STRIPLINE COMPONENTS

A stripline is a signal carrying conductor sandwiched between two layers of dielectric that are shielded by ground planes.

Figure 1. Cross section of a stripline.

The simplest form of a stripline is shown in Fig. 1. This is in contrast to the microstrip line, shown in Fig. 2, where the signal-carrying conductor is exposed and may radiate. In antenna applications, the stripline finds its greatest use in the feed structure. A popular modern antenna element is a microstrip patch radiating element being fed by a stripline. Both stripline and microstrip circuits are usually planar structures in that their properties can be controlled by changing one dimension of the circuit. For example, the characteristic impedance of a stripline can be controlled by changing the width of the line (1).

In a stripline, both the ground plates are held at the same potential. The resultant symmetry in the structure implies that the balanced homogeneous stripline supports mainly TEM (quasi-TEM) waves. A microstrip circuit, in contrast, operates in a highly inhomogenous environment and hence analysis of striplines is usually easier than the analysis of a microstrip circuit.

In antenna applications, striplines can provide some significant advantages (2). The stripline is compact and can hence replace bulky waveguides. Producing stripline components on a large scale requires the manufacturing and testing of only one component. An unlimited number of identical components can be manufactured using the same template. Therefore, in commercial applications, striplines can be significantly less expensive than waveguides. In addition, all the components required to make up the complete circuit can be placed on a single substrate. This allows for compact circuit designs and circuits that can be flush-mounted on any desired surface. This property is particularly useful in the design of airborne antenna arrays and wireless communication antennas. Furthermore, the placement of all components on a single substrate eliminates the need for interconnections, usually the source of unreliable manufacturing.

At lower frequencies, a good choice of the substrate material can lead to significant savings in circuit size. This reduces the weight and cost of many transmit and receive systems. Although traditional waveguides can usually handle higher power levels than striplines, in most applications the stripline feed structures have adequate power-handling capabilities. Also, the structured design of a stripline circuit allows for the easy interchange of components to replace defective ones.

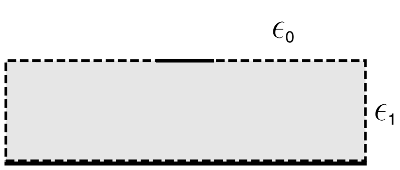

Figure 2. Cross section of a microstrip line.

The manufacturing of a stripline circuit is a complex task due to its sensitivity to small manufacturing errors. At microwave frequencies all the dimensions of the circuit are important, and small errors can lead to serious degradations in the operation of stripline circuits. The multilayer structure of the stripline leads to dielectric–dielectric and dielectric-metal interfaces. Therefore, the electromagnetic fields must satisfy different boundary conditions at these interfaces. A complete analysis of stripline circuits is hence a complex electromagnetic problem requiring extensive computer resources. Usually, a quasi-TEM (quasi-static) analysis suffices. However, even a quasi-static analysis of multiple striplines in proximity to each other is a complicated task. A stripline circuit also suffers from some practical difficulties since the line must be excited by either a coaxial line or a waveguide. In either case, the connection is a sharp discontinuity requiring the use of matching circuits to reduce reflections.

For antenna applications, striplines can be used in various sections of the feed structures. Some common applications include power dividers, directional couplers, coupled parallel lines, mixers, and switches. Stripline components such as bandpass and bandstop filters and direct coupled hybrids are also extensively used.

The design of a stripline circuit begins with the choice of dielectric material to form the substrate over which the circuit is to be printed. There is no one material that is ideal for all stripline applications. The desired properties of the dielectric material are usually in conflict with each other, resulting in a tradeoff for each requirement. Some aspects of the material that require attention are the dielectric constant and its variation with temperature or frequency, the energy dissipation in the material, and the homogeneity of the material. Other characteristics that play a part in circuit design are the dimensional stability of the material as the operating temperature or humidity changes, the resistance of the material to water, and chemicals used in the printing. The tensile and structural strength of the material, its machinability, and thermal conductivity are also important material properties (3).

The choice of dielectric material helps determine the losses, the characteristic impedance, and the power-handling capability of the line. The choice depends on whether one is interested in peak power or continuous-wave (CW) power. For example, in pulsed radar systems the peak power is significantly higher than the average power, which may lead to arcing in the dielectric substrate. Sharp edges that lead to concentration of fields are a principal cause of arcing. Smoother bends, such as a mitered bend, can help reduce the effect of a sharp corner. The average power capability is mainly a function of the permissible temperature rise of the center conductor and the surrounding material. The thermal conductivity and dielectric losses play a key role in determining the maximum permissible CW power (3,4).

The combination of guided wave circuits with radiating elements leads to a new set of tradeoffs. The properties of materials and structures that enhance printed circuit performance tend to reduce radiation performance. Furthermore, direct-current (dc) biased circuits and the packaging for the stripline feed structure disturb antenna characteristics (5).

Stripline feed circuits usually work at power levels lower than those of waveguides. Hence, a coaxial cable to stripline transition is usually used to launch a signal onto the feed

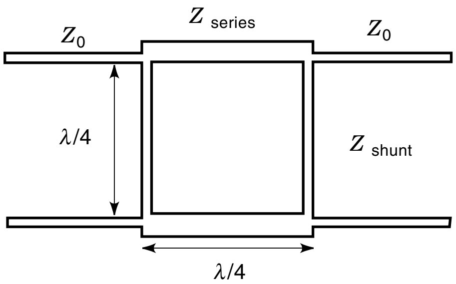

Figure 3. Narrowband directional coupler.

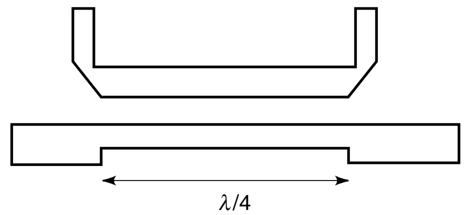

Figure 5. Broadband directional coupler.

line. The coaxial cable supports a pure TEM mode, while the stripline supports a quasi-TEM mode. This makes the transition relatively simple, and matching circuits can be designed to ensure a good match. A transition section is needed if the ground spacing of the stripline is not the same as the dimensions of the cable. If the transition from cable to stripline is ignored, the high capacitance at the transition can lead to effective shorts circuits, causing most of the transmitted energy to be reflected. Broadwall transitions from the side of cable are also possible.

The simplest and least expensive direction couplers or power dividers are by a direct coupled line or a branch line. This allows for single-plane construction as shown in Fig. 3. The ratio of the series and shunt impedances determines the coupling coefficients. This structure is narrowband in nature and a more broadband coupler can be made by extending the circuit to include multiple sections as shown in Fig. 4. A three-section stripline coupler is about the maximum that can be designed without the lines getting too thin to be reliably manufactured (3). Broadband couplers can also be designed by having a main line parallel to a secondary line as shown in Fig. 5.

In antenna applications, a stripline is used as the feed line to the antenna. The stripline must be shielded from the radiating element. In most applications, the stripline feeds the radiating element through a slot in a ground plane. An example of a stripline feed exciting a microstrip antenna element is shown in Fig. 6.

For good radiation characteristics, the patch antenna in Fig. 6 must be built on low relative permittivity materials ($\epsilon_r \simeq 1$) so as to reduce the concentration of fields in the substrate. Furthermore, the substrate should be thick so that the fields due to the patch and its image do not cancel each other. Thick substrates are also useful in building antennas with large bandwidths. A material that satisfies all these properties is foam (2). The microstrip antenna is etched on one side of a thick foam layer with the ground plane on the other side of the foam. The nonresonant slot is cut into the group plane with a stripline under the ground plane exciting the slot. This stripline–slot–foam–inverse-patch (SSFIP) structure was introduced by Zurcher and Gardiol (2).

The stripline could be etched on a foam without the ground plane backing the antenna element. However, the antenna must be mounted on some surface. If the ground plane is removed, the feed structure is affected by the mounting. The metal ground plane protects the stripline from the surface. The mounting surface must be distant from the feed, while for maximum coupling, the feed must be as close as possible to the slot. Hence, the feed is a unbalanced stripline. Furthermore, the SSFIP element is designed with metal walls to eliminate the propagation of parallel plate modes.

The stripline feed is compact and efficient, but it leads to some complications. To have sufficient coupling across the slot, the widths of the stripline must be greater than that used by the microstrip. Furthermore, completely enclosed striplines can lead to resonant frequencies. Mode suppression pins can be used to prevent resonant modes. The resulting structure can be quite complicated, and design of the feed structure requires considerable effort.

A complete analysis of stripline feeds is a very complicated task. In general, no closed-form solutions exist for the currents on the striplines and the fields in the surrounding media. The approach has been to use a numerical solution, using such techniques as the Method of Moments (6–9), to solve for the fields and currents on the stripline. The initial solution techniques accounted for only the quasi-TEM dominant mode; that is, they used a quasi-static analysis.

In Ref. 10, the authors analyzed the crosstalk and coupling between multiconductor transmission lines such as striplines, suspended striplines, and microstrip lines based on modal analysis in the frequency domain. This approach is extended

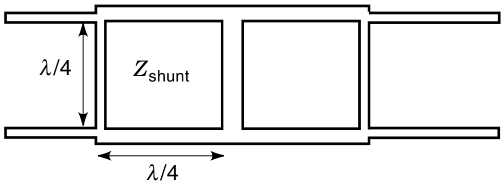

Figure 4. Multisection directional coupler.

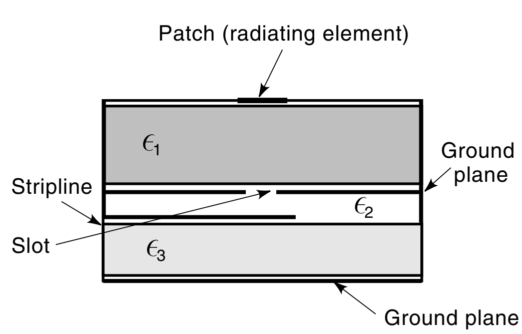

Figure 6. Microstrip patch antenna fed by a stripline through a slot.

in the commercially available software packages LINPAR (11) and MATPAR (12). A time-domain analysis of the multiconductor transmission problem (13) allows for the tracking of digital waveforms as the propagate along the stripline.

Brachat and Baracco (14) analyzed a dual-polarized slot-coupled printed antenna with a stripline feed. They assumed a quasi-TEM mode on the stripline associated with the standing wave due to the serial impedance caused by the slot. Stripline feeds for infinite arrays can be analyzed using Floquet modes (15). In Ref. 15, the stripline feeds an open slot array. Electric and magnetic currents are used in conjunction with the equivalence principle to separate the feed region from the radiation region. The currents on the feed structure are obtained by solving the coupled integral equations for the two regions (16).

As the frequency of operations and power levels have increased, the quasi-TEM approximation is less applicable. Full-wave techniques account for all modes, propagating and evanescent (17). The most popular approach to analyze striplines and microstrip lines is the Integral Equation (IE) formulation in either the space (18) or spectral domain (19,20). Goswami and Sachidananda (20) analyzed a cylindrical cavity-backed suspended stripline (SSL) antenna. The SSL feed is particularly attractive in the higher microwave and millimeter frequency regions. A more rigorous analysis of metal–dielectric bodies such as stripline feeds is possible using subsectional analysis (21).

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