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## **Patch Antennas with Heterogeneous Substrates and Reduced Material Consumption Enabled by Additive Manufacturing Techniques**

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A key aspect of future antenna design will be to investigate novel fabrication strategies to reduce costs and consider ecological issues while optimizing the material composition to improve electromagnetic (EM) performance. Printed circuit boards use destructive procedures and environmentally damaging chemicals to etch away the unwanted copper. Additive manufacturing methods avoid this material inefficiency and there is scope to further reduce the quantity of metal used while maintaining performance. This can potentially save costs, weight and increase flexibility. Such processes include inkjet and thick film printing and embroidering conductive threads (which can cost up to \$1 per meter).

This work is also related to a project investigating the fabrication and EM advantages of creating integrated antenna systems using emerging nano-manufacturing technologies (Njoku et al, IEEE AWPL, to be published in 2012 (12-11-1367)). This work has shown that the effective permittivity of a heterogeneous medium with dielectric/metallic inclusions in a homogenous host can be controlled by varying the EM and physical properties of the inclusions. This will allow the substrate to be heterogeneous which can be exploited to control the bandwidth, efficiency and improve the matching of the antenna.

EM simulations using EMPIRE XCcel finite-difference time-domain FDTD software have been used to analyze the material composition of patch antennas. The efficiency was found to be related to the conductivity of the metallic conductor material. Increasing the conductivity from 1e5 to 1e6 S/m improved the efficiency from 18 to 42% (compared to 49% for the equivalent copper version). Gridded metallic sections were also investigated. Simulations showed that the *material consumption – antenna efficiency* trade off could be improved by aligning the majority of the metallic sections in the direction of the current flow. For example the geometry with 1mm gaps horizontally and 4mm gaps vertically (left) had an efficiency of 47% compared to 30% for the figure on the right which contains the same volume of metal. Removing large quantities of metal from the patch can potentially reduce the antenna efficiency.

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