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Design and development of type-B pulse forming network for generation of low voltage rectangular pulses

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Rectangular pulses of short duration find more importance in applications like charged particle accelerators, microwave sources, Lasers and microbial deactivation in food. Rectangular pulses of short duration in the order of few microseconds are generated commonly by using pulse forming networks. In the present work, a low voltage, type-B Pulse Forming Network (PFN) for generating rectangular pulses of duration 1.8 μs is designed, and developed. Simulation is carried out in PSPICE™ and the effect of first and last stage inductances on the overshoot of the output waveform is studied. The characteristic impedance of the type-B PFN is 10 Ω. Load impedance is chosen as 10 Ω to discharge maximum energy of the generated pulses effectively into the load circuit. A low voltage rectangular pulse of output voltage of 560 V and duration 1.6 μs is achieved experimentally.

Keywords: *Type-B pulse forming network, low voltage rectangular pulses, overshoot, characteristic impedance, pulse width and PSPICE™.*

1.0 INTRODUCTION

In certain applications like charged particle accelerators, microwave sources, lasers, food treatment, Rail gun, pulse modulators [1-8] etc. high voltage rectangular pulses are required. Conventional Marx™ generators on short circuit discharge produce damped output wave due to its internal inductance. Therefore generation of high voltage rectangular pulses are not possible directly using a Marx generator. Marx with an additional circuit is used to generate the rectangular pulses.

Magnetic pulse compressors, marx modulators, Pulse Forming Network (PFN) and blumlein are some of the methods of generating high voltage rectangular pulses. PFN comprises of inductors and capacitors and form different combinations. First the required energy is stored for single pulse and then discharged into the load. There are four types of pulse forming networks Type-A, Type-B, Type-C and Type-E to generate rectangular pulses[4].

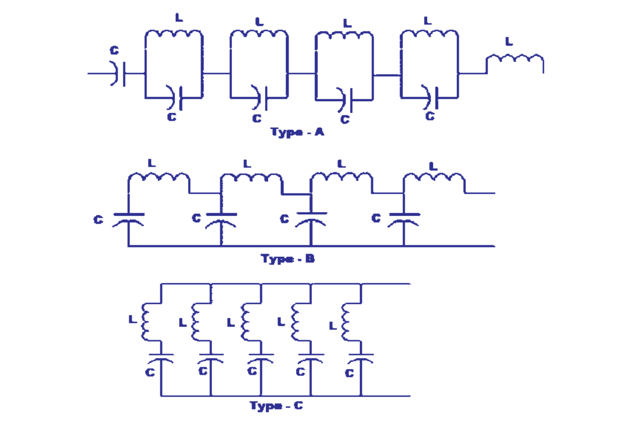

FIG. 1. PFN CONFIGURATIONS

Different PFN configurations are shown in Figure 1. Type-A is used in conjunction with Marx generators. Type-B is most commonly used because of its simple in construction and each inductor is wound on its own former. Here the

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mutual coupling is not taken into consideration. Type-C can be converted into other equivalent forms. Type-E is same as Type-B except that inductors are wound on one continuous form. Here the mutual coupling has to be taken into consideration. Type-E pulse forming networks are used in radar applications [5].

Some of the earlier researchers worked on type-b PFN are briefly presented. Ramnik *et al.* developed a 3-stage type-B PFN and experiments were conducted to study the effect of load resistance on rise and fall time [2]. Burkhart *et al.* discussed the PFN design and fourier components for a rectangular pulse [9]. S M Hassan *et al*. presented a new method to increase the output voltage of the PFN [10].Clementson *et al.* presented simulation models for type A, B and C PFN. To attain desired output current pulse, matlab programming is performed with different combination of capacitors [11].In the present work, attempts were made to design, analyse and fabricate a low voltage type-B pulse forming network for the generation of rectangular pulses. Effect of pulse forming network components on the output waveform are studied by simulation using PSPICE™. Generation of rectangularpulse is verified experimentally using prototype model.

2.0 DESIGN OF TYPE-B PFN

The PFN developed in the present work comprises of up ten stages, each stage with one capacitor and inductor. The capacitors are each of 10 nF, 3 kV rating and the inductors each of 1 μH. Generally the inductor closest to the load is made larger than the other inductors. This is done to prevent overshoot.

2.1 Design of Inductors

In the present work, inductor was made up of a conductor of diameter 2.5 mm wound on a circular wood. Here, inductance and the number of turns are arbitrarily chosen as 1 μH and 10 respectively. Therefore, the length of the former for 10 turns is 25mm. Inductance, L is given by the formulae [7]

$$L=\frac{\mu_o\mu_r \times N^2 \times A}{l} \qquad \ldots(1)$$

Where,

μ_o, absolute permeability of free space = 4π x 10^{-7} H/m

μ_r,relative permeability of air=1

N, number of turns=10

A, Area of circular former = $\frac{\pi d^2}{4}$

Length of wooden former, l =25 mm

Substituting the above values in equation (1), the estimated diameter of the wooden former is 16 mm. To reduce the overshoot, the last stage inductor is designed for 1.8 μH and the diameter of the former is 21.3 mm. The fabricated inductors are shown in Figure 2. The inductances of these inductors are measured using an LCR meter and all the measured values are in good agreement (less than 10%) with estimated values.

FIG. 2. STAGE INDUCTORS

2.2 Estimation of Type-B PFN parameters

Maximum energy is discharged into the load circuit when the load impedance is made equal to source impedance [1]. Also, there will not be any reflection of the wave. The characteristic impedance Z of the PFN circuit is given by

$$Z=\sqrt{\frac{L}{C}}=\sqrt{\frac{1\mu H}{10nF}} \qquad \ldots(2)$$

present work, the load impedance is made equal

is given by

$$\tau = 2 \times (n-1) \times \sqrt{LC} \quad \ldots(3)$$

With above L and C values and number of stages

µs.

3.0 SIMULATION OF PFN CIRCUIT

Simulation of Type-B PFN circuit is performed in PSPICE™ [12]. The equivalent circuit of PFN is shown in Figure 3.

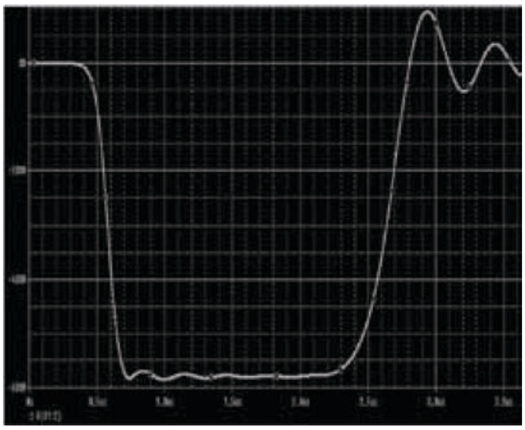

FIG. 3. PSPICE WAVEFORM OF TYPE-B PFN WITH ALL

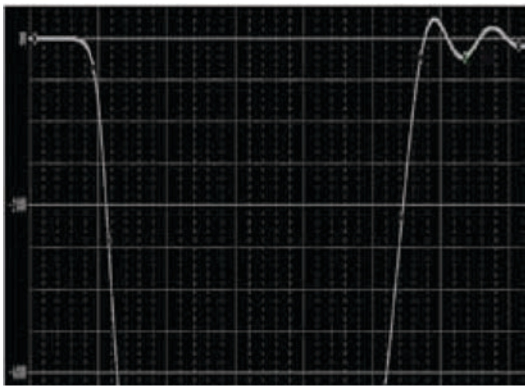

FIG. 4. PSPICE SIMULATION WAVEFORM OF TYPE-B PFN WITH L_1=0.5 & L_{10}

The simulation waveform with all stage inductors of 1 µH is shown in Figure 4. From Figure 4, it is observed that there is overshoot in the waveform and the waveform is not completely

and last stage inductor values [1, 4]. This is done by trial and error method by changing the values of L_1 and L_{10}. The best waveform was obtained with L_1 and L_{10} values as 0.5 µH and 1.8 µH. The simulated waveform for the above values is shown in Figure 5.

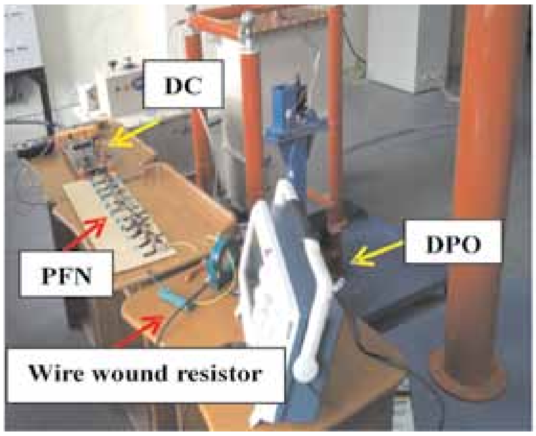

FIG. 5. EXPERIMENTAL SETUP WITH WIRE WOUND RESISTOR AS LOAD

The pulse width [1] of the waveform (between 90% points on front and tail portion) is 1.76 µs. The estimated value and the simulated value are in very close agreement and the difference is merely 2%.

4.0 PROTOTYPE MODEL OF TYPE-B PFN

A prototype model of Type-B PFN was developed to generate low voltage rectangular pulse of pulse width 1.8 µs. All the stage capacitors are of 10 nF, 3 kV rating. First stage inductor and last stage inductors are of 0.5 µH and 1.8 µH respectively. Remaining all stage inductors are of 1 µH. Maximum energy gets discharged into the load when the load impedance made equal to

Therefore, in the present work, load impedance is

wire wound resistor as load is shown in Figure 6.

The prototype model was tested for low voltage.

W is used as a load. The output wire was passed through a Pearson current monitor model no

101™. DPO3034™ is connected through a probe from Pearson coil. All the capacitors were charged

The discharge waveform is captured by the DSO and is shown in Figure 7.

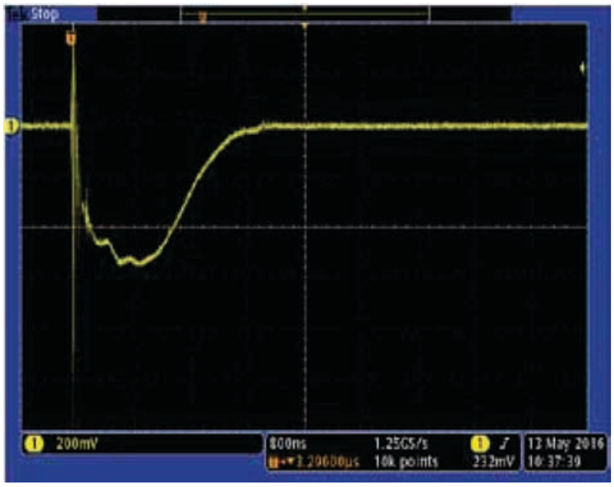

FIG. 6. EXPERIMENTAL OUTPUT WAVEFORM WITH

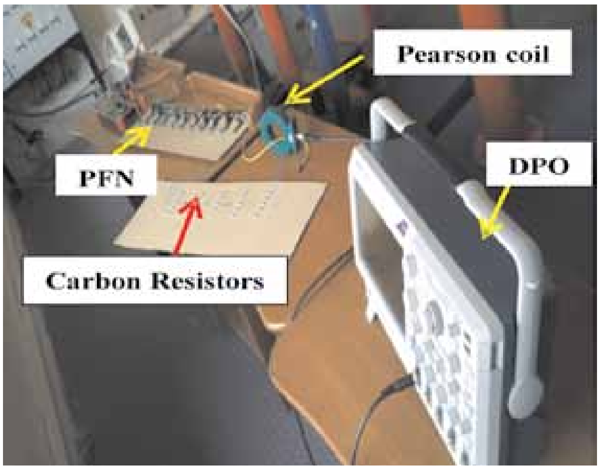

FIG. 7. EXPERIMENTAL SETUP WITH CARBON RESISTORS AS LOAD

From Figure 7, it is observed that there is damped distortion in the bottom portion of the output waveform. This is mainly due to wire wound resistor as a load. This resistor will have small inductance which has led to a distortion in the output waveform. Therefore, the Type-B PFN

The experimental set up with carbon resistors as load is shown in Figure 8 and the experimental

in Figure 9.

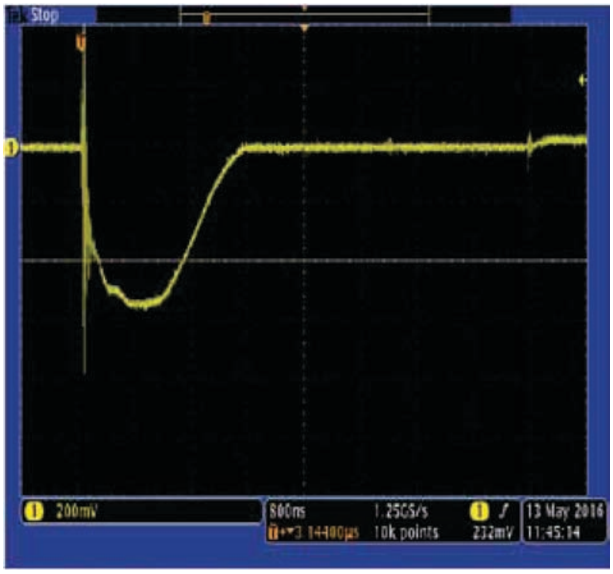

FIG. 8. EXPERIMENTAL OUTPUT WAVE FORM WITH

From Figure 9, the distortion in the bottom portion of the waveform is reduced compared to Figure 7. The pulse width of the above waveform is 1.6 µs. This is because of small differences in the inductance values of fabricated inductors and also due to stray inductance and stray capacitance. There is an 11% difference with the estimated value of pulse width which is acceptable.The Pearson current monitor model no 101™ is having sensitivity of 0.01 V/A. from Figure 9 the magnitude of the discharge waveform is 0.56 V (2.8 units x 200 mV). The discharge current is given by

$$I = \frac{0.56\ V}{\left(0.01\ V/A\right)} \qquad \text{...(4)}$$

From equation (4), the ouput current obtained is 56 A. Therefore, the voltage across the load is 560

load is 580V. The difference is around 3%. Hence this validates with the method of estimation.

5.0 CONCLUSIONS

In the present work, equivalent circuit of type-B PFN was developed in PSPCIE™. A prototype model of type-B PFN was designed and developed to generate rectangular pulses.

- Using the simulation circuit the output current, output voltage across the load and the pulse duration can be predetermined. This saves lot of time.
- To obtain better wave shape, the first stage inductor and last stage inductor has to be designed by 50% smaller and 80% higher inductance value compared to other stage inductors inductance value.
- Minimum five stages are required to produce desired rectangular pulse.
- The developed prototype model find its application in pulsed power by replacing the existing capacitors with higher rating capacitors.

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