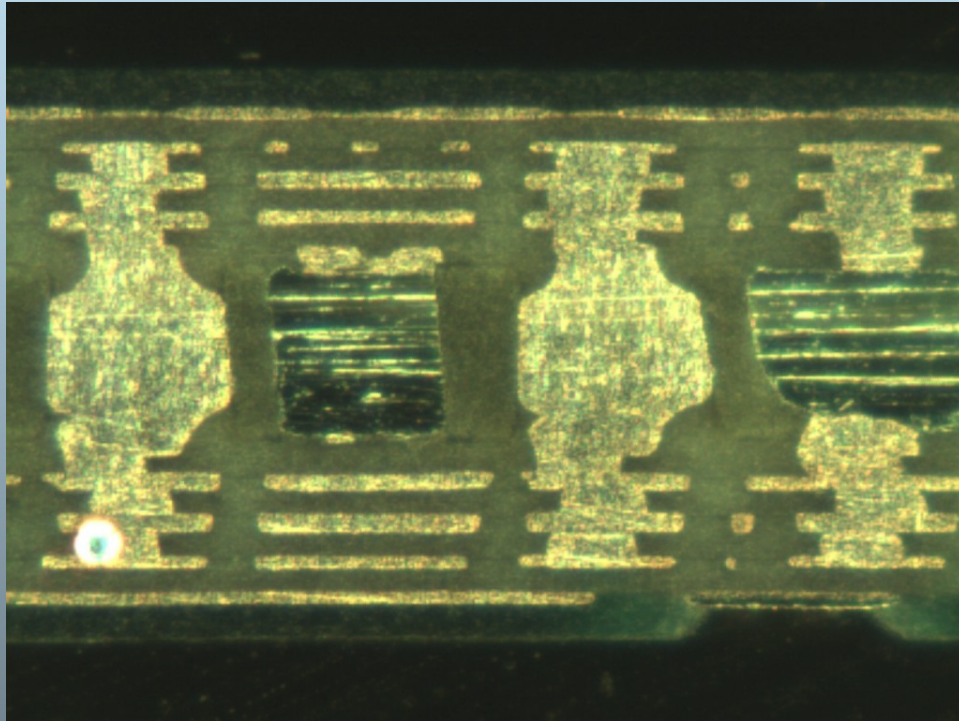


Ver. 1

XCLUSIVE IMPEDANCE VIAS



Written by Robert Tarzwell
2009

Table of Contents

	Description	Page
	Forward	
Chapter One	Introduction to Impedance	4
Chapter Two	Designing Impedance Vias	10
Chapter Three	Manufacturing Impedance Vias	14
Chapter Four	Manufacturing HDI Impedance Vias	16
Chapter Five	Manufacturing Metal Core Dielectric Vias	18
Chapter Six	Sales Notes	21
Chapter Seven	Other Technologies Available at DMR LTD.	23

The information in this book is current to April 2009. As material specifications and manufacturing practices change and evolve, please ensure you are using up to date information.

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Written by Robert Tarzwell © 2009 DMR LTD.

FORWARD

Exclusive impedance vias is a new technology to sell and add to your printed circuit board repertoire. The impedance via is a new tool that your customers and designers can use to improve signal speed and reduce ringing of the electrical signals. This new product is the result of many years of experimentation in this critical high speed area. The technology is not really tough; it's a matter of understanding what creates and controls impedance. Any reasonable board shop can easily add this to their saleable technology. Acquiring even a small inexpensive technology such as impedance vias creates the window of opportunity that your sales force can now go to your old customers and enlighten them about improvements you have made to the shop. Add a clean up and a few other perks and you have a sale. Let's face it! All of us in the business have seen customers come and go. This small technology may give you the kick to improve and create new products.

Introduction for Robert Tarzwell

One of the most amazing things that I have seen Robert Tarzwell do, and there are many, is the day he told the owner of a \$20 million board shop that he could take a walk through his shop and come up with savings of at least half a million dollars. The owner took him up on his challenge. Bob walked through the shop and came up with a list of things the owner could do to save money; all in about an hour time frame. A few months later when I was again talking to that owner, I asked him if he had ever followed any Bob's suggestions from the walk that day. "*Oh yes!*" he answered with enthusiasm, "*We took all of them and the only thing he was wrong about was that we actually are realizing savings larger than he predicted.*"

Bob Tarzwell is truly one of the Printed Circuit Board industry's technology gurus. With his grasp of today's technology and his insight into the technologies of tomorrow, he is the real "go-to" person for anyone who is looking for the right direction to take their company. Bob has that unique ability to take very complicated problems and come up with elegant and seemingly simple solutions. Whether you are talking about learning how to produce the absolutely best four layer board, in the most cost efficient way possible, or talking about fabricating a circuit board with one mil lines and spacing, Bob is literally the only person in the industry that I know of who can get it done.

Not being technical myself, Bob is the person I go to when I am working with a client who has a new technology and I need it explained to me. Bob will talk to the client for me and then come back and explain the technology in a way that makes it so clear to me that I not only understand it but then can proceed to do my job of helping the client sell it. There are not many people who can do that. As A Wang once said *The true sign of a genius is someone who can take something very complicated and make it simple enough for everyone to understand.* And this surely applies to Bob Tarzwell.

Dan Beaulieu

President

D.B.Management Group L.L.C.

Chapter One

Introduction to Impedance

Now here comes one of the most confusing aspects of electronics which I will try to demystify by taking an extremely low level approach. I have known electronic enthusiasts who still couldn't even mentally visualize the concept of impedance, even after 25 years. Impedance is one of the most misunderstood engineering terms and technology in the printed circuit field.

The easiest way to understand impedance is to think of it as available energy in an alternating circuit, if the feeding circuit has too little energy. i.e. A high impedance circuit will not supply the required signal strength into a low impedance circuit. It's like trying to power a house with a small flashlight battery.

Capacitance and inductance are important to impedance. In direct current situations, like the system of a flashlight, there is no alternating current with any capacitance or inductance which will only store energy and not affect the operation of the circuit. However, add an alternating signal and the capacitance now acts differently. The capacitance and inductance will completely remove some AC signals if the frequency and the ratio of capacitance are too far off. As the frequency of the ac signal goes up, less and less capacitance is required before you attenuate the signal. If you have no capacitance or inductance in a circuit, you cannot generate impedance. We, therefore, need to control capacitance and inductance.

Capacitance is the result of separating two conductors with a dielectric material. The dielectric material has a few properties that we can use to affect the signal at various frequencies. Properties such as Dk loss and dielectric voltage all affect the performance. We can generate capacitance with normal copper traces in a printed circuit board. The fiberglass is a dielectric and the copper traces create the capacitance and therefore, inductance. The width of the trace and the thickness of the dielectric affect impedance, as does how far the signal has to reach out to find a coupled ground.

Inductance is caused by two conductors crossing or running parallel with each other. In this case, the amount of copper and how close they are or how many turns they make, affects inductance and in the end signal speed. Both capacitance and inductance can store and release energy but out of phase with each other. The signal can disappear if coming from a low energy signal (i.e. high impedance = low energy) to a high energy signal (i.e. low impedance = high energy). To increase signal speed, we need to match the impedance of all areas of the signal path.

For those who can understand college math and electronics, I have included the real formulas for simple impedance.

Impedance is best described as the opposition to the flow of alternating current in a circuit. Represented by the letter "Z" and measured in ohms, impedance is the combination of resistance, inductance and capacitance of the circuit.

Impedance, describes a measure of opposition to a sinusoidal alternating current (AC). Electrical impedance applies to the resistance to AC circuits, describing not only the relative amplitudes of the voltage and current, but also the phases. Impedance is a complex quantity Z and the term *complex impedance* may be used interchangeably. The polar form conveniently captures both magnitude and phase characteristics.

$$Z = Z e^{j\phi}$$

where the magnitude Z represents the ratio of the voltage difference amplitude to the current amplitude, while the argument ϕ gives the phase difference between voltage, current, j is the imaginary unit and e is voltage

$$Z = R + jX$$

Where the real part of impedance is the resistance and the imaginary part is the reactance X . Dimensionally, impedance is the same as resistance; the SI unit is the ohm. The term *impedance* was spoken by Oliver Heaviside in July 1886. Arthur Kennelly was the first to represent impedance with complex numbers in 1893

The reciprocal of impedance is admittance. The meaning of electrical impedance can be understood by substituting it into Ohm's law.

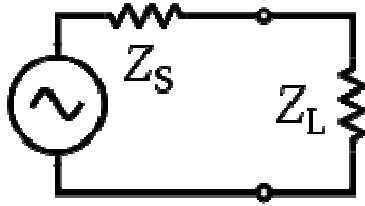
$$V = IZ = IZ e^{j\phi}$$

The magnitude of the impedance Z acts just like resistance, giving the drop in voltage amplitude across an impedance Z , for a given current I . The phase factor tells us that the current lags the voltage by a phase of ϕ (i.e. in the time domain, the current signal is shifted to the right with respect to the voltage signal.).

$$\frac{\phi T}{2\pi}$$

Just as impedance extends Ohm's law to AC circuits, other results from DC circuit analysis such as voltage division, current division, Thevenin's theorem, and Norton's theorem, can also be extended to AC circuits by replacing resistance with impedance.

Complex voltage and current



Impedance is defined as the ratio of these quantities.

$$Z = \frac{V}{I}$$

The magnitude equation is the familiar Ohm's law applied to the voltage and current amplitudes, as determined by the relative amplitudes and phases of the voltage and current.

The phase angles in the equations for the impedance of inductors and capacitors indicate that the voltage across a capacitor *lags* the current through it by a phase of $\pi/2$, while the voltage across an inductor *leads* the current through it by $\pi/2$. The identical voltage and current amplitudes tell us that the magnitude of the impedance is equal to one. The impedance of a resistor is purely real and is referred to as a *resistive impedance*.

$$Z_R = R$$

Inductors and capacitors have a purely imaginary *reactive impedance*.

Reactance

Reactance X , the imaginary part of the impedance, is a component with a finite reactance which induces a phase shift θ between the voltage across it and the current through it.

$$X = Z \sin \theta$$

A reactive component is distinguished by the fact that the sinusoidal voltage across the component is in quadrature with the sinusoidal current through the component. This implies that the component alternately absorbs energy from the circuit and then returns energy to the circuit. A pure reactance will not dissipate any power.

Capacitive Reactance

A capacitor has a purely reactive impedance which is inversely proportional to the signal frequency. A capacitor consists of two conductors separated by an insulator, also known as a dielectric. At low frequencies a capacitor is an open circuit as no charge flows in the dielectric. A DC voltage applied across a capacitor causes charge to accumulate on one

side. The electric field due to the accumulated charge is the source of the opposition to the current. When the potential associated with the charge exactly balances the applied voltage, the current goes to zero. Driven by an AC supply, a capacitor will only accumulate a limited amount of charge before the potential difference changes sign and the charge dissipates. The higher the frequency, the less charge will accumulate and the smaller the opposition to the current.

Inductive Reactance

An inductor has a purely reactive impedance which is proportional to the signal frequency. An inductor consists of a coiled conductor. Faraday's law of electromagnetic induction gives the back EMF \mathcal{E} (voltage opposing current) due to a rate-of-change of magnetic field B through a current loop.

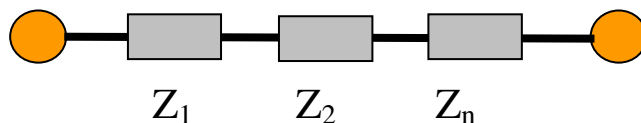
$$\mathcal{E} = - \frac{d \Phi_B}{d t}$$

The back EMF is the source of the opposition to current flow. A constant direct current has a zero rate-of-change and sees an inductor as a short circuit. (It is typically made from a material with a low resistivity.) An alternating current has a time rate-of-change that is proportional to frequency and so the inductive reactance is proportional to frequency.

Combining Impedances

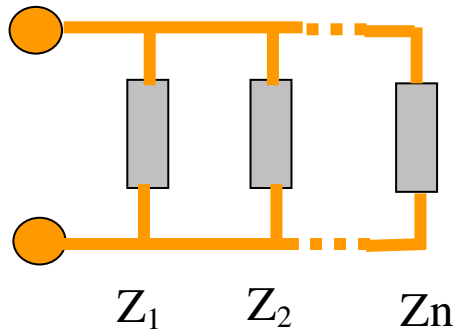
The total impedance of any network of components can be calculated using the rules for combining impedances in series and parallel. The rules are identical to those used for combining resistances, although they require some familiarity with complex number series combination

For components connected in series, the current through each circuit element is the same. The ratio of voltages across any two elements is the inverse ratio of their impedances.



$$Z_{eq} = Z_1 + Z_2 + (R_1 + R_2) + j (X_1 + X_2)$$

For components connected in parallel, the voltage across each circuit element is the same. The ratio of currents through any two elements is the inverse ratio of their impedances.



$$Z_{eq} = \frac{Z_1 * Z_2}{Z_1 + Z_2}$$

Measuring Impedance

According to Ohm's law, the impedance of a device can be calculated by complex division of the voltage and current. The impedance of the device can be calculated by applying a sinusoidal voltage to the device in series with a resistor, and measuring the voltage across the resistor and across the device. Performing this measurement by sweeping the frequencies of the applied signal provides the impedance phase and magnitude. Most printed circuit shops use Polar instruments to measure impedance in a coupon off the selable board. It represents the associated value of impedance of a panel but cannot erase the real value of a trace.

Via impedance should be as close as possible to that of the trace. The trace impedance can be found by means of a PCB trace width calculator. The adjustment of via impedance in PCBs can be achieved by changing the size of the via and the anti-pad. If an anti-pad is too large in comparison to a via barrel diameter, then this will lead to the via being more inductive than capacitive. If the gap is too tight, then the capacitance will take over and decrease the speed of the circuit.

It is sometimes overlooked, that from a signal integrity standpoint, unconnected via stubs have a far larger effect on the signal than the geometry of the via itself.

A via presents a short section of different geometry to the net and can appear as a capacitive/inductive node, resulting in reflections and attenuation of the signal as it travels through the via. In many cases, however, the effects of the change will be reflections that are, for most circuits, negligible, especially if the electrical length of the via is short compared with the rise time of the signal. In general, vias should be made so that the via delay is significantly shorter than the signal rise time. If the signal rise time period approaches the via delay time period, it will be necessary to re-design the via accurately with a 3D impedance field solver.

Via Stubs

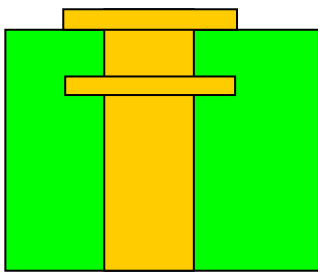
The longer the via stub, the larger the impedance difference and consequent loss to the signal path. In general, a stub presents significantly more signal degradation than the via itself.

Back-drilling

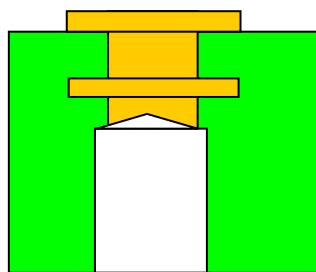
Via stubs generally serve no useful purpose in a circuit and are often removed by *back-drilling*. Back-drilling is the removal of the conductive plating in the via stub which is removed using a drill bit slightly larger in diameter than the drill bit used to create the original via hole. Back drilling can provide signal, impedance matching and reduce resonance with reduced signal attenuation, reduce EMI/EMC radiation and reduce crosstalk between vias, the longer the via stub, the more improvement. A full analysis of via stub reaction is possible with 3D full-wave simulation but many signal design engineers bypass the time consuming analysis and make the stub length as short as possible.

As communication speeds increase beyond 3Gbps, board designers try to eliminate every impedance mismatch along the high-speed signal path. The impedance mismatch generates jitter as well as a decrease in the maximum possible speed of data transmission.

Due to the increasing signal density on pc boards, more signal layers are necessary and interactions of layer to layer vias become a problem. The through vias represent a significant amount of the signal distortion because their impedance is usually around 30 ohms compared to 50 ohms for the traces. This large impedance difference can reduce the speed of the circuit and can create a large amount of jitter. As a result, board designers have either tried to avoid vias on the high-speed lines or implemented new techniques, such as counter boring blind vias, ground surround vias and dielectric ground vias.



Via stub



back drilled to remove copper

Chapter Two

Designing Impedance Vias

Four Basic Ways to Control Impedance in Vias

1. Drill the back side of the via to create a shorter internal stub. This can be difficult to perform, getting the back side holes aligned exactly to the original drilled holes after the panel has shrunk and it changes dimensional shape. It is also problematic to perfectly control the drill depth which results in very low yield. This method is more about reducing reflections in the signal path, reducing capacitance and inductance from unused nodes then controlling impedance.
2. Calculate the sizes of the antipads and pads as well as the diameter of the hole to attempt to control impedance. This method has limited success and is difficult to calculate properly and limited impedance control variation.
3. Drilling ground holes around the via and controlling the pad and antipads size, works well but overall size of the entire via with extra holes takes a reasonably large area. This works best for normal 2 to 8 layer multilayer, less expensive boards.
4. Use dielectric material and form a via inside a through hole. This method works well for HDI circuits or very tight impedance circuits or in higher count multilayers. It is the best method to create tightly controlled impedance vias but is more expensive and needs an extra process.

Please purchase the book on impedance vias to reveal the secret to manufacturing impedance via circuits.