LETTER

A Novel Resonant Coupling Type Microstrip Line Interconnect

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SUMMARY Resonant coupling type microstrip line interconnects using a bonding ribbon and dielectric pad have been designed and fabricated. The basic concept of this interconnect is the LC serial resonance of the pad capacitor and ribbon inductor. Both numerical simulation and experiment reveal low return loss and high efficiency connection at the predicted resonant frequency region, which can be readily shifted to higher frequencies by tuning the structural parameters. Improvement in bandwidth of the interconnect is demonstrated by using a pad with higher dielectric constant. Furthermore, it is also shown that a slight modification allows DC connection in addition to efficient coupling at the resonant frequency.

key words: *resonant coupling, microstrip line, ribbon bonding, dielectric pad, FDTD*

1. Introduction

Ribbon bonding has been widely used for interconnect or packaging of MMICs and T/R modules at microwave and millimeter-wave frequencies. To tolerate thermal expansion and discrepancies in chip or component size, a small gap is usually left between two substrates to be connected. Because a large part of present MMICs or modules are based on microstrip structures, efficient interconnect between microstrip lines through a gap has great importance for fabrication of high performance systems [1]–[3]. As is well known, the coupling efficiency usually deteriorates at higher frequencies, due to the parasitic inductance of the bonding ribbon [3], and special bonding configurations such as the use of tuning stub with line width compensation have been reported [1], [4].

A high-efficiency novel DC-free microstrip line interconnect which does not require the modification of the shape of the microstrip lines to be connected has been proposed [5]. This structure consists of a single ribbon and a companion rectangular dielectric pad. The ribbon and the dielectric pad constitute a series LC resonator so that high efficiency connection is achieved at the resonant frequency. Furthermore, a slight modification allows DC connection in addition to efficient coupling at the resonant frequency.

In this paper, we present both numerical simulation and experimental verification of the coupling characteristics of this new interconnect structure in detail. It is also shown that the resonant frequency can be readily shifted to higher frequencies by tuning the structural parameters of dielectric pad and that the improvement in frequency bandwidth can be realized by using a pad with higher dielectric constant.

2. Microstrip Line Interconnect

Figure 1 shows the proposed structure where two microstrip lines are connected through a gap with a metallic ribbon and a rectangular dielectric pad. The dielectric substrate for the 50Ω microstrip line used in this study is RT/Duroid with $\varepsilon_1 = 2.33$ and $h = 0.8$ mm. The ribbon used is a rectangular copper sheet with $w = 2.3$ mm, $r_1 = 4.0$ mm and $r_2 = 1.4$ mm. For the dielectric pads, two different kinds of materials with metallized top surfaces and identical widths to that of the ribbon have been investigated.

Figure 2 shows the S-parameters simulated by FDTD for conventional ribbon bonding between microstrip lines through a gap of $g = 1.6$ mm, which corresponds to the structure in Fig. 1 without the dielectric pad. The FDTD cell sizes are selected mainly to discretize the structure as accurately as possible, and are chosen as $\Delta x = 0.197$ mm, $\Delta y = 0.389$ mm, and $\Delta z = 0.400$ mm, respectively, for the simulation results shown in Fig. 2. These cell sizes correspond to less than

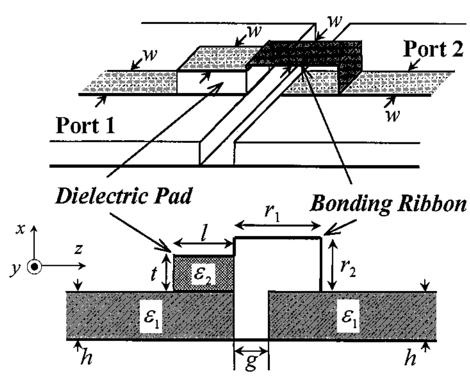

Fig. 1 Microstrip line interconnect through a gap using a bonding ribbon and dielectric pad.

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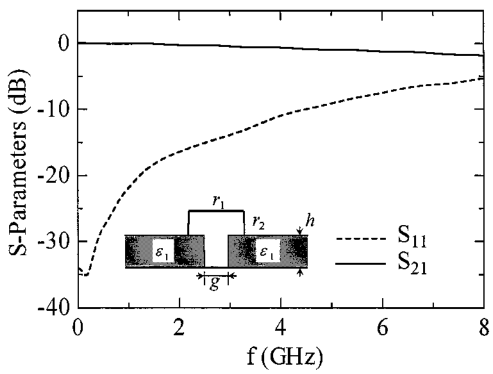

Fig. 2 Coupling characteristics of two microstrip lines connected by conventional ribbon bonding. (g = 1.6 mm, h = 0.8 mm, $\varepsilon_1 = 2.33$, $r_1 = 4$ mm, $r_2 = 1.4$ mm and $w = 2.3$ mm).

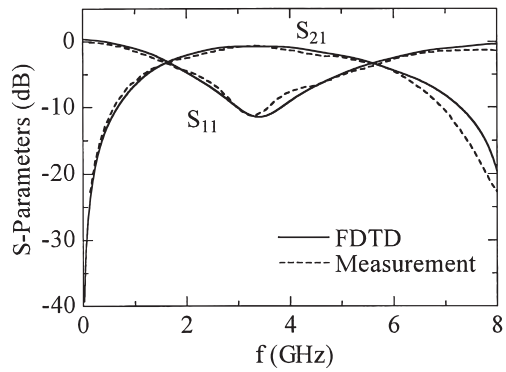

Fig. 3 FDTD simulation and measurement results of S-parameters for the microstrip line interconnect using bonding ribbon and dielectric pad with $\varepsilon_2 = 2.33$, $t = 0.8$ mm and $l = 12$ mm. Other parameters are the same as in Fig. 2.

1/60 of the smallest guided wavelength of our interest, which should give reasonably accurate results for S-parameters. In this simulation, $50 \times 40 \times 260$ FDTD cells are used for x, y, and z directions, respectively. The FDTD grid is truncated by using Mur's second order absorption boundary condition (ABC) [6]. A Gaussian pulse with 20 ps width is used for excitation of the microstrip line, and the S-parameters are evaluated by using Fast Fourier Transform (FFT) at the end of the FDTD iteration.

As expected, both insertion loss and return loss increase rapidly at higher frequencies. The deterioration of the ribbon bonding is mainly due to the parasitic inductance of the ribbon, which is estimated to be 3 nH in the present case [7]. Hence, the introduction of a dielectric pad as shown in Fig. 1 will result in an LC serial resonator, where an efficient coupling is expected around the resonant frequency.

3. Simulation and Measurement Results

In this section, we will show some FDTD numerical simulation and measurement results of the coupling efficiency of a resonant coupling type microstrip line interconnect. FDTD parameters and analytical conditions, except for cell sizes in some cases, are the same as those of the previous section. For the measurement, we use the network analyzer HP 8270A with a standard two-port calibration using HP coaxial calibration kit.

3.1 DC-Free Interconnect

Figure 3 shows both FDTD simulation and measurement results of the coupling characteristics of an interconnect using a dielectric pad with $\varepsilon_2 = 2.33$, $t = 0.8$ mm and $l = 12$ mm. In the FDTD analysis, we choose the Yee cell sizes as $\Delta x = 0.197$ mm, $\Delta y = 0.389$ mm, and $\Delta z = 0.400$ mm, which are the same as those for the simulation shown in Fig. 2. Due to the LC resonance, the insertion loss is better than

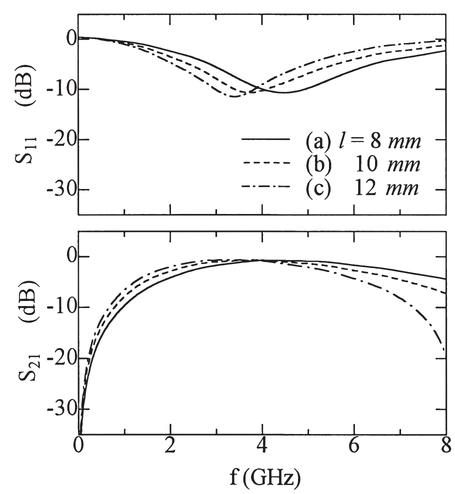

Fig. 4 S-parameters obtained by FDTD simulation for the microstrip line interconnect using bonding ribbon and dielectric pad with $\varepsilon_2 = 2.33$ and $t = 0.8$ mm where length of the pad as a parameters. Other parameters are the same as in Fig. 3.
(a) $l = 8$ mm, (b) $l = 10$ mm, (c) $l = 12$ mm.

0.8 dB from 3.0 to 3.8 GHz, and the return loss is below −10 dB within this frequency range. Good agreement between measurement and prediction has been obtained, with a discrepancy of less than 3% for the resonant frequency. The S-parameters obtained by FDTD simulation for various lengths l of the dielectric pad are shown in Fig. 4. As the length l shorten, the resonant coupling range where the efficiently connection can be achieved move to higher frequency.

To investigate this phenomenon in detail, the FDTD simulated resonant frequencies for various lengths l of the dielectric pad are shown in Fig. 5, with the other parameters identical to those in Fig. 3. Also shown in the same figure is the estimated resonant frequency of the serial LC resonator, where L and C are the ribbon inductance and pad capacitance, respectively [7]. The good correlation indicates that high-efficiency coupling should be possible at higher frequen-

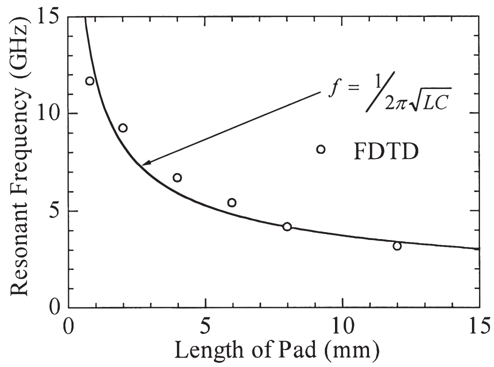

Fig. 5 Resonant frequencies of the interconnect with respect to different lengths of dielectric pad. Other parameters are the same as in Fig. 3.

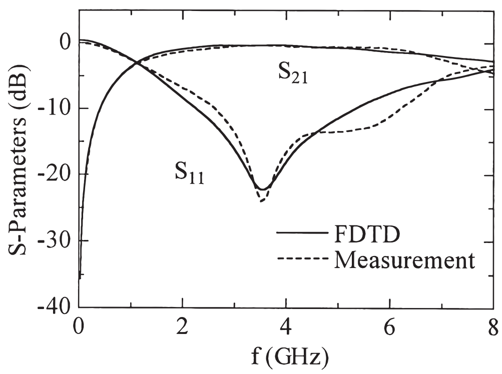

Fig. 6 Simulated and measured S-parameters of the microstrip line interconnect using bonding ribbon and dielectric pad with $\varepsilon_2 = 10.2$, $t = 0.6$ mm and $l = 4$ mm. Other parameters are the same as in Fig. 2.

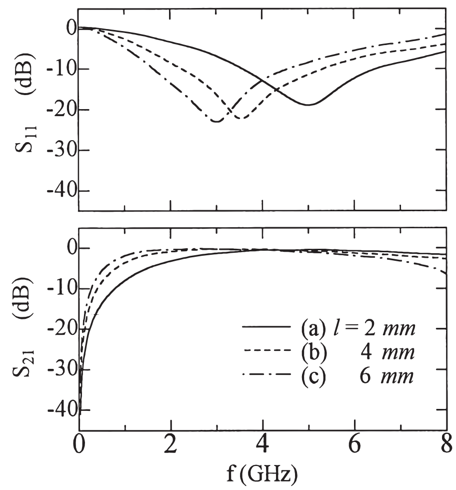

Fig. 7 S-parameters obtained by FDTD simulation for the microstrip line interconnect using bonding ribbon and dielectric pad with $\varepsilon_2 = 10.2$ and $t = 0.6$ mm where length of the pad as a parameters. Other parameters are the same as in Fig. 6.
(a) $l = 2$ mm, (b) $l = 4$ mm, (c) $l = 6$ mm.

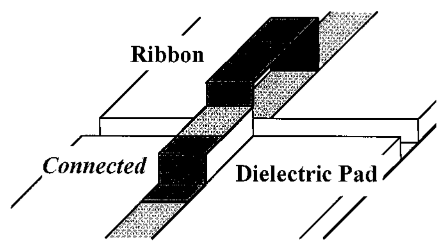

Fig. 8 Microstrip line interconnect with top conductor of dielectric pad and microstrip are connected.

cies by reducing the size of the dielectric pad. The increasing discrepancy at higher frequencies also emphasizes the necessity of full-wave simulation at these frequencies.

Figure 6 shows the S-parameters for the interconnect using a dielectric pad with $\varepsilon_2 = 10.2$, $t = 0.6$ mm and $l = 4$ mm, where $\Delta x = 0.127$ mm, $\Delta y = 0.389$ mm, and $\Delta z = 0.400$ mm Yee cells are used for FDTD analysis. In this case, S_{21} is better than 0.5 dB from 2.9 to 4.3 GHz, with the return loss below -15 dB. Again good agreement ($< 2\%$ discrepancy in resonant frequency) between theory and experiment is obtained. The results in Fig. 5 indicate that improvement in coupling efficiency and bandwidth is possible by using a thinner pad with higher dielectric constant. Figure 7 indicates the S-parameters obtained by FDTD simulation for the various dielectric pad lengths l. The high efficiency coupling is observed at the higher frequency in accordance with shortening the pad length l.

3.2 DC Interconnect

In the previous section, resonant coupling type DC-free microstrip line interconnect has been presented. For some practical applications, however, an interconnect with DC pass is also required. The microstrip line on which the dielectric pad is loaded and the top conductor of a pad are connected to each other. This can be easily achieved by a slight modification of the proposed structure as shown in Fig. 8, where the dielectric pad is connected to the microstrip line by a vertical metal plate. A simple equivalent circuit for this structure is not straightforward, thus only FDTD simulation and measurement results are presented. S-parameters of this structure simulated by FDTD, and measured are shown in Fig. 9. The structure dimensions and FDTD parameters are the same as for the simulation shown in Fig. 3, except for the additional vertical metal plate for DC connection. Efficient coupling and low return loss interconnect ($S_{21} > -0.7$ dB and $S_{11} < -15$ dB) are obtained from 6.0 to 7.0 GHz. From this result, it is expected that a high efficiency RF interconnection due to the LC resonance together with DC pass can be realized. The S-parameters estimated by FDTD simulation for the various length of dielectric pad l are shown in Fig. 10. In this case also the efficient RF interconnect range is shifted to high frequency with the length l becomes short.

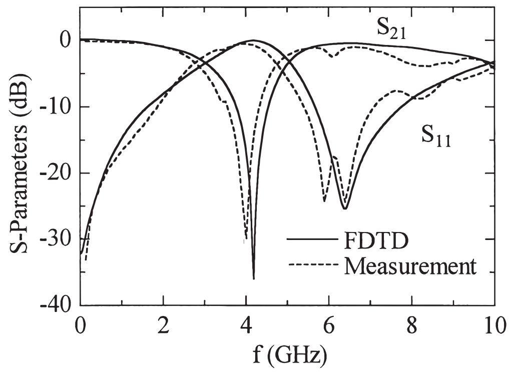

Fig. 9 FDTD simulation and measurement results of S-parameters for the modified microstrip line interconnect. The parameters are the same as in Fig. 3.

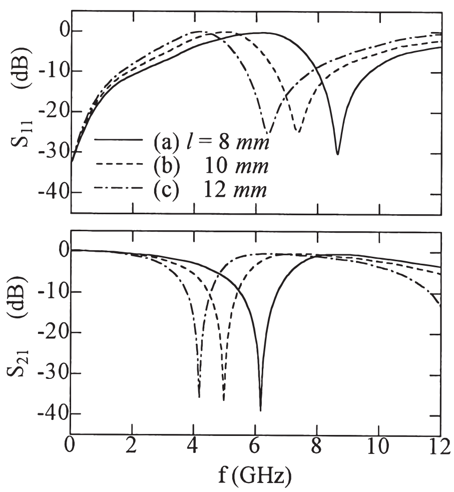

Fig. 10 S-parameters obtained by FDTD simulation for the DC pass microstrip line interconnect where the length of the dielectric pad as a parameters. Other parameters are the same as in Fig. 9. (a) $l = 8$ mm, (b) $l = 10$ mm, (c) $l = 12$ mm.

4. Conclusions

In this paper, we proposed a new resonant coupling type microstrip line interconnect using a bonding ribbon and dielectric pad. Both FDTD simulation and measurement have confirmed the design concept, and an insertion loss of better than 0.5 dB over a 40% bandwidth has been obtained for a low frequency model. The structure should be readily useful at higher frequencies as indicated by the full-wave simulation results. Furthermore, it is also shown that the structure can be easily expanded to high efficiency RF as well as DC level interconnection.

Acknowledgements

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