PROJECT III.5 : PHOTONIC CRYSTALS, METAMORPHIC MATERIALS AND NOVEL RF SYSTEMS

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Objectives

To design, optimize and fabricate photonic crystals and frequency-agile metamaterials (metamorphic materials) to be used as electromagnetically active filters and substrates/superstrates for novel embedded antenna architectures and other systems (filters, waveguides and resonators) operating in the microwave/mm-wave region, for applications in novel RF transceivers.

MAIN RESULTS IN 2010

60 GHz Meta-antennas for 3-dimensional heterogenous integration onto on-chip radio transceivers

The millimeter-wave range is gaining increasing interest for current and future communication systems. Of particular interest is the 60 GHz region, where up to 9 GHz of bandwidth world-wide is available, for wireless local and personal area networks, high-speed data synchronization for PDAs and gigabit streaming for HD video and home entertainment systems. Systems must ensure miniaturization and efficient integration in close proximity of other system components while ensuring electromagnetic reliability.

Low profile patch antenna configurations have been demonstrated as single elements and in arrays on conventional substrate materials for manufacturing with printed circuit boards allowing low cost fabrication. These suffer from severe bandwidth limitations as well as mutual coupling effects between array elements impairing beam-steering. These factors, combined with the need for high array directionality and low substrate thickness make package integration of planar antennas quite challenging for 60-GHz radio applications. To overcome these limitations, artificial materials with tailored permittivity and permeability (metamaterials) are promising as substrates for planar antenna configurations. Regarding the integration of metamaterials in a compact mm-wave system and their influence on antenna performance there have been little efforts. To date, no systemic design and integration approach exists. Furthermore, since artificial metamaterials rely on resonance properties, their sensitivity to technological fluctuations is critical.

This project relies on two fundamental physical concepts: Realization of on-package integrated metamaterials operating as Artificial Magnetic Conductors (AMC) and Surface Wave Suppressors (SWS), and design and integration of antennas and arrays on these metamaterial chip packages, so that the resulting systems

(1) Overcome the bandwidth limitations of conventional planar antennas integrated within the very thin 60-GHz radio package form-factors and simultaneously radiate on the broadside half-space. *Conventional antennas get shorted when these constraints are imposed on them*; and
(2) Allow high system integration density in very low-profile configurations and improved array performance by reducing undesired coupling and increasing scan-angle functionality.

ARTIFICIAL MAGNETIC CONDUCTORS AMC's are novel composite materials specifically designed to act as shields that totally reflect electromagnetic radiation, similar to electric conductors, but having the *opposite property* regarding the phase of the reflection coefficient S_{11}, i.e., $S_{11}(f) \approx +1$ for a specific band of frequencies {*f*}. AMC's *amplify* the tangential incident electric field by 100%, rather than canceling it as electric conductors do, and they create images of electric charges and currents that have the same sign as the original excitations that illuminate them. A homogeneous material satisfying this property on its surface would imply a conductor having "magnetic charges", which do not exist in Nature, hence natural homogeneous materials do not behave as AMC's. There are, however, artificial composite materials that do exhibit this property, which is why AMC's are a unique class of metamaterials.

Fig. 1 shows the response of a prototype AMC, scaled at the Ka-band, designed and measured at IMEL. The measurements (and corresponding simulations) are using a Ka-band rectangular waveguide and the metamaterial is excited by the dominant TE_{10} mode, de-embedded up to the metamaterial surface. We notice that the measurements are in excellent agreement with the theoretical simulations, demonstrating the accuracy of our design capabilities, and that this artificial material reaches the AMC value of +1, making it a Perfect Magnetic Conductor (PMC) at the frequency range of 30-31 GHz. The bandwidth of the AMC is traditionally taken for frequencies satisfying $\mathrm{Re}(S_{11}) \geq 0$. This prototype shows that we can achieve large AMC bandwidths approaching 40%. In Fig. 1 (b) we show the corresponding power reflection and transmission. We notice that the transmission is below -40 dB throughout the band, making this metamaterial a very effective AMC completely shielding the half-space behind it, appropriate for mm-wave applications.

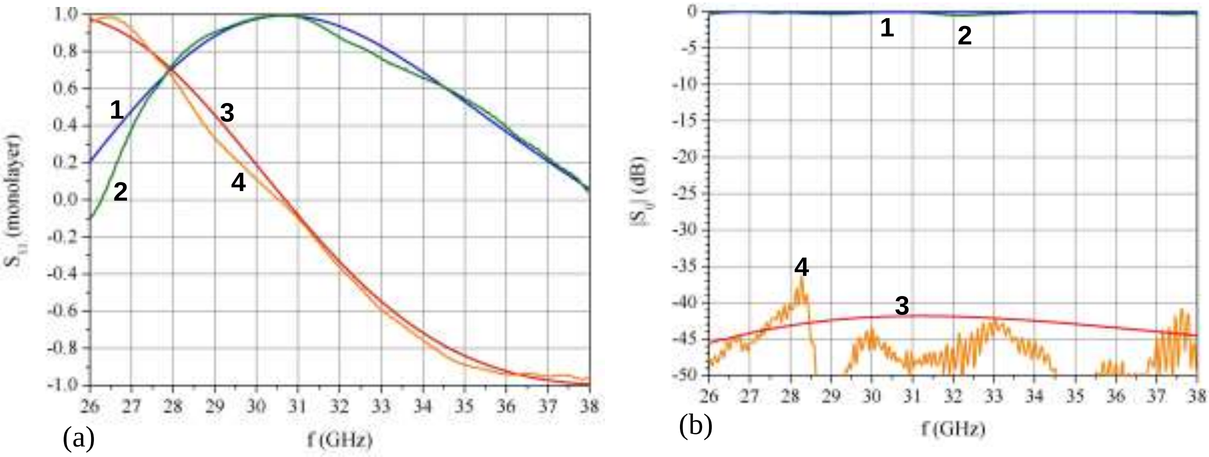

Fig. 1 (a) Reflection coefficient of a prototype broadband AMC manufactured on Rogers substrate: $S_{11}(theoretica\ l)=1+j3;S_{11}(measured)=2+j4$ (b) Theoretical reflectivity (1) and transmittivity (3) vs. their experimental counterparts (2), (4).

OPTIMIZED 60-GHz META-ANTENNA DESIGNS We conclude this summary with a metamaterial appropriately co-designed with an optimized antenna to possess both broadband AMC *and* SWS functionality simultaneously, the whole system integrated on a 3-layer package technology. The total package dimensions are 1.8 × 3 × 0.3 mm^3 or 0.36 × 0.6 × 0.06 λ_0^3, where λ_0 is the free-space wavelength at 60 GHz. The corresponding meta-antenna performance is shown in Fig. 2.

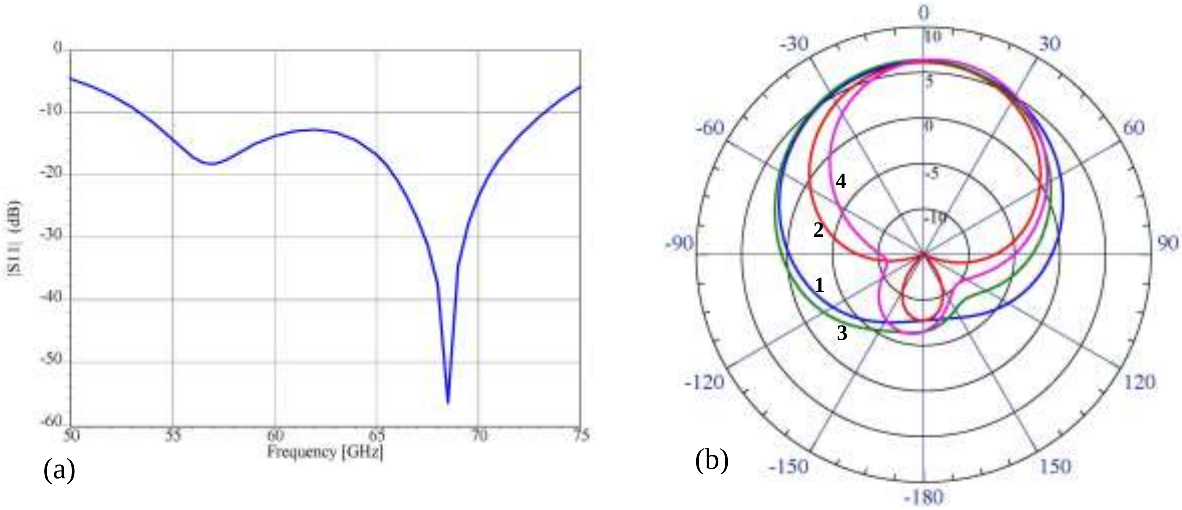

Fig. 2 a) Return loss of an optimized on-package integrated meta-antenna. b) Realized gain *G* (υ) (dBi) of the system at 57 GHz, for ϕ = 0 (1) and ϕ = 90° (2) and at 68 GHz, for ϕ = 0 (3) and ϕ = 90° (4).

In Fig. 2a we present the impedance matching of this optimized system (for a 50-Ω port), which is excellent and very broadband. The -10 dB bandwidth is 32%, extends from 53 GHz up to 73 GHz, and is 120% *larger* than is required for 60GHz radio transceivers (including all operating bands world-wide). The total radiation efficiency is 85-90% throughout this wide band, and a complete suppression of surface-wave modes has been accomplished. The radiation patterns for this optimized meta-antenna are shown in Fig. 2b, where curves **1** and **2** correspond to the ϕ = 0 and ϕ = 90° cuts at 57 GHz while curves **3** and **4** are the corresponding cuts at 68 GHz (package lies on the x-y plane). The gain reaches the very high value of 6.5 dBi in the forward direction for both frequencies with an excellent front-to-back ratio of 13 dB.