Defense Systems Information Analysis Center

# Electromagnetic (EM) Shielding With Composite Materials

Presented by:
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# Overview

- What are potential EM threats to which platforms are exposed?
- Current EM shielding approach for electronics and electrical systems
- What types of EM shielding are possible in composites?
- Multifunctional materials
- Manufacturing and fabrication concerns
- Repairability and maintainability aspects
- Future direction

# EM Threats

- EM environments challenge electronics.
  - Range from natural to man-made.
    - EM causes upset and hard failures.
- EM threats are multifrequency.
  - Various shielding levels are required.

| Threat Type | Frequency Range | EM Shielding Range |
|---|---|---|
| EMI/EMC | 9 kHz – 40 GHz | 60 – 100 dB |
| EMP | 100 MHz – 100 GHz | 80 – 120 dB |
| HPM | 1 GHz – 35 GHz | 100 – 140 dB |

EMI = EM interference; EMC = EM compatibility; EMP = EM pulse; HPM = high-power microwave.

  - Emerging threats and electronics may require more.


Images Source: [1] Luzetsky, Harry R., "Multifunctional Composite for Electromagnetic Shielding," CEMA Presentation May 3-4 2022.

# EM Threats

- Origination of threats
  - EM threats characterized as natural, civil, and military
    - Defines magnitude and influences protection requirements

| Threat Type | Natural | Civil | Military |
|---|---|---|---|
| **EMI/EMC** | Lightning, Electrostatic Discharge, Solar Flares, Auroras | Communication (Cell Towers), Generators, Power Supplies, High-Voltage Electrical Transmission Lines | Jammers, Installed Electrical Equipment, Radios |
| **EMP** | Lightning EMP, Electrostatic Discharge, Meteoric EMP, Coronal Mass Ejection | Electric Circuity Switching, Electric Motors, Gasoline Ignition Systems, Continual Switching of Digital Electric, Power Line Surges | Nuclear EMP (NEMP), Non-Nuclear EMP (NNEMP), High-Altitude EMP (HEMP) |
| **HPM** | Super Nova | High-Power Radars With Relativistic Klystron Amplifier | Backward Wave Oscillator, Directed-Energy Weapon |

# EM Threats

- EM threats are real and fielded.
  - Russian
    - Krasukha-4 mobile EW system
      - Operational since 2014/kill electronics of Israeli F-35
    - Il-22PP electronic warfare (EW) aircraft
      - Operational in 2018
  - Chinese
    - Mobile ground vehicles
      - 2018 South China Sea reefs
    - 16D EW Jet
      - Signal jammers/disable radars, missile guidance, and wireless communications

Images Source: [2] “Multifunctional Structural Composite with Integrated Electromagnetic Shielding” Presented at the AHS International 73rd Annual Forum & Technology Display, Fort Worth, Texas, USA, May 9–11, 2017.  Harry R. Luzetsky, Martha A. Klein, Graham Ostrander

# EM Shielding Techniques

- Shielding effectiveness (SE) definition
  - Ratio of radiated power received without the barrier to the power received with the barrier
    - Measurement units in decibels (dB)
  - SE contributors
    - Reflection from the surface due to the impedance mismatch between the two mediums and attenuation by absorption loss within the barrier.
    - Re-reflection at the second barrier-to-air surface and again at the first surface, with some absorption loss each time the wave traverses the barrier thickness.
    - Re-reflected component usually reduces SE by adding power to the output. The reduction may be significant if the absorption losses are low.

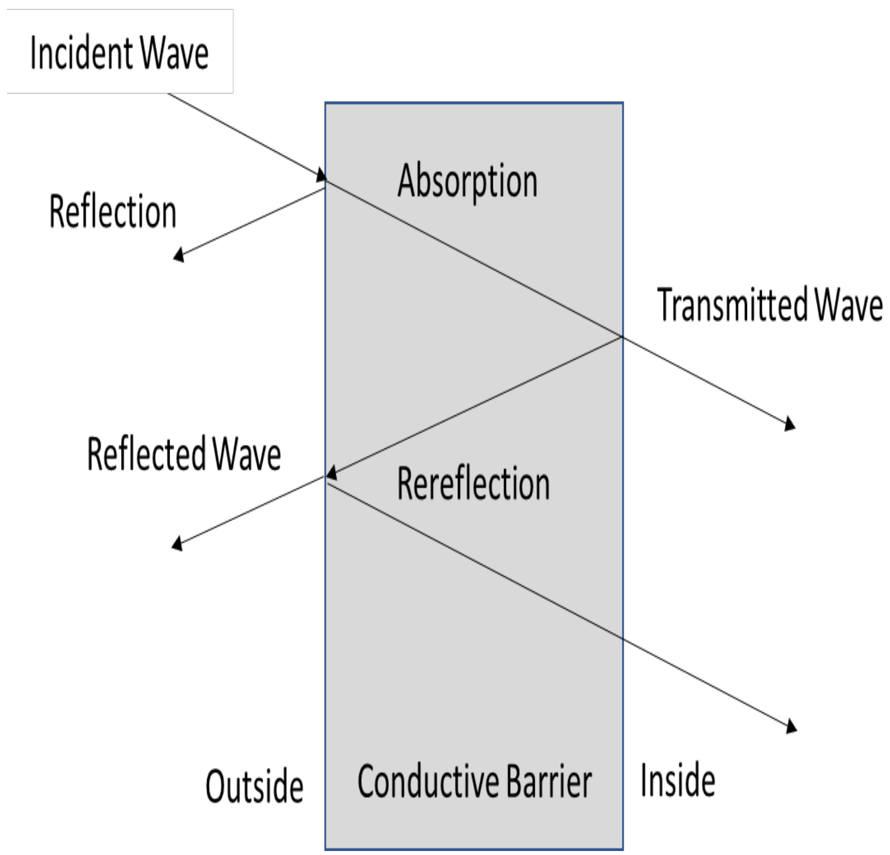


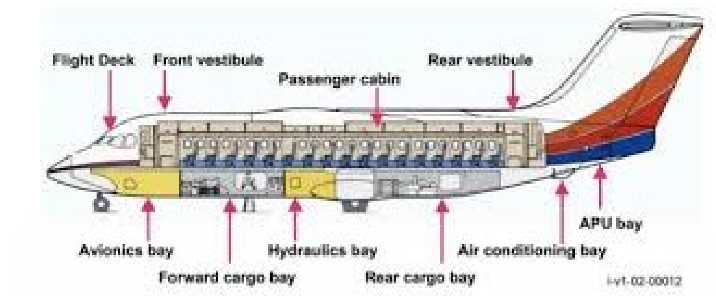

Image Source: Author generated.

# EM Shielding Techniques

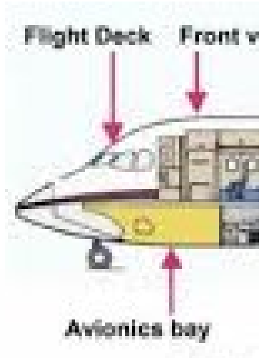
- Barrier characteristics of impacting shielding
  - Barrier thickness
    - Thin shields have internal reflections that reduce SE
  - Electrical conductivity
  - Magnetic permeability
- Construction of enclosures
  - Shaping
  - Penetrations
    - Minimize potential leakage points
  - Seals
    - Elastomers with conductive fillers
  - Platform integration

# EM Shielding Techniques

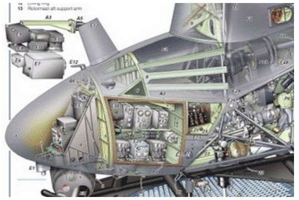
- EM shielding platform integration
  - Defines enclosure configuration
    - Accommodates heat sinks, cooling, and venting.
    - Isolates electronics into a single area.
      - Electronics platforms and racks
    - Most efficient configuration is a sealed box.
      - Minimizes penetrations and sharp corners




Platform Structure

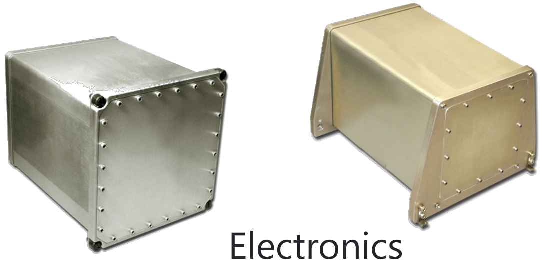



Low-Angle Ply Processed Around 0.5-in. Radius with Good Consolidation



Electronics Bay

Electronics Rack



Electronics Enclosure

Images Source: [2]

# EM Shielding Techniques

- Types of shielding materials
  - Metals (typically copper and aluminum)
    - Includes coatings and plating
  - Carbon allotropes used as fillers (forms of carbon) in polymers, ceramics, cement, and metals
    - Exfoliated graphite, graphene, carbon fibers, and carbon nanotubes
    - Filler materials due to strength and conductivity
    - Operate through multiple reflection mechanisms
  - Intrinsically conducting polymers (ICPs)
    - Special conducting polymers
    - Conduct electricity between atoms due to conjugated bonds (alternating single and double bonds)
    - Used as component to composite with metal nanoparticles and carbon filaments

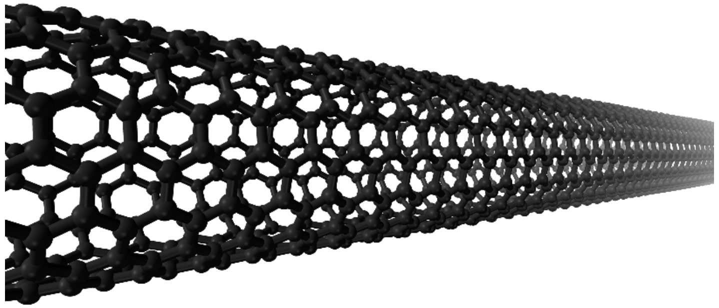
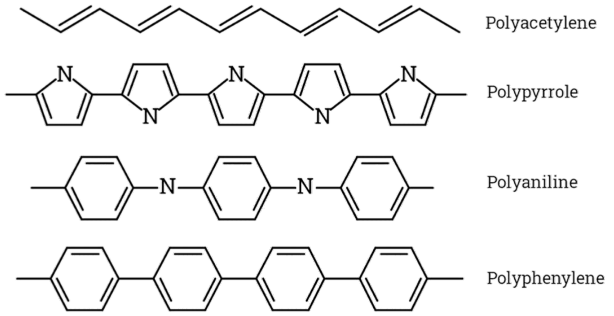


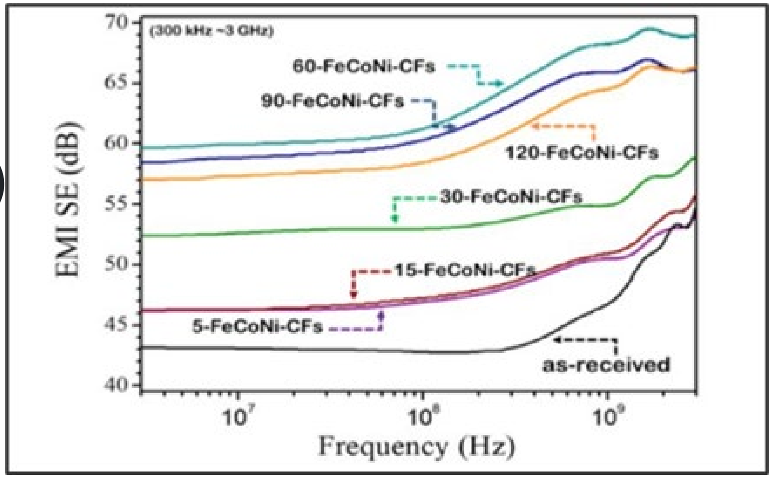
Image Source: Wikimedia Commons

Alternating Single and Double Bonds of ICPs

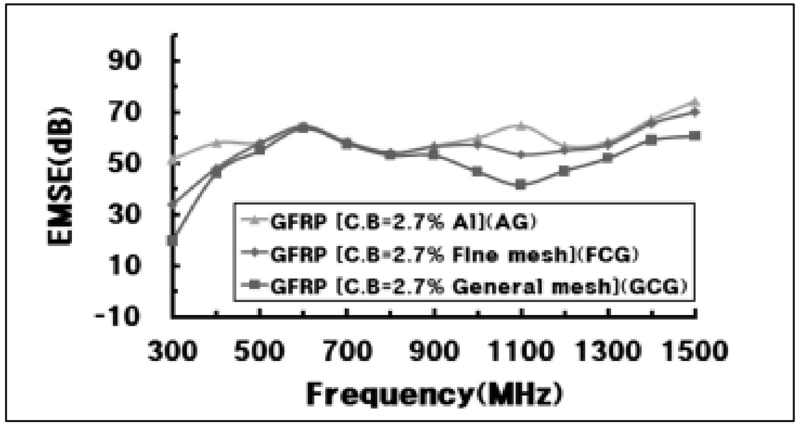


# EM Shielding Techniques

- EM shielding solutions are limited.
  - Metal enclosures (~1/8-inch-thick aluminum [Al])
    - Greater than 80 dB; 10 MHZ-100 GHz
    - Heavy approach with limited application
  - Nonmetallic enclosures
    - More weight effective than metals
    - Levels between 30 and 70 dB (DSIAC)
    - Includes added materials to increase EM SE



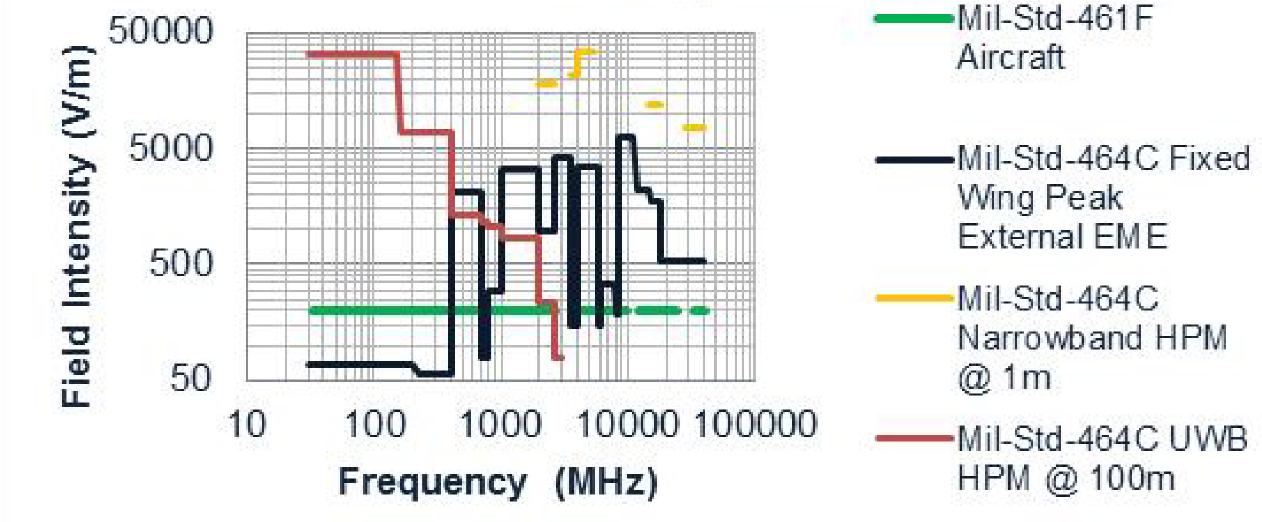

**Need: Composite that retains structural properties and EM SE equivalency to metals**




Images Source: [1]

# EM Shielding Requirements

- Based on military specifications
  - MIL-STD-461, -464, and -2169B specifications
    - Establishes electronic enclosure EM SE design envelope




**Meet Established Requirements to Defeat Identified Threats Across Broad Frequency Range**

Note: MIL-STD-2169B HEMP not included in graph due to classification

    - Modified to include SE of 1/8-inch-thick Al Air Force (AF)-supplied box

Image Source: [2]

# Multifunctional Composites

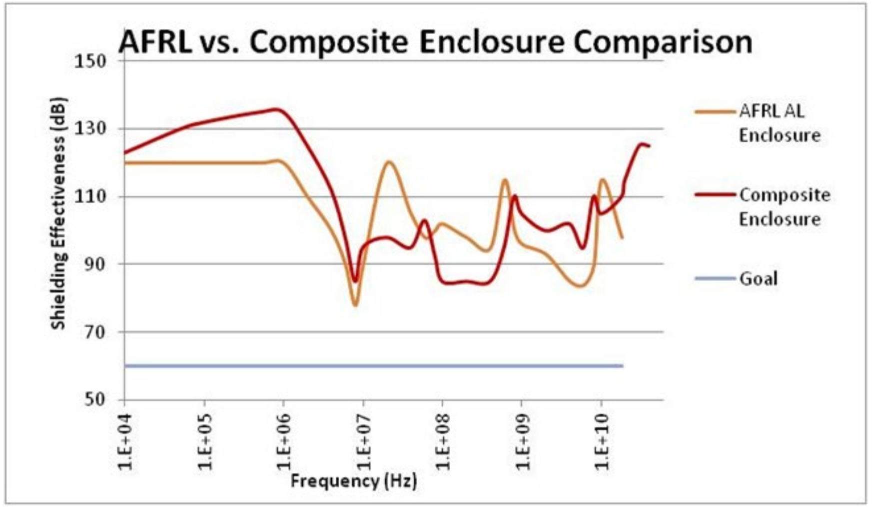
- Achieve EM SE and maintain structural properties
  - Development catalyst AF SBIR "Electromagnetic Hardened Composite Enclosures for Aircraft Systems" (Ref: AFRL-RX-WP-TR-2014-0121)
    - Based on graphite/PEEK composite
    - Maintain composite structural characteristics
      - Strength, stiffness, vibration, and damage tolerance
    - EM shielding effectiveness equivalent to Al
      - Threshold as defined by specifications
      - Objective as defined by AF Al enclosure

| AF Baseline Enclosure | Target Shielding Effectiveness | |
|---|---|---|
| | Threshold[1] | Objective[2] |
| 75-135 dB* | 60 dB min** | 80 dB min** |

* Varies by frequency
** Represents minimum value across all frequencies
[1] Based on environment
[2] Based on AF enclosure measurements

# Multifunctional Composites

- Electronic enclosure demonstration
  - Shielding effectiveness comparable to Al
    - Low- and high-frequency enhancements over Al
  - Producibility which supports scalability
  - Structural properties support substitution for Al



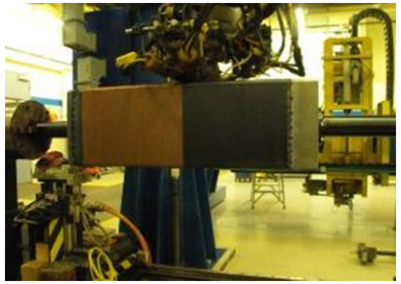

76% Weight Reduction

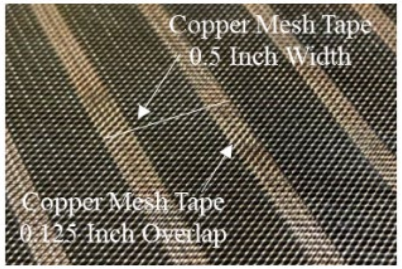
| Air Force Aluminum Box | AF 131-110 Electronic Enclosure |
|---|---|
| 32.5 lb | 7.6 lb |

Images Source: [1]

# Multifunctional Composites

- Graphite/PEEK has high EM SE.
  - High compaction pressure with in-situ tape placement yields dense laminate, high EM SE
- Copper (Cu) mesh integration process is critical.
  - Interlaminar location
    - Location relative to laminate surfaces
  - Overlapping tape and discreet placement
    - 0.50-inch tape in-situ placed with proprietary head
    - 0.125-inch overlap (no gaps)
  - Quantity of layers (defines resonance chambers)
- Ni-coated carbon fibers are examined.
  - No global impact but frequency shifts

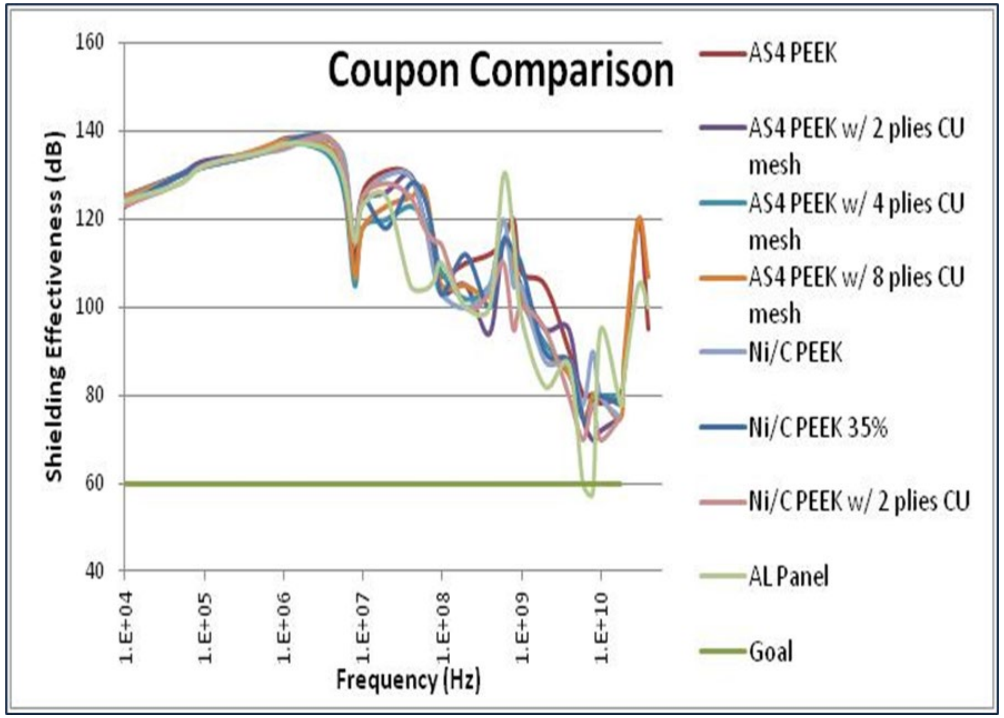


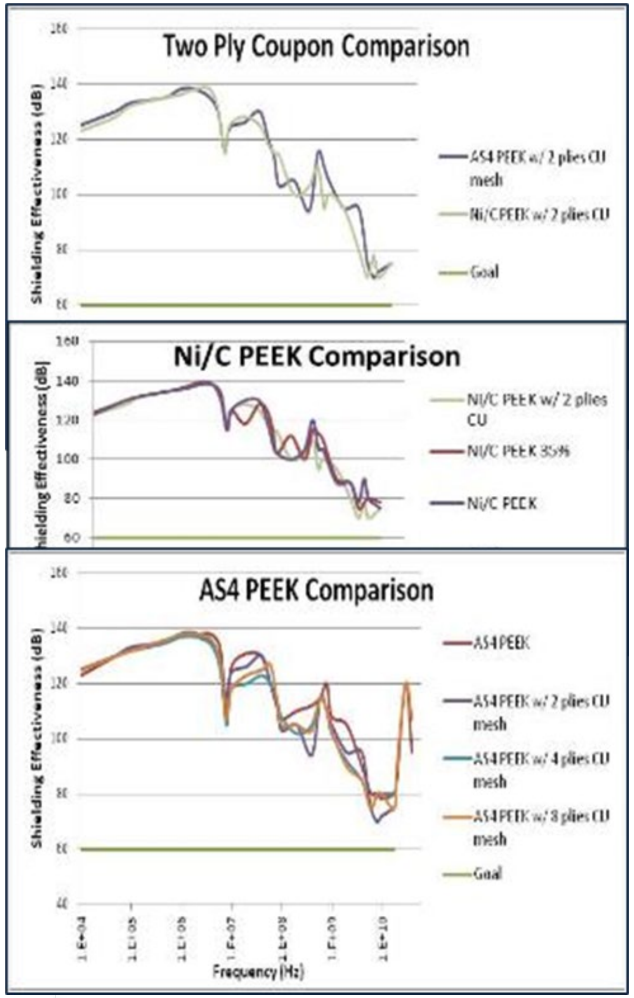



Images Source: [1]

# Multifunctional Composites

- Electronic enclosure panel data
  - Similar trending between panels

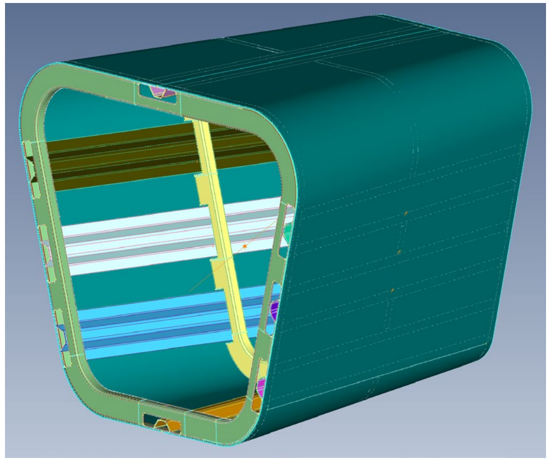



Images Source: [1]

# Multifunctional Composites

- Structure demonstration
  - Active program constructing representative helicopter tail section using the multifunctional material for EM shielding in the fuselage skin
    - EM and mechanical data pending
  - Applied to fuselage skin for unmanned aircraft system (UAS) fuselage skin structure
    - Applied bulkheads used to seal fuselage
    - EM shielding like electronic enclosure



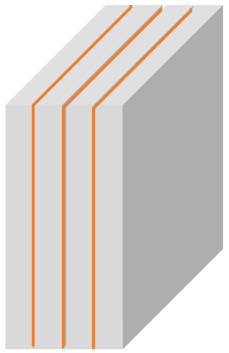
Images Source: [1]

# Multifunctional Composites

- UAS fuselage skin
  - IM7/PEEK copper mesh multifunctional composite
    - Cu mesh enhances SE
  - In-situ tape placement of UAS fuselage skin (IM7/PEEK and Cu mesh)
  - Bulkheads (fore and aft) preformed (3-D printed and pressed)
    - Seal interior of fuselage
  - Average of 60+ dB SE on average in the 50-MHz to 18-GHz range
  - Minimum SE values for each fuselage skin (2, 3, & 4 layers copper mesh)
    - 67+: 50M Hz to 600 MHz
    - 88+: 1 GHz to 5 GHz
    - 102+: 7 GHz to 18 GHz
  - Threshold requirements for EMI/EMC, EMP, and HPM EM types/threats demonstrated as achievable

# Multifunctional Composite Design Observations

- Multiple laminate configurations evaluated
  - Thicker laminate enhances EM SE at certain frequencies, and overall performance averaged across frequencies is enhanced.
    - Supports separation of Cu mesh forming interlaminar resonance chambers
      - Thinner laminate affects resonance
    - Still significantly lighter than metal and SOA
    - Resonance contributes to SE variations with frequency
      - Controlled with placement of copper mesh
  - Cu mesh placement in laminate critical
    - Can alter EM SE at specific frequencies



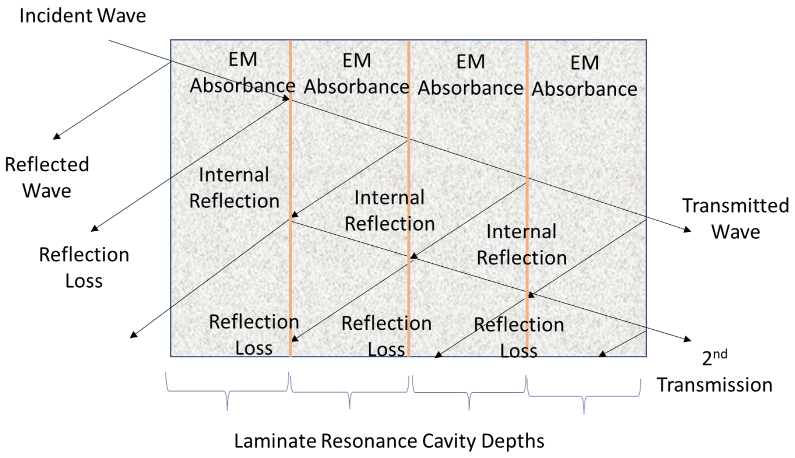



Image Source: Author generated.

# Manufacturing and Fabrication Concerns

- Configuration driven
  - Enclosures
    - Simple box configuration with generous radii preferred
    - Complex shapes difficult to fabricate and limit materials to injection molding or metals
  - Structures
    - Transfers a portion or all EM SE to external structure (i.e., platform body)
    - Installed enclosures provide added protection and shielding between installed systems
- Composite process considerations
  - Injection molding
    - Minimize resin rich areas which impact EM SE
  - Automated tape placement
    - Supports controlled placement of fibers and tailoring of EM SE properties

# Manufacturing and Fabrication Concerns

- Integration of special features
  - Cooling fans
  - Vents and heat sinks
- Enclosure and structure penetrations
  - Penetrations for cables and other hardware (hydraulics, etc.)
  - Access panels for equipment and maintenance considerations
    - Conductive seals
- Internal separations
  - Separation of components within enclosures and EM protected structures in the areas with electronics
    - Inclusion of integrated EM barriers

# Repairability and Maintainability Issues

- Corrosion control
  - Metallic structures
  - Galvanic corrosion with composite and metal interfaces
- Damage mitigation
  - Maintain structural and EM characteristics
  - Modified repair techniques
    - Maintain conductivity continuity
      - Filled polymers represent challenge
      - Fiber-reinforced composites
      - Repair applied coatings
    - Restore structural and functional integrity

# Future Direction

- Exploration of design options and EM impact
  - Inclusions of vents
  - Thermal properties for cooling
  - Electronics box spacings
  - Separation distances of electronics with appropriate shielding
  - System coupling
    - EM effects with EM structure coupled with interior enclosures
- Development of analytical methodology
  - Analytical tool development to support design
  - Frequency tailoring