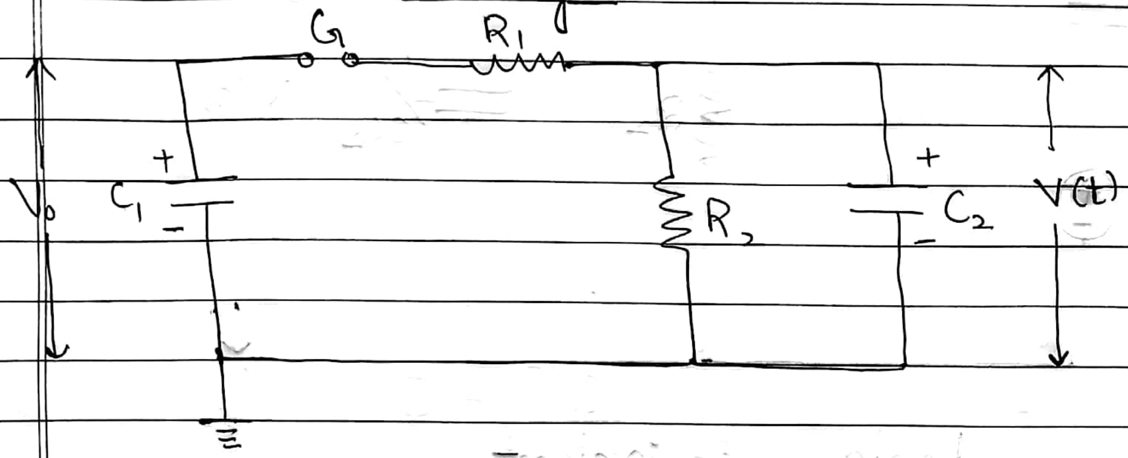
Generation of Impulse Voltages

Basic Circuit for generation of impulse voltage



$C_1 \rightarrow$ Generator Capacitance

$R_1, R_2 \rightarrow$ wave shaping resistors.

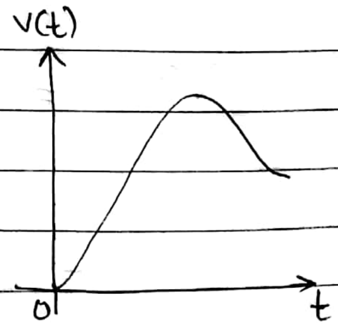
$C_2 \rightarrow$ primarily consists of the test object Capacitance.

$G \rightarrow$ spark gap (which is set of two electrodes forms a uniform field gap)

G acts as a voltage sensitive switch.

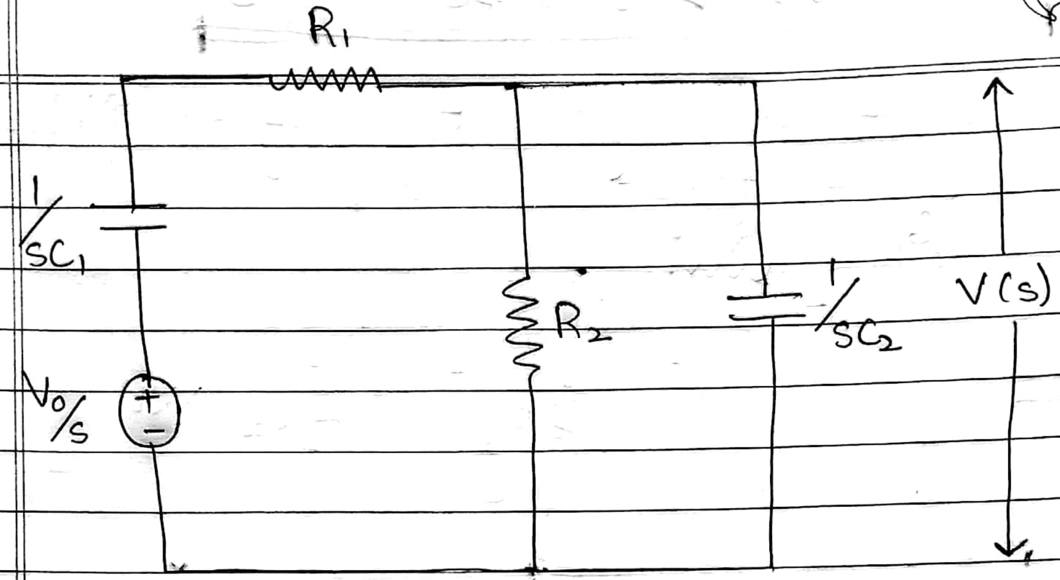
Since $R_1 << R_2$

Initially C_1 will discharge via R_2 through C_2 then a time reaches when voltages of C_1 & C_2 will be same & they will discharge through R_2.



Since R_1 Controls the rising portion of impulse, so R_1 is known as wave front resistor

R_2 Controls falling portion of impulse so R_2 is known as wave tail resistor.



Laplace equivalent.

$$V(s) = \frac{Z_2}{Z_1 + Z_2} \cdot \frac{V_0}{s} \quad — ①$$

Where $Z_1 = R_1 + \frac{1}{sC_1} = \frac{R_1C_1s + 1}{sC_1} \quad — ②$

$$Z_2 = R_2 \parallel \frac{1}{sC_2} = \frac{R_2 \cdot \frac{1}{sC_2}}{R_2 + \frac{1}{sC_2}}$$

$$Z_2 = \frac{R_2}{R_2C_2s + 1} \quad — ③$$

$$V(s) = \frac{V_0}{s} \cdot \frac{1}{1 + \frac{Z_1}{Z_2}}$$

$$V(s) = \frac{V_0}{s} \cdot \frac{1}{1 + \frac{(R_1C_1s + 1)}{sC_1} \cdot \frac{(R_2C_2s + 1)}{R_2}}$$

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$$V(s) = \frac{V_0}{s} \cdot \frac{1}{1 + \frac{R_1R_2C_1C_2s^2 + (R_1C_1 + R_2C_2)s + 1}{R_2C_1s}}$$

$$V(s) = \frac{V_0}{s} \cdot \frac{1}{\frac{R_1R_2C_1C_2s^2 + (R_1C_1 + R_2C_2 + R_2C_1)s + 1}{R_2C_1s}}$$

$$V(s) = \frac{V_0}{R_1C_2} \cdot \frac{1}{s^2 + \left(\frac{1}{R_1C_1} + \frac{1}{R_2C_2} + \frac{1}{R_1C_2}\right)s + \frac{1}{R_1R_2C_1C_2}}$$

$$V(s) = \frac{V_0}{R_1C_2} \cdot \frac{1}{as^2 + bs + c} \quad \text{—} \; (4)$$

Where
$$\left.\begin{aligned} a &= 1 \\ b &= \frac{1}{R_1C_1} + \frac{1}{R_2C_2} + \frac{1}{R_1C_2} \\ c &= \frac{1}{R_1R_2C_1C_2} \end{aligned}\right\} \text{—} \; (5)$$

$b = \alpha + \beta$ & $c = \alpha\beta$.
where $-\alpha$ & $-\beta$ are the roots of
$as^2 + bs + c = 0$

$$-\alpha, -\beta = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}.$$

$$\alpha, \beta = \frac{b}{2} \mp \sqrt{\left(\frac{b}{2}\right)^2 - c} \quad \text{—} \; (6)$$

$\alpha < \beta$

$\Rightarrow \frac{1}{\alpha} > \frac{1}{\beta}$

$$V(s) = \frac{V_0}{R_1 C_2}\left\{\frac{1}{(s+\alpha)} \cdot \frac{1}{(s+\beta)}\right\}$$

$$V(s) = \frac{V_0}{R_1 C_2(\beta-\alpha)}\left\{\frac{1}{s+\alpha} - \frac{1}{s+\beta}\right\}$$

Taking inverse Laplace.

$$\boxed{V(t) = \frac{V_0}{R_1 C_2(\beta-\alpha)}\left\{e^{-\alpha t} - e^{-\beta t}\right\}} \quad \text{--- (8)}$$

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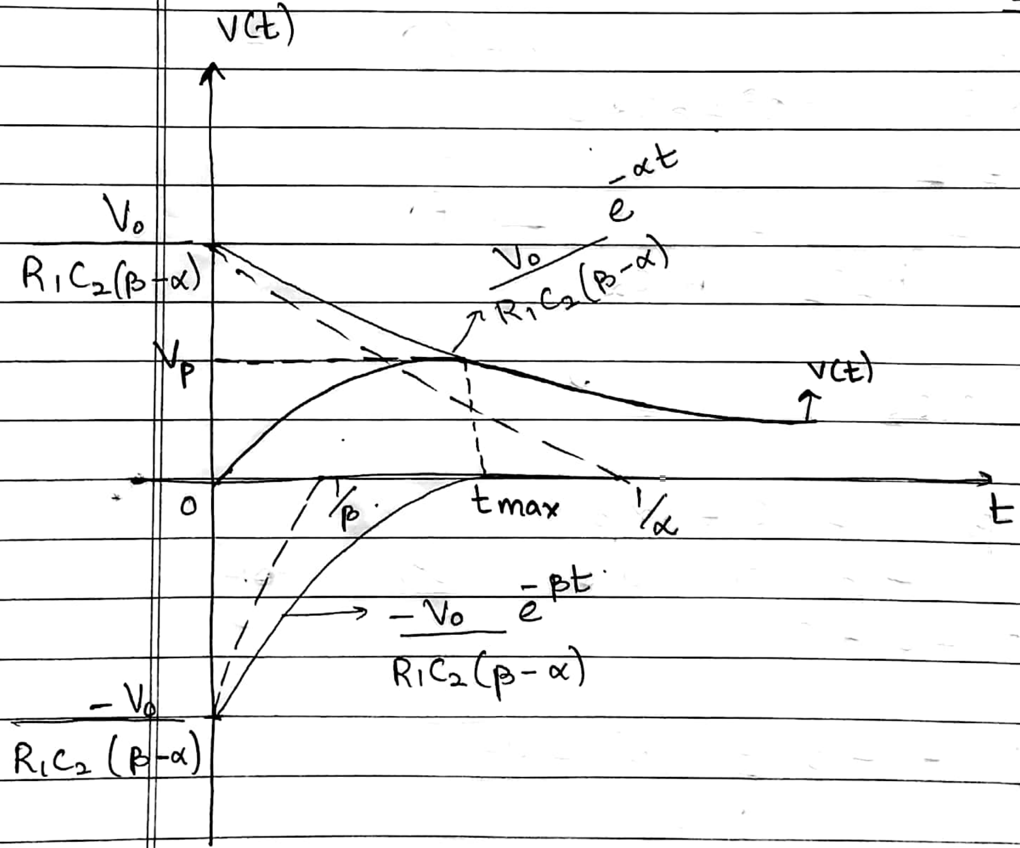
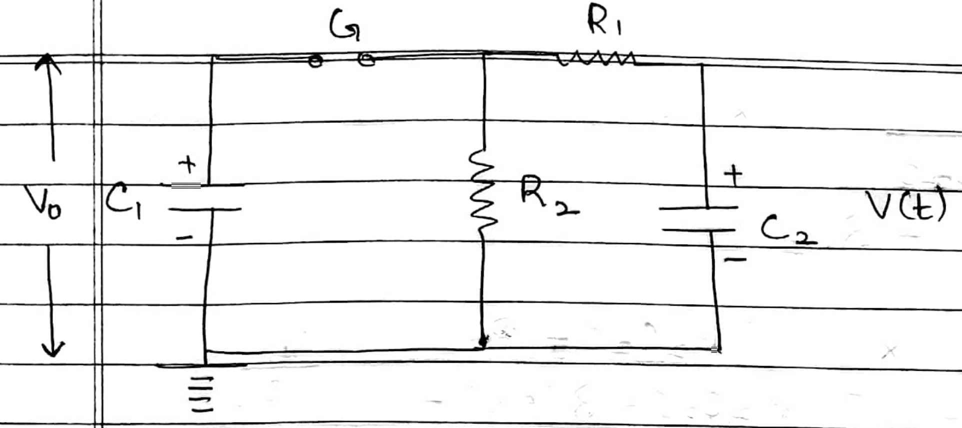
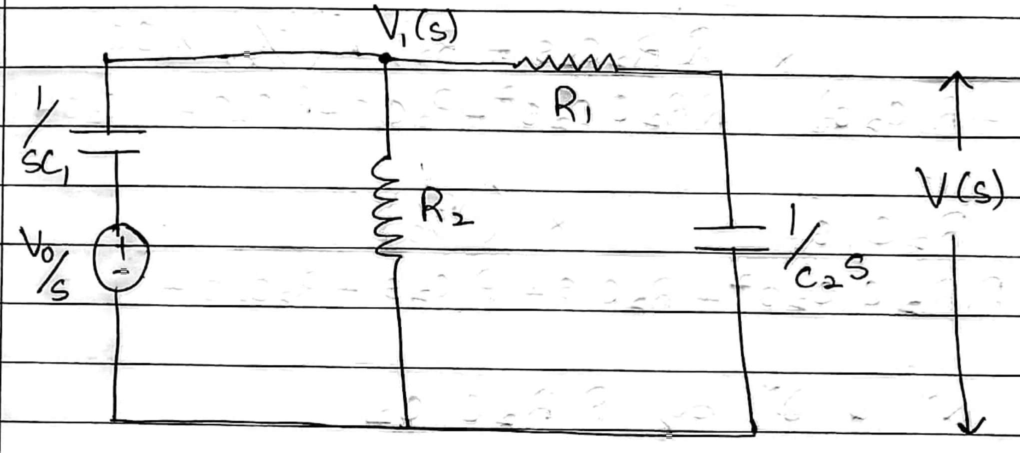


This wave shape is also known as Double exponential waveform or waveshape.



Laplace equivalent



$$Z_1 = R_1 + \frac{1}{C_2 s} = \frac{R_1 C_2 s + 1}{C_2 s}$$

$$Z_2 = \frac{R_2 \left(\frac{R_1 C_2 s + 1}{C_2 s} \right)}{R_2 + \frac{R_1 C_2 s + 1}{C_2 s}}$$

$$Z_2 = \frac{R_1 R_2 C_2 s + R_2}{R_2 C_2 s + R_1 C_2 s + 1}$$

By voltage divider rule.

$$V_1(s) = \frac{Z_2}{Z_2 + \frac{1}{sC_1}} \cdot \left(\frac{V_0}{s} \right)$$

$$V(s) = \frac{\frac{1}{C_2 s}}{\frac{1}{C_2 s} + R_1} \times V_1(s)$$

$$V(s) = \frac{1}{1+R_1C_2s} \times \frac{\frac{R_1R_2C_2s + R_2}{R_2C_2s + R_1R_2s + 1}\left(\frac{V_0}{s}\right)}{\frac{R_1R_2C_2s+R_2}{R_2C_2s+R_1C_2s+1} + \frac{1}{sC_1}}$$

$$V(s) = \frac{1}{(1+R_1C_2s)} \times \frac{(R_1R_2C_2s + R_2) \times (V_0/s) \times sC_1}{R_1R_2C_1C_2s^2 + R_2C_1s + R_1C_2s + R_2C_2s + 1}$$

$$V(s) = \frac{R_2C_1s}{R_1R_2C_1C_2s^2 + R_2C_1s + R_1C_2s + R_2C_2s + 1} \times (V_0/s)$$

Divide N^r & D^r by $R_1R_2C_1C_2$

$$V(s) = \frac{V_0}{R_1C_2} \cdot \frac{1}{s^2 + \left(\frac{1}{R_1C_2} + \frac{1}{R_2C_1} + \frac{1}{R_1C_1}\right)s + \frac{1}{R_1R_2C_1C_2}}$$

$$V(s) = \frac{V_0}{R_1C_2} \cdot \frac{1}{as^2 + bs + c}$$

Where $a = 1$

$$b = \frac{1}{R_1C_1} + \frac{1}{R_1C_2} + \frac{1}{R_2C_1}$$

$$c = \frac{1}{R_1R_2C_1C_2}$$

Let $-\alpha$ & $-\beta$ be the roots of the $=^n$ $as^2 + bs + c$.

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$$-\alpha, -\beta = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$-\alpha, -\beta = \frac{-b}{2} \pm \sqrt{\left(\frac{b}{2}\right)^2 - c}$$

$$\alpha = \frac{b}{2} - \sqrt{\left(\frac{b}{2}\right)^2 - c} \; ; \; \beta = \frac{b}{2} + \sqrt{\left(\frac{b}{2}\right)^2 - c}$$

$$V(s) = \frac{V_0}{R_1 C_2} \cdot \frac{1}{(s+\alpha)(s+\beta)}$$

$$V(s) = \frac{V_0}{R_1 C_2 (\beta - \alpha)} \left\{ \frac{1}{s+\alpha} - \frac{1}{s+\beta} \right\}$$

Taking inverse laplace.

$$\boxed{V(t) = \frac{V_0}{R_1 C_2 (\beta - \alpha)} \left[e^{-\alpha t} - e^{-\beta t} \right]}$$

This circuit has higher voltage efficiency than the previous circuit.

Time to peak Value

$$\left.\frac{d(V(t))}{dt}\right|_{t=t_{max}} = 0$$

$$\frac{V_0}{R_1 C_2(\beta-\alpha)}\left\{-\alpha e^{-\alpha t_{max}} + \beta e^{-\beta t_{max}}\right\} = 0$$

$$\alpha e^{-\alpha t_{max}} = \beta e^{-\beta t_{max}}$$

$$\ln \frac{\alpha}{\beta} = \ln e^{(\alpha-\beta)t_{max}}$$

$$\ln \frac{\alpha}{\beta} = (\alpha-\beta)\, t_{max}$$

$$t_{max} = \frac{1}{\alpha-\beta} \ln \frac{\alpha}{\beta}$$

$$\boxed{t_{max} = \frac{1}{\beta-\alpha} \ln \frac{\beta}{\alpha}}$$

Voltage Efficiency of impulse generator

It is the ratio of the peak value of the output impulse voltage to charge voltage of Capacitor 'C_1'

$$\eta_v = \frac{V_p}{V_0}$$

$$\eta_v = \frac{\left.V(t)\right|_{t=t_{max}}}{V_0}$$

$$\eta_v = \frac{1}{R_1 C_2(\beta-\alpha)} \left\{ e^{\frac{-\alpha}{\alpha-\beta} \ln \frac{\alpha}{\beta}} - e^{\frac{-\beta}{\alpha-\beta} \ln \frac{\alpha}{\beta}} \right\}$$

$$\eta_v = \frac{1}{R_1 C_2(\beta-\alpha)} \left\{ e^{\ln \left(\frac{\alpha}{\beta}\right)^{\left(\frac{-\alpha}{\alpha-\beta}\right)}} - e^{\ln \left(\frac{\alpha}{\beta}\right)^{\left(\frac{-\beta}{\alpha-\beta}\right)}} \right\}$$

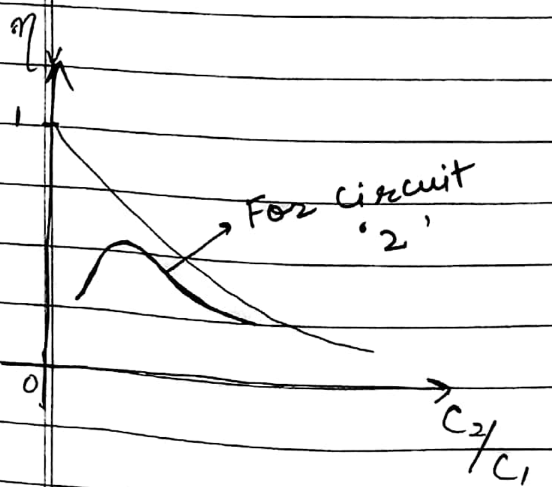
$$\boxed{\eta_v = \frac{1}{R_1 C_2(\beta-\alpha)} \left\{ \left(\frac{\alpha}{\beta}\right)^{\left(\frac{-\alpha}{\alpha-\beta}\right)} - \left(\frac{\alpha}{\beta}\right)^{\left(\frac{-\beta}{\alpha-\beta}\right)} \right\}}$$

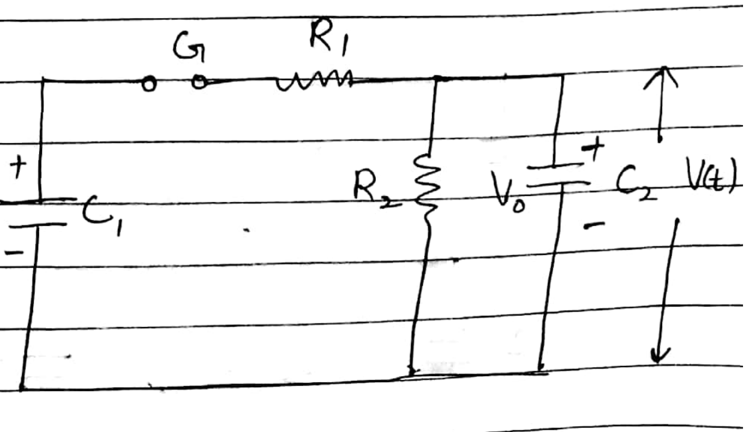
Assuming that the charge lost through R_2 is negligible during the period C_1 discharges C_2.

Initial charge of Capacitor C_1 = Sum of charges on Capacitors C_1 & C_2 at the peak voltage.

$$C_1 V_0 = C_1 V_p + C_2 V_p$$
$$C_1 V_0 = (C_1 + C_2) V_p.$$

$$\Rightarrow \boxed{\eta_v = \frac{V_p}{V_0} = \frac{C_1}{C_1 + C_2} = \frac{1}{1 + C_2/C_1}}$$





Circuit 2.

Multistage Impulse Generator

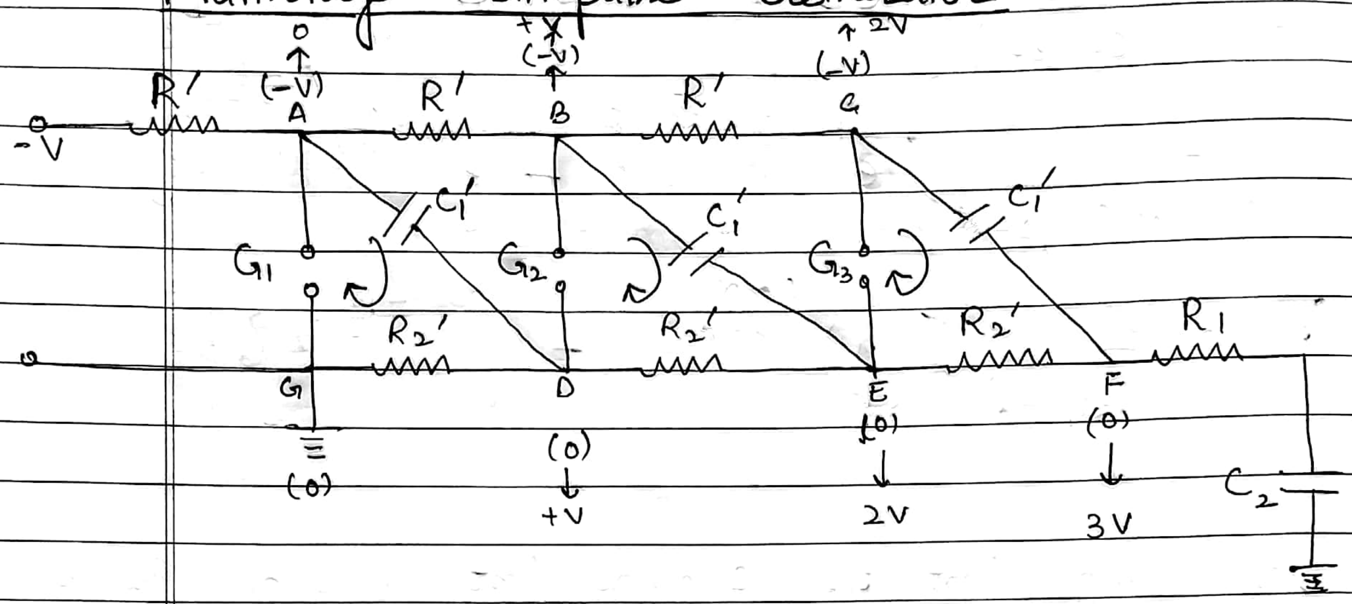
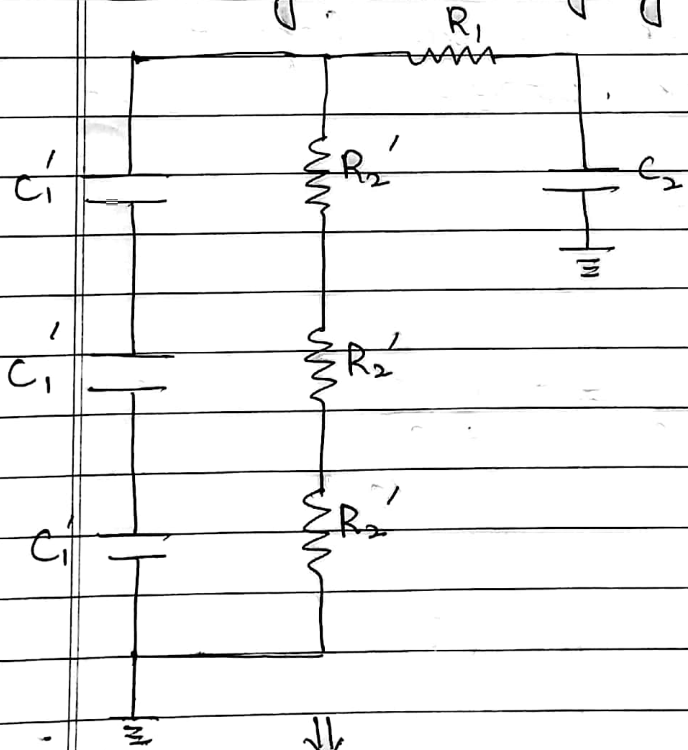


Fig. 1 : 3 - Stage Impulse Generator

During Discharging



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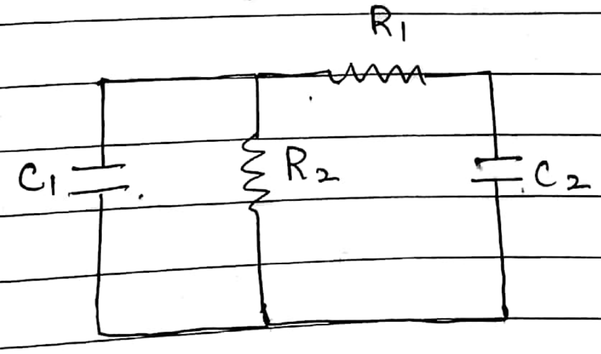

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Operation of Multistage Impulse generator circuit

For very high voltages a single stage impulse voltage generator is not feasible because a high dc charging voltage is required & the physical size of circuit elements will be excessively large. For generating impulse voltages greater than a few 100kV., Erwin Marx in 1923 suggested an arrangement where a no. of capacitors are charged in parallel through high ohmic resistors & then discharged in series through the waveshaping network. There are many although similar multistage impulse generator circuits in use today.

Fig. 1 shows a typical 3-stage impulse generator circuit. In this circuit

$R' \rightarrow$ charging resistors.
$C_1' \rightarrow$ stage capacitances.
$R_2' \rightarrow$ wave tail resistors
$R_1 \rightarrow$ wave front resistor
$C_2 \rightarrow$ load capacitance
$G_1, G_2, G_3 \rightarrow$ spark gaps.

The generator capacitances C_1' are charged from a high DC voltage supply in parallel through the high value charging resistors R' in series with wavetail resistors R_2' ($R_2' << R'$). At the end of charging period (typically several seconds to a minute), points A, B & C will be the potential of DC source e.g -V as shown in fig1.

The points D, E, F & G will remain at the earth potential. The discharge or the firing of the generator is initiated by the breakdown of gap G_1 which causes an automatic, almost instantaneous breakdown of all the remaining gaps. According to the traditional theory this rapid breakdown is caused by high overvoltages across the 2nd & remaining gaps.

When the gap G_1 fires, the potential of point 'A' changes rapidly from $-V$ to 0. Thus the potential of point D will be raised to $+V$. The potential of point B will momentarily remain at $-V$ & thus a voltage of $2V$ will appear across G_2. This high overvoltage would therefore cause G_2 to breakdown. Thus raising the potential of point B to $+V$ & that of point E to $+2V$. This creates a potential difference of $3V$ across G_3 assuming the potential of point C to $-V$ momentarily. Thus the gap G_3 breaks down & a potential of $+3V$ appears at point F. This causes the generator to discharge to the load C_2 via R_1. The wave tail resistors R_2' are divided into 3 sections. Therefore,

Generator Capacitance, $C_1 = \frac{C_1'}{n}$

$R_2 = nR_2'$

The traditional interpretation of breakdown of gaps of 2nd & other gaps is wrong because the potentials of points B & C can also follow the adjacent potentials of points A & B as the resistors R' are in between.

Goodlet Impulse Generator Circuit

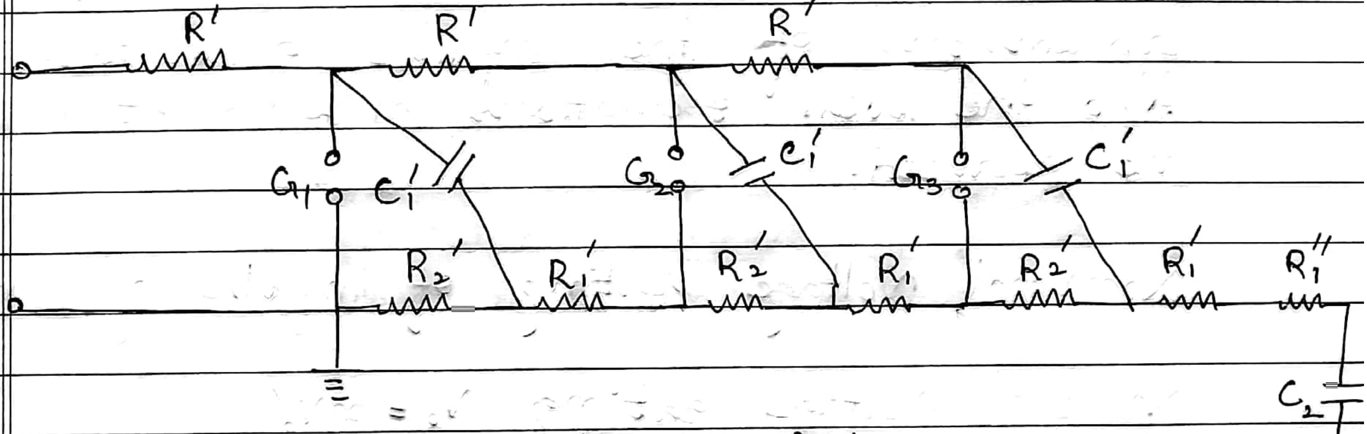


Fig. 2: 3-stage Goolet Impulse generator circuit.

In the circuit of Fig. 1, the wave front resistor R_1 is placed between the Load & the generator. Such a single external wave front resistor however has to withstand for a short time the full rated Voltage & therefore is inconvienently long & may occupy much space. This disadvantage can be avoided if either a part or whole of this resistor is distributed within the generator. Such an arrangement originally proposed by Goodlet is shown in fig 2. Adding the wave front resistance R_1'' helps to damp the oscillations otherwise excited by inductance & capacitances of external leads between the generator & Load if these leads are long.

For this circuit

$$C_1 = \frac{C_1'}{n}$$

$$R_2 = n R_2'$$

$$R_1 = n R_1' + R_1''$$

Distributing the wave shaping resistors reduces their dimensions & overall dimensions of the impulse generator. Also the local oscillations in each stage are reduced.

<u>Nominal voltage rating of impulse generator</u>

Nominal voltage rating $V_0 = nV_0'$

Where V_0' is the charge voltage of each stage.

<u>Energy rating of impulse generator</u>

$$\text{Energy rating} = \frac{1}{2} C_1 V_0^2$$

$$= \frac{1}{2} \frac{C_1'}{n} \cdot n^2 V_0'^2$$

$$= \frac{1}{2} n C_1' V_0'^2$$

Triggering of Impulse Generator

Initiation of breakdown of the first spark gap of an impulse generator.

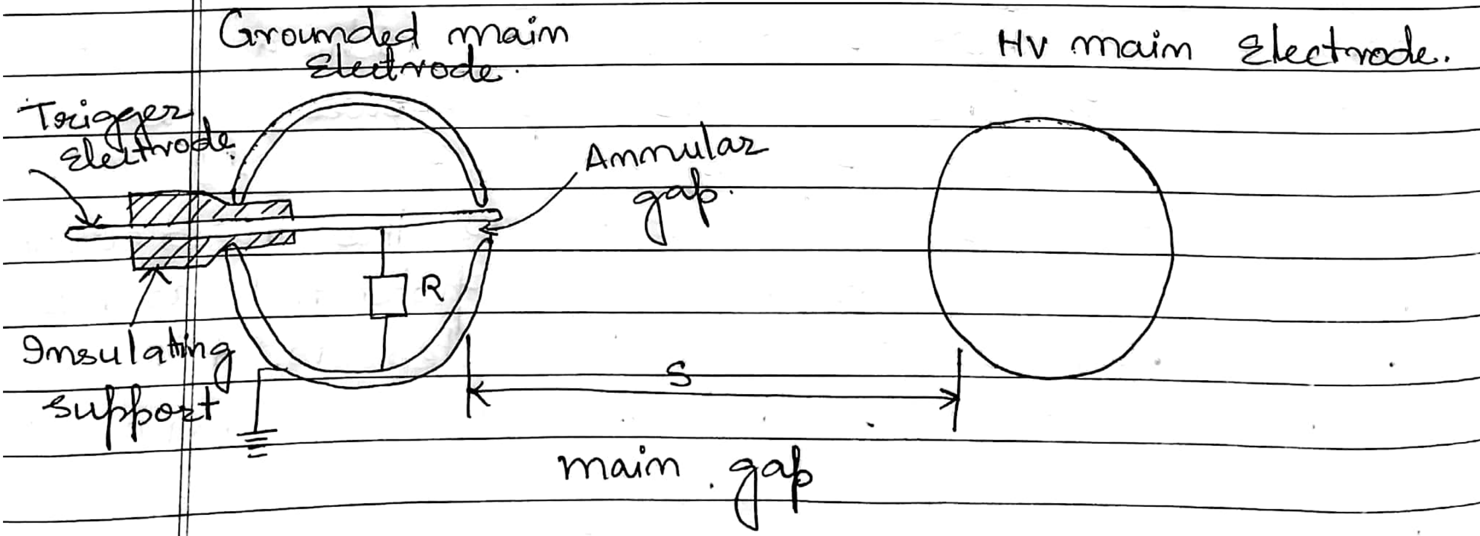
Two methods of triggering
1. Uncontrolled triggering.
2. Controlled triggering.

1. Uncontrolled triggering
The gap spacing is adjusted such that the self-firing voltage of the gap is greater than the charge voltage of impulse generator.

2. Controlled triggering
In this the spark gap has a special design known as "Trigatron". It is a 3 electrode gap. The main electrodes - indicated as H.V & earthed electrodes - may consist of spheres, hemispheres or other nearly homogenous electrode configurations. A small hole is drilled into the earthed electrode into which a metal rod projects. The annular gap between the rod and surrounding sphere is about 1mm. The metal rod or trigger electrode forms the third electrode being essentially at the same potential as the drilled electrode, as it is connected to it through a high resistance, so that the control or tripping pulse can be applied between these two electrodes. For this special arrangement, a glass tube is fitted across the rod & is surrounded by a metal foil connected to the potential of main electrode.

The function of this tube is to promote corona discharges around the rod as this causes photoionization in the pilot gap, if a tripping impulse is applied to the rod. Due to this photoionization, enough primary electrons are available in the annular gap which breaks down without appreciable time delay.

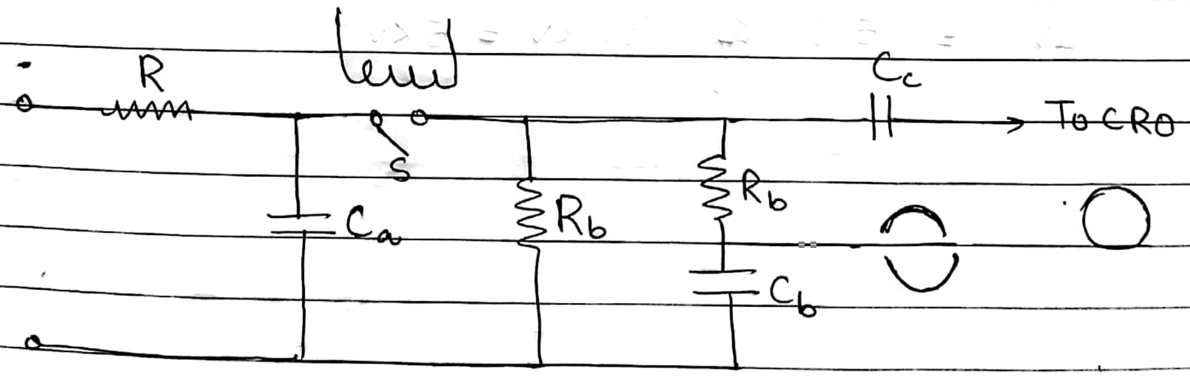
If a voltage 'V' stresses the main gap, which is not too low but always lower than the peak voltage at which self-firing i.e the breakdown in the absence of any trigger pulse occurs, this main gap will breakdown at a voltage even appreciably lower than the self-firing voltage V_s, if a tripping pulse is applied. The trigatron requires a pulse of some kilovolts, typically $\leq 10\,kV$ & the tripping pulse should have a steep front with steepness $\geq 0.5\,kV/n\,sec$ to keep the jitter of the breakdown as small as possible.



Physical Mechanism

Two types of mechanisms are active. For small spacings 'd' & a given tripping voltage V, the breakdown may be directly initiated by the distortion & enhancement of the electrical field between the trigger electrode & the opposite main electrode, leading to a direct break down between these two electrodes. The arc then commutates from the larger electrode to be drilled for the main current. The second type of breakdown takes place for larger gap distances. The trigger pulse causes a breakdown of the annular or pilot gap & the large amount of charge carriers of all types available after sparking will initiate the breakdown of the main gap.

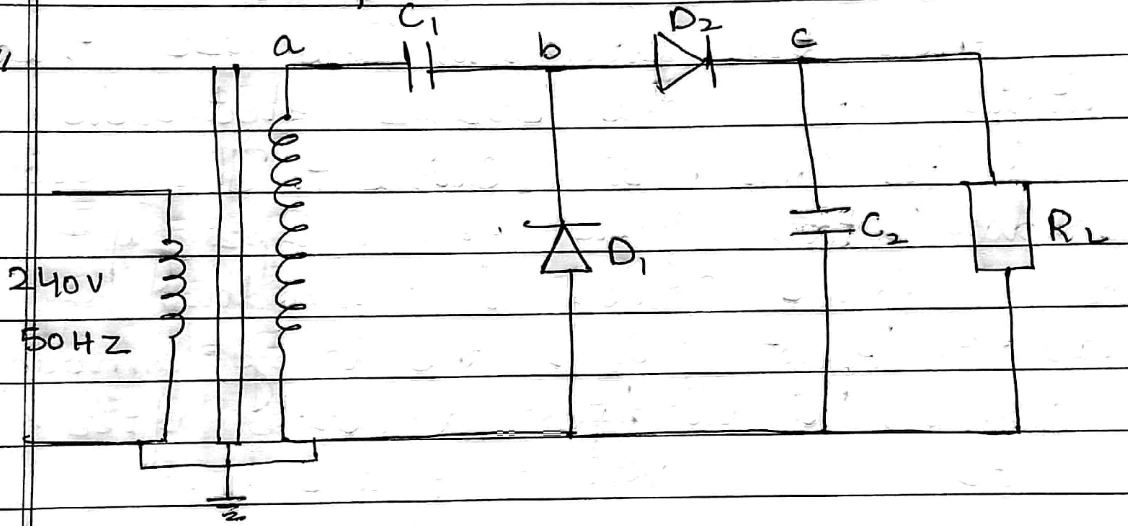
Circuit for generating trigger pulse



S is a switch which is operated by passing current in Electromagnetic field so this switch is known as Solenoid operated switch.

Q1. Simulate a Cockcroft-Walton voltage doubler circuit & plot the waveforms at various nodes of circuit at no load & loaded conditions. The circuit has to be designed to supply a load current of 10mA at 100kV with 5% peak to peak ripple voltage & 5% voltage drop. The circuit has to operate on 240V, 50 Hz mains.

Sol.

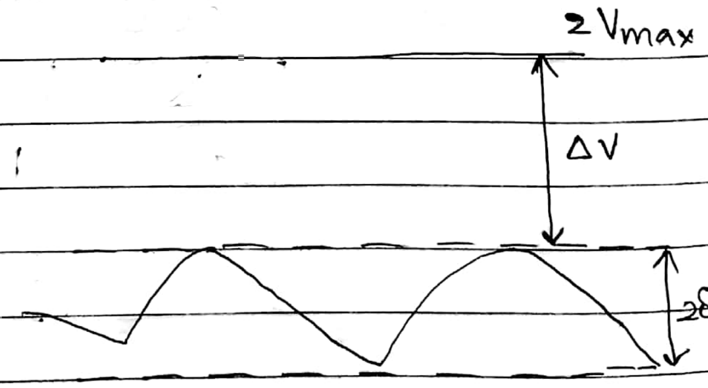


$\bar{I} = 10\ mA$ (Average current)

$\bar{V} = 100\ kV$

$2\delta V = 5\%$ of $100kV = 5kV$

$\Delta V = 5\%$ of $100kV = 5kV$



$\bar{V} = 2V_{max} - \Delta V - \delta V$

$$\bar{V} = 2V_{max} - \Delta V - \delta V$$
$$2V_{max} = \bar{V} + \Delta V + \delta V$$
$$2V_{max} = 100 + 5 + 2.5$$
$$2V_{max} = 107.5 \text{ KV}$$
$$V_{max} = 53.75 \text{ KV}$$
Transformer 2° Voltage $V_2(rms) = \frac{53.75}{\sqrt{2}} = 38 \text{ KV}$.

Calculation of Capacitances

(1) C_1
$$\Delta V = \frac{I}{fC_1}$$
$$C_1 = \frac{I}{\Delta V f}$$
$$C_1 = \frac{10 \times 10^{-3}}{5 \times 10^{3} \times 50}$$
$$C_1 = 0.04 \mu F$$

2) C_2
$$2\delta V = \frac{I}{fC_2}$$
$$\delta V = \frac{I}{2fC_2}$$
$$C_2 = \frac{I}{2\delta V f}$$
$$C_2 = \frac{10 \times 10^{-3}}{5 \times 10^{-3} \times 50}$$
$$C_2 = 0.04 \mu F$$

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Q2// Design a 3-stage Cockcroft Walton Voltage doubler circuit to supply a load current of 10 mA at 300 kV with 5% peak to peak ripple Voltage. The Circuit has to operate on 240 V, 50 Hz mains. Calculate the voltage drop assuming all the Capacitors in the circuit of same value.

$$\delta V = \frac{I}{4fc} n(n+1)$$

Simulate the circuit & plot the voltages at various nodes of the circuit.

Sol// $I = 10\ mA$; $\bar{V} = 300\ kV$

$2\delta V = 5\%$ of $300\ kV = 0.05 \times 300 = 15\ kV$

$\delta V = 7.5\ kV$

we have $\delta V = \frac{I}{4fc} n(n+1)$

$n = 3$

$$\delta V = \frac{I}{4fc} \times 3(4) = \frac{3 \times 10 \times 10^{-3}}{50 \times c}$$

$$C = \frac{30 \times 10^{-3}}{50 \times 7.5 \times 10^{3}} = 0.08\ \mu F$$

All Capacitances being equal

Voltage drop :- $\Delta V = \frac{I}{fc}\left(\frac{2n^3}{3} + \frac{n^2}{2} - \frac{n}{6}\right)$

$$\Delta V = 55 kV$$

$\bar{V} = 2 \times 3 V_{max} - \Delta V - \delta V$

$6 V_{max} = \bar{V} + \delta V + \Delta V = 300 + 7.5 + 55$

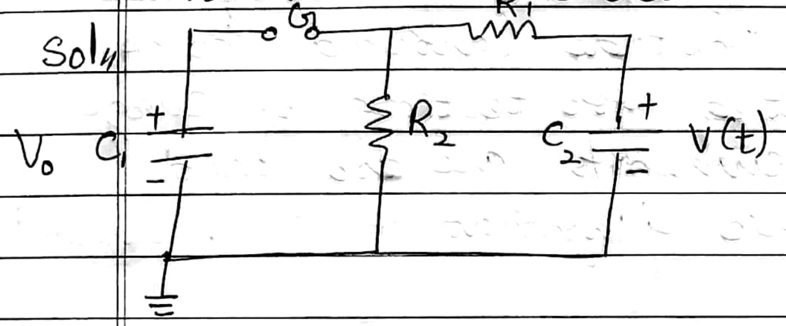
$V_{max} = \frac{1}{6}(300 + 7.5 + 55) = 60.41 kV$

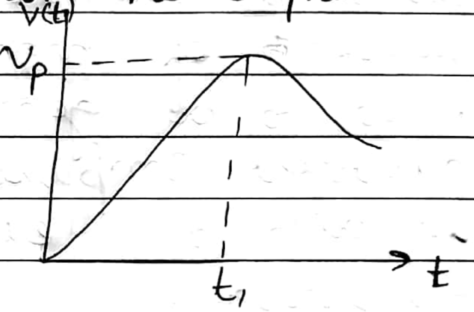
Transformer 2° voltage (RMS) $= \frac{60.41}{\sqrt{2}}$

$= 42.72 kV$

Q3// Design a single stage impulse generator to carry out lightning impulse test on an 11kV pin insulator. The insulator has a capacitance of 30PF & the test voltage has to have a peak value of 75kV. The impulse generator should have a voltage efficiency of 85%.
Simulate the circuit & plot the output voltage.

Sol//





$\eta = 85\%$

$\dfrac{V_p}{V_0} = \eta = 0.85 = \dfrac{1}{1 + C_2/C_1}$

$1 + C_2/C_1 = 1/0.85$

$\dfrac{C_2}{C_1} = \dfrac{1}{0.85} - 1 = 0.176$

$C_1 = C_2 / 0.176$

$C_2 = 30\,PF = 30 \times 10^{-12}$

$\therefore \boxed{C_1 = 170\,PF}$

$t_1 = 3R_1 \dfrac{C_1 C_2}{C_1 + C_2}$; $t_1 = 1.2\,\mu s$

$R_1 = \dfrac{(C_1 + C_2)\, t_1}{3 C_1 C_2}$

$\boxed{R_1 = 15.68\,k\Omega}$

$t_2 = 0.7\,(R_1 + R_2)\,(C_1 + C_2)$; $t_2 = 50\,\mu s$

$R_1 + R_2 = \dfrac{t_2}{(C_1 + C_2) \times 0.7}$

$R_1 + R_2 = 357.14 \times 10^3$

$R_2 = 357.14 \times 10^3 - 15.68 \times 10^3$

$\boxed{R_2 = 341.46\,k\Omega}$

Generation of High Impulse Currents

Lightning discharges on transmission system involves both high voltage impulses & high current impulses. Protective devices like surge divertors have to discharge the impulse currents without damage. Therefore impulse currents of high amplitude (around 100 kA) need to be generated for testing of surge divertors. Impulse currents are also used in studies on electric plasmas in high current discharges.

Impulse Current waveforms

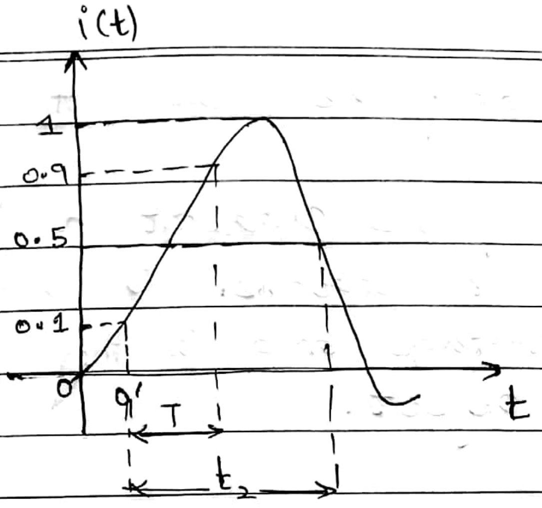
Impulse currents can have different waveshapes depending on their occurance & application. Two types of wave shapes are:-

1. Double - Exponential Impulse current / Standard lightning Impulse current / Short - Duration impulse current.

It is used to simulate lightning strokes for testing of surge divertors. The wave shapes used are:-

i) $4/10\ \mu s$, $I_p = 100\,kA$ used for high current testing of surge divertors.

ii) $8/20\ \mu s$, $I_p = 20\,kA$ used for carrying out a test known as residual voltage test.

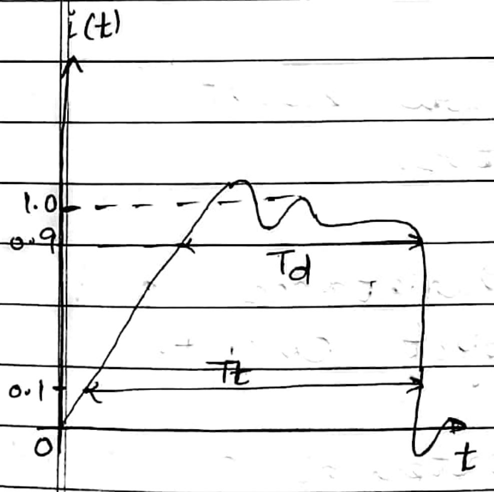


$t_1 = \frac{T}{0.8} = 1.25T$

O' is virtual origin.

2. Rectangular impulse current / Long Duration impulse current

These appear during discharging of long transmission lines.



Td is the duration for which the impulse current remains above 90%

Tt is the duration for which the impulse current remains above 10%

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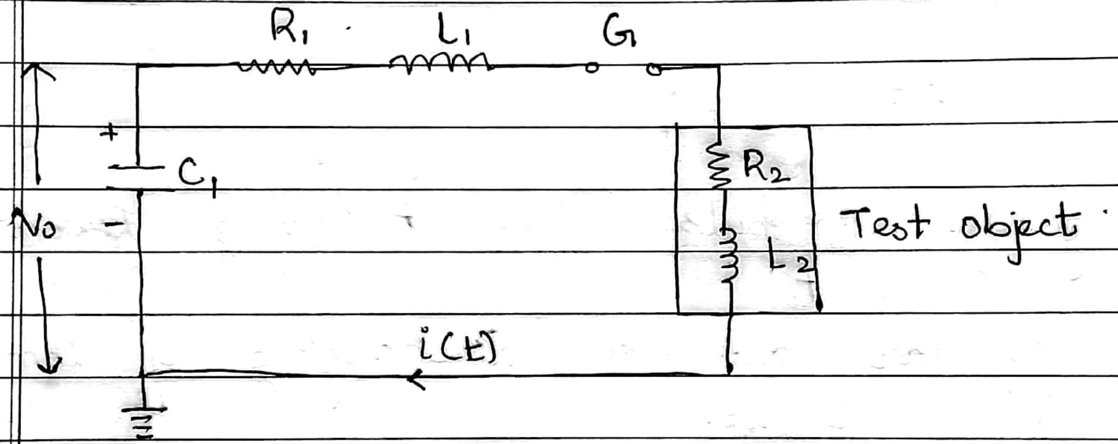
Double - Exponential Impulse Current

For producing Large impulse current, a bank of Capacitors connected in parallel is slowly charged to a specific Voltage and is then discharged through a test object.



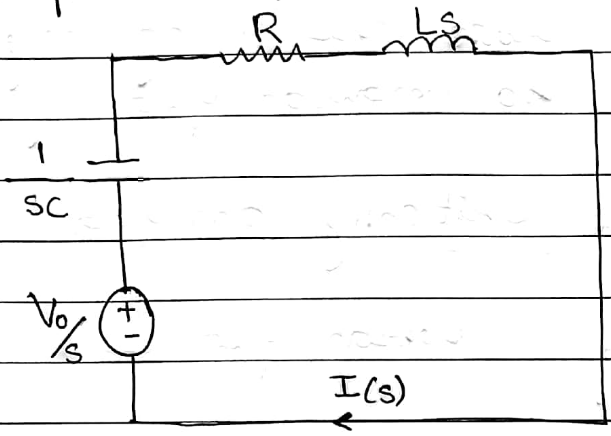
R_1 & L_1 are the unavoidable resistance and inductance of the generator.

R_2 & L_2 represent the resistance and inductance of the test object circuit.

L_2 usually includes an external air cored high current inductor as well.

$$R = R_1 + R_2$$
$$L = L_1 + L_2$$

Laplace equivalent



$$I(s) = \frac{V_o/s}{R + Ls + \frac{1}{Cs}} \quad -(1)$$

$$I(s) = \frac{V_o}{L} \cdot \frac{1}{s^2 + \frac{R}{L}s + \frac{1}{LC}} \quad -(2)$$

$$-\alpha, -\beta = \frac{-R}{2L} \pm \sqrt{\left(\frac{R}{2L}\right)^2 - \frac{1}{LC}} \quad -(3)$$

$$I(s) = \frac{V_o}{L} \cdot \frac{1}{(s+\alpha)(s+\beta)}$$

$$I(s) = \frac{V_o}{L(\beta-\alpha)} \left[\frac{1}{s+\alpha} - \frac{1}{s+\beta} \right] \quad -(4)$$

Taking Laplace Inverse

$$i(t) = \frac{V_o}{L(\beta - \alpha)} \left\{ e^{-\alpha t} - e^{-\beta t} \right\} \quad -(5)$$

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Three Cases

(i) $\left(\frac{R}{2L}\right)^2 < \frac{1}{LC}$ roots are imaginary so underdamped system

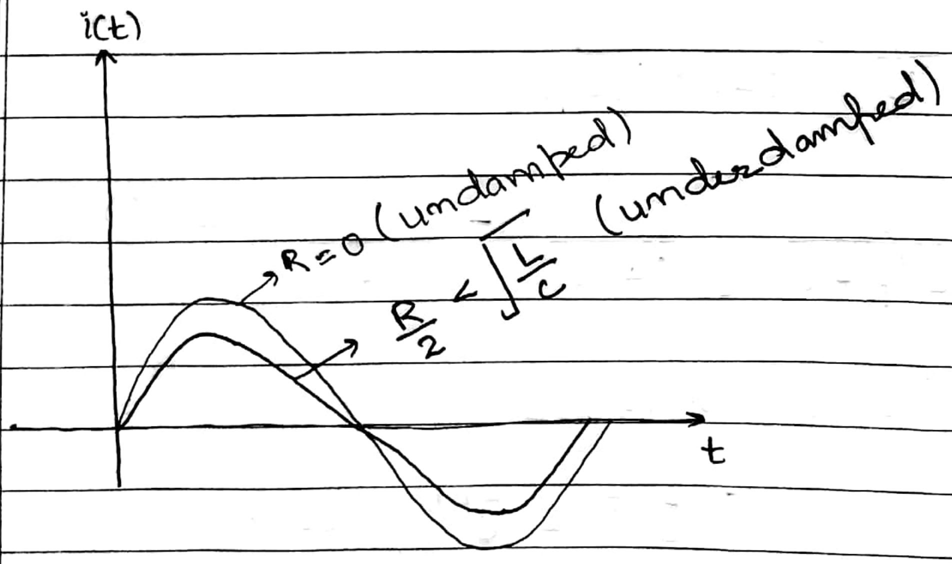
ii) $\left(\frac{R}{2L}\right)^2 = \frac{1}{LC}$ Critically damped

iii) $\left(\frac{R}{2L}\right)^2 > \frac{1}{LC}$ overdamped

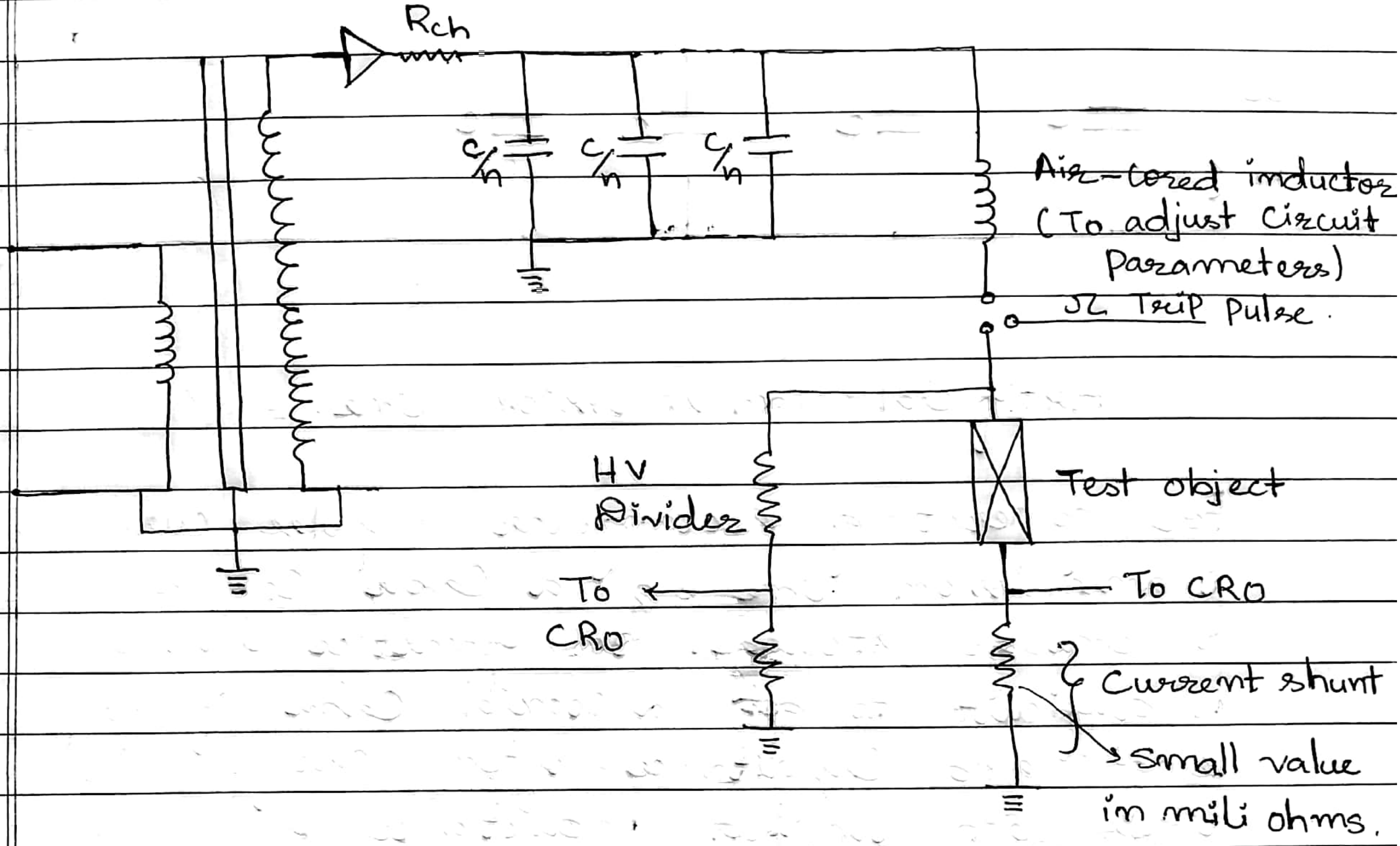
For generating impulse currents, the circuit is underdamped.

$$\boxed{i(t) = \frac{V_0}{\omega L} e^{-\sigma t} \sin \omega t} \quad — (6)$$

Where, $\sigma = \frac{R}{2L}$, $\omega = \sqrt{\frac{1}{LC} - \left(\frac{R}{2L}\right)^2}$ —(7)

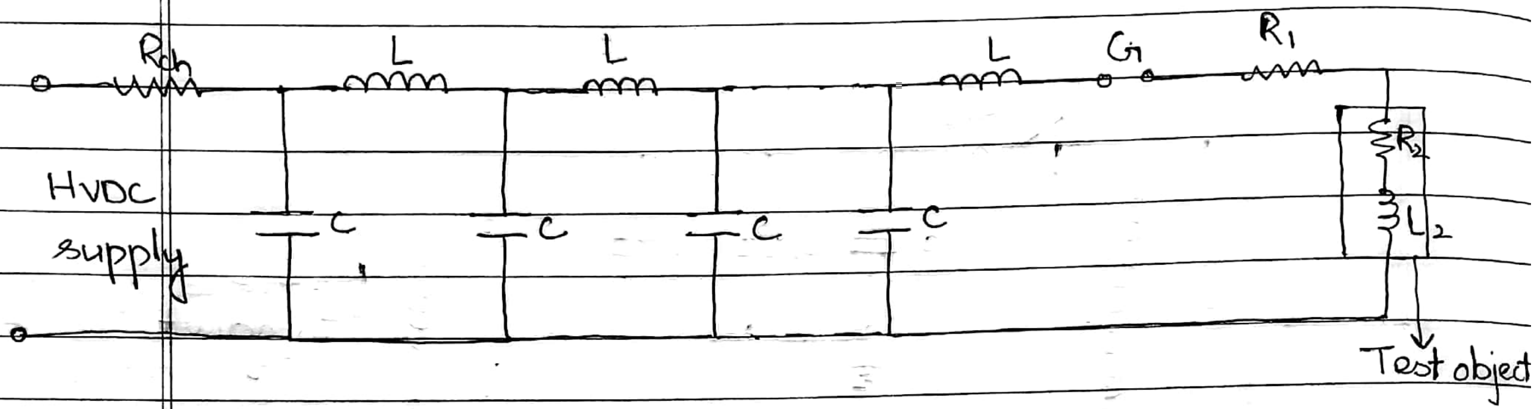


To increase the peak value, inductance of the circuit should be kept as high as possible.



Circuit Layout for testing of surge Divertor

Generation of Rectangular Impulse Current



Artificial transmission Line.

For generating rectangular impulse currents, a transmission line e.g a Cable Can be used as energy storage. In practice however, it is difficult to get a coaxial cable of sufficient length and Capacitance often artificial transmission lines with lumped inductance & Capacitance as shown in fig are used. Such a network is also known as pulse forming network. The no. of LC sections is usually 6 to 9 to achieve adequate approximation to rectangular form. The amplitude of current given by

$$I_p = \frac{V_0}{R + Z_0} \quad \text{---(1)}$$

Where V_0 is charging voltage

$R = R_1 + R_2$

$Z_0 = \sqrt{\frac{L}{C}}$ surge impedance of the line.

L & C are inductance & Capacitance of each section.

The duration of the pulse is given by

$$T_d \approx \frac{2(n-1)}{n} \sqrt{LC} \quad \text{— (2)}$$

The Last sections determine the front portion of the pulse while as the first few sections determine tail tail portion of the pulse.