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# MULTIFUNCTIONAL MATERIALS AND STRUCTURES

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*S. Yarlagadda*  
*UD-CCM*

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# Report Documentation Page

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# Enabling Transformation of the Navy

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- **Relevant Surface Platform requirements:**
  - ◆ **Autonomous Operation, Crew Reduction**
  - ◆ **Lightweight, High Performance Systems**
  - ◆ **Signature Reduction**
  - ◆ **Integrated Electric Power**
  - ◆ **Affordability**
- **Proposed Solution – “LIVE” Ship Concept**
  - ◆ **Lightweight, High Performance Multifunctional Composite Structure**
  - ◆ **Desired Functionalities: Structure, Blast, Ballistic, Fire, Network/Communications, Signature, Power, Health Monitoring, Prognostics and Repair**
- **Challenge**
  - ◆ **Develop Materials and Process Technologies that enable Modular Plug-and-Play Functionality in Composite Structure**

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# Navy After Next Surface Platforms

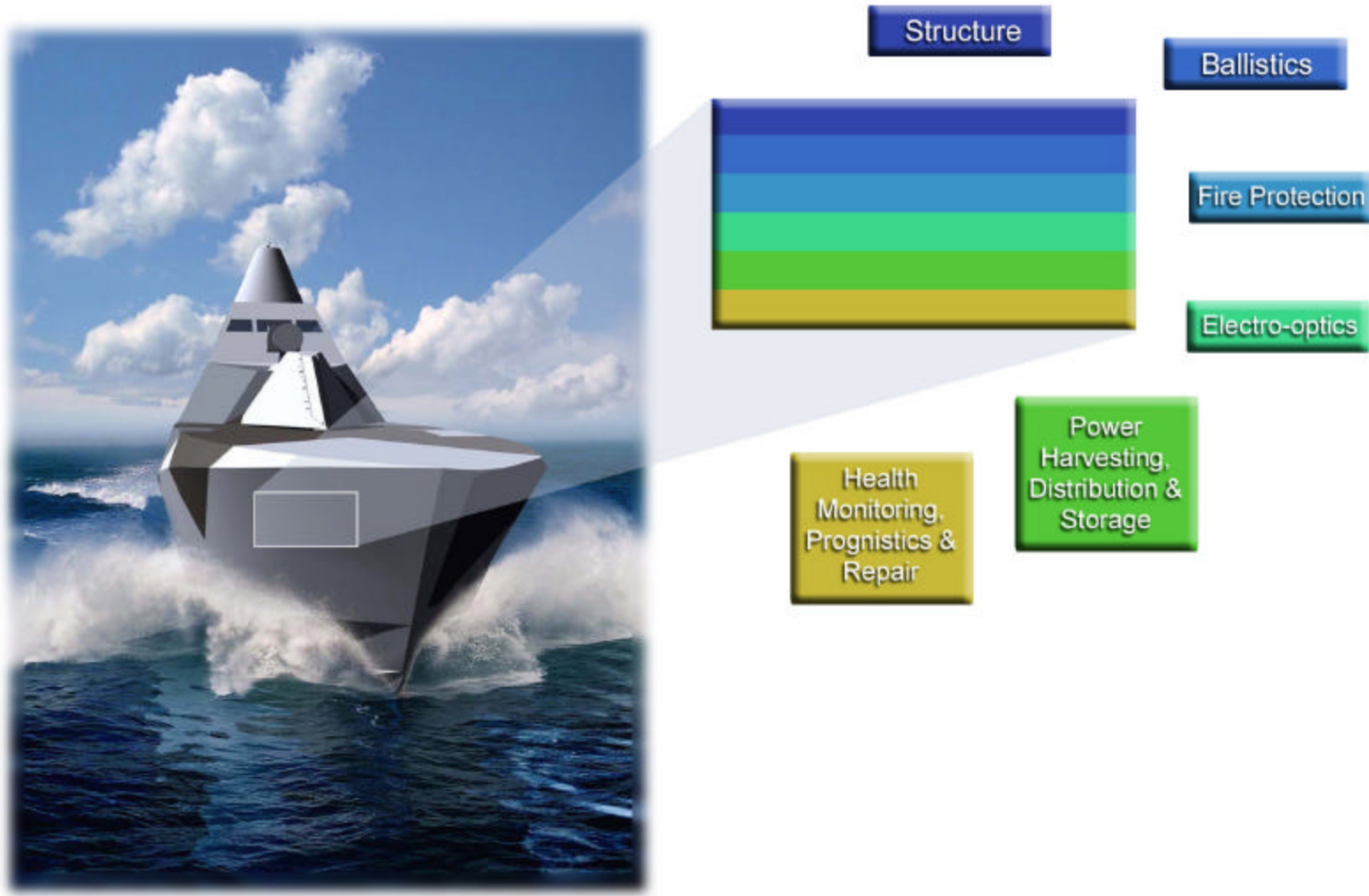
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## References

- ◆ **Technology for the United States Navy and Marine Corps, 2000-2035: Becoming a 21st-Century Force**
  - ◆ National Research Council Report initiated by the CNO (1997)
  - ◆ 9 Volume Study, Volume 6: Surface Platforms
- ◆ **Future Naval Capabilities (FNC)**
  - ◆ <http://www.onr.navy.mil/fncs/>
- ◆ **Department of Navy: Science and Technology Grand Challenges**
  - ◆ [http://www.onr.navy.mil/sci\\_tech/grandc.htm](http://www.onr.navy.mil/sci_tech/grandc.htm)
- ◆ **Navy DD(X) Program**

# “LIVE” Ship Concept



# Example: Ship Area Network (SAN)

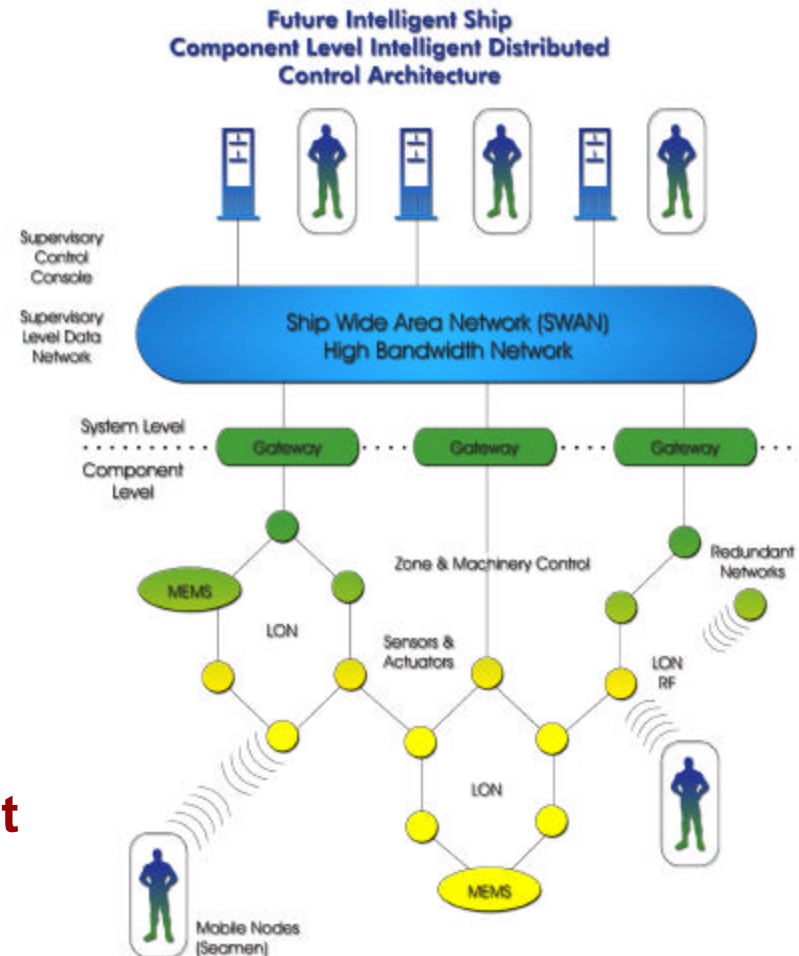


## ➤ “LIVE” Structure

- ◆ Self-Contained Network
- ◆ Communications, Signature, Health Monitoring, Damage Assessment
- ◆ Devices within Structure - Nodes
- ◆ Integration with WPAN

## ➤ Advantages

- ◆ Redundant, Reconfigurable
- ◆ Automation Capable
- ◆ Rapid Response
- ◆ Active Signature Management
- ◆ Fault Tolerant, Graceful Degradation



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# “LIVE” Ship Concept

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## ➤ Meets Navy After Next Requirements

- ◆ Next Generation Solutions for Structure, Blast, Fire and Ballistics
- ◆ Integrated Ship Area Network (SAN) and Autonomous Operation
- ◆ Reduced Crew, Flexible Architecture
- ◆ Active Signature Management
- ◆ Local Electric Power Harvesting for Self-Sufficient Systems
- ◆ Self-Diagnostics, Prognostics and Repair Capability
- ◆ Affordability

## ➤ Builds on many Individual Technologies being developed by DoD/Industry

- ◆ System Integration and Manufacturing is the Grand Challenge
- ◆ Technology Development, Manufacturing Methods and System Integration must occur simultaneously

## ➤ Similar concepts being evaluated for other Applications (Soldier Systems)

- ◆ Advantage for Ship Structures: Large Size and Large Surface Area!
- ◆ Allows integration of relatively larger systems/devices etc

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# Enabling Technologies

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- **Technologies for Multifunctional Composite Structures**
  - ◆ **Electro-Optics – Communications and Signature**
  - ◆ **Materials**
  - ◆ **Simulation tools**
  - ◆ **3-D Functionally Gradient Structures**
  - ◆ **Cradle-to-Grave Sensors and Actuators**
  - ◆ **Small-scale Devices (micro- to nano-)**
- **Manufacturing and Systems Integration**
  - ◆ **Electronic Preforms**
  - ◆ **Integration of enabling technologies into preforms/manufacturing**

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# Manufacturing Considerations

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- **Manufacturing and Systems Integration Considerations**
  - ◆ **Functionality insertion through multi-scale**
    - ✧ Fibers – Electronic Preforms
    - ✧ Resins – Multi-resin Structures (Co-Injection)
    - ✧ Fillers – Multiple fillers (micro- to nano-)
  - ◆ **Constraint of Liquid Molding (VARTM/RTM) as primary manufacturing process**
    - ✧ Inserted Technologies must survive process
  - ◆ **Compliment current structural, fire, blast and ballistic capabilities**
  - ◆ **Systems Design approach rather than design for individual requirements**
  - ◆ **Affordability**
  - ◆ **Long-term durability**

# Electro-Optics

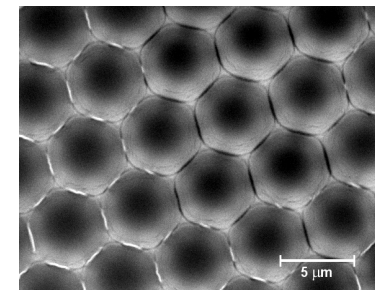
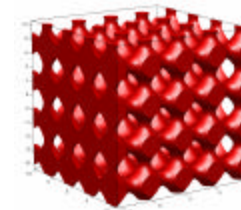
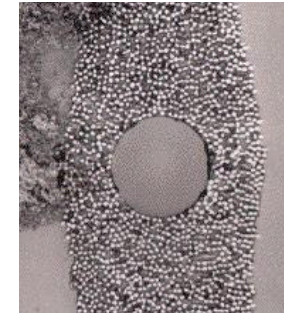


## ➤ Next Generation

- ◆ 2-D and 3-D Photonic Crystals
- ◆ Graded Dielectrics
- ◆ Frequency Selective Surfaces
- ◆ Nanostructured Systems (aerogels, foams)
- ◆ Conductive Polymers
- ◆ Left-Handed Materials

## ➤ Integration into Composite

- ◆ Micro- to Nano-particulate systems
- ◆ Tailored Porous media
- ◆ Manufacturing strategies for desired composite microstructure



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# Example: Photonics and Metal-less Masts

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- **Photonic Crystals, Graded Dielectrics and Nanostructured Materials**
  - ◆ Next generation building block material
  - ◆ Unique Tunable properties in EM spectrum
  - ◆ Networking, Communications and Signature
- **LO “Metal-less” Mast using Conductive Polymers**
  - ◆ Fluidic Antenna Concept
  - ◆ Mast structure consists of Channels/Gates Grid
  - ◆ Conductive Liquid Polymer based
  - ◆ Control Gates for Reconfigurable Geometry Antennas etc
  - ◆ Remove Polymer when not in use (LO)

# 3-D Functionally Gradient Structures

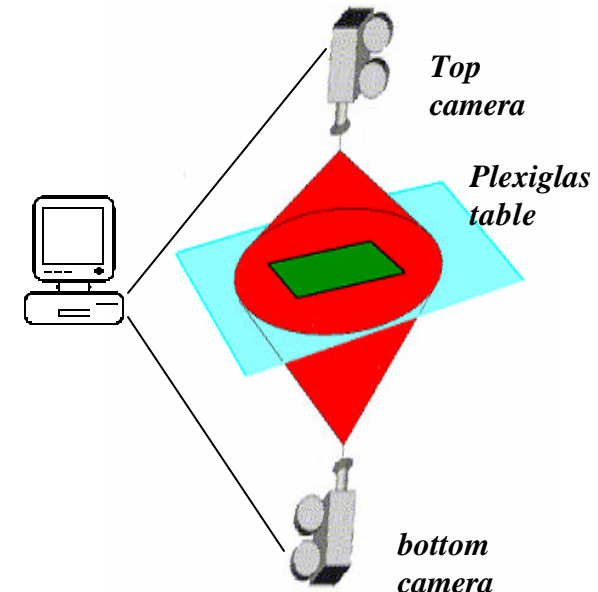


## ➤ Evaluate property-processing relationship for

- ◆ Graded fibers, resins and fillers
- ◆ Selection based on desired functionality
- ◆ Develop design and processing guidelines

## ➤ Example: Particulate fillers

- ◆ **Micro- to Nano-scale**
  - ◇ Carbon black to nanotubes
  - ◇ Dielectrics
  - ◇ Magnetic
- ◆ Particle size – preform permeability – resin viscosity relationship
- ◆ Tailor particle composition, size, preform and resin for desired graded functionality

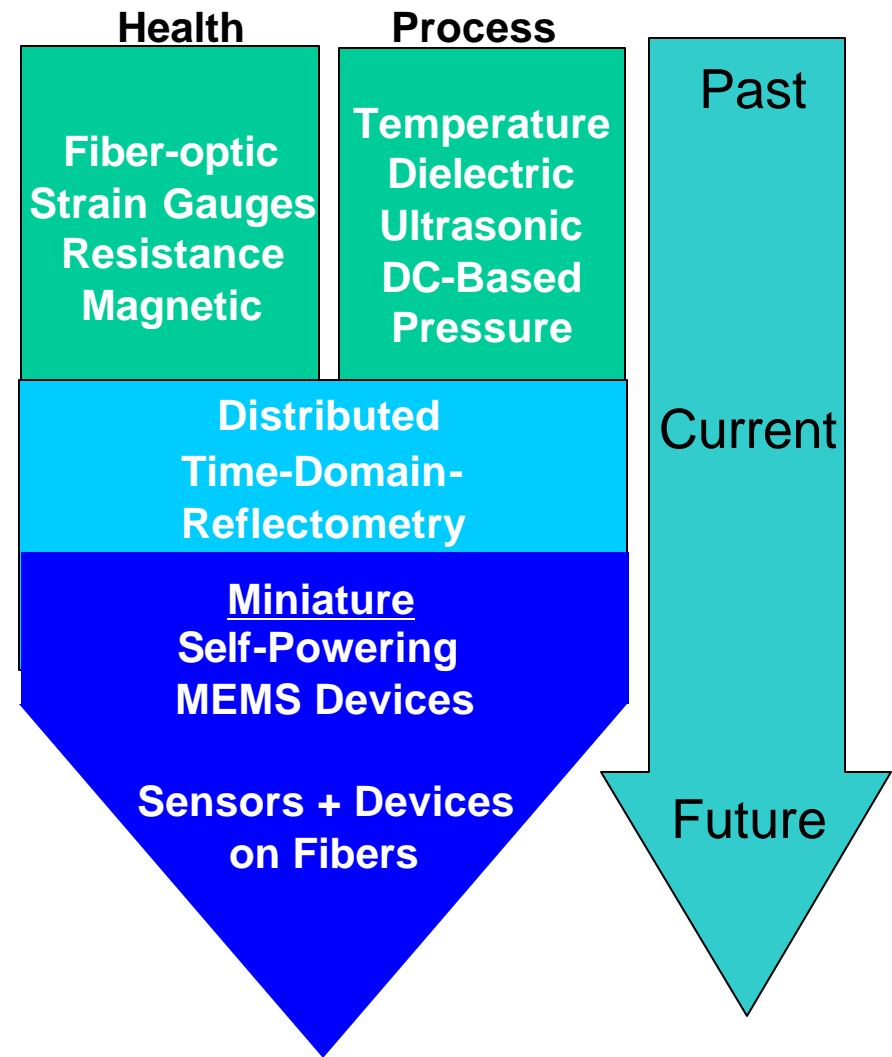


# Cradle-to-Grave Multifunctional Sensors



- ❖ **Multi-Functional Sensor Technology Requirements**
  - ❖ **Monitors Manufacturing Process**
    - ❖ Measures several quality and process parameters
  - ❖ **Embedded sensor monitors Structural Health**
  - ❖ **Distributed**
  - ❖ **Wireless**
  - ❖ **Self-Powered**
  - ❖ **Miniature Implementation**

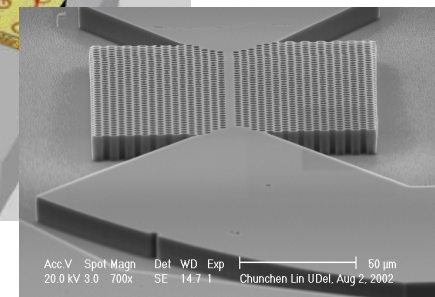
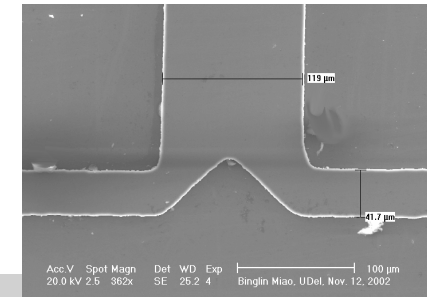
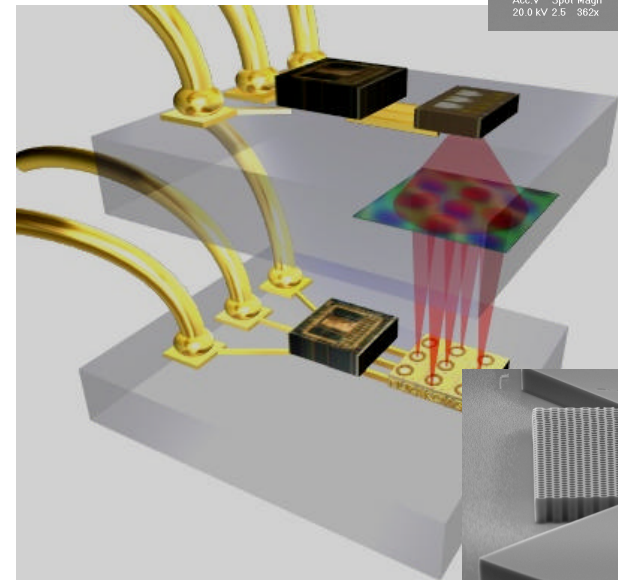
- ❖ **Transparent to Material**
- ❖ **Enables Process Control**
- ❖ **Enables QA/QC**
- ❖ **No Ingress/Egress Issues**



# Small-Scale Active Devices



- **Need Devices for**
  - ◆ **Networking – Encoders, Decoders, WDM etc**
  - ◆ **Sensors/Actuators**
  - ◆ **Energy harvesting**
- **MEMS and NEMS Technology**
  - ◆ **Passive devices**
  - ◆ **Active devices with CPU**
  - ◆ **Field Programmable**
  - ◆ **Device on fiber**
- **Integrated into Electronic Preforms**



# Electronic Preforms



## ➤ Integrated Platform

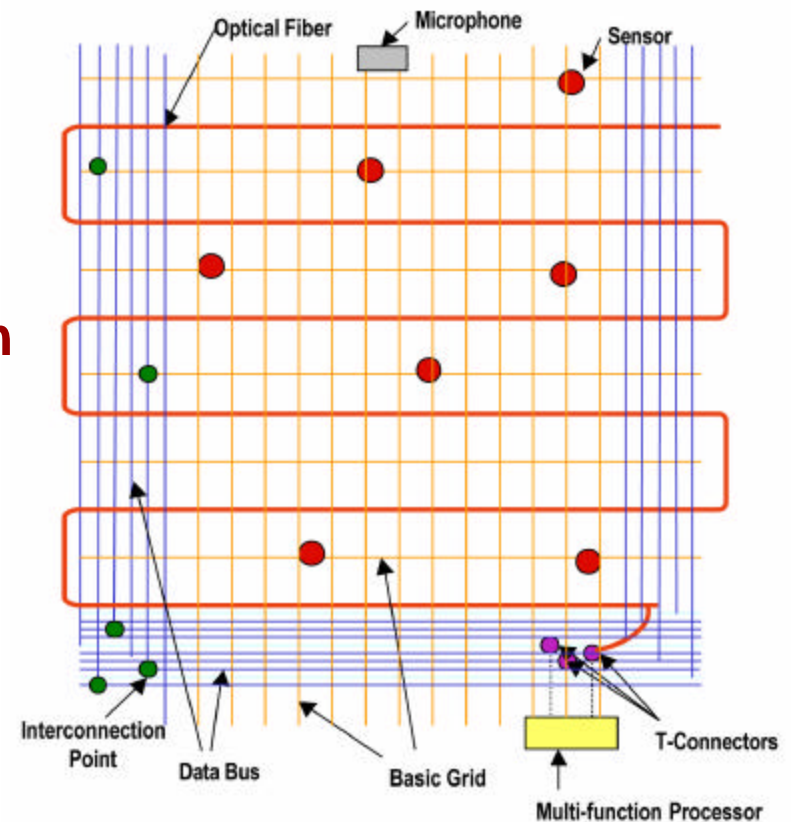
- ◆ **Electronic Textiles (E-Textile)**
- ◆ **Concept of Fabric Motherboard**
- ◆ **Large number of Active Devices**
- ◆ **Smart systems (Integrated CPU)**
- ◆ **Interconnects, System Integration**

## ➤ Growing Industry Base

- ◆ **Wearable Computing**
- ◆ **Medical, Fashion, Consumer Electronics**

## ➤ Use E-Textiles as Composite Preform

- ◆ **Structure goes “LIVE”**
- ◆ **Integration and Manufacturing Challenge**



# Multifunctional Composites Enable Transformation of the Navy



## Combine Best of Both Worlds

### New Initiatives

#### Passive Properties

- Strength
- Stiffness
- Toughness
- Fire-hardness
- Blast resistant
- Corrosion resistant
- LO



#### Active Properties

- Sensors/Actuators
- Networking and Communications
- Active LO and Signature
- Self-Healing
- Health Monitoring
- Electronics/CPU's

**Manufacturing Technologies to Integrate Multifunctionality are Essential**