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Pulsed Power Technology: Peak, Average & RMS Defined

Types of Pulse Waveforms

There are many implementations of pulse waveforms in electroplating. Most are used in R&D applications, although more advanced pulse and pulse combinations are making their way into mainstream plating. This is especially true in the manufacturing of printed circuit boards, semiconductors and other advanced electronics. For practical purposes, we will limit discussion to the three most commonly used:

1. Periodic Pulse or Uni-polar pulses (Fig. 1)
2. Periodic Pulse Reverse or Bi-polar pulses (Fig. 2)
3. Wave Sequencing (Multiple waveforms) (Fig. 3)

This month's column will focus on peak, average, and RMS signal levels, of a periodic pulse 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 the first article of this series (June 2001), we listed some of the principle defining parameters of non-DC periodic waveforms.

For those who missed the first part of this series, we have summarized the principal defining parameters in Fig. 4.

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

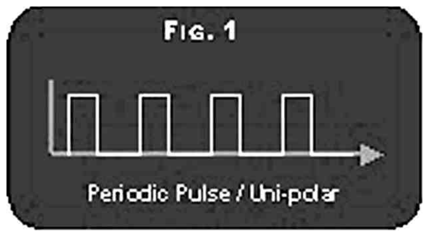

Fig. 1—Periodic pulse or uni-polar pulse.

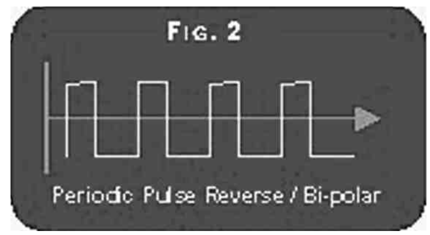

Fig. 2—Periodic pulse reverse or bi-polar pulse.

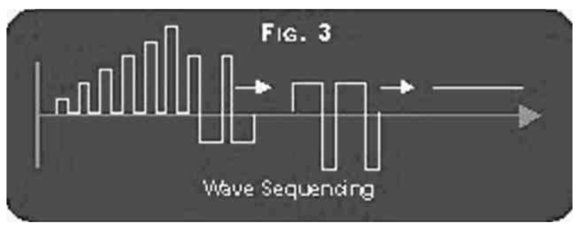

Fig. 3—Wave sequencing or multiple waveforms.

When Applying Pulse

Clearly there are numerous resulting combinations of pulse signals obtained by modifying the parameters defined in Fig. 4. Many applications of pulse plating have been unsuccessful because of the lack of setting up the appropriate waveform, duty cycle, frequency and amplitude.

Care should be taken to recognize that a pulse waveform that is successful in "Application A" might not be beneficial in "Application B." It is the appropriate combination of the four parameters shown in Fig. 4—in conjunction with the plating system—that allows the system to achieve the desired results.

Peak Pulse Signal Level

The concept of peak, average and RMS signal amplitude is basic to the electroplating process, and they define such properties as plating rates and heating effect.

The peak signal amplitude for Fig. 4 is defined by I_{PEAK}. This is the amplitude of the signal during the period T_{ON}. Note that a pulse reverse waveform will have a positive peak amplitude during the forward period and a negative peak amplitude during the reverse period.

It is important to understand the peak amplitude capability of your pulse power supply for three reasons:

1. Most pulse power supplies require the user to dial in the peak amplitude and not the average, as in the case of a DC supply.
2. If the user wishes to convert from DC to pulse signals and maintain similar plating rates, then he needs to understand that the peak amplitude capability of the power supply must exceed the DC level at which he is accustomed to plating. This is especially true when using low duty

cycles and will be discussed in greater detail.
3. In some cases, using a very high peak amplitude can cause damage to the plating process.

Average Pulse Signal Level

The average value of a pulse waveform is equivalent to the DC value. The average or DC current is the working current and defines the plating rate.

The average signal level can be visualized with the help of Fig. 5.

The average signal level for a unipolar pulse, as shown in Fig. 5, can be calculated by multiplying the peak signal level (I_{PEAK}) and the duty cycle (D).

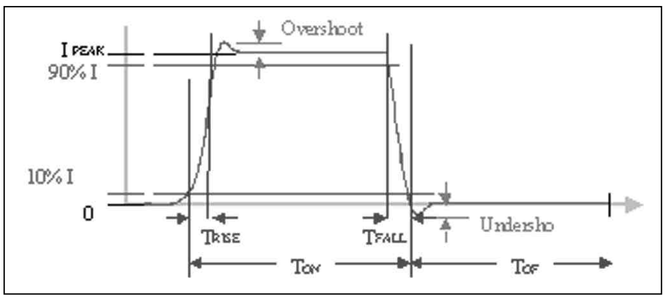

Fig. 4—Periodic waveforms.

$$I_{AVG} = I_{PEAK} \bullet D$$

For more complex time varying waveforms f(t), the average signal level can be calculated by the following formula.

$$I_{AVG} = (1/T) \bullet \int_0^T f(t)\, dt$$

Care must be taken to select the proper values for I_{PEAK} and D during plating, in order to achieve an optimal average current. Too high an I_{AVG} is equivalent to having too high of a DC current and will deplete the ions at the surface and cause burning. Too low an I_{AVG} will slow down the plating process and production throughput.

To help define the relationship between peak, average and duty cycle, see Table 1 to view the required peak current capability of a pulse power supply to maintain an average plating rate of 100 A. This demonstrates the importance of properly specifying the pulse power supply, especially when looking to benefit from narrow duty cycle pulses for such applications as small feature sizes and conformal coatings.

Table 1

Duty Cycle	I_{PEAK}	I_{AVG}
100 % (DC)	100 A	100 A
75%	134 A	100 A
50%	200 A	100 A
25%	400 A	100 A
10%	1000 A	100 A

RMS Pulse Signal Level

RMS is short for root mean square. The I_{RMS} level falls between I_{PEAK} and I_{AVG} as shown in Fig. 5. The RMS current is important because it defines the heating effect of the current. It is, therefore, the RMS and not the DC current that should be used when determining cable and shunt requirements. For DC $I_{RMS} = I_{AVG}$.

The RMS signal level for a unipolar pulse, as shown in Fig. 5, can be calculated by multiplying the peak signal level (I_{PEAK}) and the square root of the duty cycle (D).

$$I_{RMS} = I_{PEAK} \bullet \sqrt{D}$$

For more complex time varying waveforms f(t), the RMS signal level can be calculated by the following formula.

$$\mathbf{I_{RMS} = \sqrt{(1/T) \bullet \int_0^T f(t)^2 \, dt}}$$

Care must be taken to select the cables, shunts and other current sensitive devices based on the I_{RMS} current, in order to avoid underrating these devices and creating a potentially dangerous situation.

As an example to help define the relationship between peak, average, RMS and duty cycle, see Table 2 to view the RMS current for various pulse waveforms maintaining an average plating rate of 100 A.

Note that for a power supply running 100 Amps average with a 25% duty cycle the cables must be capable of 200 Amps.

Ohm's Law

We now understand the relationship between peak, average and RMS signal levels and can specify the correct power supply based on this information. One additional piece of information is required: the relationship between the output voltage, current and the load (as defined by Ohm's law).

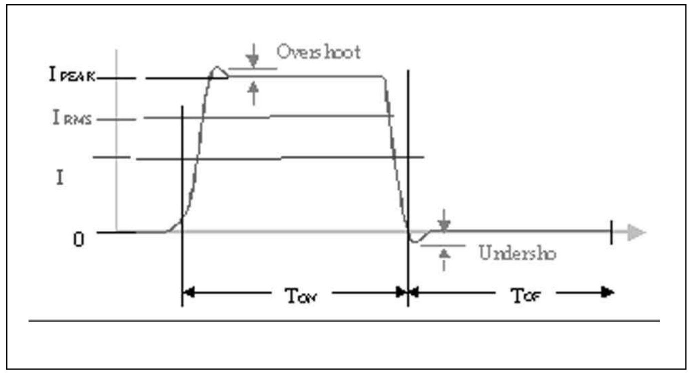

Fig. 5—Average pulse signal level.

OHM's Law V = I x R
V is defined in volts
I is defined in amperes
R is defined in ohms

We can see from Tables 1 and 2 that if we are looking to substitute a 100 A DC unit with a pulse power supply, as the duty cycle decreases, a higher peak current is required. It is important then to note that additional voltage may be required to drive this higher amperage based on the load.

When considering the average and peak amplitudes for a plating system the load must be considered to insure the power supply has sufficient voltage to deliver the peak current.

See Table 3 as an example for defining the relationship between increasing peak current, voltage and load. Again, we will maintain an average plating rate of 100 A.

Clearly, if we purchased a 9 V DC pulse power supply we could not run duty cycles below about 50 percent. Care must be taken to insure that the pulse rectifier is capable of generating sufficient voltage to drive the desired peak current based on the load.

Overshoot & Undershoot

One of challenges in the design of power supplies, is to deliver fast transition times with reasonable overshoot. Overshoot as demonstrated in Fig. 5 shows the pulse exceeding the I_{PEAK} level. Power supplies that produce large overshoots may damage the plating process.

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

- Required average plating rate.
- Target expected duty cycle range.
- Required peak current based on average current and duty cycle.
- Required voltage based on Ohm's law (Peak current x Load).

Upcoming columns will cover other important information regarding the functionality and performance of pulse power supplies. *P&SF*

Bibliography

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

Table 2

Duty Cycle	Ipeak	Iavg	Irms
100 % (DC)	100 A	100 A	100 A
75%	134 A	100 A	116 A
50%	200 A	100 A	142 A
25%	400 A	100 A	200 A
10%	1000 A	100 As	317 A

Table 3

Duty Cycle	Ipeak	Iavg	Volts
100 % (DC)	100 A	100 A	4 VDC
75%	134 A	100 A	5.36 VDC
50%	200 A	100 A	8 VDC
25%	400 A	100 A	16 VDC
10%	1000 A	100 A	40 VDC