A Low-Cost, Single Platform, Hybrid Manufacturing System for RF Passives

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***Abstract*— This research introduces a low-cost, single-platform hybrid manufacturing process for realizing canonical and wideband antenna structures. This work outlines the printing processes of thick dielectrics & thin metallic geometries in coordination with selective removal of planar copper structures and provides a proof-of-concept demonstration of the first hybrid manufactured RF structures. Using the outlined processes, demonstration of a 6 GHz inset feed patch antenna and a Vivaldi antenna array prototype are presented first of their kind approach to realizing RF passives.**

***Index Terms*— Flexible manufacturing systems, additive manufacturing, hybrid manufacturing, antenna arrays, patch antennas, Vivaldi antennas**

I. Introduction

Additive manufacturing (AM) is at a point to impact how everyday objects are created. This is partially due to the breadth of the manufacturing process that AM touches (e.g. prototyping, rapid tooling) but also due to the cost-saving nature of selectively depositing material. Despite this, AM is, in itself, not the be-all-end-all that it is often held up as. It does offer many benefits; however, it will not replace traditional (a.k.a subtractive) manufacturing technologies wholesale. This paper demonstrates that through a blending of both additive and subtractive technologies, a hybrid manufacturing (HM) approach to low-cost, single-platform device construction is a superior method of realizing and prototyping RF passives.

The objective of this proposed research is to address the issues specifically tied to material extrusion (ME) by introducing an inherently low-cost hybrid manufacturing process that can be scaled to improve quality, decrease per unit cost and lower fabrication time of digitally printed RF passives. Single platform AM of RF passives and general electronics have been shown to be viable. There are numerous cases of single-platform inkjet printed RF passives; however, these are all tied to substrates on the order of 10's of μm [1], [2], [3], [4]. On the other hand, there have been attempts to create large printed structures, but these attempts are inherently limiting due to accuracy [5] or utilizing equipment that costs >\$100k [6].

Altogether, AM is a novel technology that stands to become indispensable in the future of general manufacturing. Until this point, AM has been generally operated in isolation of other manufacturing technologies. This paper proposes the novel combination of both additive and subtractive manufacturing technologies to produce a hybrid manufacturing process through silver and polymer deposition, with copper tape subtraction. This in turn will help reduce the cost of printed electronics structures, increase resolution and reduce the time for production of the items.

II. Equipment & Materials

In order to fabricate a hybrid manufactured RF passive both metallic and dielectric materials will need to be printed, requiring multiple tools. The Hyrel System 30M, seen in Fig. 1, is a research focused manufacturing platform priced <\$10k . No other comparable 3D printer or bench top manufacturing system exists at the price. It has multiple slots that can be equipped with a wide variety of tools. The tools were used for this research are shown in Fig. 2 and were the:

1) MK1-250 hot head used for polymer extrusion (Inland acrylonitrile butadiene styrene (ABS))
2) SDS-5 syringe pump used for silver paste extrusion (DuPont CB028)
3) ST-1 spindle tool used to hold the cutting tool for removal of copper tape (Tormach vinyl cutter)

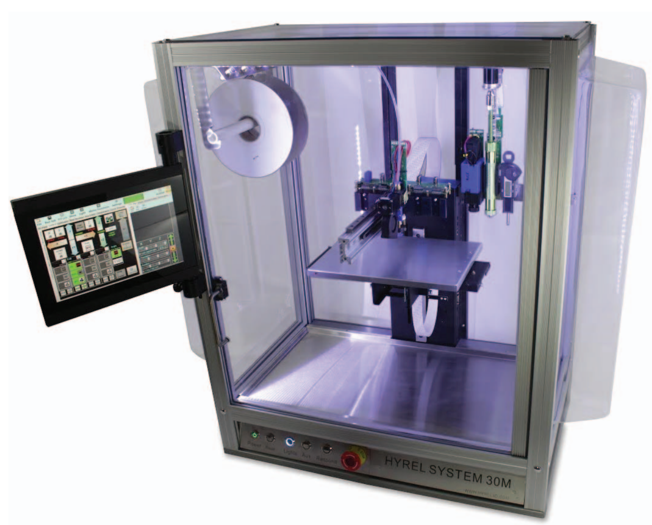

Fig. 1. Hyrel System 30M

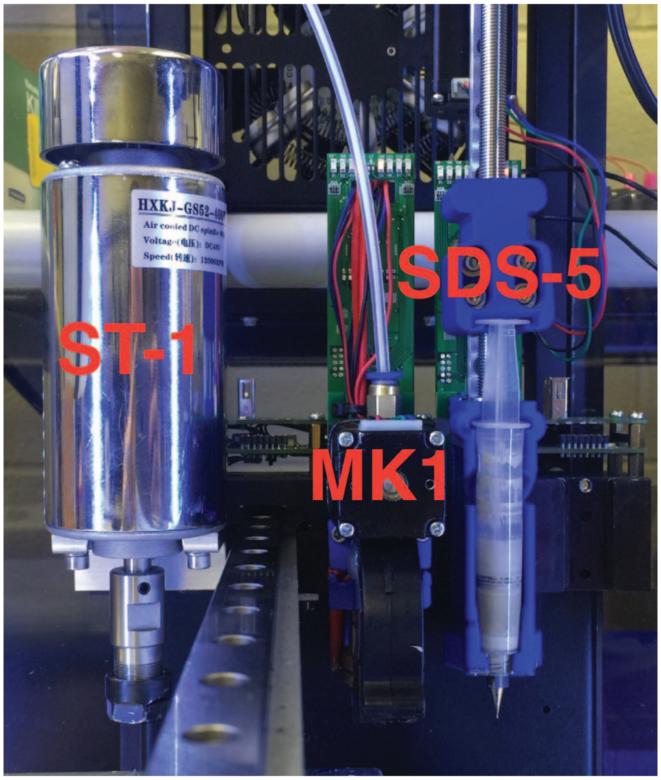

Fig. 2. Toolheads used for research effort

The dielectric layers are patterned out of Acrylonitrile Butadiene Styrene (ABS), a low-cost and commonly used polymer for ME. Nominal electronic material property ranges for ABS are provided in found in Table I [7], [6].

TABLE I
ABS MATERIAL PROPERTIES

Measured ABS Properties		Modeled Properties
Relative Permittivity	2.54-2.79	2.5
Loss Tangent	0.0067-0.0106	0.008

Metallic layers are patterned out of two conductors: additive layers use DuPont CB028 while subtractive layers use rolled copper tape. DuPont CB028 is a silver loaded paste traditionally used for screen printing. The silver loading is 60-70%, making it a highly conductive material that can be used for the electronics structures. The estimated conductivity is 5-10% of bulk silver without sintering [6]. Copper tape is readily available, relatively cheap, very thin (0.002") and highly conductive ($\sigma = 5.9E7\ S/m$). All of these factors play into making it a superior large area conductor in comparison to printing large area conductors out of silver material. Copper tape is superior for use in ground planes and large conductor structures that would otherwise be costly in terms of time for printing and material volume used.

III. MANUFACTURING PROCESS

The hybrid manufacturing process of an RF passive requires multiple steps of polymer and metal printing with copper tape subtraction. In general, these steps can be combined in any order to realize an arbitrary planar geometry; however, the process always begins with the deposition of a single 0.3 mm layer of ABS onto the print bed. This layer allows the molten plastic to absorb any non-planar imperfections inherent to the printing bed surface. This "sacrificial" layer then allows any subsequent layer after to have a flat planar surface to adhere to. Once the first layer is printed the rest of the RF structure is ready to be printed.

For the patch antenna, a single piece of copper tape is laid adhesive side down on top of the sacrificial layer and cut to the proper size with the ST-1 tool. The utilization of subtractive techniques rather than additive makes the printing process much faster. The the simple cutting motion (4 movements to cut a rectangle) can be performed quickly whereas printing the ground would take much long to additively cover the entire area. The same concept applies to the Vivaldi antenna. A simple silhouette is cut around the array rather than fill in the entire area of the Vivaldi ground structure significantly reducing the time of fabrication.

The RF substrate is then printed after the ground is created. The novel aspect of additive manufacturing allows the designer to specify the substrate height desired, rather than rely on a materials company to provided a given thickness. In this case, 3 layers, each 0.3 mm thick, of uncolored ABS were printed for a total of 0.9 mm thickness of the RF substrate. A razor blade was used to smooth any imperfections on the very top layer.

Finally, after printing the RF substrate, a single conductive layer was printed out of DuPont CB028. The CB028 was printed at 0.1 mm thick in a single pass and left on the heated print bed of 70C to completely dry out. In the case of the patch antenna, the full patch structure was printed with the feed running to the edge of the substrate. For the Vivaldi, just the open ended microstrip feed was printed out of CB028. Pictures of the manufactured antennas can be seen in Fig. 3, 4, & 5.

IV. MEASUREMENT RESULTS

The return loss of the hybrid manufactured antennas were measured on an Agilent N5242 VNA using Southwest Microwave clamp on style coaxial to microstrip connectors. The measured and simulated return loss of multiple printed patch antennas is shown in Fig. 6. Measured results for return loss compare well to simulations, showing at most a 2% deviation from the designed frequency. Similar data for the Vivaldi array can be seen in Fig. 7. There is a larger difference in return loss due to the fact that the vivaldi was modeled in an infinite array

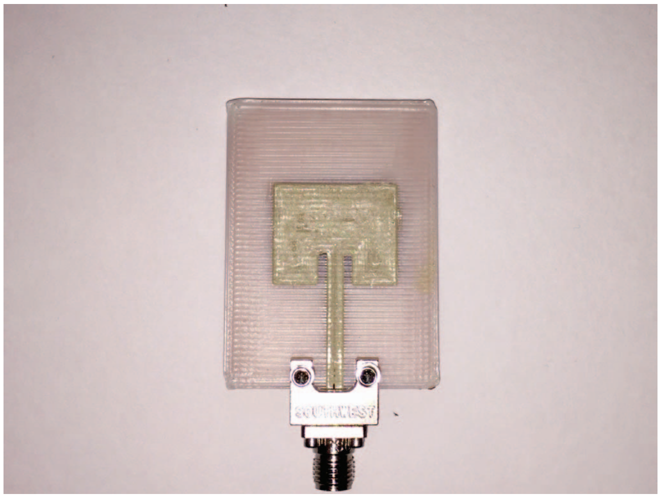

Fig. 3. Printed patch antenna

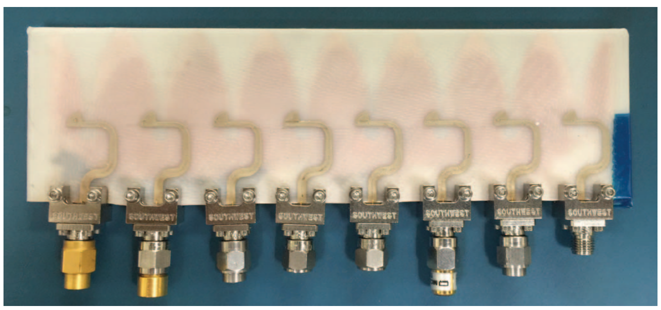

Fig. 4. Printed patch Vivaldi array - top

Fig. 5. Printed patch Vivaldi array - bottom

environment. The eight element array does not appear to be large enough to match completely.

V. Conclusion

This work outlines and demonstrates for the first time a hybrid manufacturing process for the development of RF passives. Two examples of RF passive radiators are shown using low-cost, standard equipment and materials such. Return loss measurements are performed to ensure the process is repeatable and reliable from model to fabrication. Utilizing both additive and subtractive manufacturing allows designs to be realized at a faster rate, lower cost, and greater flexibility than other typical prototyping processes.

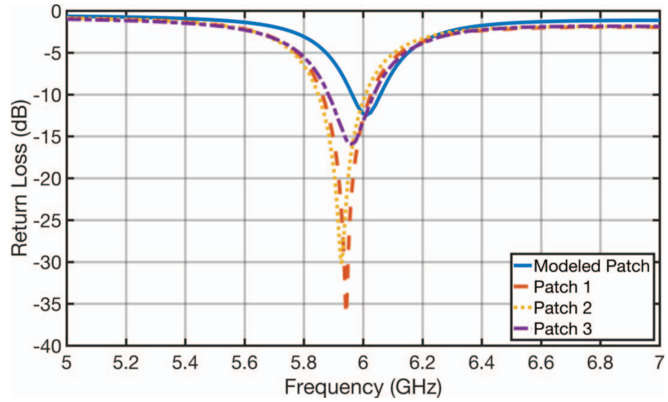

Fig. 6. Return loss of simulated and manufactured patches

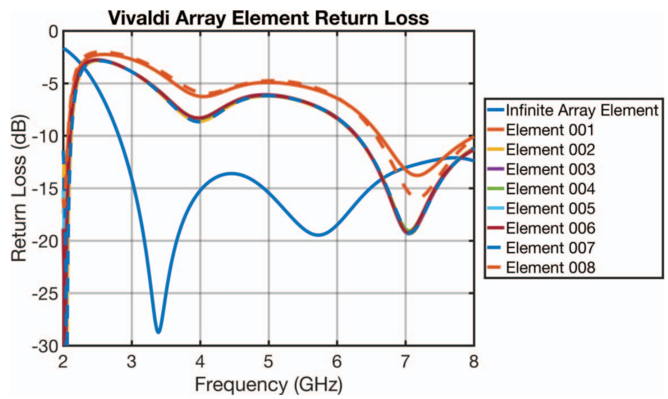

Fig. 7. Return loss of simulated and manufactured Vivaldi array elements

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