# AC Analysis of Carbon-Based Elastomeric Composites for Printed Sensors and Electronics

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## 1. Introduction

- Flexible/stretchable sensors required to tolerate large deformations without loss of function.
- Integration with irregular/frequently deformed interfaces (e.g., human tissues [1], joints of instruments [2], **soft surgical robots**).
- Conductive elastomeric inks are a popular choice for making these.
- Obtained by mixing elastomers (e.g., PDMS [3] and polyurethane [4]) with conductive fillers (e.g., carbon black(CB) [5], graphene [6] and carbon nanotubes (CNT) [7]).
- Low-cost and easy to produce.
- Suitable for large-scale fabrication of stretchable electronic devices through additive manufacturing (e.g., stencil and screen printing).

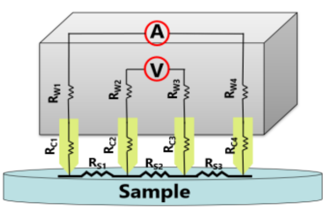
## 2. Aims & Motivation

- The AC properties of these inks are largely unknown.
- Important for evaluating the application of these inks in high-frequency circuits for:
  - ➢ interconnects
  - ➢ electronic devices (such as resistors, capacitors, inductors)
  - ➢ Sensors (e.g., bioimpedance)
- Here, the AC properties of 3 types of carbon-based composites PDMS (CB-100%-Compressed, CB-SuperP and graphite) in the frequency range of 20 Hz to 1 MHz, and the equivalent circuit model used to fit these results, are presented.

## 3. Method

Impedance measurements with:

- E4990A (Keysight, USA) impedance analyzer.
- Custom 4-point measurement probe
- Front-end Amplifier [8]




4-point measurements eliminate contact and lead impedances from the measurement.

**Figure 1**. 4-point measurement

The equivalent circuit model is built based on obtained impedance and phase data.

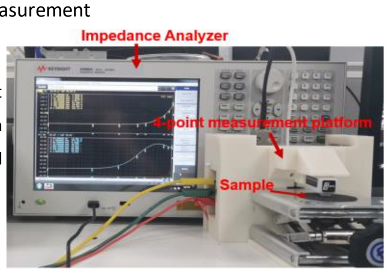



**Figure 2.** Experiment setup

## 4. Results

**Bode Plots:**

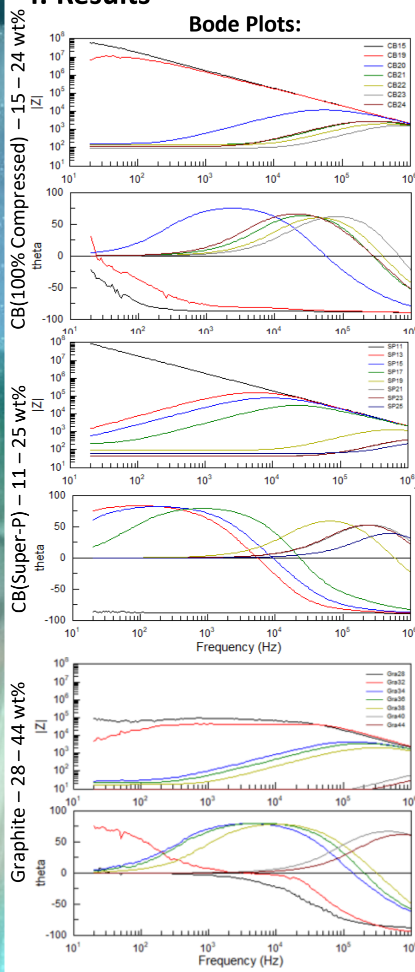



**Figure 3.** Bode Plots

**Equivalent Circuit :**

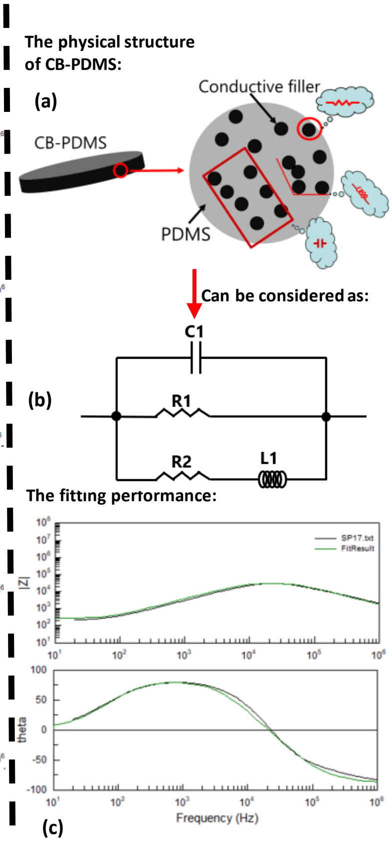



**Figure 4.** (a) Physical structure of CB-PDMS
(b) Equivalent circuit
(c) Fitting performance
(CB-SuperP 17 wt%)

## 5. Discussion & Conclusion

Conductive filler concentration affects not only magnitude, but also phase (Fig. 3):

- ➢ Low concentrations ⟶ Obvious capacitive characteristics at low frequencies.
- ➢ High Concentrations or Higher conductivity fillers ⟶ Primarily resistive characteristics in a wider frequency range.

- CB(Super P) and Graphite fillers demonstrate superior AC performance to CB(100% Compressed).
- Graphite achieves slightly better performance at high filler concentrations that CB(Super B).

As schematically illustrated in Fig 4(a), conductive composite elastomers can be modeled by an equivalent circuit formed by capacitors, resistors, and inductors in parallel, as shown in Fig 4(b).

- ➢ Filler particles in CB-PDMS ⟶ Resistors
- ➢ "Particle-PDMS-Particle" sandwich structure ⟶ Capacitors
- ➢ Conductive paths at high-frequencies ⟶ Inductors

Good fitting results (Fig. 4c) have been achieved with the proposed equivalent circuit.

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