Humidity Sensing Physics

TI Precision Labs – Humidity Sensors

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Basic Psychrometry

Relative Humidity: $\mathbf{RH} = \frac{P_W}{P_{WS}} \times \mathbf{100\%}$

- Saturation Vapor Pressure: P_{WS}
- Vapor Pressure: P_W

Absolute Humidity: $\rho_v = \frac{m_{H_2O}}{V_{net}}$

$$\rho_v = \frac{P_W \times M_W}{R \times T_K}$$

- Universal Gas Constant: R
- Molar mass of water: M_W
- Temperature in Kelvin: T_K

Dew Point: $T_d = \frac{c \times ln\left(\frac{P_W}{a}\right)}{b - ln\left(\frac{P_W}{a}\right)}$

- Constants: a, b, c

Mixing Ratio: $\mathbf{X} = \frac{M_{H20}}{M_{air}} \times \frac{\mathrm{P_W}}{\mathrm{P_{amb}} - \mathrm{P_W}}$

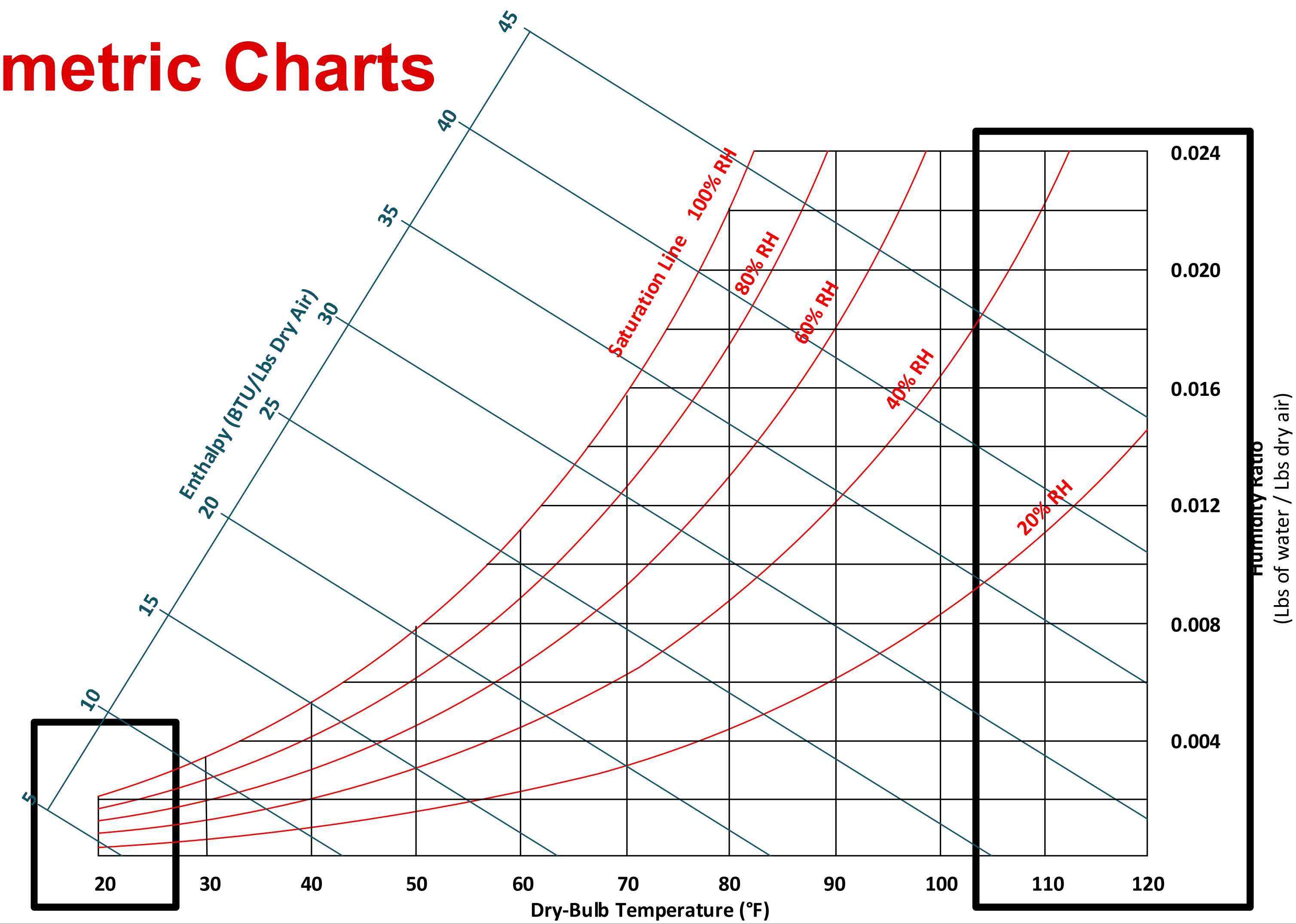
- Molecular Weight of water: M_{H20}
- Molecular Weight of air: M_{air}
- Total Ambient Pressure: P_{amb}

Enthalpy: $h = T \times (\mathbf{1.01} + \mathbf{0.00189X}) + \mathbf{2.5X}$

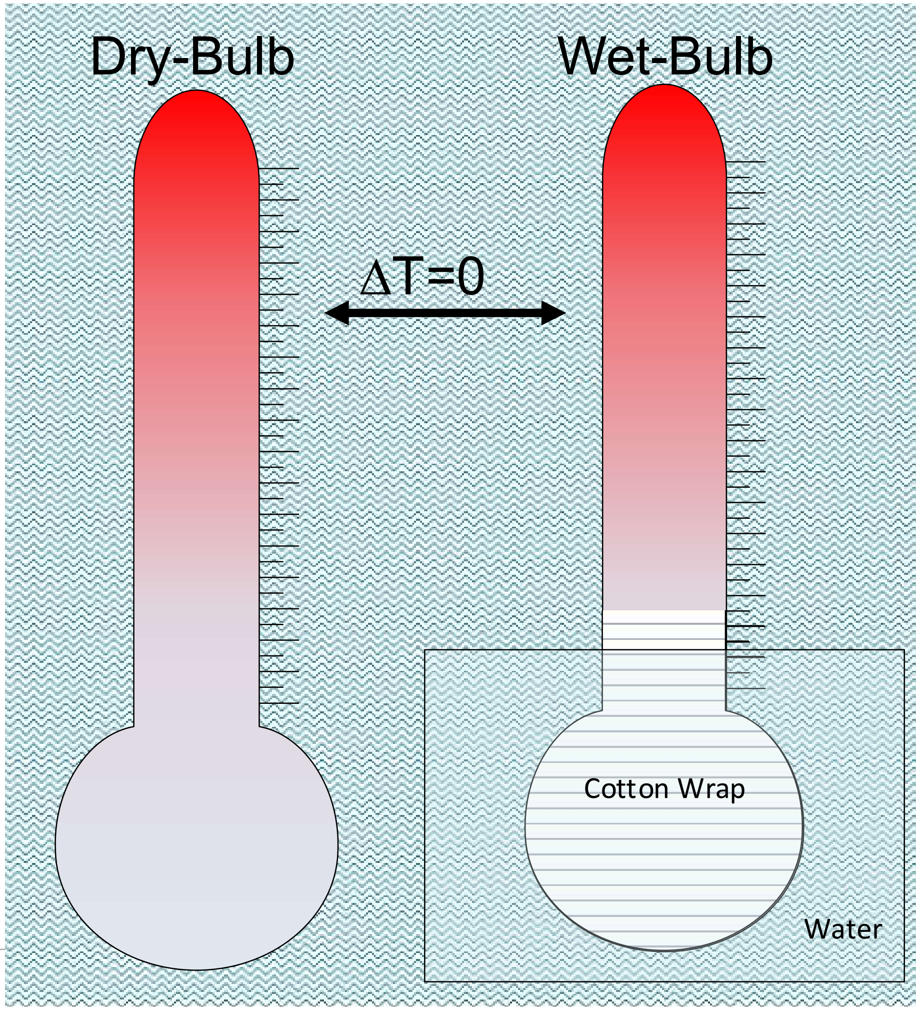
- Temperature in Celsius: T

Dry Bulb Temperature
Wet Bulb Temperature

Psychrometric Charts



Psychrometers



Psychrometric Formulas

Ferrel Equation:

$$P_W = P'_{WS} - A * P * (T - T_W)$$
$$A = (f + gT_W), f \,\&\, g \text{ are Constants}$$
$$P'_{WS} = P_{WS}(T_W)$$ [1]

Apjohn Equation:

$$P_W = P'_{WS} - P * B/755 * (T - T_W)$$
B = 0.5 or 0.44 for frozen $°C^{-1}$ [2]

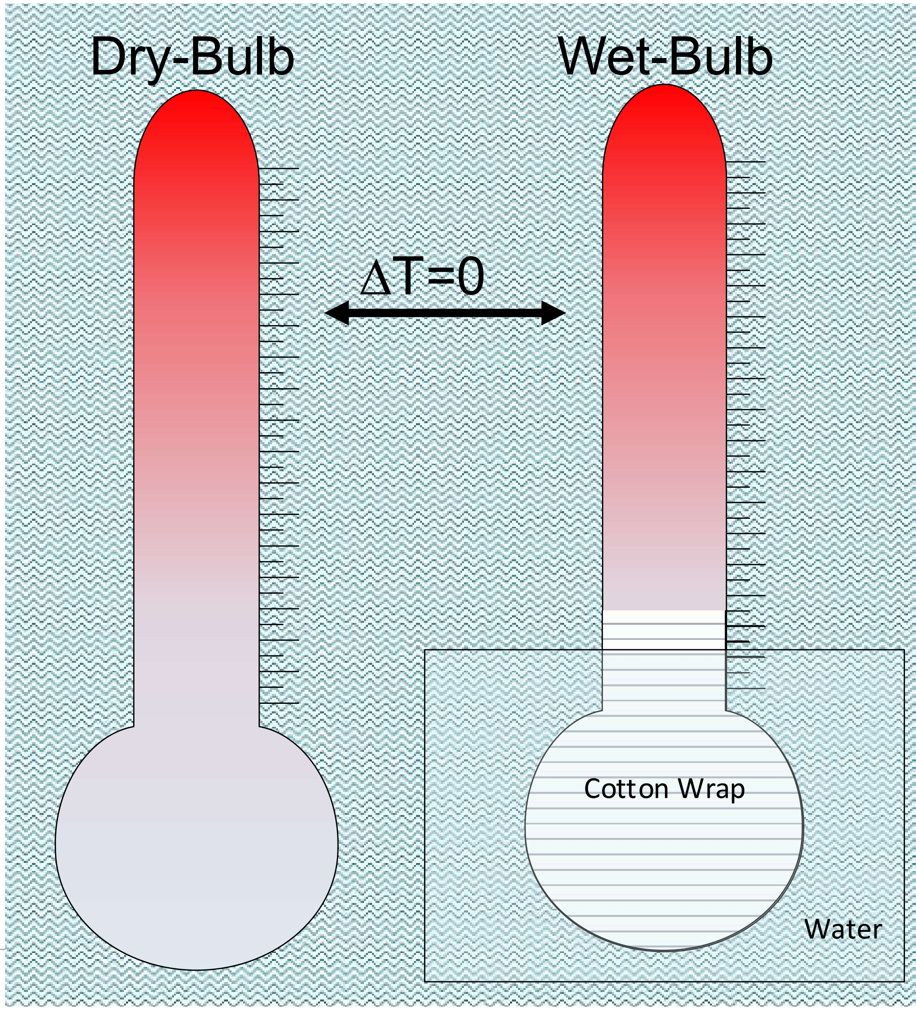
Carrier Equation:

$$P_w = P'_{WS} - \frac{(P - P'_{WS})(T - T_W)}{1527.4 - 1.3T_W}$$ [2]

In General:

$$P_W = P'_{WS} - C * f(P, T, T_W)$$
$$f(P, T, T_W) = 0 \text{ when } (T - T_W) = 0$$

Psychrometers



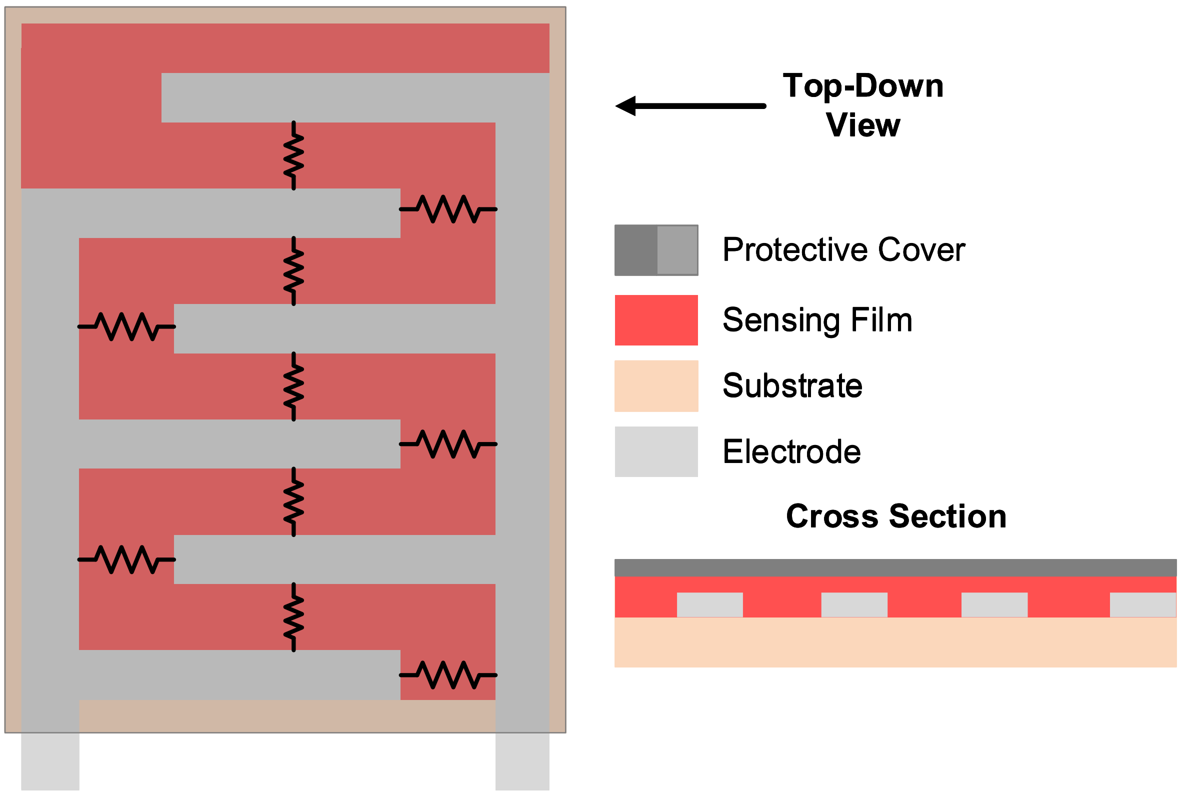
Advantages:

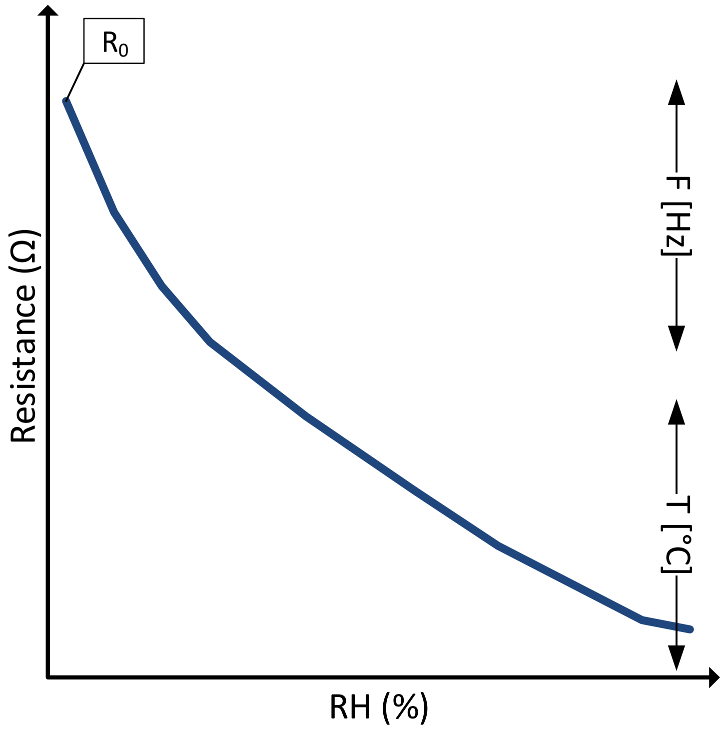
- No power required
- Wide Temperature and humidity range
- No drift
- Very low Hysteresis

Disadvantages:

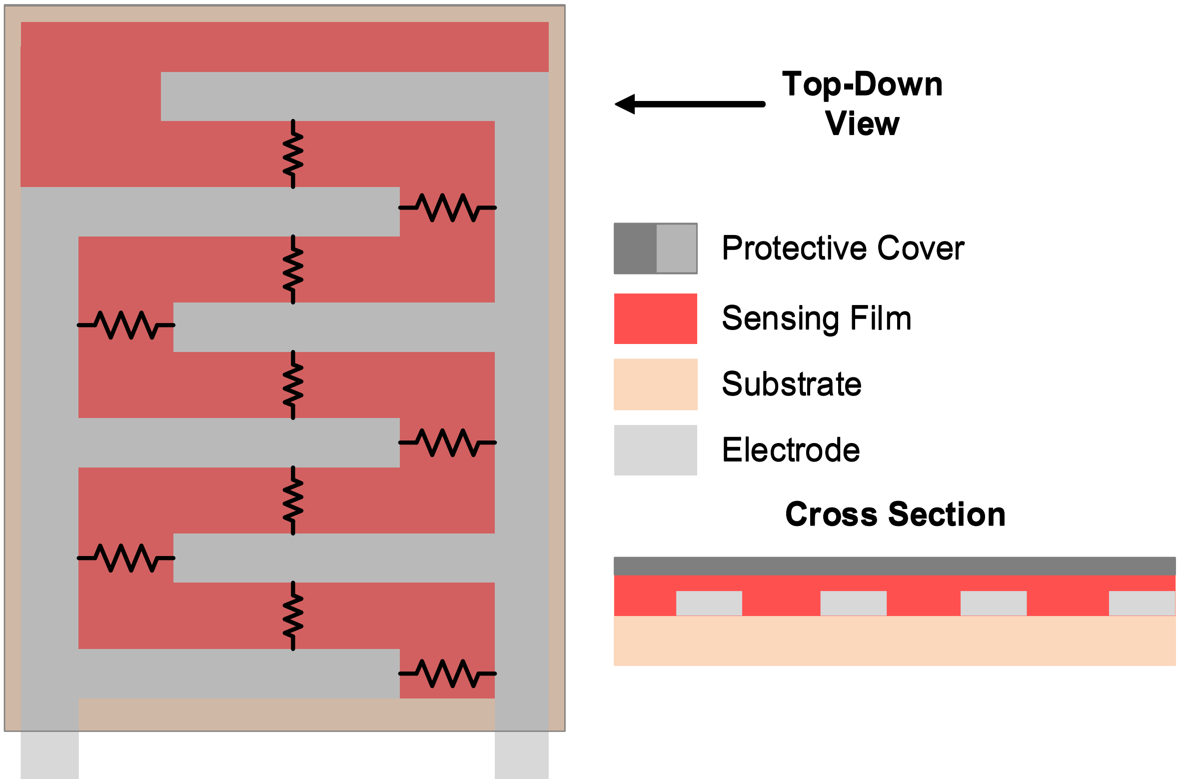
- Complex and expensive
- Requires regular maintenance

Resistive Humidity Sensors





Resistive Humidity Sensors



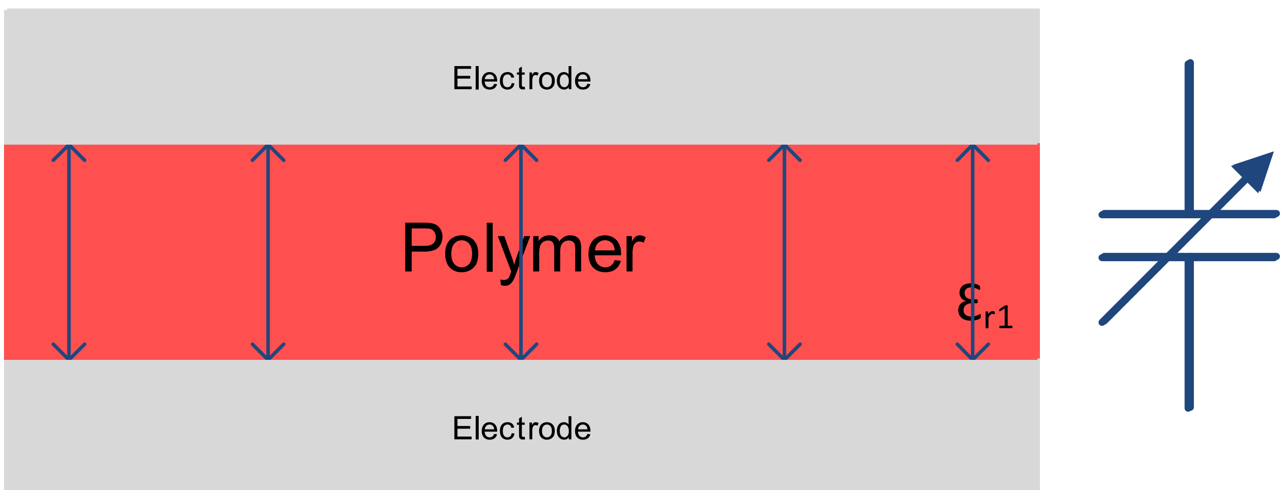
Advantages:

- Low Cost
- Easily interchangeable

Disadvantages:

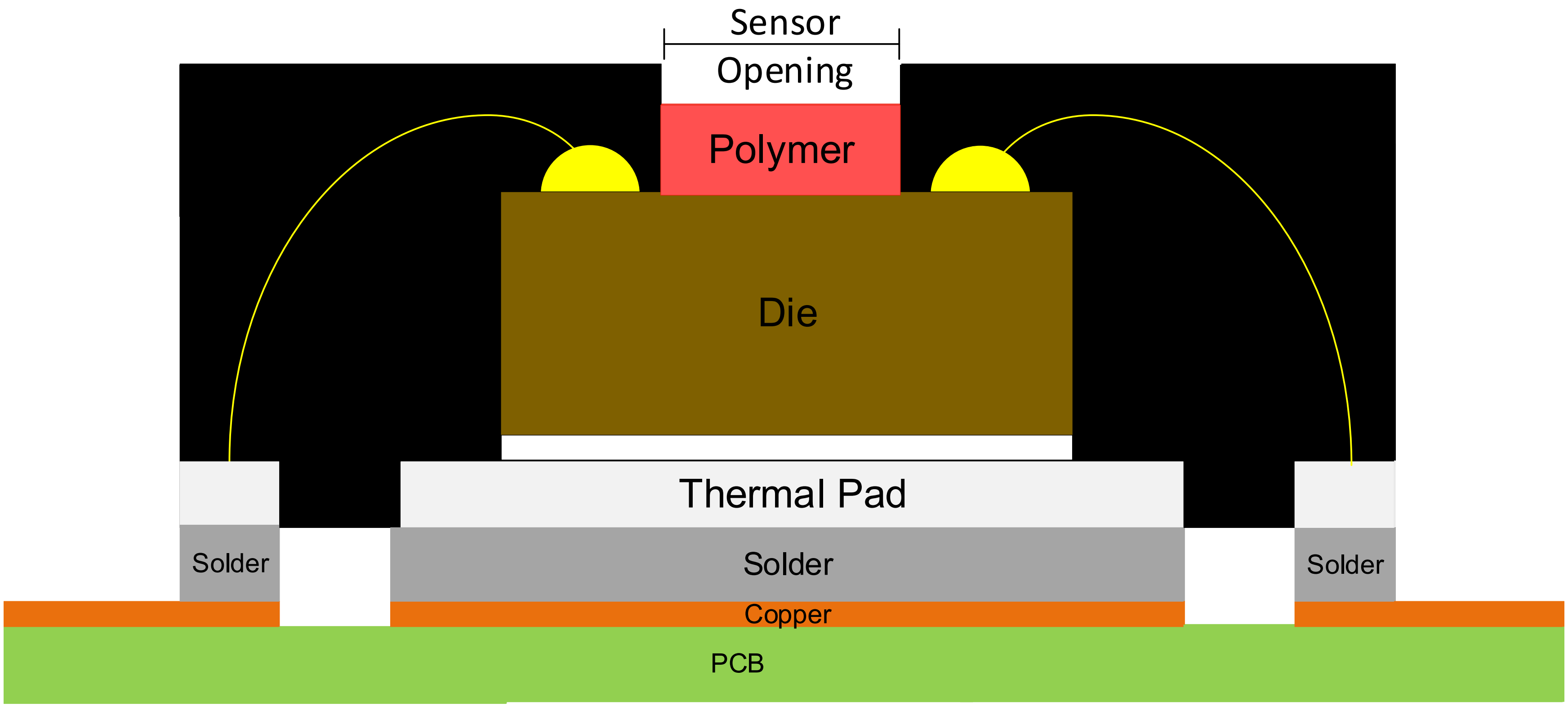
- Limited RH Range (above 15%)
- Strong temperature & Frequency dependence
- Sensitive to contamination
- Poor stability

Capacitive humidity sensors

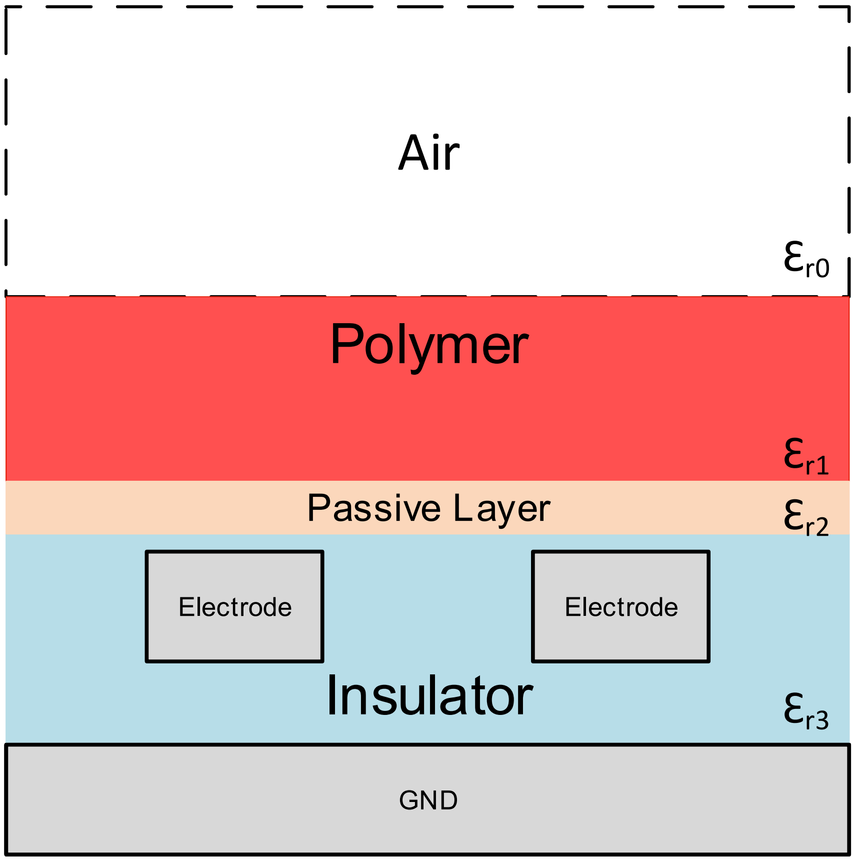


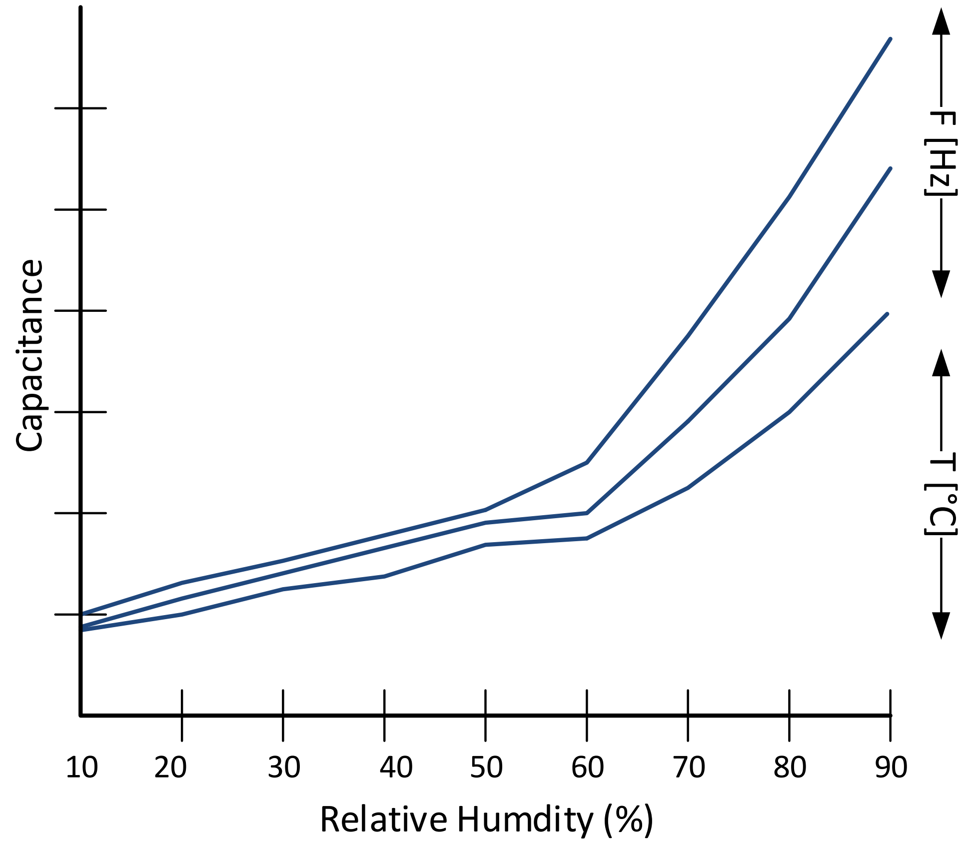
$$C = \frac{\varepsilon_{r1} A}{D} \; [F]$$

Capacitive humidity sensors

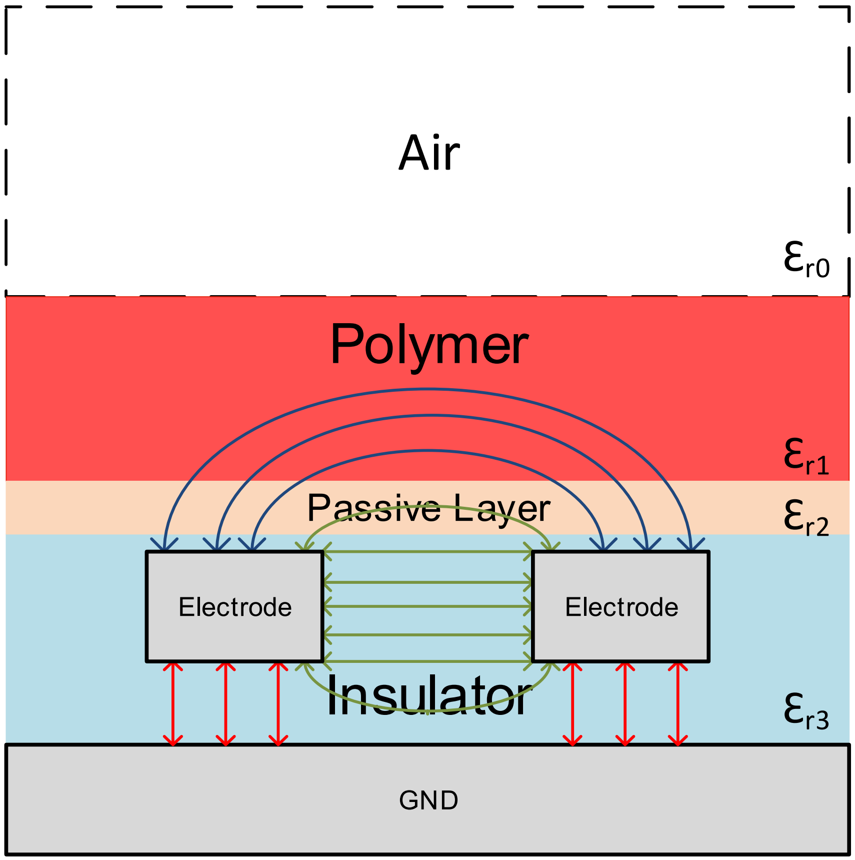


Capacitive humidity sensors





Capacitive humidity sensors



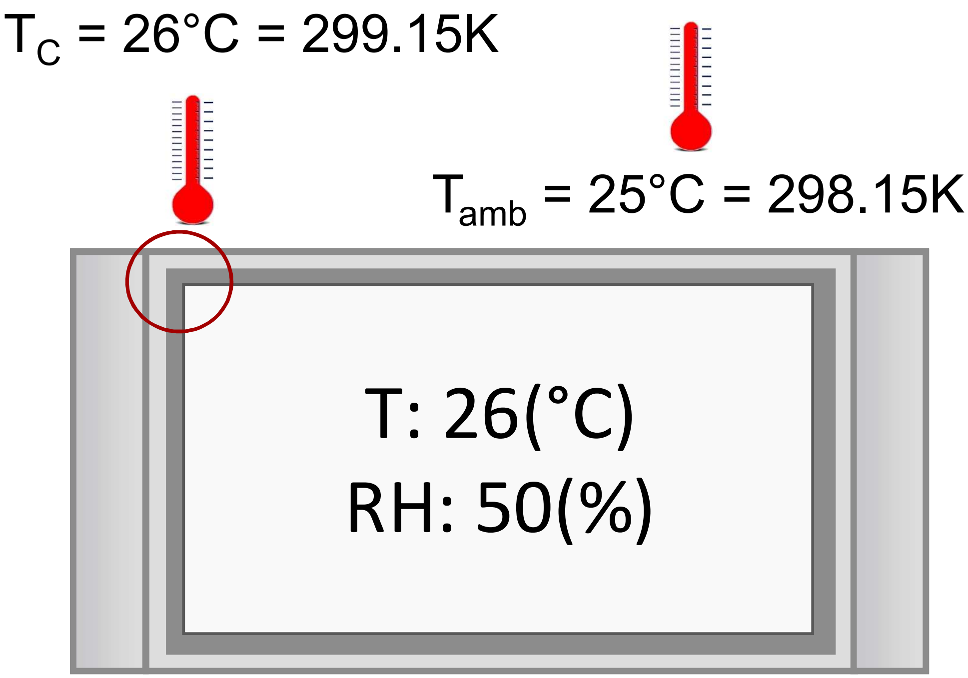
Advantages:

- Low Cost
- Good Humidity Range
- Small Hysteresis (typ. 1% or less)
- Fast Response Time
- Ease of manufacturing and integration

Disadvantages:

- Low accuracy below 5% RH
- Additional circuitry required to sample capacitance and convert to RH
- Exposed sensing polymer is sensitive to chemical contamination

Application: Compensating for Case Temperature



$$A_{\mathrm{C}} = A_{\mathrm{amb}} \qquad A_X = \frac{C \times P_{Wx}}{T_x}$$

$$C = \frac{M_W(molar\ mass\ of\ water)}{R(Universal\ gas\ constant)} = \frac{18.01528 \frac{g}{mol}}{8.3145 \frac{J}{mol * K}}$$

$$\frac{C \times P_{Wc}}{T_{\mathrm{c}}} = \frac{C \times P_{Wam}}{T_{amb}} \qquad RH_x = \frac{P_{Wx}}{P_{Wsx}} \times 100\%$$

$$\frac{P_{WS} \times RH_{\mathrm{c}}}{T_{\mathrm{c}}} = \frac{P_{WSamb} \times RH_{\mathrm{amb}}}{T_{\mathrm{amb}}}$$

$$\boldsymbol{RH_{\mathrm{amb}} = \frac{P_{\mathrm{WSc}}}{P_{\mathrm{WSamb}}} \times \frac{T_{\mathrm{amb}}}{T_{\mathrm{c}}} \times H_C}$$

Note: Temperature ratio should calculated in Kelvin, if used.

To find more humidity sensor resources and products, visit ti.com/humidity

References

[1] National Aeronautics and Space Administration, 1977. *Equations For The Determination Of Humidity From Dewpoint And Psychrometric Data*. Edwards: N.A.S.A., pp.2-15.

[2] Ramgopal, *Lesson 27 Psychrometry*, 1st ed. Kharagpur: IIT, 2006, pp. 1-16.