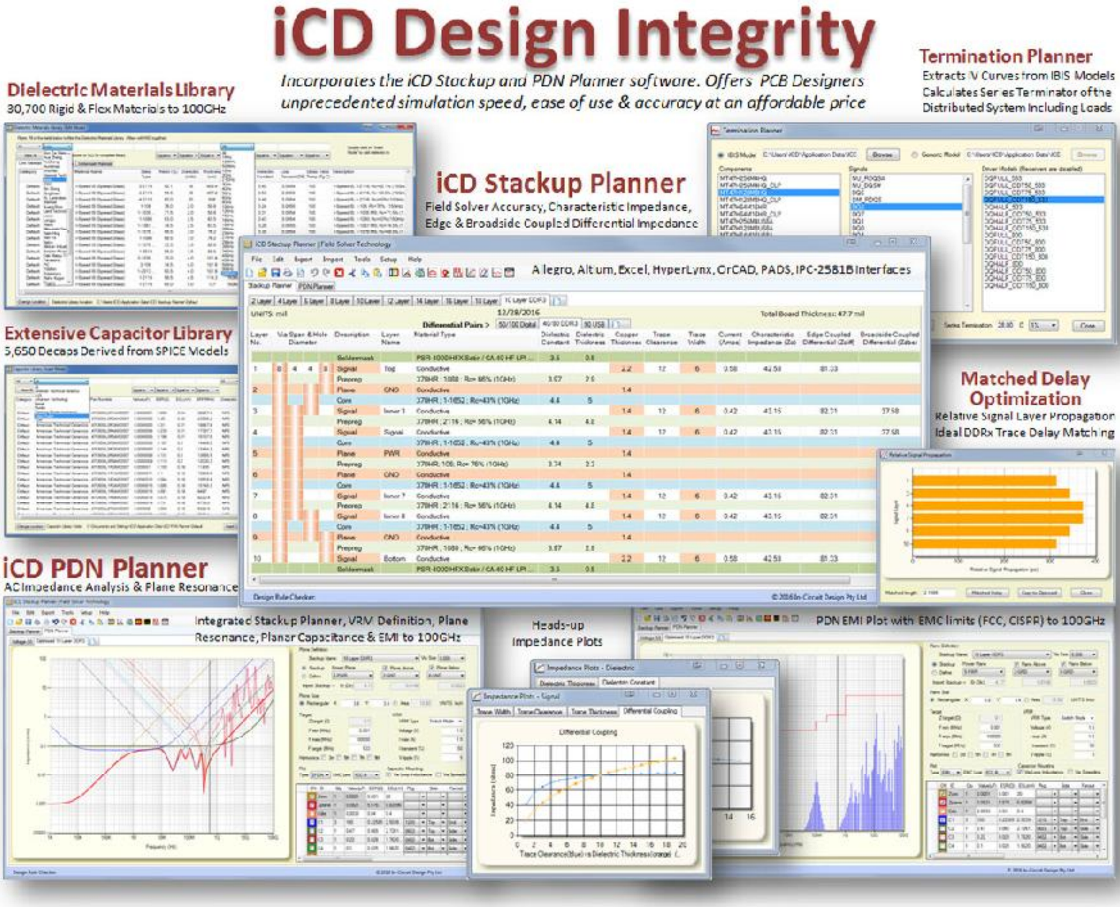

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Microstrip Coplanar Waveguides

by Barry Olney
IN-CIRCUIT DESIGN PTY LTD / AUSTRALIA

The classic coplanar waveguide (CPW) is formed by a microstrip conductor strip separated from a pair of ground planes pours, all on the same layer, affixed to a dielectric medium. In the ideal case, the thickness of the dielectric is infinite. But in practice, it is thick enough so that electromagnetic fields die out before they get out of the substrate. A variant of the coplanar waveguide is formed when a ground reference plane is provided on the opposite side of the dielectric. This is referred to a conductor-backed or grounded CPW. CPWs have been used for many years in RF and microwave design as they reduce radiation loss, at extremely high frequencies, compared to traditional microstrip. And now, as edge rates continue to rise, they are coming back into vogue. In this month's column, I will look at how conformal field theory can be used to model the electromagnetic effects of microstrip coplanar waveguides.

Simplistically, space has three dimensions. Picturing a box, we observe the three dimensions of width, height and depth (x,y,z). But, there is an obvious fourth dimension–time. The box will only exist for a certain period of time. These three spatial dimensions plus the temporal dimension are referred to as space-time. But in the intricate world of quantum physics, there can be as many as 26 dimensions used to model the complexities of quantum fields.

In 1921, Theodor Kaluza, a mathematician, proposed that our intuition has misled us and suggested that space-time actually has five dimensions. Kaluza adapted Einstein's General

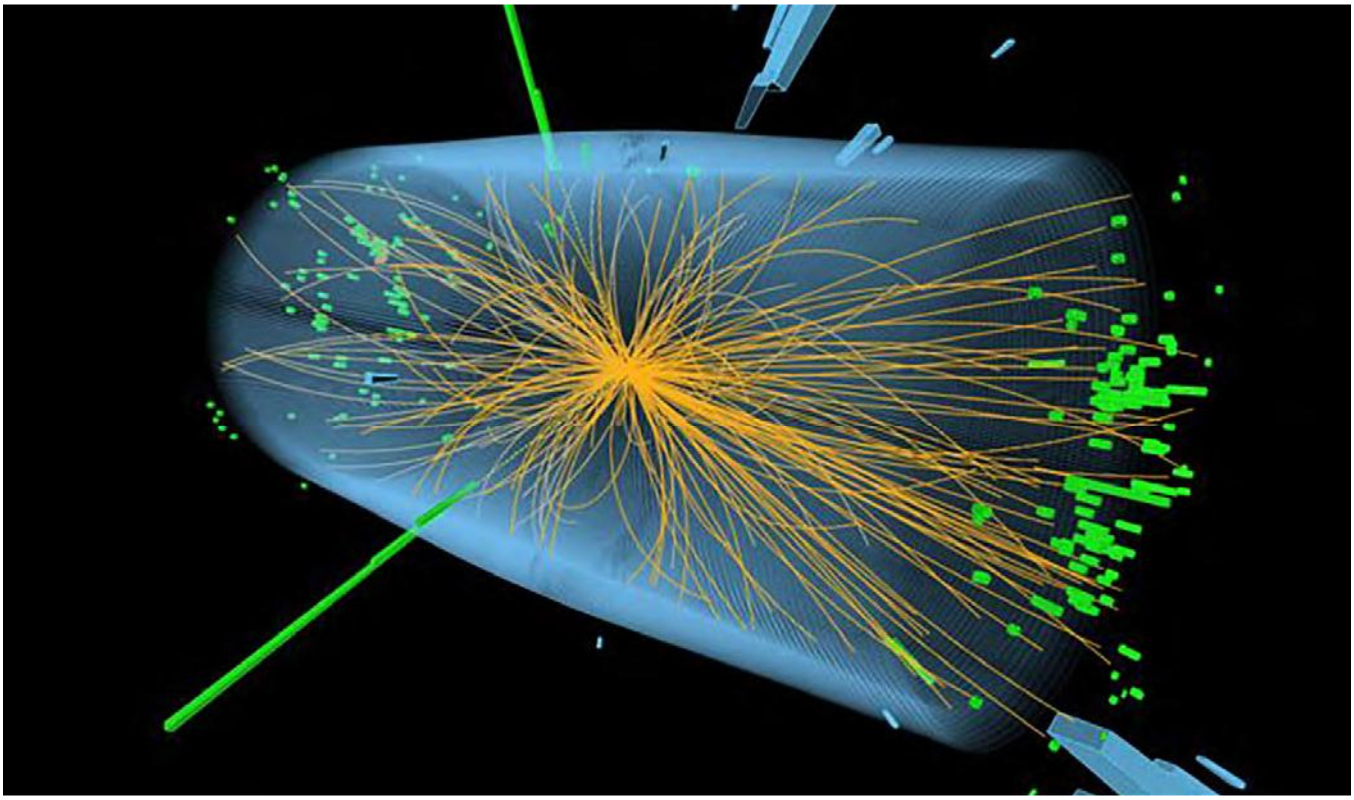

Figure 1: A Higgs boson quantum fireworks display (source: CERN).

Theory of Relativity that was formulated to the familiar four dimensions, and rewrote it to apply to five. Surprisingly, these terms corresponded precisely to the description of electromagnetism that James Clerk Maxwell had published decades before. By adding the extra dimension, Kaluza had unified gravitation and electromagnetism–two of the fundamental forces of nature.

This fifth dimension is not apparent to us at the macro scale, as it is a minuscule curling spatial dimension bound by the other larger dimensions. The analogy generally used, to help wrap your head around the concept, is to consider the large dimension to be like a drinking straw. At distant scales of magnification, it appears to be just a straight line. But close up, it has a perpendicular circumference that is curling around the central line of the dimension. This is the compactified small dimension. This fifth dimension represents the varying electric and magnetic fields that radiate at right angles to the central line.

Quantum theory defines the action of particles at the subatomic level. And general relativity has more to do with larger scale forces of nature (e.g., gravity, etc.). But, there is a gray area where these theories merge. Alternatively, string theory seeks unification, of these two theories, by replacing particles with the minute motion of strings. In string theory, the motion of a string has what is known as "conformal symmetry." This basically implies that if you've worked out a valid trajectory for a string, you can then generate another valid trajectory by warping the string, in a way that preserves angles, on the (imaginary) surface as the string sweeps out. The part of the calculation that is inconsistent, when the string trajectory is warped, is called the conformal anomaly. It's made up of the sum of the different forces with a contribution coming from each dimension of space-time. But if you pick the dimension just right, the aggregate of the anomaly adds up to zero.

Physicists then extended this theory from just gravity and electromagnetism to include additional forces of nature–the weak and strong nuclear forces. In superstring theory, there are 10 dimensions, consisting of nine spatial dimensions and one temporal dimension. In M-Theory, there are 11 dimensions: nine spatial dimensions, one temporal dimension and one energy dimension. These are:

1. Length
2. Width
3. Height
4. Time
5. Gravity/energy/electromagnetism
6-10. These are hypocritical and theoretically exist due to string theory concept.
11. This is M-Theory that proves that all the above dimensions are true if you look from this dimensional point of view.

The bosonic string theory requires 26 dimensions. This describes the Higgs boson particle, recently discovered at CERN's Large Hadron Collider particle accelerator in Switzerland (Figure 1), for example. It interprets all four fundament forces of nature and our perceived reality with space, time, matter and motion.

Conformal mapping techniques (CMT), first utilized by C. F. Gauss in 1820 whilst observing the effects of electricity and magnetism, is another approach that can be effectively used to evaluate semi-infinite conformal symmetry. Different types of solvers are optimized for solving different kinds of structures and this technique is accurate for symmetric microstrip structures. By choosing an appropriate mapping function, one can transform complex polygon geometric shapes into a much more convenient form,

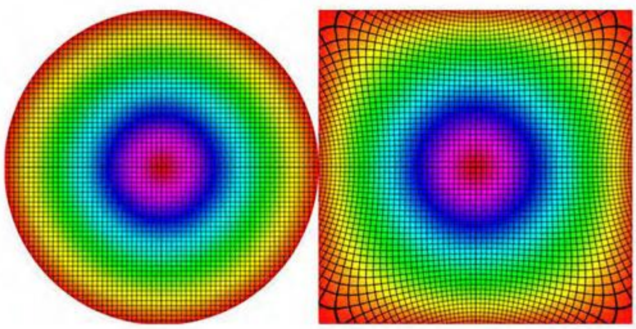

Figure 2: A circle is mapped into a square (source: flickr.com).

where they are easier to solve, and find the solution. For instance, a circle can be transformed into a square (Figure 2). Or an open geometry like that of planar traces (traces referenced to planes), on a PCB, can be transformed into a closed geometry. The CMT equivalent is a coordinate transformation and is applicable to both planar and non-planar transmission lines. CMT are ideal for analyzing coplanar waveguides (CPW) particularly those that lack a ground reference plane.

All electrical systems function based on the action of electric fields produced by charges, and magnetic fields produced by currents. To understand the working principle of these systems, the field lines, that envelop them, must be evaluated, allowing a spatial visualization of the phenomena. These maps typically represent flux, equipotential surfaces and densities distributions, having information about field intensity, potential difference, energy storage, charges and current densities.

The conformal mapping or transformation of two intersecting curves from the z-plane to the w-plane (fifth dimension), preserves the angles between every pair of curves. That is, if two curves in the z-plane intersect at a particular angle, the corresponding transformed curves will also intersect at the same angle, although the curves in the w-plane may not have any resemblance to the original curves.

The z-plane (x,y) coordinate system is an orthogonal one. And for an analytical function, the w-plane's (u,v) coordinate system, is also orthogonal. So, an elliptical electromagnetic field, can be transformed into a more useable geometry and still maintain consistency as in Figure 3. This is an example of a set of curves mapped into a set of straight lines which greatly simplifies the analysis.

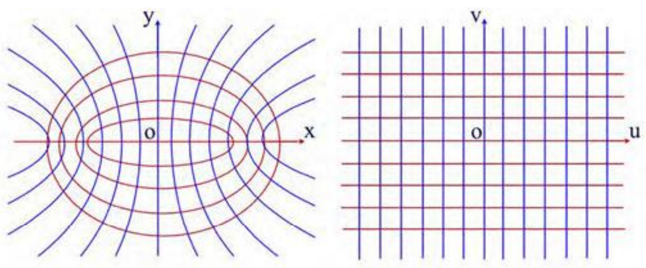

Figure 3: Electromagnetic fields in the z-plane, left, mapped to the w-plane, right (source: Gibbs).

The electrostatic energy in both the (x,y) and (u,v) coordinate systems remains space-time invariant. Consequentially, the capacitance, of a system of conductors, remains unchanged on the transformation of the arrangement of conductors. Under the conformal mapping transformation, there is a change in the geometrical shape of the conductor's arrangement without any change in the capacitance. This is a very important property for the analysis of the transmission line parameters.

CPW expressions are derived using these conformal mapping techniques and elliptic integrals to calculate the impedance of strip configurations. A conventional CPW on a dielectric substrate consists of a center strip conductor with semi-infinite ground planes on either side. This structure supports a quasi-TEM (resembling the transverse electromagnetic wave) mode of propagation. A quasi-TEM wave only exists in a microstrip line–on the outer surface of a PCB. In this mode, electric fields and magnetic fields are perpendicular to each other and perpendicular to the direction of propagation.

The CPW offers several advantages over a conventional microstrip transmission line:

- Simplifies fabrication
- Facilitates easy shunt as well as series surface mounting of active and passive devices
- Eliminates the need for via holes and wraparound (ground plating on the edge of a substrate to provide a low inductance path)
- Reduces radiation loss at very high microwave frequencies

Furthermore, the impedance is determined by the ratio of trace width to clearance, so size reduction is possible without limit, the only penalty being higher losses. In addition, a virtual ground plane exists between any two adjacent lines, as there is no field at that point. Hence crosstalk effects, between adjacent lines, are very weak.

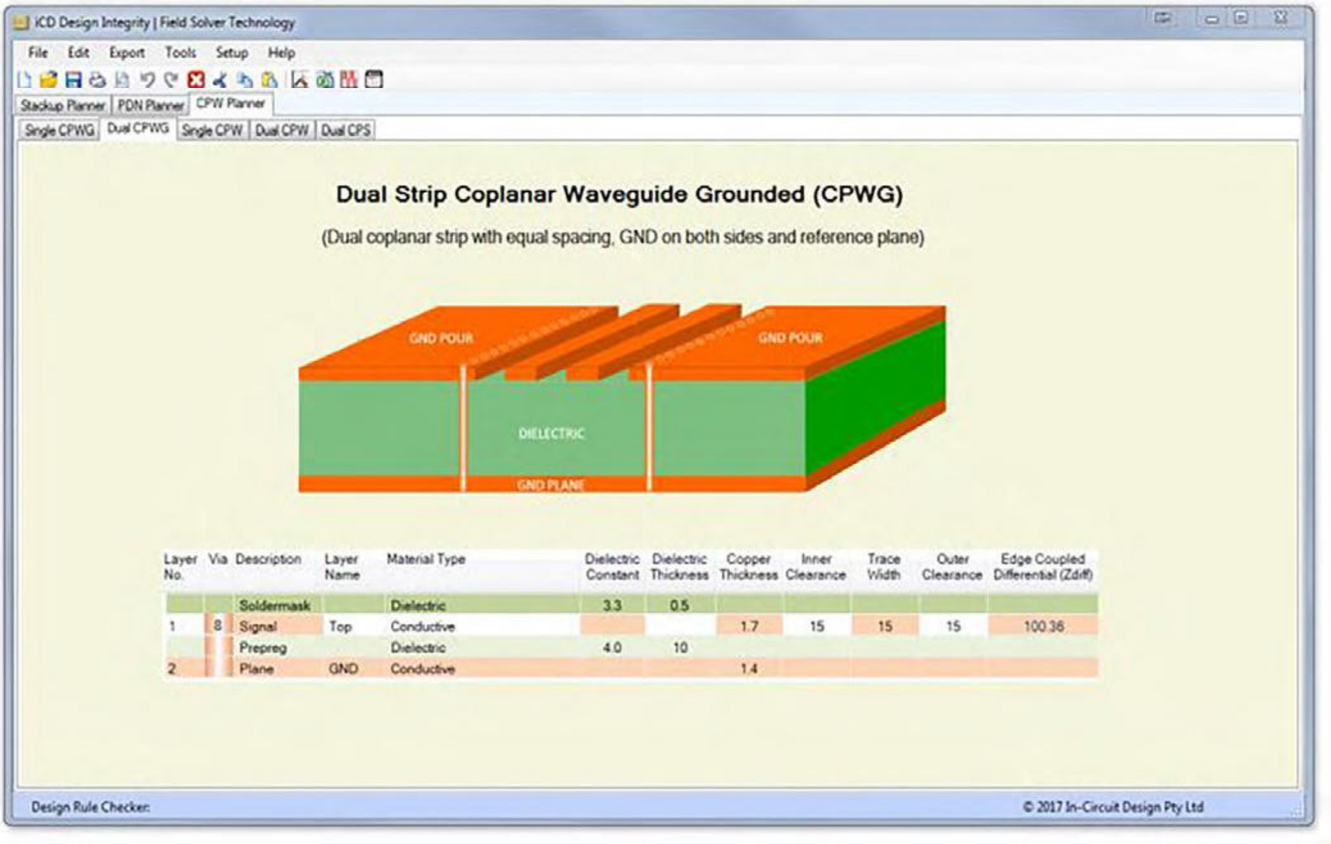

Figure 4: Dual strip coplanar waveguide grounded (source: iCD Design Integrity).

Figure 4 illustrates a dual (or differential) coplanar waveguide, analyzed in the iCD CPW Planner. This structure has equal gaps and ground pours on each side of the strips. The strips are also referenced to a solid ground plane below. Note the fence of stitching vias that are placed at less than a quarter wave length apart, close to the edge of the GND pours. This structure is used to improve isolation between components that would otherwise be coupled by electromagnetic fields. It consists of a row of plated through via holes that, if spaced close enough together, form a barrier to electromagnetic wave propagation. Planar strips readily couple to each other when in close proximity, an effect called parasitic coupling. The coupling is due to fringing fields spreading from the edges of the strip and intersecting adjacent lines or components.

Even if you are not involved in RF or microwave design, the use of CPWs is extremely useful when dealing with isolated differential strips without a ground reference plane as in Figure 5. In this case, the ground plane is cleared around a gigabit Ethernet connector to provide isolation from the outside world. So, a plane cannot exist in this area although the differential pair must maintain 100 ohms impedance to match the line. Good design practice for Ethernet ports requires over-voltage and over-current protection devices in addition to proper component creepage distances and electrical trace clearances for both sides of the Ethernet I/O connections, i.e., the line connector and driver (physical layer, or PHY) sides.

Loosely and tightly coupled grounded coplanar waveguides (CPWG) circuits respond differently to the application of conductors with and without a plating–such as electroless nickel immersion gold (ENIG) finish. A tightly coupled CPWG circuit, with an ENIG finish, will suffer greater conductor loss than a loosely coupled CPWG circuit with the same ENIG finish.

At approximately 2.7GHz, the resonant

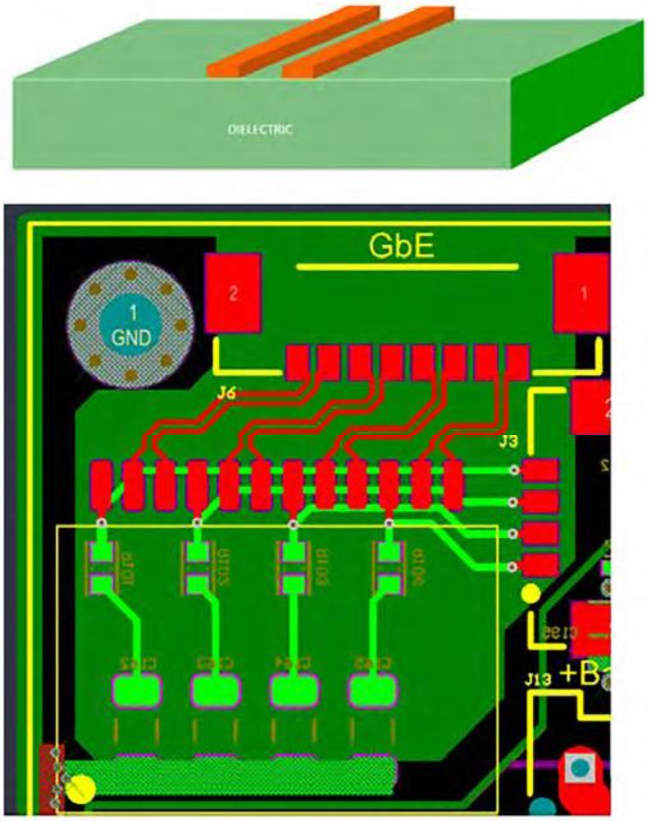

Figure 5: Dual coplanar strip, isolated.

behavior of the nickel component in ENIG increases insertion loss. This resonance is attributed to the ferromagnetic properties of the nickel layer. It is therefore wise to avoid using full body ENIG coating of microstrip and CPW traces at high frequencies. In fact, it may just be an odd 3rd or 5th harmonic, which falls on this particular lossy region, that causes radiation with much lower fundamental frequencies. Therefore, solder mask over bare copper (SMOBC) processing should be considered for all high-speed designs.

In conclusion, conformal transformation is a technique that allows one to take difficult problems, map them into a coordinate system, where they are convenient to solve, and then find a relatively simple solution. Having the property to modify only the geometry of a polygonal structure, preserving its physical magnitudes, conformal mapping is an exceptional tool to solve electromagnetic problems with known boundary conditions.

Points to Remember:

- CPWs have been used for many years in RF and microwave design as they reduce radiation loss, at extremely high frequencies, compared to traditional microstrip.
- Space-time has three spatial dimensions plus the temporal dimension.
- Kaluza adapted Einstein's General Theory of Relativity, which was formulated to the familiar four dimensions, and rewrote it to apply to five.
- By adding the extra dimension, Kaluza had unified gravitation and electromagnetism.
- This fifth dimension is not apparent to us at the macro scale, as it is a minuscule curling spatial dimension bound by the other larger dimensions. It represents the varying electric and magnetic fields that radiate at right angles to the central line.
- String theory seeks unification of quantum theory and general relativity by replacing particles with the minute motion of strings.
- Conformal mapping techniques is another approach that can be effectively used to evaluate semi-infinite conformal microstrip symmetry.
- All electrical systems function based on the action of electric fields produced by charges, and magnetic fields produced by currents.
- The conformal mapping or transformation of two intersecting curves from the z-plane to the w-plane, preserves the angles between every pair of curves.
- The capacitance of a system of conductors remains unchanged on the transformation of the arrangement of conductors.
- A conventional CPW, on a dielectric substrate, consists of a center strip conductor with semi-infinite ground planes on either side.
- CPWs reduce radiation loss at very high microwave frequencies.
- CPW impedance is determined by the ratio of trace width to clearance, so size reduction is possible without limit, the only penalty being higher losses.
- Grounded CPW structures should have a fence of stitching vias that are placed at less than a quarter wave length apart to form a barrier to electromagnetic wave propagation.
- The use of CPWs is also extremely useful when dealing with isolated differential pairs without a ground reference plane.

• A tightly coupled CPWG circuit with an ENIG finish will suffer greater conductor loss than a loosely coupled CPWG circuit with the same ENIG finish.

• At approximately 2.7GHz, the resonant behavior of the nickel component in ENIG increases insertion loss. Therefore, SMOBC processing should be considered for all high-speed designs.

• Conformal transformation is a technique that allows one to take difficult problems, map them into a coordinate system, where they are convenient to solve, and then find a relatively simple solution. **PCBDESIGN**

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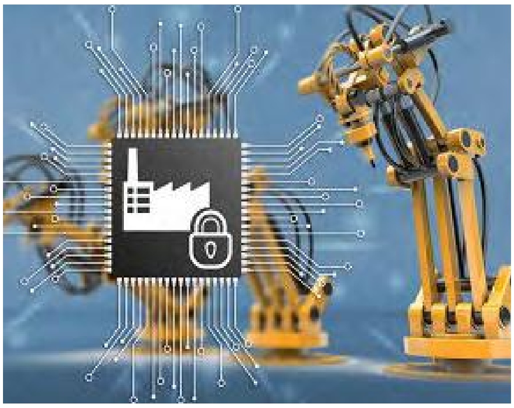
Barry Olney is managing director of In-Circuit Design Pty Ltd (ICD), Australia. This PCB design service bureau specializes in board-level simulation, and has developed the ICD Stackup Planner and ICD PDN Planner software. To read past columns, or to contact Olney, click here.

Updatable Chips for a Safer Internet of Things



Whether it's Industry 4.0, self-driving cars or smart home solutions – connected machines and high-value goods need security mechanisms that can be updated. The objective of the ALESSIO research is to develop and assess these security mechanisms. In this project under the leadership of Infineon Technologies AG, The Technical University of Munich (TUM) collaborates with companies like Siemens AG and the Munich-based Fraunhofer Institute for Applied and Integrated Security.

Every new connected device in the Internet of Things is a potential target: sensitive data and information that are not sufficiently protected could be captured and used for further attacks.

This is why reliable protection for safety-critical information is based on a combination of software and hardware. The hardware – a security chip – is comparable to a safe: a highly protected area in which data and security keys are stored separately from the software. But due to the long life-span of industrial facilities e.g. manufacturers need to be able to respond to changed or new attack methods. Hence the data and security-relevant information in these devices and industrial plants have to be updatable.

Within the next three years, the ALESSIO research partners will develop updatable security solutions for such embedded systems. One of the approaches is a conventional hardware-based Secure Element with updatable software. A Secure Element in complex, programmable logic devices (FPGA, field-programmable gate array) is also underway. In the end, three practice-oriented prototypes will show the solutions' feasibility and functional capabilities.

The project runs until the end of 2019 and is funded by the Federal Ministry of Education and Research with approximately Euro 3.9 million.