Mr. Junaid Shafaat

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Biography:
Junaid Shafaat has 20 years of experience in Product Design, Development, Reliability and Quality Engineering. He has worked in manufacturing and product development for hi-tech organizations from silicon valley California to eastern Canada. Currently, he is leading a team of engineers to develop new microelectronic products for biotelemetry applications. He has two Master's degree of science in engineering. One from San Jose State University, San Jose, California, USA and the other one from Memorial University of Newfoundland and Labrador, St. John's, Canada. He is also a part-time PhD student at Memorial University, St. John's, Canada researching on 'Effects of geomagnetic forces on reliability of tracking devices'. Junaid has previously researched on long term environmental effects on the life of microelectronic products, electronic assemblies cleaning technologies and potting materials.

Title:
Moisture Diffusion in Electronic Packaging Materials

Executive Summary:
Moisture poses a significant threat to the reliability of microelectronic assemblies, especially for scientific research products that are designed for marine environment and can be attributed as being one of the principal causes of many early-life failures. The presence of moisture in plastic packaging alters thermal stress through alteration of thermo-mechanical properties like, change of elastic modulus, shear strength and glass transition temperatures. Moisture also induces hygroscopic stress through differential swelling, reduces interfacial adhesion strength, induces corrosion and acts as an unwanted resistance when present between the two nodes of component and result in lowering the resistance which results in faster depletion of budgeted power. In this study, an analytical model was developed and validated both by experiments and simulation to determine the ingress rate of the moisture through bi-material interface. Moisture diffusion ingress rate is calculated and validated through finite element modeling. After calculating diffusion coefficients of the two polyurethane materials, moisture ingress rate was calculated using analytical model and also simulated through finite element analysis. The diffusion coefficient was experimentally determined using absorption data (M_t/M_∞) by weight gain experiment as prescribe in ASTM D570 method. Once the diffusivity coefficient is known, theoretical Fickian curve is plotted with the experimental data to see if the absorption is Fickian or not. For very prolonged times, curve becomes non-fickian, therefore, diffusion coefficient is calculated by considering only the linear part of the curve. The 99% saturation approach helps to define the limit of Fickian diffusion hence eliminate error caused by non-fickian absorption. Since the Fick's moisture diffusion equation follows the same governing differential equation as the diffusion of heat, with a change of the dependent variable, temperature, with moisture concentration and the thermal diffusivity with moisture diffusivity, commercially available heat transfer simulation software can by used to solve transient moisture diffusion problem. However, a unique problem arises in the diffusion of moisture. Since diffusion coefficient is constant for particular material, for bi-material analysis, interfacial concentration discontinuity cannot be analyzed as an interfacial discontinuity result where two materials having different saturated concentrations are joined. The results of ingress rate through FEA simulation came close to the calculated values hence validating the model.

Moisture Diffusion in Electronic Packaging Materials

Junaid Shafaat

Outline of Presentation

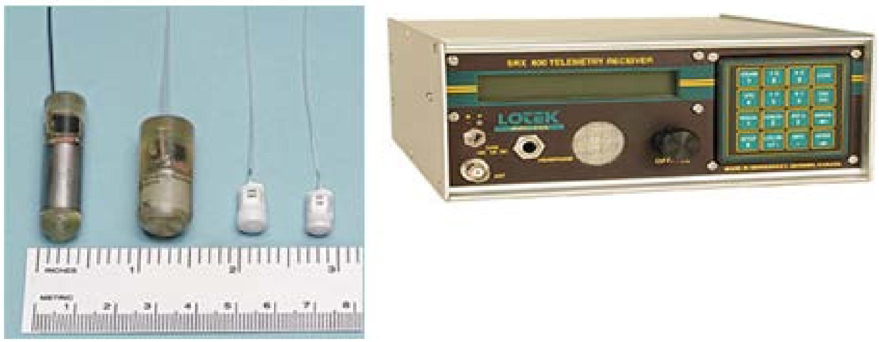
- Introduction
- Scope of Research
- Failure Data Analysis
- Design Check – Fault Tree Analysis
- Water Penetration
  - Ingress Rate
  - FEA Simulation
- Conclusions

Biotelemetry

- ***Telemetry*** *is a technology that allows the remote measurement and reporting of information of interest.*
- ***Biotelemetry*** is the remote measurement of physiological data of living species
- It is used to study wildlife, and monitoring threatened species.
- Animals under study are fitted with instrumentation ranging from simple tags to cameras, GPS packages and transceivers to provide position and other basic information to scientists.

Applications of Tags

Biotelemetry Products

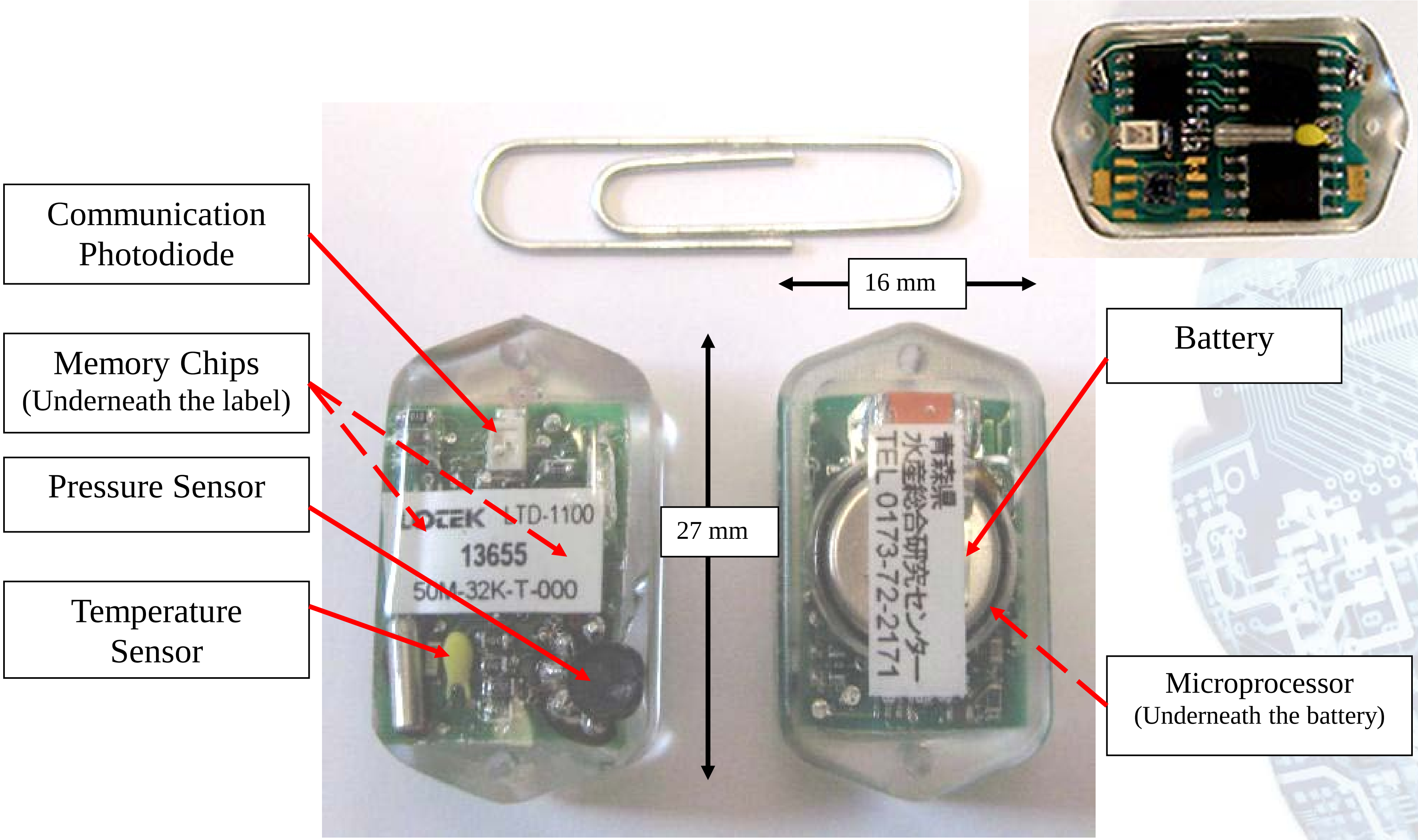


RF Transmitters

Acoustic Transmitters

Data-Recorder Tags

Courtesy of Lotek Wireless Inc.



Front Side *Back Side*

Length : 27 mm

Width: 16mm

Thickness: 8mm

Weight: 5 grams

Scope of Research

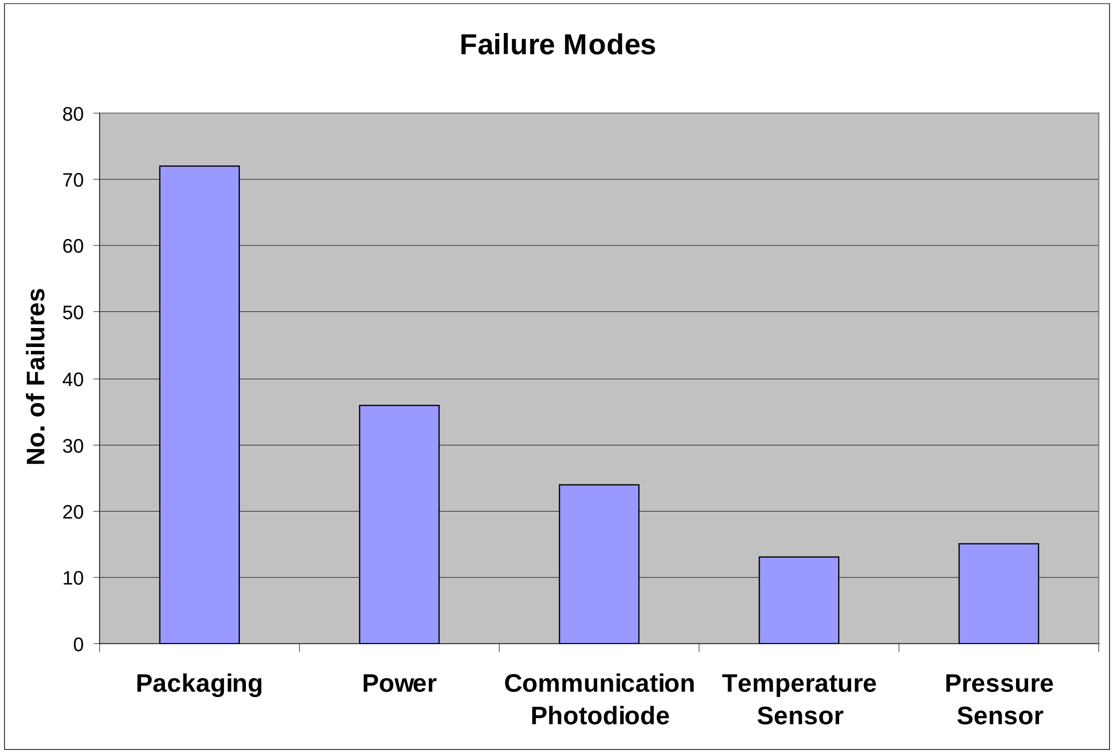
- To determine root-cause of early life failures
- Determine the ingress rate of the moisture through bi-material interface
- Analytical Model
- Validation through FEA Simulation

Failure Modes

Definition of Failure Modes:

Power: Battery dies < 2 years

Packaging: External damage causing water to penetrate electrical circuits through body or cracks/openings



Weibull Analysis

Time dependent failure rate

$$R(t) = e^{-(t/\theta)^{\beta}}$$

Where,

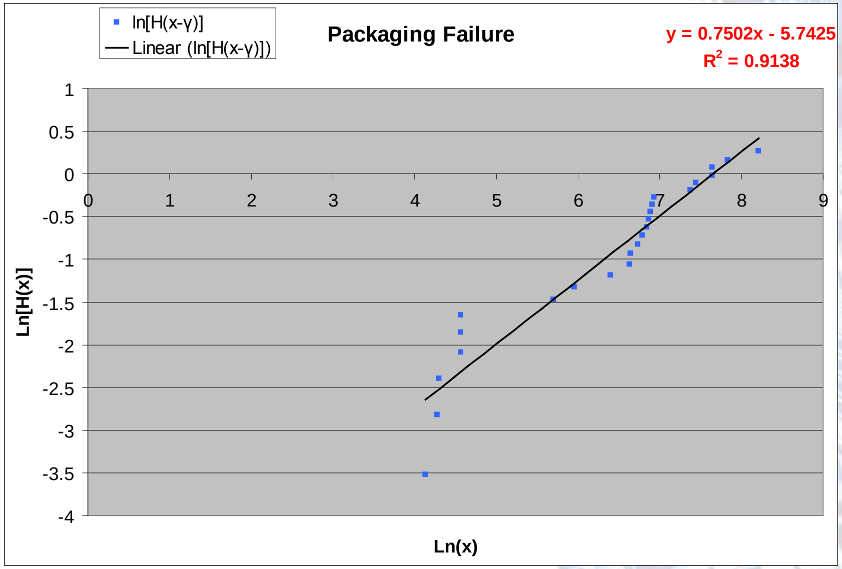
R(t) = Reliability at time t

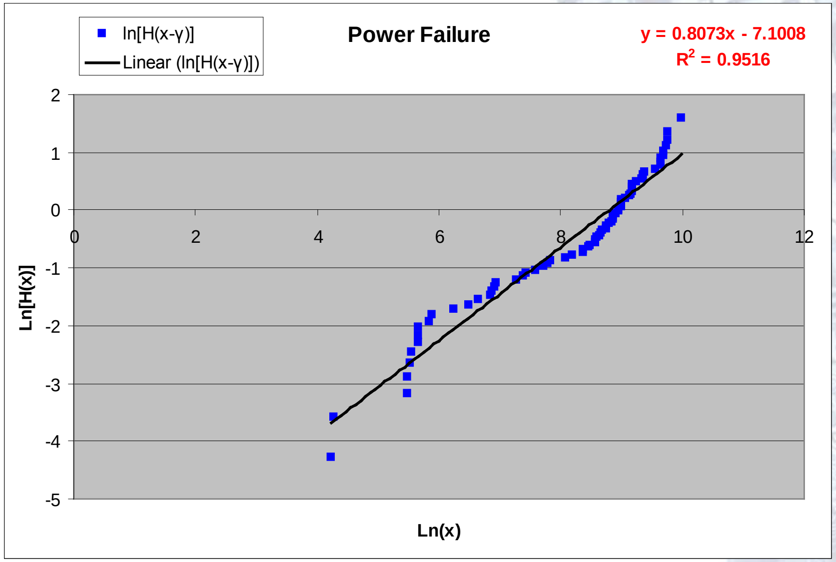
t = time

θ = Scale parameter or characteristic life. 63.2% failure will occur by the time t = θ

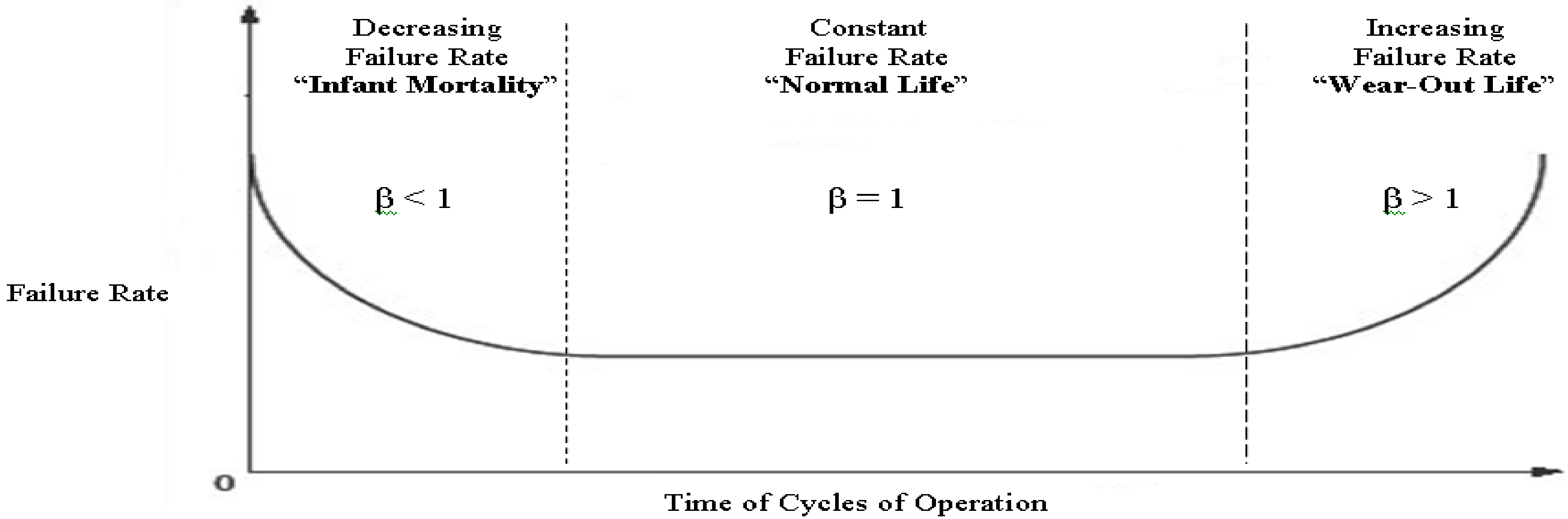
β = shape parameter, defines shape of failure rate curve

- Decreasing failure rate as Scale Parameter, β < 1





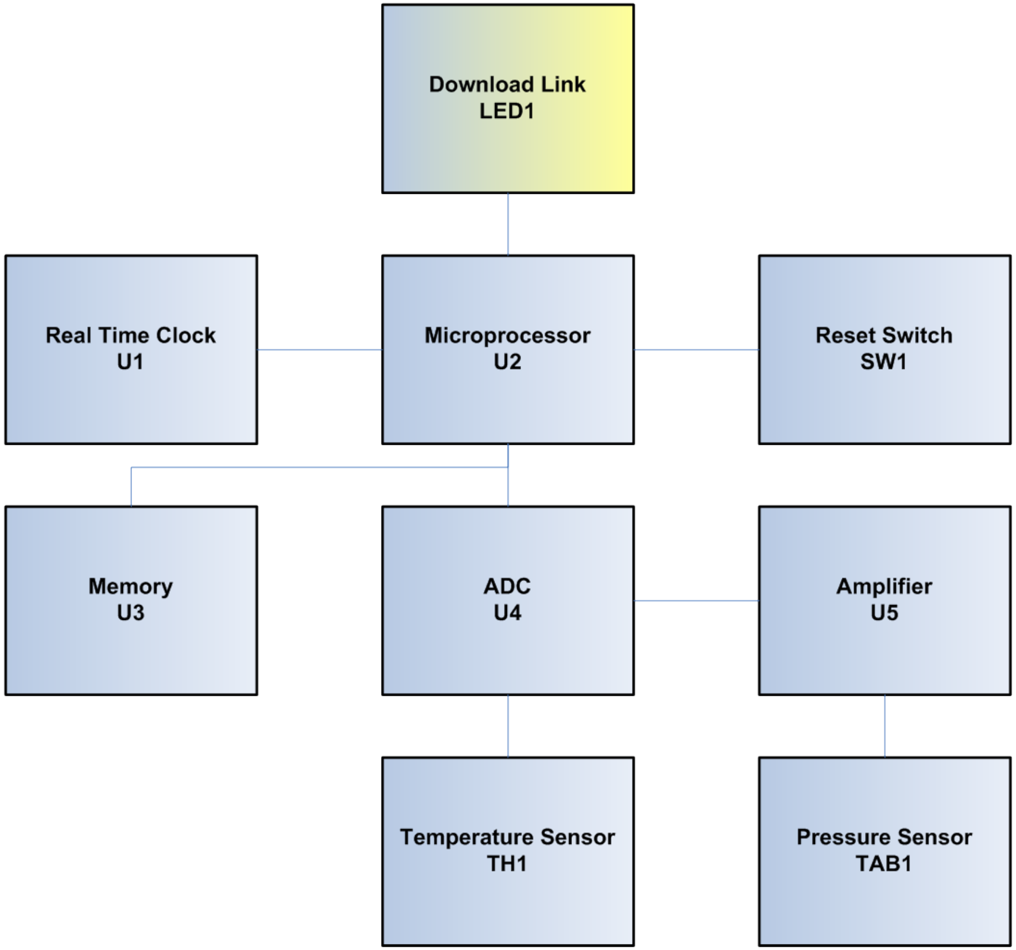
Weibull Analysis



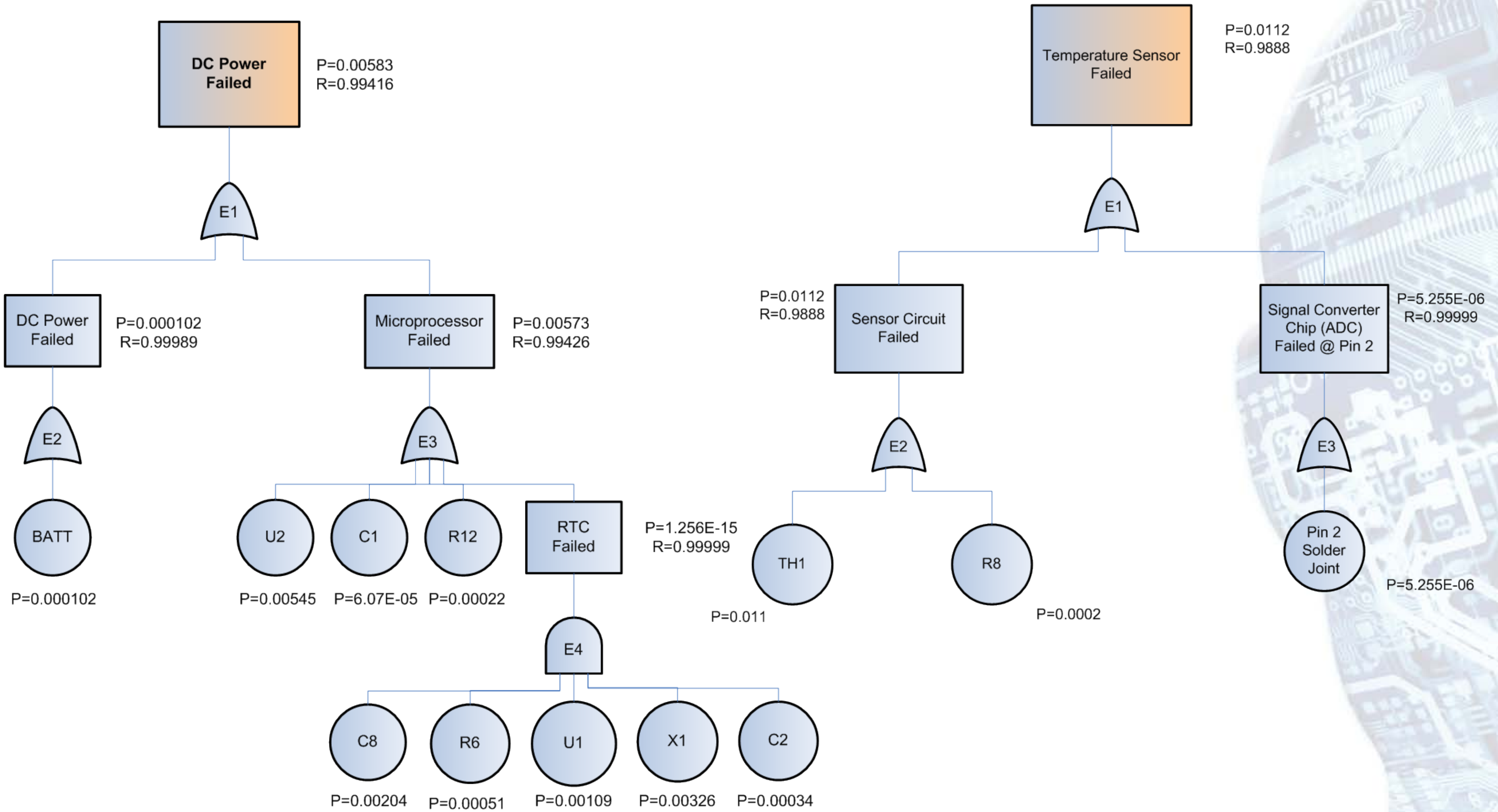
Data Set	*Shape Parameter*	*Scale Parameter*	*Result*
Power Failure	β = 0.80	θ = 6606	**Infant Mortality**
Packaging Failure	β = 0.75	θ = 2110	**Infant Mortality**

Design Check – Fault Tree Analysis

System Block Diagram

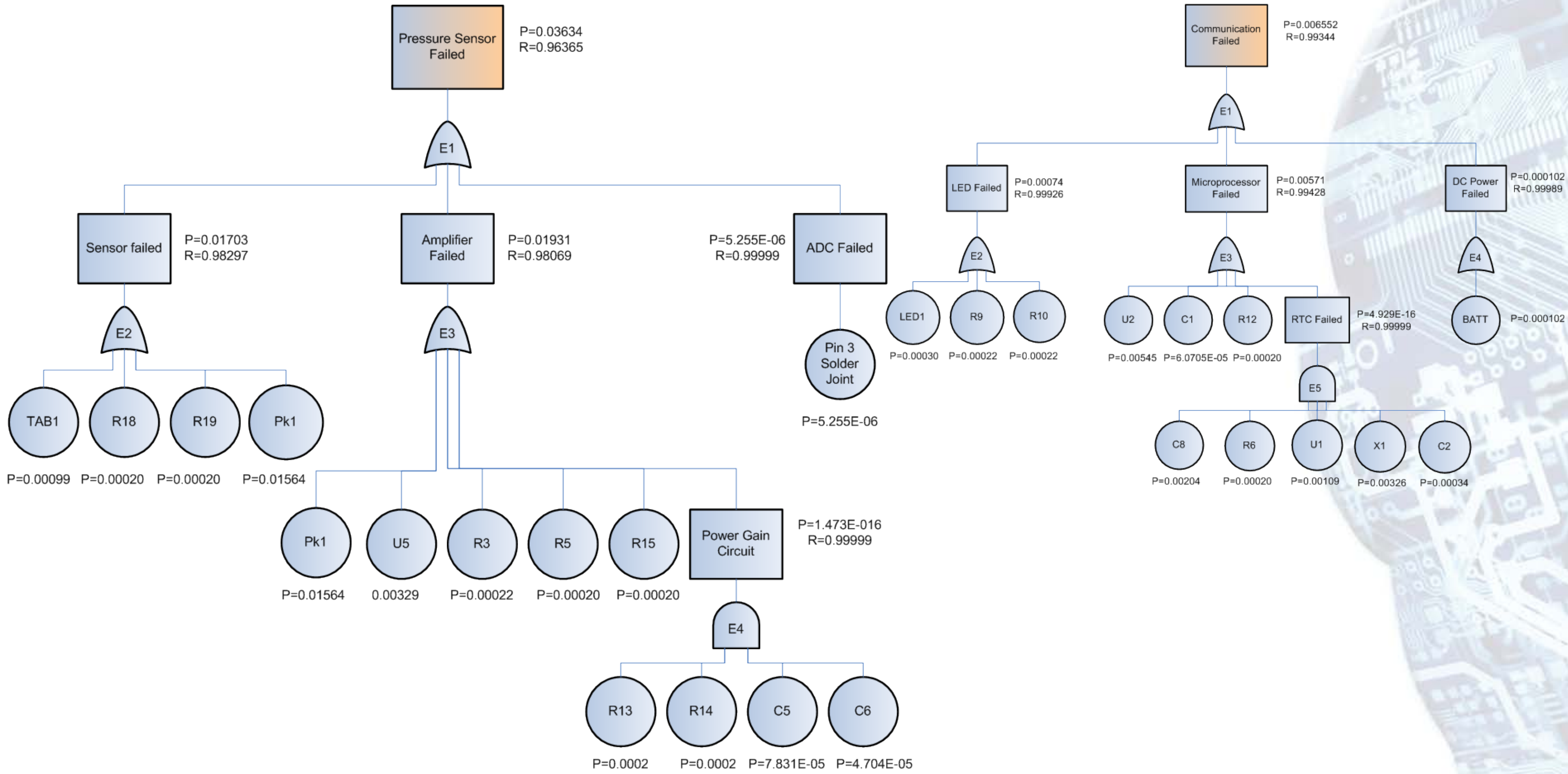


FTA - Power and Temperature Sensor Failure



Note: Failure rates from MIL-HDBK-217F

FTA - Pressure Sensor and Communication Failure



Note: Failure rates from MIL-HDBK-217F

Fault Tree Analysis - Conclusion

	Probability of Failure	***Reliability of Circuit***
Power	0.583%	99.417%
Temperature	1.121%	98.879%
Pressure	3.634%	96.366%
Communication	0.655%	99.345%

- Reliability of the circuits are within performance specifications
- Moisture failures to be explored further

Moisture Diffusion

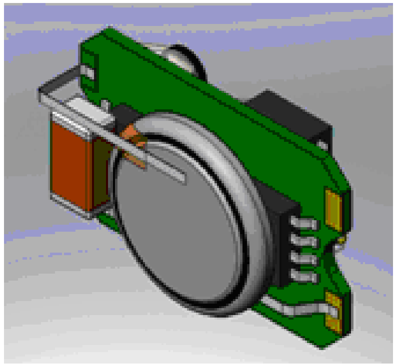
- Over a period of time moisture diffuses through body material and can reach electronics
- Moisture, if present between two nodes of any component, act as an additional resistance causing low resistance thus resulting in rapid discharge of battery
- Moisture can also completely short circuit any component on the circuit board

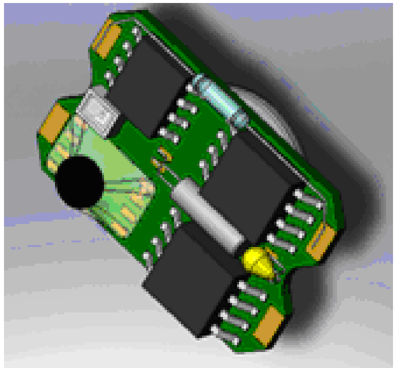
Moisture Diffusion

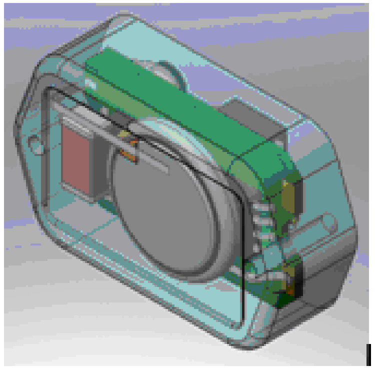
- Moisture also induces;
  - hygroscopic stress through differential swelling,
  - reduces interfacial adhesion strength,
  - induces corrosion and acts as an unwanted resistance when present between the two nodes of component and result in lowering the resistance which results in faster depletion of budgeted power.

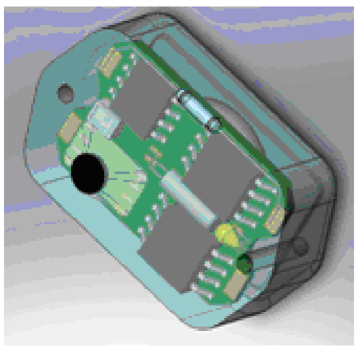
Water Penetration

- Penetration of water to electrical circuit
  - Through cracks in plastic encapsulation body
  - Through material by diffusion

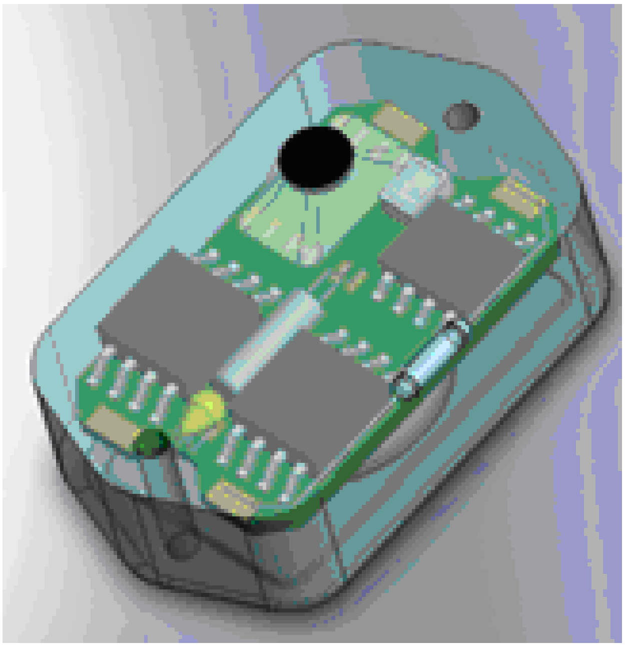


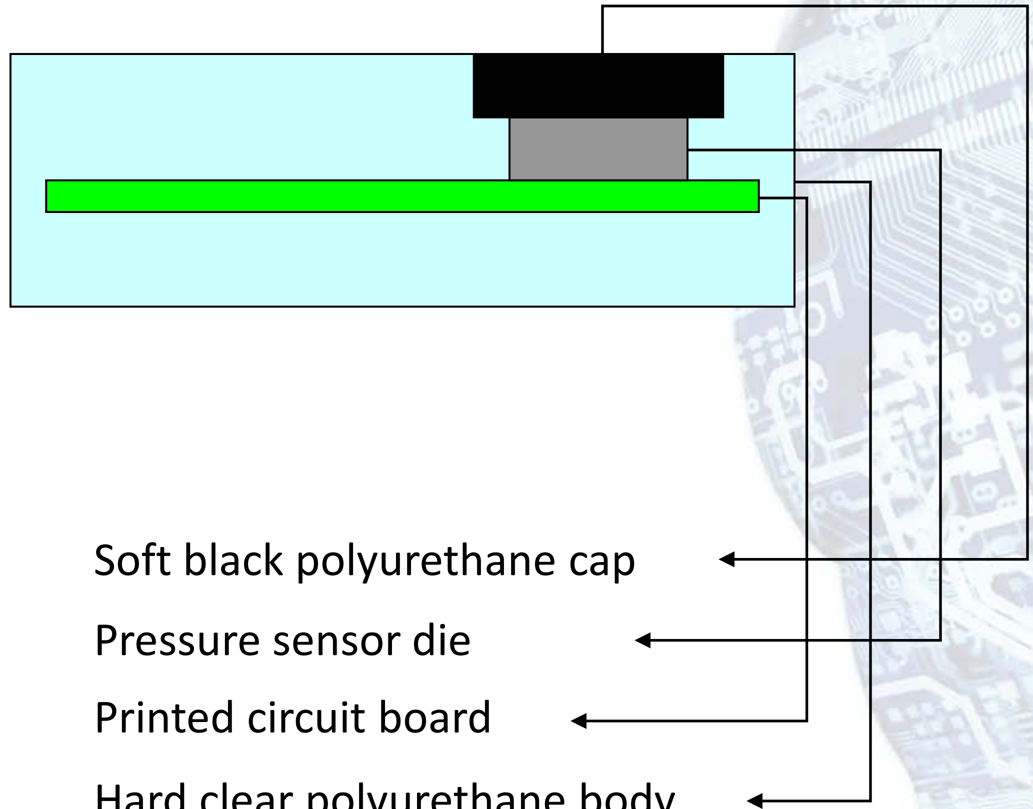






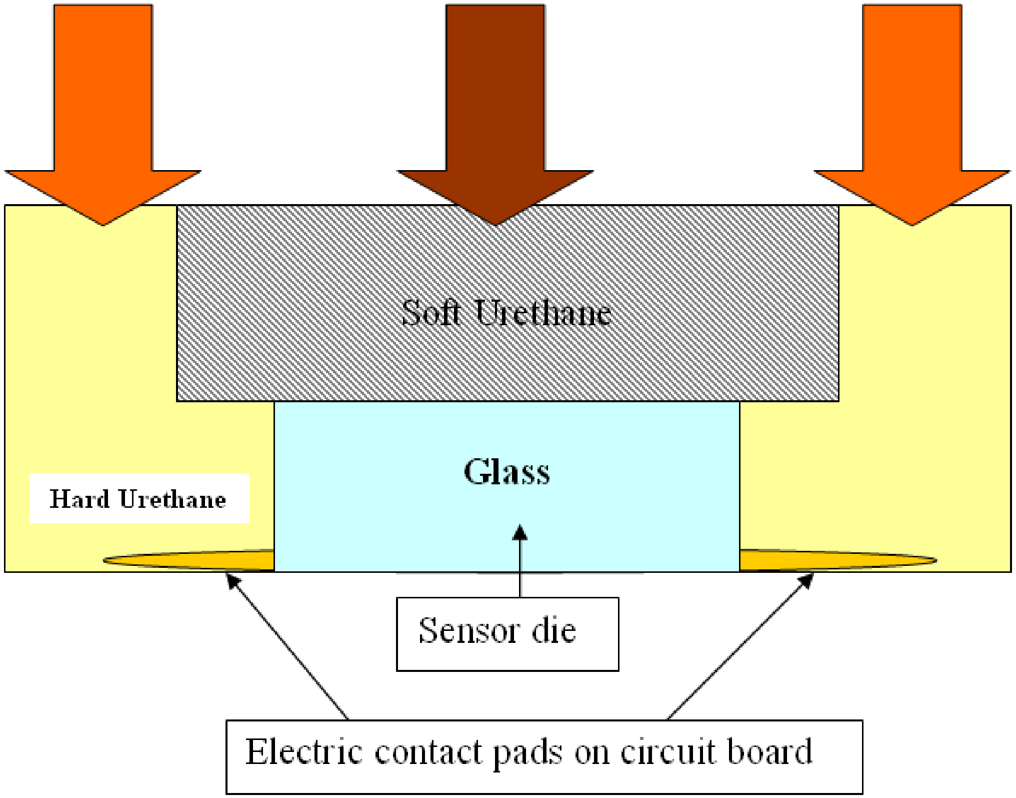
Plastic Encapsulated Electronics





Moisture Diffusion

Moisture diffusion through material



Calculating Diffusion Coefficient

- The diffusion coefficient was experimentally determined using absorption data (M_t/M_∞) by weight gain experiment as prescribe in ASTM D570 method
- Theoretical Fickian curve is plotted with the experimental data to see if the absorption is Fickian or not
- The 99% saturation approach helps to define the limit of Fickian diffusion hence eliminate error caused by non-fickian absorption

Diffusion Ingress Rate

- Material datasheet provided by manufacturer provides the values for M_t/M_∞ obtained experimentally through weight gain experiment (ASTM D570), *crank 1956*

$$D = \frac{\pi}{16}\left[\frac{M_t / M_\infty}{\sqrt{t} / h}\right]^2$$

Where,

M_t = total mass of the moisture absorbed at time t
M_∞ = Equilibrium mass of the absorbed substance
h = total sheet thickness (mm)
D = diffusion coefficient (mm^2/hr)

$$t_{99\%} = \frac{0.45\,h^2}{D}$$

Where,

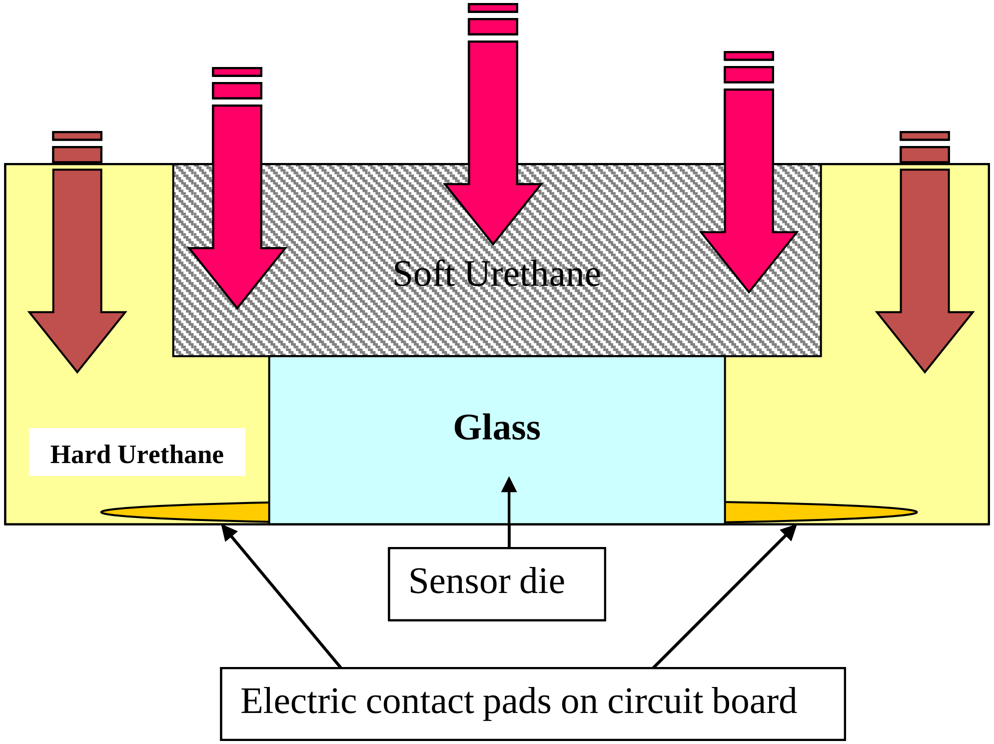
$T_{99\%}$ = time to approach 99% saturation
h = height or the thickness of the specimen
D = diffusion coefficient

Wong, E.H., et. al 2002
Shafaat, Junaid, et. al. 2009

Error introduced by 99% saturation is limited to 3% for D

Diffusion Ingress Rate

	Soft Polyurethane	Hard Polyurethane
$t_{99\%}$	178 days (6 months)	2523 days (7 years)



FEA Simulation of Moisture Diffusion

- Process of moisture ingress is similar to transient heat conduction
- Heat Transfer simulation software can be used for moisture diffusion study
- Since the Fick's moisture diffusion equation follows the same governing differential equation as the diffusion of heat, with a change of the dependent variable, temperature, with moisture concentration and the thermal diffusivity with moisture diffusivity, commercially available heat transfer simulation software can by used to solve transient moisture diffusion problem.

FEA Model for Moisture Diffusion

Variables Map

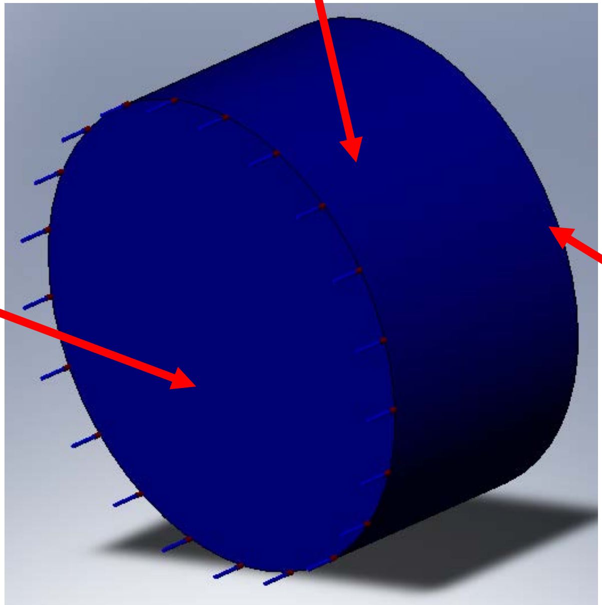
Heat Transfer (Temperature, T)	**Moisture Diffusion (Moisture Concentration, C)**
ρ, **Density** **(kg/m3)**	1
K, **Conductivity** **W/(m.K)**	D, Diffusion Coefficient (mm^2/hr)
C_{p}, **Specific Heat** **J/(kg.K)**	1

FEA Model for Moisture Diffusion

Boundary Conditions

Face 2

Moisture Concentration: x,y,z = 0,0,0



Face 1

Moisture Concentration: x,y,z = 1,1,1

Face 3

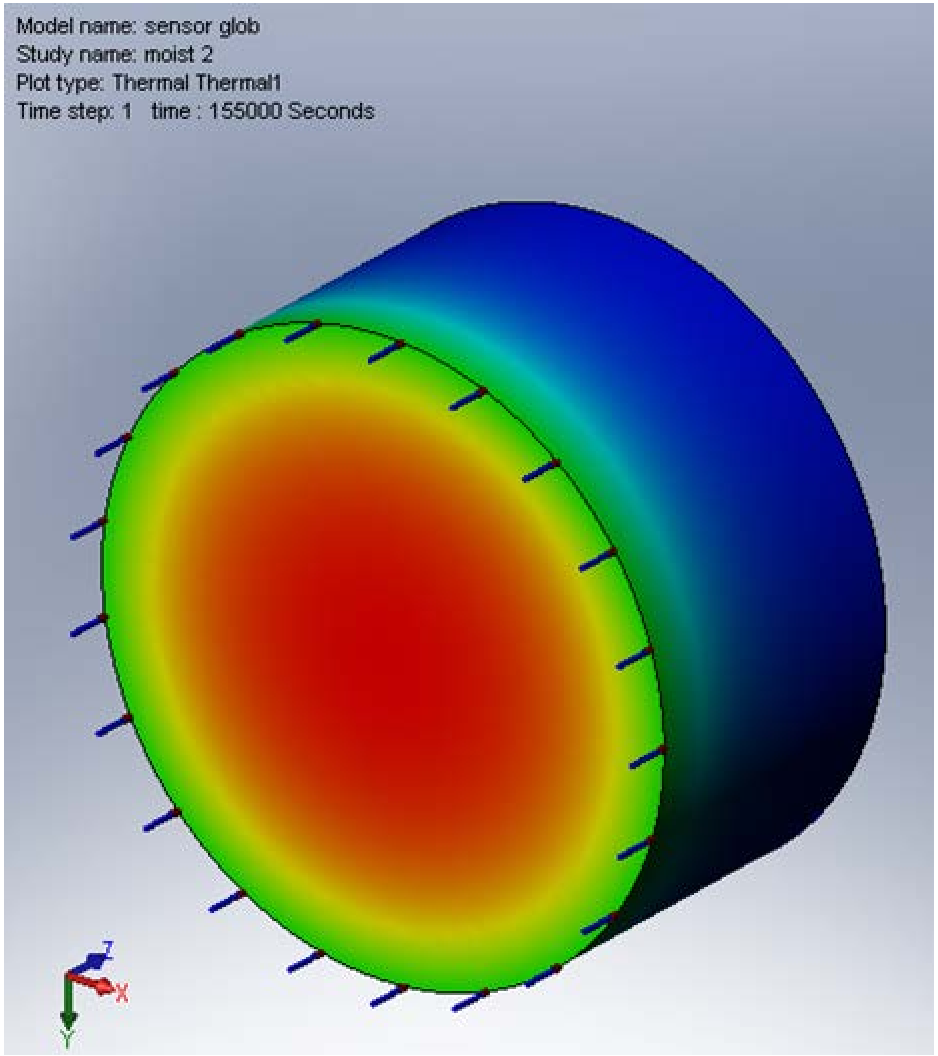
Moisture concentration: x,y,z = 0,0,0

Where;

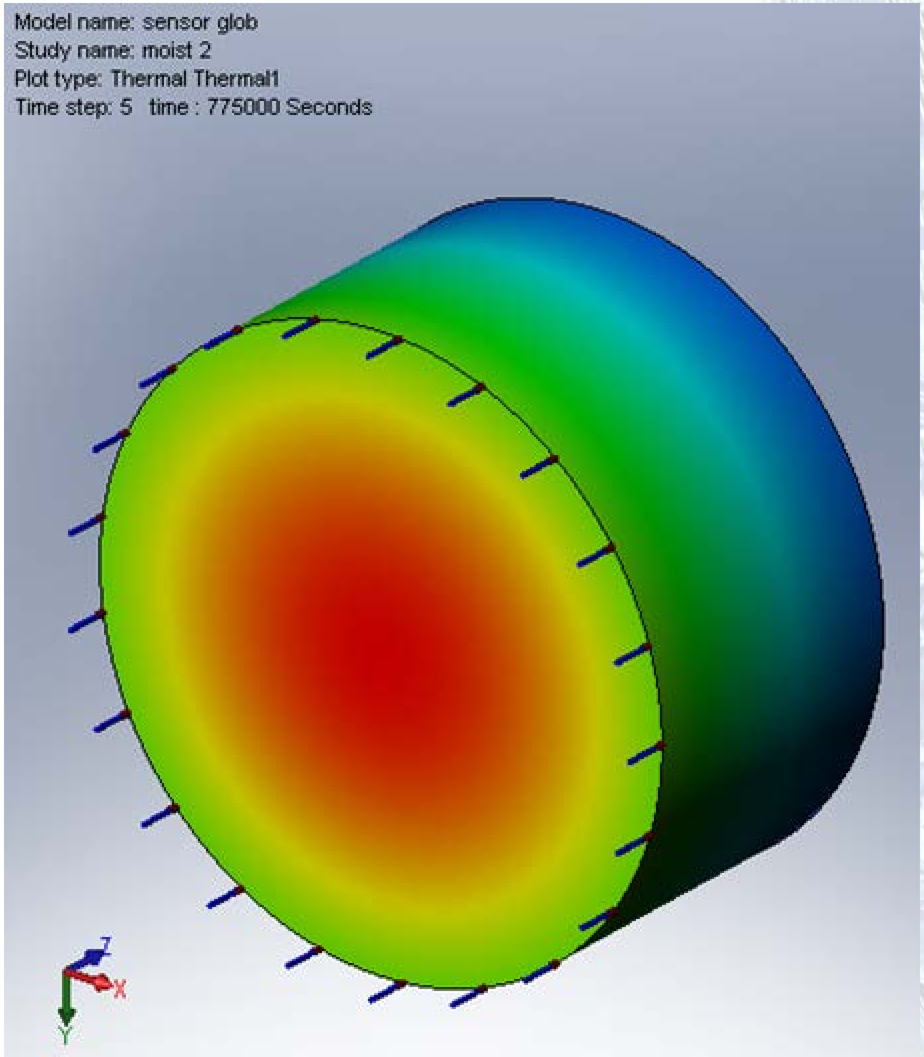
C = 0 for complete dryness

C = 1 for saturated wetness

FEA Moisture Diffusion Results

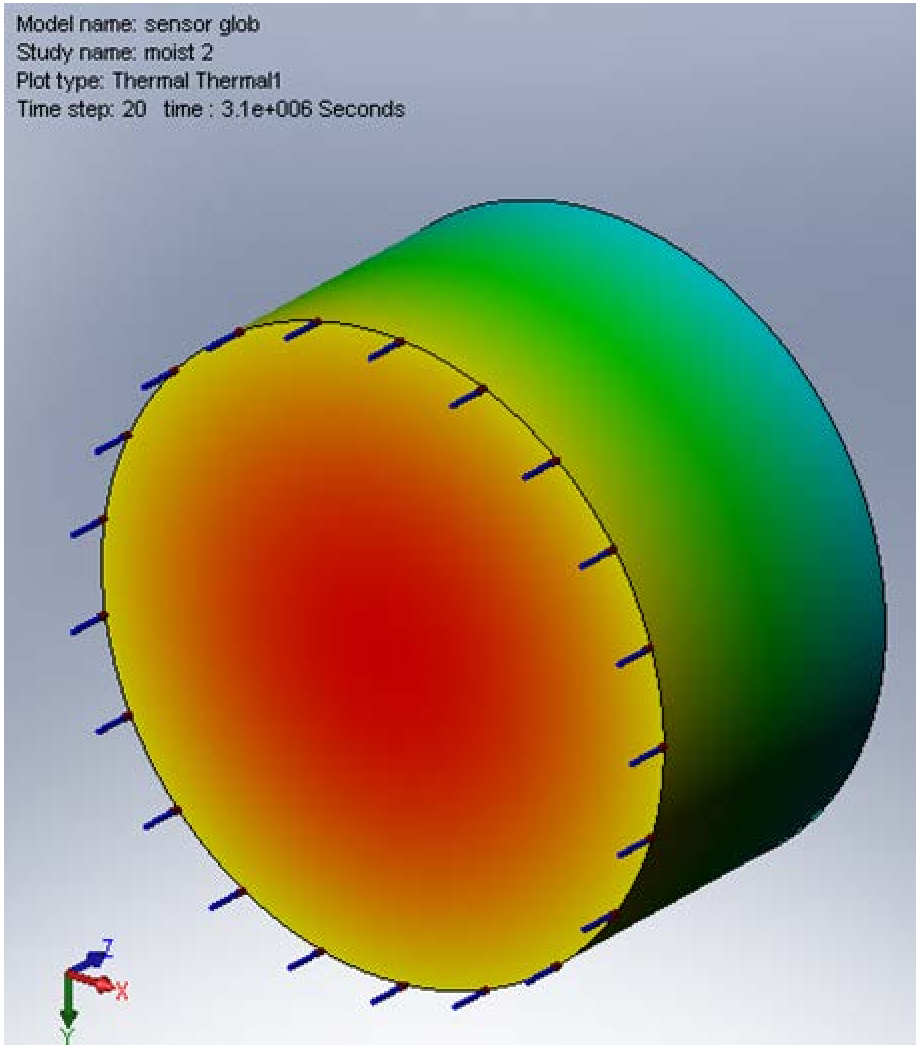


1.8 days

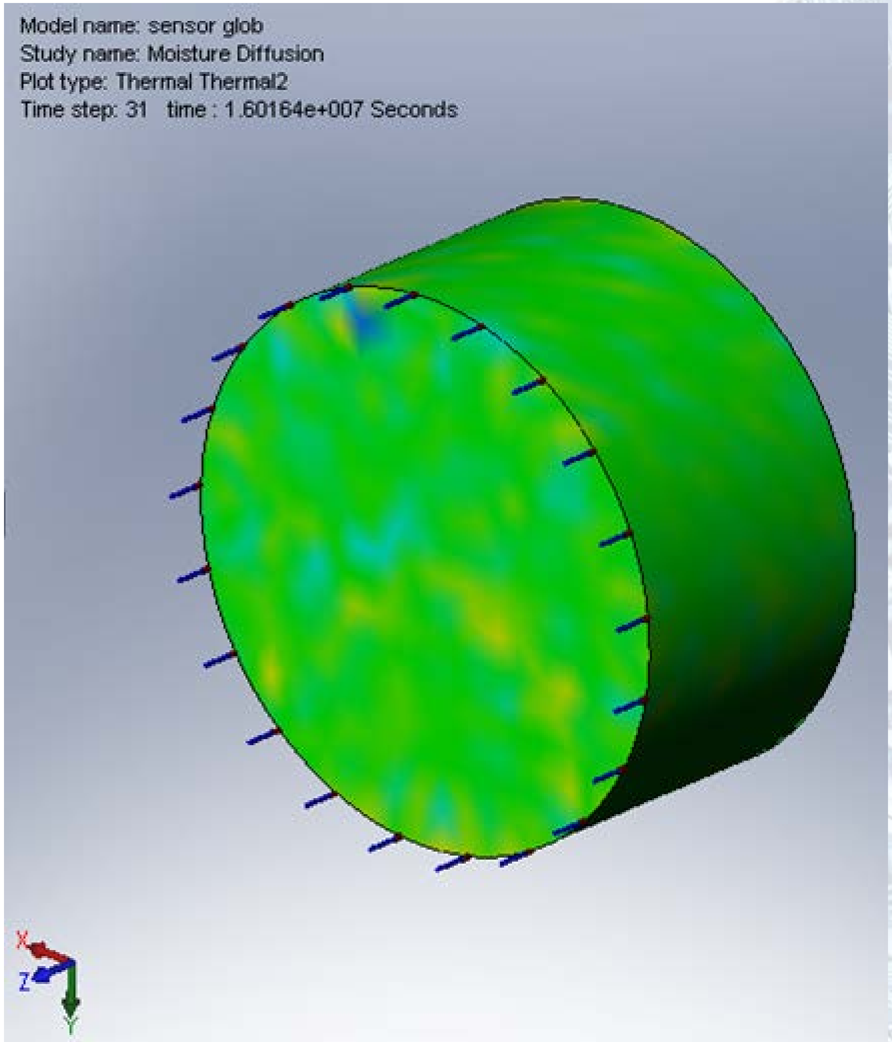


10 days

FEA Moisture Diffusion Results



35 days



185 days

Moisture Diffusion Results

- It takes approximately 6 months for soft polyurethane to saturate 99% with moisture, whereas approximately 7 years for hard polyurethane.
- Moisture to reach interconnect of pressure sensor which is below the pressure sensor die surface should take more time
- FEA simulation and calculated values match closely

Moisture Ingress Rate (Soft Black Polyurethane Cap)	
Calculated	178 days
FEA	185 days

Conclusions

- "Power Failures" are due to presence of moisture
- Moisture breaching plastic body of tag by diffusing through soft polyurethane cap is causing low resistance across component(s) resulting in power failures and/or component failures

Q & A