# Pulse Plating



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# Back to Basics: Pulse Math

Last month we looked at the diffusion zone in direct current and pulse plating. Now let's look at the simple mathematics of pulse calculations.

## On & Off

In direct current plating, the current goes on ... and on and on, or until you burn parts. You know what the current density range is for your plating system and you have calculated the total plating area. The same thing is also done for pulse plating. But there is one more burning advantage.

If you keep increasing the current in DC plating, you will eventually burn. This means that edges or highcurrent-density areas either run out of platable ions and hydrolyze water to make hydrogen, or simply receive more platable ions and outplate the rest of the part-or both. This is how to commercially make powders by DC or pulse. It is possible to increase platable current density by ten or 100 times or more than that of DC plating. It is done by concomitantly decreasing pulse current on-time. As you increase the current, you must reduce its time on (Ton). This is possible only because there is a certain number of platable ions in the diffusion zone at the work's surface during current flow. When the number of coulombs passes to reduce that number of ions, the transition time (t) has been reached (see last month's column). When Ton exceeds t, water reduction with hydrogen production occurs.

In order to manipulate this current and Ton (*e.g.*, to generate a finegrained structure), you will either get suggested values out of a book or article or else try something on your own. Generally, one would keep increasing the current at a fixed Ton, and then reduce Ton when the limiting current density has been reached. But as you reduce Ton, something happens to Toff (and grain size!).

## Duty Cycle (g)

Like the compression ratio in a motorcycle, pulse plating has a duty. It's the same mathematical concept. Engine compression ratio (C/R) is the clearance volume plus the displacement volume divided by the clearance volume [or volume of the combustion chamber when piston is at bottom dead center (BDC) divided by the top dead center (TDC) value]. Displacement volume of the engine is the difference between TDC and BDC, or the piston(s) swept volume(s).

So, (C/R) equals BDC / TDC (or [TDC + Displ.Vol.] / TDC). This is the nominal C/R. The actual C/R is less, as a result of late intake valve closing or more, if supercharged.

If TDC & Displ.Vol. represent pulse Ton & Toff, respectively, the reciprocal of the C/R is the pulse plating duty cycle,

g = Ton / (Ton + Toff)

Duty cycle is essentially the percentage of time plated, because T on + off constitute the period. Pulse frequency is equal to one thousand milliseconds divided by the period (cycle time), Ton + Toff (in milliseconds), expressed in cycles per second (Hertz, Hz).

So, if you do not decrease Toff while decreasing Ton, the duty cycle decreases, frequency increases, and effective grain size reduction (brightness or hardness) is barely realized. This is like losing power from lost compression. Engines can use variable valve timing and other measures to compensate. The same holds true for pulse plating deposit performance.

Higher or lower duty cycles are needed for grain refinement, depending on the type of plating bath and system conditions. For example, higher ratios of Ton / Toff (larger duty cycles), or longer time on or less time off, generally favor the production of smaller grains in systems such as copper and gold plating. Contrariwise, zinc and cadmium prefer lower duty cycles. Grain refiners work synergistically with pulsing by inhibiting growth of (newly plated) nuclei.

Most systems prefer to recrystallize during off time, such that smaller crystals (nuclei) formed by pulses become incorporated into the larger growing crystal centers. This is a general crystallization phenomenon for lowering the entropy of salts, silicas, and metals, etc. Other factors influence electrocrystallization, such as current density, inhibitory electroactive species in the electrolyte (citrate, tartrate), cogenerated hydrogen, etc.

### **Average Current Density**

You need to know how to calculate the average current density to compare how you're doing vs. DC, but, more importantly, to figure the time needed to get a required thickness. The values of peak and average currents to be used are also mandatory for specifying the pulse power supply you desire. There's nothing worse than purchasing an undersized, unusable unit or overspecifying and overpaying. The average current density is equal to the peak current density times the duty cycle (percent of peak),

 $jM = jP \times Ton / (Ton + Toff)$ 

#### **Pulse Reverse**

If pulse reverse means that after the forward pulse comes the reverse pulse, or vice versa, it's still relatively easy to conceptualize. There are two pulse current peaks, forward and reverse [iP(c) & iP(a)]. There are two lengths of time, pulses forward and reverse [Ton(c) & Ton(a)]. Instead of a duty cycle, it is preferred to have a "charge quotient," Qc/Qa or Qa/Qc, which is like a double duty cycle. The charge, Q, is current x time. Thus, Qc/  $Qa = [jP(c) \times Ton(c)] / [jP(a) \times Ton(c)]$ Ton(a)], or vice inversa. This is used to establish the limit of material removal for a leveling effect, or for primary geometry rectification, or even a "reverse" throwing power. Consideration must be also given to the ratio of forward to reverse current components of current density. Some

materials, such as copper, will begin anodic pitting after reaching passivating current levels.

At this time, I am not aware of any pulse plating power supplies that calculate the effective forward current.time by subtracting reverse current.time from total forward current.time. Because they only count Amp.minutes forward for the purpose of programming step markers, it behooves the user to know how to calculate actual coulombs used, for required thickness, or switching to the next pulse or other plating parameter. What percent of the total charge is employed when plating pulse reverse? The percent total cathodic charge comes from the difference in cathodic and anodic charges divided by cathodic charge,

 $\begin{array}{l} (Qc - Qa) \ / \ Qc = \left[ \ (jP(c) \ x \ Ton(c)) - (jP(a) \ x \ Ton(a)) \ \right] \ / \ (jP(c) \ x \ Ton(c)) \end{array}$ 

For example, on-time is 20x reverse time and reverse current density is 3x forward current density. (Qc - Qa) / Qc = [(1 x 20) - (3 x 1)] / (1 x 20) = (20 - 3) / 20 = 17 / 20 = 0.85 = 85%.

This means that 0.85 of the forward current.time is actually used in the deposit. So if you calculate that the actual thickness will take 28 min ([ca]/c), the power supply will stop at 32.94 min. You would need to divide your calculated number of amp.minutes by 0.85 and, of course you have already factored in the plating efficiency.

### Pulse Reverse with Off-Time

There are cases whereby an off-time is desired after the forward pulse or (and) after the reverse pulse (or before the the forward pulse). The main concern is for the length of off-time(s) and, knowing the desired forward and reverse times and currents, all that's left to calculate is for plating thickness and perhaps a relative duty cycle. These are treated in similar manner to the prior sections; just combine the equations. *PassF*