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RECENT ADVANCES IN PULSE POWER SUPPLY TECHNOLOGY & PLATING CAPABILITY

For:	5th International Pulse Plating Symposium	**By:**	Enrique Gutiérrez Jr.
	AESF SUR/FIN® 2000		TecNu, Inc.

OUTLINE

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1. CONTRIBUTIONS TO RECENT ADVANCES IN PULSE PLATING POWER SUPPLY TECHNOLOGY

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

Most of the recent advancements in electro-plating power supplies are very significant and fall into the following categories;

- Improved performance and specifications
- Ability to generate more complex wave forms
- Improved user ergonomics and capability
- Improved automation and process integration
- Size and weight benefits

2. OVERVIEW OF THE SCOPE OF PULSE WAVE FORMS

A simplified explanation of a pulse wave form 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 a Periodic Pulse wave form enables us to control the On-Time, Off-Time and On-Amplitude. More complex wave forms enable additional control variables. These variables enable us to alter our electro-chemical process by affecting such properties as diffusion layer, grain size and nucleation, as examples.

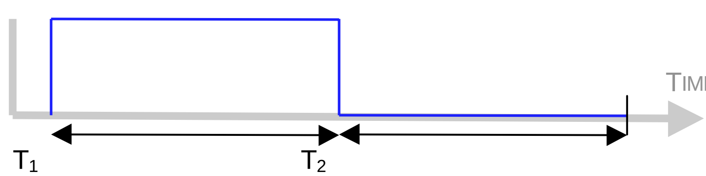
“Pulse” has become a generic term which in fact covers a very broad range of distinct wave forms and wave form properties. Before we continue we need to clarify the scope of these non-DC periodic wave forms and why implementing pulse plating requires a degree of investigation and commitment.

In order to begin to understand the broad scope of non-DC periodic wave forms we need to consider the variables they offer us.

Pulse wave forms have a duty cycle defined by T_1 / [T_1+T_2}. See Fig. A.

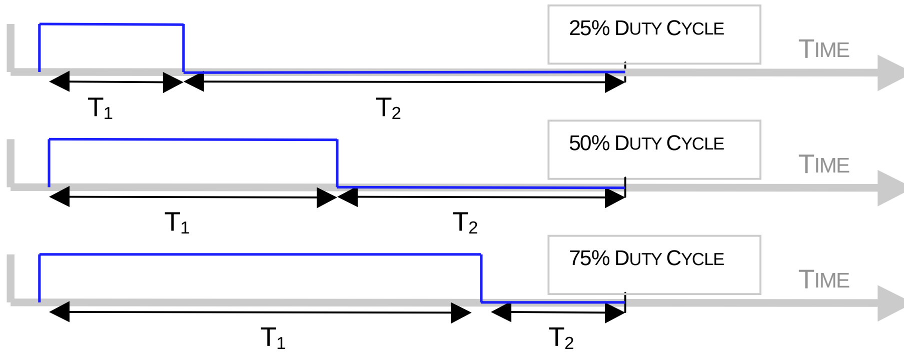
Duty Cycle

Fig. A



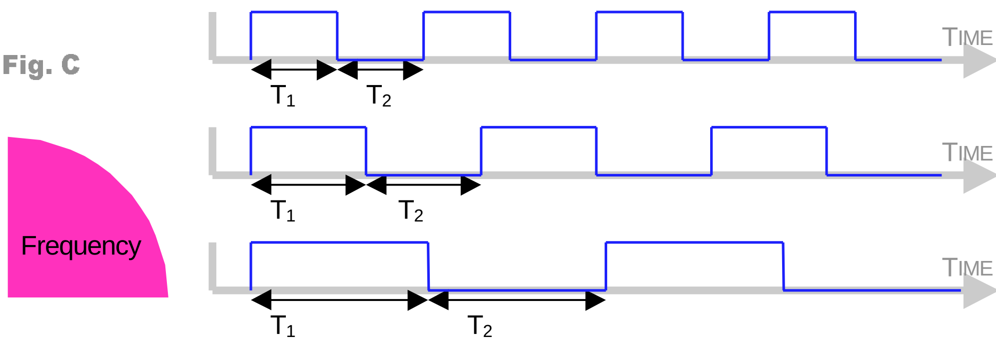
One control variable is therefore the duty cycle of the pulse wave form. Fig. B, demonstrates several of pulse wave forms with duty cycle of 25%, 50% and 75% correspondingly. Note that a duty cycle of 100% would produce a DC signal.

Fig. B



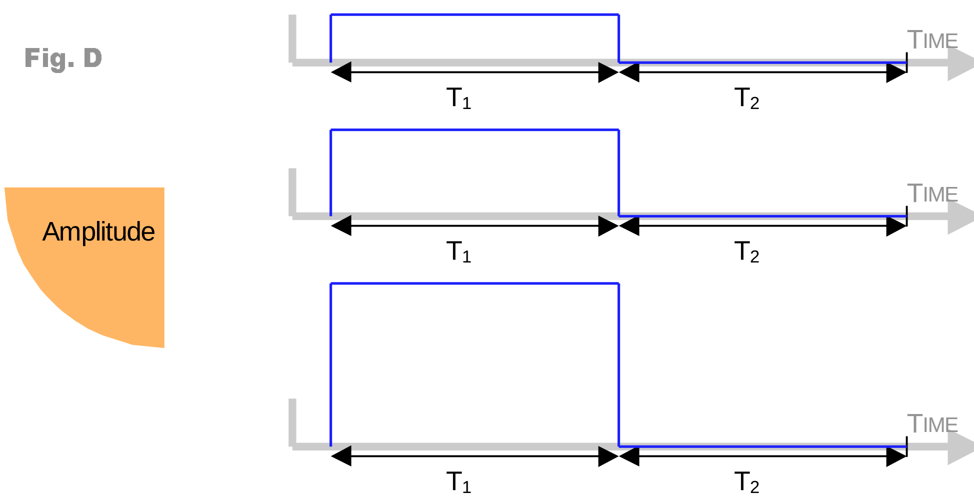
Pulse wave forms have a frequency defined by 1 / $[T_1+T_2\}$ as shown in Fig. A. A second control variable is therefore the frequency of the pulse wave form and we can see in Fig. C various pulses which vary in frequency.

Fig. C



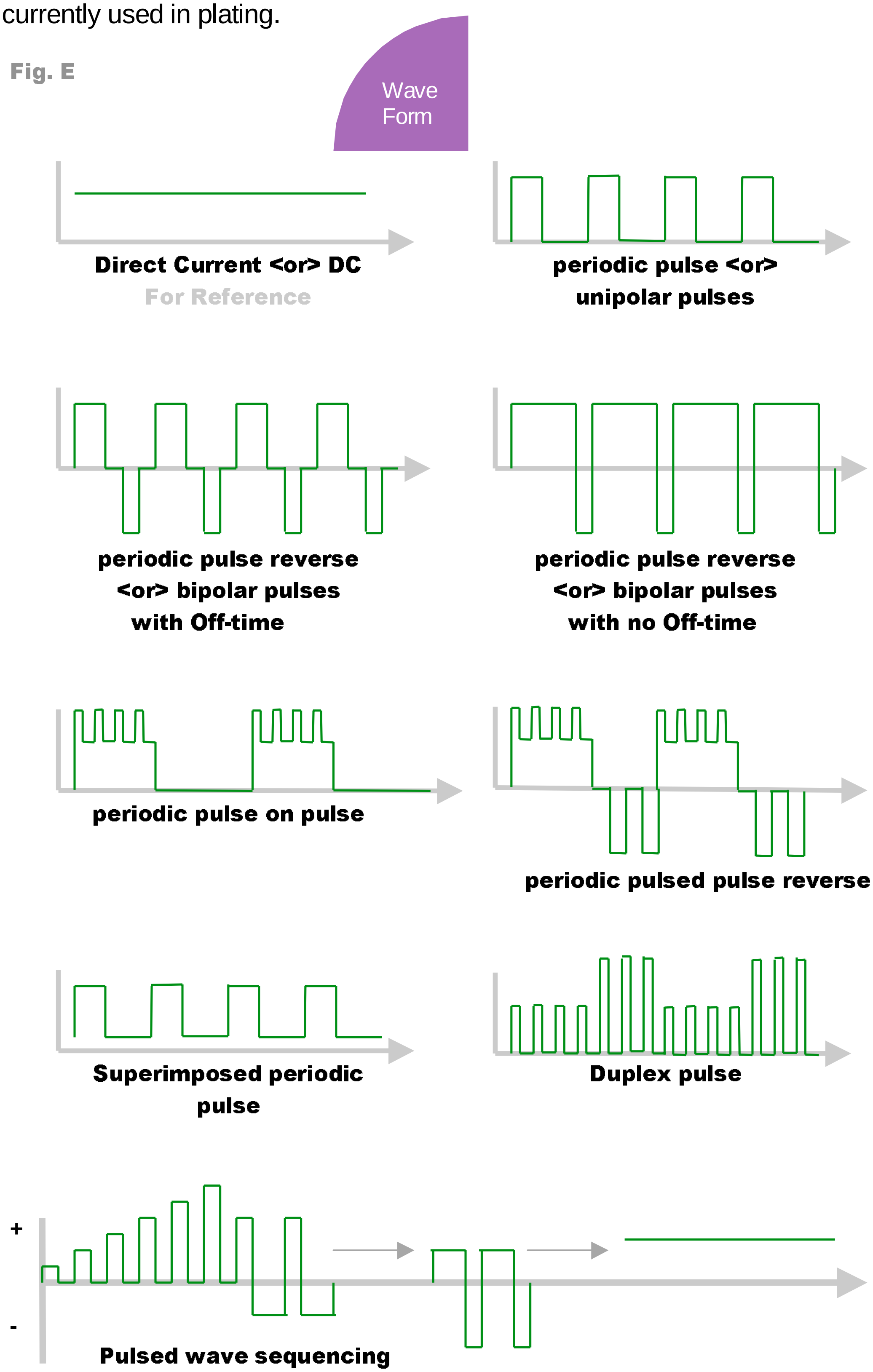
A third control variable is the amplitude as defined by the signal amplitude during the On-time as shown in Fig. D.

Fig. D



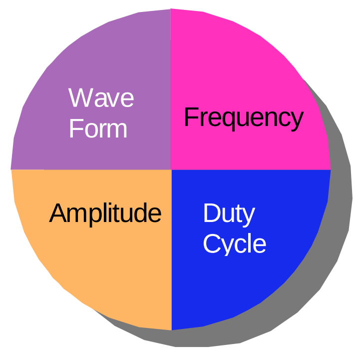
Yet another control variable is the pulse wave form itself. See Fig. E, for various pulse plating wave forms including some of the more common currently used in plating.

Fig. E



Clearly there are numerous parameters and methods of application of pulse plating resulting from the number of variables non-DC signals introduce. Many applications of Pulse plating have been unsuccessful because the lack of setting up the appropriate wave form; duty cycle, frequency and amplitude. It is the appropriate combination of these variables, shown in Fig. F, which allow the system to achieve the desired result and results which may not be able to be accomplished with simple DC. Benefits often times include improved process capability, reduce cost and ability to achieve specific characteristics (e.g. flatter deposit) or apply to complex geometry's (e.g. high aspect ratio micro-vias) which could not previously be plated.

Fig. F



3. PULSE PLATING POWER SUPPLY OVERVIEW

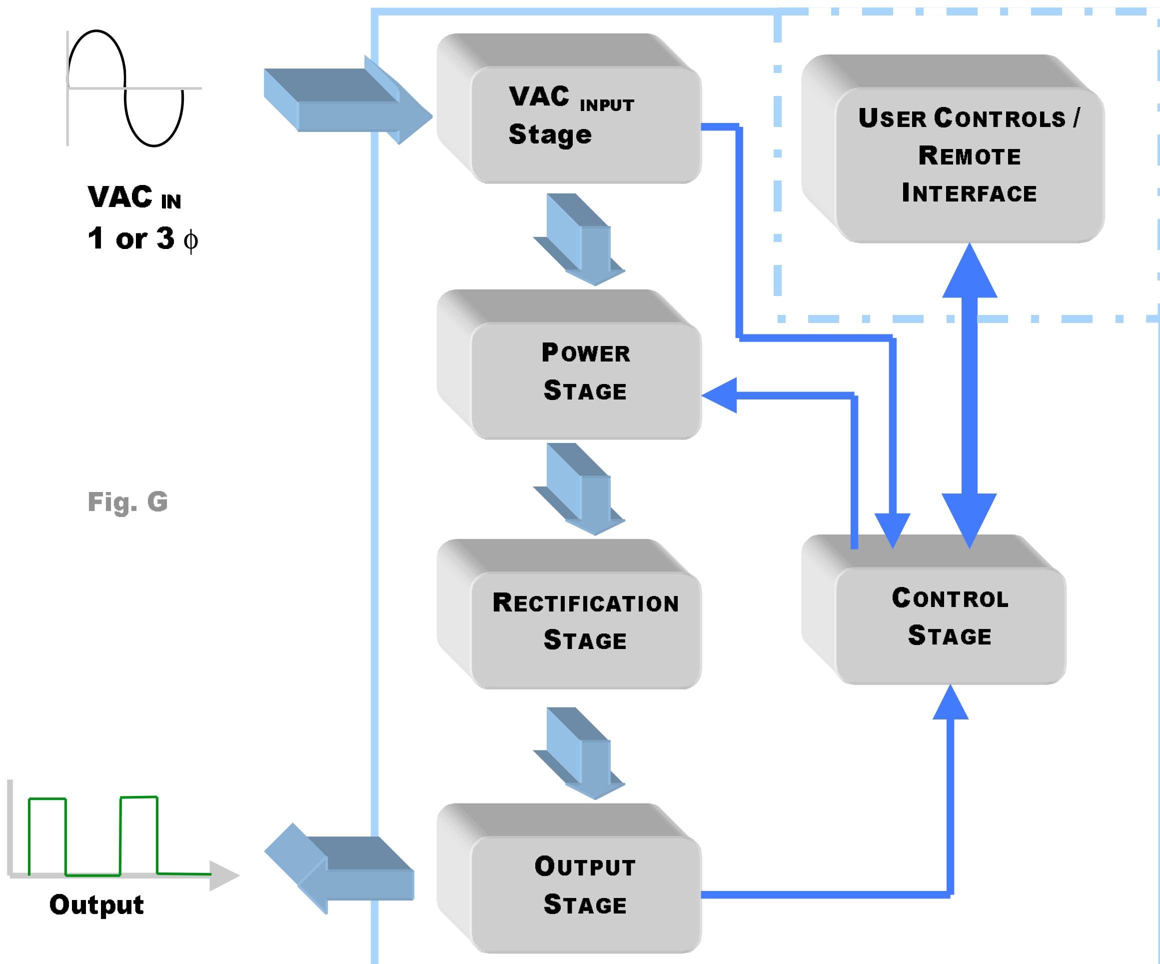


Fig. G

Fig. G provides a general flow chart for a pulse power supply. Significant advances have been made to performance and functionality of pulsed power supplies over the past 10 years.

3.1. POWER CONVERSION TECHNOLOGIES

Multiple power conversion technologies exist to convert AC input to Pulse, Pulse Reverse or Pulse Wave Sequencing output.

Technology	Pulsing Performance	Power Capability	Transition times	Unit Size & weight
SCR	Poor	Very High	Slow	Large
Linear	Good	Low	Fast	Large
Switch-mode / Phase-mode	Good	High	Medium / Fast	Small
Combination Switch-mode & Linear	Good	Medium	Fast	Small

- In general, SCR technology lacks the speed performance to generate very crisp pulse signals.
- In general Linear power supplies perform very well but are very large and limited in power.
- Switch-mode units are smaller in size and weight, have good performance and can handle higher power. These units typically are a bit slower in transition times then linear technology.
- Combination of Switch-mode and linear over come the power and transition limitations of each technology and provide the optimal performance over a wide operating range from maximum output to very low signal levels.

3.2. INPUT VOLTAGE

Electro-plating power supplies are available in a wide variety of AC line voltage configurations, including one and three phase. Power requirements are usually governed by availability in the plant, however where possible 3 phase input power should be supplied to large power devices such as electro-plating power supplies.

3.3. LINE AND LOAD REGULATION

Line regulation describes the tendency of a power supply to maintain the output constant independent of changes to the AC line voltage. This is a very desirable feature for a plating power supply. The lack of line regulation would generate a distorted output signal as AC line voltage fluctuates, adversely affecting the plating process. Today's new technologies have improved line regulation.

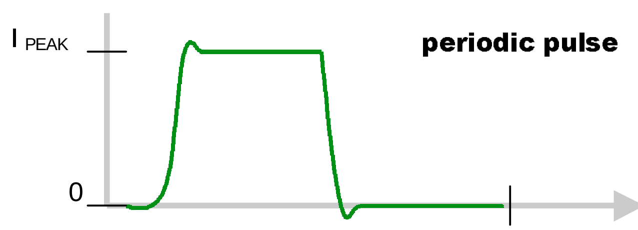
Load regulation describes the tendency of a power supply to maintain the output constant independent of changes to the load. This is a very desirable feature for a plating power supply. The lack of load regulation would generate a distorted output signal as the load varied resulting from the on going plating process. Today's new technologies have improved load regulation.

3.4. AVERAGE, PEAK AND RMS SIGNAL LEVELS

The concept of average and peak signal amplitude is basic to the plating properties and rate of deposit.

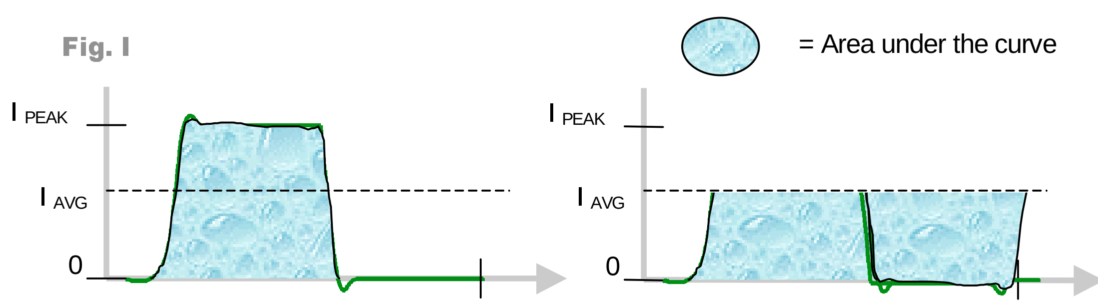
The peak signal amplitude for Fig. H is equal to the amplitude of the signal during the period the pulse is present. Note that a pulse reverse wave form will have a positive peak amplitude and a negative peak amplitude.

Fig. H



The average signal level for Fig. H can be visualized with the help of Fig. I. The area under the pulse wave form is averaged for the pulse period.

Fig. I



We can think of the average current as the amount of working current which is applied. In the case of DC the average and the DC amplitude are equal. The average current can be calculated by the following formula.

$I\_{AVG} = \{ABS[(I1\_{PEAK})\ (I1\_{DTCY})] + ABS[(I2\_{PEAK})(I2_{DTCY})\} + ABS[(I3\_{PEAK})(I3_{DTCY})] + \ldots\}$

- I_{AVG} = Average signal amplitude
- ABS = Absolute value
- $I\underline{X}\_{PEAK}$ = Peak signal amplitude for Peak X
- $I\underline{X}\_{DTCY}$ = Duty cycle for Peak X.

For Fig. H above the Average = $I1_{PEAK}(I1_{DUTYCYCLE})$ as there is only one peak during the period.

RMS or Root Mean Square Amperes is also important as shown below in the example. The A_rms falls between the A_pk and A_dc. The general formulas for any time varying wave forms f(t) are :

$$A\_dc := \left(\frac{1}{T}\right) \cdot \int_0^T f(t)\,dt$$

$$A\_rms := \sqrt{\left(\frac{1}{T}\right) \cdot \int_0^T f(t)^2\,dt}$$

For the case of the unipolar pulse, the formulas may be applied as:

$$A\_dc := A\_pk \cdot D$$

$$A\_rms := A\_pk \cdot \sqrt{D}$$

Example: for wave form of 1000 A_pk and 50% Duty cycle D.

We have A_pk=1000, A_dc=500, and A_rms=707

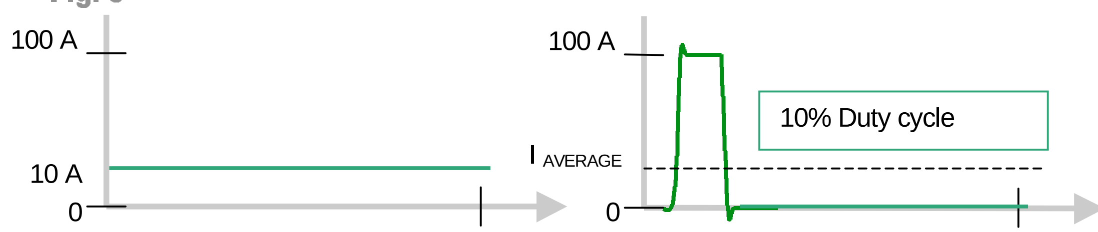
It is the RMS value and not the peak or average (dc) which governs the power rating of shunts and cables. For the previous example a 707 Amp shunt would be required although the average current is only 500 ADC.

New technology power supplies are able to achieve higher peak to average ratios. These same technologies can also be optimized to best perform at a certain average to peak ratio.

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 Fig. J.

If a given plating system requires 2 volts DC at 10 amps, then substitution of a 10% duty cycle pulse wave would require 20 volts DC at 100 Amps peak to maintain the same 10 Amps average plating rate. Although it is a mathematical interpretation, these voltage levels may not be acceptable in the plating system. Also remember that the RMS current increases for these types of pulse wave forms requiring more robust cabling.

Fig. J



3.5. VOLTAGE VS. CURRENT REGULATION

A current regulating power supply (commonly referred to as current mode) regulates the pulse amplitude in terms of the output current. For Fig. H, I_{PEAK} is defined in terms of amperes. The output voltage is determined by the output current and the resistance or impedance of the plating system, up to the limiting capability of the power supply.

A voltage regulation power supply (commonly referred to as voltage mode) regulates the pulse amplitude in terms of the output voltage. For Fig. H, I_{PEAK} is defined in terms of voltage. The output current is determined by the output voltage and the resistance or impedance of the plating system, up to the limiting capability of the power supply.

3.6. OPERATING RANGE

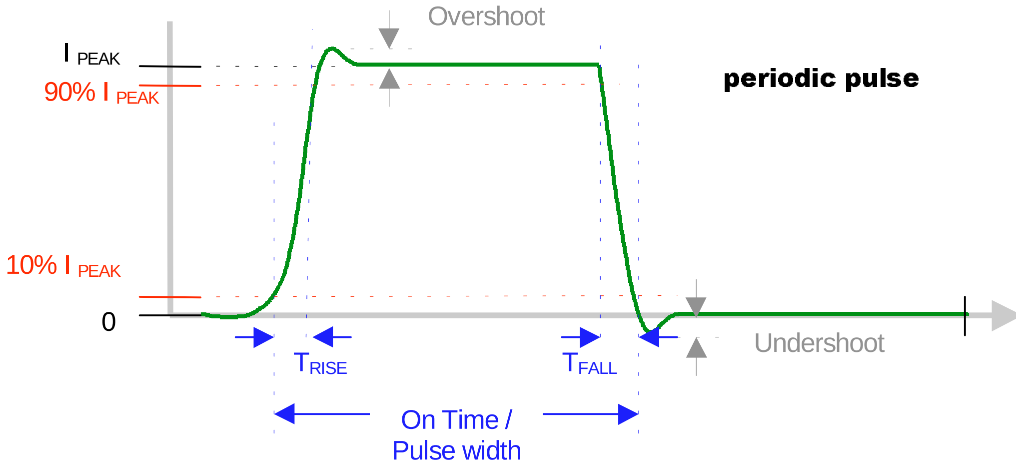
A traditional difficulty of the job shop is the need for a wide operating range power supply, due to the variety of cathodic parts from one job to the next. Traditional SCR units operate within rated parameters between 20% - 90% of the maximum rated output.

Operating range is especially critical in pulse power supplies because of the complexity of the power supply output. Technology has greatly improved the operating range of the plating power supply. Today's power supply can operate reliably between 5% -100%. Certain companies are able to producing power supplies that operate below 2-3% of maximum output through 100%.

3.7. TRANSITION TIMES

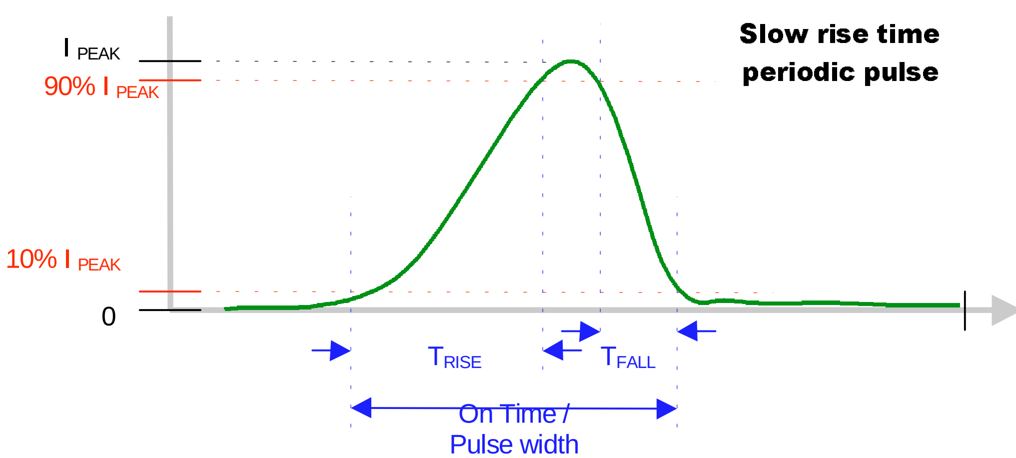
See Fig. K for a visual definition of the transition times in a periodic pulse wave form. The rise time (T_{RISE}) is typically defined as the time for the signal to move from 10% to 90% of the peak signal amplitude. The fall time (T_{FALL}), overshoot and undershoot are also demonstrated in Fig. K.

Fig. K

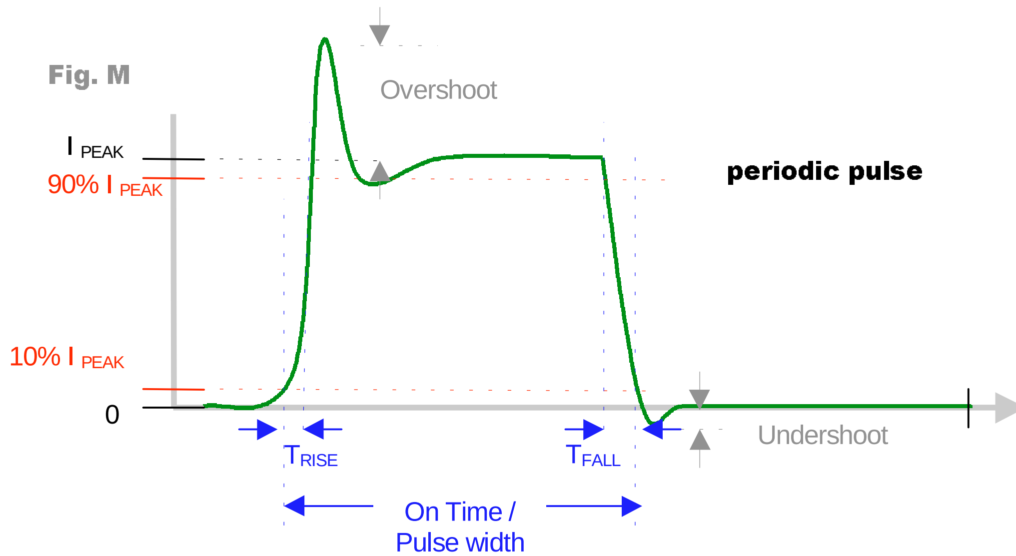


Significant improvements have been made in rise time capabilities of the wave forms. Rise and fall times are critical because they can significantly distort the wave shape. Figure L demonstrates this distortion for a periodic pulse wave form where the rise time approaches the pulse width. Numerous detrimental effects result from this distortion, including slower plating. Less energy is present so that more time is required to perform the same work.

Fig. L



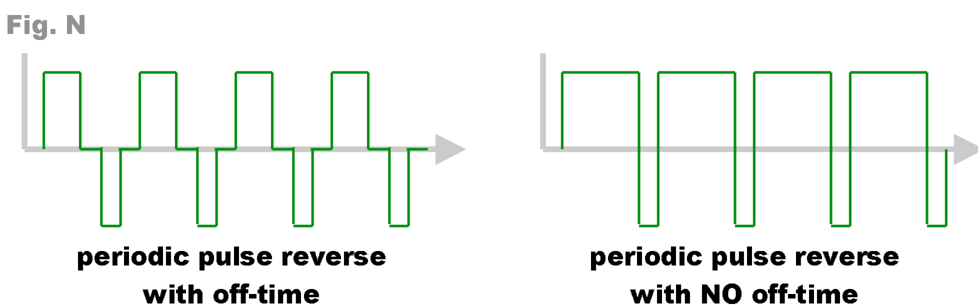
Care must be taken by the power supply manufacturer not to achieve fast rise times at the cost of excessive overshoots, as this could be damaging to the plating bath. See Fig M.



Typical rise times for pulse power supplies are in the range of 10 - 50 micro-second. This enables pulses on the order of 100 microseconds. Power supply manufactures are working to provide faster rise times on the order of 1 – 10 micro-seconds in order to reduce pulse width and increase frequency, for certain applications.

3.8. ZERO LEVEL TRANSITIONS

Pulse reverse wave forms can be divided into two categories regarding zero level transitions, as demonstrated in Fig N.



The correct choice of plating power supply, will depend on the chemistry, process and application. In general however, periodic pulse reverse with no off-time is preferred for two reasons:

- Off-time equates to no transfer of power and minimal work being done. In certain situations, off time after reverse may damage the plating bath. Plating power supplies which require a pause when switching between positive and negative cycle, potentially plate at a slower rate due to these same time delays. For narrow pulse widths this delay can be significant.7

- In certain applications which require adhesive lamination to selectively plate, the off-time contributes to delamitation.

Certain older technologies have difficulty in generating periodic pulse reverse wave forms with no off-time.

3.9. CONTROL INTERFACE AND USER ERGONOMICS

Traditional plating power supplies have had very simple controls. Enabled by the limited number of adjustments required on a DC unit (voltage & current), these have the advantage of simple user operation. As pulsing power supplies have a greater number of adjustments (Forward-time, Reverse-time, Forward-Amplitude, Reverse-amplitude, as a minimum), the user interface or control panel becomes a more critical to achieve simple error free operation.

Traditional mechanical thumb-wheel adjustments have been replaced by modern digital controls and digital displays reducing errors, improving set-up time and readability.

Advancements to simplify power supply operation for the user involve the integration of microprocessor electronics in to the unit. A more intelligent operator interface enables a series of ergonomic benefits including:

- Menu-driven digital displays
- Job libraries to store and recall preprogrammed wave forms
- Digital signal interfaces

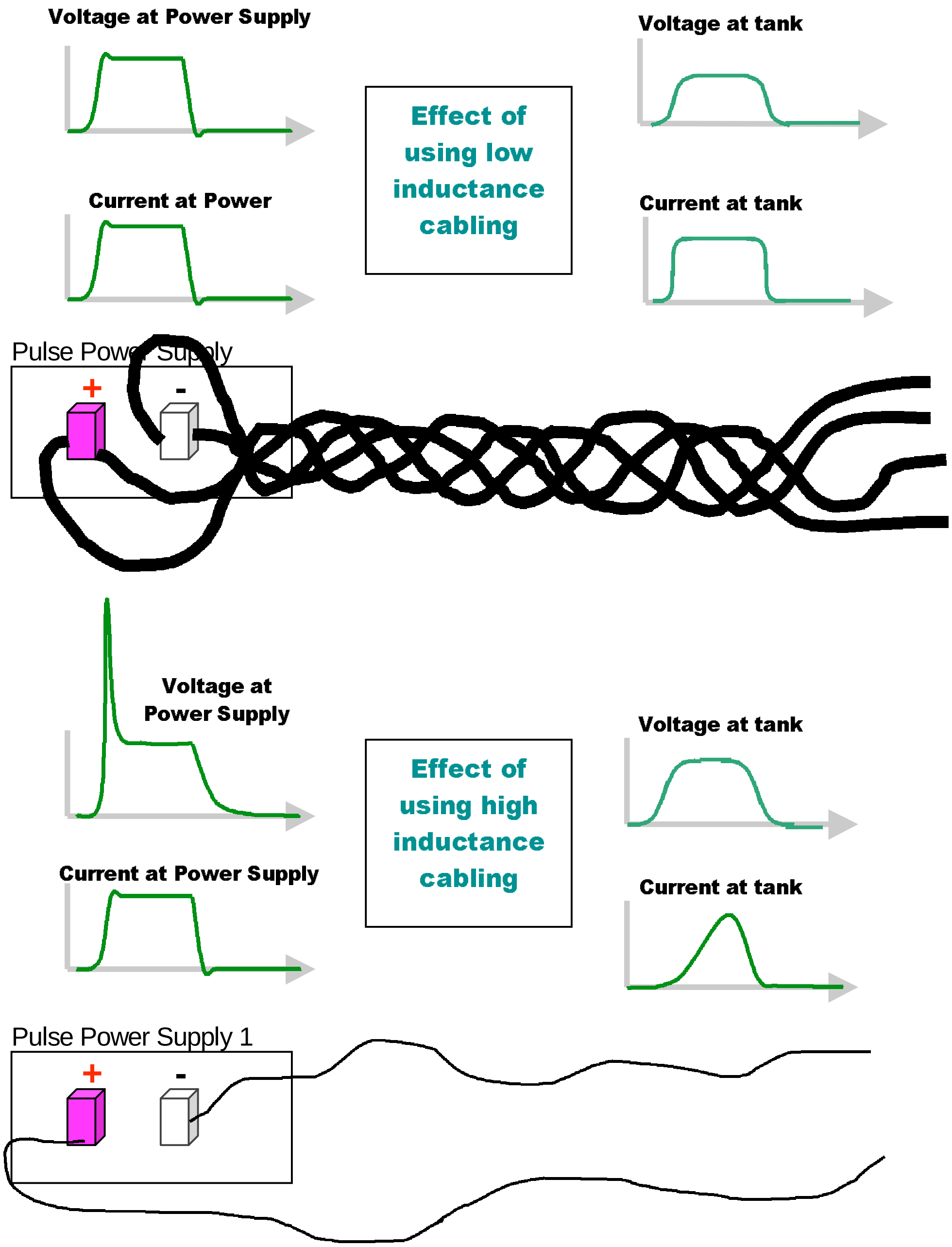
These are discussed in detail in Section 4 of this paper.

3.10. CABLE INDUCTANCE

Inductance can be though of as the magnetic resistance to the change in current in a conductor. Pulse wave forms by definition continually change current level with each pulse transition. Inductance therefore degrades pulse performance and is a critical factor in non-DC plating. Inductance degrades pulse performance by decreasing rise and fall times much as described in Section 3.7 Fig. L.

Plating power supply rise and fall times are typically rated at the output of the power supply and can be substantially different to that seen in the plating bath if no care is taken to reduce inductance. Fig. O demonstrates the output of a power supply and the effect high inductance cabling has on the current flowing in a plating bath.

Fig. 0



In general the following guidelines should be followed to reduce inductance.

- Place the power supply as close to the tank as possible to reduce the cable or bus bar length.
- Use large diameter cables or large flat bus bars to increase surface area.

- Keep the distance between the conductors as short as possible. This is more feasible by using cables with thin insulation and twisting them together over the length of the run from the power supply to the tank (twisted pair). For bus bars run them in parallel with minimal separation, as required for safe operation.
- Additional gains can be achieved by running multiple twisted pair cables dividing the current between them.

3.11. SIZE AND WEIGHT

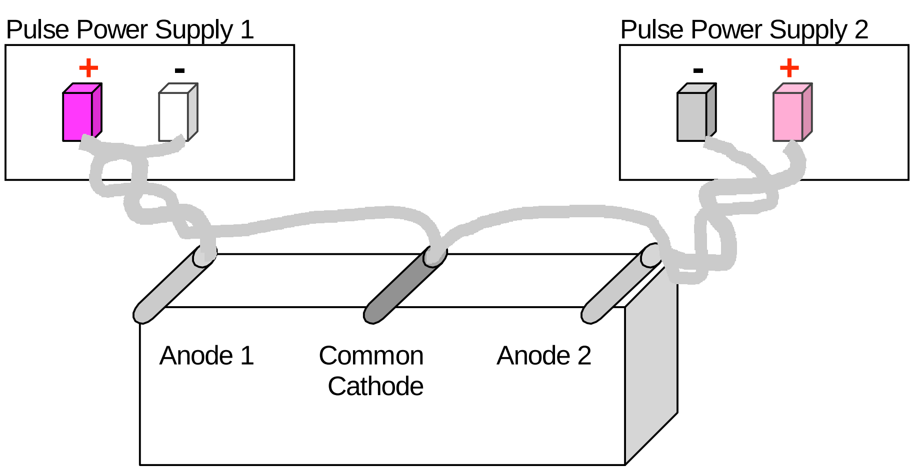
Newer technology plating power supplies offer significant reduction in both the size and weight as compared to SCR or linear units. Higher frequency electronics result in a reduction in the size and weight of the power stage and related circuitry. As a result several advantages are realized:

- Smaller units are able to be placed near the plating tank, reducing inductance as stated in Section 3.10. The cost of low inductance cabling can in some cases exceed the cost of the power supply if the unit is not able to be placed near the tank.
- Smaller units required less floor space saving valuable production floor space.
- Smaller weight units enable cost savings related to shipping freight.
- Lower weight units enable cost savings related to shipping freight.
- Lower weight units enable flexibility to move them from one location to another with out the requirement of a fork lift for the purpose of routine maintenance, calibration, line changes and process modifications.

3.12. MULTI-OUTPUT PULSE WAVE SYNCHRONIZATION

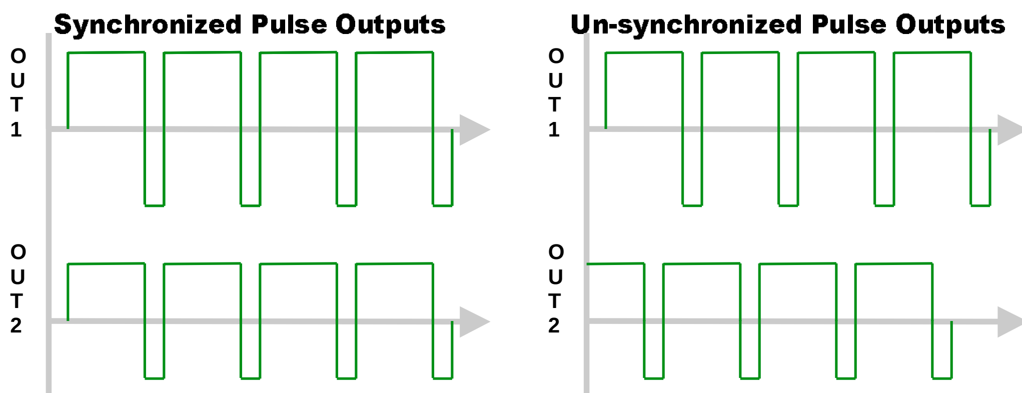
For certain applications such as two sided printed wiring boards, a power supply with two outputs or two power supplies may be required. Unlike DC power supplies non-DC power supplies should be synchronized in time to minimize interaction between then.

Fig. P



To help us visualize this, see Fig. P. The outputs of power supply 1 and power supply 2 may be synchronized or un-synchronized as shown in Fig. Q. Synchronized outputs means that they share the same frequency and duty cycle and their pulse transitions occur simultaneously. Un-synchronized means that the pulse transitions do not occur simultaneously. Note that the amplitudes of the various synchronized wave forms need not be the same. The problem with un-synchronized pulse outputs is that one power supply may have a positive polarity while the other has a negative causing the current to flow out of one power supply and into the other, adversely affecting the plating bath. This is analogous to having a second cathode and sharing the current between both. If both power supplies are synchronized (simultaneously positive and negative in polarity) their interaction will be minimized.

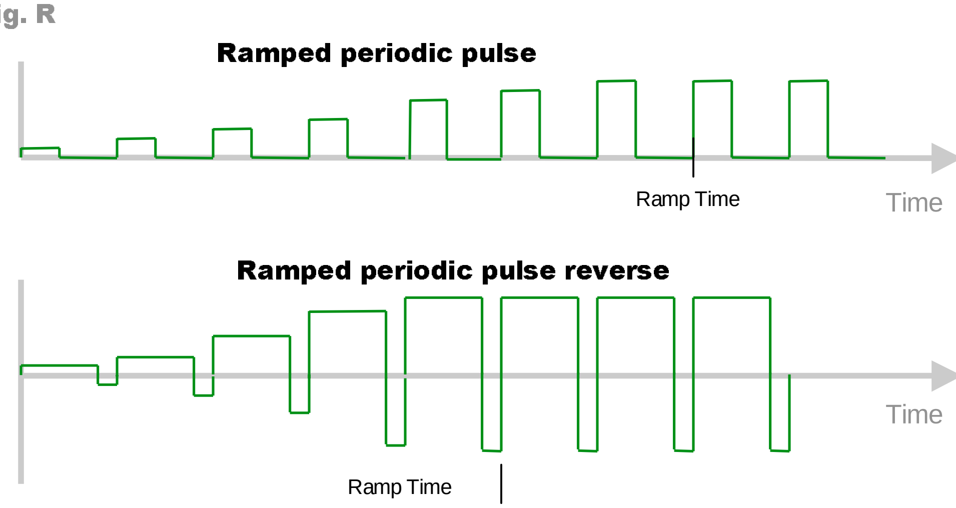
Fig. Q



3.13. RAMPED START

Ramped start periodic pulse and pulse reverse wave forms are demonstrated in Fig. R. This ability may be useful in plating very thin films or in situations where material build-up is required prior to increasing current density.

Fig. R



3.14. RELIABILITY AND ENVIRONMENTAL CONSTRUCTION

Power supply construction is critical to new technology power supplies. The primary reason is that industry standard components, printed circuit boards and assemblies are very susceptible to the corrosive environments found in most plating shops. This is especially true when companies take power supplies developed for the communications or medical industries and attempt to operate them in a plating environment. Unreliable power supplies mean production down time and loss of revenue.

The initial effort to compensate for the susceptibility to the corrosive environment, was to place the power supplies susceptible to the environment in sealed air conditioned environmental rack enclosures. This has several serious limitations;

- The racks force the power supplies to be distanced from the tanks increasing cable inductance.
- The racks are very expensive.
- The racks are large and take requiring additional floor space
- The seal is broken each time the enclosure door is opened to make adjustments and or routine maintenance.

New technology plating power supplies are now available in self contained environmentally sealed enclosures. This enables the standard lower cost circuitry to function reliably in the plating environment. Additionally the units are able to be placed near the tank to reduce inductance and ease operation for the user who can operate the unit while standing next to plating tank.

3.15. PRICING

As a result of advances in components and techniques in communications, medical and other related power conversion markets, today's new technology plating power supplies are priced very competitive and in many cases below older technology pulse power supplies. Prices do however vary widely from one vendor to the next.

4. MICROPROCESSOR INTEGRATION

The proper integration of microprocessor circuitry into a pulse plating power supply can simplify user operation, increase functionality, reduce errors and improve process efficiency and system integration.

An analogy would be the use of microprocessor circuitry in hand-held video camera operation. The complex and numerous controls have been replace by soft key, menu driven controls and new features, such as titles, have been added with out overwhelming the user. Similarly pulse power supplies with multiple adjustments can significantly benefit from the improved user ergonomics, microprocessor circuitry enables.

4.1. MENU DRIVEN DISPLAYS

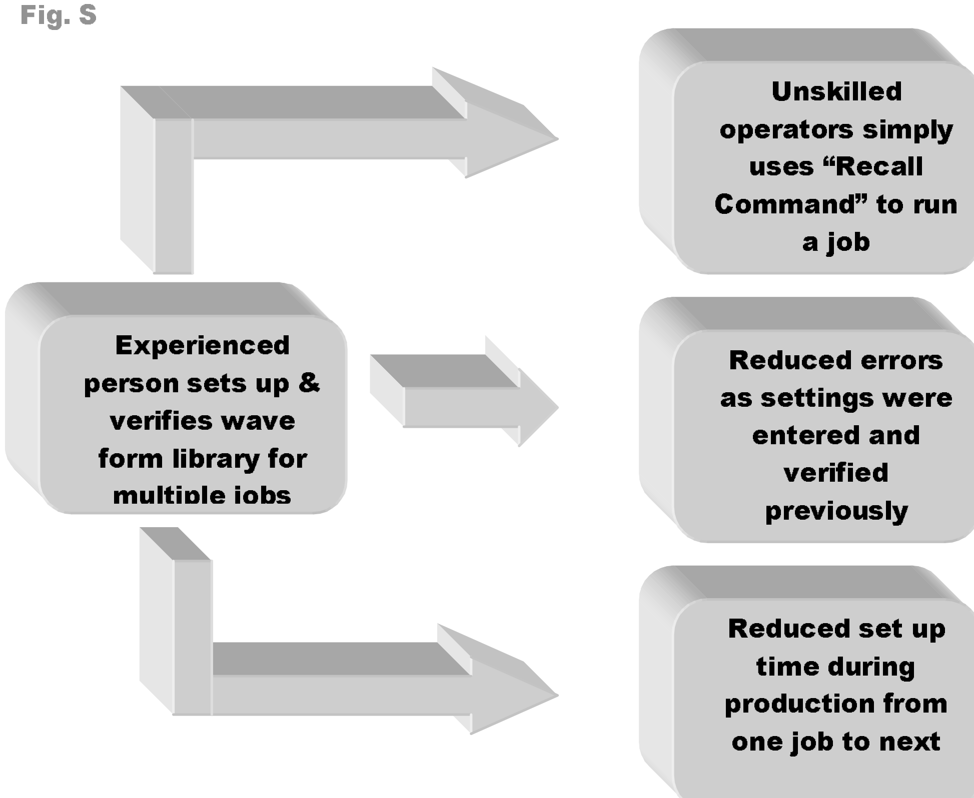
Menu driven display is a term to describe the use of multiple menus in a control panel where each menu isolates and simplifies the inputs associated with a task. A common example is a VCR which is programmed by following the screens it displays on a television monitor, enabling both parent and children to program the clock on the VCR. Similarly new technology plating power supplies can isolate and display the adjustments associated with setting up a wave form while hiding other non-related operations such as calibration or communications, allowing the user simple error free operation.

4.2. PROGRAMMABILITY AND MEMORY

Along with the integration of microprocessor circuitry, new technology power supplies incorporate non-volatile memory in order to store vital information associated with power supply operation, communication, job recipes, wave form libraries and / or a number of other process and performance related benefits.

Fig. S demonstrates a simple example of how memory and programmability benefit plating shops to reduce errors, improve quality and increase efficiency, using more complex pulse plating units.

Fig. S



4.3. NEW FEATURES AND FUNCTION

New technology power supplies which incorporate microprocessor circuitry, have numerous process and quality functions over older technology units or newer technology units which do not have an internal microprocessor.

An internal microprocessor enables the software flexibility to create custom internal instrumentation. An example could be an internal amp-hour meter for a pulse reverse power supply where the
Total A•H = {[Positive cycle A•H]-K*[Negative cycle A•H]} where K is a multiplier.
This enables is the power supply to recognize that deposition and removal of metal from the cathodic surface does not necessarily occur at the same rate. In the case where the rate of deposition and removal are equal K may be set to 1.

Further examples of the function and benefit of internal microprocessor circuitry are listed in Fig. T.

Fig. T

JOB LIBRARY

Description: The ability to enter and recall wave forms and/or plating sequences <or> recipes.
Benefit: Simplicity of operation, reduced errors, reduced operator skills, reduced set up time, increased throughput.

INTERNAL INSTRUMENTATION

Description: Integration of special meters, meters or other functionality accessed via the control panel of the unit.
Benefit: Improve productivity and system modeling by enhancing the operation of the unit to the application.

INTERNAL DIGITAL CALIBRATION

Description: The ability to calibrate the critical parameters of the unit through the use of the front panel.
Benefit: Compliance with ISO 9000, government standards or other quality policies.

DIGITAL SIGNAL INTERFACE

Description: Remote operation of the Pulse plating power supply and all it's parameters using a PC or PLC.
Benefit: Increased productivity through automation.
Compliance with ISO 9000, and quality policies.

5. AUTOMATION AND REMOTE OPERATION

Production facilities, driven by rising labor rates, a decreased labor pool, increasing competition and increased quality requirements by customers, are continually forced to find process and cost improvements.

The proper implementation of digital remote operation enables decreased process cost and increased process efficiency. Process parameters or "recipes" can be stored in a central controller and downloaded to each production location, critical factors such as chemistry, temperature, amp-hours, power supply status and system alarms can be monitored for quality control and to avoid time and material loss due to manufacturing or process error. Quality logs can also be made available for customers tracking each production lot.

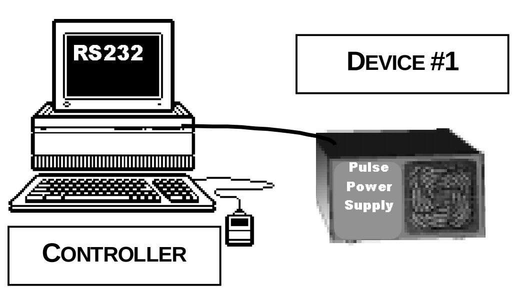
5.1. STANDARD INTERFACES

There are many versions of remote control interfaces available for power supplies including a great number of custom interfaces. We shall limit our discussion to the three most common and cost effective.

Analog 4-20mA
This interface varies a current loop signal in a range between 4 mA to 20mA. A typical implementation would be to set 4mA = O amps and 20mA = maximum output amps. In this manner control is achieved by varying the current loop signal to achieve the desired output. A second signal may be used to read the set point.

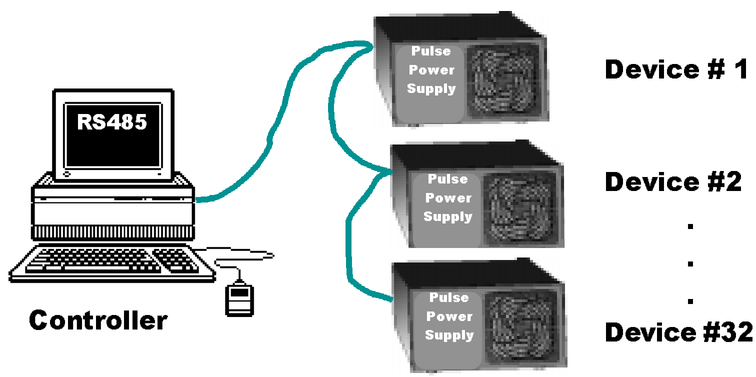
Digital RS232
This interface common to PC's is a digital serial communication port. The commands are encoded into digital format and sent across the interface to control the desired device. As the commands are digital words equivalent to "set Voltage" or "read amp-hour count", many commands may be sent sequentially over this interface. The communication is bi-directional so that the device responds to the controller. The interface is typically 3,4 or 5 wires similar to telephone data cable. RS232 is designed to be a point-to-point interface, allowing communication between 2 devices as shown in Fig. U.

Fig. U



Digital RS485
This interface common to PC's or PLC's is also a digital serial communication port. The commands are encoded into digital format and sent across the interface to control the desired device. As the commands are digital words equivalent to "set Voltage" or "read amp-hour count", many commands may be sent sequentially over this interface. The communication is bi-directional so that the device responds to the controller. The interface is typically 3,4 or 5 wires similar to telephone data cable. RS485 is designed to be a point-to-multi-point interface, allowing communication between a controller and 1 or more devices as shown in Fig. V. Typically 32 devices can communicate to a single controller using a simple daisy chain connection method. Each device must have a unique bus address and all the devices must be programmed to the same baud rate.

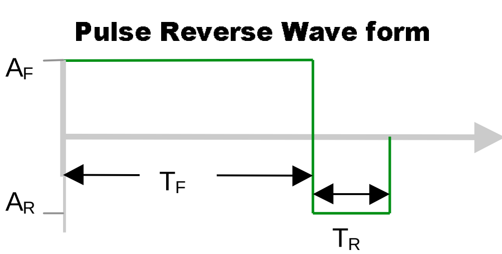
Fig. V



5.2. ANALOG VS. DIGITAL SIGNAL INTERFACES

The standard control interface in the plating industry has for years been an analog 4-20mA signal. This provides very good control and low noise susceptibility for a single control variable. This analog control signal can not however meet the needs of more complex non-DC signals, as shown in Fig. W.

Fig. W



Icon	Description
A_F	Forward Peak Amplitude
T_F	Forward Pulse Time
A_R	Reverse Peak Amplitude
T_R	Forward Pulse Time

In the case of Fig. W often times a single analog interface is used to scale the wave form peak amplitude, all other variables are inputted manually limiting the very attempt being made at process automation.

To control the variables in Fig. W for 10 power supplies with an analog 4-20 mA interface the following is required: one interface card to set/read each of the 4 variables per power supply and a matching card in the PLC. This is a total of 80 PLC card to control these 4 variables for 10 pulse reverse plating power supplies.

To control the variables in Fig. W for 10 power supplies with a digital RS485 interface the following is required: one interface card to set/read all 4 variables per power supply and one card in the PLC. This is a total of 11 PLC card to control these 4 variables for 10 pulse reverse plating power supplies. In addition to control of the 4 variables a digital interface enables complete access to the unit; set/read amp-hour meter, read/reset alarm conditions , download wave form and job libraries and all other functions which can be performed from the front control panel of the unit, at no additional cost.

A digital interface is therefore the correct choice for a remote interface to the more complex non-DC power supplies. Additionally with the advancement of computer technology digital RS485 interface cards are less expensive then their 4-20mA counterparts, combining this with the fact that less cards are required, digital interfaces represent an significant increase in control for a fraction of the cost.

5.3. PC & PLC

PC refers to the commonly available personal computer or laptop. PLC refers to Industrial computer used for control of industrial equipment.

The basic difference is reliability, programmability and cost. PLC is designed for an industrial environment and is therefore more reliable and robust. PC's being designed for the consumer market are more flexible, common programming languages and lower in cost. Digital and analog interface cards are commonly available for both devices and there are numerous vendors for each system.

6. PULSE WAVE SEQUENCING

Pulse wave sequencing power supplies are very new, covered by intellectual property, they deviate from traditional pulse power supplies in two key aspects.

- They output non-periodic wave forms by sequentially combining periodic pulse signals

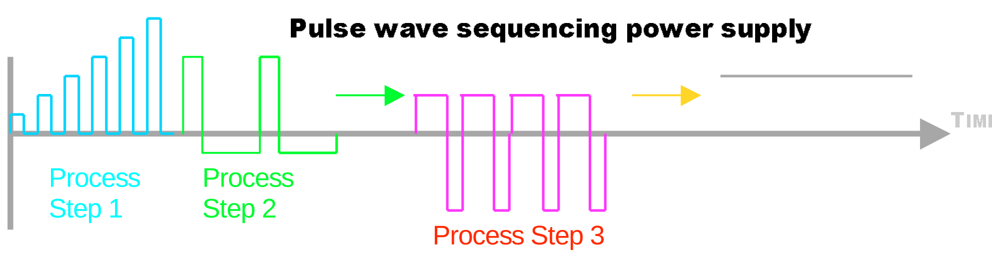
- They significantly increase process automation.

Pulse wave sequencing power supplies reduce capitol equipment cost, reduce process time, increase production throughput and reduce process errors by automatically executing a complex process preprogrammed into it's job library.

Typical applications include plating of cathodic surfaces with complex geometry's, plating of materials sensitive to the chemistry, selective plating and increased automation of the plating process.

See an example in Fig. X, of a 4 step sequential plating process for a part with multiple geometry's on a single cathodic surface.

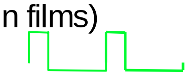
Fig. X



PROCESS STEP 1 Ramped Periodic Pulse

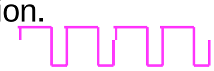
Purpose: To build up the surface gradually in order to avoid burning (applicable to plating on thin films)

PROCESS STEP 2 Periodic Pulse Reverse



Purpose: To plate micro-profile surfaces such as blind vias on PWB's. This wave form sequence is designed to fill the smaller complex geometry's requiring less material first, to avoid interaction.

PROCESS STEP 3 Periodic Pulse Reverse



Purpose: To plate macro-profile surfaces such as larger plated through holes on PWB's.

PROCESS STEP 4 DC

Purpose: This process step is not required but when applied remove the matte finish typically associated with pulse wave forms.

Note that any combination of wave forms in any order can be used making the Pulse wave sequencing power supply a very powerful and flexible tool.

Wave sequencing power supplies also save on capitol equipment by reducing the number of tanks, chemistry and power supplies associated with moving the material from one tank to another.

7. CONCLUDING REMARKS

Pulse, Pulse Reverse and Pulsed wave sequencing signals enable plating deposit properties which cannot be attained by conventional DC.

Although there are considerable rewards and advantages to applying non-DC wave forms to electro-chemical process, considerable care should be taken to select the proper Pulse Plating Power Supply and to dedicate the effort required to optimize and integrate the unit into the production process.

If you are facing challenges in the deposit characteristics, part geometry or process cost & throughput, pulse plating, through its recent advances, may enable significant benefits for process, application and bottom line.

REFERENCES

JEAN-CLAUDE PUIPPE & FRANK LEAMAN;THEORY AND PRACTICE OF PULSE PLATING, AMERICAN ELETROPLATERS AND SURFACE FINISHERS SOCIETY, 1986

ABOUT THE AUTHOR

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Enrique Gutiérrez is currently President of TecNu, Inc., a position he assumed in 1991. He serves as a member on the AESF Pulsed Electrodeposition Processes Committee.

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Prior to assuming his present position, Gutiérrez was a member of Motorola's Cellular Subscriber Division and 2-Way Radio Products Group, where he help positions responsible for business development, marketing, product development, development engineering and post sales support in various international markets. While at cellular he received several awards including Performance Recognition Awards and The CEO Award for Volunteerism. Prior to Motorola, Gutiérrez held several positions in advanced product design and development.

He is a graduate of Illinois Institute of Technology where he received a Bachelor of Science in Electrical Engineering.

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