Pulse Plating

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Pulsed Power Technology—Part I:* Technology Overview

> *“It used to be that the big ate the small. Now it’s the fast that eat the slow.”*
>
> —Geoff Yang

Geoff Yang is referring to the effect of information and technology on our capability to design and manufacture. “*Fast*” refers to the ability to be innovative and leverage new technologies and processes, deriving competitive and financial advantages.

To be *“fast,”* we must first be informed. It is knowledge of new technologies and processes that allows us to pursue their proper implementation and benefits.

Recent Advances In Pulse Technology

Advances in power semiconductor technology, microprocessor technology, manufacturing processes and networking are all contributing factors that enable the design, manufacture and availability of more precise, flexible and higher-performance pulse and wave sequencing power supplies. These advances, driven primarily by the demand in related power supply markets, such as computers, telecommunications, instrumentation and military/aerospace, are then incorporated by technology-capable companies serving the electroplating markets.

Most of the recent advancements in electroplating power supplies are very significant and fall into the following categories:

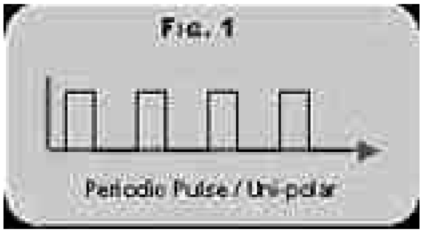

Fig. 1—Periodic pulse or uni-polar pulse.

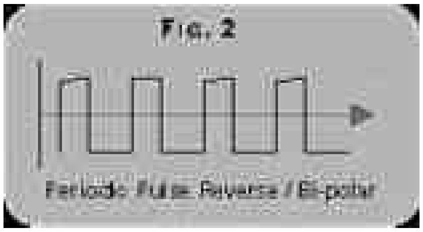

Fig. 2—Periodic pulse reverse or bi-polar pulse.

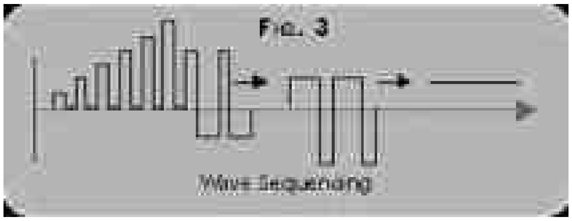

Fig. 3—Wave sequencing or multiple waveforms.

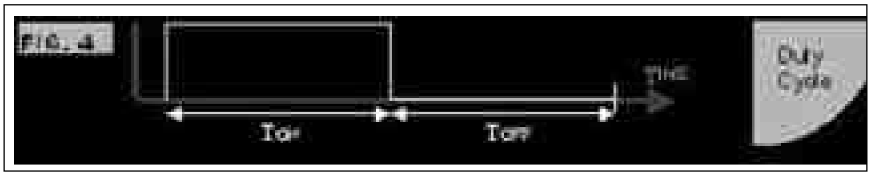

Fig. 4—Duty cycle parameter.

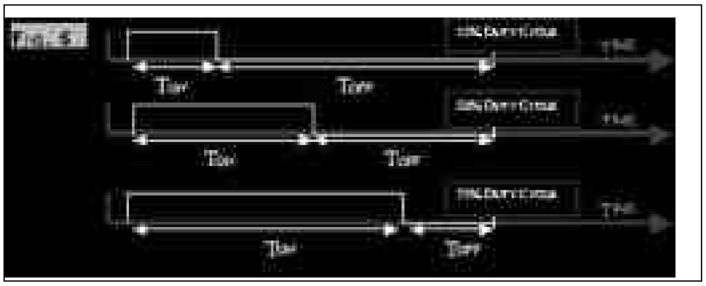

Fig. 5—Duty cycles of pulse waveforms of 25%, 50% and 75%.

- Improved performance and specifications;
- Ability to generate more complex waveforms;
- Improved user ergonomics and capability;
- Improved automation and process integration;
- Size and weight benefits.

Types of Pulse Waveforms

There are many implementations of pulse waveforms in electroplating.

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

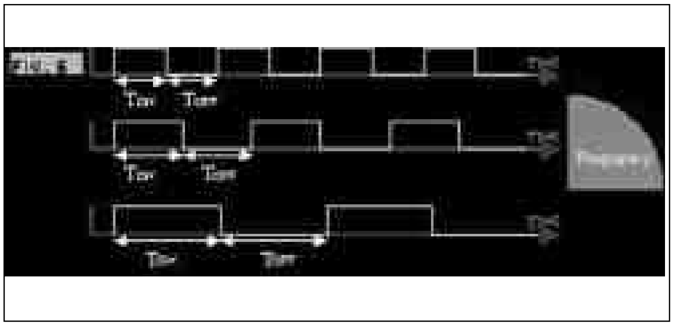

Fig. 6—Various pulse frequencies.

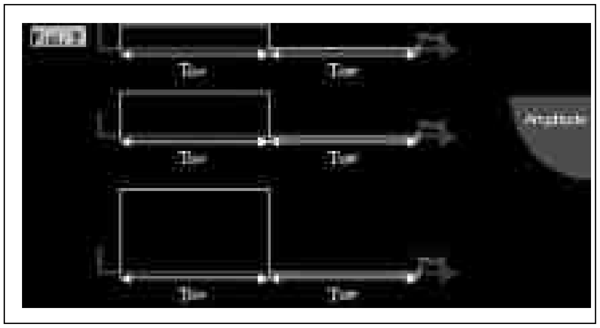

Fig. 7—Peak amplitude.

Most of these are used in R&D applications. For practical purposes, we will limit our discussion to the three most commonly used:

- Periodic pulse or uni-polar pulses (Fig. 1)
- Periodic pulse reverse or bi-polar pulses (Fig. 2)
- Wave sequencing (multiple waveforms) (Fig. 3)

Overview of Pulse Characteristics

"Pulse" has become a generic term, but in fact it covers a very broad range of distinct waveforms and waveform properties. Before we continue, we need to clarify the scope of these non-DC periodic waveforms and why implementing pulse plating requires a degree of investigation and commitment.

In order to begin to understand the broad scope of non-DC periodic waveforms, we need to consider the parameters they offer us.

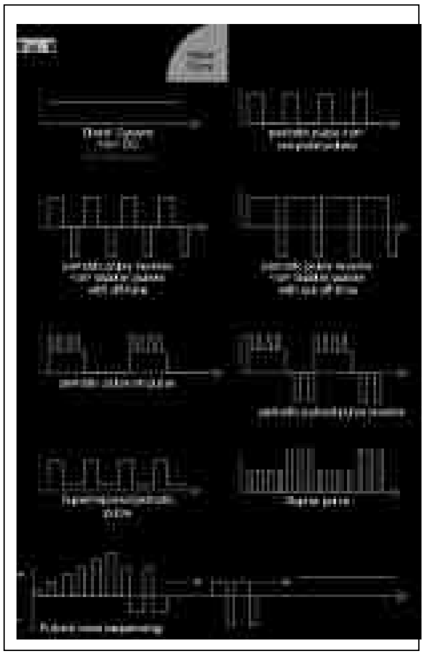

Fig. 8—Pulse waveform type.

Pulse waveforms have a duty cycle parameter (shown in Fig. 4.) defined by:

$$\text{DUTY CYCLE} = \frac{T_{ON}}{T_{On}+T_{OFF}}$$

One defining pulse parameter is therefore the duty cycle of the waveform. Figure 5 demonstrates several pulse waveforms with duty cycles of 25 percent, 50 percent and 75 percent, respectively. Note that a duty cycle of 100 percent would produce a DC signal.

Pulse waveforms have a frequency parameter, defined by:

$$\text{FREQUENCY} = \frac{1}{T_{On}+T_{OFF}}$$

A second defining pulse parameter is, therefore, the frequency of the waveform. Figure 6 demonstrates several pulses that vary in frequency.

A third defining pulse parameter is the peak amplitude, as defined by the signal amplitude during the on-time as shown in Fig. 7.

Yet another defining pulse parameter is the type of pulse waveform. Figure 8 demonstrates various pulse plating waveforms, including some of the more common ones currently used in plating.

Clearly, there are numerous parameters and resulting methods of application of pulse signals to electroplating. Many applications of pulse plating have been unsuccessful because of the lack of setting up the appropriate parameters: waveform, duty cycle, frequency and amplitude.

Care should be taken to recognize that a pulse waveform, that is successful in "Application A" may not be beneficial in "Application B." It is the appropriate combination of these four parameters shown in Fig. 9, which allows the system to achieve the (application specific) desired results.

Overview of Pulse Waveform Benefits

The application and benefits of pulse is an ongoing field and this column will do little more than provide a basic introduction into pulse waveforms. More detailed explanations and information are available in Jean-Claude Puippe & Frank Leaman's *Theory and Practice of Pulse Plating*, available from the AESF Bookstore.

A simplified explanation of pulse waveforms is an increase in the number of control variables over traditional direct current (DC). DC enables us to control the current density (or amps adjustment), while periodic pulse waveforms provide control over on-time, off-time and on-amplitude. More complex waveforms provide an increased number of control parameters. These parameters enable us to alter our electrochemical process by affecting such properties as diffusion layer, grain size and nucleation, as examples.

Pulse waveforms provide improved capability and reduce process cost over direct current.

For reference, DC provides a constant potential between the anode and cathode, while the chemistry and chemical additives create the desired deposit properties. These include such characteristics as hardness, smoothness, conductivity, throwing power, leveling, etc.

One of the most common uses of periodic pulse (PP) is in modulating the pulsating diffusion layer (not present in DC) to control grain size and nucleation sites. The pulsating diffusion layer is proportional to the on-time and, therefore, allows for control over grain size. The number of nucleation sites is proportional to the on-amplitude. Therefore, an increased on-amplitude increases the number of sites where crystals begin to grow. Common applications include low-duty-cycle, high-amplitude pulses to achieve confor-

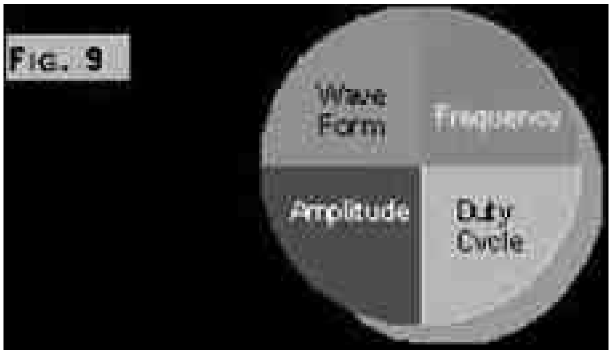

Fig. 9—Parameters for application.

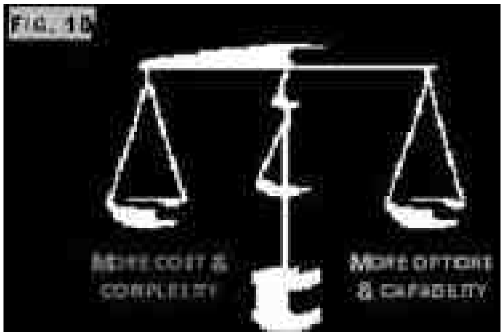

Fig. 10—Evaluate options carefully.

mal coating. Many other pulse recipes are also used, based on the geometry of the cathodic surface, desired deposit characteristics, chemistry and additives present.

One of the most common uses of periodic pulse reverse (PR) is in the redistribution of material over the cathodic surface (includes throwing power). The pulsating diffusion layer described for periodic pulse is also applicable to periodic pulse reverse, but can vary in effect during the positive and negative cycles of the pulse waveform based on the chemical additives. Different additives react differently to reverse current. It is common to need to adjust reverse-amplitude and reverse-time based on the manufacturer of the chemistry. Common implementation attempts to achieve a balance between the positive cycle to selectively deposit material (with the desired material properties) and the negative cycle attempts to selectively remove material from the high-current-density areas (to achieve proper leveling or increased throwing power). Common applications include PWBs, semiconductors and very-difficult-to-plate geometries. There is a wide variety of pulse recipes based on the geometry of the cathodic surface, desired deposit characteristics, chemistry and additives present.

Wave sequencing (WS) power supply technology is relatively new. WS power supplies benefit from their ability to combine DC, PP and PR waveforms in a controlled sequence, creating a controlled process to plate difficult cathodic surfaces or achieve special deposit characteristics. WS is analogous to creating a complex molding tool. It is fabricated by a sequence of cutting bits capable of removing a specific amount and shape of metal. Similarly, WS deposits metal by sequentially combining waveforms, each designed to yield a specific deposit result, in combination with the chemistry. Common applications of WS are designed to achieve deposits on surfaces that cannot be processed by DC or a single periodic waveform, while increasing process automation and potentially reducing the consumption of chemical additives.

What Pulse Can Do

The proper use of pulse technology in electrochemical deposition can yield numerous capability, process control and cost benefits over DC systems.

Common benefits in mature applications of pulse technology (including periodic pulse, periodic pulse reverse and wave sequencing) are:

- Deposit capability that cannot be achieved with DC;
- Flatter deposits (reduced dog-bone);
- Improved leveling;
- Improved throwing power;
- Selective deposits;
- Improved plating over difficult cathodic surfaces;
- Improved process control and data monitoring;
- Reduced consumption of additives;
- Increased throughput;
- Increased repeatability;
- Increased process automation;
- Decreased production cost.

What Pulse Cannot Do

There have been many failed attempts to implement pulse over the past 30 years. Most can be attributed to one of the following:

- Poor quality pulse power supply (slow rise times & poor performance);
- Lack of information to select the appropriate pulse parameters for the desired deposit characteristics;
- Lack of support by the chemical companies regarding information on how the additives react with pulse signal;
- Lack of sufficient laboratory development prior to production implementation.

Regardless of these shortcomings, it is important to dissipate several common misconceptions regarding pulse:

- Pulse is not magic or luck; it does not work independently of the plating system. Before embarking on pulse technology, it is vital to have an optimal cell geometry and DC plating system.
- Pulse is not a direct substitute for DC; adjustments may be required to the plating system, anodes, chemistry and additives. This is especially true with pulse technologies that reverse polarity.
- Average pulse current cannot exceed the DC threshold in order to plate faster. Pulse can achieve increased throughput over DC, especially if the results of the DC system are acceptable. Pulse can then deposit more efficiently, thereby reducing plating time.
- There is no “magic pulse waveform.” Each application requires a specific set of pulse parameters based on the metal, cathodic surface(s), plating system, chemistry and additives, desired deposit characteristics, and others.

If You are Considering Pulse

In considering implementing an electrochemical pulse deposition process, information is required in three areas (at a minimum):

- Research to obtain published information and a general under-

standing of how pulse has been successfully applied to similar applications and metals.
- Research to obtain a general understanding of pulse signals and pulse power supply technology.
- A detailed implementation plan for upgrading your DC process to pulse technology, including desired results, realistic timeline and R&D budget.

Expect setbacks when implementing pulse, as is the case with any process upgrade to improve capability and financial gain. If time is a factor, serious consideration should be given to including a consultant with extensive experience in pulse technologies.

Evaluate First, Implement Carefully

Upgrading your electrodeposition process to pulse technology is an individual decision that should be based on your budget, customer requirements, and the competitive advantage it offers your company.

Pulse is often viewed in terms of: "*more cost and complexity*" vs. "*more options and capabilities,*" (Fig. 10). It is always good to have options, and to recognize that: *"It used to be that the big ate the small. Now it's the fast that eat the slow."* Those who are first to embrace new technology and capability (innovative companies) can realize a genuine competitive and financial advantage.

We leave it to your team to investigate published application specific material and to consult with your chemical provider. *P&SF*

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About the Author

Enrique Gutiérrez is the co-founder of TecNu, Inc. and has served as president since 1991. He is a member on the AESF Pulsed Electrochemical Processes Committee. He holds a BS in electrical engineering from the Illinois Institute of Technology.