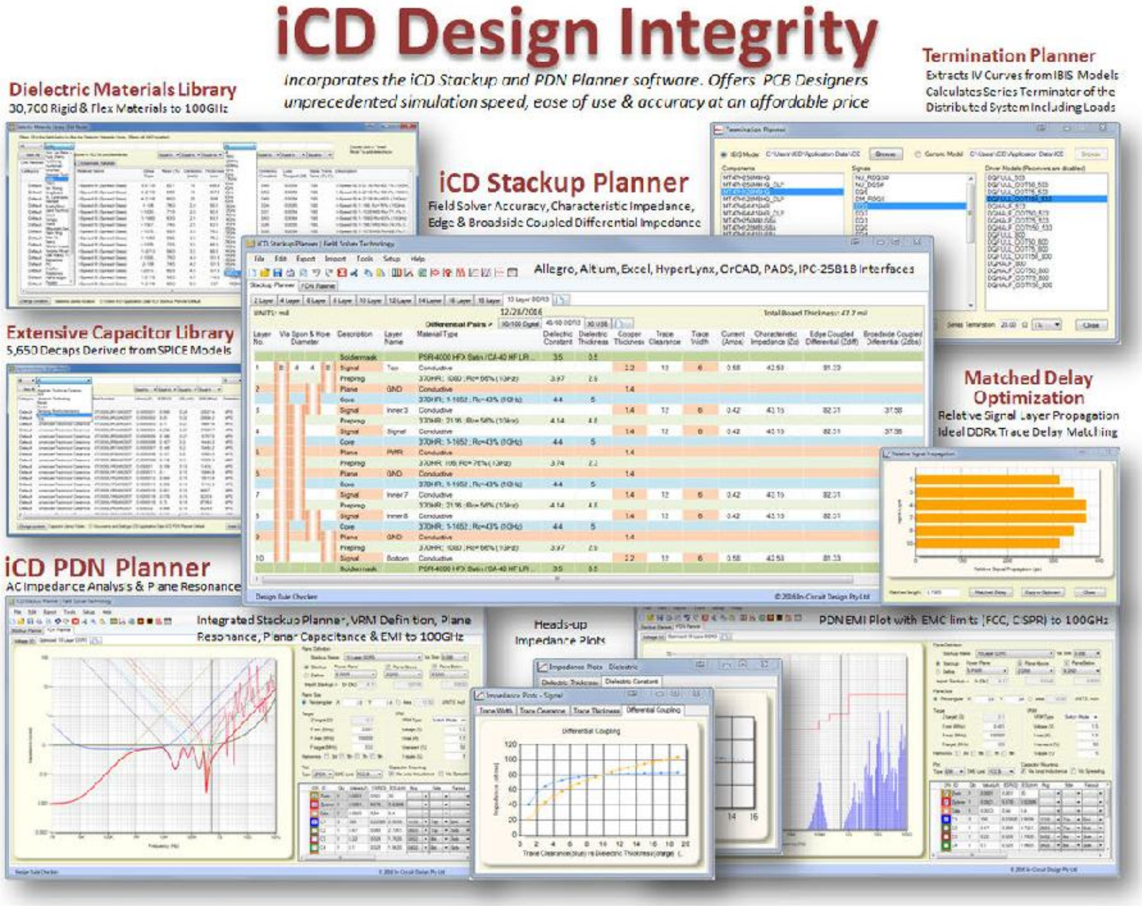

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Next-Gen PCBs—Substrate Integrated Waveguides

by Barry Olney
IN-CIRCUIT DESIGN PTY LTD / AUSTRALIA

As PCB transmission frequencies head toward 100GHz and beyond, the current mainstream PCB technology, the copper interconnect, is reaching its performance threshold. Ultimately, it is dielectric loss, copper roughness, and data transfer capacity that are the culprits. However, the biggest performance restriction for PCB interconnects is the size of the conductor. Metallic waveguides, on the other hand, are a better option than traditional transmission lines, but they are bulky, expensive and non-planar in nature. However, recently substrate integrated waveguides (SIW) structures have emerged as a viable alternative and are ideally suited to the high-speed transmission of electromagnetic waves.

SIW are planar structures fabricated using two periodic rows of PTH vias or slots connecting top and bottom copper ground planes of a dielectric substrate as shown in Figure 1 (left). In this month's column, I will review the substrate integrated waveguide and its incorporation with the microstrip transmission line.

Since SIWs are fabricated as part of the multilayer PCB stack, they can be integrated with other planar transmission lines. SIW retain the low loss property of conventional metallic waveguides and are widely used as interconnects in RF and microwave high-frequency circuits to improve bandwidth. However, the signal propagates through the dielectric material rather than through air which slows the signal transmission speed, to about half the speed-of-light, which is still more than adequate for this application.

Transmission lines in the form of microstrip, stripline, coplanar waveguide (CPW), and their derivatives of geometry, have been the backbone of the modern electronic systems for many years. Following the evolution of IC technologies and processing techniques, these fundamental structures have been continuously studied and improved to meet the constantly updated bandwidth and expanded capabilities requirements.

However, the ever-increasing demands for bandwidth and performance, as well as the highly anticipated applications of millimeter-wave (mmWave), have raised the fundamental question of whether classic copper transmission lines are able to cope with the demands for low loss and low dispersion propagation.

Note: mmWave frequencies refer to the electromagnetic spectrum with wavelengths between 1–10 mm representing the frequency range between 30–300GHz. Despite the efforts to evolve and improve the existing transmission line structures, it remains a technological challenge, which necessitates the emergence of a revolutionary concept.

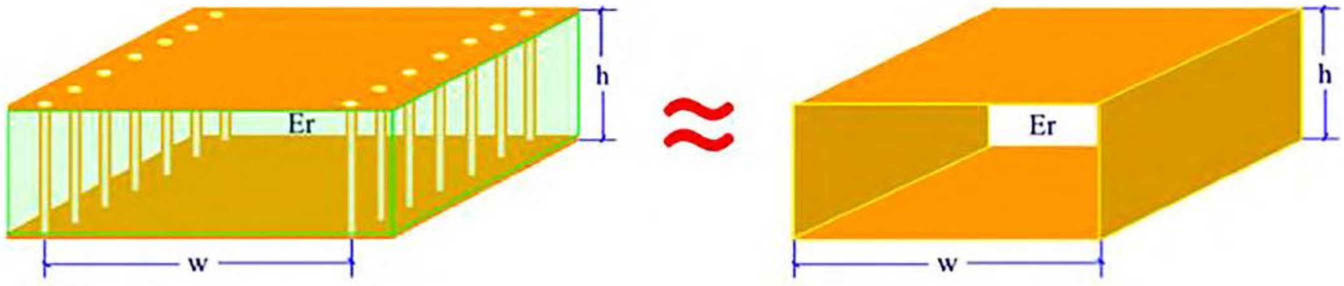

Figure 1: The SIW (left) has similar properties to the metallic waveguide (right).

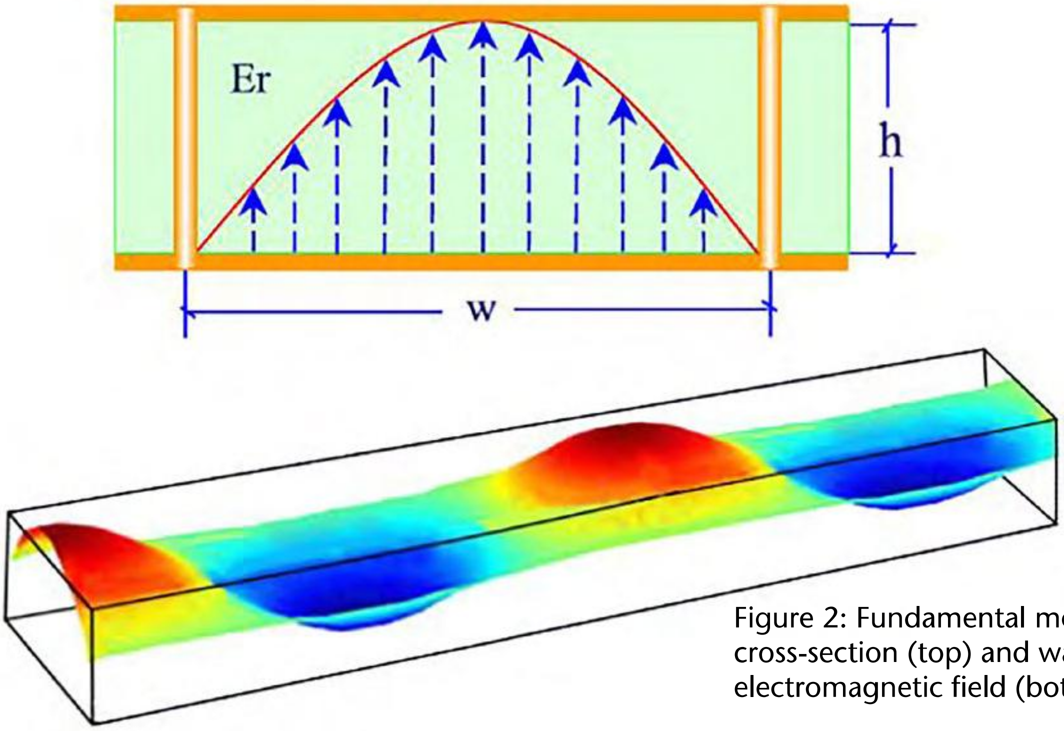

Figure 2: Fundamental mode SIW cross-section (top) and waveguide electromagnetic field (bottom).

Current high-speed PCB interconnects exhibit the following issues:

1. Limited current carrying capacity.

This is basically due to the trace width–3 to 7 mils is the typical range. That is, a signal carrying circumference of 6 to 14mil for stripline and half that for microstrip, without including the sidewall and current crowding. Current crowding, due to the skin effect, reduces the effective capacity by limiting flow, to the outer surface, regardless of the copper thickness.

2. High dielectric loss of the substrate material.

Standard high-speed materials are too lossy however, a more homogeneous, ultra-low loss dielectric solves this problem. Although, the current costs are prohibitive, compared to commonly available dielectric materials, this is likely to come down as the industry accepts them as being necessary.

3. The copper surface is too rough which increases resistive loss.

At high frequencies, the effective resistance of the copper increases relative to the additional distance over which the current must transverse the contours of the surface. This can be alleviated by using smooth copper. However, the copper foil is produced smooth and then roughened purposely, in two stages, to prevent de-lamination.

4. The signal data transfer capacity is limited by distributed losses.

Pragmatic effects, such as frequency dependent losses, come into play at clock frequencies above 1GHz. They are of concern for fast rise time signals, with long trace lengths, such as multi-gigabit serial links. This frequency dependence causes rise time degradation and reduces the upper bandwidth, of the signal, resulting in reduced channel data transfer. Substrate integrated waveguides can be used as an alternative to improve the bandwidth however, the transitioning from the familiar microstrip or CPW to a SIW can be a challenge.

Similar to the signal propagation characteristics of the traditional waveguide, the electromagnetic wave in a SIW also moves forward, reflected along a zigzag route between the two fences of vias. Since the vertical metal walls are replaced by PTH via fences for the SIW structures, propagating modes are very close to, but not identical to, those of the rectangular waveguides. Each SIW has a specific lowest transmission frequency. The cut-off frequency (fc) is proportional to the width (w) of the particular SIW where c is the speed of light and Er is the dielectric constant of the substrate material.

$$fc = \frac{c}{2\,.\,w.\,\sqrt{Er}}$$

The most distinguishing characteristic of the SIW is the current distribution of the vias. The surface current on a traditional waveguide can flow forward in any direction. However, the current on the SIW, via barrel surface, is limited to the vertical direction only. As the vias are discrete, the current cannot flow longitudinally across the regular intervals. Therefore, the electric field in the SIW can only travel in the transverse electric mode (TEM), perpendicular to the direction of propagation as shown in Figure 2 (top).

Several types of transition from SIWs to microstrip or CPW structures are possible but as mentioned previously, can be challenging to implement. They can be roughly divided into single substrate or multilayer substrate applications. Dual-layered SIW transitions to microstrip or CPW structures have been successfully applied. But multilayer SIW circuits often suffer from alignment issues. Z-axis alignment, of the multilayer laminate book, has always been a major limitation of implementing any broadside coupled application.

The requirement that the TEM field in the SIW be adapted to the fundamental mode of the transmission line is common to all transitions involving SIWs. However, due to the similarity between the traditional waveguide and microstrip modes, the microstrip to SIW transition is undoubtedly the simplest to implement.

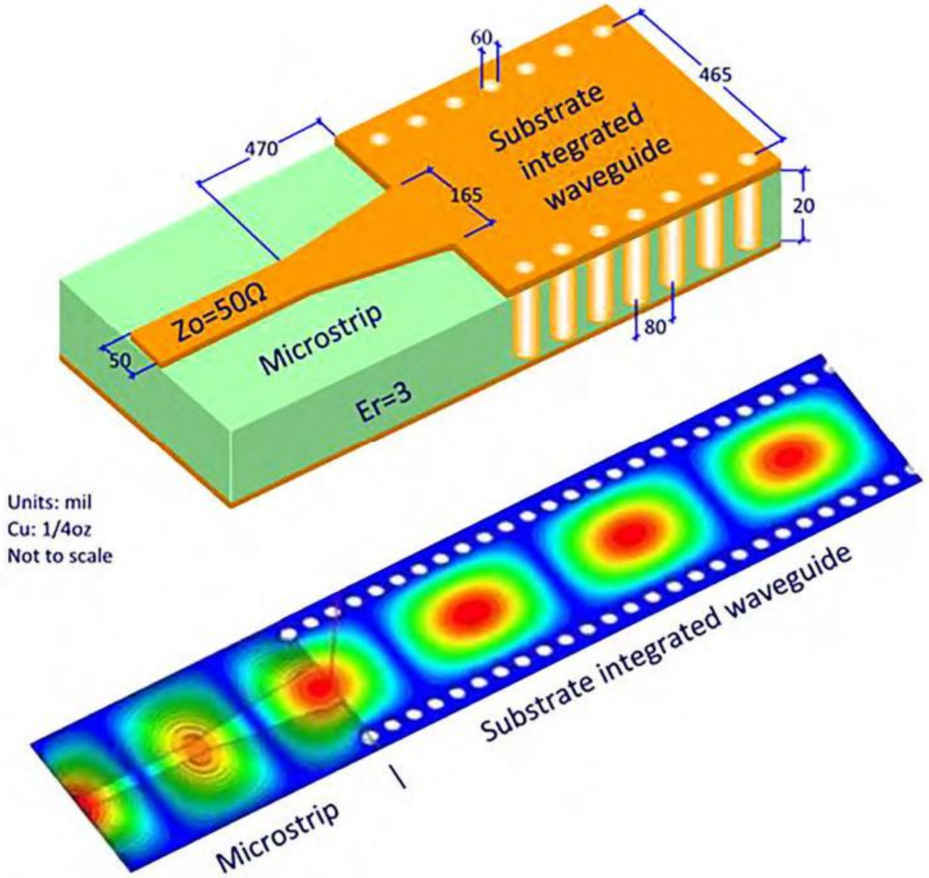

Figure 3: Microstrip to SIW transition and simulated electric field (source: Kumar[3]).

Figure 3 illustrates the transition from a microstrip transmission line to a SIW. The propagating electromagnetic wave, which is guided by the microstrip trace, travels through the dielectric, solder mask and air. However, as the wave enters the SIW, it begins to tunnel between the ground planes and as such, the dispersion losses are solely based on the losses of the substrate material. A homogeneous, ultra-low loss dielectric provides the best frequency response.

Elaborating on how the requirements, of the transition, are calculated is beyond the scope of this column however, the associated equations are provided in a paper by Kumar et al [3]. Although, I can confirm that the impedance of the microstrip trace is 50.45Ω (simulated by the iCD Stackup Planner), one would expect the impedance to remain constant at ~50Ω through the SIW to perfectly transfer the energy. The simulation, of the electric field, shows how the losses reduce as the electromagnetic wave enters the SIW. Here the field become more intense, and less distributed, providing clarity of signal and thus higher bandwidth. Obviously, another similar transition back to microstrip, at the other end to receive the signal, is also required.

Substrate integrated waveguides are low loss structures that provide high bandwidth and eliminate the need for both differential serial (SERDES channels) and space consuming parallel busses. They exhibit similar performance to traditional waveguides but, can be built as planar PCB structures. This greatly reduces the cost and tremendously improves the performance, of data transfer, compared to the traditional PCB interconnect to 100GHz and beyond.

Points to remember:

- Conductor size, dielectric loss, copper roughness, and data transfer capacity impact on the performance of copper interconnects at high frequencies.
- Recently substrate integrated waveguides (SIW) structures have emerged as a viable alternative.
- SIW are planar structures fabricated using two periodic rows of PTH vias or slots connecting top and bottom copper ground planes of a dielectric substrate.
- SIW retain the low loss property of conventional metallic waveguides.
- PCB interconnects have limited current carrying capacity, high dielectric loss, rough copper surfaces and restricted signal data transfer capacity.
- SIW propagating modes are very close to, but not identical to, those of the rectangular waveguides.
- The most distinguishing characteristic of the SIW is the current distribution of the vias, which is limited to the vertical direction only.
- Microstrip to SIW transition is undoubtedly the simplest to implement.
- Substrate integrated waveguides are low loss structures that provide high bandwidth and eliminate the need for both differential serial (SERDES channels) and parallel busses. **PCBDESIGN**

References

1. Barry Olney's Beyond Design columns: Microstrip Coplanar Waveguides, Effects of Surface Roughness on High-Speed PCBs, Transmission Line Losses.

2. SI List forum: Scott McMorrow, Yuriy Shlepnev.

3. A Review on Substrate Integrated Waveguide and its Microstrip Interconnect, by Kumar, Jadhav, Ranade.

4. Substrate-Integrated Waveguide Transitions to Planar Transmission-Line Technologies, by Taringou, Dousset, Bornemann, Wu.

5. Design for Tapered Transitions from Microstrip Lines to Substrate Integrated Waveguide at Ka Band, by Mehdi, Keltouma, Mohammed.

Barry Olney is managing director of In-Circuit Design Pty Ltd (iCD), Australia, a PCB design service bureau that specializes in board-level simulation. The company developed the iCD Design Integrity software incorporating the iCD Stackup, PDN and CPW Planner. The software can be downloaded from www.icd.com.au.To contact Olney, or read past columns, click here.