American International University- Bangladesh
Faculty of Engineering (FE)
Department of Electrical and Electronic Engineering (EEE)
EEE 2104: Electronic Devices Lab

Title of the Experiment: Study of Transistor Characteristics in Common Emitter Amplifier.

Objectives:
The objectives of this experiment are to
1. Become familiar with bipolar junction transistors (BJTs)
2. Study the biasing of a Common Emitter (CE) amplifier, and
3. Draw the input and output characteristics of a common emitter BJT circuit.

Theory:
A Bipolar Junction Transistor (BJT) is a three-terminal semiconductor device. It is widely used in discrete circuits as well as in integrated circuits. The main applications of BJ's are analog circuits. For example, BJTs are used for amplifiers, for high-speed amplifiers. BJTs can be used for digital circuits as well, but most of the digital circuits are nowadays realized by field effect transistors (FETs).
There are three operating modes for BJTs, the active mode (amplifying mode), the cut-off mode, and the saturation mode. To apply a BJT as an amplifier, the BJT must operate in active mode. To apply a BJT as a digital circuit element, the BJT must be operated in the cut-off and the saturation modes.

Device Structure of BJT:
Each BJT consists of two anti-serial connected diodes. The BJT can be either implemented as an npn or a pnp transistor. In both cases, the center region forms the base (B) of the transistor, while the external regions form the collector (C) and the emitter (E) of the transistor. External wire connections to the p and n regions (transistor terminals) are made through metal (e.g., Aluminum) contacts. A cross-section of the two types of BJTs consisting of an emitter-base junction and a collector-base junction is shown in Fig. 1.
An npn or a pnp transistor is called a bipolar transistor because both types of carriers (electrons and holes) contribute to the overall current. In the case of a field effect transistor, either the electronics or the holes determine the current flow. Therefore, a field effect transistor is a unipolar device. The current and voltage amplification of a BJT is controlled by the geometry of the device (for example width of the base region) and the doping concentrations in the individual regions of the device. To achieve a high current amplification, the doping concentration in the emitter region is typically higher than that of the base region. The base is a lightly doped very thin region between the emitter and the collector and it controls the flow of charge carriers from the emitter to the collector region.

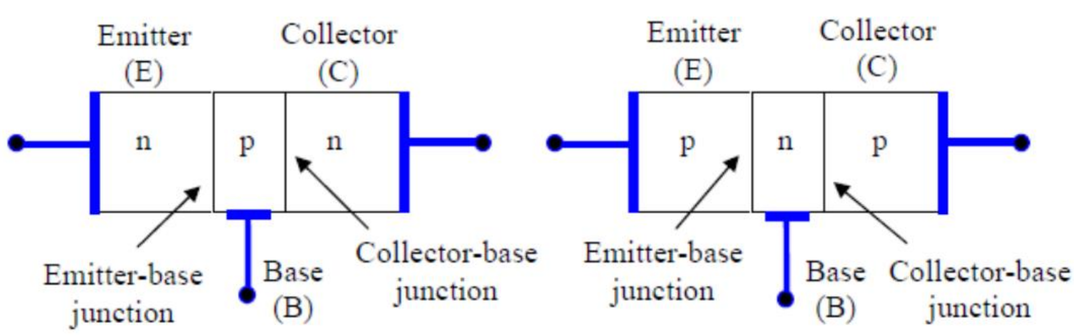
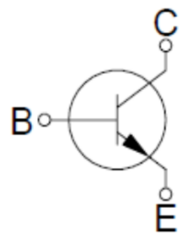
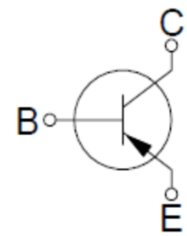


Figure 1: Construction diagram of an npn and a pnp transistors.

Circuit Configuration:
Figure 2 shows the symbol for the npn transistor and pnp transistor. The emitter of the BJT is always marked by an arrow, which indicates whether the transistor is an npn or a pnp transistor



npn BJT symbol



pnp BJT symbol

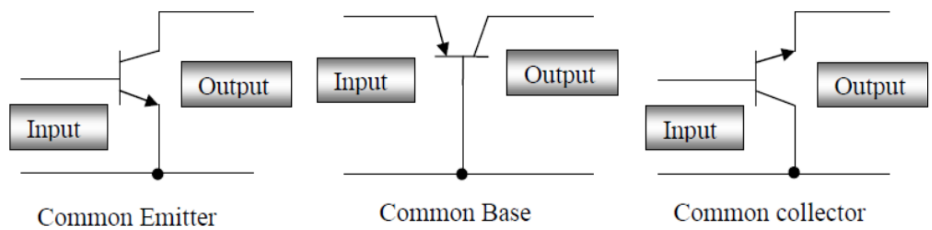


Figure 2: Emitter, collector, and base of transistors and the connection modes.

There are three basic ways in which a BJT can be configured. In each case, one terminal is common to both the input and output circuits shown in the figure above.

1. The common emitter configuration is used for voltage and current amplification and is the most common configuration for transistor amplifiers.
2. The common collector configuration is often called an emitter follower since its output is taken from the emitter resistor. It is useful as an impedance-matching device since its input impedance is much higher than its output impedance.
3. The common base configuration is used for high-frequency applications because the base separates the input and output, minimizing oscillations at high frequencies. It has a high voltage gain, relatively low input impedance, and high output impedance compared to the common collector.

Biasing of Bipolar Junction Transistors:

In most cases, the BJT is used as an amplifier or switch. To perform these functions, the transistor must be correctly biased. Depending on the bias condition (forward or reverse) of each of the BJT junctions, different modes of operation of the BJT are obtained.

The three modes are defined as follows:

1. Active Mode: The emitter junction is forward-biased and the collector junction is reverse-biased. If the BJT is operated in active mode, then the BJT can be used as an amplifier.
2. Saturation Mode: Both the emitter and collector junctions are forward-biased. If the BJT is used as a switch, the saturation mode corresponds to the on-state of the BJT.
3. Cut-off Mode: Both the emitter and collector junction are reverse-biased. If the BJT is used as a switch, the cut-off mode corresponds to the off state of the BJT.

Input and Output Characteristics:

The input characteristics curves are plotted between I_B and V_{BE} keeping the voltage, V_{CE} constant. The input characteristics look like the characteristics of a forward-biased diode. The base-to-emitter voltage varies only slightly. The input dynamic resistance is calculated from the ratio of the small change of base-to-emitter voltage to the small change of base current.

The output characteristics curves are plotted between the collector current, I_C, and the collector-to-emitter voltage drop by keeping the base current, I_B constant. These curves are almost horizontal. The output dynamic resistance again can be calculated from the ratio of the small change of emitter-to-collector voltage drop to the small change of the collector current.

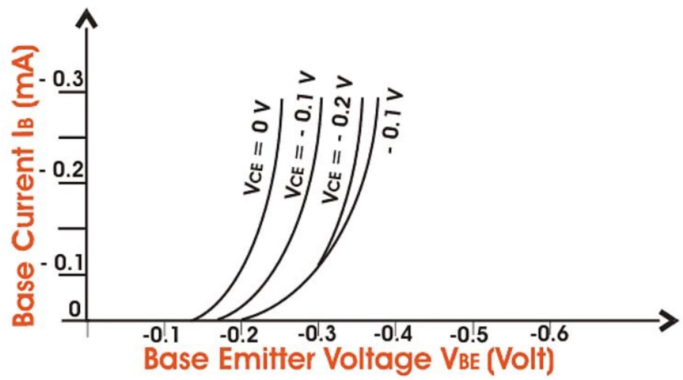


Figure 3: BJT Common Emitter Input Characteristics.

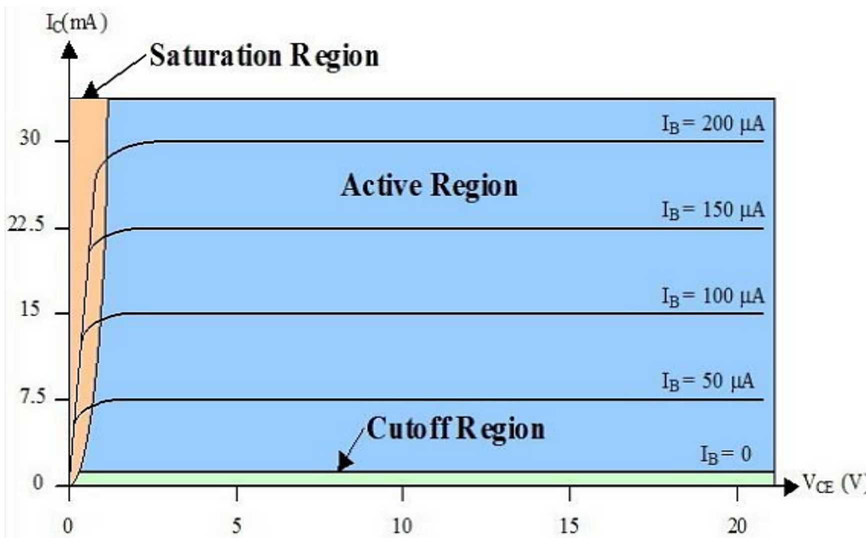


Figure 4: BJT Common Emitter Output Characteristics.

Pre-Lab Homework:

Students will be provided with the upcoming lab manuals, and they will be asked to prepare the theoretical (operations/working principle) information on the topic from the textbook.

Besides, they must implement the circuit (as given in Figure 5) using a MultiSIM simulator. Observe the input-output wave shapes through simulation with parameter (various I_B and V_{CE}) variations and take snapshots using the snipping tool. Measure the values of different key parameters and fill up the tables (Tables 1 and 2) based on the simulation results. For simulation, use a 2N2222 or a C828 transistor.

Apparatus:

SL#	Apparatus	Quantity
1	BJT (2N2222, C828)	1
2	Resistance (1 kΩ, 10 kΩ, 20 kΩ)	1 each
4	Project Board	1
7	DC milliammeter (0-50 mA)	1
8	DC microammeter (0-500 µA)	1
9	Multimeter	1
10	Connecting Leads	10

Precaution!

The following is a list of some of the special safety precautions that should be taken into consideration when working with transistors:

1. **Never remove or insert a transistor into a circuit with voltage applied.**
2. **Ensure a replacement transistor into a circuit is in the correct direction.**
3. **Transistors are sensitive to being damaged by electrical overloads, heat, humidity, and radiation. Damage of this nature often occurs by applying the incorrect polarity voltage to the collector circuit or excessive voltage to the input circuit.**
4. **One of the most frequent causes of damage to a transistor is the electrostatic discharge from the human body when the device is handled.**
5. **The applied voltage and current should not exceed the maximum rating of the given transistor.**

Experimental Procedures:

(A) Study of BJT input characteristics:

1. Measure the actual values of the 1 kΩ and 10 kΩ resistors.
2. Identify the terminals of the transistor and record the value of Beta (β).
3. Connect the circuit as shown in Fig. 5. Connect the microammeter and milliammeter as shown in Fig. 5.
4. Connect the multimeter (voltmeter mode) to measure the base resistance voltage (V_B) and input voltages (V_{BE}).
5. Turn on both the DC power supply with the voltage control nob at 0 V.
6. Rotate the voltage control nob of supply voltage, V_{CC} from 0 to +10 V and gradually fix this voltage level to get a constant collector-to-emitter voltage, V_{CE}.
7. For input characteristics, now vary the DC supply voltage, $V_{BB,}$ and calculate the base current, I_B using equation (1).

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} \qquad (1)$$

8. Measure the input voltage (V_{BE}) and current (I_B) and record them in Table 1.
9. Now, rotate the voltage control nob of supply voltage, V_{CC} from +10 to +16 V and gradually fix this voltage level to get a constant collector-to-emitter voltage, V_{CE}.
10. Repeat steps 7 and 8.
11. Record all the measured data in Table 1.
12. Record the images of the circuit diagram.
13. Turn off the DC power supply.
14. Plot the I_B -V_{BE} characteristic curve for the BJT.
15. Determine the knee voltage and static and dynamic resistance of the BJT.

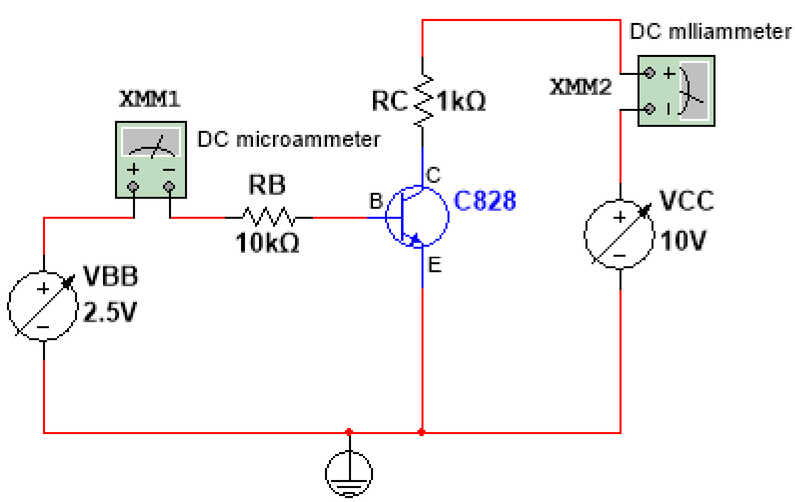


Figure 5: Circuit diagram for the determination of CE transistor characteristics

Table 1 Data for the input characteristic, I_B -V_{BE} Curve

	Collector Supply Voltage, V_{CC} = +10 V			Collector Supply Voltage, V_{CC} = +16 V		
Source Voltage, V_{BB} (V)	**Base-to-Emitter Voltage, V_{BE} (V)**	**Base Resistor Voltage, V_B (V)**	**Base Current, I_B (μA)**	**Base-to-Emitter Voltage, V_{BE} (V)**	**Base Resistor Voltage, V_B (V)**	**Base Current, I_B (μA)**
0						
0.2						
0.4						
0.6						
0.8						
1.0						
1.5						
2.0						
2.5						
3.0						

(B) Study of BJT output characteristics:

1. Measure the actual values of the 1 kΩ and 10 kΩ resistors.
2. Connect the circuit as shown in Fig. 5.
3. Connect the multimeter (voltmeter mode) to measure the base resistance voltage (V_B) and collector resistance voltage (V_C). Connect the microammeter and milliammeter as shown in Fig. 5.
4. Turn on both the DC power supply with the voltage control nob at 0 V.
5. First, open the input circuit (i.e., to make I_B = 0).
6. Vary the collector supply voltage, V_{CC} by rotating the voltage control nob of supply voltage in steps of 0.2 V from 0 V to +1 V and then in steps of 2 V from 1 V to +16 V, and calculate the collector current, I_C using equation (2). Take note of this collector current value from the milliammeter reading.
$$I_C = \frac{V_{CC} - V_{CE}}{R_C} \qquad (2)$$
7. Vary the V_{CC} gradually till to get a constant collector current, i.e., collector saturation current ($I_{C,sat}$) for all collector-to-emitter voltage, V_{CE}. Fill this table with the data as indicated in Table 2.
8. Now close the input circuit and fix the base current, I_B at 50 μA and 100 μA by varying V_{BB}. Calculate the base current, I_B using equation (1). Take note of this base current value from the microammeter reading.
$$I_B = \frac{V_{BB} - V_{BE}}{R_B} \qquad (1)$$
9. Repeat steps 6-8.
10. Record all the measured data in Table 2.
11. Record the images of the circuit diagram.
12. Turn off the DC power supply.
13. Plot the I_C -V_{CE} characteristic curve for the BJT.
14. Determine the collector saturation voltage and current, $V_{CE,sat}$ and $I_{C,sat}$ for each output characteristic curve.

Table 2 Data for the input characteristic, I_C -V_{CE} Curve

	Base Current, I_B = 0 μA			Base Current, I_B = 50 μA			Base Current, I_B = 100 μA		
Source Voltage, V_{CC} (V)	**Collector-to-Emitter Voltage, V_{CE} (V)**	**Collector Resistor Voltage, V_C (V)**	**Collector Current, I_C (mA)**	**Collector-to-Emitter Voltage, V_{CE} (V)**	**Collector Resistor Voltage, V_C (V)**	**Collector Current, I_C (mA)**	**Collector-to-Emitter Voltage, V_{CE} (V)**	**Collector Resistor Voltage, V_C (V)**	**Collector Current, I_C (mA)**
0									
0.0									
2.0									
4.0									
6.0									
8.0									
10.0									
12.0									

Questions:

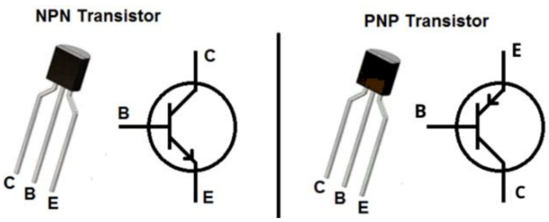
1. Show the difference between your simulated and measured values. Comment on the results and interpret the experimental and simulation data.
1. From the obtained data draw the input and output characteristic curves for a BJT. Explain the behavior of the input and output characteristics in terms of the three regions of operation, such as cutoff, active, and saturation regions.
2. Determine the BJT parameters from the plot.
3. What are the marked differences between a BJT and FET?
4. From the data of the above two experiments of Tables 1-2, plot the following curves and discuss:
    a) I_B vs V_{BE}. [Table 1]
    b) I_C vs V_{CE}. [Table 2]
    c) I_C vs I_B. [Table 2, for three different fixed V_{CE}]
5. What is the Q-point? Discuss its significance.
6. Give your suggestions regarding this experiment.
7. Discuss the overall aspects of the experiment. Did your results match the expected ones? If not, explain.

References:

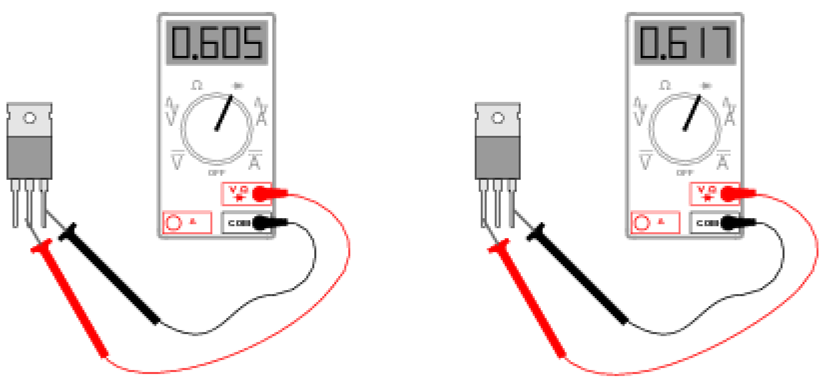
[1] Robert L. Boylestad, Louis Nashelsky, Electronic Devices and Circuit Theory, 9th Edition, 2007-2008
[2] Adel S. Sedra, Kenneth C. Smith, Microelectronic Circuits, Saunders College Publishing, 3rd ed., ISBN: 0-03-051648-X, 1991.
[3] American International University–Bangladesh (AIUB) Electronic Devices Lab Manual.
[4] David J. Comer, Donald T. Comer, Fundamentals of Electronic Circuit Design, John Wiley & Sons Canada, Ltd., ISBN: 0471410160, 2002.
[5] Resistor values: https://www.eleccircuit.com/how-to-basic-use-resistor/, accessed on 20 September 2023.

List the references that you have used to answer the “Discussion” section.

Appendix A: Identifying the terminals of an npn or a pnp transistor:



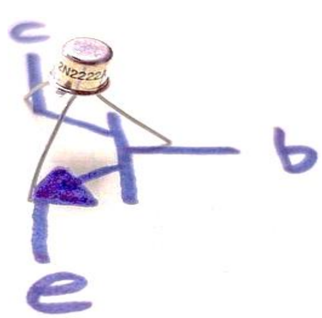
Following are the steps to identify npn and pnp transistors:
Step 1: Take the transistor you want to identify.
Step 2: Turn on a digital multimeter and set it to the DC voltage/resistance measurement mode.
Step 3: Make sure that you have connected the probes in their correct respective multimeter sockets, i.e., the black probe to the COM port and the red probe to the V/Ω/ port.
Step 4: Randomly start connecting the multimeter probes to the terminal of an unknown type of transistor and watch readings on the screen.
Step 5: Now, some random connections will give you a voltage/resistance reading on the multimeter screen.
Step 6: Once you get results i.e., any values (must be less than 1 for voltage reading) on the screen, start from the right side with the transistor's flat side upward direction, and write or mark the probes attached to the terminals of the transistor.
Step 7: If it is a black probe first and a red probe second then transfer the black probe to the third terminal (left-most terminal). If you get a similar result on the screen then write n, p, and n, that is the transistor is of npn type.
Step 8: If it is a red probe first and then a black probe second then transfer the red probe to the third terminal (left-most terminal). If you get a similar result on the screen then write p, n, and p, that is the transistor is of pnp type.
Step 9: The values you get on the multimeter screen after and before transferring the probe from the right-most side to the left-most side will differ slightly, the higher value-giving terminal is called the emitter and the lower value-giving terminal is called the collector, and the common terminal in the middle is called the base.



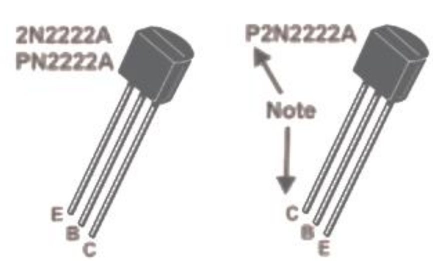
Based on the above procedural steps using a multimeter in diode mode, the left terminal of this transistor is a p-type emitter (producing larger value), the middle one is a p-type collector (less value), and the right one is called a base (common black terminal, so n-type). As such, this is a pnp-type transistor.

Appendix B: The 2N2222 Data Sheet

The 2N2222 is a common NPN bipolar junction transistor (BJT) used for general-purpose low-power amplifying or switching applications. It is designed for low to medium current, low power, medium voltage, and can operate at moderately high speeds. It was originally made in the TO-18 metal can as shown in the picture.



2N2222A in metal TO-18 package with the emitter, base and collector identified as E, B, and C respectively.



Pinout of 2N2222 variants in plastic TO-92 package.

2N2222A in metal TO-18 package with the emitter, base and collector identified as E, B, and C respectively.

Philips Semiconductors **Product specification**

NPN switching transistors 2N2222; 2N2222A

FEATURES

- High current (max. 800 mA)
- Low voltage (max. 40 V).

APPLICATIONS

- Linear amplification and switching.

DESCRIPTION

NPN switching transistor in a TO-18 metal package.
PNP complement: 2N2907A.

PINNING

PIN	DESCRIPTION
1	emitter
2	base
3	collector, connected to case

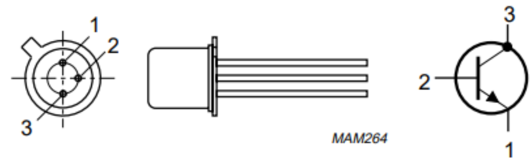


Fig.1 Simplified outline (TO-18) and symbol.

QUICK REFERENCE DATA

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_{CBO}	collector-base voltage	open emitter			
	2N2222		–	60	V
	2N2222A		–	75	V
V_{CEO}	collector-emitter voltage	open base			
	2N2222		–	30	V
	2N2222A		–	40	V
I_C	collector current (DC)		–	800	mA
P_{tot}	total power dissipation	$T_{amb} \leq 25$ °C	–	500	mW
h_{FE}	DC current gain	$I_C = 10$ mA; $V_{CE} = 10$ V	75	–	
f_T	transition frequency	$I_C = 20$ mA; $V_{CE} = 20$ V; f = 100 MHz			
	2N2222		250	–	MHz
	2N2222A		300	–	MHz
t_{off}	turn-off time	$I_{Con} = 150$ mA; $I_{Bon} = 15$ mA; $I_{Boff} = -15$ mA	–	250	ns

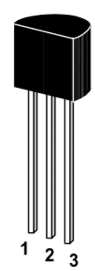
LIMITING VALUES

In accordance with the Absolute Maximum Rating System (IEC 134).

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_{CBO}	collector-base voltage	open emitter			
	2N2222		–	60	V
	2N2222A		–	75	V
V_{CEO}	collector-emitter voltage	open base			
	2N2222		–	30	V
	2N2222A		–	40	V
V_{EBO}	emitter-base voltage	open collector			
	2N2222		–	5	V
	2N2222A		–	6	V
I_C	collector current (DC)		–	800	mA
I_{CM}	peak collector current		–	800	mA
I_{BM}	peak base current		–	200	mA
P_{tot}	total power dissipation	$T_{amb} \leq 25$ °C	–	500	mW
		$T_{case} \leq 25$ °C	–	1.2	W
T_{stg}	storage temperature		–65	+150	°C
T_j	junction temperature		–	200	°C
T_{amb}	operating ambient temperature		–65	+150	°C

Appendix C: The C828 Data Sheet

ST 2SC828 / 828A is an NPN Silicon Epitaxial Planar Transistor for switching and AF amplifier applications. These transistors are subdivided into three groups Q, R and S according to their DC current gain. On special request, these transistors can be manufactured in different pin configurations. TO-92 Plastic Package Weight approx. 0.19 gm.



1. Emitter 2. Collector 3. Base

Pin configuration of TO-92 Plastic Package.

Absolute Maximum Ratings ($T_a = 25^oC$)

	Symbol	Value		Unit
		ST 2SC828	ST 2SC828A	
Collector Base Voltage	V_{CBO}	30	45	V
Collector Emitter Voltage	V_{CEO}	25	45	V
Emitter Base Voltage	V_{EBO}	7		V
Peak Collector Current	I_{CM}	100		mA
Collector Current	I_C	50		mA
Power Dissipation	P_{tot}	400		mW
Junction Temperature	T_j	150		^oC
Storage Temperature Range	T_S	-55 to +150		^oC

Characteristics at T_{amb}=25 ^{O}C

	Symbol	Min.	Typ.	Max.	Unit
DC Current Gain at I_C=2mA, V_{CE}=5V Current Gain Group Q R S	 h_{FE} h_{FE} h_{FE}	 130 180 260	 - - -	 280 360 520	 - - -
Collector Base Breakdown Voltage at I_C=10μA ST 2SC828 ST 2SC828A	 $V_{(BR)CBO}$ $V_{(BR)CBO}$	 30 45	 - -	 - -	 V V
Collector Emitter Breakdown Voltage at I_C=2mA ST 2SC828 ST 2SC828A	 $V_{(BR)CEO}$ $V_{(BR)CEO}$	 25 45	 - -	 - -	 V V
Emitter Base Breakdown Voltage at I_E=10μA	$V_{(BR)EBO}$	7	-	-	V
Collector Saturation Voltage at I_C=50mA, I_B=5mA	$V_{CE(sat)}$	-	0.14	-	V
Base Emitter Voltage at I_C=10mA, V_{CE}=5V	V_{BE}	-	-	0.8	V
Gain Bandwidth Product at I_C=-2mA, V_{CE}=10V	f_T	-	220	-	MHz
Noise Figure at V_{CE}=5V,I_E=0.2mA, R_G=2kΩ,f=1kHz	NF	-	6	-	dB