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Low Cost Strip-to-Bilateral-Slotline Transition on Wide Slotline

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Abstract—This paper presents a low-cost strip-to-bilateral-slotline transition with operating bandwidth from 0.53 to 6 GHz. The low-cost design concept is realized by utilizing conventional cheap FR-4 substrate and wide slotline with large slot width. By virtue of the low price of FR-4, less strict fabrication tolerance of wide slotline and the avoidance of metallic vias, the fabrication cost is reduced significantly compared to schemes using expensive Rogers RT laminates, extremely narrow slotline with strict fabrication tolerance and metallic vias. The broadband impedance matching difficulty caused by the high characteristic impedance of wide slotline is solved by three means. Firstly, bilateral structure is used to lower the characteristic impedance of the slotline. Then an elliptic slotline stub and an innovative half-elliptic strip stub are proposed to provide good impedance matching. Finally, multi-section stepped impedance transformers are used to match the transition from high impedance to standard 50 Ohm. The validity of the design methods is verified through experiments.

1. INTRODUCTION

Broadband source antennas are proverbially used in EMC (Electromagnetic Compatibility) test chambers. Generally, a source antenna with as large operating bandwidth as possible is desired to facilitate and expedite wideband and multi-band wireless test. To fulfill this requirement, a tapered slot antenna with bandwidth of 0.7–20 GHz has been implemented in [1] based on a broadband bilateral slotline transition proposed in [2]. The transition is based on the Rogers RT-6002 laminate which ensures good high frequency features of the transition, say 10 GHz and above; however, the dielectric material is too expensive for massive production. Besides, for quick evaluation during design progresses, 6 GHz is typically the upper end test frequency, making it surplus the remaining operating bandwidth (6–20 GHz) of the source antenna proposed in [1]. In addition, the Rogers RT material suffers from deformation problems and cannot provide good mechanical strength for large planar components. As a result, a wideband source antenna with low cost and robust mechanical strength is therefore desired to facilitate quick, economic and qualitative EMC evaluation.

The antenna design follows two steps, the feeding transition design and the antenna design. This paper mainly focuses on the former issue and works on a low-cost design concept. The transition is based on a wide bilateral slotline etched on FR-4 substrate. The bilateral slotline is wide enough to avoid strict fabrication tolerance so it increases the rate of finished products thereby lowering the fabrication cost for massive production, and so does the FR-4 laminate. Section 2 compares the characteristic impedances of conventional single-sided slotline and bilateral slotline to determine the slotline form on which the transition based. Section 3 describes the transition design. Section 4 presents the simulation and measured results. The paper is briefly concluded in Section 5.

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2. SLOTLINE IMPEDANCE ANALYSIS

To ensure enough mechanical strength, the FR-4 substrate has an overall thickness of 1.6 mm, relative dielectric constant $\varepsilon_r = 4.3$ and loss tangent $= 0.02$. There are two reasons for the use of FR-4 substrate. The first one is its low price. Although high frequency features the FR-4 provides is not ideal, it is good enough for the application of quick evaluation, as discussed in the Section 1. And the second one is its good mechanical strength. Other materials provide good high frequency features are either expensive or very soft which will cause antenna deformation problems.

The structure of traditional single-sided slotline is shown in Fig. 1(a). Although the single-sided slotline is widely used in tapered slot antenna designs, its high characteristic impedance (usually higher than 150 Ohm) makes the wideband impedance matching challengeable unless extremely narrow slotline is used. Narrower slotline provides lower characteristic impedance which facilitates the impedance matching; however, it requires much more accurate fabrication control thus not fit for low-cost massive production [3–7]. Also, wideband impedance matching from such high impedance to standard 50 Ohm usually needs a very long stepped impedance transformer section which incurs considerable insertion loss, making the transition even unusable. Since bilateral slotline, as shown in Fig. 1(b), has much lower characteristic impedance than the single-sided slotline when their slot widths and substrate parameters are the same, the length of the impedance transformation section can be reduced and the slot width can be made much wider [7]. Therefore, wide slotline transition on economic FR-4 laminate fit for low-cost massive production is possible.

Unlike traditional transition designs which use slot width much smaller than the substrate thickness to obtain low characteristic impedance [3–6], in this paper, the slot width and substrate thickness for either slotline are the same as 1.6 mm. Fig. 2 compares the characteristic impedance Z_0 of the single-sided slotline (SS) and the bilateral slotline (BS). Evidently, the BS has much lower Z_0 than the SS. This means if the SS is replaced by the BS, wideband impedance matching will be much easier and meantime,

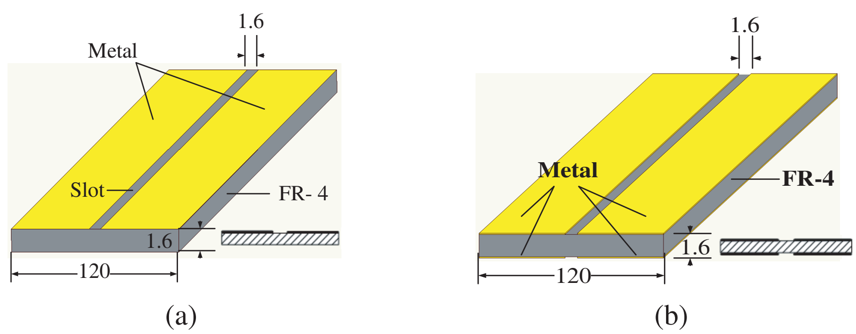


Figure 1. Configuration of (a) SS and (b) BS (unit: mm).

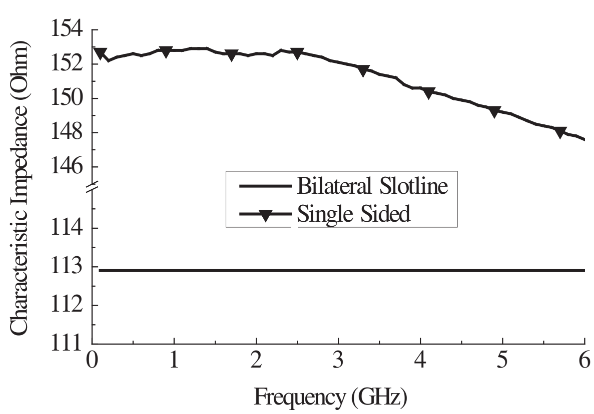


Figure 2. Simulated characteristic Impedances of SS and BS.

smaller total length as well as less insertion loss of the impedance transformers can be expected. And the reduced length also brings smaller PCB size thus lower fabrication cost. Therefore, the BS is chosen as the slotline type on which the rest of work in this paper is based.

3. TRANSITION DESIGN

The configuration of the stripline to bilateral slotline transition is shown in Fig. 3. The stripline starts from the margin of the laminate and ends with a half-elliptic open-circuited stub while the slotline is terminated with an elliptic short-circuited stub. Referring to the intersection point of the stripline and the slotline, the strip stub performs as a virtual short-circuited stub and the slotline stub as a virtual open-circuited stub. In this manner, the energy flows along the stripline and then couples to the slotline through the junction. After transmitting along the slotline, the energy again couples back to the other stripline through the junction. The dimensions of the elliptic slotline stub and the half-elliptic strip stub are determined using Equations (1)–(3). We define the minor radiuses of the slotline and stripline stub are R_1 and r_1, respectively. And the major radiuses of the slotline and stripline stub are R_2 and r_2, respectively, as shown in Fig. 3.

$$f_0 = \sqrt{f_{up} \times f_{low}} \tag{1}$$

$$R_1 = \lambda_{sl}/4 \quad R_2 = 2R_1 \tag{2}$$

$$r_1 = \lambda_{st}/4 \quad r_2 = 1.5r_1 \tag{3}$$

where f_{up} and f_{low} is upper and lower cut-off frequency of the proposed transition, f_0 is the center frequency, and λ_{sl} andλ_{st} are the waveguide wavelength of the bilateral slotline and stripline respectively, related to the center frequency f_0. The waveguide wavelength is calculated through full-wave simulation with the help of commercial simulation software CST MWS. Specifically, we have $f_{up} = 0.7\,\text{GHz}$ and $f_{low} = 6\,\text{GHz}$. Using Equation (1), f_0 is approximately 2 GHz with corresponding free space wavelength λ_0 of 150 mm. The calculated $\lambda_{sl} = 29\,\text{mm}$ and $\lambda_{st} = 18\,\text{mm}$. Using Equations (2) and (3), $R_1 = 7.25\,\text{mm}$, $R_2 = 14.5\,\text{mm}$, $r_1 = 4.5\,\text{mm}$, $r_2 = 9\,\text{mm}$.

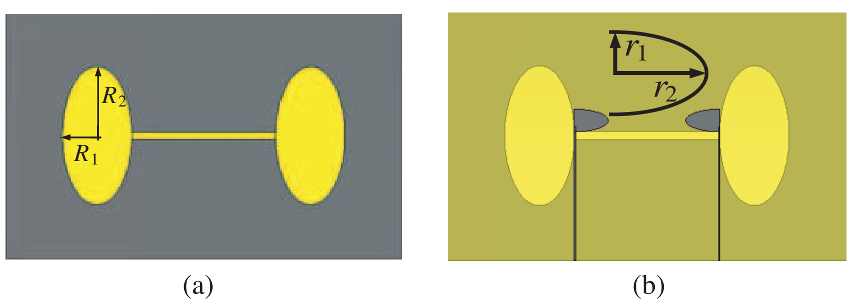


Figure 3. Configuration of the strip to bilateral slotline transition without matching: (a) the same bottom and up layer; (b) middle layer.

Since the BS width is fixed at 1.6 mm ($Z_{01} = 113\,\Omega$), the stripline's characteristic impedance Z_{02} should be designed as equal to Z_{01}. However, the presence of the slotline stub and stripline stub makes the matching condition more complicated. The slotline and stripline stubs introduce additional parasitic effect which may make Z_{01} and Z_{02} vary. So the final stripline width w_0 should be obtained through parameters sweep, as shown in Fig. 4. And it is worth noticing that in the full-wave simulation, the waveport is used and the matching circuit is not included, i.e., the characteristic impedance in the reference plane of the waveport remains the same as that of the stripline. As shown in Fig. 4, when the stripline has a width of 0.28 mm, the transition obtains the optimum S_{11} whereas the S_{21} has no notable variation for all stripline widths.

It is shown that the transition has good $S_{11} < -14\,\text{dB}$ within the frequency range from 0.7 GHz to 6 GHz. Regarding the S_{21}, it is better than $-3\,\text{dB}$ within the frequency range of 0.57–5.3 GHz, but worse at higher frequencies due to the relatively high dielectric loss of the FR-4. Though slightly large insertion loss presents at frequencies higher than 5.3 GHz, the transition's performance is still acceptable for several reasons. Firstly, only half of the back-to-back transition will be used in practical application thus less insertion loss is expected. Besides, since tapered slot antennas based on the transition usually has a growing gain with increasing frequency, the slightly large insertion loss at high frequencies will be compensated by the antenna's increasing gain thus not affecting the antenna gain notably [1–4]. On the other hand, we can also view the sacrifice of transmission performance as a cost of the reduced cost of fabrication.

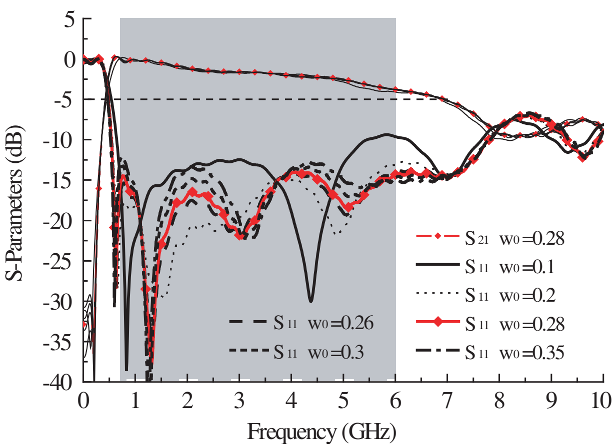


Figure 4. Parameter sweep results of the stripline width (unit: mm).

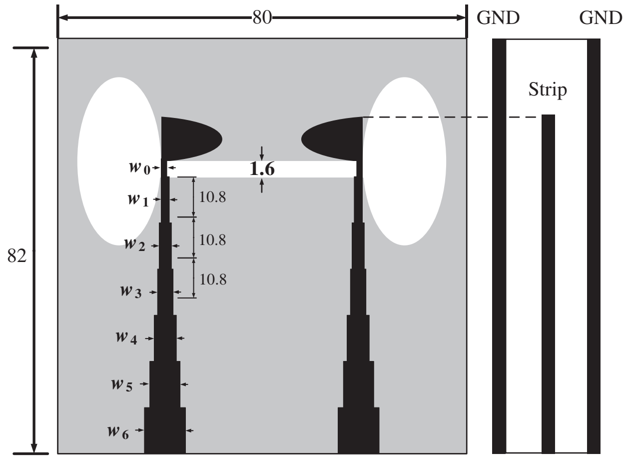


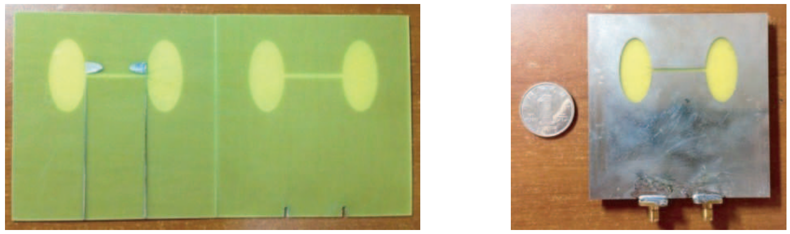
Figure 5. Configuration of the strip-to-bilateral-slotline transition with matching circuits (mm).

Since we have had the unmatched strip-to-BS transition, the only remaining step is to integrate an impedance matching section to complete the transition design, so the transition can be connected to other components like a Vector Network Analyzer. To fulfill the task of impedance matching, multi-section stepped impedance transformers are utilized with related configuration and detailed dimensions shown in Fig. 5. Two slotted metallic ground layers are in the first and third layer of the transition, while the stripline in the second (middle) layer. The dimensions are obtained through optimization via a co-simulation between the CST Microwave Studio and CST Design Studio, where $w_0 = 0.28\,\text{mm}$, $w_1 = 0.31\,\text{mm}$, $w_2 = 0.38\,\text{mm}$, $w_3 = 0.45\,\text{mm}$, $w_4 = 0.53\,\text{mm}$, $w_5 = 0.61\,\text{mm}$, $w_6 = 0.66\,\text{mm}$ and each section with a length of 9 mm. The slotline length between the two elliptic stubs is 25 mm. In fact, the slotline length can be set arbitrarily as long as the two strip stubs do not overlap with each other.

4. MEASUREMENTS AND DISCUSSION

A prototype of the proposed transition is fabricated and measured to verify the validity of design concepts and its photograph is shown in Fig. 6. Fig. 6(a) shows the middle layer of the transition. The stripline is etched on either of the two PCBs (Printed Circuit Board). When the two PCBs are connected together using the PCB Multilayer Laminating Technology, we had the final three-layer (Slotted Gournd — Stripline — Slotted Ground) transition shown in Fig. 6(b). Measurements are carried out using the Agilent N5230A Vector Network Analyzer. To facilitate the measurements, a SMA-to-stripline transition is redesigned using the concept proposed in [8].

The experimental and simulated S-Parameters are compared in Fig. 7. The simulated and measured S_{11} agree well below 2 GHz. But disagreement presents beyond 2 GHz due to the effect of the SMA-to-Stripline transition. And the transition obtains an impedance bandwidth of 0.53–8.1 GHz in terms of measured $S_{11} < -10\,\text{dB}$. Within the scheduled frequency range of 0.7–6 GHz, the measured S_{11} is better than $-12\,\text{dB}$ and S_{21} better than $-5.6\,\text{dB}$. For practical applications, $(-5.6+3)\,\text{dB} = -2.6\,\text{dB}$ insertion loss can be expected because only half of the transition will be used. Regarding the fabrication cost, the high-performance transition proposed in [2] costs 780 RMB, whereas only 20.88 RMB the low-cost transition proposed in this paper costs, only 2.7% of the former.



(a) (b)

Figure 6. Photograph of the fabricated transition.

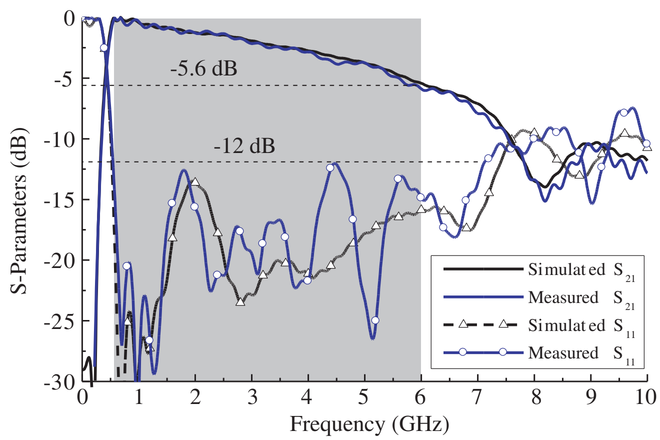


Figure 7. Simulated and measured S-Parameters of the proposed transition.

5. CONCLUSION

A low-cost stripline to bilateral slotline transition fit for massive production is presented in this paper. Characteristic impedance analysis is carried out through full-wave simulation to pave the way for the application of the bilateral slotline to the transition. Then an elliptic slotline stub and an innovative half-elliptic stripline stub are proposed which facilitate the broadband impedance matching. Corresponding design equations and procedures are provided. A prototype is fabricated and measured, which verifies the validity of the proposed design concepts. With the use of economic FR-4 substrate and wide slotline with less strict fabrication tolerance, the fabrication cost of the transition is significantly reduced at the cost of slightly large insertion loss at high frequencies, a trade-off between price and performances.

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