Design of back-to-back tapered line transition

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Abstract - A design of back-to-back tapered line transition is presented. The transition is suitable for application in feeding arrays of double-side printed antennas. Tapered transmission lines are transmission line whose characteristic impedance is tapered from one value to another. Back-to-back circuits of identical transitions are designed, measured, and their characteristics are compared with theoretical results. We will present a circuit of two $50\,\Omega$ microstrip to $100\,\Omega$ balanced stripline transitions and also we will realize tapered line feed networks for array of double sided strip dipoles to see if the scattering parameters of these circuits are in good agreement or not.

Keywords - Tapere line, Transition, Quarter wave transformer

1 Introduction

As we know arrays of double-sided printed strip dipoles fed with corporate networks of parallel striplines and backed by conductor planes were developed for radar and various military applications [3]. Various antenna structures of double-sided printed strip dipoles connected through balanced striplines having dual-band and broadband properties have been reported [1] [2] [4]. These structures are suitable for low-cost base station antennas, because they have simple configuration and can be easily manufactured. To feed a double-sided printed strip antenna from a conventional coaxial connector, however, a transition from unbalanced line to a balanced line must be used to keep the antenna in a balanced state. The transition performs conversion of electromagnetic fields and can be used as impedance transformer. Moreover, the transition must be capable of operating over a large frequency range to be compatible with the antenna performance.

Impedance transformation and matching are required in general microwave networks and antenna arrays to obtain maximum power transfer between the source and load. In addition, power often has to be divided between different network elements. At high frequencies, these common functions are usually performed with distributed elements consisting of sections of transmission lines. The most commonly used quarter-wave impedance transformer [5] is shown in Fig. 1(a). A resistive load of impedance $Z_L$ can be matched to a network with input impedance $Z_{in}$ by using a quarter-wave section of transmission line with impedance $Z_c = \sqrt{Z_{in}Z_L}$. The impedance is perfectly matched only at the frequency at which the electrical length of the matching section is $L = \lambda / 4$. A plot of reflection coefficient, $\rho$, as a function of $\theta = \beta L = 2\pi L / \lambda$ that is essentially a plot of $\rho$ versus frequency is shown in Fig. 1(b).

![Figure 1(a) Quarter wave transformer and (b) Input reflection coefficient](image-url)
The bandwidth provided by a quarter-wave transformer may be adequate in many applications, but there are also situations in which a much greater bandwidth must be provided. The bandwidth can be increased by using cascaded quarter wave transformers as shown in Fig. 2(a). Each quarter wave section has the same electrical length, and by a proper choice of their characteristic impedances a variety of pass-band characteristics can be obtained [6]. The most commonly used multi-section transformers are those with maximally flat (binominal transformer) and equal-ripple (Chebyshev transformer) reflection coefficient characteristics. A typical plot of reflection coefficient of a two-section quarter-wave Chebyshev transformer as a function of \( \theta \) is shown in Fig. 2(b).

Cascaded quarter-wave impedance transformers of more than two sections are not practical due to length constrains. Instead, a transmission line which has the characteristic impedance that varies continuously along its length can be used as a broadband impedance transformer. The broadband impedance matching properties of the transformer are obtained by utilizing a continuous transmission line taper as shown in Fig. 3(a) with its characteristic impedance changing smoothly from \( Z_L \) to \( Z_{in} \). If the variation of characteristic impedance along the taper \( Z(x) \) is known, the reflection coefficient can be easily calculated by considering the taper to be made of a number of short transmission line sections. Exponential taper and taper with triangular distribution are two examples of practical designs [6]. A more important problem is to determine \( Z(x) \) to give an input reflection coefficient with desired frequency characteristics. An example of practical importance is a taper that has its characteristic impedance tapered along its length so that the input reflection coefficient follows a Chebyshev response in the pass band as shown in Fig. 3(b). The taper has equal-ripple minor lobes and is an optimum design as it has the shortest length for a given minor lobe amplitude. As illustrated in Fig. 3(b), the length of taper is determined by the lowest operation frequency and the maximum reflection coefficient which is to occur in the pass band.

Figure 2(a) Multi-section quarter wave transformer and (b) Input reflection coefficient of a two-section quarter wave Chebyshev transformer

Figure 3 (a) Tapered transmission line and (b) Input reflection coefficient

In this paper we will explain the basic concepts of tapered transmission lines and their applications. Also we will analyze the methodology for designing back to back tapered line transition. At the end we
will design and experiment of back-to-back tapered line transition

2 Basic concepts for tapered transmission-line

A tapered line is transmission line whose characteristic impedance is gradually tapered from one value to another. Tapered lines may be used as a coupling transformer between loads and generators of unequal resistive impedances, provided that the change in impedance along the line is sufficiently gradual [7]. As we know, multi-section transformer designs have involved a monotonic change in characteristic impedance, from $Z_0$ to $R_L$. Now, instead of having a stepped change in characteristic impedance as a function position $Z$ (i.e., a multi-section transformer), we can also design matching networks with continuous tapers.

A tapered impedance matching network is defined by two characteristics—its length $L$ and its taper function $Z_1(Z)$, see figure below:

![Tapered impedance matching network](image)

Figure 4. Tapered impedance matching network

The bandwidth of a multi-section matching transformer increases with the number of sections. Similarly, the bandwidth of a tapered line will typically increase as the length $L$ is increased [9]. If the tapered-line section has an electrical length of two or more wavelengths, the impedance transformation takes place with negligible reflections over a broad band of frequencies [7]. Most tapered lines are implemented in stripline or microstrip. As a result, we can modify the characteristic impedance of the transmission line by simply tapering the width $W$ of the conductor. In other words, we can continuously increase or decrease the width of the microstrip or stripline to create the desired impedance taper $Z_1(Z)$ [8] – [9].

3 Methodology for designign back-to-back tapered line transition

This paper presents a methodology to design microstrip to balanced stripline (printed twin-line) tapered transitions, and use them to construct feed networks for arrays of double-sided strip dipoles. The transition is accomplished by narrowing the width of the ground plane of microstrip line in tapered fashion. The cross-section of the microstrip conductor is then varied to obtain the required impedance across the taper length. A quasi-TEM method is used to calculate the transmission characteristics of an asymmetric and in-homogenous line. Conductor widths of various printed microstrip to balanced stripline transition are calculated and their characteristic impedance and effective dielectric constant across the length are presented. Circuits consisting of identical back-to-back transition are fabricated and measured for two kinds of tapered liens, a 50Ω (microstrip) to 100Ω (balanced stripline) and a 100Ω (microstrip) to 50Ω (balanced stripline) transition. Experimental results on fabricated back-to-back transitions are in good agreement with theoretical ones.

4 Design and experiment of back-to-back tapered line transition

To confirm the validity of the described procedure, experiments were performed on circuits of back-to-back tapered transitions. Fig 5(a) shows a circuit of two 50Ω microstrip to 100Ω balanced stripline transitions printed back-to-back and connected through a short balanced stripline. Two prototypes circuits, $A$ and $B$, were fabricated on a dielectric substrate of height 0.8mm and dielectric constant 2.2. The circuit $A$ has both transitions printed symmetrically, while the circuit $B$ has transitions printed in inverted version. In Fig. 5(b), the computed values for scattering parameters of this circuit are compared with experimental data, showing very good agreement. Measured results of two prototype circuits were very close to each other confirming the symmetrical behaviour of the transition. The measured insertion loss was between 0.25–0.35dB, which is almost equal to the total dielectric and conductor losses of this 250mm transmission line.
A $50\Omega$ two-way microstrip power divider followed by a $100\Omega$ microstrip to $50\Omega$ balanced stripline transitions have been used to realize tapered line feed networks for arrays of double-sided printed strip dipoles [5]. A circuit of two identical back-to-back dividers, as shown in Fig. 6(a), was fabricated on a dielectric substrate of height $0.8\text{mm}$ and dielectric constant $2.2$. Theoretical and experimental results for scattering parameters of this circuit are in good agreement as shown in Fig. 6(b). The insertion loss of $0.6-0.7\text{dB}$ between two connectors was measured. For the used dielectric substrate with copper conductors and dielectric $\tan \delta = 0.0015$, the total attenuation constants due to the dielectric and conductor losses at $f = 2\text{GHz}$ of the $50\Omega$ and $100\Omega$ microstrip lines were calculated to be $0.86\text{dB/m}$ and $0.94\text{dB/m}$, respectively. The respective attenuation constants of the $50\Omega$ and $100\Omega$ balanced stripline were found to be $0.86\text{dB/m}$ and $0.96\text{dB/m}$, respectively. Using an average value for the attenuation constant of tapered line, a simple calculation showed that the insertion loss of the $600\text{mm}$ long experimental circuit to be approximately $0.55\text{dB}$. Therefore, it can be concluded that the radiation losses of this circuit were negligible.

5 Conclusion
In this paper we have presented a circuit of two $50\Omega$ microstrip to $100\Omega$ balanced stripline transitions printed back-to-back and connected through a short balanced stripline. We have computed the computed values for scattering parameters of this circuit and we compared with experimental data, showing very good agreement. We may conclude that in this case measured results of two prototype circuits were very close to each-
other confirming the symmetrical behaviour of the transition.

Also we have analyzed a 50Ω two-way microstrip power divider followed by a 100Ω microstrip to 50Ω balanced stripline transitions. We have used this to realize tapered line feed networks for arrays of double-sided printed strip dipoles. Theoretical and experimental results for scattering parameters of this circuit are in good agreement.

References:
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