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Pulsed Power Technology: Pulse Transition Characteristics*

There are many variations of pulse waveforms used in electroplating. For practical purposes we will limit our discussion to the three most common: periodic pulse (unipolar), periodic pulse reverse (bipolar) and wave sequencing (sequentially combining multiple waveform).

Overview of Pulse Characteristics

The word "pulse" has become a generic term, but in fact it covers a very broad range of distinct waveforms and waveform properties. In a previous article, we listed some of the principle defining parameters of non-DC periodic waveforms.

Pulse Waveform Transitions

Understanding the pulse wave shape and transient performance is critical in achieving the desired deposit characteristics. It is primarily the shape of the output waveform, which provides benefits such as: leveling, throwing power, flatter deposit, grain size and others.

One of the primary reasons for the lack of success using pulse plating in the past, is that older technology "rectifiers" cannot deliver quality pulse waveforms. Figure 1 demonstrates a satisfactory pulse waveform with fast transition times and low over-shoot. Figure 2 demonstrates a typical pulse waveform generated by older technology rectifiers. Note the distorted waveform shape (non-square) caused by the slower rise and fall-times of the pulse. The pulse in Fig. 2 contains less energy (per cycle) than the pulse in Fig. 1, and its performance will be significantly different in a plating bath.

Pulse Rise-time & Fall-time

The "rise-time" is traditionally defined in electronic signal analysis as the time for the signal to move (transition) from 10 percent to 90 percent of the steady-state value. This definition was selected because it is often difficult to identify the exact points in which 0 and 100 percent occur. The "fall-time" is traditionally defined in electronic signal analysis as the time for the pulse signal to move from 90 percent to 10 percent of the steady-state value.

The rise-time and fall-time are important characteristics and contribute directly to the amount of energy and shape of the pulse. Significant improvements have been made in transition time capabilities with new technology power supplies. As demonstrated in Fig. 2, slow rise- and fall-times significantly distort the wave shape. Note that if the rise-time exceeds the pulse on-time, the pulse will never reach the peak amplitude level. Pulses with slower transition times can produce numerous detrimental effects, including: slower plating, decreased modulation of the pulsating diffusion layer, and reduced nucleation sites.

One of the benefits of faster transition times is to overcome the capacitive double layer effect. This effect occurs during each pulse level transition.

Typical transition times for pulse power supplies are in the range of 10–50 microseconds. This enables power supplies to generate pulses ranging from 100 microseconds through DC.

* *This article is one in a series, designed to provide accurate and practical information on pulse plating power supply equipment (pulse rectifiers).*

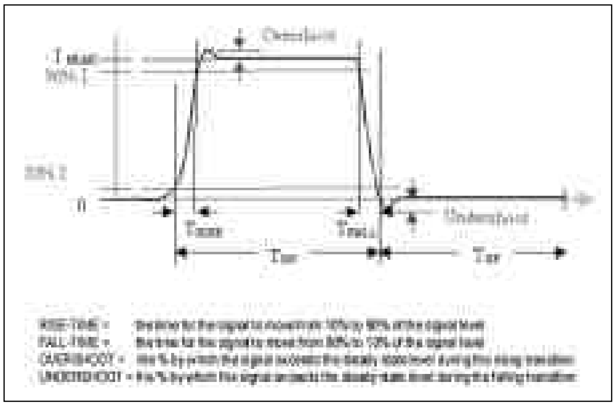

Fig. 1—Satisfactory pulse waveform.

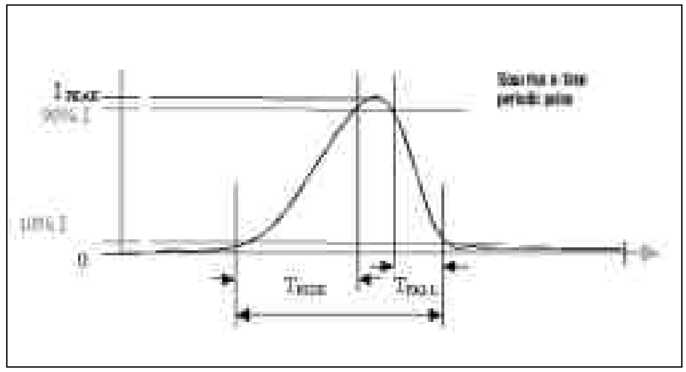

Fig. 2—Typical pulse waveform with less modern rectifiers.

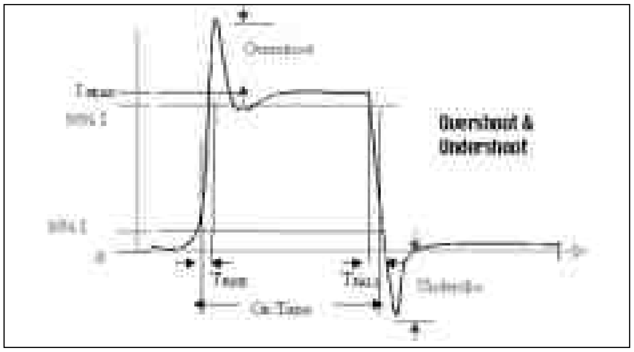

Fig. 3—Waveform with a high overshoot.

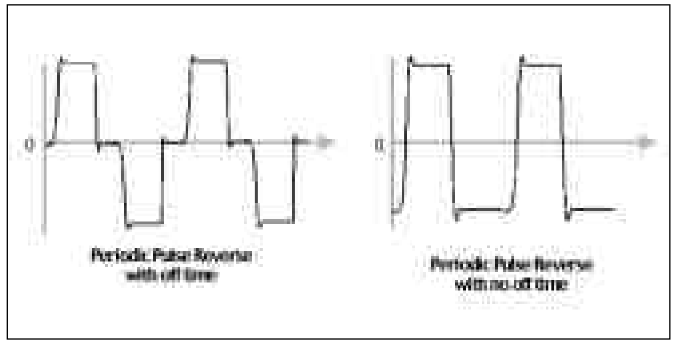

Fig. 4—Demonstration of waveform with off-time and one with no off-time.

Power supply manufacturers are working to provide faster rise times on the order of 1–10 microseconds to reduce pulse width and increase frequency for certain applications.

Pulse Overshoot & Undershoot

It is common for pulse power supplies to have some overshoot to improve the rise- and fall-times. Increasing the overshoot significantly improves the rise-times of the waveform. Similarly, increasing the undershoot will significantly improve fall-time. Some power supply manufacturers tend to significantly increase the overshoot to improve rise-time with complete disregard for its effect on the plating system.

Users should be careful to avoid devices that improve rise-time by increasing overshoot. Figure 3 demonstrates a waveform with a high overshoot that can generate excessive voltage and current spikes, causing damage to the chemistry or material in process.

As a general rule, an overshoot or undershoot on the order of 10 percent is acceptable. This allows for fast transition times without excessive transient voltage or current spikes. Additional research is required on the relationship between overshoot and the charging and discharging of the double layer.

For periodic pulse waveforms, it is common for the fall-time to be slower than the rise-time. This is because the unit supplies energy during the rise-time, then switches off, allowing the load to drop the signal level and determine the fall-time. For non-resistive loads, this can significantly increase the fall-time. With pulse systems, care should always be taken to keep cables short and highly conductive.

Pulse Zero Level Transitions

Depending on the construction method of the power supply an off-time ("rest" or "pause" at zero amplitude) may or may not be required. Figure 4 demonstrates two waveforms—one with an off-time and the second with no off-time.

The correct choice of plating power supply will depend on the chemistry, process and application. Certain older technologies cannot generate periodic pulse reverse waveforms with no off-time. Many periodic pulse reverse power supplies that can generate pulse with no off-time can also generate a waveform with off-time. Although in some cases an off-time may be desirable, in other cases the off-time can slow down the plating process or contribute to delaminating. The proper choice will depend on your plating process.

Optimized Forward: Reverse Ratio

As the relationship between the chemistry, process, cathodic geometry and the required deposit characteristics are more specifically defined, power supply manufacturers are providing valuable data. This data narrows the pulse operating range and allows for the optimization of the power supply operating and output parameters.

One example would be a power supply where the output is optimized for a specific forward: reverse amplitude ratio. A common waveform used to electroplate copper into PTH's on printed circuit board applications utilizes a forward/reverse current ratio of 1:3. This ratio, combined with the appropriate pulse forward and reverse time, performs very well for PTH plating using a specific chemistry. Because the power supply has been optimized to function at this ratio, it can deliver improved transition times. Note that this ratio is no longer appropriate with micro-vias (smaller feature sizes) or with alternative chemistries. This limits the power supply to that specific application.

As with all electrical feedback-based systems, optimizing the unit for one operating mode will improve performance in that range and limit or degrade outside that range. Typically, optimizing for a specific forward to reverse ratio will improve the performance waveform and transition time at that ratio, and it will slightly degrade the performance outside that ratio.

Special applications or performance requirements should be discussed in detail with your power supply vendor to understand the tradeoffs associated with optimizing for specific waveform parameters.

Understand System Requirements

In implementing pulse plating, be certain that you clearly understand your system requirements prior to ordering. These include:

- Required average, peak & RMS plating current and duty cycle range
- Required voltage based on Ohm's law (Peak current x Load)
- Insure that your unit performs properly (fast transition times with reasonable overshoot)

Future columns will cover other important information regarding the functionality and performance of pulse power supplies.

Bibliography

Jean-Claude Puippe & Frank Leaman; "Theory and Practice of Pulse Plating," *American Electroplaters and Surface Finishers Society*, 1986

E. Gutierrez; "Recent Advances in Pulse Plating Power Supply Technology," *AESF 5th Pulse Plating Symposium* (June 2000)