# Design and Implementation of Multistage Marx Impulse Generator for Testing Insulators

Submitted by

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In partial fulfillment for the award of the degree of

**Bachelor of Technology**

in

**Electrical & Electronics Engineering**

**School of Electrical & Electronics Engineering**
**SASTRA University**
**Tirumalaisamudram**
**Thanjavur – 613 401**

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# Chapter 1

# 1. Introduction

## 1.1 Over View Of Project:

Most of the high voltage equipments such as power transformer, surge arrester, circuit breaker, isolator and high voltage tension transmission line towers are placed in transmission substations. As these equipments are very costly and important for maintain continuity of power supply, their safety should be the major priority for utilities and personal handling equipment. These equipments are often affected by lightning surge voltages and high voltage high frequency (HVHF) which can lead to insulation failure. So inorder to protect the equipment as per International & National standards mandate testing of equipment against lightning surges and high voltage high frequency is necessary.

Generally, there are very few high voltage test center & laboratoty facilities provided, because it involves high capital cost for installation of high voltage equipment. However, to test the insulation condition of such high voltage power equipment, various types of tests are essential to access the condition of insulation systems. According to the standard value of different insulation, different tests are conducted in high voltage laboratory.

Several test are usually conducted on insulation system of power apparatus namely Insulation Resistance withstand test (IR), Lightning Impulse voltage withstand test, Puncture test on insulators, capacitance and turns measurement test and breakdown voltage test of transformer oil etc. Among all these test Impulse voltage test is important test for withstand capability of high voltage insulation since these test check for various onerous conditions.

# ABSTRACT

Impulse tests are carried out in order to investigate the influence of surges in transmission lines, line insulators, transformers and other major components of a power system to confirm the withstanding capability of the insulated equipment due to external (Lightning impulse) and internal (Switching impulse) surges.

International standards (IEC 60060) and National standards (IS 2071) mandate classical tests to be conducted on power equipment to discuss the healthiness of insulator systems. Since lightning impulse and switching impulse voltage withstand tests form invariably an inherent part of testing for analyzing the soundness of the insulation system of power equipment, this project envisages design and implementation of a multistage Marx Impulse Generator kit which would cater to lightning impulse testing of insulators.

The purpose of Marx Impulse Generator is to generate a high-voltage pulse from a low-voltage DC supply. As it is tedious to get DC supply, AC supply is rectified using diode. Then the high voltage pulse is obtained by charging a number of capacitors in parallel then discharging them in series. Thus it mainly works as high voltage impulse generator for testing insulators when the voltage levels obtained is higher than the supply voltage.

It is inferred that the overall simulated result and the observed impulse voltage result from the experimental setup is close to standard impulse generator for lightning impulse 1.2/50 µs wave shape for Marx Impulse Generator. It is observed that a small change in the resistance value can cause significant change in rise time and fall time of the impulse voltage. In the practical impulse generation circuit model spark gap is replaced by multiple pole single throw switch so that all the capacitors are discharged at one instant. Detailed observation and analysis have been carried out for testing insulators to ascertain the reliability of the proposed multistage Marx Impulse Generator Test Kit.

# LIST OF FIGURES

## ACKNOWLEDGEMENTS

First of all I express my gratitude to **Prof. R. Sethuraman** ,Vice Chancellor, SASTRA University who provided all facilities and necessary encouragement during the course of study. I extend my sincere thanks to **Dr. G. Bhalachandran** , Registrar, SASTRA University for providing the opportunity to pursue this project.

I dedicate my whole hearted thanks to **Dr. B. Viswanathan** , Dean, SEEE, SASTRA University and **Prof.M.Narayanan,** , Dean - Student Affairs, SEEE, SASTRA University, for their moral support. I also thank **Dr. K. Vijayarekha,** Associate Dean (EEE) who motivated me during the project work.

I owe a debt of deepest gratitude to my mentor (**Mr. S. Natarajan,** Asst.Prof III, SEEE) for his continuous support and guidance throughout the process during the pursuit of my project work. His deep insight in the field and invaluable suggestions helped me in making progress through my project work.

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# DECLARATION

We submit this project work entitled, "**Design and Implementation of Multistage Marx Impulse Generator**", to SASTRA University, Thanjavur in partial fulfillment of the requirements for the award of the degree of "**Bachelor of Technology**" in "**Electrical & Electronics Engineering**". We declare that it was carried out by us under the guidance of [**Mr. S. Natarajan, Asst.Prof III, SEEE**], EEE, SASTRA University.

| **Name** | **Register No.** | **Signature** |
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# Bona Fide Certificate

Certified that the project work entitled, **"Design and Implementation of Multistage Marx Impulse Generator"**, submitted to SASTRA University, Thanjavur by IYER AISHWARYA SUNDARAM (Reg.No:116005045), MALLAVARAM SAI HARINI (Reg.No:116005071), YADAMA SARANYA (Reg. No:116005157), in partial fulfillment for the award of the degree of Bachelor of Technology in Electrical & Electronics Engineering is the work carried out under my guidance during the period Dec 2015 – April 2016.

**Project Guide**

**[Mr. S. NATARAJAN]**
**[Asst.Prof III, SEEE, SASTRA University]**

**Submitted for the University Exam held on** 26/04/16

26.04.16
**External Examiner**

R. 26/4/16.
**Internal Examiner**

In this work, an attempt has been made to perform impulse voltage test using a Multistage Marx Impulse Voltage Generator Kit. Further, the simulation of same circuit has been carried out in PSPICE ORCAD software and is compared with the practical results.

## 1.2 Significance Of Project:

The following pertinent aspects weigh in favour of implementation of this projects:-

- Marx Impulse Voltage Generator Test Kit provides a facility for testing insulators.
- Artificially lightning impulse voltages are generated by using this kit in high voltage laboratory and can be used to test against high voltage on each equipment in simple semiconductor power equipment circuit for safety and completion of products within safety limits.
- The standard Lightning Impulse can be used to test the strength of all electronic equipments which are less costly by using this kit instead of othe laboratory facility.
- The kit can be designed suitably based on the requirement of various values high voltage check.

The above equation represents a unidirectional wave which usually has a rapid rise to the peak value and slowly falls to zero value. The general waveshape is given in Fig. 1. Impulse waves are specified by defining their rise or front time, fall or tail time to 50% peak value, and the value of the peak voltage. Thus 1.2/50 μs, 1000 kV wave represents an impulse voltage wave with a front time of 1.2 μs, fall time to 50% peak value of 50 μs, and a peak value of 1000 kV. When impulse waveshapes are recorded, the initial portion of the wave will not be clearly defined or sometimes will be missing. Moreover, due to disturbances it may contain superimposed oscillations in the rising portion. Hence, the front and tail times have to be defined. Referring to the waveshape in Fig. 1, the peak value *A* is fixed and referred to as 100% value. The points corresponding to 10% and 90% of the peak values are located in the front portion (points *C* and *D*). The line joining these points is extended to cut the time axis at $O_1$. $O_1$ is taken as the virtual origin. 1.25 times the interval between times $t_1$ and $t_2$ corresponding to points *C* and *D* (projections on the time axis) is defined as the front time, i.e. 1.25 $(O_1 t_1 - O_1 t_2)$. The point *E* is located on the wave tail corresponding to 50% of the peak value, and its projection on the time axis is $t_4$ .$Ot_4$ is defined as the fall or tail time. In case the point *C* is not clear or missing from the waveshape record, the point corresponding to 30% peak value F is taken and its projection $t'_1$ is located on time axis. The wavefront time in that case will be definedas 1.67 $(O_1 t_3 - O_1 t'_1)$, The allowed tolerances in the front and tail times are respectively ± 30% & ± 20%. Standard impulse specifications are 1.2/50 $\mu s$. The tolerance allowed in the peak value is ± 3%.

## 3.2 Theoretical Representation of impulse Waves:

The impulse waves are generally represented by the Eq. given earlier. $V_0$ represents a factor that depends on the peak value. For impulse wave of 1.2/50 $\mu s$, α= - 0.0146, β = - 2.467, and $V_0$ = 1.04 when time *t* is expressed in μs, α and β control the front and tail times of the wave.

$C_4$ also includes the capacitance of the test object and of any other load capacitance required for producing the required wave shape. $L_4$ represents the inductance of the test object and may also affect the wave shape appreciably. Usually for practical reasons, one terminal of the impulse generator is solidly grounded. The polarity of the output voltage can be changed by changing the polarity of the d.c. charging voltage. For the evaluation of the various impulse circuit elements, the analysis using the equivalent circuit of Fig. 2 is quite rigorous and complex. Two simplified but more practical forms of impulse generator circuits are shown in Fig. 3 (*a*) and (*b*).

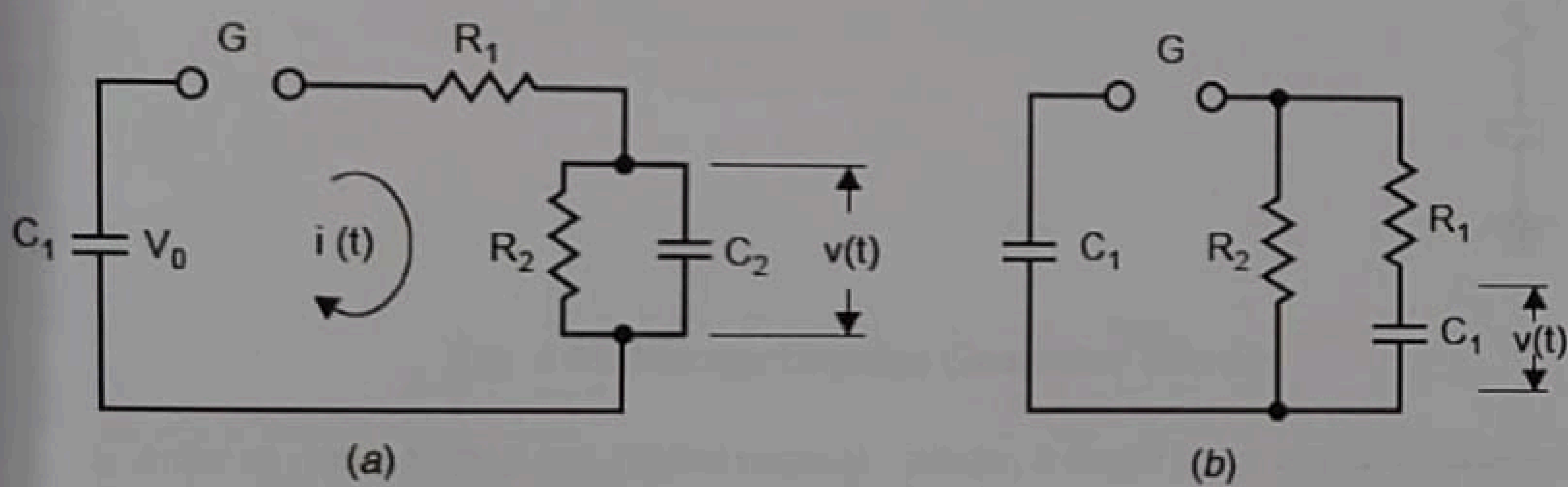



**Fig. 3 Simplified equivalent circuit of an Impulse Generator**

The two circuits are widely used and differ only in the position of the wave tail control resistance $R_2$. When $R_2$ is on the load side of $R1$ (Fig. *a*) the two resistances form a potential divider which reduces the output voltage but when $R_2$ is on the generator side of $R_1$ (Fig. *b*) this particular loss of output voltage is absent.The impulse capacitor $C_1$ is charged through a charging resistance (not shown) to a d.c. voltage $V_0$ and then discharged by flashing over the switching gap with a pulse of suitable value. The desired impulse voltage appears across the load capacitance $C_2$. The value of the circuit elements determines the shape of the output impulse voltage. The following analysis will help us in evaluating the circuit parameters for achieving a particular wave shape of the impulse voltage.

After the generator has fired, the total discharge capacitance $C1$ may be given as

$$\frac{1}{C_1}\sum^{n}\frac{1}{C_1'}$$

the equivalent front resistance

$$R_1 = \sum^{n} R_1' + R_1''$$

and the equivalent tail control resistance

$$R_2 = \sum^{n} R_2'$$

where $n$ is the number of stages.

# Chapter 4

# 4. Theoretical Aspects Related To High Voltage Test Generation

## 4.1 Analysis of Impulse Voltage Circuit:

After the gap sparks over, let the current in the generator circuit be $i\,(t)$ at any time $t$. Using Laplace transform, the impedance of the circuit is

$$Z\,(S) = R_1 + \frac{1}{C_1 s} + \frac{R_2}{R_2 C_2 s + 1}$$

$$= \frac{R_1 R_2 C_1 C_2 s^2 + (R_1 C_1 + R_2 C_2 + R_2 C_1) s + 1}{C_1 s\,(R_2 C_2 s + 1)}$$

$$I\,(s) = \frac{V_0}{sZ(s)} = \frac{V_0}{s} \frac{C_1 s (R_2 C_2 s + 1)}{R_1 R_2 C_1 C_2 C_2 s^2 + (R_1 C_1 + R_2 C_2 + R_2 C_1)\, s + 1}$$

and

$$v(s) = I(s)\,.\,\frac{R_2}{R_2 C_2 s + 1}$$

$$= V_0 R_2 C_1 \frac{1}{R_1 R_2 C_1 C_2 s^2 + (R_1 C_1 + R_2 C_2 + R_2 C_1) s + 1}$$

$$= \frac{V_0 R_2 C_1}{R_1 R_2 C_1 C_2} \cdot \frac{1}{s^2 + \frac{R_1 C_1 + R_2 C_2 + R_2 C_1}{R_1 R_2 C_1 C_2} s + \frac{1}{R_1 R_2 C_1 C_2}}$$

The roots of the expression in the denominator are

$$\frac{1}{2}\left[\frac{-(R_1 C_1 + R_2 C_2 + R_2 C_1)}{R_1 R_2 C_1 C_2} \pm \sqrt{\left(\frac{R_1 C_1 + R_2 C_2 + R_2 C_1}{R_1 R_2 C_1 C_2}\right)^2 - \frac{4}{R_1 R_2 C_1 C_2}}\right]$$

corresponding to the number of stages. Fig. 4 shows a 3-stage impulse generator circuit due to Marx employing '*b*' circuit connections. The impulse capacitors $C_1$ are charged to the charging voltage $V_0$ through the high charging resistors $R_c$ in parallel. When all the gaps $G$ breakdown, the $C_1'$ capacitances are connected in series so that $C_2$ is charged through the series connection of all the wave front resistances $R_1'$ and finally all $C_1'$ and $C_2$ will discharge through the resistors $R_2'$ and $R1'$. Usually $Rc >> R2 >> R1$.

If in Fig. 4 the wave tail resistors $R_2'$ in each stage are connected in parallel to the series combination of $R_2'$, $G$ and $C_1'$, an impulse generator of type circuit '*a*' is obtained.

In order that the Marx circuit operates consistently it is essential to adjust the distances between various sphere gaps such that the first gap $G_1$ is only slightly less than that of $G_2$ and so on. If is also necessary that the axes of the gaps $G$ be in the same vertical plane so that the ultraviolet radiations due to spark in the first gap $G$, will irradiate the other gaps. This ensures a supply of electrons released from the gap electrons to initiate breakdown during the short period when the gaps are subjected to overvoltages. The wave front control resistance can have three possible locations (*i*) entirely within the generator (*ii*) entirely outside the generator (*iii*) partly within and partly outside the generator. The first arrangement is unsatisfactory as the inductance and capacitance of the external leads and the load form an oscillatory circuit which requires to be damped by an external resistance. The second arrangement is also unsatisfactory as a single external front resistance will have to withstand, even though for a very short time, the full rated voltage and therefore, will turn out to be inconveniently long and would occupy much space. A compromise between the two is the third arrangement as shown in Fig. 4 and thus both the "space economy" and damping of oscillations are taken care of.

It can be seen that Fig. 4 can be reduced to the single stage impulse generator of Fig. 3 (*b*).

## MULTISTAGE IMPULSE GENERATOR CIRCUIT:

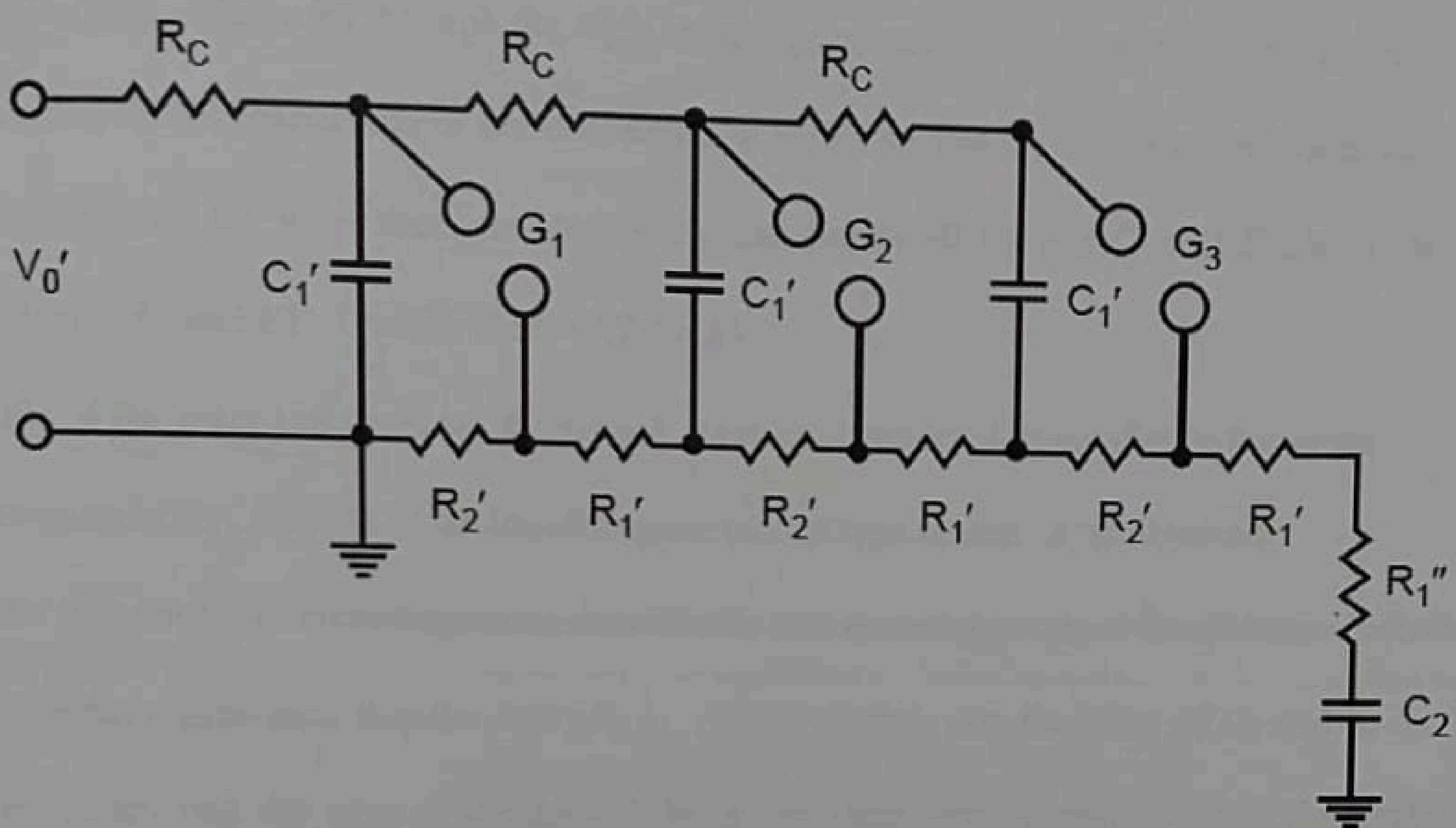



**Fig. 4 Multistage Impulse Generator Circuit**

In order to obtain higher and higher impulse voltage, a single stage circuit is inconvenient for the following reasons:

(*i*) The physical size of the circuit elements becomes very large.

(*ii*) High d.c. charging voltage is required.

(*iii*) Suppression of corona discharges from the structure and leads during the charging period is difficult.

(*iv*) Switching of vary high voltages with spark gaps is difficult.

A multiplier circuit which is commonly used to obtain impulse voltages with as high a peak value as possible for a given d.c. charging voltage. Depending upon the charging voltage available and the output voltage required a number of identical impulse capacitors are charged in parallel and then discharged in series, thus obtaining a multiplied total charging voltage

## 3.3 IMPULSE GENERATOR CIRCUITS:

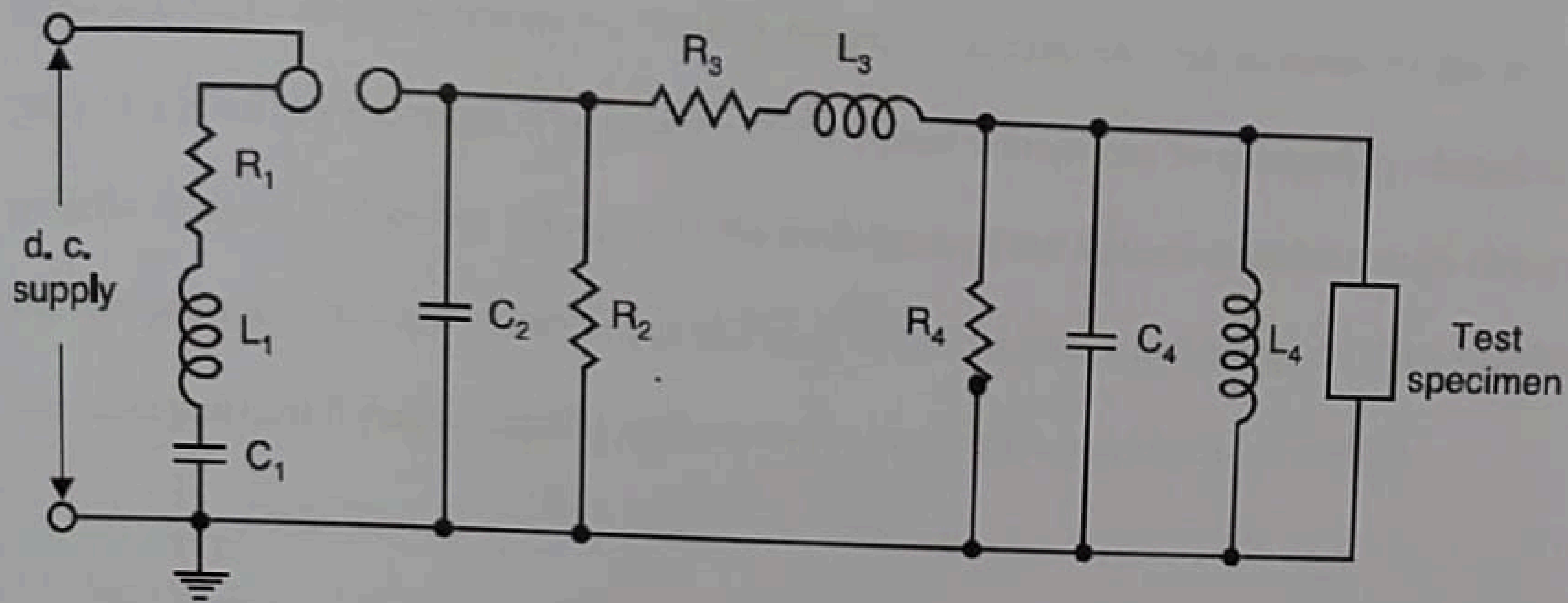



**Fig. 2 Impulse Generator Circuit**

Fig. 2 represents an exact equivalent circuit of a single stage impulse generator along with a typical load. $C_1$ is the capacitance of the generator charged from a d.c. source to a suitable voltage which causes discharge through the sphere gap. The capacitance $C_1$ may consist of a single capacitance, in which case the generator is known as a single stage generator or alternatively if $C_1$ is the total capacitance of a group of capacitors charged in parallel and then discharged in series, it is then known as a multistage generator.

$L_1$ is the inductance of the generator and the leads connecting the generator to the discharge circuit and is usually kept as small as possible. The resistance $R_1$ consists of the inherent series resistance of the capacitances and leads and often includes additional lumped resistance inserted within the generator for damping purposes and for output waveform control. $L_3$, $R_3$ are the external elements which may be connected at the generator terminal for waveform control. $R_2$ and $R_4$ control the duration of the wave.

However, $R_4$ also serves as a potential divider when a CRO is used for measurement purposes. $C_2$ and $C_4$ represent the capacitances to earth of the high voltage components and leads.

# Chapter 2

# 2. Goals And Objectives

## 2.1 Goals:

- To design and implement Multistage Marx Impulse Voltage Generator Test Kit.
- To implement a kit that would be adaptable & cater to Lightning Impulse (LI) for testing insulators.

## 2.2 Objectives:

- Simulations from PSPICE software to design and fix the values of front and tail time resistance ($R_1$ & $R_2$) according to the capacitance used in the circuit for Lightning Impulse voltages.
- Generation of Lightning Impulse voltage using this test kit and detail testing and analysis to study various types of loads and also test the insulators.

Chapter 3

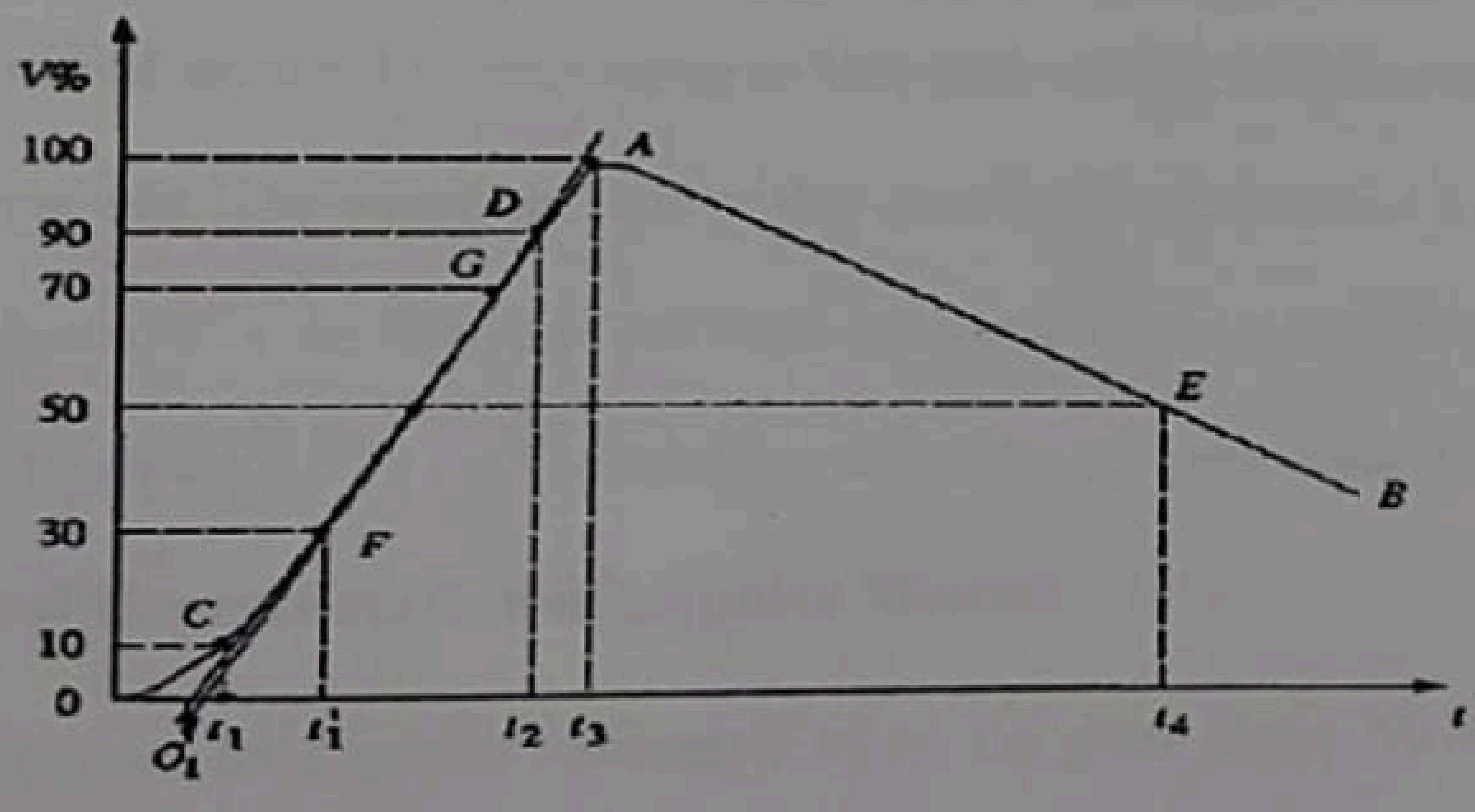
# 3. Major Concepts

## 3.1 Standard Impulse Wave Shape:

Transient overvoltages due to lightning and switching surges cause steep build-up of voltage on transmission lines and other electrical apparatus. Experimental investigations showed that these waves have a rise time of 0.5 to 10 micro seconds and decay time to 50% of the peak value of the order of 30 to 200 micro seconds. The waveshapes are arbitrary, but mostly unidirectional. It is shown that lightning overvoltage wave can be represented as double exponential waves defined by the equation

$$V = V_0[\exp(-\alpha t)-\exp(-\beta t)]$$

where α and β are constants of microsecond values.




Impulse waveform

**Fig. 1 Impulse Waveform**

Let

$$\alpha = \frac{R_1C_1 + R_2C_2 + R_2C_1}{2R_1R_2C_1C_2}$$

$$\beta = \frac{1}{2}\sqrt{\left(\frac{R_1C_1 + R_2C_2 + R_2C_1}{R_1R_2C_1C_2}\right)^2 - \frac{4}{R_1R_2C_1C_2}}$$

Therefore, the roots are $(-\alpha + \beta)$ and $(-\alpha - \beta)$. The expression for voltage can be rewritten as

$$v(s) = \frac{1}{(s+\alpha-\beta)(s+\alpha+\beta)} \cdot \frac{V_0}{R_1C_2}$$

Finding the partial fractions of the expression

$$\frac{1}{(s+\alpha-\beta)(s+\alpha+\beta)} = \frac{A}{s+\alpha-\beta} + \frac{B}{(s+\alpha+\beta)}$$
$$= \frac{As + A\alpha + A\beta + Bs + B\alpha - B\beta}{(s+\alpha-\beta)(s+\alpha+\beta)}$$

Comparing the coefficients $A + B = 0$ or $A = -B$ and $A\alpha + A\beta + B\alpha - B\beta = 1$ or $A\alpha + A\beta - A\alpha$ $+ A\beta = 1$ or $2A\beta = 1$ or

$$A = \frac{1}{2\beta} \quad \text{and} \quad B = -\frac{1}{2\beta}$$

Substituting these value of $A$ and $B$, we have

$$v(s) = \frac{V_0}{R_1C_2} \cdot \frac{1}{2\beta}\left[\frac{1}{s+(\alpha-\beta)} - \frac{1}{s+(\alpha+\beta)}\right]$$

Taking inverse Laplace transform of the voltage transform

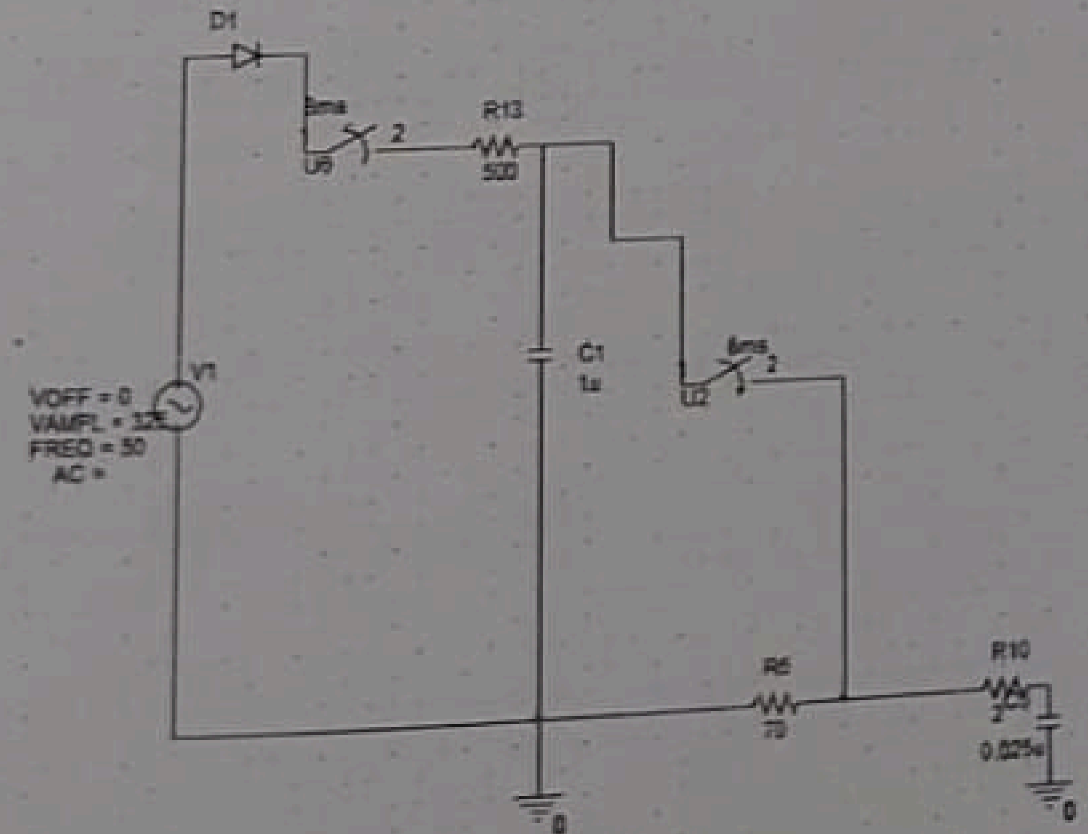
$$v(s) = \frac{V_0}{2\beta R_1C_2}[e^{-(\alpha-\beta)t} - e^{-(\alpha+\beta)t}]$$

**Steps:**

- Click the file menu and select the New option, drag the mouse to Project… and click it, give some file name.
- A blank project page is opened with circuit icons.
- Use the icons to draw the circuit diagram as in the given circuit.
- Select each component of circuit diagram and place them accordingly.
- Place the voltage probe where we need to take the output.
- Run the simulation by clicking on Run PSPICE button for obtaining the required output waveform.

## 5.4 Lightning Impulse Simulation for Single-Stage :

The Single stage impulse voltage generator was simulated using PSPICE Software. The schematic of the simulated generator is shown in Fig. 6. The values of front, tail and current limiting resistors in addition to the choice of C1 & C2 was taken based on the design aspect discussed earlier.



# Chapter 5

# 5. Simulation of HV Test Kit Observation & Analysis

## 5.1 PSPICE for Analog and Digital:

Cadence PSPICE is a full-featured,native analog and mixed-signal circuit simulator used in conjunction with PSPICE A/D, PSPICE Advanced Analysis tools help designers to improve the yield and reliability of their designs.

## 5.2 PSPICE for Simulation of Transient:

PSPICE Software 9.1 version in the ORCAD package is user friendly for electrical and electronic circuit simulation. The input circuit can be drawn in the capture executable file then output simulation wave can be obtained by using the simulation icon. Fig. 5 illustrates the working methodology of carrying out simulation for transients.

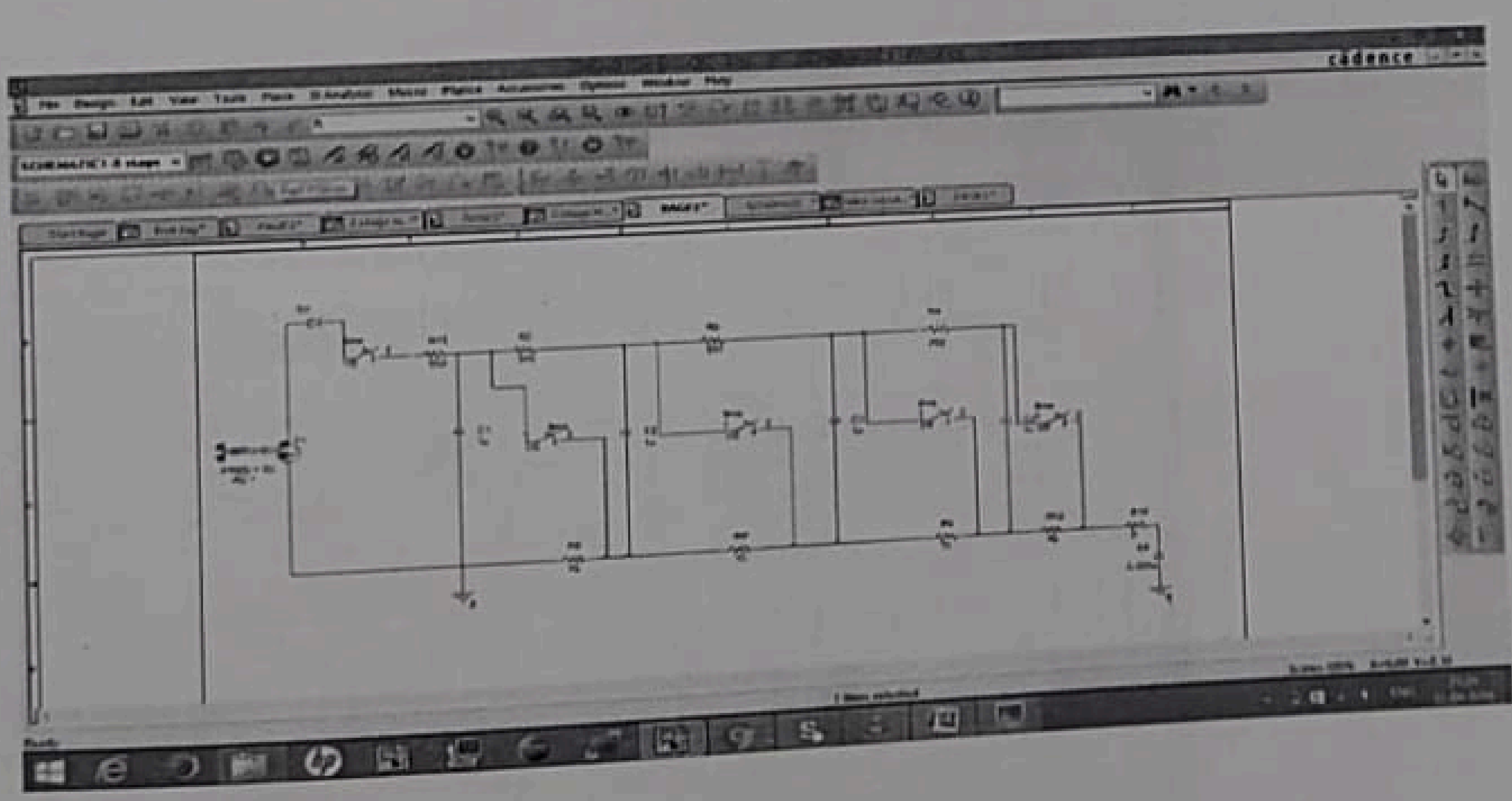
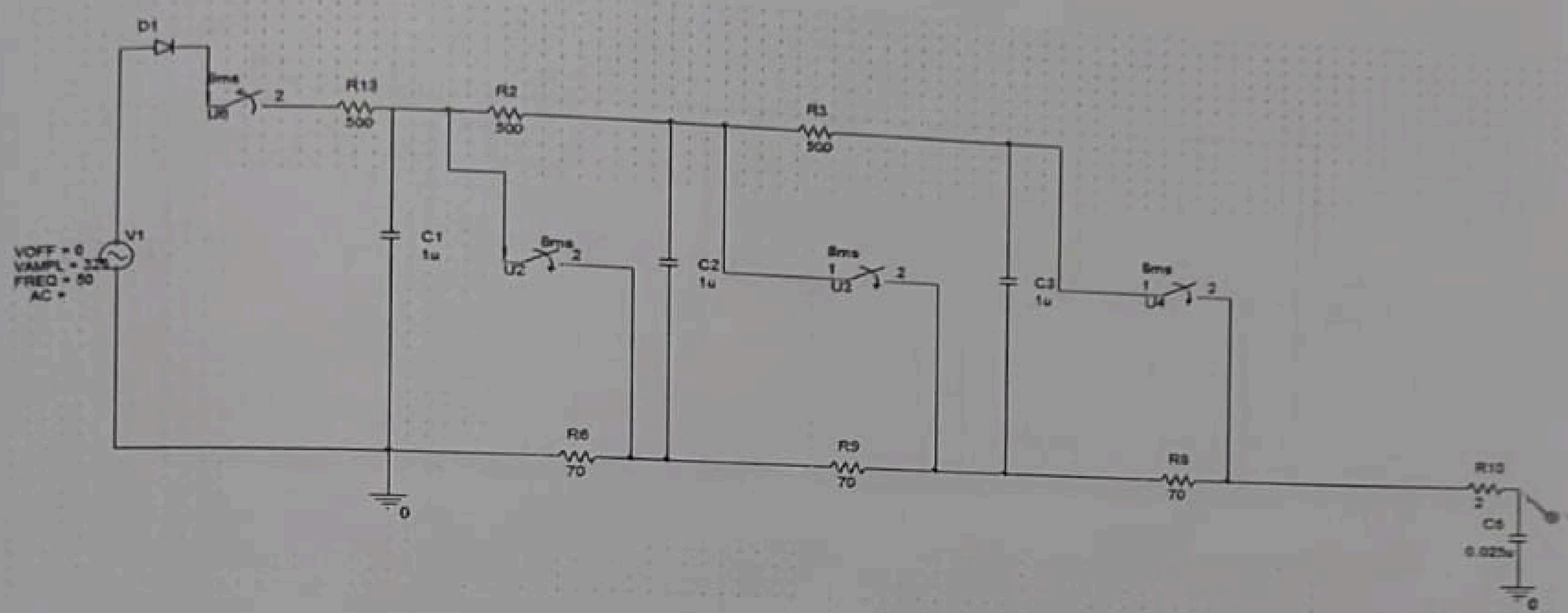
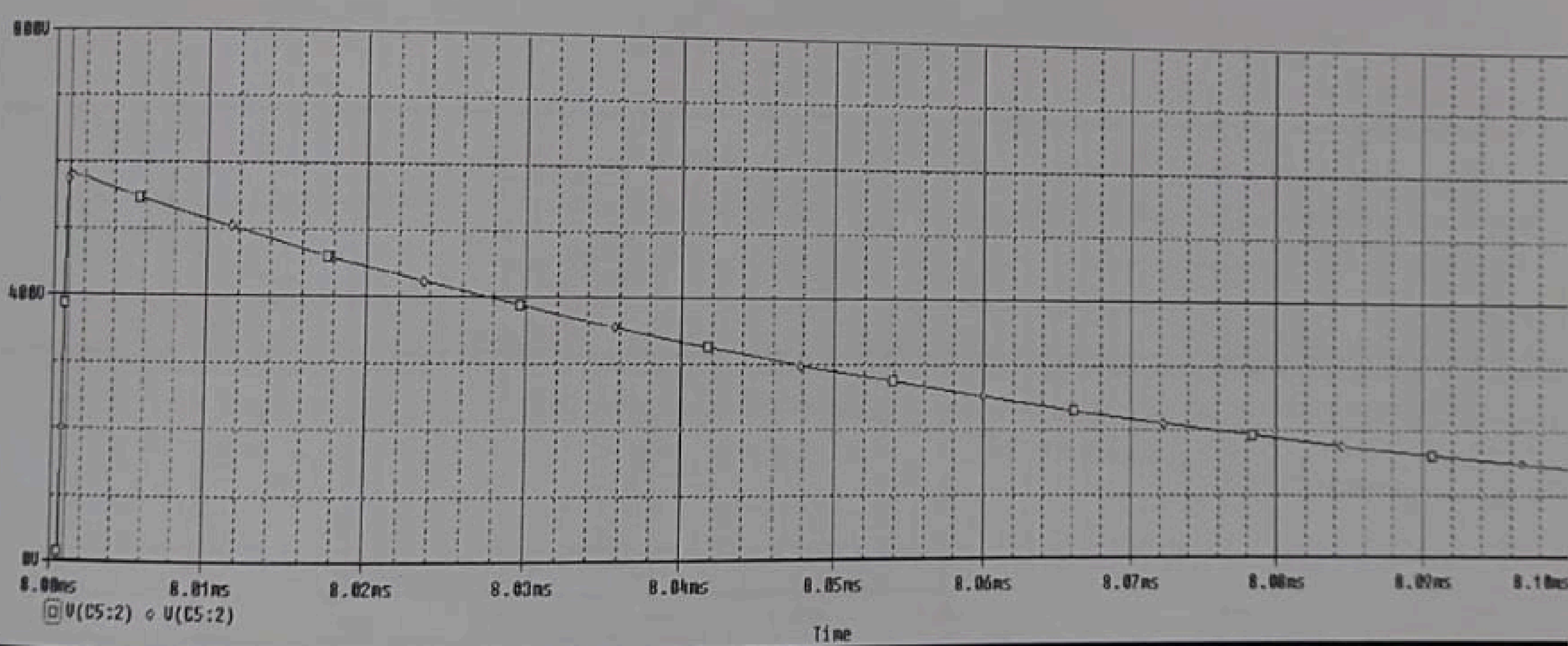



**Fig. 5 Simulation for Transients Working Method**

## 5.6 Lightning Impulse Simulation for Three-Stages:

As discussed in the section 5.5 further to develop higher voltage the three stage impulse voltage generator was simulated as is shown in Fig. 8.




| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
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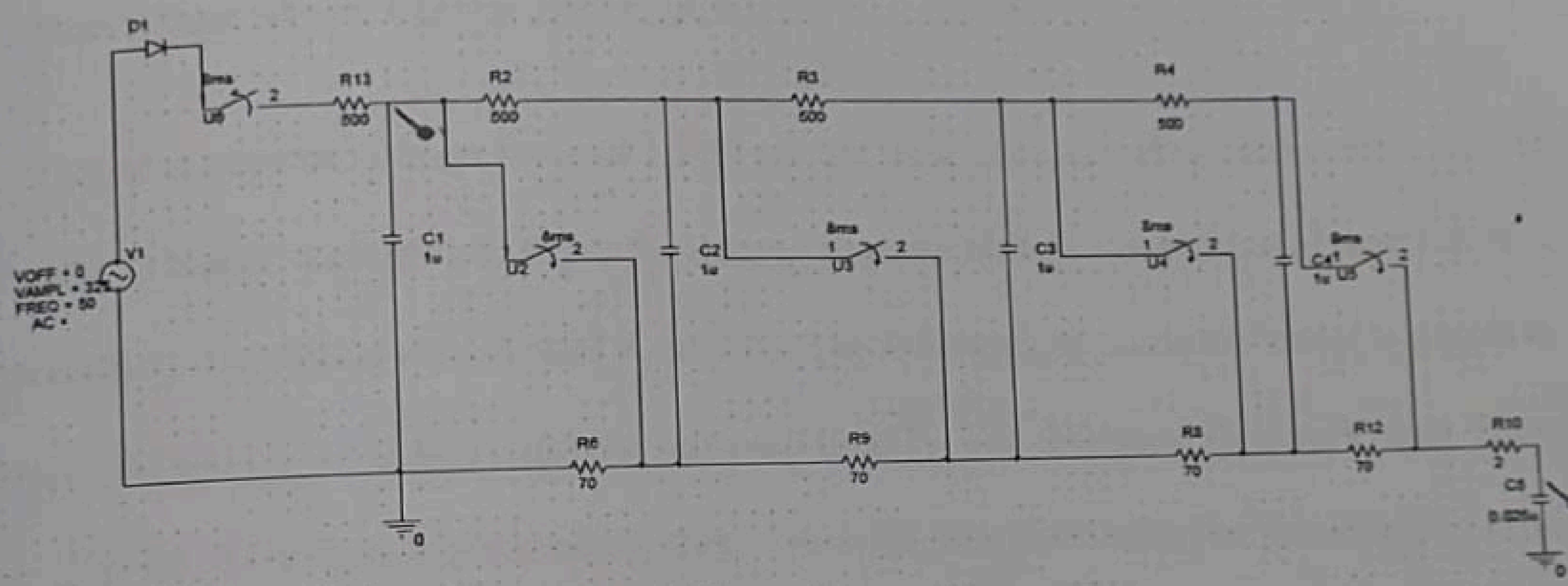
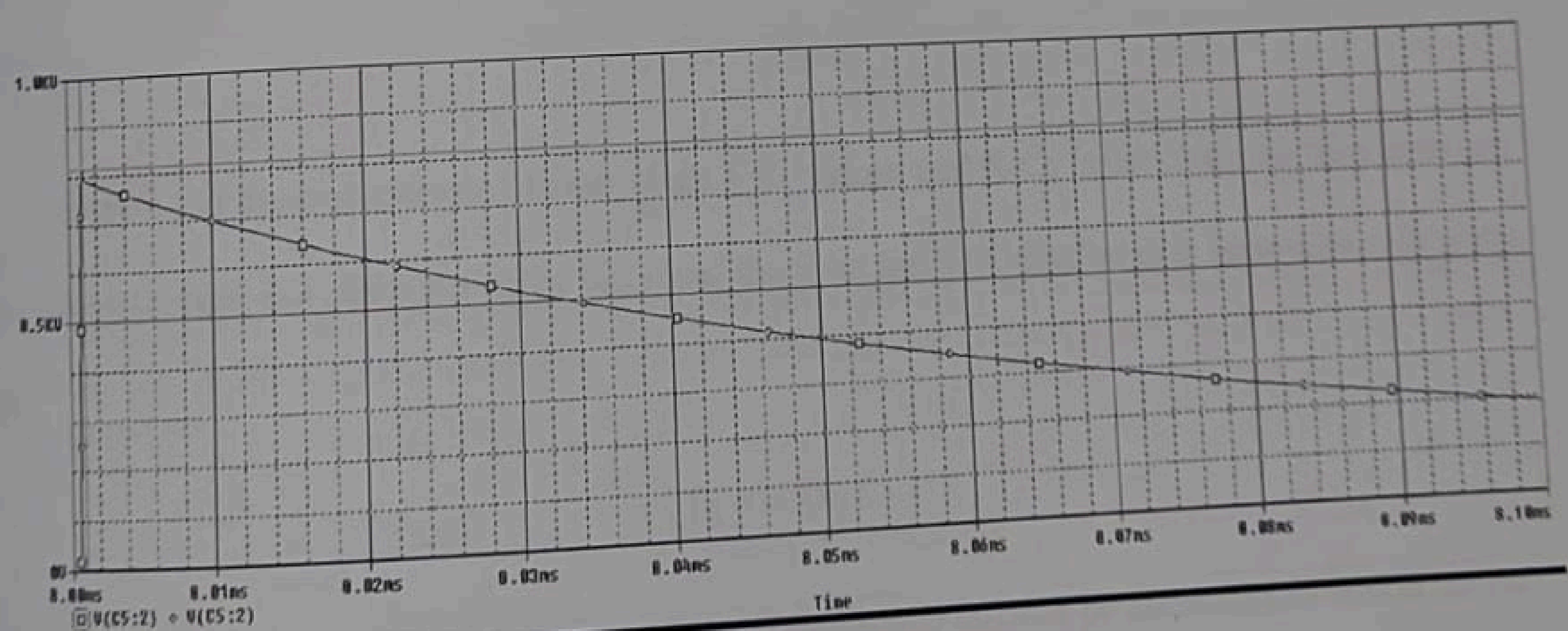
| | X Values | 8.0010m | 8.0000m | 973.612n | | Y1 - Y1(Cursor1) | Y2 - Y2(Cursor2) | Max Y | Min Y | Avg Y |
| CURSOR 1,2 | V(C5:2) | 601.164 | 2.1663 | 598.997 | | 0.000 | 0.000 | 601.164 | 2.1663 | 301.665 |
| | V(C5:2) | 599.381 | 2.1665 | 597.214 | | -1.7828 | 205.555u | 599.381 | 2.1665 | 300.774 |

**Fig. 8 Three Stage Impulse Votage Generator for Lightning**

## 5.7 Lightning Impulse Simulation for Four-Stages:

Further to develop higher voltage the circuit can be modified with parallel C1 to achieve desired terminal voltage. The schematic of the simulated generator is shown in Fig. 9.

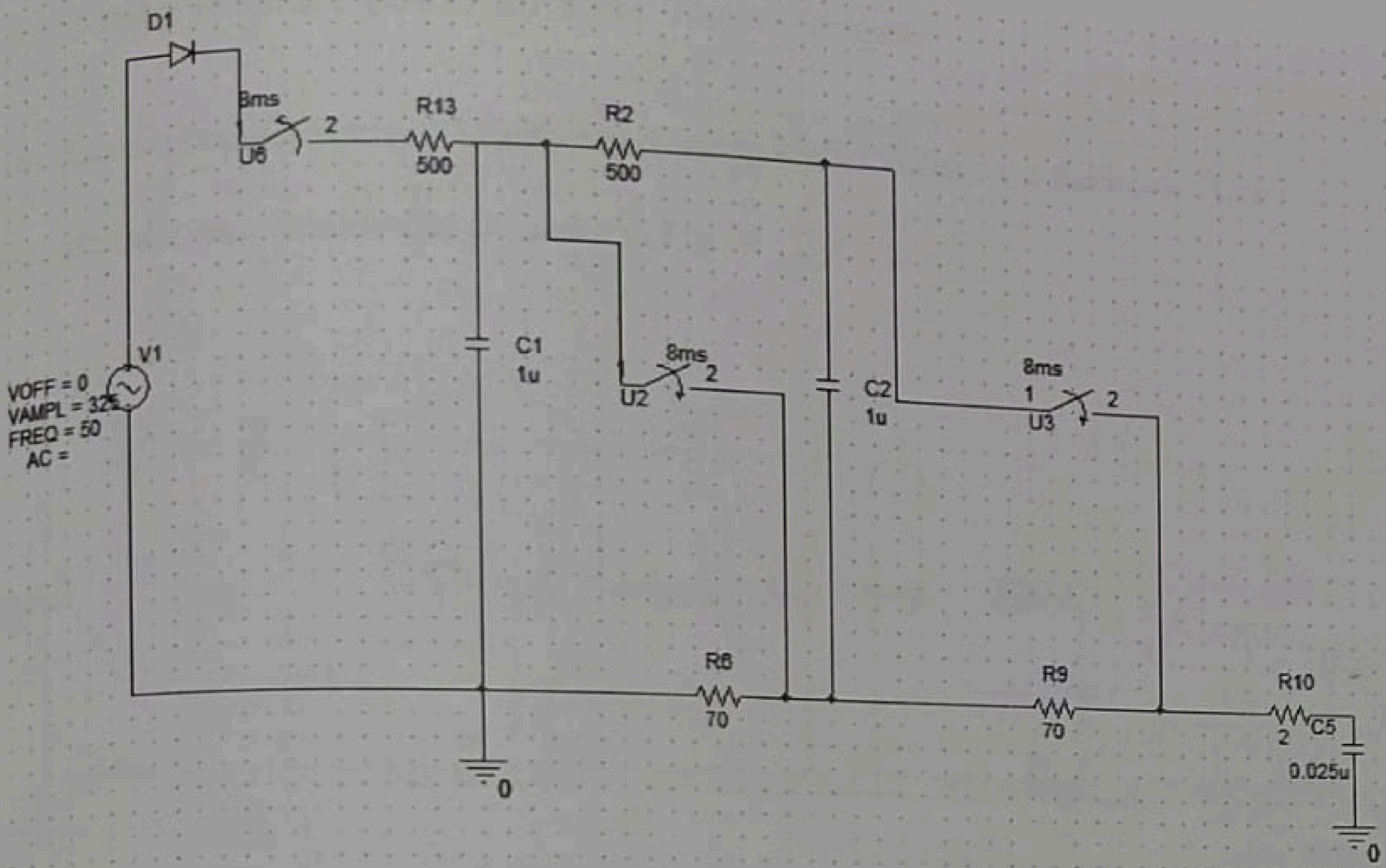


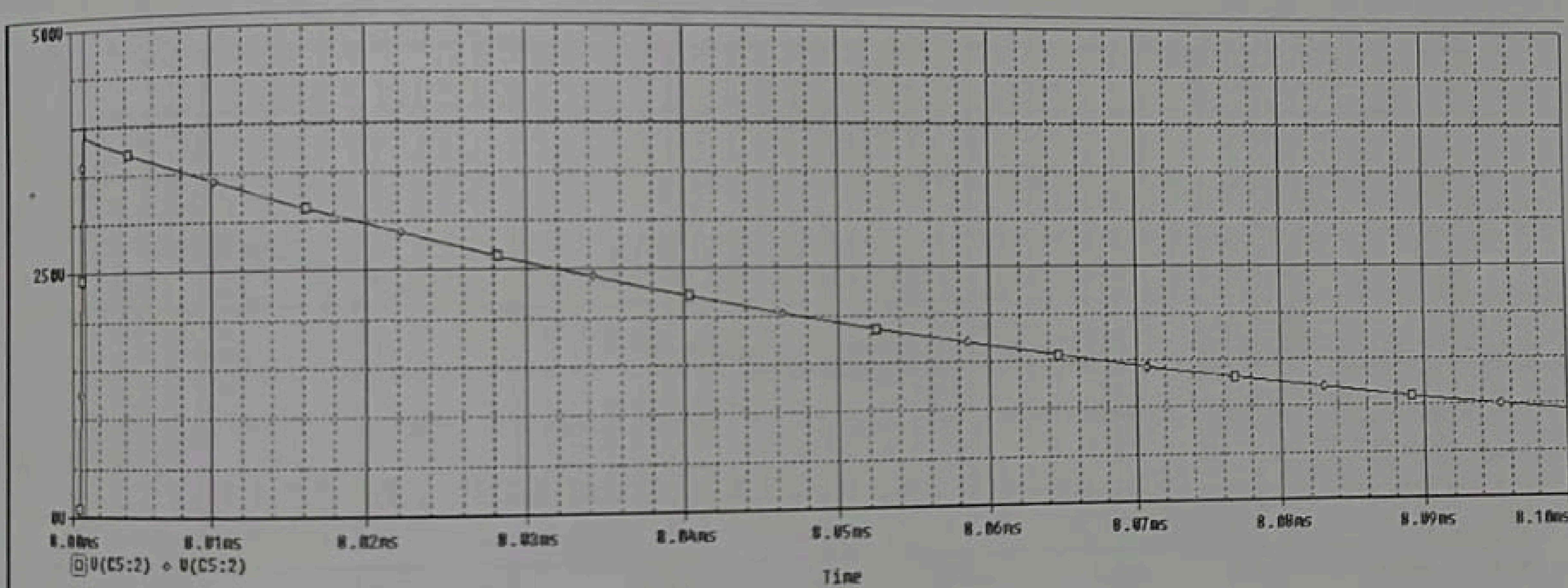



| Trace Color | Trace Name | Y1 | Y2 | Y1 - Y2 |
|---|---|---|---|---|
| | X Values | 8.0010m | 8.0000m | 973.612n |
| CURSOR 1,2 | V(C5:2) | 815.002 | 2.9374 | 812.065 |
| | V(C5:2) | 811.651 | 2.9377 | 808.713 |

| Y1(Cursor1) - Y2(Cursor2) | | 812.065 | | |
|---|---|---|---|---|
| Y1 - Y1(Cursor1) | Y2 - Y2(Cursor2) | Max Y | Min Y | Avg Y |
| 0.000 | 0.000 | 815.002 | 2.9374 | 408.970 |
| -3.3515 | 278.511u | 811.651 | 2.9377 | 407.294 |

**Fig. 9 Four Stage Impulse Votage Generator for Lightning**




| Trace Color | Trace Name | Y1 | Y2 | Y1 - Y2 | | Y1(Cursor1) - Y2(Cursor2) | | 399.607 | | |
|---|---|---|---|---|---|---|---|---|---|---|
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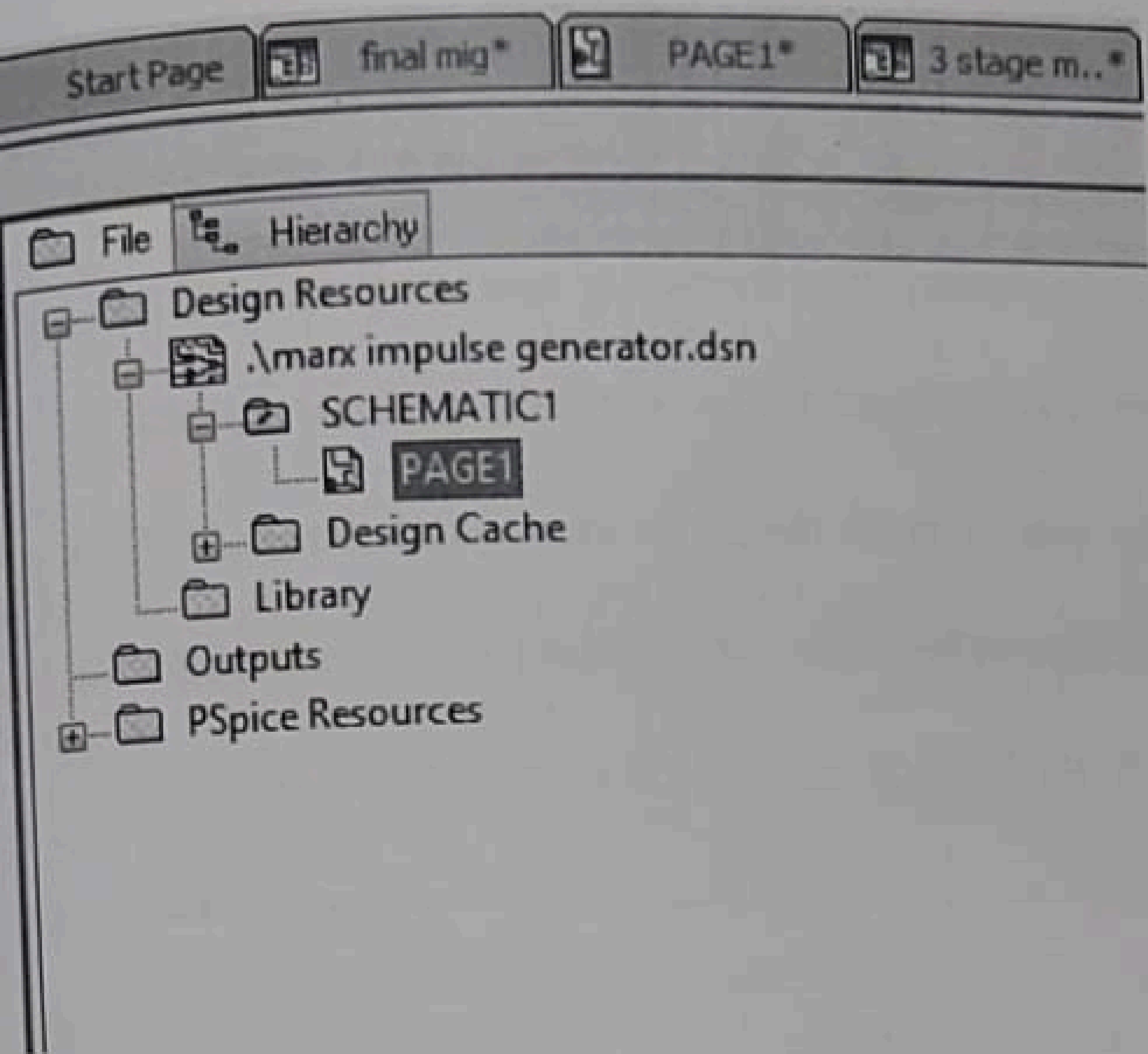
| | X Values | 8.0010m | 8.0000m | 979.200n | | | | | | |
| CURSOR 1,2 | V(C5:2) | 401.050 | 1.4432 | 399.607 | | 0.000 | 0.000 | 401.050 | 1.4432 | 201.247 |
| | V(C5:2) | 399.381 | 1.4433 | 397.938 | | -1.6695 | 136.668u | 399.381 | 1.4433 | 200.412 |

**Fig. 7 Two Stage Impulse Votage Generator for Lightning**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SCHEMATIC1
PAGE1
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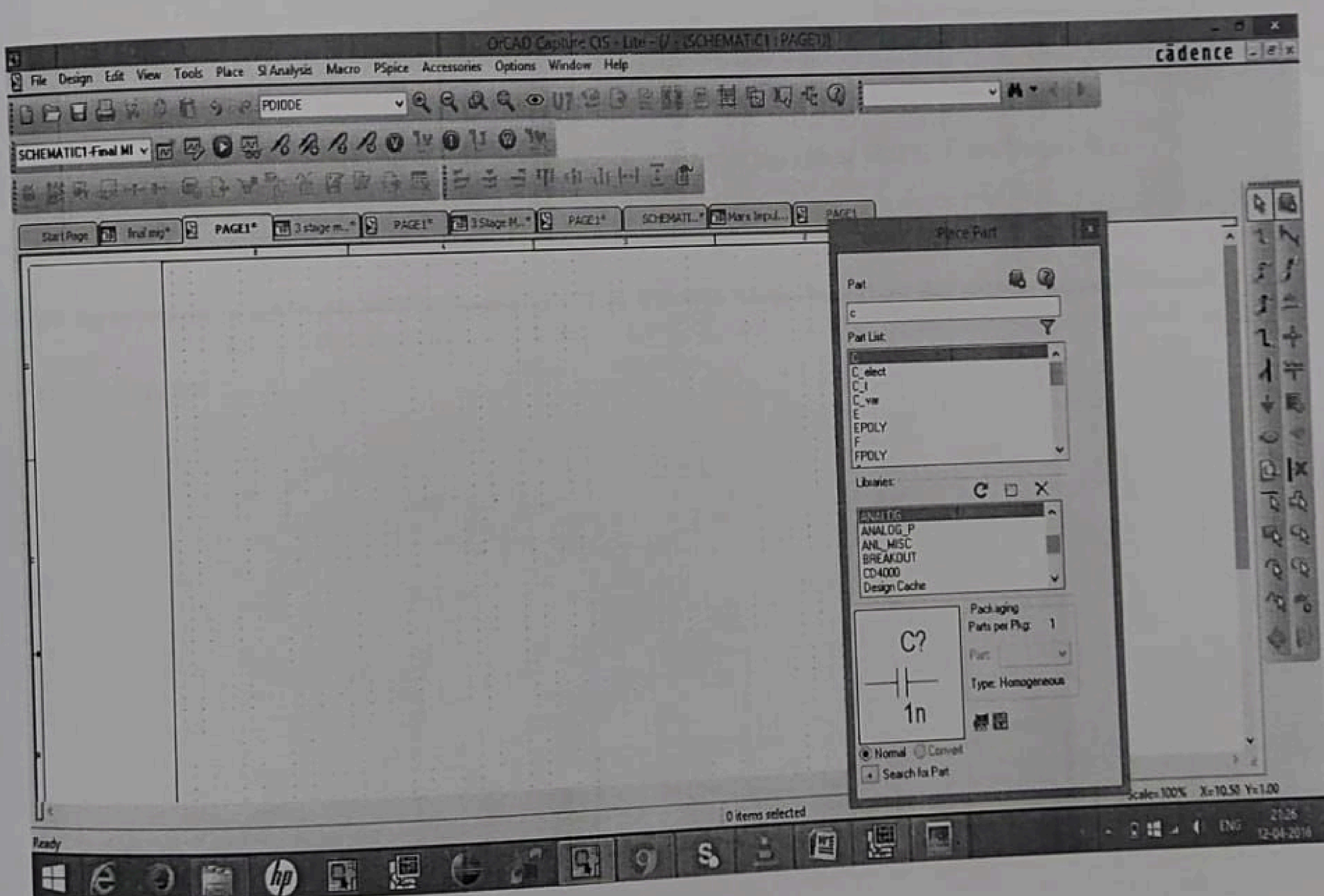
Outputs
PSpice Resources


cadence
File Design Edit View Tools Place SI Analysis Macro PSpice Accessories Options Window Help
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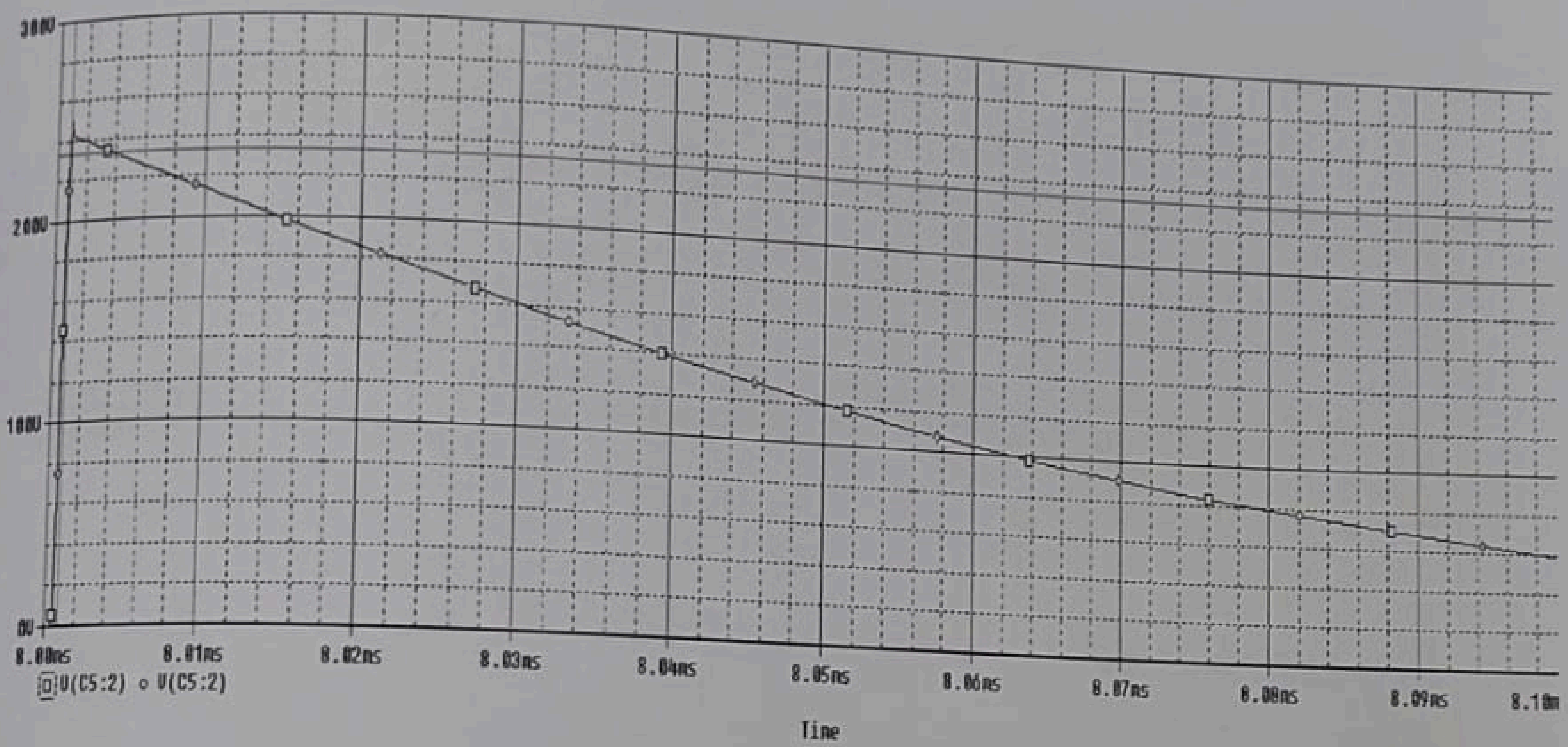
C_I
C_var
E
EPOLY
F
FPOLY
Libraries
ANALOG
ANALOG_P
ANL_MISC
BREAKOUT
CD4000
Design Cache
C?
1n
Packaging
Parts per Pkg: 1
Type: Homogeneous
Normal
Search for Part
0 items selected
Ready



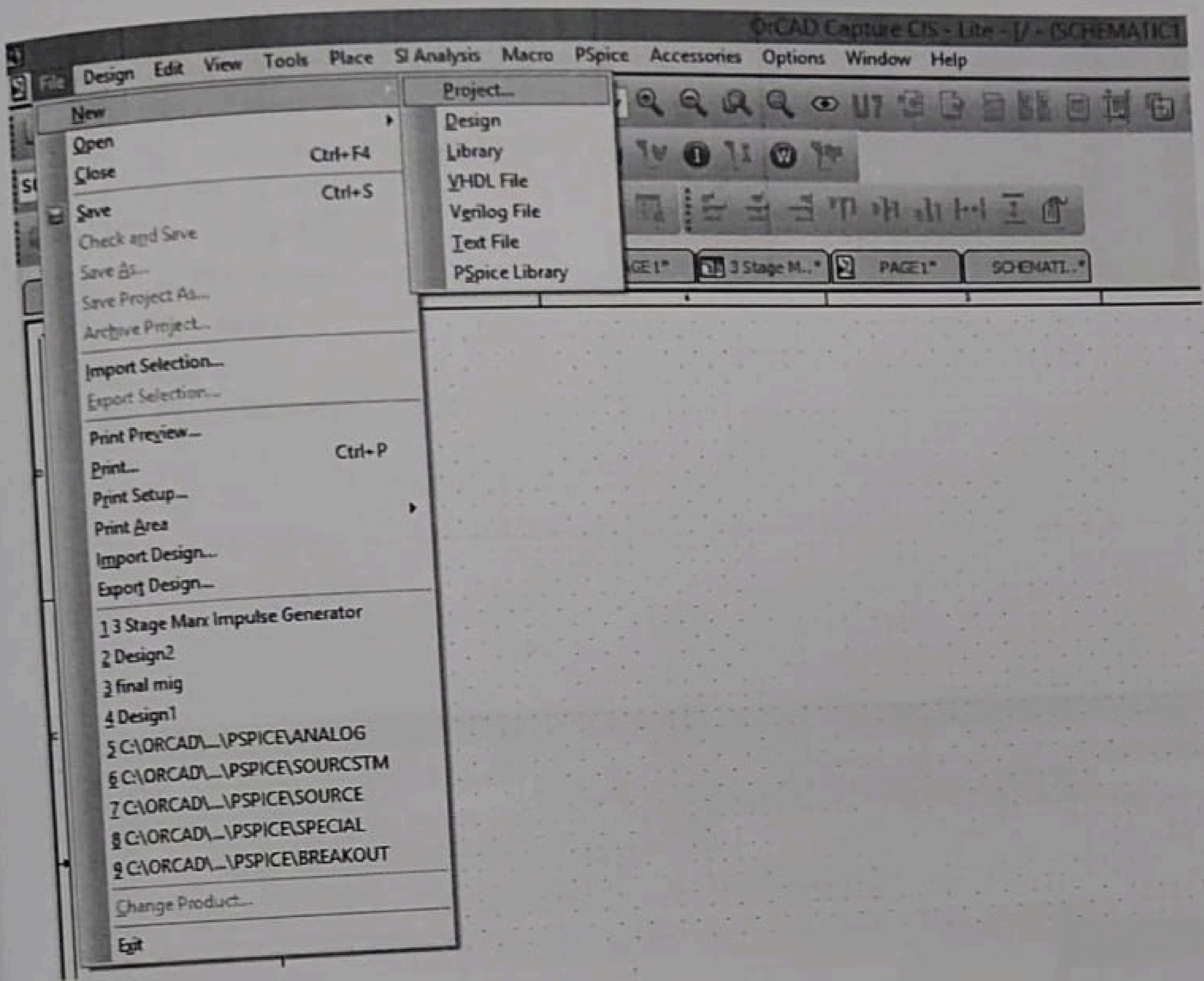

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Trace Color | Trace Name | Y1 | Y2 | Y1 - Y2 | | Y1(Cursor1) - Y2(Cursor2) | | 232.225 | | |
| | X Values | 8.0009m | 8.0000m | 892.815n | | Y1 - Y1(Cursor1) | Y2 - Y2(Cursor2) | Max Y | Min Y | Avg Y |
| CURSOR 1,2 | V(C5:2) | 233.127 | 901.595m | 232.225 | | 0.000 | 0.000 | 233.127 | 901.595m | 117.014 |
| | V(C5:2) | 233.127 | 901.680m | 232.225 | | 0.000 | 84.954u | 233.127 | 901.680m | 117.014 |

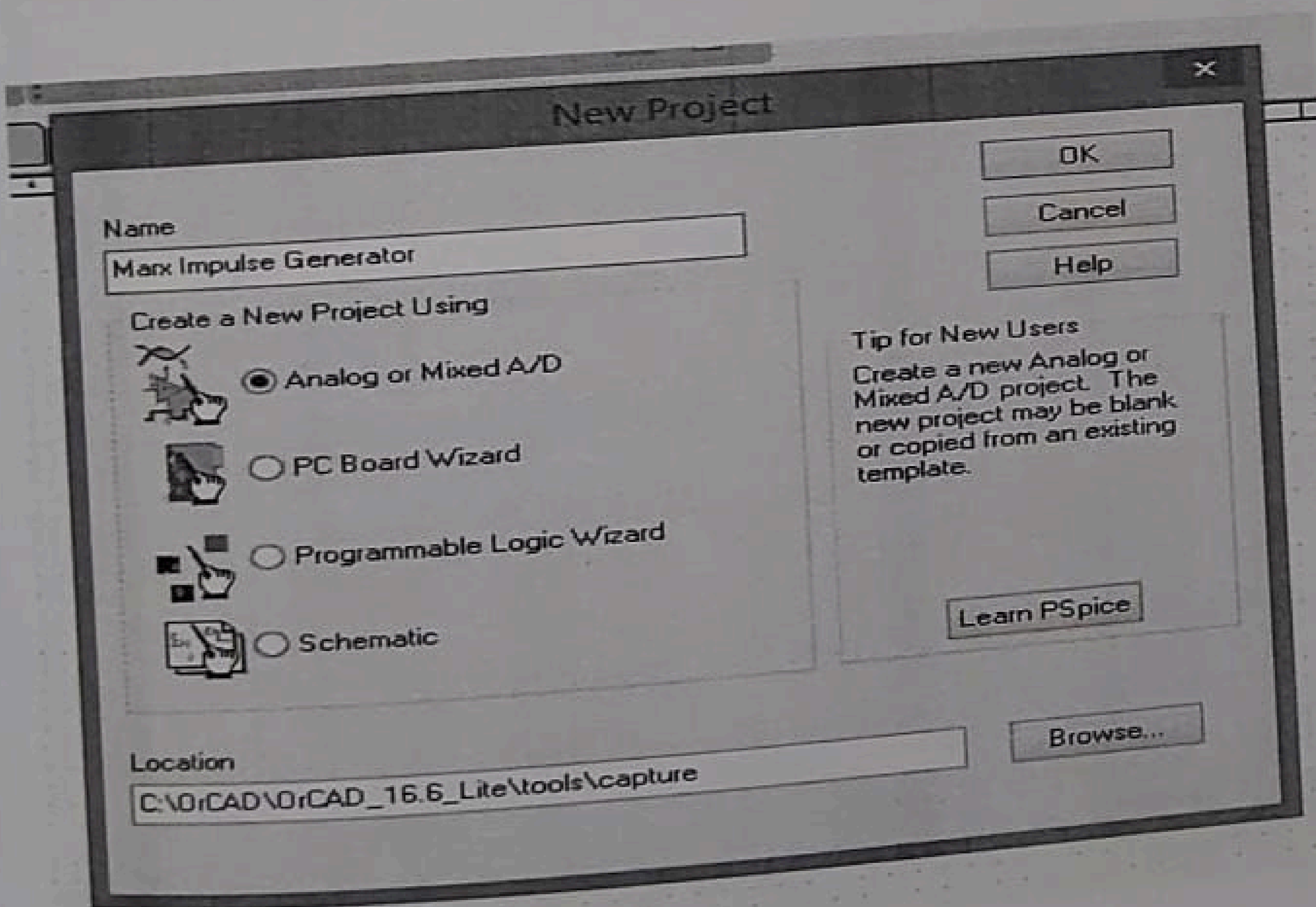
**Fig. 6 Single Stage Impulse Votage Generator for Lightning**

## 5.5 Lightning Impulse Simulation for Two-Stages:

Since implementation of single stage impulse voltage generator has associate difficulties such as complexities in fabricating large spark gaps, difficulties in designing bulky storage capacitors(C1 & C2) etc.. Two stage impulse voltage generator was simulated using PSPICE Software to ascertain the capability of the proposed multi stage generator kit to develop higher voltage. The schematic of the simulated generator is shown in Fig. 7.

## 5.3 Procedure for Impulse Voltage Generator Simulation using PSPICE ORCAD :



Let

$$V_n = \frac{V_0}{2\beta R_1 C_2}$$

$$v(t) = V_n\,[e^{-(\alpha-\beta)t} - e^{-(\alpha+\beta)t}]$$

Let $t_1$ be the wave front time and $t_2$ the wave tail time, then both $\alpha$ and $\beta$ must have unique values irrespective of the particular circuit used.

At time $t_1$, the shope of the wave is zero, therefore, $t_1$ can be obtained from the relation $dv(t)/dt = 0$

$$\frac{dv\,(t)}{dt} = V_n[-(\alpha-\beta)\,e^{-(\alpha-\beta)t} + (\alpha+\beta)\,e^{-(\alpha+\beta)t}] = 0$$

$$\frac{\alpha+\beta}{\alpha-\beta} = e^{2\beta t_1}$$

$$2\beta t_1 = \ln\frac{\alpha+\beta}{\alpha-\beta}$$

$$t_1 = \frac{1}{2\beta}\ln\frac{\alpha+\beta}{\alpha-\beta}$$

and the peak value of the voltage is then given by

$$v_m(t) = V_n\,[e^{-(\alpha-\beta)t_1} - e^{-(\alpha+\beta)t_1}]$$

To obtain $t_2$, substitute $t = t_2$ in the equation and the voltage is half of what it is when $t = t_1$ in the same equation *i.e.*

$$V_n\,[e^{-(\alpha-\beta)t_2} - e^{-(\alpha+\beta)t_2}] = \frac{V_n}{2}\,[e^{-(\alpha-\beta)t_1} - e^{-(\alpha+\beta)t_1}]$$

### 6.3 Hardware Implementation & Verifications:

As per the Marx Impulse Voltage Generator circuit the practical working model kit is made as in the Fig. 10. In the working model suitable value of capacitor is connected at the front end resistances. The value of front end resistors can be varied using knobs of the POTs available. The values of front end resistance can be changed to suit the standard wave shape.

The kit fabricated as per the circuit diagram with following components:

| | | |
|---|---|---|
| Capacitor 1μF ($C_1$) | - | 4 Nos. connected in parallel |
| Capacitor 0.1μF($C_2$) | - | 4 Nos. connected in series |
| POT resistance 10kΩ ($R_1$) | - | 4 Nos. connected as current limiting resistor |
| Resistance 20Ω ($R_2$) | - | 4 Nos. connected in series |
| Resistance 2Ω ($R_3$) | - | 1 No connected as a load |
| Diode (BY 127) | - | 4 Nos. |
| Connecting Wires | - | As Req. |
| Probes | - | 2 Nos. |
| Soldering wire and Flux | - | As Req. |
| Connecting Terminals | - | 43 Nos. |
| Variac 220/480 V | - | 1 No |

# Chapter 6

# 6. Design & Development of Marx Voltage Generator

## 6.1 One Stage Marx Generator Circuit:

Lightning impulse voltage wave of 1.2/50 μs, the peak impulse voltage appearing across the test object is higher. Referring to Fig-1 the desired impulse voltage wave shape of time 1.2/50 μs is obtained by controlling the value of $R_1$ and $R_2$. The following approximate analysis is used to calculate the wave front time $T_1$ and the wave tail time $T_2$. The resistance $R_2$ is very large. Hence time taken for charging is approximately three times the time constant of the circuit and is given by the formula given below,

$$T_1 \sim 3R_2C_2$$

Here $C_2$ is the capacitance of sum of all $1/C_1$ values and $R_2C_2$ is the charging time constant in micro-second. For discharging or tail time, the time for 50% discharge is approximately given as,

$$T_2 = 0.7R_1C_1$$

With approximate formulae the wave front and wave tail can be estimated to within ±20% for the standard impulse waves.Above equations can be written as:

$$R_1 = T_1/3C_2$$

$$R_2 = T_2/0.7C_1$$

The above pictures show the connections of major components utilized in the development of Marx Impulse Voltage Generator.

## 6.4 Overall Arrangement and Layout:

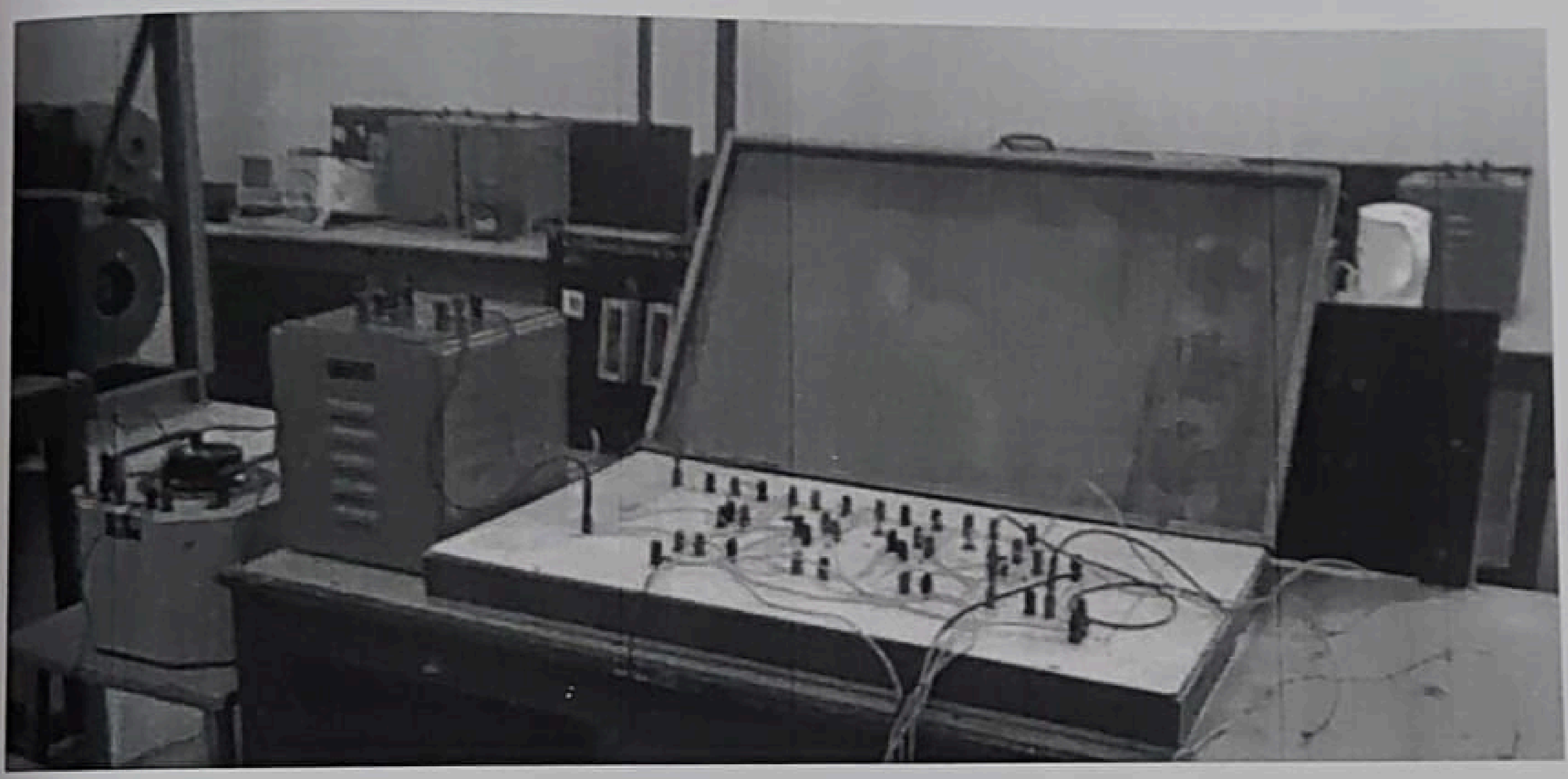


**Fig. 12 Arrangement**

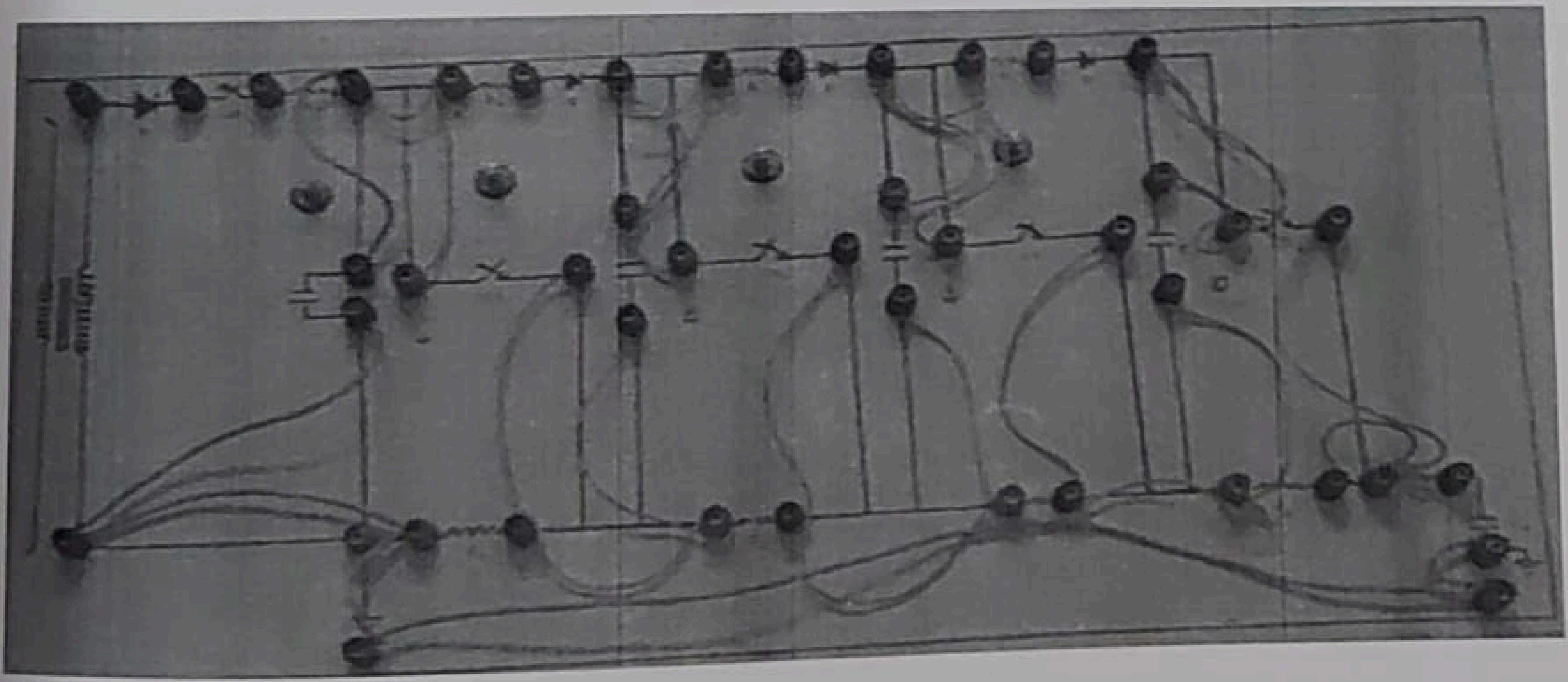


**Fig. 13 Implementation**


**Fig. 16 Lightning Impulse Voltage Wave for Four Stages**

| InputVoltage availed from a.c mains (RMS)in Volts | No. of. Stages | Lightning impulse voltage( peak value) in Volts |
|---|---|---|
| 60 | 4 | 282 |

# Chapter 8

## 8. Conclusion

The generation of Lightning impulse (LI) voltage is implemented in Marx impulse voltage generator kit and also in the simulation with the PSPICE software environment.

It is found that the overall simulated result and the observed impulse voltage result from the experimental setup is close to standard impulse generator for Lightning impulse (LI) 1.2 µs / 50 µs wave shape for all the stages of Marx generator.

The wave shapes are controlled by changing stage front resistor and tail resistor. Rise time is controlled by changing stage front resistor and tail time is controlled by changing tail resistor. Peak value of each impulse wave is varied by changing initial charging of stray capacitance or current limiting resistors.

The tolerances that is allowed in the front and tail times are respectively ±30% and ±20%. Rise time and tail time of impulse voltage wave obtained from simulated data are within limits, but variation in rise time and fall time of practical Marx circuit is due to following reasons. For obtaining maximum peak voltage the ratio of capacitance of charging capacitor and discharging capacitor is taken. The error in rise time and fall time is because of some tolerance label in damping resistor and discharging resistor and the tolerance. Allowable tolerance in the peak voltage is ±3%.

It is also observed that a small change in the resistance value can cause significant change in rise time and fall time of the impulse voltage. In the practical impulse generation circuit model sphere gap is replaced by MCB switch so that all the capacitors are discharged at one instant. In this work, generation of high impulse voltage wave shape observed in the DSO. There is an oscillation in the front wave because of manual switching. This can be corrected in future by replacing an electronic switch like IGBT or SCR etc.

Third stage and fourth stage impulse voltage tests for Lightning impulse were conducted in the HV lab and observations were listed in the chapter-VII. Further another more stages can also be tested in future.

# References

[1] RamlethSheeba, MadhavanJayaraju, ThangalKunjuNediyazhikamShanavas, "Simulation of Impulse Voltage Generator and Impulse Testing of Insulator using MATLAB Simulink", World Journal of Modelling and Simulation, Vol. 8 – 2012.

[2] Schon.k, "High impulse voltage and current measurement techniques and measuring methods", springer-2013.

[3] Anitya Kumar Shukla, Dr. Ranjana Singh, "Analysis of Impulse Voltage Generator and Effect of Variation in Parameters by Simulation",
International Journal of Electrical and Electronics Research, Vol. 2, Issue 3.

[4] M. Jayaraju, I. Daut, M. Adzman, "Impulse voltage generator modelling using MATLAB", World Journal of Modelling and Simulation Vol. 4(2008) No. 1, pp. 57-63.

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**Observation:**

1) More than ten numbers of samples are taken, the samples are repeatedly same wave shape and values are observed in the DSO.
2) While taking the samples peak overshoot is found in the output, because of manual switching instead of air gap.
3) The samples are taken in various scale factors.
4) The samples are taken by using the MCB switch instead of manual switching.
5) A small transformer primary and secondary winding insulation checked by injecting the lightning impulse wave is observed that there is sag in the wave shape which is allowable range as per the standard.

**Analysis:**

1) The impulse wave shape is as per standard due to the $R_1$, $R_2$, $C_1$, $C_2$ are acceptable values.
2) The switching error will be corrected by using proper electronic switch.

The lightning impulse tests were conducted utilizing the Marx Test Kit along with proper probe connected to Yokogawa make DL 1620 DSO of 200MHz, 2.5 Giga Samples/ second, two channel instrument for output observation.

**Fig. 17 Overall Circuit Connections**

To ensure repeatability of results during implementation, the impulse tests are conducted for several case-studies. The following major observations have been summarized.

# Chapter 7

# 7. Observation & Analysis

## 7.1 Observation & Analysis of Impulse Voltage Response due to Lightning:


Fig. 15 Lightning Impulse Voltage Wave for Three Stages

| InputVoltage availed from a.c mains (RMS)in Volts | No. of. Stages | Lightning impulse voltage( peak value) in Volts |
|---|---|---|
| 60 | 3 | 208 |

## 6.5 Internal Circuit Connections:

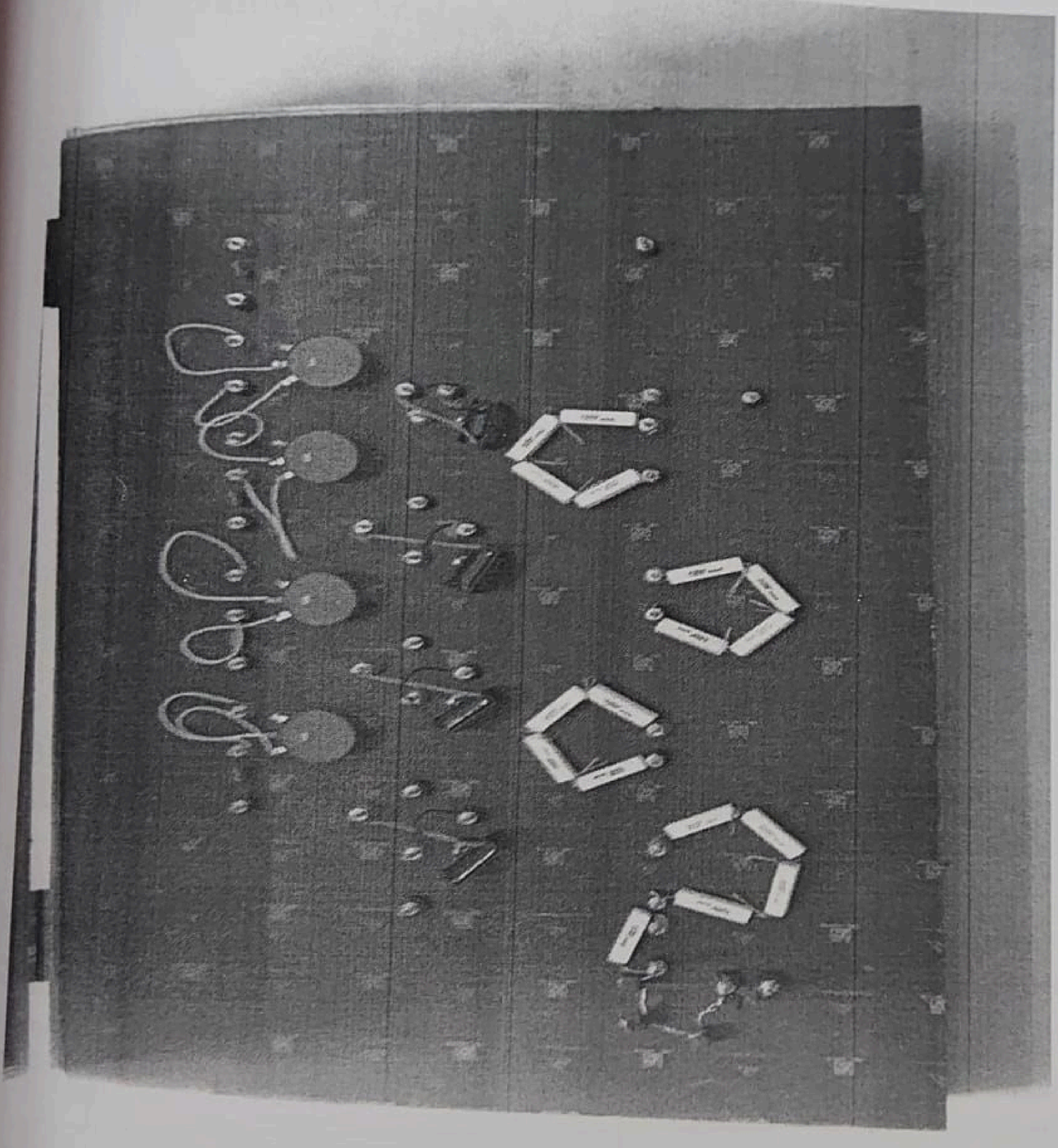

Fig. 14 Internal Circuit Connections

**Conception of Marx Impulse Voltage Generator Kit:**

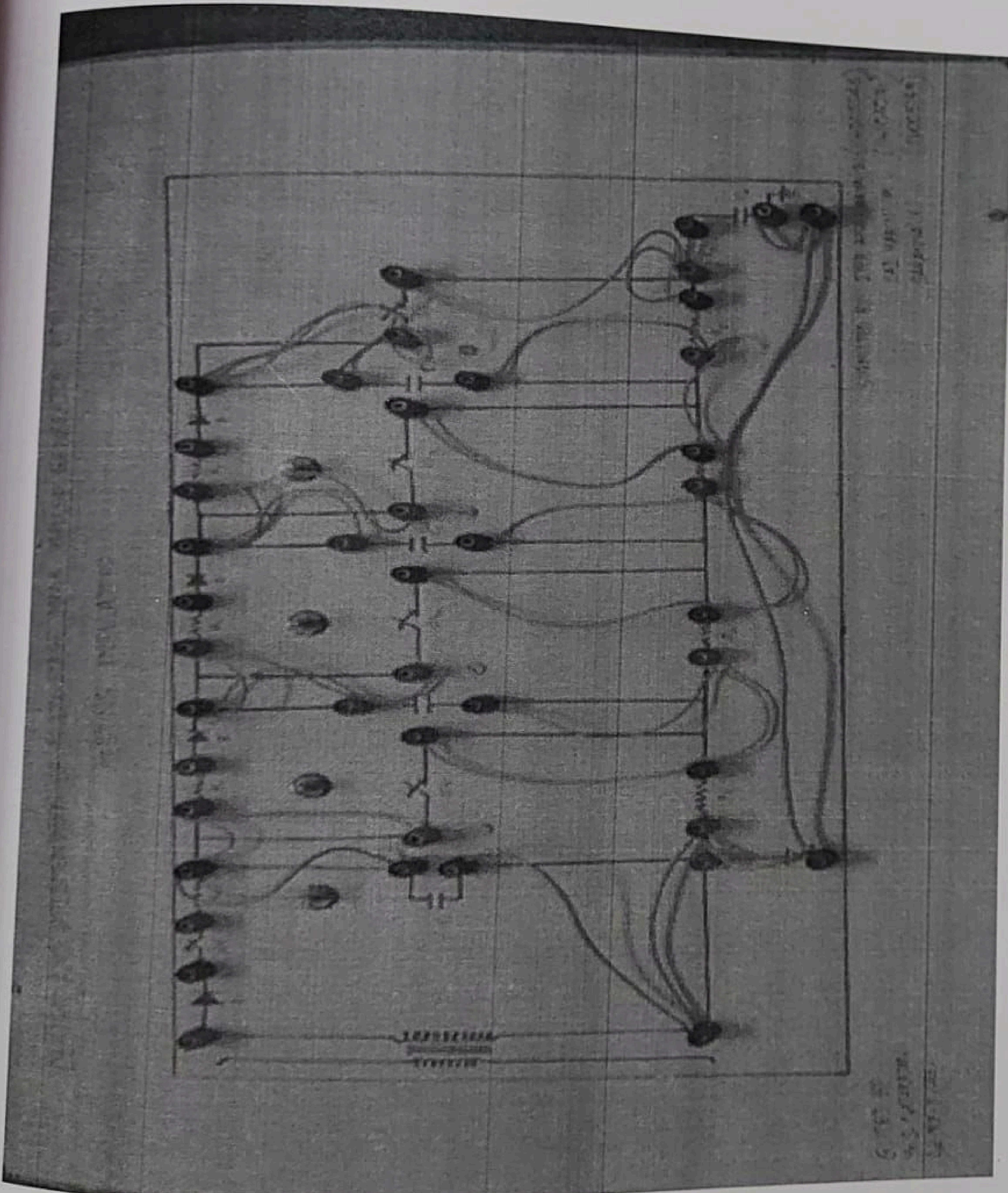

Fig. 10 Circuit Diagram of Marx Impulse Voltage Generator

The following Fig.11 shows the typical components of Marx Impulse Voltage Generator kit.

**Fig. 11 Components**

## 6.2 Multi Stage Marx Generator Circuit:

In Multistage Marx Impulse Generator circuit peak impulse voltage depend on the number of stages included in the circuit. So in Multistage Marx Generator circuit peak impulse voltage is equal to input voltage applied multiplied by number of stages. For calculating the value of damping resistor, all the charging capacitors which are connected in parallel should be taken into account. Hence $C_1$ will be replaced by $C_1/n$ where n is the number of stages. The value of charging and discharging capacitor remain same as in the one stage Marx circuit.