High temperature corrosion sensors for boiler grade stainless steel in power plants

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Harsh environments

Key issues
- **High temperatures (>1000°C)**
- **Oxidising environments leads to rapid material degradation**
- **Long operation times**

Power plants

Steel manufacturing

* Images collected from https://insideclimatenews.org/news/03052021/large-coal-plants-retirement-dates/

Need for high temperature corrosion sensors

- Effective real time monitoring will reduce cycling (start/stops)

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- In turn will reduce thermomechanical stresses, fatigue and stress corrosion cracking

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- Reduce down time in plants, reduction in operation costs, risk minimization of operation

Current sensor technologies

1) Pulsed eddy current

- Electromagnetic technique used to detect wall loss

Issues

- Time consuming
- Requires shutdown of components
- High cost

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2) Ultra sonic measurement

Issues

- An even slower technique than PEC
- Requires shutdown of components
- Not applicable for mass scale

** Images collected from https://www.eddyfi.com/en/technology/pulsed-eddy-current-pec*

Research Objective

- Development of a radio frequency identification (RFID) sensor
  - Sensor will be low cost
  - Measure corrosion accurately in real time
  - Ability to measure "through the pipe"

An example of an RFID tag design

** Image collected from AtlasRFID*

Task breakdown

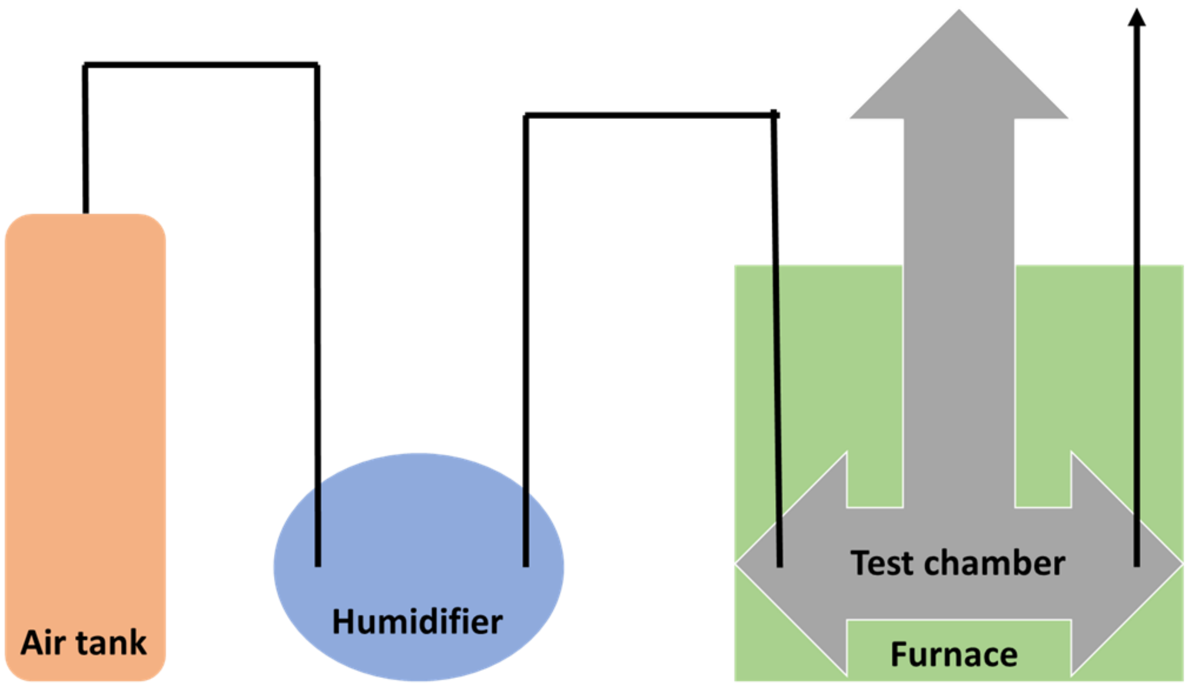
- Task 1.0 High temperature oxidation of both boiler grade steels
- Task 2.0 Dielectric film deposition on boiler grade steel
- Task 3.0 High temperature oxidation of boiler grade steels with deposited barrier layer
- Task 4.0 Split ring sensor testing

Task 1.0 experimental procedure

Two boiler grade stainless steels used in coal plants were selected

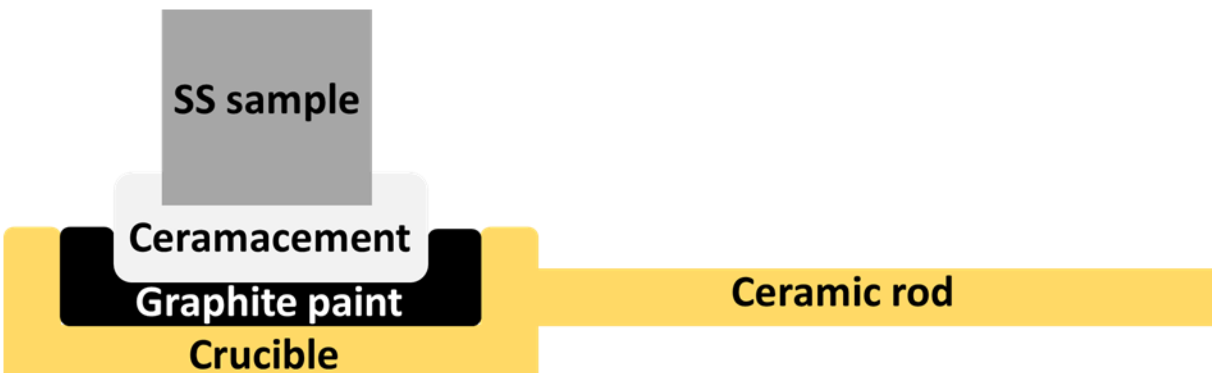
- **SS 304 H**
- **SS 347 H**

Simulation of flow through a pipe at high temperature



Task 1.0 experimental set-up

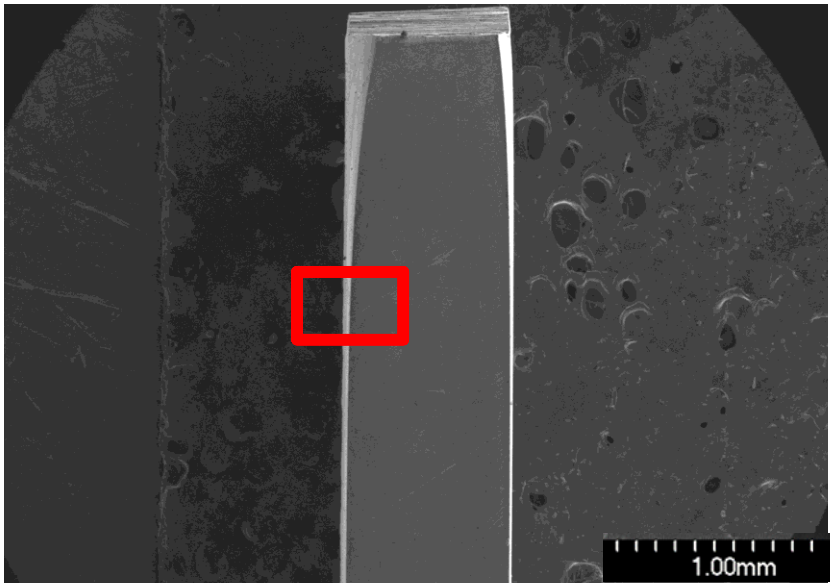
Images of our constructed test stand



Samples were removed slowly from high temperature via a crucible set up

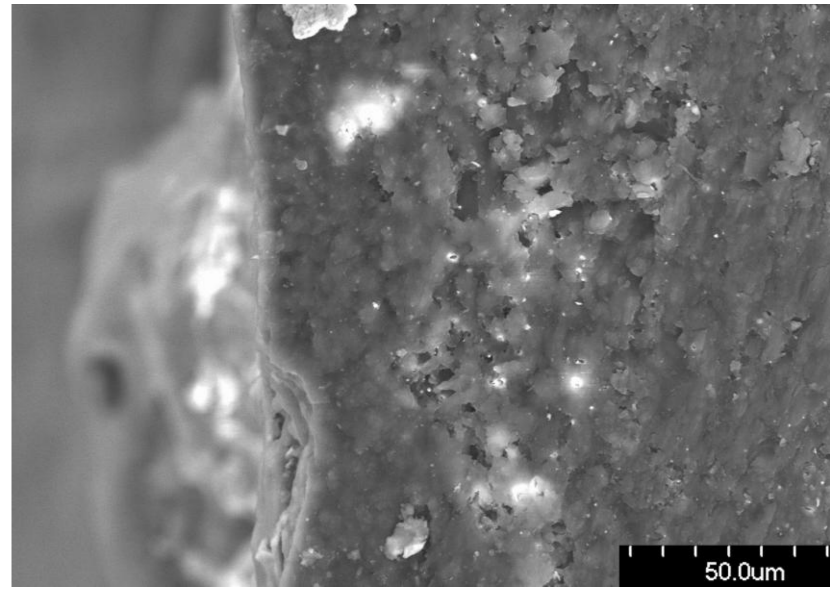
Pre corrosion and post corrosion measurements

Pre corrosion SEM



- SEM images at 30x –110x magnification were collected.
- An accurate thickness measurement was recorded via ImageJ

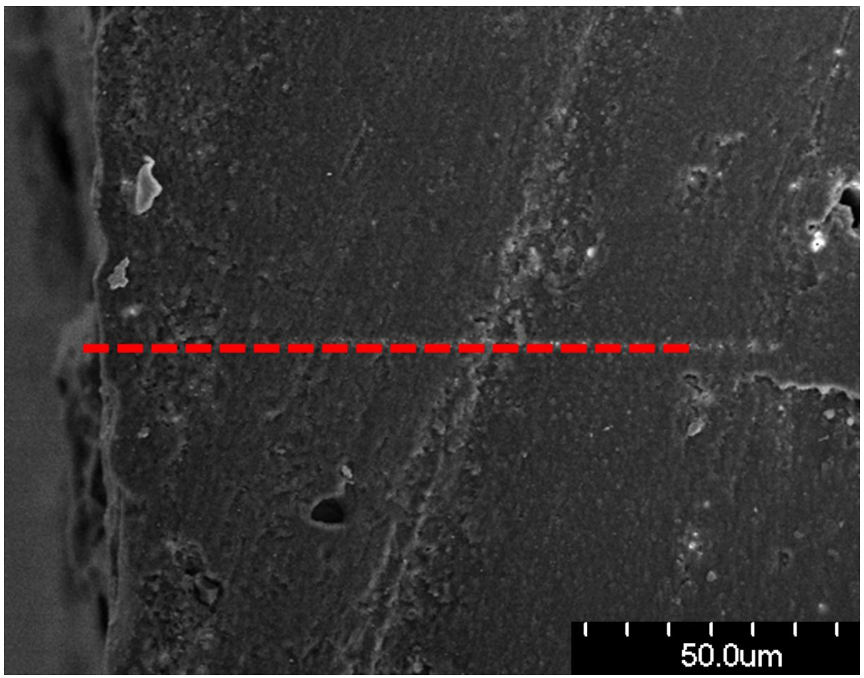
Post corrosion SEM + EDS

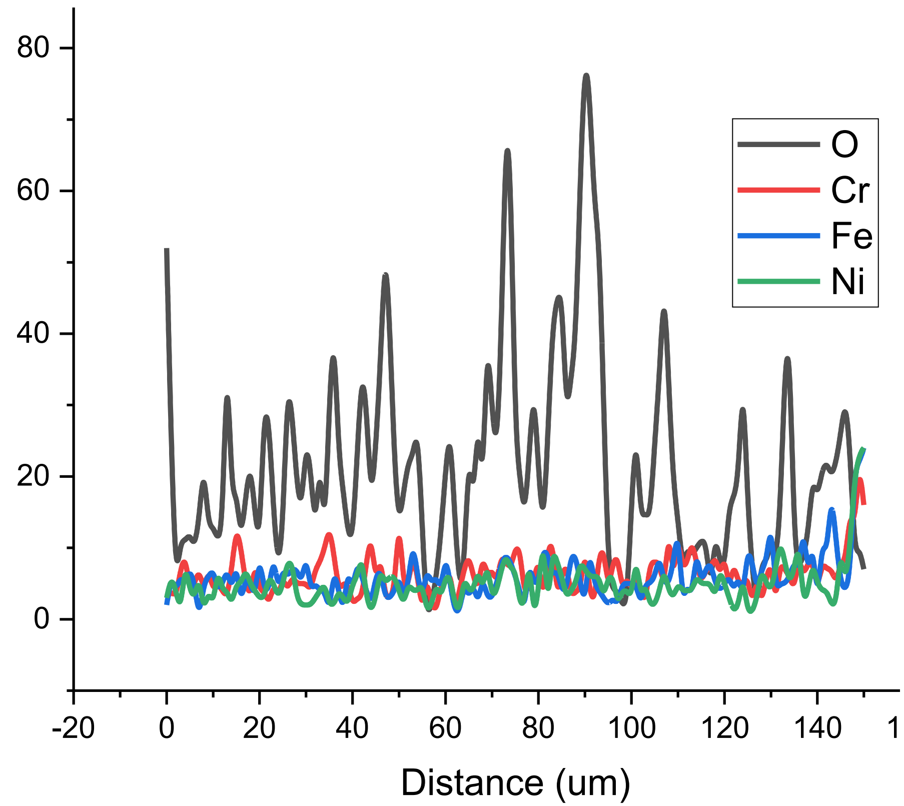


- EDS used to determine the rate of loss
- Minimizes the effects of spalling of oxide layers

Task 1.0 EDS analysis of SS 304H

- Sample was corroded at 1000°C for 48 hours with high humidity

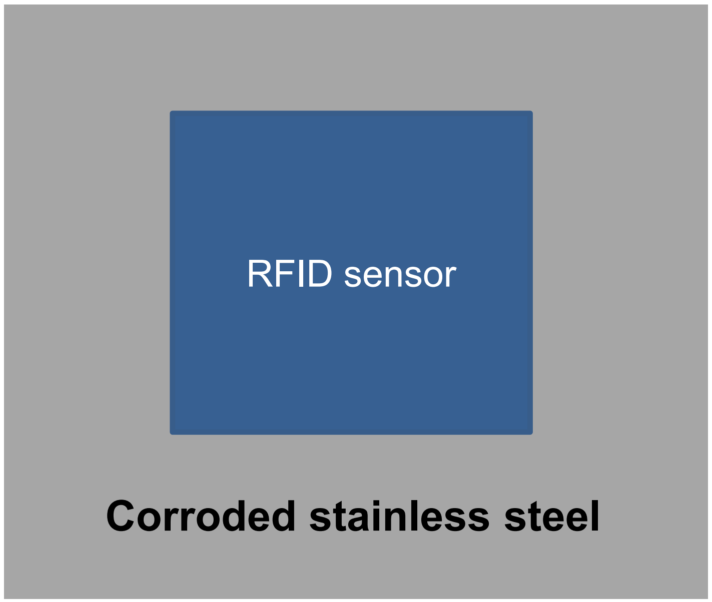


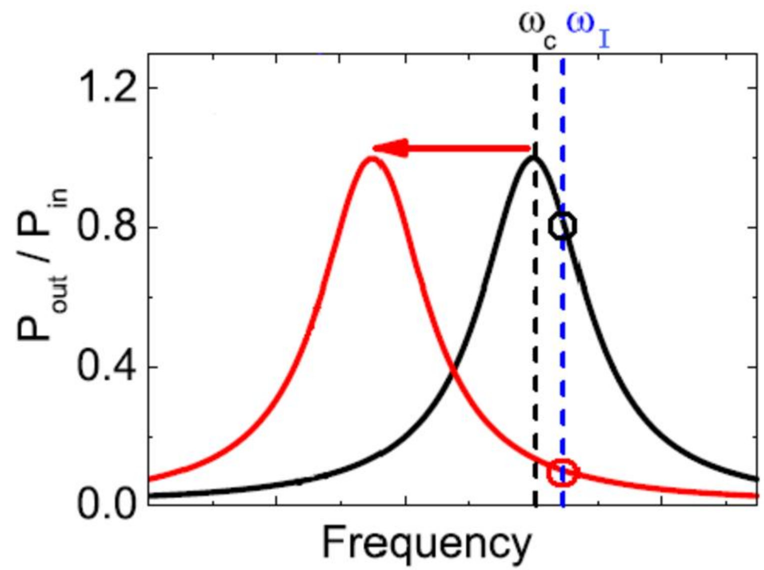


Fe_2O_3 Cr_2O_3 $FeCr_2O_4$

RFID sensor

- **Corrosion rate can be measured via a dielectric change under the sensor**

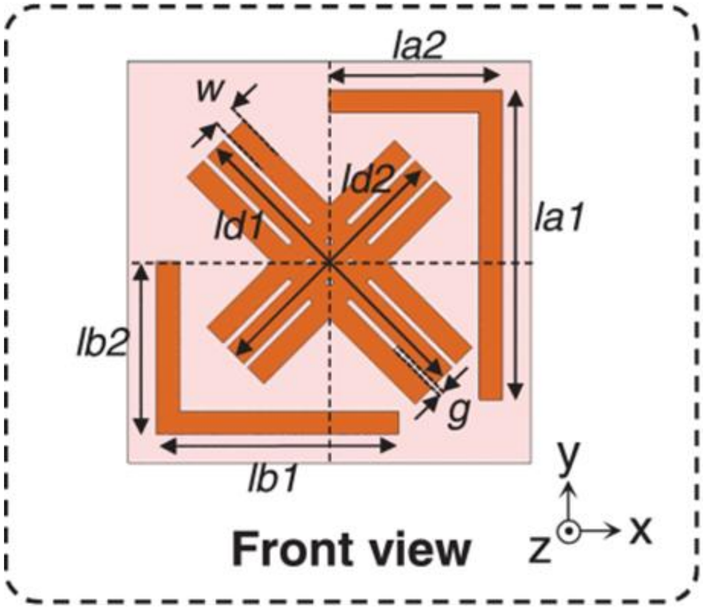


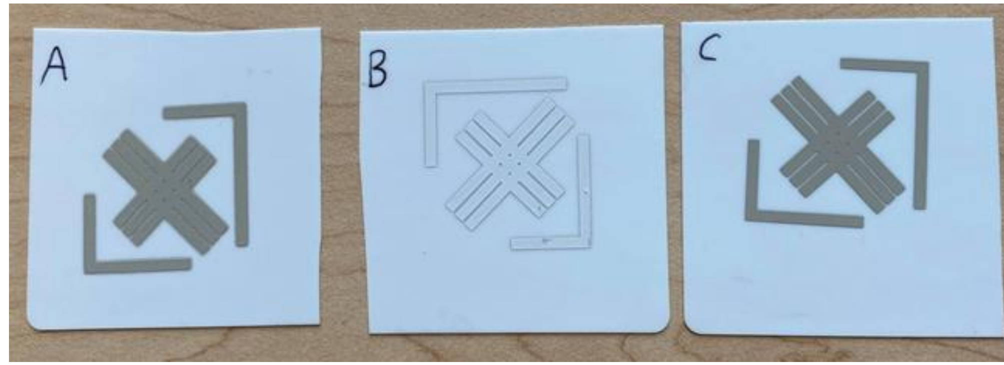


(This in turn generates a shift in the resonant frequency)

- **For future work we also propose to measure temperature simultaneously with corrosion via a Fourier transform of the collected signal**

RFID sensor design (1) Patch antenna





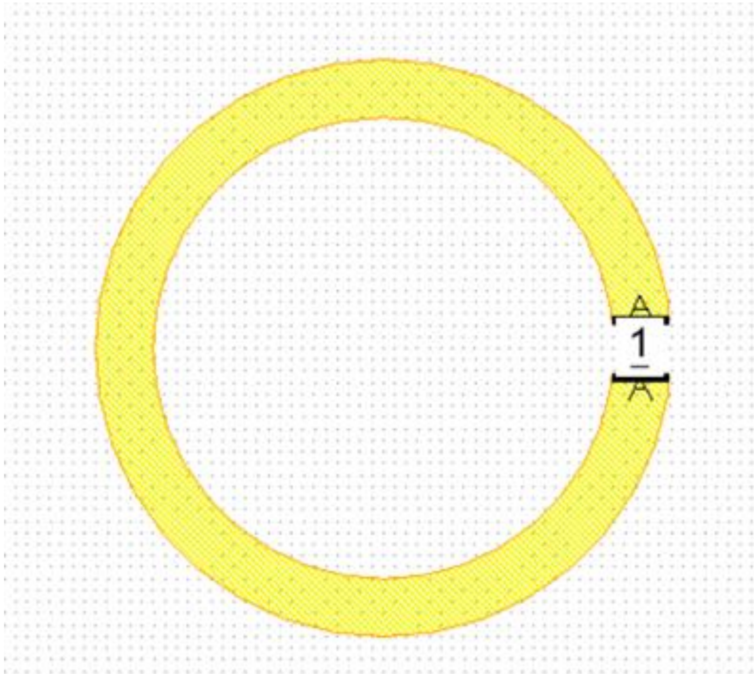
Patch antenna printed on alumina substrate with silver ink

Mechanism

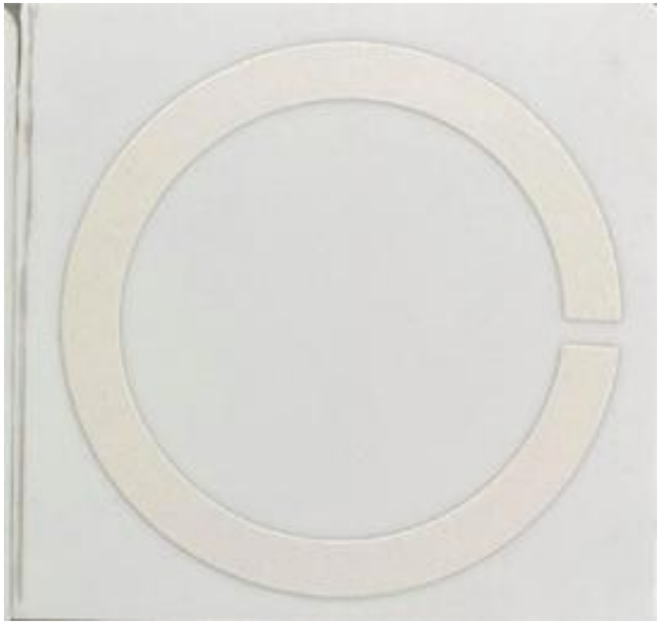
- **The intermediate layer between the antenna and metal (ground plane) form a resonant piece of microstrip transmission line.**

Marindra, A. and Tian, G., 2019. Multiresonance Chipless RFID Sensor Tag for Metal Defect Characterization Using Principal Component Analysis. *IEEE Sensors Journal*, 19(18), pp.8037-8046.

RFID sensor design (2) Split ring resonator



Sample Split Ring Design in AWR EM Simulation Environment



Split ring design printed on alumina substrate with silver ink

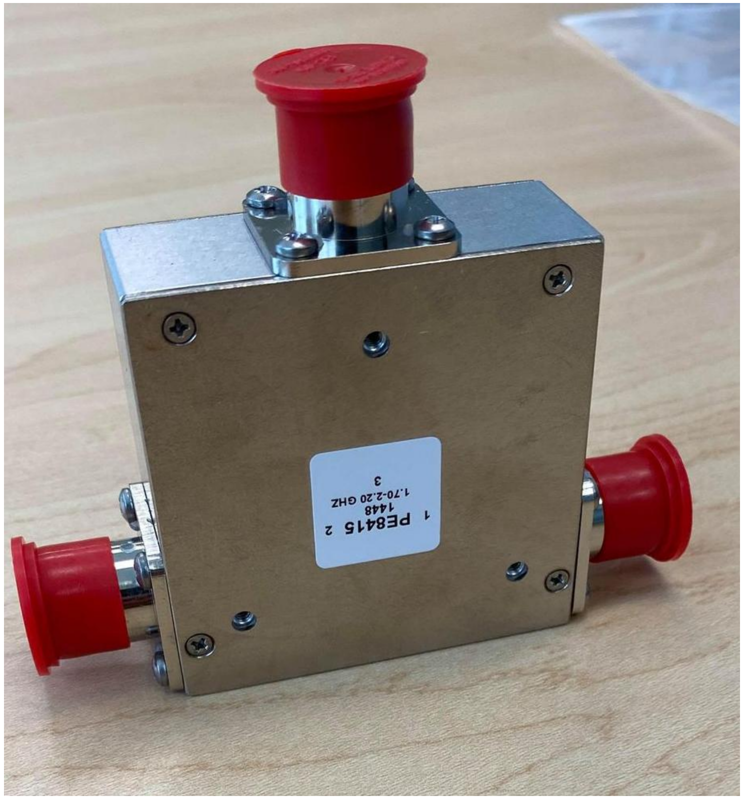
Mechanism

- **The interrogating signal induces a rotating current, the gap acts as a capacitor.**
- **The antenna operates similar to an LC circuit and the reflected signal has a specific resonant frequency.**

Task 4.0 Experimental set-up

- A VNA connected to a Yagi UDA antenna was used to transmit signal and collect the reflected signal

VNA signal generator



Circulator

Conclusion

- Demonstrated an effective method to oxidise boiler grade steel at high temperatures
- Begun analysis of the oxide films developed on the corroding stainless steel
- Demonstrated a low cost method to fabricate RFID sensor with multiple designs
- Begun developing an experimental set-up to measure the frequency shift of RFID sensors

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Thank you for your attention