Quadrant II – Transcript and Related Materials

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Unit: 1 TRANSISTOR MULTIVIBRATORS

Module Name: Transistor as a switch, switching times.

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Notes

Transistor as a switch and Switching times
(For circuit diagrams refer PPT presentation)

Switch. Electric /Electronic switch.
Switch is an electric component or device that can switch an electrical circuit interrupting the current or diverting it from one conductor to another. Electronic switches are considered binary devices because they can be in an On or Off state.

The ideal switch has the following properties:
R_{OFF} resistance is infinite (∞) Ω's, which implies that current I **through** the switch is 0 (Ohms law), i.e I = 0 Amp.
R_{ON} resistance is 0 Ω, which implies that voltage V **across** the switch is 0 (Ohms law), i.e V = 0 Volt.
Power loss in the switch P= I.V = 0 watt, both in the On and Off state. The switch does not consume or dissipate any power from its source.
Transition times (switching speed) 0 seconds.
A practical switch should approximate an ideal switch

Semiconductor Switches.
Transistor which is a bipolar current controlled device, Junction Field Effect Transistor (JFET) and Metal Oxide Semiconductor FET which are both unipolar voltage controlled devices can be used as a switch for control applications, logic circuits, computers, etc.

Advantages of semiconductor switches.
Size - small in size, density of switches is very large.
Absence of moving parts, no wear and tear, Long life.
High switching speed (frequency performance).
Reliable, very cheap
Controllable and able to turn on and off at will
Easy interface to electronic circuit,.. etc.

Non-Ideal Semiconductor Switch Properties.
A well chosen practical switch should approximate an ideal switch.
In semiconductor switches there is a breakdown voltage, leakage current in the off-state, non-zero voltage across the switch in the on-state, non-zero dissipation of power, non-zero turn-on and turn-off transition times (non-zero transition times) and others.

Bipolar Junction Transistor (BJT).
Transistor is a three terminal two junction bipolar current controlled semiconductor device, both electron and hole are responsible for the current conduction.
The transistor are either pnp type or npn type. In pnp type transistor the n-type semiconductor is sandwiched between two p-type semiconductor where as in npn type transistor p-type semiconductor is sandwiched between two n-type semiconductor.
The three terminals of the transistor are called E-Emitter, B-Base and C-Collector and the two junction are called emitter base junction (EB) and collector base junction (CB).

The transistor has three modes of operation depending upon the common terminal chosen between input and output circuit of a transistor.
1. Common Base 2. Common Emitter 3. Common Collector

The transistor starts working when current (electron and holes) starts moving across two junctions when the two junctions are biased simultaneously. Normally when EB junction is forward biased and CB junction is reverse biased, the majority carriers in the base region due to forward bias of EB junction will act as minority carrier and will cross the base region and reach the collector giving the current I_C.

Current equations for a transistor can be written as $I_E = I_C + I_E$

For Common Base mode of operation $I_C = \alpha I_E + I_{CO}$
Where α is defined as the fraction of the total emitter current that represents majority carriers which have travelled from emitter across the base to the collector and is I_{CO} called as leakage current. Since leakage current I_{CO} is small $I_C \approx \alpha I_E$

For Common Emitter.
$I_C = \beta I_B + I_{CEO}$

β is current amplification factor in CE mode and is the ratio of output collector current to the input base current. Since the leakage current I_{CEO} is very small $I_C \approx \beta I_B$

Transistor can be used as an amplifier and a switch, to understand how transistor works as both amplifier and switch we look at the output characteristics of the transistor. For proper working of transistor we have to bias the transistor i.e provide proper external voltages so as to fix the level of current and voltage i.e. fix the operating point or Q point. Common emitter configuration is the most suitable configuration for a transistor switch because the current and voltage needed for the input switching signal are very small and it is an inverter circuit. As our topic is about switches we consider the output characteristic of common emitter configuration only.

Common Emitter Configuration.
Output Characteristics. The graph is plotted between output collector – emitter voltage V_{CE} and output collector current Ic keeping input base current I_B as a constant parameter. Depending upon the type of biasing of the two junctions, transistor has three region of operation namely Linear or active, Saturation and Cut-off region.

Active Region: In this region EB junction is forward biased and CB junction is reverse biased. Output characteristics in the active region are not horizontal lines because for a fixed value of I_B the magnitude of collector current increases with V_{CE} due to early effect.

Cut off Region: Here both the junctions are reverse biased. The region below $I_B = 0$ characteristic is called as cut off region. In this region $I_C = I_{CEO}$ (collector to emitter leakage current with base open)

Saturation Region: In this region both the junctions are forward biased by at least the cut-in voltage. The current I_C is independent of I_B.

These biasing conditions for a common emitter configuration are summarised in table given below.
Transistor switch is used as either Normally OFF or Normally ON.
Normally OFF, Transistor is not biased, base resistor is not connected to the power source Vcc. The positive going input pulse at the base switches the transistor to saturation (ON) state and the negative going edge of the pulse switches the transistor back to the cut-off (OFF) state. Here the condition for the transistor to operate into saturation region is given by the relation
$h_{fe} \geq I_{C\,sat} / I_B$
Normally ON. Transistor is fixed biased, it is in saturation (ON) state in absence of the input trigger signal.

B-E Junction	B-C Junction	Region of operation	Working of transistor	Condition for CE mode (fixed bias)
Forward	Reverse	Linear or active	Amplifier	$h_{fe} < R_B/R_C$
Forward	Forward	Saturation	Switch – ON	$h_{fe} \geq R_B/ R_C$
Reverse	Reverse	Cut-off	Switch – OFF	- ve voltage to be provided to Base

Switching times.

If a pulse is applied to an inverter say normally OFF switch, the transistor acts as a switch as it operates from cut-off (OFF) state to saturation (ON) state and then returns to cut-off (OFF) state. The response of the collector current I_C to the input waveform, together with its time-relationship to that waveform shows that it does not immediately respond to the input signal instead there is a delay due to capacitive and other effects in the transistor.
The time that elapses during this delay together with the time required for the current to rise to 10% of its maximum saturation value is called delay time td.
Three factors contribute to the delay time.
1. When input driving signal is applied to the transistor, a nonzero time is required to charge up the emitter junction transition capacitance so that the transistor be brought from cut-off to the active region.
2. Even when the transistor has been brought to the point where minority carriers have began to cross the emitter junction into the base, a time interval is required before these carriers can cross the base region to the collector junction and be recorded as collector current.
3. Some time is required for the collector current to rise to 10% of its maximum.
Thus the capacitive effects in the transistor introduces a delay.
The current waveform has a non zero rise time tr. It is the time required for the current to rise through the active region from 10% to 90% of its maximum saturation value. The total turn-on time ton is the sum of the delay and rise time, **ton = td + tr**

ton --- “off” state to “on” state
td --- delay time
tr --- rise time (10% --90%) final value.
ton = td + tr

When the input returns to its initial state at some time, the current does not respond immediately, because a transistor in saturation has excess minority carriers stored in the base (n- and p- regions) the transistor (diodes in reverse voltages) cannot respond until this excess charge has been removed. The time interval which elapses between the transition of the input waveform and the time Ic has dropped to 90% of its maximum saturation level is called the storage time ts. Junction storage time is the factor that limits the speed of intergrated digital logic circuits using bipolar transistors.

The storage time is followed by the fall time tf, which is the time required for the current Ic to fall from 90% to 10% of its initial maximum value. The total turn-off time toff is the sum of the delay and fall time. **toff = ts + tf**

toff --- “on” state to “off” state
ts* --- storage time
tf --- fall time   (90% --10%) initial value
toff = ts + tf