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) for electromagnetically active filters, substrates and radomes for applications in novel embedded antenna architectures, filters, waveguides and resonators operating in the microwave/mm-wave region, for applications in novel RF transceivers.

MAIN RESULTS in 2012

Design, Fabrication and Measurement of Spiral Artificial Magnetic Conductors and Dipole Antennas integrated on-package for single-chip 60 GHz Radio Transceivers

The new generation of integrated radio transceivers operating at 60-GHz offer unsurpassed communication band width up to 9 GHz and data transmission speeds unmatched by current devices. These transceivers require antenna elements and arrays optimally designed and integrated close to transceiver dies, preferably embedded on-package. Artificial Magnetic Conductors (AMCs) are promising artificial materials for antenna integration. We develop the theory and extract the design rules of novel package-integrated dipole antennas on a spiral AMcs. Design and fabrication are subject to the essential package technology constraints and performance requirements crucial to 60GHz radios: Large bandwidths (≥15%) covering the 57-66 GHz spectrum plus extra band-edge to allow for parasitic detuning; Directional broadside radiation with minimal back radiation on the die side, necessary for realizing highly directional and steerable arrays; Small areas and thin profiles fitting on-package integration and layout rules. In this work we present novel designs of package-integrated antennas and arrays on spiral AMCs, satisfying all the above technology and performance requirements. Further, we present prototype fabrication details and measurements of a novel package-integrated dipole antenna on a spiral AMC. The design principles used, have been presented quite generally in [1]. The measured results presented here [2] show an impedance matching bandwidth far exceeding the required spectrum and 5 dBi broadside gain for a single-element AMC- antenna system occupying a package area of 1.65×2.75 mm^2.

Fabrication and measurement of On-Package Spiral AMC Dipole Antenna

The package-integrated AMC/dipole system containing 3×5 spiral AMC Unit Cells (UC), is shown as fabricated in Fig. 1a. The dipole is 1.42 mm long and 100um wide and is fed through vertical vias that traverse the whole package and end up in a Ground-Signal-Ground (GSG) pad configuration directly probed in our measurements. When connected to the underlying die, it will be fed by a coplanar-waveguide of the same characteristic impedance. Fig. 1a shows our GSG to dipole transition that has been implemented in the design for impedance matching. The AMC UC contains a square spiral leaving a margin of 15 um from the UC edges, and a metal trace width of 100um. The spiral contains 1.25 turns and the long and short spiral metal gaps are 30 um.
The spiral AMC has been designed to project tuned AMC behavior at the package metal layer where the dipole is printed, according to the design rules of [1]. Fig. 1b shows HFSS simulations

of the reflection coefficient for normal plane-wave incidence on the transversely infinite packaged AMC of Fig. 1a, de-embedded up to the antenna metallization layer. We observe a broadband AMC behavior, quantified by $\mathrm{Re}\{S_{11}(f)\} \geq 0$, ranging from 46-58 GHz. According to the design rules in [1], an appropriately designed dipole antenna printed on this material will radiate and can have excellent matching in the frequency band starting from the AMC peak (~52 GHz) and up to at least the frequency where $\mathrm{Re}\{S_{11}(f_0)\} = \mathrm{Im}\{S_{11}(f_0)\}$(~66 GHz). This on-package spiral AMC has a total thickness of λ/20, where λ is the wavelength in air at the AMC peak of 52 GHz. Hence it is appropriately thin for package integration.

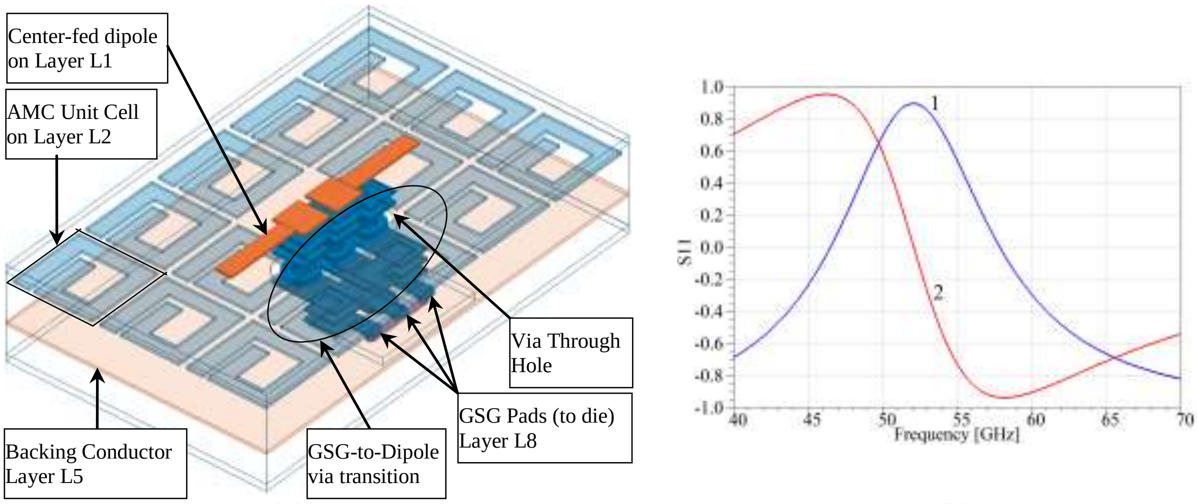
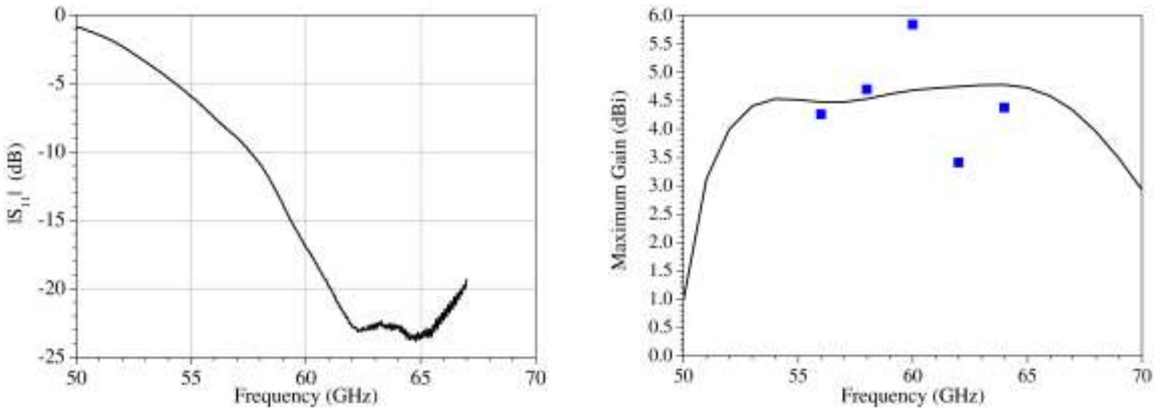


***Fig.1**. (a) 3D view of on-package spiral AMC dipole antenna. AMC UC size: 0.55×0.55 mm^2. System size: 1.65×2.75 mm^2. (b) AMC complex reflection coefficient* $S_{11} = [1] + j[2]$.

Let us now briefly describe our measurement set-up. Since the antenna operates at V band and has a coplanar differential feed we used a contact GSG 50-Ohm probe to feed it on the opposite side from where radiation occurs. To land the probe we clearly cannot use a traditional probe station set up where the sample is normally placed on a metal chuck for the measurement as that would block its radiation and corrupt the antenna return loss as well. To overcome these difficulties a dedicated system was designed. The system consists of a probe positioner mounted on a large plexiglass plate where a square hole in the center of the plate is used to support the antenna leaving free its radiating side. Probing is done on the back side (with respect to the radiation), therefore the antenna is free to radiate downward during probing. The system is mounted on an optically isolated table for easy probing, equipped with a digital microscope. A computer-controlled rotating arm with a V band receiver moves around the antenna to collect its radiation. Antenna, probe and receiver antenna can be rotated by 90° individually, to allow collecting four radiation patterns at each frequency (E-plane, H-plane, Co-pol and Cross-pol). A conical horn having 21dB gain is used to calibrate the system and extract the absolute gain information of our antenna.

In Fig. 2a we show the measured return loss of the system of Fig. 1a. The antenna is quite broadband, with excellent matching and a -10 dB matching band extending from 57 GHz up to well above 67 GHz (maximum frequency of our analyzer), by far exceeding the 60-GHz radio application range (57-66 GHz). Fig. 2b shows the maximum antenna gain above the dipole center, versus frequency. Simulations and measurements are in good agreement and the maximum measured gain averages to 5dBi, showing a directive compact antenna.



(a) (b)

***Fig.2**. (a) Measured return loss of the system of Fig. 1a. (b) HFSS simulations (solid curve) and measurements (discrete points) of the maximum gain.*

In conclusion, we presented the design and measurements of a novel antenna and spiral AMC system integrated on-package appropriate for on-chip 60 GHz radio transceivers. A single-element shows measured gain of about 5 dBi and impedance bandwidth far greater than needed for these applications. The overall on-package system size is quite small, at 1.65×2.75 mm^2, making this system very promising for on-package array implementations, for 60 GHz radio applications.

PROJECT OUTPUT in 2012

Publications in International Refereed Journals

1. *Space-Frequency projection of Planar AMCs on integrated antennas for 60 GHz radios,*
   C. Kyriazidou, H. Contopanagos and N. Alexopoulos, IEEE Transactions on Antennas and Propagation, Vol. 60, No. 4 (April 2012), pp. 1899-1909.

Published Conference Proceedings

1. *Planar Spiral AMCs integrated on 60 GHz Antennas,*
   H. Contopanagos, C. Kyriazidou, F. De Flaviis and N. Alexopoulos, IEEE Antennas and Propagation Society Intl. Symposium Digest, Chicago, IL, USA, 8-14 July 2012, pp.1-2.