Silicon Controlled Rectifier (SCR)

Lecture – 12

TDC PART – I

Paper - II (Group - B)

Chapter - 5

by:

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SCR Turning-ON Methods

- The **SCR or Thyristor** is one kind of **Semiconductor Device** and it is specially designed to utilize in **High-Power Switching Applications.** The operating of this device can be done in a **Switching Mode** only and **acts as a switch.** When the SCR is **Turning-ON** by its **Gate (G) Terminal** into the circuit, then **it will supply the current constantly.** When designing an SCR based circuit, special concentration should require for activating or Turning-ON the circuit. The working of the entire region of the **SCR** circuit mainly depends on the way of its Turning-ON. Here we will discuss **different methods** of **SCR Turn-ON.** There are different Turning-ON methods are available based on various entities which include **temperature, voltage supply, gate current etc.** We will discuss some of them which are frequently used in SCR Turning-ON methods.

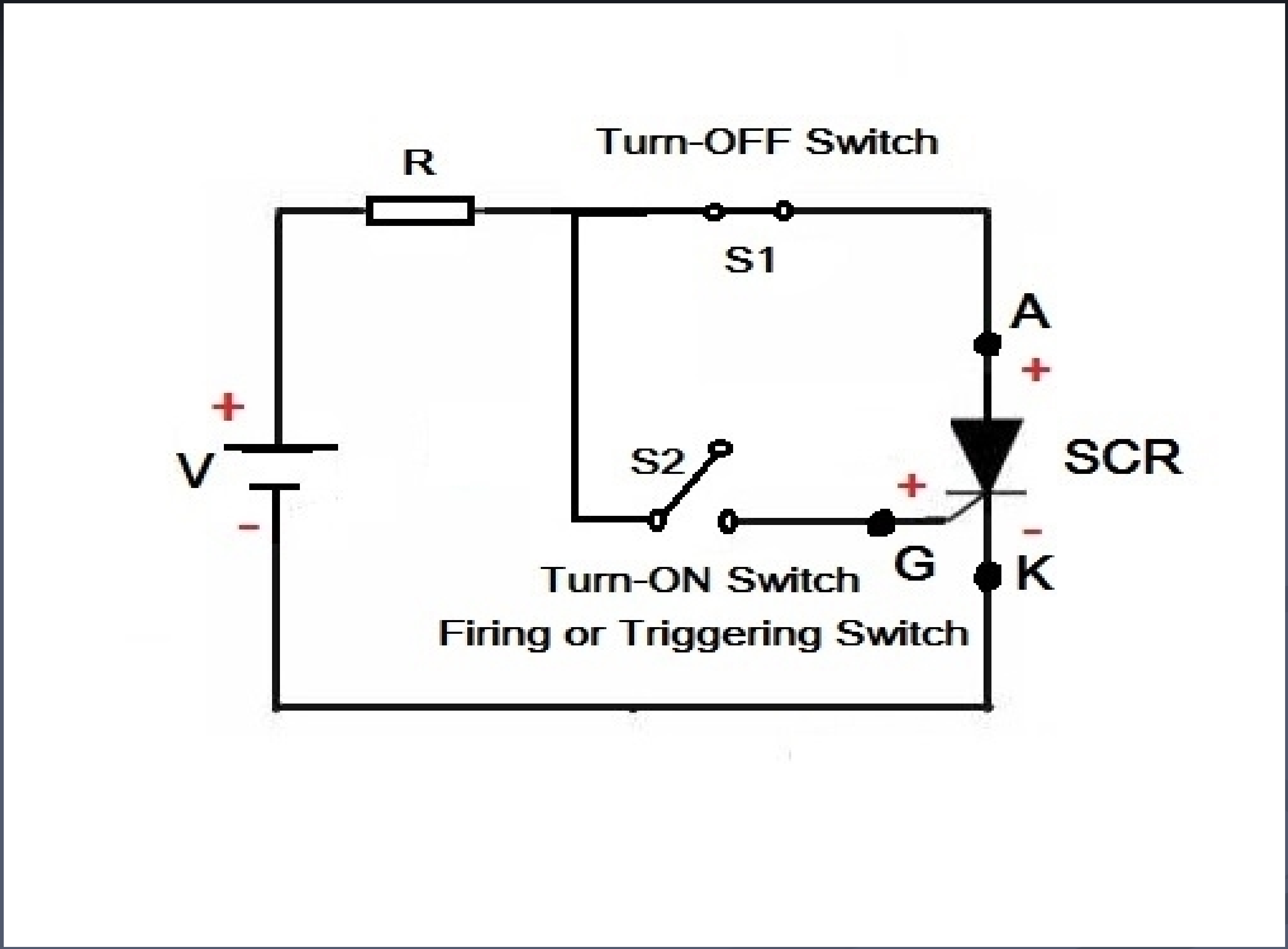
What is SCR Turning-ON Method?

- We know that **Silicon Controlled Rectifier (SCR)** or thyristor has two stable states namely **Forward Conduction State** and **Forward Blocking State**. **SCR** Turning-ON **method can be defined as, when the SCR is switching from Forward Blocking State to Forward Conduction State which means OFF State to ON State,** then it is known as **SCR Turn-ON Process.** It is also called as **Triggering.**

- The **Turning-ON Process** of the SCR is known as **Triggering.** Hence SCR **Turn-ON** methods are the techniques to bring an SCR in **Forward Conduction Mode (ON-State)** from **Forward Blocking Mode (OFF-State).** In other words, the method through which turning the SCR from **Forward Blocking State** to **Forward Conduction State** is **known as Turn-ON Method or Triggering Method.** An SCR in **Forward Conduction Mode (ON-State)** is characterized by **Low Impedance, Low Voltage Drop across Anode & Cathode** and **High Anode Current.** The value of **Anode Current** is determined by the load. Thus it allows for the **flow of Current.** Therefore, an SCR in **Forward Conduction Mode** is called its **ON-State** and may be treated as a **Close Switch.** In fact, **Turn-ON or Triggering** itself means to bring the SCR (thyristor) to **ON-State** from its **OFF-State**.

SCR Turn-ON Methods (SCR Triggering)

- The SCR Turn-ON Method or Triggering Method mainly depends on different variables such as temperature, voltage supply, gate current, etc. When the Voltage (V) is applied to the Silicon Controlled Rectifier (SCR) and if the Anode (A) Terminal can be made Positive (+) relating to the Cathode (K), then the SCR turn into Forwarding Biased. Therefore this means SCR (thyristor) enters into the Forward Blocking State (OFF-State). Fig (57) Shown Basic SCR Turning-ON or Triggering Circuit Arrangement.



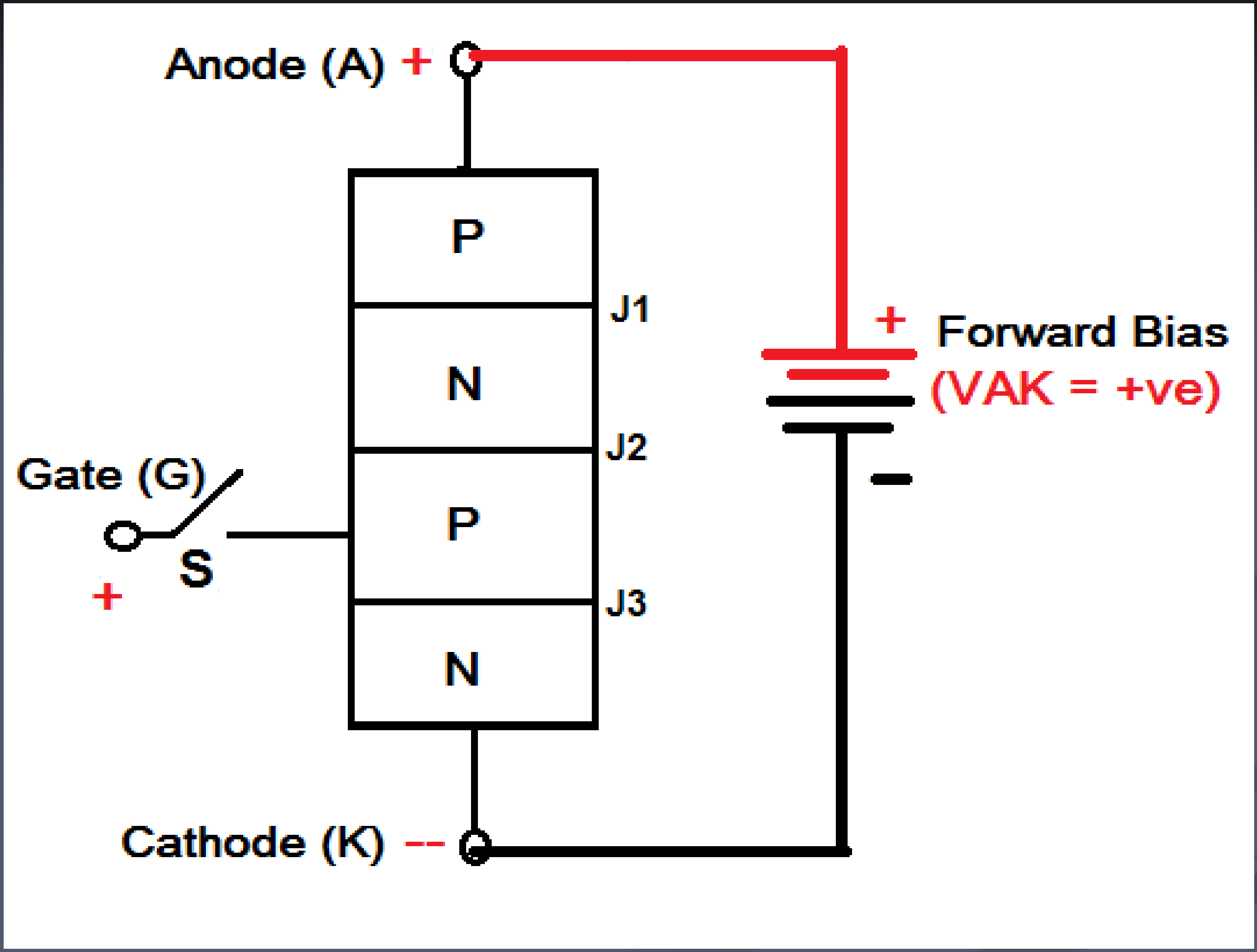
- **Fig (57)** Shown Basic SCR Turning-ON **or** Triggering Circuit Arrangement.

- The SCR can be made to **activate into Conduction Mode** and it performed by using **different** type of the **SCR Turn-ON methods.** There are **different types of Turn-ON methods** for **activating the SCR** which include the following. The various methods of SCR **Turn-ON or triggering** are discussed here one by one. The various SCR **Turn-ON Methods** are,

- **(1) Forward Voltage Triggering**
- **(2) dv/dt Triggering**
- **(3) Thermal or Temperature Triggering**
- **(4) Radiation or Light Triggering**
- **(5) Gate Triggering**

(1) Forward Voltage Triggering

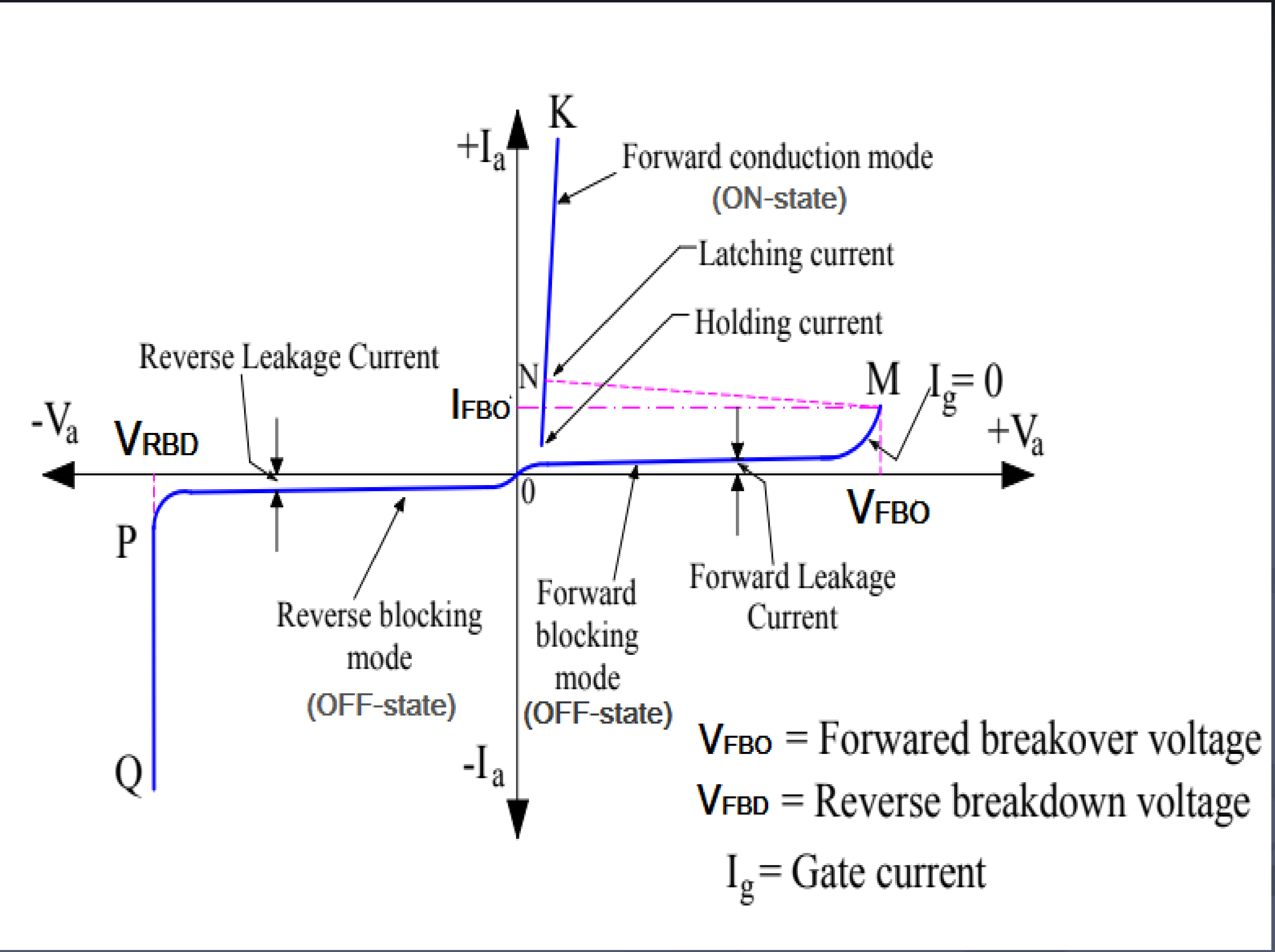
- Carefully read the name of this method. It says **"Forward Voltage Triggering".** This means we will make **SCR ON** by applying **Forward Voltage** across its terminals as shown in **Fig (58).** What does this mean? This simply means that we will make it **Forward Biased** and will **increase** this **Forward Bias Voltage** till **SCR gets ON**. Lets us now see how increasing forward bias voltage make **SCR Turn-ON.**



- **Fig (58)** Shown Forward Voltage Triggering method to make SCR Turn-ON.

- In a **Forward Biased SCR** or Thyristor, **junction J1 and J3** is **Forward Biased** whereas **junction J2** is **Reversed Bias.** This kind of **Triggering or Turn-ON method** is mainly used to increase the voltage among the Anode (A) and Cathode (K) terminal. So that the width of the depletion layer can be increased and makes to increases the accelerating voltage of minority charge carriers at **J2 junction.** Further, this can be lead to an **Avalanche Breakdown of J2 junction** at a **Forward Breakover Voltage (**V_{FBO}**).**

- Therefore, increasing this **Forward Bias Voltage** will **narrow down the width of the depletion region** of **junction J2** and at a particular voltage, **this depletion region will vanish.** At this stage, **Reversed Biased junction J2** is said to have **Avalanche Breakdown** and this particular voltage is called the **Forward Breakover Voltage (V_{FBO}).** The name **Forward Breakover Voltage** is given as at this voltage the **V-I characteristics of SCR** breaks and shifts to its **ON Position.** Refer the **V-I characteristics of SCR** shown in **Fig (59)** below.



- **Fig (59)** Shown V-I characteristics of SCR.

- You may notice that at **Forward Breakover Voltage (V_{FBO})**, the V-I curve breaks at **Point M** and shift to its **O-N Position at Point N** with **Forward Breakover Current (I_{FBO}).** This is the reason that this critical voltage is called **Forward Breakover Voltage (V_{FBO}).**

- As soon as **Avalanche Breakdown at junction J2 occurs**, a huge current (anode current) with a less drop of voltage, starts flowing from **Anode (A) to Cathode (K) terminal of SCR.** The value of this **Anode Current (Ia)** is only limited by the **External Load Resistance.** Thus SCR is now in its **Conduction Mode (ON-State) in Forward Direction i.e. from Anode to Cathode.** This is **Forward Triggering Method of turning SCR ON.**

- **In practical,** this method cannot be used as it requires an **extremely Large Forward Bias Voltage** among the Anode (A) and Cathode (K)**.** Once the **voltage is higher** than the **Forward Breakover Voltage (V_{FBO})**, then it offers to flow extremely **huge currents through Anode to Cathode terminal of SCR. This may cause harm to the SCR or thyristor.** So, in **most of the situations,** this kind of **SCR Turning-ON or Triggering method cannot be used.**

- Normally this method is not used to **Turn-ON SCR** as it may damage it. Generally the **Forward Breakover Voltage (V_{FBO})** is less than **Reverse Breakdown Voltage (V_{RBD})** and hence **Reverse Breakdown Voltage (V_{RBD})** is considered as final voltage rating while **designing SCR.** It must also be noted and bear in mind that, once **Avalanche Breakdown** takes place at **junction J2**, the blocking capability of **junction J2 is lost.** Therefore if **Anode Voltage (Va)** is reduced below **Forward Breakover Voltage (V_{FBO})**, the SCR will continue to conduct. The SCR can now be **Turned -OFF** by bringing its **Anode Current (Ia)** below a certain value called the **Holding Current (I_H).**

(2) dv/dt Triggering

- **dv/dt** Triggering is the technique in which **SCR** is **Turned-ON** by changing the **Forward Bias Voltage** with respect to time. **dv/dt** itself means rate of change of voltage w.r.t time.

- As we have discussed earlier, in a **Forward Blocking Mode** when the SCR device is in Forward Biased, **junction J1 and J3** is in forward biased and junction J2 will be in reverse biased. A **Reversed Biased junction J2** may be treated as a **Capacitor** due to presence of **Space Charges** in the vicinity of **Reversed Biased** junction. Let us assume its **Capacitance** to be **'C' farad**.

- The **Charge** on **Capacitor Q, Voltage** across the **Capacitor V** and **Capacitance C** are related as below:-
- $Q = CV$
- **Differentiating both sides w.r.t time, we get**
- $dQ / dt = C (dV / dt)$
- **But Current** $I_c = dQ / dt$
- $\Rightarrow I_c = C.(dV / dt)$

- In other way we can illustrate the whole process as, **if Voltage** across the device is **V,** the **Charge** by **Q** and **Capacitance** by **C** then,

- $I_C = dQ / dt$

- $Q = C V$

- $I_C = d(CV) / dt$

- $I_C = C. dV/dt + V. dC/dt$

- as $dC / dt = 0$

- $I_C = C.(dV / dt)$

- Thus the current through the **Reversed Biased junction J2** is directly proportional to **(dv/dt). Therefore if the rate of rise (change) of forward voltage i.e. (dv/dt) across the device is high, the charging current Ic will also be high. This charging current acts like gate current** and this may **Turns-ON the SCR or thyristor** even though the **Gate Current is zero ($I_g = 0$).** It should be noted that, it is rate of rise of voltage which is responsible for turning the **SCR-ON.** It is independent of magnitude of voltage. The voltage may be low, but the rate of its rise should be high enough to **Turn-ON the SCR.**

(3) Thermal or Temperature Triggering

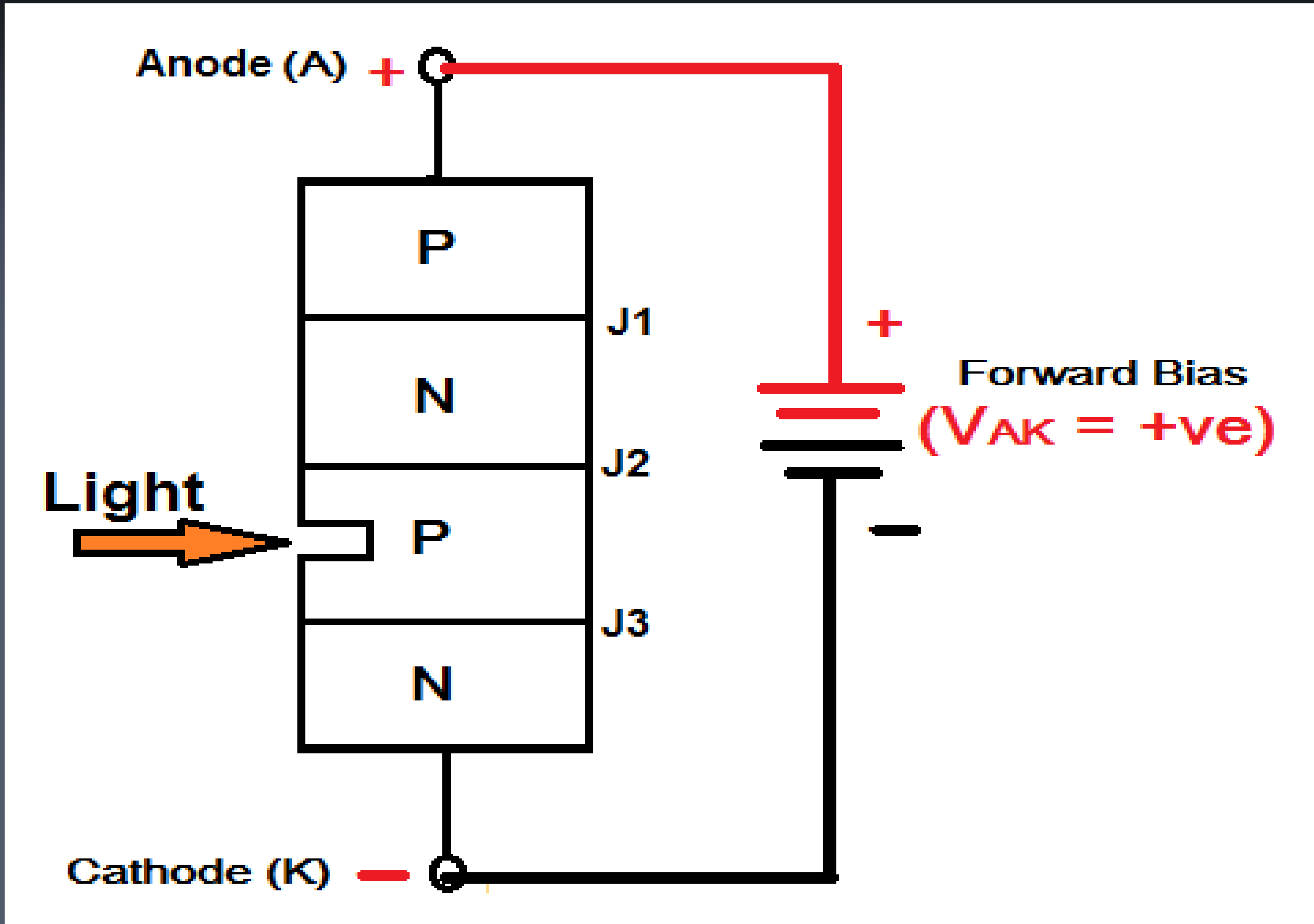
- Temperature triggering is also called **Thermal Triggering**. During Forward Blocking Mode operation of **SCR**, when **Forward Voltage** applied then **Anode (A)** made Positive with respect to **Cathode (k)** terminal, this will be make **junction J1 and J3** become **Forward Biased** whereas **Junction J2** become **Reverse Biased.** From the above biasing rule most of the applied voltage appears across **Reverse Biased Junction J2.** As we know that in reversed biased **junction J2** a **Reverse Saturation Current also known as Reverse Leakage Current** flows whose value depends on the temperature of the junction.

- This means, in Forward Blocking Mode of SCR or thyristor, there will be a flow of **Reverse Leakage Current (Reverse Saturation Current)** across the **junction J2.** This current will **increase the temperature** of the **junction J2 which in turn will result in further increase in Reverse Leakage Current.** This increased **Reverse Leakage Current** will again **increase the junction J2 temperature** and hence **will further increase the Reverse Leakage Current. Thus, this process is Cumulative** and will **eventually lead to vanishing of depletion region** of Reversed Biased **junction J2** at some temperature. At this temperature, the **SCR** will get **Turn-ON.**

(4) Radiation or Light Triggering

- In light triggering, **a pulse of light** of **suitable wavelength** guided by **optical fibers** is irradiated to turn SCR ON. A Special Terminal **"Recess" or "Niche" is made in the inner P layer** instead of gate terminal **for light triggered SCR** as shown in **Fig (60)** below.

- When this **"Recess" or "Niche"** is **irradiated,** free **charge carriers** i.e. **Electron and Hole Pairs** are generated just like when **Forward Voltage** applied on the **Anode (A) to Cathode (k)** terminal of **SCR.**

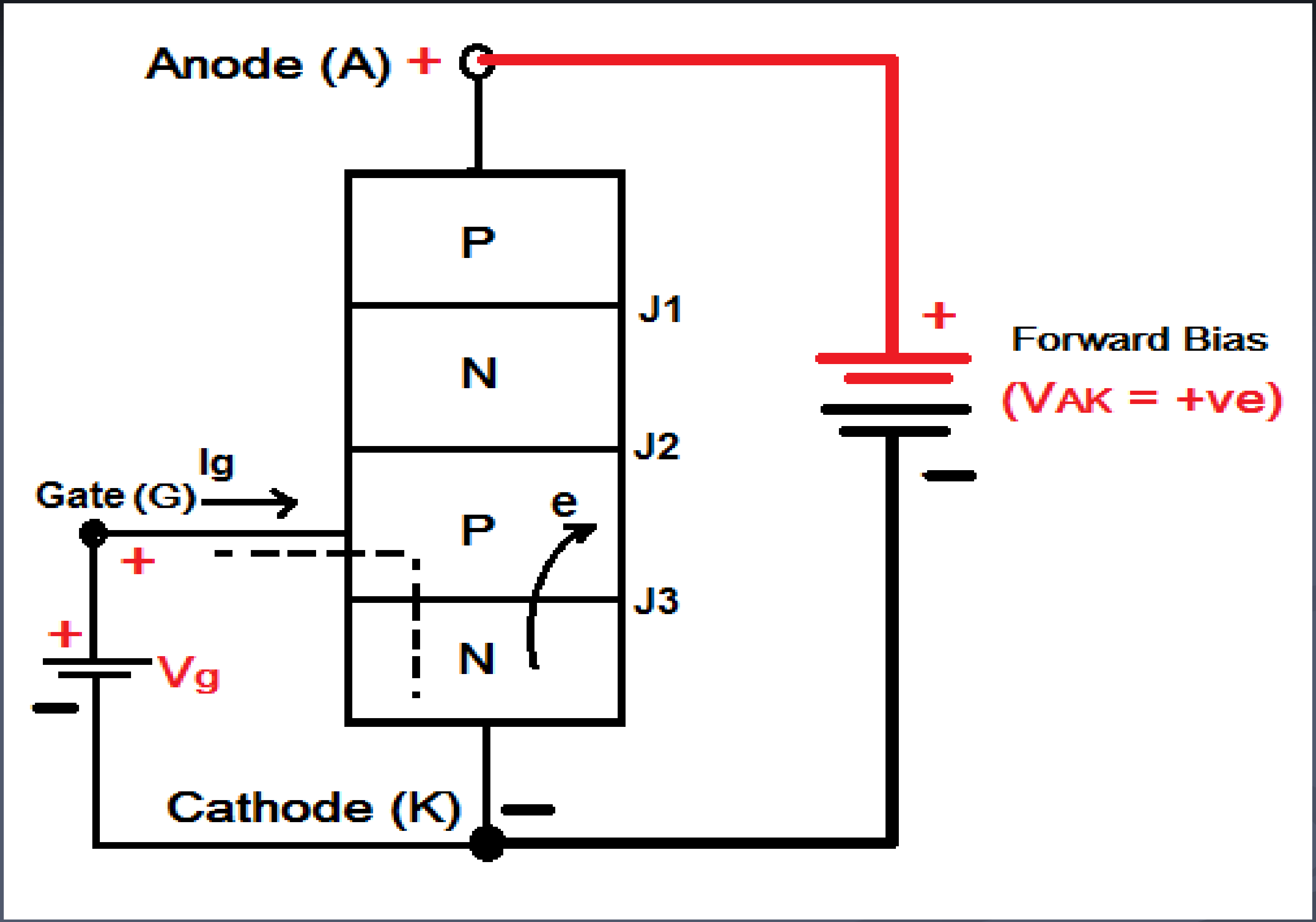


- **Fig (60)** Shown **a Recess or Niche is made in the inner P-type layer for light triggered SCR.**

- Again when **light** is thrown on **silicon material** and if the **intensity of irradiated light** is **exceeds a certain** value, the **Electron-Hole Pairs increase.** When the pulse of light of appropriate **Wavelength** is guided by **Optical Fibers** for **irradiation** and if the **intensity** of this **light thrown** on the **"Recess" or "Niche" exceeds a certain value,** the **Electron-Hole Pairs increase** then **Forward Biased SCR** is **Turned-ON.** Note there that, irradiated light produces free charge carries which is just like in case of gate current. There charge carries move near the reversed biased **junction J2** and reduces the **Forward Breakover Voltage (V_{FBO}).** This is the reason, the **SCR** gets **Turned-ON**. The **SCR** which is **Turned-ON** by **using light** is called **Light Activated SCR or LASCR.**

(5) Gate Triggering

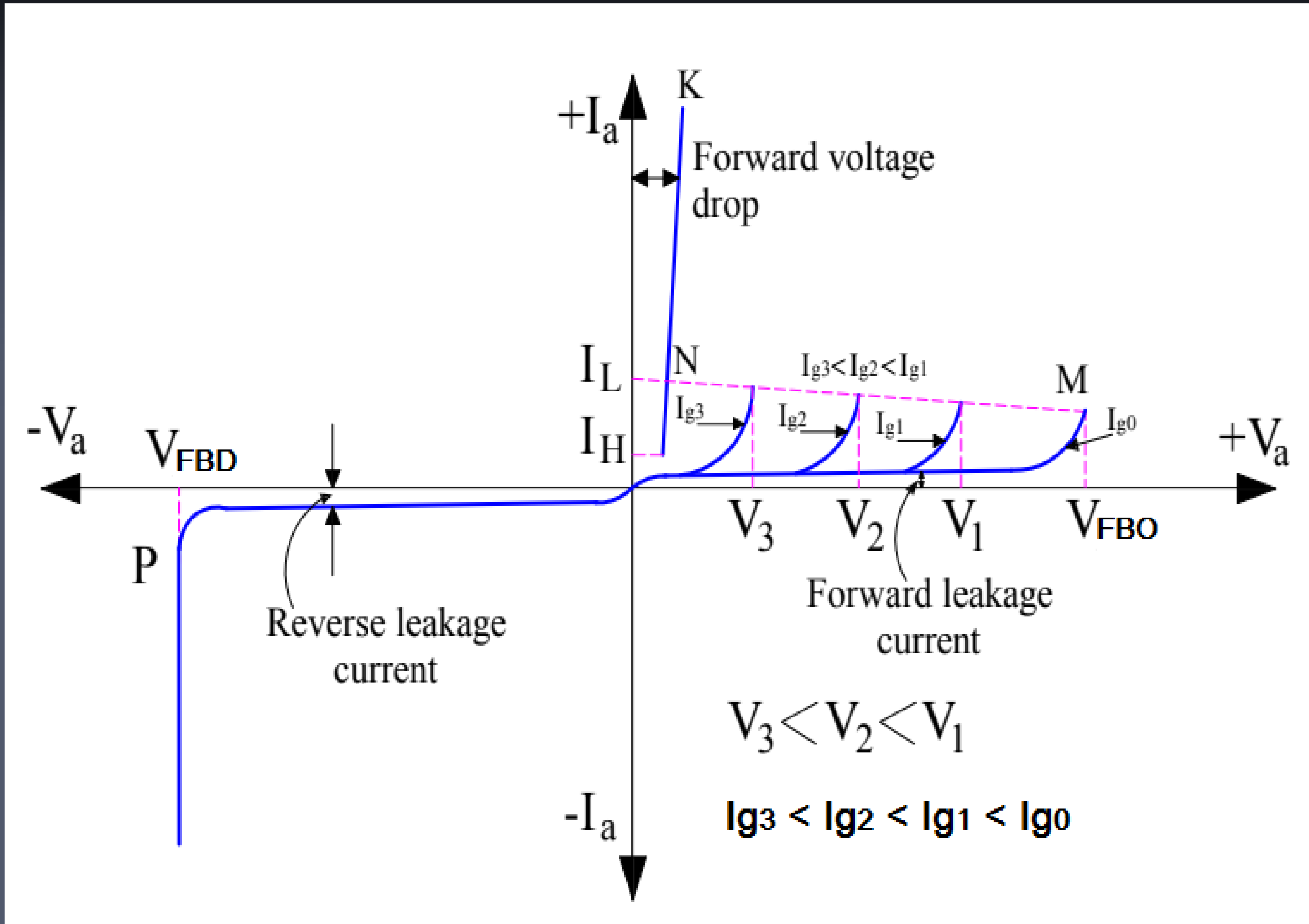
- Gate triggering is the method in which **Positive Gate Current** is flown in **Forward Biased SCR** to make it ON. **Gate triggering** is in fact the most reliable, simple and efficient way to **Turn-ON SCR.** In this method, **Positive Gate Voltage** between **Gate (G) and Cathode (K) terminals** are applied in **Forward Biased SCR** which establishes **Gate Current** from **Gate (G) terminal to Cathode (K) as** shown in Fig (61) below.



- **Fig (61)** Shown Gate Triggering method in which **Positive Gate Current** is flown in **Forward Biased SCR** to make it ON.

- When **Positive Gate Current** is applied, **Gate P-type layer** is flooded with **Electrons** from the **Cathode (N-type side).** This is because the **Cathode N-type layer** is **heavily doped** as compared to **Gate P-type layer.** Since **junction J1 and J3** are already **Forward Biased,** the injected **Electrons** in **Gate P-type layer** may reach **junction J2** and hence **reduces the width of depletion region.** This result is reduction of **Forward Breakover Voltage (V_{FBO}).**

- In fact, the **more the injected Electrons** in **Gate P-type layer,** the more will be chance of **Electrons** reaching **junction J2.** This means the more the value of **Gate Current,** the more will be reduction in **Forward Breakover Voltage (V_{FBO}). Thus Gate Current and Forward Breakover Voltage are inversely proportional.** Please refer the **Figure (62) below. Fig (62)** Shown below the **V-I characteristics of a SCR** for different values of **Gate Current Ig.**



- **Fig (62)** Shown the **V-I characteristics of a SCR** for different values of **Gate Current (Ig).**

- Following points can be observed and noted from the above **Figure (62) shown the V-I characteristics** curve **of a SCR.**

- (1) When **the Gate Current Ig** is **zero**, the **Forward Breakover Voltage is V_{FBO}.**

- (2) As **Gate Current increases** from **zero to Ig1,** the **Forward Breakover Voltage reduces** from **V_{FBO} to V1.** Similarly, its value reduces from **V1 to V3** as the **Gate Current** increases from **Ig1 to Ig3. The reason behind this is that** the current which is applied to the gate terminal is high then additional electrons will be inserted into the J2 junction & consequences to approach into the conduction position at less applied voltage.

- Thus the **SCR** may be **Turned-ON** by applying **Gate Current.** It should be noted that **SCR** is **Turned-ON** due to **Forward Breakover Voltage (V_{FBO})** though this voltage is reduced considerably due to **Positive Gate Current.**

- Once **SCR Starts Conducting** in **Forward direction**, **reversed bias Junction J2** no **longer exists**. Therefore, no **Gate Current** is required for **SCR or thyristor** to remain in **ON-State.** Therefore if **Gate Current** is removed, the conduction of current from **Anode to Cathode** is not affected. However, if **Gate Current** is reduced to zero before the rising of **Anode Current** to a specific value called the **Latching Current (I_L) the SCR or thyristor will Turn-OFF again.** This means we should not make **Gate current OFF** until **Anode Current** has crossed **Latching Current**.

- **Latching current is defined as the minimum value of anode current which must be attained during turn on process of SCR to main the conduction even when gate current is removed.**

- Once SCR or thyristor starts conducting, gate losses its control. The SCR or thyristor can now be **Turned-OFF** only if the **Anode current** reaches below a specified value of **Anode current.** This value of **Anode current** below which **SCR gets Turned-OFF** is called **Holding Current (I_H).** As can be seen from the V**-I characteristics of SCR,** the value of **Latching Current** (I_L) is more than the **Holding Current (I_H).**

- **Holding Current is defined as the minimum value of anode current below which it must fall for Turning-OFF the SCR or Thyristor.**

Different Type of Gate Triggering Method

- This is most common and efficient method to **Turn-ON the SCR.** When the SCR is **Forward Biased**, a sufficient voltage at the **Gate (G) terminal** injects some electrons into the **junction J2**. This result to increase **Reverse Leakage Current (I_{RL})** and hence the **breakdown of junction J2** even at the voltage lower than the **Forward Breakover Voltage (V_{FBO}).**

- Depends on the size of the SCR the **Gate Current (Ig)** varies from a few **milli-amps to 200 milli amps or more.** If the **Gate Current (Ig)** which is applied to the gate terminal is more, then more electrons are injected into the **junction J2** and results to come into the **Conduction State** at much lower applied **Forward Voltage** between **Gate (G) and Cathode (K) terminals of the SCR.**

- There are three methods of Triggering the SCR device by using **Gate Control Method** also well known as **Gate Triggering Method.**

- In **Gate Triggering Method**, a **Positive Voltage** applied between the **Gate (G) and the Cathode (K)** terminals. We can use three types of **Gate Signals** to **Turn-ON** the SCR. Those are,

- **(a) Triggering by DC Gate Signal,**
- **(b) Triggering by AC Gate Signal and**
- **(c) Triggering by Pulse Gate Signal.**

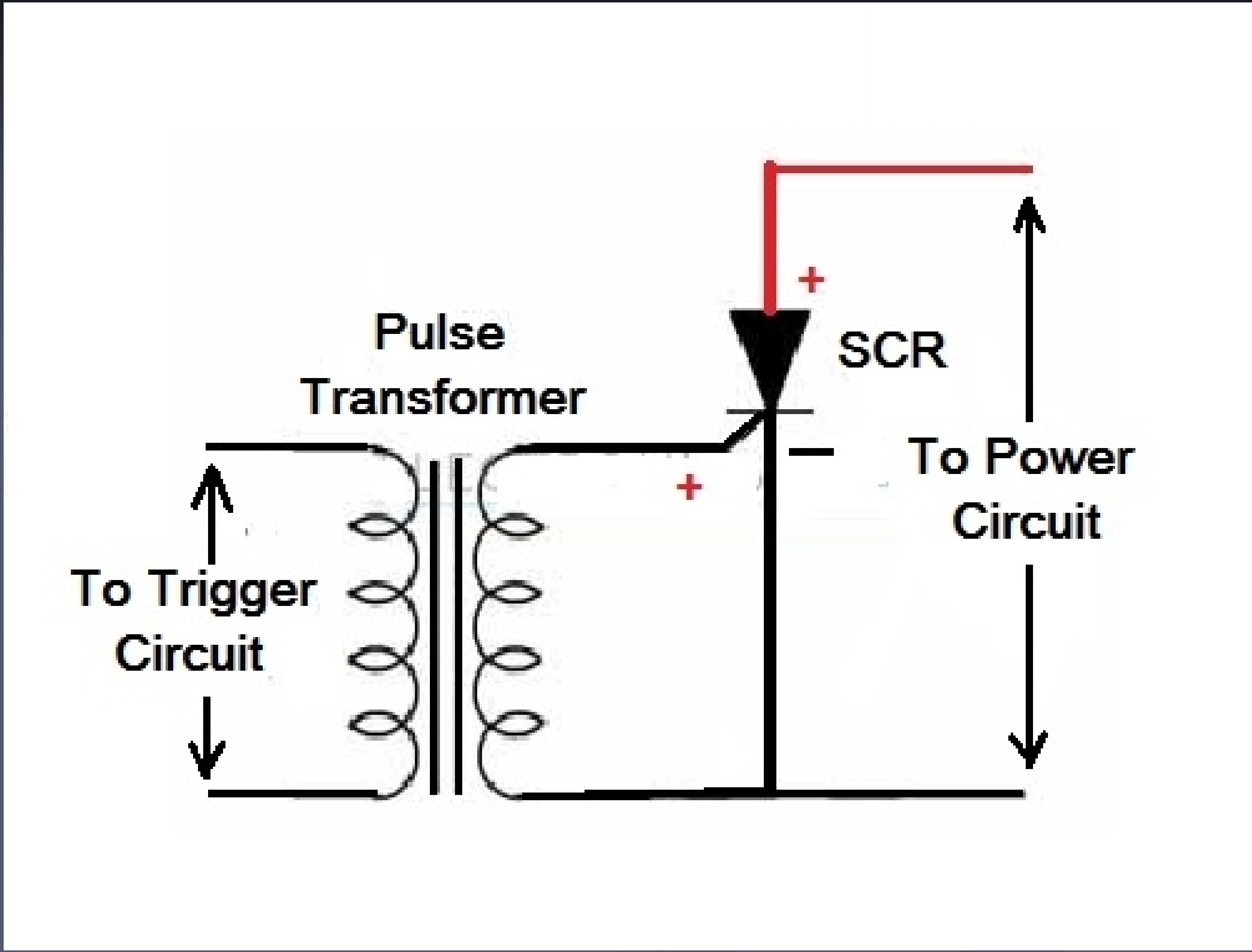
(a) Triggering by a DC Gate Signal

- In this method, a **DC Voltage of proper polarity and magnitude is applied** between the **Gate (G) and the Cathode (K) terminal** in such a way that the **Gate (G)** terminal is made **Positive** with respect to the **Cathode (K)** terminal when the device is to be **Turned-ON**. It must, however, be noted that the **SCR is a Current-Operated device** and it is the **Gate Current (I_g)** that **Turns-ON the SCR** device.

- When applied voltage is sufficient to produce the required **Gate Current (I_g),** the device **Starts Conducting (Turn-ON).** The **Gate Current (I_g)** drives the SCR into **Conduction Mode (ON-State).** The drawback of this method is that **DC Gate Signal** has to be **continuously applied** resulting in **increase in Internal Power Dissipation** or more **Power Loss** and that there is no **Isolation** of the **Gate-Control Circuit** from the **Main Power Circu**it.

(b) Triggering by an AC Gate Signal

- In many **Power-Control Circuits** that use **AC Input,** the **Gate-to-Cathode Voltage** is obtained from a **Phase-Shifted AC Voltage** derived from the main supply. This is the most commonly used method for **AC** applications where the SCR is employed for such applications as a **switching device.** With the proper isolation between the **Power Circuit and Control Circuit (Trigger Circuit),** the SCR is triggered by the **Phase-Shift AC Voltage** derived from the main supply. The **Firing Angle** is controlled by changing the **Phase Angle** of the **Gate Signal.** Fig (63) Shown below a circuit diagram for SCR Triggering by an AC Gate Signal.



- **Fig (63)** Shown SCR Triggering by an AC Gate Signal.

- The main advantage of this method is that proper isolation of **Power Circuit and Control circuits (Trigger Circuit)** can be provided. The **Firing Angle** control is obtained very conveniently by changing the **Phase Angle** of the **Control Signal.** However, the **Gate drive** to control the **Firing Angle** is maintained for **one Half-Cycle** after the device is **Turned-ON** and a **Reverse Voltage** is applied between the **Gate and the Cathode** during the **Negative Half-Cycle.** This is one of the limitations of **AC Gate Triggering** and also separate **Step-Down or Pulse Transformer** is needed to **supply the voltage to Gate drive** from the **main supply.**

(c) Triggering by a Pulsed Gate Signal

- The **most popular method of triggering the SCR** is the **Pulse GateTriggering**. In this method, **Gate (G)** is supplied with **Single Pulse** or a **Train of Pulses** appearing periodically, or a **Sequence of High-Frequency Pluses.** This is called **the Carrier Frequency Gating.** The main advantage of this method is that **Gate drive** is discontinuous or doesn't need continuous pulses to **Turn-ON the SCR** and hence **Gate losses** are **reduced in greater amount** by **applying Single** or **Periodically appearing Pulses.** For isolating the **Gate drive** from the main supply, a pulse transformer is used.

How to Turn-ON an SCR?

- As mentioned earlier, the **SCR (thyristor)** can be **Switched-ON** either by **increasing the Forward Voltage** beyond **Forward Breakover Voltage (V_{FBO})** or by applying a **Positive Pulse Gate Signal,** when the **SCR device** is **Forward Biased.** Of these **two methods, the latter**, called the **Pulse Gate-Control Method also well known as Pulse Gate Triggering Method** is used as it **is more efficient and easy to implement** for P**ower Control.** While designing the **Pulse Gate Triggering Circuit,** the following important points must be kept in your mind.

- **(1)** Appropriate **Gate-to-Cathode Voltage** must be applied for Turn-ON when the device is **Forward Biased.**
- **(2)** When the SCR is triggered and device is **Turned-ON**, then the **Gate Signal** must be **detached instantly**, otherwise, the **Power Loss** will be there within the **Gate Junction J2.**
- **(3)** No **Gate Signal** should be applied when the device is **Reverse-Biased.**
- **(4)** When the SCR device is in the **OFF-State,** a **Negative Voltage** applied between the **Gate and the Cathode** will improve the characteristics of the device. In such an instance, a **Large Positive Voltage** will be required to overcome this **Negative Bias** for **Turn-ON.**
- **(5)** The **Gate Signal's Pulse width must longer than the required time** used for the **Anode Current** for increasing to the value of **Holding Current.**

SCR Turning-ON Using Pulsed Gate Signal

- For **SCR Turn-ON** purposes, the **Pulse Gate Signal** or **Gate Voltage (V_g)** shown in **Fig (64)** will be applied to the **Gate (G)** terminal of the **SCR Two Transistor Model** circuit diagram shown in **Fig (65).**

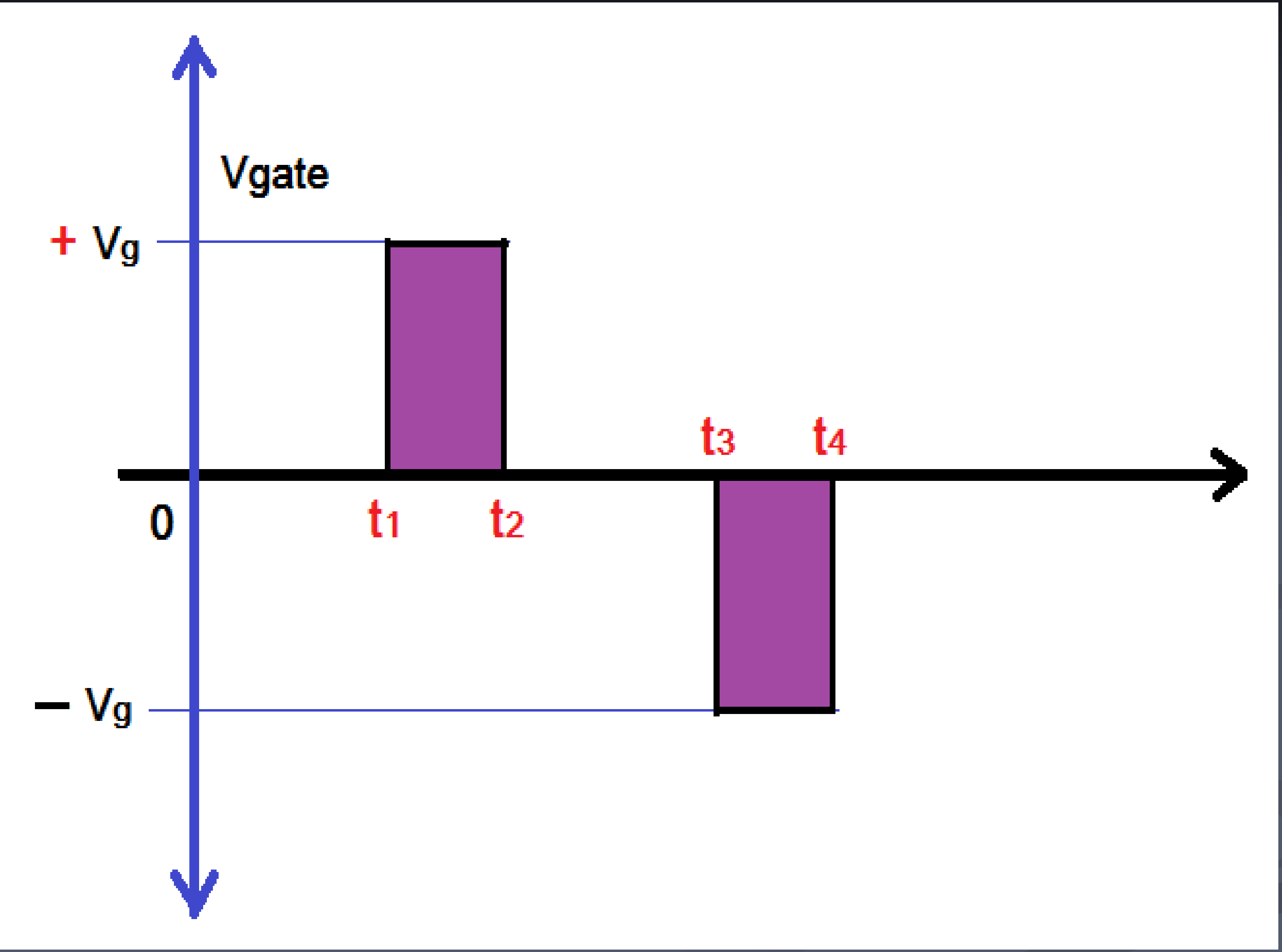
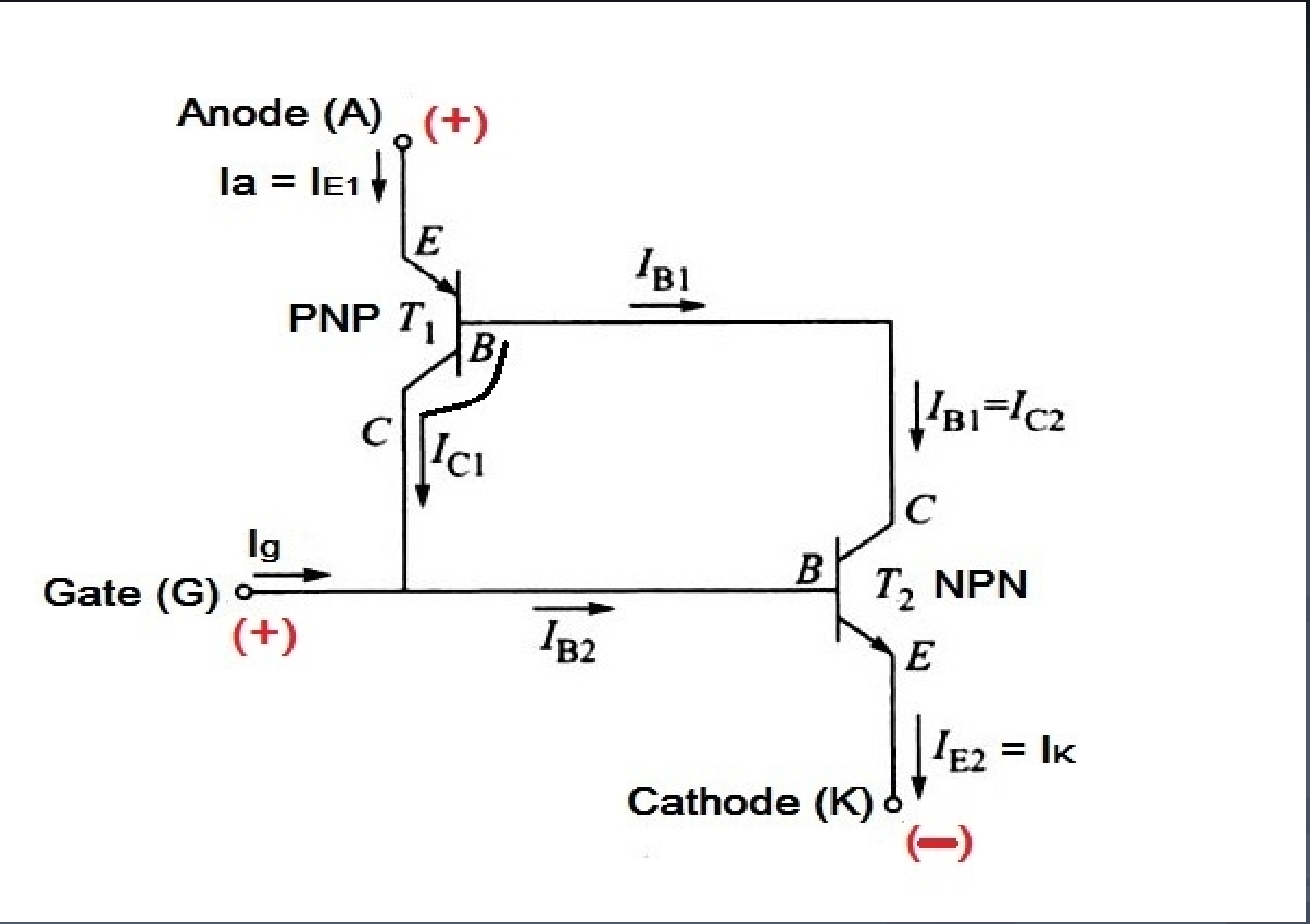


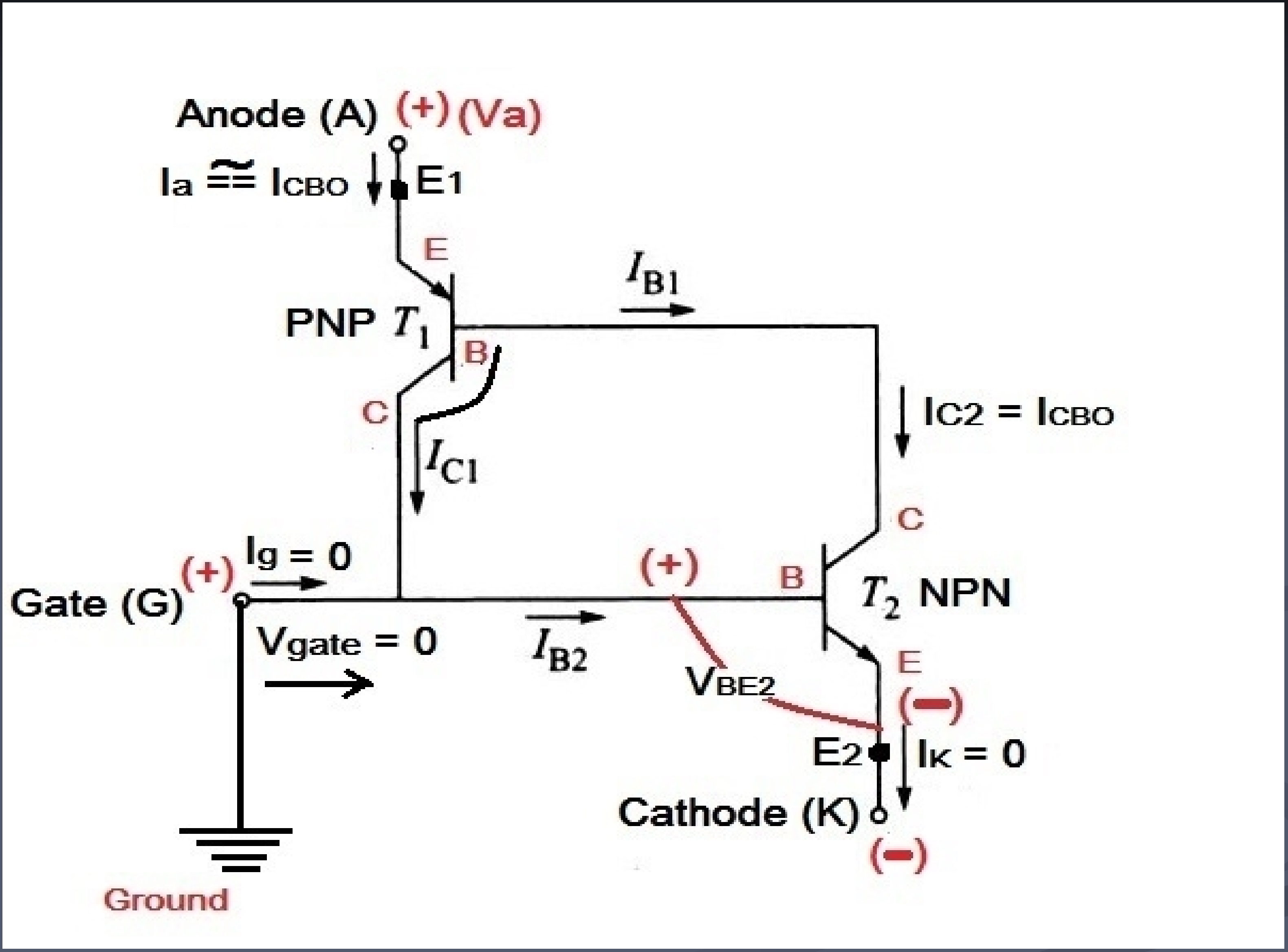
Fig (64) Shown a Gate Pulse (voltage) applied to the Gate (G) terminal of the SCR Two Transistor Model Circuit Diagram.



- **Fig (65)** Shown SCR Two Transistor Model Circuit Diagram during the no **Gate Pulse applied.**

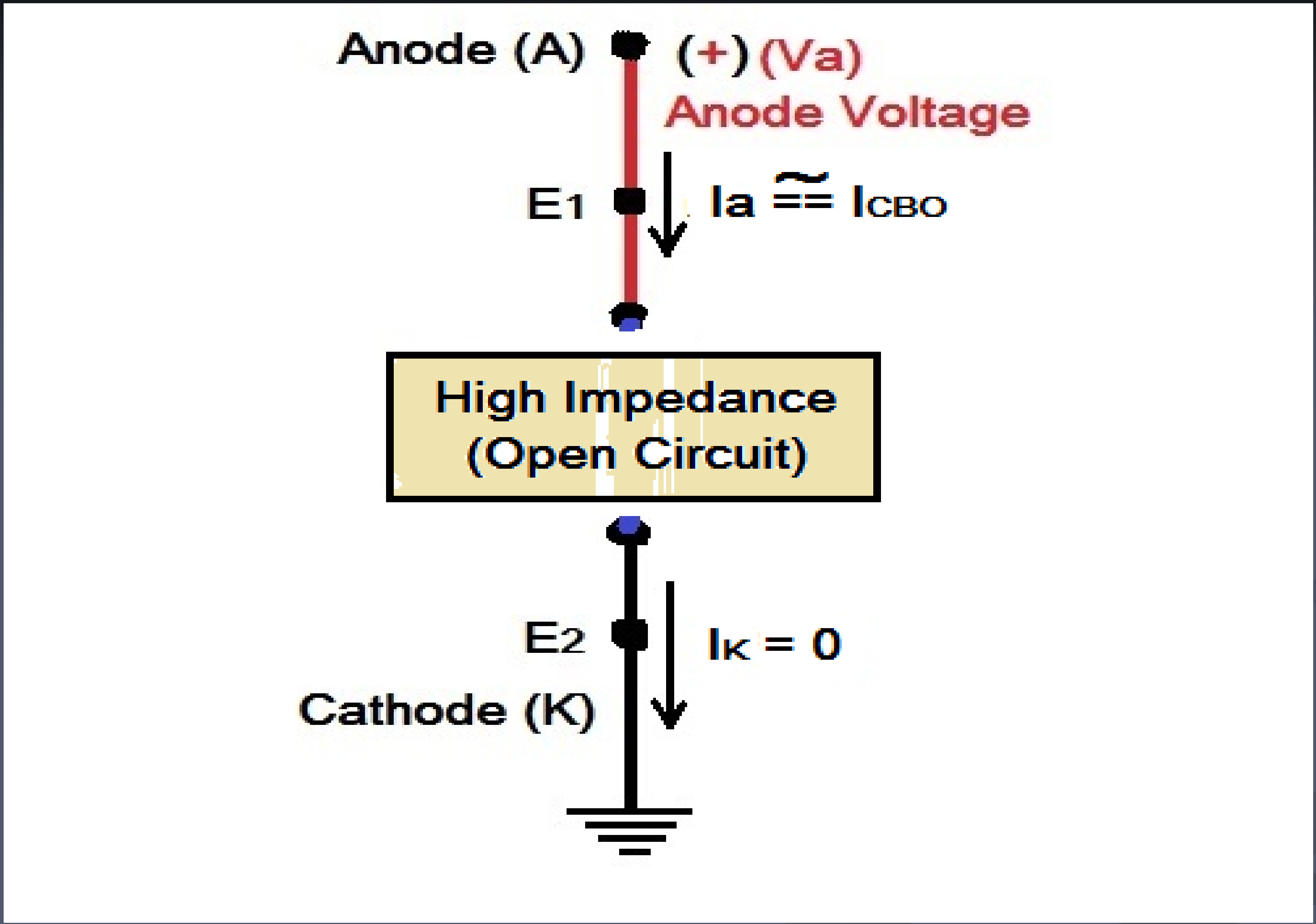
- **During the interval 0 – t1 from Fig (1) :-**

- During the **interval 0 – t1, V_{gate} = 0**, the circuit of **Fig (65)** will appear as shown in **Fig (66). V_{gate} = 0** is equivalent to the **Gate (G) terminal of SCR** being **Ground** as shown in the **Figure (66).**



- **Fig (66)** Shown **OFF-State of the SCR** Two Transistor Model Circuit Diagram during the **Gate Pulse interval 0 – t1, Vgate = 0**

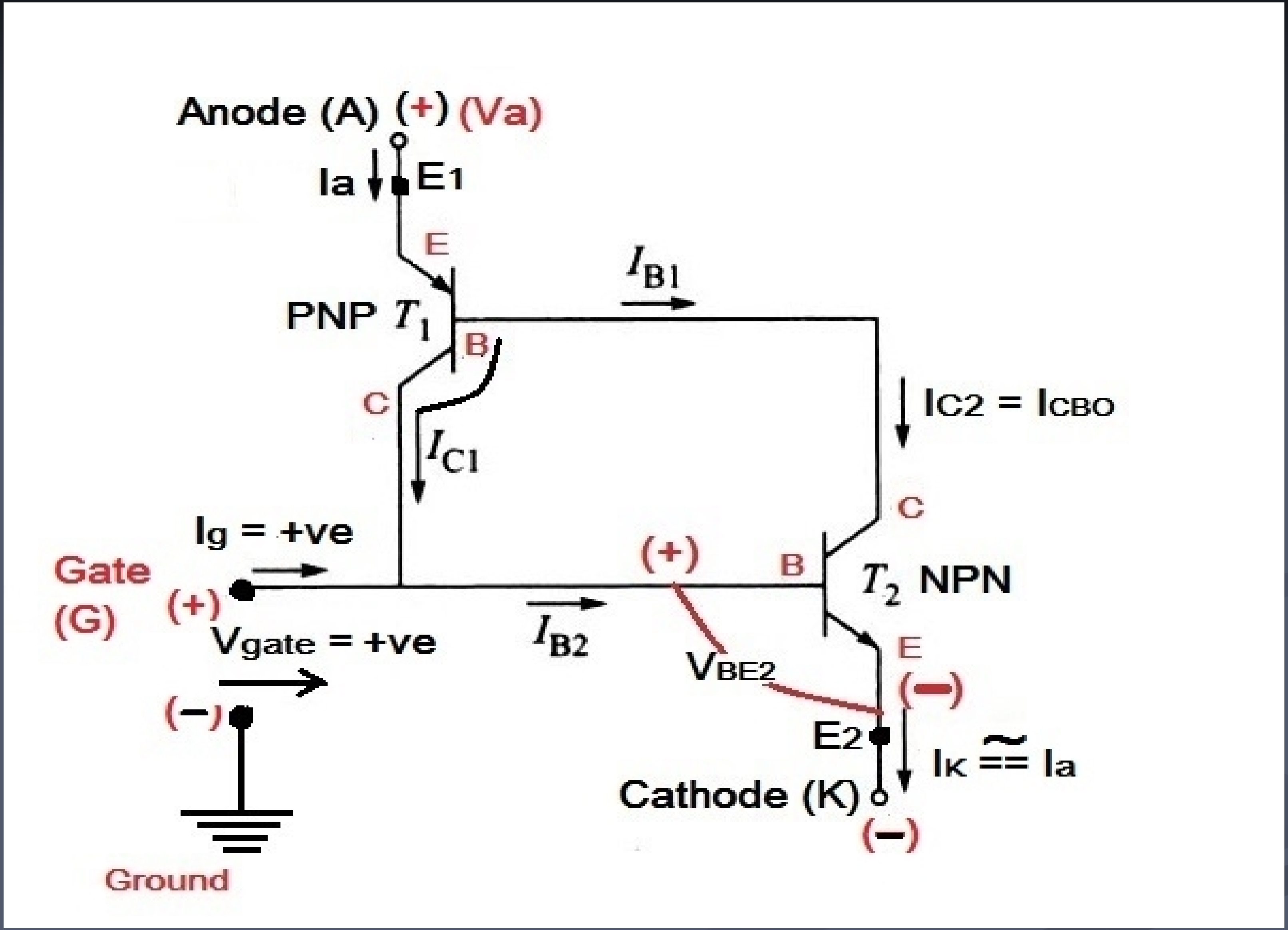
- **For V_{BE2} = V_{gate} = 0V,** the **Base Current I_{B2} = 0 and I_{C2}** will be approximately **I_{CBO}.** The **Base Current** of **Transistor T1**, **I_{B1} = I_{C2} = I_{CBO},** is too small to **Turn Transistor T1 ON.** Both **Transistors T1 and T2** are therefore in the **OFF-State,** resulting in a **High Impedance** between the **Collector and Emitter** of each transistor and the **Open-Circuit** representation for the **Silicon Controlled Rectifier (SCR)** as shown in **Fig (67)** below.



- **Fig (67)** Shown **High Impedance** or **Open-Circuit representation** for the **Silicon Controlled Rectifier (SCR).**

- **During the interval t1 – t2 from Fig (1) :-**

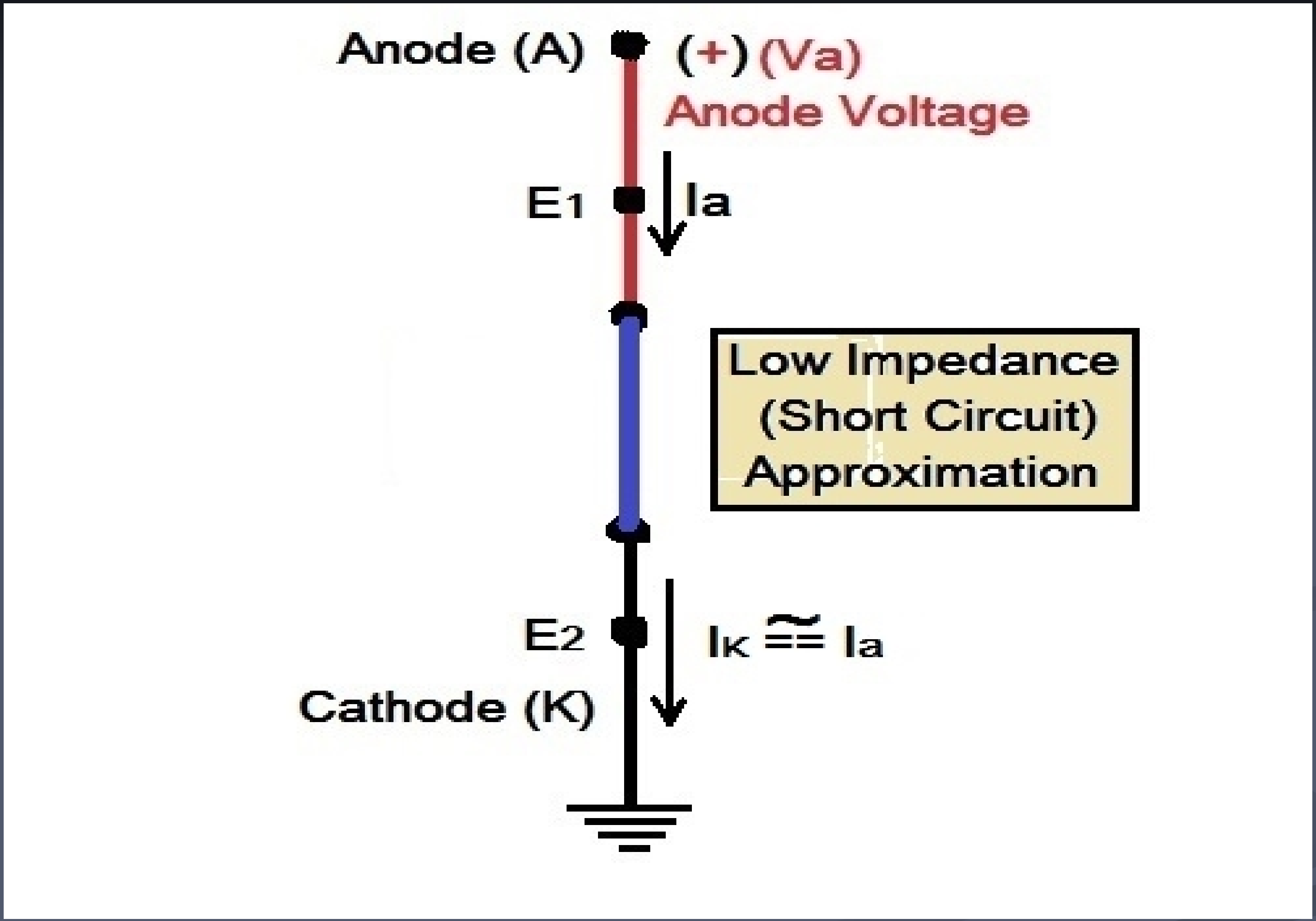
- From **Fig (68),** at **interval t1 – t2, Vgate = +Vg**, a pulse of **Gate Voltage Vg** volts will appear at the **SCR Gate (G) terminal.** The circuit conditions established with this input are shown in **Fig (68).** The **Gate (G) Potential Vg** was chosen sufficiently large to **turn Transistor T2 ON (V_{BE2} = Vg).** The **Collector Current I_{C2} of Transistor T2** will then **rise** to a value sufficiently large to **turn Transistor T1 ON (I_{B1} = I_{C2}).** As **Transistor T1 Turns ON, Collector Current IC1 will increase,** resulting in a corresponding increase in **Base Current I_{B2} of Transistor T2.** The increase in **Base Current I_{B2} for Transistor T2** will result in a further **increase in Collector Current IC2. The net result is a Regenerative Increase in the Collector Current of each transistor.**



- **Fig (68)** Shown **ON-State of the SCR** Two Transistor Model Circuit Diagram during the **Gate Pulse interval t1 – t2, Vgate = +ve or Vgate = +Vg**

- The resulting **Anode to Cathode Resistance (RSCR = Va / Ia) is then small** because **Gate Current Ia** is large, resulting in the **Short-Circuit Representation** for the **SCR** as indicating in **Fig (69)** below. The **Regenerative Action** described above results in **SCRs** having typical **Turn-ON time of 0.1 to 1 micro-second.** However, high power **SCR devices in the range 100 to 400 A may have 10 to 25 micro second Turn-ON times.**

- In addition to **Gate Triggering,** SCR can also be **Turn -ON** by sufficiently raising the temperature of the device or raising the **Anode (A) to Cathode (K)** Voltage to the **Forward Breakover Voltage (V_{FBO})** value which already discussed above.



- **Fig (69)** Shown **Low Impedance Short-Circuit representation** for the **Silicon Controlled Rectifier (SCR).**

to be continued ………………..