Functional Digital Materials for Electromagnetic Structures and Circuits

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Abstract— We demonstrate a digital manufacturing paradigm applied to the assembly of electromagnetic systems. These *digital materials* are constructed from a small set of discrete parts that fit together in a coded manner with discrete orientations. Additively assembled digital materials offer a new mode of electronic device fabrication with affordances for new device geometries as well as device disassembly and reuse.

Subtractive and additive manufacturing processes have long been the norm for electronics production, using methods like lithography or micromachining to pattern elements onto bulk materials [6]. Additive processes have started replacing subtractive ones for high-throughput production, but it is still difficult to print high-Q structures. Furthermore, as devices grow in complexity and size they impose ever-greater requirements on process control, increasing cost and decreasing yield. Finally, traditionally-fabricated electronic devices cannot easily be reused, resulting in millions of tons of e-waste each year [1].

Instead of shifting from subtractive to additive manufacturing, we propose moving from the analog world to the digital. Just as the digital paradigm revolutionised communications and computation, digital materials will change how we assemble the built world. Codes can dictate how devices are constructed from elemental parts, much like the genome dictates how organisms are constructed from proteins. The parts can be error-correcting, with the materials dictating precision instead of the assembler. Furthermore, devices can be disassembled and their parts reused to make new devices.

To explore new circuit geometries and fabrication methods that allow for disassembly and reuse, we propose to use functional digital materials for electronic device manufacturing. Digital materials have already been proposed for certain types of manufacturing [3–5, 7, 8], and preliminary designs for assemblers that place or recycle digital materials have also been proposed [2, 9–11]. However, there has not yet been a study of digitally fabricated electromagnetic devices.

This paper describes the characteristics and geometries of several different digital material bricks: conductive, resistive, insulative, dielectric, and ferromagnetic. Different part geometries, manufacturing techniques, and electronic properties of each brick are outlined, using both simulated and experimental data. The bricks are designed to be placed by a high-speed assembler for automated construction and disassembly.

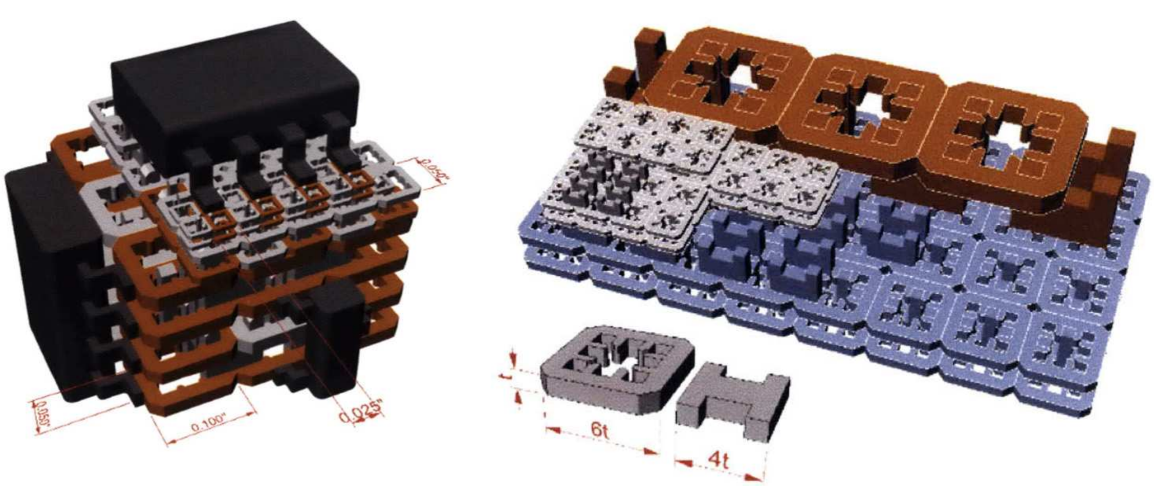

Figure 1: An example of a digital material geometry which can be used as an alternative to printed circuit boards for components with SOIC-pitch [10]. We propose integrating passive components into the 3D structure itself.

Using these bricks as material building blocks we demonstrate how to make circuits with 3D structure and integrated passive components as well as 2-port electromagnetic networks such as microstrip transmission lines and matching networks. We characterise the performance of these devices under various amounts of mechanical loading. Finally we demonstrate a fully functioning data radio circuit including integrated matching network and antenna, fabricated using only digital materials and standard semiconductor devices.

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