Advances in Developing Transitions in Microwave Integrated Circuits*

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Abstract Advances in developing transitions in microwave integrated circuits during the last ten years are reviewed. Some typical structures of transition are introduced. Transition structures can be classified into two basic types: one is transition between the same kind of transmission lines on different planes of a common substrate, the other transition between different types of transmission lines. Furthermore, future development of transition structures is discussed.

Key words advance; transition structure; microwave integrated circuits; transmission line

An increasing system complexity leads to new challenges in circuit design. One way to cope with this is the combination of different types of transmission lines to achieve optimal performance. Indeed, the association of different planar structures of propagation brings interesting, simple, and original circuits. Transition structures are employed to transform electromagnetic energy between two types of transmission lines. To guarantee smooth transition, not only the impedance match, but also the field match should be sustained.

Transition structures can be classified into two basic types: one is transition between the same kind of transmission lines on different planes of a common substrate, the other transition between different types of transmission lines. There are two main techniques for the transition. One is electrical contact, and the other electromagnetic coupling. Transitions by electrical contact usually require via holes, bonding wires, or abrupt steps in the conductor. These transitions provide compact size and wide bandwidth, but the majority of them involve some degree of mechanical complexity. Transitions by electromagnetic coupling require no wire bonds or via holes, but most of them suffer from narrow bandwidth and large size.

1 Transitions between the Same Kind of Transmission Lines

Fig.1a shows two back-to-back microstrip-to-microstrip transitions\(^\text{[1]}\). A coplanar wave-guide (CPW)-microstrip transition is needed so as to allow W-band coplanar-probe measurements. The electromagnetic coupling between the top and bottom microstrip surfaces occurs in the strip overlay. For different overlay lengths of the transition, there are different S-parameters. An optimum overlay length for the transition is around 200μm for W-band applications.

![Layout of back-to-back microstrip-to-microstrip transitions](image)

![Layout of slotline-to-slotline transition](image)

Fig.1 Transitions between same kinds of transmission lines

Fig.1b shows two back-to-back CPW-to-CPW
transitions[1]. The top CPW and bottom CPW have an overlay. The dimensions of the overlay region are designed so that the even- and odd-mode impedances result in a perfect match at the frequency of interest.

Fig.1c shows a transition with electromagnetic coupling between two slotlines that are on opposite sides of a wafer[2]. The transition is fabricated and characterized on a high resistivity silicon wafer. The coupling takes place at the location where the upper slotline is terminated in a short circuit. The arc of the short circuit crosses the underside slotline at right angle.

2 Transitions between Different Types of Transmission Lines

2.1 Microstrip-Slotline Transitions

Slotline, which was proposed as a novel planar transmission line, offers a lot of advantages in the design of microwave and millimeter-wave circuits, especially when shunt-connected active devices are involved. In addition, a hybrid combination of slotline with microstrip circuits allows a design flexibility and leads to many attractive applications, such as hybrid branch-line couplers, ferrite phase shifters, multi-layer MMICs and a feed for tapered-slot antennas.

Fig.2a shows a microstrip-slotline (M-S) transition[3]. The microstrip line and slotline are placed at the opposite sides of a substrate. The microstrip feed line is assumed to extend infinitely, and its transverse direction makes an inclination angle with the slotline axis. A perfect impedance matching can be obtained by a proper choice of the inclination angle between the microstrip and slotline without any extra circuitry. The transition shown in Fig.2b is mainly composed of five parts[4]. In Part I and Part II, the electric field is mostly parallel to the substrate, while in Part V, it is mostly vertical to the substrate. Thus, the function of Part III is to rotate the electric field by about 90°. The geometry of Part IV plays an essential role in reducing the return loss of overall transition. While the current distributes mainly on the edges of both strips in Part I, Part II and Part III, it concentrates in the region between strip and ground plane of the microstrip in Part V. If the width of the ground plane is large compared that of the strip, the edge currents of the ground plane can be ignored.

Fig.2c shows an M-S transition[5]. The slotline (dash line) is in the ground of the microstrip. Practical limitations in the design of very broadband transitions from microstrip to slotline are due to the limited realizability of high characteristic impedance slotline stubs and low characteristic impedance microstrip stubs. However, such limitations may be alleviated by the use of junctions of stubs. In order to minimize the stub coupling, angles α and γ should be as large as possible.

Fig.2d shows two back-to-back uniplanar M-S transitions geometry[6]. It consists of a 50Ω microstrip line which branches into two orthogonal paths. The characteristic impedance of each microstrip path is chosen as 70Ω for easy fabrication. The two microstrip paths are made of $0.8\lambda_{c\text{(microstrip)}}$ to compensate for the right angle bends parasitics and $0.25\lambda_{c\text{(microstrip)}}$ long, respectively, at the design frequency of 10GHz so that the fields at the locations ‘a’ and ‘b’ are 180° out of phase. This is necessary to excite the odd mode on the coupled microstrip lines so that the intermediate coupled microstrip line section transitions easily into a slotline. The transitions are compact and easily adaptable to be used in MIC/MMIC and antenna applications.

The structure of back-to-back M-S transitions is illustrated in Fig.2e[7]. Electric field of the slotline is formed across the two strip lines and on the contrary, electric field of the microstrip line is formed normal to
the substrate. Hence, the radial stub is rotated with an angle $\phi$ to change electric field orientation from parallel to vertical against the substrate. The high slotline characteristic impedance, 184 $\Omega$, can be transformed to microstrip line’s 50 $\Omega$ by a smooth insertion of the ground plane toward the microstrip line. Since it dose not employ any quarter wavelength transformer, which limits the bandwidth, wideband performance is achieved.

2.2 Microstrip-CPW Transitions

Fig.3a shows a microstrip-CPW (M-CPW) transition\(^8\). The transition consists of a conductor backed CPW (CBCPW) that connects the CPW to the microstrip. The characteristic impedance of the CBCPW is the parallel combination of two characteristic impedances: the CPW mode ($Z_{GW}$) and the microstrip mode ($Z_{MS}$). The splitting of the characteristic impedance into the CPW and the microstrip is the basic idea of the proposed structure.

The transition shown in Fig.3b does not require via holes, wire bonds, or air bridges\(^9\). The design is based on vertical resonant coupling between the microstrip and CPW. The center conductor of the CPW is integrated with the ground plane of the microstrip. The end of the microstrip line is connected to two open stubs. These stubs are extended past the two short slot arms of the CPW on the opposite sides of the substrate. The lengths of open stub and short arm are designed to be approximately one quarter of the guided wavelength. The open stub and shorted arm are radial in shape to allow wider bandwidth operation. Under the constraint of 50 $\Omega$ input/output impedance, the width of microstrip and slot of CPW are tapered near the resonant coupling region to achieve a better impedance match.

Fig.3c shows a micromachined grounded CPW-microstrip transition\(^10\). The electromagnetic power coupled to the CPM mode will be negligible if the characteristic impedance of this mode in the grounded CPW feed line is much higher or lower than 50$\Omega$. To reach this condition we have to modify the electrical characteristics of the silicon substrate for the CPM mode without changing the 50$\Omega$ characteristic impedance for the CPW mode. These conditions are satisfied by etching an air cavity underneath the grounded CPW feed line. The etched cavities below grounded CPW feed lines increase the characteristic impedances of CPM mode by a factor of three without affecting the propagation of the useful CPW mode. The etched cavity can effectively suppress the parasitic CPM modes in the grounded CPW input lines.

2.3 Slotline-CPW Transitions

Fig.4a shows a slotline-CPW (S-CPW) transition\(^11\) in involves the use of slotline ring resonator. The ring resonator includes two types: CPW-feed slotline ring resonator and slotline-feed slotline ring resonator. The resonator dose not suffer from open-end or short-end effects and, therefore, gives more accurate resonance frequency, provides an accurate localized zero or infinite impedance point, and maintains low- or high-input impedance values over a wide frequency range.

A new ultra-wideband, low-loss and small-size S-CPW transition is shown in Fig.4b\(^12\). The transition connects CPW with slotline by the reformed air-bridge. Two ground planes of CPW are tied at their ends by a line and the center of the line is connected to the ground strip of slotline by another line. Owing to the symmetry of the structure, the currents of two ground planes of CPW are combined with the same phase and transferred to the ground strip of slotline.

Fig.4c shows the S-CPW transitions using virtual CPW shorts and virtual slotline opens\(^13\). Both of the CPW and slotline virtual terminations use broadband radial open stubs. The angles of the CPW and slotline radial opens are both chosen as 45° to avoid interfering each other. No via-holes are needed for ground connections, and integration with solid-state devices is easy.
Fig. 4d shows a S-CPW transition. The slotline hollow patch creates open circuit conditions on one arm of the CPW and resonates the transition so that maximum power transfer may occur. Since the transition is uniplanar, no via-holes are needed for ground connections; it is therefore much easier to fabricate and to perform the integration with other circuitries.

The transition shown in Fig.4e is often used in CPW passive circuits. The transition consists of three parts, including a uniform CPW, phase shifter, and slotline. The transition utilizes S-CPW mode-conversion to convert CPW-mode field to slotline-mode field, and the transition bandwidth is broadened by use of air-bridges.

A novel reduced-size lumped-element S-CPW...
transition is shown in Fig.4f\cite{16}. The transition uses planar parallel and series inductor-capacitor circuits to realize the effective open circuit and short circuit. The transition size is much smaller than conventional ones.

A S-CPW transition is shown in Fig.4g\cite{17}. The transition structure includes six parts, i.e., the symmetric CPW, the asymmetric CPW tapered linearly in the lower slot, the asymmetric CPW tapered linearly in the upper ground plane, the unterminated slotline open, the asymmetric coplanar stripline tapered linearly in the upper strip, and the symmetric coplanar stripline.

Transitions mentioned above are summarized in Tab.1.

3 Conclusions

Through the analyze of all kinds of transition structures mentioned above, we conclude that many kinds of transition structures can be produced by combination of a few kind of transmission lines. However, each transition structure has its own advantage and shortage, and is only suitable in a limited area. Transition structure that have the following advantages are expected in the future: adequate bandwidth and small insertion loss; good performance of repetition and coherence; easy to fabrication and low cost; and easy to integrate with other circuits.

References


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