Power and Temperature

TIPL 1160
TI Precision Labs – Op Amps

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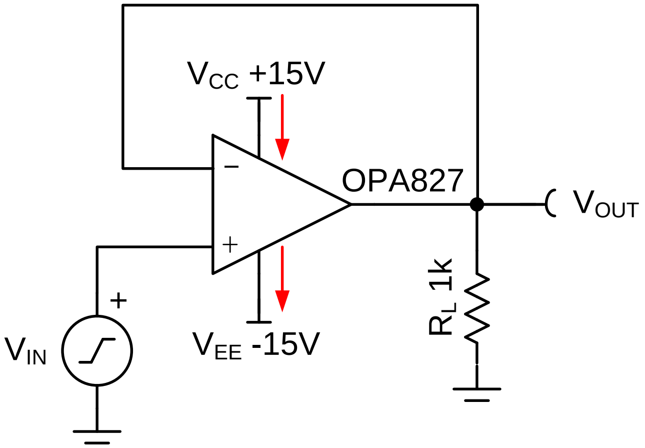
Power Dissipation – Quiescent Current

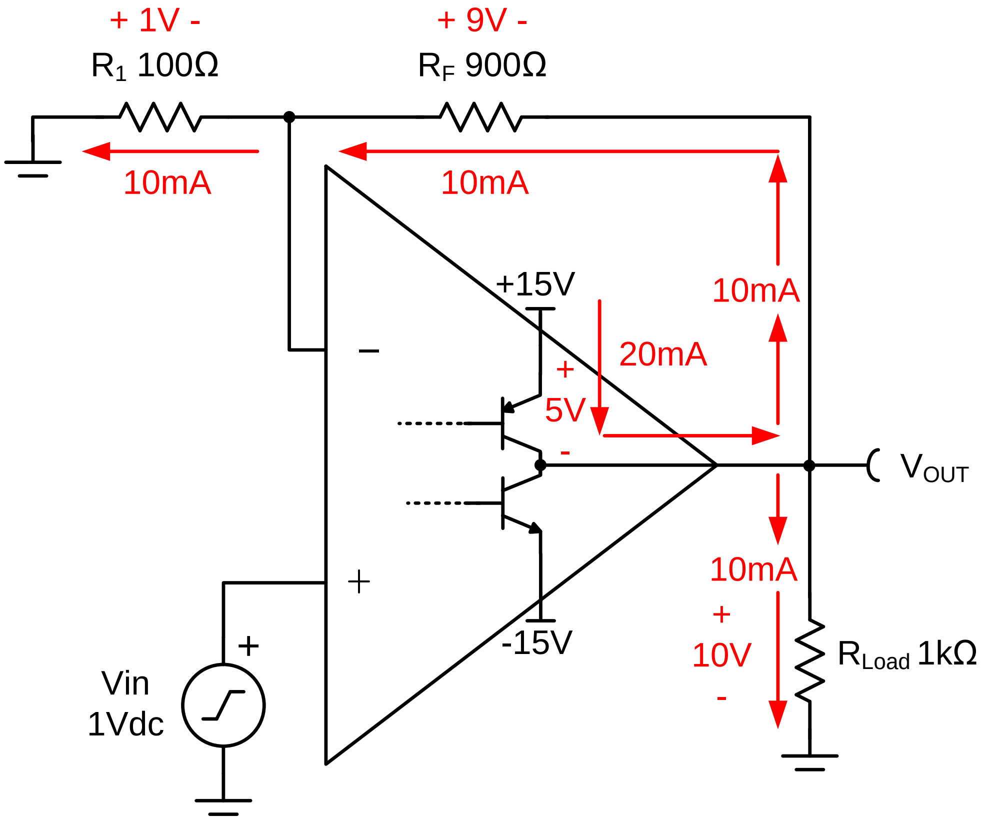
PARAMETER		CONDITIONS	OPA827AI MIN	TYP	MAX	UNIT
POWER SUPPLY						
Specified Voltage	V_S		±4		±18	V
Quiescent Current (per amplifier)	I_Q	I_{OUT} = 0A		4.8	5.2	mA
Over Temperature					**6**	**mA**



P_Q = quiescent power = $I_Q * V_S$
I_Q = quiescent current
V_S = total supply voltage
$V_S = V_{CC} – V_{EE}$ = (15) – (-15V) = **30V**

Example: worst case over temperature
$P_Q = I_Q \cdot V_S$ = (6mA)(30V) = 180mW

Power Dissipation – DC Load



Effective load:

$R_L = R_{Load} \,||\, (R_F + R_1)$

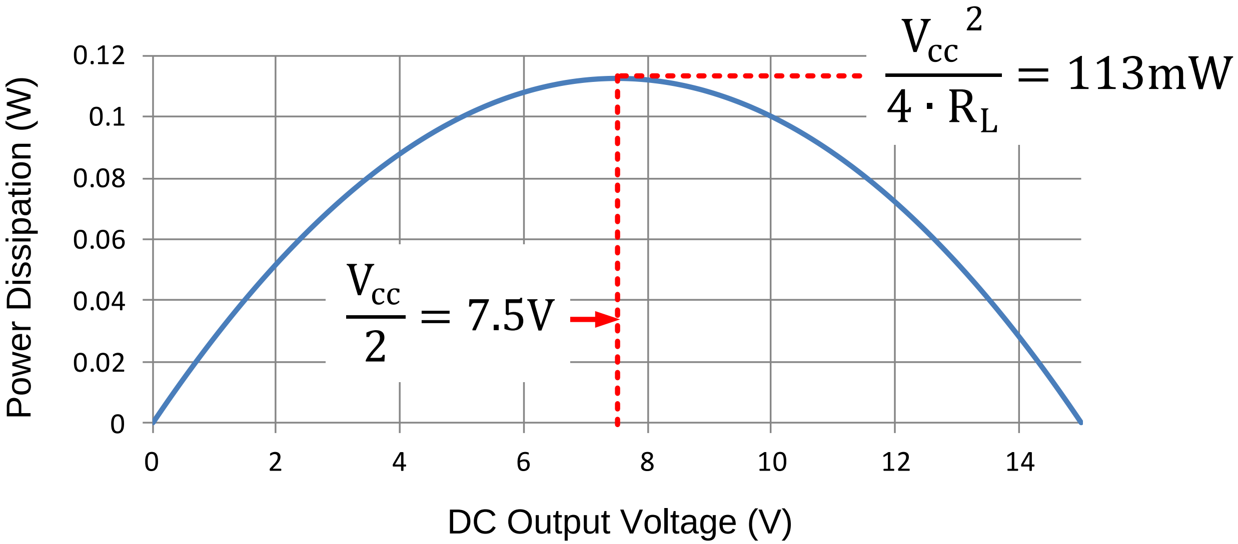
$R_L = (1k\Omega) \,||\, (900\Omega + 100\Omega)$

$\mathbf{R_L = 500\ \Omega}$

Maximum DC Power Dissipation

$$P_{dc} = \frac{V_{out}}{R_L}(V_{cc} - V_{out})$$

$$P_{dc\_max} = P_{dc}\left[\frac{V_{cc}}{2}\right] = \frac{V_{cc}{}^2}{4 \cdot R_L}$$



Derivation of DC Maximum Power Transfer

$$P_{opa} = (V_{cc} - V_{out}) \cdot \frac{V_{out}}{R_L}$$ (1) Power dissipated in op amp

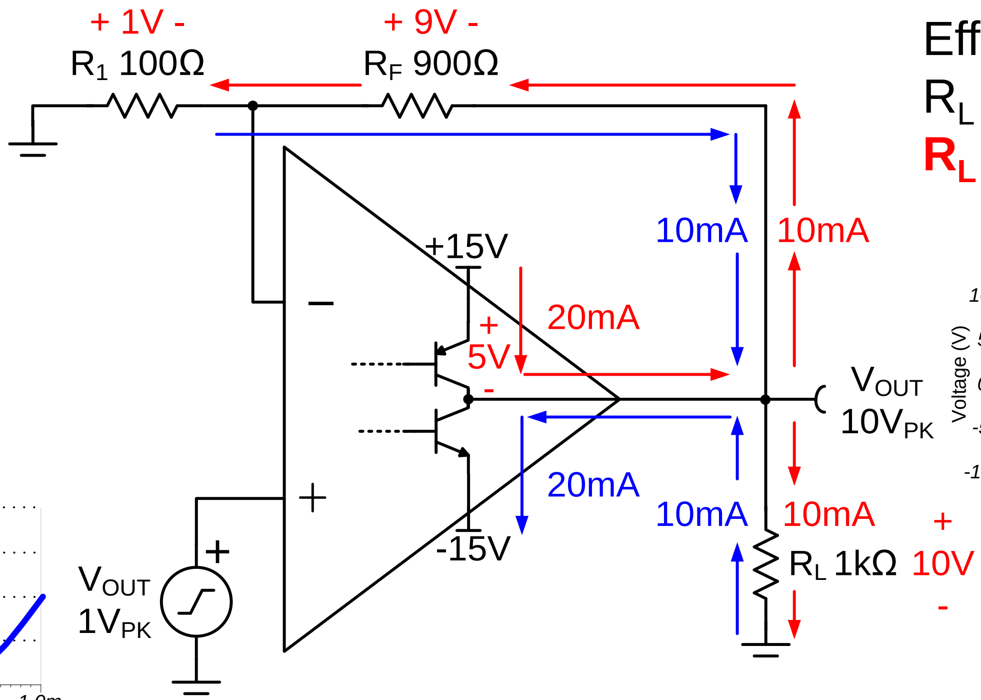
$$P_{opa}(V_{out}) = \frac{V_{out} \cdot V_{cc}}{R_L} - \frac{{V_{out}}^2}{R_L}$$ (2) Dc output voltage

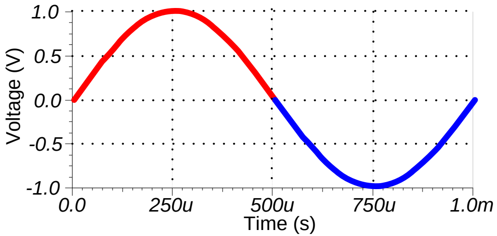
$$\frac{\partial P_{opa}}{\partial V_{out}} = \frac{V_{cc} - 2 \cdot V_{out}}{R_L} = 0$$ (3) Take the partial derivative. Set to zero and solve for maxima.

$$V_{out} = \frac{V_{cc}}{2} \quad \text{when} \quad \frac{\partial P_{opa}}{\partial V_{out}} = 0$$ (4) Solve (3) for value of Vout that yields maximum power

$$P_{dc\_max} = P_{opa}\left(\frac{V_{cc}}{2}\right) = \frac{{V_{cc}}^2}{4 \cdot R_L}$$ (5) Substitute (4) into (2) to determine maximum dc power in Op Amp

Power Dissipation at AC

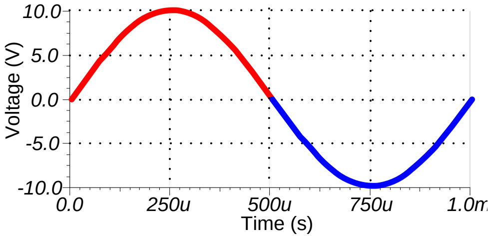




Effective Load:

$R_L = R_{Load} \parallel (R_F + R_1)$

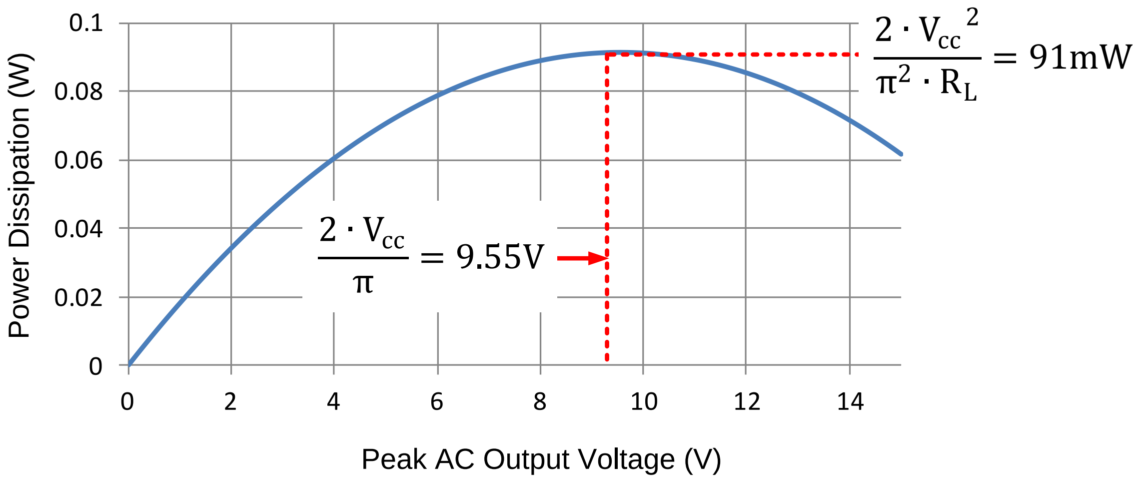
$R_L = 500\ \Omega$



Maximum Average AC Power Dissipation

$$P_{ac\_avg}(V_{outpk}) = \frac{2 \cdot V_{cc} \cdot V_{outpk}}{\pi \cdot R_L} - \frac{{V_{outpk}}^2}{2 \cdot R_L}$$

$$P_{ac\_max\_avg} = P_{opa\_avg}\left[\frac{2 \cdot V_{cc}}{\pi}\right] = \frac{2 \cdot {V_{cc}}^2}{\pi^2 \cdot R_L}$$



Derivation of AC Maximum Power Transfer

$$P_{opa} = (V_{cc} - V_{out}) \cdot \frac{V_{out}}{R_L}$$ (1) Power dissipated in op amp

$$V_{out}(t) = V_{outpk} \cdot \sin(\omega \cdot t)$$ (2) ac sinusoidal wave out

$$P_{ac}(t) = \left(V_{cc} - V_{outpk} \cdot \sin(\omega \cdot t)\right) \cdot \frac{V_{outpk} \cdot \sin(\omega \cdot t)}{R_L}$$ (3) Substitute (2) into (1)

$$P_{ac}(t) = \frac{V_{cc} V_{outpk} \cdot \sin(\omega \cdot t)}{R_L} - \frac{V_{outpk}{}^2 \cdot \sin^2(\omega \cdot t)}{R_L}$$ (4) Power dissipated in op amp as a function of time

$$\omega = \frac{2\pi}{T}$$ (5) Angular frequency as a function of period

$$P_{ac}(t) = \frac{V_{cc} V_{outpk} \cdot \sin(\frac{2\pi}{T} \cdot t)}{R_L} - \frac{V_{outpk}{}^2 \cdot \sin^2(\frac{2\pi}{T} \cdot t)}{R_L}$$ (6) Substitute (5) into (4)

$$P_{ac\_avg} = \frac{1}{T/2} \int_0^{T/2} \left[\frac{V_{cc} V_{outpk} \cdot \sin(\frac{2\pi}{T} \cdot t)}{R_L} - \frac{V_{outpk}{}^2 \cdot \sin^2(\frac{2\pi}{T} \cdot t)}{R_L}\right] dt$$ (7) Find the average power

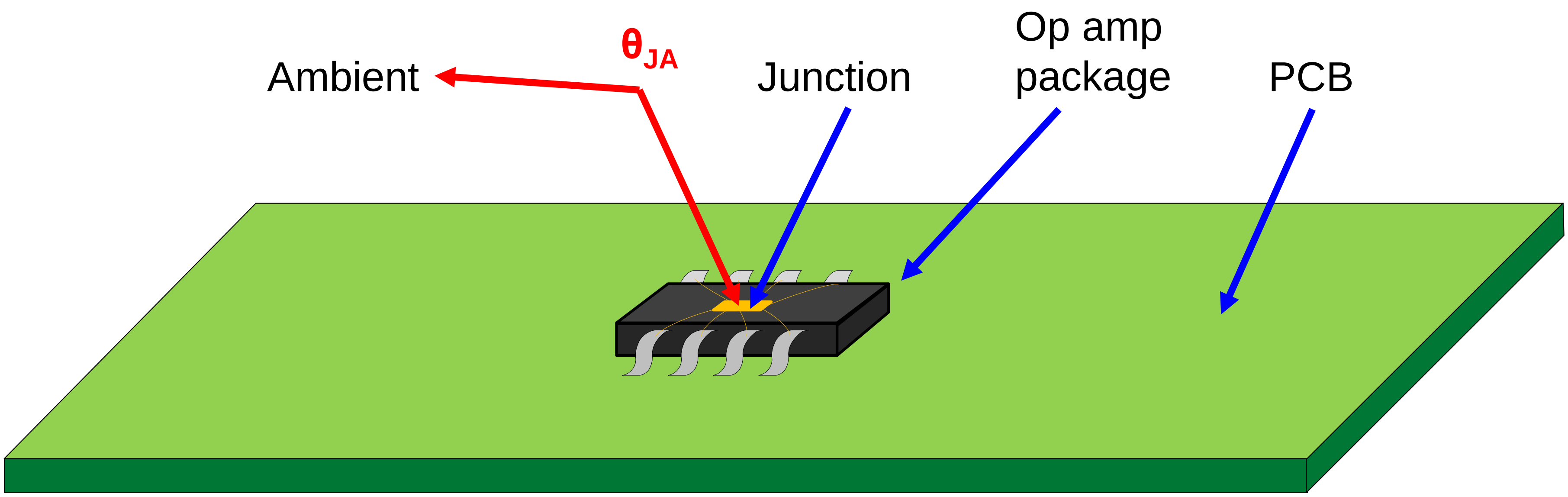
$$P_{ac\_avg}(V_{outpk}) = \frac{2 \cdot V_{cc} \cdot V_{outpk}}{\pi \cdot R_L} - \frac{V_{outpk}{}^2}{2 \cdot R_L}$$ (8) Average power as a function of peak output voltage

$$\frac{\partial P_{opa\_avg}}{\partial V_{outpk}} = \frac{2 \cdot V_{cc}}{\pi \cdot R_L} - \frac{V_{outpk}}{R_L}$$ (9) Take the partial derivative to find maxima. Set to zero and solve for maxima.

$$P_{ac\_max\_avg} = P_{opa\_avg}\left[\frac{2 \cdot V_{cc}}{\pi}\right] = \frac{2 \cdot V_{cc}{}^2}{\pi^2 \cdot R_L}$$ (10) Maximum power and the peak output voltage where max power occurs

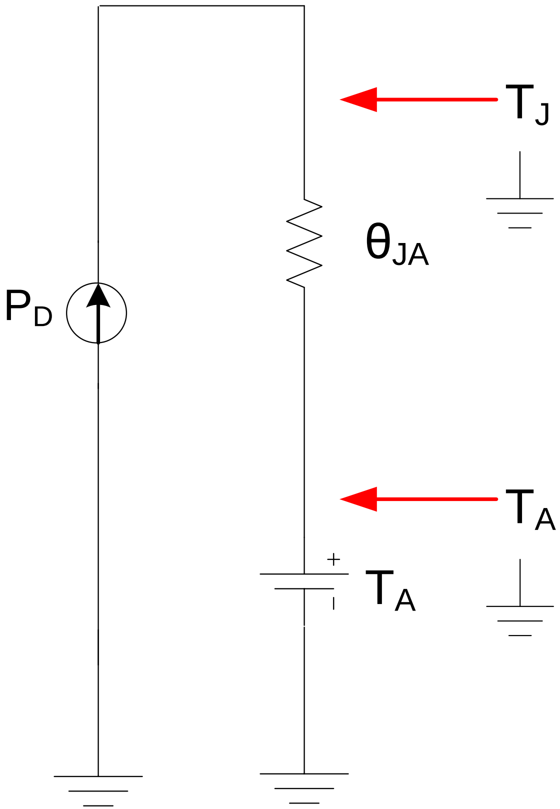
Derivation courtesy of Miro Oljaca

Thermal Device Model – No Heat Sink



θ_{JA} includes the effects of the package and PCB!

Analogous Electrical Model – No Heat Sink



$T_J = (P_D * \Theta_{JA}) + T_A$

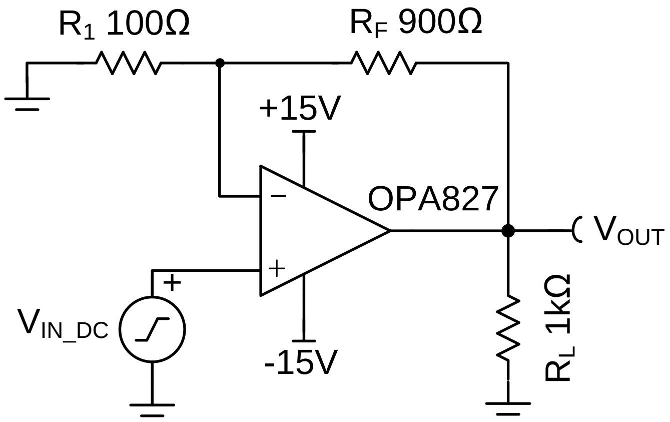
T → voltage

θ → resistance

P → current

Temperature Rise – Maximum DC Load

PARAMETER		CONDITIONS	OPA827AI MIN	OPA827AI TYP	OPA827AI MAX	UNIT
TEMPERATURE RANGE						
Specified Range	T_A		–40		+125	°C
Operating Range	T_A		–55		+150	°C
Thermal Resistance	θ_{JA}					
SO-8, MSOP-8				150		°C/W



$$P_Q = I_Q \cdot V_S = (6\text{mA}) \cdot (30\text{V}) = 180\text{mW}$$

$$P_{dc\_max} = \frac{{V_{cc}}^2}{4 \cdot R_L} = \frac{(15\text{V})^2}{4 \cdot (500\Omega)} = 113\text{mW}$$

$$P_{total} = P_Q + P_{dc\_max} = 180\text{mW} + 113\text{mW} = 293\text{mW}$$

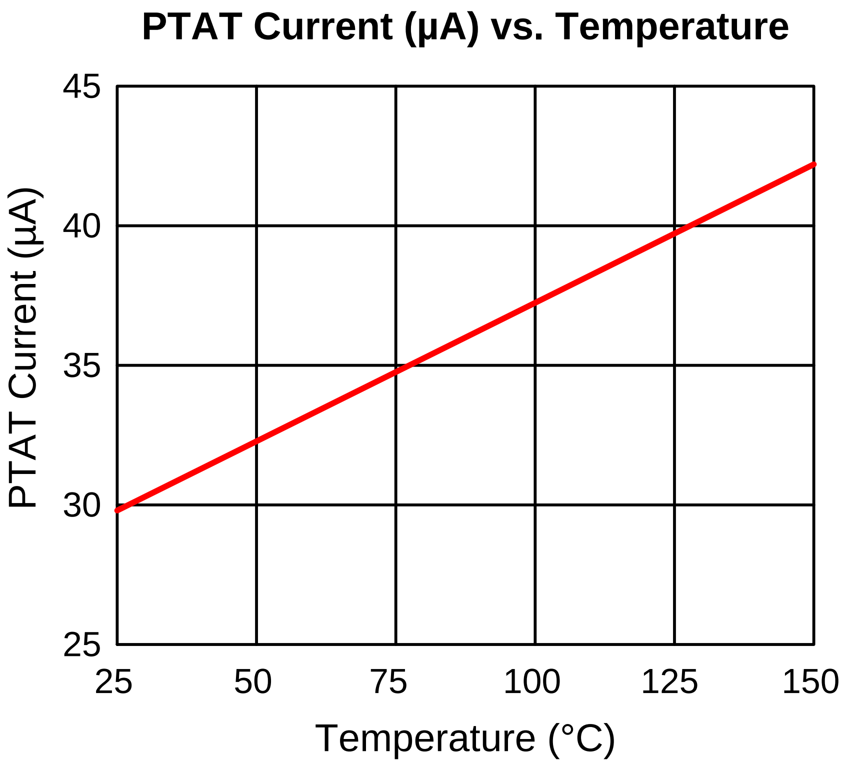
$$T_J = P_{total} \cdot \theta_{JA} + T_A = 293\text{mW} \cdot (150\,°\text{C/W}) + 25°\text{C} = 67.5°\text{C}$$

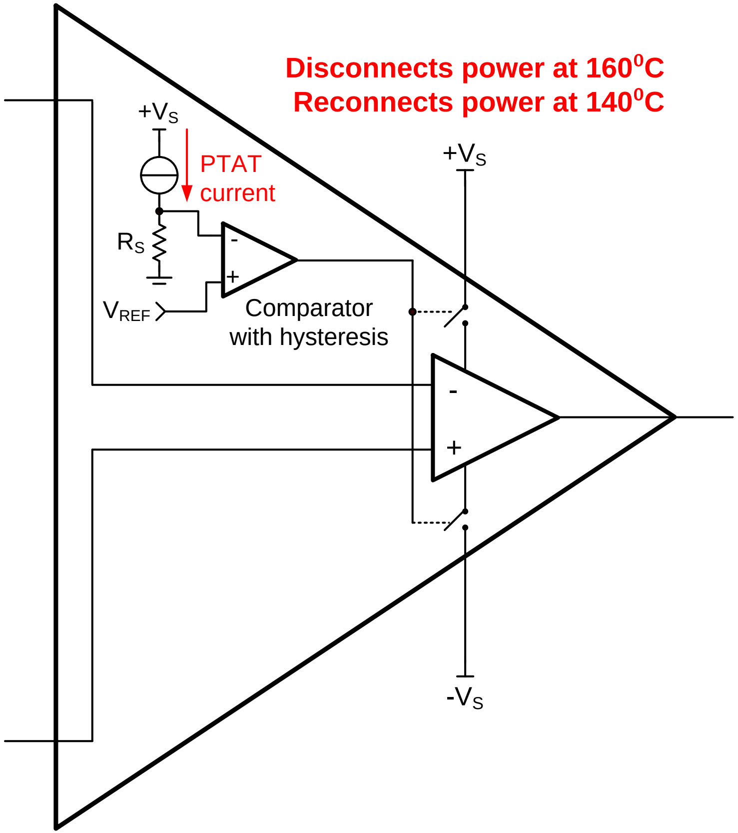
Absolute Maximum Ratings

Over operating free-air temperature range (unless otherwise noted).

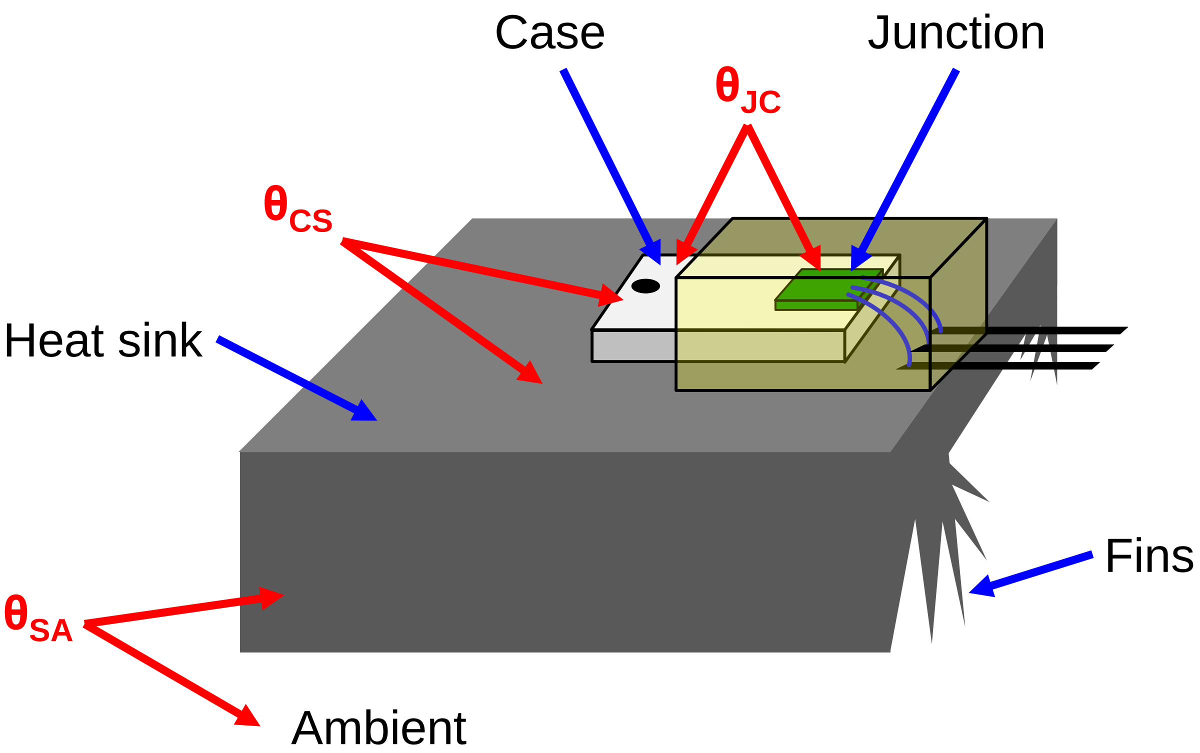
PARAMETER			VALUE	UNIT
Supply Voltage		$V_S = (V+) - (V-)$	40	V
Input Voltage [2]			(V–) – 0.5 to (V+) + 0.5	V
Input Current [2]			±10	mA
Differential Input Voltage			$\pm V_S$	V
Output Short-Circuit [3]			Continuous	
Operating Temperature		T_A	–55 to +150	°C
Storage Temperature		T_A	–65 to +150	°C
Junction Temperature		T_J	+150	°C
ESD Ratings	Human Body Model (HBM)		4000	V
	Charged Device Model (CDM)		1000	V

Thermal Protection

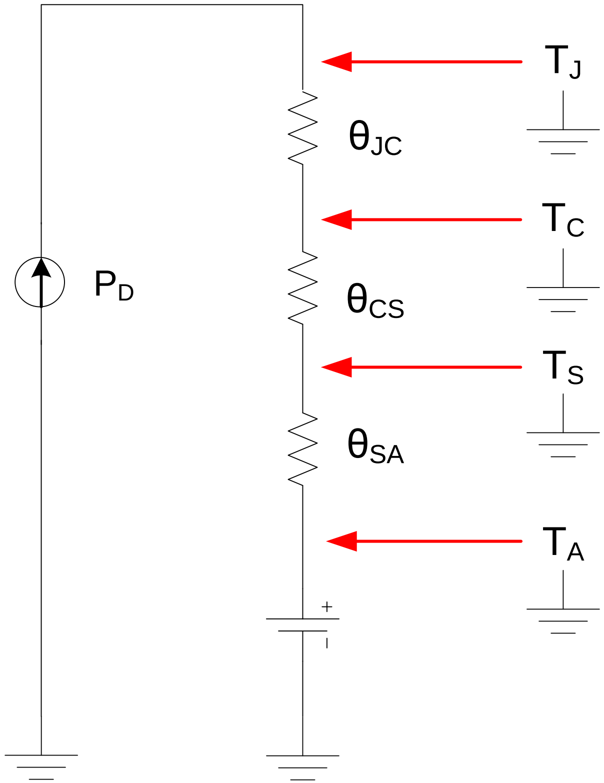




Thermal Model – Device with Heat Sink



Analogous Electrical Model – Device with Heat Sink



$T_J = P_D*(\theta_{JC} + \theta_{CS} + \theta_{SA}) + T_A$

P_D = total power dissipation

T_J = junction temperature

T_C = case temperature

T_S = heat sink temperature

T_A = ambient temperature

Thermal Resistance – Θ_{JC} (Junction to Case)

THERMAL RESISTANCE								
θ_{JC} (Junction-to-Case)[2]	AC Output f > 60Hz		2.5					°C/W
θ_{JC}[2]	DC Output		3					°C/W
θ_{JA} (Junction-to-Ambient)	No Heat Sink		40					°C/W
OPA541AP (Plastic)			40					°C/W

$$T_J = P_D*(\theta_{JC} + \theta_{CS} + \theta_{SA}) + T_A$$

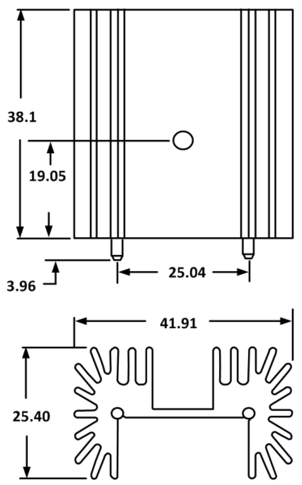
Thermal Resistance – Θ_{CS} (Case to Sink)

Typical Interface Resistances for Various Mounting Methods with a TO-220 (interface area = 1 in^2):

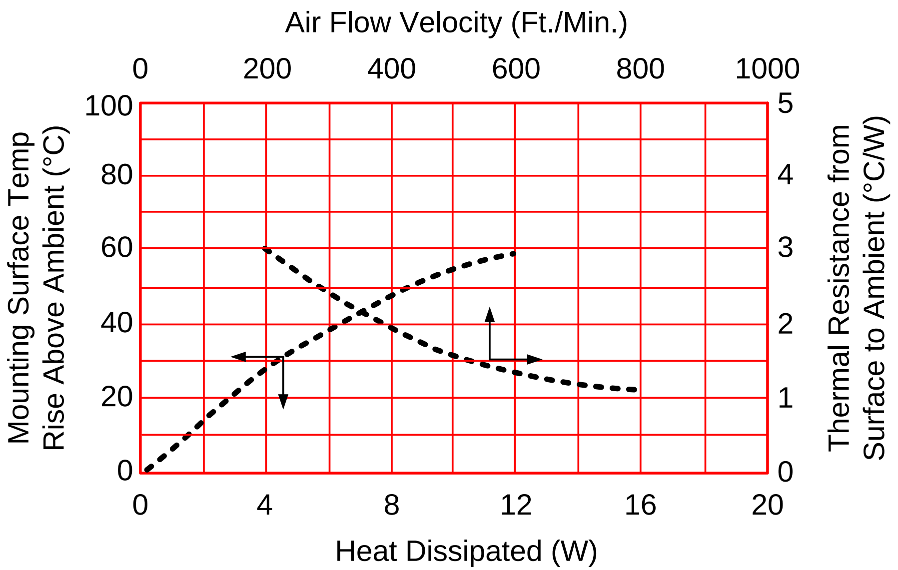
Thermal Joint Compound only (0.001 thick)	θ = 0.056°C/W
Mica (0.005) and Joint Compound (0.002)	**θ = 0.44 °C/W**
Series 177 Beryllium Oxide Wafers (0.062) And joint Compound (0.002)	θ = 0.13 °C/W
DeltaPad™ 173-9 (0.009)	θ = 0.50 °C/W
Dry Mounting (0.001 assumed)	θ = 1.2 °C/W

$$T_J = P_D*(\theta_{JC} + \boldsymbol{\theta_{CS}} + \theta_{SA}) + T_A$$

Thermal Resistance – Θ_{SA} (Sink to Ambient)



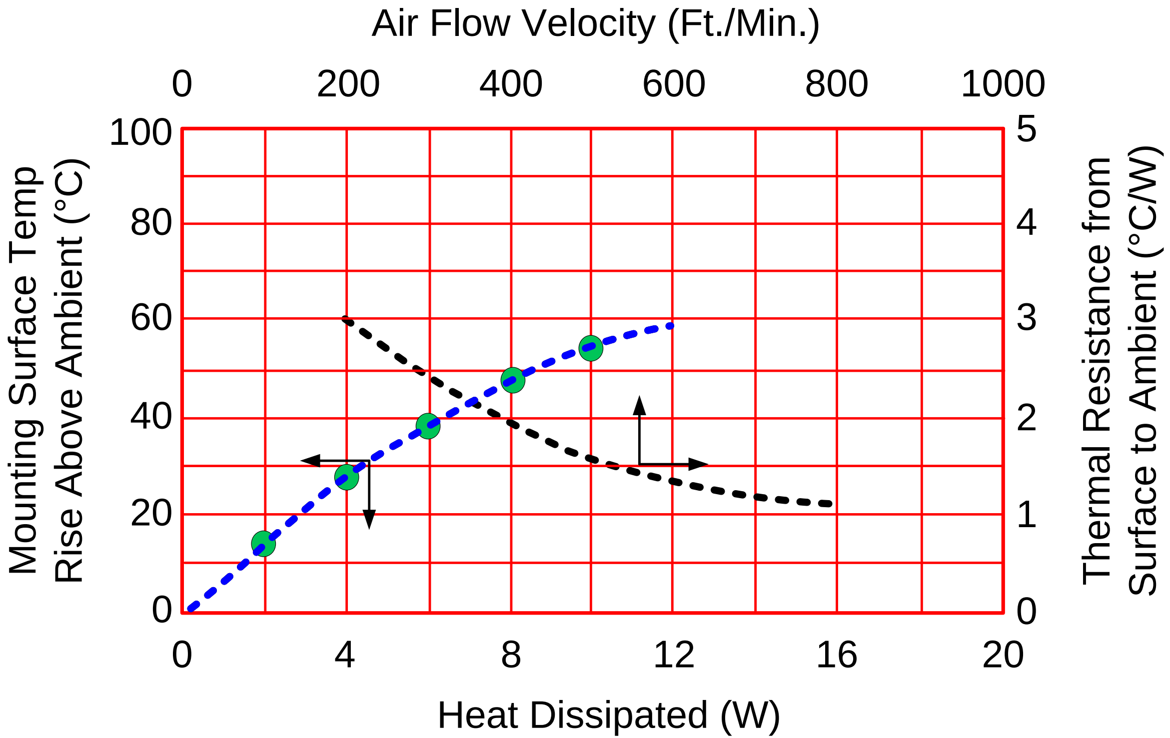
Example: Aavid Thermalloy 6398BG



$$T_J = P_D*(\theta_{JC} + \theta_{CS} + \theta_{SA}) + T_A$$

Thermal Resistance in Natural Convection*

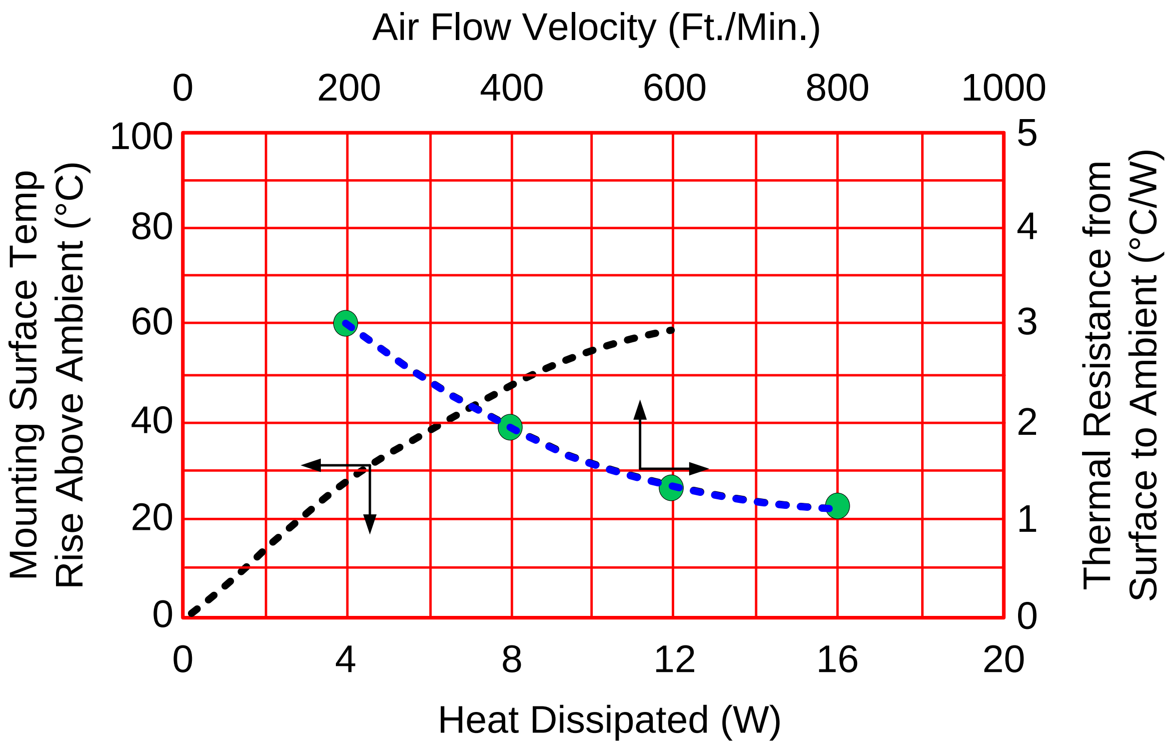
*air flow ≤ 100 ft./min



Device Power (W)	θ_{cs} Thermal Resistance (°C/W)
2	7.5
4	7.0
6	6.33
8	6.0
10	5.5

$$\theta_{SA} = \frac{\Delta T_{mount}}{P_{total}} = \frac{15°C}{2W} = 7.5\,°C/W$$

Thermal Resistance in Forced Airflow



Air Velocity (ft./min)	θ_{cs} Thermal Resistance (°C/W)
200	3
400	2
600	1.8
800	1.1

Example – Calculate Total Power

PARAMETER	CONDITIONS	OPA541AM/AP			UNITS
		MIN	TYP	MAX	
POWER SUPPLY					
Power Supply Voltage, $\pm V_S$	Specified Temperature Range	±10	±30	±35	V
Current, Quiescent			20	25	mA

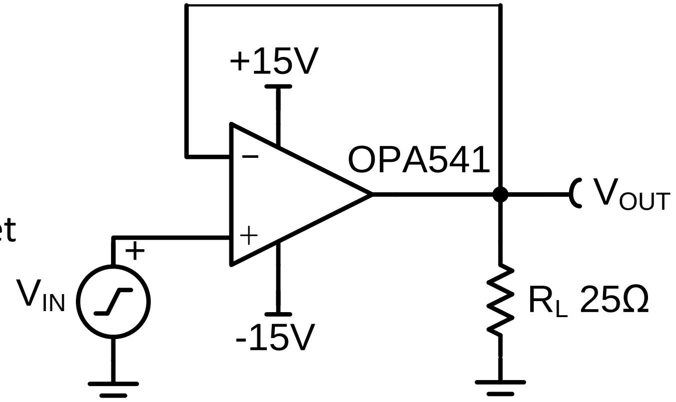
$$P_{dc} = \frac{{V_{cc}}^2}{4 \cdot R_L} = \frac{(15V)^2}{4 \cdot (25\Omega)} = 2.25W$$ Maximum dc Power

$$V_s = V_{cc} - V_{ee} = 15V - (-15V) = 30V$$ Total Supply Voltage

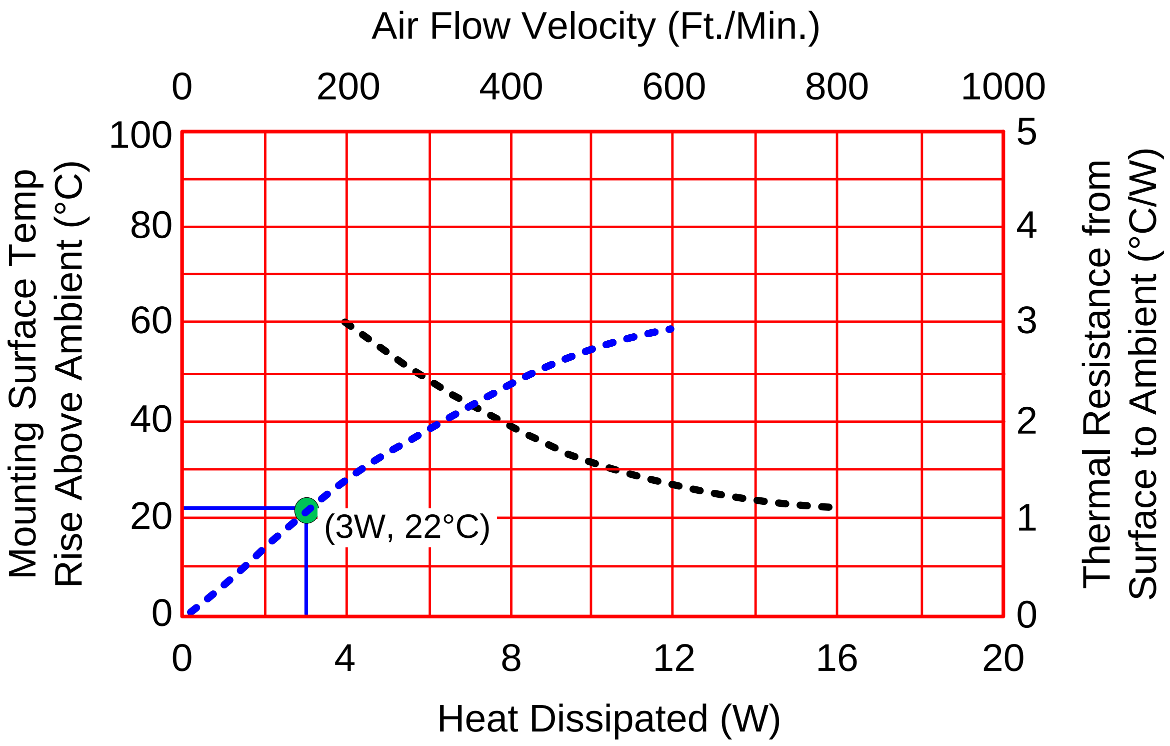
$$I_Q = 25mA$$ From OPA541 Data Sheet

$$P_Q = I_Q \cdot V_s = (25mA) \cdot (30V) = 0.75W$$ Quiescent Power

$$P_{total} = P_{dc} + P_Q = 2.25W + 0.75W = 3W$$ Total Power



Example – Calculate θ_{SA} for Given Power



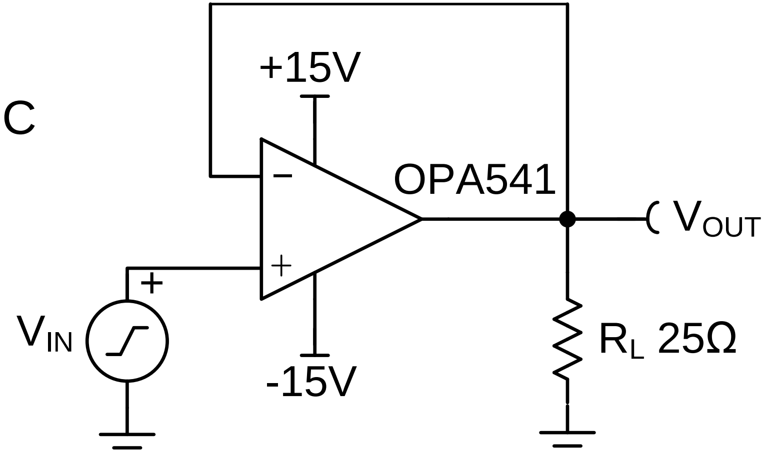
$$P_{total} = 3W$$

$$\theta_{SA} = \frac{\Delta T_{mount}}{P_{total}} = \frac{22℃}{3W} = 7.33\,℃/W$$

Example – Calculate Junction Temperature

θ_{JC} = 3°C/W from OPA541 data sheet (TO-220)
θ_{CS} = 0.44°C/W (Mica and joint compound)
θ_{SA} = 7.33°C/W (Heat sink specification at 3W)
T_A = 25°C
P_D = 3W

$T_J = P_D*(\theta_{JC} + \theta_{CS} + \theta_{SA}) + T_A$
T_J = (3W)*(3°C/W + 0.44°C/W + 7.33°C/W) + 25°C
T_J = 57.3°C



Thanks for your time! Please try the quiz.