Battery-less Wireless Sensors for Structural Health Monitoring for In-Situ Decommissioning Tasks

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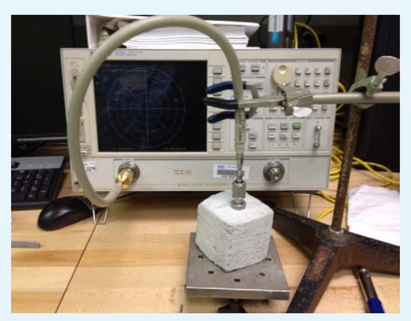
Introduction

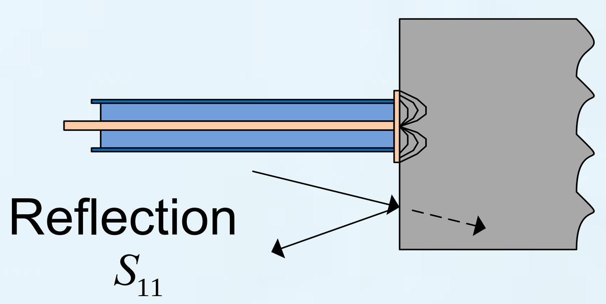
The Department of Energy (DOE) has been involved in many in-situ decommissioning (ISD) tasks at old nuclear plants, including filling the reactors with special grouts and covering with a concrete slab. With ISD, monitoring of parameters such as temperature, humidity, and strain during the curing process becomes an important task. This research intended to demonstrate the feasibility of using battery-less RFID devices such as the Wireless Identification and Sensing Platform (WISP) for measuring different parameters inside decommissioned structures filled with concrete and grout. It is important to understand how to properly position the sensors and how the losses must be overcome for proper performance.

Methods

1. *Measuring Complex Dielectric Permittivity*

This method covers frequencies from 100 MHz to 1 GHz. It is used for characterizing the dielectric complex permittivity of lossy materials. It uses a commercial open-ended coaxial probe and a vector network analyzer.



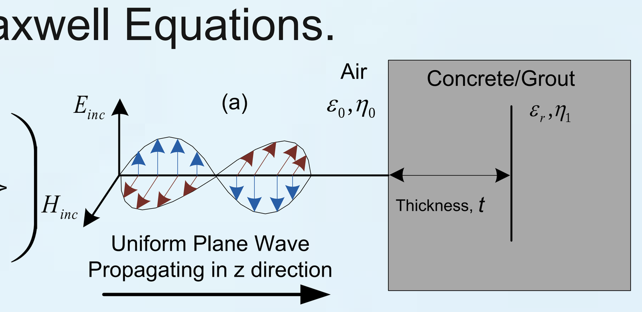


2. *Mathematical modelling of propagation of microwaves inside materials*

After measuring the dielectric permittivity of concrete and grout, the transmission and propagations losses of a uniform plane wave inside both materials can be calculated via Maxwell Equations.

Transmission Loss

$$A_t = 10 * \log_{10}\left(|T|^2 * \mathrm{Re}\left\{\frac{\eta_0}{\eta_1}\right\}\right)$$

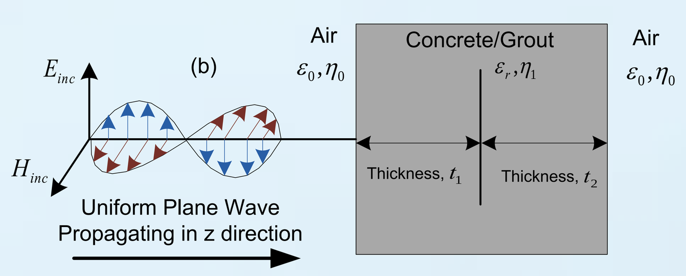


Propagation Loss

$$A_p = 10 * \log_{10}\left(e^{-2\alpha t}\right)$$

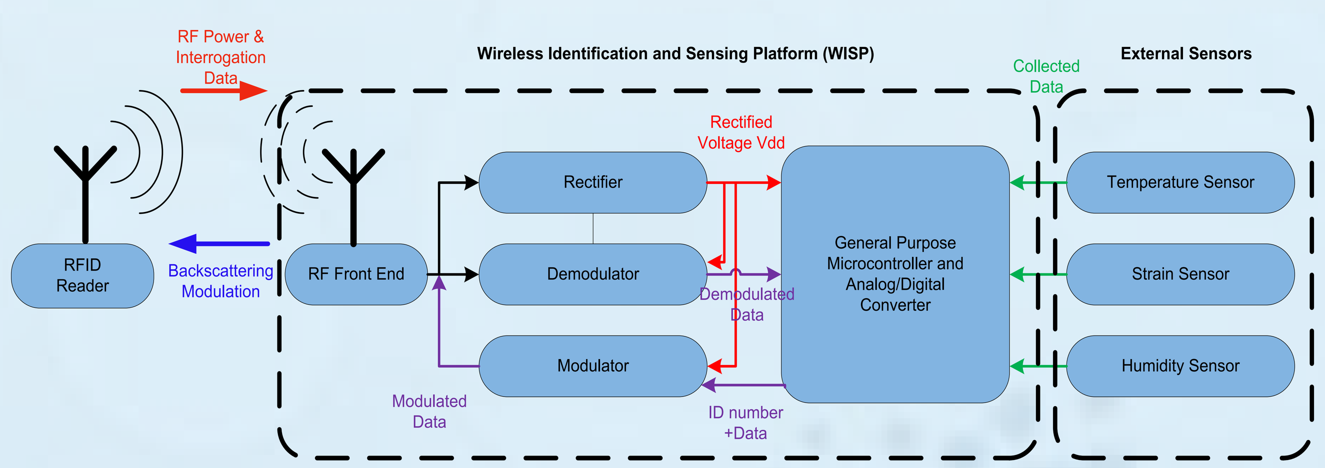
Total Loss

$$A_{total} = A_t + A_p$$

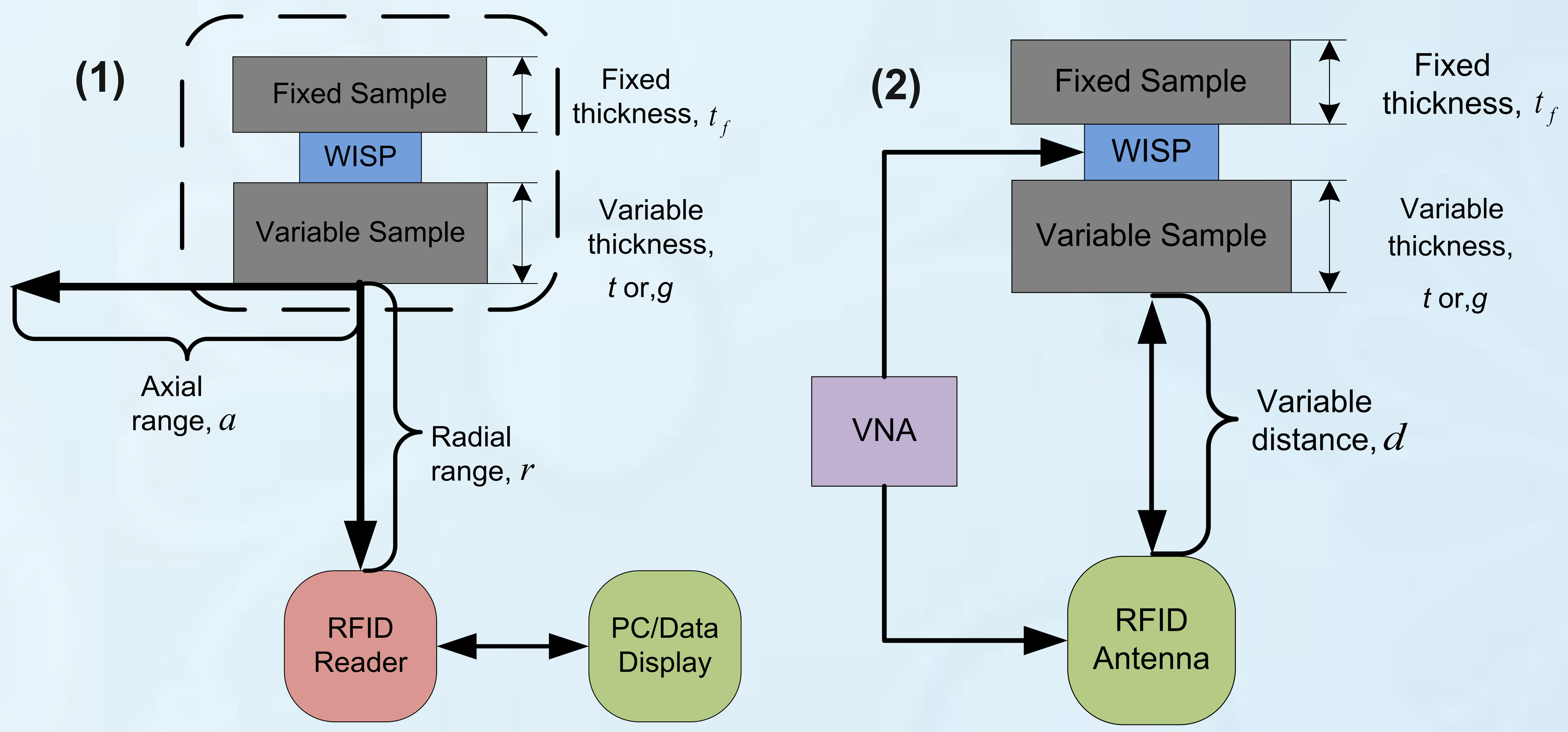


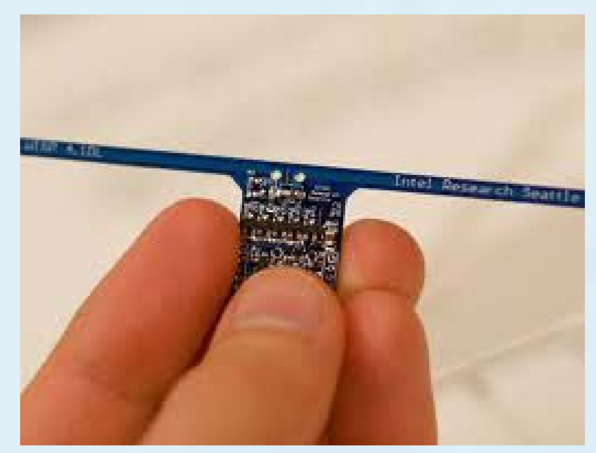
3. *Wireless Identification and Sensing Platform (WISP)*

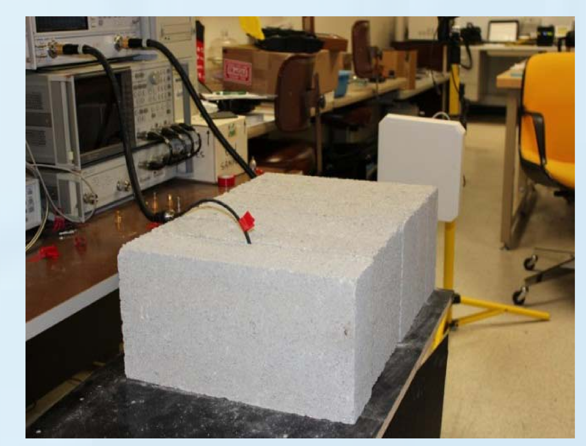
The WISP was created by Intel Research Lab. This device combines RFID (wireless communication), computing (data transfer), and sensing. Advantages: Battery-less device; flexible platform that can add different sensors such as temperature, strain, and acceleration; small size and easy installation. The WISP operates as any other RFID device.



4. *Experimental Setup*: In order to validate the feasibility of using the WISP inside concrete and grout, two experimental setups were conducted: (1) to determine the maximum radial and operational range for the WISP inside concrete and grout, and (2) to determine the power transfer efficiency between a commercial RFID antenna and the WISP.

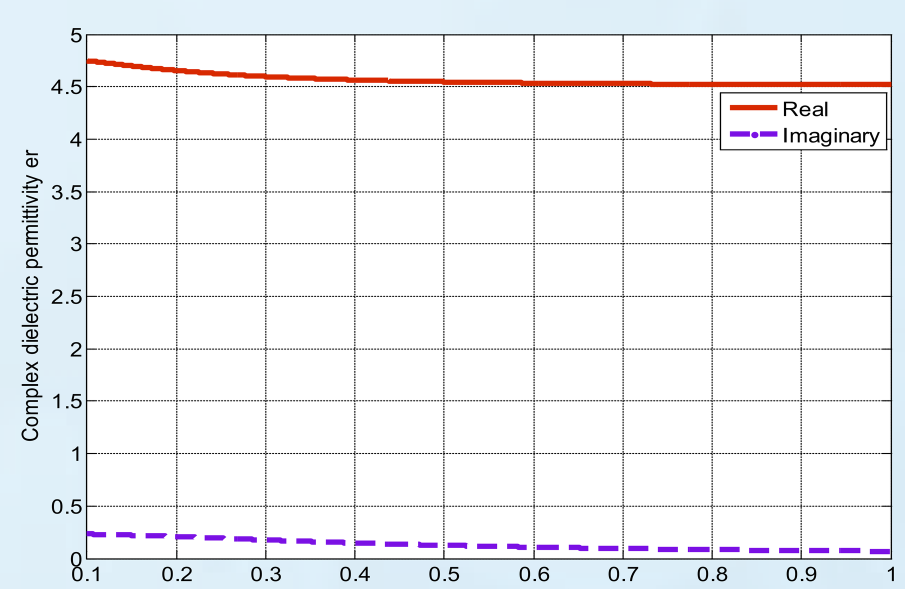




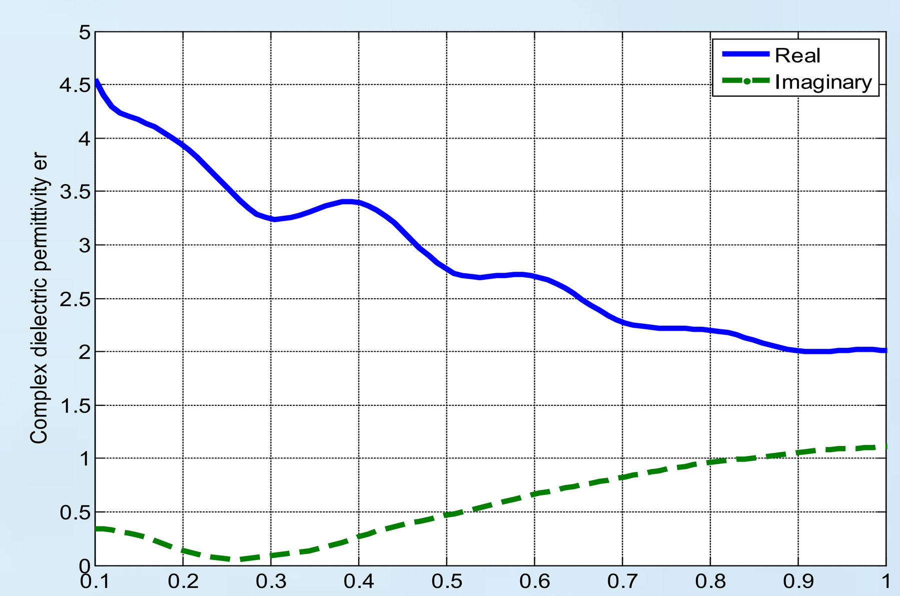


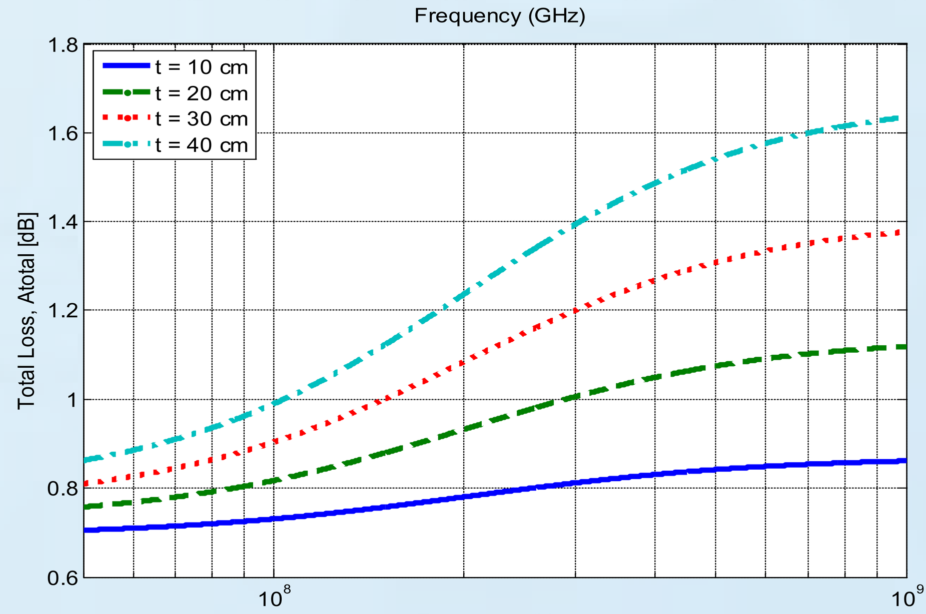
Results

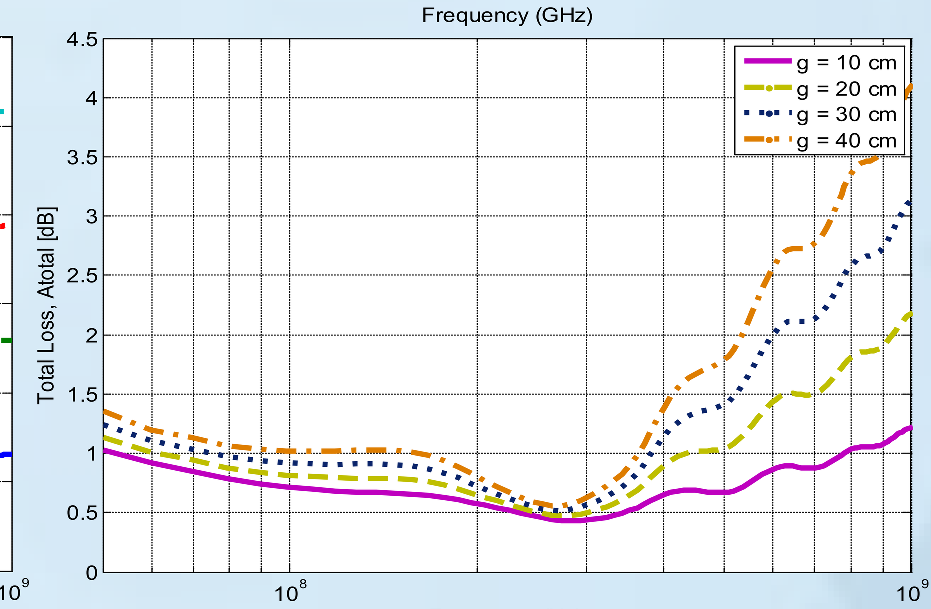
CONCRETE



GROUT





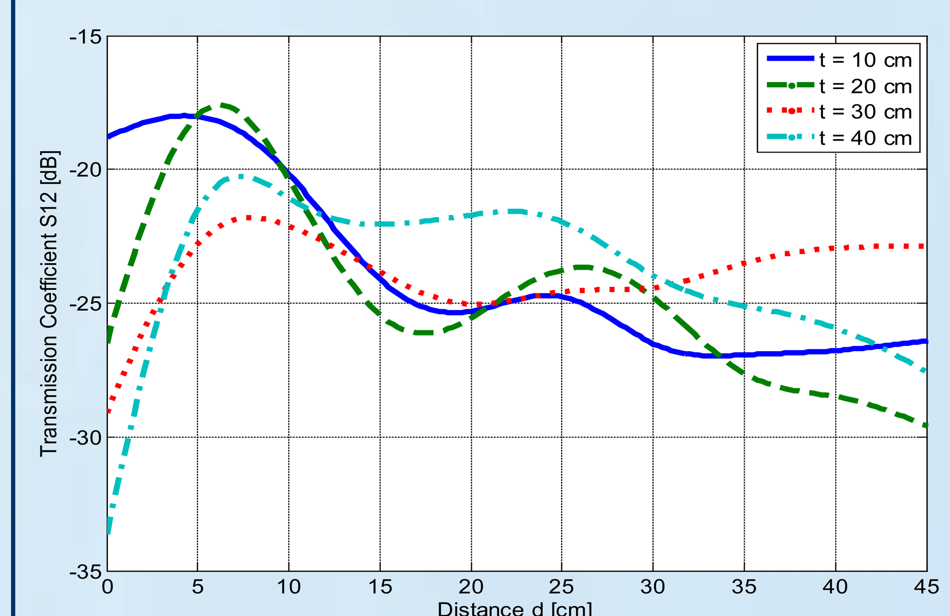


Results (Continuation)

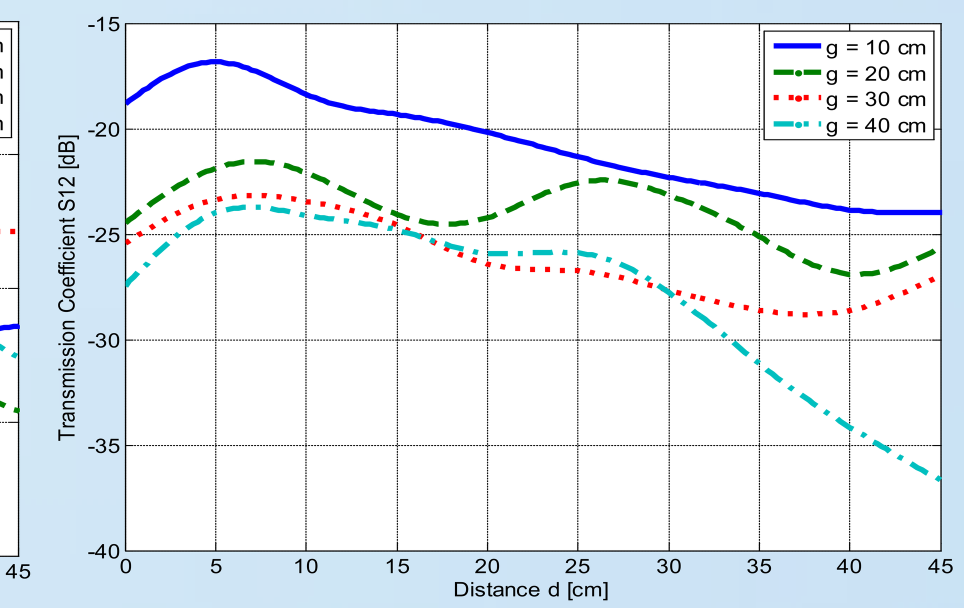
CONCRETE	Thickness, *t*			
	10 cm	**20 cm**	**30 cm**	**40 cm**
Radial range, *r*	1.289 m	0.629 m	0.597 m	1.238 m
Axial range, *a*	0.381 m	0.457 m	0.502 m	0.527 m

GROUT	Thickness, *g*			
	10 cm	**20 cm**	**30 cm**	**40 cm**
Radial range, *r*	1.289 m	0.629 m	1.182 m	0.826 m
Axial range, *a*	0.749 m	0.508 m	0.356 m	0.210 m

CONCRETE



GROUT



Conclusions

This research presents experimental results confirming the effective use of WISP for monitoring temperature, humidity and strain inside lossy media, such as concrete and grout. It was determined that the WISP will continue to operate from 0.6 m to 1.28 m for different thicknesses of both materials. Further measurements were conducted in order to determine the power transfer between a WISP and a commercial RFID reader antenna, which confirmed the oscillatory behavior of the corresponding antenna coupling due to the existence of standing waves. Therefore, it can also be assessed that the optimal separation between the RFID antenna and the material surface is around 5 to 10 cm. In addition, the mathematical analyses which corroborate that concrete presents lesser loss than grout was also confirmed by experimental results.

Future Work

- ❑ Improve the WISP antenna design by introducing a more directive antenna such as a patch antenna in order to obtain a more efficient power transfer between the antennas.
- ❑ Design a signal conditioning circuitry for adding humidity and strain sensors to the WISP.

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