Final author version. EuCAP 2010, Barcelona, Spain

Microwave Aperture Antennas Using Nanomaterials

William Whittow*[1] and Yiannis Vardaxoglou*[2]

* *Department of Electronic and Electrical Engineering – Loughborough University, Loughborough, UK*

[1] w.g.whittow@lboro.ac.uk; [2] j.c.vardaxoglou@lboro.ac.uk

***Abstract*— In this paper, computer simulations are used to investigate the concept of designing microwave aperture antennas, potentially fabricated using metallic nanomaterials. Nanomaterials are considered as they facilitate fabrication and electromagnetic advantages. Aperture radiating structures have been excited by a plane wave in a microstrip line. The aperture was modified with the addition of fine scale structures; vertical strips shorter than the height of the aperture. These initial simulation results have shown that these fine structures inside the aperture can decrease the resonance frequency at the expense of the bandwidth.**

I. Introduction

The end goal of this work is to fabricate antennas constructed from many suitably arranged metallic nanoparticles. Nanoparticles are by definition extremely small and therefore have a large surface area to volume ratio; this pertains to interesting properties including increased conductivity, strength, and scratch resistance. These antennas will operate in the microwave spectra where there are many communication related applications. When metallic nanoparticles (*dots*) are closely spaced the surface will resemble a metal sheet. However, by reducing the density of the dots in certain locations, apertures can be created where the structure is effectively transparent at microwave spectra, see Fig. 1. Furthermore, fine scale metallic structures can be formed inside the aperture via suitably arranged nanoparticles. By varying the local concentration of dots between densely and loosely packed, the electromagnetic performance can be controlled. Note, depending on the fabrication techniques used, the nanoparticles may be uniformly or randomly distributed.

Potential electromagnetic advantages of this research include: improved electromagnetic performance (bandwidth, gain and efficiency); potential size reduction; novel dual-resonance behaviour. Physical advantages include; reduced weight, increased strength, less raw material requirements. Potentially, the substrates and ancillary RF components can be fabricated in the same process as the antenna which may also reduce production costs. Current antenna designs are limited by having to use fixed values of permittivity for the substrate (ε_r = 2.2 or 4 etc). The nanomaterial host medium can become the substrate, where novel bespoke dielectric properties can be created by controlling the density of metallic and non-metallic particles and tailored for a specific antenna design. The authors have previously shown that a small size, high efficiency and high bandwidth antenna can be designed by using a substrate with equality of permittivity and permeability and low losses [1]. The aim is to facilitate such novel substrates which would allow great flexibility in antenna design.

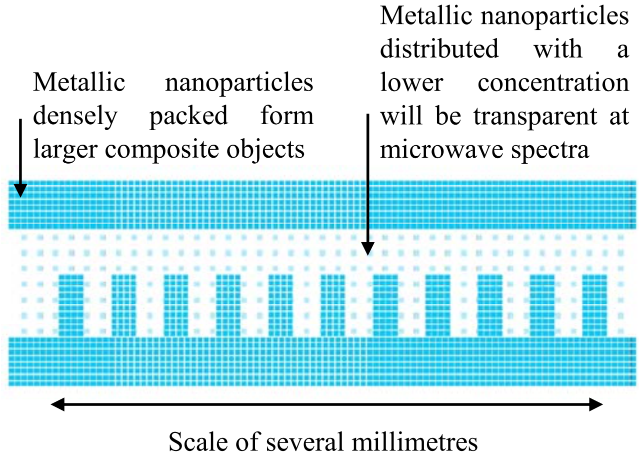

Fig. 1. A sketch (not-to-scale) demonstrating how nanoparticles can be arranged to form larger objects

An antenna composed of nano-sized periodic structures, can be suitably arranged to have metamaterial characteristics. Mittra [2] has reviewed the subject of small antennas and concludes that the key challenges are size reduction, directivity enhancement, bandwidth widening and backlobe suppression, and he suggests that new advances in metamaterials may be the answer for improved antenna performance. Caloz [3] has shown that using smaller unit cells of metamaterials can improve the homogeneity and the isotropy, extend the bandwidth, enhance the functionality and reduce refraction and diffraction losses at interfaces with other media.

Nano-electromagnetics is a rapidly growing area, however, the research is mainly focused at much higher frequencies, including nano-waveguides, nano-antennas, semiconductors, nano-scale resonators [4, 5]. Previously, the authors have shown that antennas composed of very small conducting metallic *dots* have different behaviour at microwave spectra, depending on their size and the gaps between them [6].

II. Simulation Setup

EMPIRE commercial finite-difference time-domain (FDTD) software (www.empire.de) has been used in this work. A vertically polarised plane wave travelling in the X direction from Port 1 to Port 2 (see Fig. 2) was created using an air-filled microstrip line (MSL) which acts as a parallel plate waveguide. The cut off frequency of the cavity is f_c*=c/MAX(W or H)* and therefore, to consider the microwave spectra up to 40GHz, the height and width of the MSL were set to 7500µm (7.5mm). The MSL was a very memory efficient method of examining the reflection and transmission coefficients between the two ports. Half way along the MSL, a 5µm thick silver sheet was positioned which extended to all four walls of the MSL. A horizontal aperture (5500µm wide and 100µm high) was cut into the middle of this sheet, see Fig. 2. Due to the electric and magnetic boundaries, the structure is infinitely periodic in two dimensions. Note, Port 1 is the only excitation in the model and the aperture is a passive radiating structure.

Fine scale vertical strips were added to the aperture. The strips has the same thickness as the silver sheet (5µm). In all cases the strips were evenly distributed along the Y axis. Simulating structures down to several microns is extremely computationally expensive at microwave frequencies and computational memory requirements and runtimes prohibit using nano-scale resolutions. Previously, the authors have approximated nanomaterials using larger *dots* and gaps [6].

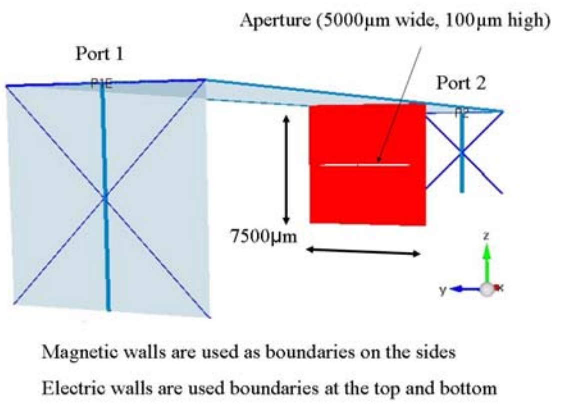

Fig. 2. The simulation setup

III. Results

The horizontal aperture without any vertical strips demonstrated a pass band resonance with near total transmission at 26.8GHz. The aperture was then modified by adding 100µm long 10µm wide 5µm thick vertical strips were added inside the aperture which touched both the bottom and top of the aperture. This shorted out the aperture and effectively reduced its size. However, if the strips were shorter than 100µm with a gap at the top of the aperture (see Fig. 3 (a) and (b)), the behaviour changed. As the number of strips increased, the resonance frequency decreased and the S_{21} also decreased in magnitude as shown in Fig. 4. Therefore, the aperture becomes electrically larger but a less efficient radiator. As larger numbers of strips were added, the change in resonance frequency becomes smaller and begins to converge, this can be seen in Fig. 5. The behaviour was different when the strips were attached alternately to the top and bottom of the aperture, see Fig. 3 (c); with 200 strips (in total) alternately touching the top and bottom, the resonant frequency decreased to 6GHz compared to 10.6GHz with 200 strips touching only the bottom of the aperture. The magnitude of the S_{21} also decreased.

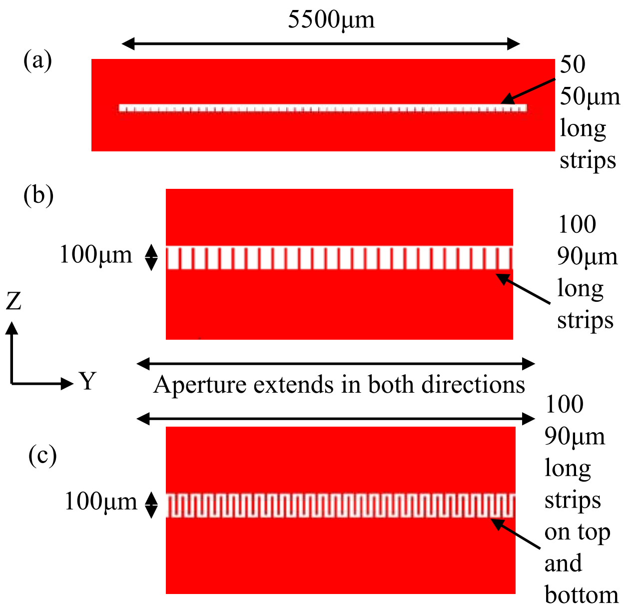

Fig.3. Aperture geometry; (a) Fifty 50µm long strips, (b) zoomed in view of aperture with one hundred 90µm long 10µm wide strips and (c) zoomed in view of aperture with one hundred 90µm long 10µm wide strips on both top and bottom sides of the aperture

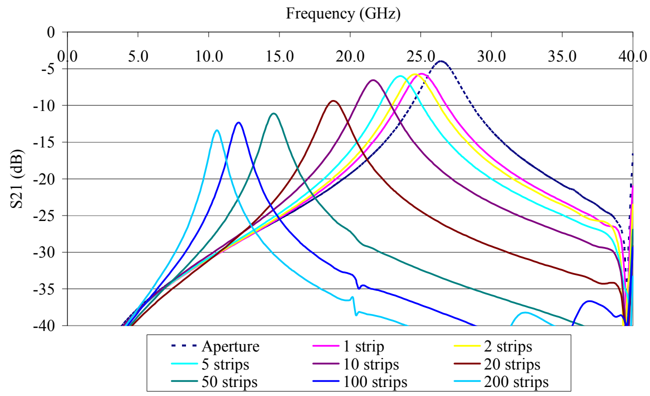

Fig. 4. Increasing the number of 90µm long 10µm wide strips vertical strips

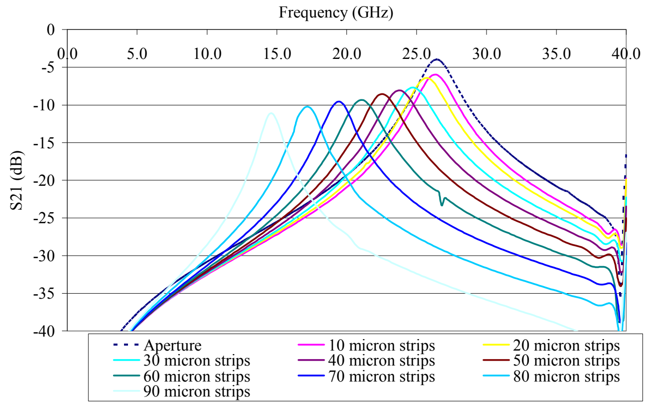

Fig.6. Varying the length of fifty 10µm wide strips

The effect of varying the length of 50 strips was similar to increasing the length of 90µm strips and the results are shown in Fig. 6. As the length of the strips increased, the frequency and S_{21} decreased. The compromise between the S_{21} and the electrical size can be optimized to suit the antenna requirements.

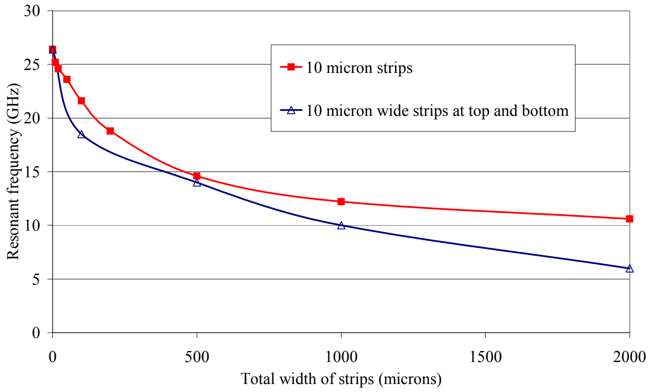

Fig.5. The resonant frequency of 90µm long 10µm wide vertical strips touching the bottom only compared to the top and bottom of the aperture

The effect of varying the width of the strips from 5 to 1000µm was also investigated with the length fixed at 90µm and the thickness fixed at 5µm. Generally, as the total width of the strips (number of strips ´width of strips) increased, the resonance frequency decreased. However, this increased electrical size came at the expense of a decreased bandwidth and a reduced transmission (S_{21}).

Note, the resonance frequency was different with the same total width of strips composed of different number of strips (i.e. 100´10µm ≠ 20´500µm ≠ 10´100µm ≠ 1´1000µm). Therefore, the performance was dependent on the width of the strips and not just the total width of all the strips.

There was a linear relationship between the resonant frequency and the product of the fractional 3dB bandwidth and the magnitude of the S_{21} as shown in Fig. 7. Therefore, the trade-off between reduced frequency and decreased bandwidth and efficiency caused by additional strips was balanced. Fig. 7 shows that similar curves were found with different strip widths and all strip widths produced equivalent results in terms of overall performance.

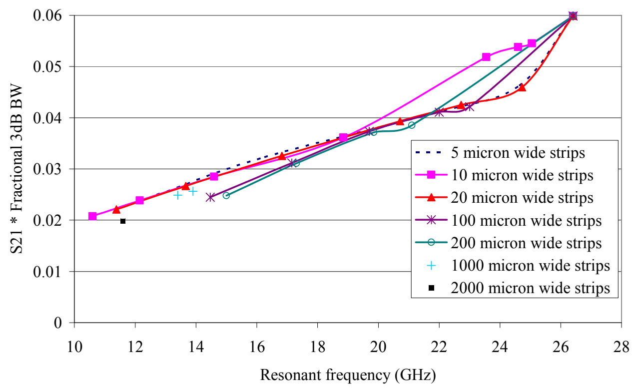

Fig.7. The effect of using different strip widths

IV. Conclusions and Future Work

In this paper, computer simulations have been used to analyse fine structures inside an aperture radiating structure. This work is the precursor to the overall aim of producing structures using nanomaterials. The addition of vertical strips that were shorter than the height of the aperture decreased the resonant frequency. However, the bandwidth and the S_{21}were also decreased. The performance with different thicknesses of strips produced the same linear relationship between frequency and the fractional 3dB bandwidth-S_{21} product. Therefore, a group of aperture antennas with different behaviour but equivalent overall performance can be designed using fine structures inside the aperture depending on the antenna requirements.

Future work will fabricate samples using nanomaterials. Possible fabrication methods include; Spin coating and screen printing methods to generate mesoporous interpenetrating nanocomposites of TiO2 (metal oxides) and metal particle composites, Spin coating techniques used to create thin films, Nano templating of metal-polymer structures, using laser scribers to create patterns, ion beam microtoning, nano-lithography and vacuum evaporation techniques.

References

[1] M. I. Kitra, C. J. Panagamuwa, P. McEvoy, J. C. Vardaxoglou, and J. R. James, "Low SAR ferrite handset antenna design," *IEEE Trans Antennas and Propagation*, vol. 55, pp. 1155-1164, 2007.

[2] R. Mittra, "Performance enhancement of small antennas using metamaterials; challenges and future directions," 19th International Conference on Applied Electromagnetics and Communications (ICECom 2007), 2007.

[3] C. Caloz, A. Lai, and T. Itoh, "The challenge of homogenization in metamaterials," *New Journal of Physics*, vol. 7, pp. 1-14, 2005.

[4] C. Rutherglen, D. Jain, and P. Burke, "RF resistance and inductance of massively parallel single walled carbon nanotubes: Direct, broadband measurements and near perfect 50 Ω impedance matching," *Applied Physics Letters*, vol. 93, 2008.

[5] Y. Bayram, Y. Zhou, and J. Volakis, "Conductive textiles and polymer-ceramic composites for novel load bearing antenna," IEEE Symposium on Antennas and Propagation, San Diego, USA, 2008.

[6] W. G. Whittow and Y. Vardaxoglou, "Nano-metamaterial Antennas At Microwave Frequencies," Nanometa 2009, Seefeld, Austria, 2009.