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A HIGH-VALTAGE EQUIPMENT
(High Voltage Supply, High-Voltage Pulse Generators, Resonant Charging Inductance, Synchro-instruments for Gyrotron Frequency Measurements)
FOR PLASMA APPLICATIONS

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1.Introduction

The Gyrotron Project at INPE Plasma Laboratory (fig.1) 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 sistem, a large capacitor bank (2,0 u F,100 kV) 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,caled line-type pulser, was proposed since the gyrotron is operating at 10 us pulse length.In addition,the cost involved in building a line -type pulser is significantly lower than for a hard-tube one.

The Plasma Immersion Ion Implantation (PIII) was developed during the late 80's for the surface treatment of nonplanar components in contrast with the traditional method of implantation using ion accelerators.There are two basic limitations of the ion implantation: technique based on accelerators;line-of-sight and high cost of equipment and processing.PIII technique overcomes these limitations by extracting directly the ions of interest from a plasma where the samples to be irradiated are immersed.The application of negative high voltage pulses between the plasma and the sample and the subsequent sheath expansion in the presence of the high voltage allows a three dimensional implantation of the samples.Preliminary result of INPE PIII research showed successful N implantation in an Al sample, but indicated the necessarity of better plasma optimisation and confirmed a need of a higher pulse recurrence frequency and negative high voltage pulse generator (fig.2).

Both needs of high voltage pulse generator (tuneable voltage from 0 to 50 kV,pulse duration several microseconds),a higher repetition frequency were the motivation of the design and its construction.The main goal of my work at INPE Plasma Laboratory was to design ,construct and test a suitable high-voltage pulse generator for Plasma Applications and my efforts were concentrated on several important objectives:

Design of high-voltage resonant power supply with tunable output (0 - 50 kV) for line-type high -voltage pulse generator.

Design of line-type pulse generator (pulse duration 4 microseconds, tunable voltage 0 - 25 kV) for nonlinear loads such as a gyrotron and PIII reactor.

Design of resonant charging inductance for resonant line-type pulse generator.

Design of high resolution synchro instrument for gyrotron frequency measurement

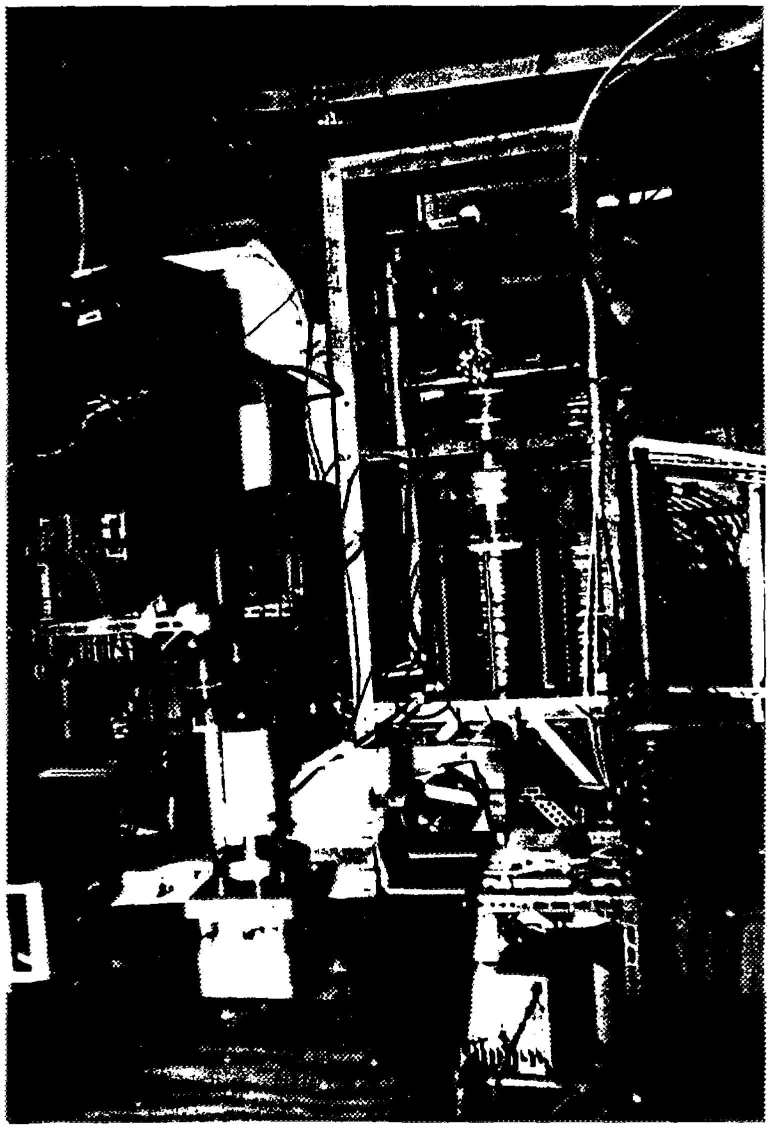


fig.1 A general view of INPE 32GHz,100kW Gyrotron

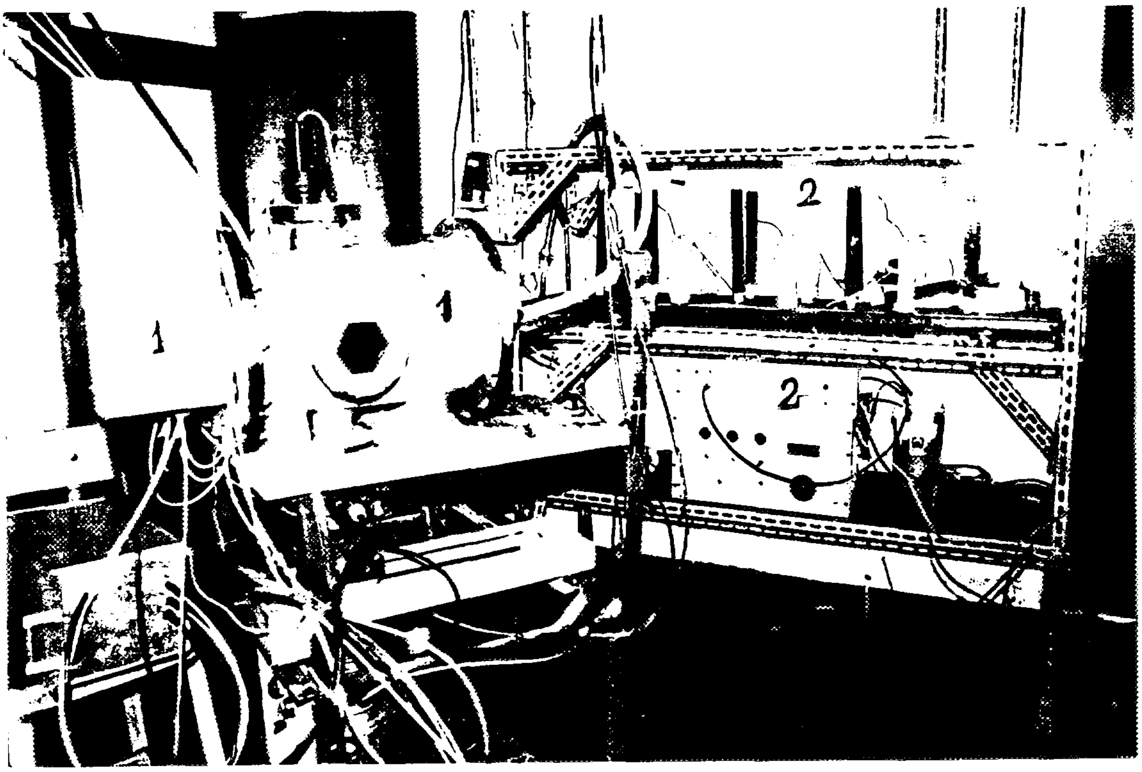


fig.2 A view of INPE PIII experimental setup

(1) PIII-reactor with microwave plasma generator

(2) High-voltage line-type pulse generator

2.Fundamental Parameters of Pulse Generators

There are certain parameters of pulse generators that are common to all types and that affect design.The most important of these parameters are pulse duration, pulse power, average power, pulse recurrence frequency, duty ratio,and impedance level.It is worth introducing the parameters by defining some terms and indicating the ranges which have been common in the plasma application field.

The term "pulse duration" is the time during which voltage or current maintains a value different from zero or some other initial and final value.The term "pulse shape" is used to refer to the form obtained when the pulse amplitude is plotted as a function of time.If a pulse of voltage or current is truly rectangular in shape, that is, has a negligible time of rise and fall and is of constant amplitude for the interventing time interval, the pulse duration is simply the time elapsed between the deviation from and the return to the initial value.The term "negligible time" is, of course, relative and no strict boundaries can be attached.For most practical purposes, however, if the rise and fall times for a pulse are about a tenth or less of the pulse duration,the pulse is considered substantially rectangular.

In the Plasma application field the voltage required across the experimental setup ranges from as low as 1 kV to as high as 100 kV.

If a voltage pulse is applied to some type of dissipative load,a gyrorton or PIII reactor for example, there will be a corresponding pulse of current which depends on the nature of this load.The pulse current through the experimental setup ranges from a few ampers to several hundred ampers.The combined consideration of short pulse duration and rectangularity therefore requires that careful attention be given to the behavior of the pulser circuit and its components under condition of high rates of change of voltage and current.The rate of change of voltage may be as high as several hundred kilovolts per microsecond, and the current may built up at the rate of hundreds to thousands of amperes per microseconds.

The product of the pulse voltage and the pulse current is the pulse power.When the voltage and current are rectangular, the corresponding pulse power is unambiguous.When the pulses are irregularly shaped, however, the meaning of the term "pulse power" is not clear because somewhat arbitrary methods are often used to average the product of voltage and current during the pulse.The peak power of pulse is the maximum value of the product of the voltage and current.Thus, for rectangular pulses the peak power and the pulse power are the same, but for irregular shaped pulses the peak power is greater than the pulse power.

In this connection ,there are two general types of load,the linear load, such as a pure resistance, and the nonlinear load, such as the gyrotron or PIII reactor.The latter two loads can be approximatelly represented as a biased diode with a dynamic resistance that is low and static resistance that is about ten times higher.Static resistance is the ratio of the voltage across the load to the current through the load, whereas the dynamic resistance is the ratio of a small change in voltage to the corresponding change in current.When the dynamic resistance of the load is small,the magnitude of the pulse current varies greatly with only small variations of the pulse voltage, and for loads such a gyrotron or PIII reactor, for example, the behavior of the pulse generator with a linear load is not necessarily a good criterion.

Since the pulse power output of pulse generators for gyrotron or PIII applications has ranged from as low as 100 W to as high as 100 MW , the average power output as well is important to the design.The average power corresponding to a particular pulse power depends on the ratio on the aggregate pulse duration in a given interval to the total time and this in turn depends on the pulse recurrence frequency (PRF), which is the number of pulses per second (pps).If the pulse duration is τ and the time between the beginning of one pulse and the beginning of the next pulse is Tr, then

$$Pav = (\tau / Tr).Ppulse = \tau (PRF).Ppulse$$

A similar equation can be written in terms of the current if the pulse voltage is essentially constant during the time corresponding to the current pulse, thus

$$I\ av = (\tau / Tr).Ipulse = \tau (PRF).Ppulse$$

The ratio τ / Tr or the product τ (PRF) is commonly called the pulser "duty", "duty ratio"and is expressed as a fraction or a percentage.For example 1 microsecond pulses repeated at the rate of 1000 pps correspond to a duty ratio of 0.001 or 0.1 per cent.Pulse generator for gyrotron or PIII applications have been constructed with a duty ratio of0.002.

As with any power device, the overall efficiency of a pulser is an important consideration in its design. This is particularly true when the average power output is high, that is, a combination of high pulse power and high duti ratio.

This point is stressed in the discussion and is frequently a desihng factor in choosing one type of pulse generator in preferance to another.

The choice of the internal impedance of the pulse generator depends on the load impedance,the pulse power level and practical considerations of circuit elements.Impedance matching between generator and load is of prime importance in some cases, especially with regard to the proper utilisation of the available energy and the production of a particular pulse shape.Impedanse matching is not always convenient with the load connected directly to the pulser output, however, matching can readily be attained by the use of pulse transformer.By this means ,it is possible to obtain impedance transformation between pulse generator and load as high as 150/1, that is, transformer with a turn ratio of about 12/1.The gyrotrons and PIII reactors have static impedances ranging from about 400 ohms to about several thousands ohms, in general, the higher the power of the load, the lower its imput impedance.The impedance transformation characteristic of the pulse transformer also provides a means of physic separating the pulse generator and the load.Thus the power may be transmitted from the pulse generator to the load through low impedance coaxial cable,provided that the pulse transformers are used to match impedances.The pulse transformer has another function that is important to pulser design, namely , it provides a means for reversing the polarity of a pulse.This feature of the pulse transformer together with the impedance-transformation property considerably extends the range of usefulness for pulse generators of any type.

2.1 The Basic Circuits of a Pulse Generators

The pulse generators depend on the storage of electrical energy either in a electrostatic field or in an magnetic field, and the subsequent discharge of a fraction or all of this stored energy into the load.The two basic categories into which the largest number of pulser designs logically fall are those in which only a small fraction of the stored electrical energy is discharged into the load during the pulse,and those in which all of the stored energy is discharged during each pulse.These two basic categories of pulse generators are generally referred to as "hard-tube pulsers"and "line type pulsers".

To accomplish this discharge, it is necesary to provide suitable switch that can be closed for a length of time corresponding to the pulse duration and maintained open during the time required to build up the stored energy again before the next succeeding pulse.In its simplest form, therefore, the discharging circuit of a pulse generator can be represented schematically as shown in fig. 3.The characteristics required for the switch will be different depending on whether or not all stored energy is discharged into the load during the single pulse.Some pulse shaping will be necessary in the discharging circuit when all energy is to be dissipated.

2.2 Hard-tube Pulse generators

The energy storage device for these pulse generators is simply a condenser that is charged to some voltage V, thus making available an amount of electrical energy $0.5CV^2$ .The term "hard tube"refers to the nature of the switch, which is most commonly a high-vacuum tube containing a control grid.The closing and opening of this switch are therefore accomplished by applying properly controlled voltages to the grid.Since only a small fraction of the energy stored in the condenser is discharged during the pulse, the voltage across the switch immediately after the pulse and during the charging interval is nearly the same as it is at the beginning of the pulse.It is therefore necessary that the grig of the vacuum tube switch have complete control over the conduction through the tube.

The combination of the discharging and charging circuits of the "hard tube"pulse generator is shown in fig.4. In order to avoid short-circuiting the power supply during the pulse interval,some form of isolating element must be provided in series with power supply.This element may be a high resistance or inductance,and the particular choice depends on the requirements of overall pulser design.

The primary consideration is to keep the power supply current as small as possible during the pulse interval.However, the impedance of this isolating element should not be so high that the voltage on the condenser at the end of the interpulse interval differs appreciably from the power supply voltage.

2.3 "Line -type"pulse generators

Pulse generators in this category are refered to as "line-type"pulsers because the energy srorage device is essentially a lumped-constant transmission line.Since this component of the line type pulse generators serves not only as the source of electrical energy during the pulse but also as the pulse-shaping element, it has become commonly known as a "pulse-forming network",PFN.There are essentially two classes of PFN, namely, those in which the energy for the pulse is stored in an electostatic field in amount $0.5CV^2$, referred to as voltage-fed networks, and those in which energy is in a magnetic field in the amount $0.5LI^2$ are refered to as current -fed network .Networks of the voltage-fed network type are used almost universal in practice because only with this type can gaseous-discharge switches, such as spark gaps and thyratrons be used.The current -fed networks have certain important advantages, but thus far no suitable switch is available that permit high-power operation.The most useful circuit of voltage-fed network is given in fig. 5 , and basic circuit for generating pulses of rectangular shape is in fig. 6 .

For the current in the last circuit we obtain

$$i(t) = \frac{Vo}{Zo + R_l}\{1 - U(t-2\delta) - \frac{Z_o - R_l}{Z_o + R_l}[U(t-2\delta) - U(t-4\delta)] + \left(\frac{Z_o - R_l}{Z_o + R_l}\right)^2 [U(t-4\delta) - U(t-6\delta)] + ...\}$$

where R_l - is the load impedance

$\delta = N \sqrt{LC}$; $\sqrt{LC}$ delay time per section,N -number of section LC cels

$U(\Delta t) = 1$ for $\Delta t > 0$

$U(\Delta t) = 0$ for $\Delta t < 0$ $n = 2,4,6,.......$

$Zo = \sqrt{L/C}$ -output impedance of PFN

If Rl = Zo, that is , if the PFN is matched to the load, the current consist of single rectangular pulse of amplitude Io = Vo/2Zo and duration $\sigma = 2\delta$. Voltage pulses for Rl = Zo; Rl = 2Zo and Rl = 0,5 Zo are shown in fig. 7.

The voltage appearing across a load that matches the impedance of a non dissipative voltage-fed network is equal to one half of the voltage to which the network is charged just before closing the switch.

The effect of mismatching the load is to introduce a series of steps into the transient discharge.The step are all of the same sign when Rl > Zo, and alternate in sign when Rl < Zo.

The PFN in a line -type pulse generators consists of inductances and condensers which may be put together in any one of the number of possible configurations.The configuration chosen for the particular purpose at hand depends on the ease with which the network can be fabricated, as well as on the specific pulser characteristic desired.The values of the inductance and capacitence elements in such a network can be calculated to give an arbitrary pylse shape when the configuration, pulse duration, impedance and load characteristics are specified.

The discharging circuit of a line -type pulser using a voltage-fed network may represented schematically as shown in fig. 5 .If the energy has been stored in the network by obtaining the capacitance elements, closing the switch will allow the discharge of this energy into the load.

When the load impedance is equal to the characteristic impedance of the network, assuming the switch to have negligible resistance, all of the energy stored in the network is completely discharged. The time required for this energy transfer determinates the pulse duration and depends on the values of the capacitances and inductances of the network.

The consideration of impedance-matching is of extreme importance in designing a line -type pulser because it affects the utilization of the energy stored on the network, as well as ultimate shape of the voltage and current pulses at the load. For these reasons, the nature of tne load must be known before procceding to the desigh of the pulse generator.If the load is nonlinear, as in the case of gyrotron or PIII vessel, it very often happens that the load characteristics can be taken into account only approximately, and the ultimate design of the network may have to depend on experimental tests with subsequent modification to obtain the desired pulse shape.When the network impedance is different from the load impedance, the matched condition is attained by the use of a pulse transformer (fig. 8) .

The pulse transformer therefore becomes an essential part of the discharging circuit in a low impedance pulse generator used with high-impedance load,and such characteristics have an effect on the pulse shape and the over-all behavior of the discharging circuit . It is desirable and often necessary that the design of the pulse transformer and the design of the PFN be coordinated in order to obtain the most satisfactory pulser operation.

Since the impedance transformer ratio for a transformer is equal to the square of the voltage-transformation ratio , the use of a low impedance pulse generator with a load of hifher impedance requires the use of a pulse transformer that gives a voltage stepup between pulse generator output and load input. Thus, when a line -type pylse generator with 100 ohm voltage-fed network is used to pulse on 1600 ohm load, for example, the voltage stepup ratio is about 4/1, and the current in the discharging circuit of the pulser becomes about four times the load current.

According by the switch in the discharging circuit of a line-type pulse generator is required to pass very high pulse power into the load.

When a pulse generator uses a voltage -fed network, the voltage across the switch falls to zero at the end of pulse because the stored energy is completely discharged.This consideration, in conjunction with the high-current carrying capacity and low resistance required of the switch suggests the use of a form of gaseous-discharge device, which must remain nonconducting during the unterpulse interval if it is desired to apply a sucession of pulses to the load.

A grid controlled gaseous-discharge tube such as the thyratron is particularly well suited to this application since it is a possible to start the discharge in a tube of this type at any desired time, within a very small fraction of a microsecond, by the application of proper voltage to the grid.

Several different methods are used to charge a voltage-fed network in a line-type pulse generator . Since the general aspects of these methods are not appreciably affected by the discharging circuit, the requirements imposed on pulser design by the charging circuit can be considered separately. If the time allowed for the charging of the network is sufficiently long compared with the pulse duration,the charging cycle is simply that corresponding to the accumulation of the charge on a condenser. Fig . 5 indicates schematically the relation between the charging and discharging circuits of a pulser generator with voltage -fed network . For example, the network may be recharged from a DC power supply through a high resistance, in which case the equilibrium voltage on the network can be nearly equal to the power supply voltage. The requirement on the series resistance isolating element in this charging circuit is simply that it must be large enough to allow only negligible current to be taken from the power supply during the pulse and deionizing time for the switch, but not so large that RC time constant becomes comparable to the interpulse interval . To get the highest network voltage from a given power supply with this arrangement, the length of the interpulse interval should be several times greater than the RC time constant in the charging circuit . The method of charging the network is inherently inefficient - its maximum possible efficiency is only 50 per cent.

Since the efficiency of the network-charging circuit with a resistance as the isolating element is very low, the use of a nondissipative element, such as an inductance, suggests itself (fig. 9). When a capacitance is charged through an inductance from a constant potential source the voltage across the capacitance is in the form of a damped oscillation the first maximum of which is approximately equal twice the supply voltage if the initial voltage across the capacitance and the current through the inductance are zero.The maximum occurs at a time equal to $\pi\sqrt{LC}$ after the voltage source is connected to the inductance-capacitance combination.The inductance to be used with a given network is , therefore, calculated by setting the interpulse interval equal to $\pi\sqrt{LC}$, where C is the sum of all capacitances in PFN.This tipe of network charging is called "resonant charging" . If the pulse recurrence frequency is les than $1 / \pi\sqrt{LC}$, some current will still be flowing in the inductance at the beginning of each charging period and,under equilibrium conditions, this initial current will be the some for all charging cycles . The network will again be charged to approximatelly twice the power supply voltage.This type of network charging is called "linear charging".

With careful design of the inductance,the efficiency of the charging circuit is as high as 90 to 95 per cent, and the power supply needs to be sligthly greater than one half of the desired network voltage, resulting in a great advantage over resistance charging.A factor of 1.9 to 1.95 between network and supply voltage can be obtained if the charging inductance is designed so that the quality factor Q of the charging circuit is high.

2.3 A Comparison of a Hard -Tube and Line -type Pulse generators.

The comparisions made here concern such things as :
power output and efficiency, pulse shape,impedance matching, high voltage versus low voltage power supply, circuit complexity

CHARACTERISTICS	HARD-TUBE PULSER	LINE-TYPE PULSER
Efficiency	Lower	High, particularly when the pulse-power output is high
Pulse shape	Better rectangular pulses	Poorer rectangular pulses, particularly through pulse transformer
Impedance matching	Wide range of mismatch permissible	Smaller range of mismatch permissible (20 -30 %) pulse transformer will match any load, but power input to nonlinear load cannot be varied over a wide range
Voltage supply	HV supply usually necessary	Low voltage supply, particularly with charching inductance
Circuit complexity	Greater,leading to greater difficulty in servicing	Less permitting smaller size and weight

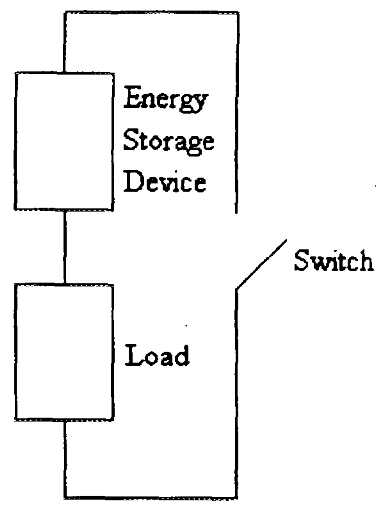


Fig.3 - Basic discharging circuit of a pulse generator

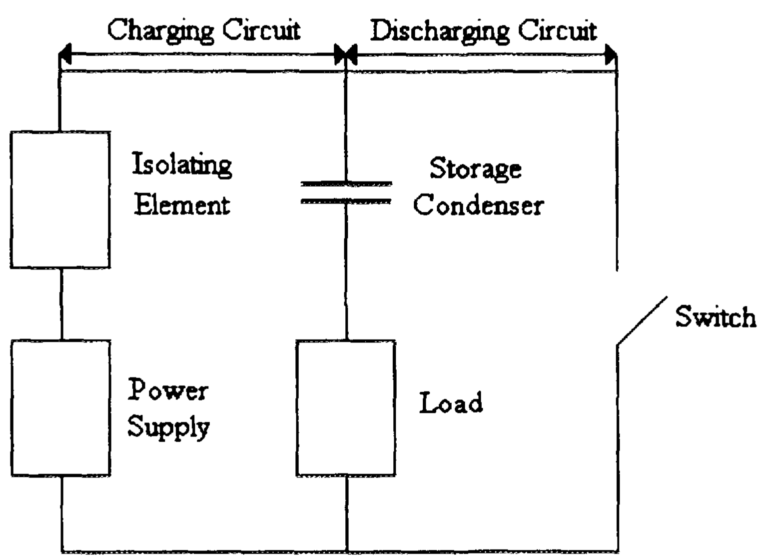


Fig.4 - Charging circuit for a hard-tube pulse generator

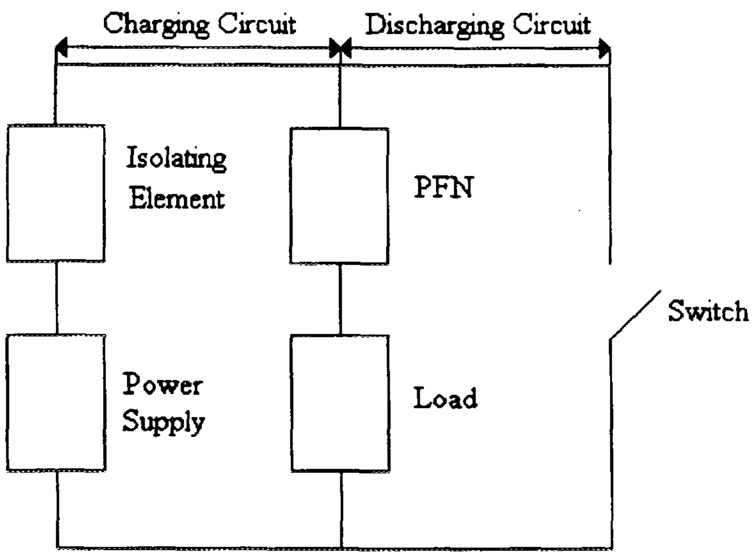


Fig.5 - Charging and discharging circuit for a voltage-fed network

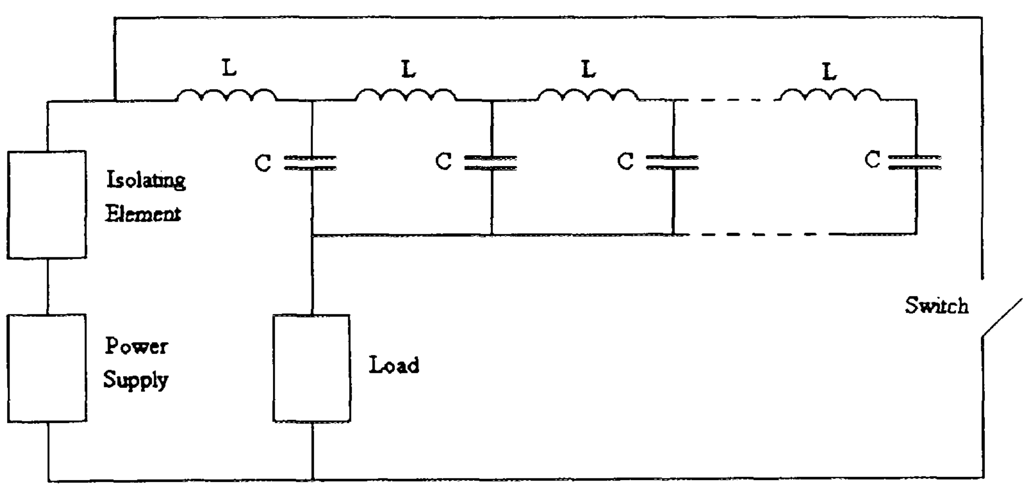


Fig. 6 - Charging and discharging circuit for a line-type pulser

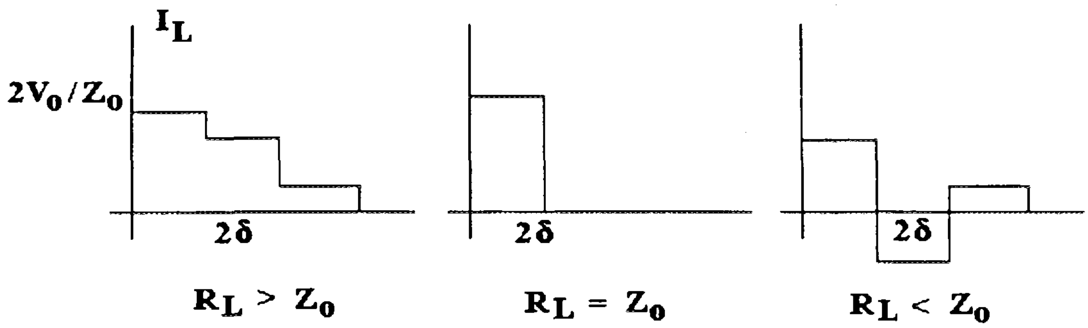


Fig.7- Current pulses for a lossles discharging into a resistance load

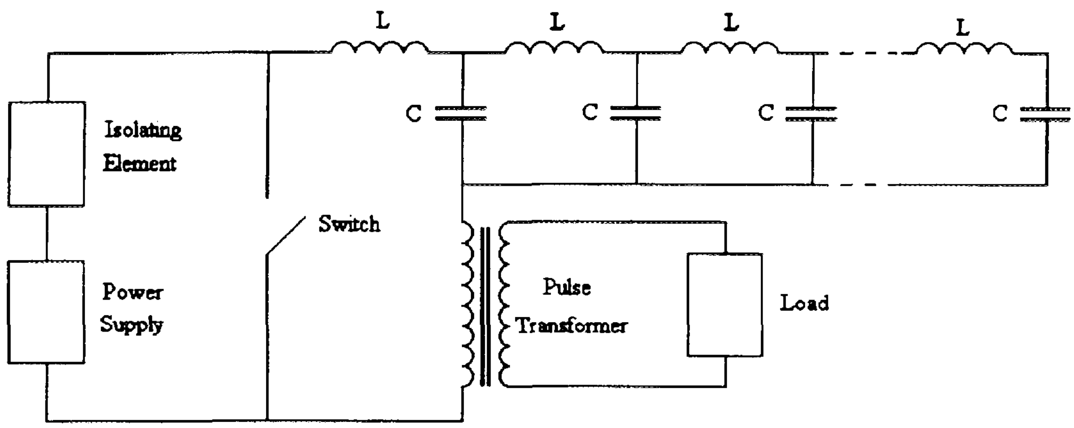


Fig.8 - Circuit of line-type pulse generator with matching pulse transformer between load and output of pulser

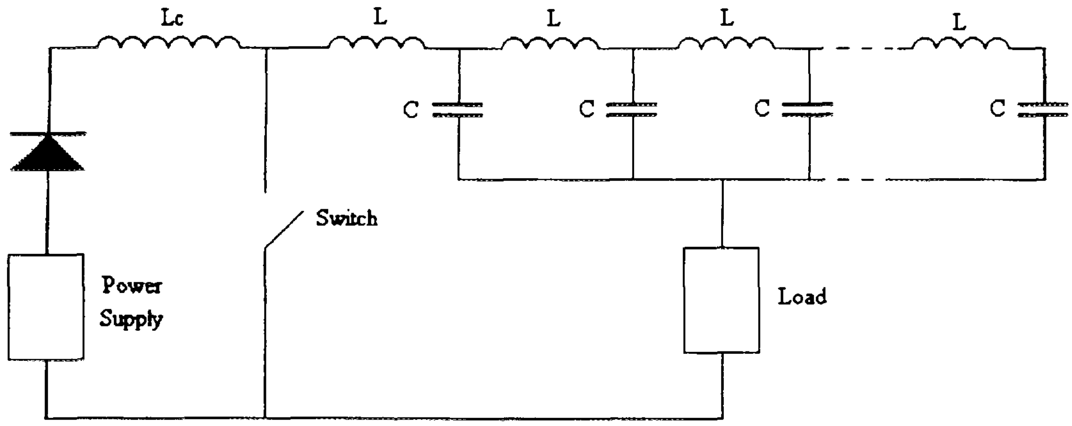


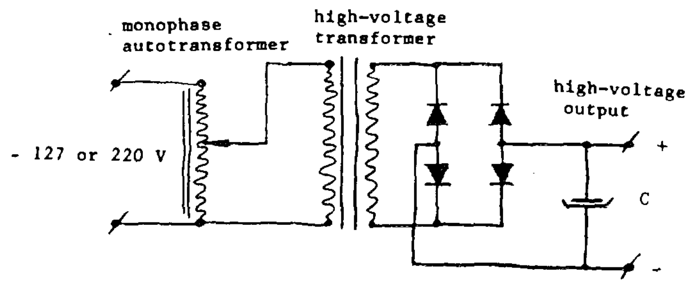
Fig.9 - Circuit of line-type pulser with ressonant charging inductance

2.4 High-voltage power supply

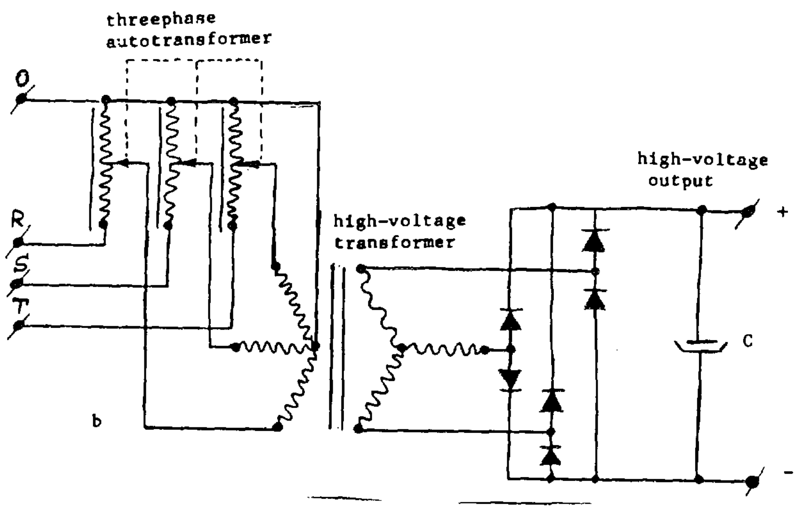
An important part of high-voltage pulse generators is the power supply.The simplest construction of high-voltage power supply for plasma applications consists of a transformer with a voltage ratio that depends of the needs. In addition of the output current the transformer may arranged one or three fases of the power low-voltage network. It is possible to tune the output voltage from 0 to a maximal value by use of autotransformer in the low-voltage circuit of the power supply.The high-voltage diodes are used for rectifiering of the secondary voltage from the transformers.A general view of *these circuits are shown in fig.10.*

Another posibility of realisation of high -voltage supply is by means of an encrease of the voltage with diodes and capacitores .This circuit is shown in fig.11.

The recent technological development in the research of high-voltage power supply has led to the construction of modern devices, called resonant voltage supplies. In the next section we describe a design of this kind of instrument.



a



b

fig.10 Circuits of monophase (a) and threephase (b) high-voltage tunable power supply

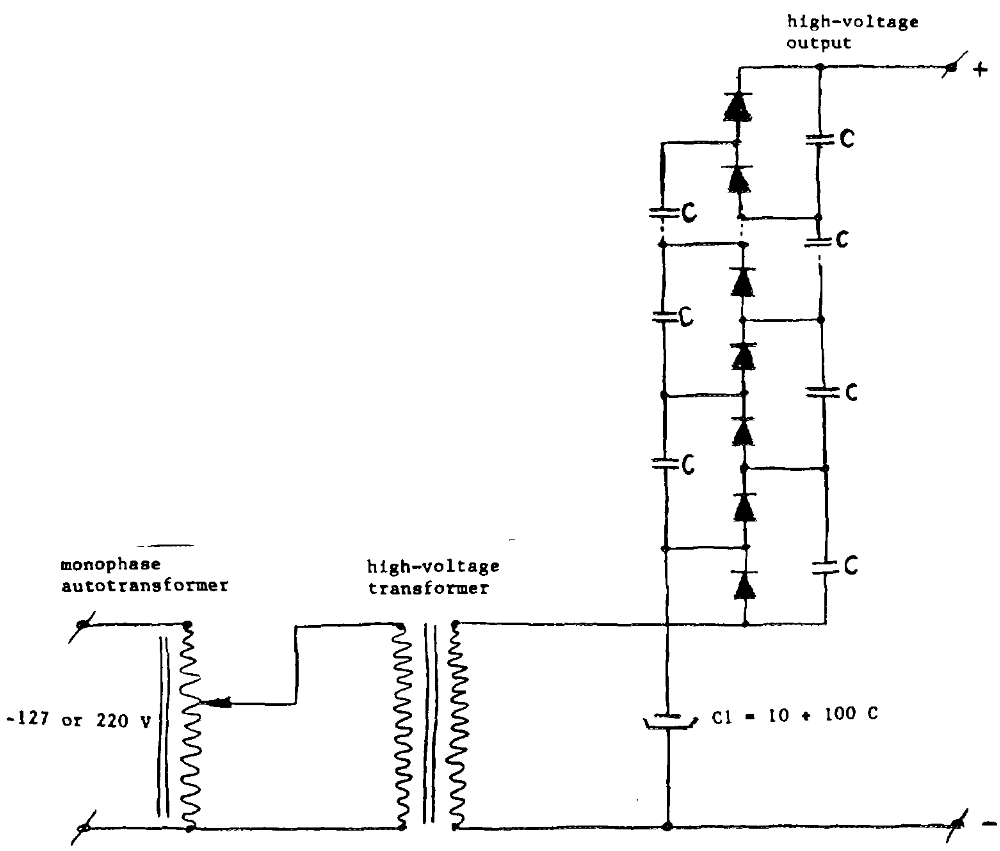


fig.11 Circuit of high-voltage power supply with augmentation on the voltage

3.High Voltage Resonant Power Supply for Scientific Experiments in Plasma Physics

It is necessary to use in the experimental work in plasma physics laboratory a suitable and portable high voltage supply, which is a highly efficient, easy for operating and maintenanceable.The present design of high voltage supply corresponds to these requirements and have the following features:

Tunable high voltage output 0 - 50 kV

Lack of heavy HV conventional transformers and another parts

Efficiency of voltage transformation - more than 90 %

Low output resistance.Practically this supply is a current source and it is an ideal device for capacitor charging.

Maximal output current, depending on output high voltage:

High voltage (kV)	Maximal current (mA)
7	178
10	125
15	83
20	62
30	42
40	25
50	25

Consumption power - 1250W

3.1 Operation Principle

The high voltage power supply works on the electric resonance in series circuit with inductance L1, capacitor C13 and high voltage transformer Tr3.The resonance frequency of the circuit is given by

$$\nu_o = \frac{1}{2\pi\sqrt{L_1 C_{13}}}$$

where L1 is in henrys, C13 in farads and ν_o -in Hz
The input inductance of the high voltage transformer is negligibly small and it does not change the conditions of resonance in this circuit usualy the resonance frequency is in the range between 10 and 100 kHz,depending on the choice of ferrits for high voltage (Tr3) and driver (Tr1, Tr2) transformers.

There is a possibility to flow AC through resonant circuit by alternatively turn on and off of the fast transistor switch groups (T3, T6) and (T4, T5). When the frequency of switching is equal to the resonance frequency , there is a current resonance in the circuit.

The voltage in the input of the high voltage transformer Tr3 has maximal value, and that is corresponding of the maximal output voltage of the same transformer. The input voltage of the transformer Tr3 in the resonance is much more greater then the DC voltage from the power supply of the circuit L1,C13,Tr3 and depends on the quality factor of the same circuit.The output high voltage from Tr3 is rectified by high voltage diode group (D7 - D10) and charged the capacitor C14.

The high voltage power supply consists of:

a generator of equidistant rectangular pulses, based on the timer 555, which repetition frequency is given by

$$f = \frac{1.44}{\left[R_A + 2\left(R_{B1} + R_{B2}\right)\right]C}$$

It is possible to tune the frequency of the generator by the potentiometer R_{B1} (fine) and R_{B2} (coarse).

two independent, but alternatively changing in the time, pulse sources, based on the integrated circuit 75450 the driver transistors T1 ,T2 and pulse transformers Tr1,Tr2 direct the transistor switches (T3,T6) and (T4,T5) respectively (fig. 12)

a resonance circuit L1C13Tr3, which is between the transistor switches (T3,T6) and (T4,T5).The diodes D3 - D6 are for switch prevention (fig. 13) .

a comparator, based on the integrated circuit 311,for tuning of the output high voltage from 0 to 50 kV respectively by the potentiometer R6.

a power supply of the whole instrument with three independent voltages:150 V,15V and 5 V (fig. 14).

The high voltage transformer Tr3,diode rectifiers D7 - D10, voltage divider R26, R27 and charging capacitor C14 are assembled in additional block , immersed in transformer oil.

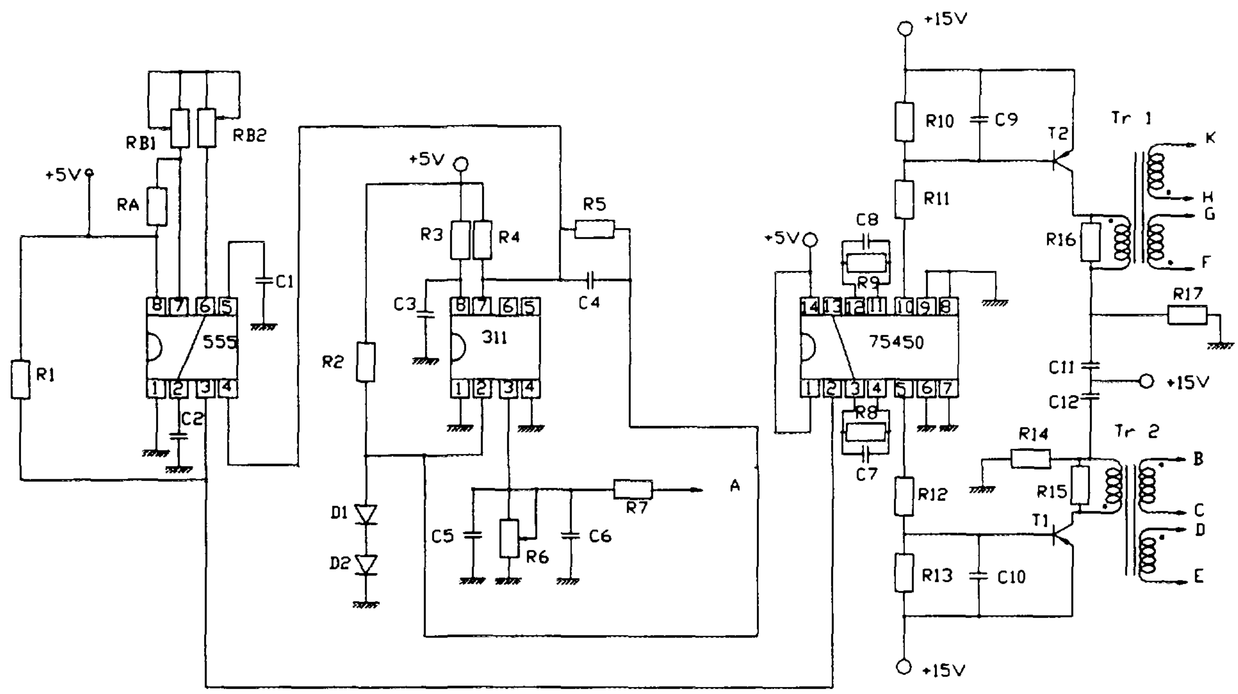


Fig. 12: Circuit for direction of speed transistor switches and tunable regulation of output high voltage

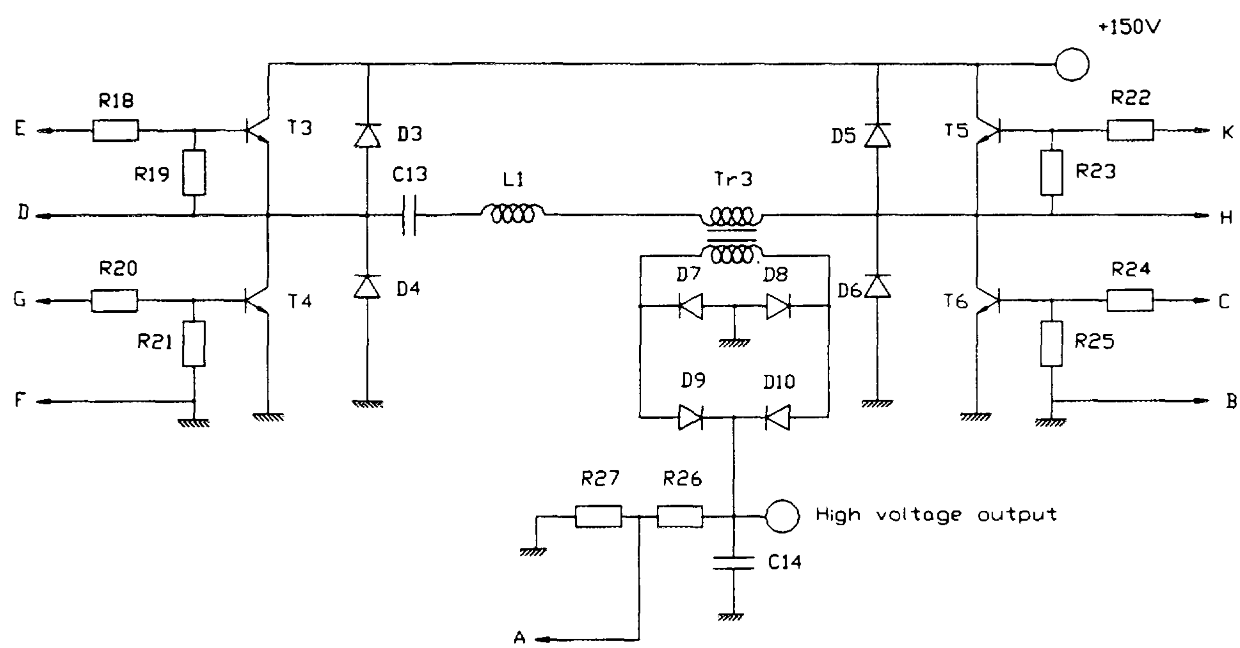


Fig. 13: Resonant circuit with high-voltage transformer between high speed transistor switches.

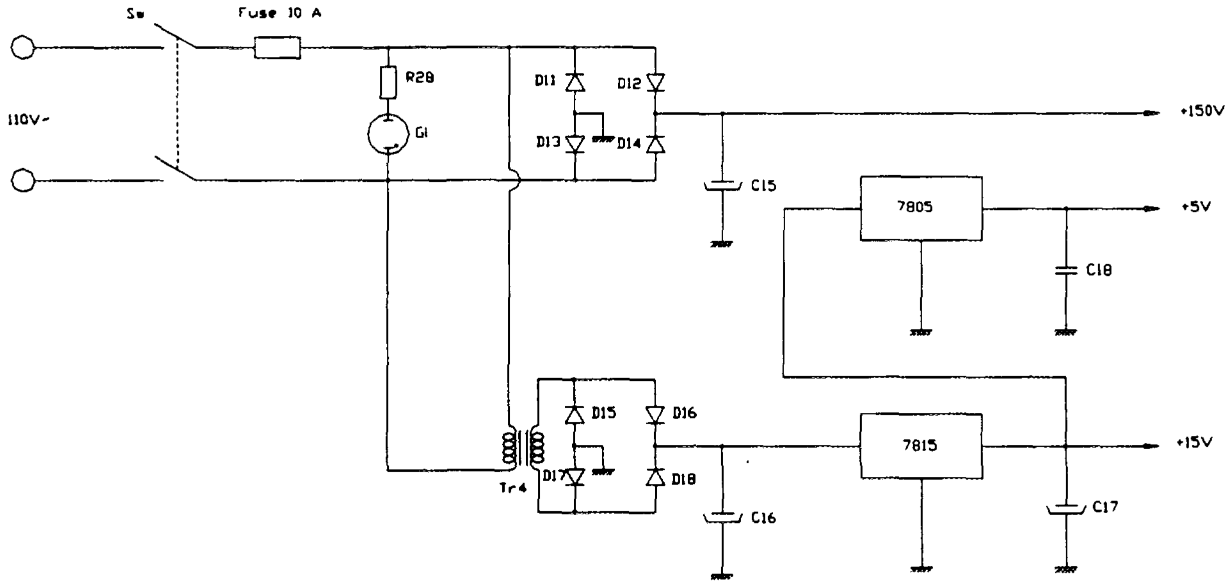


Fig. 14: Power supply of all components of the instruments.

3.2 Switching systems

There are used chiefly fast electronic switches such as thyratrons in the design of high voltage pulse generators. The advantages of the thyratron are many:the switch is small and light, it can be triggered accurately by applying low-voltage pulses to the grig,it has a high efficiency and it can operate over a wide range of plate voltages.To compare to another electronic switches such as electronic tubes and high-voltage semiconductor components (bipolar and MOSFET transistors,IGBT-transistors) , the thyratron is without concurence in the voltage above 3 kV.

It is shown in fig. 15 a working circuit of high-voltage switch system based on the thyhuratron 5C22 . It is a distinctive feature of the circuit that constant negative voltage is applied to the grid of the thyratron to decrease the time of deionization.The direction of the thyratron is accomplished by applying of a positive voltage pulses with amplitude 250 - 300 V and time duration 2 miliseconds with a pulse recurence frequency between 8 and 20 Hz on the thyratron grid.Manual switching is optional by pressing of the button switch.The general view of the switching system is shown in fig. 16 (including a high-voltade supply).

The test of this sistem has shown the main deffects after starting .The device worked normally during the first 15 - 20 seconds.After that there ocurred a non-harmonic time sequence of high-voltage pulses and complete stopping of pulse generation.

This working condition of high-voltage pulse generator has not met the requirement of work for a long time (up to 1 hour).This was a motivation to start the design of new high-voltage pulse system based also on the thyratron 5C22 with stable work for a long time (more than 1 hour without interrupting) with a repetition frequency in the interval 0,5 - 20 Hz.

Block-diagram of the new design is shown in fig. 17 . A trigger positive voltage of 150 V and negative cutoff voltage of 300 V are applied in consecutive order to the thyratron grid by two fast switches and the general circuit of the system is shown in fig.18.

By means of integrated timer 555 , a tunable oscillator is constructed with rectangular pulses and they are applied to the input of the circuit 75450.Two independent alternatively changed in the time pulse sequences are obtained and they direct the fast transistor switches T3,T4 by driver transistors T1,T2 and pulse transformers Tr1,Tr2 respectively.The capacitor C is included to prevent a switch circuit from thyratron high voltage.A general view from the high-voltage pulser is shown in fig. 19 .The test of the instrument has shown a high stability in the high voltage pulse amplitude and in continuos work (more than 2 hours).The shape of a grid pulse and output pulse on the resistance load of 100 ohms is shown in fig.20 and fig. 21, respectively.The working voltage of high voltage power supply of the pulser is 15 kV.This is a maximal anode voltage for the thyratron 5C22.To overcome this disadvantage a circuit with two thyratrons in series is proposed as a high-voltage switch for the voltages up to 30 kV.The pulse transformer for direction on the thyratrons is immersed in transformer oil and control circuit is under development (fig. 22).

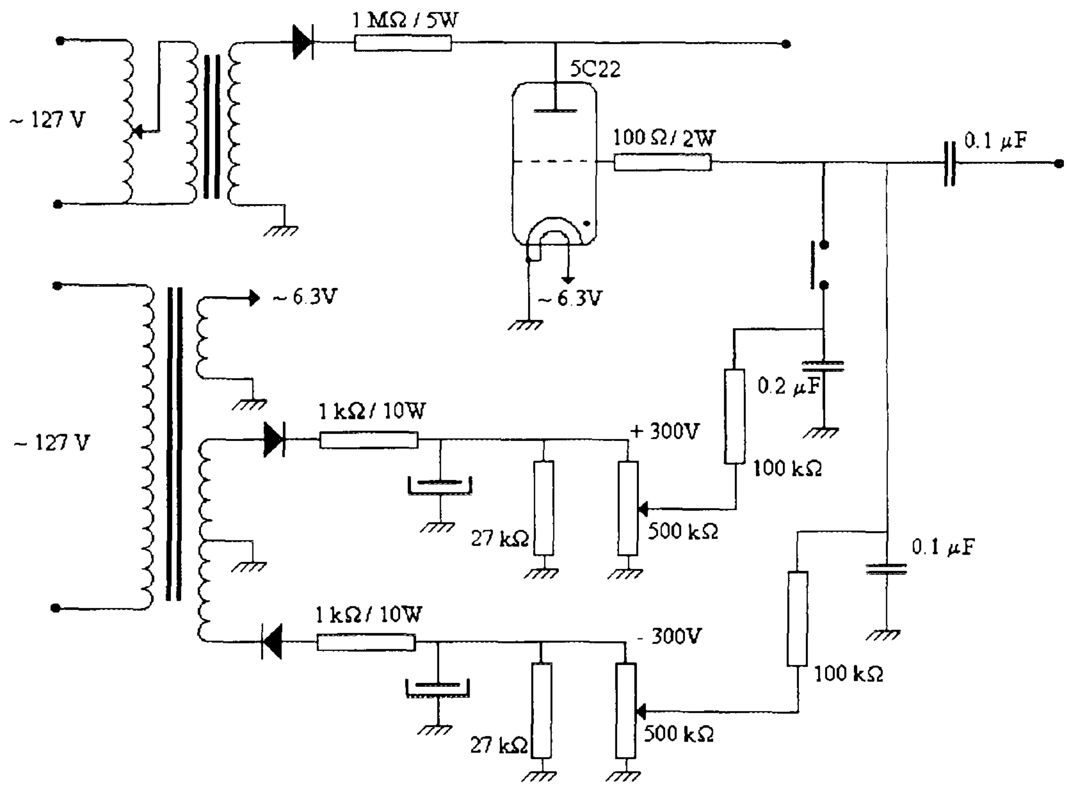


Fig.15 - Circuit of high-voltage switch based on 5C22 thyratron

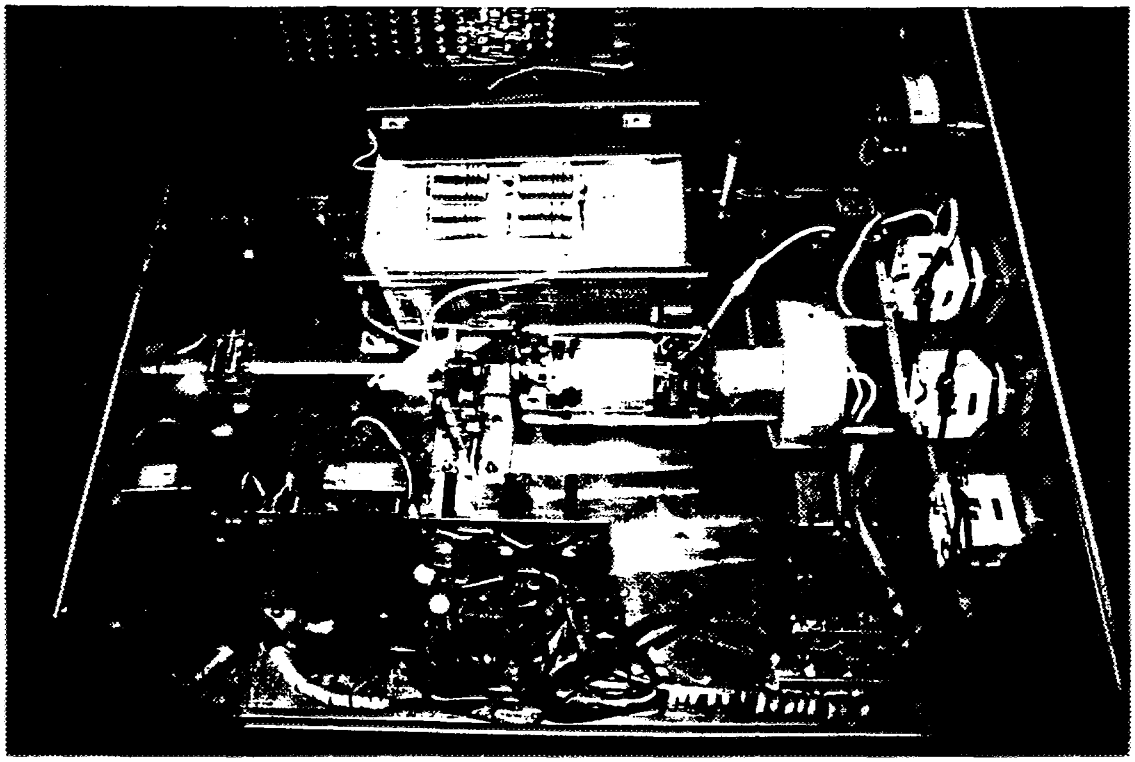


fig.16 View of the first design of the fast switch with 5C22 thyratron

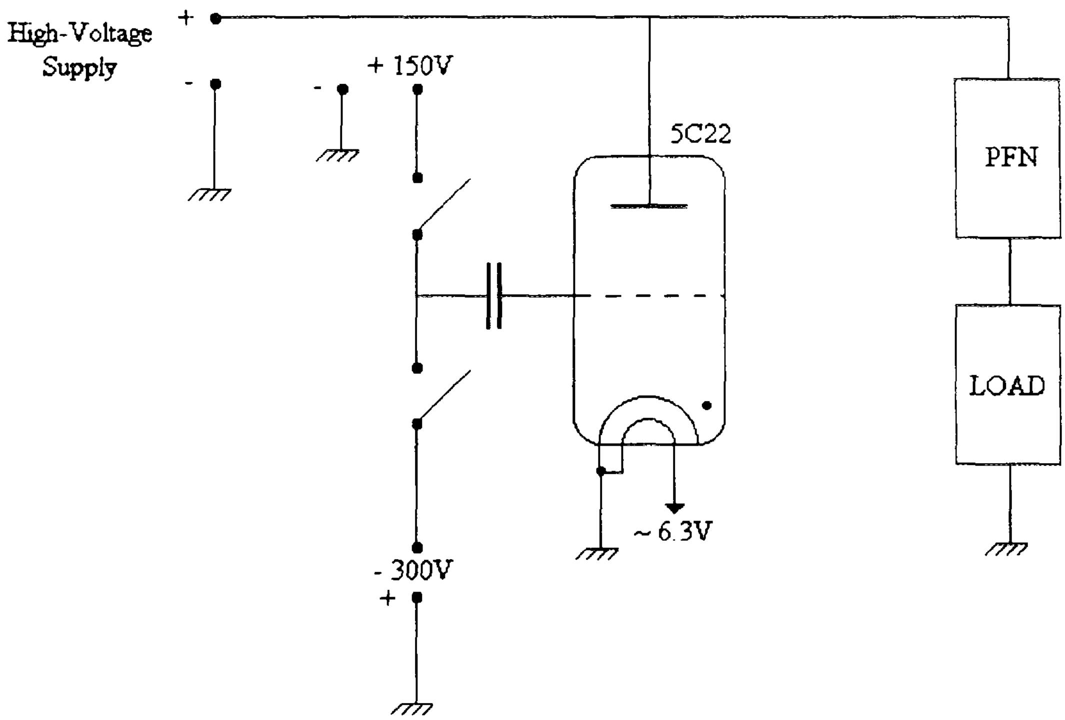


Fig.17 - Block-Circuit of the fast switch for the line-type pulser based on thyratron 5C22

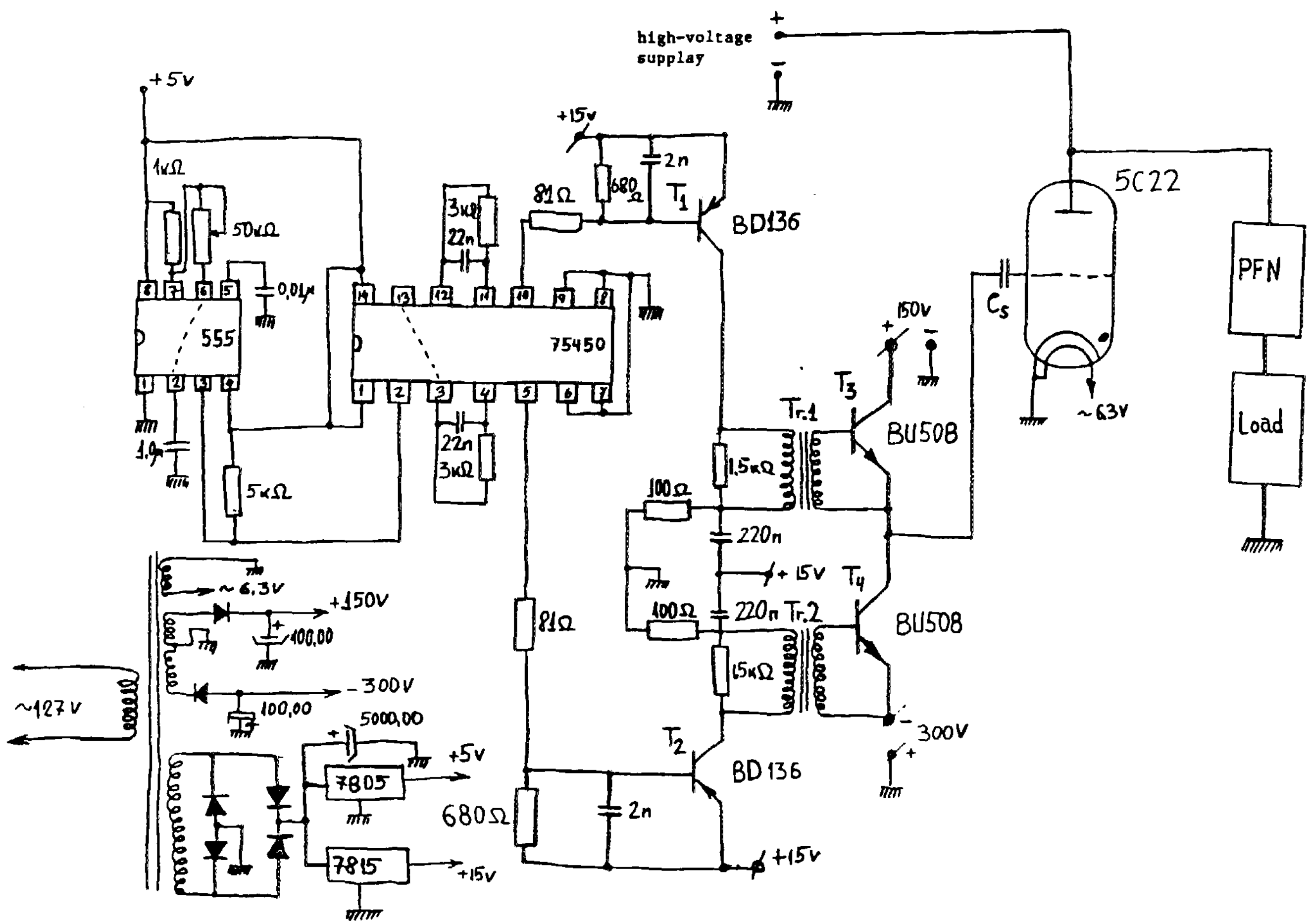


fig.18 General circuit for fast switch based on thyratron 5C22

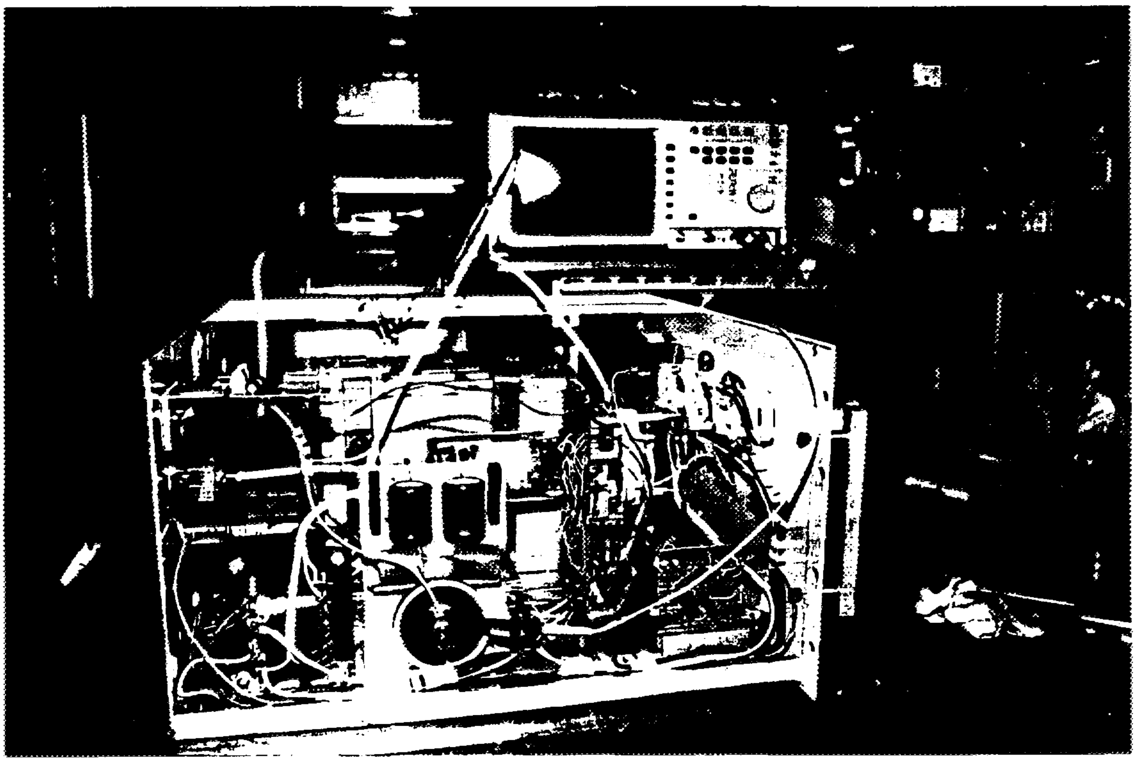


fig.19 View of the second design of the fast switch based on thyratron 5C22

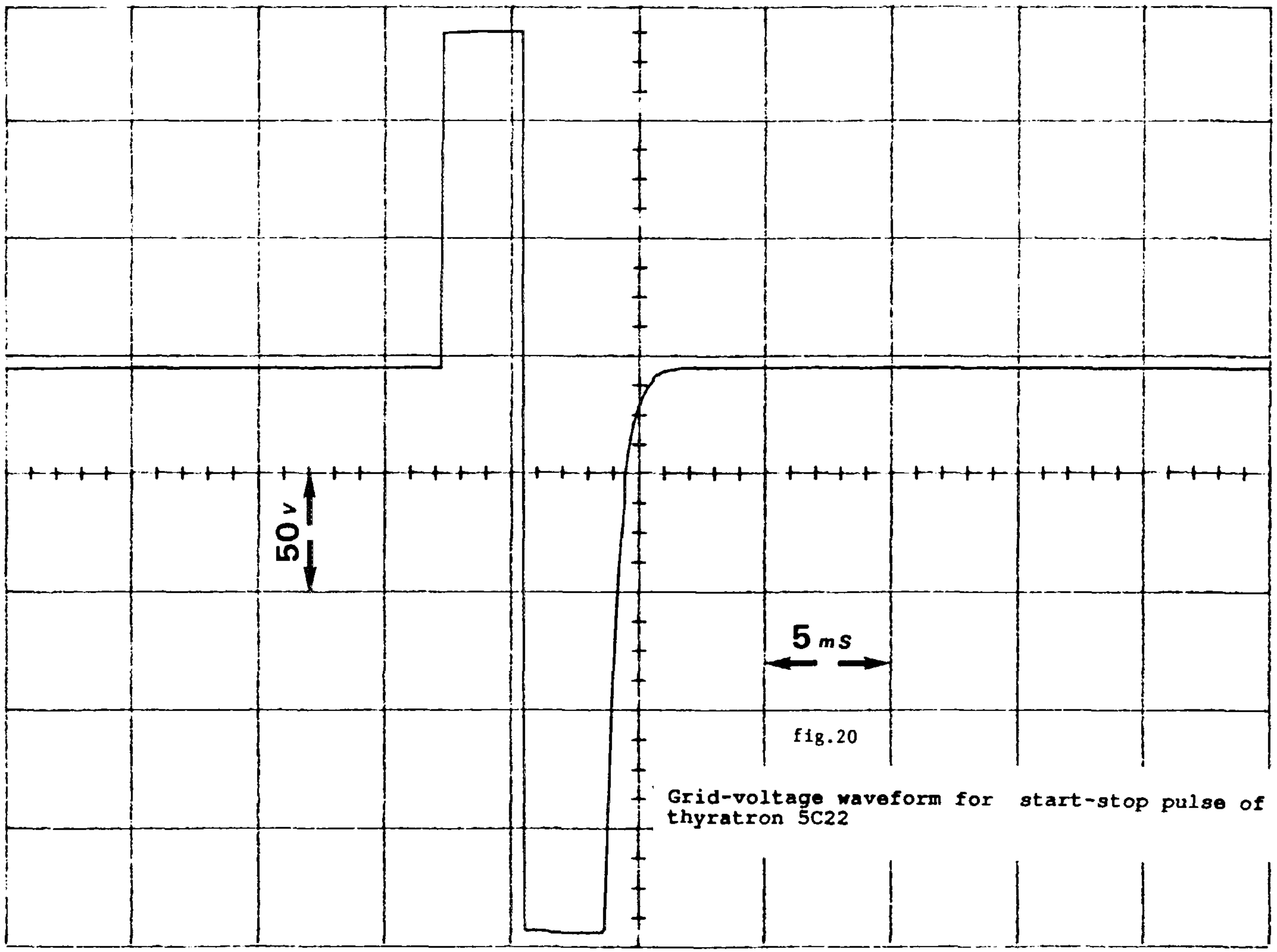


fig.20

Grid-voltage waveform for start-stop pulse of the thyratron 5C22

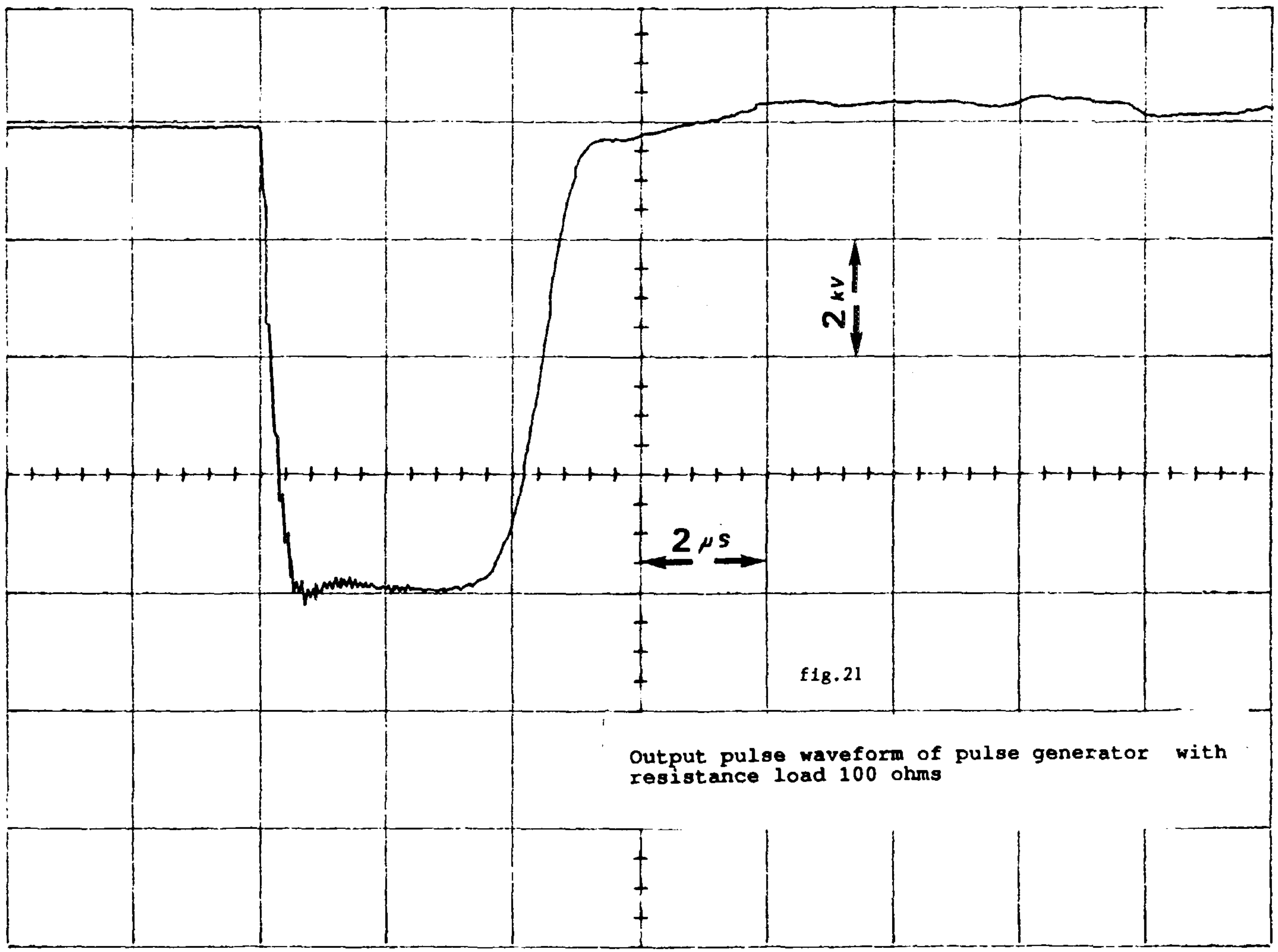


fig.21

Output pulse waveform of pulse generator with resistance load 100 ohms

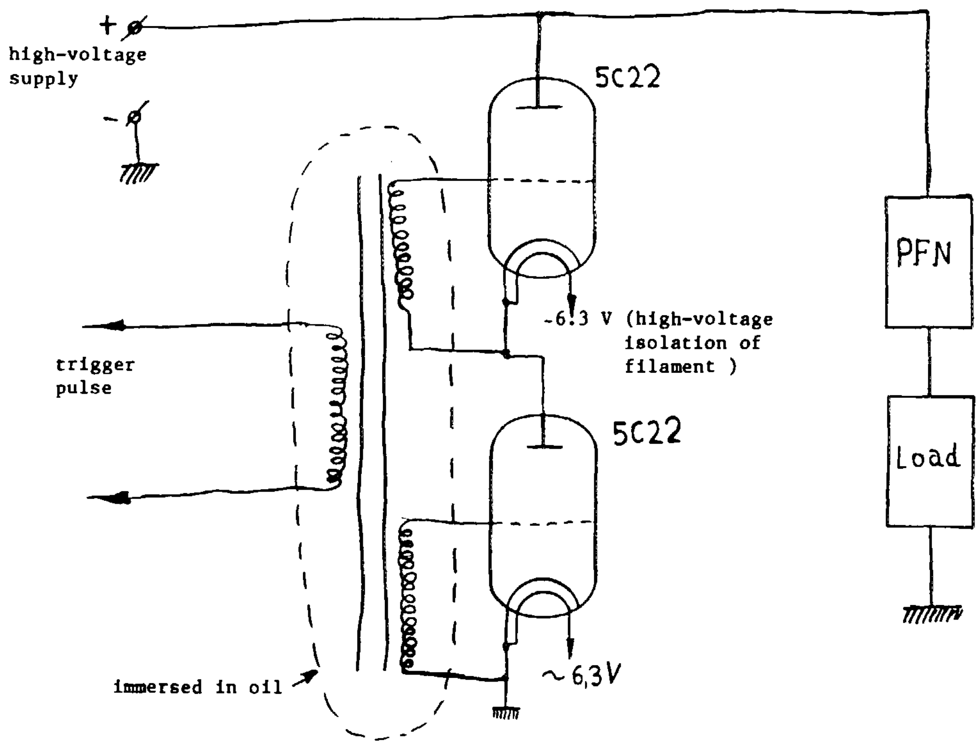


fig.22 High-voltage switch with two thyratrons in series

3.3 Resonant charging inductance

By means of computer simulation it was obtained that the value of charging inductance L_c is equal to 1,39 H and pulse frequency is 20.8 Hz and it is possible to gain an output voltage with factor 1.8 higher than the voltage supply of the pulse generator.

Designed and constructed charging inductance is shown in fig.23 and the experiment about using such isolating element in line-type pulser is under development. During the experiment the inductance must be immersed in transformer oil for better insulation.

3.4 Design of high-resolution synchro instrument for gyrotron frequency measurement

The voltage pulsation in the cavity gyrotron magnet coil due to insuficient current filtration have led to a time variation of the frequency of gyrotron radiation.To avoid of this annoying situation case for experimental work with the gyrotron , it was designed an electronic instrument for synchronization between gyrotron frequency and magnet inductance of the coil.

The instrument consists of:

voltage divider which puts a small fraction of the coil voltage to the comparator based on the integrated circuit 311 to produce a synchro pulse with the change of the coil voltage shape.

two standby oscillators based on the integrated timer 555 .The first one produce a pulse with tuneable longitude by means of the potentiometers P_2,P_3.The output signal direct the second oscilator which produce a pulse on the pulse end of the first oscilators.The position of this pulse is very stable between the minimal and maximal value of the coil voltage.In fact, the second oscillator produces a pulse sequence for synchronization of a frequency measurement equipment with the concrete point of the curve of magnet inductance.

The general circuit of the instrument is shown in fig.24 and voltage waveform of the main points in the circuit are shown in fig.25

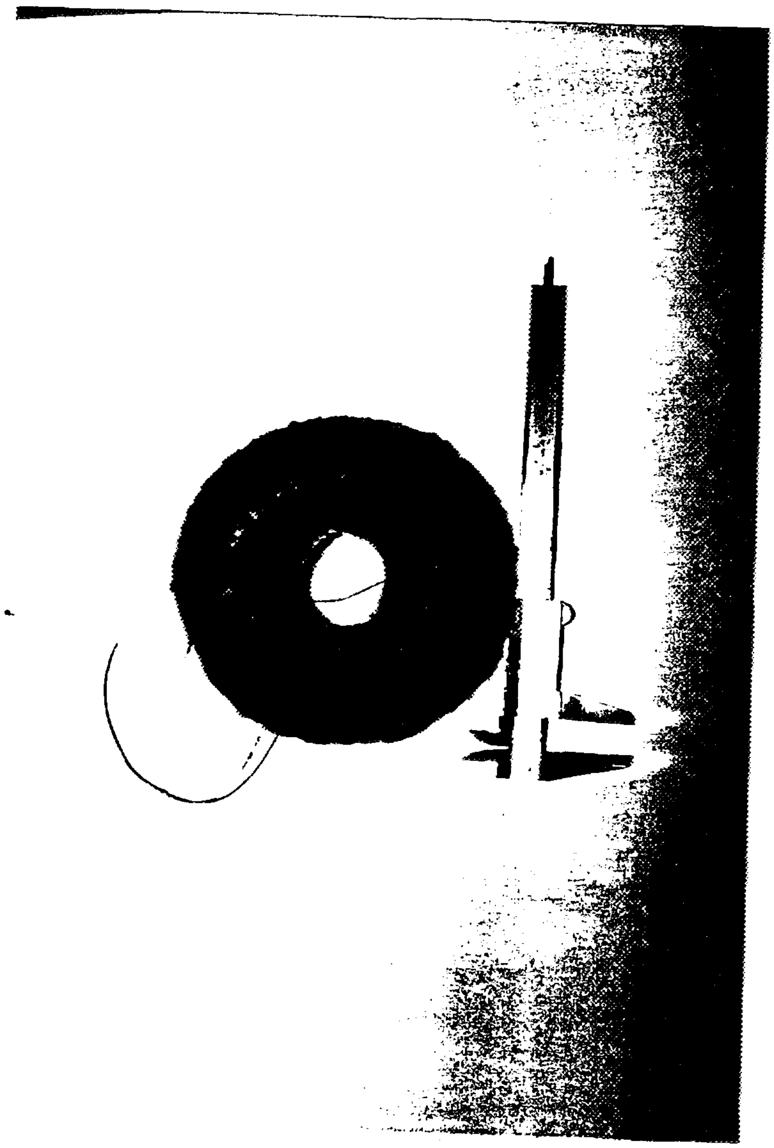


fig.23 View of a resonant charging inductance

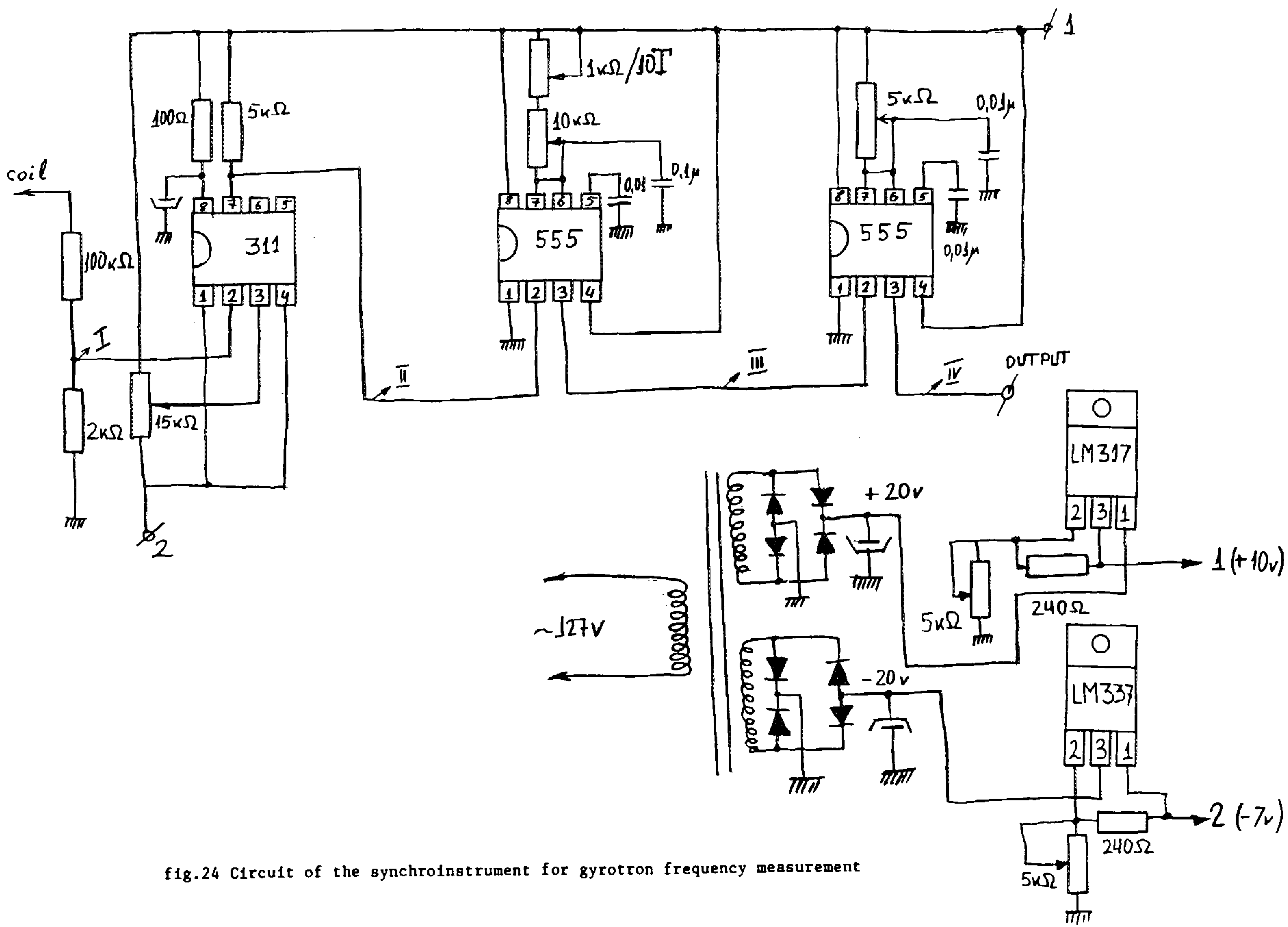


fig.24 Circuit of the synchroinstrument for gyrotron frequency measurement

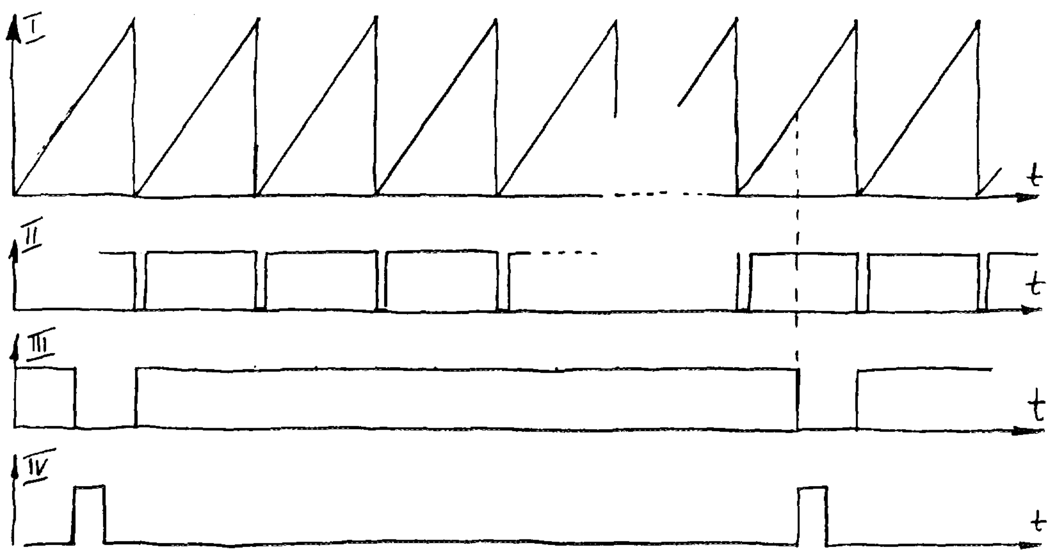


fig.25 Voltage waveform in the circuit of synchroinstrument for gyrotron frequency measurement