User's Manual

STUDY OF P-N JUNCTION
Model : PN-01
(Rev : 16/8/2017)

Manufactured by:

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COPYRIGHT AND WARRANTY

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COPYRIGHT NOTICE

LIMITED WARRANTY

SES Instruments Pvt. Ltd warrants this product to be free from defects in materials and workmanship for a period of one year from the date of shipment to the customer. SES Instruments Pvt. Ltd will repair or replace, at its option, any part of the product which is deemed to be defective in material or workmanship. This warranty does not cover damage to the product caused by abuse or improper use. Determination of whether a product failure is the result of manufacturing defect or improper use by the customer shall be made solely by SES Instruments Pvt. Ltd. Responsibility for the return of equipment for warranty repair belongs to the customer. Equipment must be properly packed to prevent damage and shipped postage or freight prepaid. (Damage caused by improper packaging of the equipment for return shipment will not be covered by the warranty). Shipping costs for returning the equipment, after repair, will be paid by SES Instruments Pvt. Ltd.

EQUIPMENT RETURN

Should this product have to be returned to SES Instruments Pvt. Ltd, for whatever reason, notify SES Instruments Pvt. Ltd BEFORE returning the product. Upon notification, the return authorization and shipping instructions will be promptly issued.

Note : No equipment will be accepted for return without an authorization.

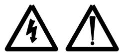
When returning equipment for repair, the units must be packed properly. Carriers will not accept responsibility for damage by improper packing. To be certain the unit will not be damaged in shipment, observe the following rules:

1. The carton must be strong enough for the item shipped.
2. Make certain there is at least two inches of packing material between any point on the apparatus and the inside walls of the carton.
3. Make certain that the packing material can not displace in the box, or get compressed, thus letting the instrument come in contact with the edge of the box.

SAFETY INFORMATION

This Section addresses safety considerations and describes symbols that may appear on the Instrument or in the manual.

A **Warning** Statement identifies conditions or practices that could result in injury or death. A **Caution** statement identifies conditions or practices that could result in damage to the Instrument or equipment to which it is connected.

 **Warning**

To avoid electric shock, personal injury, or death, carefully read the information in Table-1, "Safety Information," before attempting to install, use, or service the Instrument.

GENERAL SAFETY SUMMARY

This equipment is Class 1 equipment tested in accordance with the European Standard publication EN 61010-1.

This manual contains information and warnings that must be observed to keep the Instrument in a safe condition and ensure safe operation.

To use the Instrument correctly and safely, read and follow the precautions in Table 1 and follow all safety instructions or warnings given throughout this manual that relate to specific measurement functions. In addition, follow all generally accepted safety practices and procedures required when working with and around electricity.

SYMBOLS

Table 2 lists safety and electrical symbols that appear on the Instrument or in this manual.

Table 2. Safety and Electrical Symbols

Symbols	Description	Symbols	Description
	Risk of danger. Important information. See Manual.		Earth ground
	Hazardous voltage. Voltage >30Vdc or ac peak might be present.		Potentially hazardous voltage
	Static awareness. Static discharge can damage parts.		Do not dispose of this product as unsorted municipal waste. Contact SES or a qualified recycle for disposal.

Table 1. Safety Information

⚠ ⚠ Warning

To avoid possible electric shock, personal injury, or death, read the following before using the Instrument:

- **Use the Instrument only as specified in this manual, or the protection provided by the Instrument might be impaired.**
- **Do not use the Instrument in wet environments**
- **Inspect the Instrument in wet environments.**
- **Inspect the Instrument before using it. Do not use the Instrument if it appears damaged.**
- **Inspect the connecting lead before use. Do not use them if insulation is damaged or metal is exposed. Check the connecting leads for continuity. Replace damaged connecting leads before using the Instrument.**
- **Whenever it is likely that safety protection has been impaired, make the Instrument inoperative and secure it against any unintended operation.**
- **Have the Instrument serviced only by qualified service personnel.**
- **Always use the power cord and connector appropriate for the voltage and outlet of he country or location in which you are working.**
- **Never remove the cover or open the case of the Instrument before without first removing it from the main power source.**
- **Never operate the Instrument with the cover removed or the case open.**
- **Use only the replacement fuses specified by the manual.**
- **Do not operate the Instrument around explosive gas, vapor or dust.**
- **When servicing the Instrument, use only specified replacement parts.**
- **The equipment can remain Switched on continuously for five hours**
- **The equipment must remain Switched off for at lease fifteen minutes before being switched on again.**
- **The equipment is only for the intended use**
- **Use the equipment only as specified in this manual.**

Unpacking and Inspecting the Instrument

Every care is taken in the choice of packing material to ensure that your Instrument will reach you in perfect condition. If the Instrument has been subject to excessive handling in transit, there may be visible external damage to the shipping container and packing material for the carrier's inspection.

Carefully unpack the Instrument from its shipping container and inspect the contents for damaged or missing items. If the Instrument appears damaged or something is missing, contacts the carrier and SES immediately. Save the container and packing material in case you have to return the Instrument.

Storing and Shipping the Instrument

To prepare the Instrument for storage or shipping, if possible, use the original shipping container alongwith thermocoal corners, as it provides shock isolation for normal handling operations. If the original shipping container is not available, use any good cardboard box which is at least 2-3 inches bigger than the instrument on all sides, with cushioning material (thermocoal or styrofoam etc) that fills the space between the instrument and the side of this box.

To store the Instrument, place the box under cover in a location that complies with the storage environment specification described in the "Environment Sections" below.

Environment

Temperature

Operating …………………………………. 0°C to 50°C

Storage …………………………………… 40°C to 70°C

Warm Up …………………………………15 min to full uncertainty specification

Relatively Humidity (non-condensing)

Operating …………………………………Uncontrolled (<10°C)
<90 % (10°C to 30°C)
<75 % (30°C to 40°C)
<45 % (40°C to 50°C)

Storage………………………………….. -10°C to 60°C <95 %

Power Considerations

The Instrument operates on varying power distribution standards found throughout the world and must be set up to operate on the line voltage that will power it. The Instrument is packed ready for use with a line voltage determined at the time of ordering.

Replacing the Fuses

The Instrument uses one fuse to protect the line-power input and two fuses to protect current-measurement inputs.

Line-Power Fuse

The Instrument has a line-power fuse in series with the power supply. Table 3 indicates the proper fuse for each of the four line-voltage selections. The line-power fuse is accessed through the real panel.

1. Unplug the power cord.
2. Rotate the fuse holder cap to the right until the fuse POPS out.
3. Remove the fuse and replace it with a fuse of an appropriate rating for the selected line-power voltage. See Table 3.

⚠ ⚠ Warning

To avoid electric shock or fire, do not use makeshift fuses or short-circuit the fuse holder.

Table 3. Line Voltage to Fuse Rating

Line Voltage Selection	Fuse Rating
220/ 240 V	1A, 250V (Slow Blow)
100/ 120 V	2A, 250V (Slow blow)

Connecting to Line Power

⚠ ⚠ Warning

To avoid shock hazard, connect the factory supplies three conductor line power cord to a properly grounded power outlet. Do not use a two-conductor adapter or extension cord, as this will break the protective ground connection. If a two conductor power cord must be used, a protective grounding wire must be connected between the ground terminal and earth ground before connecting the power cord or operating the Instrument.

1. Verify that the Line voltage is set to the correct setting.
2. Verify that the correct fuse for the line voltage is installed.
3. Connect the power cord to a properly grounded three-prong outlet. See Figure 3 for line-power cord types available from SES. Refer to Table 4 for description of the line-power cords.

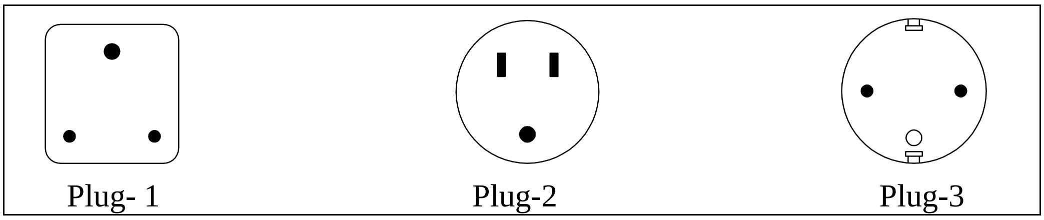


Figure 3. Line-Power Cord Types Available from SES

Table 4. Line-Power Cord Types Available from SES

Type	Voltage/Current	SES Model Number
India	240 V/ 5 A	Plug-1
North America	120 V/15 A	Plug-2
Universal Euro	220 V/16 A	Plug-3

Turning Power On

The On-Off switch on the front panel when points towards “ON” signs, indicates that the equipment has been switched on.

Cleaning the Instrument

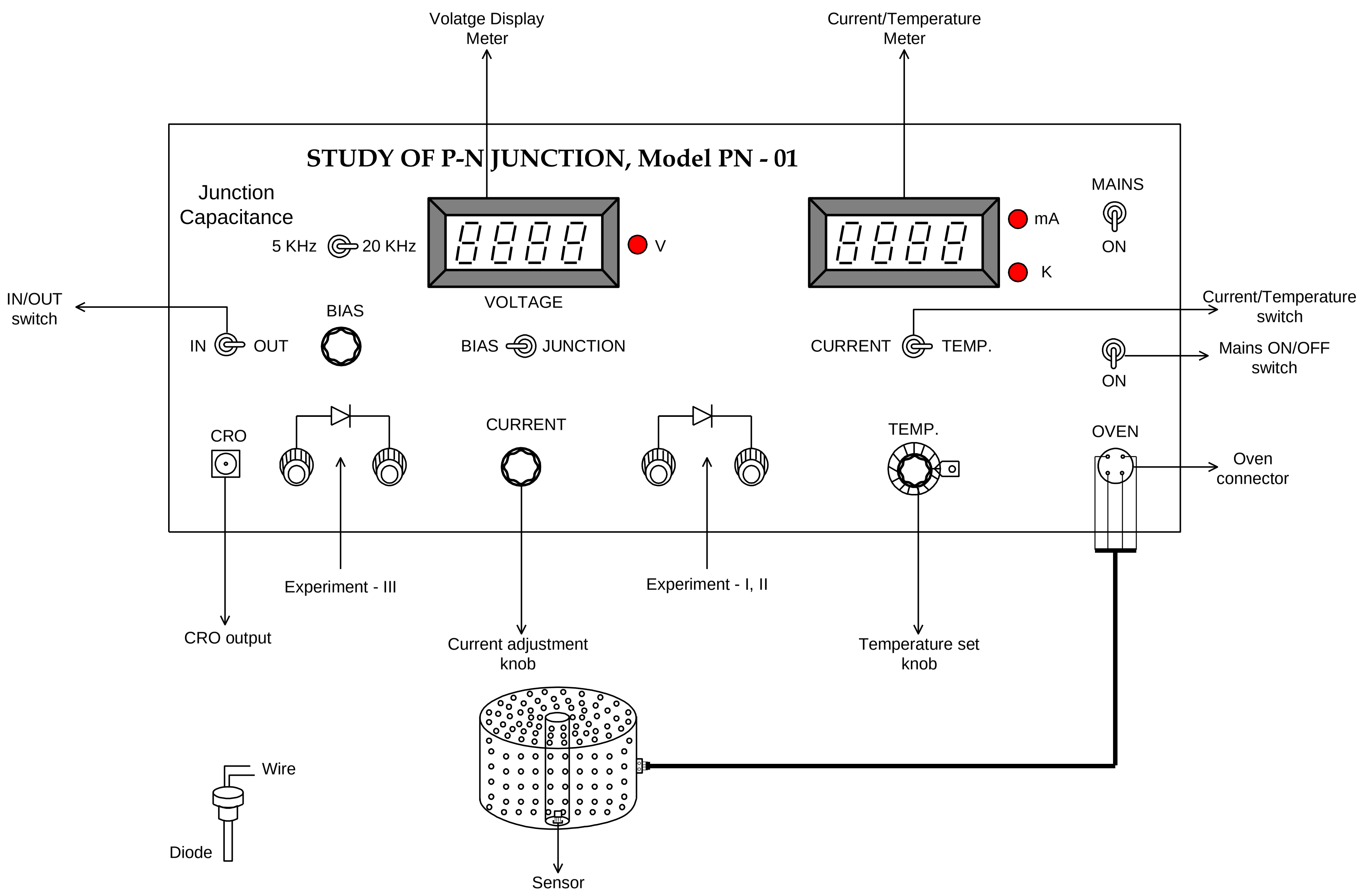
Warning

To avoid electric shock or damage to the Instrument, never get water inside the Instrument.

Caution

To avoid damaging the Instrument’s housing, do not apply solvents to the Instrument.

If the Instrument requires cleaning, wipe it down with a cloth that is lightly dampened with water or a mild detergent. Do not use aromatic hydrocarbons, alcohol, chlorinated solvents, or methanol-based fluids when wiping down the Instrument.



Panel diagram of Study of P-N Junction, Model PN-01

OBJECT

To study various characteristic of p-n junction.

INTRODUCTION

This is an advanced level experiment for studying commercially available p-n junctions like germanium and silicon rectifiers, various types of light emitting diodes (LED's), zener diodes and transistor junctions. Besides obtaining the static characteristics of the device, the results also reveal the material characterisitcs of the semiconductors used.

Referring to the panel diagram shown in Fig. 1, the following subsystems and controls may be identified :

(a) Constant Current source, adjustable from 0 to 12 mA.

(b) Temperature controlled oven with ON/OFF display, adjustable from room temperature to 360 K (approx.)

(c) Display-1, for directly reading CURRENT or oven TEMPERATURE through switch setting.

(d) Display-2, for showing JUNCTION voltage in experiments I and II or BIAS voltage in experiment III. Details of the experiments are given later.

(e) Switch selectable internal oscillator at 5 KHz/20 KHz.

(f) Sockets for OVEN, SENSOR, CRO and diode.

PACKING LIST

1. Study of P-N Junction, PN-01 : One
2. Oven : One
3. Sample Set : One

   (BC-109-Si & IN-34-Ge : Mounted on Teflon Plug and IN5408-Diode)

THEORY

The three experiments which may be performed on the unit are described below in some detail.

EXPERIMENT - I

Determination of reverse saturation current I_0 and material constant η

The current I in a p-n junction is given by

$$I = I_0 \left(e^{\frac{qV}{\eta kT}} - 1 \right) \qquad (1)$$

Where,

q, electronic charge = 1.602×10^{-19} coulomb

η, material constant = 1 for Ge

= 2 for Si

k, Boltzman constant = 1.381×10^{-23} J/K

T, Temperature in Kelvin

V, Junction voltage in volts

The reverse saturation current is usually too small to be measured directly. An indirect graphical method may be obtained by taking logarithm of eqn. (1) for $e^{qV/\eta kT} >> 1$ as,

$$\ln I = \ln I_0 + \frac{qV}{\eta kT}$$

If, V and ln I are plotted on a graph paper a straight line is obtained. This line intersects the current (ln I) axis at $\ln I_0$ and its slope may be solved to compute η,

$$\eta = \frac{q}{kT} \frac{\Delta V}{\Delta \ln I}$$

The diode to be tested is connected to the terminals with the polarity as indicated. Readings are now recorded from the two display set to JUNCTION and CURRENT respectively with the current source adjusted in steps from 100 μA to 10 mA.

EXPERIMENT - II

Determination of Temperature Coefficient of junction Voltage and Energy band-gap.

With the connections as in Experiment-I, the OVEN and SENSOR leads are inserted in the respective sockets. The diode is put in the oven and its forward current is set to a low value (say 1 mA) to avoid heating. The display-1 is now switched to TEMP, to read the oven temperature.

The Oven temperature can now be varied from room temperature to about 360 K in suitable steps and the junction voltage may be recorded. The temperature controlled oven requires about 5 minutes to stabilize at every new setting. Before noting any readings, one must ensure that a few ON/OFF cycles of the oven have been completed as shown by the indicator.

The reverse saturation current is given by

$$I_0 = kT^m \, e^{\frac{-V_{G0}}{\eta V_T}}$$, and the diode forward current by

$$I = I_0 \,(e^{\frac{V}{\eta V_T}} - 1) \approx I_0 \, e^{\frac{V}{\eta V_T}}$$

$$= kT^m \, e^{\frac{V - V_{G0}}{\eta V_T}}$$, where for Si: m = 1.5, η=2 and for Ge: m=2.0, η=1

Also $V_T = \frac{kT}{q}$. taking logarithm,

$$\ln I = \ln k + m \ln T + \frac{V - V_{G_0}}{\eta V_T}$$

At I = constant, differentiating w.r.t. T

$$0 = 0 + \frac{m}{T} + \frac{d}{dT}\left[\frac{(V - V_{G_0})q}{\eta kT}\right]$$

$$0 = \frac{m}{T} + \frac{q}{\eta kT}.\frac{dV}{dT} - \frac{(V - V_{G_0})q}{\eta k}.\frac{1}{T^2}$$

$$0 = \frac{m}{T} + \frac{q}{\eta kT}.\frac{dV}{dT} - \frac{q}{\eta kT^2}(V - V_{G_0})$$

$$0 = \frac{\eta kT^2}{q}.\frac{m}{T} + T\frac{dV}{dT} - (V - V_{G_0})$$

$$\boxed{V_{G_0} = V - T\frac{dV}{dT} - \frac{m\eta kT}{q}}$$

At 300 K for Si,

$$\frac{m\eta kT}{q} = (1.5 \text{ x } 2 \text{ x } 1.381 \text{ x } 10^{-23} \text{ x } 300)/1.602 \text{ x } 10^{-19}$$

$$= 0.078 \text{ V}$$

Where slope of the V-T curve is the temperature coefficient of the junction voltage and V_{G0} is the energy band-gap.

EXPERIMENT - III

Study of depletion capacitance and its variation with reverse bias

The measurement is based on the circuit of Fig. 2 where C_D and G_D are the depletion capacitance and leakage resistance, respectively, of the diode under test.

The outputs V_1 and V_2 at two frequencies ω_1, ω_2 may be written as, $(\omega_2>\omega_1)$

$$V_1 = -V (G_D + j\omega_1 C_D) R$$

$$V_2 = -V (G_D + j\omega_2 C_D) R$$

V is the input signal of same magnitude both for ω_1 and ω_2.

Squaring and subtracting after taking magnitudes,

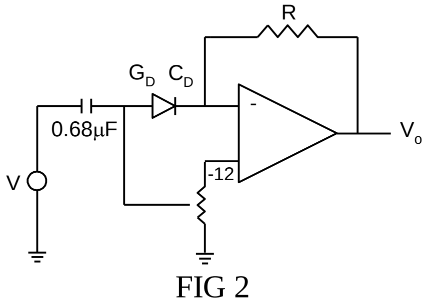
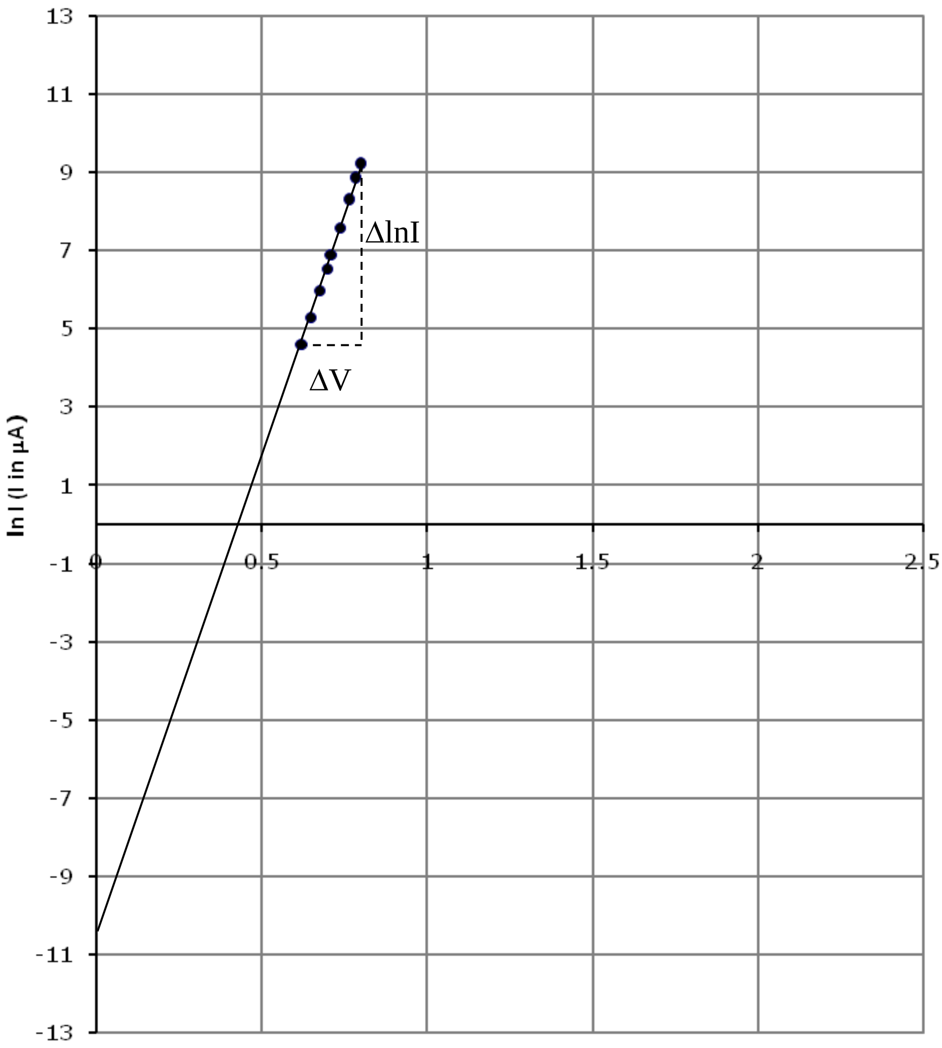


FIG 2

$$(V_2^2 - V_1^2) = V^2 R^2 (\omega_2^2 - \omega_1^2)\, C_D^2$$

$$C_D = \frac{\sqrt{V_2^2 - V_1^2}}{VR\sqrt{\omega_2^2 - \omega_1^2}}$$

Reserve Saturation Current



Graph 1

In the present unit

$V = 200$ mV p-p
$R = 100$ K
$\omega_1 = 2\pi.5.10^3$
$\omega_2 = 2\pi.20.\ 10^3$

Which gives

$$C_D = 0.41\sqrt{V_2{}^2 - V_1{}^2}\ \text{pf}$$

where, V_1 is the p-p output voltage in mV at 5 KHz and V_2 is the p-p output voltage in mV at 20 KHz

For this experiment the p-n junction is connected to the left side socket. **Note that no extra wire should be present with the diode**. The display 2 is set to BIAS and a CRO is connected to measure the input and output voltages for the particular bias and frequency settings.

TYPICAL RESULTS

Experiment - I (Reverse saturation Current I_0)

Sample : BC 109 (Base - Emitter Junction)

S. No.	Forward Current I in μA	ln I	Junction Voltage V in Volts
1.	100	4.61	0.623
2.	200	5.30	0.649
3.	400	5.99	0.677
4.	700	6.55	0.699
5.	1000	6.91	0.712
6.	2000	7.60	0.738
7.	4000	8.29	0.764
8.	7000	8.85	0.785
9.	10000	9.21	0.800

From graph no. 1, we get

$\ln I_0 = -11.5$

Slope of the curve $\dfrac{\Delta V}{\Delta \ln I} = \dfrac{0.18}{4.7}$

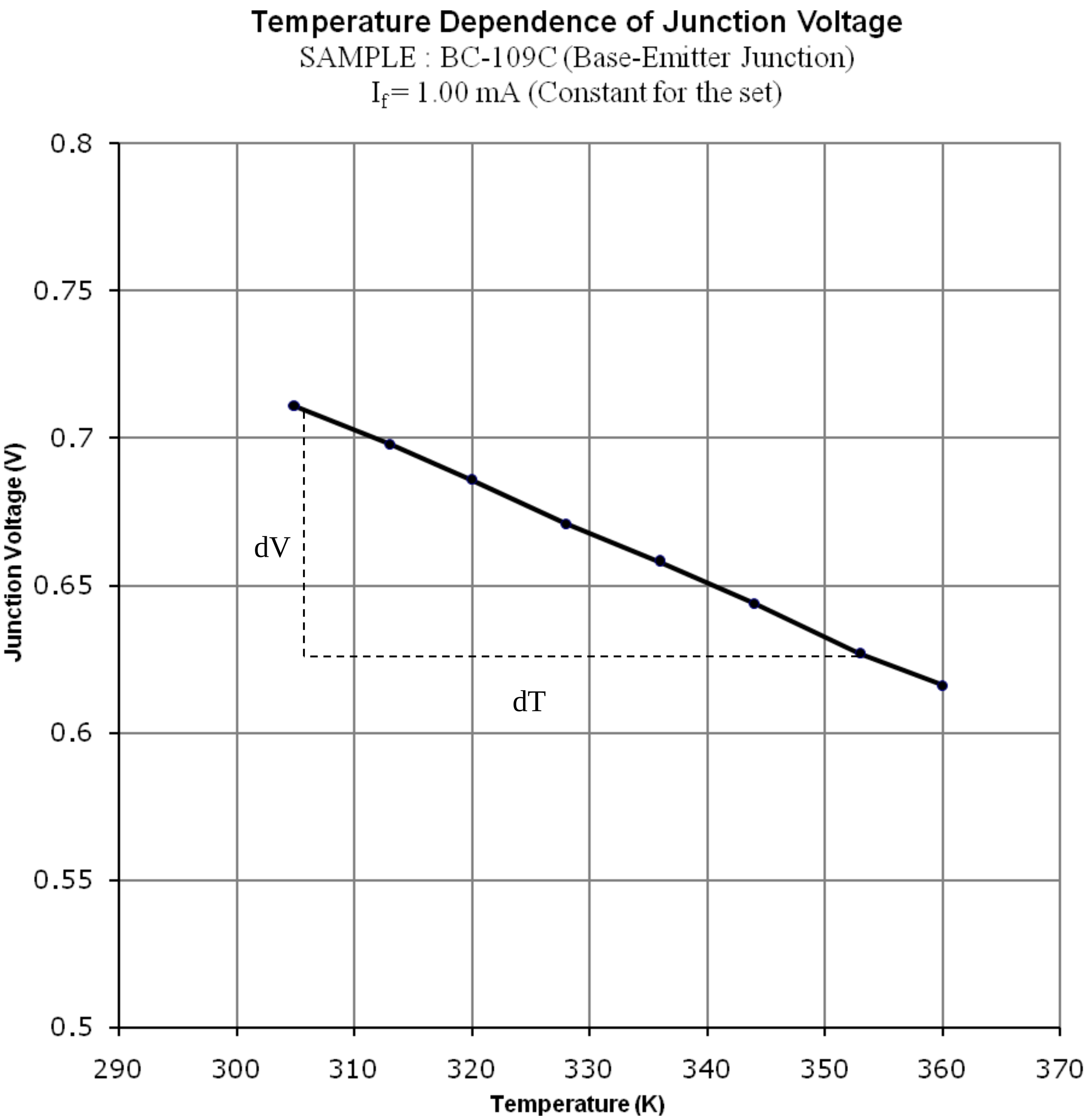
Therefore,

$I_0 = 0.10 \times 10^{-10}$ A

and,

$$\eta = \frac{q}{kT}\frac{\Delta V}{\Delta \ln I} = \frac{1.602 \times 10^{-19} \times 0.18}{1.381 \times 10^{-23} \times 305 \times 4.7}$$

$\eta = 1.46$



Temperature Dependence of Junction Voltage
SAMPLE : BC-109C (Base-Emitter Junction)
I_f= 1.00 mA (Constant for the set)
Junction Voltage (V)
0.8
0.75
0.7
0.65
0.6
0.55
0.5
dV
dT
290
300
310
320
330
340
350
360
370
Temperature (K)

Graph 2

Experiment - II

Sample : BC 109 (Base - Emitter Junction)

I_f = 1.00 mA (constant for the set)

S. No.	Temperature	Junction Voltage
1.	305	0.711
2.	313	0.698
3.	320	0.686
4.	328	0.671
5.	336	0.658
6.	344	0.644
7.	353	0.627
8.	360	0.616

We know,

Energy Band gap $V_{G_0} = V(T) - T\frac{dV}{dT} - \frac{m\eta kT}{q}$

From graph no. 2

At T = 300 K, V(T) = 0.720V, $\frac{dV}{dT} = -1.79 \times 10^{-3}$ V/K

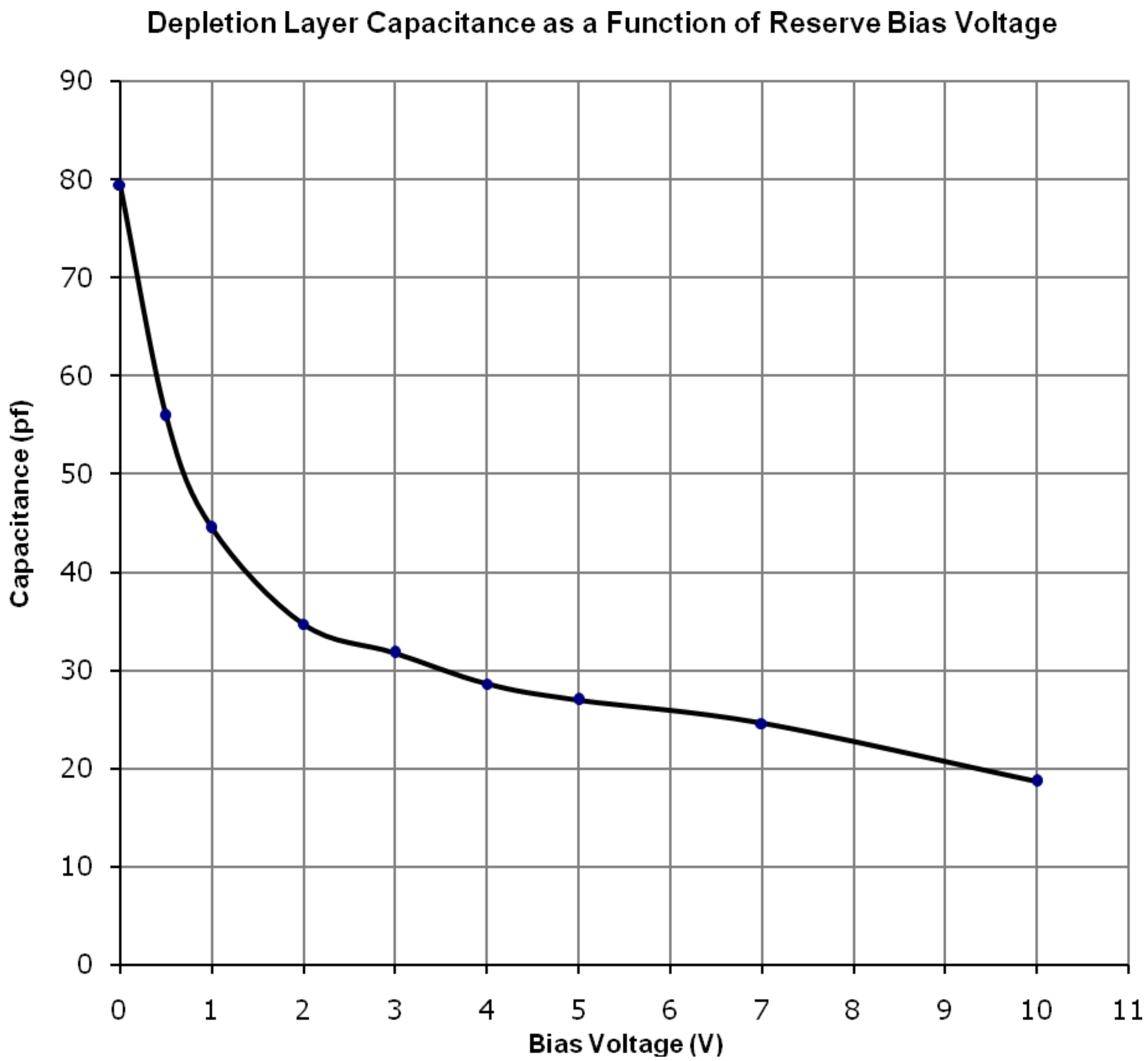
& for Si at 300 K, $\frac{m\eta kT}{q} = 0.078$ V

$$V_{G_0} = 0.720 - \left[300\left(-1.79 \text{x} 10^{-3}\right)\right] - 0.078$$

$$= 0.720 - [-0.357] - 0.078$$

$$= 0.720 + 0.537 - 0.078$$

$$= 1.18 \text{ eV}$$



Depletion Layer Capacitance as a Function of Reserve Bias Voltage
Capacitance (pf)
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
11
Bias Voltage (V)

Graph 3

Experiment - III

Sample : Si diode 1N 5408

S. No.	Bias Voltage volt	V_1 (ω_1) mV p-p 5 KHz	V_2 (ω_2) mV p-p 20 KHz	C_D pf
1.	0.00	50	200	79.4
2.	-0.50	32	140	55.9
3.	- 1.00	28	112	44.5
4.	- 2.00	24	88	34.7
5.	- 3.00	20	80	31.8
6.	- 4.00	18	72	28.6
7.	- 5.00	17	68	27.0
8.	- 7.00	16	62	24.6
9.	-10.00	15	48	18.7

CONCLUSIONS

With this set-up some of the very important characteristics of a P-N Junction and its material properties may be determined as a simple laboratory experiment. The basic technique follows from the reference given below. The unit however has been carefully designed for the student environment, with built-in and protected current and bias sources, signal sources, digital displays and temperature controlled oven.

CAUTION

(i) In experiment 1 and 2, ordinary diodes used in power supplied should not be used due to their poor material quality.

(ii) In the experiment III: Junction capacitance of the diode/transistor junction, the devices should be directly connected with the terminals, connections through leads would result in additional capacitance and pick ups.

REFERENCE

[1] Charles W. Fisher, "Elementary technique to measure the energy band-gap and diffusion potential of p-n junction", Am. J. Phys. 50 (12), Dec. 1982.

TECHNICAL SUPPORT

Feed Back

If you have any comments or suggestions about this product or this manual please let us know. **SES Instruments Pvt. Ltd.** appreciates any customer feedback. Your input helps us evaluate and improve our product.

To reach SES Instruments Pvt. Ltd.

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Contacting for Technical Support

Before you call the SES Instruments Pvt. Ltd. Technical Support staff it would be helpful to prepare the following information:

- If you problem is with the SES Instruments Pvt. Ltd apparatus, note :
  - Model number and S. No (usually listed on the label at the backside of instrument).
  - Approximate age of the apparatus.
  - A detailed description of the problem/ sequences of events may please be sent by email or Fax.
- If your problem relates to the instruction manual, note;

  Model number and Revision (listed by month and year on the front cover).

  Have the manual at hand to discuss your questions.