LAB 1 & LAB 2

LAB 1: Introduction to Experimental Modules

LAB 2: MOSFET and IGBT Characteristics and Measurement

SECTION NUMBER: ……………………………………

GROUP NUMBER : …………………………………….

GROUP MEMBERS : ……………………………………..
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LAB 1 Introduction to Experimental Modules

You will get used to the kit which will be used during the labs. You will learn the modules on the kit and the functions of these modules.

BEFORE COME TO THIS LAB, YOU SHOULD

- Read the kit manual.
- Make some research on how to handle integrated circuits.

AFTER COMPLETING THIS LAB, YOU SHOULD

- Know the modules on the experiment kit.

  - RMS Meter
  - Differential Amplifier
  - DC Power Supply

- Know the ports and the peripheral hardware available on the kit.

REQUIREMENTS

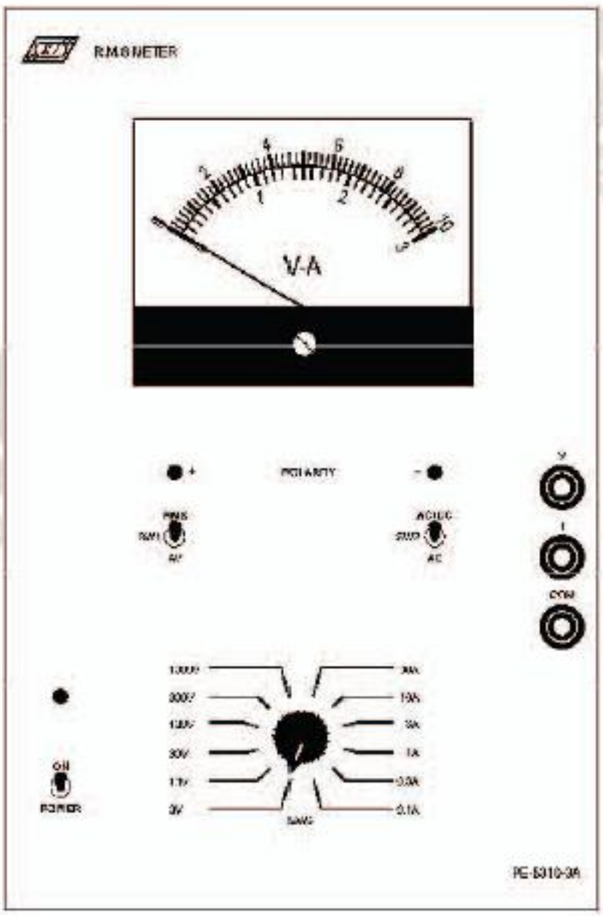
- RMS Meter
- Differential Amplifier
- DC Power Supply

1-2 Introduction to Experimental Modules Required

This Chapter will proceed to the basic experiments of power electronics including the use of often used measuring instruments and the characteristic measurements of thyristors. The required experimental modules and instruments are listed below.

1. PE-5310-3A R.M.S Meter
2. PE-5310-2B Differential Amplifier
3. PE-5310-5D SCR/TRIAC Set
4. PE-5340-3A Isolating Transformer
5. Digital Storage Oscilloscope (DSO)

1-2-1 PE-5310-3A R.M.S Meter



Specifications

1. Measuring range:
   (1) Current: 0.1/0.3/1/3/10/30A
   (2) Voltage: 3/10/30/100/300/1000V
2. Three measuring methods available:
   (1) RMS and AC+DC: for measuring the rms value of ac voltage or current with dc component
   (2) RMS and AC: for measuring the rms value of pure ac voltage or current
   (3) AV and AC+DC: for measuring the average value of ac voltage or current with dc component
3. With overload protection
4. Polarity indicators: positive (+) and negative (-) indicator LEDs
5. Accuracy: 2% full scale
6. Operating power supply: single-phase, 220V AC, 60Hz

Purpose

The voltage or current in power electronic circuits could be sinusoidal and nonsinusoidal. Analog multimeter is a moving coil instrument (actually a dc current meter), the ac signal to be measured is first rectified and scaled by the effective value of sinusoidal wave. Therefore, analog multimeters are unsuited for measuring nonsinusoidal voltages and currents in power electronic circuits. If a nonsinusoidal signal is measured with an analog multimeter, the meter reading is incorrect and meaningless.

The PE-5310-3A R.M.S Meter module, true R.M.S. design, is suited for the measurements of sinusoidal or nonsinusoidal signal used in power electronic circuits.

The R.M.S Meter contains three selector switches for selecting the type, range and value of the signal to be measured.

1. V/I Range selector switch, for voltage or current measurement.
2. RMS/AV selector switch, for average value (AV) or rms value (RMS) measurement.
3. AC+DC/AC selector switch, for ac plus dc component (AC+DC) or pure ac.

Table 1-1 shows the combinations of selector switches.

Table 1-1 Combinations of selector switches

	RMS	AV
AC+DC	RMS value of ac plus dc signal or total RMS value.	Average value of ac plus dc signal or dc component
AC	RMS value of ac signal only, or the rms value of ripple signal	

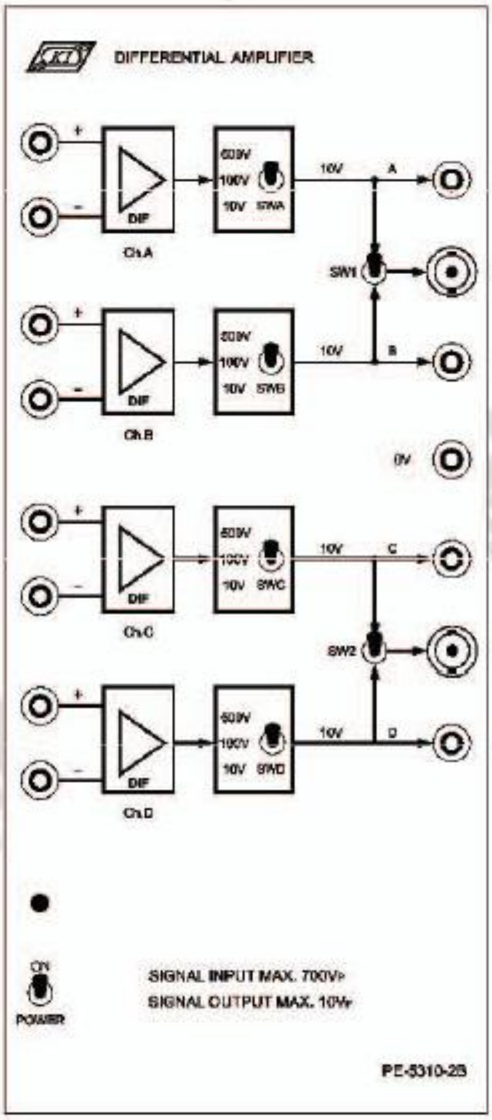
Since the voltage coil has quite large internal resistance (10MΩ) and the current coil has quite small internal resistance (0.01Ω), so the loading effect can be omitted.

When the POLARITY indicator LED (-) illuminates, the measured value is still correct but reverse in polarity of voltage or the direction of current flow.

Usage

1. To measure a voltage value, connect the V and COM terminals in parallel with a circuit or component. To measure a current value, connect the I and COM terminals in series with a circuit or component.
2. Select signal type and measuring method; for example, if you want to measure the average value, set the selector switches RMS/AV and AC+DC/AC to AV and AC+DC, respectively.
3. Set the V/I Range selector switch to an appropriate position, for example, 300V for the measurement of 220V, the pointer needle should stop at 2.2 position on the lower scale 0-3. If the voltage or current value is unknown, place the V/I Range selector switch in the highest range and gradually set it from high to low according to actual reading. Keep in mind that always place the V/I Range selector switch in the position just higher than the actual value for accurate measurements.
4. Place the power switch in the ON position and read the measured value.
5. **Note:** To measure a voltage value, the circuit or component must be connected in parallel with the V and COM terminals. If the circuit or component is connected in parallel with the I and COM terminals, short circuit will occur since the current meter has a low internal resistance.

1-2-3 PE-5310-2B Differential Amplifier Module



Specifications

1. Four individual differential amplifiers: Ch.A, Ch.B, Ch.C, and Ch.D
2. Maximum measuring voltage: 700V peak
3. Maximum output voltage: 10V peak
4. Maximum measuring frequency: 200kHz
5. Input voltage range: 500V, 100V, 10V

6. Output terminals:
   (1) 2 BNC connectors used to connect the outputs of two of four Differential Amplifiers to the inputs of oscilloscope.
   (2) 4 output terminals for connecting to other modules.
7. Input ac supply: single phase, 220V AC, 50/60Hz

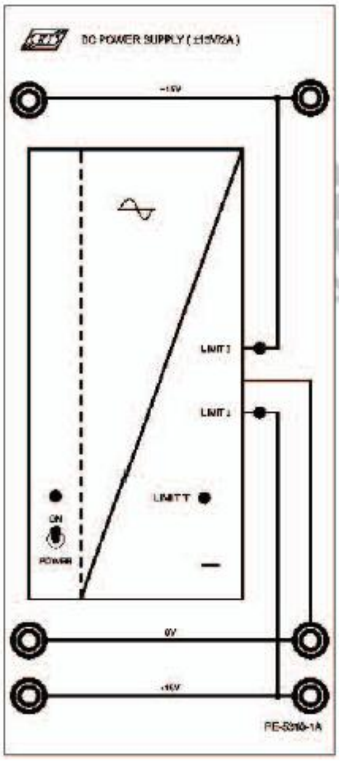
Purpose

Since the peak voltage in power electronic circuits is sometimes greater than the input voltage of oscilloscope, this module equipped with four Differential Amplifiers (Ch.A to Ch.D) provide attenuation and isolation so that the output signals can be measured by general-purpose oscilloscopes. Each of Differential Amplifiers has a V Range selector switch with three positions: 500V (the Vi/Vo ratio=500V/10V=50), 100V (the Vi/Vo ratio=100V/10V=10), and 10V (the Vi/Vo ratio=10V/10V=1).

Usage

1. Connect an input signal to the input terminals of a differential amplifier (Ch.A to Ch.D). If there are two input signals, Ch.A and Ch.C (or Ch.B and Ch.D) are recommended.
2. Place the V Range selector switch of Differential Amplifier to an appropriate position according to the peak value of input voltage; for example, if a 220VAC voltage is to be measured, the V Range selector should be set to the 500V position. If position 100V or 10V is selected, a distorted signal will be displayed on oscilloscope.
3. Connect the BNC connector on this module to the input of oscilloscope using the BNC cable.
4. Use Ch selector switch to select the desired output of Differential Amplifier for display. For example, if the two Ch selectors are placed in up position, the scope screen will display the output signals of Differential Amplifiers Ch.A and Ch.C.
5. Turn power on. Read the peak value from the scope screen and then multiply it by the Vi/Vo ratio to obtain the actual peak value of input voltage.
   Note: Period is independent of the Vi/Vo ratio.

2-2-8 PE-5310-1A DC Power Supply (±15V/2A)



Specifications

1. With over current and over temperature protection
2. With over current (LIMIT I) and over temperature (LIMIT T) indicator LEDs
3. Input power source: Single phase, 220V AC, 50~60Hz
4. Rated output: ±15V/2A
5. With power switch and power on indicator LED

Purpose

In the experiments of electronic power circuits, this module provides the required DC power supply to Reference Variable Generator and 3ϕ Phase Angle Controller modules.

Usage

1. Connect the output terminals +15V, 0V and -15V of this module to the terminals +15V, 0V and -15V of Reference Variable Generator module respectively using bridging plugs or connecting wires.
2. When the over current (LIMIT I) or over temperature (LIMIT T) indicator LED glows, turn off the power and check circuit connections.

LAB 2 MOSFET and IGBT Characteristics and Measurement

You will learn IGBT and power MOSFET structures and characteristics. You will conduct two (2) experiments to observe IGBT and power MOSFET characteristics.

BEFORE COME TO THIS LAB, YOU SHOULD

- Read the experiments.
- Make some research on IGBT and MOSFET.

AFTER COMPLETING THIS LAB, YOU SHOULD

- Know what is IGBT and its characteristics.
- Know what is Power MOSFET and its characteristics.

REQUIREMENTS

- Digital Storage Oscilloscope
- PE 5310 – 1A Module
- PE 5310 – 5E Module
- PE 5310 – 2B Module

4-3 Insulated Gate Bipolar Transistor (IGBT)

A number of power semiconductor devices such as power transistor, power MOSFET, IGBT, and power IC, etc., are widely used in a variety of applications such as automotive, power supplies, electrical machine drives, portable electronic equipment, lighting, and electric appliance. The most popular use and well known are the bipolar transistors (BJTs) and power MOSFETs. An Insulated Gate Bipolar Transistor (IGBT) recently received attention is a MOS gate turn on/off bipolar transistor which combines the attributes of the MOSFET. The IGBT device has the high input impedance of a MOSFET but a low on-state conduction drop similar to a bipolar transistor. The switching speed and safe operating area (SOA) of bipolar transistor are retained. The storage time of the bipolar tends to be long because of its incapability to drive negative base current. However, the device has thyristor-like reverse voltage blocking capability.

The IGBT plays an important role in the field of power electronics and is widely used in many applications such as the Uninterruptable Power Supplies (UPS), variable-speed motor control in air conditioning systems, and robot control in factory automation.

In terms of operating frequency, current and voltage ratings, a comparison among IGBT, MOSFET, and BJT is as follows. The BJT has the highest current rating and lowest operating frequency. The MOSFET has the lowest current and voltage ratings, but highest operating frequency. The IGBT current capability is close to the BJT and has highest voltage rating, but operating frequency is lower than MOSFET. However, the operating frequency of the IGBT is high enough to use in the power stage of an audio amplifier. The advantages of high voltage rating, high current rating and low saturation voltage drop make the IGBT an excellent power device particularly suited for use in power amplifiers for higher reliability.

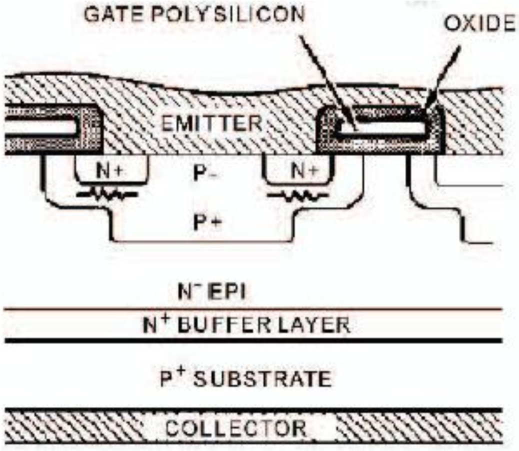
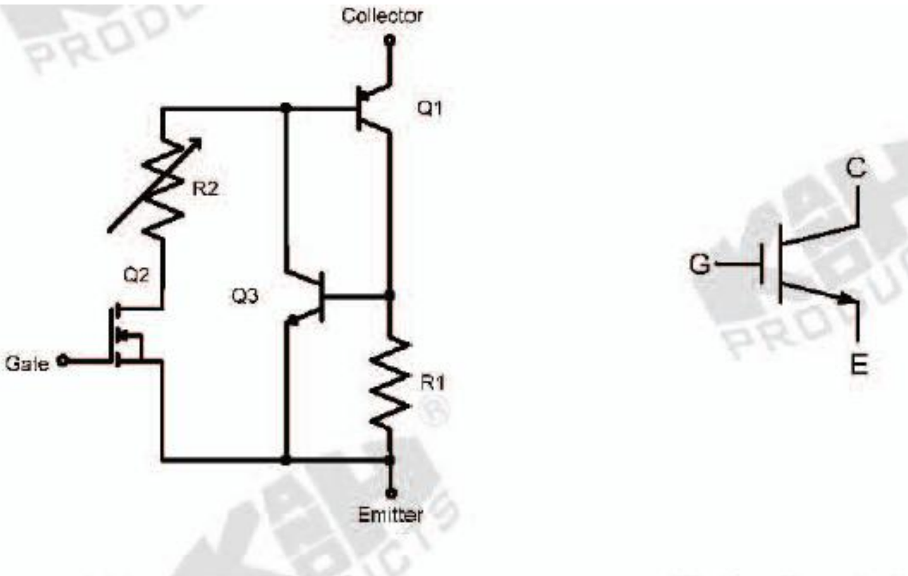


Figure 4-3 N-channel IGBT structure

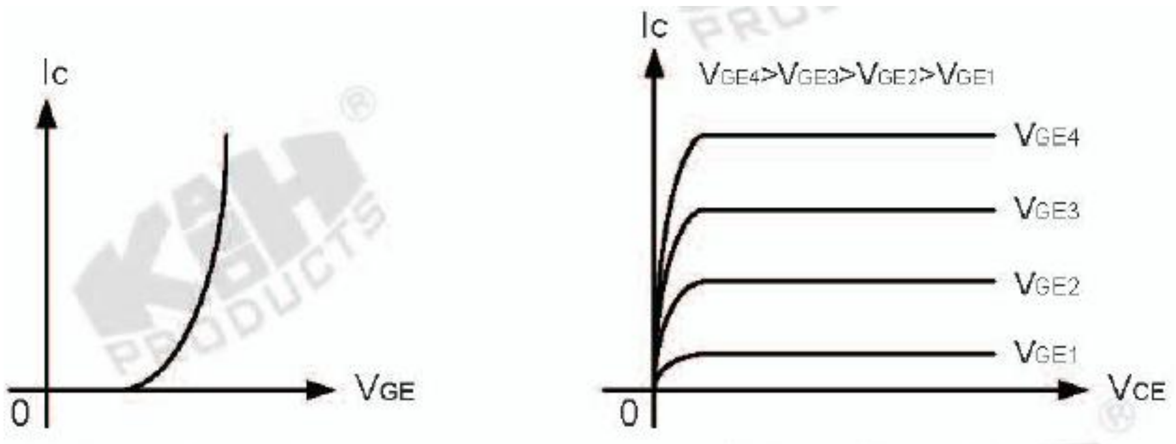
The IGBT has been developed to combine the properties of both MOSFET and bipolar devices. This overcomes some of the limitations of enabling high voltages to be switched and high currents to be controlled with the use of relatively simple gate drive circuitry. Figure 4-3 shows a typical IGBT structure. The structure is very similar to that of a vertically diffused MOSFET featuring a double diffusion of a p-type region and an n-type region. An inversion layer can be formed under the gate by applying the correct voltage to the gate contact as with a MOSFET. The major difference is the use of a p+ substrate layer for the drain. This effect is to change this into a bipolar device as this p-type region injects holes into the n-type drift region.



(a) Equivalent circuit (b) Circuit symbol

Figure 4-4 IGBT equivalent circuit and circuit symbol

Unfortunately a parasitic thyristor exists in the typical IGBT structure. When the parasitic thyristor conducts, latch-up effect is thus triggered. For examining the operation of latch-effect mechanism, review the IGBT structure in Figure 4-3 and the equivalent circuit of Figure 4-4. The parasitic NPN transistor Q3 is formed by the n^+-type MOSFET source, the p-type body region and the n^--type drift region. Also shown is the lateral resistance of the p-type region. If the current flowing through the resistor R1 is high enough, it will produce a voltage drop that will forward bias the junction with the n^+ region turning on the parasitic transistor Q3 which forms part of a parasitic thyristor. Once this happens there is a high injection of electrons from the n^+ region into the p region and all gate control is lost. This phenomenon is known as latch up and usually leads to device destruction. According to the results of experimentation and simulation, the wider the polysilicon gate area, the smaller the latching current becomes. The IGBT transfer characteristic and output characteristic are illustrated in Figure 4-5.



(a) Transfer characteristic

(b) Output characteristic

Figure 4-5 IGBT characteristics

Experiment 4-0
IGBT Characteristic Measurement

1. Place the Digital Storage Oscilloscope on workbench. Put modules PE-5310-1A, PE-5310-5E, PE-5310-2B in Experimental Frame.

2. Complete the connections by referring to the wiring diagram in Figure 4-6 using bridging plugs (curved lines) and connecting wires. Connect 220V AC supply to DC Power Supply and Differential Amplifier modules by plugging in the grounded 3-prong outlets.

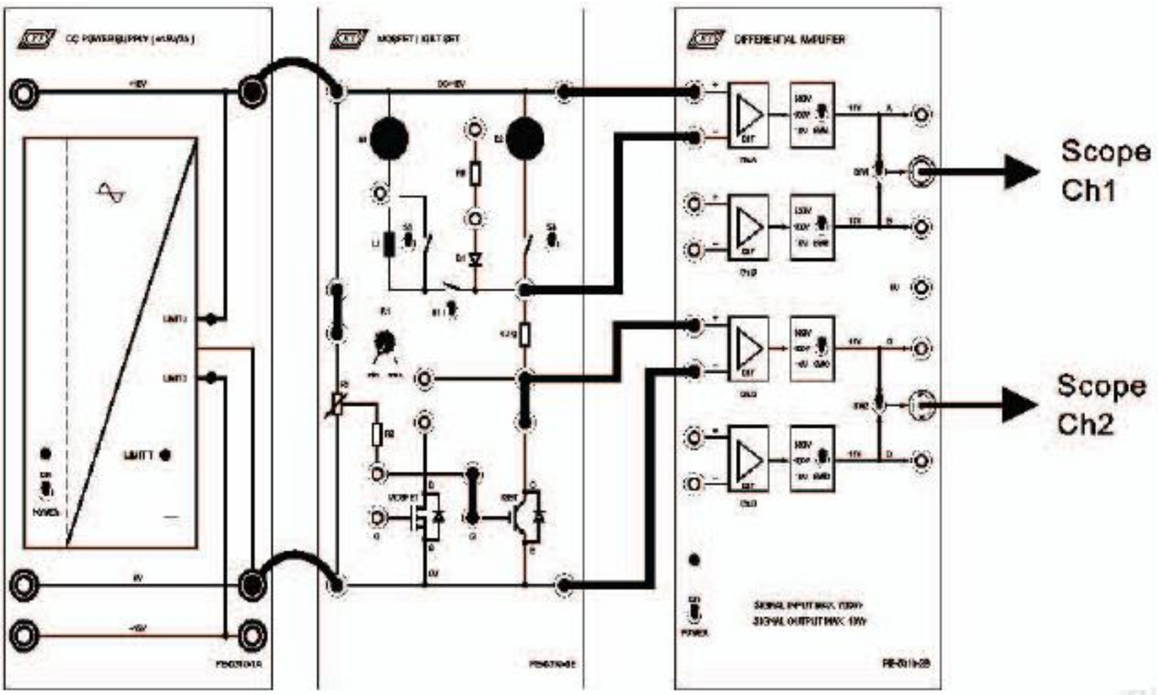


Figure 4-6 Wiring diagram for IGBT characteristic measurement

3. The CH1 input of DSO is connected to measure the load voltage V_L of the IGBT via the Differential Amplifier Ch.A, whereas the CH2 input is connected to measure the C-E voltage V_{CE} of the IGBT via the Differential Amplifier Ch.C.

4. On Differential Amplifier, place the V Range selector(SWA,SWC) switches of DIF Ch.A and Ch.C in 100V position (the Vi/Vo ratio = 100/10=10) and place Ch Selector (SW1,SW2) switches in A and C, respectively.

5. On MOSFET/IGBT Set, switch on S1 (left position), S2 (up position) and S3 (up position) to connect load lamps E1 and E2 in parallel. Set the R1 knob to min position. This set the gate voltage V_G of IGBT to zero.

6. Turn all power on. Measure and record the load voltage V_L and C-E voltage V_{CE} of IGBT as shown in Figure 4-7.

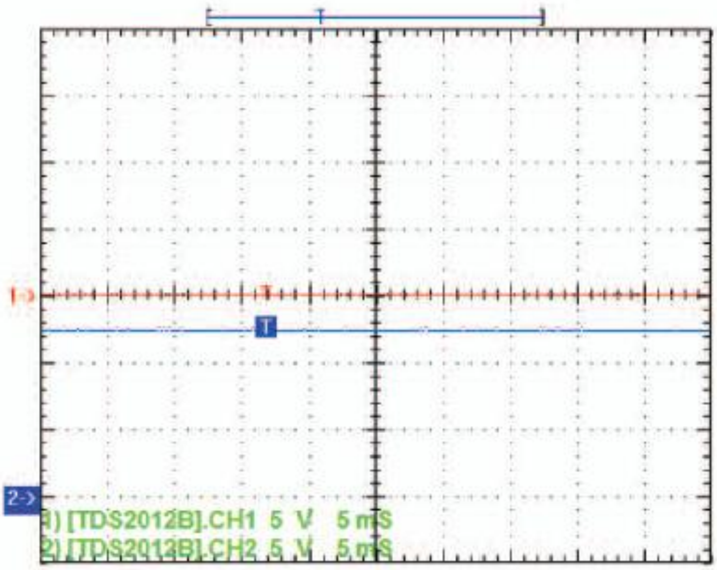


Figure 4-7 Measured load voltage V_L (CH1) and V_{CE} (CH2)

7. Slowly turn the R1 knob toward max to increase the gate voltage V_G until the IGBT is turned on. The measured load voltage V_L (CH1) and C-E voltage V_{CE} (CH2) as shown in Figure 4-8.

   Using R.M.S Meter (not shown in wiring diagram), measure and record the gate voltage V_G = __________ V (*5.6V approximately*). The measured V_G is the gate threshold voltage V_T of the IGBT.

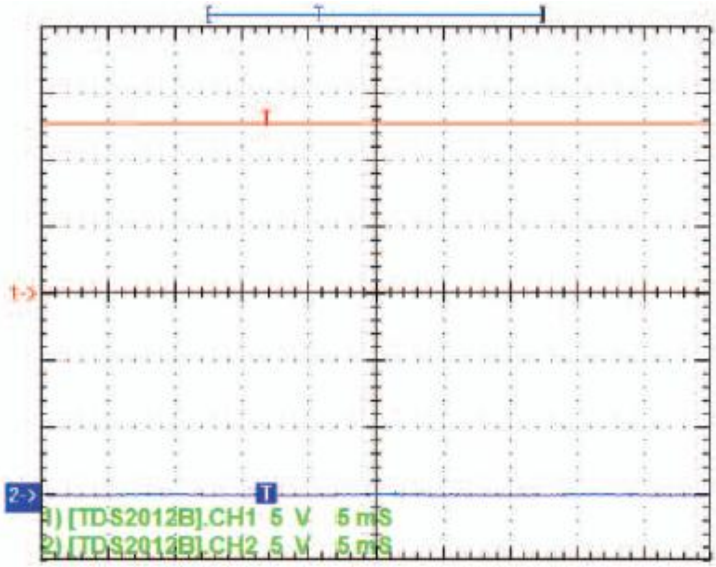


Figure 4-8 Measured load voltage V_L (CH1) and V_{CE} (CH2)

8. Turn the R1 knob to max position (maximum V_G). Measure and record the load voltage V_L and C-E voltage V_{CE} of IGBT as shown in Figure 4-9.

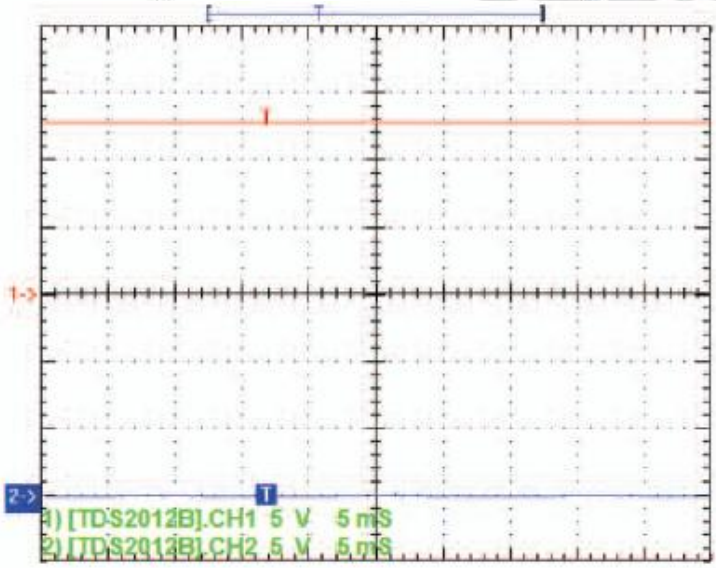


Figure 4-9 Measured load voltage V_L (CH1) and V_{CE} (CH2)

9. Turn the R1 knob to min position (minimum V_G). Measure and record the load voltage V_L and C-E voltage V_{CE} of IGBT as shown in Figure 4-10.

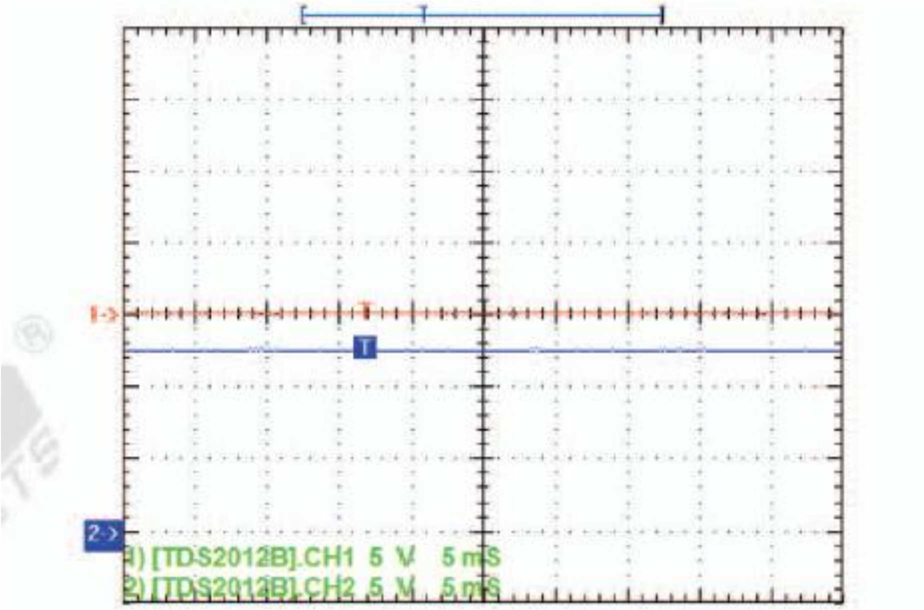
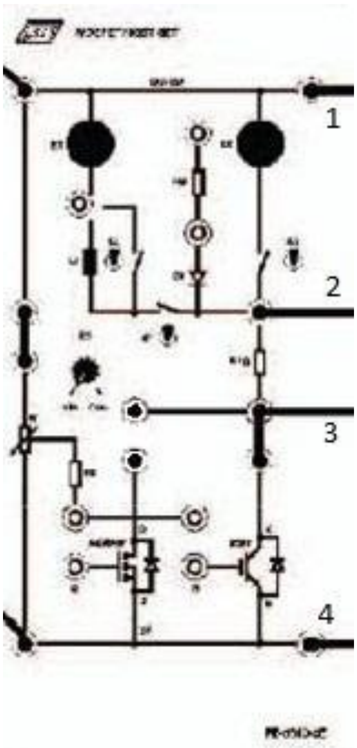


Figure 4-10 Measured load voltage V_L (CH1) and V_{CE} (CH2)

10. Find V_{in} and I_c.

At PE 5310 – 5E Module make some measurements with multimeter and find V_{in} (Between points 1&4) and I_c.



1. Measure the voltage V_1, between the points 1&2. (Bulb). There is an I_c current.

………………………………………………………………………

2. Measure the voltage V_2, between the points 2&3. (Resistance) Find the current I_c on the resistance.

………………………………………………………………………

3. Measure the voltage V_3, between the points 3&4. (IGBT)

………………………………………………………………………

Calculate;

V_{in} = ………………………………

I_c = ………………………………

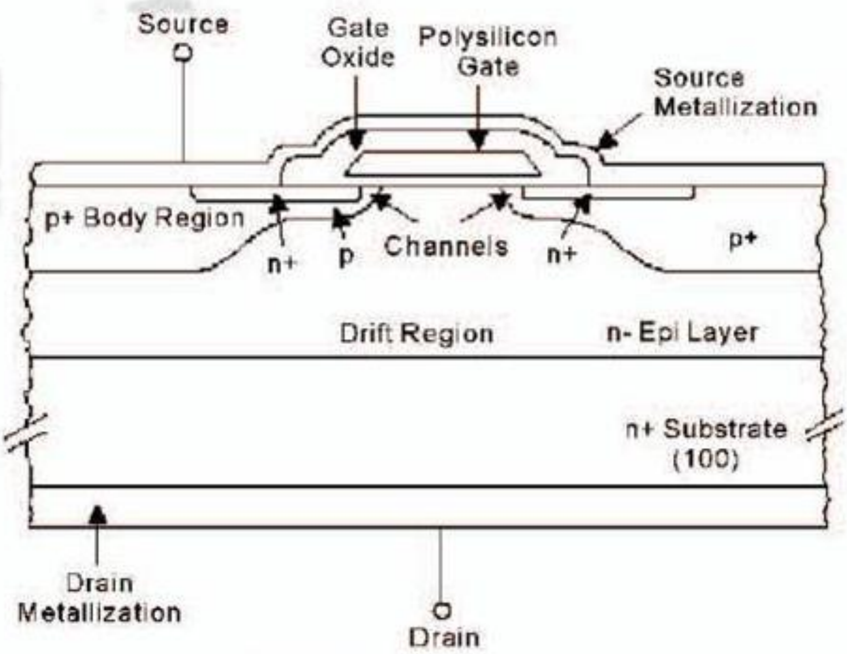
Note: In the lab report (due next lab), include your own ossiloscope figures for steps 6,8, and 9. The title will be Experimental Waveforms. Clarify which figures belongs to which sections. The MS Word document that includes the figures will be printed and attached to this manual. Do the same for Experiment 6.0.

6-3 Power MOSFET

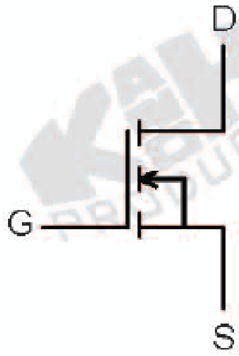
The power Metal-Oxide-Semiconductor FET (power MOSFET) is a unipolar and voltage-controlled device. The power MOSFET has the features of fast switching speed, good high-frequency characteristic, high input impedance, small drive power, excellent thermal stability, no second breakdown, wide Safe Operating Area (SOA), and high operating linearity, etc. Since the key advantages of small size and lightweight, the power MOSFET provides a high speed, high power, high voltage, and high gain device. The power MOSFET is widely used in high-power switching applications such as power supplies, converters and PWM drives.

Structure of Power MOSFET

Power MOSFET is an integrated power device which contains tens of thousands small MOSFETs interconnected in parallel. Figure 6-7 shows the typical structure and circuit symbol of an n-channel power MOSFET. Two higher-doped n^+ regions are constructed as source and drain terminals. An insulating layer (SiO_2) exists between gate and channel.



(a) Structure



(b) Circuit symbol

Figure 6-7 N-channel power MOSFET

The power MOSFET shown in Figure 6-7 is a 4-layer sandwich configuration of $n^+(n^-)pn^+$. The lower-doped n^- region is a drift region which increases the device voltage rating. In the device, two back-to-back pn-junctions exist between drain and source. If no gate voltage is applied, the device is always in off state whenever the drain-source voltage is either positive or negative.

Characteristics of Power MOSFET

Power MOSFET's output characteristic curves have two distinct operating regions: a constant-resistance region and a constant-current region. In the constant-resistance region, the drain current is direct proportion to the increase in the drain-source voltage until the drain-source voltage reaches at its pinch-off voltage. Beyond this point, the drain current remains constant and the device operates in the constant-current region.

Figure 6-8 shows the characteristics of N-channel enhancement power MOSFET. When the power MOSFET is used as an electronic switch, the drain-source voltage drop V_{DS} is proportional to the drain current I_D, that is, the MOSFET operates in the constant resistance region and it can be considered as a resistive component. The on-state drain-source resistance $R_{DS(on)}$ is the key parameter which determines the power losses at a given drain current. The drain current starts to flow at the applied gate-source voltage V_{GS} over the threshold voltage V_T (typically 2 to 4 V). Once the gate-source voltage is over the threshold voltage, the relationship between drain current and gate voltage is approximately linear.

The common-source forward transconductance gm or g_{fs} specifies the power MOSFET ac amplification. It is measured with drain-source shorted and indicates how much the ac drain current will change due to an applied ac gate-source voltage.

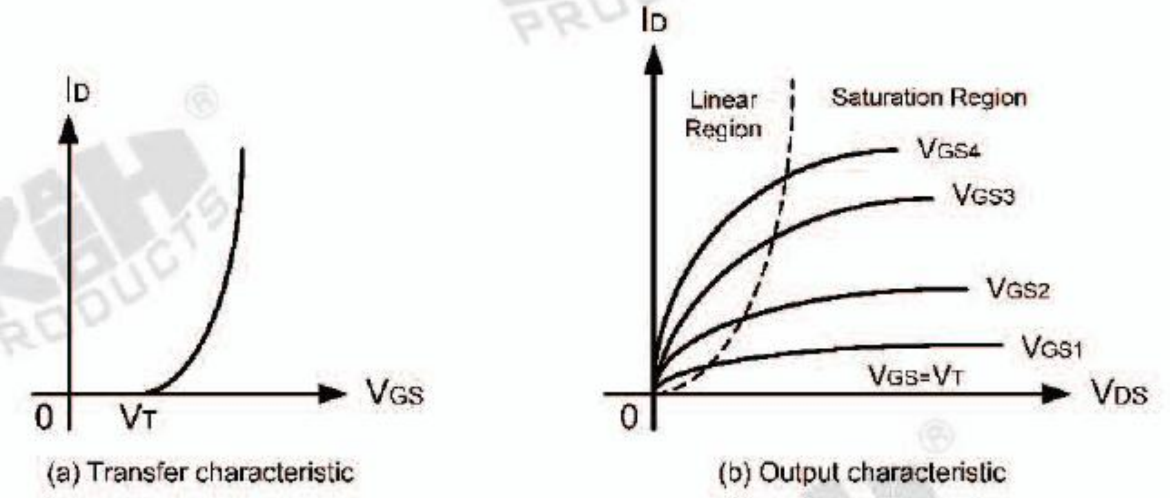


Figure 6-8 Characteristics of N-channel enhancement power MOSFET

Experiment 6-0
Power MOSFET Characteristic Measurement

1. Place the Digital Storage Oscilloscope on workbench. Put modules PE-5310-1A, PE-5310-5E, PE-5310-2B in Experimental Frame.

2. Complete the connections by referring to the wiring diagram in Figure 6-9 using bridging plugs (curved lines) and connecting wires. Connect 220V AC supply to DC Power Supply and Differential Amplifier modules by plugging in the grounded 3-prong outlets.

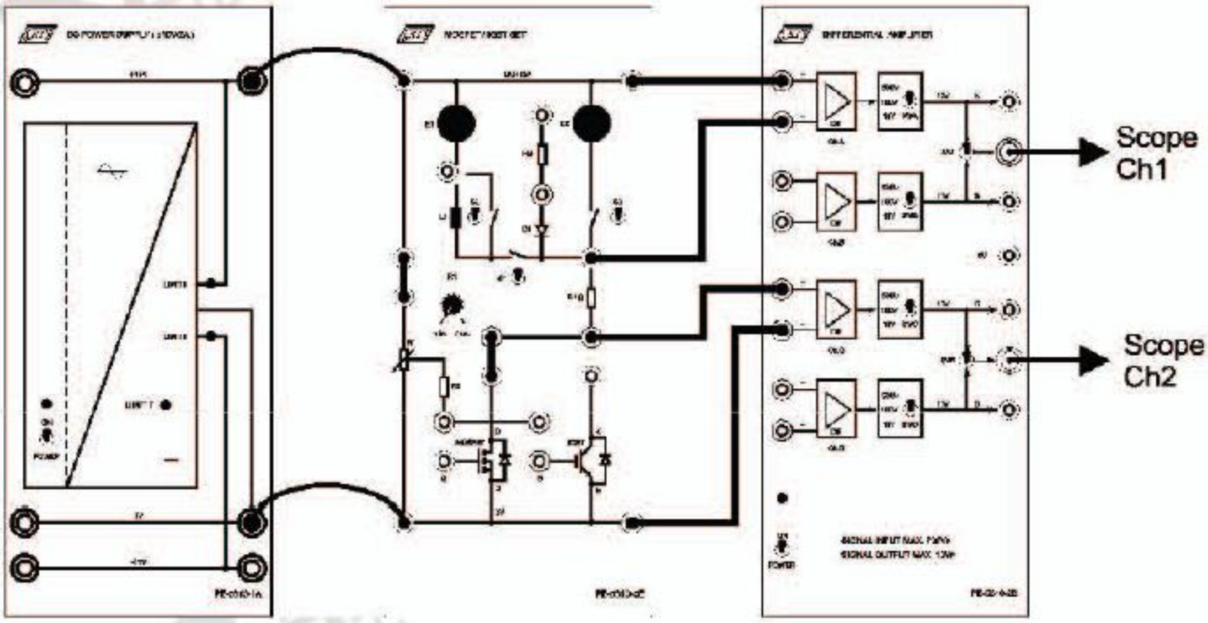


Figure 6-9 Wiring diagram for power MOSFET characteristic measurement

3. The CH1 input of DSO is connected to measure the load voltage V_L of the power MOSFET via the Differential Amplifier Ch.A, whereas the CH2 input is connected to measure the D-S voltage V_{DS} of the power MOSFET via the Differential Amplifier Ch.C.

4. On Differential Amplifier, place the V Range selector(SWA,SWC) switches of Differential Amplifiers Ch.A and Ch.C in 100V position (the Vi/Vo ratio =100/10=10) and place Ch Selector(SW1,SW2) switches in A and C, respectively.

5. On MOSFET/IGBT Set, switch on S1 (left position), S2 (up position) and S3 (up position) to connect load lamps E1 and E2 in parallel. Set the R1 knob to min position. This set the gate voltage V_G of MOSFET to zero.

6. Turn all power on. Measure and record the load voltage V_L and D-S voltage V_{DS} of MOSFET as shown in Figure 6-10.

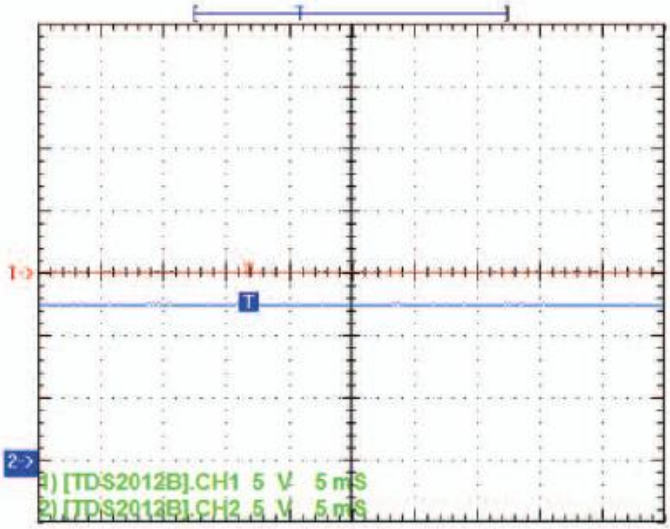


Figure 6-10 Measured load voltage V_L (CH1) and D-S voltage V_{DS} (CH2)

7. Slowly turn the R1 knob toward max to increase the gate voltage V_G until the MOSFET is turned on. The measured load voltage V_L (CH1) and D-S voltage V_{DS} (CH2) as shown in Figure 6-11. Using R.M.S Meter (not shown in wiring diagram), measure and record the gate voltage V_G = __________ V (*4.1V approximately*). The measured V_G is the gate threshold voltage V_T of the MOSFET.

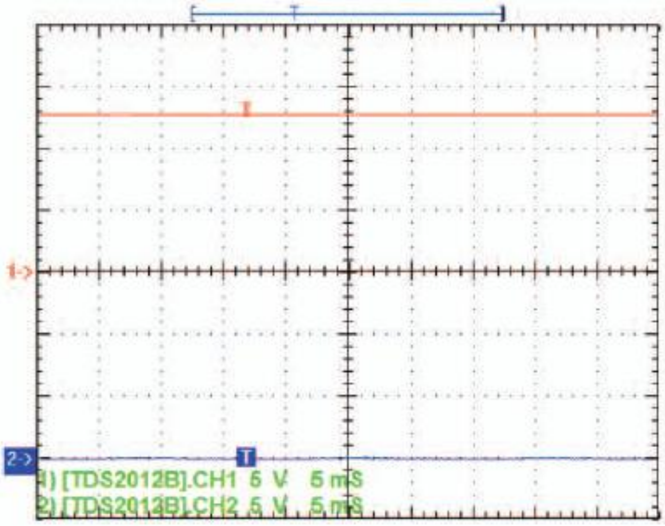


Figure 6-11 Measured load voltage V_L (CH1) and D-S voltage V_{DS} (CH2)

8. Turn the R1 knob to max position (V_G maximum). Measure and record the load voltage V_L and D-S voltage V_{DS} of MOSFET as shown in Figure 6-12.

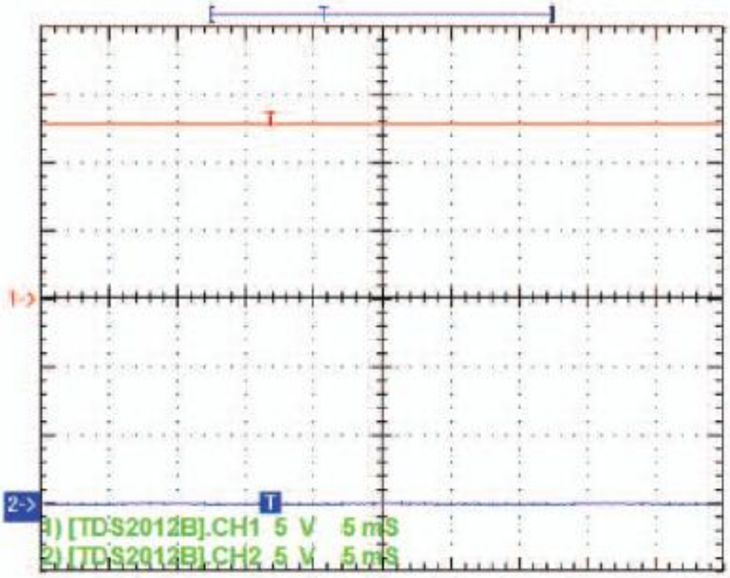


Figure 6-12 Measured load voltage V_L (CH1) and D-S voltage V_{DS} (CH2)

9. Turn the R1 knob to min position (minimum V_G). Measure and record the load voltage V_L and D-S voltage V_{DS} of MOSFET as shown in Figure 6-13.

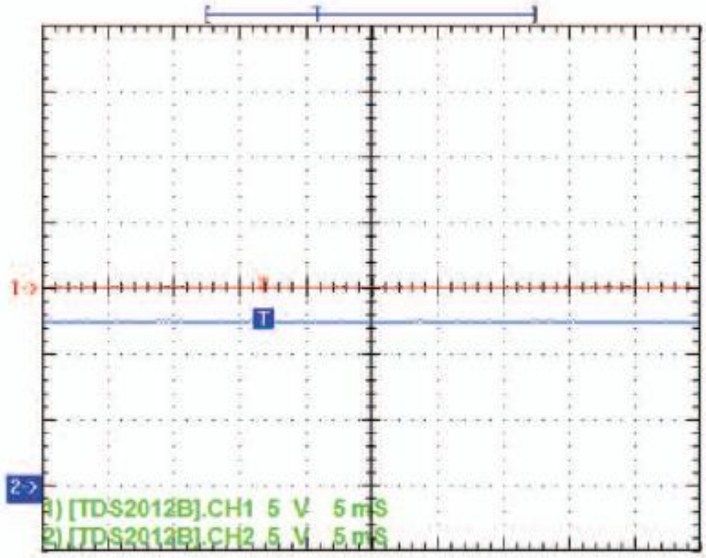
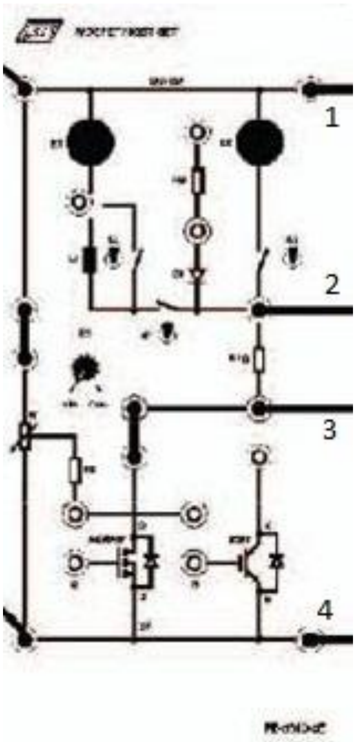


Figure 6-13 Measured load voltage V_L (CH1) and D-S voltage V_{DS} (CH2)

10. Find V_{in} and I_c.

At PE 5310 – 5E Module make some measurements with multimeter and find V_{in} (Between points 1&4) and I_c.



1. Measure the voltage V_1, between the points 1&2. (Bulb). There is an I_c current.

……………………………………………………………………

2. Measure the voltage V_2, between the points 2&3. (Resistance) Find the current I_c on the resistance.

……………………………………………………………………

3. Measure the voltage V_3, between the points 3&4. (MOSFET)

……………………………………………………………………

Calculate;

V_{in} = ………………………………

I_c = ………………………………

Note: In the lab report (due next lab), include your own ossiloscope figures for steps 6, 8, and 9. For preparing the lab report, follow the instructions explained at the end of Experiment 4.0.