Dept. of Electronics and Instrumentation Engineering

B.E.-VI semester

Power Electronics Lab

LIST OF EXPERIMENTS

1. SWITCHING CHARACTERISTICS OF
   a) Power MOSFET b) IGBT

2. MOSFET BASED SINGLE QUADRANT DC CHOPPER

3. SINGLE PHASE CYCLOCONVERTER WITH RESISTIVE LOAD

4. SINGLE PHASE SERIES INVERTER USING SCR

5. SINGLE PHASE FULLY CONTROLLED BRIDGE RECTIFIER WITH R AND R-L LOAD

6. SINGLE PHASE AC VOLTAGE CONTROLLER WITH R AND R-L LOAD

7. VOLTAGE COMMUTATION CIRCUIT FOR SCR

8. SIMULATION OF SINGLE QUADRANT DC CHOPPER AND SINGLE PHASE AC VOLTAGE CONTROLLER USING ORCAD SOFTWARE

Ex.No.:
DATE:

SWITCHING CHARACTERISTICS OF a) POWER MOSFET AND b) IGBT

a) METAL-OXIDE SEMICONDUCTOR FIELD EFFECT TRANSISTOR (MOSFET)

AIM

To study the switching characteristics of a MOSFET and to determine the timing parameters.

APPARATUS REQUIRED

1. MOSFET module
2. CRO

THEORY

Bipolar Junction Transistor (BJT) is a current controlled device. In this device, the flow of collector current is controlled by base current and hence, current gain is highly dependent on the junction temperature.

However, a power MOSFET is a voltage controlled device, which requires only a small input current. The switching times of these devices are of the order of nanoseconds. Power MOSFETs are finding increasing applications in low-power, high frequency converters. MOSFETs do not have the problems of second breakdown phenomena as do in BJTs. However, MOSFETs have the problem of electrostatic discharge and requires special care in handling. In addition, it is relatively difficult to protect them under short-circuited fault condition.

MOSFETs are generally classified into two types: Depletion MOSFETs and Enhancement MOSFETs. The three terminals of MOSFET are named as gate (G), drain (D) and source (S) as shown in Fig.1. In case of MOSFET, the gate voltage controls the flow of current from drain to source. From the output characteristics, drain current (I_D) is a function of drain-to-source voltage V_{DS} with gate-to-source voltage at constant V_{GS} as shown in Fig.2(a) for an n-channel MOSFET. The output characteristics for p-channel device are the same except, that the current and voltage polarities are reversed and hence the characteristics for the p-channel device would appear in the third quadrant of the I_D-V_{DS} plane.

In power electronics applications, the MOSFET is used as a switch to control the flow of power to the load. In these applications, the MOSFET traverses the I_D-V_{DS} characteristics from cutoff region to ohmic region through active region as the device turns ON, back again when it turns OFF. The cutoff, ohmic and active regions of the characteristics are shown in Fig.2(a). The MOSFET is in cutoff, when $V_{GS} < V_{GS\ (th)}$, then the device will act as an open circuit and also the drain-source breakdown voltage (BV_{DSS}) must be larger than the applied V_{DS} to avoid breakdown due to avalanche effect.

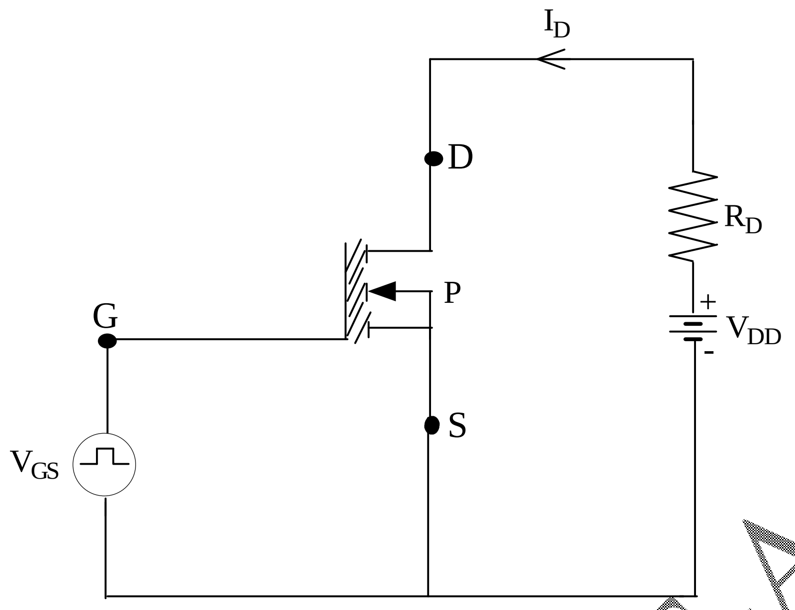

Fig.1. Schematic diagram of n-channel Power MOSFET.

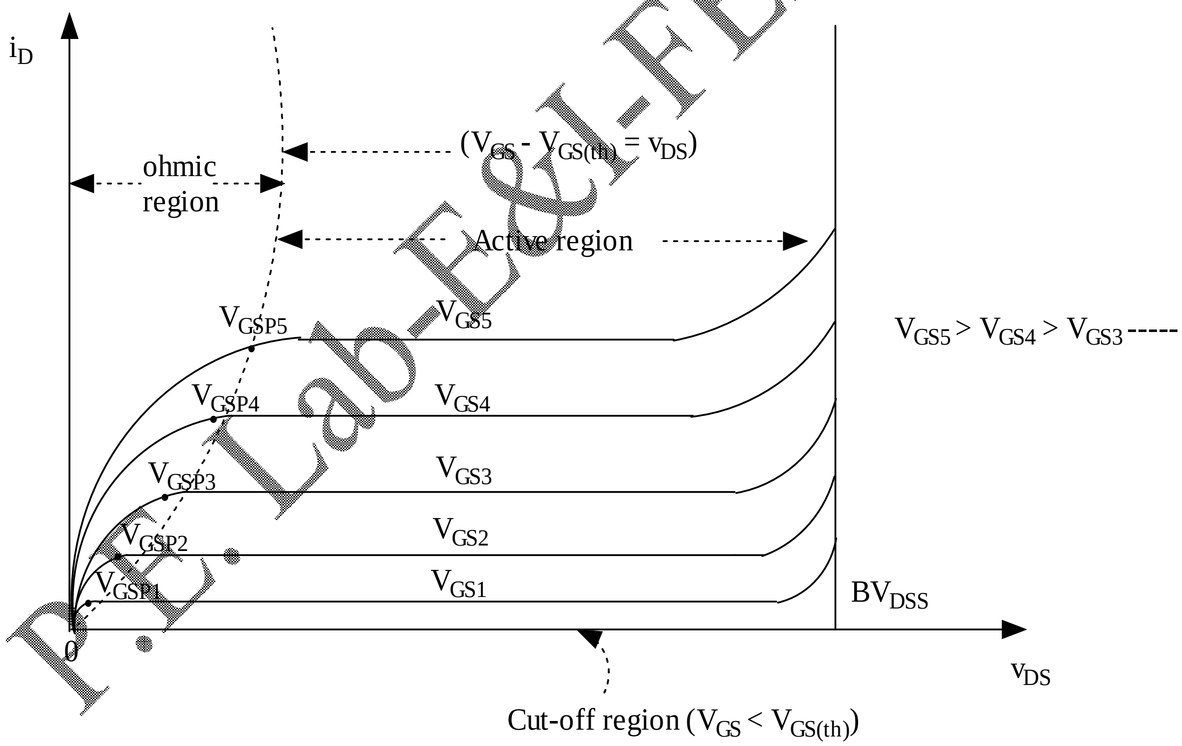

Fig.2(a). Drain characteristics of n-channel E-MOSFET.

When the device is driven by a large V_{GS}, it is driven into the ohmic region, where the voltage $V_{DS\,(on)}$ is small that is

$$\left(V_{GS} - V_{GS(th)}\right) > v_{DS} > 0$$

In the active region, the current I_D is independent of the drain-source voltage and depends only on gate-source voltage. The current is sometime said to have saturated, and consequently this regions is sometimes called the saturation region or pentode region.

$$i_D = K\left(V_{GS} - V_{GS(th)}\right)^2$$

In this experiment, a gate pulse V_{Gate} is applied to the n-channel MOSFET, the drain current I_D is noted down for the given V_{GS} (as shown in Fig.2 (b) and 2(c)). The parameters like t_{dn}, t_r, t_{df}, and t_f are represented in Fig.3.

DEFINITIONS

From the graphical representation shown in Fig.3, the following parameters are defined:

Turn on delay time (t_{dn})

It is the time in which, input capacitance of MOSFET charges to gate threshold voltage $V_{GS\,(th)}$.

Rise time (t_r)

It is the time in which, drain current 'I_D' rises to steady state value when the gate voltage rises from $V_{GS\,(th)}$ to V_{GSP}.

Turn-on time (t_{on})

It is the summation of the delay time 't_{dn}' and rise time 't_r'.

$$t_{on} = t_{dn} + t_r$$

Turn off delay time (t_{df})

It is the time in which, the drain current does not change while reducing the input signal. During t_{df}, input capacitance discharges from V_1 to V_{GSP}.

Fall Time (t_f)

It is the time in which, the drain current falls from I_D to zero and input capacitance falls from V_{GSP} to $V_{GS\,(th)}$.

Turn off time (t_{off})

It is the summation of turn off delay time and fall time

$$t_{off} = t_{df} + t_f$$

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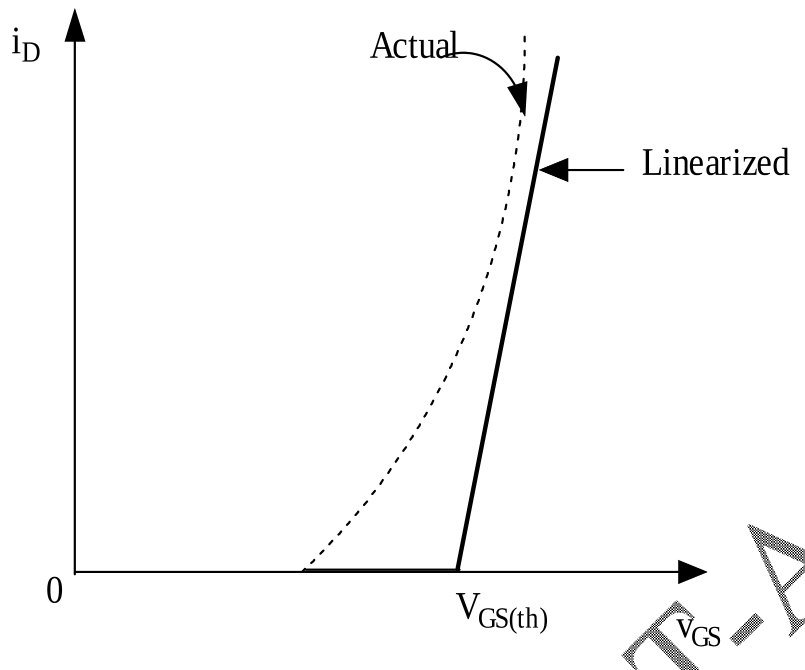


Fig.2(b). Transfer characteristics of n-channel E-MOSFET.

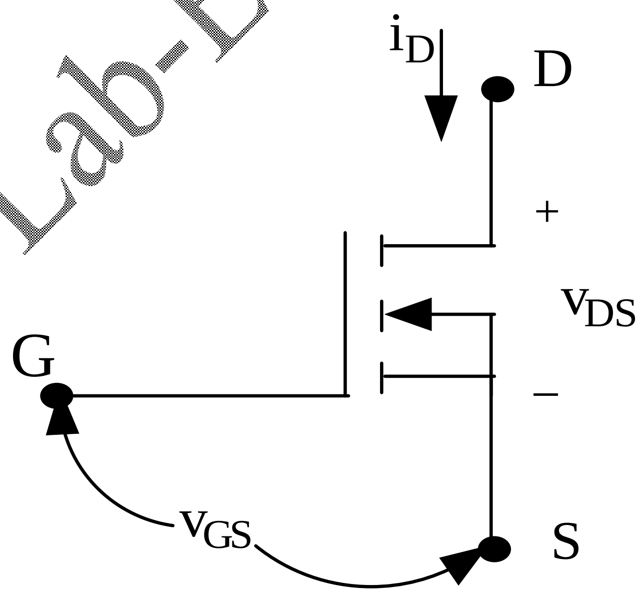


Fig.2(c). Symbolic representation of n-channel E-MOSFET.

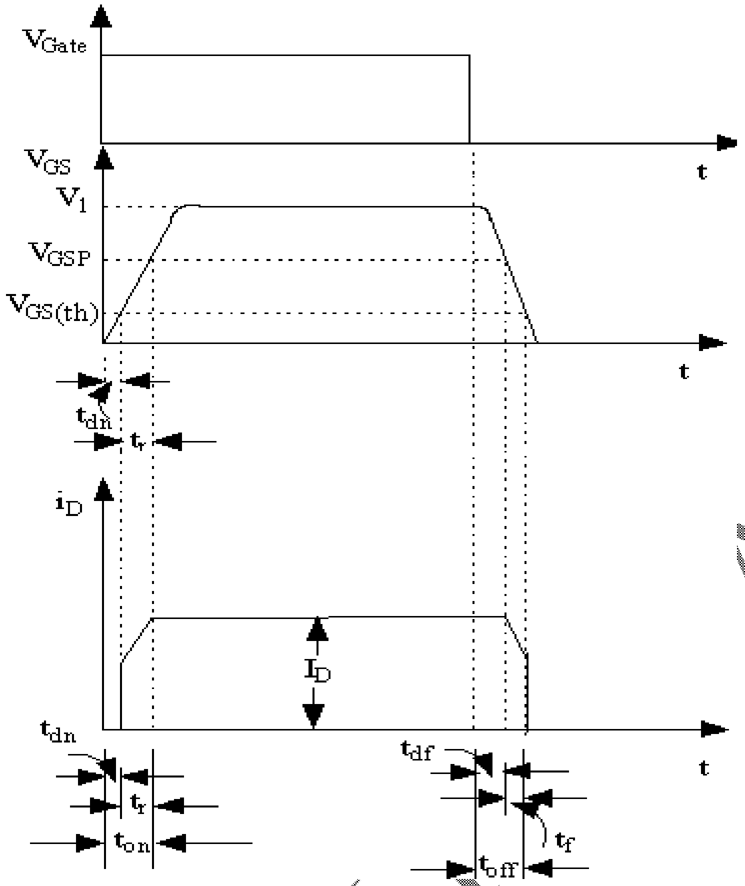


Fig.3. Switching characteristics of E-MOSFET.

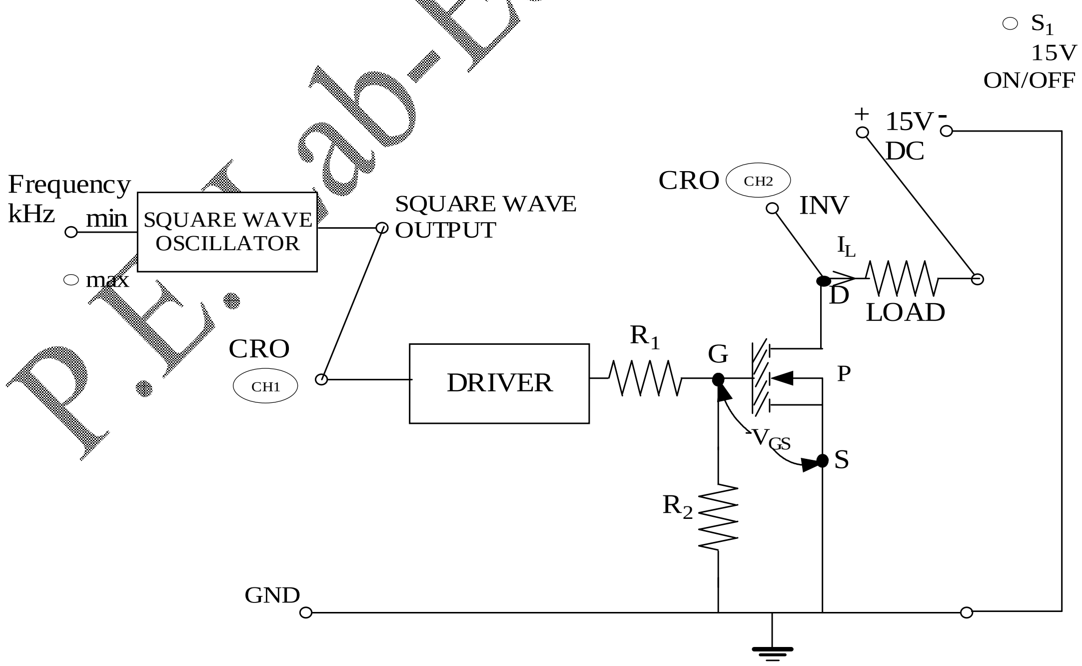


Fig.4. Schematic diagram of E-MOSFET.

PRECAUTIONS

1) Keep the oscillator switch in maximum frequency position.

2) Before giving connections, check whether all the switches are in OFF position.

PROCEDURE

1. Give connections as per the circuit diagram shown in Fig.4.

2. Switch ON the CRO and fix with x10 magnifying mode.

3. Turn ON the trainer power switch.

4. Turn ON the 15V DC selector switch.

5. To observe the device voltage (V_{DS}), connect the channel 2 of CRO to drain of MOSFET with respect to ground. The load voltage is the inversion of the device voltage, so the channel-2 is in invert mode. Since the load is R, the measure of the load voltage is proportional to the load current I_L and hence I_D.

6. To observe the trigger pulse (V_{GS}) applied to the gate through the driver, connect the channel 1 of CRO at the input of the driver with respect to ground.

7. Compare the above two signals. Determine the parameters t_{dn}, t_r, t_{df}, and t_f and tabulate the values in Table1.

Table 1. Switching parameters of n-channel E-MOSFET for gating signal frequency 1.8kHz.

Turn ON time (ms)			Turn OFF time (ms)		
t_{dn}	t_r	t_{on}	t_{df}	t_f	t_{off}

b) INSULATED GATE BIPOLAR TRANSISTOR (IGBT)

AIM

To study the switching characteristics of IGBT and to determine the timing parameters.

APPARATUS REQUIRED

1. IGBT module
2. CRO

THEORY

IGBT combines the advantages of BJT and MOSFET. It has high impedance gate like MOSFET and low on-state conduction losses like BJT. Also there is no second breakdown problem like BJT. It is a voltage controlled device, similar to the power MOSFET and has lower switching and conduction losses. IGBT is inherently faster than BJT. However, the switching speed of IGBT is inferior to that of MOSFET. IGBTs are used in medium power applications such as DC and AC motor drives, power supplies, solid- state relays and contactors. The I-V characteristics, transfer charactyeristics and symbol of an n-channel IGBT are shown in Figs.5(a), (b) and (c) respectively.

In the forward direction, they appear qualitatively similar to those of a logic-level BJT except that the controlling parameter is an input voltage, the gate-source voltage, rather than an input base current. The transfer characteristics I_D-V_{GS} is shown in Fig.5(b) is identical to that of E-MOSFET. The curve is reasonably linear over most of the drain current range and becomes nonlinear only at low drain currents, where the gate-source voltage is approaching the threshold. If $V_{GS}<V_{GS\ (th)}$, then the IGBT is in OFF state. The maximum voltage that should be applied to the gate-source (V_{GS}) terminal is usually limited by the maximum drain current (I_D) that is permitted to flow in the IGBT. It is basically a BJT with a MOSFET gate input and thus the modified BJT for the n-channel IGBT as shown in Fig.5(a). The schematic diagram of an IGBT is shown in Fig.6.

In this experiment, a gate pulse V_{Gate} is applied to the IGBT, the collector current I_C is noted down for the given V_{GE}. The parameters like t_{dn}, t_r, t_{df}, t_{f1} and t_{f2} are noted down as represented in Fig.7.

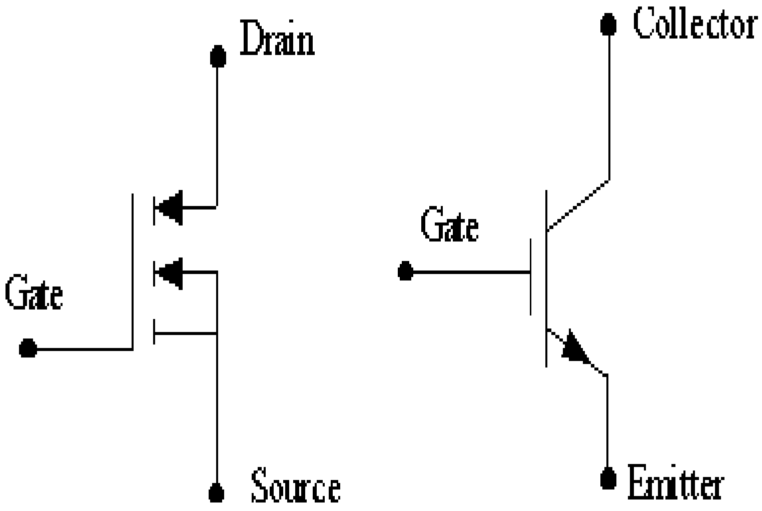


Fig.5(a). Symbolic representation of IGBT and its analogy to E-MOSFET.

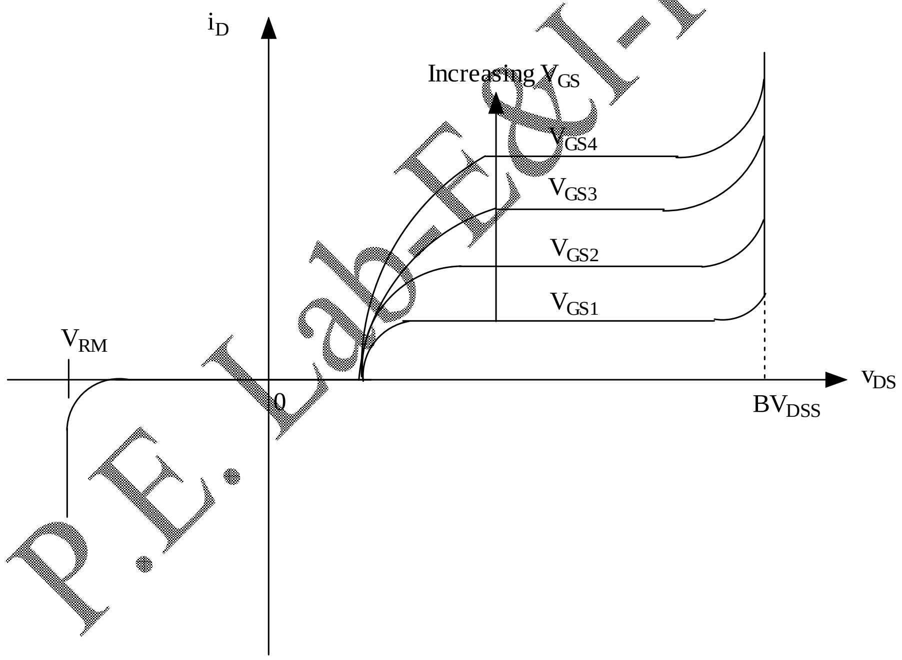


Fig.5(b). The IGBT I_D-V_{DS} characteristics.

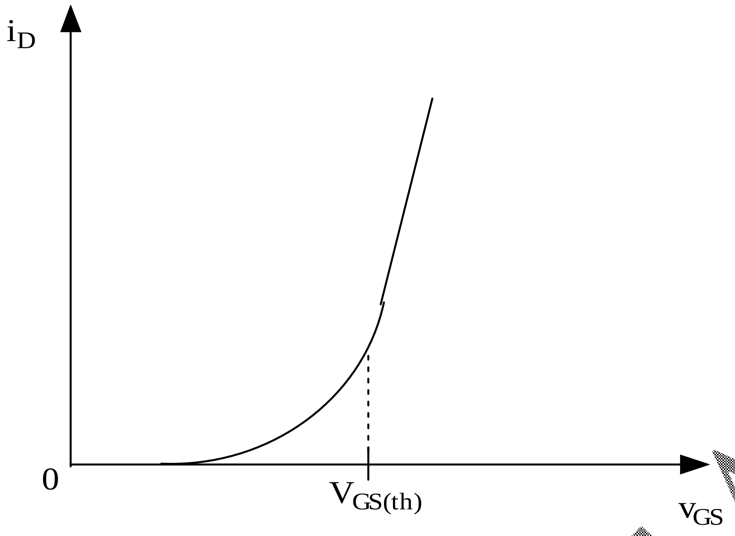


Fig.5(c). Transfer characteristics of IGBT.

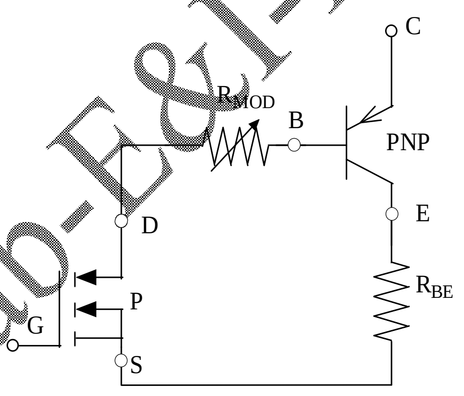


Fig. 6. Schematic diagram of IGBT.

DEFINITIONS

Form the graphical representation shown in Fig.7, the switching parameters are defined as follows:

Delay time (t_{dn})

It is the time in which, the collector current rises from collector-emitter leakage current (I_{CEO}) to 10% of collector current.

Rise time (t_r)

It is the time in which, the collector current rises from 10% of I_C to steady state collector current (I_C).

Turn–on time (t_{on})

It is the summation of the delay time and rise time.

$$t_{on} = t_{dn} + t_r$$

Delay time (t_{df})

It is the time in which, the collector current falls from 100% to 90%.

Initial fall time (t_{f1})

It is the time in which the collector current falls from 90% to 20%.

Final fall time (t_{f2})

It is the time in which the collector current falls from 20% to10%.

Turn off time (t_{off})

It is the summation of delay time, initial fall time and final fall time.

$$t_{off} = t_{df} + t_{f1} + t_{f2}$$

PRECAUTIONS

1) Keep the oscillator switch in maximum frequency position.

2) Before giving connections, check whether all the switches are in OFF position.

PROCEDURE

1. Give connections as per the circuit diagram shown in Fig.8.

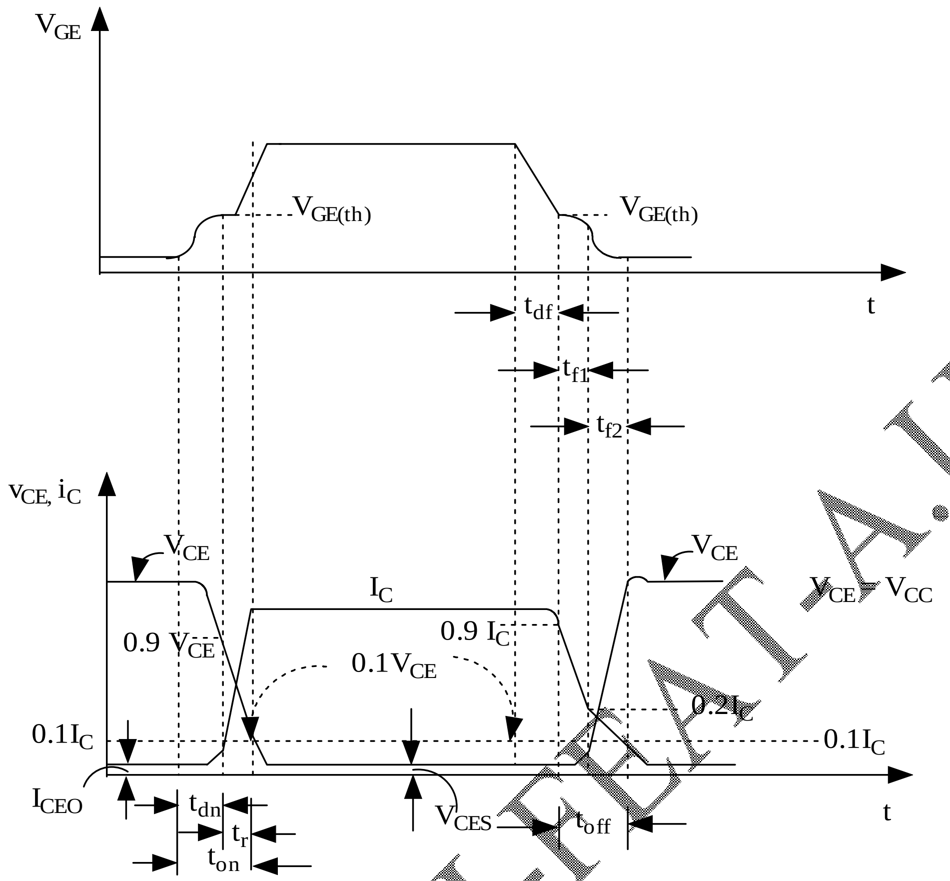
2. Switch ON the CRO and fix with x10 magnifying mode.

3. Turn ON the trainer power switch.
4. Turn ON the 15V DC selector switch.

5. To observe the device voltage (V_{CE}), connect the channel 2 of CRO to collector of IGBT with respect to ground. Since the load voltage is the inversion of the device voltage, so the channel-2 is in invert mode. Since the load is R, the measure of the load voltage is proportional to the load current I_L and hence i_C.

6. To observe the trigger pulse ($V_{GE} = V_{GS}$) applied to the base, connect the channel 1 of CRO at the input of the driver, with respect to ground.

7. Compare the above two signals. Determine the parameters t_{dn}, t_r, t_{df}, and t_f and tabulate the values in Table 2.



I_{CEO} – Collector emitter leakage current
V_{CES} – Conduction drop of IGBT

Fig.7. Switching characteristics of IGBT

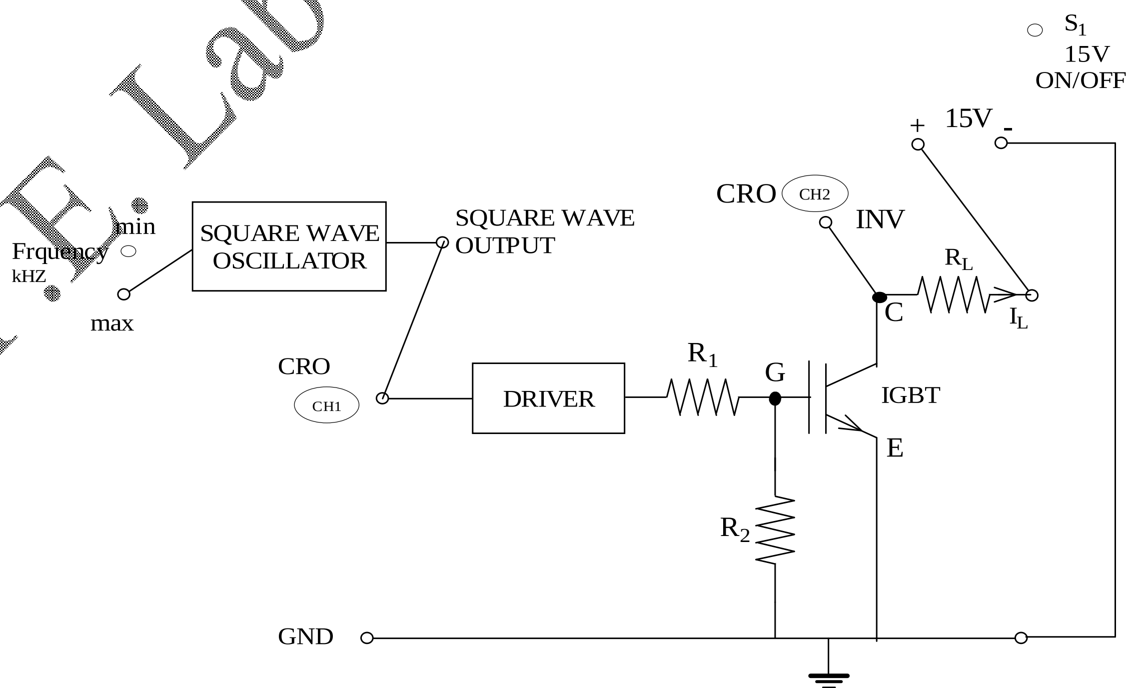


Fig.8. Connection diagram of IGBT.

Table 2. Switching parameters of IGBT for gating signal frequency 10kHz.

Turn ON time (ms)			Turn OFF time (ms)			
t_{dn}	t_r	t_{on}	t_{df}	t_{f1}	t_{f2}	t_{off}

RESULT

Switching characteristics of E-MOSFET and IGBT were studied and the parameters were determined and tabulated.

Ex.No.:
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MOSFET BASED SINGLE QUADRANT DC CHOPPER

AIM

1. To study the operation of a single quadrant step-down DC chopper
2. To obtain the output voltage waveforms.

APPARATUS REQUIRED

1. VPET-208 module - DC Chopper Control Circuit
2. DMM
3. CRO

THEORY

In a.c. circuits, the transformer converts electric power efficiently from one voltage level to another voltage level. DC-DC converters do a similar job in DC circuits are called choppers. The operation of transformer is based on an alternating magnitude field. But in choppers, the voltage conversion is achieved using high frequency power semiconductor switches, which operate either in fully ON or fully OFF state.

Choppers are widely used for DC motor control, electric vehicles, trolley cars, lamp loads, heater loads and in DC voltage regulators. DC choppers provide smooth acceleration control, high efficiency and fast dynamic response in electric vehicles. They are classified as

1. Buck converter i.e. $V_o \le V_{in}$ (step down)
2. Boost converter i.e. $V_o \ge V_{in}$ (step up)
3. Buck Boost converter (combination of both)

The circuit configuration of a chopper can be designed either to step down or step up the input voltage level. In this experiment, the operation of step down chopper circuit is studied. The two modes of operation of step down chopper are explained as follows:

TWO MODES OF OPERATION OF CHOPPER

Mode 1: 0 dt dT_{ON}

When the switch (S) is ON by applying a gating pulse V_G as shown in Fig.1(a), the device voltage V_d (drop across the switch) becomes zero and the load voltage $V_o = V_{in}$. Hence

$V_o = V_{in} = I_o * R$

Fig.1(a). Mode 1: Circuit diagram of step-down DC chopper

Fig.1(b). Mode 2: Circuit diagram of step-down DC chopper

Therefore the load current

$$I_o \quad \frac{V_{in}}{R}$$

Mode 2: T_{ON} dt dT

When the switch (S) is OFF (V_G=0) as shown in Fig.1(b), the device voltage (V_d) becomes V_{in} and the output voltage V_o = 0 and the load current I_o = 0. Hence, the power dissipation in the switch (P_d) is zero.

Combining Mode 1(M_1) and Mode 2 (M_2)

Theoretical waveforms for input voltage (V_{in}), gating pulse (V_G), output voltage (V_o) and the device voltage (V_d) are shown in Fig.2. Referring the waveforms, it is clear that

1. The switch closes for T_{ON} seconds in M_1 and for this period, the input voltage appears across the load.
2. The switch opens for T_{OFF} seconds in M_2 and for this period, the load voltage becomes zero.
3. The sum of T_{ON} and T_{OFF} is called chopping period, T and chopping frequency is equal to 1/T.

STEP DOWN CHOPPER

A chopper which gives an output voltage less than or equal to the input voltage is called a step down chopper. Neglecting, the voltage drop across the switch, the average output voltage $V_{o,avg}$ is given by

$$V_{o,avg} = \frac{1}{period}\int_0^{period} V_o(t)\,dt \qquad (1)$$

Where $V_o(t) = V_{in};\ 0 \le t \le T_{ON}$

And $V_o(t) = 0;\ T_{ON} \le t \le T$

Period $T = T_{ON} + T_{OFF}$

Therefore the equation (1) becomes

$$V_{o,avg} = \frac{1}{T}\int_0^T V_o(t)\,dt$$

$$= \frac{1}{T}\left[\int_0^{T_{ON}} V_o(t)\,dt + \int_{T_{ON}}^{T} V_o(t)\,dt\right]$$

Fig.2. Waveforms of stepdown DC chopper.

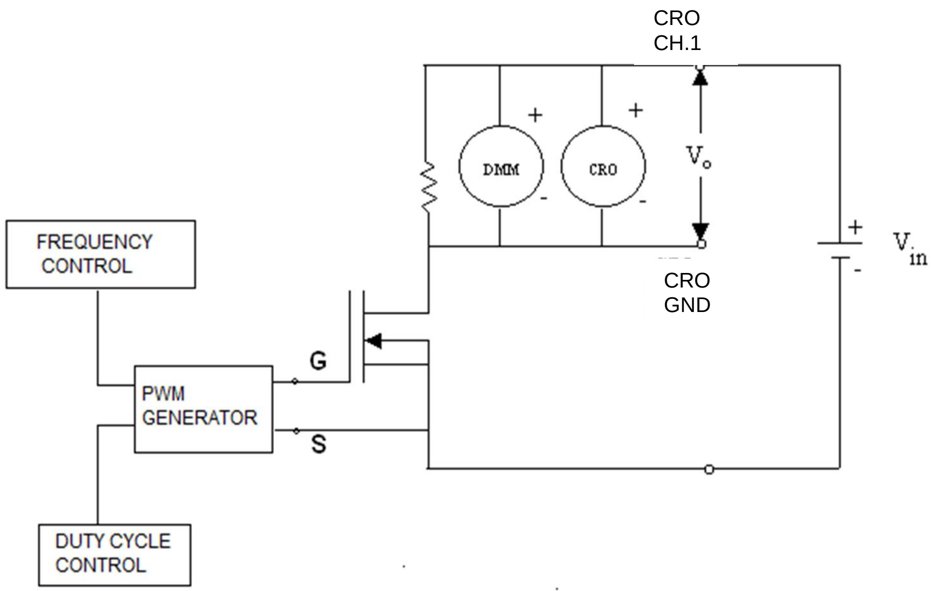

Fig.3(a). Circuit diagram of DC chopper.

$$= \frac{1}{T}\left[\int_0^{T_{ON}} V_{in}\,dt + \int_{T_{ON}}^{T} 0\,dt\right]$$

$$\frac{1}{T}\,[V_{in}]\,[t]_0^{T_{ON}}$$

$$\frac{V_{in}}{T} * T_{ON}$$

$$V_{o,avg} \quad V_{in} * \frac{T_{ON}}{T} \qquad (2)$$

where T = Chopping period and

$\frac{T_{ON}}{T}$ = Duty cycle ratio

From Eqn. 2, it is clear that the average output voltage $V_{o,avg}$ depends on the T_{ON} and T. It can be varied by varying either the chopping frequency (f) or by varying T_{ON}. Thus the power flow in the circuit can be controlled.

The switch shown in Fig.3, can be any one of the following power semiconductor devices: i) SCR, ii) power transistor (power-BJT), iii) power-MOSFET, iv) IGBT and v) GTO. In this experiment, IGBT [Insulated Gate Bipolar Junction Transistor] is used as a switch.

PRECAUTIONS

1. Ensure the switch is in OFF position while doing circuit connection.
2. Ensure pulse release switch in OFF position whenever power is switched ON.

EXPERIMENTAL PROCEDURE

I) Fixed Frequency Variable Time Ratio Control (FFVTRC)

1. Connect the load and the device as shown is Fig.(3a).
2. Connect channel-1 of CRO and ground across the load (R), to measure the output voltage. Connect Channel-2 of CRO to measure the input voltage (V_{in}) as shown in Fig. (3a).
3. Fix the carrier frequency knob at one position and adjust T_{ON} and T_{OFF} as given in Table 1.

4. Trace the output voltage on CRO for different T_{ON} settings and simultaneously note down the average output voltage using DMM and verify with theoretical value as given below:

$$V_{o,avg} \quad \frac{T_{ON}}{T} V_{in} \qquad (3)$$

5.

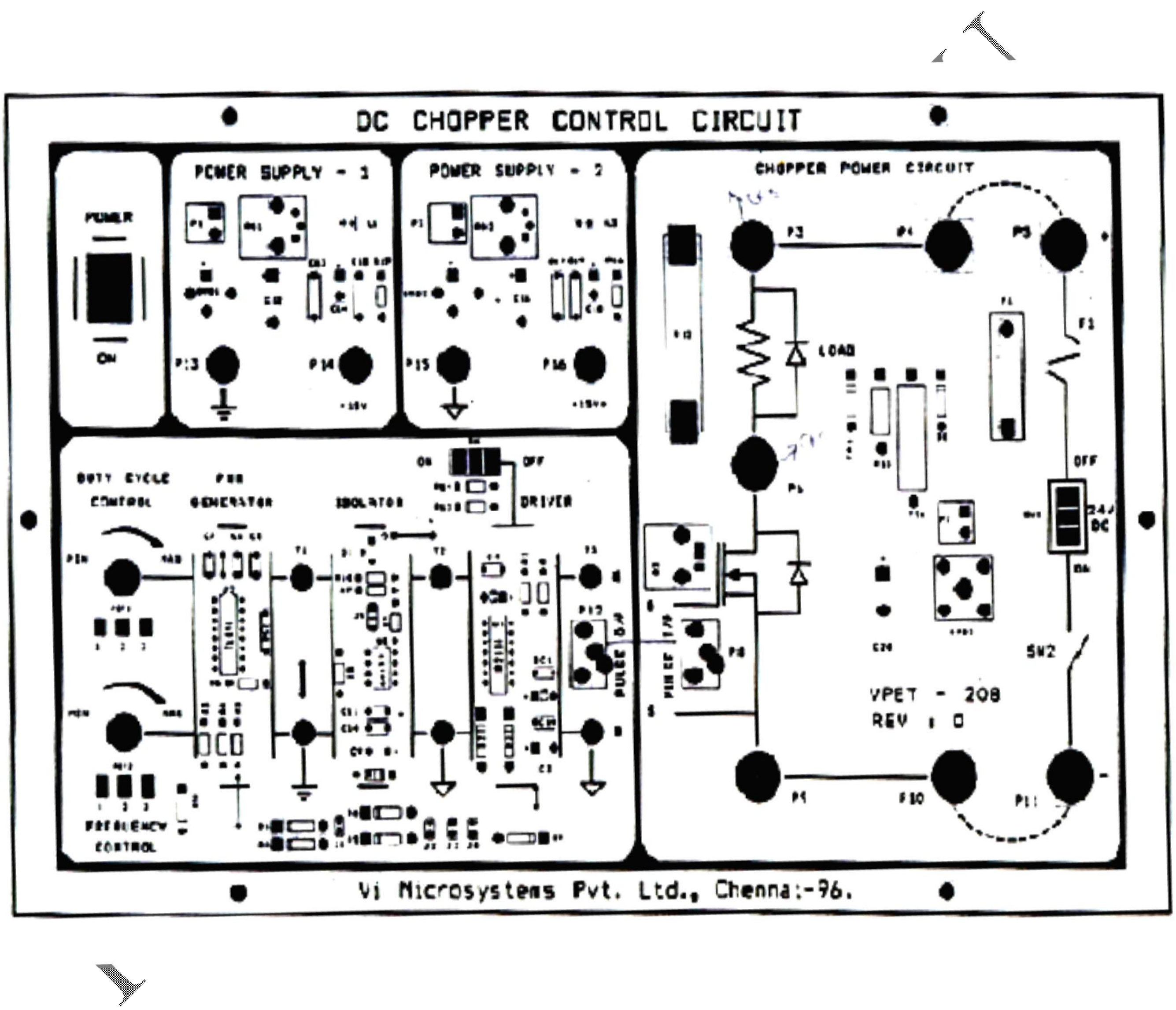

Fig.3(b). Connection diagram of step down DC chopper.

Table 1. Fixed Frequency Variable Time Ratio Control (FFVTRC)

Chopping frequency f_s	Chopping period T	Off period T_{off}	On period T_{on}	Theoretical output voltage V_o (avg) (V)	Practical output voltage V_o (avg) (V)	Input voltage V_{in} (V)

Table 2. Variable Frequency Variable Time Ratio Control (VFVTRC)

Chopping frequency f_s	Chopping period T	Off period T_{off}	On period T_{on}	Theoretical output voltage V_o (avg) (V)	Practical output voltage V_o (avg) (V)

II) Variable Frequency Variable Time Ratio Control (VFVTRC)

1. The connection and procedure are similar to the FFVTRC.
2. Vary both the carrier frequency knob and voltage knob simultaneously to keep T_{ON} fixed and T_{OFF} variable, as given in Table 2.
3. Trace the output voltage for different T_{OFF} settings and simultaneously note down the average output voltage using DMM and verify with theoretical value as given below:

$$V_{o,avg} = \frac{T_{ON}}{T_{ON} + T_{OFF}} V_{in} \qquad (4)$$

Result

The operation of a single quadrant step-down DC-DC converter (chopper) with fixed load was studied and output waveforms were obtained.