ENVIRONMENTAL TEMPERATURE AND MATERIAL CHARACTERISATION OF PLANAR MICROWAVE EVANESCENT SENSORS FOR ENVIRONMENTAL ANALYSIS

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INTRODUCTION

We discuss here a patented microwave planar evanescent sensor for possible UAV platform skin-embedded sensing applications, e.g. surface ice build-up, or temperature sensing [1]. Evanescent sensors can probe the surface region on millimetre to metric scales, with minimal detectable radiation into the external environment, ideal for evading detection, yet capable of detecting changes adjacent to a sensing surface. We examine evanescent use as an environmental sensor to detect and quantify metal and dielectric loss, presenting results for two different temperature configurations, exhibiting embedded sensor temperature hysteresis.

Waveguide Advantages

Our microwave sensors seek to replicate similar integrated optics planar sensor designs [2]. Attenuated Total Reflection is used widely to couple optical radiation into thin film waveguide modes [2] and recently microwave planar geometries [3-4], but optical environmental applications have limitations as they only sense the near surface (tens of wavelengths). However, planar waveguides geometries offers high sensitivity for *in-situ microwave* probing near surface properties because of their extended path lengths. Microwave guides are usually considered as a passive means of passing radiation along metal guides, rather than as sensors in their own right. We select a waveguide surface region to access fields, increasing sensitivity to environmental changes. Robust dielectric embedded microwave planar waveguides can monitor absorption changes in adjacent '*optically*' thick layers, or changes in environmental or weather dependent microwave refractive index properties, due to temperature dependent effects.

Waveguide Fabrication and Experimental Arrangement

Fabrication was divided between planar waveguides, some with embedded sensors, others with a recess for refractive index measurement, or 1-D surface periodic gratings. Various guide materials were used; for demonstration purposes, wax guides with Aluminium metal boundaries provided greatest design flexibility, and may be regarded as 'leaky' Fabry Perot waveguides [4], with loss increasing with length. Small air inclusions result in low/moderate scatter loss, but improved fabrication uses homogeneous materials i.e. (PTFE) **[5] fig 1.**

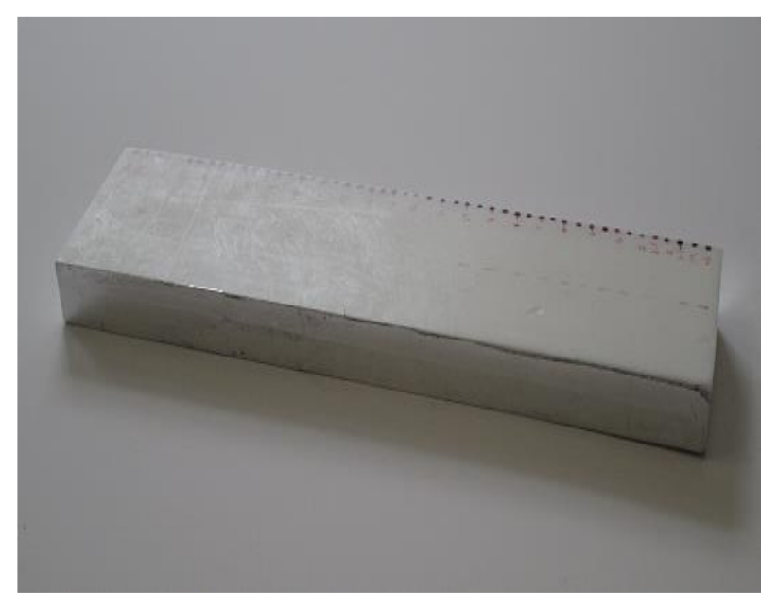


Fig. 1 Perspex waveguide

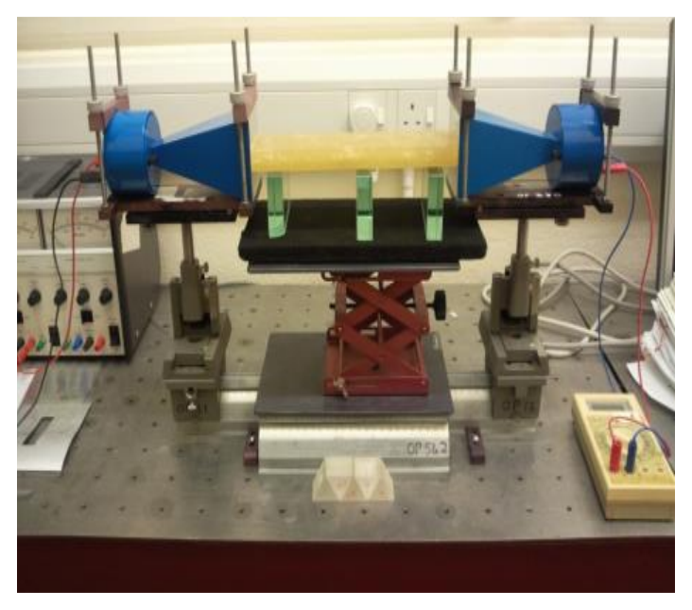


Fig. 2 Experimental Coupling

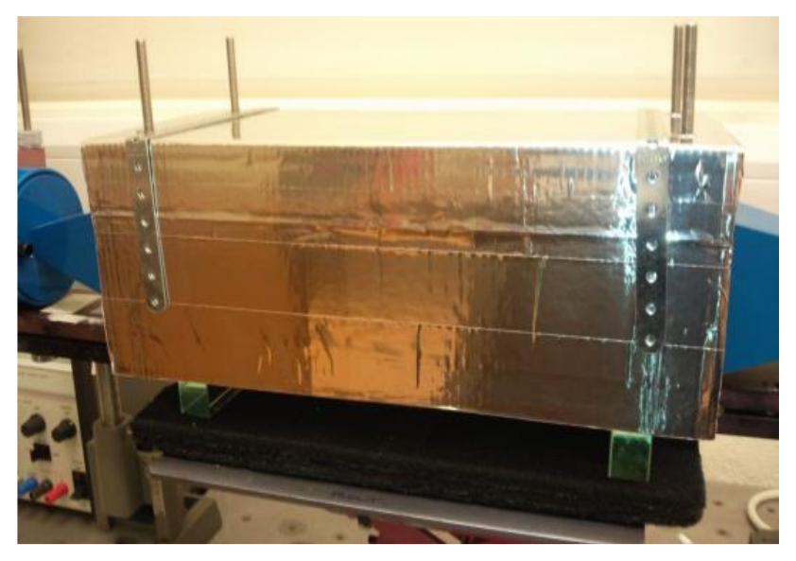


Fig. 3 Shielded guide

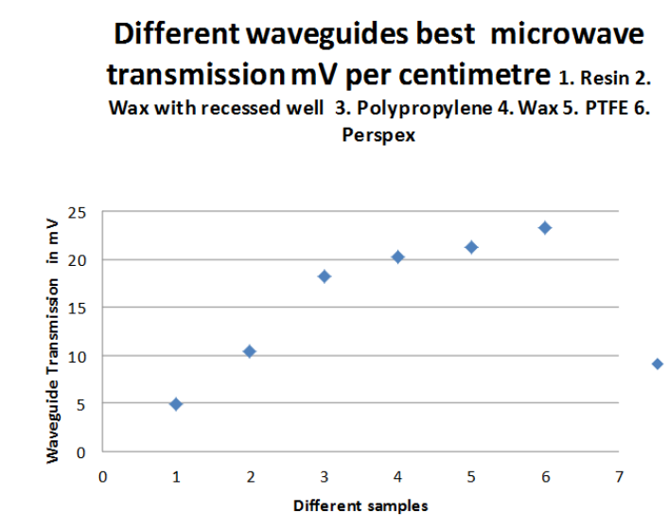


Fig. 4 Different Waveguide materials

Wax was used in early designs- it was easy to pour into pre-fabricated moulds, sculpt into intricate designs, or add functionality. Guide dimensions were: 2cm thick, 6.5mm wide, 25.2cm long for coupling to a microwave horn, **fig. 2**. The horn source was powered by a Farnell LT30-2 dual power supply (nominal output 10V, checked with a Farnell DM141 multi-meter for stability monitoring. Receiver output voltage (mV) was monitored with digital multi-meters: a RS T100B and Fluke 89 IV data logger. Ambient temperature was monitored with a dual readout digital RS 427-461. A thermocouple unit (RS 610-067) measured - test samples, surfaces and waveguides. A Fluke 89 IV multimeter logged temperature readings during tests. A cavity shield 300 × 150 × 150mm was constructed, clad with aluminium / aluminium foil tape to cover the cavity to prevent stray radiation leakage (**fig. 3**).

RESULTS AND DISCUSSION

Waveguide Materials Used: Six different guide materials were investigated, with maximum output recorded in **fig. 4**, yielding maximum guide output per centimetre length.

Waveguide Cladding Materials:
Different materials were examined placing 6.5cm square targets on a PTFE guide surface with the near edge placed along the guide's centreline. Results for different materials are shown in **fig. 5**.

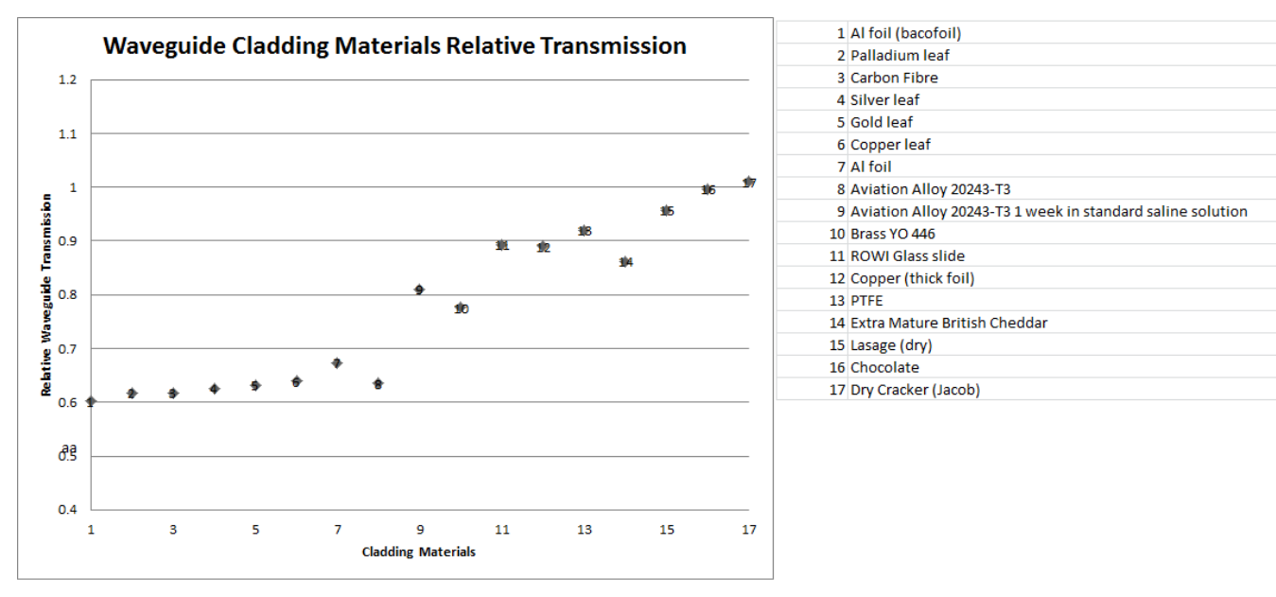


Fig 5. Guide Cladding Materials

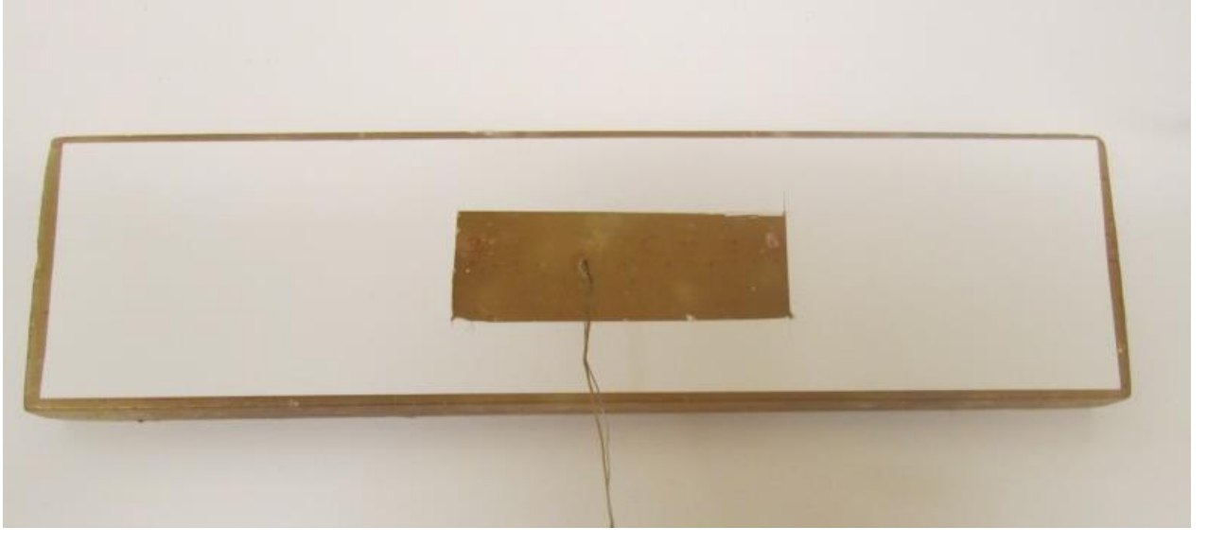


Fig. 6 Embedded sensor

Thermal Measurements: waveguide output is seen to change with forced heating. A fabricated wax guide with a small area exposed whilst the rest is covered with a reflective non-metal 'mask' as metal will make a '*leaky waveguide'* into a highly guiding one. A thermocouple was *embedded* in the guide (**fig. 6**), and a heat source placed 20cm above the mask for 2100 seconds, whilst monitoring TM radiation. Ambient temperature rose 1.6°C and the waveguide + 5.4°C (**fig.7**). The source was switched off, with cooling over 5250s and guide temperature falling to ambient. Hysteresis is seen in the guide thermal response.

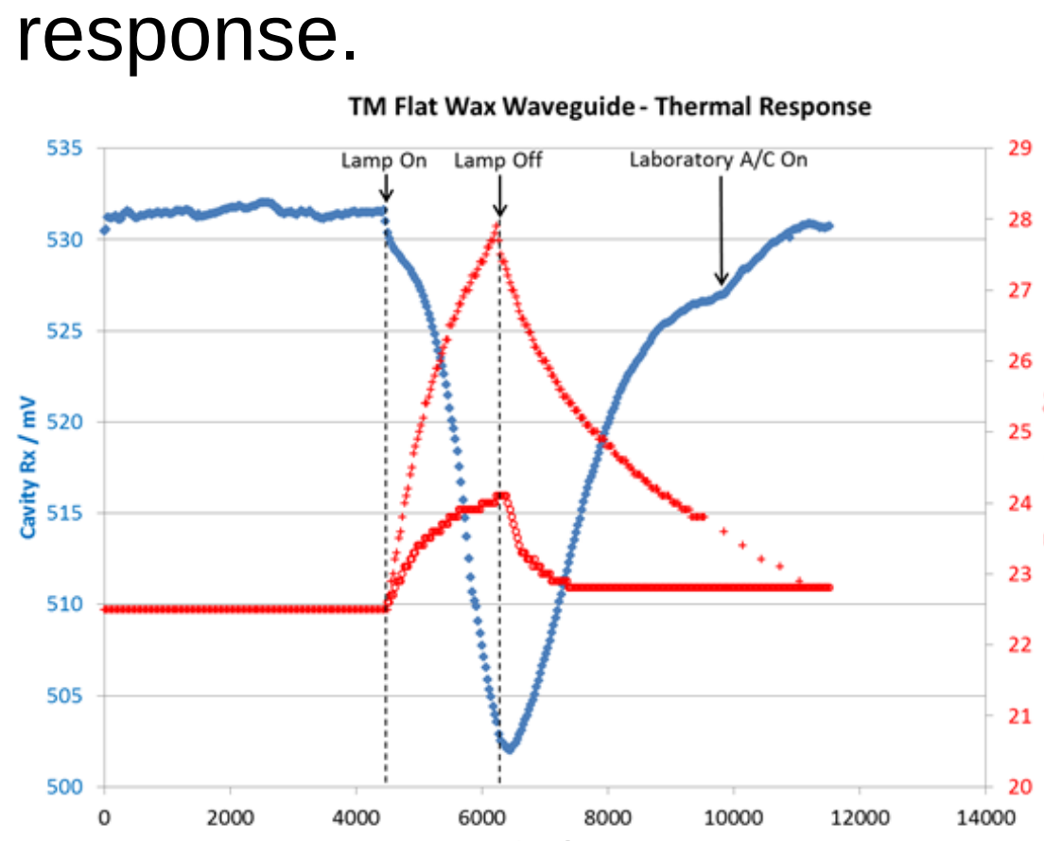


Fig. 7a: left TM Wax guide Heating/Cooling Cycle

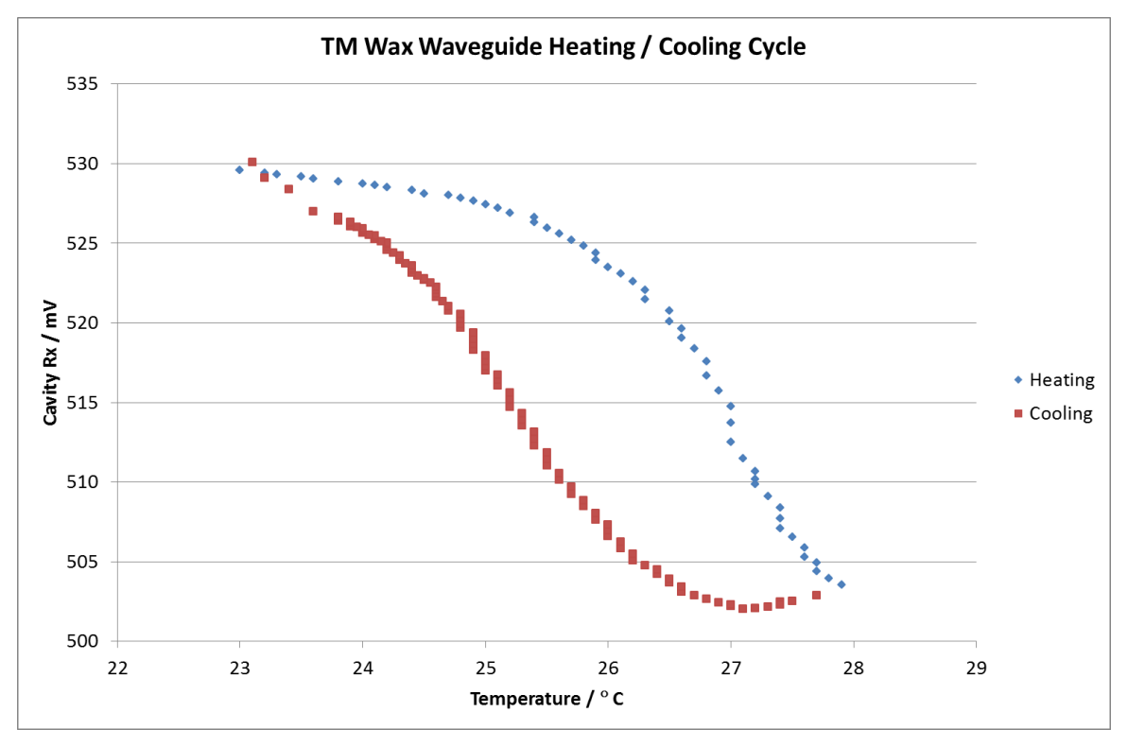
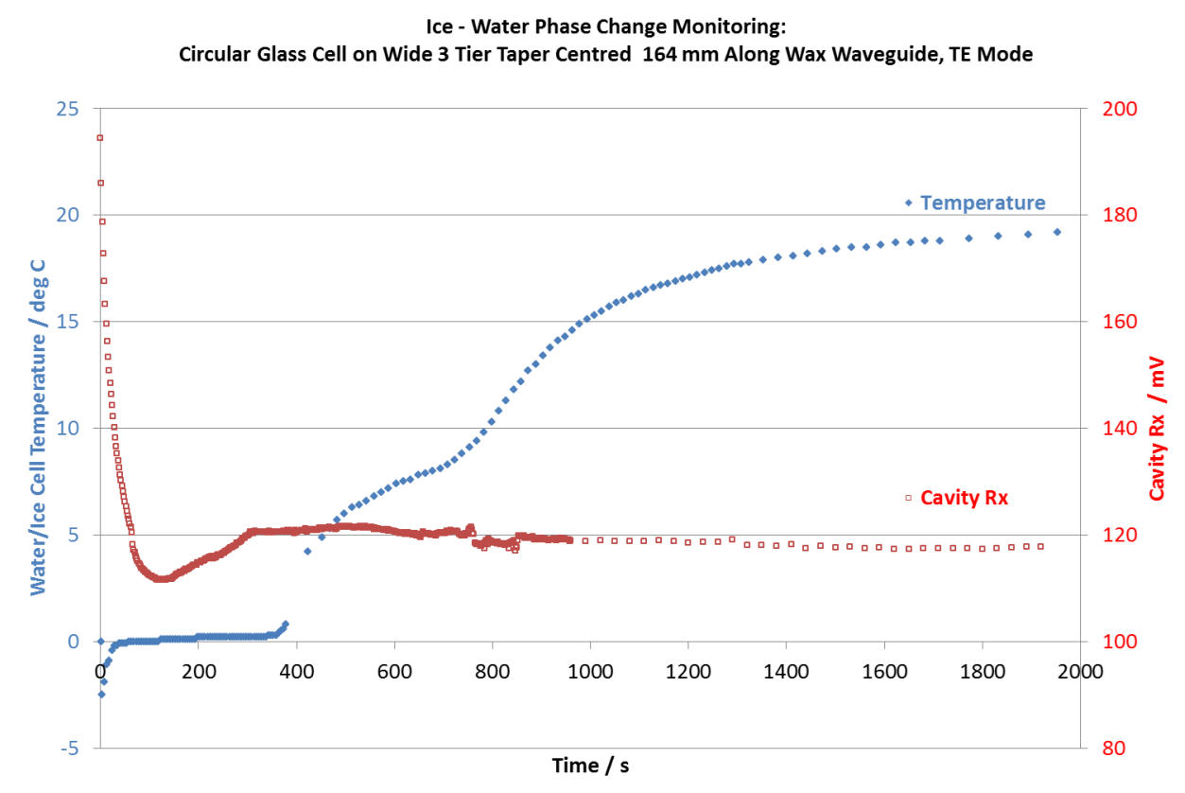


Fig. 7b: right Waveguide Temperature Hysteresis

Ice Melting: Studies on phase change: solid to liquid are presented as icing is relevant to UAV platform surfaces and microwave sensitivity. Glass pots were filled with 4ml deionised water, a thermocouple immersed, and then frozen. Pots were placed on guides, and TE mode output recorded whilst ice warmed or melted.



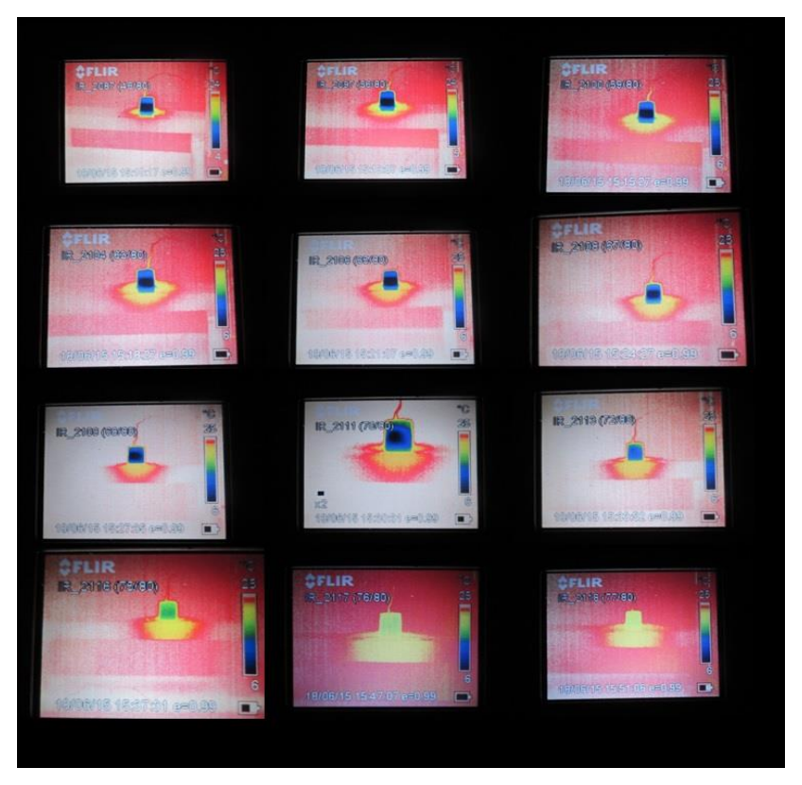


Fig. 8: Ice – Water phase change monitoring. Fig. 9 FLIR images of a frozen water pot left to right then down at intervals of time showing diffusion related cooling of a frozen pot installed on the wax guide, with either the warming or melting of the water.

The temperature record starts at -2.5°C, after guide installation on the experimental apparatus. As the test progresses phase transition: ice to water, occurs holding steady at about 0°C for c. 280 seconds during the soli to liquid phase transition; then the pot warms to ambient 22.5°C. The cavity output rapidly falls, reaching a minimum at the phase change, followed by a rise to steady temperature (**fig. 8**). The signal 'dip' is likely a result of a complex situation where a cavity experiences a combination of chilling when a cold pot cools a guide, combined with the changing dielectric behaviour as ice melts to water, altering the absorbed evanescent microwave energy. The pure water dielectric loss at 10GHz (near our frequency) is maximum, when close to 0°C.

A FLIR E320 radiometric thermal camera sequence (**fig. 9**) shows heating / melting of a frozen pot, (top row left to right then after at 3 minute intervals). Initially ice appears cold 'black', whilst the guide cools over time, with "cold diffusion" from pot into guide.

CONCLUSIONS

1. Planar waveguides allows microwave output temperature response to be examined.

2. Temperature response demonstrates clear hysteresis.

3. Microwave output transmission shows loss as a function of target material, showing PTFE or Perspex^{TM} to provide low loss, exhibiting cladding material selectivity.

Sensitivity over time for small water volumes provides good output correlation with temperature. Thermal imagery of a combined pot/guide shows guide cooling accompanies cell warming. Separating the individual thermal contributions of pot cooling / waveguide heating is difficult. In other work metal targets have also been detected through layers of sand as a function of depth [5].

Acknowledgements
Mr Benjamin Lavers M. Eng. for waveguide fabrication.

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5. Lavers, C.R., Fisk, J.D., "*An Evanescent Channel Microwave Waveguide Sensor for Metal Detection through Variable Sand Depth*", International Journal of Recent Trends in Electrical & Electronics Engg., Dec., 2017. ISSN: 22316612 ,Volume 6, Issue 1: 08-16.