Overview of Embedded Technology

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IPC Standards Activity –
Last spring at EXPO, embedded passives came into its own by being escalated from a sub-committee with 4 task groups to a general committee with 4 sub-committees. Dave McGregor of Dupont now chairs the new general committee D-50 with Richard Snogren of Bristlecone as vice chair. Under that we have:

D-51 Embedded Devices Design Sub-committee
Chair – Kim Fjeldsted of Arrowsmith
Chair – Richard Snogren of Bristlecone

D-52 Embedded Component Materials Sub-committee
Chair – Dave McGregor of Dupont
Vice chair – Rocky Hilburn of Gould

D-53 Embedded Devices Performance Sub-committee
Chair – Michael Luke of Raytheon
Vice chair – Sidney Cox of Dupont

D-54 Embedded Devices Test Methods Sub-committee
Chair – Jan Obrzut of NIST
Chair – Robert Croswell of Motorola

Sub-committee progress to date has been significant.

The D-51 design sub-committee had decided some time ago to start with a design guideline which is now known as IPC 2316, “Design Guide for Embedded Passive Device Printed Boards”. It follows the path of the HDI and microvia standards development of a few years ago. The design guideline is in its final “working draft” stage, ready to be submitted for “final draft for review” at the Fall 2005 Works meeting and will soon be sent out for “proposal for ballot”. The design standard activity will start up soon after the guideline goes for ballot.

The D-52 materials sub-committee has created two documents. IPC 4811 “Resistor Materials for Rigid and Multilayer Printed Circuit Boards” is currently in its 5th working draft status and IPC 4821 “Capacitor Materials for Rigid and Multilayer Printed Circuit Boards” is in the “proposal for ballot” status.

The D-53 performance sub-committee has in the early working draft stage, IPC 6017 “Qualification and Performance Specification for Printed Boards Utilizing Embedded Devices”.

Finally, the D-54 test methods sub-committee has created and received approval for IPC TM650 Test Method 2.5.5.10 “High Frequency Testing to Determine Permittivity and Loss Tangent of Embedded Passive Materials”.
Test Method 2.5.7.2 “Dielectric withstanding Voltage for Thin Embedded Capacitor Layers for Printed Circuit Boards (PCBs)” is in working draft number 3 status.

Underwriters Laboratories has continued its participation in committee and sub-committee activities.

ECIT (Emerging Critical Interconnect Technology) Embedded Passives Test Bed
The Naval Surface Warfare Center at Crane, Indiana has undertaken this initiative to facilitate the implementation of interconnect technology to industry, with emphasis on both military and commercial applications. Briefly, the ECIT was conceived by the folks at Crane primarily to assure that current and future Military programs had clear access to developing interconnect technologies including adequate domestic sources to satisfy the Military needs. In reality, the program extends beyond the Military with a clear mission to support the US PCB industry and serve in close partnership with the IPC and its membership. The “Embedded Passives Test Bed” is a project within ECIT and includes:

- Supporting industry in technical working groups and committees.

- Establishing embedded passive manufacturing processes.
- Encouraging industry and academic cooperative activities within the ECIT facilities.
- Integrating embedded passives technology within military applications.
- Creating an environment that provides for participation and engagement of OEMs, material and equipment suppliers, and PCB manufacturers in project activities such as: demonstration days, conferences, seminars, training and product prototyping.

Since the start of the Embedded Passives Project, just over a year ago, OEMs, material suppliers, PCB manufacturers, the IPC and universities have been engaged in several project activities including:

- The "Demonstration Project" which has worked with resistor capacitor materials from 4 suppliers, developed processes and demonstrated manufacturing capabilities using test vehicles carried over from the AEPT Program.
- Support of the IPCs standards development program, primarily in the D-51 Design sub-committee.
- CAD and CAM development and evaluation.
- The test vehicle team has collaborated on and created 4 test vehicles. Two high frequency TVs for characterizing materials at frequencies from DC to 12 GHz, one thermal TV for characterizing the power dissipation of resistor materials as affected by the PWB construction, and one called resistor learning TV (RLTV) to be used as an aid in establishing resistor manufacturing processes. Plans are being made to fabricate and test a number of materials with these TVs.
- A product emulator project is in the proposal stage.

EPUG

The embedded passives users group sponsored by IPC and lead by Dennis Fritz and Susan Fils conducts monthly pre-scheduled conference calls that include a special speaker on a topic of interest, news and events of interest, discussions, and actions.

EPUG has recently been asked to assist the IPC in developing initiatives to help promote the awareness and understanding of embedded passive components for its membership. Crane's ECIT staff is actively supporting EPUG with this request.

The language of what we have been calling "embedded passives" is rapidly changing. IPC now refers to "embedded components". Japan (JISSO) has adopted "embedded active/passive devices. Not just passives, but actives. Not just materials, but discrete parts. This technology is on many national as well as corporate roadmaps. It is ironical that before we have even figured out the best way to apply the recently developed sets of high performance materials, the world is talking about embedding anything and everything.

For reasons that seem puzzling to a lot of folks, embedded passives seem to be moving at a much slower than expected pace. Although barriers are reported, in my opinion, none of these really need to get in the way of implementation. IPC has found through a recent study that lack of design tools and cost are the two largest barriers, with lack of understanding the technology a strong third. On the other side of the world, JISSO reports that inspection and QA is the largest barrier with lack of design tools a strong second.

Common Language

IPC, NEMI and JISSO are striving to agree on some common terms to keep us from getting confused (Figure 1). Key words are "inserted" and "formed".

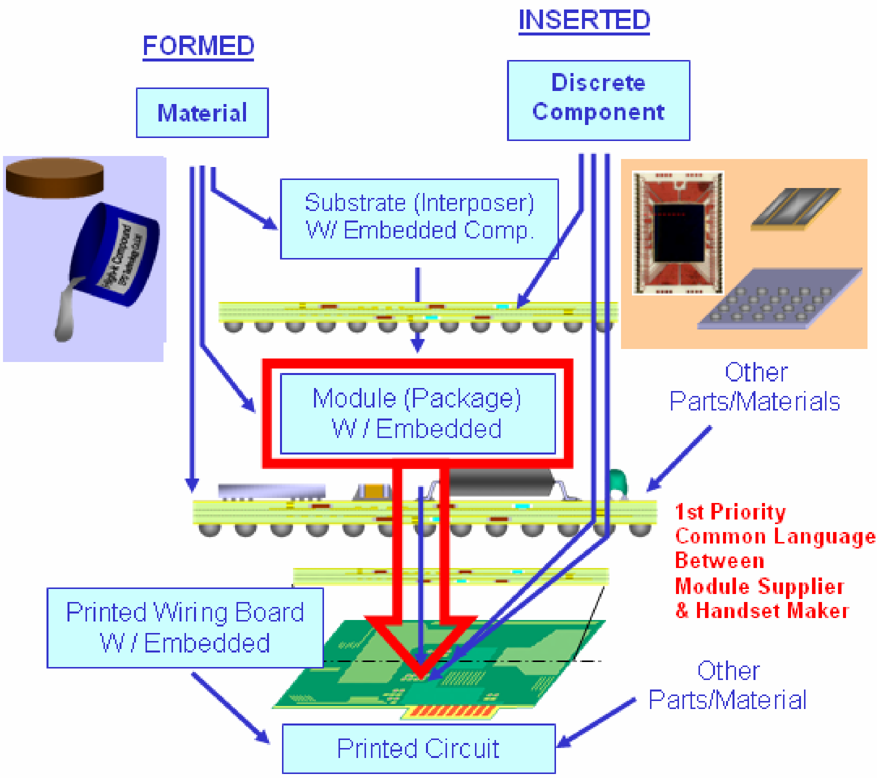

Figure 1

On the right side of the figure we have "INSERTED" discrete components (these may be passive or active), but in either case they are conventional surface mounted parts. They are "inserted", soldered or otherwise metallurgically attached to land pads in the substrates, or modules or printed circuit boards. "Inserted" is the key word for everything on the right side. As you flow down through substrates or interposers to modules or packages on to printed circuit boards, keep in mind that these are all PCBs. The interposers and package substrates are simply very small PCBs, they may be single, double sided or MLBs.

On the left side we have "FORMED" which are materials incorporated in the PCB (these may be discrete or planar). These materials are formed or integrated into the substrates, modules or printed circuit boards, thus forming passive components as resistors, capacitors and inductors. "Formed" is the key word for everything on the left side. Said another way, we are manufacturing the passive components as an integral part of the PCB manufacturing process.

The Market

Let's rewind a little and look at what we are going to embed. In 2004 it is estimated that we used over 700 billion resistors in the value range of 10 to 10K ohm. That represents 86% of the total resistors used. Similarly, over 525 billion capacitors in the range of 100 pF to 1 uF were used, representing 75% of the total capacitors used. Why embed them? To remove the SMT parts from the surface of the PCB, creating room, real estate, for more functionality, or creating a smaller and/or lighter board. Smaller is usually consistent with less expensive. Another reason is to get the passive function as close as possible to the active silicon, shorter path, reduced impedance and inductance, cleaner, faster signal performance. For what ever the reason, there are over a trillion discrete passive components used which equates to a lot of opportunities for embedding.

Sanmina reports that the market for buried capacitance grew 15% in 2004, and is expected to grow larger this year, especially in the 1 mil and thinner dielectrics as well as the standard BC2000 type materials. Predominate markets are servers, networking equipment and telecoms. In general, usage is growing in Asia and is very low in North America and Europe.
Of the approximate 61 total licensees, only 25% are in Asia compared to 60% in North America, 23% in Europe and 3% in the rest of the world. However, if this were expressed in capacity of the licensee facilities, Asia by far would be the largest share.

Thin-film resistors are found largely in telecom, automotive, and military applications. The customers are spread globally. However, there are many instances of North American and European OEMs using Asian fabricators.

One supplier reports PTF resistor material sales in US is about 10 Kg/month, equating to about 10K panels with resistors. However, in addition, we believe Motorola (using an Asian produced resistive material) has the largest PTF resistor usage.

How New are Embedded Passive Component Materials?

In some circles we talk of embedded passives as an emerging technology. Emerging does not necessarily mean new. It is more like being re-discovered.

Thin-film resistor and carbon resistor materials debuted in the early 1970s. Ceramic thick-films on ceramic hybrids appeared in the early 80s and found their way into harsh environments including aerospace and automotive. In 1983 fellow PCB colleagues Greg Lucas and Jim Howard patented a material (or concept) called ZBC 2000. The Z referred to their employer at the time, Zycon; the BC for buried capacitance, and the 2000 for the fact that it was 2 mils thick.

Think of how many circuit boards are designed with power and ground planes – the vast majority. Now look at a power and ground plane designed and manufactured on a single piece of dielectric core, i.e., as a double sided layer detail. Walla – you have a capacitor. Two copper plates separated by a dielectric. Over the years a substantial technology licensing business has developed. The ownership of this technology has changed hands several times and is currently controlled by Sanmina-SCI Inc. Yes, there is some evidence that this was prior art. Jim Howard, in a later life, as well as Joel Peiffer of 3M individually researched the patents and satisfied themselves that there was prior art. They found that using power and ground planes for capacitance has been in the public domain for over 45 years. Non-the-less, Sanmina's licensing business stands strong and continues to grow. Dupont recently joined forces with its HK series of distributed capacitance materials.

The resistor story is similar, less the licensing enterprises. PTF resistors have been used since the early 70s on and in PCBs as a relatively low cost alternative to resistors. These are available in a broad range of resistance values from single digit ohms to megohms. Although tolerances, moisture sensitivity, TCRs, and stability are not in the precision category, if these are not performance requirements in the end application, the PTFs are excellent.

Thin-films debuted about the same time as PTF. Although available in a relatively narrow sheet resistance range, varying the aspect ratio of the resistor design can enable a broad range of resistor values. Thin-films are more stable than PTFs, show improved moisture resistance and better TCRs. They are also slightly more expensive due to higher material and processing costs.

Embedded capacitors and resistors have been in full production for several years using thick-film materials and a structure developed by Motorola know as "mezzanine". Sanmina/Siemens's "SIMOV" incorporate capacitors and resistors in the same structure.

As described above, we know that the core materials and concepts that can be used to form resistors and capacitors right in the PCB are not really new.

But, in the last few years many more products have become available. We move forward with a new family of high performance planar or distributed capacitor materials. Thinner and thinner dielectrics and higher and higher Dks resulting in higher capacitance densities and lower power and ground impedance and inductance. From 1983 with a single available material, BC2000, a copper clad FR-4 50 micron thick laminate with a Dk of about 4 and a capacitance density of 78 pF/cm^2, to 2005 with over a dozen high performance materials available from several sources with thicknesses as low as 8 microns and Dks of 30 and capacitance densities of 1700 pF/cm^2. A very significant improvement in a relatively short time span. These all fit the definition of thick-films in that the dielectric thickness is greater than one micron. As we speak, several academic and industrial laboratories are working on thin-film (less than one micron) dielectrics. These ferroelectric type dielectrics are so thin, less than a micron, that they can produce capacitance densities of one microfarad/cm^2. Work is also going on in the US at Crane Naval Weapons Center to develop test vehicles that hopefully will become standardized to characterize both resistor and capacitor materials as well as subtle design features at frequencies up to 12 GHz.

Since the debut of Ohmega-Ply in the early 70s, 3 additional material suppliers have developed and brought a range of thin-film products to market including an additive process material.

What's the Future?

There needs to be a compelling reason to implement embedded passives. Cost and performance seem to be the leading drivers. Unfortunately for a relatively new technology, I believe that the order of these drivers may be backwards. The most compelling driver should be performance. Yet, it appears that many of those looking to adopt, are looking primarily for cost savings and if they get a little performance boost, that's a free bonus.

Think for a minute about Jack Kilby's invention of the integrated circuit September 12th, 1958. He created a future for electronics. This was a pivotal event. Prior to that we could design complex digital systems, we just couldn't manufacture them because each transistor was a separate discrete part. Remember those T05 cans? Every pin needed to be soldered. The system size was big and bulky with unending reliability problems due to so many solder joints. The IC solved that interconnection problem, enabling us to manufacture complex digital systems.

We have had two major pivotal events in the world of printed circuit boards. First, the invention of the PTH in the early 50s enabled the industry to leap forward to MLBs. Then in the 90s the microvia enabled board densities to leap forward. Without these technological events we would not have the PCBs that we have today.

Could we have a pivotal situation today with embedded passives? Maybe not as dramatic as the IC, but certainly a solution to many performance and cost issues that could allow electronics to take another leap forward. What if we really did learn to embed passive components right into the PCB composite? Envision where this will take electronic packaging. The PCB industry is driving to higher density circuits, smaller vias and smaller lands. If these PCB improvements couple with embedded passive components, the printed circuit board could take a giant leap forward.

What Is The Real Barrier?

With all the new high performance materials available, years of history on a basic family of materials, design tools emerging, a new positive history being written, the question remains, why is the adoption of embedded passive component technology moving so slow? IPC says design tools and cost, and education. JISSO says inspection and design tools. Somehow, these just don't answer the question. There has to be another barrier. The surveys have missed it.

I think Walt Kelly in about 1953 summed it up quite well with his character Pogo the Possum (Figure 2). Although looking at a different issue one day Pogo while looking in the mirror made this profound statement, "We have met the enemy and he is us"

If we want embedded passive component technology to gain momentum, it is clearly up to us. Therefore, if it makes sense, there are no barriers except us. Just do it!

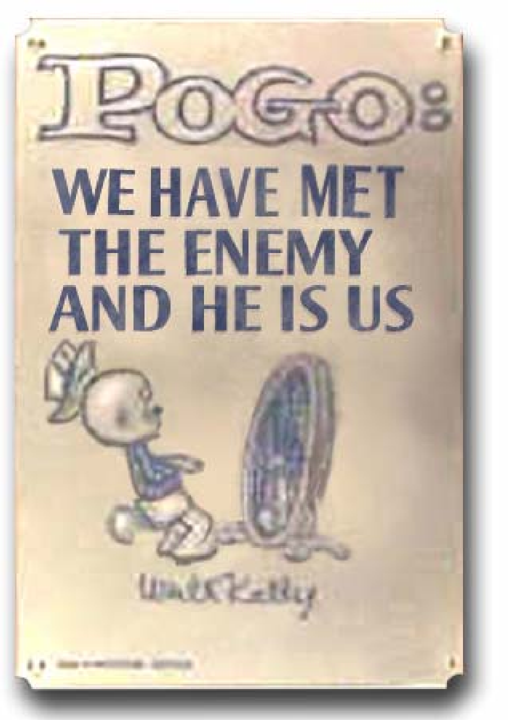

Figure 2 – Pogo the Possum Walt Kelly, circa 1953