Passive Radio Frequency Tags and Sensors for Process Monitoring in Advanced Reactors

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Program: Advanced Reactor Development

ABSTRACT:

The objectives for this proposed work are to develop next generation specialized wireless sensing and monitoring using passive and semi-passive tags integrated with sensors for the remote process monitoring of advanced reactors. To date, much of the nuclear power plant sensing is currently through wired and wall-powered systems. This conventional sensing through cables has posed significant issues with long-term reliability and requires a high-degree of maintenance. Even the wireless sensor communications systems considered for NPPs rely on batteries or wall power. Although significant research on power harvesting through Thermoelectric generators and Gamma harvesting power supply is in progress for nuclear power plants with reported successful results, these power harvesting methods could limit the position of the sensors to the location of the power source.

To complement the existing effort in self power wireless sensors and power harvesting techniques, Dirac Solutions Inc. (DSI) in collaboration with Idaho National Laboratory (INL), University of California (UCSC), and Massachusetts Institute of Technology (MIT) proposes to develop state-of-the-art wireless RF remote powering and remote switching techniques focusing on passive (i.e. battery-free) tags and sensors for sensors with lower power requirements and semi-passive (battery-assisted-passive) tags and sensors for longer range monitoring operations of sensors that require higher operational power. The semi-passive tags/sensors proposed here, use a small battery for their communications, however, through smart power management the battery is remotely activated through a remote RF switching signal. Therefore, the lifetime of the battery can be significantly extended. The advantage of the proposed RF power harvesting/switching is that the sensors will have more flexibility to move around inside the reactors and will not be limited to specific locations where the power source is located. In addition, DSI will address the data fusion and real-time multimodal sensor data analysis of the data in process monitoring applications and will use the passive tags for tracking and inventory automation of high value assets such as nuclear sources. These battery-free RF tags also have applications in tracking of materials, tools, and equipment (MTE) for foreign materials exclusion zone (FMEZ).

This proposed project is a natural extension to the three successfully executed past and existing DOE SBIRs. The UWB communications aspects of this work stems from successful results obtained in field experiments on current Phase 2 SBIR funding from DOE's NE program, where DSI has been developing a novel active (battery-powered) wireless sensor communications system based on ultra-wideband (UWB) signaling and software-defined-radio (SDR). The backscattering UHF aspect of the proposed project stems from many years of multiple SBIR funding (Phases 1 through 3) from DOE's DNN-R&D, where DSI has developed and manufactured passive (battery-free) tags for hostile RF environments for IAEA applications with high survivability around nuclear materials. In addition, a recent Phase 1 and 2 DOE SBIR from DNN-R&D office has made very long-range passive unique ID detection from 1 Km distance possible. Therefore, DSI based on past experience is uniquely positioned to develop a new passive and semi-passive tag/sensor technology for remote process monitoring of existing and advanced reactors.

The outcome of this research is to remotely power tags integrated with sensors through the thick concrete walls where the wall power is available as shown in Figure 1, below.

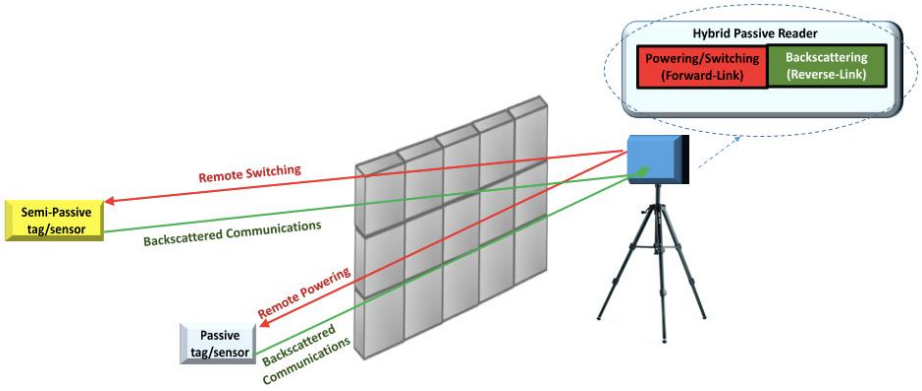

Figure 1: Conceptual block diagram for RF remote powering and remote switching of passive and semi-passive tags respectively using a hybrid signaling reader.

The proposed wireless passive and semi-passive sensor suite for advanced reactors will not only allow much required automation, but also improve reliability and reduce the cost of operation by eliminating the need for several power and signal cables to sensors. The proposed technology also enables the deployment of a larger number of sensors at low cost to improve the process monitoring for safety and security of advanced modern reactors where sensor fusion and multimodal sensor data analysis allows operators to make an informed decision based on a collection of sensor data for detection of irregular plant conditions and to help initiate safety steps such as: reactor shutdown, notification of functioning of the containment building, or heat removal from the reactor, etc. Furthermore, this unique sensor suite has crosscutting benefits for Light Water Reactor Sustainability (LWRS) to eliminate aging cables and is easily deployable in existing nuclear power plants without any change to their infrastructure. A high level plan of tasks and deliverables of the project include:

1) **Task 1:** Requirement document and test plan, **Milestone:** Requirement document for operational requirements of RF remote powering, and test plan for remote powering and radiation testing.
2) **Task 2:** Passive tag-sensor integration, **Milestone:** sub-set of passive tags integrated with various sensors including: temperature, strain, pressure, flow, and vibration sensors.
3) **Task 3:** Item identification and inventory at NPPs, **Milestone:** Demonstration of a passive item identification / personnel monitoring at a representative facility.
4) **Task 4:** Semi-passive tag-sensor development, **Milestone:** sub-set of semi-passive tags integrated with various sensors.
5) **Task 5:** RF remote powering/switching, **Milestone:** Functional power harvesting circuitry with the optimal frequency band for tag-sensor communications.
6) **Task 6:** Processing of wireless sensor data, **Milestone:** Prototype multimodal analysis software and graphical user interface for data representation.
7) **Task 7:** Graphical user interface, **Milestone:** Prototype graphical user interface.
8) **Task 8:** Laboratory and field experiments, **Deliverable:** Laboratory and field test and experimental results for remote powering and radiation testing.
9) **Task 9:** Final report, **Deliverable:** Final report, documenting experimental results and path to future Phases manufacturing.