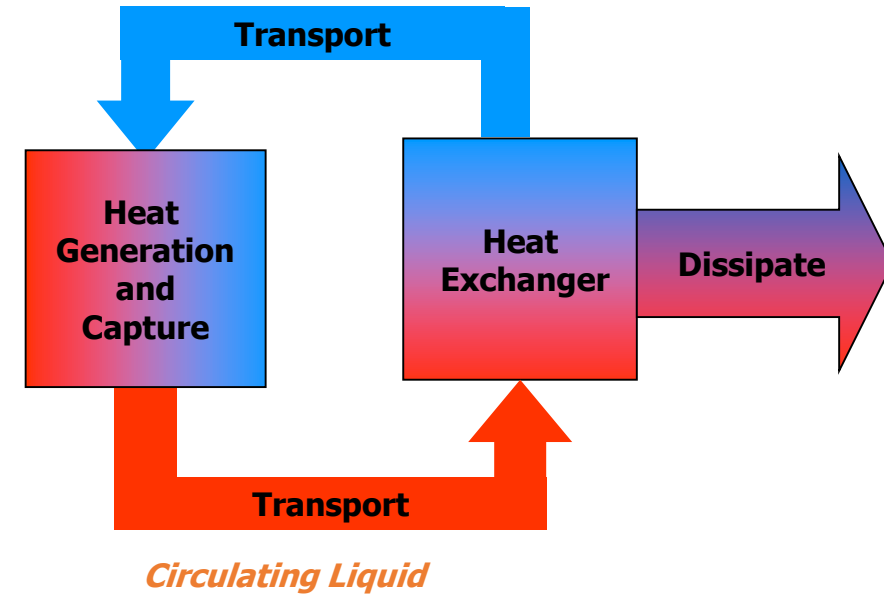
- Initial Accuracy – The difference between the delivered current and the programmed value as measured within a short time of applying the command
  - Long Term Accuracy and Drift – The difference between the delivered current and the programmed value over a longer period of time
  - Output Regulation – The effects of changing load impedance or input power voltage on the delivered current
  - Read-back Accuracy – The difference between the actual delivered current and the measured value delivered back to the system via the module
  - Precision or Resolution – The smallest individual increment of output current that can be accurately programmed
- **Mercury Flex and LiquaBlade operate with 12Bit Digital Resolution and deliver Typical Accuracy of 0.1% of Full Scale**





# Cooling

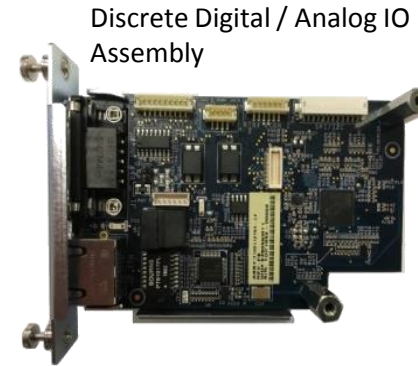
- **Liquid-Cooling provides advantages in High Power Systems**
  - Load Circuits generally employ liquid-cooling so it's already available
- **Liquid-cooling Benefits:**
  - Reduces converter size
  - Reduces susceptibility to ingested contaminants which can cause premature system failure
  - Reduces Audible Noise
  - Reduces Component Operating Temperatures for Improved Reliability
- **Considerations:**
  - Coolant Type (Water, DI Water, Polypropylene-Glycol-Water, Fluorinert) and its ability to carry heat
  - Coolant Circuit Temperature, Flow Rate and Pressure
  - Wetted Parts Compatibility (Copper vs. Aluminum vs. Stainless Steel)
    - ATDI utilizes Hard-Anodized Aluminum which has proven to be compatible with multiple coolant types and other materials



# Control Interface

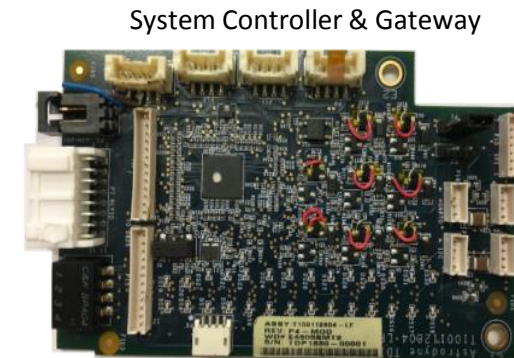
- **High Speed, Near Real-Time Control to Integrate Delivered Power into Host System Process – Protocols can vary by Industry and Companies**

- Semiconductor Applications - EtherCAT
- Other Industrial – CAN Open or Analog
- Medical Applications – ProfiNET
- Military Systems – High Speed Ethernet
- Automotive Systems – CAN Bus



- **ATDI Mercury Flex and LiquaBlade:**

- High speed CAN interface embedded in each PSU Node
- Controller/Gateway configurable to required host interface
  - Ethernet MODBUS TCP, EtherCAT, ProfiNET, etc.
- Low Latency - System Update Rates <10ms



# Summary

- **Controllable DC Power suitable for High Tech Processes oftentimes becomes a tradeoff between Size, Cost and Functionality**
- **Traditional Solutions not well optimized for these applications**
- **New Generation, Modular Solutions provide Improved Performance specifically targeting these applications**

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