

- [54] **IMPROVED PFN VOLTAGE REGULATOR**
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 [58] Field of Search **328/65-67; 307/297; 320/1**

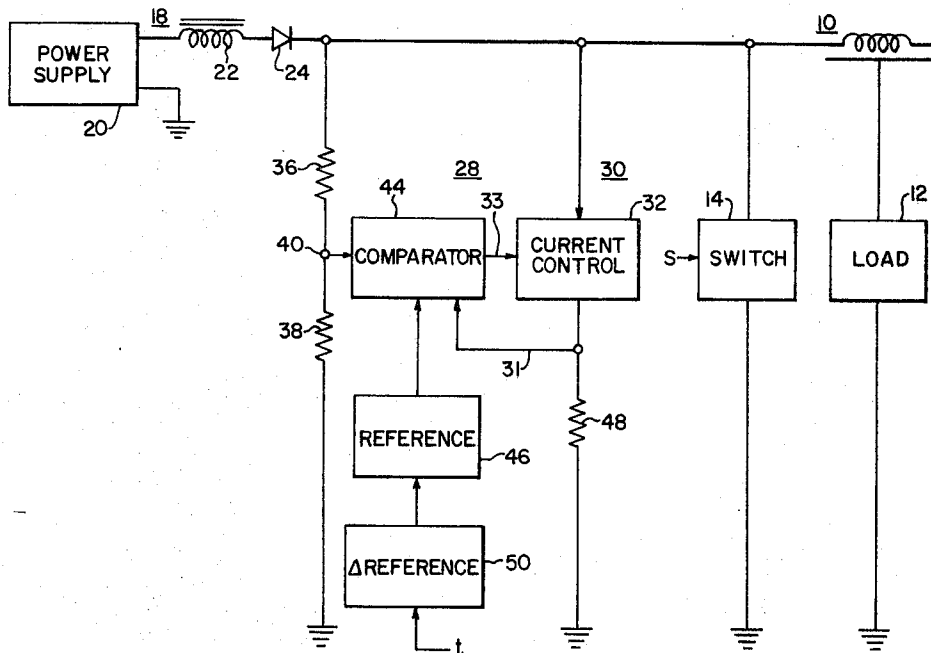
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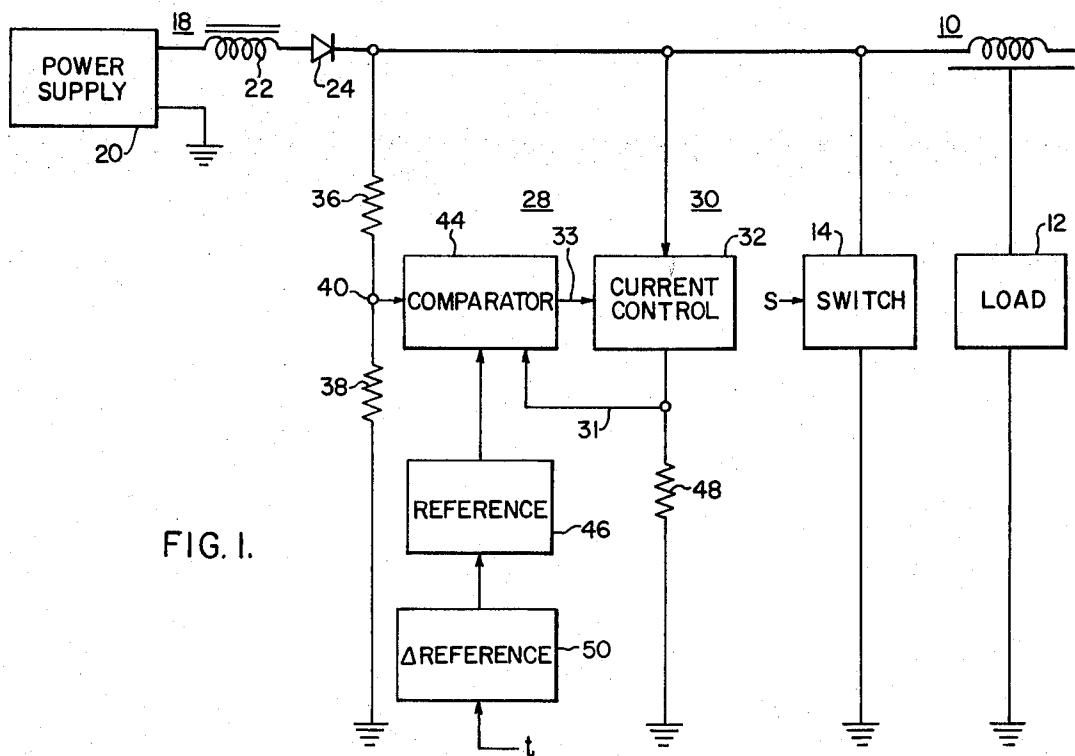
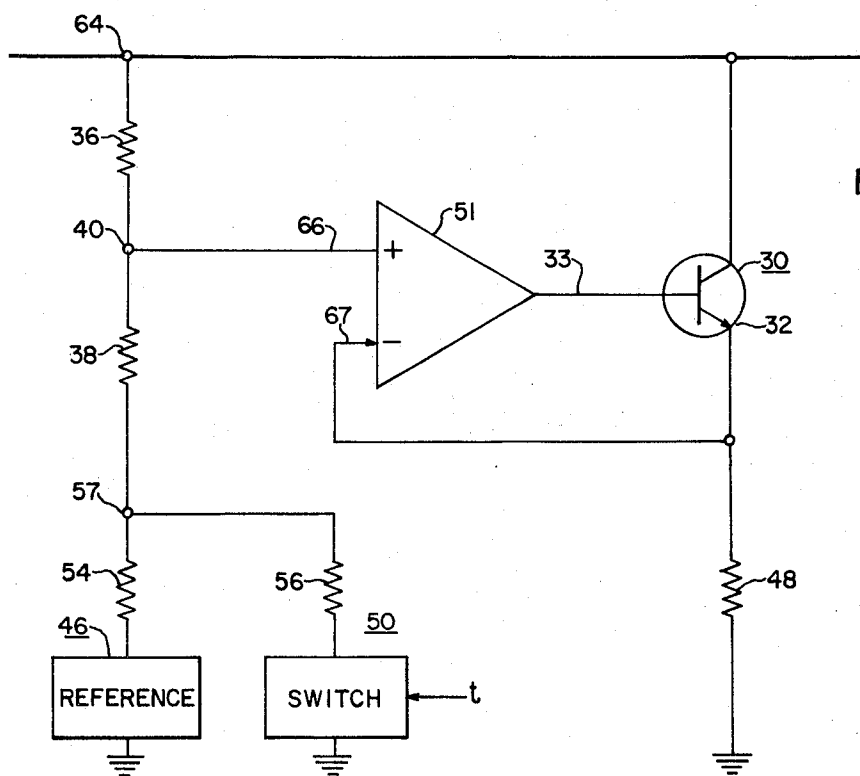
Primary Examiner—John Zazworsky
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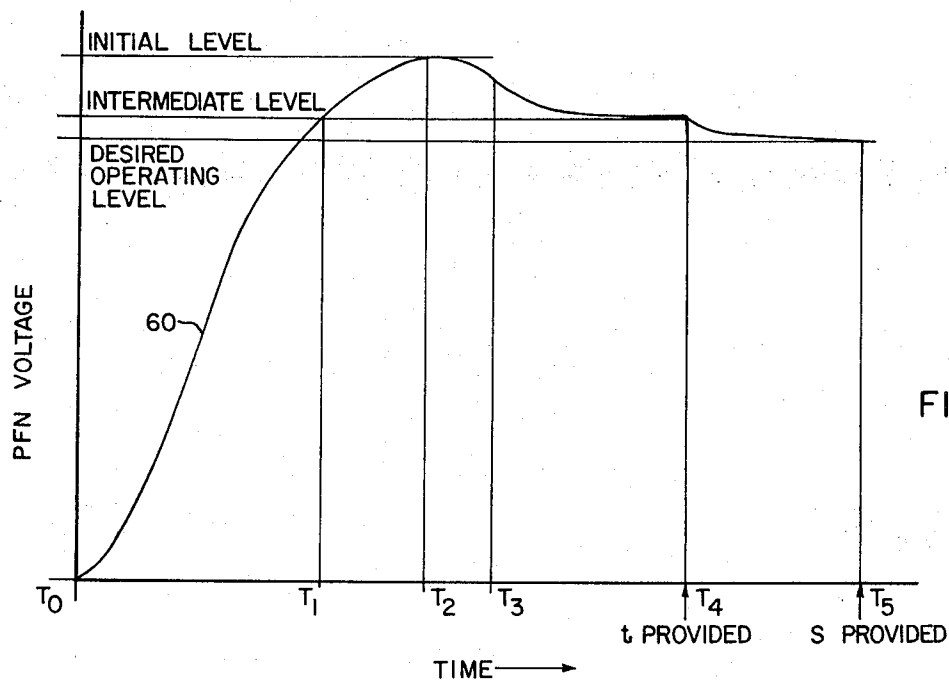
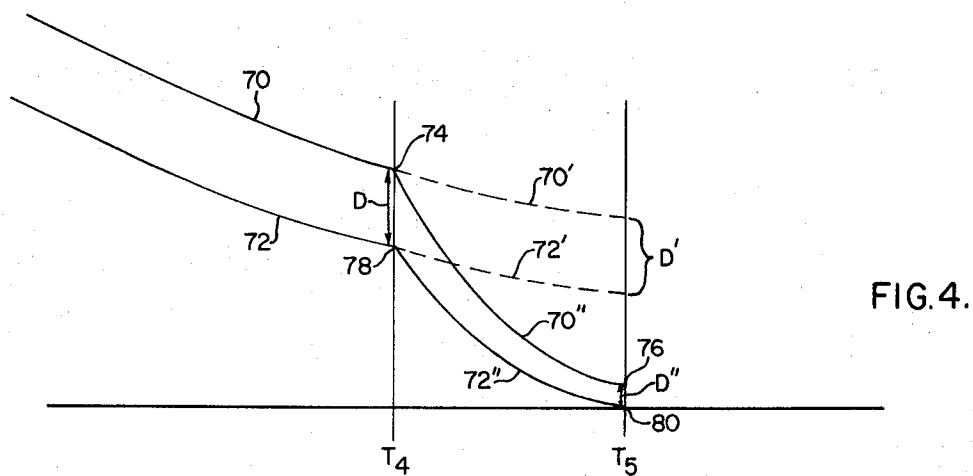
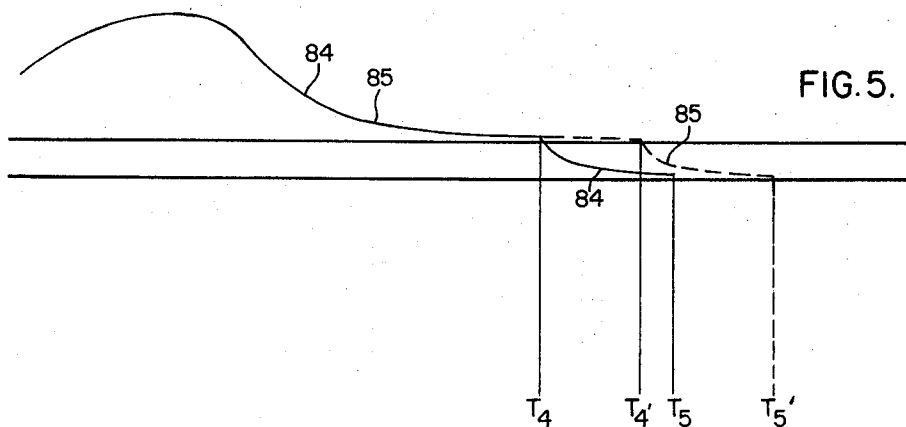
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[57] **ABSTRACT**
 A pulse forming network (PFN) is charged to an initial voltage level above a desired operating level. The PFN is then slowly discharged by a controlled discharge path first to an intermediate voltage level and thereafter, beginning at a set time before the main discharge into a load, it is further discharged to the desired operating level.

6 Claims, 5 Drawing Figures







IMPROVED PFN VOLTAGE REGULATOR

CROSS REFERENCE TO RELATED APPLICATION

This application is related in subject matter to application Ser. No. 176,190 entitled PFN REGULATOR, filed Aug. 30, 1971 and assigned to the same assignee as the present invention.

BACKGROUND OF THE INVENTION

Field of the Invention

Pulse forming network voltage control circuitry.

Description of the Prior Art

A typical PFN consists of a series of inductors having capacitors interposed in parallel therebetween and operates by storing up energy supplied to it over a relatively long period of time and then discharging the stored energy in a short period of time as a pulse.

Such networks find particular utility in radar systems, laser systems and other systems which require repetitive pulses. Ideally after each discharge, the PFN should charge up to the same voltage each time so that the output pulses will all be of the same voltage. However, due to variations in the power supply, stray capacitance, and/or inductive coupling from other circuits, there is pulse to pulse variation in the repetitive operation of the PFN. In order to reduce the pulse to pulse voltage variation on the PFN, a regulator is generally used. One form of regulator which has been proposed utilizes zener diodes in shunt configuration with the PFN. The breakdown voltage of these diodes, however, drift with temperature and their use precludes fine adjustment. Another proposal utilizes an auxiliary discharge circuit such as described in U.S. Pat. No. 3,124,754. In that arrangement, a PFN is initially charged to a value greater than the value of the pulse finally required. A sawtooth voltage is compared with the PFN voltage and at a predetermined difference a pulse is produced to a thyatron switch tube to place a resistor in shunt circuit configuration across the PFN whereby the PFN is discharged toward ground potential at a substantially linear rate until the main discharge. Such circuit decreases the pulse to pulse voltage variation, however, the uncontrolled discharge at a fixed rate still results in objectionable and unacceptable variations. Additionally, such a circuit would not give satisfactory operation in systems utilizing variable pulse repetition times.

SUMMARY OF INVENTION

A PFN is provided with charging current and is operable to provide a main discharge output pulse in repetitive cycles.

The PFN is charged to an initial voltage level subject to deviation from cycle to cycle. Means are provided for regulating the voltage of the PFN down to an intermediate voltage level and at a set time before main discharge, regulation down to a desired operating voltage level is commenced.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates an embodiment of the present invention;

FIG. 2 illustrates a portion of FIG. 1 in somewhat more detail;

FIG. 3 is a curve of PFN voltage illustrating the operation of the present invention;

FIG. 4 is an enlargement of a portion of the curve in FIG. 3; and

FIG. 5 illustrates the operation of the present invention with a variable pulse rate system.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In FIG. 1, there is illustrated a PFN 10 operable to discharge stored energy through a system load circuit 12 when switch 14 is activated by a system signal S.

Charging current is supplied to the PFN 10 by a charging circuit 18 including a power supply 20, a charging choke 22 and a diode 24. A resonant charging arrangement is formed by the choke 22 and the capacitance of the PFN 10 to charge the PFN to a voltage somewhat less than twice the power supply voltage. Due to power supply variations as well as other factors, the PFN will not necessarily get charged up to the same voltage after each main discharge.

In order to insure that all the pulses provided by the PFN 10 do not vary in voltage by more than a few hundredths of a percent, there is provided the regulation circuit 28, which during each cycle allows overcharge of the PFN and then regulates the voltage down to an intermediate level and during said regulation, upon a system command, will commence regulation down to a final desired voltage level, at a set time before main discharge.

The regulation circuit 28 includes a discharge path 30 having a current control means 32 operable to control the value of current in the path 30 in response to a control signal provided thereto on line 33.

Generation of the control signal to accomplish the operation set forth is dependent upon a comparison of the actual PFN voltage with a desired voltage level. Accordingly, an indication of the actual PFN voltage is obtained by, for example, a voltage divider network including resistors having a predetermined ratio so that the voltage at point 40 is lower than, but indicative of, the PFN voltage.

A comparator means 44 is provided for comparing the voltage at point 40 with a reference voltage provided by reference means 46.

To better maintain regulator stability, resistor 48 is placed in the controlled discharge path 30 to provide a feedback signal on line 31 to the comparator means 44.

As will be described, this circuitry will allow an overcharge of the PFN to an initial voltage level and will thereafter provide for a discharge to an intermediate voltage level in a controlled manner, which may vary from cycle to cycle. As this intermediate voltage is reached or approached, the PFN is further discharged toward a final desired level at a set time before the provision of signal S. This operation may be accomplished in various ways, one of which is illustrated by the change of reference means 50 which operates to change the reference signal to comparator 44 upon application of input signal t which occurs at a fixed time before S. Although not illustrated, another method to accomplish this would be to change the voltage at point 40 by changing the ratio of resistance values of voltage divider resistors 36 and 38 upon provision of signal t.

In FIG. 2, the principle of operation of the voltage divider network and reference means is similar to that in FIG. 1, however, they are illustrated in an alternative arrangement. Instead of the lower end of divider volt-

age resistor 38 being connected to ground as in FIG. 1, it is connected to the reference means 46 having a negative reference supply and a resistor 54. The lower end of the voltage divider resistor 38 is also connectable with ground by way of the reference changing means 51 having a resistor 56 and a switch, for example, operable to effect the connection to ground for a period of time upon application of input signal t . The error signal at point 40 is provided as one input to differential amplifier 51.

The current control means 32 may take various forms and is illustrated as a transistor having one electrode connected to the PFN, another electrode connected to a reference potential, such as ground, by way of resistor 48, and a third connected to receive the output signal from differential amplifier 51.

Operation of the circuitry will be explained with additional reference to FIG. 3, illustrating the PFN voltage as a function of time.

Initially, a desired operating level is chosen. That is, the voltage of the PFN output pulse is determined by system requirements. Component values are chosen so that the PFN will charge to an initial level higher than the final desired level. For example, the initial level may be 5 percent higher than the final. The over voltage may vary, however, due to power supply variations, etc. The discharge path 30 is controlled to regulate the voltage down to an intermediate voltage level, chosen for example to be 1 percent above the final desired level and determined by the value of the voltage reference 46.

At time T_0 in FIG. 3, the resonant charging arrangement begins charging of the PFN to an initial voltage level which is reached at time T_2 . Prior to that time, the curve 60 crosses the intermediate voltage level. Due to the negative reference, the voltage at point 40 is initially negative with respect to the voltage at point 64, the PFN voltage. The input to the positive input 66 of the differential amplifier is therefore negative and no output signal is provided to initiate conduction of transistor 32. Just past the intermediate regulation level at time T_1 , the voltage at point 64, the PFN voltage, is such as to make point 40 very slightly positive so that differential amplifier 51 provides an output signal to start conduction of transistor 32, and some charging current goes through path 30. The current through resistor 48 causes a voltage drop thereacross and a feedback signal is provided to the negative input 67 of the differential amplifier. By this negative feedback arrangement, the voltage across resistor 48 is approximately equal to the voltage at point 40, and the current in transistor 32 is directly proportional to the difference between the actual and the intermediate PFN voltage level.

At time T_2 , the current from the charging system is substantially equal to the current through the shunt regulator, transistor 32, and the PFN is charged to its peak level. Current continues through the transistor 32 but as the charging circuit current decreases, some current is drawn from the PFN, reducing its voltage as seen by curve 60 from T_2 to T_3 . At T_3 when no more charging current is available, the transistor draws all its current from the PFN in accordance with how far the voltage on the PFN is away from the intermediate level. Ideally, the discharge follows an exponential decay with a time constant τ determined by the capacitance of the PFN and the apparent resistance of the regula-

tion circuit. This apparent resistance is equal to the value of resistor 36 multiplied by the value of resistor 48 and divided by the value of resistor 38.

As the exponential decay approaches the intermediate level, the voltage of the PFN also exponentially approaches the intermediate level to where the error signal at point 40 would again be zero.

At a set time T_4 prior to the main discharge at T_5 , regulation is initiated to the desired operating level.

One way of accomplishing this second regulation is by changing the value of reference voltage. In the embodiment illustrated in FIG. 2, this change in value is brought about by the provision of switch means 50 which upon application of signal t will connect point 57 to ground, through resistor 56. The percentage of reference voltage change can be chosen by proper choice of resistors 54 and 56. That is, the percent change is approximately equal to the ratio of resistor 54 to resistor 56.

At time T_4 , the voltage at point 57 is immediately changed by the effect of closing switch 50. Accordingly, there will be an error signal to cause the transistor 32 to conduct as before until the voltage of the PFN is brought down to substantially the desired operation level and at time T_5 the PFN is discharged through the load by application of signal S to switch 14 (see FIG. 1).

The curve of FIG. 3 is somewhat idealized and serves to explain the operation of the circuitry. The actual shape may deviate to some extent depending on the various ways of implementing the circuitry and dependent upon component characteristics and values.

FIG. 4 serves to illustrate one benefit derived with the present invention. Curve 70 represents a portion of the PFN voltage curve for one pulse and curve 72 represents the same portion for a subsequent pulse. The curves are not coincident due to the initial charging (portion not illustrated) to different levels. At a time T_4 , the curves are separated by a distance D representing a difference in voltage at that time on the PFN from one pulse to the subsequent one. If the curves were continued as illustrated by the dotted portions 70' and 72' to a firing time T_5 there would still exist a voltage difference D' . However, in accordance with the present invention, at time T_4 the curves are regulated to a new level and the decay, if exponential, will bring the PFN voltage 63.2 percent closer to the desired voltage in one time constant. In other words, the value of curve 70 at point 74 will reduce according to curve 70'' and will bring the PFN voltage 63.2 percent closer to the desired voltage, in one time constant. If the time distance between T_4 and T_5 is several time constants, the distance from the desired PFN voltage will decrease by 63.2 percent after each time constant until a final value at point 76 is reached at T_5 .

Similarly, the decay along curve 72'' will reduce the value of point 78 to a new value at point 80, at which time firing occurs. The voltage difference between curves 70'' and 72'' reduces exponentially and the difference D'' at T_5 is substantially reduced and within acceptable limits.

Another benefit derived with the present invention is its usefulness in systems wherein the pulse repetition rate is varied. That is, the provision of signal S is varied. FIG. 5 illustrates the PFN curves for two different pulses with a non-uniform repetition rate. Let it be assumed that for the two pulses, the charging is exactly

the same and the PFN voltage accordingly will be the same. Hence, the curves 84 and 85 are superimposed. The PFN for curve 84 discharges at time T_5 and for curve 85, discharges at time T_5' . Due to the varying pulse rate, T_5 and T_5' do not occur simultaneously. At a set time T_4 before the main discharge at T_5 and as the PFN voltage approaches the intermediate level, the voltage to which regulation is made is lowered to the desired operating level as previously explained. The curve 84 decays to some final value at T_5 .

Since signal t occurs a set time before the main discharge, curve 85 will start regulation to the new level at T_4'' and reach a final value at discharge time T_5' . The final values are within acceptable tolerances by operation of the present invention. Accordingly, with the extra regulation beginning at the known time before main discharge the present invention provides pulse to pulse values with less deviations than achievable with prior art systems.

Although the pulse forming network has been indicated as including a plurality of inductors and capacitors, it is to be understood that the term "pulse forming network" is equally applicable to any network, such as one or more capacitors, which is charged and discharged repetitively to provide pulses.

What is claimed is:

1. Pulse forming network regulation circuitry comprising:
 - A. a pulse forming network operable to store energy and provide said energy as a discharge pulse to a load circuit;
 - B. means for charging said pulse forming network to an initial voltage level subject to deviation from one pulse time to another;
 - C. means for regulating the voltage of said pulse forming network down to an intermediate voltage level; and
 - D. means for regulating the voltage of said pulse forming network down to a desired operating level starting at a set time before the provision of said discharge pulse.
2. Pulse forming network regulation circuitry comprising:
 - A. a pulse forming network operable to store energy and provide said energy as a discharge pulse to a load circuit;
 - B. means for charging said pulse forming network to an initial voltage level subject to deviation from one pulse time to another;
 - C. a discharge path including current control means operatively connected to said pulse forming network;
 - D. means for obtaining an indication of pulse forming network voltage;
 - E. means for providing a reference signal indicative of an intermediate voltage level to which said pulse forming network voltage is to be regulated;
 - F. means for comparing said reference signal and said indication of pulse forming network voltage for

- providing an error signal;
- G. said error signal being connected to control said current control means; and
 - H. means for changing said error signal, at a set time before the provision of said discharge pulse.
3. Apparatus according to claim 2 wherein:
 - A. said current control means includes a three electrode device, a first electrode being connected to said pulse forming network, a second electrode being connected to a reference potential and a third electrode constituting an input; and which includes
 - B. amplifier means having an input for receiving said error signal and an output connected to said third electrode.
 4. Apparatus according to claim 3, wherein:
 - A. said amplifier means is a differential amplifier having first and second inputs;
 - B. said error signal being connected to said first input; and additionally including,
 - C. means for providing a feedback signal indicative of the current through said current control means; and
 - D. said feedback signal being connected to said second input.
 5. Pulse forming network regulation circuitry comprising:
 - A. a pulse forming network operable to store energy and provide said energy as a discharge pulse to a load circuit;
 - B. means for charging said pulse forming network to an initial voltage level subject to deviation from one pulse time to another;
 - C. a discharge path including current control means operatively connected to said pulse forming network;
 - D. a voltage divider network for providing at a point thereon a voltage indicative of said pulse forming network voltage;
 - E. voltage reference means connected to said voltage divider network whereby the voltage at said point is an error signal indicative of the difference between said voltage reference and said voltage indicative of said pulse forming network voltage;
 - F. means responsive to said error signal for controlling said current control means; and
 - G. means for changing the value of said voltage reference at a set time before the provision of said discharge pulse.
 6. Apparatus according to claim 5, wherein said means of clause G) includes:
 - A. normally open switch means connected to the circuit arrangement of said voltage divider network and voltage reference means at a point of connection;
 - B. said normally open switch means closing upon application of a signal (t) to connect its point of connection to a reference potential.

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