A Robust Wireless Communication System for Harsh Environments Including Nuclear Facilities

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Outline

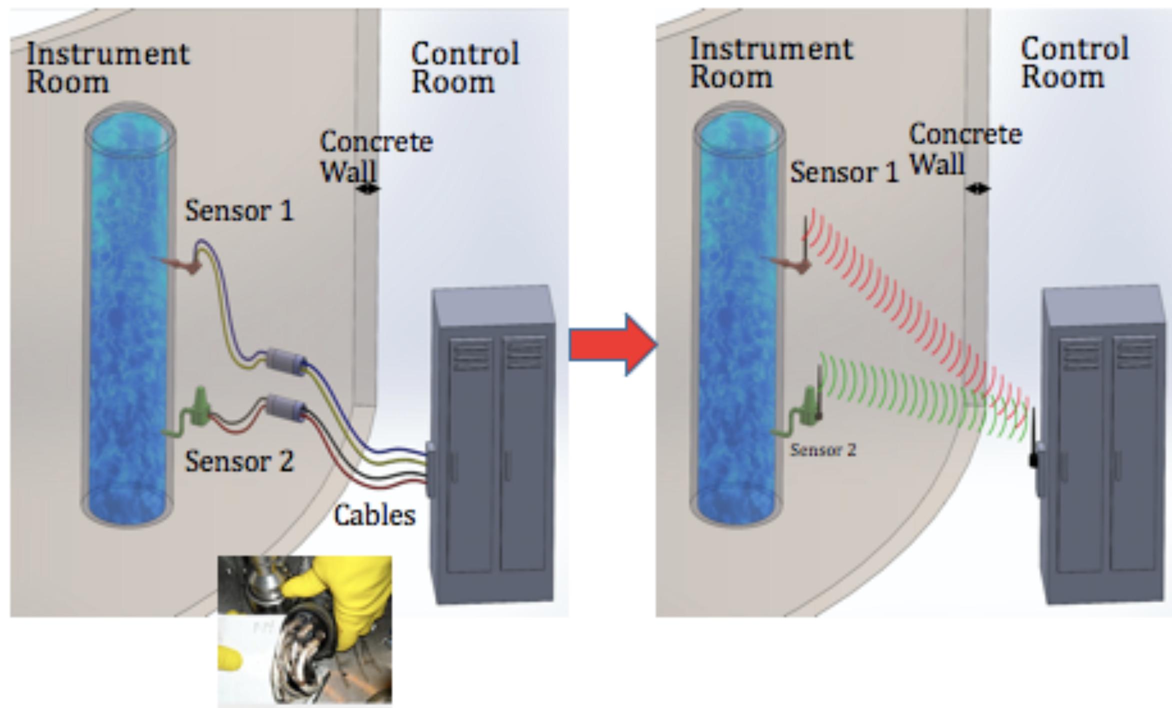
- ❑ Project Overview
- ❑ Background
- ❑ Summary of Phase I accomplishments
- ❑ SBIR Phase II tasks
- ❑ Current SBIR Phase II progress
- ❑ Conclusion and path forward

Project Overview

- Goal: Develop and evaluate a secure and reliable wireless sensor communications system to address the unique challenges of RF communications nuclear facilities
- Participant: Dirac Solutions Inc.
- Project: Phase II SBIR
- Schedule: 2 years (2018-2020)

Background - Wireless sensor communications improves I&C reliability and process efficiency in next generation reactors

- Cable integrity and maintenance is a major challenge in reliable sensor data reporting in current NPPs
- Nuclear reactors pose a hostile environment for RF signals
  - Lots of metal
  - Thick concrete walls
  - Liquids
  - Clutter
  - EMI from / or to other wireless systems
- Conventional wireless communications face significant limitations in reporting sensor data in NPPs



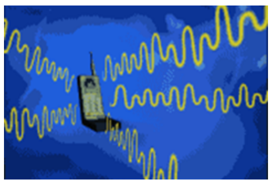
Source: IAEA

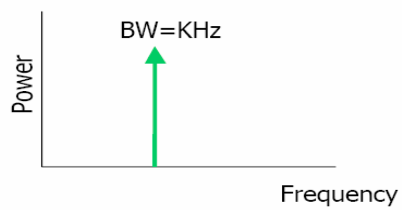
Objectives

- Based on the results from our Phase I software simulations, design considerations, and field experiments, in Phase II we plan to develop, field evaluate, and manufacture reliable wireless sensor communications system based on ultra-wideband (UWB) technology to address the concerns associated with the performance of conventional wireless technology in nuclear reactors.

Narrow RF pulses as building blocks for communications in UWB technology significantly differentiate their performance over conventional narrowband systems

Traditional RF systems use Narrowband signaling (Continuous waveforms, with high power and narrow frequency band) to transmit/receive information.

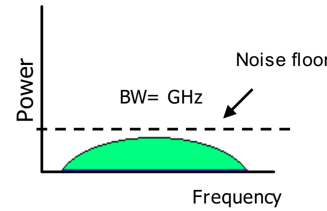




Key disadvantages of narrowband signaling:

- Vulnerable to signal jamming and spoofing
- Limited penetrability in harsh environments
- Easy to detect
- Low channel capacity (data rate)
- Low Precision
- Needs sophisticated encryption techniques
- Complex hardware architecture
- Limitations in worldwide operation

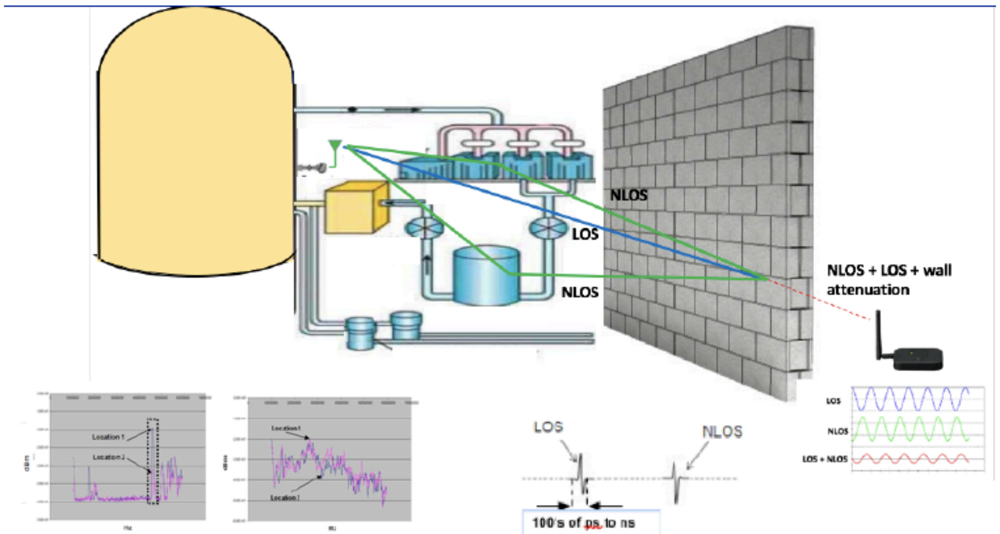
Ultra-wideband systems use narrow pulses (sub-nano second duration, with low power, ultra-wide frequency band) to transmit and receive information



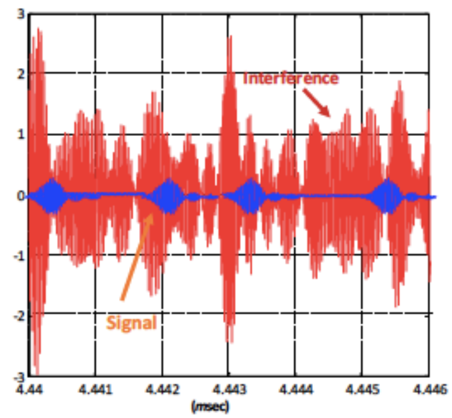
Key advantages of UWB signaling are:

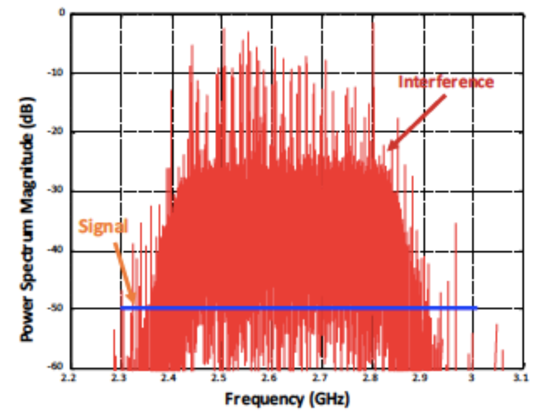
- Resistant to signal jamming and tampering
- Good penetration properties of signal in harsh environments
- Secure transmission by pulse coding
- High channel capacity (data rate)
- Accurate ranging and geolocation
- Inherently encrypted by pulse coding
- Simple architecture – small formfactor, low cost
- Unlicensed spectrum– Global operations

UWB RF signals offer unique advantages in sensor data reporting at NPPs



- UWB Pulses are less sensitive to multipath phenomenon



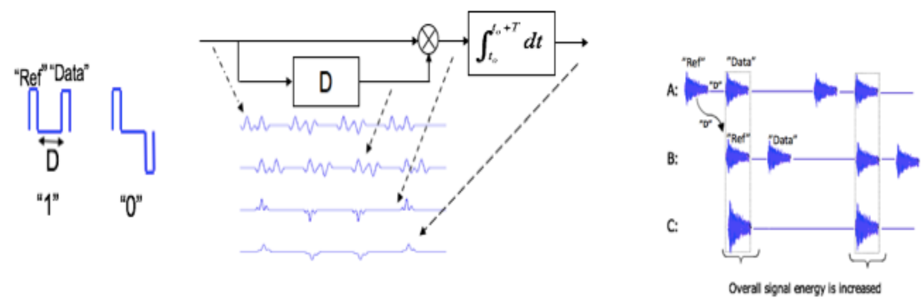


- UWB pulses offer physical layer encryption and look like noise to other receivers

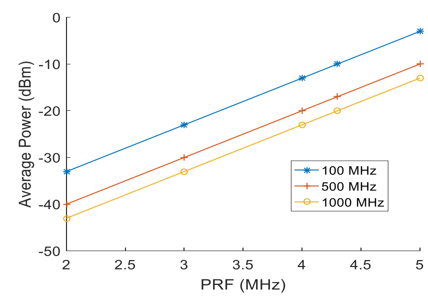
Phase I goal: Uniquely designed UWB pulses allow sensor communications in extremely harsh environments (i.e. behind closed metallic doors, or through tick walls) and offer data security

Summary of Phase I SBIR Accomplishments

- Developed a unique UWB modulation technique "Encrypted Transmitted-Reference (ETR)" with the following features:
  - Robust performance in reflective environments
  - Physical layer security
  - Asynchronous transmission

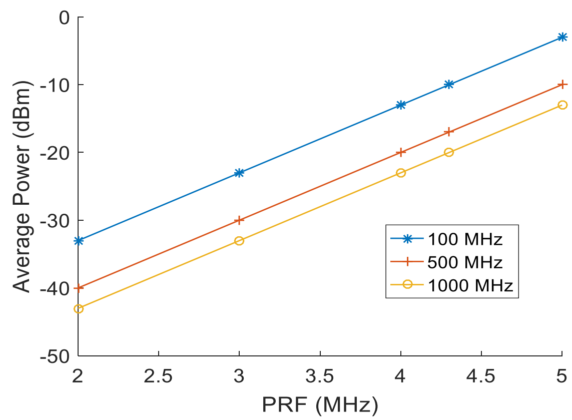


- Communications system analysis - Investigated the effects of EMI and interfering RF signal based on the following parameters:
  - Frequencies
  - Modulation
  - Bandwidth, pulse duration

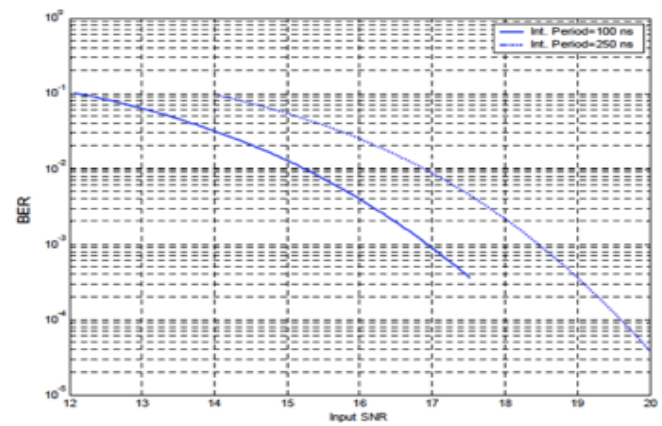


- Conducted field experiments to characterize UWB signal transmission at MIT research reactor (MITR)

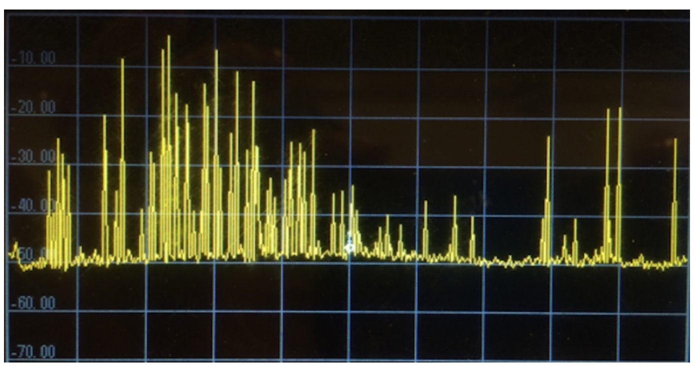
SBIR Phase I Accomplishments – Software simulations for UWB pulse design

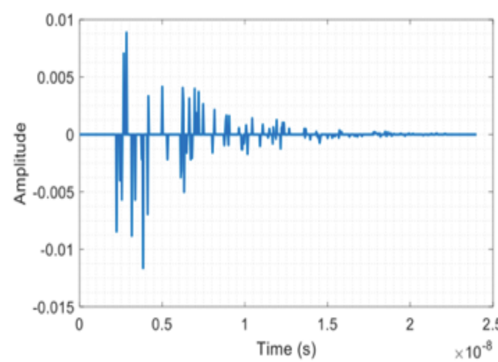


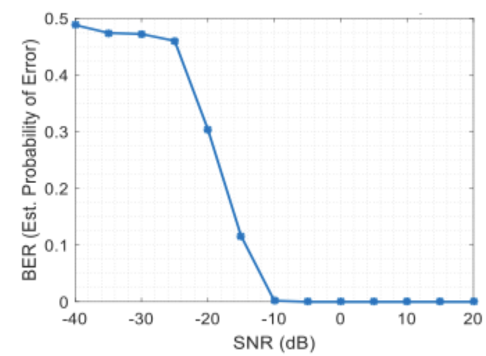
Pulse Repetition Frequency Study



Pulse Integration Period Study

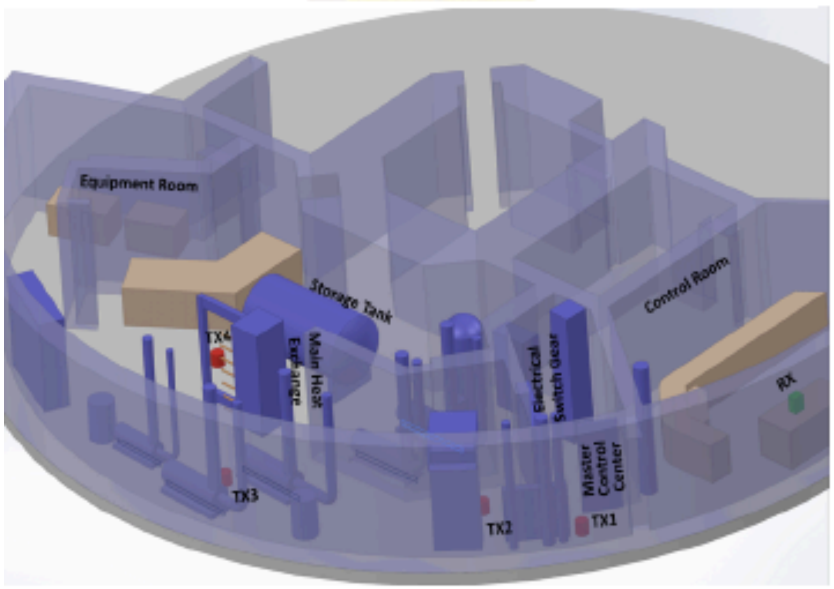






NPP Channel Modeling

DSI experiments at MITR demonstrated great success for sensor data transmission in hostile RF environments



Behind the First Wall (TX1)

```
Packet # 565 | Node 5 | TX ID 083 | Temp 83.4 F | Light 79 lx
Time 00:05:04 | dT 00:00 | RSSI 13.30mW | Humidity -- % | Extrnl 1211 mV

Packet # 566 | Node 5 | TX ID 083 | Temp 83.4 F | Light 79 lx
Time 00:05:05 | dT 00:01 | RSSI 15.17mW | Humidity -- % | Extrnl 941 mV

Packet # 567 | Node 5 | TX ID 083 | Temp 83.2 F | Light 75 lx
Time 00:05:05 | dT 00:00 | RSSI 14.83mW | Humidity -- % | Extrnl 1220 mV

Packet # 568 | Node 5 | TX ID 083 | Temp 83.2 F | Light 75 lx
Time 00:05:05 | dT 00:00 | RSSI 14.55mW | Humidity -- % | Extrnl 1092 mV

Packet # 569 | Node 5 | TX ID 083 | Temp 83.2 F | Light 79 lx
Time 00:05:06 | dT 00:00 | RSSI 13.58mW | Humidity -- % | Extrnl 1121 mV

Packet # 570 | Node 5 | TX ID --- | Temp 83.2 F | Light 75 lx
Time 00:05:06 | dT 00:00 | RSSI 12.42mW | Humidity -- % | Extrnl 1226 mV

Packet # 571 | Node 5 | TX ID 083 | Temp 83.2 F | Light 75 lx
Time 00:05:07 | dT 00:01 | RSSI 11.86mW | Humidity -- % | Extrnl 1144 mV

Packet # 572 | Node 5 | TX ID 083 | Temp 83.2 F | Light 79 lx
Time 00:05:07 | dT 00:00 | RSSI 7.73mW | Humidity -- % | Extrnl 1147 mV
```

10 ft beyond second Wall (TX2)

```
Packet # 41 | Node 5 | TX ID 083 | Temp 85.6 F | Light ------ lx
Time 00:01:30 | dT 00:03 | RSSI 1.91mW | Humidity -- % | Extrnl 997 mV

Packet # 42 | Node 6 | TX ID 083 | Temp 85.0 F | Light 11 lx
Time 00:01:30 | dT 00:07 | RSSI 1.63mW | Humidity -- % | Extrnl 1205 mV

Packet # 43 | Node 5 | TX ID 083 | Temp 85.5 F | Light ------ lx
Time 00:01:32 | dT 00:02 | RSSI 2.00mW | Humidity -- % | Extrnl 1101 mV

Packet # 44 | Node 5 | TX ID 083 | Temp 85.5 F | Light ------ lx
Time 00:01:35 | dT 00:03 | RSSI 1.63mW | Humidity -- % | Extrnl 1121 mV

Packet # 45 | Node 6 | TX ID 083 | Temp 85.2 F | Light 11 lx
Time 00:01:37 | dT 00:07 | RSSI 1.53mW | Humidity -- % | Extrnl 1188 mV

Packet # 46 | Node 5 | TX ID 083 | Temp 85.7 F | Light ------ lx
Time 00:01:40 | dT 00:05 | RSSI 2.00mW | Humidity -- % | Extrnl 1141 mV

Packet # 47 | Node 5 | TX ID 083 | Temp 85.7 F | Light ------ lx
Time 00:01:42 | dT 00:02 | RSSI 1.85mW | Humidity -- % | Extrnl 1028 mV

Packet # 48 | Node 5 | TX ID 083 | Temp 85.7 F | Light ------ lx
Time 00:01:46 | dT 00:03 | RSSI 1.85mW | Humidity -- % | Extrnl 1127 mV
```

Behind heat exchanger (titanium), 3 walls (2 walls are shielded with steel), at the door in control room (TX3)

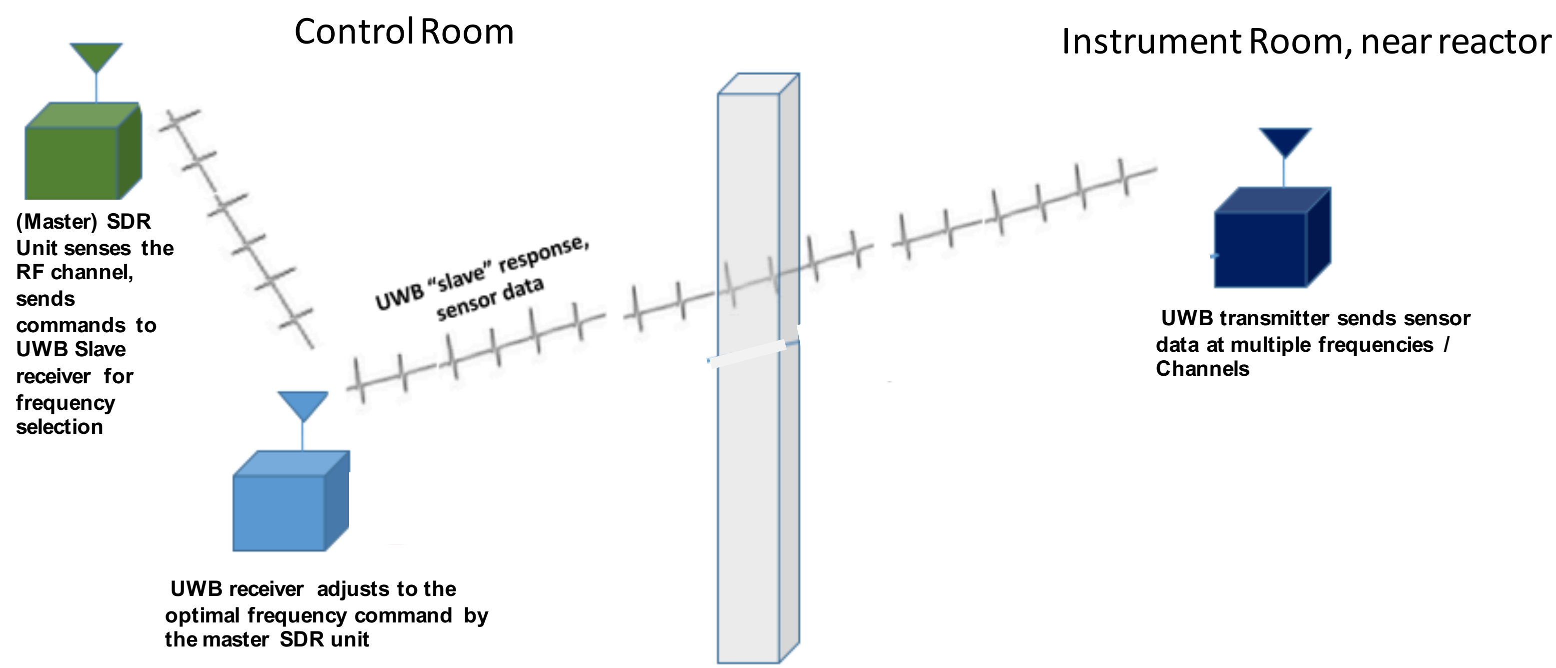
```
acket # 170 | Node 5 | TX ID 083 | Temp 86.9 F | Light ------ lx
Time 00:12:16 | dT 00:00 | RSSI 18.16mW | Humidity -- % | Extrnl 919 mV

Packet # 171 | Node 5 | TX ID 083 | Temp 86.9 F | Light ------ lx
Time 00:12:17 | dT 00:01 | RSSI 19.86mW | Humidity -- % | Extrnl 985 mV

Packet # 172 | Node 5 | TX ID --- | Temp 86.9 F | Light ------ lx
Time 00:12:17 | dT 00:00 | RSSI 18.16mW | Humidity -- % | Extrnl 1165 mV

Packet # 173 | Node 5 | TX ID 083 | Temp 86.9 F | Light ------ lx
Time 00:12:18 | dT 00:01 | RSSI 17.86mW | Humidity -- % | Extrnl 1055 mV

Packet # 174 | Node 5 | TX ID 083 | Temp 86.9 F | Light ------ lx
Time 00:12:18 | dT 00:00 | RSSI 18.16mW | Humidity -- % | Extrnl 1020 mV

Packet # 175 | Node 5 | TX ID 083 | Temp 86.9 F | Light ------ lx
Time 00:12:19 | dT 00:01 | RSSI 5.48mW | Humidity -- % | Extrnl 1141 mV

Packet # 176 | Node 5 | TX ID 083 | Temp 86.9 F | Light ------ lx
Time 00:12:20 | dT 00:01 | RSSI 4.46mW | Humidity -- % | Extrnl 1240 mV

Packet # 177 | Node 5 | TX ID 083 | Temp 87.1 F | Light ------ lx
Time 00:12:22 | dT 00:02 | RSSI 0.56mW | Humidity -- % | Extrnl 1115 mV
```

Phase I Outcomes for wireless communications design parameters

Communications Parameter			
Frequency (MHz)	400	700	900
Pulse Duration (ns)	30	20	1 0
Pulse Repetition Frequency	Adjustable from 10 KHz to 100 KHz		
Delay between pulses	Adjustable fro 5 ns to 30 ns		

Phase II SBIR Plan

Develop a secure and reliable UWB communications system based on Phase I simulation studies and field experiments in a software-defined- radio (SDR) that can adapt it's communications parameters to the dynamic environment of various nuclear reactor facilities



Phase II SBIR Tasks (Two years)

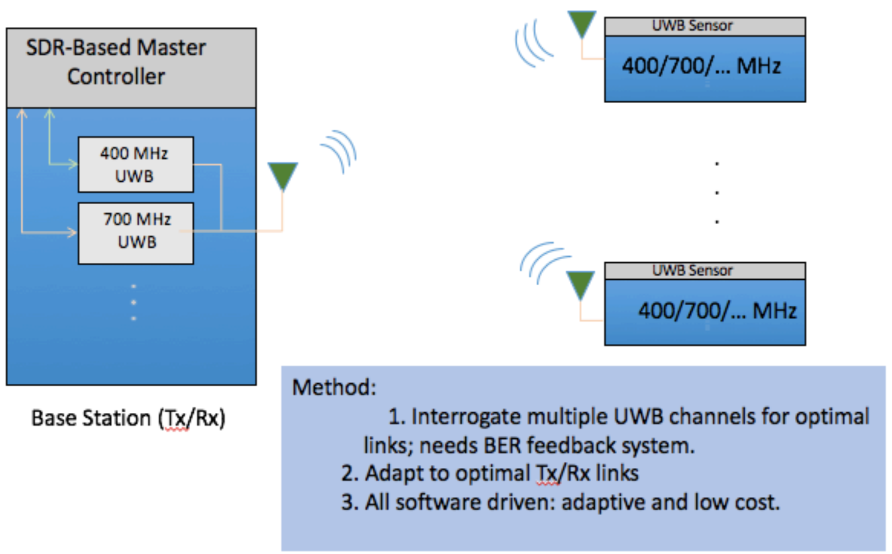
- ❑ Develop hardware for SDR master unit to sense the RF channel for best communication frequency selection
- ❑ Develop hardware for multiple UWB pulsers at various frequencies (400 MHz, 700 MHz, 900 MHz)
- ❑ Develop UWB transmitters and receivers with self adapting frequency adjustment capability
- ❑ Integrate sensors (temperature, humidity, radiation) with the adaptive transmitter unit
- ❑ Laboratory and field testing of the hardware
  - ❑ MIT research reactor
  - ❑ Testbed at ORNL Technical Testing and Analysis Center (DSI internally funded CRADA)
- ❑ Fully functional integrated hardware software for a UWB SDR communications system that can adapt it's communications parameters to the operating environments
- ❑ Low volume manufacturing

Phase II SBIR Current accomplishments

- Currently working on software development for SDR master unit to sense the channel using commercially available USRP SDR platform

- In process of developing pulser circtuit boards with multiple frequencies including 400 MHz, 700 MHz, 900 MHz

- Design of switch circuitry for adaptive frequency selection



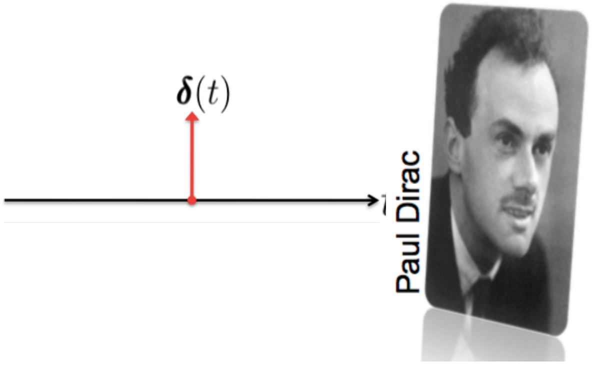
Conclusions and Path Forward

- The secure UWB sensor communications allows for:
  - Eliminating cables, reducing the risk of unpredictable cable health and time consuming maintenance, lower cost, improved reliability,
  - Modernization of next generation nuclear reactors, allowing modular reactors to benefit from reliable wireless technology
  - Published a conference paper and a journal paper

- Path forward includes:
  - Fully develop the required hardware and software for field deployments
  - Extensive laboratory and field tests for performance evaluations and refinements
    - MITR, ORNL, and more
  - Small scale manufacturing

  - Large scale manufacturing and introducing the UWB wireless communications systems to nuclear reactor operation facilities (Phase III)

About Dirac Solutions Inc. (DSI)



- Dirac Solutions Inc. is a small business located in Pleasanton, CA with core expertise in Ultra-wideband Communications/RADAR, as well as Active and Passive RF tagging/tracking.

- A spin-off from Lawrence Livermore National Laboratory

- Extensive R&D program (DOE, NSF, DOD, DHS)

- Growing products lines for national security applications in collaborations with national laboratories and industry

- DSI was the recipient of the "2016 DOE Small Business of the Year award"