REPORT

ON

DIODE AS TEMPERATURE SENSOR

By

SONTU NARENDRA GAUTAM **1700357C204**

Prepared in the partial fulfillment of the

Practice School II Course

AT

RESEARCH CENTRE IMARAT, DRDO

RCI ROAD, VIGYNANA KANCHA, HYDERABAD, TELANGANA 50069

Practice School II Station of

BML MUNJAL UNIVERSITY

(May-June ,2019)

A REPORT

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Certificate of authenticity

CERTIFICATE

This is to certify that Practice School Project of **SONTU NARENDRA GAUTAM** titled **DIODE AS TEMPERATURE SENSOR** is an original work and that this work has not been submitted anywhere in any form. Indebtedness to other works/publications has been duly acknowledged at relevant places. The project work was carried during **23rd MAY 2019** to **10th JULY 2019** in **RESEARCH CENTRE IMARAT,DRDO HYDERABAD**.

Signature of PS-II faculty	**Signature of Industry Mentor**
Name: Dr. A.K. Prasada Rao	**Name:** Gopala Krishna Murthy
Designation: Professor, SOET	**Designation:** Scientist F
(Seal of the organization with Date)	***(Seal of the organization with Date)***

ACKNOWLEDGMENTS

I have taken endeavours in this internship. However, it would not have been conceivable without the benevolent help and help of numerous people and associations. I would like to stretch out my true gratitude to every one of them.

I am profoundly obligated to **RESEARCH CENTRE IMARAT, DRDO HYDERABAD** for their direction and consistent supervision and for giving essential data with respect to the undertaking and likewise for their help in finishing the project.

I would like to express my gratitude towards my faculty mentor **Dr. A K PRASADA RAO** and my industry mentor **M GOPALA KRISHNA MURTHY** for their kind cooperation and encouragement throughout the internship period.

I would like to offer my uncommon thanks and gratitude to industry people for giving me such consideration and time. And I would like to thank the people from the university who kept me told about the updates and cleared every one of my questions right away.

My thanks and appreciations also go to my university and my dean in developing such a unique program which exposed me to the industry during the early years of my graduation.

OBJECTIVES

The main objective of the project is to create a temperature sensor using a diode.

The sub objectives include

1: Diode characteristics when biased.

2: Operational Amplifiers working.

3: Design and Schematic of sensor.

4: NI Multisim (Software) for stimulations.

5: Hardware implementation.

PROBLEM STATEMENT

Most of the variables assessed in planning applications depend, by fluctuating degrees, on temperature. This requires the synchronous estimation of temperature nearby the variable of excitement for solicitation to perform high dedication temperature compensated estimations. Silicon diode based temperature sensors have the advantages of being ease, having an out and out temperature estimation capacity similarly as giving the decision of on-chip joining with equipment circuits and a wide temperature estimation go. Using these focal points, we have chosen to use silicon diodes in temperature arranged application. The assurance of the temperature reliance of the immersion current in invert one-sided or in forward one-sided PN silicon intersection diodes so as to decide the prevailing commitment to the immersion current. So when a chip gets heated the diode which is mounted on it would recognise it.

COMPANY PROFILE

DRDO acquired approximately 2100 acre of land in the 1970's for the purpose of Anti Tank Missile Testing. *Dr A.P.J. Abdul Kalam* the then Director of DRDL persuaded Govt of Andhra Pradesh to give the land for setting up RCI. The area occupied by RCI has been named as Vignyana Kancha. On 5th Aug 1985, former Prime Minister Late Shri Rajiv Gandhi laid the foundation stone for this establishment. Former *President of India Shri R. Venkatraman* inaugurated the laboratory on 27th Aug 1988. RCI, a premier R&D organization in the country with the objective of developing frontier technologies for Defence applications.

RCI has considered as **'Avionics Hub'** of DRDO. It is one of the three DRDO Labs of 'Missile Complex'. It houses different work centers, integration and testing facilities.RCI is a leading laboratory of Defence Research Development Organization (DRDO) and responsible for the development of missile system and also design, development and participation in the production of missile avionics like Inertial Navigation Systems, Control Systems, Real Time Embedded Computers, Imaging Infrared Seeker, Radio Frequency Seeker and Power Supply Systems. Telemetry and Telecommand systems are also developed in RCI to evaluate missile performance during its development phase. RCI is an ISO 9001-2000 laboratory.

The Infrastructure facilities established include state-of-the–art Electromagnetic interference / Electromagnetic Compatibility, Environmental test facility for climatic and dynamic testing of Missile Avionic Systems and Compact Antenna test facility. The first indigenous Trishul missile was successfully flight tested with indigenous Control and Navigation Systems. Subsequently Prithvi and other missiles were successfully flight tested with indigenous avionic systems after thorough testing in simulation laboratory and extensive Environmental testing.

Shri BHVS NARAYANA MURTHY, Outstanding Scientist is the present Director of RCI

The main offerings of RCI are

- Junior Research Fellowship (JFR).

- Internships programs

METHODOLOGY

1. Required skills

a. Knowledge of Operational Amplifiers.

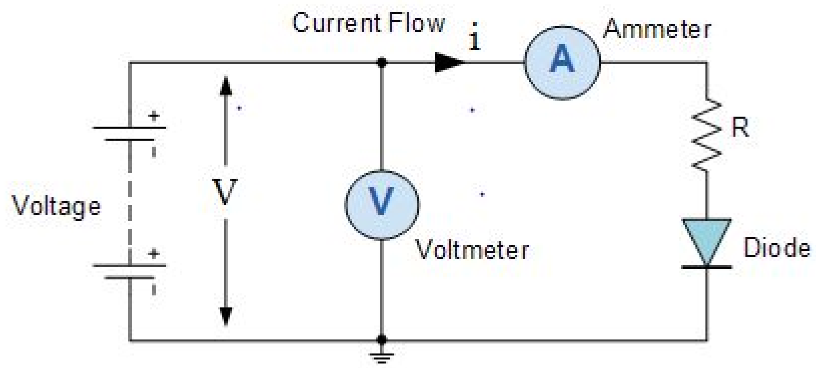
b. Knowledge on Diode Characteristics.

c. Knowledge of Ni Multisim

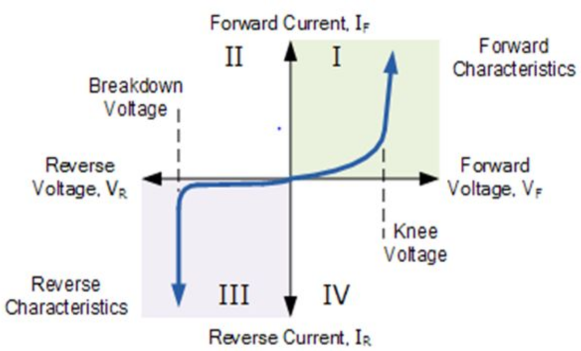
   i. Used to create or stimulate responses.

2. Data collection and survey

At the point when the diode is forward biased, anode positive regarding the cathode, a forward or positive current goes through the diode and works in the upper right quadrant of its I-V attributes bends as appeared. Beginning at the zero crossing point, the bend increments bit by bit into the forward quadrant yet the forward current and voltage are very little.



At the point when the forward voltage surpasses the diodes P-N intersections inside hindrance voltage, which for silicon is about 0.7 volts, torrential slide happens and the forward current increments quickly for a little increment in voltage delivering a non-direct bend. The "knee" point on the forward bend.



Moreover, when the diode is reverse biased, cathode positive as for the anode, the diode squares current aside from an amazingly little spillage current, and works in the lower left quadrant of its I-V trademark bends.

The diode keeps on blocking current move through it until the invert voltage over the diode winds up more prominent than its breakdown voltage point bringing about an abrupt increment in switch current creating a genuinely straight line descending bend as the voltage misfortunes control. This turn around breakdown voltage point is utilized to great impact with zener diodes.

At that point we can see that the I-V Characteristics Curves for a silicon diode are non-straight and altogether different to that of the past resistors direct I-V bends as their electrical qualities are extraordinary. Flow Voltage attributes bends can be utilized to plot the activity of any electrical or electronic part from resistors, to speakers, to semiconductors and sun powered cells.

The current-voltage characteristics of an electronic component tells us much about its operation and can be a very useful tool in determining the operating characteristics of a particular device or component by showing its possible combinations of current and voltage.

The expression for the (forward bias) diode voltage V_D is as follows:

$$V_D = \frac{kT}{q} \ln \frac{I_D}{I_S}$$

Where:
V_D = applied voltage across the diode
k = Boltzman constant (1.38E-23 Joules/Kelvin)
T = the absolute temperature in Kelvin
q = the electron charge (1.6E-19 Coulombs)
I_D = the actual current through the diode
I_S = the diffusion current (a device dependent constant)
(The so called thermal voltage, V_T, is *kT/q* = 26 mV at room temperature.)

The equation above can be rearranged to provide I_D:

$$I_D = I_S\left(e^{\frac{V_D q}{kT}} - 1\right)$$

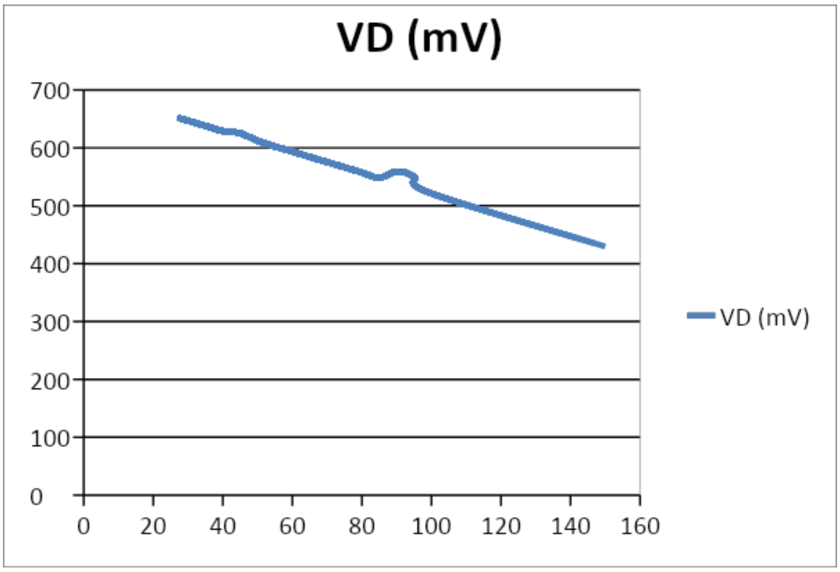
Diodes can be used for temperature sensing due to the strong temperature dependence of their forward bias voltage drop. Many different semiconductor materials have been reported in literature for diode temperature sensors.

If the diode current is held constant, we can see that the diode voltage decreases as the temperature is increased. For a silicon diode, this change is about −2mV/◦C. The diode voltage under a constant current condition is therefore an indicator of its operating temperature.

Temperature ©	VD (mV)
27	652.122
30	646.819
35	637.935
40	629.073
45	625.173
50	612.255
55	602.319
60	593.566
65	584.396
70	575.411
75	566.407
80	557.388
85	548.353
90	559.302
95	550.236
100	521.155
150	429.559
200	336.675
250	242.833
300	149.971

These values are stimulated values, done in Multisim software.

Here is the Temperature Vs Diode voltage (VD) graph



As the temperature is increasing, the diode voltage is decreasing. This concept is used for making the temperature sensor.

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3. Experimental Setup

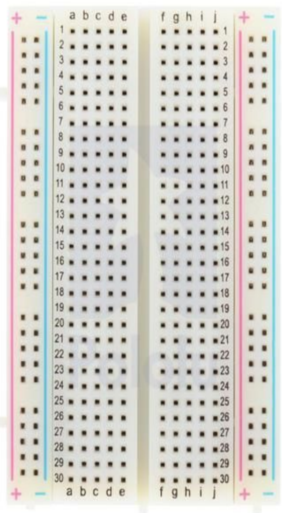
Materials Used

1. Op-Amp 741 IC

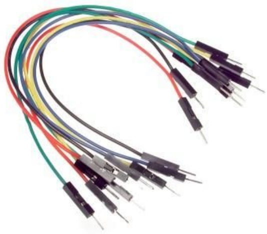
2. Diode 1N4007

3. Thermistor 1 M NTC 10k

4. Breadboard



5. Connecting Wires



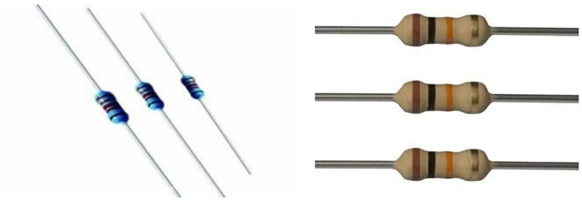
6. Power Supply GWINSTEK GPS3303

7. Multimeter Agilent 34401A

8. Temperature – Air blowing gun

9. Resistors

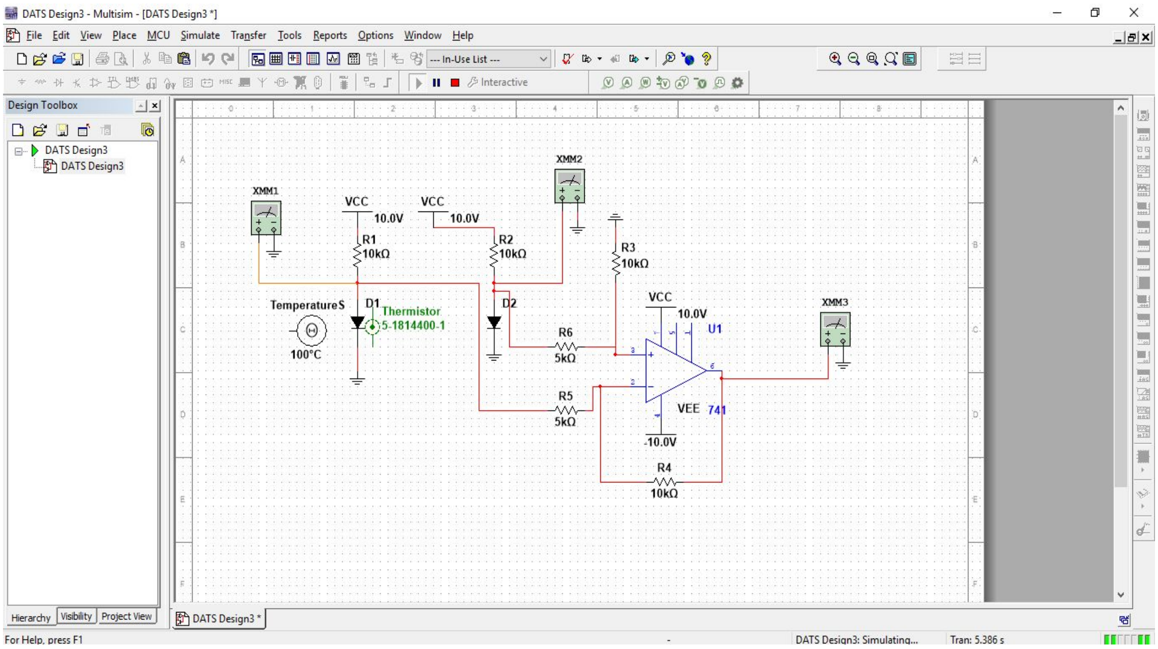
   a. 5k Ohm - 2
   b. 10k Ohm - 4



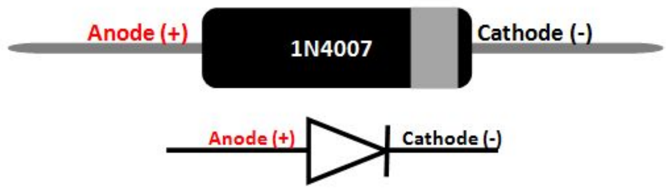
Theory/Procedure

The diode voltage under a constant current condition is therefore an indicator of its operating temperature.

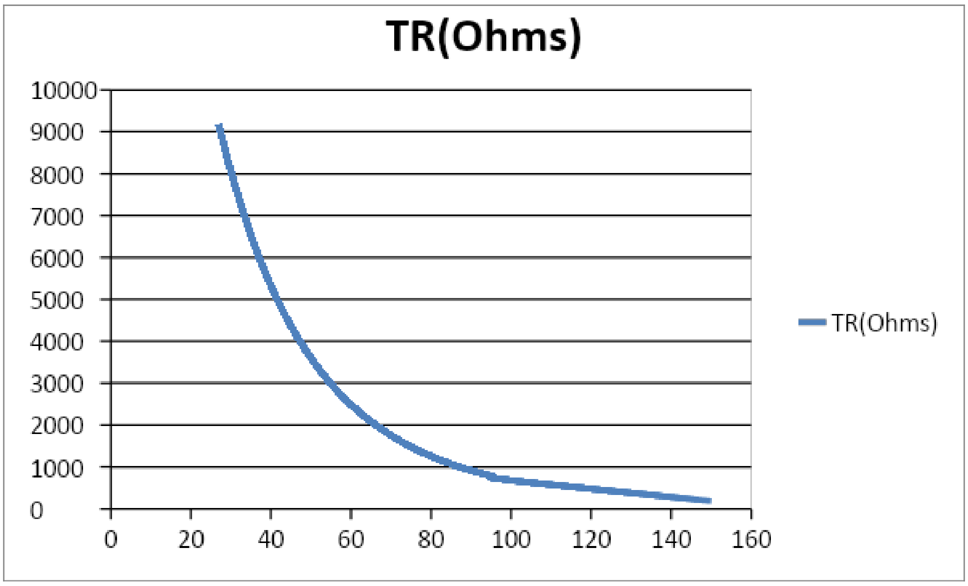
This is the setup for the temperature sensor,



Here, Diode (D1) will be mounted on the chip which got heated up, assume that the chip is at 100 degrees so the diode will be at 100 degrees, but in the setup we provided temperature externally using the gun and did the experiment.



Thermistor is attached to diode to verify the temperature, thermistor is an electrical resistor whose resistance is greatly reduced by heating.



A thermistor is an opposition thermometer, or a resistor whose obstruction is subject to temperature. The term is a blend of "warm" and "resistor". It is made of metallic oxides, squeezed into a globule, circle, or tube shaped shape and afterward exemplified with an impermeable material, for example, epoxy or glass.

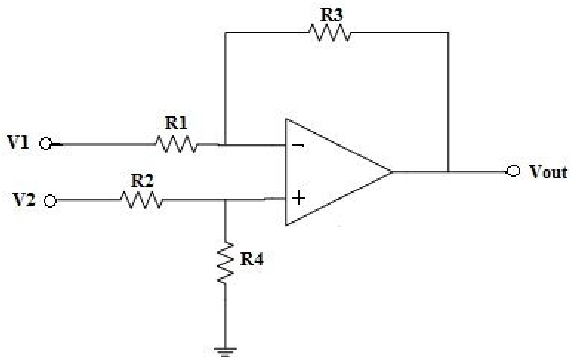
There are two kinds of thermistors: Negative Temperature Coefficient (NTC) and Positive Temperature Coefficient (PTC). With a NTC thermistor, when the temperature builds, obstruction diminishes. Alternately, when temperature diminishes, obstruction increments. This kind of thermistor is utilized the most.

A PTC thermistor works somewhat better. At the point when temperature builds, the obstruction increments, and when temperature diminishes, opposition diminishes. This sort of thermistor is commonly utilized as a wire.

Ordinarily, a thermistor accomplishes high exactness inside a constrained temperature scope of about 50ºC around the objective temperature. This range is reliant on the base opposition.

°C	R Val (Ω)	°C	R Val (Ω)	°C	R Val (Ω)	°C	R Val (Ω)	°C	R Val (Ω)
-80	7,296,874	-30	176,683	20	12,493.70	70	1,751.60	120	388.59
-79	6,677,205	-29	166,091	21	11,943.30	71	1,693.00	121	378.44
-78	6,114,311	-28	156,199	22	11,420.00	72	1,636.63	122	368.59
-77	5,602,677	-27	146,959	23	10,922.70	73	1,582.41	123	359.05
-76	5,137,343	-26	138,322	24	10,449.90	74	1,530.28	124	349.79
-75	4,713,762	-25	130,243	25	10,000.00	75	1,480.12	125	340.82
-74	4,327,977	-24	122,687	26	9,572.00	76	1,431.87	126	332.11
-73	3,966,352	-23	115,613	27	9,164.70	77	1,385.37	127	323.67
-72	3,655,631	-22	108,991	28	8,777.00	78	1,340.68	128	315.48
-71	3,362,963	-21	102,787	29	8,407.70	79	1,297.64	129	307.53
-70	3,095,611	-20	96,974	30	8,056.00	80	1,256.17	130	299.82
-69	2,851,363	-19	91,525	31	7,720.90	81	1,216.23	131	292.34
-68	2,627,981	-18	86,415	32	7,401.70	82	1,177.75	132	285.08
-67	2,423,519	-17	81,621	33	7,097.20	83	1,140.71	133	278.03
-66	2,236,398	-16	77,121	34	6,807.00	84	1,104.99	134	271.19
-65	2,064,919	-15	72,895	35	6,530.10	85	1,070.58	135	264.54
-64	1,907,728	-14	68,927	36	6,266.10	86	1,037.40	136	258.09
-63	1,763,539	-13	65,198	37	6,014.20	87	1,005.40	137	251.82
-62	1,631,173	-12	61,693	38	5,773.70	88	974.56	138	245.74
-61	1,509,639	-11	58,397	39	5,544.10	89	944.81	139	239.82
-60	1,397,935	-10	55,298	40	5,324.90	90	916.11	140	234.08
-59	1,295,239	-9	52,380	41	5,115.60	91	888.41	141	228.50
-58	1,200,732	-8	49,633	42	4,915.50	92	861.70	142	223.08
-57	1,113,744	-7	47,047	43	4,724.30	93	835.93	143	217.80
-56	1,033,619	-6	44,610	44	4,541.60	94	811.03	144	212.68
-55	959,789	-5	42,314.60	45	4,366.90	95	786.99	145	207.70
-54	891,689	-4	40,149.50	46	4,199.90	96	763.79	146	202.86
-53	828,865	-3	38,108.50	47	4,040.10	97	741.38	147	198.15
-52	770,880	-2	36,182.80	48	3,887.20	98	719.74	148	193.57
-51	717,310	-1	34,366.10	49	3,741.10	99	698.82	149	189.12
-50	667,828	0	32,650.80	50	3,601.00	100	678.63	150	184.79
-49	622,055	1	31,030.40	51	3,466.90	101	659.10		
-48	579,718	2	29,500.10	52	3,338.60	102	640.23		
-47	540,530	3	28,054.20	53	3,215.60	103	622.00		
-46	504,230	4	26,687.60	54	3,097.90	104	604.36		
-45	470,609	5	25,395.50	55	2,985.10	105	587.31		
-44	439,445	6	24,172.70	56	2,876.90	106	570.82		
-43	410,532	7	23,016.00	57	2,773.20	107	554.86		
-42	383,712	8	21,921.70	58	2,673.90	108	539.44		
-41	358,806	9	20,885.20	59	2,578.50	109	524.51		
-40	335,671	10	19,903.50	60	2,487.10	110	510.06		
-39	314,179	11	18,973.60	61	2,399.40	111	496.08		
-38	294,193	12	18,092.60	62	2,315.20	112	482.55		
-37	275,605	13	17,257.40	63	2,234.70	113	469.45		
-36	258,307	14	16,465.10	64	2,156.70	114	456.76		
-35	242,195	15	15,714.00	65	2,082.30	115	444.48		
-34	227,196	16	15,001.20	66	2,010.80	116	432.58		
-33	213,219	17	14,324.60	67	1,942.10	117	421.06		
-32	200,184	18	13,682.60	68	1,876.00	118	409.90		
-31	188,026	19	13,052.80	69	1,812.60	119	399.08		

In the setup, Diode (D2) is the reference one, this diode is at room temperature.
Power Supply GW INSTEK GPS3303 is used to provide the required voltage supply.
VD1 is the voltage across the diode D1 and VD2 is the voltage across diode D2.
VD1 and VD2 are given as input to differential amplifier.
VD1=V1 and VD2 =V2,



The difference amplifier is a combination of both inverting and non-inverting amplifiers. If the non-inverting terminal is connected to ground, the circuit operates as an inverting amplifier and the input signal V_1 is amplified by – (R_3 / R_1). Similarly, if the inverting input terminal is connected to ground, the circuit behaves as a non-inverting amplifier. With the inverting input terminal grounded, R_3 and R_1 function as the feedback components of a non-inverting amplifier.

Input V_2 is potentially divided across resistors R_2 and R_4 to give V_{R4}, and then V_{R4} is amplified by $(R_3 + R_1) / R_1$.

With $V_2 = 0$,

$$V_{O1} = -(R_3 / R_1) * V_1$$

With $V_1 = 0$,

$$V_{R4} = \{R_4/(R_2+R_4)\}*V_2$$

and

$$V_{O2} = \{(R_1+R_3)/R_1\}*V_{R4}$$

Therefore,

$$V_{O2} = \{(R_1 + R_3) / R_1\} * \{R_4 / (R_2 + R_4) \} * V_2$$

If the input resistances are chosen such that, $R_2 = R_1$ and $R_4 = R_3$, then

$$V_{O2} = \{R3 / R_1\} * V_2$$

Now, according to the superposition principle if both the input signals V_1 and V_2 are present, then the output voltage is

$$V_O = V_{O1} + V_{O2}$$
$$= \{-(R_3 / R_1) * V_1\} + \{R3 / R_1\} * V_2$$

Which results in,

$$V_O = (R_3 / R_1) * \{V_2 – V_1\}$$

When the resistors R_3 and R_1 are of the same value, the output is the direct difference of the input voltages applied. By selecting R_3 greater than R_1, the output can be made an amplified version of the difference of the input voltages.

So here, R1= 5k Ohms
R2= 10k Ohms
R3= 10k Ohms
R4= 5k Ohms

$$\text{Gain (Av)} = (R_3 / R_1) = 2$$

When both the diodes are at room temperature i.e. 27 degrees the differential amplifier output should be zero,

$V_O = (10 / 5) * \{VD1 – VD2\}$ [VD1=VD2 at room temperature]

$V_O = 0$, but due to input offset voltage we get some small output voltage.

Pin No's: V1(VD1)= 2
V2(VD2)= 3
Vo = 6

Now, by changing the temperature at diode D1(using the temperature gun) we performed the experiment.

4. Timeline of activities

a. First Week

i. Revised concepts of Operational Amplifiers.

b. Second Week

i. NI Multisim (software) working.

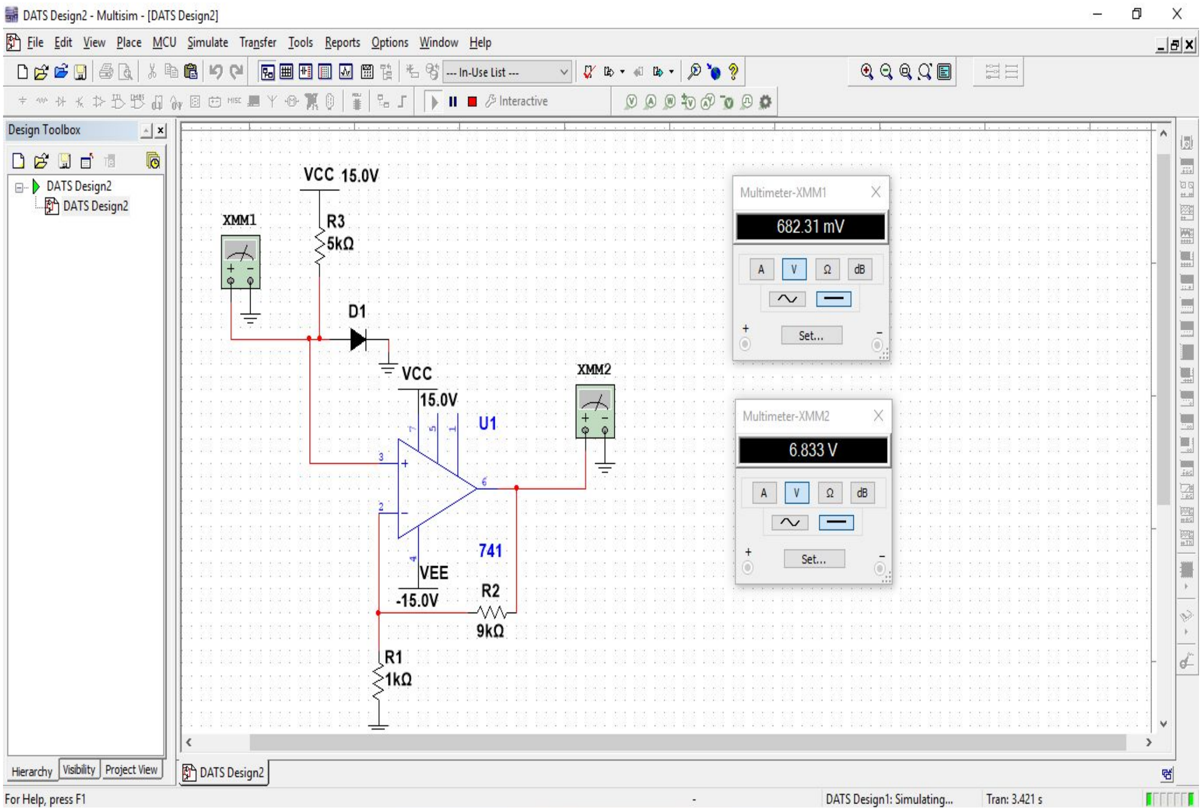
ii. Stimulations of Operational Amplifiers
- Band-pass filter
- Notch filter

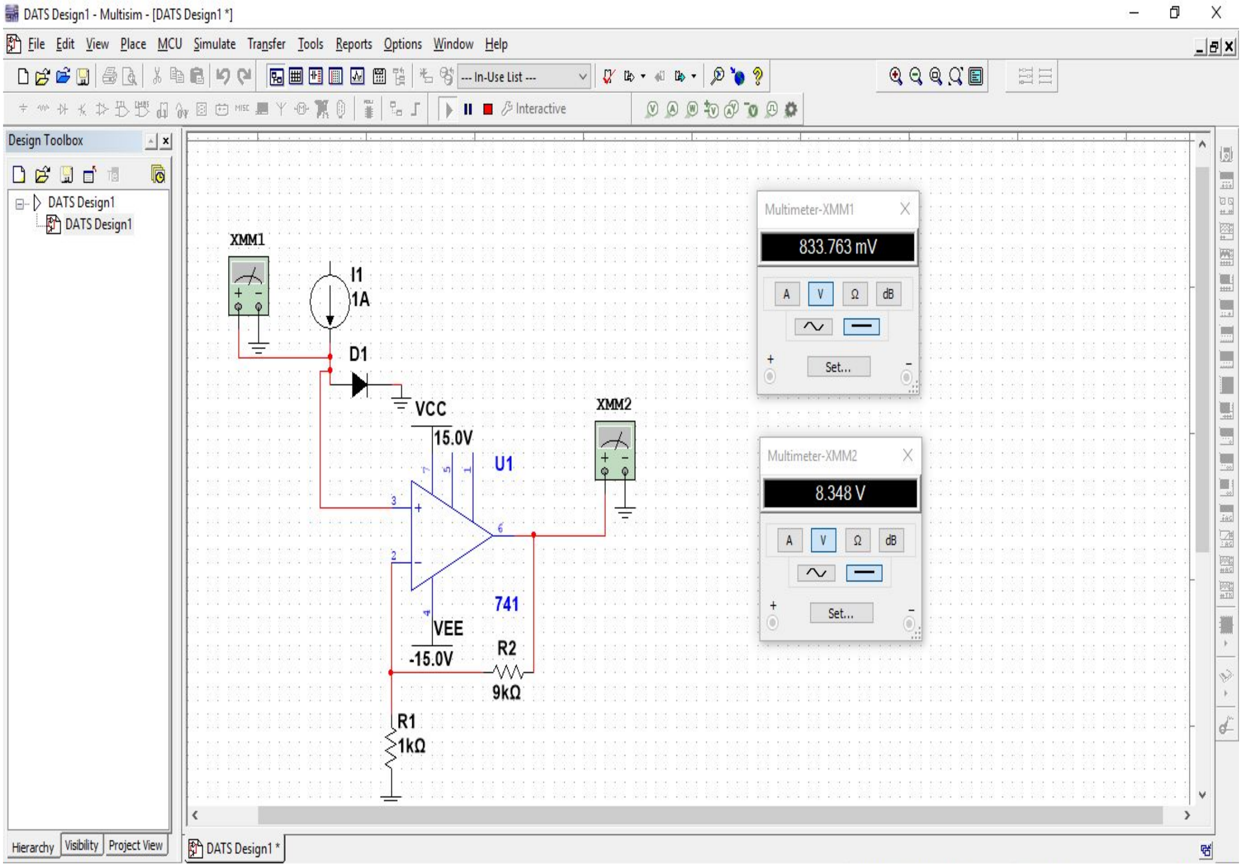
c. Third Week and Fourth week

i. Revised concepts of Diode characteristics.
ii. Prepared mid-term synopsis.
iii. Mentor Verification on 12-June 2019.

d. Fifth week

i. Designing/ Modelling of temperature sensor.
ii. Used NI Multisim for stimulation of the design.





iii. Completed the minor tasks given on daily basis

e. Sixth week

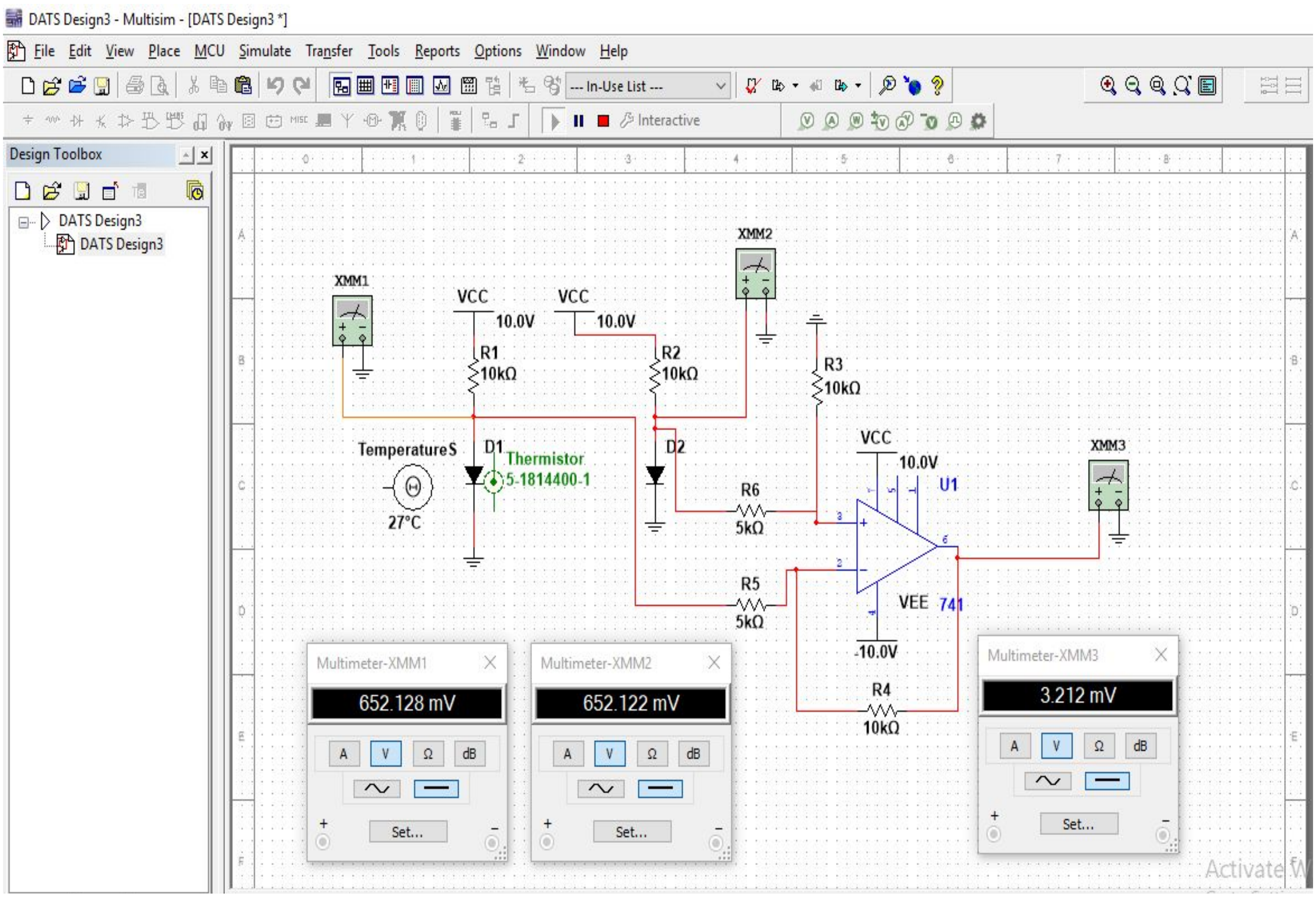
i. Hardware Implementation and analysis.

5. Results and illustrations

Stimulated results,

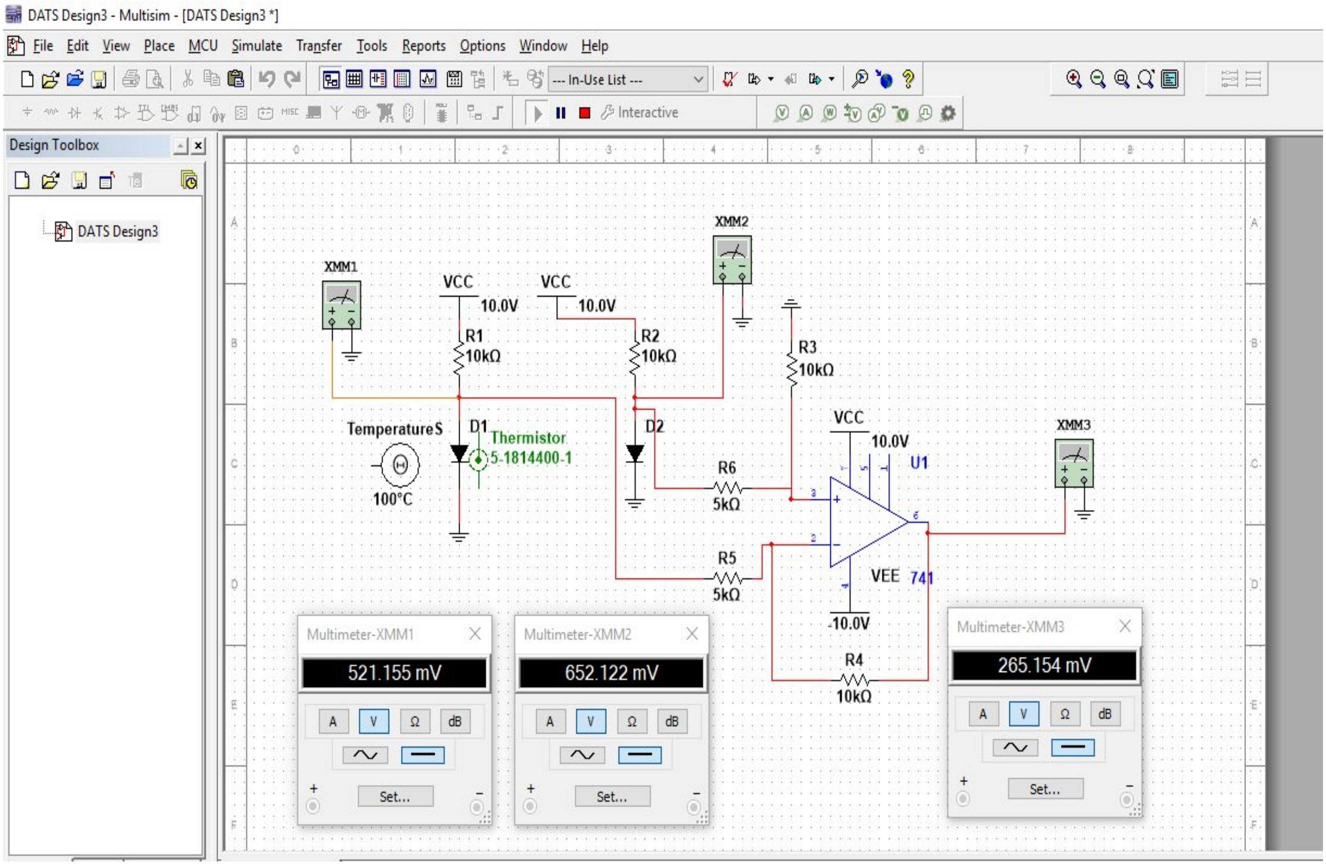
- Diode (D1) will be mounted on the chip which got heated up and D2 is the reference diode which is always at room temperature.
- VD1 is the voltage across diode D1
- VD2 is the voltage across diode D2
- Vo is the differential output with gain 2.

When D1 is at room temperature degrees,
VD1= 652.128 mV
VD2= 652.122 mV
Vo= 3.212 mV



** We are getting 3.212 mV which is more than the differential output in theoretical, because of noise.

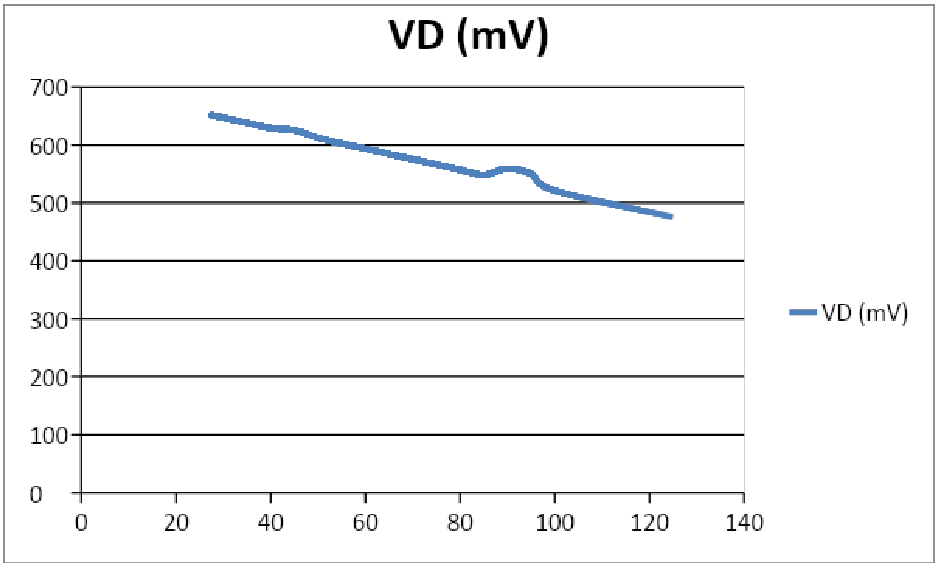
When D1 is at 100 degrees,
VD1= 521.155 mV
VD2= 652.122 mV
Vo= 265.154 mV



** We are getting 265.154 mV which is more than the differential output in theoretical, because of noise.

Here is the simulated result,
Where, VD2 will be 652.128 as it is in room temperature (reference).
T_R is the thermistor resistance in ohms.

Temperature ©	VD1 (mV)	Vo(mV)	T_R(ohms)
27	652.122	3.212	9164
30	646.819	13.8	8056
35	637.935	31.55	6530.1
40	629.073	49.321	5324.9
45	625.173	67.121	4366.9
50	612.255	84.957	3601
55	602.319	112.829	2985.1
60	593.566	120.734	2487.1
65	584.396	138.674	2082.3
70	575.411	156.646	1751.6
75	566.407	174.652	1480.12
80	557.388	192.69	1256.17
85	548.353	210.756	1070.58
90	559.302	228.86	916.11
95	550.236	246.992	786.99
100	521.155	265.154	678.63
125	475.559	366.343	340.82

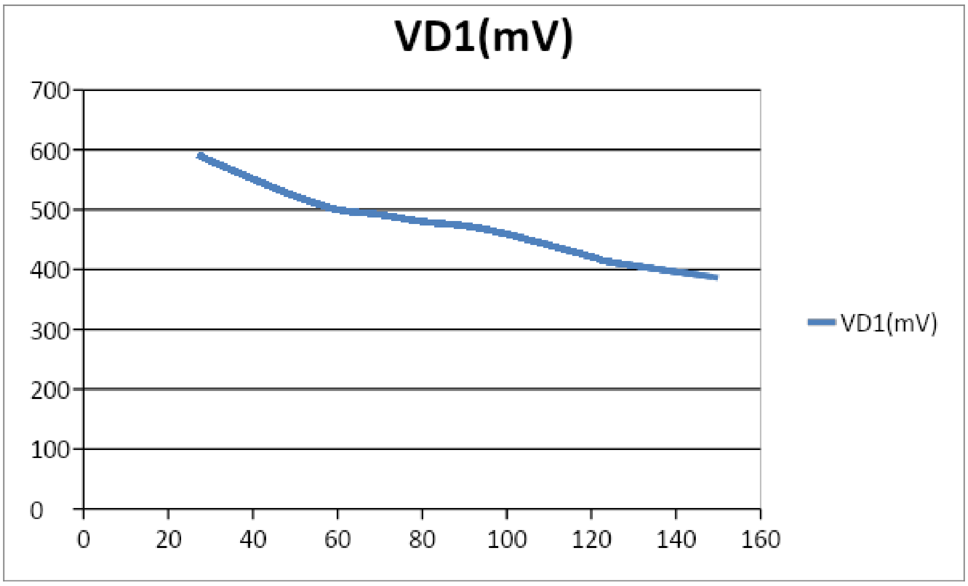


Here is the practical result,

Where, VD2 will be 591.91 mV as it is in room temperature (reference).

T_R is the thermistor resistance in ohms.

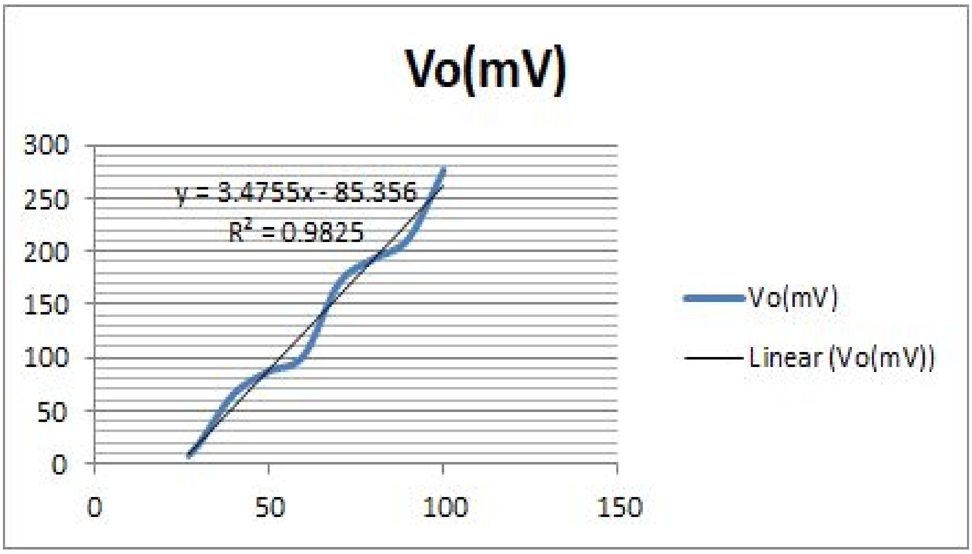
Temperature ©	VD1(mV)	Vo(mV)	TR(ohms)
27	592.16	7.9	9281
30	518.73	19	8127
40	551.21	66	5299
50	522.47	87	3517
60	500	102	2021
70	491.69	170	1719
80	480	193	1140
90	473	212	967
100	459	276	628
120	421.36	324.66	396.12
125	411.89	351.49	351.29
150	386.19	424.51	212.58



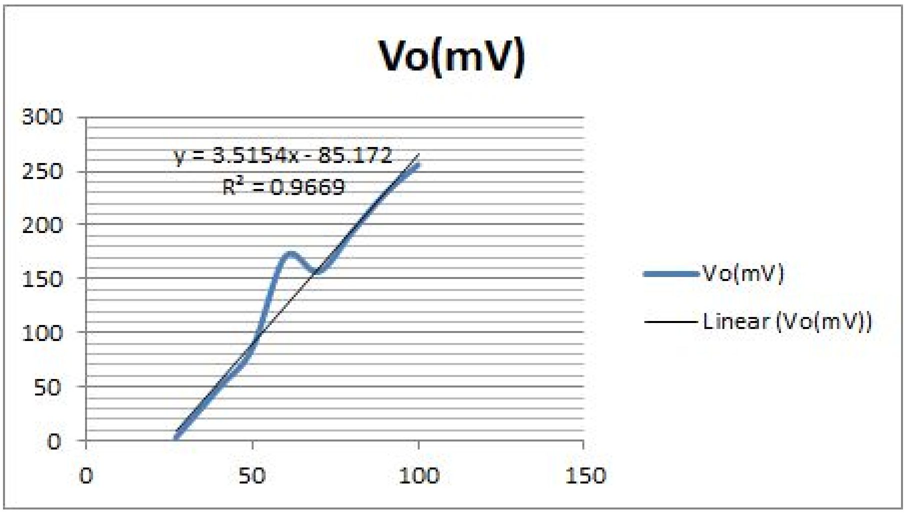
Here is the comparison on practical and stimulated work

	Practical			Stimulated		
Temperature ©	VD1(mV)	Vo(mV)	TR(ohms)	VD1(mV)	Vo(mV)	TR(ohms)
27	592.16	7.9	9281.21	652.122	3.212	9164.7
30	518.73	19.23	8127.67	646.819	13.8	8056
40	551.21	66.48	5299.36	629.073	49.321	5324.9
50	522.47	87.91	3517.2	612.255	84.957	3601
60	500	102.56	2021.57	593.366	170.734	2487.1
70	491.69	170	1719.01	575.41	156.646	1751.6
80	480	193.35	1140	557.388	192.699	1256.17
90	473	212.27	967.66	593.301	228.86	916.11
100	459	276.88	628.94	521.155	256.154	678.63

Temperature Vs Vo {Practical}



Temperature Vs Vo {Stimulated}



Sensor Equation

The sensor equation can be represented as

Output = Input x Slope + Offset

So, for the temperature sensor we made, the sensor equation is

Vo = T x Slope + Offset

Vo = T x 3.4755 - 85.356

Vo = Output
T = Input

RESULTS

- Temperature sensor using diode.
- Low cost.
- Less hardware implementation.

CONCLUSIONS

This report gives a brief account of temperature sensing techniques and the reasons for the widespread use of silicon diodes as temperature sensors. The analytical equations that govern behaviour of silicon diodes when operated in constant current and constant voltage mode have been briefly discussed. The characteristic of a semiconductor junction under reverse-biased conditions and the reverse current flow is directly proportional to the temperature of the silicon. As a result, once biased properly, any inexpensive diode can generate a reverse voltage proportional to its temperature. Thus, silicon diodes can be used as temperature sensors.

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