$= (11)(10\ mV) + 10 \times 10^3 \times 50 \times 10^{-9}$

$= 110 mV + 500 \times 10^{-6}$

$= 110 mV + 0.5 \times 10^{-3}$

$= 110.5 mV$

Thermal drift :

→ Bias current, offset current, and offset voltage change with temperature.

→ A circuit carefully nulled at $25°c$ may not remain so when the temperature rises to $35°c$. This is called drift.

→ Often offset current drift is expressed in $nA/°c$ and offset voltage drift in $mV/°c$. These indicate the change in offset for each degree celsius change in temperature.

Techniques used to minimize the drift

→ Carefully printed circuit board (PCB) must be used keep op-amps away from source of heat.

→ Forced air cooling may be used to stabilize the ambient temperature.

11Q: A non-inverting amplifier with a gain 100 is nulled at $25°C$. What will happen to output voltage if the temperature rise to $50°c$ for an offset voltage drift of $0.15\ mV/°c$.

Ans: Input offset voltage due to temperature rise

$= 0.15\ mV/°c\ (50°c - 25°c) = 3.75\ mV.$

→ The output voltage will change by $V_o = V_{os} \cdot A_{CL}$

$= 3.75\ (100) = 375\ mV.$

12Q: In an inverting amplifier $R_1 = 1k\Omega$, $R_f = 100k$

The op-amp has the following specifications:

$$\frac{\Delta V_{ios}}{\Delta T} = 30\ \mu V/^\circ C \ \text{max.}$$

$$\frac{\Delta I_{os}}{\Delta T} = 0.3\ nA/^\circ C \ \text{max.}$$

Assume that the amplifier is nulled at $25^\circ C$. Calculate the value of the error voltage and the output voltage V_o at $35^\circ C$, if (i). $V_i = 1$ mV dc (ii) $V_i = 5$ mV dc.

Ans: Input offset voltage due to temperature rise $= 30\ \mu V/^\circ C\ (35$

$= 300\ \mu V$

$= 0.3$ mV

Input offset current due to temperature rise =

$0.3\ nA/^\circ C\ (35-25)$

$= 3\ nA$

$$V_{OT} = \left(1 + \frac{R_f}{R_1}\right) V_{ios} + R_f I_{os}$$

$$= \left(1 + \frac{100k\Omega}{1k\Omega}\right) \times 0.3mV + 100k\Omega \times 3nA$$

$$= (101) \times 0.3\,mV + 300\ \mu V$$

$$= 30.3\ mV + 0.3\ mV$$

$= 30.6$ mV = maximum output offset voltage.

(i) For $V_{in} = 1$ mV dc, the output voltage

$$= V_o = \left(-\frac{R_F}{R_1}\right) V_{in} \pm V_{OT}$$

$= \left(\frac{-100k\Omega}{1k\Omega}\right) 1mV \pm 30.6\,mV$

$= -100\,mV \pm 30.6\,mV$

$= -130.6\,mV$ or $-69.4\,mV$

ii) $V_i = 5\,mV$ dc, the output voltage $= V_o$

$= \left(\frac{-R_f}{R_1}\right) V_i \pm V_{OT}$

$= \left(\frac{-100k\Omega}{1k\Omega}\right)(5mV) \pm 30.6\,mV$

$= -500\,mV \pm 30.6\,mV$

$= -530.6\,mV$ or $-469.4\,mV$.

13Q: Repeat the problem (12) for non-inverting amplifier.

Ans: $V_{OT} = 30.6\,mV$

(i) For $V_{in} = 1\,mV$ dc, the output voltage =

$V_o = \left(1 + \frac{R_F}{R_1}\right) \cdot V_i \pm V_{OT}$

$= \left(1 + \frac{100k\Omega}{1k\Omega}\right) \cdot 1\,mV \pm 30.6\,mV$

$= 101\,mV \pm 30.6\,mV = +131.6\,mV$ or $+70.4\,mV$

(ii) For $V_i = 5\,mV$ dc, the output voltage $= V_o$

$= \left(1 + \frac{R_F}{R_1}\right) V_i \pm V_{OT}$

$= 101 \cdot (5\,mV) \pm 30.6\,mV = 505\,mV \pm 30.6\,mV$

$= +535.6\,mV$ or $+474.4\,mV$

Infinite Slew-rate: The slew rate is defined as the maximum rate of change of output voltage caused by a step input voltage. An ideal slew rate is infinite. which means that Op-Amp's output voltage should be change instantaneously in respond to input step voltage. It is expressed as

$$S = \frac{dv}{dt}_{max}$$ and measured in Voltage/second.

Usually $V/\mu s$

For Example: A $1V/\mu s$ slew rate means that the output rises or falls by 1 V in one micro second.

There is usually a capacitor within (or) outside an op-amp to prevent oscillation. It is this capacitor which prevents the output voltage from responding immediately to a fast changing input. The rate at which the voltage across the capacitor increases is given by,

$$\frac{dV_c}{dt} = \frac{I}{C}$$, here I is the maximum current furnished by Op-amp to the capacitor C.

This means that to obtaining faster slew rate, Op-amp should have either a higher current or a small compensating capacitor.

For IC741 , $I = 15 \mu A$

So, slew rate $= \left.\frac{dV_c}{dt}\right|_{max} = \frac{I_{max}}{C} = \frac{15 \mu A}{30 PF}$

$= 0.5 V/\mu s.$