Thermal Resistance Measurements of Bypass Diode / Junction Boxes for Predicting Field Stressors

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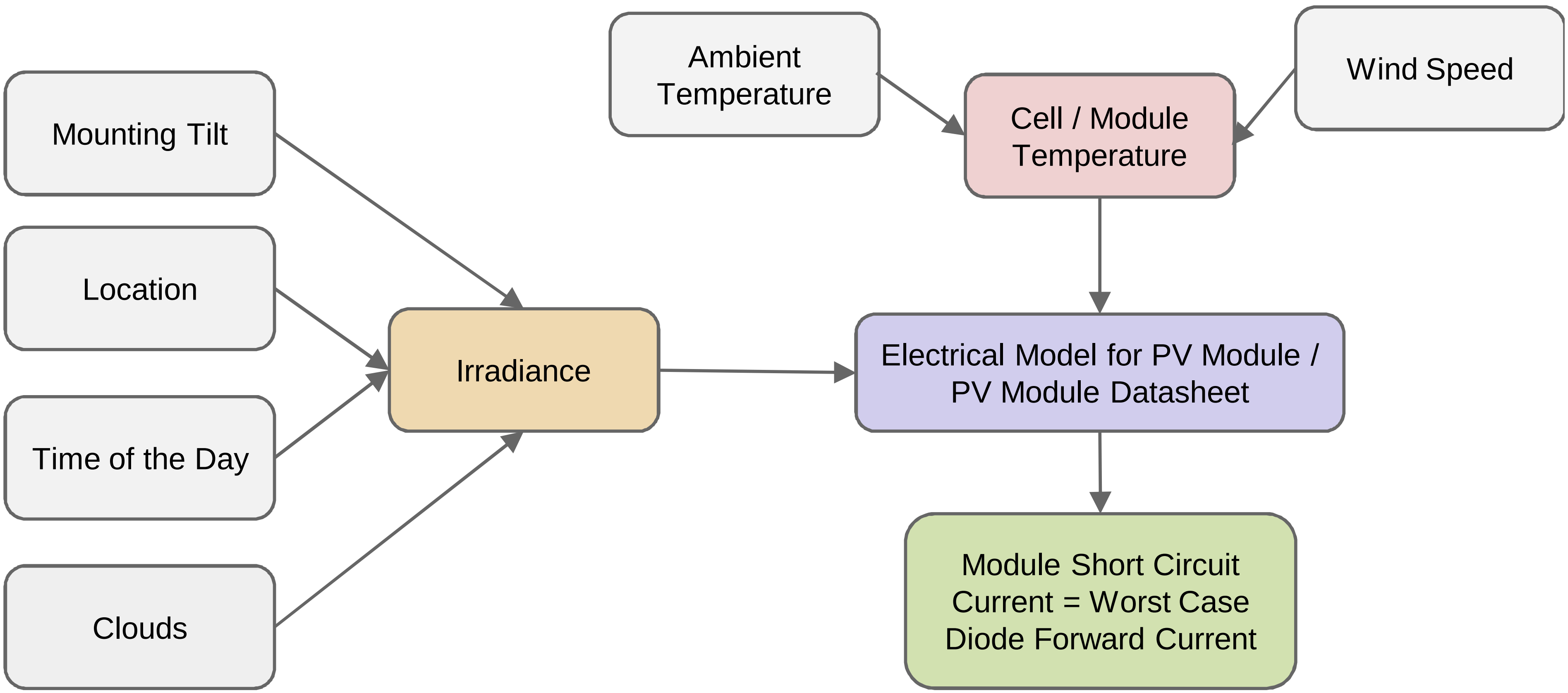
Bypass Diode Reliability

- Bypass diodes are primary components in PV modules that provide protection against shading by limiting the reverse voltage across a shaded cell.
- A bypass diode failed in short circuit results in immediate PV module failure, while a bypass diode failed in open circuit can cause significant safety hazards.
- The operating junction temperature (TJ) and difference between maximum and minimum temperature during thermal cycling (ΔTJ) of bypass diodes in field deployed modules determines their long term reliability.
- The stressors TJ and ΔTJ need to be estimated for diodes in modules deployed in various climatic zones during service life.

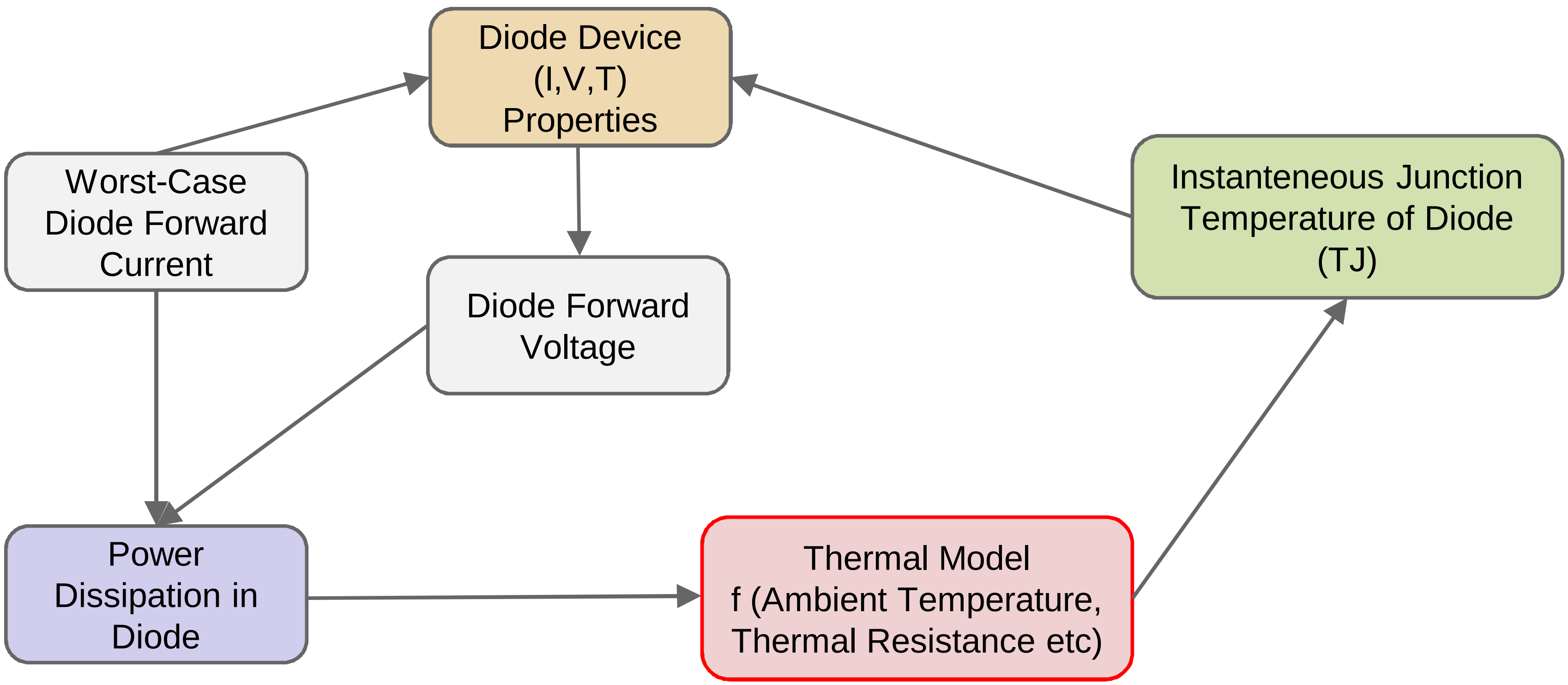
Estimating Stressors in Field

- In order to quantify the thermal stresses experienced by a bypass diode in the field, it is necessary to estimate the junction temperature (TJ) as a function of environmental and shading conditions.
- Worst-case shading for bypass diode is when the module is short circuited and a cell is 100% shaded.
- Worst-case stressors experienced by bypass diodes in various climatic zones can be quantified if TJ of the diode can be predicted from the Typical Meteorological Year (TMY) data.
- The goal is to perform thermal characterization of bypass diodes / junction boxes in the lab and then use models to predict TJ in field based on the TMY data.

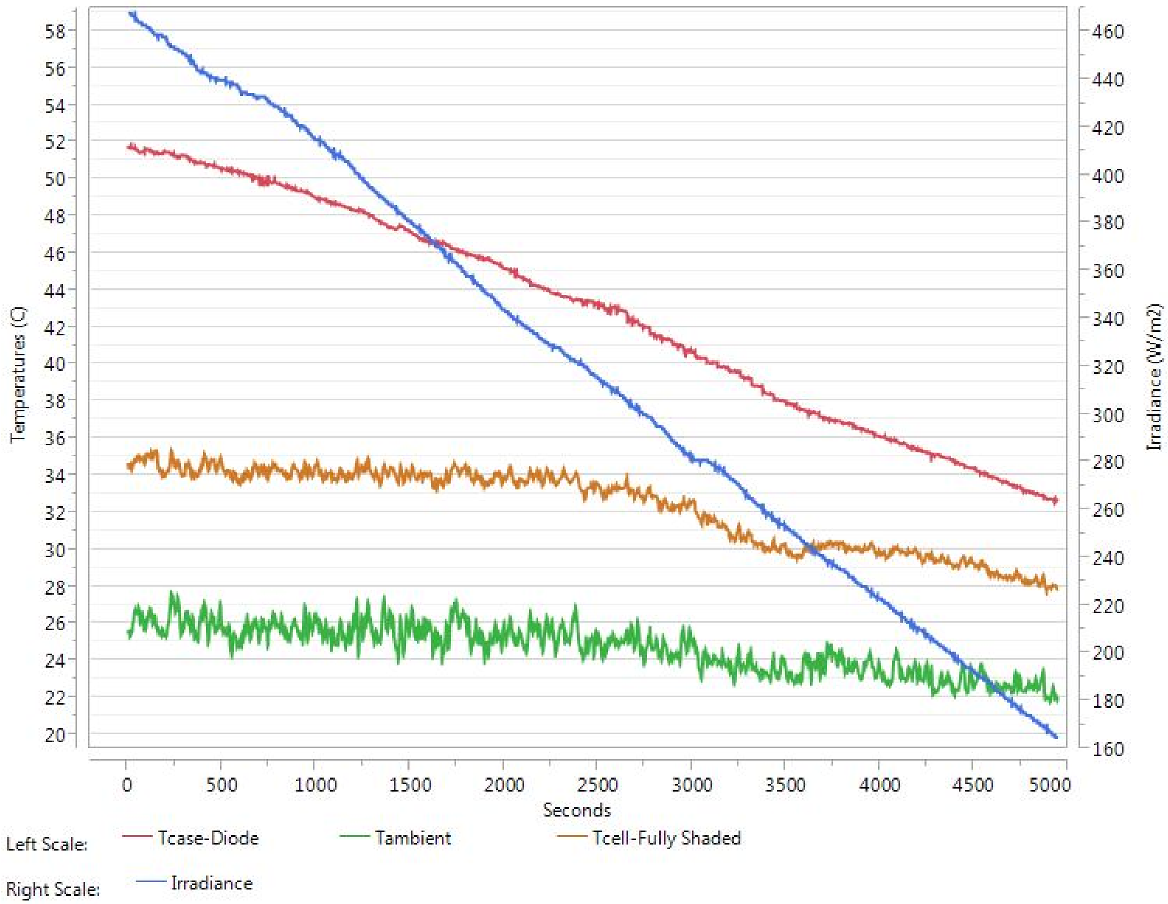
Predicting Worst-Case Diode Forward Current from TMY Data



Predicting Diode Junction Temperature from Power Dissipation

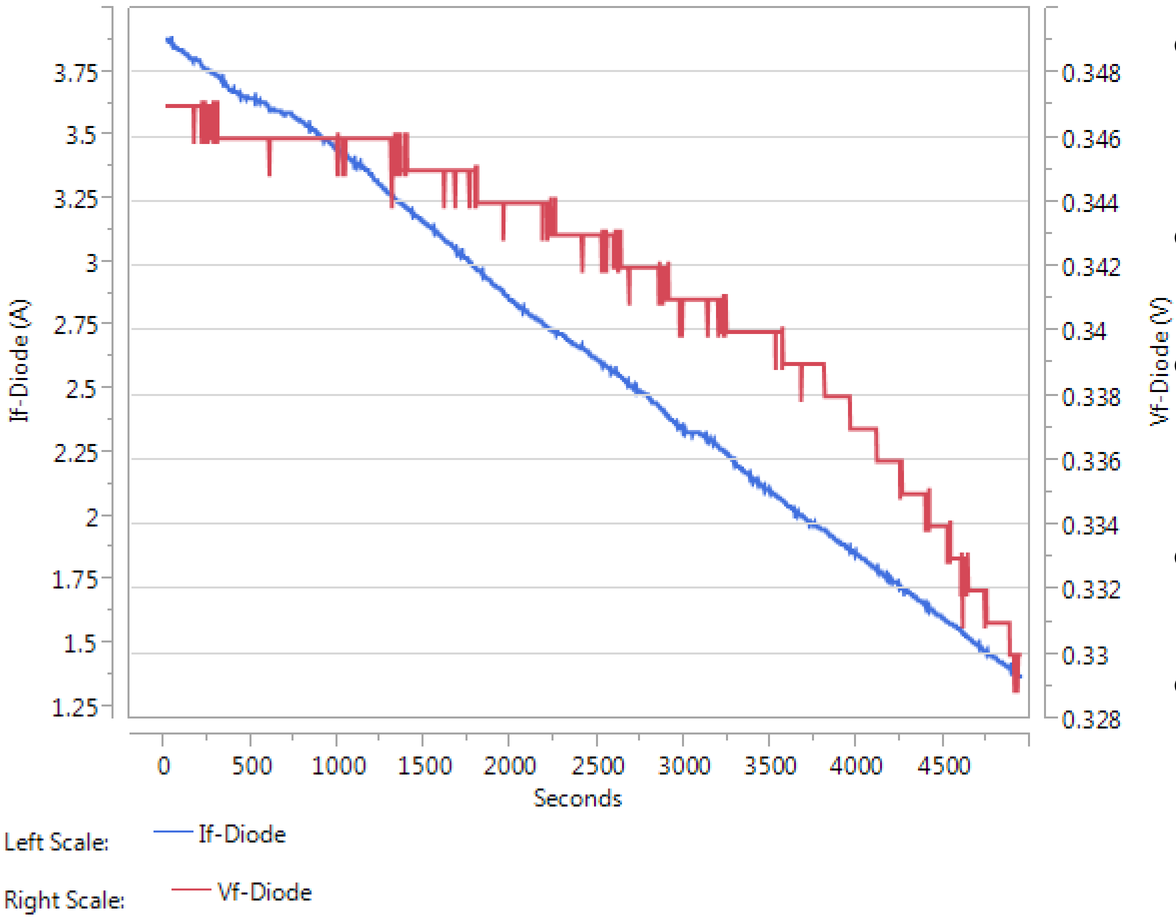


Outdoor Measurements: Irradiance and Temperatures



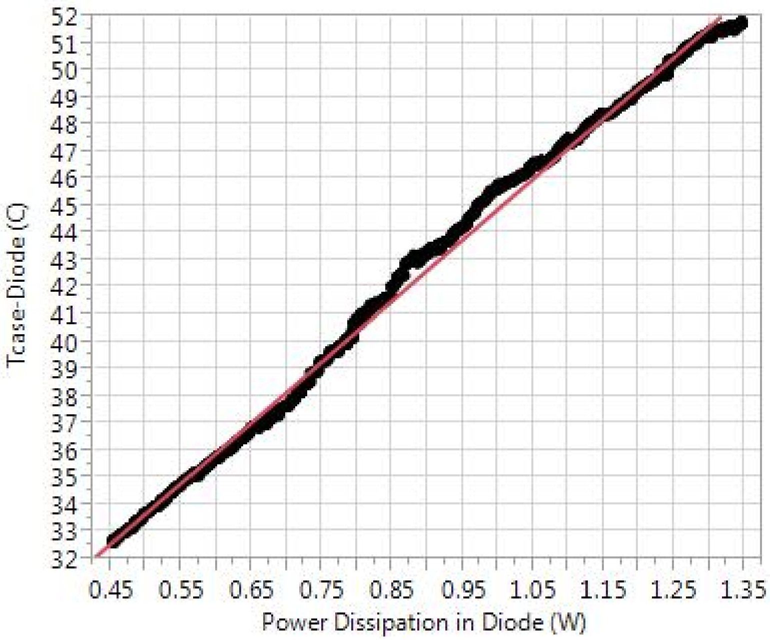
- Diode case temperature follows the irradiance on a sunny day
- Even for low irradiance and ambient temperature values, diode temperature could be significantly higher.
- Wind has introduced noise in the ambient and cell temperature measurements

Outdoor Measurements: Diode Current and Voltage



- Diode Current reduces as irradiance reduces over time.
- Reduction in current causes reduction in Tcase.
- However, Vf shows setp-wise behavior due to two balancing forces:
- Lower current → Lower Vf, and
- Lower current → (Lower temperature)→ Higher Vf

Diode Temperature vs Power Dissipation



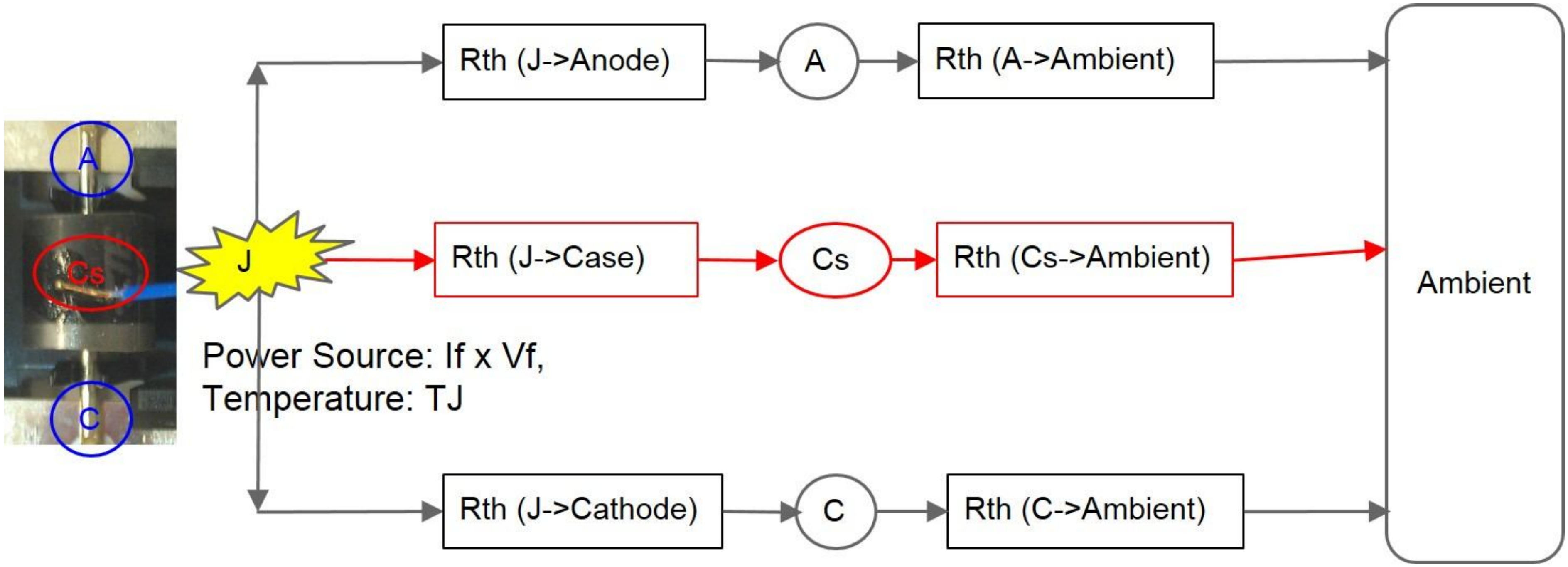
- On a sunny day, steady reduction in diode current results in gradual reduction in Tcase over time.
- A state of quasi-thermal equilibrium is maintained throughout the process.
- Correlation between electrical and thermal properties can be best described by an “apparent” ambient temperature and thermal resistance.

Tcase-Diode (C) = 22.50 + 22.42 x Power Dissipation in Diode (W)

“Apparent” Ambient Temperature (Tambient)

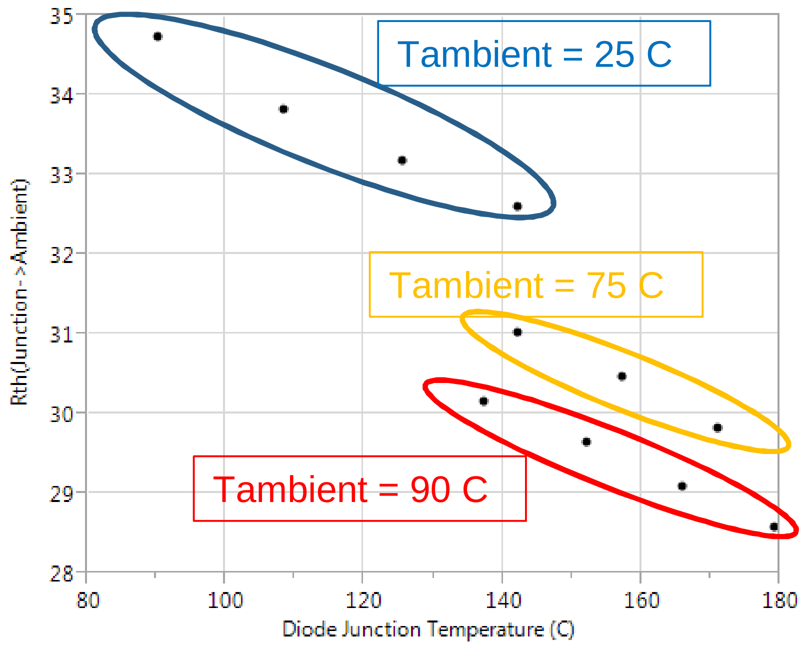
“Apparent” Thermal Resistance (Rth)

Simplified One-Dimensional Thermal Model



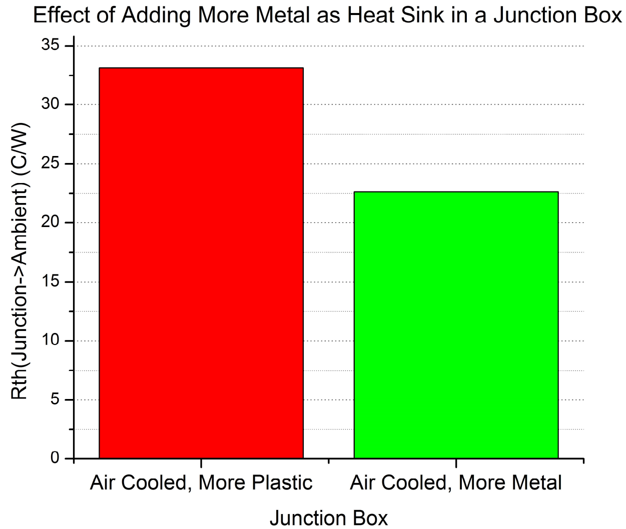
$$At\ Thermal\ Equilibrium: Rth(Junction \rightarrow Ambient) \sim \frac{(TJ - TAmbient)}{(If \times Vf)}$$

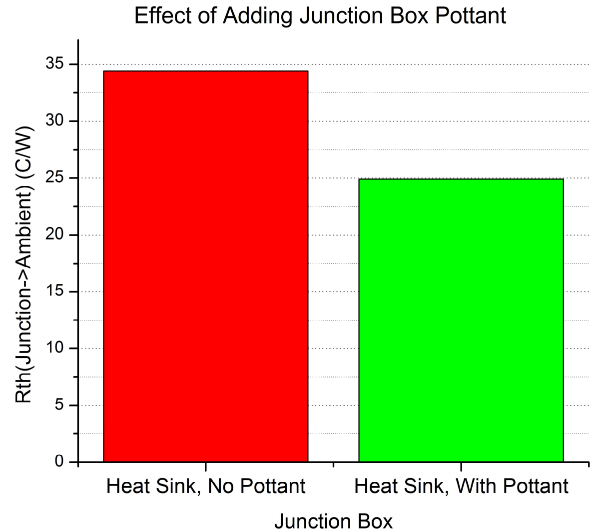
Rth(Junction→Ambient) vs TJ



- The value of Rth(Junction→Case) = 3.5 was used from diode datasheet to calculate TJ from Tcase.
- In an environmental chamber, Rth(Junction→Ambient) was calculated for Tambient = 25 C, 75 C and 90 C. and If = 6,8,10,12 A.
- However, Rth(Junction→Ambient) was found to vary significantly with Tambient and TJ itself.
- This may be because of increasing heat transfer by radiation at elevated temperatures which is not accounted for by simplified 1-D thermal model.

Rth(Junction→Ambient) @ Standard Conditions for Comparing Performance of Junction Boxes





- Rth(Junction→Ambient) was compared for different types of junction boxes at Tambient = 25 C, If = 10 A.
- For large, air cooled junction boxes, adding more metal (and surface area) as a heat sink can significantly reduce the thermal resistance.
- For small junction boxes with metallic heat sink, addition of junction box pottant can significantly reduce the thermal resistance

Conclusions and Future Work

- On a sunny day, under worst-case shading scenario for a diode, the diode is in a state of quasi-thermal equilibrium as current changes gradually with the irradiance.
- The diode case temperature is directly proportional to the power dissipated in the diode with "apparent" ambient temperature and thermal resistance as the coefficients.
- However, Rth(Junction→Ambient) calculated from the simplified 1-D model is found to vary with Tambient and TJ itself. Therefore, this approach is of limited value for predicting field stressors.
- Rth(Junction→Ambient) when measured at standard conditions can be useful to compare thermal properties of bypass diodes / junction boxes.
- We are exploring other approaches for predicting field stressors from thermal characterization of bypass diodes / junction boxes.