Design for Electrical Performance of Wideband Multilayer LTCC microstrip-to-stripline transition

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Abstract

A high impedance compensation technique is proposed to improve the wideband performance of the microstrip–to-stripline transition for multi-layer LTCC substrate. A section of high impedance transmission line, which induces additional inductance, is added between the transition and 50 Ω transmission line to compensate the capacitance of the transition. In the paper, various lengths and widths of the high impedance transmission line are simulated by HFSS and compared to optimize the electrical performance which achieves a return loss better than 17 dB over a band from DC to 70 GHz.

Introduction

LTCC (low temperature co-fired ceramic) is suitable for multi-layer integrated circuit design with nearly arbitrary number of layers and applied a lot in microwave applications. Ceramic substrates as well as the gold and silver pastes have excellent physical and electrical properties such as good thermal conductivity, low loss tangent, high packaging flexibility and high integration density [1]. In order to build high efficiency LTCC multi-layer circuits, various well-designed transitions and interconnects are essential since their geometry may have significant effect in the performance of the system [2].

By adjusting via hole diameter and adding vias connecting upper and lower ground around, the 5-via microstrip-to-stripline transition structure is developed and optimized to reach a return loss level above 20 dB up to 20 GHz [3]. Return loss can also achieve above 24 dB up to 50 GHz when the board of small permittivity, 3.0, is used [4].

Consider the substrate with a larger relative permittivity of 7.8, as is used in the work, the capacitive effect of step discontinuity increases significantly as frequency goes higher. To overcome the parasitic effects of the transition, a wideband microstrip-to-stripline transition is provided based on the concept of high impedance compensation for the flip-chip transitions in [5]. Additional inductive effect is realized by high impedance transmission lines to compensate the excessive capacitance of the transition.

LTCC Microstrip-to-Stripline Structure

The transition of a multilayer structure connects one line at the top of the board, which is needed for surface mounting elements and one line on the inner layer. Microstrip and coplanar waveguide are mainly concerned as the former ones. On the other hand, within the LTCC structure, stripline represents an advantageous choice of buried transmission lines because radiation and dispersion are negligible and upper and lower ground provide shielding and may be used as ground for other lines. Therefore, stripline is chosen as the buried transmission line. On the premise, microstrip can be a better choice of the top line than coplanar waveguide since its ground is also upper ground of the stripline.

The LTCC consists of DuPont 951 substrate with the silver via and transmission lines inside. Each layer has a thickness of 3.1 mil and a relative permittivity of 7.8. In accordance with the LTCC process specifications, 2 ceramic layers for the microstrip and 5 ceramic layers for the stripline are chosen. This yields reasonably sized widths for 50 Ω transmission lines.

Fig. 1(a) illustrates the size and the structure of the traditional transition. Fig. 1(b) illustrates its top view and equivalent circuit where C_M and C_S denote parasitic capacitance of two sides of the transition. The compensation structure shown in Fig. 2(a) is constructed by adding a high impedance transmission line between the transition and 50 Ω transmission line, microstrip and stripline, respectively. Its top view together with equivalent circuit is shown in Fig. 2(b) where L_M and L_S denote the high impedance lines. To reduce width discontinuity between high impedance line and via, L(length)/W(width) in Fig. 2(b) are chosen as 6 mil/ 6 mil, respectively. The goal is to make the inductance of the two high impedance lines and the capacitance caused by step discontinuities match to a system impedance as close to 50 Ω as possible.

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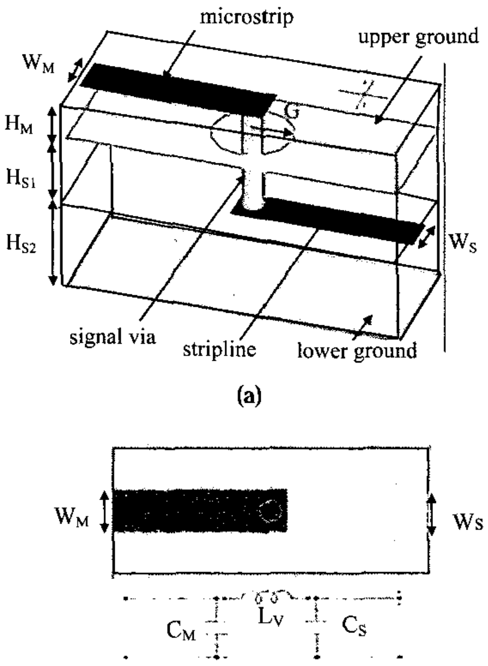

Fig. 1 Structure of the traditional microstrip-to-stripline transition: (a) 3-D view and (b) upper view and its equivalent circuit. W_M = 8mil, W_S = 7.1 mil, H_M = 6.1 mil, H_{S1} = H_{S2} = 15.31 mil, ε_γ = 7.8, G = 7mil.

High Impedance Compensation

A. Changing the gap size

The hole on the microstrip ground, also the upper ground of the stripline, causes capacitive effect. Good impedance matching can be accomplishing by adjusting the gap size G in Fig. 2(a). Five cases are simulated in Fig. 3. In the simulation, only the effect of the gap size is considered, so we don't add high impedance transmission lines. It is reasonable that a small gap, G = 3 mil, have a worst return loss than a wide gap, due to its capacitive effect between via and the microstrip ground. However, increasing gap size too much may also deteriorate return loss in the high frequency. Considering the cases of G = 6 mils and G = 7 mils, when frequency exceeds 50 GHz, their return loss can be 10dB higher than the case of G = 5 mil. We observed that a large gap affects the impedance of transmission line and causes it deviate from 50 Ω. Considering the overall return loss, the case of G = 7 mil has a small increasing rate in the frequency higher than 60 GHz, which results in a minimum overall return loss. Hence, the case of G = 7 mil is chosen for further discussions.

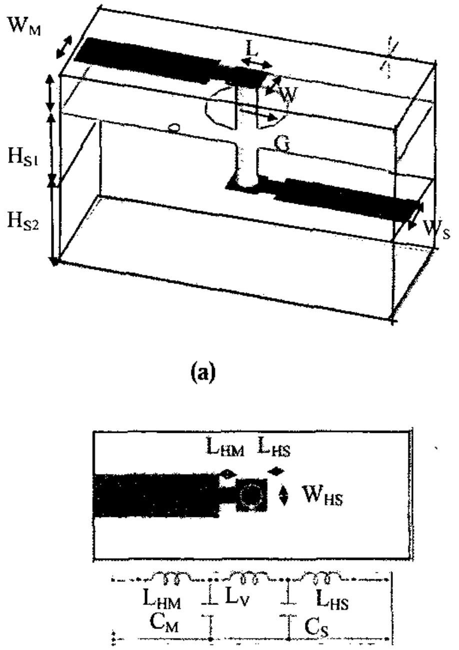

Fig. 2 Structure of the compensation microstrip-to-stripline transition: (a) 3-D view and (b) upper view and its equivalent circuit. L = 6mil, W = 6mil.

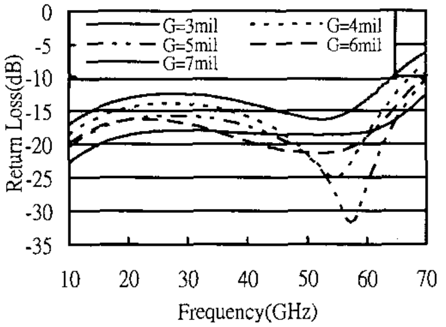

Fig. 3 Return loss versus Frequency of the high impedance compensation structure with different gap sizes G.

B. Changing the length of high impedance transmission line

The high impedance compensation structure in Fig. 2 is constructed by adding a high impedance line between the transition and the 50 Ω transmission line. Fig. 4 fixes the length of the high impedance stripline, L_{HS} as 0 and simulates return loss for different L_{HM} , length of

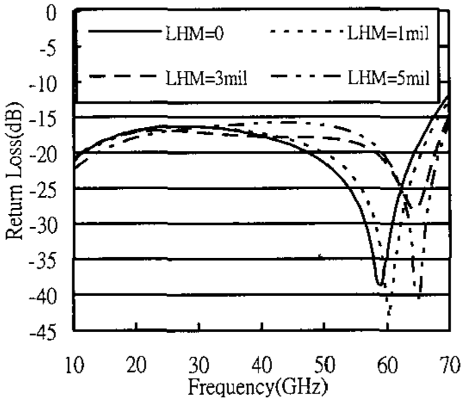

Fig. 4 Return loss versus Frequency of the high impedance compensation structure for different microstrip lengths L_{HM}.

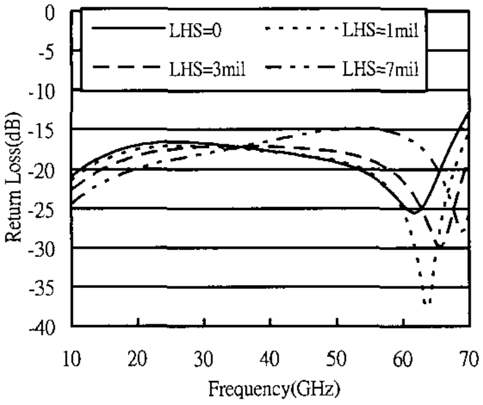

Fig. 5 Return loss versus Frequency of the high impedance compensation structure for different stripline lengths L_{HS}.

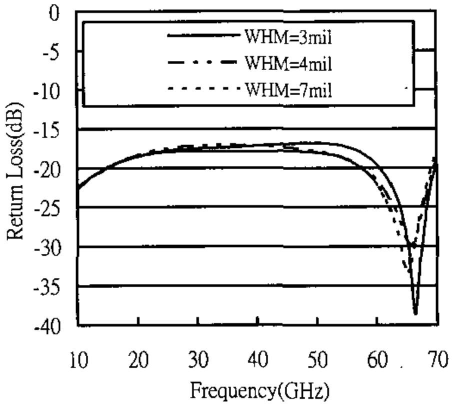

Fig. 6 Return loss versus Frequency of the high impedance compensation structure for different microstrip widths W_{HM}.

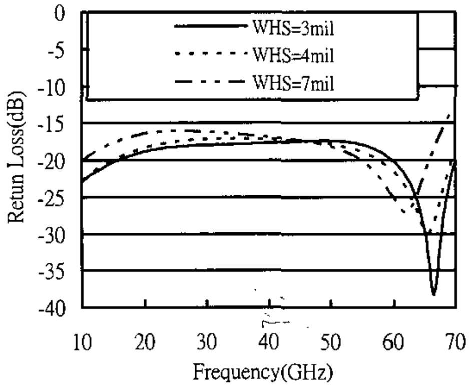

Fig. 7 Return loss versus Frequency of the high impedance compensation structure for different stripline widths W_{HS}.

the high impedance microstrip. Fig. 5 fixes the length of the high impedance microstrip, L_{HM} as 3 mil and simulates return loss for different L_{HS}, length of the high impedance stripline.

These two figures show similar tendency on the overall performance but changing L_{HS} affects performance more than changing L_{HM}. The two parameters, L_{HM} and L_{HS} have no significant effects on the return loss at low frequency since their values don't affect the impedance of the two added transmission lines. As shown in Fig. 5, long transmission line compensates return loss in the range of DC to 40GHz, but it deteriorates return loss in the range of 40 GHz to 60 GHz. It is noted that the zero frequency, which corresponds to the dip in the return loss, goes higher as L_{HM} or L_{HS} increases. This causes better performance of return loss at 70 GHz when larger L_{HM} and L_{HS} is used. To consider the overall performance, lengths of the two high impedance transmission lines, L_{HM} = 3mil and L_{HS} = 3mil are chosen since they reduce return loss at 70 GHz as well as low frequency, and still keep return loss better than 17 dB in the frequency range 40 GHz to 60 GHz.

C. Changing the width of high impedance transmission line

Fig. 6 fixes the width of the high impedance stripline, W_{HS} as 4 mil and simulates return loss for different W_{HM}, width of the high impedance microstrip. Fig. 7 fixes the width of the high impedance microstrip, W_{HM} as 4 mil and simulates return loss for different W_{HS}, width of the high impedance stripline. Changing width of the impedance line has almost no effect on the return loss up to 55 GHz. We can assume that due to its more significant width discontinuity on both sides, narrower high impedance line causes larger capacitive effect which in turn cancels

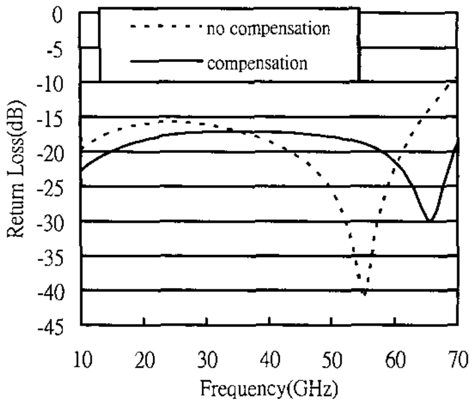

Fig. 8 Return loss versus frequency of the traditional microstrip-to-stripline transition and the high impedance compensation structure.

part of its inductive effect.

Compare these two figures, we can also find that changing W_{HS} affects performance more than changing W_{HM}. This is similar to the case of Fig. 4 and Fig. 5. Also, these two figures suggest that the narrower hi-impedance transmission line which has higher impedance, and the better overall performance than wider transmission line. To meet the limit of the minimum line width, W_{HM} = 4mil and W_{HS} = 4mil are chosen.

Combining all the parameters chosen above, G = 5mil, L_{HM} = 3mil, L_{HS} = 3mil, W_{HM} = 4mil, W_{HS} = 4mil, Fig. 8 compares return loss of the compensation structure and that of the traditonal structure. Compensation structure has higher zero frequency and reduces return loss over the frequency range DC to 35 GHz and 60 GHz to 70 GHz. In the frequency range over DC to 60 GHz, its return loss is still better than 17 dB.

Conclusions

A wideband microstrip-to-stripline transition is provided. Based on the conception of high impedance compensation, several factors, which may affect return loss, are simulated and compared. The most significant factor is the size of the gap, G. There exists an optimal gap size to minimize the return loss. The effect of the line length is significant especially in the high frequency range. We carefully chose the size of the high impedance line to achieve a return loss better than 17 dB over DC to 70 GHz.

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