The Theory behind Pulse Plating Reversal Current

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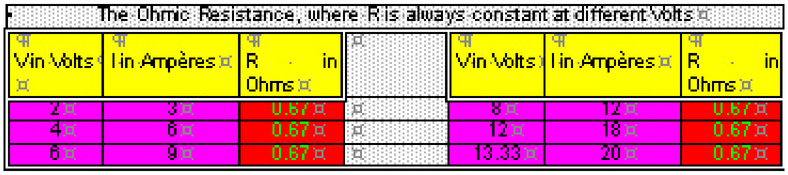
Direct Current (D.C.) - plating

Conventional Direct Current plating is far the most common way and the oldest method of electroplating. In Printed Circuit Boards manufacturing, the sulfuric acid copper bath is very popular. To influence the grain structure formation, grain refiners and wetting agents as well as brighteners are added to the plain electrolyte mixture of water, coppersulfate, and sulfuric acid. During electroplating, the copper ions are distracted from the solution. To maintain the copper ion concentration at a constant level, copper metal is dissolved in the electrolyte. Under influence of electric current, the following reactions take place: Cathodic reaction : $Cu + 2e_{lectrons} \text{-->} Cu_{metallic}$ Anodic reaction: $Cu_{metallic} \text{-->} Cu^{2+} + 2_{electrons}$ However, during the anodic reaction some side effects are observed. In some cases, copper anode material is covered with an unknown layer. This layer is slightly soluble in sulfuric acid and is capable of blocking electrical current. The anode is then becoming passive or it is polarized. With the introduction of pulseplating reversal equipment, this polarizing property is used in improving the distribution of the electroplated metal. For a short time the current is reversed and the printed circuit board is becoming temporarily anodic.

Electrochemical behaviour during the REVERSE pulse

Since electroplating is dealing with charged particles placed in an electric field, ions can freely move in this medium. At the cathode surface positive ions are attracted and discharged or neutral molecules or atoms get extra electrons to be negatively charged. At the anode surface, neutral atoms or molecules will be charged positive and negative ions lose their extra electrons and become neutral or are forming new components with nascent metal ions. If the electrolyte is considered as a normal electric resistance, it will follow Ohm's law.

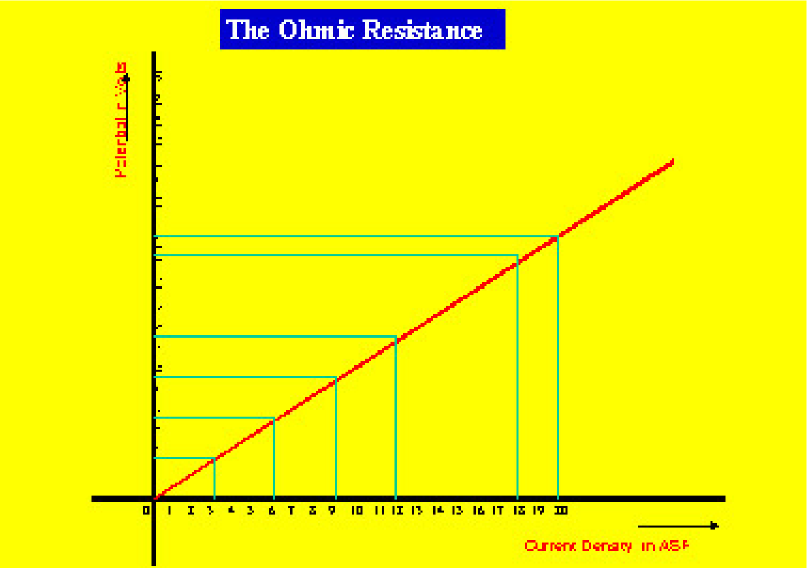


The Ohmic Resistance, where R is always constant at different Volts

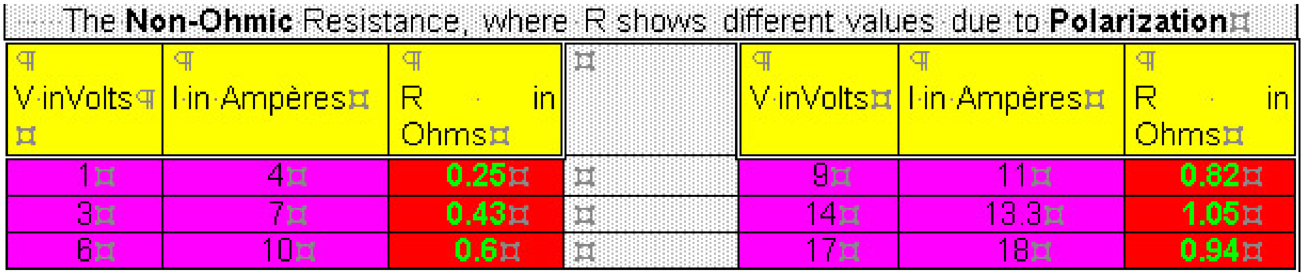
Vin Volts	I in Ampères	R in Ohms		Vin Volts	I in Ampères	R in Ohms
2	3	0.67		8	12	0.67
4	6	0.67		12	18	0.67
6	9	0.67		13.33	20	0.67

Ohmic Resistance
Ohm's equation is expressed as: $V = I \times R$
V is in Volts, I is in Amp?res
R is in Ohms and is constant in relationship to V and I, thus

R = V / I = is constant and always has the same value.



If the contents of Table 1 are put in a graph, as in Diagram 1, a straight line is depicted. The Ohmic resistance shows a straight line, which is typical for constant values.

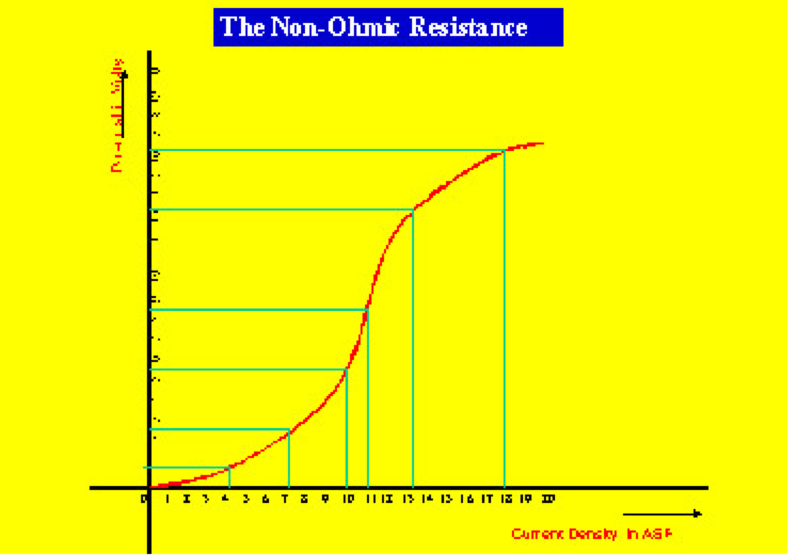


The **Non-Ohmic** Resistance, where R shows different values due to **Polarization**

V in Volts	I in Ampères	R in Ohms		V in Volts	I in Ampères	R in Ohms
1	4	0.25		9	11	0.82
3	7	0.43		14	13.3	1.05
6	10	0.6		17	18	0.94

Non-Ohmic Resistance

The Non-Ohmic Resistance will show a curved line, because the Resistance R has not a constant value: V / I does not equal R.



Note: All Table contents and Diagrams in this discussion do not represent the reality. They contain hypothetical values and are meant to simplify the Reverse Pulse theory.

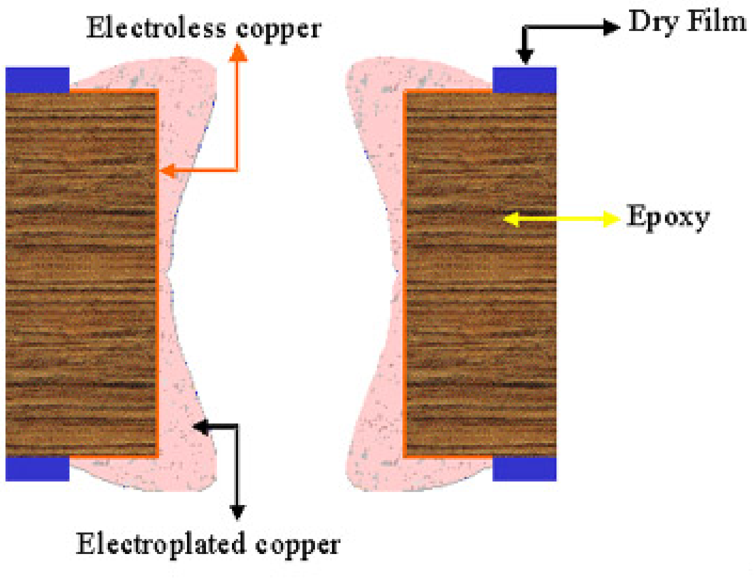
To maintain the same current values, as in Table 1 and in Diagram 1, the voltage has to be increased. Voltage variations could only happen if the Resistance undergo physical/chemical changes. Passivation under influence of electrochemical reactions and electric current is also called Polarization. In Table 2 and Diagram 2 shows the influence of polarization on the Potential Difference. (Potential Difference is in Volts) The 'Fat' and curved line represents the Non-Ohmic resistance, the actual polarization curve.

Pulse Plating Reversal Current

In Pulse Plating Reversal Current, the cathodic plating current is disturbed and reciproked i.e. turned anodic for a short time. The anodic (= Reverse) current causes certain molecules to drift. These additives are then attracted to the high current density areas and adsorbed on the PCB's surface. The adsorbed additive on the copper surface acts as an insulator, it will shield the current and thus temporarily preventing copper being deposed during the Forward pulse.

How it works

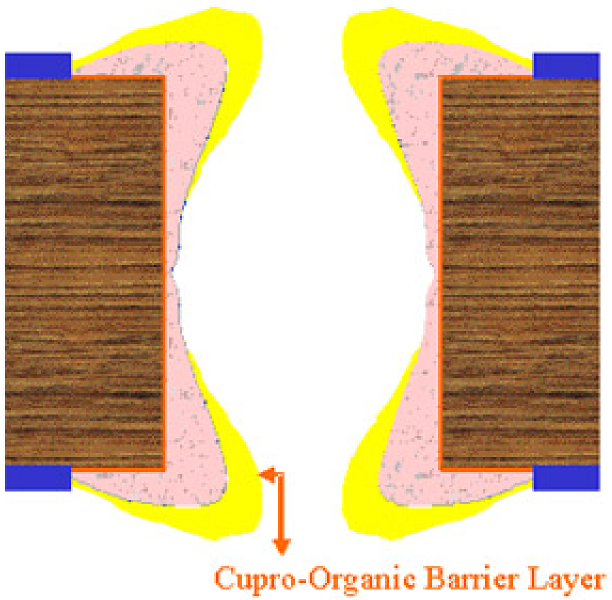
Copper deposition during the Forward Pulse



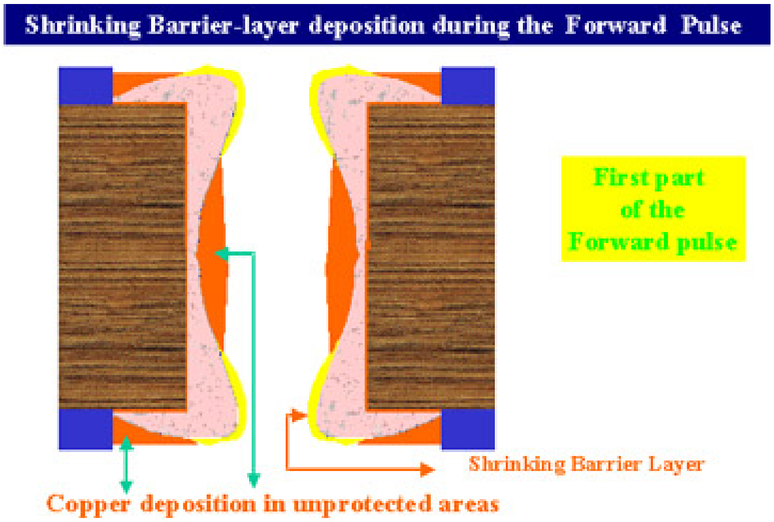
During the Forward Pulse, copper is deposited everywhere on the Printed Circuit Board - -most on the hole entrances and less in the middle of the barrel.

The Forward current is nothing more than a single pulse in D.C. and the deposit is 'dogboned'. When the Reverse Pulse comes, the additive is attracted ('electroplated') to the edges of the drilling hole.

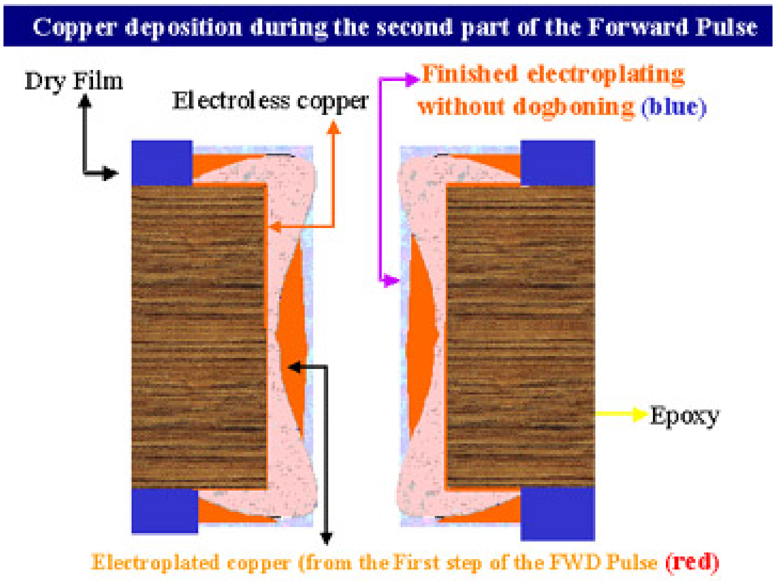
Barrier-layer deposition during the Reverse Pulse



Because the Reverse Pulse is also a kind of pulsed D.C., the additive layer is dogboned too.



In Picture 3 the unshielded areas are electroplated, and the organic layer is partially removed.



The last half of the Forward pulse finishes the electrodeposition without dogboning. (The light-blue coloured area).

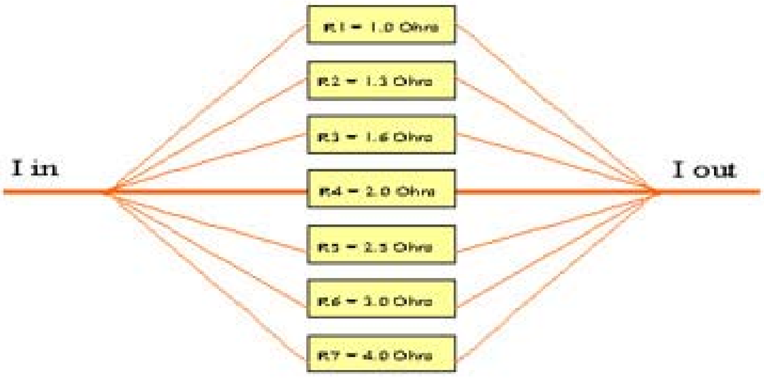
Benefits

The benefits of pulseplating are obvious. In this paper only two advantages are mentioned: Improved distribution and shorter plating cycles.

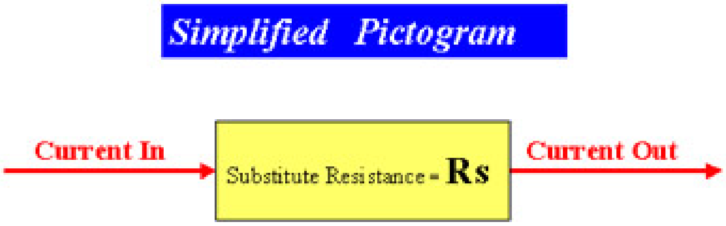
Making it work

Consider the holes in a Printed Circuit Board as resistances connected in a parallel way to each other. Bigger holes have less electrical resistance than smaller holes. Compare the holes with a copper wire: a thicker copper wire has less resistance than a thinner copper wire if their lengths are equal to each other.

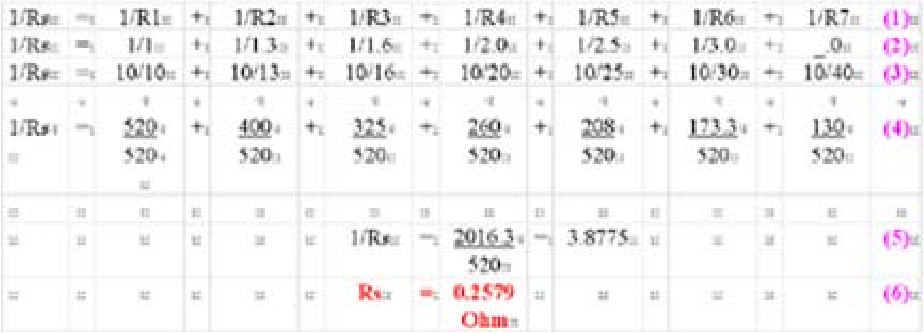
To make things less difficult to understand, above statement will be explained using some numerical examples.



This drawing shows a scheme of resistances which are connected in a parallel way.



Let's make the above diagram a little bit more simple to show what the Substitute Resistance is and to make things easier to calculate.



1/Rs	=	1/R1	+	1/R2	+	1/R3	+	1/R4	+	1/R5	+	1/R6	+	1/R7	(1)
1/Rs	=	1/1	+	1/1.3	+	1/1.6	+	1/2.0	+	1/2.5	+	1/3.0	+	_0	(2)
1/Rs	=	10/10	+	10/13	+	10/16	+	10/20	+	10/25	+	10/30	+	10/40	(3)
1/Rs	=	$\frac{520}{520}$	+	$\frac{400}{520}$	+	$\frac{325}{520}$	+	$\frac{260}{520}$	+	$\frac{208}{520}$	+	$\frac{173.3}{520}$	+	$\frac{130}{520}$	(4)
						1/Rs	=	$\frac{2016.3}{520}$	=	3.8775					(5)
						Rs	=	0.2579 Ohm							(6)

The calculation of Rs is shown here:

Rs is the Substitute Resistance. Now Rs is known, the Substitute Current and the partial currents flowing through each individual resistance can be computed.

Computing the Substitute Currents (I_{subst} or I_s)

Assume that the potential difference = 1.5 Volts. Since V = I x R, then I = V / R.

Rs = 0.2579 Ohm = 0.26 Ohm and Is = 1.5 / 0.26 = 5.82 Amps.

The Substitute Current Is is equal to I in and I out. (see Picture 5)

Examples:
The individual currents for:

I_1 = (520 / 2016) x 5.82 = 1.50 Amps

I_2 = (400 / 2016) x 5.82 = 1.15 Amps

I_3 = (325 / 2016) x 5.82 = 0.94 Amps

I_4 = (260 / 2016) x 5.82 = 0.75 Amps

I_5 = (208 / 2016) x 5.82 = 0.60 Amps

I_6 = (173 / 2016) x 5.82 = 0.50 Amps

I_7 = (130 / 2016) x 5.82 = 0.38 Amps

$I_1 + I_2 + I_3 + I_4 + I_5 + I_6 + I_7$ = 5.82 Amps, which is the actual preset current density.

Volts	1.5	1.0	3.0	4.5	6.0	9.0
I_1	1.50	1.00	3.00 *	4.50 *	6.00	9.00
I_2	1.15	0.77	2.30 *	3.45 *	4.60	6.90
I_3	0.94	0.61	1.84	2.78 *	3.68 *	5.52
I_4	0.75	0.50	1.50	2.25 *	3.00 *	4.50 *
I_5	0.60	0.40	1.20	1.80	2.40 *	3.60 *
I_6	0.50	0.33	1.00	1.50	2.00 *	3.00 *
I_7	0.38	0.25	0.76	1.14	1.52	2.28 *

The Partial Currents--the actual local current densities--for other voltages are put in table 3.

Practice

Suppose, polarization only occurs if the current density lies between 2 ASD and 4.5 ASD. (Remark: in Diagram 2, polarization lies between 4 ASD and 17 ASD). Below 2 ASD and beyond 4.5 ASD there is no polarization. Depending on the type of the used additive, copper is stripped away. If the current density has the value of the digits marked with an asterisk and green background then these areas are polarized.

Only in column 4 until 7 (the green areas) the local reverse current density is high enough to cause surface passivation. To obtain the optimum distribution, four reverse cycles are needed then.

Batchprogramming / Multi-Cycle-plating

From Table 3 we get a lot of information to create our 'Batchprogramme' or the Multi Cycle. The table also shows that 3.0 Volts, 4.5 Volts, 6.0 Volts and 9.0 Volts are usable Voltages.

From these Voltages we can derive the appropriate preset Reverse current densities.

In fact the Batchprogramme consists of two separate steps:
1. Plating step
2. Finishing step

The Finishing step is also called the 'Cosmetic step.' In the last cycle, the decision is taken whether the copper finish should be matte, semi-bright or silk-bright. This last step is then the 'Finishing step' or the 'Cosmetic step'.

Batchprogramme according Table 3:

Forward voltage Arbitrary, for instance 1.0 Volt

Reverse voltage 1 9.0 Volts

Reverse voltage 2 6.0 Volts

Reverse voltage 3 4.5 Volts

Reverse voltage 4 3.0 Volts

Reverse voltage 5 1.0 Volts, (semi bright finish)

(See Table 3 for the corresponding local current densities)

Note: Your comments and suggestions are very much appreciated, please send it

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