Enabling Monitoring and Inspection with Wireless Power and Data Hotspots Through Barriers

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Research & Development
- Through barrier sensing, communications, and power

Application Specific Design
- Specializing in defense, oil and gas, and underwater technologies

Custom Electronics
- Pressure tolerant communications, control, and data acquisition platforms
What is the problem?

• Harsh environment are typically contained or isolated using conductive materials (Steel, Aluminum, etc.)
  – Oil and gas pipe contains high pressure high temperature
  – ISS contains 1ATM from vacuum and large temperature fluctuations
  – Submarine contains 1ATM from subsea pressures

• Want to make measurements and pass data through these barriers without making a penetration
Why Magnetic Based Wireless and Sensing Instead of RF?

- RF is limited by conductivity of a media. As such communications or sensing through most metals is impractical.
- Magnetic field penetration is (at low frequencies) dominated by magnetic permeability.
- Comparing attenuation through air versus common structural materials, magnetic fields are much less affected.
- Additionally, magnetic fields can wirelessly transfer significant amounts of power.

<table>
<thead>
<tr>
<th></th>
<th>Air</th>
<th>Carbon Steel (1010)</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductivity</td>
<td>$3.0 \times 10^{-15}$ S/m</td>
<td>$7.0 \times 10^{6}$ S/m</td>
<td>$2 \times 10^{21}$</td>
</tr>
<tr>
<td>Relative Magnetic Permeability</td>
<td>1.0</td>
<td>$1.0 \times 10^{3}$</td>
<td>$1.0 \times 10^{3}$</td>
</tr>
</tbody>
</table>
Why Magnetic Based Wireless and Sensing Instead of Acoustic?

• Acoustic communications is strongly limited by the path and variations in acoustic properties of the path. Through thin (<1m) materials, multi-path reflection causes major distortion.

• Multipath reflection in acoustics is an issue due to the relatively slow propagation speed of acoustics. With magnetic fields the propagation is on the order of the speed of light and thus multi-path distortion is avoided at reasonable scales.
WiΨ - Wireless Power and Signal Interface

- System uses the modulation of magnetic fields to transmit data and power wirelessly
- Works through metals (incl. X65, 1010, Inconel, Super Duplex, aluminum), seawater, concrete, air, and layers of multiple materials
- Deployed on a US Navy Los Angeles class submarine as part of a mission and safety critical system
- Recent work focused on application specific oil and gas embodiments as well as major overall technology improvements
WiΨ — Block Diagram

[Diagram showing the block diagram of a system involving sensor or equipment, signal conditioning, digital signal processor, magnetic transducer, amplifier, and bidirectional data and power transmission.]
**WiΨ Hardware**

**WiΨ RX**: sends power through barrier. Demodulates received data signal. FPGA software defined radio architecture for configurability in new applications. RS485 interface to other data acquisition/logging equipment.

**WiΨ TX**: inductively powered through barrier. Interfaces to analog or digital (RS485) data sources. Sends modulated data through barrier

**WiΨ transducer**: used for both RX and TX. On TX side, it generates a magnetic field. On RX side the transducer converts a magnetic field to a detectable voltage. Both power and data can be sent over the same transducer link.
Extreme Example of Magnetic Communications
- sensor data through 12” of structural steel

FSK modulated receive data
(yellow is TX signal, blue is RX)
Non-penetrating Valve Sensor

- In this application phase and amplitude of received data signal indicate path obstructions
- Allows us to sense the presence of a valve gate from the outside

Sensor installation

Demo software

Sensor registers 100% opened.

Sensor registers 50% opened.
# WiΨ Data Rate and Power Transfer Through Various Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness</th>
<th>Data Rate</th>
<th>Power Transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>304 Stainless Steel</td>
<td>0.5”</td>
<td>500 kbps</td>
<td>5W</td>
</tr>
<tr>
<td>304 Stainless Steel</td>
<td>1”</td>
<td>100 kbps</td>
<td>1W</td>
</tr>
<tr>
<td>Titanium</td>
<td>0.5”</td>
<td>500 kbps</td>
<td>5W+</td>
</tr>
<tr>
<td>Inconel</td>
<td>0.5”</td>
<td>500 kbps</td>
<td>100W</td>
</tr>
<tr>
<td>Aluminum</td>
<td>0.5”</td>
<td>100 kbps</td>
<td>1W</td>
</tr>
<tr>
<td>Plastics or other low conductivity media</td>
<td>0.5”</td>
<td>1 Mbps+</td>
<td>5kW+</td>
</tr>
<tr>
<td>Steel (1010, X65, 4130, etc)</td>
<td>1”</td>
<td>1 kbps</td>
<td>~1mW *</td>
</tr>
<tr>
<td>Steel (1010, X65, 4130, etc)</td>
<td>7”</td>
<td>10 bps</td>
<td>-</td>
</tr>
</tbody>
</table>

* Recent advances may lead to radical improvement in high μ material power transfer
WiΨ System Can Also Detect Barrier Breach

Receiver (magnetic “transmitter” enclosed in box)

Hole, varied in test from 0.06” to 0.5”

Lid (1/2” aluminum), not bolted down in this image

Sealed (welded) ¼” thick 12”x12” aluminum box
Swept frequency probe can be done along with power and data transmission
WiΨ TX connected to monitoring or inspection equipment

When monitoring or inspection equipment comes in proximity to hotspot (within ~18” radially, ~6” standoff) it receives power and can send data

WiΨ RX powered by station power bus. Senses when TX is near and begins sending power and receiving data.

WiΨ RX connects to any inboard systems. RS485 currently but can develop other interfaces.
Potential Monitoring and Inspection Applications with WiΨ HotSpot

- Interface with traditional eddy integrity sensors.
- Charge batteries or super-capacitors on inspection or monitoring equipment.
- Charge and download data from extra-vehicular inspection robot moving along hull.
- Provide primary or backup hull integrity monitoring.
- Provide a through-barrier hotspot for multiple inspection and monitoring sensor platforms.
The Take Home

• WiΨ can be used for:

1. Data communications through thick, conductive barriers or layers of conductive barriers
2. Transferring power through conductive barriers
3. Characterizing changes in a barrier (i.e. holes, moving valve gate)

Or a combination of the above