# SYNTHESIZED PULSE FORMING NETWORKS FOR LONG PULSE HIGH DUTY CYCLE MAGNETRON OR OTHER TYPE LOADS*

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*Abstract*

A variable pulse length, high duty cycle Pulse Forming Network (PFN) is constructed by time sequentially, transforming and switching single sections of a Guilliman type B PFN element. This is a realizable approach because it is possible to accomplish a very efficient energy transfer between a type B PFN element and a non-linear magnetron type load. Efficient energy transfer can also be optimized in the cases of resistive or diode loads. Only a limited number of single sections are used, typically four; however, they are used over and over in a time programmed sequence to achieve a synthesized PFN of any arbitrary length. The limited number of basic sections results in a very small size apparatus having the capability to perform functions normally requiring an apparatus of many times the size and weight. The PFN elements operate at low voltage and drive the primary of a step-up transformer. A high efficiency charging regulator, which can accommodate a wide range of source voltage variation, closely regulates the voltage to which the PFN elements are charged. The secondary of the transformer has a full wave rectifier, which passes the pulse energy to the load in a continuous sequence of properly phased and nested increments.

## I. BACKGROUND INFORMATION

Magnetrons have a nonlinear voltage-current characteristic as illustrated in Fig.1. As voltage is applied to the cathode, virtually no current flows until the approximately 90% of rated voltage is reached. Over the last 10% of the voltage range the current rises from essentially zero to full rated value. To insure that the magnetron starts oscillation in the proper mode, the rate of voltage application near the current "turn on" point must be carefully controlled. The sensitivity to voltage rate of application can be greatly reduced for high duty cycle tubes by maintaining a current level of a few milli-amperes through the tube during the inter-pulse period. This maintains the tube in low level oscillation and greatly enhances the turn on process. The details of magnetron theory and operation can be found in the literature [1]. The low dynamic impedance of a magnetron requires that modulators used to operate them provide a satisfactory degree of current stabilization. Although in principle it is possible to operate a magnetron from a voltage source, the control and regulation requirements are very demanding. Two common approaches, which are more compatible with magnetrons, are the PFN [2] and "Hard Tube" [3] type modulators. The PFN approach is rather inflexible in terms of accommodating several pulse widths and also requires a very large number of sections for long pulses. The PFN typically uses a pulse transformer to accommodate the difference between optimum PFN/switch impedance and the load. The transformer must be designed for the full range of pulse widths. Long pulses require a large and expensive transformer. The "hard tube" modulator accommodates pulse width diversity; and usually does not need a pulse transformer interface to the load. Hard tube disadvantages are high cost and low efficiency because of the plate voltage drop.

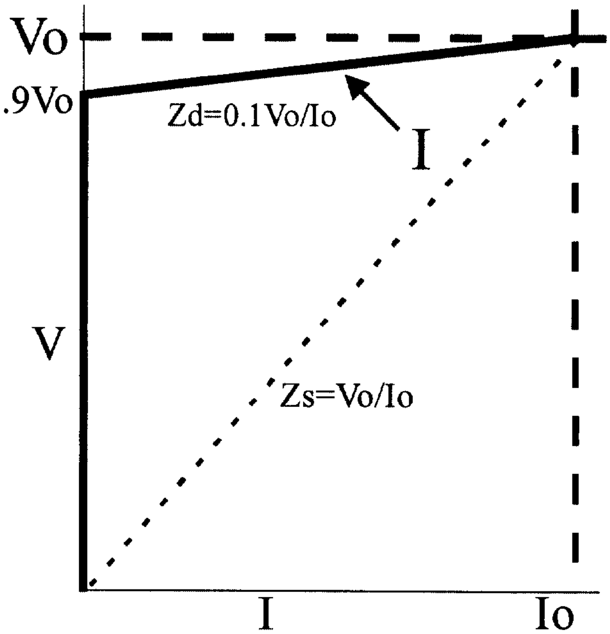


**Fig.1**
**Typical Magnetron V-I Characteristic**

## II. SYNTHESIZER APPROACH

The new approach is based on the B type Guilleman PFN. Only a limited number of B sections are used, typically four: however, they are used over and over in a time sequence program to synthesize a PFN of any arbitrary length, including CW operation. Although the E type Guilleman PFN is frequently used in magnetron modulators and performs very well, it requires a mutual inductance coupling between sections. The mutual

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14. ABSTRACT

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inductance cannot be isolated to terminals that can be electrically switched and therefore precludes the use of a type E PFN as a "building block element". For the new approach we choose the B type PFN which has no coupling between sections. Each section of a type B is identical and completely "stand alone" in that it consists of a single capacitor and inductor with no mutual connection to anything else. It is therefore electrically transportable from place to place in a circuit by means of a switch. Type E and Type B PFN's are shown schematically in Fig.2.

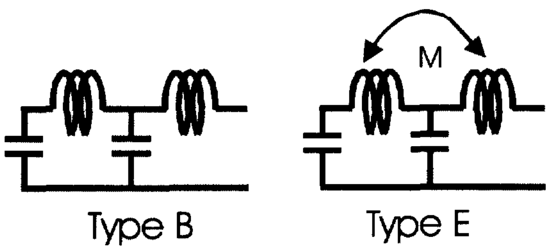
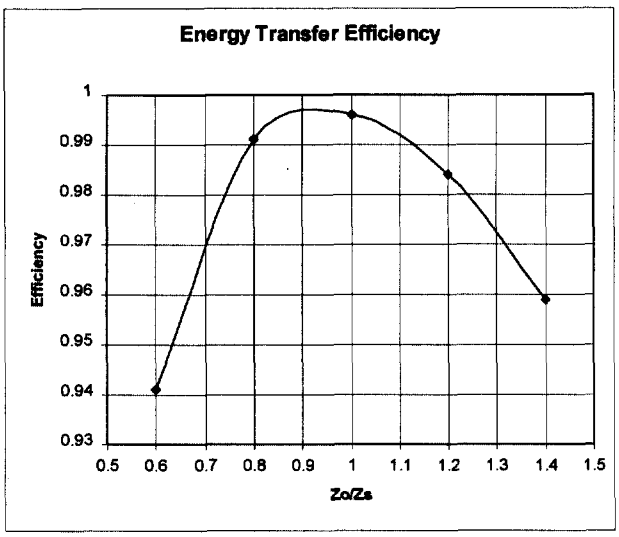



**Fig.2**
**Types B and E**
**PFN Configurations**

The excellent energy transfer efficiency of a type B section to a magnetron type load is shown in Fig.3.



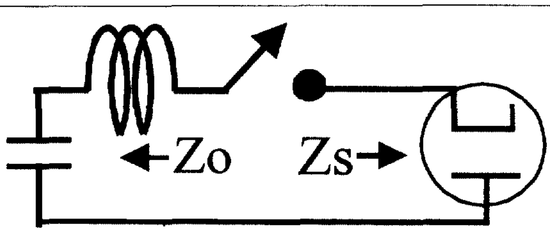
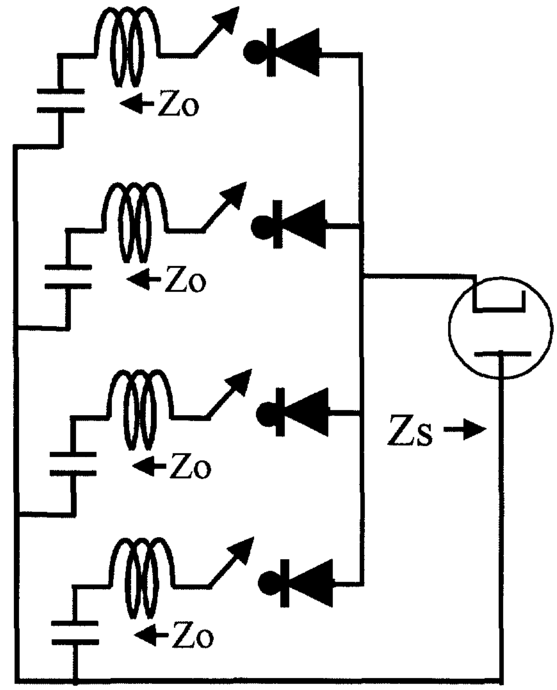




**Fig.3**
**Energy Transfer Efficiency**

In Fig.4, four identical B sections are shown which are consecutively switched into a magnetron load, in time sequence, such that the current overlaps at the 50% level. The characteristic impedance is set equal to the static impedance of the magnetron load and the energy transfer efficiency of the single section as shown in Fig.3 is maintained. The general concept of the PFN synthesizer approach is illustrated in Fig.5. using four B sections.



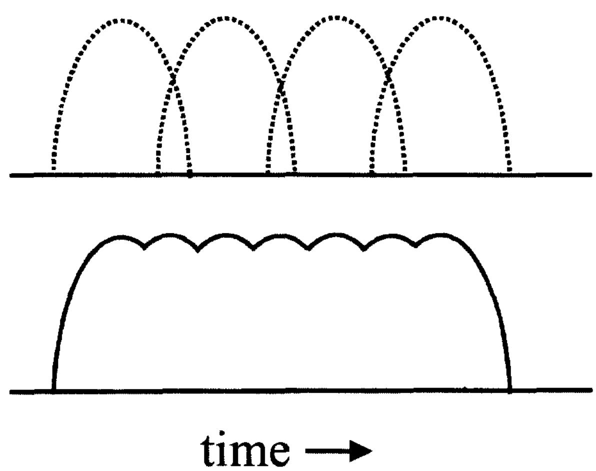




**Fig.4**
**Load Current of 4 Combined "B" Type Sections**

At any one time no more than two sections are delivering power to the load, one section has been recharged and is ready to be switched to the load connection, and one section is being recharged. It is clear that this process can be sustained indefinitely or terminated at any time, therefore it is possible to synthesize any wave pulse length from a single section to any number of sections out to and including continuos (CW) operation. It is also possible to synthesize any combination of pulse widths in any random sequence. This process has an inherent ripple on the current waveform on the order of 5% rms.

This ripple therefore must be compatible with the application.

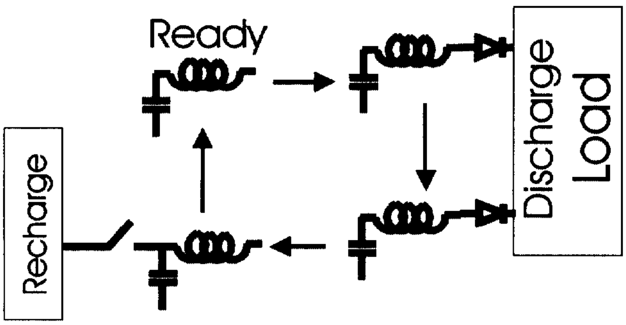



**Fig.5**
**Synthesizer Concept**

## III. CIRCUIT IMPLEMENTATION

To implement the concept shown in Fig.5 requires 4 type B (L-C) sections each matched to the load static impedance, Zs=Vo/Io, through the transformer. Additionally, means for sequentially switching and recharging each PFN must be provided. A simplified circuit similar to a switching inverter, shown in Fig.6, combined with a high efficiency-charging regulator, shown in Fig.7, accomplishes these functions. Each switching circuit uses two PFN's, two charging regulators, one transformer, a bridge type switch configuration, and a bridge rectifier on each transformer secondary. The transformer provides a means of matching the load impedance or equivalently, accomplishes the use of low voltage solid state switches with a high voltage load. The rectified, but not filtered, outputs of the transformers are combined and passed to the load but are isolated from each other by the bridge rectifiers. It is essential not to filter the output of the bridge rectifier because this would destroy the impedance match, provided by the transformer ratio, between the PFN and load impedance.

The charging regulator, see Fig.7, is a high efficiency resonant type as described in US Patent 3,716,798 titled "Anticipatory Charging Regulator". This patent was issued on 13 Feb 1973 to James P. O'Loughlin and assigned to Raytheon Company. Well over seventeen years have elapsed since the issue, so it is now in the public domain. The operation of this regulator is based on maintaining a real time accounting record of the total energy in the circuit and then interrupting the input energy flow when a predetermined level has been achieved. The circuit is so constructed that after a short period of time from the interruption of the energy flow, all of the energy in the circuit becomes trapped in the load capacitor. Since that amount of energy is accurately measured and predetermined at a given level, the result is a regulated energy or voltage being established at the load capacitor in spite of input power variations. The energy record is maintained be measuring the current in the inductor and the voltage on the capacitor. The total instantaneous energy in the circuit is, $J = 0.5LI^2 + 0.5CV^2$.

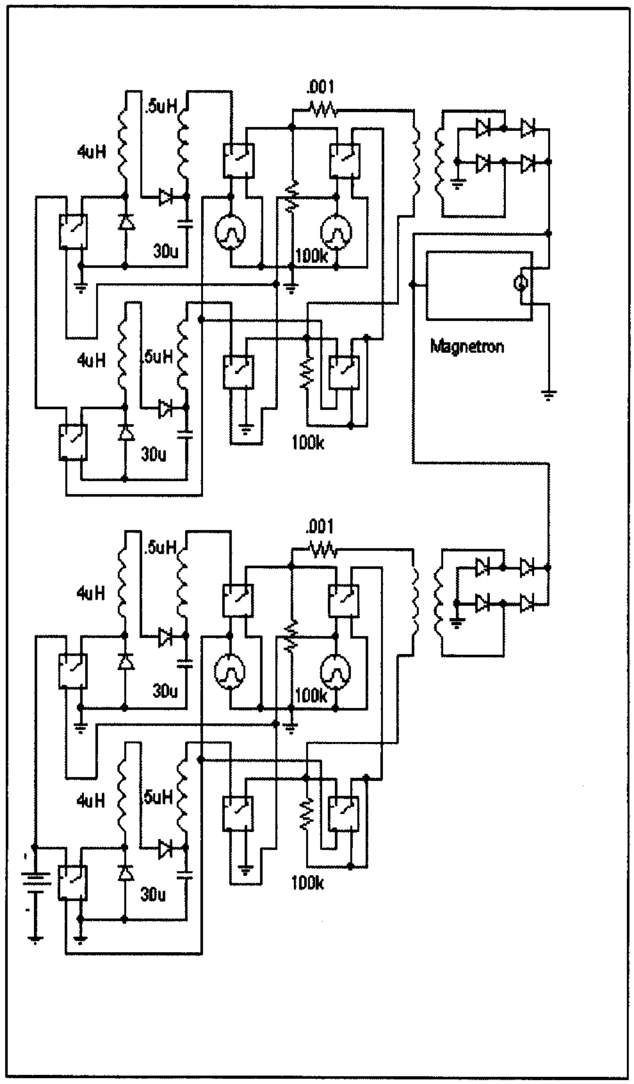



**Fig.6**
**Simplified Circuit of**
**PFN Synthesizer**

When J reaches the predetermined level the switch opens. The circuit simulation model performance of the regulator is shown in Fig.8 for input voltages of 400VDC and 800VDC.

## IV. SUMMARY

Buy using only four single L-C sections of a type B PFN it is possible to synthesize an equivalent PFN of any arbitrary number of sections. Although the four sections in the synthesizer may run at an effective PRF much higher than the synthesized PFN; there is a very substantial saving in size, weight, and cost when long PFN lengths are synthesized. The savings are in the number of sections of the PFN, never being more than four; and also the pulse transformer that operates in a bipolar mode and is therefore only required to have a pulse width capability of the single "building block" section instead of the pulse width capability of the long synthesized pulse.

The synthesizer consists of two switching inverter like circuits with the outputs coupled to the load through bridge rectifiers. Such a synthesized PFN can be efficiently matched to a magnetron type load by means of a transformer. The pulse width can range from a single section of the Type B building block to CW. The transformer is only required to have a bandwidth capability equal to that of a single section of the Type B building block. The circuit can be stabilized against wide prime power voltage variations by using a high efficiency resonant type regulator based on US Patent 3,716,798 which is now in the public domain. The synthesizer provides a capability for generating an instantaneously variable and random pulse width. This flexibility is valuable for industrial processing, microwave heating, and other similar applications.

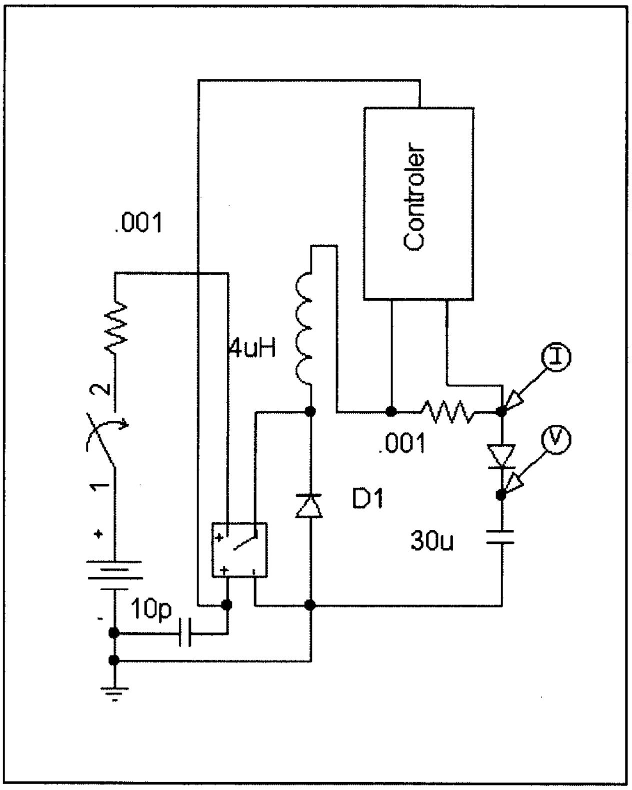



**Fig.7**
**High Efficiency Charging Regulator**

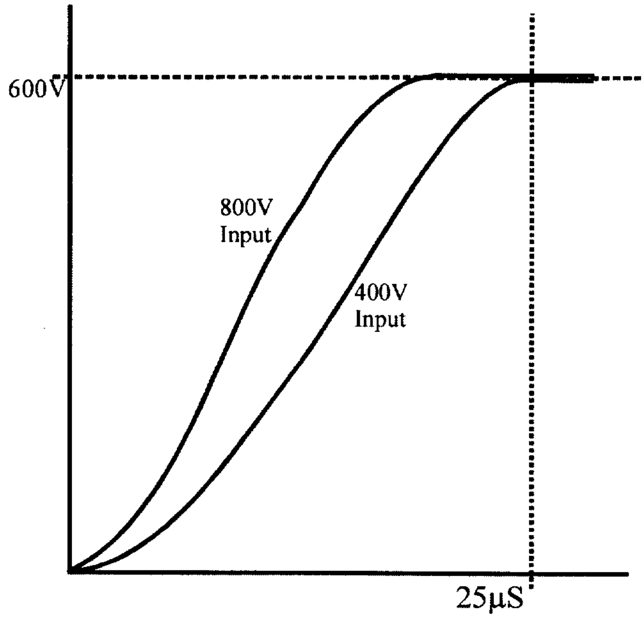



**Fig.8**
**Charging Regulator Output for 400V and 800V Inputs**

## V. REFERENCES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[2] G. N. Glasoe and J. V. Lebacoz, "Pulse Generators, MIT Radiation Laboratory Series, Vol.5 Part II, Boston Tech. Publishers, 1964.

[3] G. N. Glasoe and J. V. Labacoz, op. cit. Part I.