Tyco Electronics

ICC Educational Session, Cable Accessory Didactic

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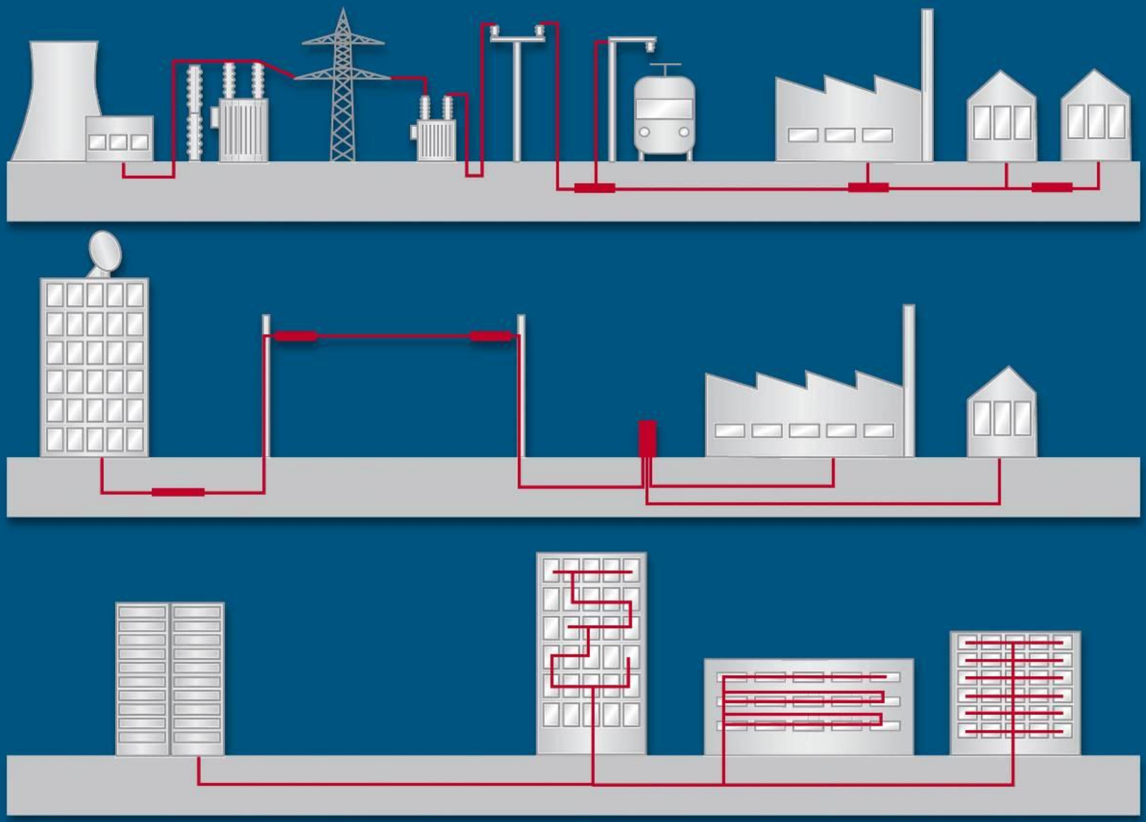
Cable System Applications

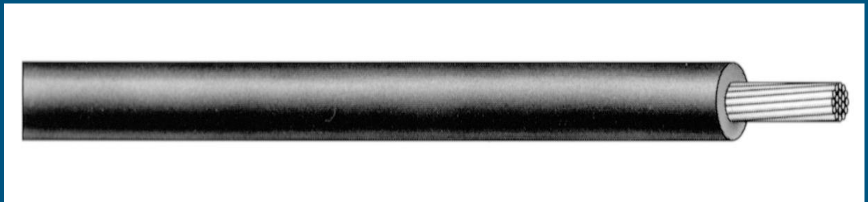


Energy- Grid to Residential

Communication Service Providers (including under sea)

Building Networks

Typical UG LV Cable Construction



- **Conductor**
  - Carries Current Efficiently
  - Copper (Cu) or Aluminum (Al)
  - Different shapes: Concentric, Compact, Compressed, Sectored (3/C)
  - Moisture Blocking Filler
- **Insulation**
  - **Generally Inexpensive compared to MV**
  - **Provides the 3 main requirements:**
    - **Mechanical Protection- conductor**
    - **Environmental Seal- chemical attack**
    - **Electrical Insulation- retains voltage**
  - **Materials include PE, XLPE, EPR, TP**
  - **Typical Ratings: XHHW, THHN, TW, USE**

Remember:

P-S-I

Good Cable & Accessory System Balances Material Properties & Economics to Suit Application

- **Stranding Versus Solid: applies to conductor only**
  - **Solid: non-vibration applications**
  - **Stranding: flexibility & vibration resistance**
- **Conductor or Connector (accessory)**
  - **Cost: aluminum is typically less expensive**
  - **Power required: higher power can drive towards copper**
  - **Environment: copper is usually more corrosion resistant & can tin coat**
- **Insulation: applies to cable & accessories**
  - **Toughness: direct buried, conduit, tray, drag, etc.**
  - **Flexibility: application, installation & seals**
  - **Environment: bulk material substrate & sealing medium (adhesive, mastic, gel, grease or interference/grommet)**
    - Chemical & biological: hydro carbons, fungus, acids, etc.
    - Temperature: low and/or high
    - Radiation: solar and nuclear

MV Cable Systems: Must Address the LV Requirements plus High Electrical Stresses

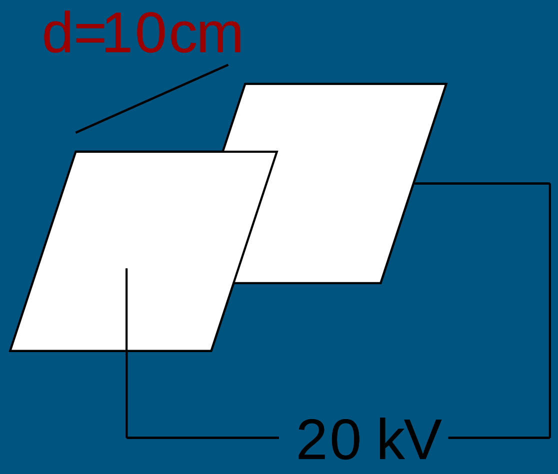
- What is Electrical Stress?
  - **Electrical Stress *E*** is the force applied on a medium to move a unit charge.
  - **Electrical Stress *E*** is the applied voltage divided by the linear distance.
  - Air is an insulator under 21.6 kV/cm
  - Above this stress level air is a conductor and not a very pleasant one with a lot of moving charges:

$$E = \frac{V}{d}$$

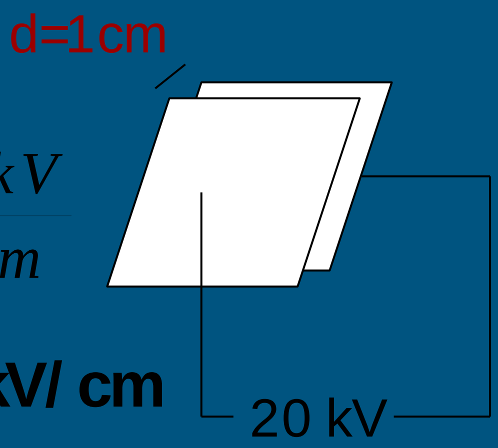
- **Lightning is a good example.**

Electrical Stress- Voltage and Distance

- **Electrical Stress** requires a potential difference (voltage V) but is dependent on the distance (D) that divides this potential:



$$E = \frac{20kV}{1cm}$$



E = 20 kV/ cm

$$E = \frac{20kV}{10cm}$$

E = 2 kV/ cm

Electrical Stress calculations with the same voltage and different distances

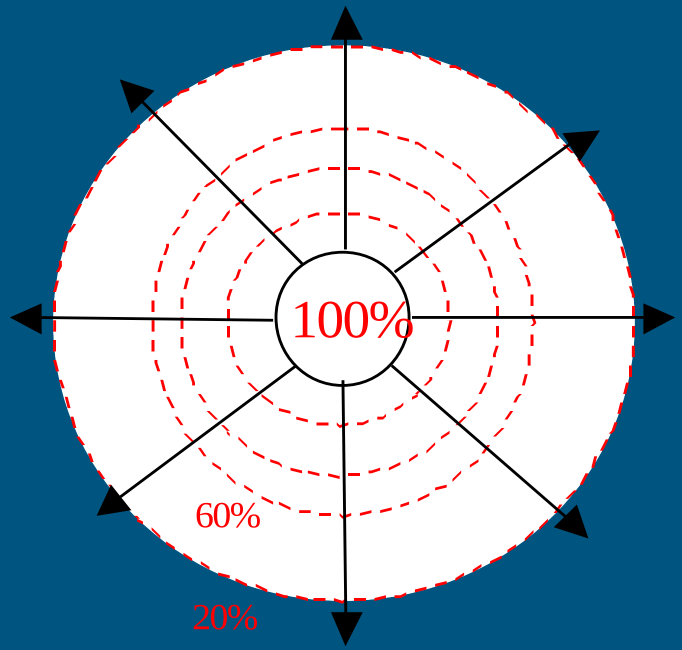
Working Voltage and the stresses in LV through MV cable insulations

- Dielectrics are classified by their breakdown and working voltages
- Working voltage is the voltage that an insulation system can operate at for a systems designed life
- As the cable voltage class increases, the working voltage stress levels increase significantly. This means that the cable system has less and less margin or tolerance for manufacturing defects & workmanship deficiencies.

Cable Class	Nominal Insulation Thickness	Typical Applied Voltage or Es	Operating Stress
600 V	60-110 mils	300V L-G	300/110=2.7 – 5 V/mil
15 kV	175-220 mils	8000 V	8000/175= 45.7 V/mil
25 kV	260 mils	14.4 kV	14400/260= 55.4 V/mil
35 kV	345 mils	20.2 kV	20200/345= 58.5 V/mil

Cable Electrical Stress Distribution & Flux without the Influence of a Ground

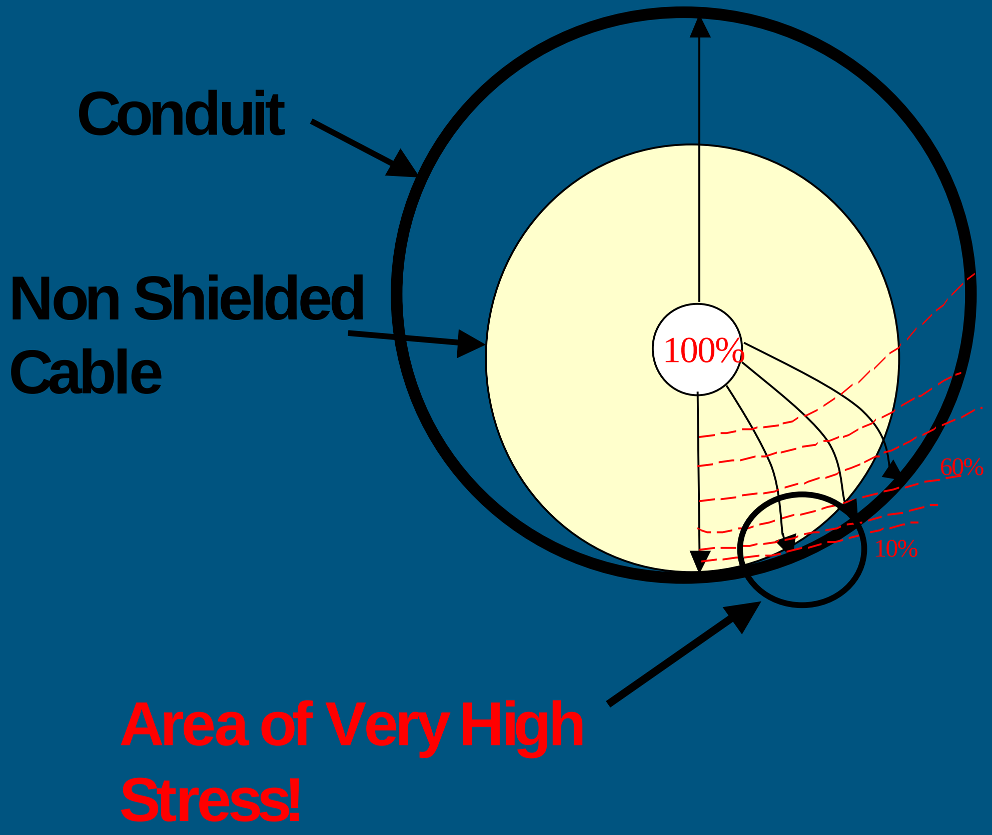
- **Without a Ground Plane** electrical field is radial and symmetrical.
- **Equipotential lines** are concentric circles. Basically the voltage drop across the insulation.
- Flux lines are perpendicular to the electrical stress or equipotential lines (current being pushed through the insulation). All insulations leak.
- This is also true if the insulation is very thick.



Cable Stress Distribution Influenced by a Ground Plane

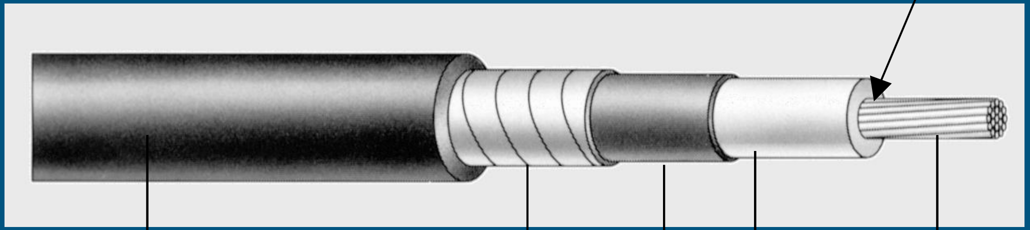
- Non Shielded Cable in a conduit influences the electrical field non uniformly. Field lines bend to ground plane at contact area.

- The Equipotential lines are also bent and produce high potential difference over small distance = High Stress.



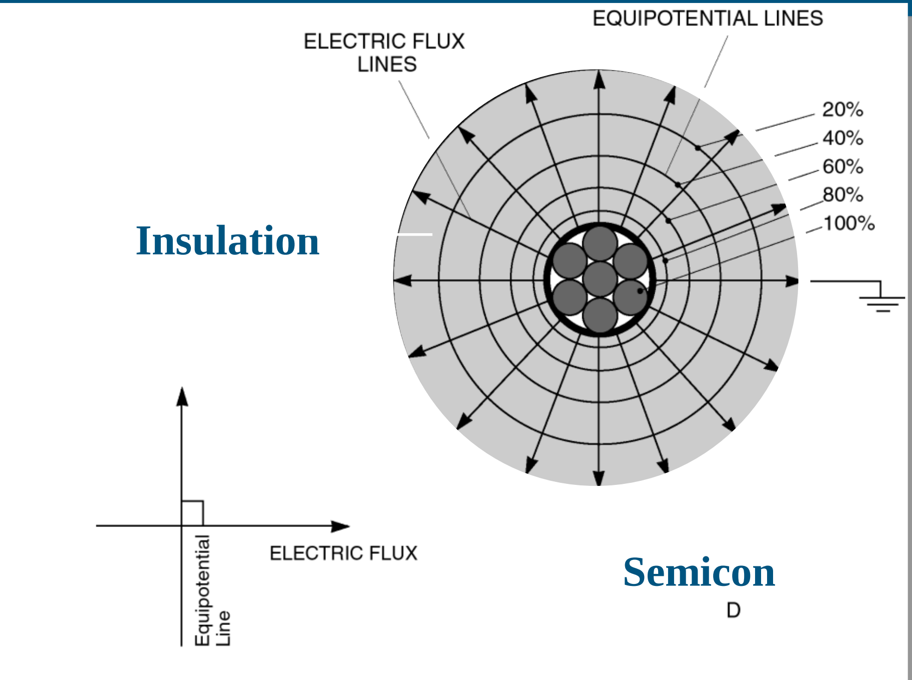
MV Cable Design to Manage Electrical Stress, Economics & Installability

- **Conductor**
  - Carries Voltage and Current
- **Strand Shield**
  - Fills in voids in conductor strands
- **Insulation**
  - EPR/XLPE/PILC
  - Provides Electrical Insulation
- **Semicon Shield**
  - Confines E field into insulation
  - Bonds to Insulation: Eliminates air voids
  - Symmetrical Ground Plane
- **Metallic Shield**
  - Improves Semicon conductivity
- **Jacket**
  - Provides Mechanical Protection and Seal



Why is MV Shielded Cable such a Clever Design?

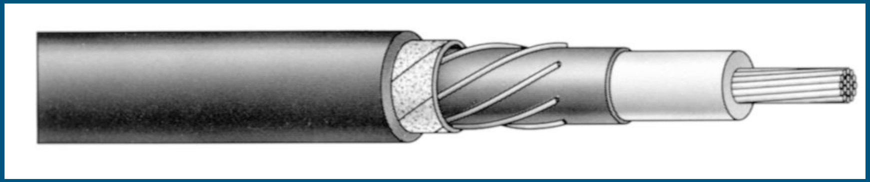
- The semicon shield places the ground plane equally around the conductor
- Flux lines become symmetrical
- Electrical Stress is reduced at conduit contact
- E field is contained in dielectric insulation
- Cable is safe to touch
- Cable has symmetrical ground path for leakage or fault currents
- Cable is compact for handling
- Cable is economical to manufacture and deploy
- Cable system life meets industry requirements



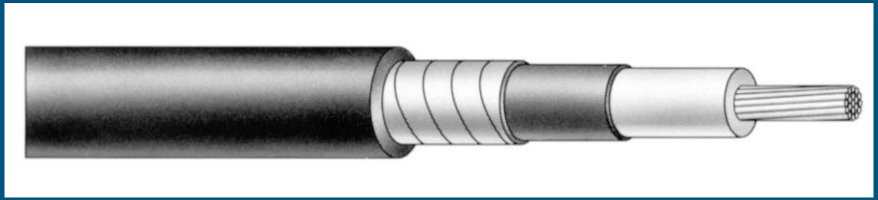
Equipotential lines are always normal (perpendicular) to electrical flux lines

Some Typical Cable Constructions

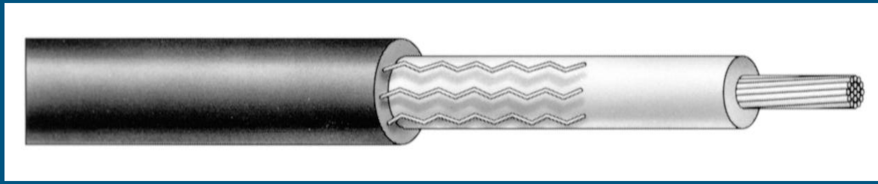
- **Wire Shield or JCN**
  - JCN has large wires and is a Utility cable



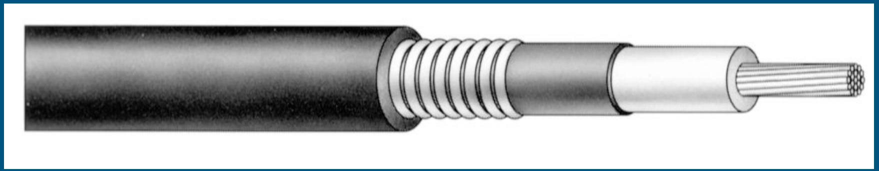
- **Metallic Tape Shielded**
  - Usually EPR and an Industrial or large feeder Utility



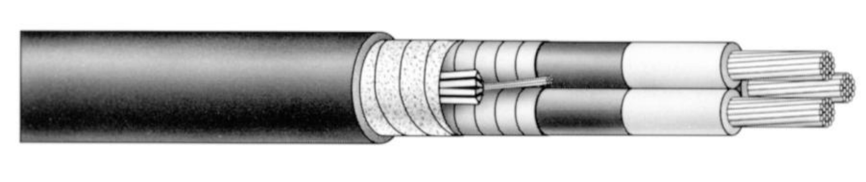
- **UniShield**
  - EPR Industrial cable with drain wires IN THE SHIELD- Shield is the Jacket



- **LC Shielded Cable**
  - Utility Premium EPR Cable



- **3/C Armor**
  - Industrial Cable at Paper mills & Large facilities



So Since the Cable Engineering Design is so Clever, why are there problems in the Field?

- ***To splice & terminate the cable the first thing that must be done is to mess up all of the great cable engineering***
- Damage from transit, handling and installation allows the environment to access the cable's interstices
- All organic materials degrade with stress. These can be temperature, radiation, chemical, mechanical & electrical, especially if they are exposed to extremes or long durations.
- Great care must be taken during manufacturing such as:
  - Compound formulations, quality & cleanliness
  - Extrusion speeds, temperatures (both extrusion & curing)
  - Take up & spooling
- Same is true for field working conditions. Importance increases with the cable system voltage

Preparation & Workmanship

- End cuts- Square & uniform to allow proper tool depth setting
- Tool setting- Knowledge & skill to select, set & use tools properly
  - Right dies
  - Right number, location and application of crimps
  - Stripping tool set-up
- Conductor damage issues- typically longitudinal scores are not an issue, but any circumferential scores can cause the conductor to break with cycling
- Cleanliness- contamination creates failures & as voltage stress increases so does the degree of cleanliness (and good cable preparation or stripping)
- Checking connector & accessory match-right product for the right applications

Good Cable Accessory Design Considerations

- Sealing: conductor, jacket & body (pressure retention for PILC & some polymer systems)
- Weathering & environment stable: includes chemical, heat & biological
- Stable material properties that are compatible with the cable system materials
- Good thermal design: minimal trapped air, uniform and stable interfacial pressure, & no cable choke points
- Repeatable installation by trained workforce in the environments required
- Economical

Terminations Design Requirements & Definitions

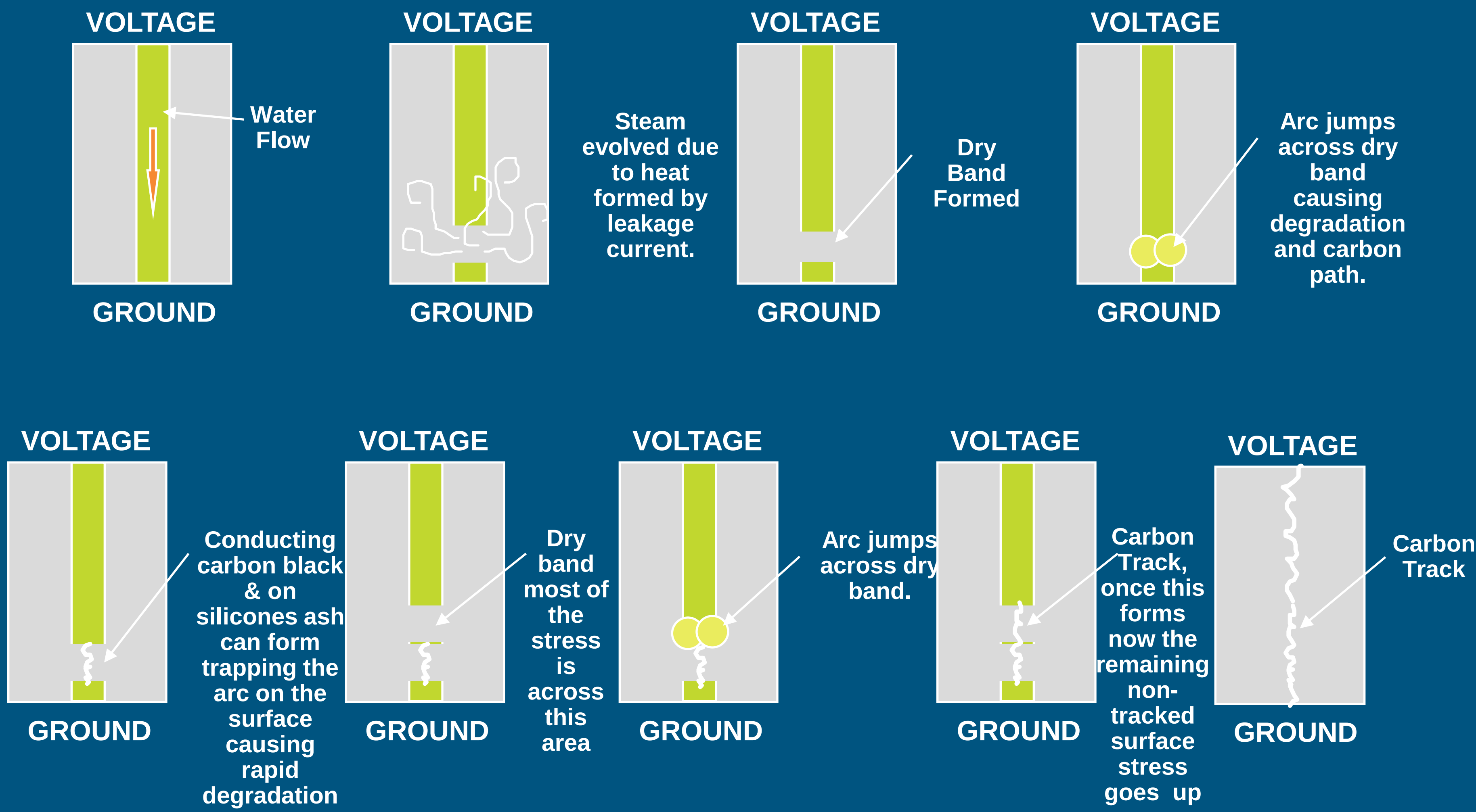
- Design requirements:
  - Terminates the insulation shield of a power cable
  - Provides tracking and erosion resistance
  - Provides a environmental seal
- Application definitions:
  - Device fitted to the end of a cable to ensure electrical connection with other parts of the system and to maintain the insulation up to the point of connection.
  - Indoor termination**:** Termination intended for use where it is **not exposed** to either solar radiation or weathering.
  - Outdoor termination**:** Termination intended for use where it **is exposed to** solar radiation or weathering or both.

Termination Design & Important Terminology

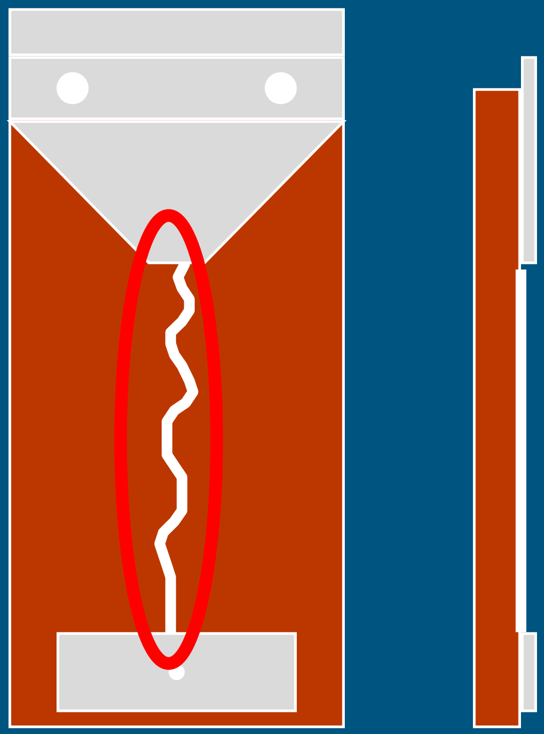
- Expected life-time > 40 years.
- Must meet relevant standard
  - IEEE 48.
- Easy, reproducible field installation.
- Termination lug
  - Lug to meet relevant specification, (ANSI 119.4)
- Stress grading
  - Axial and radial stress.
    - ≤max. E-stress of the cable.
    - ≤break-down stress in air.

- Dry Arc distance.
  - In accordance with national / international standards.
- Creepage distance.
  - In accordance to pollution levels.
- Environment
  - Track & erosion resistant material i. e. ASTM D2703.
  - Low leakage current under humidity
  - Low water absorption

How Does Tracking Occur?

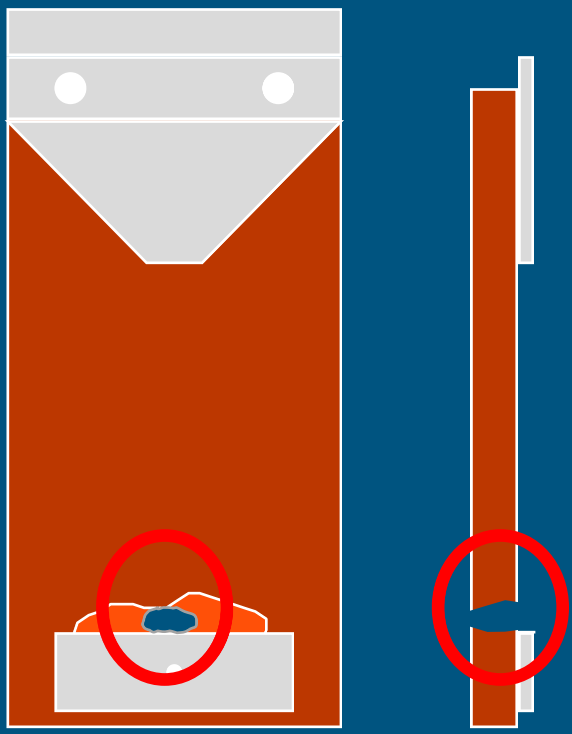


TERT Failure Mechanisms



Sample - Front View   Side View

Tracking failure
(rapid process)



Sample - Front View   Side View

Erosion failure
(slow process)

EXAMPLE OF TRACKING

Outdoor Polymer Material Testing

- Surface properties...ASTM D2303 inclined plane..looks for tracking, flame failure & erosion rate
- Puncture properties..tested as installed..do not rely on material tests alone
- Salt Fog under energized conditions
- Multiple Stress Testing
- <u>It is important to think about the environments materials are exposed to when determining the required testing protocols</u>

Creepage distance selection guide (IEC 815)

	Creepage	ESDD mg/cm^2	Pollution Level
Class 1	16mm/kV	0.03 – 0.06	Light
Class 2	20mm/kV	0.1 – 0.2	Medium
Class 3	25mm/kV	0.3 – 0.6	Heavy
Class 4	31mm/kV	>0.6	Very Heavy

Cable & Accessory Material Characteristics: Heat Transfer

- Conduction
- Convection
- Radiation

Thermal Conductivities at 32F

Material	**k W/mK**
Copper	388
Lead	35
Silicone Oil	0.300
EPDM Rubber	0.180
Air	0.024

Conductor & Insulation Thermal Characteristics

- Average Coefficient of Linear Expansion:

	α (10^{-6}/ °C)
Aluminum	23
Copper	17
Steel	11

$\Delta l = \alpha l \, \Delta T$

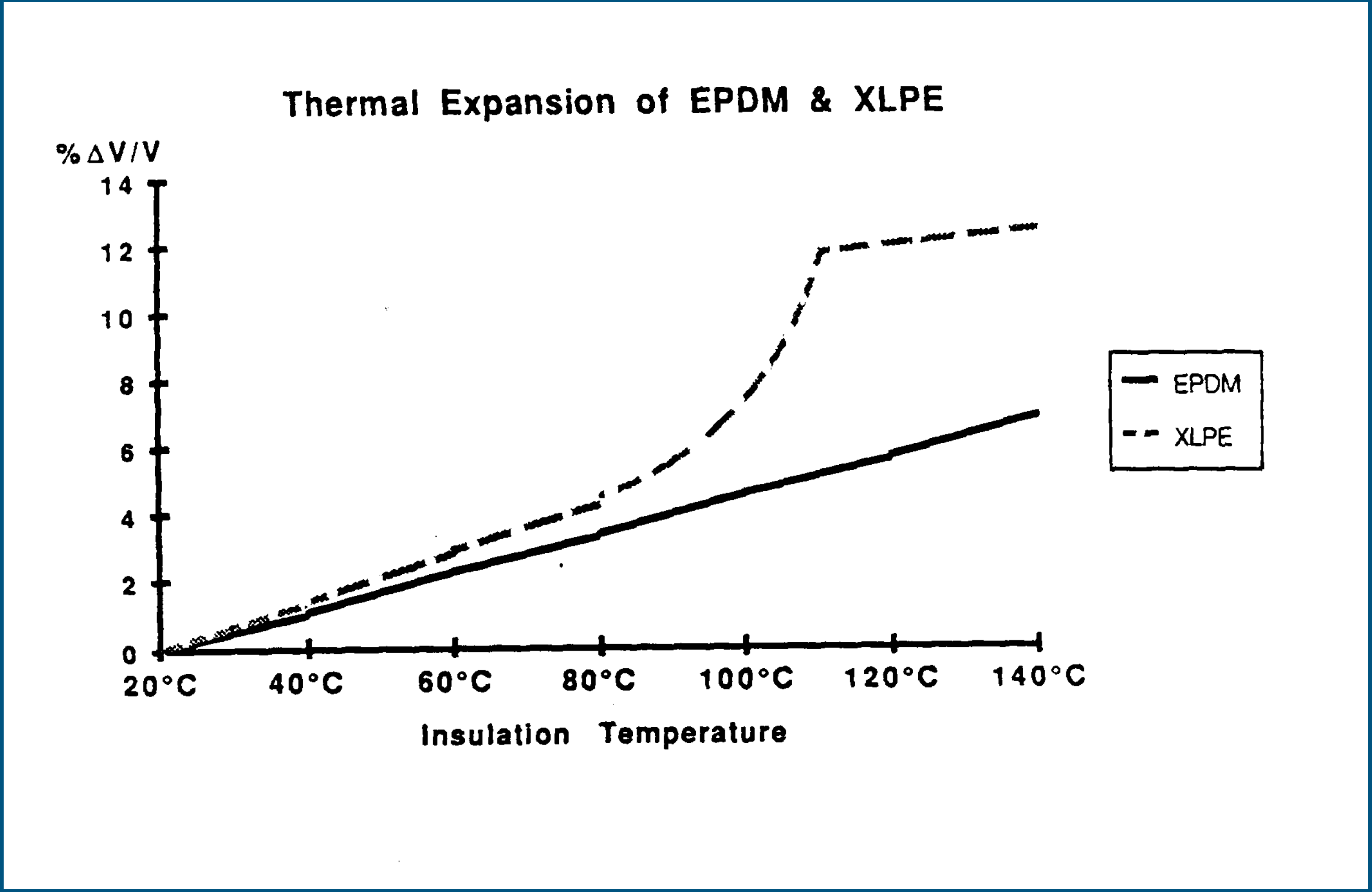
$\Delta V = 3\alpha V \, \Delta T$

- Average Coefficient of Linear Expansion:

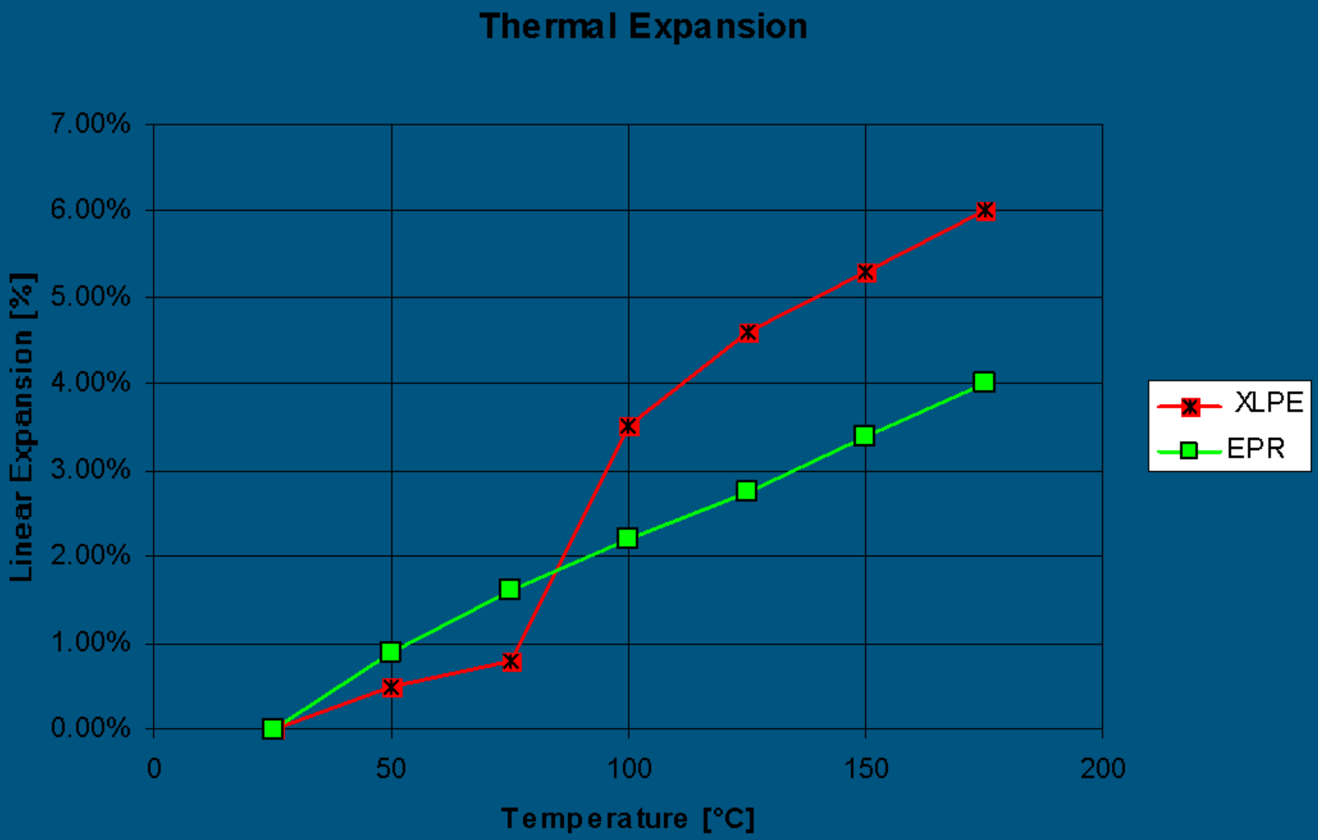
	α (10^{-6}/ °C)
XLPE	100-180
EPDM	80

- Load and emergency operating currents can cause the cable to expand up to 12%.

Insulation Thermal Characteristics: Volume Expansion with Temperature



Insulation Thermal Characteristics: Linear Expansion with Temperature



Cable Accessory Considerations because of Volume & Longitudinal Thermal Expansion

- Are key cutback dimensions going to be affected?
  - Semi-con cutback with stress management
  - Connector shielding or faraday cage
  - Cable and cable jacket sealing
- Will tension set or other basic material property changes affect original design performance?
- Material tension set characteristics can deteriorate dielectric interfacial pressure & sealing, thus the system performance
- Other material properties deterioration can have similar performance impacts

Basic Material Properties- it is extremely important that these properties do not change significantly during the product's design life

- **Tension Set** $$\text{Tension set} = \frac{\text{Recovered length} - \text{Gauge length}}{\text{Strained length} - \text{Gauge length}} \times 100\%$$

- **Tensile strength – Force per area at break**
- **Ultimate elongation – Percentage of original gauge length at break**
    - **M(100) – Nominal stress (MPa) at 100% elongation**
    - **M(200) – Nominal stress (MPa) at 200% elongation**
    - **M(300) – Nominal stress (MPa) at 300% elongation**

- **Shore Hardness: typically A or D (ASTM D2240)**

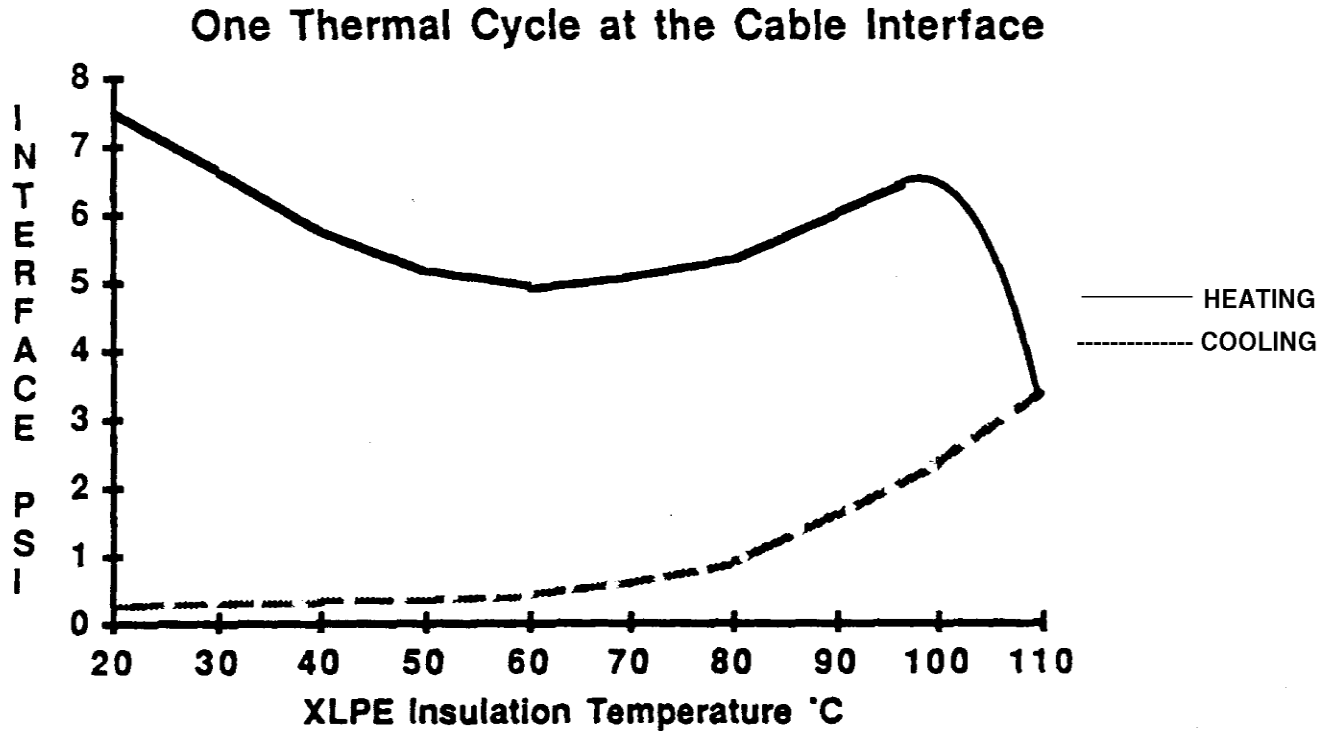
Material	Durometer	Scale
Rubber Band	25	A
Auto Tire Tread	70	A
Soft Skateboard Wheel	75	A
Hard Skateboard Wheel	98	A
Hard Hat	75	D

How are Splice System Insulations Affected by Heat?

- **Hot connectors or overloading increases the splice cable temperature above the glass transition temperature of XLPE**
- **Cable insulation softens, allowing permanent profile deformation**
- **Splice body naturally resists the expansion of the cable, which extrudes the cable insulation away from the splice body**
- **Cable insulation softens, allowing permanent profile deformation**
- **Insulation life, physical, and electrical properties rapidly decrease with increasing operating temperatures**
- **The deteriorating physical properties reduce the splice bodies compressive force on the substrate cable insulation**
- **The permanent deformation of the cable insulation reduces the splice body's compressive force on the cable insulation**

Example of Cable Deformation after Load Cycling

Accessory to Cable Interfacial Pressure after One Load Cycle



Latest Generation Materials & Designs are Addressing many of the Historical Issues

- TR-XLPE & EPR
  - Must keep in mind that EPR leaks more current than XLPE for economic considerations
- Strand blocking to prevent moisture migration
- Linear low density polyethylene: tough & flexible jackets
- Accessory designs:
  - Better environmental sealing
  - Uniform geometries eliminating many of the cable choke points
  - New materials such as LSR allowing more flexibility & easier installaion
  - Air elimination or minimization around connectors to avoid the oven affect
- Shear bolt connectors

Issues with Tolerances & Thermo Mechanical

- Longitudinal movement, outside of things like faraday cages or geometric stress control, even can cause body to move toward smaller conductor side in size transitions
- Grease required to pass initial qualification?
  - What is long-term stability of grease?
  - Require qualification without grease?
- Cable & accessory manufacturing tolerances, variability & drift
- Designs that allow more tolerance for real world installations
- Insulation shrinkback
- General chemical & temperature material property changes
  - Elasticity
  - Tension Set
  - De-polymerization

Don't the Accessory Standards such as IEEE 48 & 404 and ANSI 386 Guarantee that Cable Accessories will Perform?

- ***Std IEEE 404-1993 section 5.3 states****:*

  "The joint shall be designed for operating with the conductor and connector within the joint at the same maximum temperature limitations as those for the conductors of the cables being joined"

- Smallest conductor size in use range.
- No requirement for conductor type.
- No requirement for insulation type.
- No requirement for thermal shock.
- No requirement for product range testing.
- No requirement for connector type.
- 386 for Elbows: completely different test levels & load cycling requirements?

Product Range Testing

- Can qualify by product line by testing only one kit out of the entire series.
- Larger splice bodies take longer to reach cable operating temperatures, thus exert more pressure on substrate cable insulation.
- During cooling cycles, the conductor transfers heat away from the cable insulation rapidly, weakening the interface
- Smaller diameter cables have less electrical stress on the accessory to cable interface and more on the conductor shield
- High end of accessory range has more cable insulation or termination surface stress and the accessory insulation is less because of the larger substrate

What is Thermal Shock and Why is it Important

- Thermal shock occurs when the cable is running hot and is then submersed water.
- Typically occurs during the summer:
  - Hot day with high loads from air conditioners.
  - Heavy afternoon downpour and thunderstorm.
  - Vaults fill or soil becomes saturated rapidly with water.
  - Rapid temperature change causes seals to fail.
- Sealing in general, especially long-term should be looked at closely for all designs.
- LV ANSI tests have thermal shock included

Connector Evaluation Specifically to the System (Cable Type & Accessory) is Critical

- Aluminum connectors can be the weak link in the splice system.
- Air pockets exacerbate the problem by thermally insulating the connector and creating an “oven” affect
- Thermal cycles and high temperatures accelerate creep.
- Thermal runaway is very common.
- Strand fill is problematic to make good connections
- Workmanship is often deficient:
  - Wire brushing
  - Tool & die calibration
  - Proper indents & installation method, ie. Start from the center and work out to avoid loosing crimps in the alternate order

Summary of the Additional Test Requirements Needed

- Test largest and smallest cable diameter in product use range
- Require testing on Aluminum, XLPE cable
- Require a test similar to ANSI C119.1, Section 4.3.10
- Better long-term seal tests are needed
- After test cable and connector inspection
- Criteria for post test pass/fail dimensional changes
- Requirements to test on specialized designs such as strand-fill
- 386 alignment with 404?
- Material property changes, especially after thermal & environmental exposure (UV, chemicals, mechanical & biological)