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What is New about Thin Laminates in 2013?

Istvan Novak, Oracle, February 2013

It is almost two years ago that the QuietPower column “Thin Laminates: Buried Capacitance or What” was posted. The column gave a summary of benefits and possible usage models for thin laminates. Recently I was asked to give an update to see what is new with thin laminates in 2013.

The column in 2011 [1] focused on the fundamentals of thin laminates, though several of the earlier and later columns were also related to power planes, see e.g., [2] – [5]. [1] showed that thin laminates provide much more static capacitance than power-ground plane pairs with big separation, when for instance there is one or more signal layers inserted between power and ground. It was also shown that however much capacitance we get from the thin laminates, it is usually orders of magnitude lower than what we need to still add to it to keep the low-frequency impedance within target values for anything other than the extremely low power electronic circuits. Also, similar to any real bypass capacitor, power-ground plane pairs also exhibit a series resonance, followed by an inductive upslope of impedance, with a double infinite series of additional resonances. [1] concluded that it is the inductance of the thin laminate that gives the ultimate value for the user: the lower the inductance, the lower impedance we can achieve at high frequencies.

The conclusion about the usefulness of low inductance of thin laminates resonates well (pun intended) with the impedance curve of regular bypass capacitors and can help us answer a frequent question about the ‘working frequency range’ of bypass capacitors or planes. One of my friends reminded me about this typical question after he read the column on the inductance of bypass capacitors [6]. He wrote: “I especially like the statement that bypass caps (as well as distributed capacitance) can work effectively ABOVE its SRF. Unfortunately, many in the industry do not believe that any type of capacitor works above its SRF because it is acting inductively. … For example, comparing the performance of two different MLCC capacitors (with the same capacitance) at a given frequency, say 150 MHz. The first capacitor has has a SRF of 175 MHz and an impedance of 1 ohm at 150 MHz. The second MLCC cap has a SRF of 125 MHz but has an impedance of only 0.5 ohm at 150 MHz. The thinking of many in the industry would be to use the first cap for 150 MHz because it is below the SRF and not to use the second cap because the frequency of interest is beyond its SRF. However, the better choice (for decoupling at 150 MHz) would be to use the lower impedance cap regardless of whether it is before or after the SRF.

I know I am trying to make a complex decoupling situation very simple but I receive a huge amount of push back for using thin dielectric materials between power and ground because the SRF of the embedded capacitor material has a low SRF." We illustrate this scenario in Figure 1.

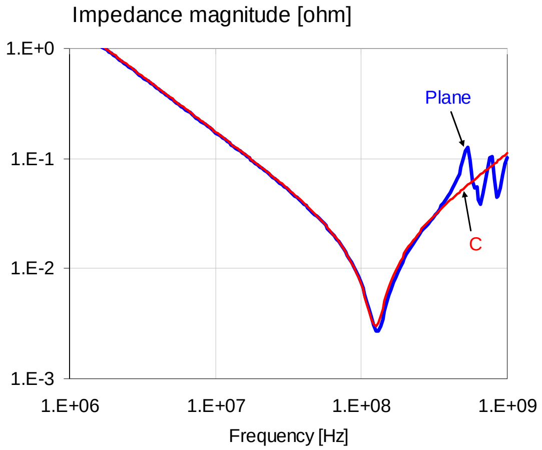

Figure 1: Comparison of impedance magnitude of a discrete capacitor and a thin dielectric.

The blue curve shows the impedance magnitude of a square pair of planes with 1-mil laminate in between. The dielectric constant of the 1-mil (or 25 micrometer) laminate is assumed to be 4, the loss tangent at 1 GHz is 0.01. We simulate the impedance in the middle of a 10" x 10" (25.4 x 25.4 cm) square plane pair. The simulation uses a full causal SPICE grid, solved independently with the frequency dependent dielectric and conductive properties frequency-point by frequency-point. The red line shows the impedance magnitude of a single bypass capacitor with a simple series C-R-L model, with C = 90 nF, R = 3 mOhm, L = 18 pH. The two curves agree quite well at all frequencies except around the modal resonance frequencies, which are already highly attenuated by the thin nature of the laminate [5]. Though finding a discrete bypass capacitor with a 18 pH mounted inductance would be quite a challenge (if not outright impossible), but we could for instance assume that we have 90 pieces of 1 nF bypass capacitors with 90 * 18 = 1620 pH inductance each. All of these constructions give us a Series Resonance Frequency (SRF) of 130 MHz.

Are these devices really useless for bypassing above 130 MHz just because the impedance is inductive? It turns out that to achieve a given (frequency-independent) target impedance, the optimum impedance for bypass applications is neither capacitive nor inductive: the optimum is resistive. This is because either with capacitive or inductive impedance the impedance magnitude cannot be flat (constant) as a function of frequency: it has to drop with increasing frequency if the impedance is capacitive, and it has to increase with increasing frequency if the impedance is inductive. We approximate the flat impedance requirement with a combination of these bypass components: DC sources, bulk capacitors, high-frequency capacitors and power planes. There are impedance synthesis approaches where the resulting impedance profile is very close to wide-band resistive impedance, but there are other very popular solutions where at different frequencies the impedance may be capacitive while in other frequency ranges it is inductive. Ultimately what matters is the impedance magnitude value and the overall frequency response (shape of curve) of the power distribution network. As it was pointed out earlier, thin laminates provide such a low inductance, which is equivalent to a large number of discrete capacitors connected in parallel at higher frequencies. This is the true benefit, regardless of the nature of the impedance, whether it is inductive or capacitive.

In the early days of thin laminates, a couple of decades ago, only a select few designs really needed thin laminates for their electrical performance. In those days a probably more attractive feature was the geometrical advantage: small specialty printed circuit boards and flexible circuits benefitted from the thin laminates. As power levels and operating speeds went up, the demand for lower impedance over a wider frequency range in power distribution network rose sharply, especially in those days and in those applications where single-ended signaling was dominant. This triggered further applications of thin laminates, but as with many aspects of power distribution network design, alternate solutions were also available. It was eventually the designer’s call to sort out the pros and cons related to thin laminate applications in any particular design.

As we look around in the various applications of printed circuit boards, we see a slow but steady growth of applications as well as offerings. Just a few weeks ago a PCB007 article [6] announced a new thin laminate from 3M. The ceramic-filled thin laminate is available in thickness values ranging from 3 micrometer to 14 micrometer [7]. The C2006 laminate with its 6 micrometer thickness offers 20 nF per square inch static capacitance.

Filled and unfilled thin laminates from Oak-Mitsui Technologies also have new offering in the last couple of years. As John Andresakis and Bob Carter explained, the FaradFlex ^{R} Standard Dk Products added the MC25L, a 25-micrometer low-loss material, with a dielectric loss tangent of 0.005 at 1 GHz. The High Dk Products family expanded with two new 25-micrometer laminates, the MC25ST and MC25LD. The MC25ST has a Dk of 18.0 and Df of 0.008 at 1GHz. The MC25LD offers a Dk of 7.1 and Df of 0.0025 at 1 GHz. Together with the other family members already on the market [8], these thin laminates see typical applications in chip packaging, MEMS modules, military, aerospace, computer, telecom and medical applications.

Bob Carter of Oak-Mitsui Technologies said:

"- Oak-Mitsui has added new variations targeted for the chip packaging market space. These material dielectrics are 25 micron to as thin as 8 micron. The important factors are that they have very low loss and the properties such and DK, Df, have very little change over frequency and over temperature and humidity. This is a huge benefit for high speed devices that are exposed to the environment.

- Materials that are thinner with higher DK and higher capacitance are also targets of designers, especially in the high data rate applications such as servers, edge and core routers. In the early 2000's dielectrics moved from 2 mil to 1 mil. The 1 mil is almost standard thinnest thickness dielectric at almost all PCB shops. Many OEM's have used this thickness for power grounds. In the last 2-3 years there is a growing number of OEM's and PCB fabricators pushing down in thickness from 1 mil to 1/2 mil. Today between 1/3 and 1/2 of our business is this thinner dielectric.

- The growth of thin embedded capacitance dielectrics has had a very large impact on the growth of MEMS for multiple applications including microphones, gyroscopes, GPS, sensors, and other applications. This primary substrates in many MEM's devices are embedded capacitance dielectric laminates 8-12 micron thick with high Dk.

- High Speed SSD Memory are now being used in high volume in servers. The substrates for these use 25 micron or less to maintain thickness improved power delivery.

- Medical devices that use embedded capacitance devices to deliver a charge and stimulate neural systems in the body. These substrates are highly filled with high Dk particles to increase capacitance.

- RF filters and module substrates are using substrates with low Df and High Dk.

- A significant expansion into internet infrastructure systems including multiple devices to improve power delivery and increase system data rates. The highest data rate systems use embedded capacitance laminates that are 12- 25 micron. The thin core yields less resonance at higher speed.

- Cloud computing devices including servers and internet/ cloud data storage."

David McGregor from DuPont mentioned a trend, which is also in line with my personal experience: “We are seeing an increase in inquiries from designers who have heard about embedded capacitance but want to learn more. We have given a number of presentations to designers in the last 12 months. In these days more OEMs and fabricators willing to use thin laminates for power delivery networks. Up until recently customers have wanted to use our 1 mil thick core, the DuPont™ Interra® HK04J polyimide laminate [9] and there has been virtually no interest in thinner laminates. Within the past 6 months we have had inquiries from customers who want to qualify the half mil core HK04J. As we talk with designers and OEMs we are promoting use of thin laminates for Z-axis thickness reduction as well as weight reduction in rigid boards.”

Whether it is MEMs device or high-speed computer board, board designers are finding that thin laminates provide multiple benefits: at the same time when they ensure solid electrical performance due to their low inductance, their thin nature helps the designers to keep the overall board thickness under control.

References:

[1] “Thin Laminates: Buried Capacitance or What,” available at http://www.electrical-integrity.com/Quietpower_files/Quietpower-13.pdf

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[3] “Do not perforate planes unnecessarily,” available at http://www.electrical-integrity.com/Quietpower_files/Quietpower-10.pdf

[4] “Resonances in power planes,” available at http://www.electrical-integrity.com/Quietpower_files/Quietpower-14.pdf

[5] “How thin laminates suppress resonances,” available at http://www.electrical-integrity.com/Quietpower_files/Quietpower-15.pdf

[6] “3M: Embedded Capacitance Material at DesignCon,” available at http://www.pcb007.com/pages/zone.cgi?a=89571

[7] “3M™ Embedded Capacitance Material (ECM) data sheet” available at www.3Mcapacitance.com

[8] “Ultra Thin Materials for Higher Performance PCBs.” Oak-Mitsui Technologies product brochure, 2013.

[9] “Interra™ Planar Capacitor Laminate Materials,” available at http://www2.dupont.com/Interra/en_US/products/laminate/index.html