

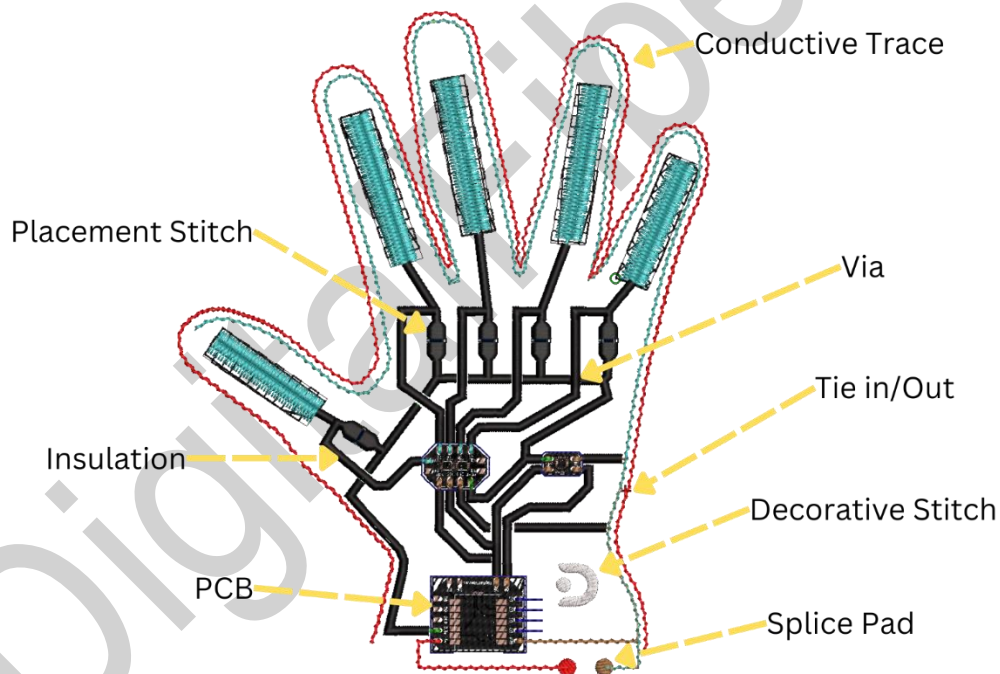
# The Anatomy of an Embroidered Circuit

## Design Guide for Electronics Engineers

DigitalFiber.us

Rodney Trusty

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This document provides an introduction to the fundamental components of embroidered circuits. It is designed primarily for electronics engineers with prior circuit knowledge, but anyone curious about this innovative field can benefit from the information shared. Here, I guide you through the anatomy of an embroidered circuit, detailing the purpose of each element. This serves as a solid foundation for embarking on your journey into embroidered circuit design.

My goal is to help establish e-textile design and manufacturing as commonplace as PCB electronics. To support this vision, I have created this guide along with many other resources available at [digitalfiber.us](http://digitalfiber.us). I believe that freely sharing information and tools with the engineering community will foster the growth of a new and innovative industry.

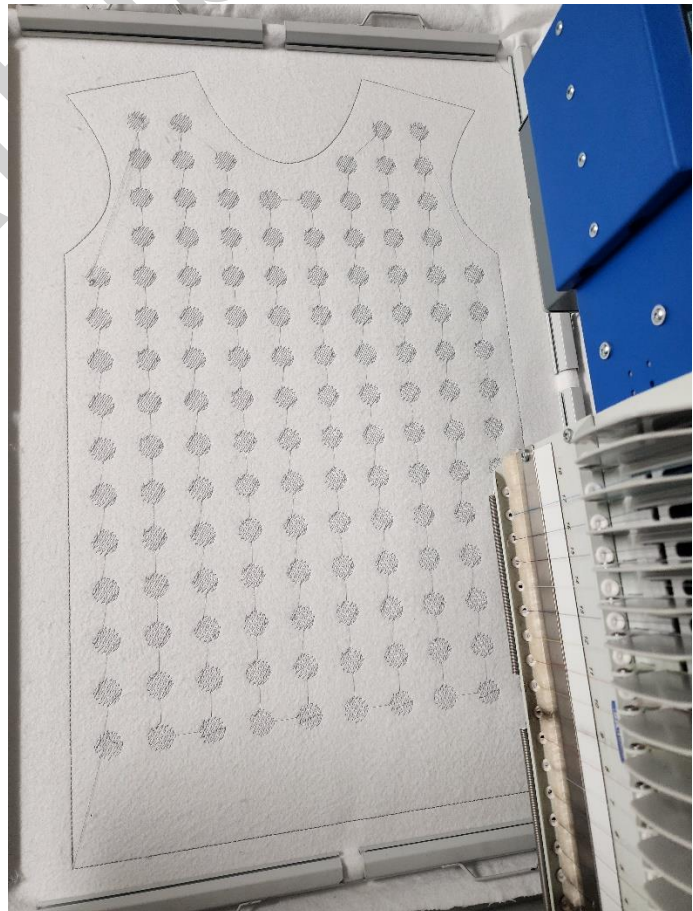
Rodney Trusty

## Placement Stitch: Foundation of Accurate Component Placement

### What is a Placement Stitch?

A **Placement Stitch** is a lightly filled stitch area embroidered directly onto the fabric. Its shape and size are carefully designed to match the outline of a PCB (Printed Circuit Board) used in circuit embroidery. These stitches act as a guide for placing components in the correct position during the embroidery process.

Small patches of thread sewn into a shirt before placing an array of components



## Purpose of Placement Stitches

Placement Stitches serve multiple vital functions in circuit embroidery:

1. **Fabric Stabilization:**  
During the embroidery process, Placement Stitches secure the fabric to the stabilizing material. This prevents the fabric from shifting a component out of place during embroidery.
  2. **Visual Alignment:**  
The stitched outline acts as a visual and physical guide for positioning the PCB or other components. Whether components are placed manually or by a machine, the Placement Stitch ensures precision.
  3. **Reliability and Accuracy:**  
Proper alignment is crucial for the functionality of embroidered circuits. Placement Stitches act as a jig, ensuring that components are placed precisely, reducing the chance of circuit failure.
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## How to Use Placement Stitches

- Run Placement Stitches before placing any PCBs or electronic components.
  - Use the stitched outline to position your PCB or component.
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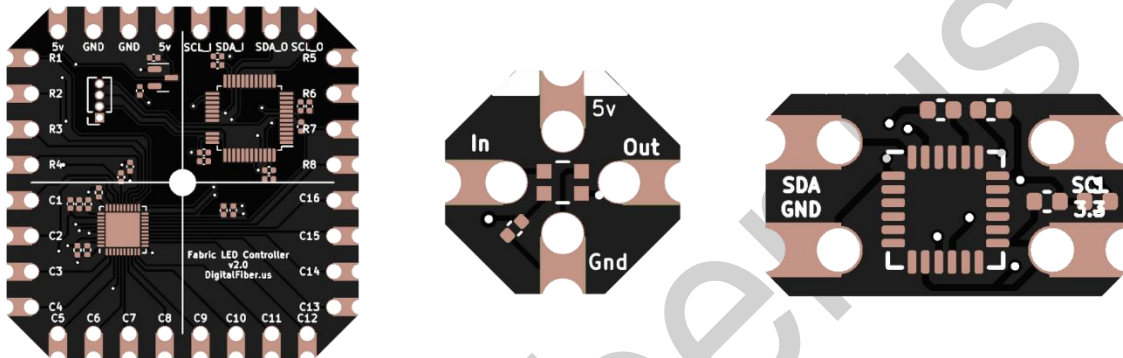
## Tips for Designing Placement Stitches

1. **Match the Outline:** Ensure the placement stitch shape matches the component's outline.
  2. **Use Light Fills:** Keep the stitch density light to avoid unnecessary bulk under the component.
  3. **Use High-Contrast Colors:** Select a thread color that contrasts sharply with the fabric!!!
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## PCBs: The Brain of Embroidered Circuits

### What is a PCB?

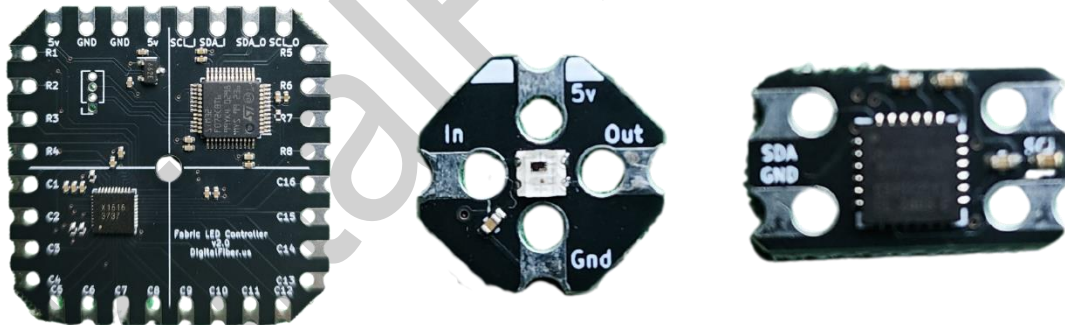
A **Printed Circuit Board (PCB)** is a rigid or flexible board that houses electronic components and establishes electrical connections between them. In e-textiles, PCBs bring control, sensing, and processing capabilities to the fabric-based circuits.



LED Matrix Controller

Addressable LED

MPU6050 IMU



PCBs are integrated into the textile by sewing conductive thread through specially designed contact holes, creating reliable electrical connections. They serve as the foundation for embedding advanced functionality into embroidered circuits.

### Purpose of PCBs in E-Textiles

PCBs play a crucial role in e-textile designs, enabling a wide range of electronic functionalities:

1. **Control Systems:**

- PCBs act as control hubs, allowing users to program and manage the behavior of the circuit (e.g., LED patterns, sensor triggers).
2. **Sensing Capabilities:**
    - Sensors embedded in PCBs can measure environmental or biological data, such as temperature, motion, or heart rate.
  3. **Interconnection:**
    - PCBs provide fixed points for connecting components using conductive threads, ensuring stable and reliable electrical pathways.
  4. **Multi-Functionality:**
    - With PCBs, you can replicate most traditional electronic applications in textiles, from lighting and data transmission to complex computing and wireless communication.
  5. **Durability and Structure:**
    - PCBs add structural stability to the circuit, anchoring components securely to the textile substrate.
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#### When and How to Use PCBs

- Prepare the fabric with Placement Stitches that match the PCB's outline.
  - Position the PCB onto the Placement Stitches, aligning it precisely.
  - Use conductive thread to sew through the PCB's contact holes, ensuring tight and clean connections.
  - Test continuity with a multimeter to verify proper electrical connections.
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#### Tips for Designing and Using PCBs in E-Textiles

1. **Avoid Sharp Corners:**
  - Sharp corners on PCBs can be mildly hazardous in textiles, especially those intended for wearables or frequent human contact. Go for rounded corners.
2. **Spacing for Contact Holes:**
  - Ensure that contact holes are spaced at least **4mm** apart. This minimizes the risk of short circuits and allows sufficient space for sewing conductive threads without overlap.
3. **Hole Diameter:**
  - Design contact holes with a diameter of at **1.6mm – 2mm** to accommodate conductive threads and sewing needles.

#### 4. PCB Thickness:

- Use PCBs with a thickness between **0.8 mm and 1.6 mm**. This range provides a balance of flexibility for wearability and durability to withstand sewing and handling.

#### 5. Use Castellated Holes:

- Castellated holes—semi-circular notches along the PCB edge—are ideal for e-textiles. They improve electrical contact reliability and aid in component alignment.

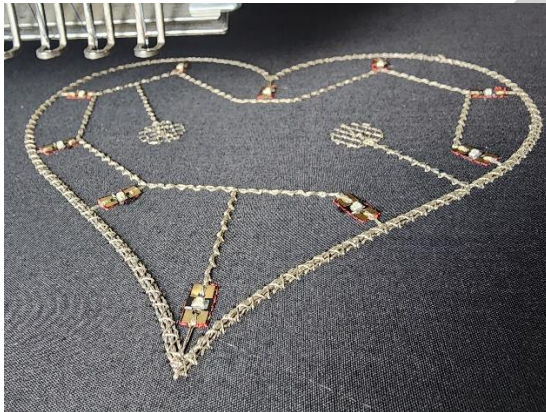
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## Conductive Traces: Electrical Pathways of Embroidered Circuits

### What Are Conductive Traces?

**Conductive Traces** are electrical pathways created by stitching conductive thread into textiles. These threads form the electrical connections in embroidered circuits, allowing signals or power to flow between components such as PCBs or sensors.

The conductive thread can be used in the top thread, bottom thread, or both, which affects the overall conductivity. Multiple passes of thread along the same path are used to improve electrical performance and durability. In the same way, the resistance of individual traces can be precisely controlled.

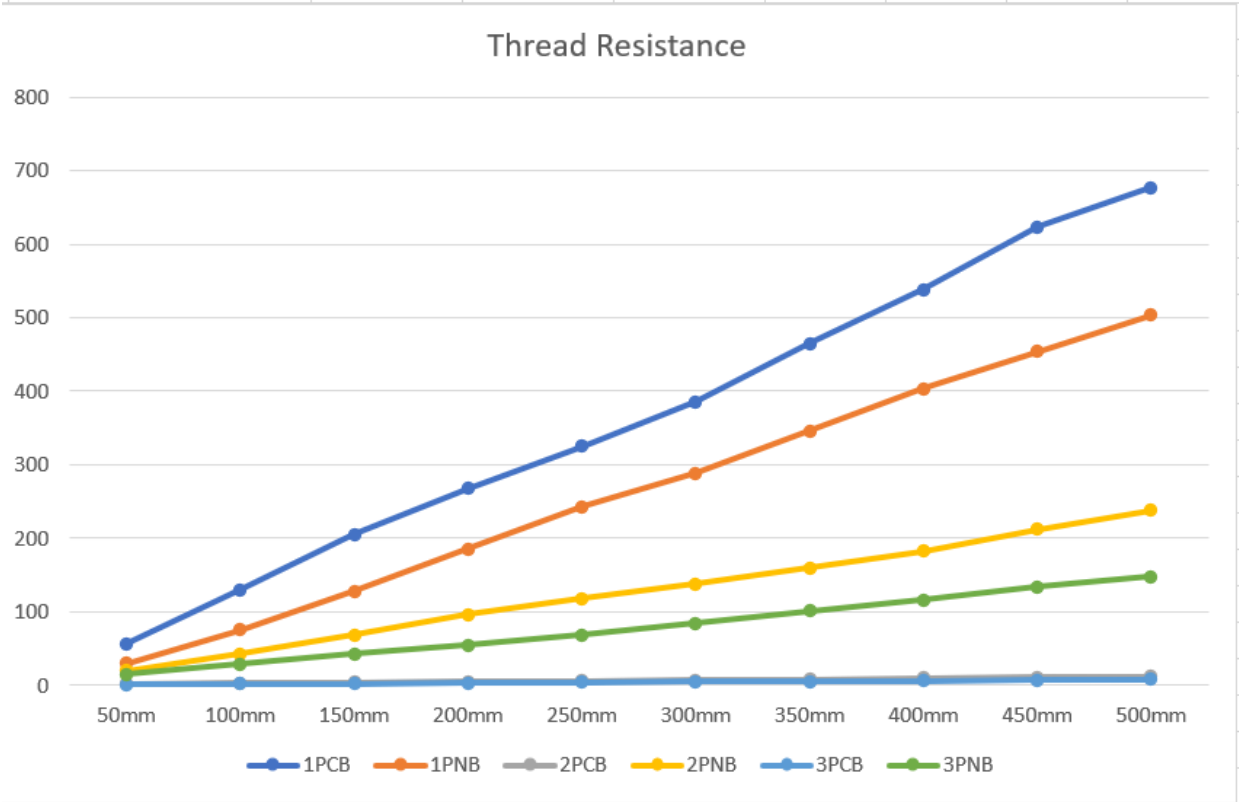


Electrical traces can and should be used as art



Close up electrical trace

#P - Number of passes							
CB - Conductive Bobbin							
NB - Normal Bobbin							



Conductivity Analysis Chart

### Purpose of Conductive Traces

#### 1. Interconnection for PCBs:

- Conductive traces connect PCBs, acting as the "wiring" of the textile circuit.

#### 2. Electrodes for Textile Sensors:

- Conductive traces serve as functional elements in sensors, such as:
  - **Pressure sensors** (detecting force).
  - **Capacitive sensors** (measuring touch or proximity).

### When and How to Use Conductive Traces

- Stitch conductive traces when connecting components like PCBs, sensors, or LEDs within an embroidered circuit.



- Stitch electrodes with conductive thread to create a wide range of textile-based sensor designs.

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### Tips for Designing Conductive Traces

#### 1. Use 45-Degree Angles:

- Avoid sharp turns. Use 45-degree angles to reduce the underside pull of bobbin thread

#### 2. Use At Least 2 Passes:

- Stitch each trace with at least two passes of conductive thread along the same path. This enhances conductivity and creates redundancy, ensuring reliability even if a single pass gets damaged.

#### 3. Avoid Conductive Bobbins When Possible:

- Only use conductive bobbin thread when absolutely necessary. Conductive bobbins can increase the risk of unintentional short circuits if threads cross on the underside of the fabric. Stick to non-conductive bobbins for most designs to reduce this risk.

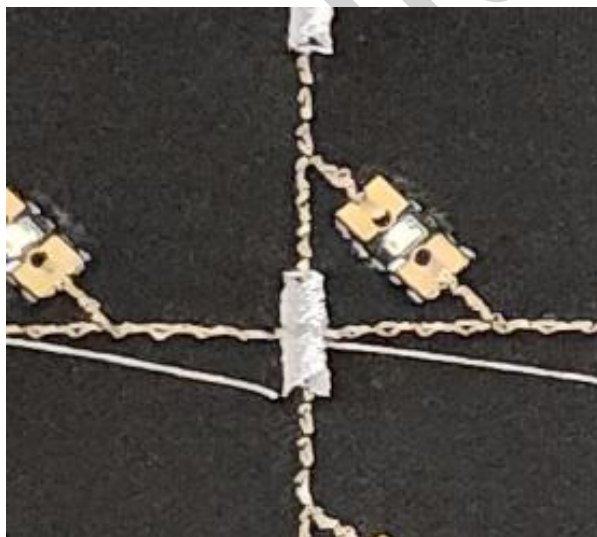
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## Vias: Enabling Crossovers in Embroidered Circuits

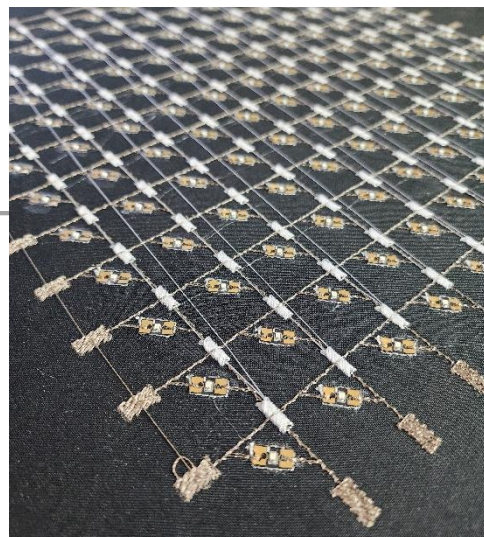
### What Are Vias?

**Vias** are small satin stitches made with non-conductive, standard embroidery thread. They are used to cover a conductive trace, allowing another conductive trace to pass over it without making electrical contact.

Vias are essential for creating complex embroidered circuits where conductive paths need to cross.



Via acts as bridge for traces to crossover



Vias enable complex matrix circuits



## Purpose of Vias

### 1. Electrical Isolation:

- Vias isolate overlapping conductive threads, preventing short circuits when two traces cross.

### 2. Design Flexibility:

- By allowing conductive traces to cross at different layers, Vias enable more complex circuit layouts within a limited embroidery area.
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## Tips for Creating Effective Vias

### 1. Cross Vias at a Perpendicular Angle When Possible:

- Aim to position the crossing conductive trace at a **90° angle** to the Via. This reduces the chance of contact and interference between the two threads, improving reliability.

### 2. Double Satin Stitches at Opposite 45° Angles:

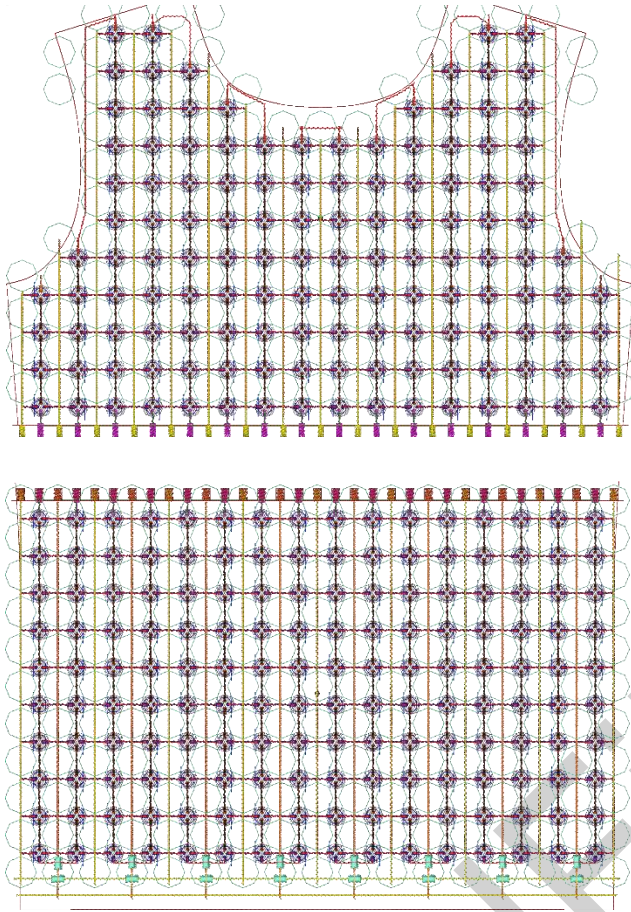
- Use two satin stitches at **opposite 45° angles** when creating Vias. This ensures that conductive traces can cross from any angle while maintaining isolation.
  - The crisscrossed stitches also provide added stability, preventing wear or fraying of the Via over time.
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## Splice Pads: Multi-Circuit Connectivity

### What Are Splice Pads?

Splice Pads are conductive pads embroidered onto fabric that serve as bridges for extending circuits. They allow the connection of two separate embroidered circuits or the integration of multiple layers in complex designs.

Addressable LED shirt Prototype



Top & bottom pieces  
spliced in the middle  
with splice pads



Addressable LED shirt  
Demonstration

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## Purpose of Splice Pads

### 1. Extending Circuitry:

- For very large applications, Splice Pads enable you to connect two circuits seamlessly.

### 2. Layer Integration:

- They allow the connection of circuits embroidered on different layers of fabric, creating multi-layered designs.

## Tips for Using Splice Pads

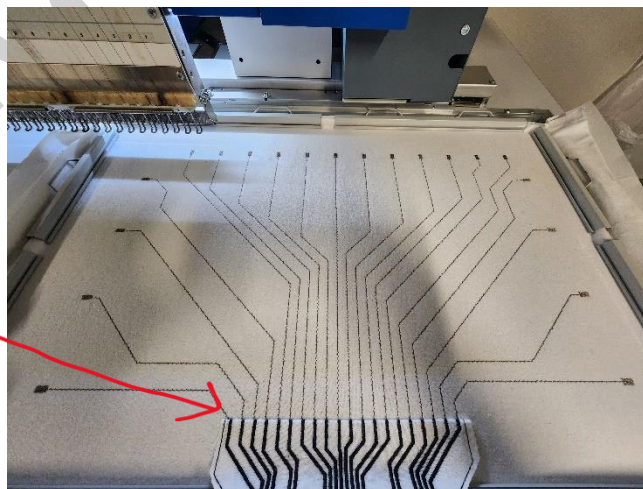
- Ensure precise alignment of pads on both layers or circuits for optimal conductivity.
  - Use a sufficient number of passes with conductive thread to enhance reliability.
  - Test the connection with a multimeter.
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## Attachments

### What Are Attachments?

Attachments refer to additional materials added to the fabric during the manufacturing process. These materials can serve various purposes depending on the design and application of the embroidered circuit.

External connector  
attached to circuit design  
during manufacture



## Types of Attachments

### 1. Insulating Layers:

- Prevent short circuits by insulating conductive traces.

### 2. Interposing Layers:

- Crosses over connections of one circuit to another

### 3. Connectors:

- Facilitate connections between components or external devices.

### 4. Appliqués:

- Enhance aesthetics or add functionality to the design.

## Purpose of Attachments

- Improve durability and reliability of circuits.
  - Provide insulation and protection for conductive traces.
  - Add aesthetic value to the overall design
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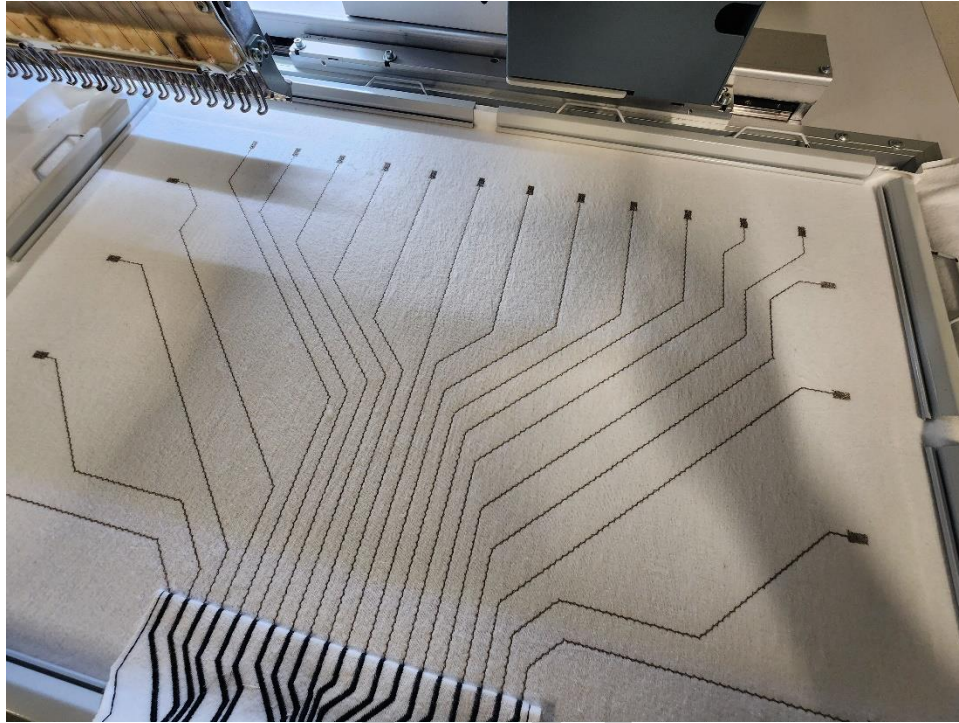
## Insulation

### What Is Insulation?

Insulation involves covering conductive traces so they don't make unintended electrical connection with anything. This technique also protects the conductive thread from wear and interference.



## Insulation by additional layer



Uninsulated traces



Traces insulated with additional fabric

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## Purpose of Insulation

### 1. Protection:

- Prevents conductive threads from fraying or wearing out due to fabric movement or washing.

### 2. Electrical Isolation:

- Reduces electrical interference and minimizes the risk of short circuits.

### 3. Reliability:

- Enhances the longevity and performance of embroidered circuits.

## Tips for Applying Insulation

- Use the insulated traces as art.
  - Ensure the satin stitch fully covers the conductive trace without exposing edges.
  - Trim stitches top and bottom before insulating if possible
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## Decorative Stitches

### What Are Decorative Stitches?

Decorative Stitches are standard embroidery stitches added for aesthetic purposes. They are not part of the functional circuit but contribute to the visual appeal of the design.





Electronic circuits can be integrated into normal decorative stitches

#### **Purpose of Decorative Stitches**

- Enhance the visual design of the embroidered fabric.
- Integrate artistic elements into functional e-textiles.

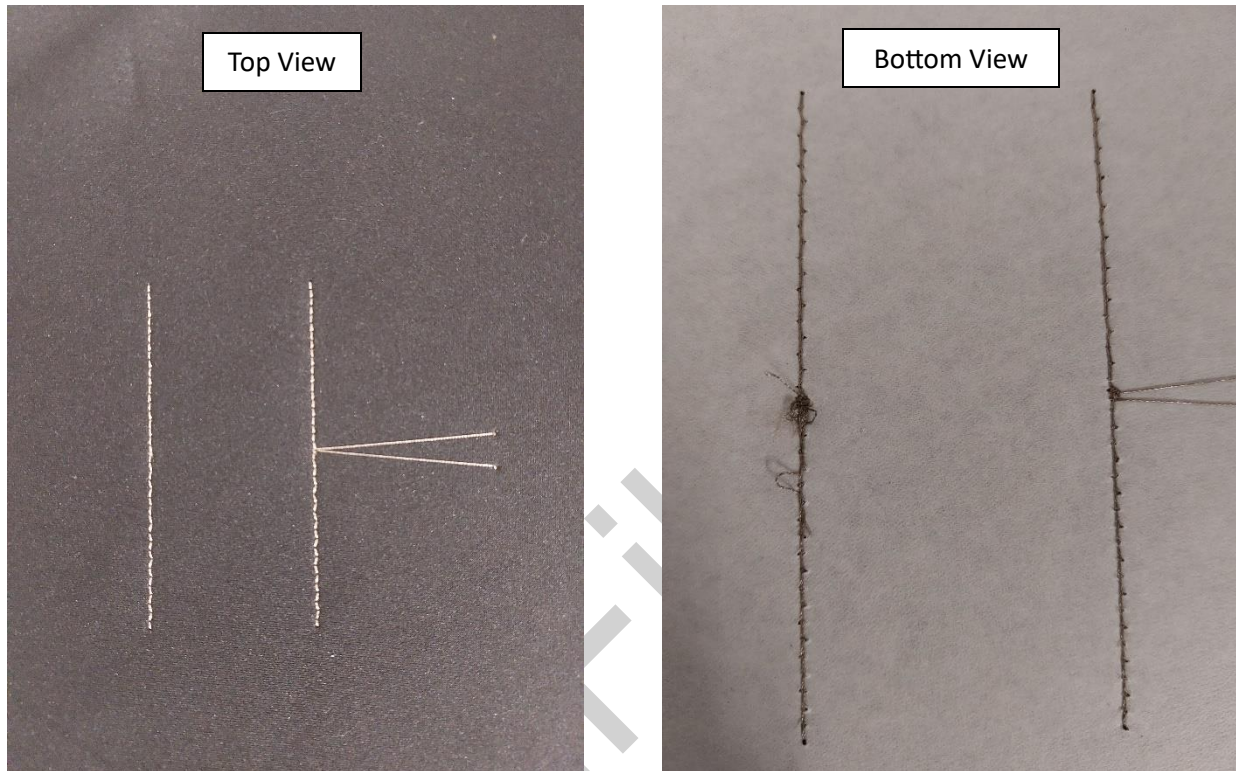
#### **Tips for Using Decorative Stitches**

- Find ways to make the circuit traces look like art
  - Choose thread colors and patterns that complement the circuit design.
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## Tie-Ins and Tie-Outs

### What Are Tie-Ins and Tie-Outs?

Tie-Ins and Tie-Outs are lock stitches placed at the start and end of conductive traces. They prevent loose conductive thread tails from causing short circuits or compromising the circuit's reliability.



Look Closely at these 2 example traces. The trace that does not use a tie-in has a bird's nest where the needle started and stopped. The thin fraying conductive strands cause shorts and circuit malfunction. Tie-Ins/Outs controls this.

### Purpose of Tie-Ins and Tie-Outs

1. **Circuit Stability:**
  - Secure the start and end of conductive traces to prevent unraveling.
2. **Short Circuit Prevention:**
  - Minimize the risk of conductive tails causing unintended electrical connections.

### Tips for Creating Effective Tie-Ins and Tie-Outs

- Place Tie-Ins and Tie-Outs away from other traces to avoid short circuits.
  - If jumping from trace to trace, try to ensure at least 10mm spacing
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