Journal of the
Institute of Circuit Technology

Vol.10 No.2 Spring 2017 Issue

2016 Events

1st March *Tuesday* — **ICT Evening Seminar & AGM**
at the Hilton Puckrup Hall Hotel, Tewkesbury.
bill.wilkie@InstCT.org

11th-14th April *Monday - Thursday* — **ICT Annual Foundation Course**
at Loughborough University
bill.wilkie@InstCT.org

13/14th April *Wednesday- Thursday* — EMPS-7th Electronic Materials and Processes for Space Workshop
at Portsmouth University
http://emps.port.ac.uk/documents.html

1stJune *Wednesday* — **ICT Annual Symposium**
at M Shed, Bristol
bill.wilkie@InstCT.org

20th September — **ICT Hayling Island Seminar**
bill.wilkie@InstCT.org

1st December — **ICT Harrogate Seminar**
at the Majestic Hotel, Harrogate
bill.wilkie@InstCT.org

2017Events

14th March Tuesday — **ICT Evening Seminar and AGM**
at the Best Western Plus Manor Hotel,Meriden
bill.wilkie@InstCT.org

24th-27th April — **ICT Annual Foundation Course**
at Chester University
bill.wilkie@InstCT.org

9th - May Tuesday — **ICT Annual Symposium**
at the Black Country Museum
bill.wilkie@InstCT.org

The Next Revolution.

"Safety and Security" robot

Continuing Bruce's theme of productivity led me to wonder about the impact robots will have on our working lives. Appended is a photograph of a "Safety and Security" robot I saw in March at the Juniper Networks HQ in California. It autonomously patrols the car parks, collecting real-time on-site data using its sensors. The data includes car licence plates, facial recognition and people's movements. The robot then analyses the data and determines when to alert the authorities relaying video back to security control. When it needs charging it goes to its parking station, other than that it doesn't need feeding or breaks, it follows its instructions meticulously and doesn't complain about working conditions or pay. There are over 100,000 licensed security guards in the UK. Considerable productivity savings could be made if say, half of them, were to be replaced by autonomous roving robots; this would also seem to be a logical extension of the move towards CCTV surveillance in recent years. The question then arises, what will all the unemployed security guards do? They won't be able to find work driving taxis where over 300,000 people are employed as these will become self-driving, nor in the freight business where 600,000 HGV drivers may also be looking for another job for the same reason. Low skilled labour of all kinds will be impacted by the Robot revolution. It doesn't end there though, alongside this is the Artificial Intelligence (AI) revolution where knowledge workers in banking, accountancy, law and the medical profession are also at risk of being replaced.

The 1st Industrial Revolution of the 18th and 19th centuries resulted in unprecedented sustained growth of average income and population. The current, or 4th Industrial Revolution will doubtless have a profound impact on all of our lives, and maybe, just maybe, humans will be granted more time with family and friends whilst the robots do all the work.

Here's hoping!

Alun Morgan

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Review of :-

Institute of Circuit Technology Spring Seminar, Meriden, UK, 14th March 2017

by **Pete Starkey**

ICT Treasurer Chris Wall

There has long been debate over the exact location of the geographical centre of England, but the village of Meriden has traditionally laid claim to the title, and it offered an appropriate Midlands venue for the Institute of Circuit Technology 2017 Spring Seminar, which followed the Annual General Meeting of the Institute.

Introduced by **ICT Treasurer Chris Wall**, the seminar programme commenced with a presentation from **Dr Tom Jones**, Research Associate at Heriot-Watt University, who discussed the results of a research project carried out jointly with Merlin Circuit Technology to investigate how copper electrodeposition in via interconnects could be enhanced by megasound acoustic agitation.

Copper electrodeposition in via interconnects could be enhanced by megasound acoustic agitation.

It had been demonstrated that, with megasonic-assisted plating, higher-aspect ratio via holes could be incorporated in high-layer-count multilayer builds, simplifying the construction and reducing the number of bonding and drilling operations required. In his 26-layer example, bonding operations had been reduced from six to four, and drilling operations from ten to six.

Dr Tom Jones
Research Associate at Heriot-Watt University

Megasonic agitation enabled higher limiting currents to be achieved, by reducing the Nernst diffusion layer thickness from the 600 micron to the 0.6 micron level, and gave greatly improved solution circulation within small holes, as Dr Jones illustrated with high-speed video of microbubbles penetrating into a high-aspect-ratio 40 micron through-hole. He showed a series of examples produced on his experimental set-up at Merlin PCB Technology, comparing the effects of no agitation, conventional air and panel agitation, and megasonic agitation, using for purposes of demonstration a conventional non-filling copper chemistry and both simple DC and reverse-pulse rectification. The megasonically agitated examples showing substantial improvements in throwing power.

But although megasonic plating assistance gave some clear benefits inside via holes, it could lead to some interesting but potentially undesirable surface effects. Dr Jones explained how surface acoustic waves induced unwanted variations in plated copper topography, in the form of ridges on surfaces and ringlets around holes, with a pitch related to the wavelength of the megasonic agitation. The thickness variations had been shown to correspond with changes in grain structure resulting from alternate concentration and depletion of additives. These resonance effects could be overcome by acoustic modulation techniques, although the impact on plating enhancements had not yet been investigated.

LED lighting in automotive, industrial, municipal and domestic applications

There have been many presentations at ICT seminars related to the rapidly accelerating adoption of LED lighting in automotive, industrial, municipal and domestic applications, but these have generally concerned substrates and materials, with an emphasis on efficiency and thermal management. LED devices sold in Europe carry a "CE" marking - what does it signify, and what are the supplier's responsibilities and obligations? LED expert **Peter Dobromylski**, Technical Sales Manager

Peter Dobromylski
Technical Sales Manager
LUX-TSI

of LUX-TSI, unravelled the mysteries of CE marking compliance for LED lighting products.

He explained that "CE", an abbreviation of ConformitéEuropéne, was introduced in the 93/68/EEC Directive in 1993, as the basis for demonstrating that a product met minimum standards of safety and performance, ensuring protection of the end user and expected performance and reliability in normal use.

Quality of lighting, particularly in the workplace, was extremely important for the well being and performance of the workforce, and Dobromylski described the effect of light on the circadian rhythm, a natural cycle regulating many physiological processes. He demonstrated the difference in the "flicker effect" between two nominally similar LED light bulbs, the "bad" example showing a distinct stroboscopic effect when a pencil was waved in front of it. The human eye had evolved to respond to natural light with a spectral peak at 555nm, but LED light had an additional peak at about 460nm, which was not visible and presented a photobiological hazard that required to be assessed during the CE certification process, and labelled for eye safety when a Risk Group 2 hazard was determined to exist.

For LED products for use in general lighting applications the route for CE marking was through self-certification, and involved a process of identifying the applicable directives, the conformity assessment and the relevant standards, ensuring that the product complied, identifying whether independent assessment was required, maintaining the technical document file, preparing the document of conformity, affixing the CE mark and suppling instructions.

Key directives were the following :-
Low Voltage Directive (LVD) - 2014/35/EU,
Electro-Magnetic Compatibility (EMC) Directive - 2014/30/EU,
Restriction of Hazardous Substances (ROHS) Directive - 2011/65/EC
Eco Design Directive (ERP) - 2009/125/EC.

Applicable standards were Safety :-
IEC 62560 (Lamps),
IEC 60598 (Luminaires),
IEC 62031 (LED Modules)
IEC 61347 (Drivers, Ballasts and Gear).

Photobiological -
IEC 62471/62778 (LED Packages, LED Modules, Lamps and Luminaires).

Electro Magnetic Effects (EMC/F)
IEC/EN 62493 (Lamps and Luminaires), CISPR 15 ed8.0 (2013-05),
IEC 61547 ed2.0 (2009-06),
IEC 61000-3-2 ed4.0 (2014-02),
IEC 61000-3-3 ed3.0 (2013-05).

Once the manufacturer was confident that the product met all the requirements, "Is it safe? Will it do the job? Will it deliver the savings I expect over life?" he could declare the conformance and apply the CE mark. It was stressed, however, that the self-certification process was not rigorously policed!

Use of PCB technology as an alternative to systems based on low-temperature co-fired ceramic

Jim Francey, Sales Manager Northern Europe for Optiprint AG, announced that a significant opportunity existed to use PCB technology as an alternative to systems based on low-temperature co-fired ceramic in future 5G cellular mobile communication networks, where it was expected that millimetre-wave radio architectures would be employed to ease "spectrum congestion" in current 4G and earlier configurations.

With reference to Optiprint's collaboration in the FP7 MiWaveS project, he discussed the technology needed to satisfy interconnect and antenna requirements related to the use of PCB for access-point and wireless backhaul to provide mobile access up to 5 Gbps peak and 250

Jim Francey
Sales Manager Northern Europe
Optiprint AG

Mbps of typical data rate per user. The use of millimetre-wave radios and directive antennas in short-distance links would result in a reduced emitted power requirement, more efficient transmitter implementation and a better efficiency of the spectrum usage, as well as reducing people's exposure to microwave radiation.

Organic, as opposed to ceramic, substrates offered an attractive solution for millimetre-wave hardware interconnect and antennae, with mature PCB fabrication and assembly technologies and numerous fabricators and assemblers, although from a PCB manufacturing perspective the effective distribution and propagation of signals in millimetre wavelengths placed critical demands on the choice and thickness of substrates and the dimensional and positional accuracy of PCB features: "It's all about managing losses and maintaining consistency" and "Most of the loss in millimetre-wave is in the conductor"

Liquid crystal polymer had been recognised as a technology-enabling substrate, not only for its low-loss characteristics but because it was available both as thin non-reinforced laminates with low-profile copper, and as bond-plies for thermoplastic fusion bonding at 290°C. But laser-based metrology was necessary to quantify material movement at multiple process stages and maintain critical layer-to layer registration. Likewise, LDI was the essential imaging technique.

Microstrip, stripline and co-planar waveguide transmission line technologies were all deployed in millimetre-wave PCB design, but increasingly designers were using substrate integrated waveguide (SIW) technology, which had the benefits of lower losses and component performance approaching that of conventional air-filled waveguides, with the additional advantages of low radiation leakage and interference.

Francey showed examples of beam-switching Rotman Lens antennae which at 1GHz would be huge but were economically attractive at millimetre-wave frequencies, typically 75mm across, with the advantage of being planar and unobtrusive rather than in the form of a horn.

Component packaging technology was evolving to meet the needs of the millimetre-wave industry, and the embedded wafer-level ball grid array (eWLB) was now available for frequencies up to 86 GHz. Flip-chipping of monolithic microwave integrated circuits (MMIC) was another promising technology for high performance millimetre-wave interconnects. For some MMIC devices like very high power amplifiers, designers had no option but to use bare-die, mounted in laser-machined recesses and gold-wire or gold-ribbon bonded, to minimise losses and inductance. Silver-based, rather than nickel-based conductor finishes were preferred to minimise losses: auto catalytic silver immersion gold gave good results and was wire-bondable.

In his summary, Francey reminded delegates that PCB technology was a viable and cost-effective alternative to low-temperature co-fired ceramic, but made it clear that fabricators would require a high level of expertise in thin-core processing and fine-line close-tolerance imaging and etching, together with the capability to manage variable material movement. He listed the facilities he considered essential for success: off-contact metrology, clean-room conditions, liquid resist with laser direct imaging, laser machining, automatic alignment systems for drilling, milling and routing, controlled-depth drilling and milling, and plasma treatment, together with the right systems to test and inspect. Above all, a culture for working with small-form, high-precision components.

Promising that this would be the final wrap-up of the MACFEST project, **Professor Martin Goosey** summarised the outcome of the Innovate UK supported project to develop new PCB solderable finishes

MACFEST - the finality

Professor Martin Goosey

deposited from ionic liquids, which had followed-on from the European Commission funded ASPIS project.

MACFEST had been a two year project that concluded at the end of 2016. Novel metal coating processes had been developed and the deposits evaluated as solderable finishes. Ionic liquid chemistries had been used to deposit good quality palladium and gold coatings onto conventional electroless nickel and the results had been very promising with good solderability and performance comparable to that of coatings deposited from aqueous chemistries.

The coatings developed in the MACFEST project also had the potential to reduce environmental impacts through the elimination of cyanide-based aqueous chemistries and to reduce the amount of palladium consumed, whilst meeting the requirements of the industry and current IPC standards and eliminating known reliability issues with nickel-palladium-gold coatings, for example black pad, brittle joints and void formation. Professor Goosey was currently looking at other funding routes to take the project forward. The initial project was a relatively low Technology-Readiness-Level research project with much of the fundamental work done by the University of Leicester. There was a need to move towards larger scale trials in a working PCB fabricator environment. He was considering applying for Horizon 2020 funding as and when an appropriate call was available.

He reiterated the benefits of ICT's Engagement in R&D Projects - a way for the ICT to be directly involved with the development of new technology, with benefits for members in gaining access to new developments and information, as well as being a source of additional income for the Institute

2016 UK PCB Market analysis

Francesca Stern
Market analyst and ICT Council member

Market analyst and ICT Council member **Francesca Stern** rounded off the proceedings with her review of the UK PCB industry for 2016 and outlook for 2017.

Total UK PCB production in 2016 was £122M (slightly down on 2015 although imports had increased), categorised by technology: Multilayer 34%, HDI 17%, D/S PTH 17%, Rigid-Flex 13%, IMS 4%, Flex 3%, and by market sector: Industrial/Instrumentation 40%, Military and Government 15%, Civil Aerospace 12%, Communications 8%, Automotive 4.8%, Space 3.5%, Medical 2.4%.

The UK market for PCBs in 2016 was £174M, up from £168M in 2105, categorised by sector: Industrial/Instrumentation 40%, Military and Government 15%, Civil Aerospace 10%, Communications 6.3%, Automotive 4.2%, Medical 3.2%, Space 2.7%.

UK electronics production had been on a growth curve since the end of 2016, and this would likely continue until the end of 2017. By comparison, German year-on-year production had declined slightly but was forecast to return to positive growth during 2017.

Although the PCB business in the UK is these days a comparatively small and specialised industry, it is characterised by a very special camaraderie and sense of community. The membership of the ICT continues to grow and this seminar proved once more to be not only a platform for sharing knowledge and inspiring future developments, but equally an opportunity to renew acquaintances, make new ones, share industry news and gossip and build the network. As is usual, the network-building continued well into the evening...

I am grateful to Alun Morgan for kindly allowing me to use his photographs.

Pete Starkey
I-Connect007

PCB Technology Requirements for Millimeter-Wave Interconnect and Antenna

by ***Jim Francey - Optiprint AG***
Terry Bateman - Optiprint AG

1. INTRODUCTION

Optiprint AG was founded in 1985 and is a manufacturer of printed-circuit-board (PCB) products. Since its inception Optiprint has specialized in fabricating PCB products for radio-frequency (RF) and microwave (MW) applications. In recent years, there has been commercial exploitation of so-called millimetre-wave (mmW) frequencies. Generally speaking this commenced with automotive-radar however increasingly the telecommunications sector is offering radio products operating in V-band (57 – 66 GHz) and E-band (71-76 GHz & 81-86 GHz) portion of the radio-spectrum [1]. The attraction being the comparatively-high volume of data that can be transmitted wirelessly to cope with a demand for bandwidth driven by growth in mobile data traffic for portable devices and machine-to-machine communications. The expectation is mmW radio architectures will be deployed in future "5th generation" cellular mobile" (5G) networks and to ease "spectrum congestion" in current 4G and earlier configurations.

In 2013 Optiprint joined a European collaborative project called "MiWaveS" [*2*], a three-year project to develop key technologies for mmW wireless access and backhaul in future 5G heterogeneous cellular mobile networks. Optiprint's role in MiWaveS was to support the collaborative partners in the design and manufacture of PCBs for local access and backhaul radio transceivers & antennas. This paper describes the PCB technology requirements of fabricating PCB articles designed for the distribution and propagation of mmW signals with emphasis on the work done to support MiWaveS project.

11. TECHNOLOGY OVERVIEW

PCB, often referred to as "organic substrate", represents an economically-attractive and mature technology for mmW hardware interconnect and antenna given the ubiquity of PCB and PCB assembly manufacturing capability. Interestingly the MiWaveS project also involved LTCC "ceramic substrate" technology however the review of it is outside the scope of this paper.

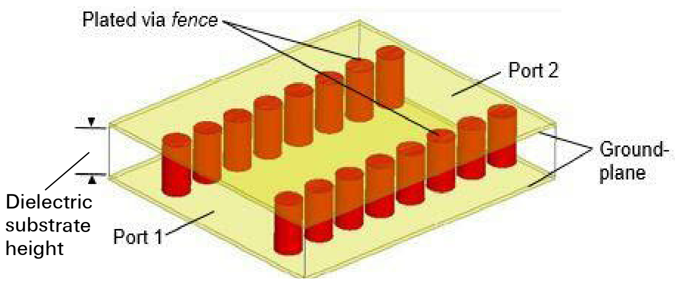
From a PCB manufacturing perspective, the needs for distributing and propagating signals in millimetre wavelengths have a direct influence on the choice and thickness of substrate, PCB feature (and feature-to-feature) *positional* accuracy and feature *dimensional* accuracy. The requirements for matching manufacturing and metrology capacities are discussed in this paper.

111. MATCH NEEDS

A. Raw material Selection

Microstrip, stripline and co-planar waveguide transmission line technologies are all deployed in mmW PCB design. Increasingly designers are using Substrate Integrated Waveguide (SIW) and this was true of circuitry used in MiWaveS. SIW sees a rectangular waveguide created within the dielectric by adding a top metal over the ground plane and *fencing* the structure with rows of plated vias on either side. A sketch depicting the SIW PCB feature configuration is depicted in Fig. 1. Benefits of SIW are potentially lower losses than with microstrip and coplanar waveguides since dielectric losses are

Fig.1. *Sketch depicting SIW Configuration; ground-plane either side of dielectric withPTH (via) fence.*



typically lower than conductor losses at millimetre waves. The via fence needs to be dense enough to prevent field leakage and signal loss from the waveguide to the substrate. Many traditional wave guide components such as power dividers, signal couplers, filters and antennas can be realized by SIW technology. Component performance approaches conventional air-filled waveguide performance and has the advantage of low radiation leakage and interference compared to microstrip and coplanar circuits.

A defining requirement for raw material selection is minimizing loss (dielectric loss, conductor loss). Much has been published regarding raw materials and loss, the article "Managing Circuit Materials at mmW Frequencies" is recommended reading [*3*]. Several low-loss materials were used in MiWaveS and in some instances combined with FR4 to form so called mixed-dielectric multilayers (FR4-based layers being used to satisfy the *digital* function of the designs with consideration for the long-term economic aspects) however Liquid Crystal Polymer (LCP), a low-loss thermoplastic base-material was identified at the outset for the mmW functions. LCP is a good candidate for mmW *multilayer* PCB structures; it has a stable dielectric constant through the frequency range, exhibits low moisture absorption and has comparatively low-loss. Rogers Corporation offer a non-woven based copper-clad laminate and matching bond-ply [*4*]. The combination of laminate and bond-ply simplifies the design process inasmuch it provides opportunity for homogenous dielectric properties. A *mechanical* benefit of such a combination is the opportunity to maximize MLB planarity (flatness). The challenge from a fabrication perspective (with LCP) however is coping with material movement:

* Typically, mmW MLB dielectric separations are comparatively thin. For transmission, the dielectric spacing (signal to ground-plane) is governed by wavelength. In MiWaveS 100 µm thick laminates and bond-plies were deployed. The combination of thin-substrate without woven-glass reinforcement has a negative effect on dimensional stability. Inner-layers change dimensionally during processing (etching and so-forth). Typically, they shrink in both X & Y planes, the degree of retained metal of course has an influence on the degree of shrinkage.

* Being a thermoplastic the materials "soften" during thermal excursion, MLB lamination induces further mechanical distortion, often ocalized.

* Further dimensional change occurs during outer-layer processing.

Since positional alignment of drilled/plated features to printed feature is a critical attribute (some mmW designs required positional accuracy in the order ± 20 µm) there is the need to gather accurate X/Y measurement data and compensate dimension change in the CAM data. Measurement and compensation must be repeated at outer-layer formation. The corollary is the dimensional-change must be measured and compensated over the course of multilayer-board (MLB) manufacture. Experience showed that despite refining the CAM data, LCP based MLB exhibit discrete dimensional stability *variation*. Back-end machining say for cavity formation need to make use of localized optical targets (fiducials) to satisfy positional accuracy requirements. Laser-based metrology and laser-direct imaging (LDI) are mandatory capabilities.

B. Circuit Requirements

Consider that each aspect of the circuitry must be defined in relation to minimizing signal degradation (loss). Transmission line tolerance is a key factor. In MiWaveS typically ±10% was specified. For features <150 μm this means $\pm$15 μm which challenges PCB manufacturing capabilities for multilayer RF boards. Millimetre wave circuits on PCB use very narrow line widths around 100 µm or even 75 μm. A single microstrip or coplanar line impedance itself does not change very rapidly due to geometry variations but problems can arise with flip-chip component pads, filter circuits and antenna center frequency change due to under/over-etching. The line mismatches are also cascaded that can exacerbate problems due to standing waves between circuit blocks. Repeatability of the etching tolerance is also important for optimization of mmW circuits.

An attribute of low-loss materials is the use of *low-profile* Copper-foil, this helps the etch process which is isotropic in nature. Naturally the aspects of a subtractive process versus *semi*-additive (or *fully*-additive) have a major bearing on feature resolution capability. Regardless the processor must have the opportunity to deploy liquid photoresist (i.e. <10µm thickness) and the right level of etching control.

As mentioned in section II above feature-to-feature accuracy is an important factor for managing transmission losses. It's not uncommon in mmW type work to have blind or buried vias placed within 20µm location *alignment* to an underlying feature (pad for example). This is complicated in achieving the requirement over an 18" x 12" (457mm x 305mm) manufacturing panel and on materials with inconsistent dimensional stability. In such a requirement, *inner-layers* are bonded *sequentially*. Optical targets in the underlying layer are spot-faced and LDI is deployed and optimized to define the *over-lying* layer features. Additional targets can be added for localized/critical positional accuracy requirement. Fig. 2 shows an image of a LCP MLB that deployed this technique.

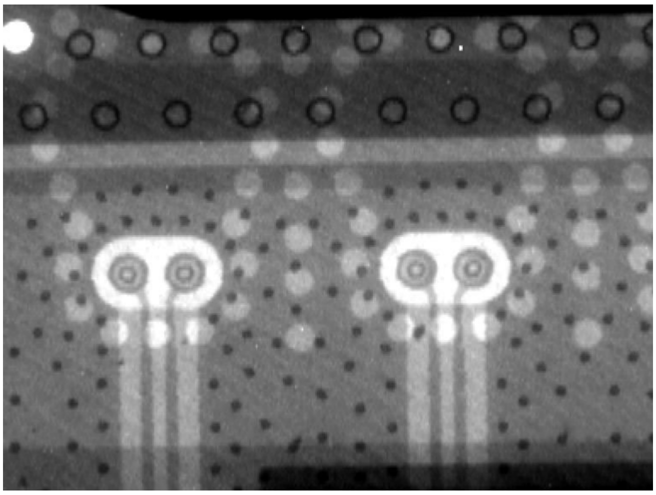


Fig. 2. X-ray image of laser-drilled plated via in sequentially laminated LCP MLB. located using localized optical alignment and LDI

In terms of componentry the mmW industry is benefiting from packaged devices (e.g. QFN and BGA). This is an evolving process. An example of packaging developed recently for the mmW industry is the eWLB (embedded Wafer Level Ball Grid Array) package developed and used by Infineon Technologies [5]. eWLB packaged components are available up to 86 GHz (BGT80) from Infineon. Flip-chipping of MMIC dies is also a promising technology for high performance mmW interconnects. Flip-chip bumps or pillars are typically less than 100 µm in height and have low parasitic inductance. However there are problems with flip-chipped high-power circuits due to thermal issues. A multitude of bumps would need to be dedicated for thermal transfer from the die to PCB. For some MMIC devices like very high power amplifiers (PA) designers have no option but to use *bare*-die. These are invariably Gold-wire (or preferably ribbon) bonded (to provide interconnect) and typically 50-100 μm thick. Similarly managing signal loss and wire inductance are key to performance and limiting the *length* of the Gold-wire (or ribbon) is an important consideration in mmW PCB assemblies viz. the *shorter* the connection, the *lower* the losses and inductance. Ribbon bondwires have superior performance but in most cases two or three parallel single bondwires are good enough. An established practice is to recess the dies within cavities that are either mechanically-milled or laser-ablated. A ground-plane of Copper will form the *floor* of the cavity. The ground plane is required by the MMIC for both low impedance electrical grounding and for good thermal coupling from the die. The thermal dissipation of a single PA mounted on a PCB cavity can be several watts in an area <10 mm2 which needs very efficient cooling through the PCB laminate. In such instances, thermal-via and embedded *coins* are features that can satisfy the thermal management aspects. In a 100 μm thick (Copper-clad) laminate there is the convenience to remove the dielectric and allow the MMIC device (with wire-bond pads atop) to be flush (or *near*-flush) with connecting bond-pads on the PCB. as it is apparent the proximity of MMIC bond-pad to PCB bond-pad is a key factor for short bond-wires. The use of laser-ablation works well in this aspect as positional accuracy of it is typically better than that of mechanically milling. In MiWaveS work the *gap* between PCB bond-pad and *cavity wall* was typically <25 μm. Consider too mechanical milling requires process tolerance in Z-plane and burring is prevalent. Fig. 3 shows an image of a laser-ablated MMIC cavity with the PCB bondwire pads meeting the top of the cavity wall.

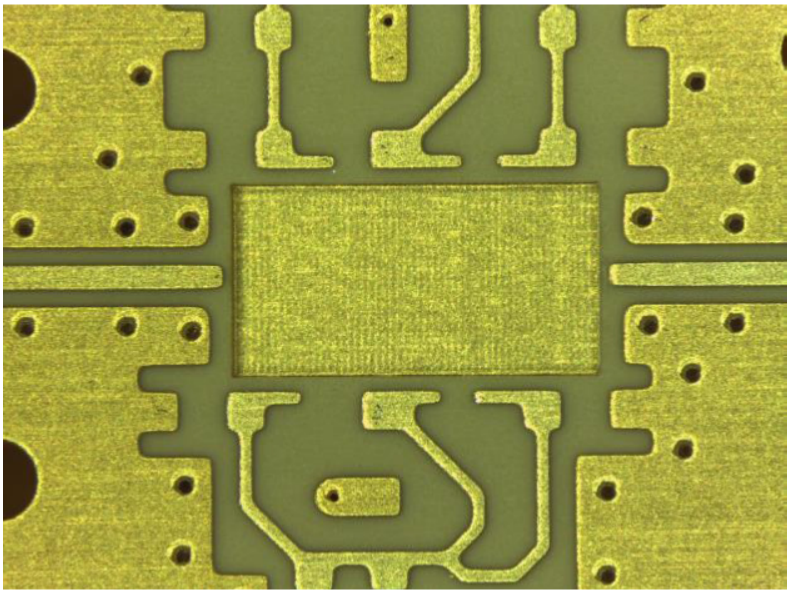
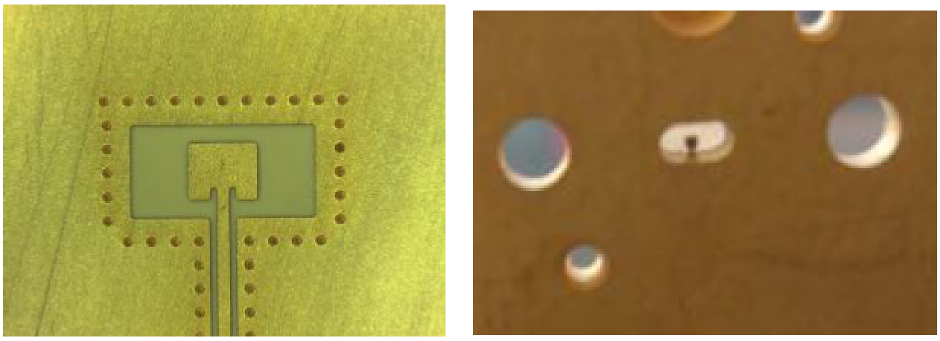


Fig. 3. Micrograph of laser machined MMIC cavity in 100□m LCP dielectric depicting circuitry and bondwire pads defined in layer 1 and exposed cavity floor in layer 2 (ground).

A key feature of mmW PCBs are waveguide transitions. Often the mating waveguide (in a transceiver assembly the waveguide will lead to the antenna) will mechanically locate with side 2 of the PCB and the RF energy is fed by a mechanically-milled conduit. An etched resonator on side 1 completes the transition. In MiWaveS mechanical depth-milling was used to form the cavity in the bonded PCB, an end-mill was used to machine within ~50 μm of the side one resonator. Often the walls of the cavities are plated that adds to the complexity of manufacture. In such circumstances two depth-milling steps are required to reveal a non-metalized *opening* to the side 1 resonator. The Z-axis depth-milling capability required being ± 35 μm. Figure 4 shows images of a depth -

-milled cavity from top and bottom perspectives.



(a) (b)

Fig. 4. Micrograph (a) shows etched resonator on side 1 and (b) shows depth-milled cavity on side 2, machined into dielectric and within ~50 μm of side 1 resonator

In circumstances where plated-vias require "capping" the accepted practice of via-filling (with epoxy-based "pastes") is impracticable because mechanical planarization can *mechanically* distort the non-reinforced base-materials. The sequential plating steps can also hamper conductor definition because of the overall Copper thickness result. Galvanic Copper via filling is the only practical route. Here the via geometries (height versus diameter) require careful consideration to maximize the Copper filling process. This is a process not unique to mmW PCB product but is a trend prompted by the availability of mmW packaged devices particularly BGA types.

C. Plating and Finish Requirements

It's generally accepted in the PCB industry that "panel plating process", whereby all surfaces of a drilled panel are Copper plated results in a more uniform Copper-deposit thickness in comparison to "pattern-plated process". The latter is regarded as *semi-additive* whereas "panel-plate process" is *subtractive* in the formation of conductors. Uniformity of Copper thickness results in more consistent electrical performance (e.g. line-width variation). As mentioned in part B, Copper etching is an isotropic process and the industry practice of "etching-down" Copper was deployed in MiWaveS to meet dimensional tolerance needs.

Much of the PCB work in MiWaveS required both SMT and Gold wire-bond. ASIG (Autocatalytic Silver Immersion Gold) and ISIG (Immersion Silver Immersion Gold) are two Silver-based finishes that were used. Both finishes are "universal" i.e. they support both SMT and Gold wire bond. ENEPIG (Electroless Nickel Electroless Palladium Immersion Gold) was a *universal finish* candidate but being Nickel based losses are higher.

IV. CONCLUSIONS

The work done by Optiprint AG in support of MiWaveS substantiates that PCB technology can satisfy the engineering requirements for mmW circuitry providing the manufacturing capabilities can match the positional accuracy, feature tolerance and surface finish requirements.

ACKNOWLEDGMENT

The research leading to this paper has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n°619563 (MiWaveS).

The authors would like to thank Professor Ronan Sauleau, Université de Rennes 1 and Dr Jussi Säily, VTT Technical Research Centre of Finland Ltd for their valuable inputs.

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[5]https://en.wikipedia.org/wiki/Embedded_Wafer_Level_Ball_Grid_Array

Jim Francey - Optiprint AG   **Terry Bateman** - Optiprint AG

A brief history of the UK Independent PCB Fabricators

By **Bill Wilkie**

The following, is a list of UK Independent PCB Fabricators of which the Institute was aware in 1990

1 ACS Electronics
2 ALN Printed Circuits
3 Anglia Circuits
4 Argos Electronics
5 Artetch Circuits
6 Ashdown Printed Circuits
7 Astra Circuits
8 Attewell Ltd
9 Barr and Stroud
10 Bartek Electronics
11 Bepi Circuits
12 BHK Circuits
13 Bicc Vero
14 Border Circuits
15 Burroughs, Cramlington
16 Cambridge Circuits
17 Carlton Comelin Circuits
18 Central Circuits
19 Chanor Circuits
20 Cheshire Circuits
21 Circaprint
22 Circast Electronics
23 Circonix
24 CITI Circuits
25 Classical Circuits
26 Cleveland Circuits
27 Cochrane and Johnson
28 CPL Electronics
29 Cranford Circuits
30 Drewton Beck Ltd
31 ECP Circuits
32 Electroconnect Ltd
33 Electropac (UK)
34 Eurotech Ltd
35 Exact Systems
36 Exacta Circuits
37 Express Circuits
38 Ferranti International
39 Flexability Ltd
40 Flexible Technology
41 Flextronic Ltd
42 Fortin circuits
43 Forward Circuits
44 GEC Alsthom Protection
45 Gemini Electronics
46 Grange and Hodder
47 Graphic Electronics
48 GSPK Circuits
49 Hallmark
50 Hamlet Circuits
51 Hewlett Packard
52 Hughes Microelectronics
53 Huntrose (UK)
54 IBM (UK)
55 ICL Ltd
56 Intercole Circuits
57 Interconection Sysems Ltd
58 Interconics Limited
59 Ipswich Electronics
60 Irish Printed Circuits
61 Irlandus Circuits
62 Kam Circuits
63 Kelan Circuits
64 Kemitron Circuits
65 Kirby P&S
66 Labtech Ltd
67 Lantrax
68 Leicester Circuits
69 LPG Circuits
70 Maiden Plymouth Ltd
71 Mainstream PCB
72 Manchester Circuits
73 Mannin Circuits
74 Marconi Ltd
75 Masslam Systems
76 MBM Technology
77 MCI
78 MDR Leictreonach
79 MEPD
80 Micaply
81 Micrometallic
82 Microponents
83 Microtech PC
84 Mid Kent Circuits
85 Milton Keynes Circuits
86 Minerva Circuits
87 Modern Circuits
88 Munster Electronics
89 Neutrik (UK)
90 Northern Circuits
91 OneWay Circuits
92 Option Circuits
93 P &L Circuits
94 Palm Circuits
95 Photel Ltd
96 Photo Etch Consultants
97 Photoprinting Products
98 Pioneer Circuits
99 Plessey Circuits
100 PR Circuits
101 Precision Photofabrication
102 Prestwick Circuits
103 Printed Wiring Technology
104 Qualitech Components
105 Quartz Technical Services
106 Rolls Royce Ltd
107 Sangria Designs
108 SEEL Ltd
109 Select Reason Ltd
110 Shannon Circuits
111 Ship Co Ltd
112 Southern Circuits
113 Southport Electronics
114 SPL Circuits
115 Stanley Tools
116 Stevenage Circuits
117 Stratford Tools
118 Strathclyde Circuits
119 Swift Circuits
120 T S Electronics
121 Tate Circuits
122 TDS Circuits
123 Technacron Circuits
124 Technet Electronics
125 Teknoflex
126 Thomas Walter
127 Trulon Printed Circuits
128 UK Corporation
129 Wasco Circuits
130 Welwyn Circuits
131 Wrekin Circuits
132 Yeovil Circuits
133 Zlin Electronics
134 Zot Engineering

The following are late arrivals and feedback from Jim Douglas and Tony Hunt.

135 BAE Systems
136 Brecon Circuits, Wales
137 Arnold Circuits, Rugby
138 B&T Witham
139 BAC Filton
140 Berbat Engineering
141 BPC
142 Bribond
143 Clarydon
144 Commercial Circuits, Ware
145 Daleba
146 DJ Circuits
147 Doplar Electronics, Swindon
148 Eurocircuits
149 Garner Osnorne
150 Gatwick Circuits
151 GW Circuits
152 Knopp
153 LEF
154 LHC
155 Lyncolec
156 Marconi, Basildon
157 Marconi,GreatBaddow
158 Marconi, St Albans
159 Martin Graphic
160 Masslam
161 MDR/Errigal
162 Mhotrack
163 Micam, Mallow
164 Nevin Lonsdale
165 Nevin, Colnbrooke
166 Opsec
167 Photomechanical ✯
168 Photomechanical ✹
169 Basildon
170 Plessey, Addleston
171 Plessey, Poole
172 Printed Circuit Labs
173 Proto Designs, Basildon
174 Quick Circuits
175 Resolution Circuits
176 Sommerville Labs
177 South East Circuits
178 Speedboard
179 System Circuits, Norwich
180 Tailor Made Circuits
181 Technograph and Telegraph
182 Telford Circuits
183 Trackwise
184 Transmetrix
185 Victory Circuits

✯ Option Circuits
✹ Services

Bill Wilkie

Abridged Minutes of the 2016 AGM of the Institute of Circuit Technology

Held at Meriden, 4.30 PM on Tuesday 14th March 2017

Present: Steve Payne,(vice-chair), Martin Goosey, Lynn Houghton, Maurice Hubert, Lawson Lightfoot, Pete Starkey, Francesca Stern and 23 members.

Apologies for absence; Received from Andy Cobley, Richard Wood-Roe, Bruce Routledge,Bob Willis,and Bill Wilkie.

Steve Payne, (Vice Chairman), chaired the proceedings supported by Chris Wall, (Treasurer}. Steve Payne opened the meeting with a mention of the former Honorary Secretary, John Walker, who had served on the committee for many years. He passed away last year and a replacement has not yet been found so proceedings possibly not as well organised as last year.

He also commented on the health of the ICT. in 2016. In the year 2000 membership was possibly 130 and it is now up at 374 and so in good standing.

1: Minutes: The 2015 Minutes were approved

2: Chairman's Report:: Andy Cobley had provided a report summarising the events and activities of the past year. It was another good year for the ICT. The foundation course was successful. The Institute was very active in the provision of a Journal and monitoring/participating collaborative research.

3: Honorary Secretary's Report: As this post does not have a holder, there was no report.

4: Treasurer's Report: Accounts had been distributed to the membership prior to the meeting and copies circulated among attendees. The finances are in good shape. There is £43k in savings accounts and £31k in current accounts. Surplus for year was £4.935k (not £6k as shown in the draft accounts circulated prior to the meeting). There were no questions.

5: Technical Director's Report: The Technical Director's report summarized the events that he had organised in 2016. The membership numbers are up to 374 from 352 in the previous year, included in which are 20 corporate members.

6: Nomination and Election of a New Council. Emma Hudson proposed re-electing the current Council and this was seconded by Tony Cornish. The motion was approved by a show of hands.

7: Re - Appointment of a Director : As a mandatory requirement of the ICT's limited company status, a Director must be elected. William Wilkie provides a sterling role and makes a big difference to the success of the organisation. Pete Starkey proposed his reappointment, Emma Hudson seconded and a show of hands from the floor confirmed.

8: Appoint of Accountants and Auditors: Chris Wall proposed that Hilden Park Accountants Ltd continued to act as both our Accountants and Auditors. This was seconded by Alun Morgan and approved by the floor.

9: Treasurer's Authorisation: Steve Payne requested that the Treasurer be authorised to continue to agree the remuneration for our Accounts and Auditors. This was proposed by Tony Cornish and seconded by Alun Morgan.

10: Proposals: None received.

11: Future Activities: Include :-

The Foundation Course 24 - 27th April at Chester.

The Annual Symposium 9th May will take place at Black Country Museum

The Hayling Island Seminar will take place in September – date to be confirmed.

12: Any other business: None.

Steve Payne thanked everyone for turning out and declared the meeting closed at 16.45

Reported by :-

Francesca Stern

ICT Chairman's Report 2016 AGM

It has been another good year for the ICT although overshadowed by the passing away of one of our stalwarts, the ICTs Honorary Secretary John Walker. His loss will be particularly felt at this time of year since, in the words of Pete Starkey, "... at the Annual General Meeting, where with great authority he ensured that the business was enacted in proper accordance with the Constitution, gave his report and recorded and published the minutes." John will be sadly missed.

On a more positive note membership has increased slightly and corporate membership has been maintained at 20.

This year saw the 36th ICT Annual Foundation Course. Twenty-three delegates attended the course which was held at Loughborough University (including a visit to the MTC). It is very encouraging to see that we maintain these good numbers year on year. This indicates that the course is clearly considered a very valuable part of the training for new recruits to the PCB industry and that is mainly thanks to our industry and academic experts who give up their time to lecture and I would like to express my thanks to all those who lectured this year. The continued success of the course is in a very large part down to the efforts of the ICTs Technical Director Bill Wilkie who advertises the course, recruits the delegates, organises the lecturers as well as entertaining the delegates during their 'free' time. I would like to thank Bill for ensuring the ICT Foundation Course as maintained its standing as a key training tool for the UK PCB Industry.

As ever, the 9th volume of the ICT journal was interesting, informative and thought provoking. The journal's editor Bruce Routledge has had a tough year health wise but he has not let this stop him putting together the journal every quarter. This has required considerable efforts for Bruce and I am extremely grateful to him for this invaluable contribution to the ICT.

The ICT has continued to support exiting projects related to PCB manufacture. The MACFEST project came to a successful conclusion over the last year in its efforts to develop solderable finishes deposited from ionic liquid electrolytes and the project findings have been disseminated at various ICT seminars. The ICT is also supporting a large research council funded project with Loughborough University called SYMETA (SYnthesizing 3D METAmaterials for RF, microwave and THz applications) and the aims of this project were disseminated at the ICT evening seminar in Harrogate last year.

The ICT website (www.instct.org) provides a number of valuable resources to our members including access to all the ICT Journals as well as presentations given at our seminars and annual symposiums. The public section includes reports on seminars and symposia dating back to 2002 and acts as a valuable repository of information on trends and innovation in PCB technology since this date. The website is supported by a number of sponsors whose logo is linked to an article about their company with a further link to their own company web site and we are very grateful to these sponsors. I must thank Richard Woodroe who does a magnificent job in maintaining the site and Pete Starkey for his seminar reports.

The evening seminar series were again very successful this year with good numbers attending the 3 evening seminars in Tewkesbury, Hayling Island and Harrogate. The Annual Symposium had to be quickly rearranged for the Motorcycle Museum in Birmingham and thanks to Bills efforts this was successfully achieved. I would like to thank all those who gave talks at these events and also to the companies who sponsored them. The ICT is investing in new equipment and software for the delivery and recording of these seminars which we hope will improve the experience not only for those attending but for those members who could not attend and want to 'catch up' after the event It has been a year of change both on the national and global scale and the uncertainty that has resulted has had an impact on all industry not least the PCB sector. It is still unclear how this will affect our industry long term and as Chairman of the ICT I am open to ideas on how the ICT can help our members during this time. Of course the Institute couldn't function without the ouncil members who give their time and services voluntarily to the ICT and I thank them personally and on behalf of our membership.

Andrew Cobley

ICT Chairman, February 2017

Technical Director's Report – 2016 AGM

2016 Programme of Events

1st March 2016	Evening Seminar and AGM at the Puckrup Hall Hotel, Tewkesbury
11th - 14th April 2016	Annual Foundation Course at Loughborough University
1st June 2016	Annual Symposium – National Motorcycle Museum
20th September 2016	Evening Seminar at Hayling Island
1st December 2016	Evening Seminar at Majestic Hotel, Harrogate,

Membership and Recruitment : We enrolled 26 new members, plus 5 reinstatements, with 7 leavers and ended the year with 374 individual Members, up from 355 last year. Our Corporate membership was maintained at 20. Our membership is drawn from over 100 companies with around 70% representing Fabricators and Suppliers. Companies supporting the Industry are strongly represented at 20% and designers and design houses are also significant at 10%. We are fortunate to have Members representing four universities and a number from Assemblers and Contract Manufacturers.

We have always enjoyed a high level of support from the Industry, and this year has been no exception with over 30 companies sponsoring us at various levels.

Website: www.InstCT.org Richard Wood-Roe has completely redesigned the website with mobiles in mind and it is now much easier to access with more aids for members such as a page for Corporate Members and a front page of news items.

Membership Benefits: During 2016, we continued to have close relationships with a number of like-minded groups and have incorporated a BSI page on our website to enable our members to keep abreast of changes in specifications. Our on-line journal celebrated its ninth year and we are fortunate once again to be able to bring Walt Custer's Market Outlook Columns to our members. We were also engaged in a number of publically funded projects with other Associations for the benefit of our members and the Industry.

Bill Wilkie

AGM 2016

Corporate Members of The Institute of Circuit Technology April 2017

Organisation	*Address*	*Communication*
Adeon Technologies BV	Weidehek 26,A1 4824 AS Breda, The Netherlands	+31 (0) 76-5425059 www.adeon.nl
ALR Services Ltd.	Unit 9 Thame Business Park , Thame, Oxon OX9 3XA	01844 217 487 www.alrpcbs.co.uk
Anglia Circuits Ltd.	Burrel Road, St.Ives, Huntingdon PE27 3LB	01480 467 770 www.angliacircuits.com
Atotech UK Ltd.	William Street, West Bromwich. B70 0BE	0121 606 7777 www.atotech.com
CCE Europe	Wharton Ind. Est., Nat Lane, Winsford CW7 3BS	01606 861 155 www.ccee.co.uk
ECS Circuits Ltd.	Unit B7, Centrepoint Business Park, Oak Road, Dublin 12, Ireland	+353-(0)1-456 4855 www.ecscircuits.com
Electra Polymers Ltd.	Roughway Mill, Dunks Green, Tonbridge TN11 9SG	01732 811 118 www.electrapolymers.com
The Eurotech Group	Salterton Industrial Estate, Salterton Road Exmouth EX8 4RZ	01395 280 100 www.eurotech-group.co.uk
Exception PCB Solutions	Alexandra Way, Ashchurch Business Centre, Tewkesbury, Gloucestershire. GL20 8NB	01684 292 448 wwwinfo@exceptionpcbsolutioncom
Merlin PCB Group *(was Falcon Group)*	Hawarden Industrial Park, Manor Ln, Deeside, Flintshire, North Wales, CH5 3QZ	01244 520510 www.merlinpcbgroup.com
Faraday Printed Circuits Ltd	15-19 Faraday Close, Pattinson North Ind. Est., Washington. NE38 8QJ	01914 153 350 www.faraday-circuits.co.uk
Graphic plc	Down End, Lords Meadow Ind. Est., Crediton EX17 1HN	01363 774 874 www.graphic.plc.uk
GSPK (TCL Group)	Knaresborough Technology Park, Manse Lane Knaresborough HG5 8LF	01423 798 740 www.gspkcircuits.ltd.uk
Invotec Group Ltd	Hedging Lane, Dosthill , Tamworth B77 5HH	01827 263 000 www.invotecgroup.com
PMD (UK) Ltd.	Broad Lane, Coventry CV5 7AY	02476 466 691 sales@pmdgroup.co.uk
Rainbow Technology Systems	40 Kelvin Avenue, Hillington Park Glasgow G52 4LT	01418 923 320 www.rainbow-technology.com
Spirit Circuits	22-24 Aston Road, Waterlooville, Hampshire PO7 7XJ	02392 243 000 info@spiritcircuits.com
Stevenage Circuits Ltd	Caxton Way, Stevenage. SG1 2DF	01438 751 800 www.stevenagecircuits.co.uk
Ventec Europe	1 Trojan Business Centre, Tachbrook Park Estate Leamington Spa CV34 6RH	01926 889 822 www.ventec-europe.com
Zot Engineering Ltd	Inveresk Industrial Park Musselburgh, B19 EH21 7UQ	0131-653-6834 www.data@zot.co.uk

ICT 43rd Annual Symposium at the Black Country Museum

Registration 09:30 for 10:00

KEYNOTE SPEAKER - **Martin Cotton** of Ventec International

2017 will be Martin Cotton's 50th year since he designed his first PCB in 1967 at International Computers and Tabulators (ICT) in Letchworth. As the Keynote Speaker, Martin will have the opportunity to speak about those 50 years of PCB design involvement, included some key moments, probably one involving a Mr Goodwin!

Michael Ford of Mentor Graphics

Will deliver a paper on tackling DFx

Joan Tourne of NextGen Technologies in Holland

Will talk on VeCS technology, about creating high density routing with an alternative to micro via connections.

Francesca Stern Market Analyst and ICT Council Member

Will give her annual update of the UK PCB Industry

Enquiries to :-
bill.wilkie@instct.org

Registration - £95 inc. Fish and chips Lunch, refreshments and Museum entry

Tabletops available

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