



Transistors (TRA)

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A. Introduction



The **transistor** is a solid state semiconductor device that can be used for amplification, switching, voltage stabilization, signal modulation and many other functions. It acts as a **variable valve** that, based on its input voltage, controls the current it draws from a connected voltage source. Transistors are made either as separate components or as part of an integrated circuit.

Transistors are divided into two main categories: *bipolar junction transistors* (BJTs) and *field effect transistors* (FETs). Transistors have three terminals where, in simplified terms, the application of voltage to the input terminal changes the conductivity between the other two terminals and hence controls current flow through those terminals. The physics of this "transistor action" are different between BJT and FET.

Digital circuits include logic gates, RAM (random access memory) and microprocessors.

1. History

The first patents for the transistor principle were registered in Germany in 1928 by Julius Edgar Lilienfeld. In 1934 German physicist Dr. Oskar Heil patented the field-effect transistor. It is not clear whether either design was ever built, and this is generally considered unlikely.

In 1947 William Shockley, John Bardeen and Walter Brattain of Bell Labs succeeded in building the first practical point-contact transistor. This work followed from their war-time efforts to produce extremely pure germanium "crystal" mixer diodes, used in radar units as a frequency mixer element in microwave radar receivers. Early tube-based technology did not switch fast enough for this role, leading the Bell team to use solid state diodes instead. With this knowledge in hand they turned to the design of a triode, but found this was not at all easy. Bardeen eventually developed a new branch of surface physics to account for the "odd" behaviour they saw, and Bardeen and Brattain eventually succeeded in building a working device.

Bell put the transistor into production at Western Electric. They also licensed it to a number of other electronics companies, including Texas Instruments, who produced a limited run of transistor radios as a sales tool. Another company liked the idea and decided to also take out a license, introducing their own radio under the brand name Sony. Early transistors were "unstable" and useful for low-power needs only, but as construction techniques improved, these problems were overcome. Over the next two decades, transistors replaced vacuum tube technology in most electronics and later made possible many new devices such as integrated circuits and personal computers.

Shockley, Bardeen and Brattain were honored with the Nobel Prize in Physics "for their researches on semiconductors and their discovery of the transistor effect".

2. Importance

The transistor is considered by many to be one of the greatest inventions in modern history, ranking in importance with inventions such as the printing press, the automobile and the telephone. It is the key active component in practically all modern electronics. Its importance in today's society rests on its ability to be mass produced using a highly automated process (fabrication) that achieves vanishingly low per-transistor costs.

Although millions of individual (known as *discrete*) transistors are still used, the vast majority of transistors are fabricated into integrated circuits (also called *microchips* or simply *chips*) along with diodes, resistors, capacitors and other components to produce complete electronic circuits. A logic gate comprises about twenty transistors whereas a microprocessor, as of 2006, can use as many as 300 million transistors.

3. Types

Transistors are categorized by:

- Semiconductor material: germanium, silicon, gallium arsenide, silicon carbide
- Type: BJT, JFET, IGFET (MOSFET), IGBT, "other types"
- Polarity: NPN, PNP, N-channel, P-channel
- Power rating: low, medium, high
- Operating frequency: low, medium, high, radio frequency (RF), microwave
- Application: switch, general purpose, audio, high voltage
- Physical packaging: through hole, surface mount, ball grid array

Thus, a particular transistor may be described as: *silicon, surface mount, BJT, npn, low power, high frequency switch*. In this lab session, you will experiment with an *npn* BJT, an *n*-channel JFET and an *n*-channel MOSFET. The principles of operations of BJTs and FETs are as follows:

3.1 Bipolar junction transistor

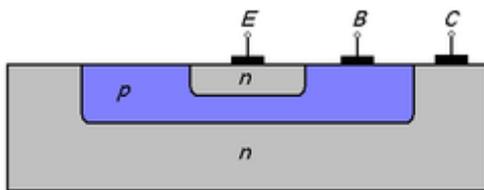


Fig. A1 Simplified cross section of an *npn* bipolar junction transistor

The **bipolar junction transistor** (BJT) was the first type of transistor to be commercially mass-produced. Bipolar transistors are so named because conduction channel uses both majority and minority carriers for electric current. A BJT consists of three doped semiconductor regions, the *emitter* region, the *base* region and the *collector* region. For a PNP transistor, these regions are, respectively, *p* type, *n* type and *p* type; and for NPN, *n* type, *p* type and *n* type. Each semiconductor region is connected to a terminal, appropriately labeled: *emitter* (E), *base* (B) and *collector* (C).

The *base* is physically located between the *emitter* and the *collector* and is made from lightly doped, high resistivity material. The collector surrounds the emitter region, making it almost impossible for the electrons injected into the base region to escape being collected. A cross section view of a BJT indicates that the collector-base junction has a much larger area than the emitter-base junction.

The bipolar junction transistor, unlike other transistors, is not a symmetrical device. This means that the interchange of the collector and the emitter makes the transistor leave the forward active mode, starting to operate in the reverse mode. Because the transistor internal structure is usually optimized to forward mode operation, interchanging the collector and the emitter makes the current gain of reverse operation much smaller than those found in the forward operation.

Small changes in the voltage applied across the base-emitter terminals causes the current that flows between the *emitter* and the *collector* to change significantly. This effect can be used to amplify the input current.

Basics of operation

An npn transistor can be considered as two diodes connected anode to anode. In typical operation, the emitter-base junction is forward biased and the base-collector junction is reverse biased. As an npn transistor example, when a positive voltage is applied to the base-emitter junction, electrons are injected into the base region. These electrons wander (or "diffuse") through the base from the emitter towards the collector. The electrons in the base are called *minority carriers* because the base is doped p-type which would make holes the *majority carrier* in the base (this should not be interpreted that the level of injected electrons is small). The base is made very thin so that electrons spend little time in the base: most of the electrons diffuse over to the collector before they can recombine with holes in the base.

The collector-base junction is reverse biased, thus no electron injection occurs from the collector to the base. Electrons which diffuse through the base towards the collector are swept into the collector by the electric field in the depletion region of the collector-base junction.

The proportion of electrons able to cross the base and reach the collector is a measure of the BJT efficiency. The heavy doping of the emitter region and light doping of the base region cause many more electrons to be injected from the emitter into the base than holes to be injected from the base into the emitter. The base current is the sum of the holes injected into the emitter and the electrons that recombine in the base—both small proportions of the emitter to collector current. Hence, a small change of the base current can translate to a large change in electron flow between emitter and collector.

BJT in circuits

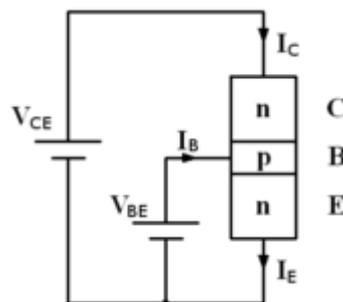


Fig. A2 npn transistor

The diagram is a schematic representation of an npn transistor connected to two voltage sources. To make the transistor conduct appreciable current (on the order of 1 mA) from C to E, V_{BE} must be equal to or slightly greater than the cut-in voltage. The cut-in voltage is usually between 600 mV and 700 mV for silicon based BJTs. This applied voltage causes the lower p-n junction to 'turn-on' allowing a flow of electrons from the emitter into the base. Because of the electric field existing between

base and collector (caused by V_{CE}), the majority of these electrons cross the upper p-n junction into the collector to form the collector current, I_C . Some electrons exit the base to form the base current, I_B . As shown in the diagram, the emitter current, I_E , is the total transistor current which is the sum of the other terminal currents:

$$I_E = I_B + I_C$$

(Note: the arrows point in the directions of the electric or conventional current; the flow of electrons is in the opposite direction since electrons carry negative charge).

The ratio of the collector current to the base current (I_C/I_B) is called the DC *current gain*, and represented by β or h_{fe} . This gain is usually quite large and is often 100 or more. It should also be noted that the base current is related to V_{BE} exponentially. For a typical transistor, increasing V_{BE} by just 60 mV increases the base current by a factor of 10!

Transistors have different regions of operation. In the "linear" region, the collector current is approximately proportional to the base current but many times larger, making this the ideal mode of operation for current amplification.

The BJT enters "saturation" when the base current is increased to a point where the external circuitry prevents the collector current from growing any larger. At this point, the C-B junction also becomes forward biased. A residual voltage drop of approximately 100 mV to 300 mV (depending on the amount of base current) then remains between collector and emitter.

A transistor is said to operate in the "cut-off" region when the base-emitter voltage is too small for any significant current to flow. In typical BJTs manufactured from silicon, this is the case below 0.7 V or so. BJTs that operate only in 'cut off' and 'saturation' regions can be viewed as electronic switches.

Less commonly, bipolar transistors are operated with emitter and collector reversed, thus a base-collector current can control the emitter-collector current. The current gain in this mode is much smaller (e.g., 2 instead of 100), and it is not a value that is controlled by manufacturers so it can vary dramatically among transistors.

3.2 Field-effect transistor

Field-effect transistors (occasionally called *unipolar transistors*) use only one of the two carrier types (either electrons or holes, depending on the subtype). The terminals of the FET are named *source*, *gate* and *drain*. In the FET a small amount of voltage is applied to the gate in order to control current flowing between the source and drain. In FETs the main current appears in a narrow conducting channel formed near the *gate*. This channel connects the *source* terminal to the *drain* terminal. The channel conductivity can be altered by varying the voltage applied to the gate terminal, enlarging or constricting the channel and thereby controlling the main current.

The drain current for the linear operation of a FET in its saturation region is given by:

$$I_d = I_{dss} \left[1 - \frac{V_{gs}}{V_p} \right]^2$$

Where: I_{dss} is the drain current at zero gate-source voltage
 V_{gs} is the gate-source voltage
 V_p is the pinch off voltage

FETs are divided into two families: **junction FET (JFET)** and **insulated gate FET (IGFET)**. The IGFET is more commonly known as **metal oxide semiconductor FET (MOSFET)**. Unlike MOSFETs, the JFET gate terminal forms a diode with the channel which lies between the source and drain.

FETs are further divided into **enhancement mode** and **depletion mode** types. Mode refers to the polarity of the gate voltage with respect to the source when the device is conducting. For an N-channel FET: in depletion mode the gate is negative with respect to the source while in enhancement mode the gate is positive. For both modes, if the gate voltage is made more positive the source/drain current will increase. For P-channel devices the polarities are reversed. Most IGFETs are enhancement mode types (especially the devices used for power switching) and nearly all JFETs are depletion mode types, because the pn junction at the gate is biased into conduction when used in enhancement mode, thus leading to gate current which is undesirable.

The **metal oxide semiconductor field-effect transistor (MOSFET)** is by far the most common field-effect transistor in both digital and analog circuits. The MOSFET is composed of a channel of n-type or p-type semiconductor material, and is accordingly called an NMOSFET or a PMOSFET.

The **gate** terminal is a layer of polysilicon (polycrystalline silicon; why polysilicon is used will be explained below) placed over the channel, but separated from the channel by a thin insulating layer of what was traditionally silicon dioxide, but more advanced technologies used silicon oxynitride. When a voltage is applied between the gate and source terminals, the electric field generated penetrates through the oxide and creates a so-called "inversion channel" in the channel underneath. The inversion channel is of the same type—p-type or n-type—as the source and drain, so it provides a conduit through which current can pass. Varying the voltage between the gate and body modulates the conductivity of this layer and makes it possible to control the current flow between drain and source.

MOSFET Structure

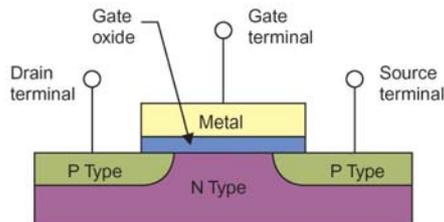


Fig. A3 Cross Section of an NMOS

A Metal Oxide Semiconductor Field Effect Transistor (MOSFET) is based on the modulation of charge concentration caused by a MOS capacitance. It is basically

constituted of two electrodes (source and drain) each connected to a highly doped N region. These two regions are separated by a P-doped zone. This latter zone constitutes a MOS capacitance with a third electrode (the gate), located above.

When a positive Gate-Body voltage is applied, it creates a *N-channel* at the surface of the P region, just under the oxide. This channel spreads from the source to the drain and provides conductivity of the transistor. When no or a negative voltage is applied between gate and body, the channel disappears and the transistor is said to be OFF.

Modes of Operation

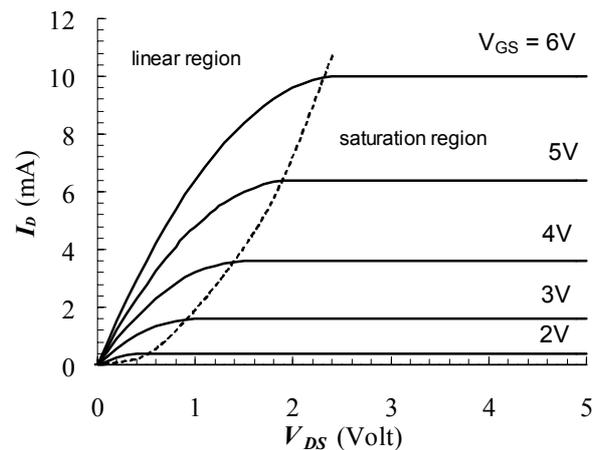


Fig. A4 Evolution of the drain current of a MOSFET with the drain-to-source voltage for several $V_{GS} - V_{th}$ values.

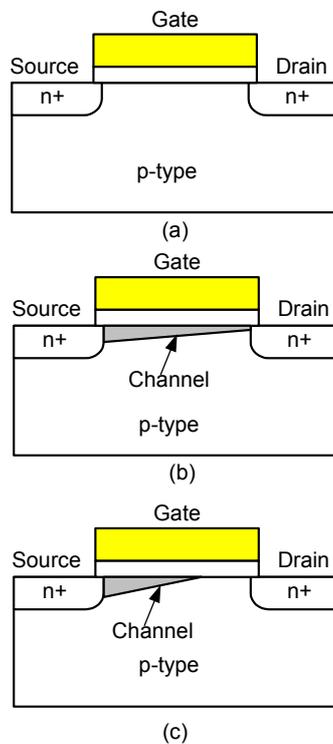


Fig. A5 Cross section of a MOSFET operating in the (a) cut-off, (b) linear and (c) saturation region

The operation of a MOSFET can be separated into three different modes, depending on the voltages at the terminals. For an **enhancement mode, n-channel MOSFET** the modes are:

1. Cut-off or sub-threshold mode: When $V_{GS} < V_{th}$ where V_{th} is the threshold voltage of the device.

The transistor is turned off, and there is no conduction between drain and source. While the current between drain and source should ideally be zero since the switch is turned off, there is a weak-inversion current, or subthreshold leakage.

2. Triode or linear region: When $V_{GS} > V_{th}$ and $V_{DS} < V_{GS} - V_{th}$

The transistor is turned on, and a channel has been created which allows current to flow between the drain and source. The MOSFET operates like a resistor, controlled by the gate voltage. The current from drain to source is,

$$I_D = \frac{\mu_n C_{ox}}{2} \frac{W}{L} (2(V_{GS} - V_{th})V_{DS} - V_{DS}^2)$$

where μ_n is the charge-carrier mobility, W is the gate width, L is the gate length and C_{ox} is the capacitance at the gate.

3. Saturation: When $V_{GS} > V_{th}$ and $V_{DS} > V_{GS} - V_{th}$

The switch is turned on, and a channel has been created which allows current to flow between the drain and source. The onset of this region is also known as pinch-off. Since the drain voltage is higher than the gate voltage, a portion of the channel is saturated. The drain current is now relatively independent of the drain voltage (in a first-order approximation) and the current is only controlled by the gate voltage such that,

$$I_D = \frac{\mu_n C_{ox}}{2} \frac{W}{L} (V_{GS} - V_{th})^2$$

this equation can be multiplied by $(1 + \lambda V_{DS})$ to take into account the channel length modulation (λ).

In digital circuits MOSFETs are operated in cut-off and saturation modes. The triode (linear) mode is mainly used in analog circuit applications.

4. Usage

In the early days of transistor circuit design, the bipolar junction transistor, or BJT, was the most commonly used transistor. However, the MOSFET has several desirable properties for digital circuits and are now commonly used for both analog and digital purposes.

4.1 Amplifiers

From mobile phones to televisions, vast numbers of products include amplifiers for sound reproduction, radio transmission, and signal processing. The first discrete transistor audio amplifiers barely supplied a few hundred milliwatts, but power and audio fidelity gradually increased as better transistors became available and amplifier architecture evolved.

Transistors are commonly used in modern musical instrument amplifiers, where circuits up to a few hundred watts are common and relatively cheap. Transistors have largely replaced valves in instrument amplifiers. Some musical instrument amplifier manufacturers mix transistors and vacuum tubes in the same circuit, to utilize the inherent benefits of both devices.

4.2 Computers

The "first generation" of electronic computers used vacuum tubes, which generated large amounts of heat and were bulky, fragile, and unreliable. The development of the transistor was key to computer miniaturization. The "second generation" of computers, through the late 1950s and 1960s featured boards filled with individual transistors and magnetic cores. Subsequently, transistors, other components, and their necessary wiring were integrated into a single, mass-manufactured component: the integrated circuit. Transistors incorporated into an integrated circuit has taken the place of most discrete transistor design applications in modern digital electronics.

B. Experiments

The following experiments can be divided into three main parts: transistor checks, curve tracer, and transistor characteristics. The experiments have in total 20 sub-experiments; do NOT waste time.

1. Transistor Checks

Transistors are the most important component in any electronic circuit. When they malfunction, a follow-on effect will render the whole circuit or even the whole system useless. Transistors are usually damaged by operating them at voltages and currents higher than their ratings. For example, if a transistor is rated at 1mW and you pass a current of 1mA through it with a driving voltage of 1V, the transistor is said to be operating at (consuming) 1 mW. Which is OK. But if you increase the current to 1.5mA at the same driving voltage of 1V, the transistor is consuming 1.5mW of power, which is higher than the maximum power it can dissipate (1mW). The excess heat is thus built up inside the transistor and when the heat is too much, the transistor literally melts and dies.

It is thus important to check that your transistors are OK before proceeding with more elaborate characterisations. Symptoms of dead transistors are short- and open circuits (just to keep things simple). Diagnosis is easily done by measuring the resistances among the terminals. Shorts will give you 0Ω or very low resistances, while opens will give you very large resistances. Using an Ohm meter, you can check whether your transistors are OK or not.

1.1 BJTs

The structure of a BJT can be considered as two diodes (p-n junctions) connected back-to-back. By probing the resistances between pairs of leads, it is possible to determine whether an unknown BJT is of type *pnp* or *nnp*. Thus, the Base lead can be identified at this stage. Measure the resistances between pairs of leads and complete the table

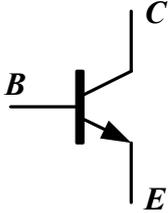
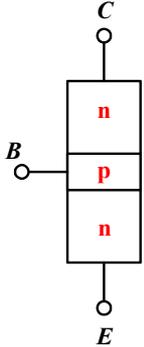
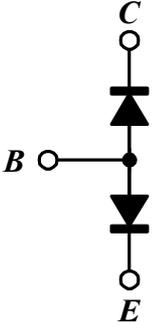
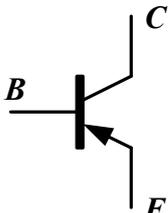
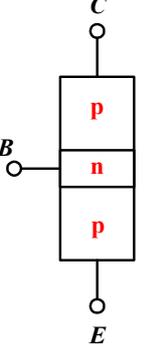
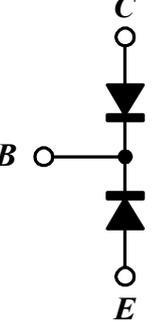
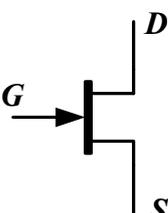
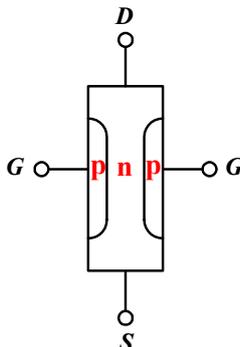
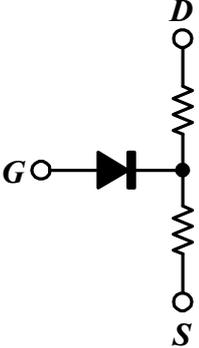
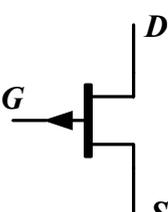
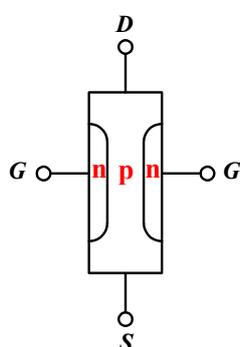
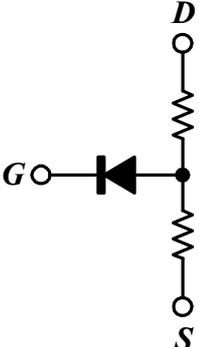
(To identify the remaining leads as the Collector and Emitter, you need to use the curve tracer and carry out the procedure explained in 3.3 ii).

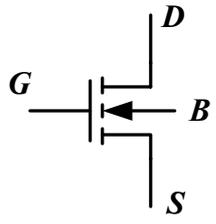
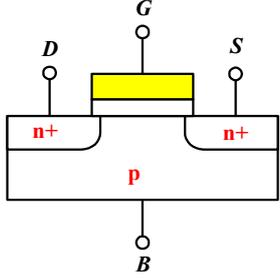
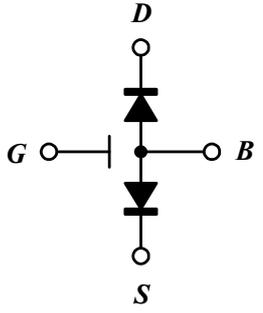
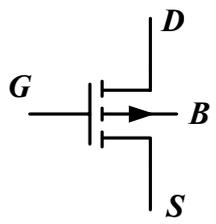
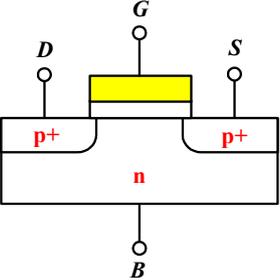
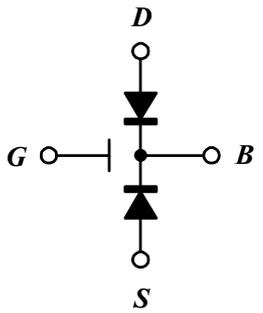
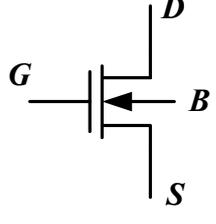
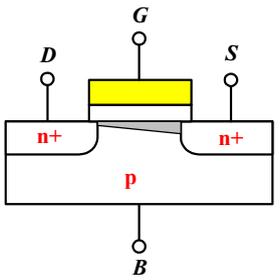
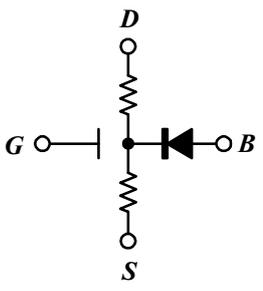
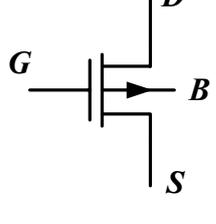
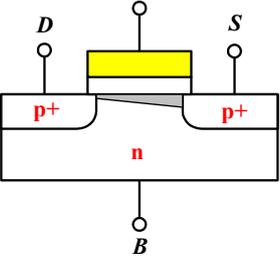
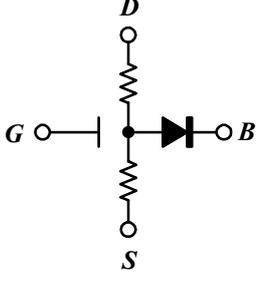
1.2 JFETs

A JFET is simply an FET with p-n junction as a gate. A p-n junction allows current to flow in one direction (low resistance) and suppresses current flow in the other direction (high resistance). Asymmetry resistances are indicative of good-quality p-n junctions. Confirm the integrity of the JFET by measuring the resistances among the G/S/D leads and complete the table.

1.3 MOSFETs

A MOSFET has a thin oxide layer separating the gate and the channel (an electrical conduit between the source and drain). The oxide can easily be damaged by improper handling. Electrostatic discharge (ESD) from the human body can destroy the oxide. Confirm the integrity of the oxide (insulator) by measuring the resistances between the gate (G), source (S) and drain (D) and complete the table provided.

Name	Symbol	Structure	Simplified equivalent circuit
BJT nnp			
BJT pnp			
JFET n-channel			
JFET p-channel			

Name	Symbol	Structure	Simplified equivalent circuit
MOSFET n-channel enhancement			
MOSFET p-channel enhancement			
MOSFET n-channel depletion			
MOSFET p-channel depletion			

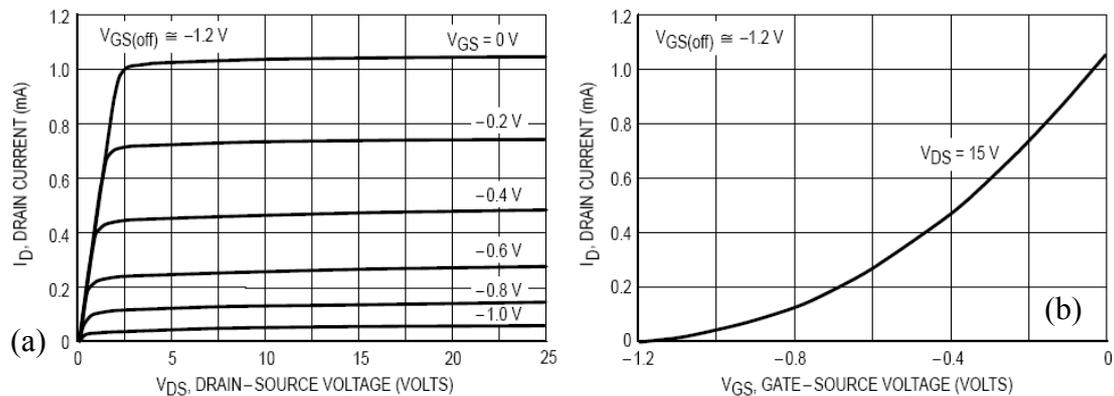
2. Curve Tracer

Once you have confirmed that the transistors are OK, you need to supply some waveforms to the transistor's *three* terminals in order to characterise them. This task is easily accomplished with a curve tracer. Basically, a curve tracer provides *two* waveforms: one is a varying V_{DS} (for FET) or a varying V_{CE} (for BJT) waveform, and the other is a staircase voltage (for FET) or a staircase current (for BJT). But there are *three* transistor terminals, so why are there just *two* waveforms? The answer is that one terminal is used as a reference (or a ground potential). Remember that all voltages are relative!

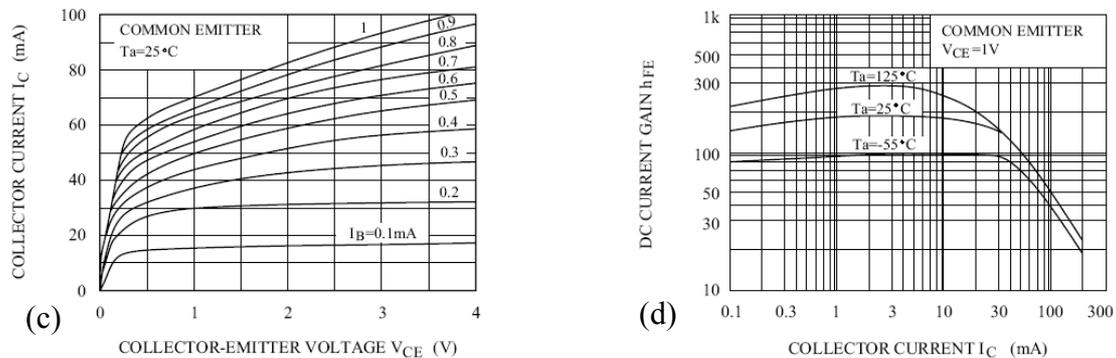
3. Transistor Characteristics

When electronic engineers design intelligent circuits (with decision-making or signal-processing capability), they naturally look for suitable transistors to do the job. And where do they look? Manufacturer's datasheet, of course. A typical datasheet contains geometrical and electrical data of the device, with temperature sensitivity information. In this lab session, however, you will concern yourself with only electrical data; specifically, the *output-* and *transfer* characteristics of the transistors.

Device Type	characteristics	
	output-	transfer-
FET	I_D - V_{DS} (sweep V_{GS})	I_D - V_{GS} (fixed V_{DS})
BJT	I_C - V_{CE} (sweep I_B)	I_C - I_B (fixed V_{CE})



JFET N-Channel 2N5457



BJT NPN 2N3904

Fig. B1 Examples of electrical characteristics of an FET and a BJT.

Output characteristic refers to the relationship between the voltage and current at the exit or output terminals, as a function of control voltage (FET) or current (BJT). In the case of FETs, this means the I_D - V_{DS} relationships—see Fig. B1(a). The controlling terminal (the Gate) is fixed at a certain voltage (V_{GS}) during one I_D - V_{DS} sweep. Multiple I_D - V_{DS} sweeps at various V_{GS} values constitute the output characteristic of an FET. In the case of BJTs, however, the controlling terminal is the Base, which is current controlled. Consequently, multiple I_C - V_{CE} curves at various I_B values constitute the output characteristic of a BJT—see Fig. B1(c).

Transfer characteristic in the case of FETs refers to the relationship between the *input* voltage (V_{GS}) and the *output* current (I_D). And in the case of BJTs, it refers to the relationship between the *input* current (I_B) and the *output* current (I_C). The *input-output* plot reflects how much the change in *input* is *transferred* to *output*. For FETs, this is illustrated in the form of I_D - V_{GS} plot (at a fixed V_{DS})—see Fig. B1(b). For BJTs, I_C - I_B plot (at a fixed V_{CE}). However for BJTs, the DC current gain ($h_{fe} = I_C/I_B$) is more useful for circuit designers and the h_{fe} - I_C plot as shown in Fig. B1(d) is preferred over the straightforward I_C - I_B plot (although the two are equivalent).

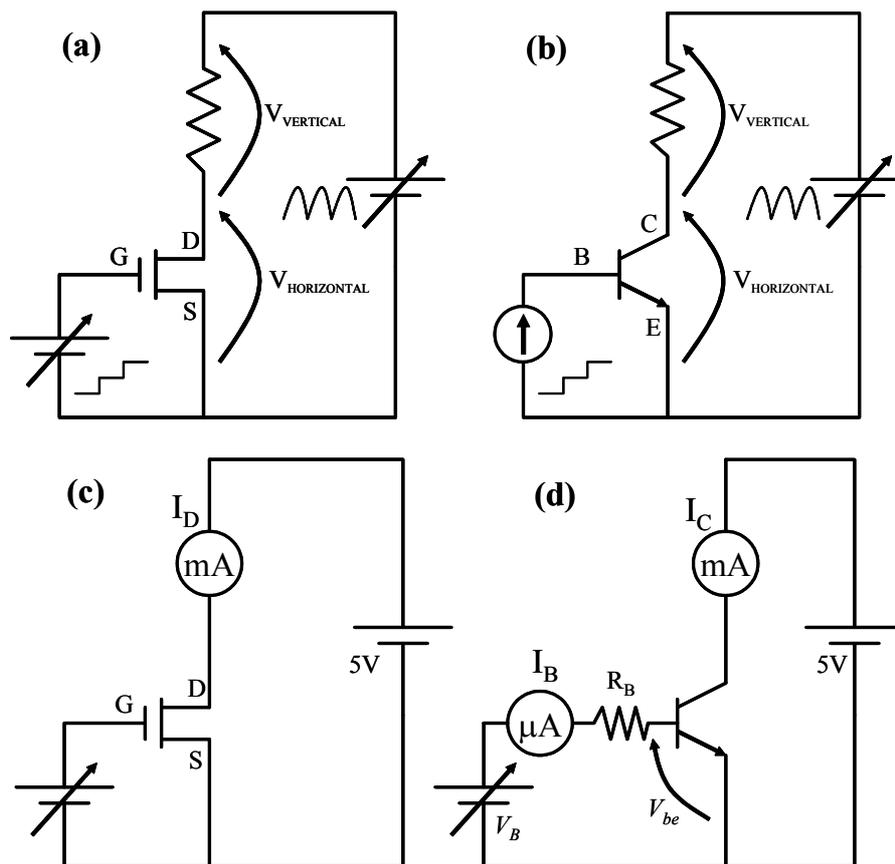


Fig. B2. Circuits used to obtain output (upper circuits) and transfer (lower) characteristics of FETs (left) and BJTs (right).

Circuit designers use electrical characteristics shown in Fig. B1 to determine, among other things, amplifier gains in analog circuits and ON/OFF voltages in digital circuits.

Each of the following 3 experiments (3.1, 3.2 and 3.3) has 4 sub-experiments with the same labels—i) to iv)—and are designed so as to assist you in observing the:

- i) output characteristic,
 - ii) symmetry (or asymmetry) of output terminals,
 - iii) breakdown characteristic, and
 - iv) transfer characteristic
- of the three different types of transistors.

3.1 BJT

i) While the curve tracer is off, connect the BJT's E/B/C terminals to the curve tracer. The equivalent circuit of the connection is as shown in Fig. B2(b). Check the curve tracer settings: refer to the table given in curve tracer manual. Then, connect HORIZONTAL to CH1 (or X) of the CRO and VERTICAL to CH2 (or Y). Set the CRO to X-Y mode. Switch on the curve tracer. Adjust some setting on the curve tracer to obtain a nice curve on the CRO screen. Plot the *output* characteristic. Label the axes appropriately.

*Both inputs to X and Y channels are voltages. In order to obtain correct current values for the Y axis, you need Ohm's law and the value of the resistor R (referred to the curve tracer for the value of this resistor).

ii) Increase the V_{CE} limit to maximum, observe whether the breakdown occur or not?

iii) Switch off the curve tracer, *swap* the E/C terminals, then switch on the curve tracer. Adjust some setting on the curve tracer to obtain a nice curve on the CRO screen. Do you notice any differences in the output characteristic? Do you notice whether the breakdown occurs or not?

iv) From the output characteristic obtained from 3.1 i), plot the *transfer* characteristic (I_C-I_B) and the $h_{fe}-I_C$ characteristic at $V_{CE} = 5\text{ V}$ such as the one shown in Fig. B1(d).

3.2 JFET

i) While the curve tracer is off, connect the JFET's G/S/D terminals to the curve tracer. The equivalent circuit of the connection is as shown in Fig. B2(a). Check the settings: N-CHANNEL, V_{DS} limit = 10V, FET. Then, connect HORIZONTAL to CH1 (or X) of the CRO and VERTICAL to CH2 (or Y). Set the CRO to X-Y mode*. Switch on the curve tracer. Plot the *output* characteristic. Label the axes appropriately.

ii) Switch off the curve tracer, *swap* the S/D terminals, then switch on the curve tracer. Do you notice any differences in the output characteristic?

iii) Undo the *swap*. Increase the V_{DS} limit until breakdown occur. *Quickly* note the values of V_{DS} at the onset of breakdown for each I_D-V_{DS} curve before returning the V_{DS} limit to 10V. (if you take too long to do this experiment, a *break-down* will turn into a *melt-down*: do it within 1 min.)

iv) From the output characteristic obtained from 3.1 i), plot the *transfer* characteristic (I_D - V_{GS}) at $V_{DS} = 5$ V such as the one shown in Fig. B1(b).

3.3 MOSFET

Repeat 3.2 i)-iv).

Curve Tracer Manual

Curve tracer can be used to display a semiconductor characteristic on a CRO display. This home-brewed curve trace is designed to use with the following devices:

- Diode
- BJT: NPN and PNP
- JFET: P and N-channel
- MOSFET: P and N-channel with both depletion and enhancement mode

General Specifications

<p>-Collector/Drain Sweep Voltage</p> <p style="padding-left: 20px;">Sweep frequency:</p> <p style="padding-left: 20px;">Sweep voltage:</p> <p style="padding-left: 20px;">Maximum output current:</p>	<p>Ramp signal with 100-500 Hz</p> <p>± 15 V continuously adjustable</p> <p>40 mA (limited by the short circuit current of LM324)</p>
<p>-Step Generator (Base current or Gate voltage)</p> <p style="padding-left: 20px;">No. of Steps</p> <p style="padding-left: 40px;">Current per step</p> <p style="padding-left: 20px;">Volt per step</p>	<p>7 lines for base current</p> <p>8 lines for gate voltage</p> <p>10, 20, 50 μA; 0.1, 2 mA</p> <p>0.1, 0.2 and 0.5 V</p>
<p>-Power supply</p> <p>-Device current</p>	<p>220 V 50 Hz</p> <p><i>Calculated from the voltage across the 100-Ω series resistor (inside the box)</i></p>

Controls and Connections

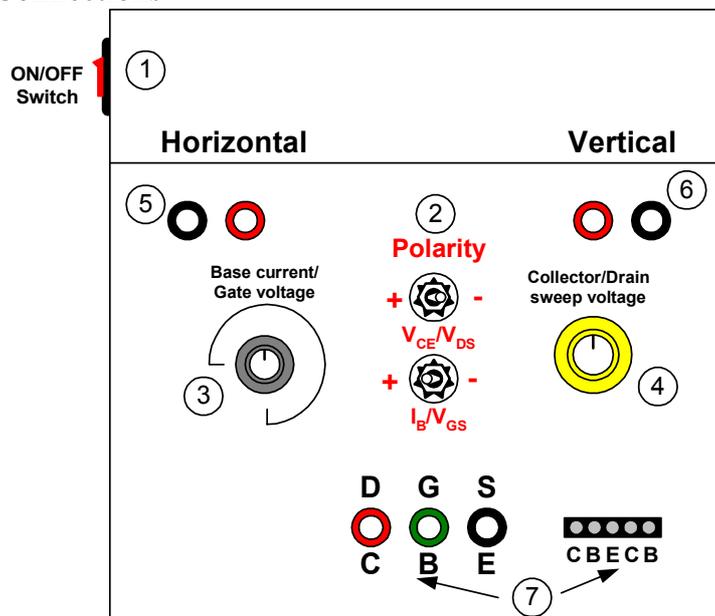


Fig. 1 The layout of controls and connectors on the curve trace

- | | |
|----------------------------|--|
| 1) ON/OFF switch | Turn on the AC power |
| 2) Polarity switches | Select the mode of operations (see table 1) |
| - V_{CE}/V_{DS} | |
| - I_B/V_{GS} | |
| 3) Base current/ | Sets the step of base current or gate voltage |
| | Gate voltage switch |
| 4) Collector/Drain | Adjusts the amplitude of the sweep voltage |
| | across Sweep voltage control device under test |
| 5) Horizontal jacks | Connections to horizontal CRO input |
| 6) Vertical jacks | Connections to vertical CRO input |
| 7) Device connection jacks | Connections to the device under test |

Table 1 Polarity settings for various semiconductor devices

Device		Polarity	
		I_B/V_{GS}	V_{CE}/V_{DS}
BJT	NPN	+	+
	PNP	-	-
JFET	N-channel	-	+
	P-channel	+	-
Enhancement MOSFET	N-channel	+	+
	P-channel	-	-
Depletion MOSFET	N-channel	-	+
	P-channel	+	-

Testing Procedures

1. While the curve tracer is off, connect the curve tracer to a CRO (Horizontal to CH1 and Vertical to CH2), set the CRO to X-Y mode.
2. Set the Polarity switches according to the type of the device (see Table 1 for reference)
3. Connect the device to the curve tracer
4. Adjust the Collector/Drain sweep voltage control to the fully minimum position (turning counter clockwise), switch on the curve tracer
5. Set the Base current/ Gate voltage switch (for BJT set the bias in μA or mA range and for JFET or MOSFET set the bias in V range) For instance, at $10 \mu\text{A}$ setting, the curve trace will inject the base current I_B into BJT with $10 \mu\text{A}$ step, starting from 0, 10, 20, 30, 40, 50 and $60 \mu\text{A}$, 7 lines in total. If we set the control at 0.1 V , this equipment will apply V_{GS} to the Gate with 0.1 V step, starting from 0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6 and 0.7 V , 8 lines in total
6. Adjust Collector/Drain Sweep voltage control to the desired value (turning clockwise position)
7. Adjust the X-scale and Y-scale of CRO to obtain the best viewing on the CRO screen
8. Record your results.
9. Turn Collector/Drain Sweep voltage control to the minimum position, switch off the curve tracer, disconnect the device. Repeat the procedures from step 2 for the new testing.

Note the device current can be calculated from the voltage on the Y-axis by dividing with the resistance value of 100- Ω . This 100- Ω resistor is connected in series with the device under test.

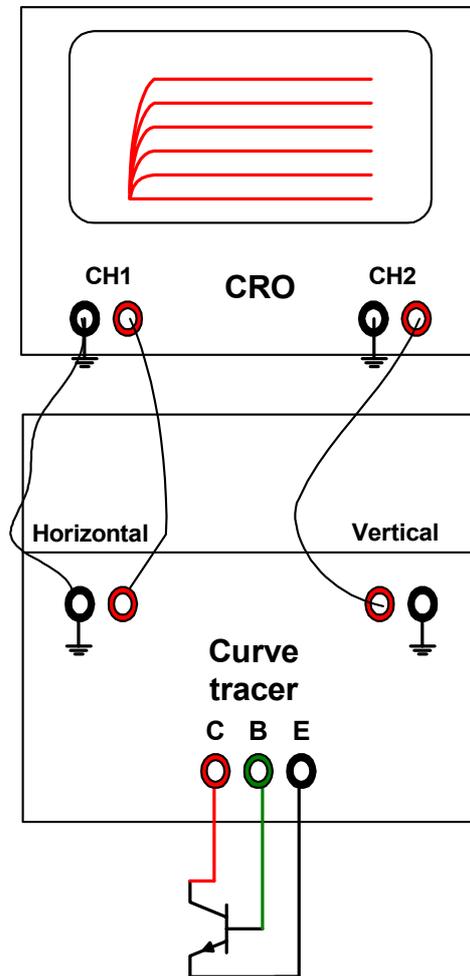


Fig. 2 Connecting between CRO and curve trace for device characterization.

Name: _____ ID: _____
 Date: _____ Group: _____ Instructor signature: _____

Lab Report
Transistors (TRA)

Exp. 1 Transistor Checks

BJT # _____

+ Voltage	- Voltage	Resistance (Ω)
B	E	
E	B	
C	E	
E	C	
B	C	
C	B	

BJT Type _____

JFET # _____

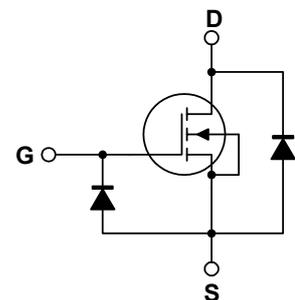
+ Voltage	- Voltage	Resistance (Ω)
G	S	
S	G	
D	S	
S	D	
G	D	
D	G	

JFET Type _____

MOSFET # _____

+ Voltage	- Voltage	Resistance (Ω)
G	S	
S	G	
D	S	
S	D	
G	D	
D	G	

MOSFET Type _____
 (obtained from the above data)



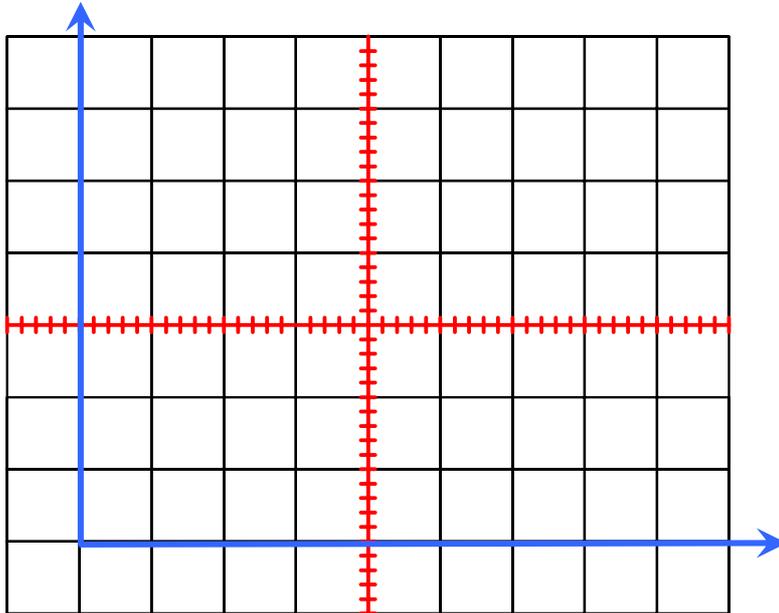
Equivalent circuit of MOSFET in the experiment
 (MOSFET type: n-channel Enhancement)

Discussion

3. Transistor Characteristics

3.1 BJT (type: _____)

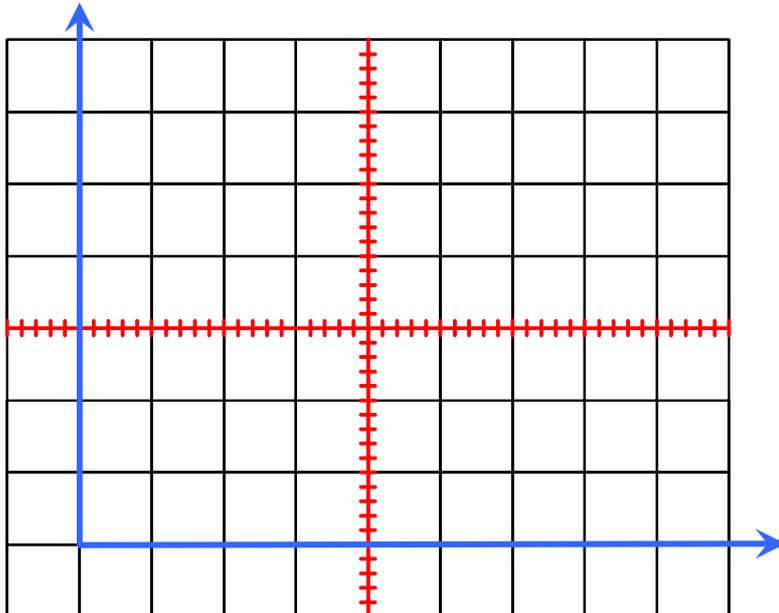
i) BJT's output characteristics



CH1 =	V/DIV
CH2 =	V/DIV
I _C =	A/DIV
I _B step =	A

ii) Can you see the breakdown Characteristic?

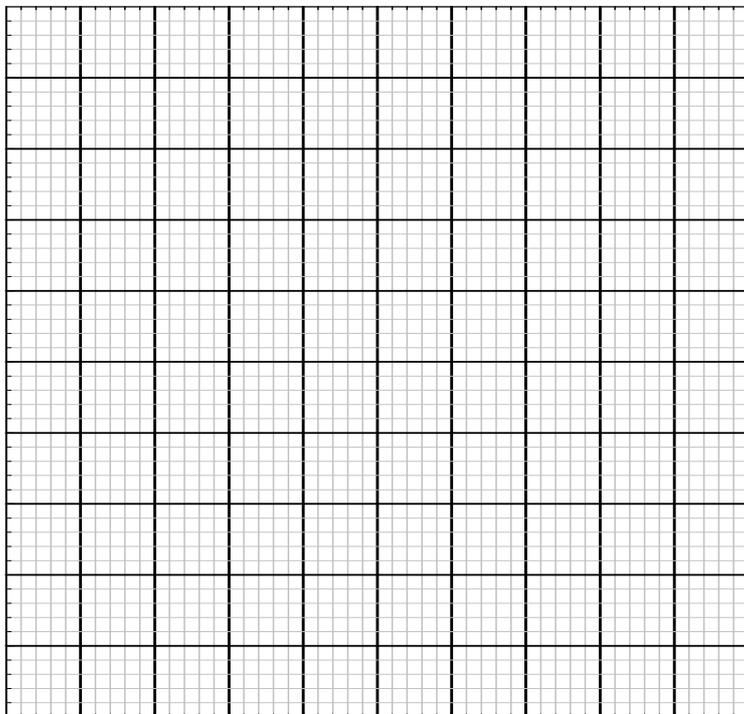
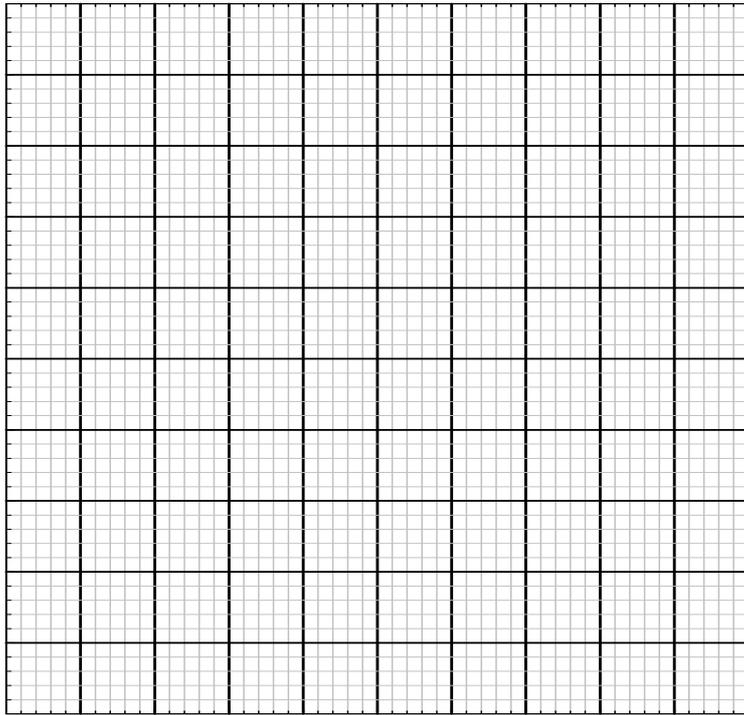
iii) Swap C/E terminals



CH1 =	V/DIV
CH2 =	V/DIV
I _C =	A/DIV
I _B step =	A

Can you see the breakdown Characteristic?

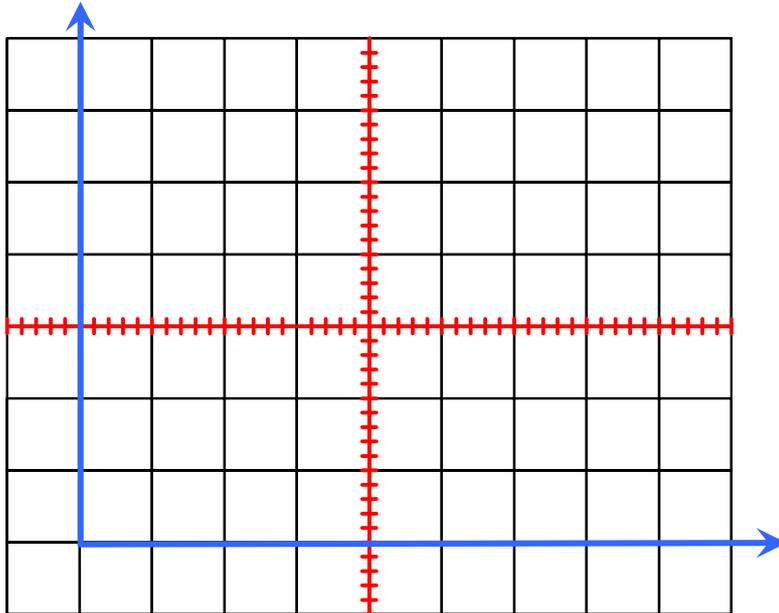
iv) BJT's transfer characteristics (I_C-I_B and $h_{fe}-I_C$)



Discussion

3.2 JFET (type: _____)

i) JFET's output characteristics

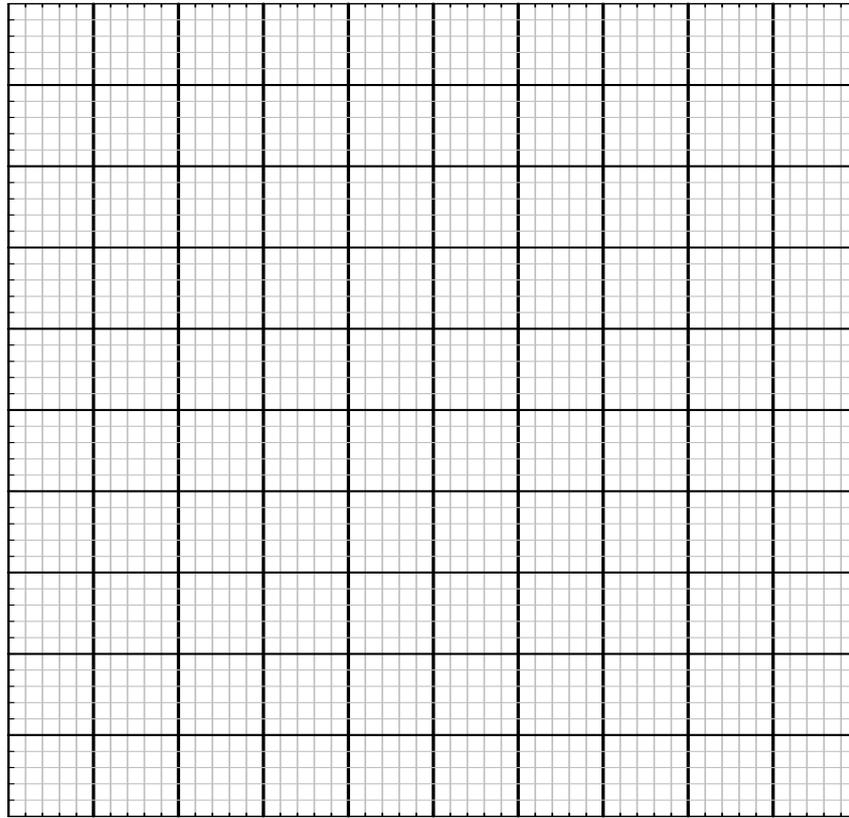


CH1 = V/DIV
CH2 = V/DIV
 I_D = A/DIV
 V_{GS} step = V

ii) what happened when you swap the S/D terminals?

iii) Can you see the breakdown characteristic?

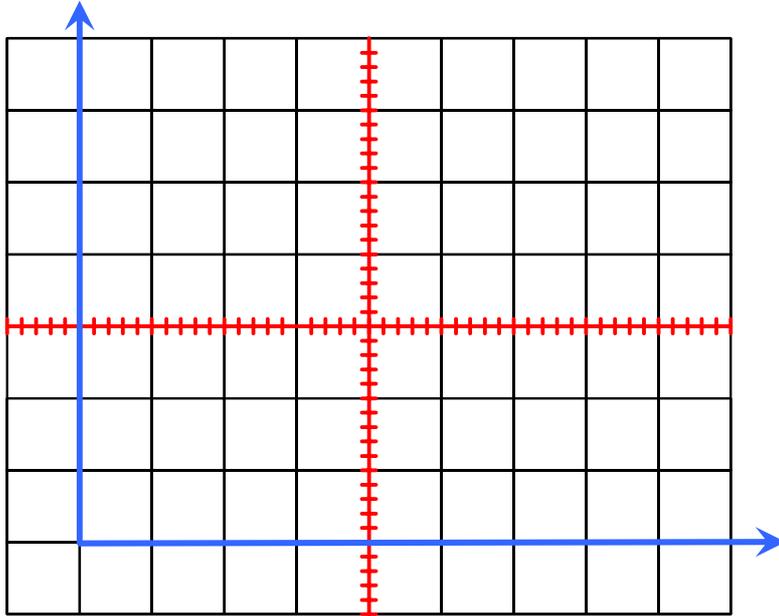
iv) JFET's transfer characteristics ($I_D - V_{GS}$)



Discussion

3.2 MOSFET (type: _____)

i) MOSFET's output characteristics

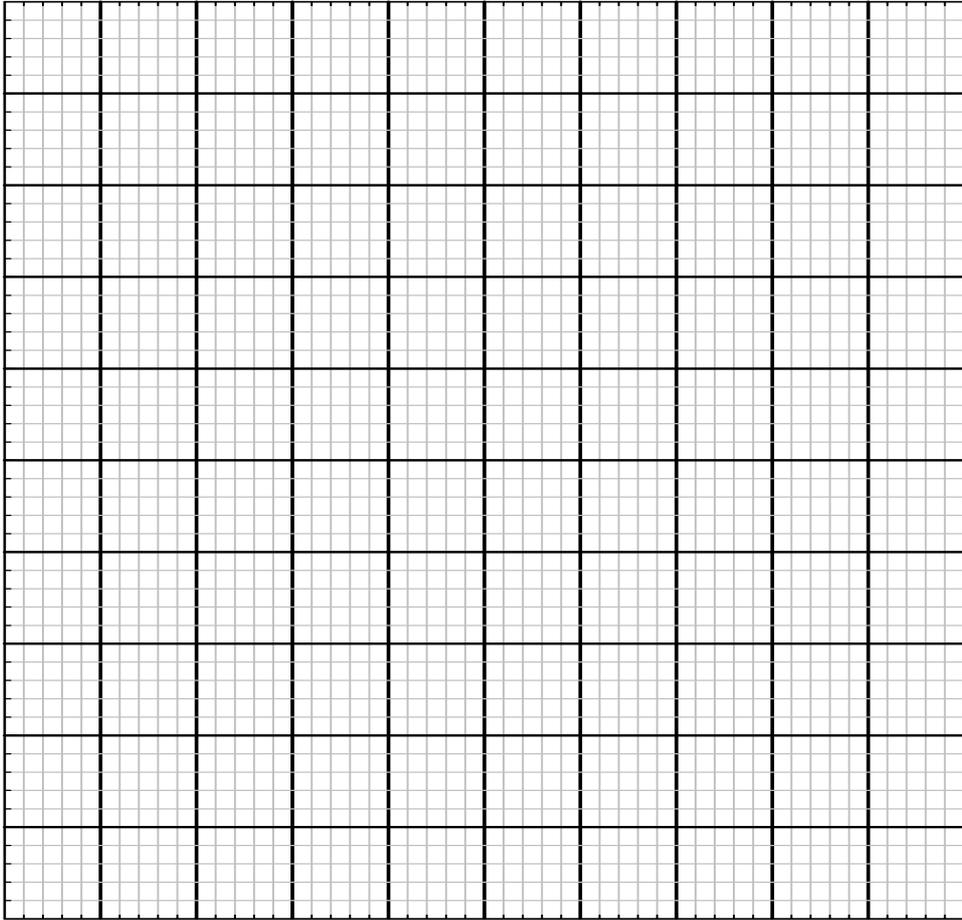


CH1 =	V/DIV
CH2 =	V/DIV
$I_D =$	A/DIV
$V_{GS}step =$	V

ii) what happened when you swap the S/D terminals?

iii) Can you see the breakdown characteristic?

iv) MOSFET's transfer characteristics ($I_D - V_{GS}$)



Discussion