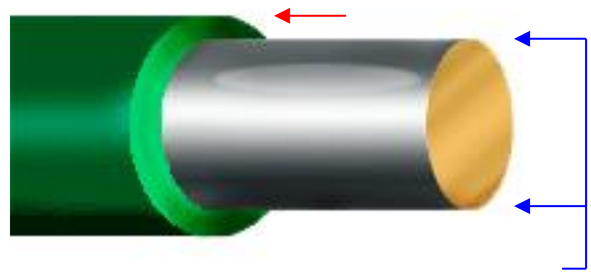
## EIU Course 104: Types of Electrical Insulation Materials (EIM)



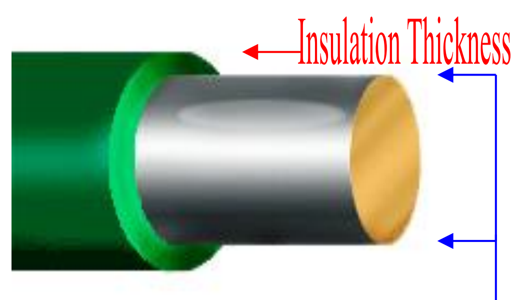
### Section 1 – General Description

Electrical Insulation Materials (EIM) are any of the materials which are used for the purpose of providing an electrical insulation barrier within a device or end-product. There is no real limit to the range of different materials which can be considered for use as an EIM. Basically any material that is not conductive to electrical energy flow (current) can be considered a potential EIM.

No material is a perfect EIM. All EIM allow for some level of electrical energy to pass out of the conductor and into or through the insulating material. Electrical energy passing into but not through the EIM [stored within the EIM] is known as Dielectric Constant of the EIM; electrical energy transferred through the EIM is known as Dissipation Factor when at low levels, and as the Power Factor when the level is higher. The lower the level of electrical energy transfer out of the conductor, the better the material functions as an EIM.

There are many categories of materials which can be identified and selected for use as an EIM.

### Section 2 – General Types of EIM for Conductor Insulation

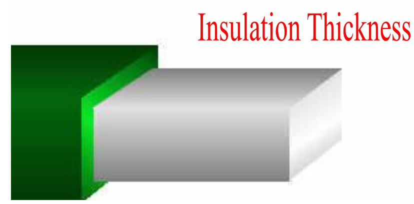



Cross Section of Conductor

*Round Conductor Wire*

#### 2.1 Conductor

While of the natural elements both gold and silver may be better conductors of electrical energy, the most common metals used as the conductor are Copper (-C) or Aluminum (-A). For some applications, the copper or aluminum may be over coated with a metal which gives better conductance for the frequency or processing. Metals such as Tin (Tinned or Tin-coated) pre-tinned for faster soldering, Nickel (Ni-coated) or even Copper Cladding over Aluminum (Copper Clad Aluminum = CCAW) are used.




*Shaped Conductor*

Cross Section of Conductor

The shape of the conductor wires are described as either round or shaped. Shaped is anything other than round - square, rectangular or any other non-round shape.

The cross-section (size) of the conductor is selected based on the current flow required; this is Amperage load. The insulation thickness is determined by the voltage stress encountered during operation; this is Voltage Stress Level.

## 2.2 Magnet [Winding] Wire Coatings and Magnet Wire

**2.2.1** Magnet wire coatings are any of the various chemistries which are applied directly over the conductor to provide an electrical insulation covering. The insulated conductors are tested and evaluated in accordance with Standards, such as NEMA MW 1000 for the US market, or to International Standards, such as the IEC 60213 series. These Standards also provide recommended insulation thickness ranges for various conductor sizes.

*Magnet Wire*

**2.2.2** In the US market, this type of insulated conductor is commonly referred to as a **magnet wire,** since the purpose of the wire is to convert the electrical energy to magnetic energy. The international term is **winding wire,** since the process of use is to wind coils of the insulated wire. The US and International Standards for this type of EIM are almost completely harmonized.

Since there are only a few chemistries used this way, the common types described below are separated into generic types or grades. Generic means the chemistries from different manufacturers are so similar in composition the performance is considered to be the same when used for conductor insulation.

**2.2.3** The most common chemistries of these insulating coatings are:

A. **Polyurethanes**: usually selected because the coating decomposes very rapidly in the temperature range of molten solder, allowing for fast soldering of connections. This is needed for high speed production lines. To have the property of rapid decomposition at solder temperatures limits this chemistry to the lower temperature applications. Thermal classifications of 155C [Class F] and lower are the expected range of applications.
B. **Polyesters**: usually selected for high temperature applications and for applications needing resistance to certain environmental conditions, such as moisture. With high thermal stability, the polyester chemistries do not rapidly decompose in the range of temperatures of molten solder and are considered non-solderable. Polyester chemistries can be modified in several ways to increase thermal stability. If the ester radical is replaced with the modified –amide {A} radical, the stability is much more heat stable. Replacement of the ester or amide radicals with an imide {I} radical provides even better thermal stability.
    a. The level (amount) of ester, amide or imide radicals in the length of the total molecule determines the actual thermal stability.
    b. These groups of insulation coatings are abbreviated with letters to indicate the type of modification.
        i. Polyester = lowest thermally stable
        ii. PEA = Polyester-amide
        iii. PEAI = Polyester-amide-imide
        iv. PAI = Polyamide-imide
        v. PI = Polyimide [most thermally stable]

**2.2.4** Insulation thickness

As stated above, the insulation thickness is defined in domestic or international standards. The thickness selected for an application is determined by the voltage stress level of the application.

In the US market, the thickness levels are defined by words and letters:

A. Single build = thinnest recommended thickness
B. Heavy build = basically double the thickness of single build
C. Triple build = basically three times that of single
D. Quad = basically four times that of single

In the international market, the thickness levels are defined by grade numbers:

A. Grade [Type] 1 = basically the same as Single
B. Grade [Type] 2 = basically the same as Heavy
C. Grade [Type] 3 = basically same as Triple
D. Grade [Type] 4 = basically same as Quad

**2.3 Wrapped or Served Conductors**

**2.3.1** Conductors can be insulated by wrapping the conductor with insulation that is not able to be applied as a liquid and "cured" or processed after the application. Wrapping or serving is accomplished by using tapes, sheets, films or combinations of these materials.

This application of an electrical insulating material is needed when the shape or size of the conductor, or the operating temperature, requires the conductor to be outside of the range that can be handled by magnet/winding wire insulations.

*Wrapped Wire*

In certain situations, the conductor dimensions needed require the conductor to be processed as a foil or wide sheet of conductor; this shape does not lend itself to the application of the insulation using the procedures called magnet wire or winding wire.

**2.3.2** While there are actually only a few EIM utilized for this type of construction, within any established EIS, the conductor may be wrapped with any of the materials tested and identified as a Major Electrical Insulation Material [EIM] for that specific EIS. The most common EIMs used for this construction are flexible sheets/films, or a few types of resins.

**2.4 Single-layered or Multi-layered Wire**

*Multi-Layered Wire*

**2.4.1** The earlier reference to this type of insulated conductor was Triple-Insulated Wire (TIW or TIWW). The original performance requirement being satisfied by this construction was to fulfill the need for a heavier insulated wire with more than one layer of insulation. As industry needs and requirements have changed, the construction and designation has also changed.

**2.4.2** The insulation thickness of this type of insulated wire is many times greater than that of a magnet/winding wire. This increased thickness allows this category of insulated wire to be evaluated for use in some electrical devices as a major insulation without the need for any additional EIM being required. This application allows for designs in which two coils can be wound or placed in direct contact without a separate EIM if the electrical stress level is not in excess of the value evaluated during the EIS test.

**2.4.3** At this time, this category of insulated wires does not have generic substitutability which is common for the magnet wire category. This means that at this time, users of an established EIS cannot interchange or substitute one vendor wire for another.

## 2.5 Appliance Wire

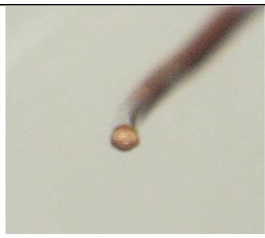
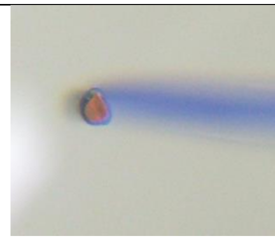
**2.5.1** Appliance wire is similar to single and multi-layered wire in the basic construction; i.e., thick-walled insulation. However, this category has different performance requirements and is therefore a separate category.

**2.5.2** This type of heavily insulated conductor has been used for applications such as the sensor loop in transformers.

## 2.6 Key properties for this category

- Adhesion
- Flexibility
- Initial Breakdown Voltage value
- Long-term retention of performance as an EIM

## Conductor Comparisons

| Magnet Wire | Wrapped Wire | Multi-Layered Wire | Appliance Wire |
|---|---|---|---|
|  |  |  |  |
| Key Properties:<br><br>• Thin Insulation Thickness – Many times smaller than the thickness of the wire | Key Properties:<br><br>• Insulation is wrapped onto the conductor<br>• Tapes, sheets, and films can be used for the insulation | Key Properties:<br><br>• Insulation thickness is many times greater than magnet wire<br>• Multiple layers of insulation | Key Properties:<br><br>• Much thicker insulation than multi-layered wire, oftentimes 100% of the diameter of the conductor<br>• Can have an outer layer of insulation that is a different chemistry than the interior insulation |

## 2.7 Applications

The various types and grades of conductor insulations are used in all types of end-products.

- Motors
- Generators
- Coils
- Transformers

## Section 3 – General Types of EIM for Ground Insulation / Major Insulation / EIM

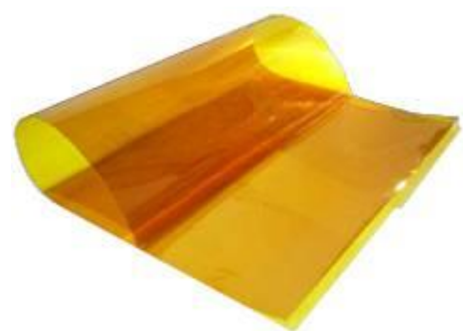
**3.1** This is a very general title for a category of EIM. This category refers to any of the very wide range of materials used to separate

- Coil windings from dead-metal (grounded) parts,
- Sections within a coil operating at different voltage levels
- Phases in motors or generators
- Or to provide protection from electrical shock to anyone coming into contact with energized coils or windings.

**3.2 Films** are a common type of material used in this category. Films are thin sheets with excellent flexibility. Films are non-porous. This characteristic is excellent for some applications, but not beneficial in other applications.

Films are excellent when the application requires a non-porous barrier in the device. But by being non-porous, these products can restrict passage of impregnating resins or varnishes. Being non-porous may also cause some processing problems in designs which need to have air removed from the windings to maximize the penetration of impregnating resins.

Common chemistries used in electrical grade films are Polyethyleneteraphthlate [PET]. Polyethylenenaphthalate [PEN], and Polyimide [PI].



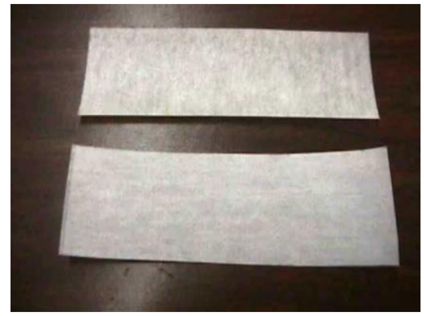
*Film*

**3.3 Fibrous Papers / Sheets** offer the ability of impregnating resins to penetrate the fibers and form a more rigid total product when cured. Fibrous sheets offer increased performance when used with an impregnating resin or varnish. The impregnating resins, or varnishes, fills the voids between the fibers and solidifies the total isolative construction.

When untreated with an impregnating resin or varnish, or when not bonded to a film, the fibrous sheets can be susceptible to migration of moisture. If this were to occur, the moisture can provide a pathway through the fibrous sheet insulation. The insulation characteristics of the sheet material would then be bypassed while not actually causing the sheet material to deteriorate.

Fibrous paper can be made with organic natural fibers, such as wood, or synthetic fibers such as aramid or polyester fibers.

Wood fiber paper is often referred to as Cellulosic paper. It is also known as Electrical Grade paper or Kraft paper. The chemical composition of the wood fibers is determined in part by the soil where the trees grow. Some undesired chemicals can be removed from the fibers during the process of making the fibers into paper sheet.



*Fibrous Paper*

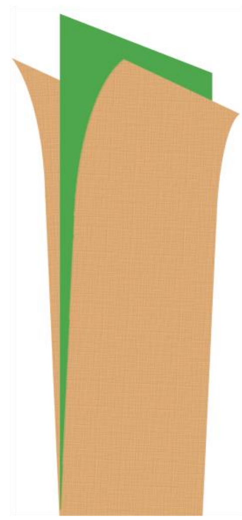
While there are some differences in the chemical composition of the fibers, it is industry practice to consider all sources of electrical grade papers and board to be interchangeable. Due to their organic nature, these products are usually limited to low temperature applications [commonly 90 to 130-class applications] unless tested to confirm higher temperature use is justified.

Synthetic fibers are expected to have a more controlled chemical composition.

Fibers are processed into paper sheet in the same basic manner as regular paper used for writing or printing.

**3.4 Composite / Laminated Sheets** are constructed with two or more layers of materials bonded to each other by an adhesive or by heating.

Common constructions are polyester mat (fibers) bonded to polyester film. The adhesive or bonding material is one of the critical components of any composite sheet. The adhesive / resin can provide an oxygen inhibiting layer which can greatly extend the life at elevated temperatures compared to the life of the polyester film without the adhesive component being part of the total construction.



*Composite Sheet Illustration – layers separated for visual representation*

The most common type of this construction is described as DMD.

Common constructions of composite sheets have the adhesive or bonding resin filling an average of 70% [for example DMD-70] or 100% [for example DMD-100] of the voids in the fibrous layer or layers. This fill level of an oxygen inhibitor component in the composite can significantly increase the thermal performance of the composite.

Composite sheets are also made with combinations of high-temperature films and high-temperature fibrous papers.

**3.5 Tape** is a material which is shaped into a long strip for application. Any construction which is many times longer than wide can be described as being a tape. There are no specified proportions between width and length for this word.

*Non-Adhesive Tape*

A tape may be used as a major insulation material in a specific EIS if the tape was (1) tested as part of the original EIS, or (2) constructed with one of the ground insulation materials in that specific EIS, as long as the thickness meets the requirements of the EIS.

If the tape is made using one of the ground insulation material [EIM], the adhesive or other added components need to be evaluated for compatibility for use with that EIS. The thickness can be accomplished by a single layer or multiple layers of the tape being used; the backing [EIM portion of the tape] is the only measurement being considered when addressing the meeting of insulation thickness for applications related to an established EIS.

**3.6 Pressure Sensitive Adhesive Tape** refers to a tape with an adhesive applied. The adhesive applied may be selected to provide easier application and/or possible increased electrical insulation characteristics.

The adhesive is expected to be B-staged. Adhesives are

described as having three stages:

[1] A-stage: Remains tacky or starting stage, the condition when applied;

[2] B-staged: Processed to a point short of being “cured” or of being fully processed;

[3] C-staged: processed to a cured or fully processed stage.

**3.7 Presspapers** are papers made from organic cellulosic fibers.  The paper is processed through rollers to compress the fibers and provide a smooth surface to the paper.

**3.8 Pressboards** are made from electrical grade papers processed to a thickness to give rigidity. Presspaper refers to thicknesses which are still flexible, while pressboard refers to thicknesses which are inflexible. As the layers of presspaper are bonded or processed together to form pressboard, the bonding may be due to the natural intertwining of the fibers, by heat bonding, or by use of binding resins.

**3.9 Prepreg** refers to paper or board products which are impregnated with a resin during processing as a paper or board. That is, resin impregnated prior to shipment to the user; **Pre**-im**preg**nated board or paper.

*Pressboard*

**3.10 Injection molding resins** are used to form molded components. One very common application is known as a coil form or a bobbin. A coil form/bobbin is used to hold the insulated wire or wires and protect and separate the windings from contact with grounded metal parts.

*Coil Form (Bobbin)*

Molding resins used as ground insulation may be required to exhibit several performance characteristics. These requirements may include functioning as the electrical insulation barrier, providing physical support, holding connection pins, and assisting in dissipation of heat. Each characteristic requires results in the need for formulation of different chemistries.

Each formulated chemistry is expected to be of a unique total chemical composition; therefore, this category does not offer much in terms of interchange or substitutions.

**3.11 Key Properties for this category**

- Flexibility for sheets, films, tapes, papers and composites; rigidity for injection molding resins, pressboard
- Initial breakdown voltage value
- Long-term retention of performance as an EIM
- Initial physical strength

- Long-term retention of performance for physical strength

## Section 4 – Other Types of EIM

**4.1 Impregnating resins** are applied in a liquid form and "cured" or hardened after application. Impregnating resins, by international definition, do not have solvents or components intended to volatize during processing. The resin system may have a co-polymer which is a small molecular size and is used to disperse the larger molecules of the resin. The co-polymer is expected to chemically interact with the resin to form a solid composite.

Impregnating resins are expected to add to the total insulating of the end-product. They can also add to the physical strength.

**4.2 Varnishes** are used in the same manner as impregnating resins. The difference between varnishes and impregnating resins is varnishes have a component which is expected to volatize (evaporate). This component is called a solvent. The solvent may be traditional solvents or water.

*Varn*

**4.3 Encapsulants** are resins which are used to totally enclose a coil or component without being held in place by a housing or shell. An encapsulant must have both physical and electrical insulation strength characteristics. This resin may be used in a manner in which it is the only insulation between the coil winding and the metal core or stack; this situation may be more clearly understood by referring back to the explanation of a Major Insulation Material referenced in section 3.1 above. A mold or shell may be used during processing, but the mold or shell is expected to be removed for application.

*Encapsulant*

The encapsulant may have requirements for heat dissipation such as sound reduction, high physical strength, minimum requirements of electrical insulation, or one of several other characteristics.

**Potting compounds** are not the same as encapsulants. Potting compounds are resins which are similar to encapsulant in terms of processing the material in a mold or housing, except with a potting compound the mold or housing remains in place. Potting compounds cannot be the only material separating the windings

*Potting Compound and Housing*

from the metal core or stack. The potting compound is not expected to be the only material used to hold the coil(s) in a protected enclosure. Therefore, it is a minor (non-electrical insulation) material, which will be covered in more detailed in a separate EIU class.

There may be designs which require a review of the design drawings to clarify if the resin is actually an encapsulation or potting compound application.

**Comparison**

| **Encapsulant** | **Potting Compound** |
|---|---|
| Key properties as a major Electrical Insulating Material:<br><br>• Resin that encloses a component.<br>• Does **not** require housing for support.<br>• Can be used as the only material to hold the component. | Key Properties as a minor material:<br><br>• Resin that encloses a component.<br>• Requires the housing to remain in place.<br>• Is **not** the only material used to hold the component in a protected enclosure. |

### 4.4 Applications

The various types and grades of conductor insulations are used in all types of end-products.

- Motors
- Generators
- Coils
- Transformers

These topics are covered in a separate EIU class.