



IPC-8952

2022 - December

**Design Standard for
Printed Electronics
on Coated or Treated
Textiles and E-Textiles**

An international standard developed by IPC



BUILD ELECTRONICS BETTER



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Design Standard for Printed Electronics on Coated or Treated Textiles and E-Textiles

Developed by the E-Textiles Printed Electronics Design Standard
Task Group (D-73a) of the E-Textiles Committee (D-70) of IPC

Users of this publication are encouraged to
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Acknowledgment

Any document involving a complex technology draws material from a vast number of sources. While the principal members of the E-Textiles Printed Electronics Design Standard Task Group (D-73a) of the E-Textiles Committee (D-70) of IPC are shown below, it is not possible to include all of those who assisted in the evolution of this standard. To each of them, the members of the IPC extend their gratitude.

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Design Standard for Printed Electronics on Coated or Treated Textiles and E-Textiles

1 SCOPE

This standard establishes specific requirements for the design of printed electronic applications and their forms of component mounting and interconnecting structures on coated or treated textile substrates. Textile substrate, as pertains to this standard, could be a bare textile or an integrated e-textile (e.g., woven or knitted e-textile).

Coated or treated textile substrates, as pertain to this standard, are textile substrates which have or will have a coating or treatment localized or across the full substrate.

1.1 Purpose The purpose of this standard is to establish specific design details, materials, test requirements, mechanical properties, physical properties, thermal management, interconnections and quality assurance for printed electronics on coated or treated textile substrates.

Coatings and treatments may be applied for printability of the textile substrate and/or for performance of the textile substrate or finished printed electronics e-textile (e.g., hydrophobic, water retardance, flame retardance, surface energy). Coatings or treatments may be applied using printing, lamination or other processes.

This standard does not cover printed electronics on nontextile substrates that may have some amount of pliability or stretchability (e.g., stretchable films).

1.2 Classification IPC standards recognize that electrical and electronic assemblies are subject to classifications by intended end-item use. Three general end-product classes have been established to reflect differences in manufacturability, complexity, functional performance requirements, and verification (inspection/test) frequency. It should be recognized that there may be overlaps of equipment between classes.

CLASS 1 General Electronic Products

Includes products suitable for applications where the major requirement is function of the completed assembly.

CLASS 2 Dedicated Service Electronic Products

Includes products where continued performance and extended life is required, and for which uninterrupted service is desired but not critical. Typically, the end-use environment would not cause failures.

CLASS 3 High Performance/Harsh Environment Electronic Products

Includes products where continued high performance or performance-on-demand is critical, equipment downtime cannot be tolerated, end-use environment may be uncommonly harsh, and the equipment must function when required, such as life support or other critical systems.

1.3 Measurement Units All dimensions and tolerances in this specification are expressed in hard SI (metric) units and bracketed soft imperial [inch] units. Users of this specification are expected to use metric dimensions. All dimensions ≥ 1 mm [0.0394 in] will be expressed in millimeters and inches. All dimensions < 1 mm [0.0394 in] will be expressed in micrometers and microinches.

1.4 Definition of Requirements The words **shall** or **shall not** are used in the text of this document wherever there is a requirement for materials, preparation, process control or acceptance.

The word “should” reflects recommendations and is used to reflect general industry practices and procedures for guidance only.

Line drawings and illustrations are depicted herein to assist in the interpretation of the written requirements of this Standard. The text takes precedence over the figures.

1.5 Process Control Requirements The primary goal of process control is to continually reduce variation in the processes, products, or services to provide products or processes meeting or exceeding user requirements. Process control tools such as IPC-9191 or other user-approved system may be used as guidelines for implementing process control.

A documented process control system, if established, **shall** define process control and corrective action limits.

This may or may not be a statistical process control system. The use of statistical process control (SPC) is optional and should be based on factors such as design stability, lot size, production quantities and the needs of the manufacturer (see 11.2).

When a decision or requirement is to use a documented process control system, failure to implement process corrective action and/or the use of continually ineffective corrective actions **shall** be grounds for disapproval of the process and associated documentation.

1.6 Order of Precedence The contract **shall** take precedence over this standard, referenced standards and drawings.

In the event of conflict, the following order of precedence applies:

- 1) Procurement as agreed and documented between user and supplier.
- 2) Master drawing, design brief or tech pack reflecting the user's detailed requirements.
- 3) When invoked by the customer or per contractual agreement, this standard.

When documents other than this standard are cited, the order of precedence **shall** be defined in the procurement documents. The user can specify alternate acceptance criteria.

1.6.1 Conflict In the event of conflict between the requirements of this standard and the applicable drawing(s) and documentation, the applicable user-approved drawing(s) and documentation govern.

Some examples of documentation include the contract, purchase order, technical data package, engineering specification or performance specification. In the event of a conflict between the text of this standard and the applicable documents cited herein, the text of this standard takes precedence. In the event of conflict between the requirements of this standard and drawing(s) and documentation that has not been user approved, this standard governs.

1.6.2 Clause References When a clause in this document is referenced, its subordinate clauses apply, unless the requirement references specific subordinate clauses.

1.6.3 Procurement Documentation The procurement documentation **shall** provide sufficient information to the supplier so the supplier can produce printed boards containing embedded active and passive circuitry and ensure the user receives the desired product. The procurement documentation should specify the requirements that can be selected from within this standard.

1.6.3.1 Selection for Procurement For procurement purposes, performance class **shall** be specified in the procurement documentation. The documentation **shall** provide sufficient information to the supplier so that one can fabricate the printed board and ensure that the user receives the desired product. Information that should be included in the procurement documentation is shown in IPC-D-325.

1.6.4 Appendices Appendices to this standard are not binding requirements unless separately and specifically required by this standard, the applicable contracts, assembly drawing(s), documentation or purchase orders.

1.7 Quality Conformance This standard establishes a quality conformance system for suppliers to demonstrate the continual conformance of materials to the quality requirements of the standard. See Section 4 for quality conformance inspection requirements.

1.8 Abbreviations and Acronyms When used, periodic table elements are abbreviated in the standard. See Appendix A for full spellings of abbreviations (including elements) and acronyms used in this standard.

1.9 Terms and Definitions Terms and definitions **shall** be in accordance with IPC-T-50, IPC-T-51 and the following.

1.9.1 Bonded Textile A layered fabric structure wherein a face or shell fabric is joined to a backing fabric, such as tricot, with an adhesive that does not significantly add to the thickness of the combined fabrics. Will pull this if it is not referenced in the standard.

1.9.2 Textile A structure made from any combination of natural or manufactured fibers, having either a measurable staple length or a filament having a continuous length that is woven, nonwoven, braided, plaited, knitted, entangled, twisted or otherwise transformed into a flexible planar configuration.

1.9.3 Textile, Coated Textiles which have additional layers, commonly polymeric, applied to one or both sides via a liquid or aerosol deposition process (direct coating, transfer coating, spray coating, extrusion coating, foam coating, etc.).

1.9.4 Textile, Laminated A textile in which one or both sides have been bonded to a continuous sheet or film material, commonly polymeric.

1.9.5 Textile, Treated A textile which has undergone a mechanical, chemical, or thermal process intended to improve specific characteristics of the textile.

1.9.6 Textile Substrate A textile upon which an electronic structure is built, laminated or otherwise integrated. Textile substrates relevant to this standard may be coated or laminated prior to electronic structure integration.

1.10 Printed Electronics E-Textiles Types Any printed electronics e-textiles design will be incumbent on requirements from the customer, materials to be used and the printing processes. The following printed electronics types represent the known variations

of printed electronics. These types cover all known processes for printing electronics (e.g., screen, aerosol, 3D, etc.). As other types or printing processes are made known, they will be added to this standardized list of types.

The printed electronics type **shall** be specified on the procurement document as agreed upon between user and supplier (AABUS). If the printed electronics type is not designated below, a unique type designation will be used.

Printed Electronics E-Textiles Types

Type 1 – Printing on Textiles With a Planar Surface

This type is specific to printing on coated/prepared* or nontreated/noncoated/unfinished** textiles.

Type 2 – Printing on Textiles With Nonplanar Surfaces

This type is specific to printing on textiles with preformed 3D features. The textiles can be coated/prepared* or nontreated/noncoated/unfinished**. This type does not include microscopic features inherent in textiles.

Type 3 – Integrated Printing of Form and Functionality

This type is specific to simultaneously printing the textile material (substrate) and functionality in a 3D space with no starting substrate.

Type 4 – Transfer Printing

This type is specific to printing electronics on a substrate for pressure or pressure and heat transfer to a textile.

*Coated/prepared textiles include:

- Coating or treatment localized or across full textile
- Coatings added for printing purposes/to accept inks
- Coatings added for other purposes (e.g., flame retardants)
- Laminated (nonwoven) textiles

**Nontreated/noncoated/unfinished textiles include:

- Non-altered textiles (no coating or additives)
- Plain textiles
- Virgin textiles
- Applying coatings over the functional elements after printing

1.11 Standard Printed Electronics Design (SPED) Classifications Standard print electronics design (SPED) types **shall** be in accordance with this section. For purposes of explanation, a basic variation of each SPED is shown in this section.

Each SPED consists of the following components:

- Substrate– Any conformable nonconductive and/or conductive material (e.g., flexible, stretchable, recoverable, extensible, and/or pliable).
- Printed element– Any conductive, semiconductive or dielectric material applied using printing processes.
- Surfaces –The top and bottom sides of the substrate (group wondered if this language makes sense here)
 - First surface is the top of substrate.
 - Second surface is the bottom of substrate.

Each process required to manufacture the finished flexible printed electronic is identified by an alphanumeric designation. The letter F (first/top surface) or S (second/bottom surface) indicates the side of the substrate. The number indicates the print/process step.

For example:

F1 = first print on the first/top surface

F2 = second print on the first/top surface

S1 = first print on the second/bottom surface

S2 = second print on the second/bottom surface

It is important to note that the print/process step numbers can be repeated on each side, because the numbers only apply to printing elements on a specific side.

1.11.1 SPED1 SPED1 has printed element(s), which can include vias between printed conductive elements, on one or both surfaces of a substrate. SPED1 does not have electrical/electronic interconnections from printed element(s) to the substrate.

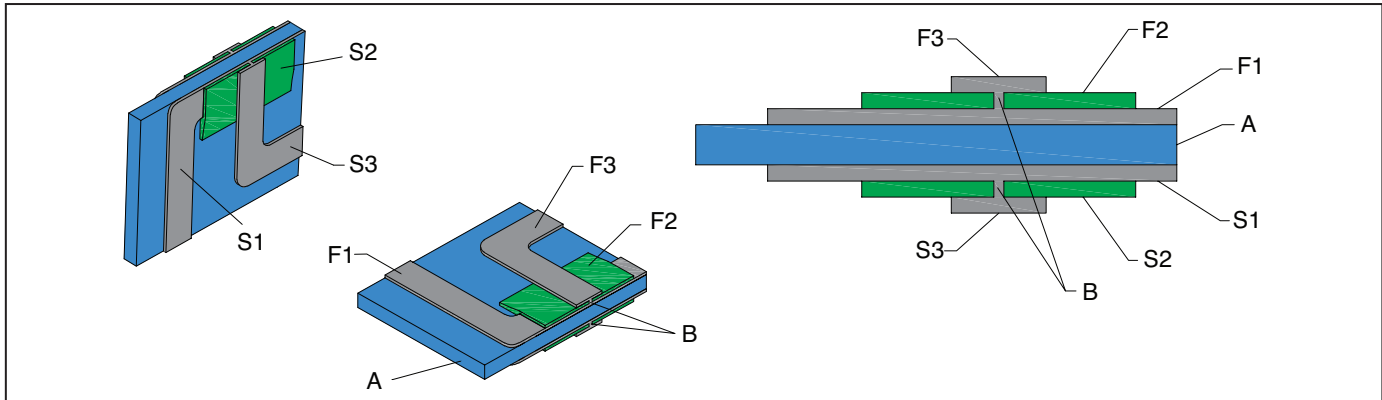


Figure 1-1 SPED1

A – Substrate
B – Via through printed dielectric

Color legend applies to Figure 1-1, Figure 1-2, Figure 1-3 and Figure 1-4.

	Conductor
	Dielectric
	Substrate

1.11.2 SPED2 SPED2 has printed element(s), which can include vias between printed conductive elements, on one or both surfaces of a conductive substrate and which are interconnected to the conductive substrate.

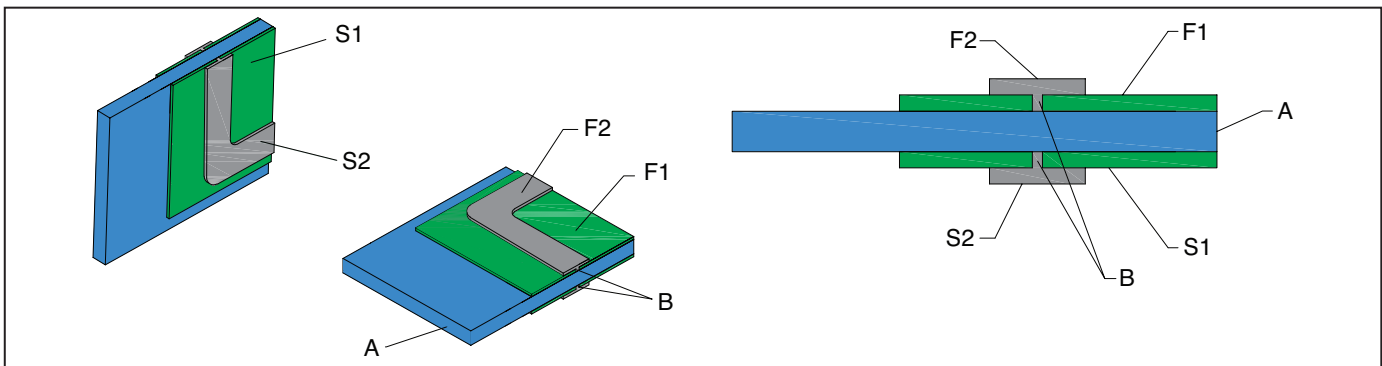


Figure 1-2 SPED2

A – Substrate
B – Via through printed dielectric

1.11.3 SPED3 SPED3 has printed element(s) on both substrate surfaces (F and S), and those printed elements are connected through the substrate(via).

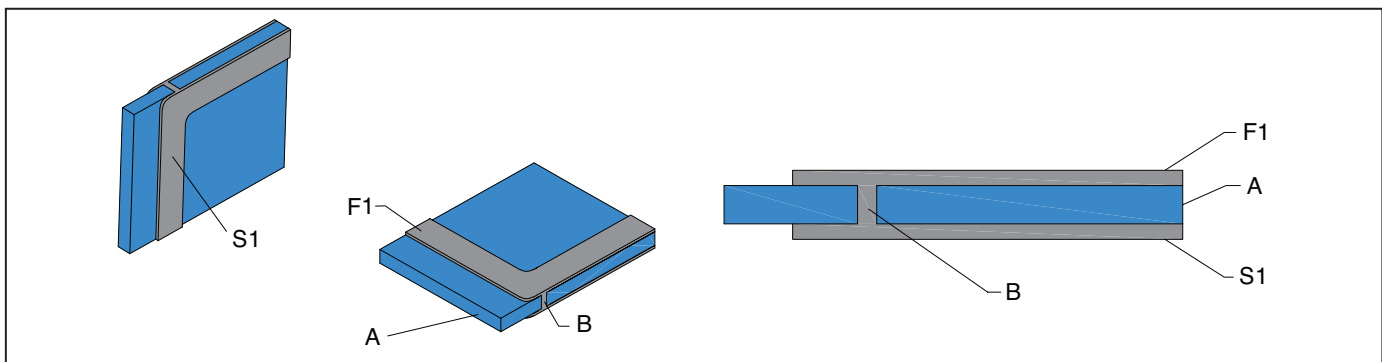


Figure 1-3 SPED3

A – Substrate
B – Via through substrate

1.11.4 All SPEDs Example Figure 1-4 shows an example of a printed electronic device incorporating all three IPC-8952 SPEDs. The F and S alphanumeric designators also depict the process steps to print this device.

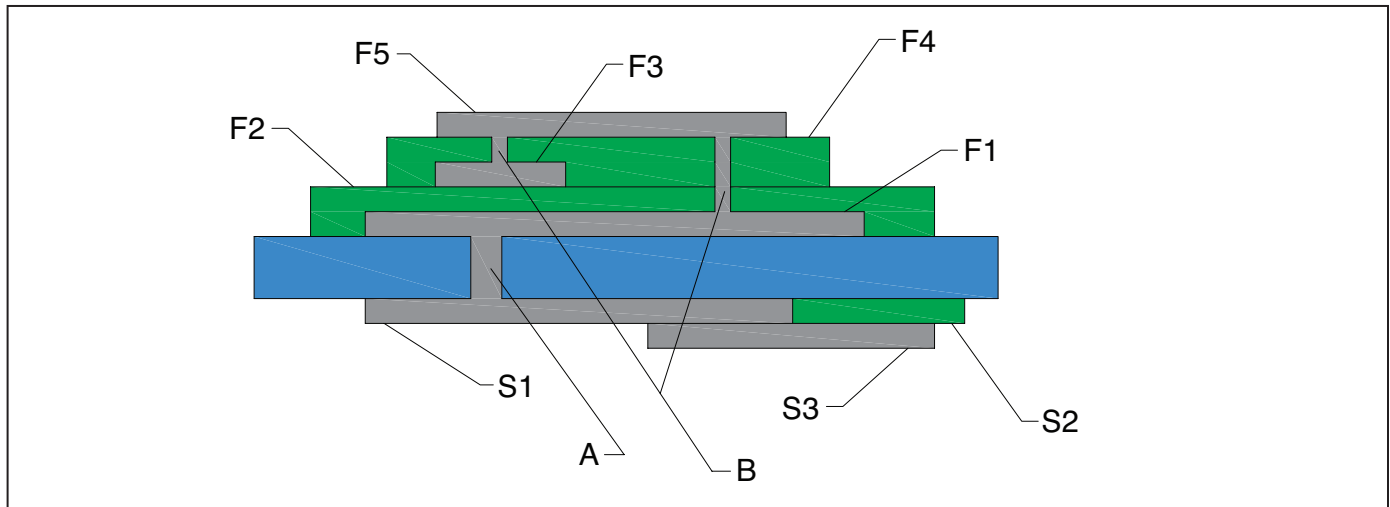


Figure 1-4 Example of Printed Electronic Using Every Standard Printed Electronic Design (SPED) Type in One Device

A – Via through substrate
B – Via through printed dielectric

2 APPLICABLE DOCUMENTS

2.1 IPC¹

IPC-T-50 Terms and Definitions for Interconnecting and Packaging Electronic Circuits

IPC-T-51 Terms and Definitions for Design and Manufacture of Printed Electronics

IPC-FC-234 PSA Assembly Guidelines for Single- & Double-Sided Flexible Printed Circuits

IPC-OI-645 Standard for Visual Optical Inspection Aids

IPC-TM-650 Test Methods Manual

Method 2.5.4.2 Conductor Temperature Rise Due to Current Changes in Conductors for Printed Conductor Materials on Textiles

Method 2.5.6 Dielectric Breakdown of Rigid Printed Wiring Material

Method 2.5.7 Dielectric Withstanding Voltage, PWB

Method 2.5.7.2 Dielectric Withstanding Voltage (HiPot Method) – Thin Dielectric Layers for Printed Boards

IPC-CM-770 Guidelines for Printed Board Component Mounting

IPC-SM-780 Component Packaging and Interconnecting with Emphasis on Surface Mounting

IPC-CC-830 Qualification and Performance of Electronic Insulating Compound for Printed Board Assemblies

IPC-2221 Generic Standard on Printed Board Design

IPC-2251 Design Guidelines for Electronic Packaging Utilizing High-Speed Techniques

IPC-2316 Design Guide for Embedded Passive Device Printed Boards

IPC-2500 series

IPC-2610 series

IPC-4202 Flexible Base Dielectrics for Use in Flexible Printed Wiring

IPC-4203 Adhesive Coated Dielectric Films for Use as Cover Sheets

IPC-4204 Flexible Metal-Clad Dielectrics for Use in Fabrication of Flexible Printed Circuitry

IPC-4591 Requirements for Printed Electronics Functional Conductive Materials

IPC-4592 Requirements for Printed Electronics Functional Dielectric Materials

IPC-4921 Requirements for Printed Electronics Base Materials (Substrates)

IPC-6902 Qualification and Performance Specification for Printed Electronics on Flexible Substrates

¹ www.ipc.org

IPC-7092 Design and Assembly Process Implementation for Embedded Components

IPC-7351 Generic Requirements for Surface Mount Design and Land Pattern Standard

IPC-8921 Requirements for Woven and Knitted Electronic Textiles (E-Textiles) Integrated with Conductive Fibers, Conductive Yarns and/or Wires

IPC-8971 Requirements for Electrical Testing of Printed Electronics on E-Textiles

IPC-9191 General Guideline for implementation of Statistical Process Control (SPC)

IPC-9204 Guideline on Flexibility and Stretchability Testing for Printed Electronics

2.2 ASTM²

ASTM D1434 Standard Test Method for Determining Gas Permeability Characteristics of Plastic Film and Sheeting

ASTM F1681 Test Method for Determining the Current Carrying Capacity of Printed Conductive Material

ASTM F1896 Test Method for Determining the Electrical Resistivity of a Printed Conductive Material

ASTM F1995 Test Method for Determining the Shear Strength of the Bond between a Surface Mount Device (SMD) and Substrate

ASTM F2749 Standard Test Method for Determining the Effects of Creasing a Membrane Switch or Printed Electronic Device

ASTM F2971 Standard Practice for Reporting Data for Test Specimens Prepared by Additive Manufacturing

ASTM F3147 Test Method for Evaluating of a Surface Mount Device (SMD) Joints on a Flexible Circuit by a Rolling Mandrel Test

2.3 NCSL³

ANSI/NCSL Z 540.1 Calibration Laboratories and Measuring and Test Equipment – General Requirements

2.4 SAE International⁴

EIA649 Configuration Management Standard

3 GENERAL REQUIREMENTS

The information contained in this section describes the general parameters to be considered by all disciplines prior to and during the design cycle.

Designing the physical features and selecting the materials for printed electronics e-textiles involves balancing the electrical, mechanical and thermal performance as well as the reliability, manufacturing and cost of the printed electronics.

3.1 End-Product Performance Requirements The end-product performance requirements **shall** be defined prior to design start-up. Maintenance and serviceability requirements are important factors which should be addressed during the design phase. Frequently, these factors affect layout and conductor routing. Finished printed electronics **shall** meet the performance requirements AABUS.

3.2 Design Considerations The design process should include a formal design review of details by as many affected disciplines within the company as possible, including fabrication, assembly and testing. The approval of the layout concepts by representatives of the affected disciplines will ensure these production-related factors have been considered in the design.

The success or failure of a printed electronics e-textile design depends on many interrelated considerations. From an end-product usage standpoint, the impact on the design by the following typical parameters should be considered:

- Product form factor requirements (e.g., bending, curvature, flexibility/drapability, stretchability thickness and transparency)
- Protection of electrical conductors with regard to migration and/or corrosion and washability
- Equipment environmental conditions in which the printed electronics are being used as a part of the e-textile (e.g., ambient temperature, humidity/moisture, UV, chemical exposure (wash detergents, cosmetic and antiperspirants, accidental chemical exposure, etc.), heat generated by the printed electronics, ventilation, shock, vibration, wash cycles)
- If an assembly is to be maintainable, repairable and recyclable, consideration **shall** be given to:
 - Printed component/circuit density of the printed electronics e-textile
 - Selection of conformal coating or final finish protective materials (although not normally considered for printed electronics)
 - Installation interface that may affect the size and location of mounting lands, connector or electrical interface locations
 - Placement of other hardware

² www.astm.org

³ www.ncsl.org

⁴ www.sae.org

- Testing/fault location requirements that might affect printed component placement, conductor routing and pattern, circuit placement with respect to fold or crease location, interface or connector contact assignments, designated contact pads for placing test probes to streamline testing, etc.
- Manufacturing limitations (e.g., minimum conductor thickness, stretchability, flexibility, width, spacing, shape, profile, size)
- Coating and marking requirements
- Assembly technology used (e.g., surface mount technology (SMT))
- Materials selection (see Section 4)
- Producibility of the printed electronics e-textile assembly as it pertains to manufacturing equipment limitations (includes flexibility (flexural) and stretchability requirements)
- Electrical/electronic function of the final device
- Electrostatic discharge (ESD) sensitivity considerations
- Conductor density per layer
- Balanced construction of printed electronics e-textile to achieve intended electrical functionality without hindering the properties of the textile and the form factor
- Compatibility of materials, effect on adhesion, thermal-dimensional stability (thermal expansion coefficient), etc.
- Partitioning (see Note below) of design for signal integrity, test and ease of design reuse, etc.
- Clear identification of power line(s) and electrical ground plane
- Memory component placement, classification between integrated or detachable memory component
- Process conditions (e.g., thermal cure, ultraviolet (UV) curing, photonic, ultrasonic bonding, thermal bonding)
- Materials' chemical and physical compatibilities between layers
- Addition of localized stiffness and/or stretch lockout to protect components

Note: Partitioning is performed in the preliminary printed electronics e-textile design phase. It includes trade-off studies, usually including several design concepts that could solve the problem. These design concepts are functionally block diagrammed and, as with any trade-off, a set of advantages and disadvantages is formulated and evaluated by the designer to make the decision on which solution is optimal for this design.

It is important to ensure all functional requirements, test connections and any known growth requirements are considered. These should flow from the project requirements as documented in the design requirements. The test requirements and growth requirements may not need to be implemented during the electrical design phase, but the interfaces (including printed elements, SMT components) should be allocated.

The designer partitioning for each concept needs to evaluate what can be implemented on the printed electronic e-textile. The following questions should be answered:

- What are the I/O requirements?
- What are the data path requirements?
- What are the memory requirements?
- What are the power requirements?
- What are the control requirements?

It is difficult to convey all the considerations that should be evaluated. The considerations listed in this section have been included to provoke the thought process. Users are encouraged to consult with experienced designers if there is a need for assistance.

3.2.1 Disposal and End-of-Life (EOL) Requirements End-of-life (EOL) requirements for the printed electronics e-textile product should be AABUS. The considerations for design towards the EOL should be determined accordingly such as:

- Creation of high-value material streams, materials recycling and reuse (e.g., silver)
- Provide readily identifiable and removable hazardous components (e.g., silver nanoparticles, carbon nanotubes)
- Eliminate/minimize worker health
- Environmental impacts at EOL