Additively Manufactured Flexible & Origami-reconfigurable Antennas and RF Sensors

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Additive manufacturing has become an increasingly growing field over the last decade due to its increasing number of inherent fabrication advantages. The most obvious benefit is the lower volume of material needed, often lowering the cost of raw materials in a design for a reduced tooling cost, that has opened up its applicability to a variety of applications. For example, a 3D-printed wrench has been fabricated in space verifying additive manufacturing's capabilities in virtually any location. There is a reduction in tooling costs that would previously be needed to remove the material. The reduction of tooling needs opening up accessibility to a variety of locations. A 3D-printed wrench was created in space, which opens up the doors of manufacturing devices in any location. In some industries, design verification can account for more than half of all costs on a project, and additive manufacturing techniques generally allow rapid prototyping of new designs. For example, prototyping of turbines taking 16-20 weeks is now reduced to 48 hours.

All these beneficial properties can be directly applied to radio frequency (RF) designs. Inkjet printing has been already successfully applied to the realization of ultra-low-cost wireless sensors, antennas, passives and other 2D and 3D electromagnetic (EM) structures on a variety of substrates ranging from paper and flexible organics (LCP) to silicon wafers and glass. Recently, 3D printing has also been of interest for the fabrication of fully 3D RF sensors, initially focusing around polymer structures, while lately taking advantage of various novel metallization techniques. A recent interest has been 3D printing, which is relatively new on the field of RF devices. 3D printing generally focuses around polymer structures, though there are several methods for metallization that open a new world for RF design.

The recent growth of 3D printing manufacturing processes and its potential integration with inkjet printing techniques has created the possibility to rapidly prototype fully 3D novel designs for RF devices and sensors. There are a wide variety of 3D technologies available including Fused Deposition Modeling (FDM), Selective Laser Sintering (SLS), PolyJet, Stereolithography (SLA), and more. Each one has advantages and disadvantages, but all of them require several common design steps in order to prepare for manufacturing. The first step of the process is to characterize the 3D printable materials of interest, whether it be a polymer or a conductor. Design considerations need to be made considering the permittivity, loss, surface roughness, achievable resolution, conductivity, porosity, printing infill, flexibility and even color which alter the electrical and mechanical properties. Many enterprise grade materials have already been characterized, though with the recent expansion of 3D printing, new base materials are constantly created. A material named NinjaFlex, a versatile, stretchable, and flexible filament for FDM printing, has been completed in order to facilitate new designs. A flexible patch antenna design was built as a proof-of-concept. Additional designs with common substrates with known properties such as ABS have been created and verified, allowing the designs of 3D antennas for RFID wearables to be integrated into clothing. Electromagnetic waveguides have been created to conform to a variety of shapes that were previously difficult to manufacture. A cavity resonator-based sensor with microfluidic channels has been manufactured to detect fluids and their properties. Strain sensing flexible designs have been created that can detect pressure upon an arbitrary 3D shape. Almost all 3D printing techniques can achieve resolutions of 100 microns and maximum design sizes over 30 cm, allowing a wide range of designs that may be large or miniaturized, depending on the interested frequency of design. Most focus manufacturing of a single material, though certain printers print 10 or more materials in a single design. These designs are modeled through simulators such as CST and HFSS, with the ability to directly export both substrates and conductors to build prototypes that are identical to their CAD-designed counterparts. Many manufacturing tools can be incorporated into 3D printers, allowing drop-on-demand (DoD), aerosol jet printing, inkjet printing, or a variety of 2D-targetted tools to be used for their conductive or otherwise chemical deposition properties. These tools often require the surface roughness, porosity, and temperature compatibility with the base substrate.

After going from 2D inkjet printing to 3D printing, one would assume maximal dimensions have been achieved. With a variety of memory materials, designs can be achieved in the 4th dimension: time. These designs generally employee memory materials that are reactive to stimuli that cause a shift between two separately designed structures. The memory polymers with PolyJet 3D printing are based off of VeroWhite and TangoBlack mixtures, allowing hybrid designs that have gradients of flexibility and memory. This allows self-deploying designs that can be created for space-constrained systems. In one design, an origami structure has been manufactured to create a foldable cube from a 2D design. With antennas on the surface, the folded cube now accommodates variably oriented antennas to improve energy harvesting and diversity from multipath signals. With a proper design, shape-memory 3D structures can be built that fold or unfold automatically, with heat or small voltage triggering, and without manual force. This enables for the first time on-the-fly “origami” reconfiguration of EM systems’ properties such as operating frequency or radiation pattern, effectively building smart antennas and RF sensors.