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# 3D Printable Solid Tissue-Mimicking Material for Microwave Phantoms

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***Abstract*— Phantoms provide valuable platforms for testing of medical devices including microwave diagnostic systems. This work describes a 3D printable solid tissue-mimicking material (TMM) for the production of such phantoms. The TMM is fabricated from ABS, SEBS and Carbon Black. The polymers ABS and SEBS produce a material that is 3D printable, robust and mechanically stable. Adjustment of the percentage of Carbon Black in a mixture alters the dielectric properties of the mixture. A variety of such mixtures were fabricated into 3D printable spools and the dielectric properties were measured across the 0.5 – 8.5 GHz band. The dielectric properties of a wide biological range are covered with the ability to emulate tissues within the range. The material hence can be used to print anatomically realistic and dielectrically accurate phantoms that can be multi-layered and as complex as desired depending on the study.**

***Keywords*— dielectric materials; tissue-mimicking materials; phantoms; 3D printing; microwave imaging**

## I. Introduction

Microwave Diagnostics (MWD) represents an important research area in biomedical imaging. MWD is based on the contrast in the dielectric properties, specifically, the relative permittivity ($\varepsilon_r$) and conductivity ($\sigma$), that exists between healthy and diseased biological tissues [1]. Images can be produced that are maps of these dielectric properties within the body of interest [2]. Biomedical imaging using MWD offers the potential for a diagnostic modality that is non-invasive, portable and non-ionizing [3], [4]. To date, popular areas of research include breast and head imaging for pathologies such as cancer and hemorrhage [2]–[4].

Phantoms are physical objects that emulate the biological properties of interest. They represent an invaluable test platform in a controlled environment before trials on animals or humans [5]. An ideal phantom should offer realistic anatomy, accuracy in dielectric properties and long lifespan [5]. Tissue-mimicking materials (TMMs) are used to construct phantoms. Due to the close relationship between tissue water content and the dielectric properties, many TMMs are based on water as liquids and semi-solids. These suffer from disadvantages including dehydration and the need to often use a container to achieve the desired shape. Solid TMMs are free from these issues and can be used to produce anatomically realistic, dielectrically accurate phantoms that are stable. However there is a lack of phantoms based on solid TMMs due to issues such as complexity of fabrication and material costs [5]. Phantoms based on 3D printed materials exist but primarily as a container for liquid based TMMs [6].

This study introduces solid TMMs based on a composite of acrylonitrile butadiene (ABS) and poly(styrene-b-ethylene-butylene-b-styrene) (SEBS). The composite produced is both 3D printable and offers an augmentation in elasticity and toughness compared to a pure ABS base polymer [7]–[9]. The addition of a highly electrically conductive form of Carbon Black (CB) [10] as a filler in the composite enables the dielectric properties of the TMMs to lay within the range of properties of biological tissues, as measured in the 0.5 – 8.5 GHz microwave band.

## II. Materials

The base composite used in this study consisted of ABS and SEBS in the ratio 4:1 respectively by mass. The thermoplastic ABS is a commonly used material for 3D printing [11]. It was found however that direct use of CB with ABS resulted in a very brittle material, particularly at higher concentrations of CB [11], [12]. SEBS is a polymer composed of a tri-block structure, with two end hard blocks and an elastomeric rubbery mid-block [9]. The composite of ABS and SEBS was found to offer good toughness, material strength but also flexibility and malleability including upon addition of CB. ABS was provided as solid pellets, with SEBS as flakes.

The CB used was Ketjenblack EC-600JD [13]. This highly conductive form of CB allows higher values of $\sigma$ and also $\varepsilon_r$ to be achieved across the microwave band at much lower concentrations than other forms of CB [13]. The CB was used in concentrations ranging from 5.5 % - 11 % by weight in the base composite.

## III. Fabrication

Five separate mixtures were prepared differing in the percentage of CB (5.5 %. 6.5 %, 8 %, 9.5 %, 11 % by weight). Following weighing out of the appropriate masses of each material sufficient to make 450 g of final product, the three materials were mixed thoroughly by hand. Prior differential scanning calorimetry gave the melting temperature at about 240 °C.

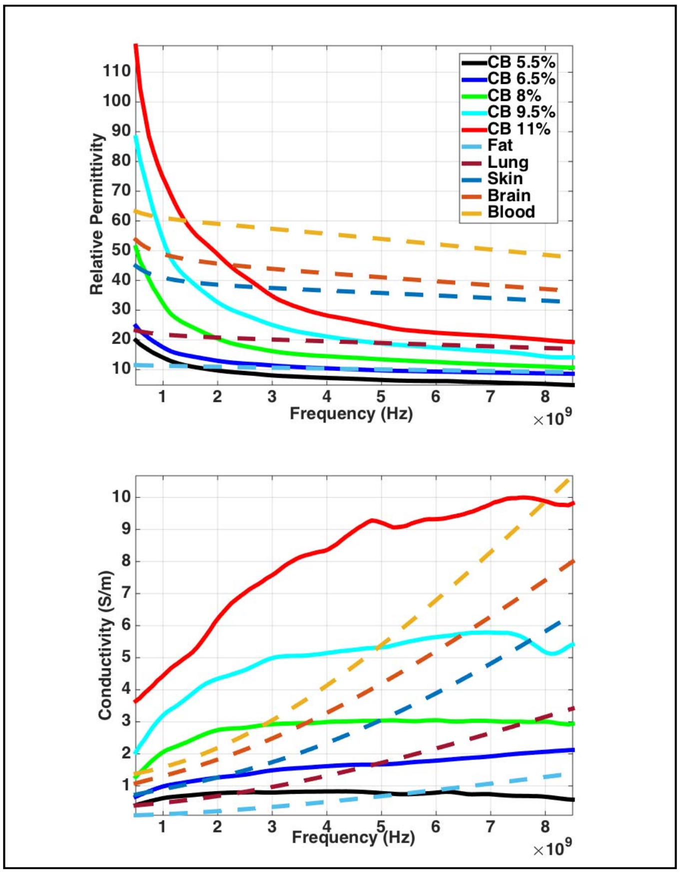


Fig. 1. Relative Permittivity (top) and Conductivity (bottom) curves of the various TMM mixtures as compared to reference tissues (fat, lung, skin, brain and blood) over the 0.5 – 8.5 GHz band.

Fabrication of the mixtures into 3D printable filaments was by extrusion using a twin screw co-axial extruder. A temperature profile of 210 – 240 °C was used over the 5 zones (feed, melting, compression, mixing and metering) with a L/D ratio of 20:1, torque profile below 16 N.mm and die pressure of 7 – 21 MPa (higher for higher CB concentrations). The result was homogenous TMMs in the form of 3D printable filaments of diameter approximately 2.85 mm (the diameter of the die used).

## IV. Dielectric Properties

A Keysight E5063A ENA Network Analyzer was fitted with a slim form probe from the Agilent 85070E Dielectric Probe Kit. This setup was used to measure the dielectric properties of each TMM filament from 0.5 – 8.5 GHz in a linear sweep across 100 points. The dielectric measurement was repeated at multiple sites on each TMM sample. The resultant measurements of $\varepsilon_r$ and $\sigma$ for each TMM are shown in Fig. 1, alongside the dielectric properties of sample reference tissues [14].

Fig. 2. Example of the 3D printable TMM filaments.

## V. Conclusions

The solid TMMs are capable of emulating the dielectric properties of a range of tissues. While the broadband properties may not suffice for all tissue types or frequency ranges, good matches are attainable at discrete frequencies. Importantly, these TMMs are 3D printable and hence can be used to fabricate both anatomically and dielectrically accurate phantoms for MWD systems. A sample of the filament is shown in Fig. 2.

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