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CPW-TO-STRIPLINE VERTICAL VIA TRANSITIONS FOR 60 GHZ LTCC SOP APPLICATIONS

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Abstract—In this work, CPW-to-stripline (SL) vertical via transitions using gradually stepped vias and embedded air cavities are presented for V-band LTCC System-on-Package (SoP) applications. In order to reduce radiation loss due to abrupt via discontinuities, gradual via transitions are proposed and investigated. In addition, in order to reduce increased parasitic shunt capacitance due to stepped via structures, air cavities are embedded below the transition vias. Using a 3-D EM simulation tool, the proposed transitions are designed and analyzed, compared to the conventional transition. Three-segment transmission lines (CPW-SL-CPW) in 7-layer LTCC dielectrics were fabricated and measured. The two stepped via (STV2) transition embedding air cavities shows an insertion and return losses of 1.6 dB and below −10 dB, respectively, over 60 GHz. The transition loss per one STV2 transition is 0.7 dB at 60 GHz.

1. INTRODUCTION

Recently, various wireless communication systems for mm-wave video transmission, wireless-LANs, and wireless Ethernet applications have been constantly proposed and developed [1–4]. In order to implement these systems commercially, technologies for compact and low-cost radio systems are indispensable. The low temperature ceramic co-firing (LTCC) based SoP approach is one of the most promising solutions for integration of the radio system due to its multi-layer integration capability, excellent metal conductivity, low-loss characteristics, and a temperature coefficient of expansion (TCE) close to semiconductors.

For the three dimensional (3-D) integration of mm-wave radio systems, several vertical transitions such as CPW-to-stripline (SL) transition [5, 6], microstrip-to-SL transition [7, 8] and CPW-to-CPW transition [5, 9] are required. These transitions allow the integration of passive and active circuits to be placed in inner layers or mounted on the top layer. Therefore, various interesting methods for the improvement of their RF performance have been presented. They are roughly divided into two categories: impedance matching [6, 7, 9] and parasitic compensation [5, 6]. In order to match the transition impedance, the coaxial-like transition [7, 9] and intermediate ground planes [6] have been investigated. And also, various attempts were tried for reduction of the capacitive effect in the transition region [7] or the inductive effect of vertical vias [6]. However, if the total height of the vertical vias connected in a row is more than one tenth of the wavelength in the mm-wave frequencies, their physical discontinuities can generate a significant amount of radiation as well as reflection.

In this work, CPW-to-SL vertical via transitions using gradually stepped vias and embedded air cavities are presented. The stepped vias are devised for reduction of their structural discontinuities and the embedded air cavities are designed for compensation of the increased shunt capacitive effect of the proposed stepped vias. Transitions are designed in back-to-back configuration and analyzed using a 3-D Finite Integration Technique (FIT) simulator [10] and they are implemented using a 7-layer LTCC dielectric.

2. DESIGN AND ANALYSIS OF CPW-TO-STRIPLINE VERTICAL VIA TRANSITIONS

2.1. Structures of the Vertical Transitions

CPWs and SLs have been used for signal lines and embedded devices, respectively, for the 3-D system integration because they have low-radiation and high-isolation characteristics. The CPW is insensible to interference from several higher surface modes because its ground planes are on the same layer as the signal line. The SL is principally used for miniaturization of passive circuits through vertical deployment of their elements, because it is basically a buried structure, its radiation and dispersion are negligible. However, embedded passive devices based on the SL require vertical via transition for 3-D interconnection with other circuits or in/output ports.

Figure 1(a) shows a cross-sectional structure of the conventional CPW-to-SL vertical via transition in a 7-layer LTCC substrate. The total height of the vertical vias in the transition region is $300\,\mu$m. The wavelength (λ) on the LTCC CPW with a relative dielectric constant of 7.0 is 2.56 mm at 60 GHz. Therefore, the rate of the vertical transition to λ is 11% at 60 GHz. It roughly accounts for the degree of the discontinuity. As a result, radiation and reflection can be induced by the physical discontinuity of the vias. In this work, in order to reduce the physical discontinuity, the directly stacked vias are subdivided into small-length elements relative to the wavelength as shown in Fig. 1(b) and (c). Fig. 1(b) and (c) show one and two stepped vertical via transition (STV1 and STV2), respectively. Therefore, the critical dimension, which primarily influences the discontinuity, is decreased from 300 to 200 and 100 μm for the STV1 and STV2, respectively. However, the stepped vias lead to the increase of the shunt capacitance between the vias and SL ground planes. For reduction of the increased shunt capacitance, the embedded air cavities are inserted below the stepped vias.

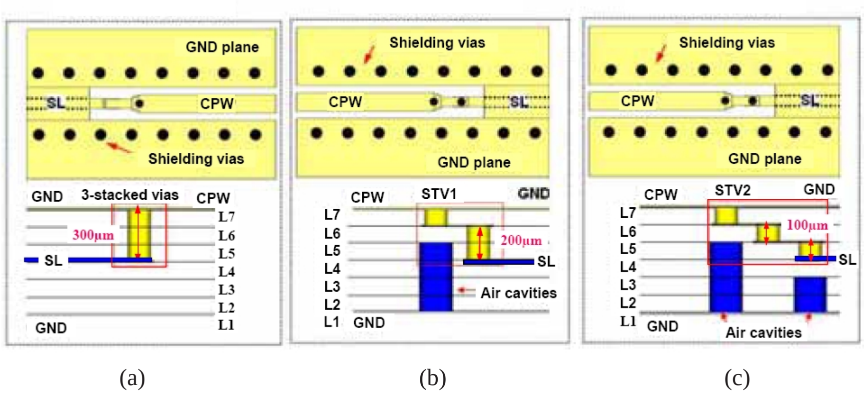

Figure 1. Cross-sectional structures of the CPW-to-SL vertical via transitions. (a) the conventional transition, (b) the novel one-STV1, and (c) the novel one-STV2 (Lx: the number of LTCC layers).

2.2. Design of the Vertical Transitions

For evaluation of the proposed vertical transitions compared to the conventional one, three-segment transmission lines (CPW-SL-CPW) have been designed in back-to-back configuration using the transitions. The ground planes of the CPWs and SL are connected by shielding vias. The STV1 and 2 structures consist of the stepped vias through the 5th and 7th layer. The height and diameter of signal vias are 100 and 135 μm, respectively, and they are connected through lines of 100 μm wide. The CPWs are placed on the top layer, and the SL is placed on the 4th layer. In order to maintain the characteristic impedance of 50 Ω for both CPWs and the SL, the width and gap of the CPWs are 250 and 99 μm, respectively, and the SL is 135 μm in width. The air cavities for the STV1 and the STV2 are inserted through the 2nd to 5th layer below the 7th layer via. In addition, they are embedded through the 2nd to 3rd layer below the 5th layer via for the STV2. In the case of the conventional case, two CPW lines of 526 μm are connected at the both ends of the stripline of 2,650 μm. In the case of STV1 and STV2, two CPW lines of 1003 and 526 μm, respectively, are connected at the both end of the SL of 2,050 μm.

2.3. Calculated Results

Figure 2 presents simulated S21 and S22 of the CPW-SL-CPW using the STV1 and STV2 transitions compared to the conventional ones. The proposed transitions, STV1 and STV2, show better S22 and S21 characteristics than the conventional ones. These results come from the reduction of via discontinuity. As the directly stacked vias of 300 μm in the vertical transition region are subdivided into the small elements of 200 and 100 μm for the STV1 and STV2, respectively, their rate of the critical dimension to λ is decreased to 7.8% and 3.9%, respectively, and the structural discontinuities of the vertical via transitions are improved. In the case of the transitions, poles of their S22 shift a little to higher frequencies, due to their increased inductance and shunt capacitance.

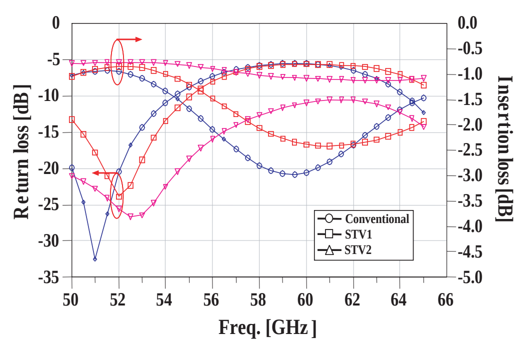

Figure 2. Calculated results of three-segment transmission lines using the conventional vertical transitions, the STV1 ones, and the STV2 ones.

Figure 3 shows simulated loss results of the CPW-SL-CPW using STV1 transitions without embedded air cavities and with their different diameters. Compared to the STV1 without embedded air cavities, all of the STV1 with them demonstrate that their integration can reduce the shunt parasitic capacitance in the vertical via transition region. Therefore, S22 and S21 characteristics are improved; as their diameter increases, an insertion and return loss decrease and it is optimized to 250 μm.

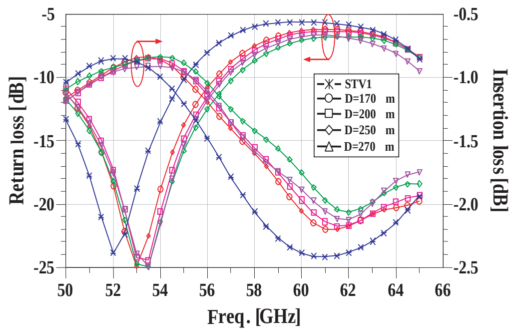

Figure 3. Calculated results of three-segment transmission lines using STV1 transitions with different diameters of embedded air cavities and without them.

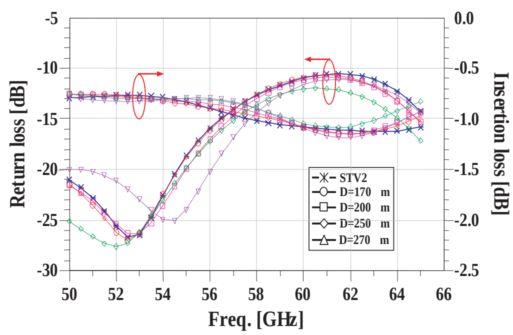

Figure 4. Calculated results of three-segment transmission lines using STV2 transitions with different diameters of embedded air cavities and without them.

Figure 4 displays calculated results of the CPW-SL-CPW using STV2 transitions with a different diameter of air cavities, compared to the transitions without them. For this experiment, the diameter of air cavities below the 7th layer vias was fixed to 170 μm and that below the 5th layer ones were changed from 170 to 270 μm. Unlike the STV1, the effect of the embedded air cavities on the transmission characteristics is very little and the improvements are slight. This result shows that the increased series inductance and shunt capacitance for the STV2 are well matched each other because of reactance cancellation.

3. FABRICATION AND MEASUREMENT

The designed three-segment transmission lines were implemented using seven LTCC dielectric layers with a dielectric constant of 7.0 at 60 GHz and its thickness between the metal layers is 100 μm. The Ag and Ag/Pd conductors were screen-printed on the unfired layers for internal and external conductors, respectively. Signal vias and air-cavities of 150 μm and 190 μm in diameter were formed through the standard mechanical punching process because the design rule between vias was 300 μm in our process, while the optimum diameter of the air cavities for the STV1 was 250 μm. For implementation of embedded air cavities, the metal filing step in punched vias was omitted. The ground planes of the CPWs and stripline are interconnected to each other using shielding vias. The spacing between ground vias (edge to edge) is 320$\sim$360 μm. Fig. 5(a) shows the fabricated CPW-SL-CPW in back-to-back configuration using CPW-to-SL vertical transitions and their cross-sectional views of the part A-A' of (a) are shown in (b) and (C), respectively, for the STV1 and the STV2. Embedded air cavities were clearly defined and no crack and depression were observed around them.

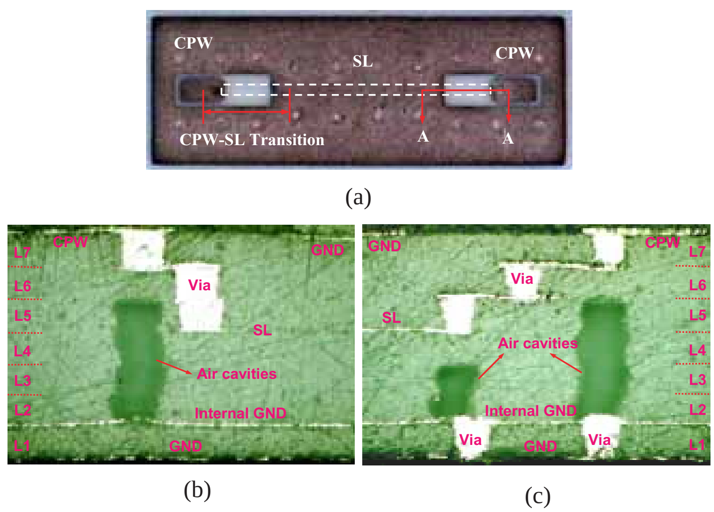

Figure 5. Fabricated CPW-SL-CPW transmission line. (a) and the cross-sectional views of the STV1, (b) and STV2 (c) with embedded air cavities.

Figure 6 presents measured S22 and S21 of the fabricated three-segment lines. As the step of the vertical via transition with embedded air cavities increase from the directly stacked vias to one and two stepped via, respectively, their characteristics are improved. In other words, as the critical height in the vertical via transition is decreased, the return loss is also improved. These results imply that a key parameter mainly impacting on the structural discontinuity is the critical dimension rather than total height of the vertical via transition. In the STV2 case, the measured S22 and S21 of the CPW-SL-CPW are less than −10 dB and −2.0 dB, respectively, from 50 to 65 GHz. In particular, its low-S21 of −1.6 dB is achieved at 60 GHz. These values represent all losses along the three-segment transmission lines and the two vertical via transitions. Considering the total loss of transmission lines with −0.19 dB, which is calculated by using a conventional line calculator, the transition loss per a STV transition is 0.7 dB at 60 GHz.

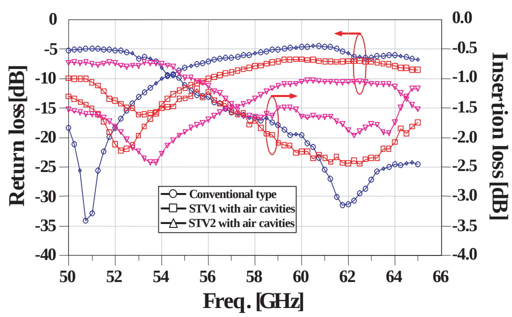

Figure 6. Measured resultss of the fabricated three-segment CPW-SL-CPW transmission lines using the STV1 and STV2 transitions and embedded air cavities in comparison with the conventional transitions.

4. CONCLUSION

We present CPW-to-SL vertical via transitions utilizing stepped via structures and embedded air cavities for V-band SoP applications and demonstrate that the STV structures and embedded air cavities reduce discontinuity and parasitic shunt capacitance of the vertical via transition through 3-D EM simulations and the measurements of three-segment transmission lines (CPW-SL-CPW) designed in back-to-back configuration. The fabricated CPW-SL-CPW using two stepped via (STV2) transitions shows an insertion loss of −1.6 dB and return losses of −10 dB at 60 GHz. Compared to the conventional ones using directly stacked vias, an insertion and return loss are improved by

0.4 dB and 5 dB, respectively. The transition loss of 0.7 dB per STV2 transition is achieved at 60 GHz.

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