Fabrication Tolerance Analysis of a 60GHz Stacked Circular Patch Antenna Based on LTCC technology

[#]Woojin Byun, B.-S Kim, K.-S Kim, M.-S Kang and M.-Sun Song
Advanced Radio Technology Department, Electronics and Telecommunications Research Institute, 138 Gajeong-no, Yuseong-Gu, Daejeon, 305-350, KOREA, wjbyun@etri.re.kr

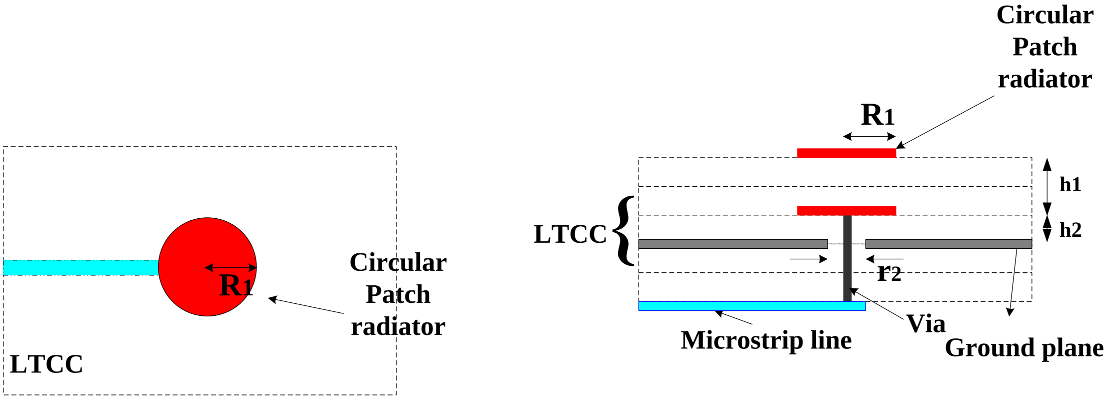
1. Introduction

Recently a lot of applications in the millimeter (mm) wave band such as point-to-point communications at 70 to 80GHz, car radar at 77GHz and image sensor at 94GHz, are in service. Furthermore since the FCC has assigned 57~64GHz of unlicensed frequency for wireless applications, there have been standard organization activities such as IEEE 802.15.3c and 802.11 VHT for mm-wave short-range applications with a goal to transmit a few Gbps multimedia data[1]. There have been widespread trend toward higher levels of integration to reduce cost, size and complexity. Low temperature co-fired ceramic (LTCC) technology is one of several candidates for mm-wave system in a packaging solution. It can be operated over 60GHz (low dielectric loss) and has flexibility in realizing module with easy-to-integrate circuit components like via-holes and cavity-buried components. Therefore one may expect mm-wave based products shall be commercialized within a few years with the advances of process technologies and low cost integration circuit design technologies such as Si CMOS and LTCC packaging. In general, high gain antennas such as a switched beam-forming or phased array antenna due to the relatively high free space path loss at mm-wave band [2] should be used in order to secure communication distance for WPAN applications and widen beam coverage. However, these kinds of antennas are very expensive and difficult to implement. On the contrary if the communication distance is more limited within 1~2m, an omni-directional antenna will also become one of the candidates for the WPAN application like several Gbps data transfer in between PC and an external hard disk [3] due to its extremely low cost. Previously we proposed a TM_{01} mode excited stacked circular patch antenna using LTCC substrates [4]. The antenna was fed by a microstrip transmission line through a signal via and showed the radiation pattern similar to that of a monopole type antenna. Simulated and measured results were shown, but working mechanism of the proposed structure is not shown and explained. In addition there were some mismatches in between those results due to LTCC manufacturing tolerances.

In this paper, working mechanism of the proposed antenna is explained with simulation results and mode field patterns are shown. And the effects of various geometrical parameters are investigated in order to determine the critical factors in designing and manufacturing of a signal via-fed stacked circular patch antenna using LTCC substrates. This design is applied to Ferro A6 LTCC substrate and manufactured at RN2 Tech Inc., Korea. Typical properties of LTCC substrate are the relative permittivity of 5.9, a loss tangent of 0.002 at 60GHz and one layer thickness of 100μm. Experiment results are compared with the simulated results after manufacturing tolerances are investigated and analyzed.

2. Simulation of a Stacked Circular Patch antenna

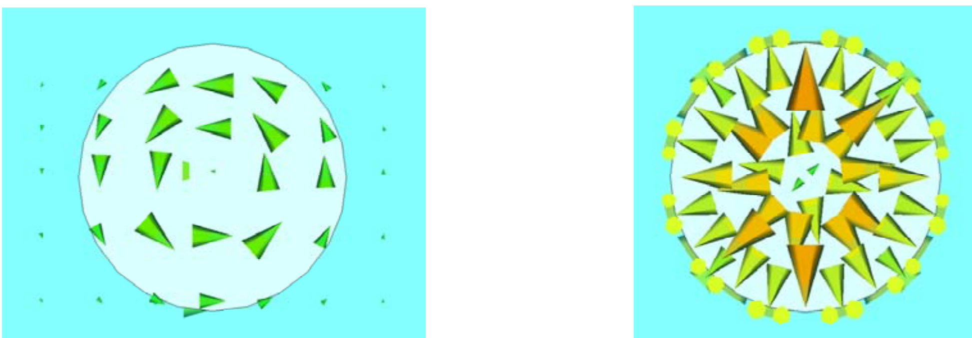
Fig. 1 shows the proposed structure of a stacked circular patch antenna. It composed of 5 dielectric layers with a total thickness of 500um. The stacked circular patch antenna consists of two circular patches. A lower patch of two circular ones is fed by a microstrip line through a signal via in a ground plane. Another upper patch is electromagnetically coupled between the two patch resonators. In general, the fundamental TM_{11} mode and the higher order TM_{21} mode of a circular microstrip resonator radiate a boresight directed beam [5]. However TM_{01} mode shows the radiation pattern similar to that of a monopole antenna. For TM_{01} mode excitation, a signal via should be connected to the center of the lower circular resonator.



(a) (b)

Figure 1: Proposed structure of stacked circular patch antenna. (a) Top view. (b) Cross-sectional view.

The TM_{01} mode resonates at a frequency between the TM_{21} and TM_{31} modes. Therefore the effective radius of the circular resonator for the TM_{01} mode is about twice the radius for the TM_{11} mode. Modelling and simulation have been carried out with a 3-dimensional electromagnetic commercial simulator, CST Microwave Studio. Fig. 2 shows TM_{01} mode field patterns of the proposed antenna such as magnetic field and surface current. As shown in Fig. 2, TM_{01} mode of the proposed structure is exactly excited and its geometrical parameters are the radii of the lower and upper circular patches, R_1=1.05mm, the diameter of the circular aperture, r_2=200um, the diameter of a via of 80um, the thicknesses of the substrate, h_1=200um and h_2=100um.



(a) (b)

Figure 2: TM_{01} mode field patterns of the proposed antenna. (a) Magnetic field. (b) Surface current.

3. Fabrication and Tolerance Analysis

In LTCC processes, the LTCC dielectric tape is first cut into blanks for each of the layers. The vias are punched in these blanks and filled with conductive ink. And screen printing of the conductors is followed and the printed blanks are collated, laminated and then co-fired. In order to determine the critical factors in designing and manufacturing of the signal via-fed stacked circular patch antenna using LTCC substrates, the effects of various geometrical parameters are investigated. Two of the most important mechanisms are related to both misalignment between the via positions and shrinkage of the printed conductor.

3.1 Misalignment of a Signal Via

As the first parameter, the positions of a signal via are changed to consider the effects of misalignments of LTCC process. A signal via consists of three metallic vias at each layer. The positions of a signal via by ‘dx’ and ‘dy’ at xy-plane are simultaneously shifted. As shown in Fig. 3, input matching performance becomes severely degraded comparing with original simulation result due to the position of a signal via shifted.

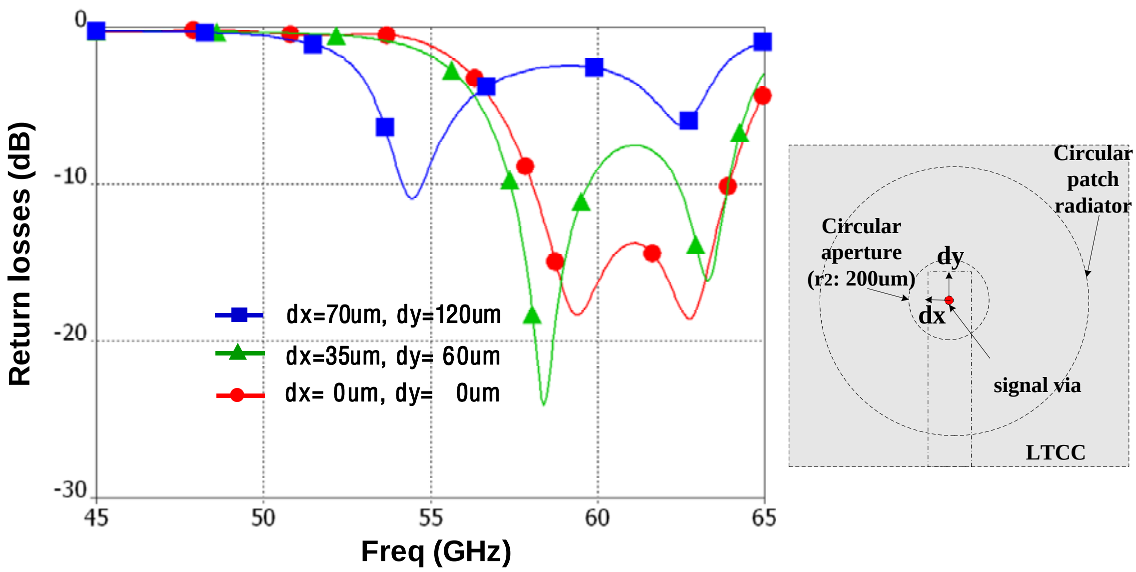


Figure 3: Variations of return losses vs. the shift of a signal via.

3.2 Shrinkage of a Stacked Circular Patches

As the second parameter, radius of two stacked circular patches is changed to consider a shrinkage error of LTCC process. Resonance frequency of the circular stacked patch antenna goes up as radius is decreased and input matching performance also becomes degraded.

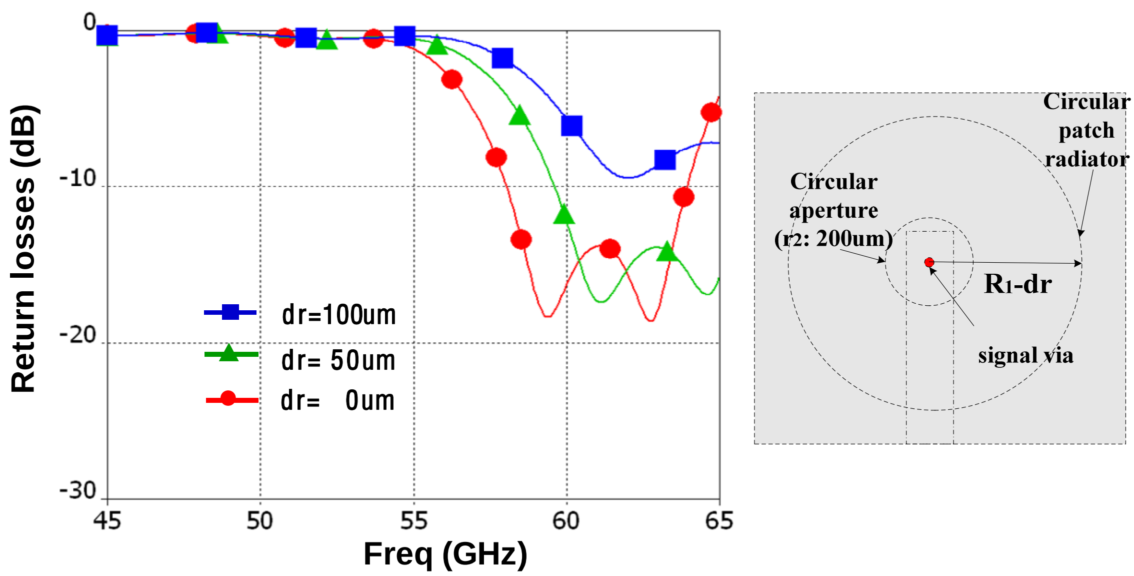


Figure 4: Variations of return losses vs. the shrunk size of circular patches.

3.3 Comparison of Simulated and Measured Results

Two parameters, that is, radii of two circular patches and the position of a signal via are simultaneously changed. From Fig. 5, variations of simulated return losses are compared with measured results. Measured result shows good agreement with simulated results of the stacked circular patch antenna with parameter dx=17um, dy=30um and dr=50um.

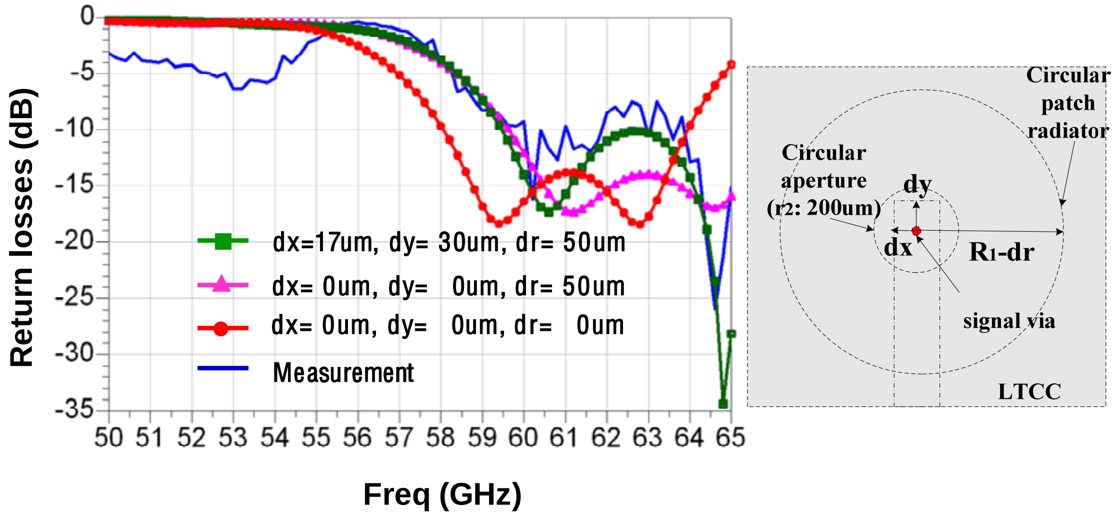


Figure 5: Variations of return losses vs. the shift of a signal via and the shrunk size of circular patches.

4. Conclusion

The shifted position of a signal via due to misalignment and shrinkage of the printed conductor are the critical factors to have an effect on the electrical performances of the stacked circular patch antenna. Besides these factors, the variations of dielectric thickness due to shrinkage and the relative dielectric permittivity should be also considered to check the fabrication tolerances.

Acknowledgments

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