Session 1

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Model-Based Specification and Simulation-Based Design and Procurement

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"System of Systems" Design Challenges

Today

- Rule Based Design
- Standard Parts
- Increasing Complexity
- Specifications, Documents
- Small Samples Statistics

Tomorrow

- Relational Based Design
- Standard Processes
- Increasing Detail
- Model is the Specification
- Physics Based Analysis
- Statistics from All of Industry

Complexity

(From "Modeling and Simulation in System Engineering: Whither Simulation Based Acquisition?" By Andrew P. Sage and Stephen R. Olson, George Mason University)

- The more identical that a model must be to the actual system to yield predictable results, the more complex the system is.
- Complex systems "...have emergence ... the behavior of a system is different from the aggregate behavior of the parts and knowledge of the behavior of the parts will not allow us to predict the behavior of the whole system."
- "In systems that are 'complex,' structure and control emanate or grow from the bottom up."
- A system may have an <u>enormous number of parts</u>, but if these parts "<u>interact only in a known, designed, and structured fashion, the system is not complex</u>, although it may be big."
- Although a physical system maybe not be complex, if humans are a part of the system, it becomes complex

Example: The Electrical System and The Power Electronics Thesis

- Present electrical power systems are complex.
  - At equilibrium, 60Hz. Supplies power to 60Hz loads the system is stable and predictable.
  - If perturbed, the system can become unstable and unpredictable – bifurcation can occur.
  - Humans are needed to operate the system
- Future <u>PEBB based power electronic systems</u> will not be complex.
  - Automation is possible -- reduced operating costs
  - Progressive integration -- reduced system costs
  - Higher availability due to physics-based health prediction – reduced maintenance costs
  - Increased reliability and life by controlling overstresses
  - Increased applications and technologies

New Technology Drivers

⇧ Power Density

⇧ Energy Density

⇧ System Efficiency

⇧ Control

⇩ Conversion Steps

⇩ Number of Phase Legs

⇧ Reconfiguration

⇧ Voltage

⇧ Current

⇧ Frequency

Source Voltage, rms Line-Line (volt)	***Estimated Device Blocking Voltage (volt)***	***Notes***
13,800	40,000	Many circuits are needed --parallel, series, and steps
4,160	12,000	Emerging solid-state solutions
440	1,300	Solid-state solutions available
115	350	

- Pulse forming networks require charging circuits ranging from **10kV to 40kV**.
- Pulse forming discharge circuits can require up to **100kV switching**.
- Modulator circuits require **10kV to 50kV** for input voltages and output voltages ranging from **50kV to 1MV**.

Ericsen, T., "Future Navy Application of Wide Bandgap Power Semiconductor Devices," Proceedings of the IEEE, Vol. 90, NO. 6, June 2002, pp. 1077-1082.

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Level of Invention

by Michael S. Slocum
"Technical Maturity Using S-Curve Descriptors," TRIZ Journal Archives, http://www.triz-journal.com/archives/1998/12/a/

Level	Nature of Solution	Number of Trials or Variants Required to Find a Solution	Where Did The Solution Come From	Percentage of Patents in This Level
I	It was obvious!	A few	The designer's narrow specialty field	~30%
II	Some modifications were made	Dozens	A single branch of technology	~55%
III	A radical change was made	Hundreds	Other branches of technology	<10%
IV	Solution is broadly applicable	Thousands to tens of thousands	From science – little known effects and phenomena of physics, chemistry and geometry	3-4%
V	A true discovery – previously unknown	Hundreds of thousands to millions	Beyond limits of contemporary science	< 1%

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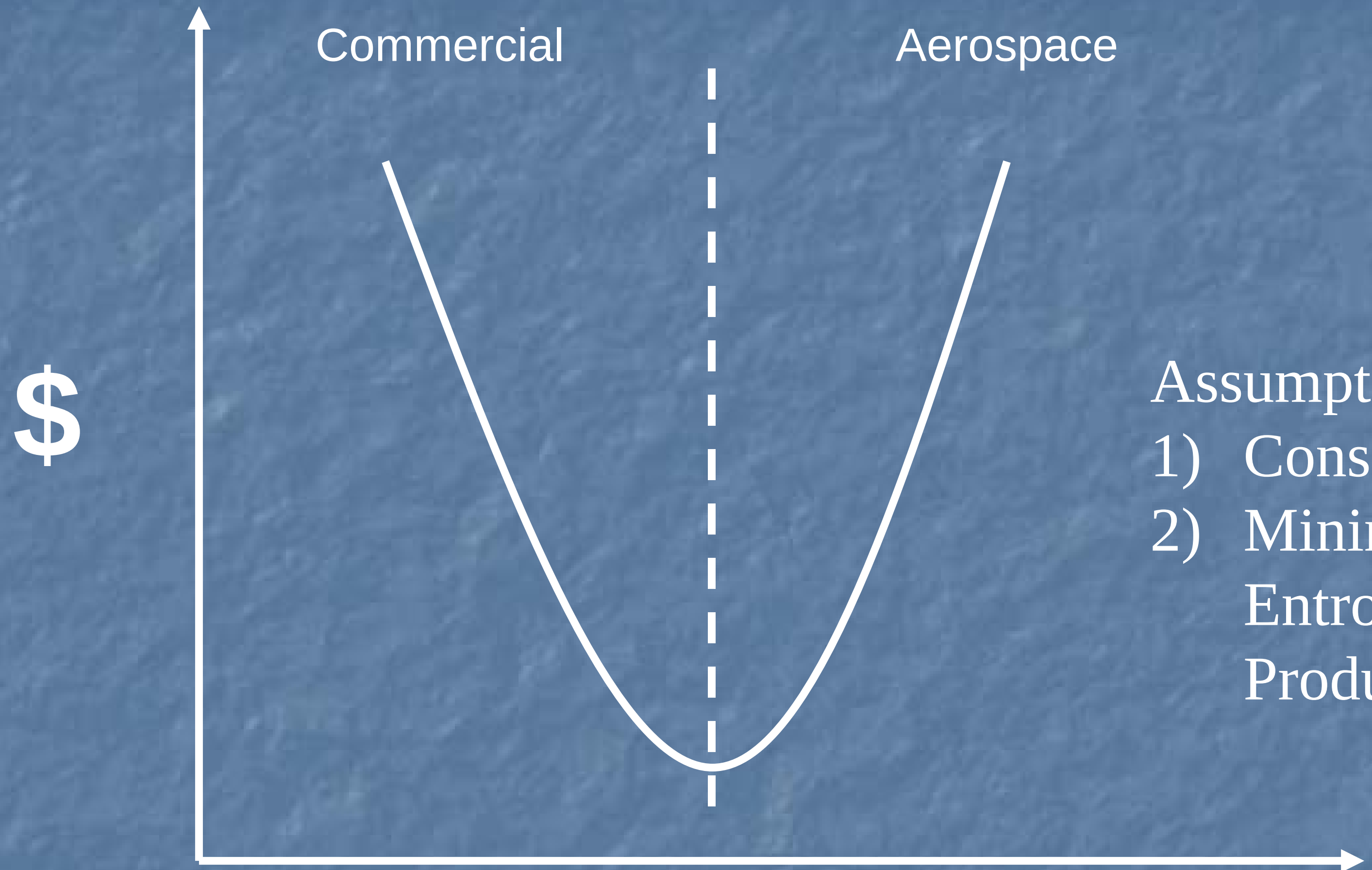
Development Processes



Performance

(Power Density, Specific Power, Reliability, and etc.)

Assumptions:

1) Conservative
2) Minimum Entropy Production

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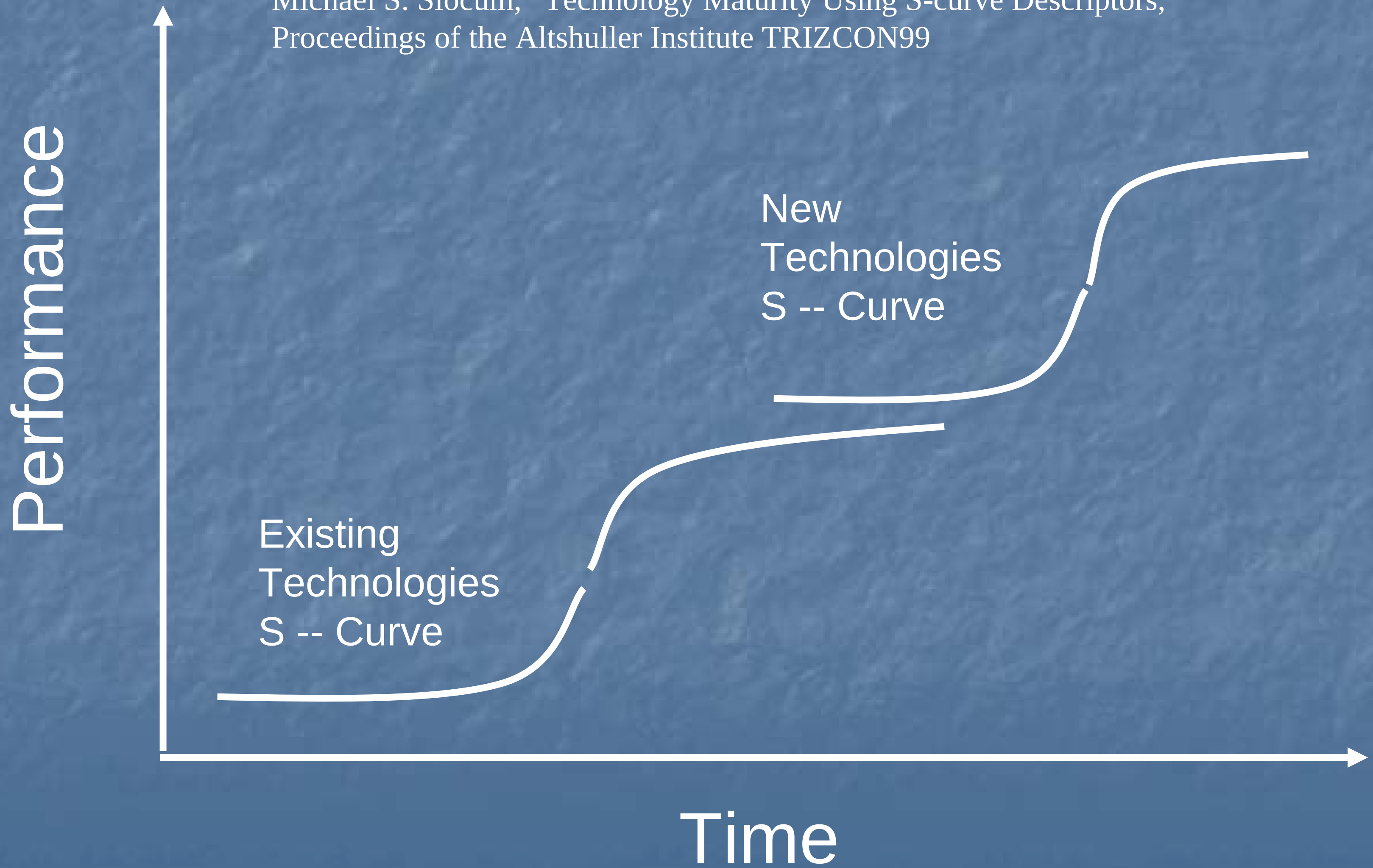
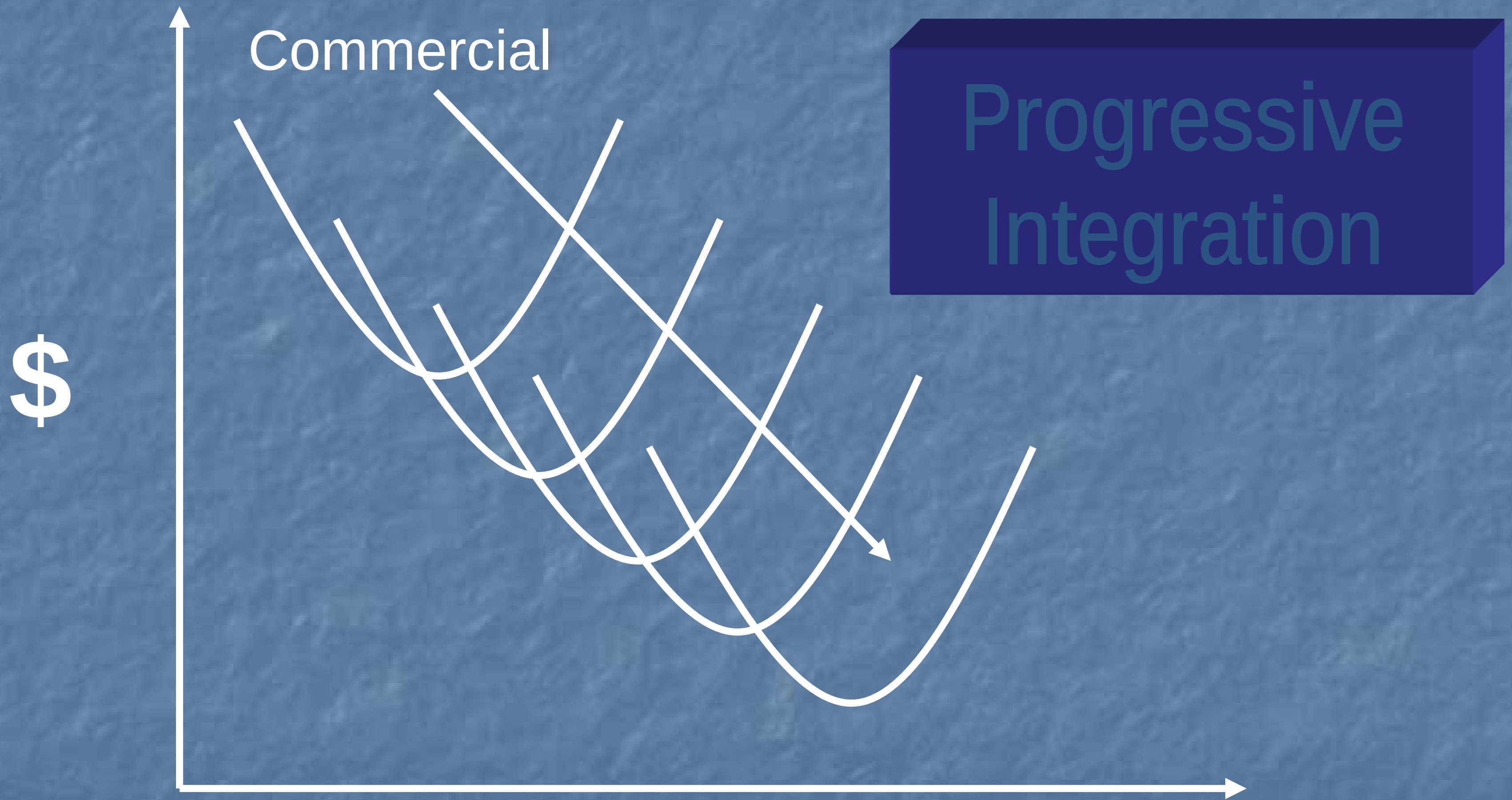
Technology Maturity Based on the Micro-Evolution of Biological Systems

Michael S. Slocum, "Technology Maturity Using S-curve Descriptors," Proceedings of the Altshuller Institute TRIZCON99



Development Process Continuum



Performance

(Power Density, Specific Power, Reliability, and etc.)

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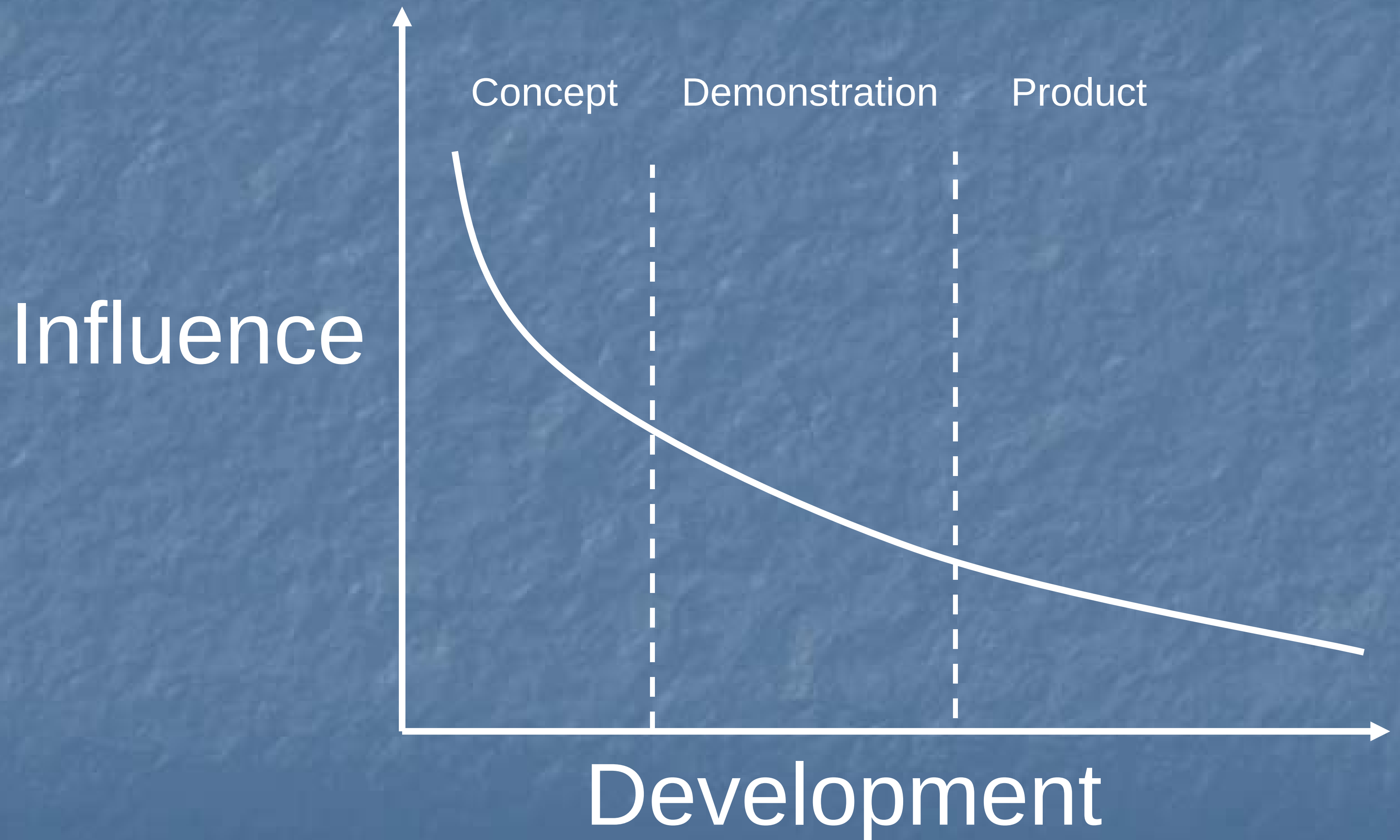
Management Influences



Modeling and Simulation as Early as Possible in a Project

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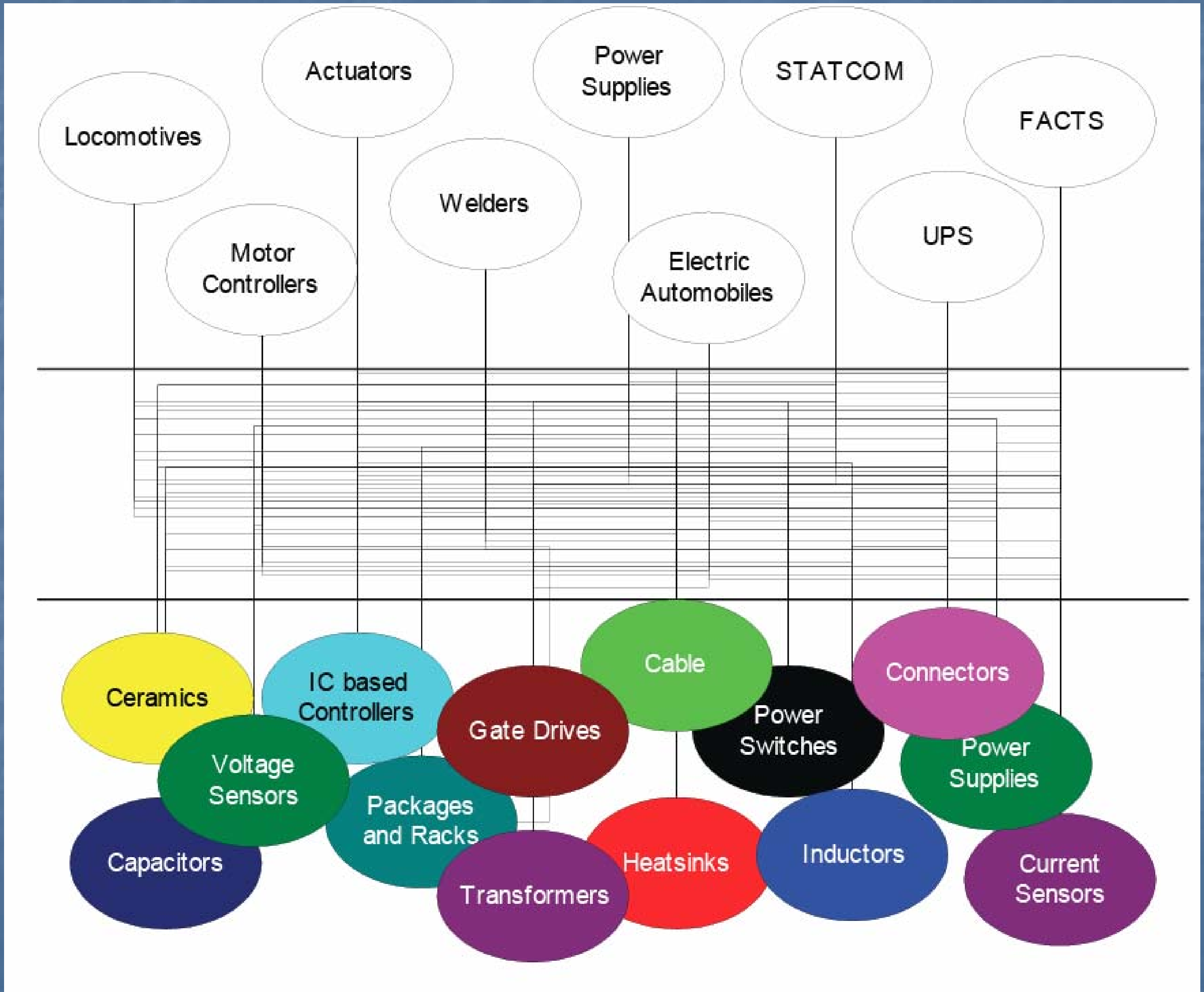
Traditional Power Electronics Industry



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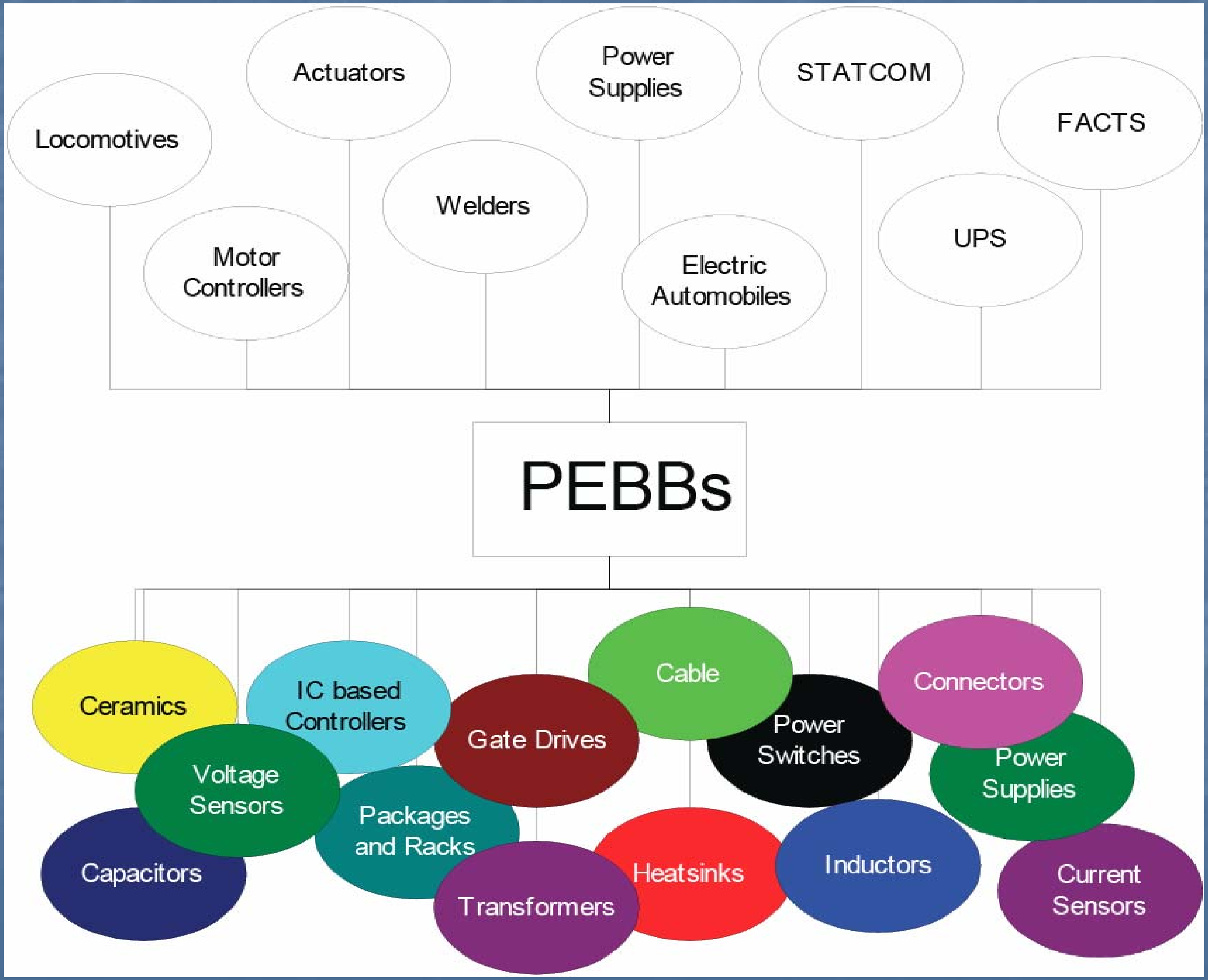
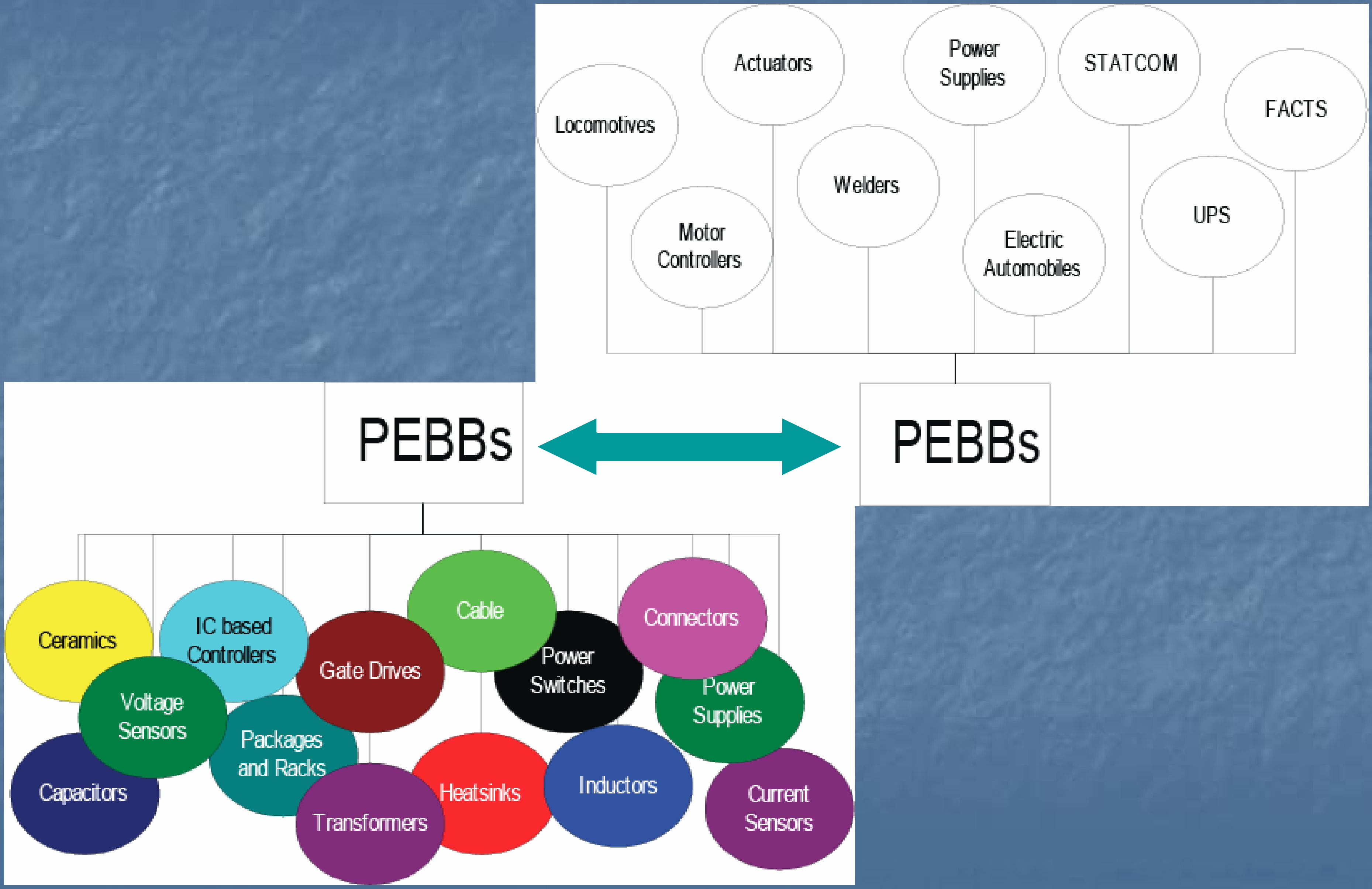
PEBB Based Power Electronics Industry



Asynchronous Processes for Multiplicative Product Development -- Concurrent Engineering



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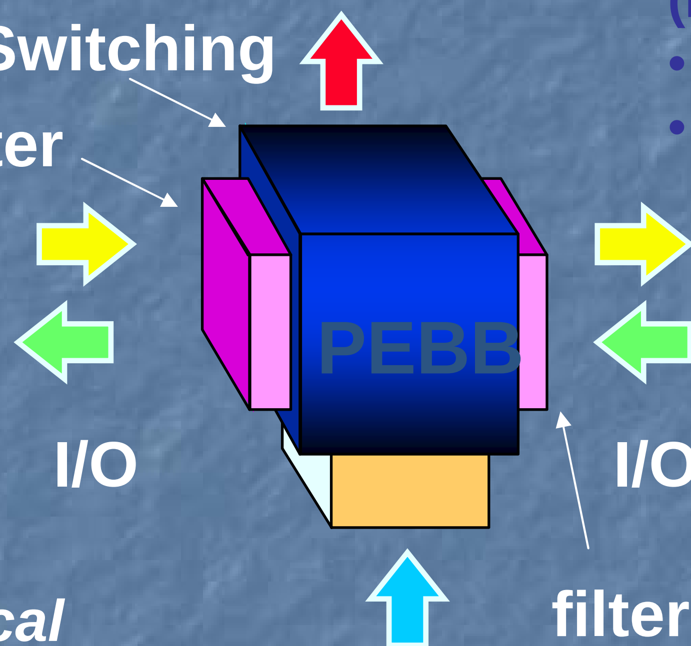
PEBB -- A Simple Set of Blocks for Power System Development (Functional)

- PEBB defined by IEEE (Power Engineering Society)
- WG I8
- TF2, PEBB Technologies



Senses what they are plugged into...

Senses what is plugged into them...

Makes the electrical conversion needed via software programming

Functions In Software
Inverter
Breakers
Frequency Converter
Motor Controller
Power Supply
Actuator Controller

Industry Standards Initiated

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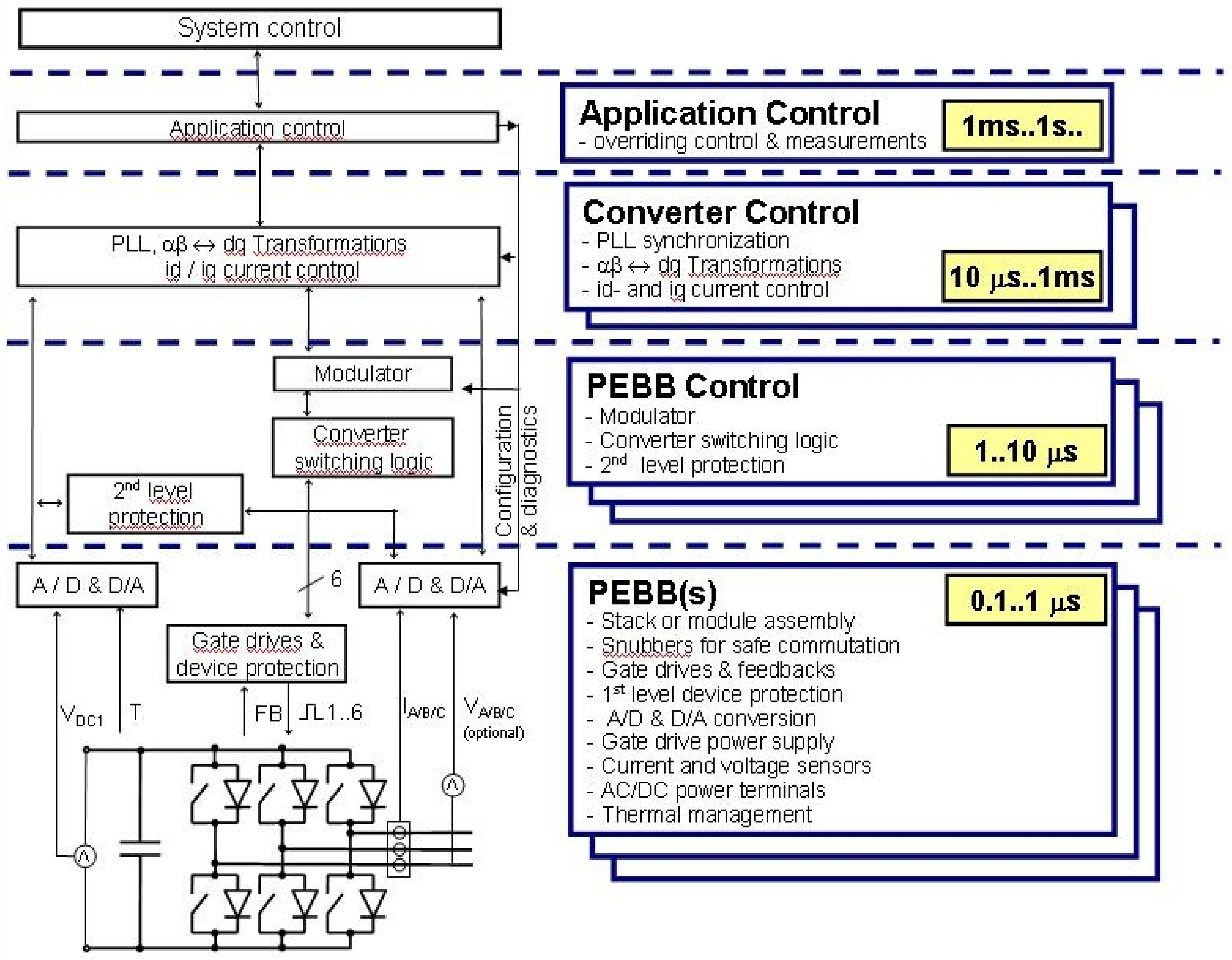
Universal Control Architecture for Control Interfaces (temporal) , IEEE Guide Initiated

PEBB Concept for Power Electronics



The Changing Role of Simulation

- **Today,** simulation is used for evaluation -- **Analysis**.
  - Simulation programs require detailed design information
    - Circuit parameters are entered before simulation begins.
    - Variations in design can be analyzed
- **Tomorrow,** simulation will become part of the design process -- **Synthesis**.

The Model Will Be The Specification

Future Design Process

Today

Tomorrow

The Design Cycle

Customer Designer

Products

Requirements

Supplier Designer

Physics-Based Models are Required

- Product models must be specific
- Requirement models can be general
  - In fact, requirement models with very specific details, in the design phase, can lead to an overly constrained problem.

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Validation, Emulation, and Incremental Prototyping

- Validation of models
  - Controller In the Loop
  - Processor In the Loop
  - Hardware In the Loop
- Real-time simulation is needed for real hardware
- High speed real-time simulation is need for high-speed controllers
- Multi-rate simulation for distributed simulation environments

Needs

- Modeling Standards
- Benchmark Models
- Public Library of Models
- A body of international volunteer experts for all of the above
- And ...

Vehicle System Power Problem

$$p = \varepsilon \frac{dw}{dt}$$

W = energy which is equal to the ceiling amount of the installed generation capacity (may increase over time with technology – fractionally)

p, power requirements are increasing multiplicatively by 10x to 100x

ε = efficiency

Conditions:

1) Size, weight, cost stay the same or decrease
2) Open architecture, plug and play

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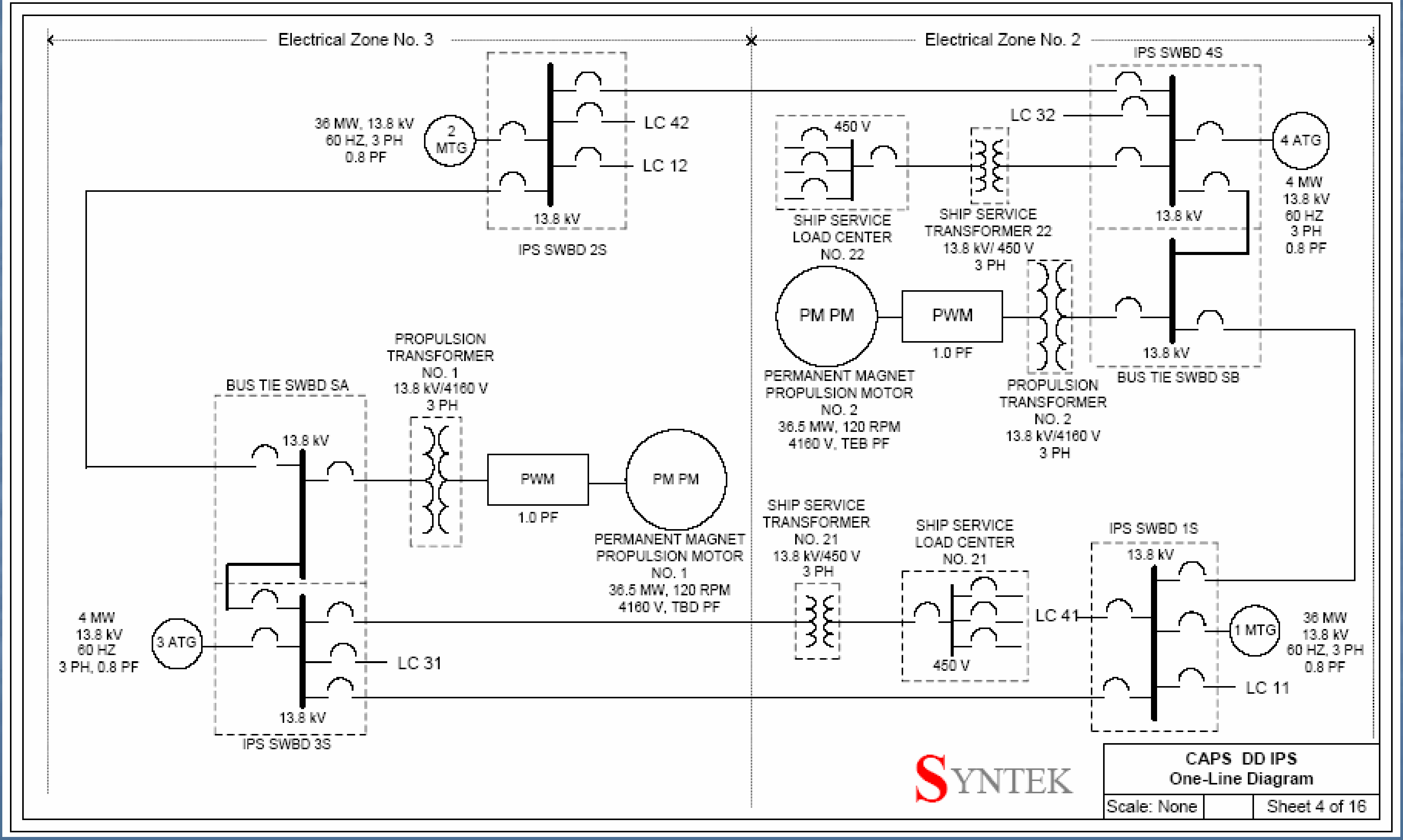
Notional Integrated Power System (IPS)



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Architectural Transformation