Lightweight CNT Cables for Aerospace

Tom Kukowski
Minnesota Wire

NESC NDE Technology Assessment
NASA NDI Workshop
Johnson Space Center  Houston, TX
February 29 & March 1, 2012
Substitution of copper with CNT can reduce the weight of aerospace cables.

...CNT = carbon nanotube...
...aerospace cables = COTS = Commercial Off the Shelf cables...
...performance of lightweight CNT cables meets or exceeds that of COTS
Objectives

– Introduce the lightweight CNT wire and cable to valued customers for light weight applications.
– Identify unique properties added to wire representative of value to the market place
– Briefly review CNT properties and performance to frame a mindset for determining if CNT fits in your “envelope of application”.
– Stimulate interest and collaboration.
“Lightweight CNT Cables”

Presentation Agenda

- Introduction
- Objectives, Value Proposition & Feasibility
- Background of Present CNT Interest
- Growing Need for Lightweight Cables
- Materials Enable Lightweight Cables
- CNT Materials: Yarns and Tapes
- Wire Processing
- Lightweight CNT Cables
- CNT Cost
- MNW‘s Mission: “Add Value to Wire”
“Lightweight CNT Cables”

Origin of Present CNT Interest

– MND has been in “nanotechnology” for 8 years
– Application of nanocomposites, nano-coatings and pure CNT for EMI shields and conductors
– Introduced stretchy wire and shields
– Prior developments in medical and aerospace wire integrity
– Funding from defense SBIR Grants & prime contractors
– Collaboration with defense agencies & primes
– Built a development methodology to design and process CNT cables compliant with aerospace requirements.
“Lightweight CNT Cables”
Growing Need for Lightweight Cables

– Market desire for network-centric operations

*Infrastructure moves toward connectivity as that is the nature of progress:*
  - Increases incorporation of more electronic systems
  - Growing presence of more cables leads to concern over EMI protection

– Usage Logistics for vehicle apps

*Reduced weight translates to a number of significant economic and operational benefits, including:*
  - Improved operating range and time-on-station capabilities
  - Capability to carry larger payload
  - Reduced in-theater logistics for fuel management
  - Economic saving from greater fuel efficiency

One area of significant opportunity for increased weight savings is wiring. All of this drives the value for lightweight cables.
“Lightweight CNT Cables”

Introduction: Who is Minnesota Wire?

HQ and R&D
St Paul, MN
28,000 sq ft

Manufacturing Center
Eau Claire, WI
58,000 sq ft

Minnesota Wire is a vertically integrated, custom manufacturer of wire, cable and interconnect assemblies.

Minnesota Defense is a division of Minnesota Wire
“Lightweight CNT Cables”
R&D Laboratory Capabilities

**Mechanical Lab**
- tensile, multi-flex, multi-impulse
- precision weight scales
- Fused Deposition Modeling
- utilize NRTL’s for environmental & HALT

**Signal Integrity Lab**
- precision electrical measurement
- high frequency measurement
- signal & data integrity platforms

**EMC Lab**
- shielding effectiveness

**Nano Technology Lab**
- CNT process development
- wet chemistry
- Super Critical Fluid, RESS

**Imaging Lab**
- FLASH digital scope
- electron microscopy access UofMN for TEM, SEM-EDS, XPS, Confocal Raman, AFM
“Lightweight CNT Cables”

Aerospace Wiring Capabilities

- Braiding, twisting, serving of conductors
- Wrapping of tapes, foils, insulations, dielectric
- Polyimide wrapping & sintering
- Fluoropolymer extrusion: ETFE, PFA, FEP
- Mil-spec terminations and over molding
- Automation for high volume lines
“Lightweight CNT Cables”
MND Development History in Aerospace Wire Integrity

**TYPICAL WIRE FAILURE MODES**

- Unspecified Failure: 6%
- Short due to corrosion: 1%
- Failure due to corrosion: 7%
- Miswire: 8%
- Connector Failure: 9%
- Short circuit unspecified cause (includes arcing incidents): 3%
- Loose connection: 2%
- Insulation failure: 3%
- Chafed wire insulation leading to short circuit and/or arcing: 31%
- Other: 19%

---

Source: Navy Safety Center Hazardous Incident Data
“Lightweight CNT Cables”
Nanotechnology for Electrical Conductors and Shields Strategy

• Introduce unique properties of nanotechnology integrated cables into the interconnection (wire and cable) market for value added performance

• Leverage integration of hybrid conductors into the mainstream interconnection market thru development of nano-based electrical conductor technologies for high-end aerospace, medical and commercial market applications

• Substitute CNT for copper in niche as well as mainstream markets where conductivity performance is acceptable

• Develop partnerships for advanced technology transfer for value added integration and application

Interconnection Supply Chain
A Hierarchy of Value
“Lightweight CNT Cables”
Nanocomposites and CNT

• Are mixtures of nanomaterials like CNT (carbon nanotubes) and a polymer either in liquid or solid processing techniques
• EMI applications examples include plastic shielded electronic enclosures, transparent display coatings, elastomeric shields for stretchy wire, etc
• Applications are limited due to the low electrical conductivity
• The CNT products of *yarns* for wires and *tapes* for shielding material are more “pure” CNT
• This process involves making the CNT’s and converting them into finished product simultaneously so they are potentially more conductive by nature
**“Lightweight CNT Cables”**

**Conductivity is the Goal**

**Experienced Challenges**

- Polymer composites of SWCNT’s achieve conductivity for few applications beyond ESD or EMI shielding, certainly no where near copper $60 \times 10^6 \text{S-cm}^{-1}$ for electrical power conductors.

- Intrinsically conductive polymers like polyacetylene, polyaniline, polythiophene and polypyrrole have been recorded to have reached levels up to $10^5 \text{S-cm}^{-1}$ but they are impractical or unavailable.

- A practical choice for coatings is silver conductive ink at $17 \times 10^{-6} \Omega \text{-cm}$, or $5 \times 10^6 \text{S-cm}^{-1}$.

Nobel Prize Work: A Heeger, A MacDiarmid, S Shirakawa
“Lightweight CNT Cables”

**CNT Materials: Yarns and Tapes**

CNT yarns and sheets are fabricated into braided constructions for conductors and shielding tapes respectively for key electrical cable components that are OEM purchased.
“Lightweight CNT Cables”

Wire Processing With CNT

Braiding Conductor

The Braider braids CNT yarns peripherally around a center core of multiple CNT yarns to essentially fabricate a conductor.
“Lightweight CNT Cables”

Wire Processing With CNT
Fluoropolymer Insulation Extrusion

*Davis Standard Fluor polymer Wire Extruder*
for application of FEP, PFA, ETFE insulations

ETFE insulated conductor primary for CAN Bus & RS485 cable
ready for fabrication, assembly and impedance optimization for twisted pair transmission lines
“Lightweight CNT Cables”

Wire Processing With CNT

Wrapping CNT Tape and Insulation

The "ejr" Wrapper

for Kapton/Oasis wrap and sinter insulation this is a 50 foot machine with payoff, 2 head wrapper, 10' sintering oven and take up.
“Lightweight CNT Cables”
Wire Processing With CNT
Finished Cable Assembly

CNT Yarn
Braided conductor
Conductor braiding

CNT tape
CNT twisted pair cable
CNT Coax

Shielding Effectiveness
“Lightweight CNT Cables”

Conductor Material Performance Attributes

- Conductivity
- Tensile
- Flex life
- Weight advantage
- General aerospace wire standards
“Lightweight CNT Cables”

CNT Cost

• Estimated cost of a CNT modified aerospace cable is presently high (n x COTS), whereas, an aerospace coax COTS equivalent is typically <$5/ft.

• CNT presently has potential application in shielding, low signal and data communications.

• The CNT commodity market may be very similar to semiconductor evolution? When will price drop?
Space Applications

Desired Cost of CNT cables

Lifecycle savings per pound of weight reduction

Present

Future

Military Fighters

UAVs

Helicopters

Commercial Aviation

>>> Meet COTS

Minnesota Wire
Life Saving Connections

Minnesota Defense
Military Interconnect Solutions
“Lightweight CNT Cables”

CNT Commodity Cost vs Value Proposition

- Present cost of CNT material is high, not unusual to “early adopters” of any innovative technology… flashback … silicon to integrated circuits … are we at “The Chasm”…?
- CNT insertion into high valued markets enables commercial market development
- Cost benefits are high in aerospace markets:
  - **Satellites**: weight savings equates to launch cost savings
  - **UAV’s**: weight savings equates to mission time
  - **Aircraft**: lifetime cost savings for an aircraft is equated from fuel savings
The following is representative of our background in wire integrity … appropriate for aerospace wiring quality.
HISTORY OF WIRE INTEGRITY

TYPICAL WIRE FAILURE MODES

Source: US Coast Guard Aging Aircraft Branch
HISTORY OF WIRE INTEGRITY
SAFETY ISSUES RISING COMMERCIAL AIRCRAFT

• CATOSTROPHIC CRASHES
  – TWA 800 IN 1996 IN NY DUE TO FUEL PROBE ARC FAULT
  – SWISS AIR 111 IN 1998 NOVA SCOTIA DUE TO COCKPIT WIRE ARC FIRE

• NUMEROUS MISSION CRITICAL EXAMPLES:
  – 10/2000, Continental Flight 1579, DC-9, electrical fire
  – 8/2000, AirTran Flight 913, DC-9, electrical fire
  – 1/9/98, United Airlines 767-200, electrical fire
  – 7/5/97, Northwest Airlines DC-9-15, electrical fire
  – 6/17/97, Sun Country Airlines, DC-10-10, smoke in aircraft
  – 2/20/97, Northwest Airlines DC-9-15, electrical fire
  – 1/11/96, Colombian DC-9-14, in-flight fire, fatal accident
  – 6/5/96, Delta Airlines 767-225, electrical fire
  – 6/6/96, Continental Express Beech 1900, in-flight fire
  – 9/5/96, Federal Express DC-10-10, smoke in cabin
DEVELOPMENTS TO IMPROVE WIRE INTEGRITY PERTINENT TO AEROSPACE WIRING

GOAL:

Exceed the tensile strength and flex life of COTS stranded copper wire by braiding. Finished wire has same electrical conductivity and insulations but would be superior in fatigue resistance.

• Wires of metal content including cadmium, beryllium, 2 alloys, tin copper and silver copper wire represent the core of COTS cables today.
• Insulations included PFA, ETFE, XL-ETFE, Kapton wrap and sinter and PTFE
• 28 to 18 AWG by electrical equivalence
• Standards: 810F, 461E, 464, 4372 wire performance, 4373 wire test methods, 915-C flex, B470 bare wire
• Volume flex test capabilities necessary because there is a wide standard of deviation
QUICK LOOK AT
MNW/MND COMMERCIALIZATION STRATEGY
BASED ON R&D CONTRIBUTIONS
Hybrid Conductor Development

<table>
<thead>
<tr>
<th>Performance Attribute</th>
<th>Market Value</th>
<th>Global Initiative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light weight</td>
<td>Energy Savings, Payload Expansion</td>
<td>Potential of CNT over traditional copper:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Energy Efficiency</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Raw material manufacturing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Transportation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Green for Environment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Carbon footprint</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Recyclable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Competitiveness (Payload expansion)</td>
</tr>
<tr>
<td>Flex life &amp; Strength</td>
<td>Reliability, Life Cycle Extension</td>
<td>Advanced Technology Competitiveness</td>
</tr>
<tr>
<td>Radiotranslucence</td>
<td>MRI &amp; Imaging Compatible</td>
<td>Health Care Costs, Quality of Life</td>
</tr>
<tr>
<td>Inflammability &amp; Heat Dissipation</td>
<td>Light Weight Flame Retardancy, Low IR Emission</td>
<td>Safety, Life Saving, Insurance Cost Reduction</td>
</tr>
<tr>
<td>Corrosion Resistance</td>
<td>Reliability, Life Cycle Extension</td>
<td>Advanced Technology Competitiveness</td>
</tr>
<tr>
<td>High Conductive Nano Coatings (low</td>
<td>Prognostic Health Management</td>
<td>Safety, Life Cycle Cost Reduction, End of Life</td>
</tr>
<tr>
<td>volume, low weight)</td>
<td></td>
<td>Prediction</td>
</tr>
</tbody>
</table>
“Lightweight CNT Cables”

Applications for CNT Component Cables
“Lightweight CNT Cables”

CLOSURE

THANK YOU FOR YOUR TIME AND ATTENTION!

– DISCUSSION?
– ACTION ITEMS?

Tom Kukowski, R&D Manager
Minnesota Wire
1835 Energy Park Drive
St Paul, MN 55108
main(651-642-1800
office(651)659-6763
cell(612)209-1178
email: tkukowski@mnwire.com