A HIGH VOLTAGE PULSE-FORMING NETWORK FOR PLASMA APPLICATIONS

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Abstract

The design and construction of a pulse-forming network (PFN) to provide the input electron beam power for the LAP/INPE 32 GHz gyrotron are described in this report. The PFN was designed to produce a flat 50kV. 4 A pulse for 4µs at a repetition rate of 8-100Hz. This kind of pulse generator is also known as line-type pulser. in that its energy-storage device is a lumped-constant transmission line. It is verified that in our nine-section network. that is no longer possible to obtain satisfactory pulse shapes by using the same inductance per section.

Introduction

The recent technological development in the research of high power microwave sources has led to the construction of modern devices. called gyrotrons. which are capable of producing millimeter waves at operating frequencies higher than 100 GHz with a DC power level above 500kW. Such high values of frequency and power has greatly enlarged the area of applications of millimeter waves in many fields. such as plasma heating in fusion research. advanced communications systems. processing of materials and linear accelerators.

The Gyrotron Project at INPE Plasma Laboratory was devised with the main purpose of designing. constructing and operating a high power microwave radiation source. In order to aim this goal. it was necessary to employ and handle special technologies as. for instance. high-voltage switching and pulsed power techniques. In particular. for the gyrotron experiment a high-voltage pulse modulator was built at INPE in a circuit category known as hard-tube pulser to provide the input electron beam power. In this system. a large capacitor bank (2µF. 100kV) discharges through a high-voltage tetrode (TH5188) connected in series with the gyrotron. Although this equipment is still in operation. its circuit complexity has led to great difficulty in maintenance and servicing. To overcome such a drawback. the construction of another kind of modulator. called line-type pulser. was proposed since the gyrotron is operating at 10µs pulse length. In addition. the cost involved in building a line-type pulser is significantly lower than that for a hard-tube one. Therefore. the main goal of this work is to describe the design and the implementation of this new pulser as well as to show the preliminary experimental results obtained so far.

Pulser Design

The line type pulser is commonly known as a pulse-forming network (PFN). since it has a lumped-constant transmission line which serves not only as the source of electrical energy during the pulse occurrence but also as the pulse-shaping element. The PFN in this pulser consists basically of inductors and capacitors put in a specific configuration in order to provide a desired pulse shape. Fig. 1 shows the electrical diagram of the pulser circuit. In this scheme. the PFN capacitors are charged from a DC power supply (5.7kV / 30mA) through a resistance of 3.3kΩ. The charging operation is completed when the equilibrium voltage on the network is nearly equal to the power supply voltage. The energy stored in the capacitance elements is discharged into the load upon closing a fast switch tube (thyratron 5C22). The requirement on the series-resistance isolating element in this charging circuit is simply that it must be large enough to allow negligibly small current to be taken from the power supply during the pulse and the deionizing time for the switch. but. not so large that charging RC time constant becomes comparable to the interpulse interval.

For the analysis of the pulse conformation. the PFN can be considered as a discrete lossless transmission line. Using this model. the PFN characteristic impedance Z_0 can be determined as $Z_0 = \sqrt{L.C}$. where L and C are. respectively. the inductance and capacitance values of each cell. Under load mismatching conditions. a series of steps is introduced in the output current pulse. as shown in Fig.2 These steps have the same sign when $RL > Z_0$ and alternate sign when $RL < Z_0$. The effect can be explained in terms of reflections caused at the terminal of the line. These reflections propagate along to the input terminal in a transmission time $\delta = N.\sqrt{L.C}$. where $\sqrt{L.C}$ stands for the delay time per section and N is the number of the sections or LC cells. Then. they are completely reflected there and travel back to the load terminal in a total time 2δ. where they appear.as positive or negative steps depending upon the mismatch ratio. The reflections proceed in this way. with constantly decreasing amplitude. until the energy initially stored in the line is dissipated in the load resistor. As shown in Fig. 2. when the line is matched to the load (Z_0= RL) the output current consists of a single rectangular pulse of amplitude $I_L = V_0/2.Z_o$ with duration of 2δ [1]. where V_o denotes the PFN charging voltage.

On using the Pspice code [2] . the computed voltage pulse on an optimum load of 112Ω for maximum power transfer is presented in Fig.3(a). A high initial voltage. followed by a series of damped oscillations. is clearly in evidence as well as a backswing voltage on the trailing edge of the pulse. This indicates that a nine-section uniform-line network is a poor equivalent for a transmission line and a larger number of sections would give better line-simulation. Considerable improvement in the pulse shape con be attained by departure from the theoretical value of the inductances. Fig.3(b) shows the improvement over Fig.3(a) resulting when a compensating inductor of 25μH disconnected in series to the inductance of the first section of the line.

SIMULATION AND TEST RESULTS

Experiments have been performed on the PFN of Fig.1 using a 5.7kV DC power supply connected via a 3.3kΩ resistor to a 5C22 hydrogen thyratron. The tube is coupled to a low-power trigger generator which produces 200V pulses. at an adjustable recurrence frequency from 8 to 100Hz. to drive the thyratron. A typical variation of tube drop with time is shown in Fig.(4). The sharp transition of the curve represents the ionization period. which for the 5C22 tube is 0.07μs at nominal operating pressures.

After the gas is fully ionized. the voltage drop during the conduction period remains relatively constant. Ionization time and the shape of the voltage-time curve are almost independent of the external circuit. that is. they are a function of the tube characteristics only. In Fig.5. for a 100Ω load. we plot the observed voltage pulse produced by the pfn with a 30μH compensating inductance. The PFN inductors are wound with 85 turns of the n° 14 wire on a 25-mm-diameter PVC pipe. It may be noted in fig.5. that by the presence of the compensating inductor. the pulse shape does not exhibit any initial spike. The top of the pulse is relatively flat and a comparison of this pulse with the pulse produced by a lossless transmission line. as show in Fig.3(b). reveals a close similarity.

CONCLUSIONS

A nine-section PFN using a resistance as the charging element has been designed and tested. Such an arrangement has inherent efficiency of never greater than 50 percent. in that the output pulse voltage is at most half of the charging voltage. In the next step of the PFN development. we will use an inductance as the charging element to increase the charging efficiency and to obtain better isolation between the power supply and the switch. Also. a pulse transformer will be included to raise the pulse voltage to 50kV in addition to transfer the energy from the line to the proper impedance level of the gyrotron.

REFERENCES

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[2] Paul W. Tuinenga. _A Guide to Circuit Simulation and Analysis Using Pspice_. Prentice Hall. New Jersey. 1988.

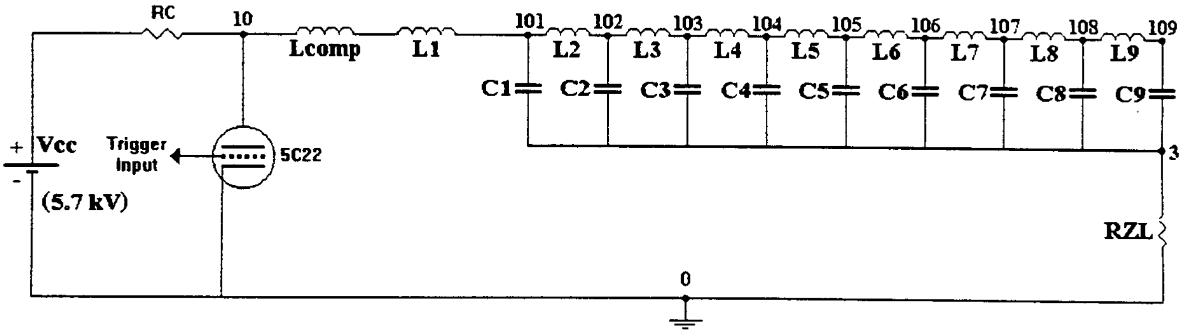

Fig.1 - Electrical scheme of the pulser circuit.

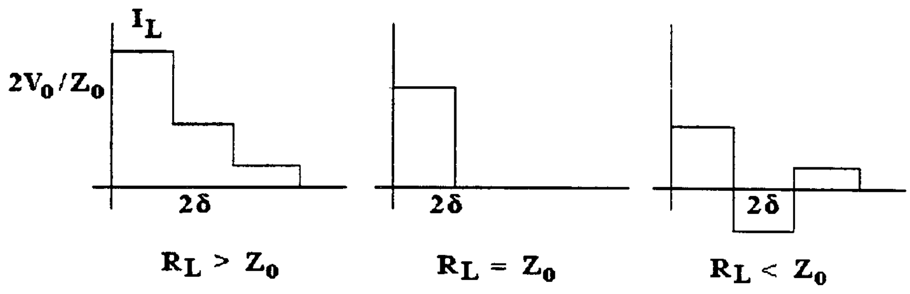

Fig.2 - Output current for a lossless transmission-line discharging into a resistance load.

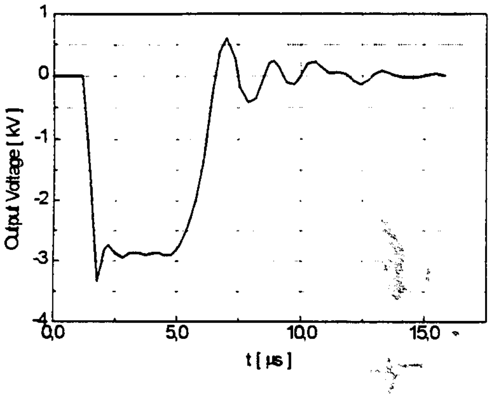

Fig.3 (a) - Output voltage without compensation inductor

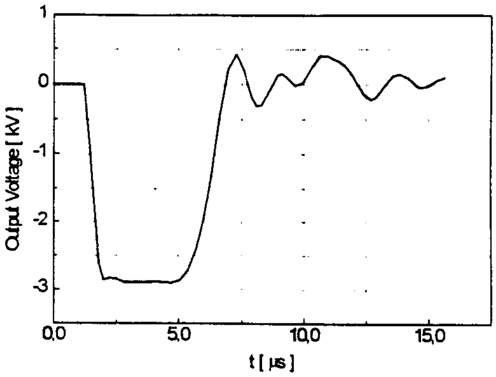

Fig.3 (b) - Output voltage with compensation inductor

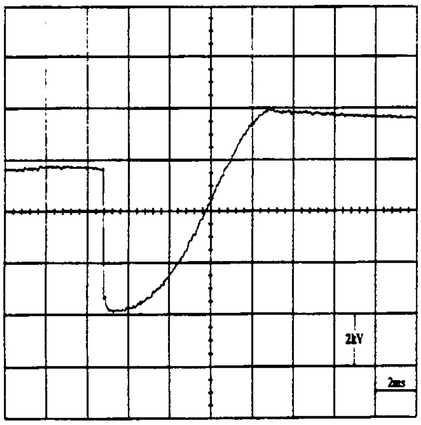

Fig.4 - Thyratron anode voltage.

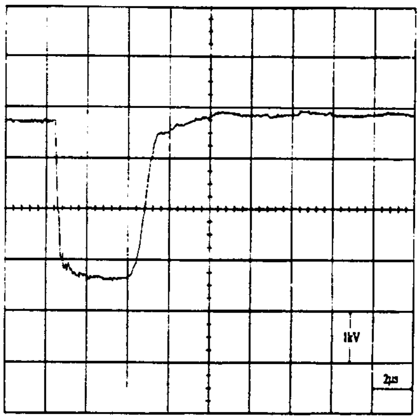

Fig.5 - Observed voltage pulse on a 100Ω load.