

PCB-Embedded Antenna for 80 GHz Chip-to-Chip Communication

Jae-Young Chung^{1,*} · Wonbin Hong² · Kwang-hyun Baek² · Young-ju Lee²

Abstract

We propose a printed circuit board (PCB)-embedded antenna for millimeter-wave chip-to-chip communication. The antenna is 0.18 mm in height which is $1/20$ wavelength at 80 GHz. In order to realize such a low profile, a zeroth-order resonator antenna with a periodic array of four unit cells is employed, and its geometry is optimized to cover an 8-GHz bandwidth from 76 to 84 GHz. With this, the antenna is capable of radiating in a direction parallel to the board length despite the short distance between the ground and the radiator. Simulation and measurement results show that the optimized design has low reflection coefficients and consistent radiation patterns throughout the target bandwidth.

Key Words: Antenna, Millimeter-Wave, Printed Circuit Board, Zeroth-Order Resonance.

I. INTRODUCTION

The demand for multi-gigabit data transfer over a wireless link is expediting the advent of millimeter-wave applications (30 to 300 GHz) [1]. In virtue of a shorter wavelength compared to the microwave frequency, a much broader bandwidth can be obtained with physically smaller electronic components, such as waveguides, cavities, and antennas. One promising application utilizing the millimeter-wave band is chip-to-chip communication [2]. A wireless link between electronic chips may reduce the portion of wired connections, for instance, bonding wires, ball grids, and printed circuit board (PCB) traces, resulting in better manufacturability and less dissipation loss in high data rate communication.

In this letter, we report a novel PCB-embedded antenna for millimeter-wave chip-to-chip communication. The antenna is designed to operate in the frequency band of 76 to

84 GHz and to radiate horizontally to the PCB surface. It is extremely low profile as the height of the antenna is only 0.18 mm, which is 0.05λ at 80 GHz. Such a close distance from the antenna radiator to the ground restricts the radiation of electromagnetic energy vertically to the PCB surface. In order to avoid this undesirable effect, antennas are often lifted off the ground or have a fill cut on the ground to direct the energy horizontally to the PCB surface [3]. There is no fill cut in our design; instead we utilize a special radiation mode originating from the zeroth-order resonance (ZOR). The ZOR antenna is known to provide a monopole-like radiation pattern despite its low profile [4, 5]. The drawback is the narrow bandwidth, which is typically 3% to 7%. In the proposed design, the feed and unit cells are properly arranged to improve the bandwidth up to 10%. Furthermore, a unique butterfly-like radiation pattern is successfully generated throughout the target bandwidth.

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¹Department of Electrical & Information Engineering, Seoul National University of Science & Technology, Seoul, Korea.

²Samsung Electronics, Suwon, Korea.

*Corresponding Author: Jae-Young Chung (e-mail: jychung@seoultech.ac.kr)

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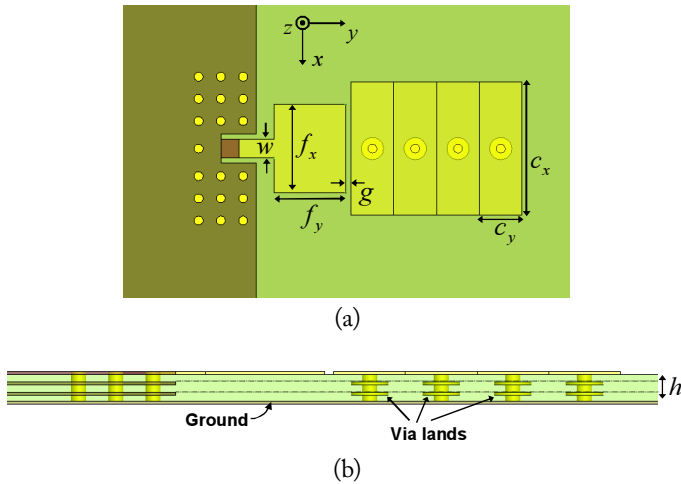


Fig. 1. Geometry of the proposed antenna. (a) Top view, (b) side view.

II. ANTENNA DESIGN

Fig. 1 depicts the top and side view of the proposed antenna. As mentioned, the antenna height is restricted to $h = 0.18$ mm, implying the antenna is embedded in the top three layers of a conventional 10-layer PCB. As in Fig. 1(a), a periodic array of four unit cells is employed as the ZOR radiator to generate both the zeroth- and first-order modes in the target frequency band. Each unit cell consists of a rectangular patch and via connecting to the ground. The antenna feed is composed of a coplanar waveguide and a fat stub. The latter plays a role as a matching circuit responsible for a smooth transition in the bandwidth of 76 to 84 GHz. The side view, Fig. 1(b), shows that the via lands stay in the design as they are not electrically small at 80 GHz, thus significantly affecting the resonance frequency and bandwidth of the antenna. The diameter of the via land provided by the PCB manufacturer is 0.25 mm.

Parametric studies based on a full-wave simulation tool (Ansys high-frequency structure simulator [HFSS]) show that the antenna resonance frequency and bandwidth can be tuned by the parameters c_x , c_y , f_x , f_y , w , and g (see Fig. 1). Among them, g , the gap between the stub and the first unit cell, is the most critical parameter for the bandwidth. Fig. 2 shows the change in the simulated reflection coefficients (S_{11}) by varying g . As observed, the bandwidth increases as g decreases from 0.1 to 0.06 mm at the expense of poor matching. With $g = 0.08$ mm, the $S_{11} < -10$ dB bandwidth spans from 75.4 to 84.2 GHz covering the target 8 GHz bandwidth.

The optimized antenna design is carried out with $c_x = 1.5$, $c_y = 0.47$, $f_x = 1.2$, $f_y = 0.8$, $w = 0.21$, and $g = 0.08$ mm. Based on these values, a prototype is fabricated on the top three layers of a 10-layer FR4 PCB with a dielectric constant of $\epsilon_r = 4.6$ and a loss tangent of $\tan \delta = 0.019$. The coplanar feed of the fabricated antenna is probed with a ground-signal-ground (GSG) probe, and then the S_{11} is col-

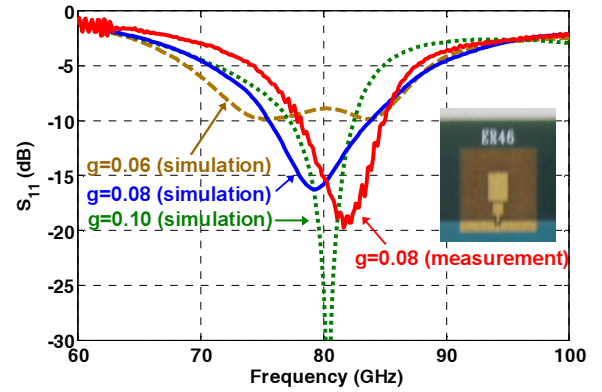


Fig. 2. Simulated and measured S_{11} of the antenna (inset is the fabricated antenna).

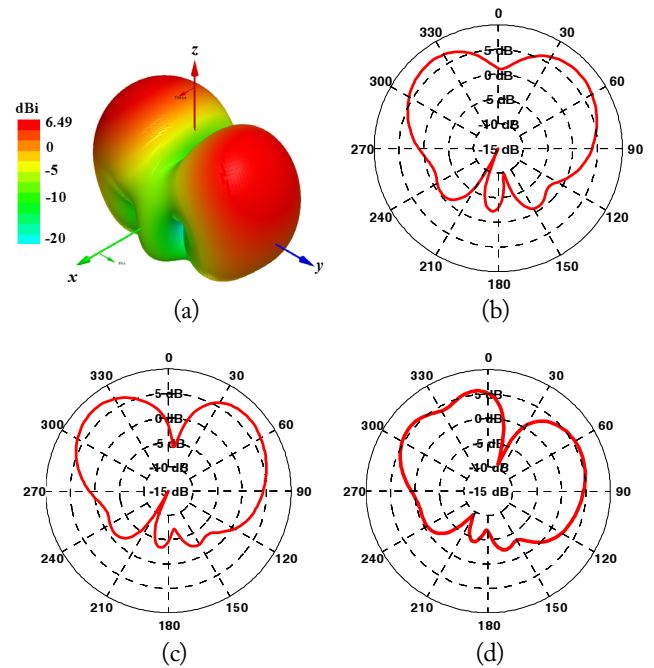


Fig. 3. Butterfly-like radiation patterns of the antenna. (a) 3D pattern at 80 GHz, (b) yz-cut at 76 GHz, (c) yz-cut at 80 GHz, and (d) yz-cut at 84 GHz.

lected using a network analyzer. Fig. 2 shows the measured S_{11} on top of the simulation data. They are in good agreement except that the resonance frequency of the measured data is about 2 GHz higher than that of the simulation. This may be due to the discrepancy in the FR4 dielectric constant. A further study shows that the difference significantly decreases by assigning $\epsilon_r = 4.4$ instead of 4.6 in the simulation.

Fig. 3(a) depicts the simulated three-dimensional (3D) radiation pattern of the optimized design at 80 GHz. A "butterfly-like" radiation pattern is observed. This unique pattern originates from the combination of two different radiation modes: the zeroth- and first-order modes. They exhibit a monopole-like and patch-like radiation pattern, respectively. Their combination makes a null not only in the z -di-

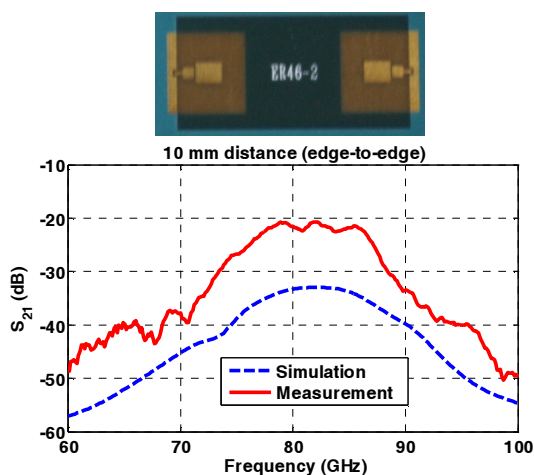


Fig. 4. Simulated and measured S_{21} .

rection but also in the x-direction, resulting in the butterfly-like radiation pattern. Successive 2D plots in Fig. 3(b)–(d) refer to the yz-cut of the radiation pattern at 76, 80, and 84 GHz, respectively. As can be seen, the butterfly-like pattern remains throughout the bandwidth in that the proposed antenna not only provides a consistent matching condition but also a radiation pattern. Note that the butterfly-like radiation pattern is somewhat deformed at 84 GHz, implying the first-order mode starts to become dominant over the zeroth-order mode. Although a maximum gain of 6.5 dBi occurs at $\theta = 60^\circ$ (30° off from the PCB surface), an average of 2.6 dBi gain is provided in the direction of $\theta = 90^\circ$ (horizontal to the PCB surface). Note that the realized gain, including the mismatch, is around 1.7 to 2.7 dBi in the range of 76 to 84 GHz. The radiation efficiency is around 68% to 72%.

Having verified that the proposed antenna successfully delivers the radiated energy alongside the PCB surface, we proceed to measure the transmission coefficient (S_{21}) between two antennas. Fig. 4 shows the fabricated test configuration together with the simulation and measurement results of S_{21} . The two antennas face each other with an edge-to-edge distance of 10 mm. Based on a link budget analysis, $S_{21} > -40$ dB guarantees reliable chip-to-chip communication over a 10-mm range. As observed in the figure, the simulated S_{21} ranges from -36.6 to -32.9 dB at 76 to 84 GHz, satisfying the above requirement. The measured data exhibit a similar trend as the simulation but with a much higher S_{21} value, from -25.3 to -20.8 dB. The reason for this 10-dB differ-

ence is that the GSG probe mount behind the antenna feed acts as a reflector, therefore, the backward radiation adds up to the forward radiation.

III. CONCLUSIONS

A millimeter-wave PCB-embedded antenna is presented for use in chip-to-chip communication. A metamaterial-inspired ZOR antenna design technique is employed to avoid radiation vertically to the ground while keeping the antenna at an extremely low profile. Simulation and measurement results demonstrated that more than 10% of the bandwidth can be covered by optimizing the microstrip stub feeding section. It further provides a distinctive butterfly-like radiation pattern suitable for wireless communication along the PCB surface.

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REFERENCES

- [1] J. Wells, "Faster than fiber: the future of multi-Gb/s wireless," *IEEE Microwave Magazine*, vol. 10, no. 3, pp. 104–112, May 2009.
- [2] K. Kawasaki, Y. Akiyama, K. Komori, M. Uno, H. Takeuchi, T. Itagaki, Y. Hino, Y. Kawasaki, K. Ito, and A. Hajimiri, "A millimeter-wave intra-connect solution," *IEEE Journal of Solid-State Circuits*, vol. 45, no. 12, pp. 2655–2666, Dec. 2010.
- [3] A. L. Amadjikpe, D. Choudhury, C. E. Patterson, B. Lacroix, G. E. Ponchak, and J. Papapolymerou, "Integrated 60-GHz antenna on multilayer organic package with broadside and end-fire radiation," *IEEE Transactions on Microwave Theory and Techniques*, vol. 61, no. 1, pp. 303–315, Jan. 2013.
- [4] A. Lai, K. M. Leong, and T. Itoh, "Infinite wavelength resonant antennas with monopolar radiation pattern based on periodic structures," *IEEE Transactions on Antennas and Propagation*, vol. 55, no. 3, pp. 868–876, Mar. 2007.
- [5] Y. K. Jung and B. Lee, "Compact metamaterial-based tunable zeroth-order resonant antenna with chip variable capacitor," *Journal of Electromagnetic Engineering and Science*, vol. 13, no. 3, pp. 189–191, Sep. 2013.