PULSE PLATING

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Conventional pulse plating can simply be defined as metal deposition by pulsed electrolysis. Explanation in the simplest form is using interrupted D.C. current to electroplate parts. This is accomplished with a series of pulses of D.C.current, of equal amplitude and duration in the same direction, separated by periods of zero current. The pulse rate (frequency) and ON and OFF times (duty cycle) are controllable to meet the needs of a given application. T he shape of the pulsed current is generally thought of as shown in Figure 1A. An oscilloscope should be used to reveal how well the equipment controls the output. (See Figure 1B)

This method of plating has gained acceptance in a number of metal finishing industries, especially the electronics industry. With the advent of solid state pulse plating power supplies, the art has been taken out of the process. The amount of time the current is off and the amount of time the current is on are set directly on the digital thumbwheel switches or on units with the software, programmed directly prior. There are two different modes of operation possible; constant current or constant voltage pulses. Figure 2 illustrates the constant current mode of operation. The tops of the current pulses are kept flat by allowing the voltage to vary during the pulses ON time. The situation is different in the constant voltage mode illustrated in Figure 3. The tops of the voltage pulses are kept flat by varying the current.

Because of the shape of the current pulse in this mode, the peak current is not useful to control the plating rate. An ampere-minute controller is needed to accurately control the plating thickness.

The advantages of pulse plating vary from one user to another. However, the most common are:

1. Pulsing the current produces dense fine-grained deposits and in some cases such as gold plating, less gold is needed to meet an end-use specification.

2. The variation in thickness from one part to the next is reduced considerably.

3. Plating speeds can normally be increased. The current efficiency in most instances is better than conventional D.C. plating.

4. The need for organic additives in most cases is reduced by 50 to 60%.

5. The properties from the pulsed coating is summarized as follows:

   a. The coating is free from dendritic growth even if devoid of additives.

   b. The coating has fine crystalline structures.

   c. The coating is smooth.

   d. The coating is nearly free of pinholes.

   e. The current efficiency, in most instances, is better than D.C. plating.

The disadvantages, although minimal, are:

1. In most cases the costs of a pulse rectifier are much greater than a D.C. unit. It is a highly regulated and sophisticated design that costs more to manufacture.

2. The technology requires one to think and plan ahead with a series of various procedures to follow to obtain the best results

3. For the chemical manufacturer., the requirement for additives is reduced.

4. To take best advantage of the pulse capabilities, one must optimize the mechanics of the plating equipment design before applying the pulse unit. Areas of use for the pulse rectifiers are:

   a. Reel to reel plating for speeds, distribution, and reasons mentioned prior.

   b. Rack plating for the prior statements.

   c. Gold (both pure and alloy), nickel, silver, copper, chrome, tin/lead, palladium and anodizing are all areas of use.

   d. In some select cases pulse is being used in etching, cleaning, and electroforming.

The theory behind pulse plating is simple. The cathode film is kept as rich in metal ions as possible and as low in impurities as possible. During the period when the current is ON, the metal ions next to the cathode are depleted and a layer which is rich in water molecules is left.

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During the portion of the cycle when the current is OFF, the metal ions from the bulk of the plating solution diffuse into the layer next to the cathode. Then the process is repeated again. Also during the time the current is OFF, gas bubbles, and impurities which have been adsorbed on the cathode have a chance to desorb.

Typical ON times are from 0.1 to 9.9 milliseconds and typical OFF times from 1 to 99 milliseconds. If an ammeter is inserted into a plating circuit which uses pulsed current it would respond to the average current. In order to have the same plating rate using pulsed current as with D.C., the average current must be the same. Either the peak current, ON time or OFF time can be adjusted. By carefully picking the plating parameters the physical and chemical properties of the deposit can be very precisely controlled.

One of the most dramatic advances in modern electroplating has been the recent use of microprocessor-controlled modulation of applied direct current to improve the electrodeposition process. The method has found application across a broad spectrum of the industry for both precious and non-precious metal plating. It is being used in reel-to-reel selective plating, in automatic tab platers, on barrel lines, in still plating, electroforming, anodizing, electrocleaning, electro-polishing and machining and, most recently, has been adapted by the semiconductor bump and wafer plating technologies.

Results obtained with this sophisticated power control include (in addition to greatly increased plating speeds) improved distribution, lower deposit stress, finer grain structure, increased ductility, improved adhesion, increased micro-throwing power, reduced hydrogen embrittlement, and a markedly decreased need for additives.

A careful selection of a select few marketed series of modulated D.C.power supplies embodies the most advanced electronic circuitry to control output patterns with extreme precision.

Simply speaking, a high quality unit will superimpose periodic reverse on high frequency pulse. The power pattern that results, however, is quite complex with a wide range of profiles. The output, a series of pulses with controllable amplitude, frequency, duration and polarity, has an influence on the deposition characteristics of any solution which is far different from that of conventional pulse or periodic reverse. By "tuning" or shaping the output power pattern to a given plating application, the rate of deposition and the character of the deposit can be enhanced dramatically.

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In periodic reverse plating, the polarity of a constant D.C.output is switched back and forth in a regular pattern. Figure 4A depicts the ideal output; Figure 4B shows the actual output from a slow-response control unit.

The sharpness of the output current pattern as revealed by a scope depends upon the degree of ripple in the rectifier output and the quickness of response in the internal switching circuitry of the controller. Quality units produce extremely sharp square wave patterns when seen on a scope as shown in Figures 3 and 4.

Figure 5 illustrates the wave form of the Forward (cathodic) and Reverse (anodic) output of a quality unit.

The duration of the current in each direction, called the Forward and Reverse envelopes, can be individually controlled from 0.1 millisecond to 99.99 seconds. (The zero current delay of less than 0.1 millisecond indicated in the diagram between Forward and Reverse is a design feature of high quality units to prevent transistor failure due to "shoot through".)

The simple, square-wave in Figure 3 is a precisely controlled periodic reverse output upon which pulse frequencies are then superimposed. Within each envelope a square-wave pulse is generated as depicted in Figure 6. The frequency and the duration of the pulses are set independently for the forward and reverse envelopes. Frequency range is from 10 to 9,999 Hertz. Duty cycle settings in percentages determine ON and OFF for each pulse.

On some quality models, forward and reverse amplitude can be controlled individually as illustrated in Figure 7. This permits, for example, a higher current density in the reverse (deplating) stage than in the forward (plating) stage - highly desirable for some applications. For a more complete explanation of output control with specific manufactured units, refer to the operational manuals supplied by the manufacturer.

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In order to avoid confusion, a very condensed "**Glossary of Terms**" follows:

Cathodic, Anodic

Used to describe current direction - i.e., Cathodic indicates flow is in normal (plating) direction; Anodic indicates flow is in reverse (deplating) direction.

Forward, Reverse

Used interchangeably with Cathodic and Anodic to indicate direction of current. In normal operation of a reversing pulse unit, current direction alternates in a controllable forward and reverse pattern.

Envelope

The time span during which current may flow in only one direction. The time spans of the Forward Envelope and the Reverse Envelope are set individually.

Pulse Train

A regularly interrupted current flow in either cathodic or anodic direction. A Pulse Train exits within the envelope.

Pulse

The individual interval in a pulse train, consisting of an "ON and OFF" period.

Pulse Rate

The number of times the current is switched on in a given period of time, usually a second.

Duty Cycle

The ratio of time an individual pulse is ON compared to the total pulse time (ON and OFF). For an example: 5 m/sec ON and 5 m/sec OFF is a 50% duty cycle; 4 ON and 1 OFF is an 80% duty cycle, etc. (Note that if the duty cycle is set for 100%, there is no OFF time. The current will be on for the duration of the envelope and there will be no pulse or frequency.)

Frequency

The pulse rate expressed as Hertz units, e.g., 100 Hertz = 100 pulses per second.

Pulse Width

The time span of the ON portion of a pulse. Pulse width is a function of both frequency and duty cycle. For example: a 1,000 Hertz pulse with a duty cycle of 50% has a pulse width of 0.5 milliseconds.

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Bath Considerations

With the changes that take place in the tank when a modulated periodic reverse pulse is impressed on the electrolyte, changes in the other operating conditions or even in the formulation may be required. Generally speaking, better results are obtained with simpler, rather than sophisticated, formulations.

The polarization imposed by the power pattern on the bath reduces, or even eliminates, the need for some addition agents. Typical formulations used in pulse plating:

NICKEL: reel-to-reel with insoluble anodes, Watts type

Nickel Sulfate	650 g/L
Boric Acid	50 g/L
Temperature	60 °C
pH	3 to 4
Anodes	Platinized Niobium
Organic additives	None

Note: When using soluble nickel anodes and reversing pulse modes, the need for an anode activator such as chloride is not required as the reversing current keeps the anode active and soluble.

PURE GOLD

Potassium Citrate	150 g/L
Citric Acid	15 g/L
Potassium Phosphate	26 g/L
Boric Acid	72 g/1
Gold Metal	8.2 g/1
Temperature	140 °F
pH	3.5 to 4.0
Anodes	Platinized titanium

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HARD GOLD

Citric Acid	65 g/L
Potassium Citrate	50 g/L
Cobalt	0.5 to 0.6 g/L
Gold	8.2 g/L
pH	3.8 to 4.0
Temperature	90 to 100 °F

With pulse, you have a higher voltage than with D.C. plating. As voltage favors the deposition of the alloying agent, one must analyze the deposit to determine if an adjustment to the amount of cobalt in solution must be made. In most cases, the reduction of available cobalt or any alloying agent must be reduced to obtain the desired hardness etc.

In many cases, additives can actually inhibit the effectiveness of the power pattern. Large molecule additives do not respond as they do under conventional power. In a high frequency pulse field, their molecular size is a disadvantage. Small molecule organics or inorganics will generally function well as additives. In many cases, brighteners can be reduced as much as 90% without diminishing the brightness of the deposit because of the improved grain structures. (If brightener level is not reduced, longer pulses - i.e., lower frequency and/or higher duty cycle, may be required.)

It is vital that the conductivity of the electrolyte be maintained at a high level to allow the peak pulse current to be completely effective. If the conductivity is not high enough, an excess in voltage will be required to attain the desired peak current. Such peaks are power-inefficient and less effective.

Note that anode-to-cathode ratios are rarely the same as for conventional power applications. Generally speaking, in acid or alkaline non-chelating formulations, the anode area should be reduced. In a cyanide or other chelating formulations, the reverse is generally the case, and a greater anode area is required.

Temperature and agitation conditions may also have to be altered from normal for modulated power pattern plating. Unfortunately, no general rule applies; each application has its own requirements.

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EQUIPMENT CONSIDERATIONS

One factor which should always be checked when planning a change in power is the tank electrical contact system. Although perfectly suitable for conventional plating, some anode and/or cathode contacts may present unwanted resistance to high frequency peak currents. Overlooking this factor may prevent the realization of the true benefits of a modulated power supply.

The major consideration, of course, is the power system itself. Existing rectifiers may or may not be suitable for use with modulated periodic reverse or direct pulse units. A high voltage, quick response rectifier is required, and the lower the ripple the more precise and predictable the output.

Although pulse units are available for use with existing power supplies, the models with self-contained rectifiers specifically designed for this function give greater assurance that full benefit of the control system will be realized.

Quality pulse units with self contained power may be operated in either a constant average current or constant voltage mode. The significance of this option is illustrated graphically in Figure 8.

Figure 8A is a depiction of a pulse train with a 50% duty cycle The <u>average</u> current delivered is 50% of the <u>peak</u> value, represented by the dotted line. Figure 8B illustrates the effect of reducing the duty cycle to 25% when in a constant voltage mode. The peak current remains the same, but the average current changes directly with the duty cycle, in this case dropping to half its former value. Note that the current density of the pulsed current will remain the same, but twice as much real time will be required to deliver the same ampere-minutes of current.

Figure 8C shows the effect of reducing the duty cycle from 50% to 25% when operating in constant average current mode. In this case, the peak current changes inversely to the duty cycle, increasing in value to maintain the same average current delivered as before but in shorter pulses.

Figure 9 illustrates what should be apparent; that a change in frequency, although it, too, changes the pulse width, does not effect either peak or average current regardless of output mode.

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There is one other consideration that must be made, and which, unfortunately, is occasionally overlooked in "sizing up" the unit required. Unlike conventional plating rectifiers which are rated by average current capacity (ignoring the ripple), modulated periodic reverse pulse units are normally rated by their peak current capacity. Since both peak and average current values are intrinsic to modulated power pattern plating, both output capacities must be considered. Depending upon the internal circuitry of the unit, the average current output capacity of some makes may be as low as 25% or 30% of the peak capacity.

With that low value for average current, the rated peak current output would be attained even at average current capacity only if a duty cycle as low as 25% or 30% was used. Attempting to push average current up would drastically shorten the life of the unit. Since experience has shown that effective duty cycles are rarely less than 50% most units are designed to deliver an average current capacity of 50 to 60% of the peak current capacity rating. However, any desired duty cycle may be used or specified, keeping in mind that the average current is the percentage (duty cycle) of the peak rating.

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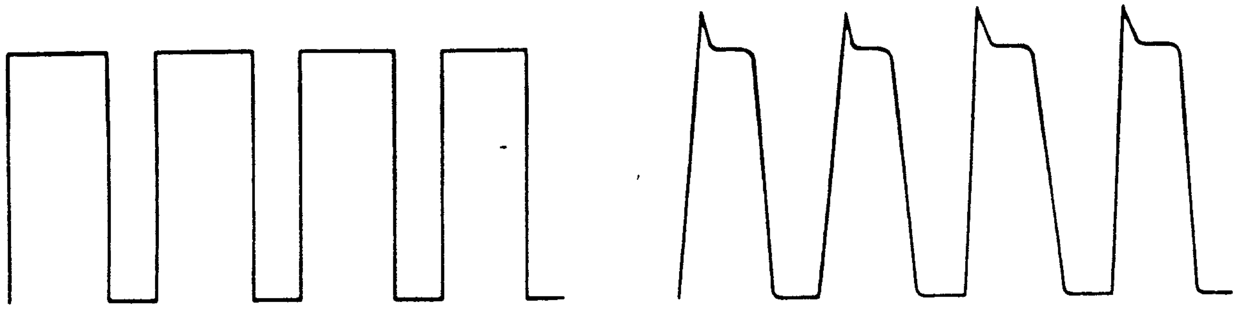
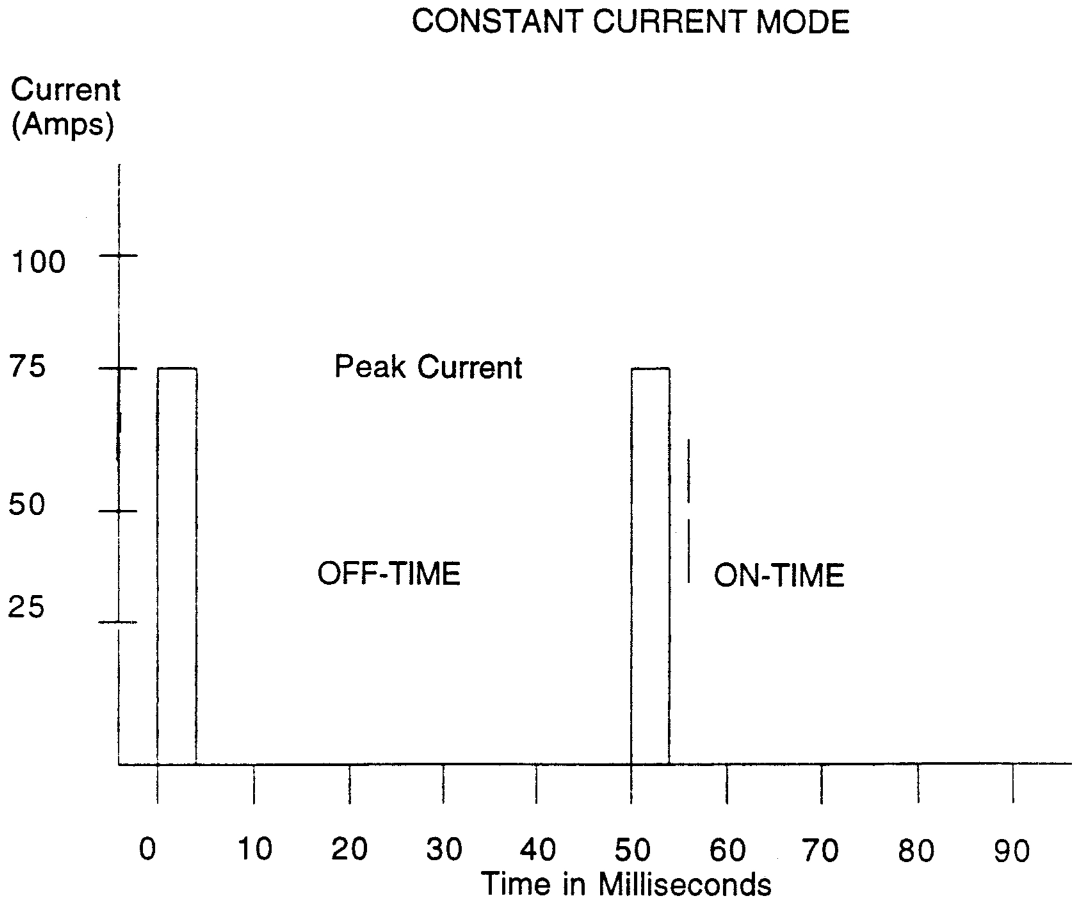


Ideal Pulse Current
A

Pulse as seen on Scope
B

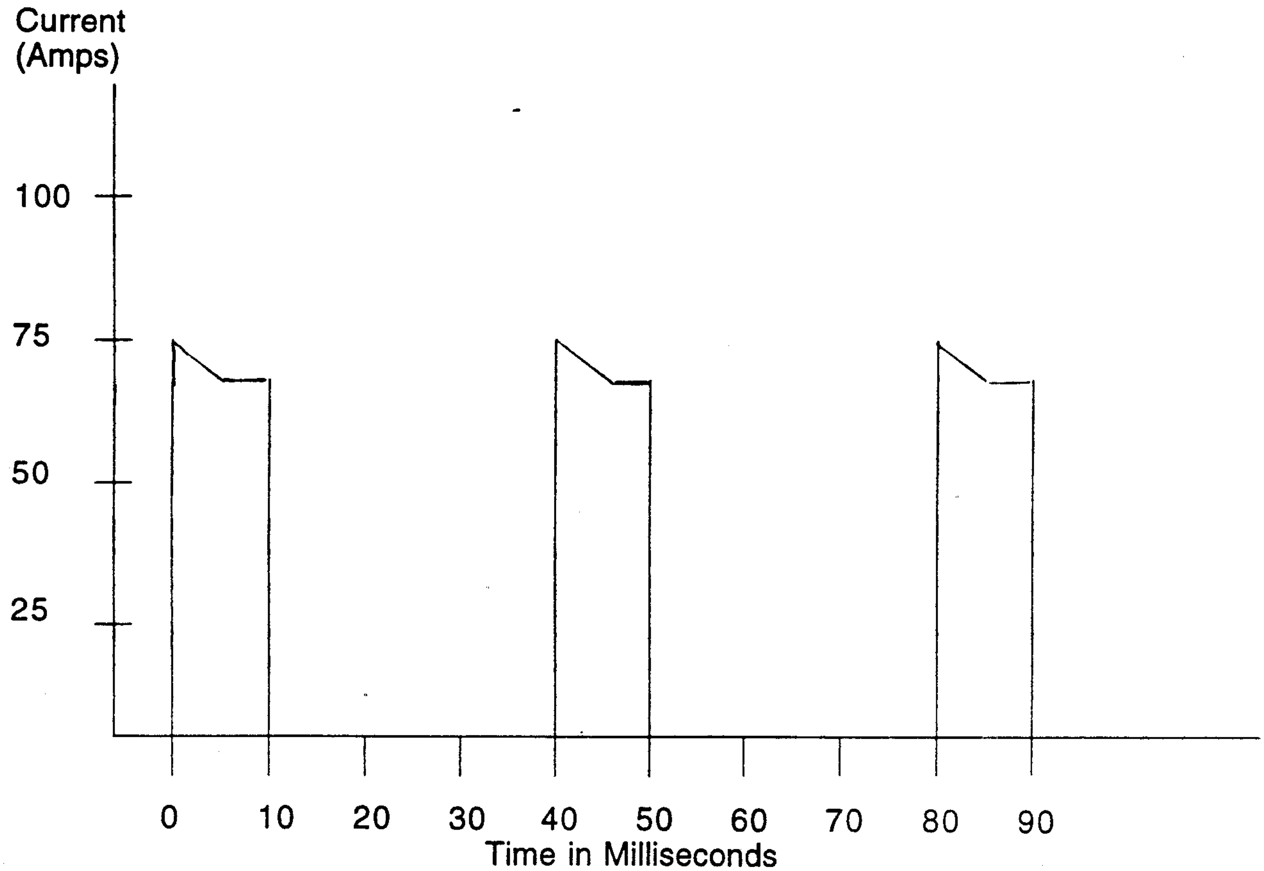
Figure 1



This illustrates the constant current mode of operation with an ON time of 5 milliseconds and an OFF time of 45 milliseconds. The peak current is 75 amps. Since the current is on 1/10 of the time, the average current is 7.5 amps.

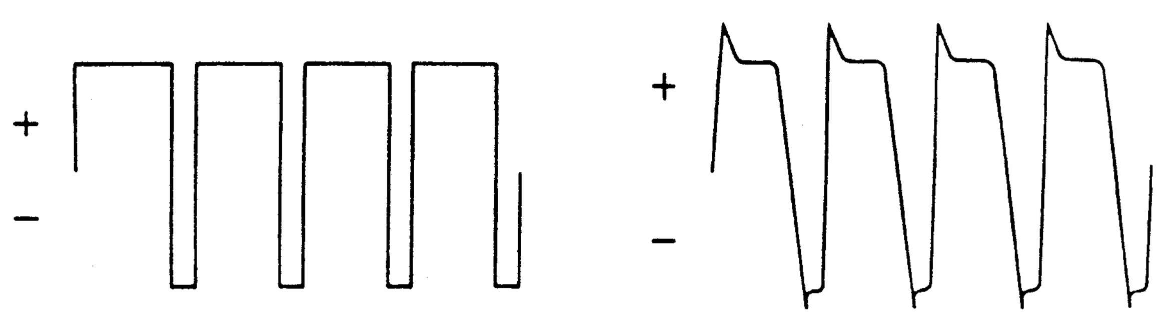
Figure 2

CONSTANT VOLTAGE MODE



This is typical of the constant voltage mode of operation. The current falls during the ON time because the resistance of the cathode film increases; a 10 milllisecond ON time and 30 millisecond OFF time is illustrated.

Figure 3



Ideal Periodic Reverse
A

As seen on Scope
B

Figure 4

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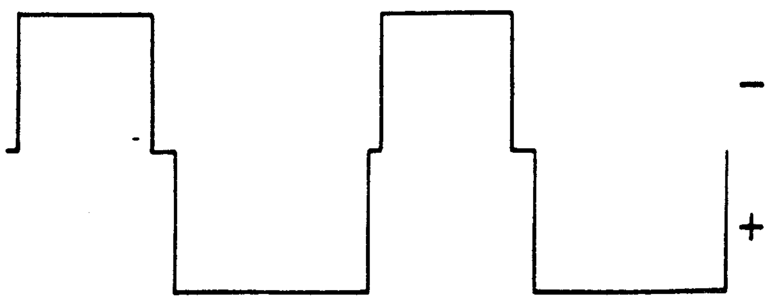
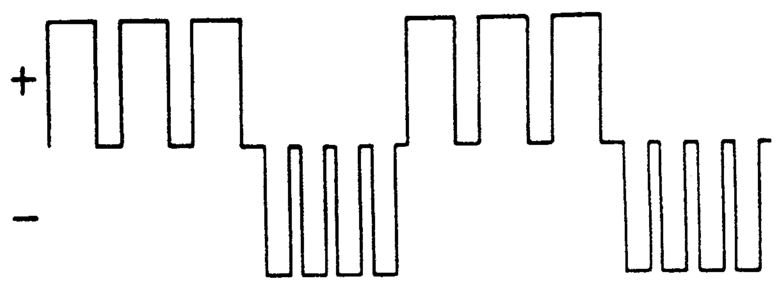


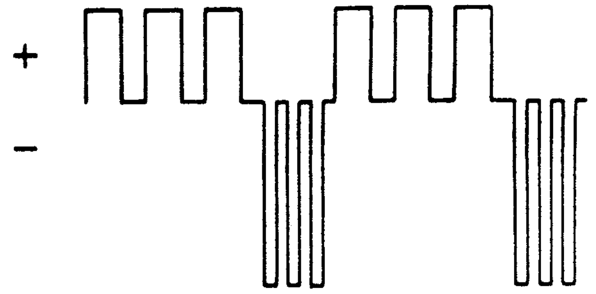
Forward and Reverse Envelopes
Without Pulse Frequencies

Figure 5



Pulse Frequencies Applied
to Forward and Reverse Envelopes

Figure 6



Some quality models permit
different current densities for
the positive and reverse phases.

Figure 7

50% Duty Cycle
Note Average Current
A

Average Current

Duty Cycle reduced to 25%
at Constant Voltage
B

Average Current

Duty Cycle Reduced to 25%
at Constant Current
C

Average Current

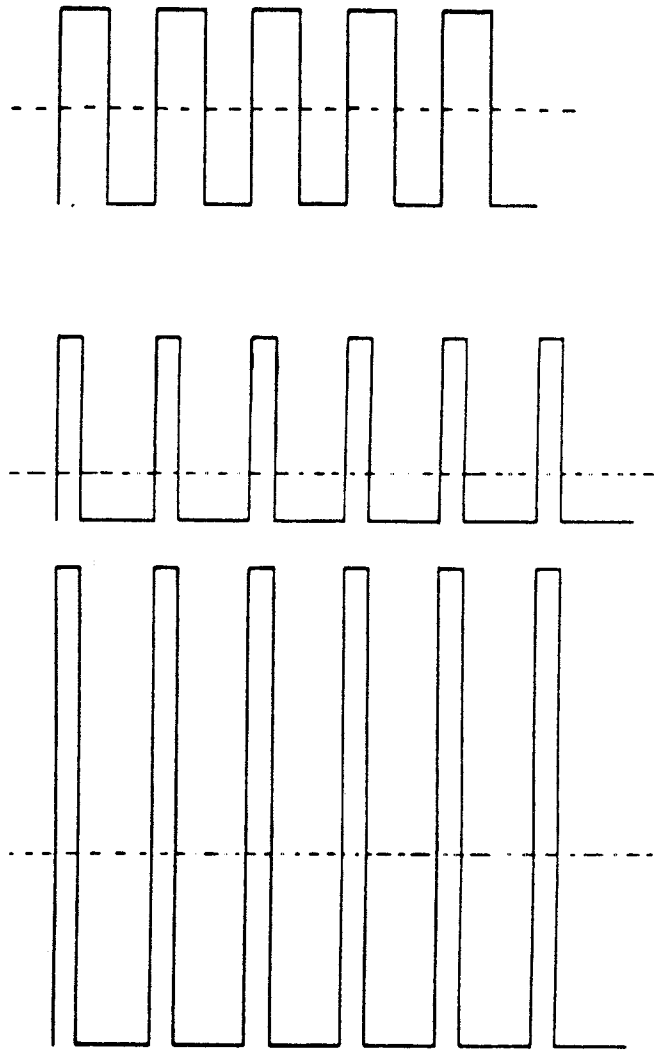


Figure 8

Changing Frequency affects only Pulse Width; Peak Current, Average Current, Duty Cycle remain constant.

Average Current

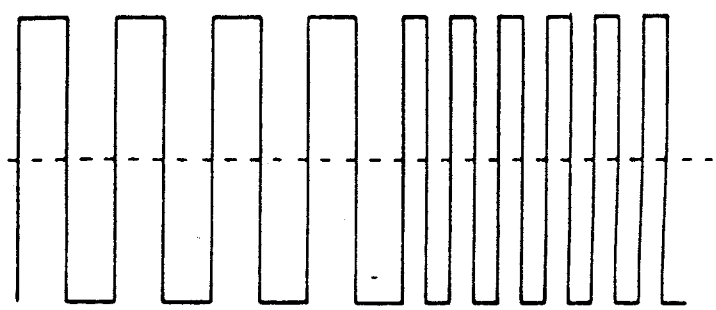


Figure 9

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