GRAPHENE RF DEVICES FOR THE INTERNET OF THINGS

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Introduction

Radio frequency identification (RFID) devices have a wide range of applications within the internet of things (IoT), some of which require flexible, low cost antennas. Graphene ink is a candidate to replace metal-based inks because it is compatible with low-temperature processing, and can therefore be printed onto substrates such as paper [1].

This project investigates the feasibility of screen-printed graphene antennas impedance matched to encoded RFID chips and chipless antennas with a frequency-dependent response S_{11} sensitive to changes in humidity.

Methods

Antennas were designed and simulated in CST Microwave Studio, and were impedance matched to 16-j136Ω for used with RFID chips. Other dipole antennas, including a log-periodic dipole antenna (LPDA) [2] and a meander-line [3] antenna were designed for humidity sensing at 915MHz. Changes in humidity were simulated by adjusting the sheet resistance of the graphene ink and the conductivity and permittivity of the substrate.

Screen printing of binder-free graphene ink, synthesised by microfluidization [4], was used to fabricate antennas on polyimide and paper substrates. The use of polyimide substrates enabled the investigation of the effect of thermal annealing on the antennas.

Realised antennas were measured using a vector network analyser (VNA), used in conjunction with a humidity controlled chamber for measuring response to humidity.

Results

The optimization of the impedance-matched antenna is shown in Fig. 1, where it is compared to the realized antenna performance. A loop-type design, shown in Fig. 2a, was used to match the capacitive impedance of the RFID chip. The antenna enabled reading and writing of an RFID chip, albeit over a distance of ~5cm, and performance was found to be sensitive to bending radius.

Figs. 2b and 2c show designs for chipless RFID sensors. Fig. 3 shows the attenuation of the magnitude of the meander-line's S_{11} response with relative humidity, with hysteresis suggesting that the absorption of water by the paper substrate contributed to the sensing effect. However, Fig. 4 shows the increasing magnitude of S_{11} at resonance and up-shift in resonant frequency for the LPDA: this is in contrast to the meander-line, where no change in resonant frequency was observed.

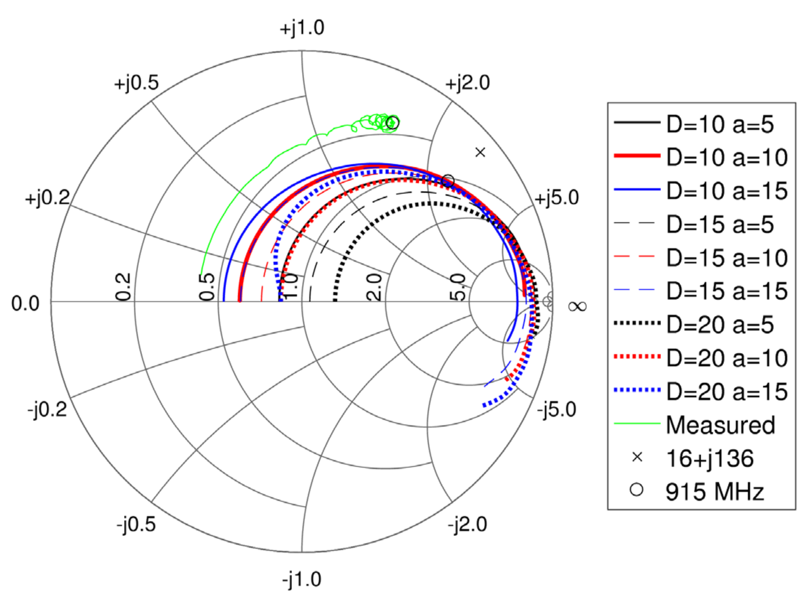

Figure 1: Optimisation of impedance matched antenna. D is internal diameter, a is line width. (Smith chart normalized to 50Ω)

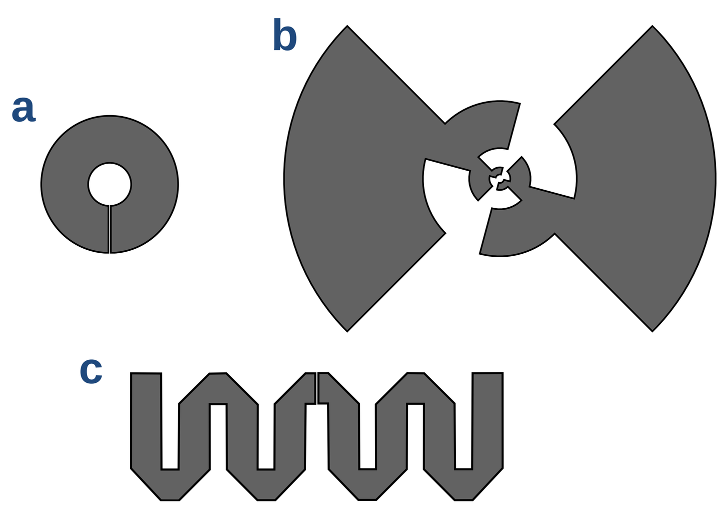

Figure 2: Antenna designs (actual size).
a) Impedance matched antenna
b) Log-periodic dipole
c) Meander-line dipole

Discussion

RF characterization of graphene ink transmission lines, in conjunction with comparisons of simulated and experimental results, shows the frequency-dependence of the printed ink's impedance. In addition to increased contact resistance between the graphene flakes, simulations suggest that a capacitive component arises from intralayer spaces between flakes.

The change in graphene's sheet resistance (R_s) due to adsorbed water was expected to contribute to the RF sensing capability, in addition to the increased permittivity (ε) and conductivity (σ) of the paper substrate due to absorbed water [5,6]. Simulations suggest that while increased ε and σ may lead to a down-shift in resonant frequency, concomitant increased R_S may lead to an up-shift in resonant frequency. The different antenna geometries show conflicting results (Figs. 3 and 4), therefore further work is required to establish which of these factors is dominant in the sensing mechanism.

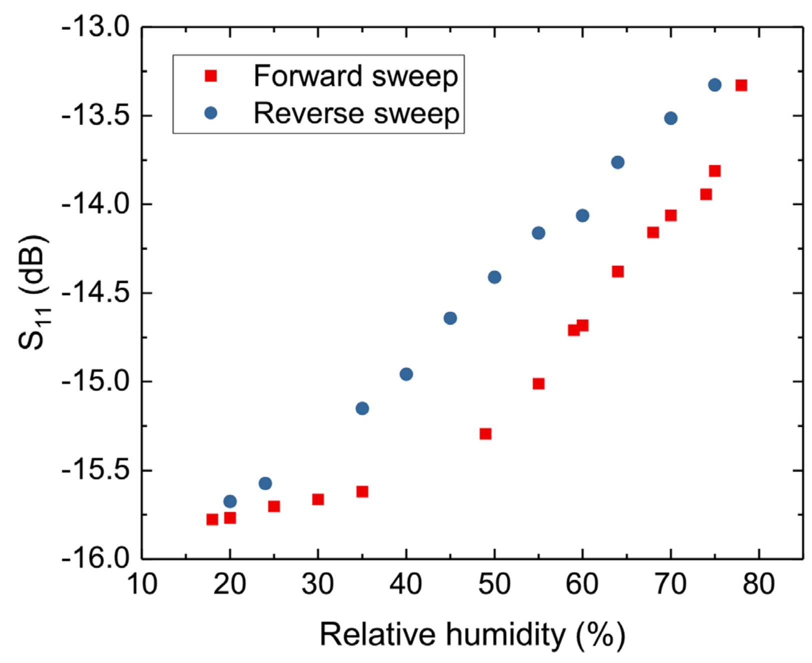

Figure 3: Response of meander-line antenna to changing humidity at 915MHz

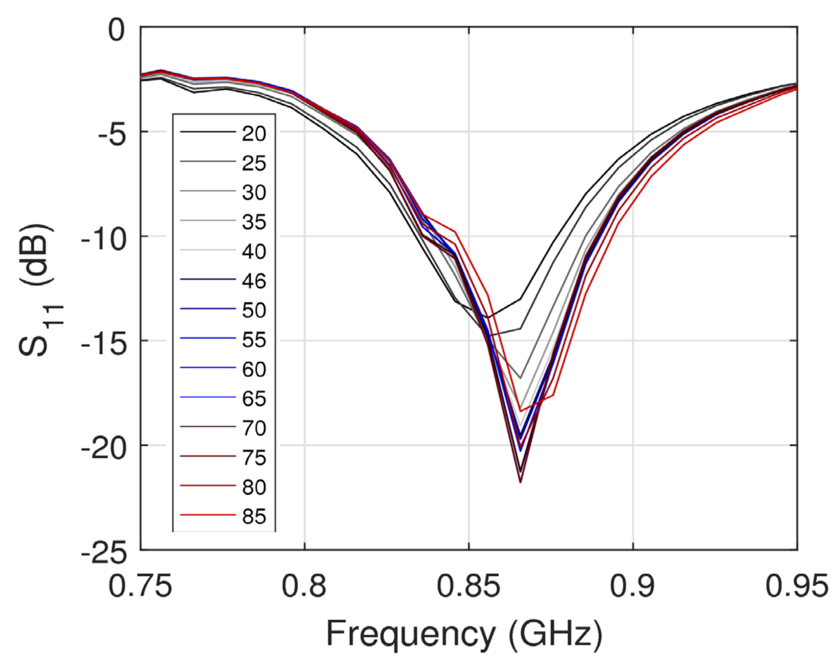

Figure 4: Response of LPDA resonance with changing relative humidity (%)

Conclusions and outlook

This work has demonstrated the potential for the manufacture of RFID antennas from graphene-based inks, which can be scalably produced by microfluidization, and which are compatible with the high-throughput technique of screen printing. In addition, preliminary results suggest that graphene antennas printed on paper substrates may provide chipless RFID sensing functionality.

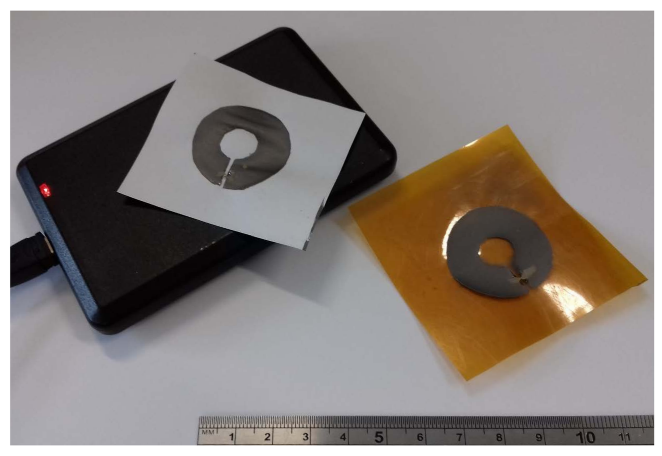

Figure 5: Realized loop antennas and RFID reader

However, limitations of the antennas include their short read range: this may be improved by reducing ohmic losses. For example, Ref [1] reduced the sheet resistance of printed graphene inks by compression rolling. Additionally, further work on quantifying the change in S_{11} response of the LPDA and meander-line antennas to changing humidity is required before they can be implemented as sensing devices.

The printing of RFID antennas onto flexible substrates at low temperature suggests applications in wearable electronics, and with the additional functionality of incorporated sensing provided by graphene come potential applications in medical and health-monitoring devices. Furthermore, the sensitivity of these antennas to humidity may be improved by the incorporation of graphene oxide or reduced graphene oxide [7].

The production for low-cost, highly scalable production of RFID devices with added sensing functionality has potential for a wide range of applications in the IoT.

References

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