Gain Enhancement of On-Chip Antenna at 60 GHz Using an Artificial Magnetic Conductor

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***Abstract*— Wireless data communication within and between CMOS chips at 60GHz is very attractive for short range wireless transmission. The objective of the work is to enhance antenna gain and improve the radiation efficiency with the use of the Jerusalem-Cross Artificial Magnetic Conductor (AMC) to mitigate the effects of the silicon and improve data transmission within and between chips. The Yagi is optimized for an endfire radiation in the plane of the chip. Its performance is studied when it is placed in the center of the chip and along the edge, with the AMC layer extending only below the feed system and then compared when it extends over the entire chip. The results show that the AMC layer improves the gain by 2.5 dB and radiation efficiency by a few percent. All simulations are performed using ANSYS HFSS.**

Keywords—Artificial Magnetic Conductor (AMC), Jerusalem Cross, Yagi antenna

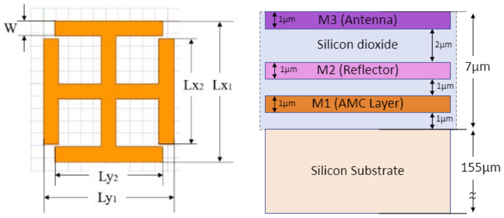
I. INTRODUCTION

The motivation for this work comes from the increased demand for short range high frequency data communication within and between integrated circuit (IC) chips. This has been accomplished at 60GHz with the use of directional antennas placed in the top metal layer of a CMOS stack-up. These antennas have very low radiation efficiency caused by the silicon substrate beneath the antennas. The silicon substrate has a high permittivity and a low resistivity which distorts the radiation pattern of the antenna, thus reducing the gain, directivity and the overall radiation efficiency.

The objective for this work is to improve the radiation efficiency of a directional antenna in a CMOS stack-up It is known that a Frequency Selective Surface (FSS) placed in SiO_2, between the antenna and the silicon substrate improves the radiation efficiency and antenna gain [2]. In the present work, a Jerusalem Cross AMC layer is designed and optimized for zero phase of S11 at 60 GHz. A Yagi antenna is designed [2] to have a good directional beam in the plane of the chip. The antenna performance is studied when it is placed in the center of the chip and along the edge, with the AMC layer extending only below the feed system and then compared when it extends over the entire chip.Artificial Magnetic Conductor Design

A. Unit Cell Design

The AMC unit cell was designed using HFSS. Using equations from [1] the AMC unit cell shown in Fig. 1 was optimized to have a 0 degree phase at 60GHz. The AMC unit cell dimensions are: $L_{x1} = 56.5\mu m$, $L_{x2} = 42.5\mu m$, $L_{y1} = 52.5\mu m$ $L_{y2} = 43.5\mu m$, $W = 5\mu m$.



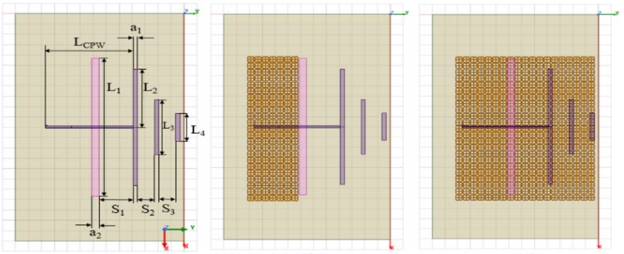
(a) (b)

Fig. 1. (a) AMC Unit Cell Dimensions (b) Cross section of Chip stackup

II. YAGI ANTENNA ON SMALL SUBSTRATE

A. Antenna Design

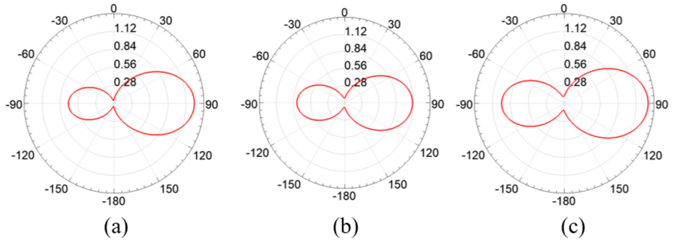
The Yagi antenna is optimized on a substrate just large enough to fit the antenna, 1.3 × 2.2 mm^2 to limit the effect of the silicon. The antenna was fed with a coplanar waveguide (CPW), and was composed of a driven element and two directors in the top metal layer, and one reflector 2µm below. The antenna design and dimensions are shown in Fig. 3(a). They are as follows: $L_1 = 1334.31\mu m$, $L_2 = 563\mu m$, $L_3 = 533.68\ \mu m$, $L_4 = 266.84\mu m$, $S_1 = 261.12\mu m$, $S_2 = S_3 = 131.5\mu m$, $a_1 = 32.54\mu m$, $a_2 = 58.7\mu m$, $L_{CPW} = 676.5\mu m$, $S_{CPW} = 1\mu m$, $W_{CPW} = 10\mu m$. Where S_{CPW} is the spacing between the CPW lines and W_{CPW} is the width of each CPW line.



(a) (b) (c)

Fig. 2. Yagi Antenna (a) without the AMC layer (b) with the AMC layer under the feed system, (c) with a AMC layer over entire chip

Fig. 3 shows the radiation patterns of the three configurations in Fig. 2 where gain enhancement is seen.



(a) (b) (c)

Fig. 3. 2D Radiation Patterns of the Antennas shown in Fig. 2, (a) without the AMC layer, (b) with the AMC layer under the feed system, and (c) with a full AMC layer.

The Return Loss of the three configurations are shown in Fig. 3 where the antenna resonant frequency is not affected much when the AMC layer is just below the feed. The AMC over the entire chip lowers the resonant frequency to 54 GHz.

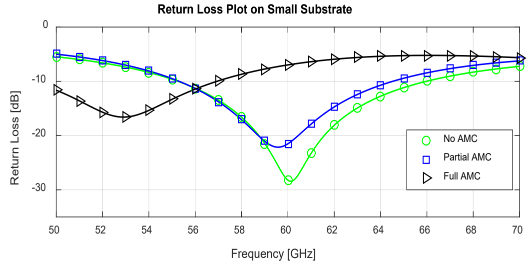


Fig. 4. Return Loss of the Yagi witoutt and with AMC

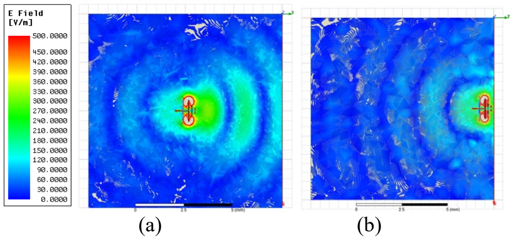
The antenna parameters from the three configurations are presented in Table 1.

Table 1: Small Substrate Antenna Parameters

	No AMC	Partial AMC	Full AMC
Gain [dB]	0.98	0.45	1.178
Radiation Efficiency	54%	56%	69%

III. YAGI ANTENNA ON LARGE SUBSTRATE

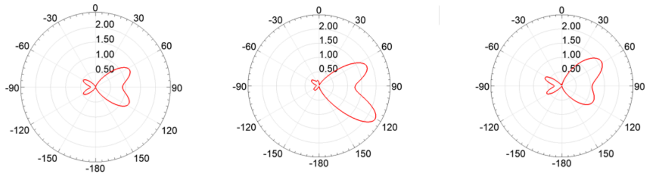
To test the effect of the silicon, substrate is extended to 10mm by 10mm. The Yagi antenna is placed in the center of the substrate, then at the edge of the substrate, Fig. 5 shows the two orientations with the electric field magnitudes displayed.



(a) (b)

Fig. 5. E field for Yagi in 10 × 10mm^2 Substrate (a) Antenna in the center (b) Antenna at the edge

Both of the configurations shown in Fig. 5 were simulated with the AMC layer under the feed system and without the AMC layer. The radiation patterns for the configuration in Fig. 5(a) with and without AMC layer ar shown in Fig. 6.



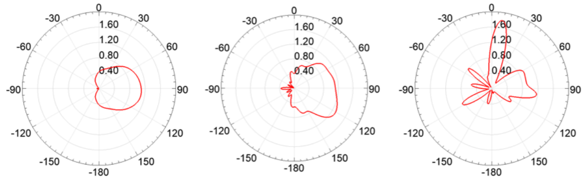
(a) (b) (c)

Fig. 6. 2D Radiation Patterns of the Antennas shown in Fig. 5 (a), (a) without the AMC layer, (b) with the AMC layer under the feed system, and (c) with a full AMC layer.

Table 2: Antenna Parameters for the Center Configuration

	No AMC	Partial AMC	Full AMC
Gain [dB]	1.04	3.59	2.12
Radiation Efficiency	27%	33%	33%

The radiation patterns for the configuration in Fig. 5(a) with and without AMC layer.



(a) (b) (c)

Fig. 7. 2D Radiation Patterns of the Antennas shown in Fig. 5 (b), (a) without the AMC layer, (b) with the AMC layer under the feed system, and (c) with a full AMC layer.

The gain and radiation efficiency of this antenna have improved. The antenna parameters are shown in Table 3.

Table 3: Antenna Parameters for the Edge Configuration

	No AMC	Partial AMC	Full AMC
Gain [dB]	0.43	1.27	2.92
Radiation Efficiency	49%	51%	46%

IV. CONCLUSIONS

The Jerusalem-Cross Artificial Magnetic Conductor (AMC) is designed and implemented to improve the gain of a Yagi antenna in a chip. Its performance is studied when it is placed in the center of the chip and along the edge, with the AMC layer extending only below the feed system and then compared when it extends over the entire chip. The results show that the AMC layer improves the gain by 2.5 dB and radiation efficiency by a few percent.

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