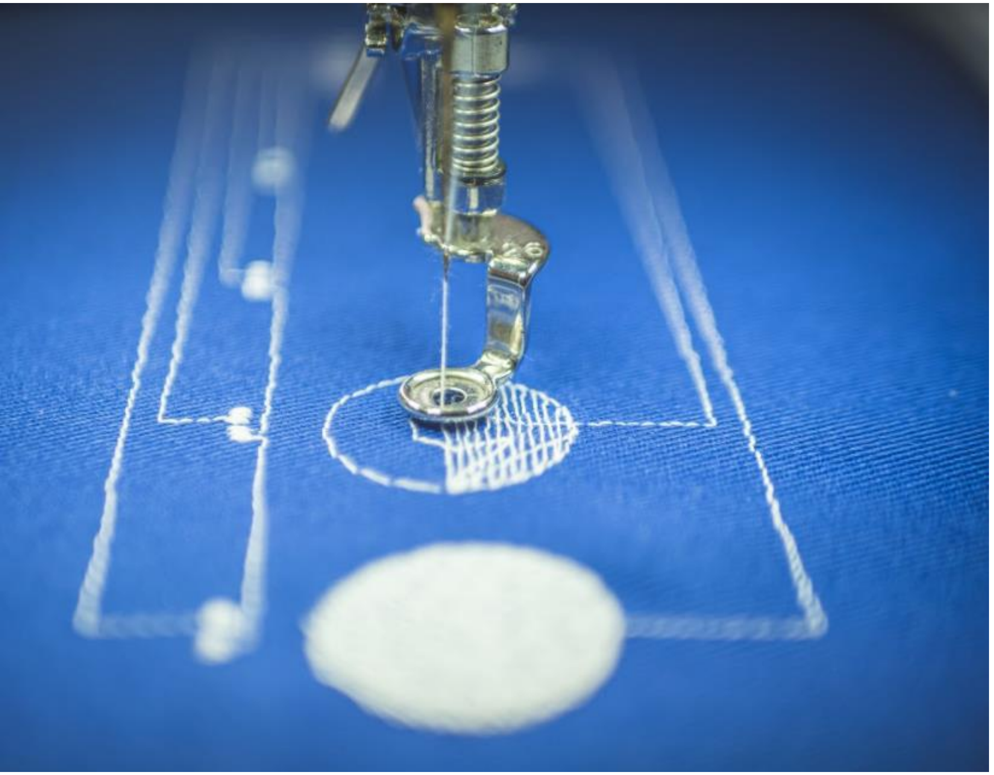

Technical Embroidery for E-Textiles

Lecture at the Hellenic Mediterranean University, Chania

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University of West Bohemia

19th May 2023

FACULTY OF ELECTRICAL ENGINEERING
UNIVERSITY OF WEST BOHEMIA

RICE

Erasmus+

1. Agenda

1. **Short introduction – University of West Bohemia**
2. **Smart textiles introduction**
   2.1 Smart textiles - definition
   2.2 E-textiles
3. **Conductive threads**
   3.1 Metallized polymer yarns
   3.2 Hybrid conductive threads
4. **E-broidery**
5. **Design and digitizing of technical embroidery – theory**
6. **Design and digitizing of technical embroidery – practical examples**
7. **Demonstration videos**

1. Short introduction – University of West Bohemia

City	Pilsen (CZ)
Founded in year	1991 (1950)
Number of employees	2032
Number of students	12 500
Annual sales	79 million €
Core business	University, Research institute

FACULTIES AT THE UNIVERSITY
Faculty of Applied Sciences
Faculty of Economics
Faculty of Electrical Engineering (FEE)
Faculty of Education
Faculty of Law
Faculty of Mechanical Engineering
Faculty of Health Care Studies
Faculty of Art and Design

1. Short introduction – Pilsen

Pilsen

European Capital of Culture

ŠKODA
TRANSPORTATION

1. RICE – Research and Innovation Centre of Electrical Engineering

115	1400 m²	2013	25 M€
R&D workers	Laboratories	Established	Investment

MAIN RESEARCH TARGETS

Transportation
- Traction vehicles and systems
- Automotive (HEV/FEV)
- E-mobility and complex transport systems

Power Engineering & Industry
- Power distribution technology
- Nuclear technology
- Electricity and heat production
- SMART CITY and SMART GRIDs
- Industrial drives and automation

Printed Electronics and Smart Textiles
- Organic electronics
- Printed and flexible electronics
- E-textiles
- Sensors and smart sensor systems
- IoT components and systems

INDUSTRIAL PARTNERS

RICE

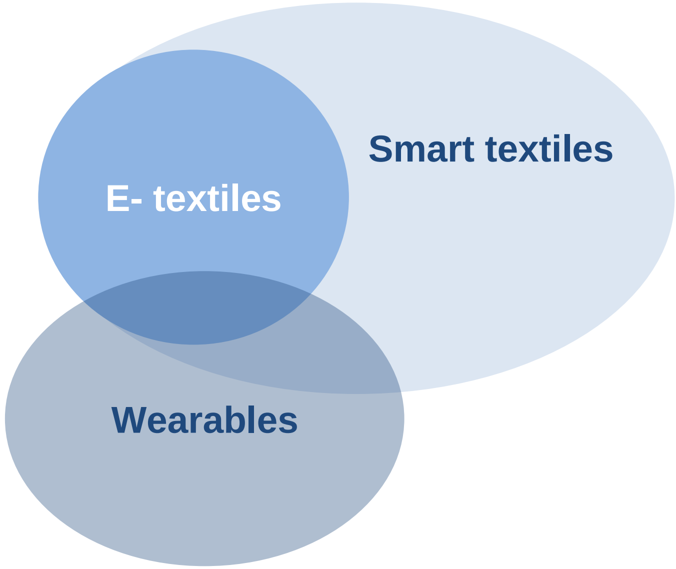
- Mechanical Engineering
- ICT
- Natural Science
- R & D Partners

CORE COMPETENCIES
- Power electronics & Drives
- Material research
- Electronics, Embedded systems, ICT
- Control theory, Modeling and Computation
- Diagnostics, Testing and Validation

2. Smart textiles introduction

2.1 Smart textiles - definition

- The smart textiles segment is a fast-growing market with very good forecasts
- In 2020, the global smart textiles market reached **$2.5 billion** and by 2025, the market is projected at **$5.55 billion** with a compound annual growth rate (CAGR) of **30.4%**, according to Grand view research
- Smart textiles are also textiles without an electronic function (shape memory textiles, photochromic textiles, thermochromic textiles, etc.)
- The global demand for smart textile products is mainly driven by the increasing penetration of smartphones and other smart devices that are equipped with **Bluetooth Low Energy** (BLE).
- **Smartphone** for visualization and processing of measured sensor data.
- Miniaturization of electronics will significantly boost further market growth.



Video 1

The relationship between wearable electronics, smart textiles and e-textiles.

2.1 Smart textiles - definition

- Several standardization bodies are involved in standardization of Smart textiles: ISO (the International Organization for Standardization), CEN - European Committee for Standardization, ASTM, IPC, AATCC etc.
- Adjectives such as “smart” or “intelligent” are mainly intended for marketing purposes.

Smart textile product / Intelligent textile product / Interactive textile product

Functional textile product***** which interacts reversibly with its environment, or responds or adapts to changes in the environment.

ISO/CEN - *PD CEN ISO/TR 23383:2020*

Smart textiles are textiles or textile material systems having additional intrinsic and functional properties not normally associated with traditional textiles.

CEN *FD CEN/TR 16298*

*** Functional textile product**

textile product to which a specific function is added by means of material, composition, construction and/or finishing (applying additives, etc.)

PD ***CEN ISO****/TR 23383:2020*

2.2 E- textiles

E-textile - A textile structure (fiber, yarn, fabric or finished product) permanently integrated with electrical and/or electronic functionality.

IPC

Wearable - A fully functional, finished electronic product specifically designed to be worn on the body. *IPC*

E-Textile Wearable - A textile-based end product permanently integrated with electrical and/or electronic functionality designed to be worn on the body, with or without detachable components. *IPC*

Possible elements of e-textiles.

- Lack of standards slows down the smart textiles industry
- The first standards are coming.
- The Standards are important - they can set the 'rules of the game' for markets that want to develop and adopt new technologies.

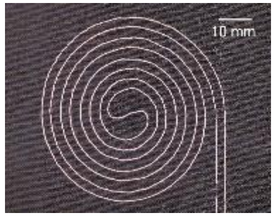
2.2 E- textiles

High

Level of integration

Low

4th Level of integration	**Full textile solution** - all components of the electronic equipment are made of textiles or have a textile finish,
3rd Level of integration	**Mixed solution** - an electronic device consisting of one or more components made of a textile or textile treatment and combined with permanently or non-permanently attached electronic components, e.g. a smart firefighting suit..
2nd Level of integration	**Permanent integration** . The electronic device is attached to the textile in such a way that it cannot be removed without destroying the product, e.g. sewn, welded, glued, etc. to the textile.
1st Level of integration	**Removable solution** - The electronic device is integrated into the fabric in such a way that it is removable (e.g. via pocket, Velcro, button, etc.) without destroying the product, e.g. during washing,

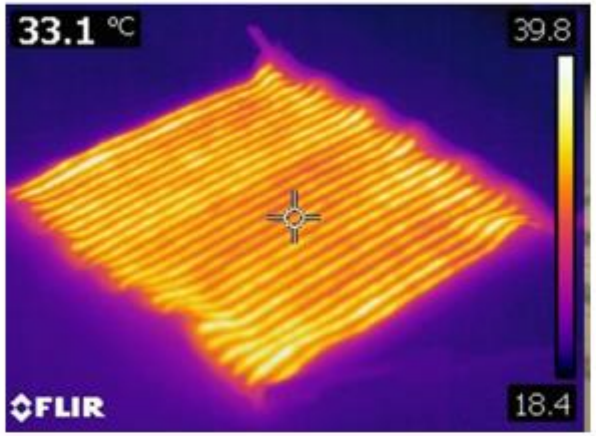


- CEN - European Committee for Standardization suggested 4 integration levels for intended standard for e-textiles

2.2 E-textiles

Textiles have unique properties that are desirable for a variety of applications, not only in the apparel sector:

- Textiles allow rapid dynamic stretching and shrinkage and three-dimensional deformation
- Textiles are lightweight, soft and breathable materials
- Ability to create a large surface area, allowing the creation of large geotextiles with integrated sensors detecting (e.g. landslides, leakage of liquids in water or product pipelines, and or on flat roofs).
- The textiles are relatively inexpensive to produce in relation to their surface area.



Heated textiles

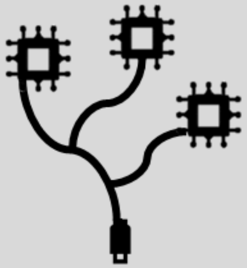
Textiles

- Soft
- Light
- Breathable
- Flexible
- Shapeable in 3D
- Flexible
- Comfortable
- Washable
- Low thermal stress max. up to 250 °C

E-textiles

- After integrating electronics into textiles, it is necessary to preserve as many textile properties as possible
- Hence the need to use miniaturized electronics, new contacting, encapsu-lation and integration technologies

Electronics

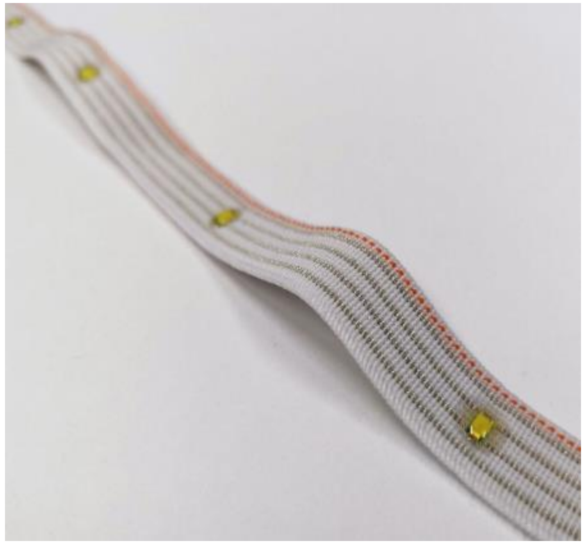


- Hard
- Solid
- Inflexible
- Dimensionally stable
- Sensitive to moisture
- Relatively higher weight
- Higher temperatures > 230 °C required for processing and conventional assembly

Properties of textiles and electronics and their relation to e-textiles.

E-textiles (clothing) must fulfill

- User comfort and convenience
- Light weight and not bulky electronics and sensors
- High washing resistance
- High mechanical durability
- Breathability
- Comply with norms and standards
- Protective clothing: Withstand harsh environment Video



Challenges for e-textiles

- Flexible batteries and energy harvesting systems (e.g. photovoltaics, piezoelectric systems, etc.) suffer from low levels of generated.
- Most of the industrial electronics manufacturing technologies (soldering, surface mount, vacuum technologies, etc.) are not compatible with textile manufacturing. It is necessary to come up with new technologies.
- A number of textile products suffer from a lack of resistance to washing.

3. Conductive threads

3. Conductive yarns

- E-Textiles are based on the electrically conductive fibers and yarns that can be used in combination with textile techniques such as sewing, weaving and knitting.
- Most conductive yarns are produced by the industry for anti-static, EMF shielding and for textiles with antibacterial effects for yarns containing silver.

- Conductive yarns can be used to:

  a) Interconnection

  b) Heating

  c) Sensor (Temperature, humidity, strain, capacity, presence, interruption detection, tactile sensors etc.)

  d) Textile electrodes (textrodes)

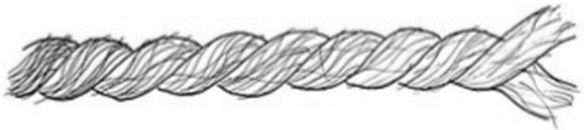
  e) Antennas

  f) Electrostatic shielding

  g) Antistatic application

3. Types of conductive fibres

- **Yarn** is a generic term for a continuous strand of textile fibers, filaments, or material in a form suitable for knitting, weaving, or otherwise intertwining to form a textile fabric.
  - Spun yarns (made from short **staple filament fibres)**

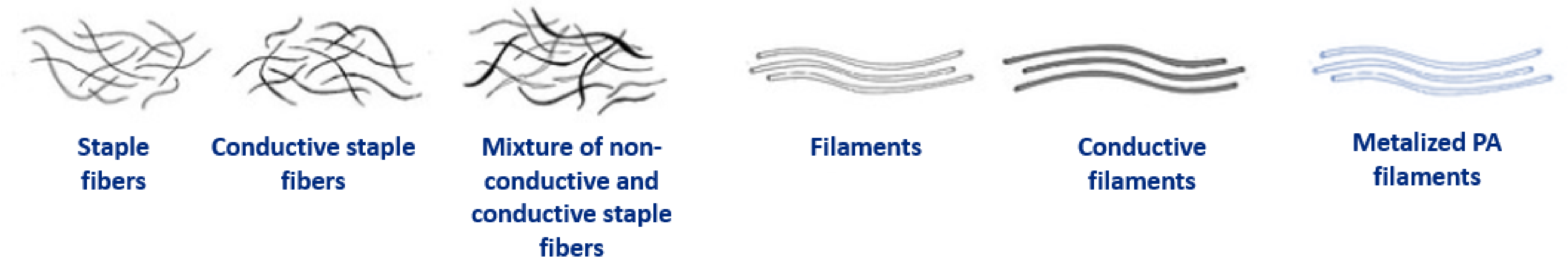


  - Filament yarns (made from continuous **filament fibres)**

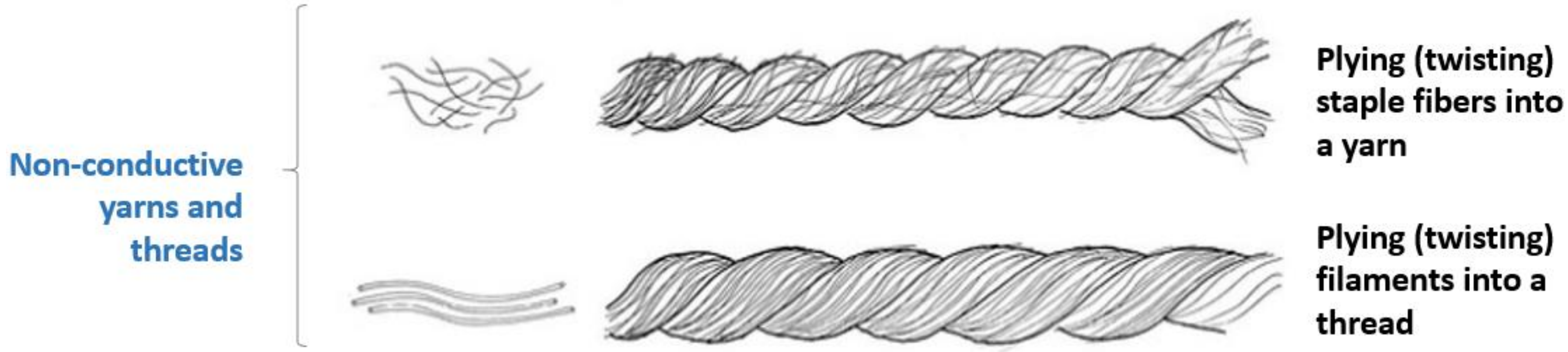
- **Thread** is a type of yarn intended for sewing by hand or machine.

  - Sewing threads are mostly finished with wax or other lubricants to withstand the stresses involved in sewing and embroidering.

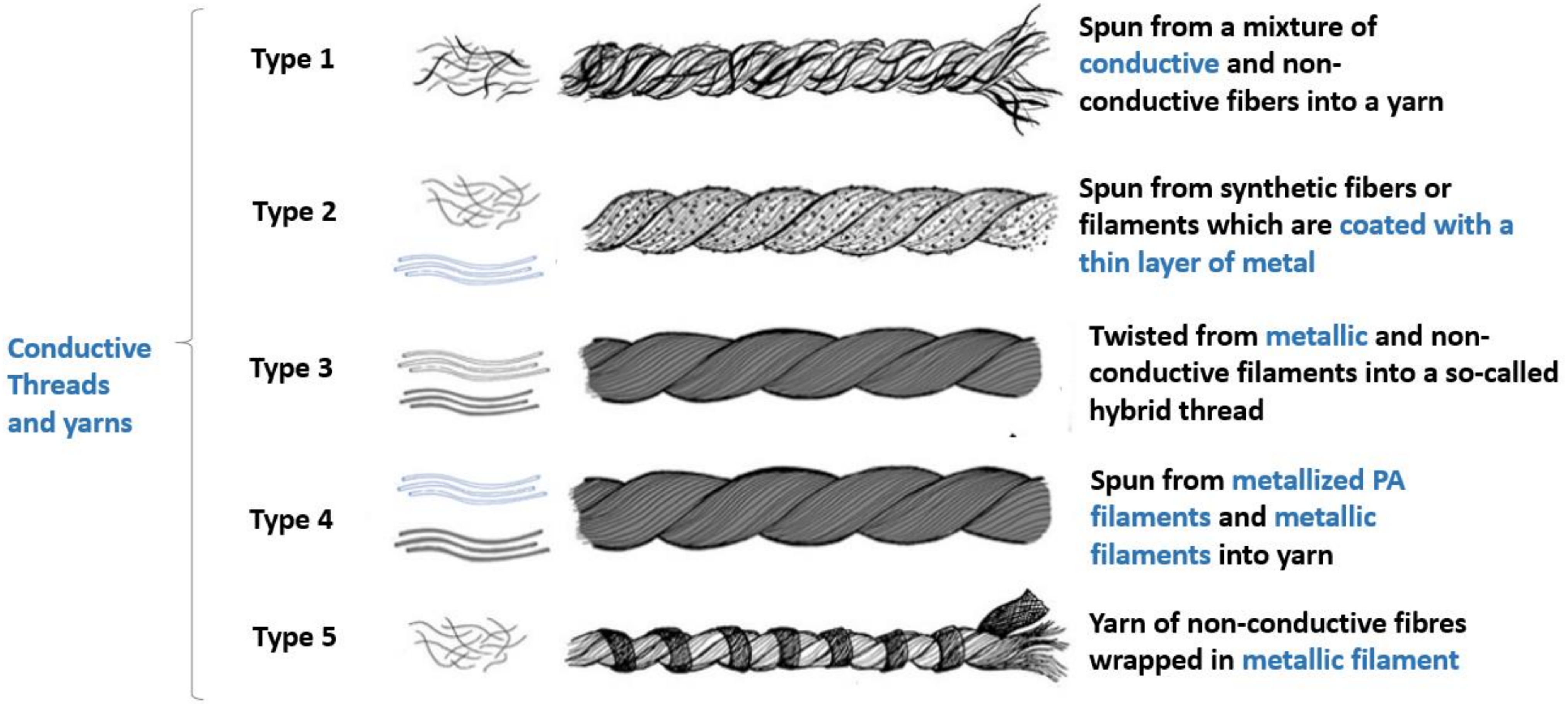
3. Types of conductive fibres



Input materials for conductive yarns.



3. Types of conductive fibres



Overview of the conductive threads and yarns.

3. Linear resistance of yarns

- The electrical resistance R of an object is a measure of its opposition to the flow of electric current.
- Its reciprocal quantity is electrical conductance G. It is expressed by the relations:

$$R = \frac{V}{I} \qquad G = \frac{1}{R} \qquad \boxed{R = \rho \frac{l}{A}}$$

where

V … Voltage (V)

I … Electrical current (A)

R …. Electrical resistance (Ω)

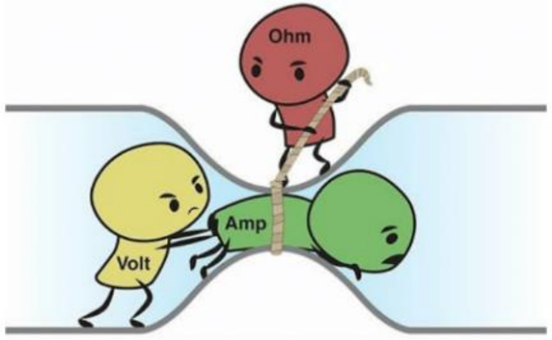
G …. Conductance (S)

ρ … specific electrical resistance of material (Ω)

A … cross-sectional area of the conductor [m^2]

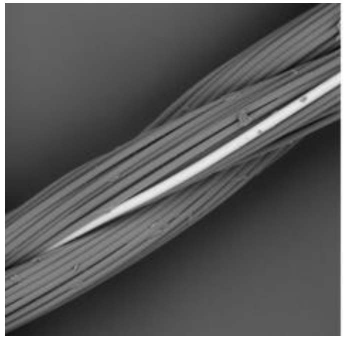
l …. length of the conductor [m]

Linear resistance …. [Ω/m]

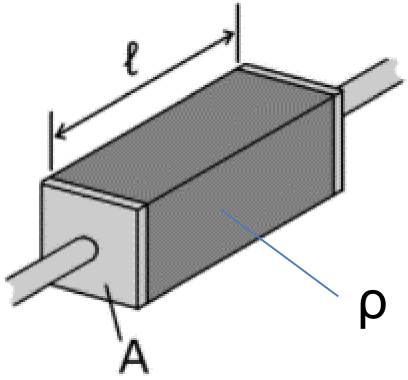


Ohm´s law.

- Resistance of the thread/yarn depends upon 3 major factors:
  - Conductive material used
  - Percentage of conductive fibers/material
  - Longitudinal and horizontal configuration



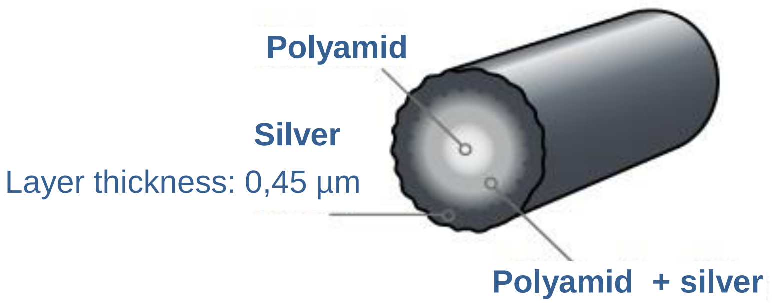
Example of the hybrid thread.



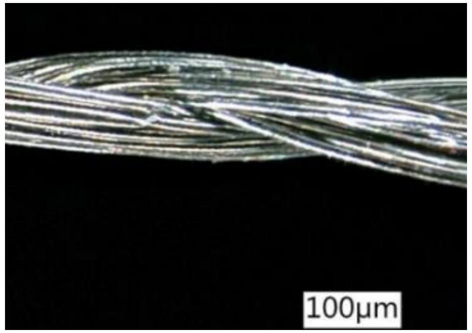
Electrical resistance is dependent on the specific resistance of the conductive material, its length and cross section.

3.1 Metallized synthetic fibres

- Synthetic fibres are coated because they are smooth (most often polyamide and polyester).
- **Applications:** antimicrobial, ESD, electromagnetic shielding, shielding from thermal radiation, textile conductors, heating and sensors, textrodes, decorative purposes.
- Compared to metallic wires, electroplated threads can **stretch up to 7%** without noticeably reducing their conductivity.
- Metallized threads are extremely resistant to stress and bending, but not very resistant to wash cycles (endurance of about 30 cycles, than starts to increase dramatically, exception Amann Silver-Tech can last about 100 cycles).
- Under high electrical loads, the plated polymer threads interrupt the current supply, but no sparks or hot spots are generated. Due to the high temperature, the threads shrinks and all filaments spontaneously tear.
- Textile electroplating is the technology of applying metals to flat textiles and yarns.
- The **linear resistances** of the yarns are relatively high **100 Ω/m to 1000 Ω/m**.



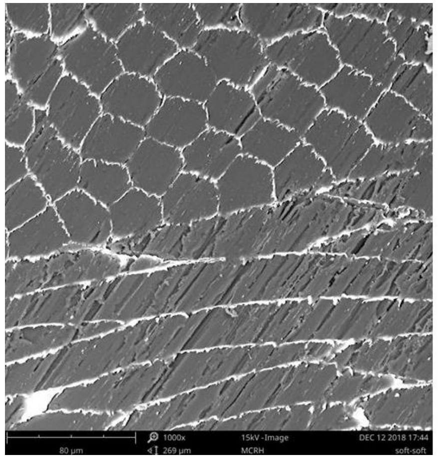
SilveR.Stat monofilament structure (Ag plated polyamide fiber)



Shieldex twisted thread from monofilament Ag coated fibers.

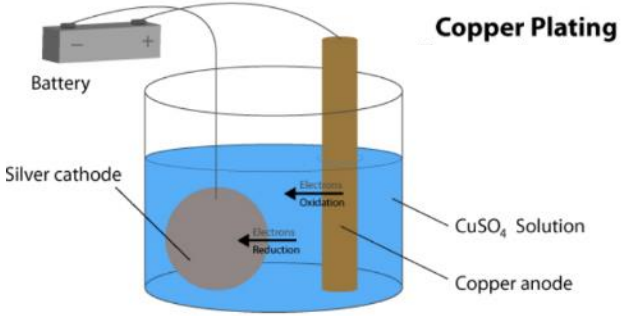
3.1 Metallized synthetic fibres

- **Electroplating (galvanization) of textile materials:**
  - Since textile materials are not conductive, an electrically conductive layer must first be applied that adheres well. Some of the common techniques (plasma pre-treatment, etching, chemical coating) can be used for this.
  - This is followed by electrochemical deposition (ECD) of the metal.
  - Most often silver is applied, to a lesser extent copper (oxidation problem).
  - With the help of electroplating, metal layers from hundreds of nanometers to a few micrometers thick can be formed.
  - The thinner the metal layer, the more noticeable the textile properties of the yarn, but the less conductive they are.



Crossing of the 2 threads SilveR.Stat (Ag plated polyamide fiber).

- **Manufactures:** X-static, SilveR.Stat, Statex, Madeira, Amann (SilverTech).
- **Advantage of the threads:** make good contact, conductive throughout their circumference, relatively flexible - suitable for functional underwear
- **Disadvantage:** relativity el. high resistance, cannot be soldered, cannot withstand high temperatures



Electrochemical cell.

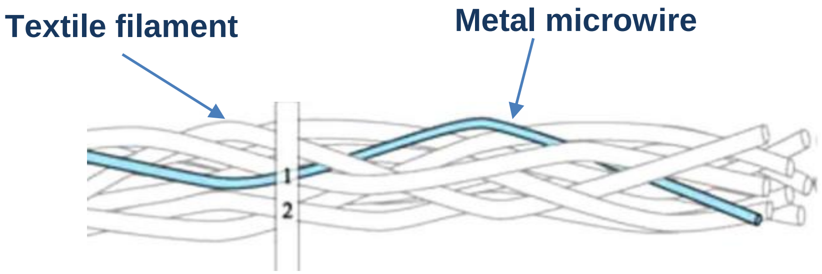
3.2 Hybrid conductive threads

- Threads twisted (plied) from textile filament fibers and metallic microwires with a diameter of 20 µm - 30 µm.
- Synthetic filament fibers are most often PESh mutifilament fibers (14.5 µm), but can also be PA or flame retardant meta-aramide or elastic fibers, etc.
- Metallic microwires (silver plated copper, brass, bronze, constantan, stainless steel, etc. with a diameter of 20 µm - 30 µm).
- The mechanical properties of yarns can be divided into those determined by

  a) **The textile part** of the thread, which ensures its strength (strength 20 -50 cN/tex, dry tenacity 10-20 %, thread fineness)

  b) **Metallic filaments** - stiffness - adapting to textiles, roughness - higher for wires, it is necessary to use needles with a special eye with a **titanium nitride** layer to reduce friction, abrasion resistance.

- **Difficult to manufacture:** conductive fibers are taken as impurities in conventional textiles (machine stops), suffer from machine grommets, wire looping, etc.



Hybrid sewing thread made of 1) metallic micro wires and 2) filament textile fibers.

The directions of the twisting (plying) - S and Z turns - is visible when looking at the thread.

Plying machine.

3.2 Hybrid conductive threads

- **Advantages:** hybrid threads have almost the same mechanical properties as textile threads (can be used for sewing, weaving and knitting), can be soldered, crimped, can be produced in an insulated design, high resistance to washing cycles.
- **Disadvantages:** they are not conductive around their entire circumference like metallized threads ➡ sometimes more complicated contacting, better for threads with more wires.

- Stainless steel and constantan threads have higher stiffness, worse deformability ➡ worse for sewing.
- UWB developed in cooperation with the company VUB hybrid conductive sewing threads, in 2015 it received a utility model for these threads, in 2018 the threads were launched on the market.
- There are few manufacturers of hybrid sewing threads on the market due to complicated production: e.g. Swiss Shield company, which uses them for electromagnetic shielding.

CLEVERTEX®

Different types of hybrid threads from VUB Company under the CLEVERTex brand.

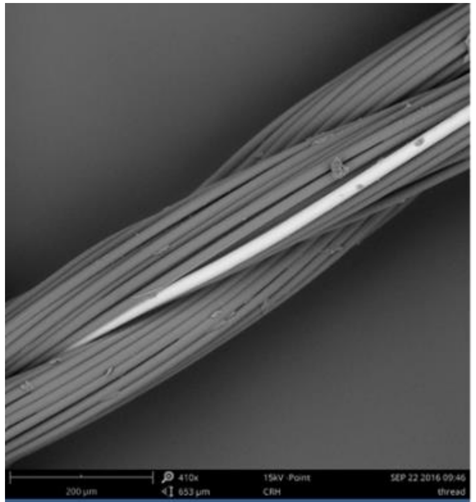
3.2 Hybrid conductive threads

- They may have a low linear el. resistance below 0,6 Ω/m
- These yarns are fully compatible with all standard textile processes (sewing, embroidery - maximum yarn loading, knitting, weaving) to create conductive paths.
- **Applications:** conductive interconnections, heating structures, flexible printed circuit boards of textile electrodes, textile sensors.
- High resistance to mechanical stress and maintenance (automatic drying and washing - more than 80 wash cycles).
- Harmless according to REACH 1907/2006 / EC (in addition, silver threads have antibacterial effects).

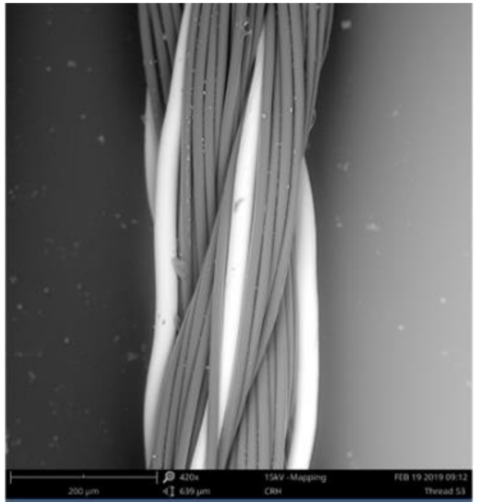
Code	Length density of yarns [Tex]	Optical diameter [mm]	Metallic filament	Strength [cN/tex]	Elongation [%]	Linear resistance [Ω/m]
25A	72	0,25	Brass (8)	21,80	10,20	8,90
53	50	0,23	Cu/Ag (4)	31,60	14,10	6,50
45 FR	54	0,24	Brass (5)	11,10	8,90	14,80
92	22,2	0,14	Bronze (4)	40,68	15,14	141,5
7A	38	0,23	Stainless steal (1)	53,10	14,39	2420,2
91	128	0,26	Cu/Ag (16)	15	16	1,6

Different types of hybrid conductive threads and their mechanical and electrical parameters.

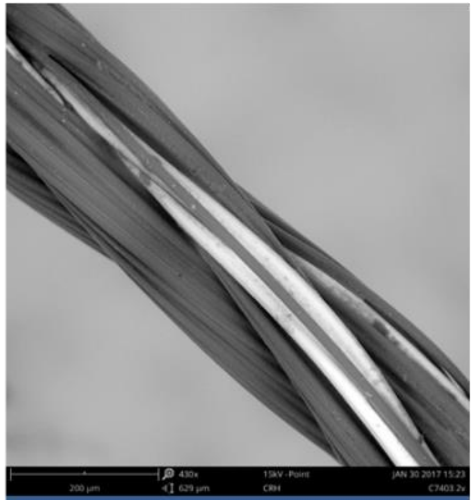
3.2 Hybrid conductive threads



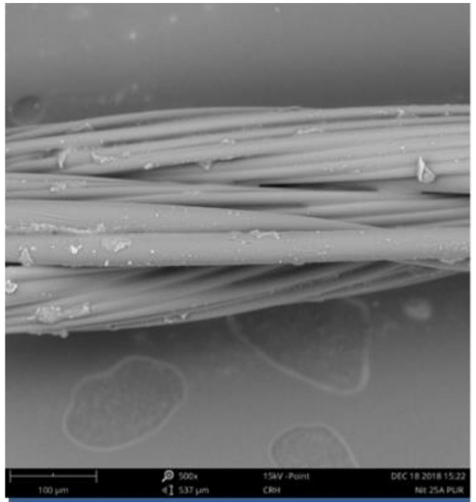
7A
1x stainless steel microwire
Temperature sensor thread



53A
4x brass microwire
Conductive thread



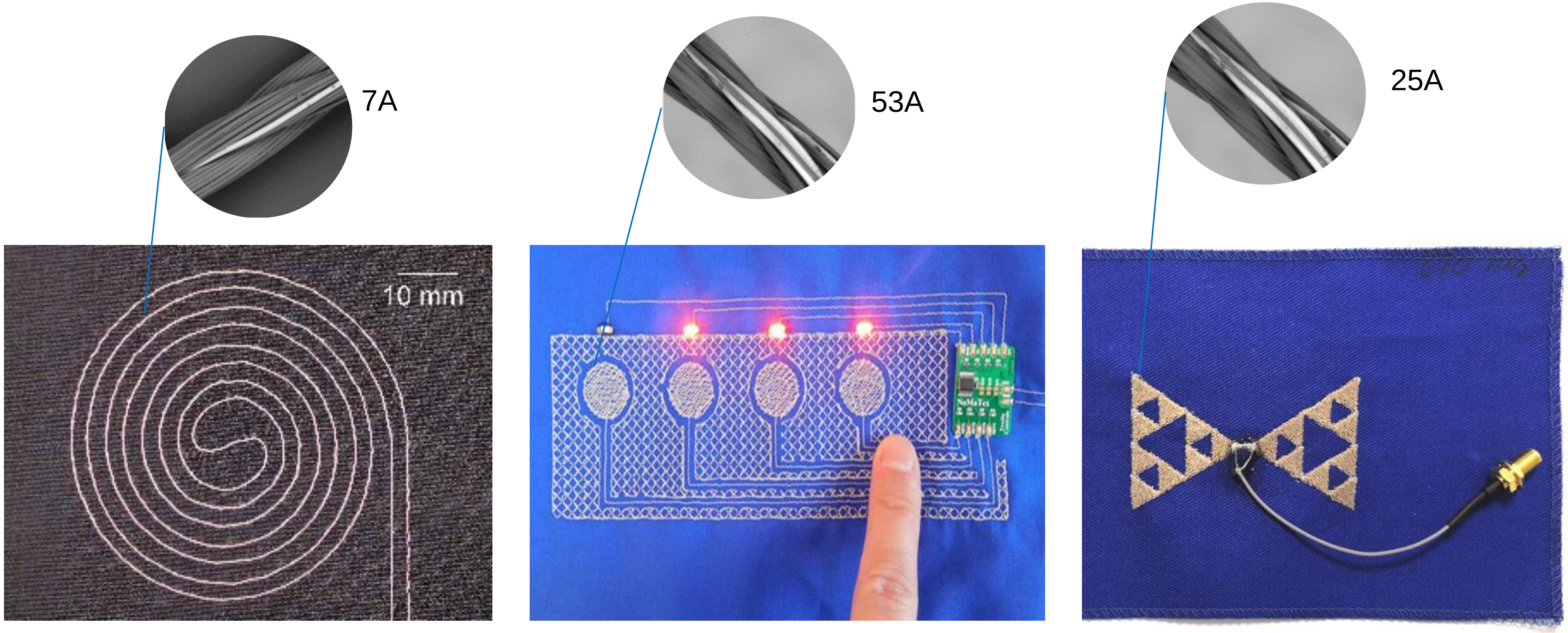
25A
4x Cu/Ag microwire
Conductive thread



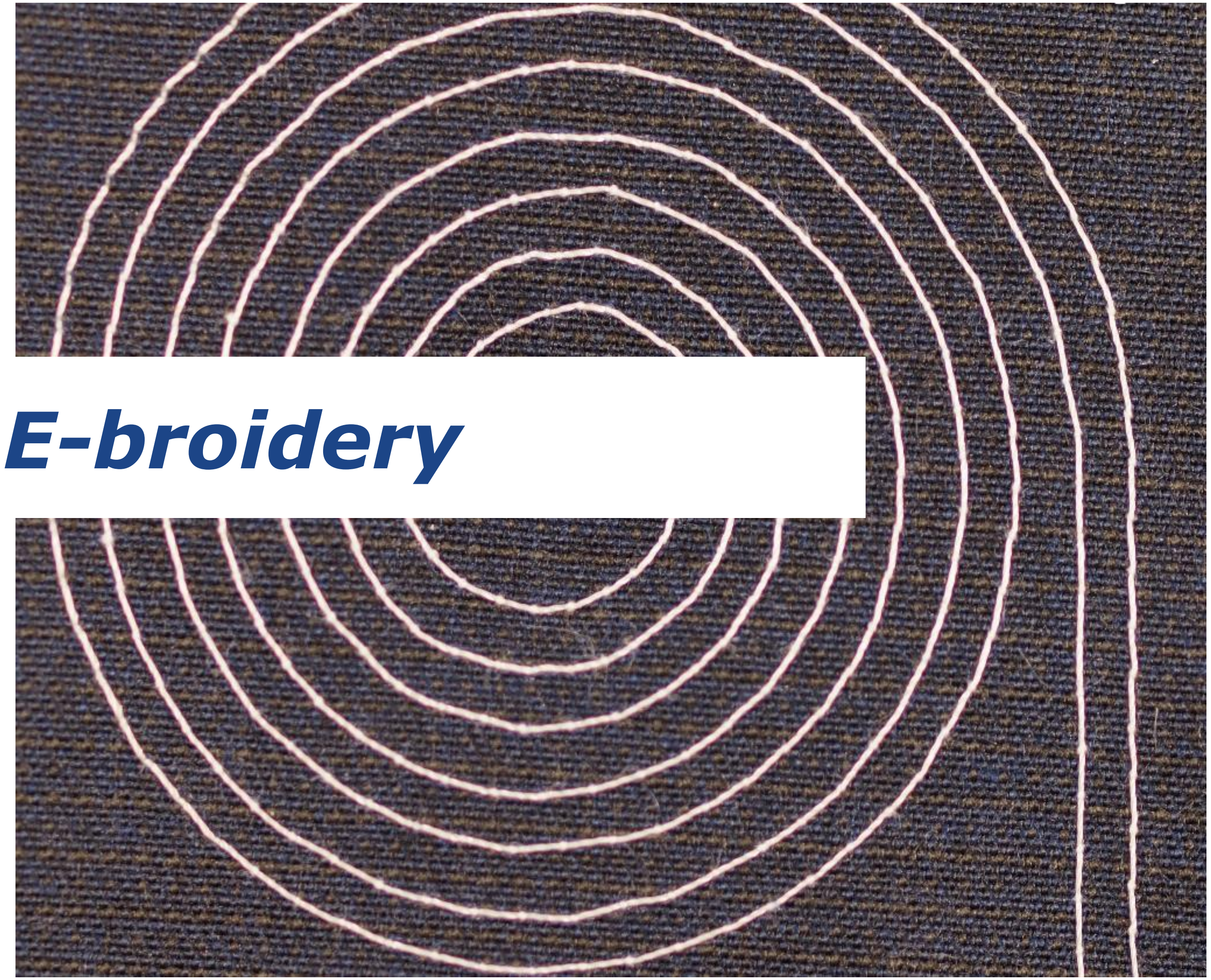
25A PUR
4x Cu/Ag PUR insulated microwire
Conductive thread

SEM microscope images of hybrid sewing threads (white fibers - metallic filaments).

3.2 Hybrid conductive threads



Examples of embroidered el. elements: left embroidered thermometer, capacitive buttons, "bow tie" antenna.



4. E-broidery

4. Conductive flat fabrics

- Flat fabrics are fabrics whose 2 dimensions are proportional and whose thickness with respect to the other 2 dimensions is negligible
- The flat fabrics can be divided into:
  - a) Woven
  - b) Non-Woven
  - c) Knitted

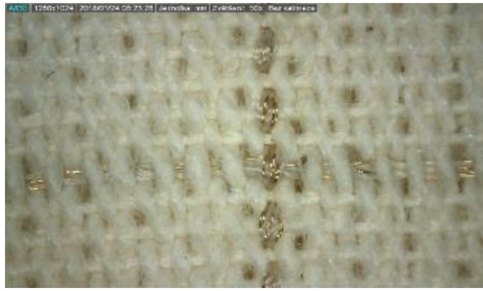
- Flat e-textiles can be prepared:
  - a) Knitting conductive threads into knitted fabrics
  - b) Electroplating of nonwovens
  - c) By embroidery with conductive threads
  - d) Fix wires on conductive fabrics with needle and thread (TFP -Tailored Fiber Placement technology)
  - e) Weaving conductive threads into woven fabrics
  - f) Printing of conductive pastes and inks

a)

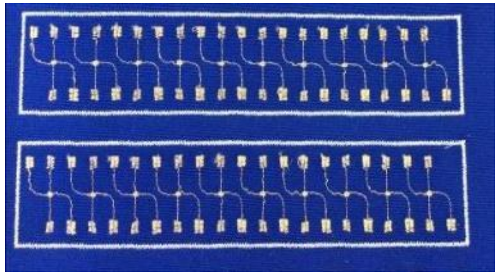
d)

b)

e)

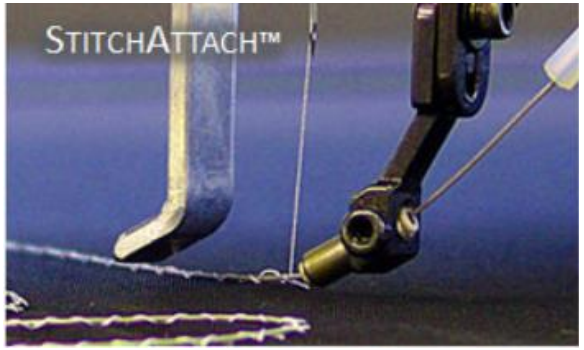


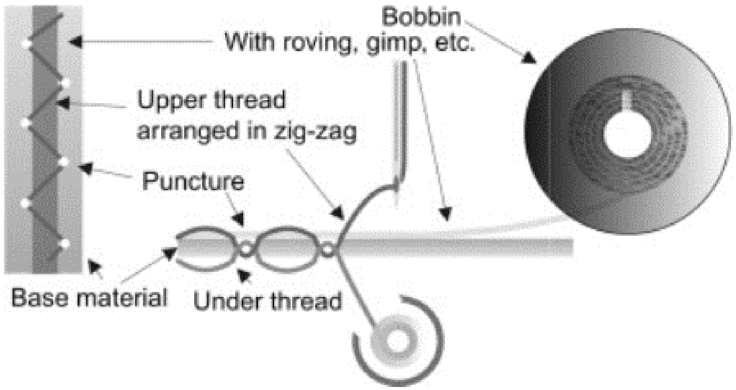
c)

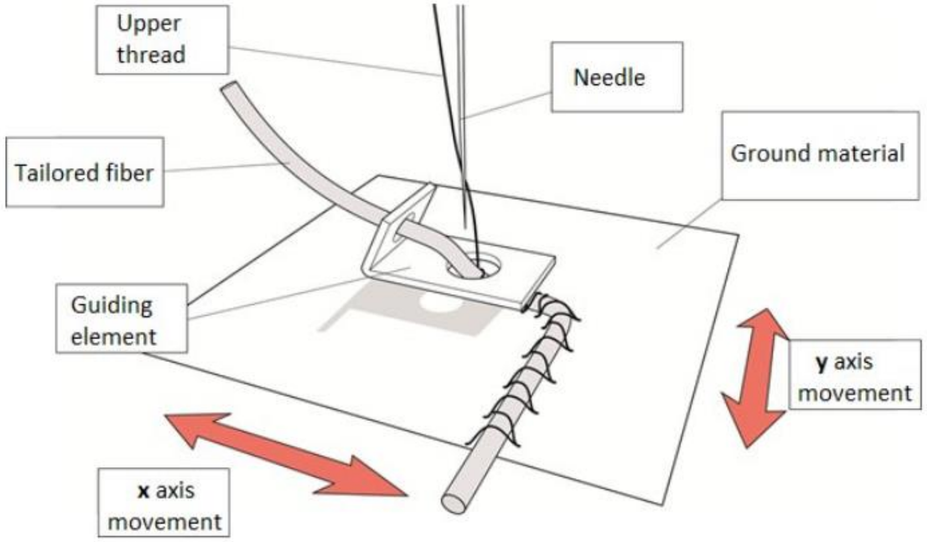


f)

- Industrial embroidery machines (e.g. ZSK, TAJIMA) have been modified to lay and sew ropes, wires, tubes and carbon fibers, etc.
- The technology originated in the 1990s in Dresden.
- Wire laying technology used for fixation wires / cables on textile substrate, in case of carbon, aramid fibers it is called tailored fiber placement (TFP)
- The roving material is fed through the bobbin into a tube that is placed in front of the sewing needle.
- The so-called roving tube and the machine frame where the supporting textile substrate is attached move synchronously with respect to the position of the needle to perform the zigzag stitch.
- The sewing head equipped with the roving bobbin, tube and needle can rotate freely through 360 degrees.
- During each stitch, the upper thread is pulled through the base material and wrapped around the wire/filament of the lower thread.

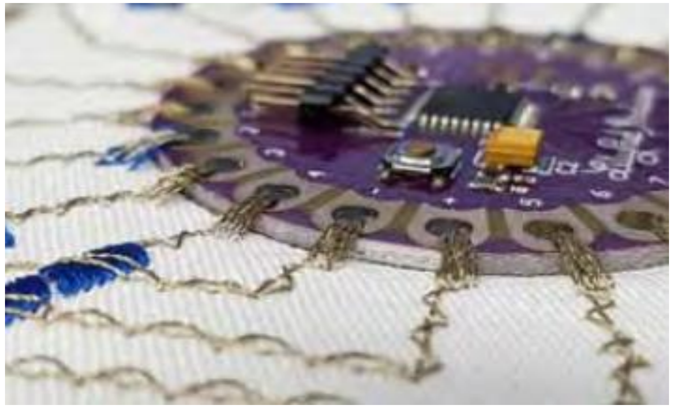




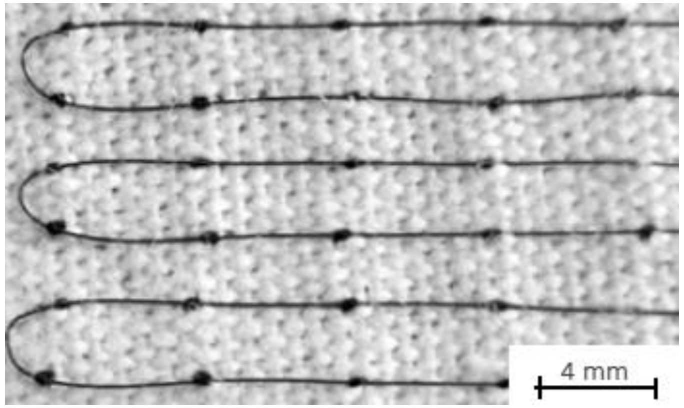


Wire laying technology.

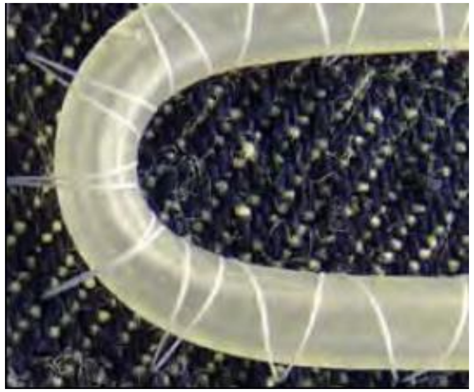
4. Wire laying technology



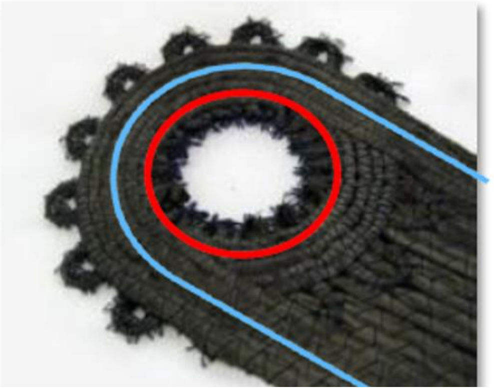
Connecting el. modules by wire laying technology.

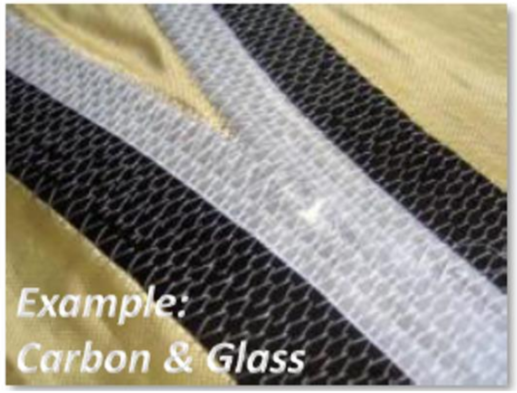


Nitinol wire (nickel alloy (55%) and titanium) as a strain sensor fixed by wire laying technology.



Tube for cooling purposes integrated into the garment by wire laying technology.



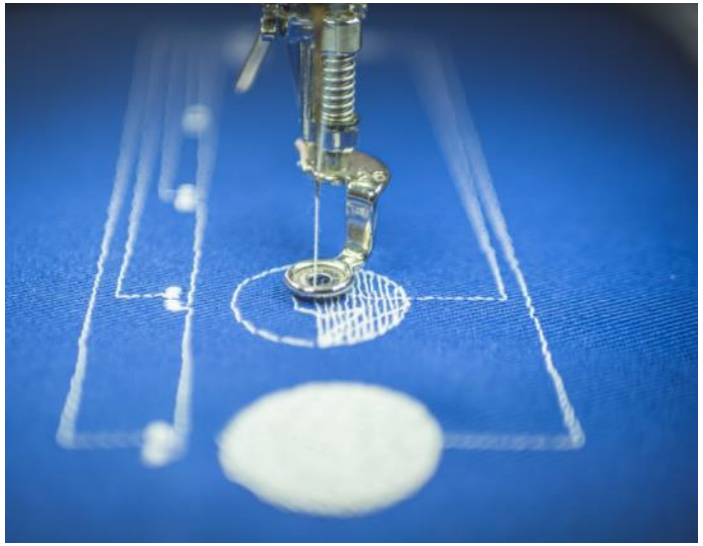


Carbon preforms for composites created using TFP (tailored fiber placement) technology by LayStitch Technologies

Heater wire sewing machine (TAJIMA TLMX series).

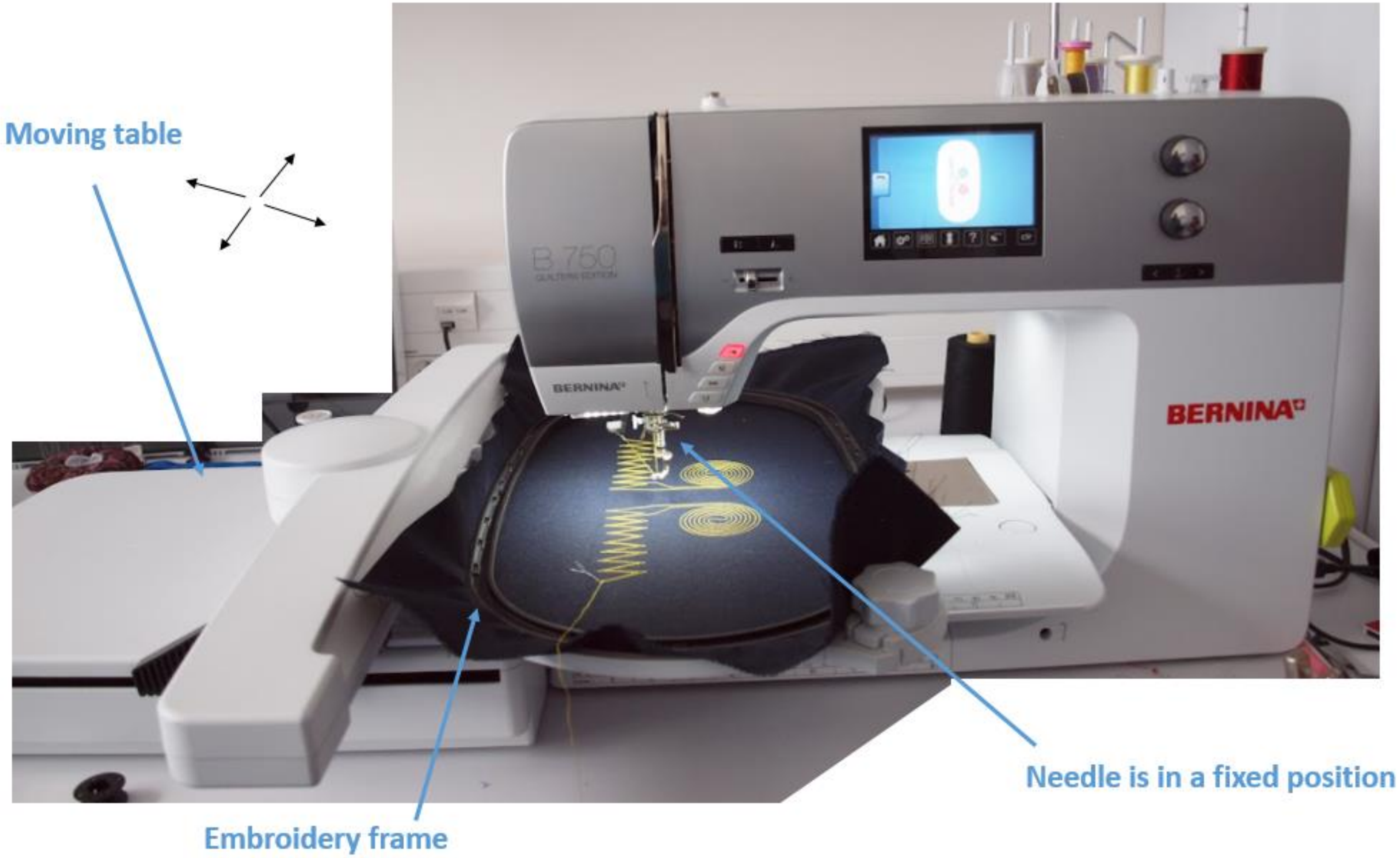
4. Embroidered conductive fabrics

- Embroidery is a traditional technique of textile decoration. First hand embroidery was used, then machine embroidery.
- There are large industrial automatic machines with a 2 m x 2.5 m work table (e.g. Tajima, ZSK) or semi-industrial machines (e.g. Brother, Bernina, Pfaff, Janome).
- There is a big difference between decorative embroidery and functional embroidery (sometimes also called technical **E-broidery = electronic embroidery**)
- If the thread breaks in **decorative embroidery**, the machine goes back a few cm and continues sewing **x technical (functional) embroidery** loses function (breaks the circuit)
  - ⇨ Functional embroidery is much more demanding in terms of sewing settings, patterns are embroidered more slowly
- Conductive threads and yarns are most commonly used for this technique, but also embroidered with twisted metallic filaments.



TAJIMA embroidery machine

4. Embroidered conductive fabrics

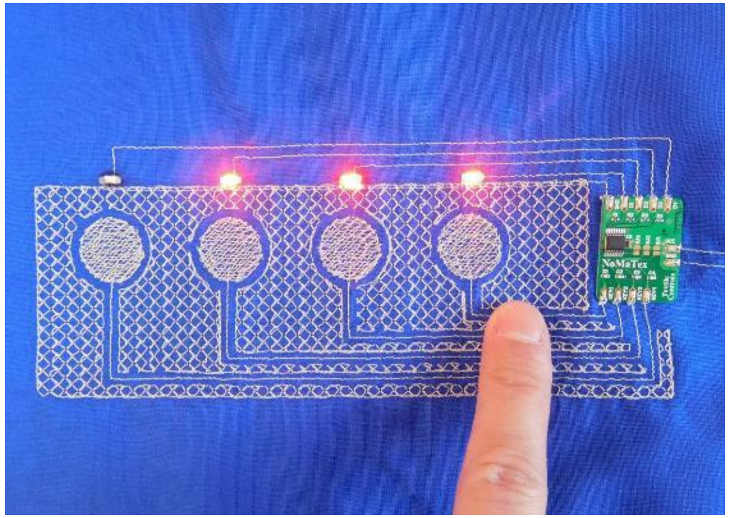


4. Embroidered conductive fabrics

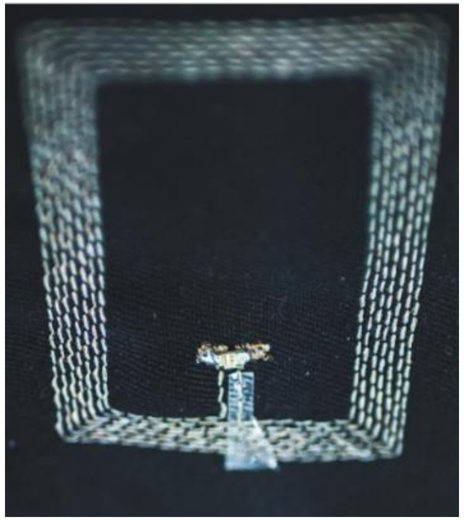
E-broidery – Video (ZSK Company)

4. Embroidered conductive fabrics

Examples of realizations from our university



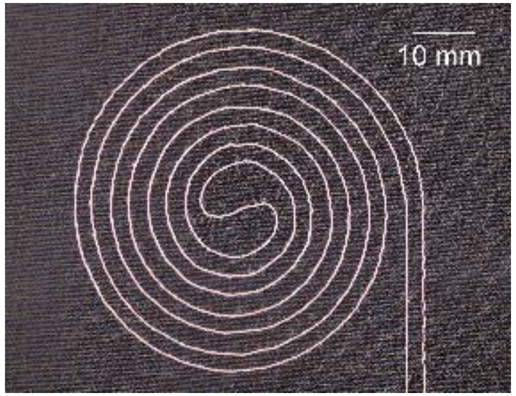
Capacitive buttons with feedback LEDs.



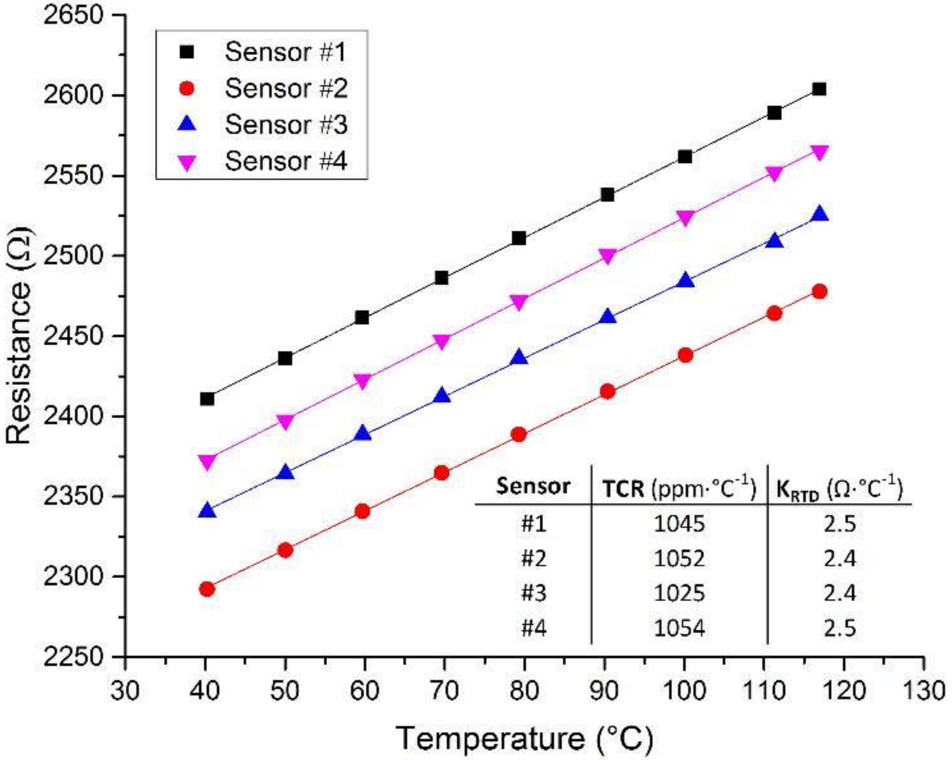
Embroidered RFID tag.

4. Embroidered conductive fabrics

Examples of realizations from our university



- RTD (resistive temperature device) thermometer allowing temperature measurements from a large area.
- Based on a chrome-nickel steel microwire
- Fast response to sudden temperature changes
- Resistance to more than 30 wash cycles
- Easy integration into textiles



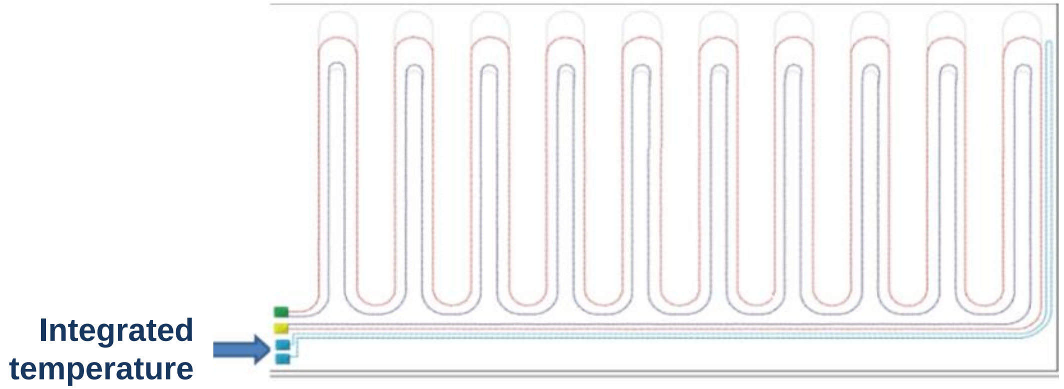
Example of calibration curves for embroidered thermometers.

R. Polanský, et al., A novel large-area embroidered temperature sensor based on an innovative hybrid resistive thread, In Sensors and Actuators A: Physical, Volume 265, 2017, Pages 111-119, ISSN 0924-4247

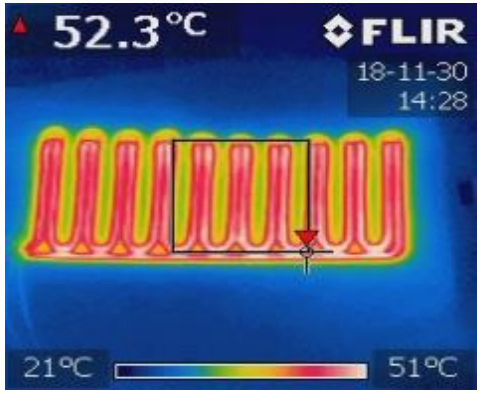
4. Embroidered conductive fabrics

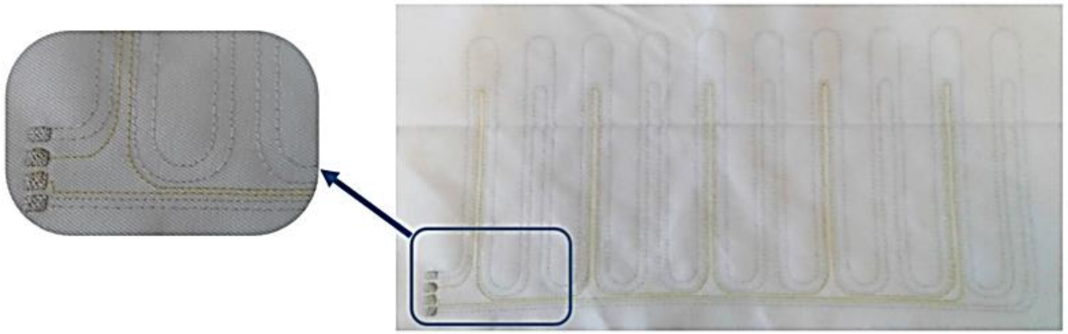
Examples of realizations from our university

- Fabric with embroidered meander - the active part was embroidered with brass hybrid thread (7.7 Ω /m) and Cu/Ag hybrid thread (7.4 Ω /m).
- On an area of 30 x 10 cm, 10 fingers were stitched with two parallel threads, the total resistance of the heating fabric was 8.6 Ω.
- In each odd finger of the pattern is integrated an embroidered temperature sensor made of a hybrid sewing thread based on chrome-nickel steel (yellow thread) ➡ surface temperature measurement that more closely matches the real condition.



Design of heated fabric with integrated thermometer.

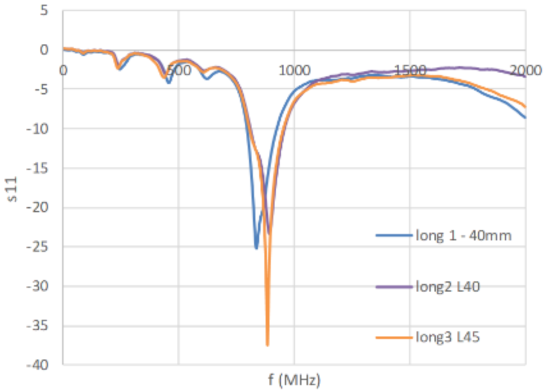




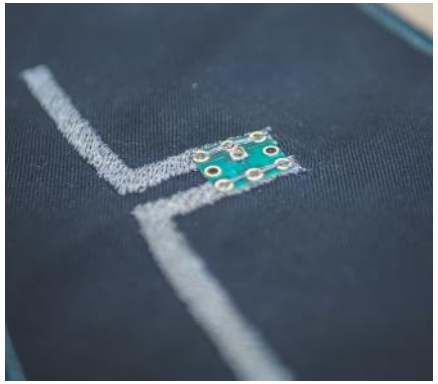
Realized heated fabric with embroidered motif and integrated thermometer.

- Textile based dipole and bowtie antennas (868 MHz).
- Hybrid construction (printing and embroidering).
- Benefits: flexibility, breathability, wear comfort.

Textile dipole antenna with hybrid construction antenna.

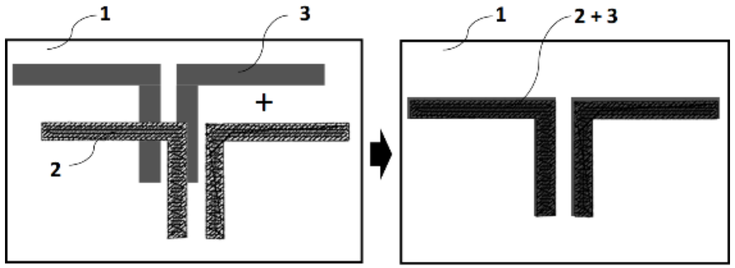


The dependence of the S_{11} parameter (reflection coefficient or return loss) on frequency



Textile dipole antenna with interposer.

Textile bow tie antenna with hybrid construction.



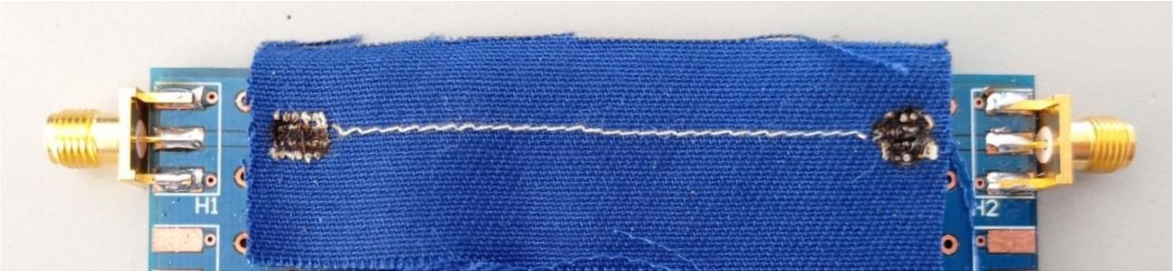
Antennas layout.

*Patent **CZ 308636 B6**, „A method of making a textile-based antenna and an antenna made in this way“, 2020.*

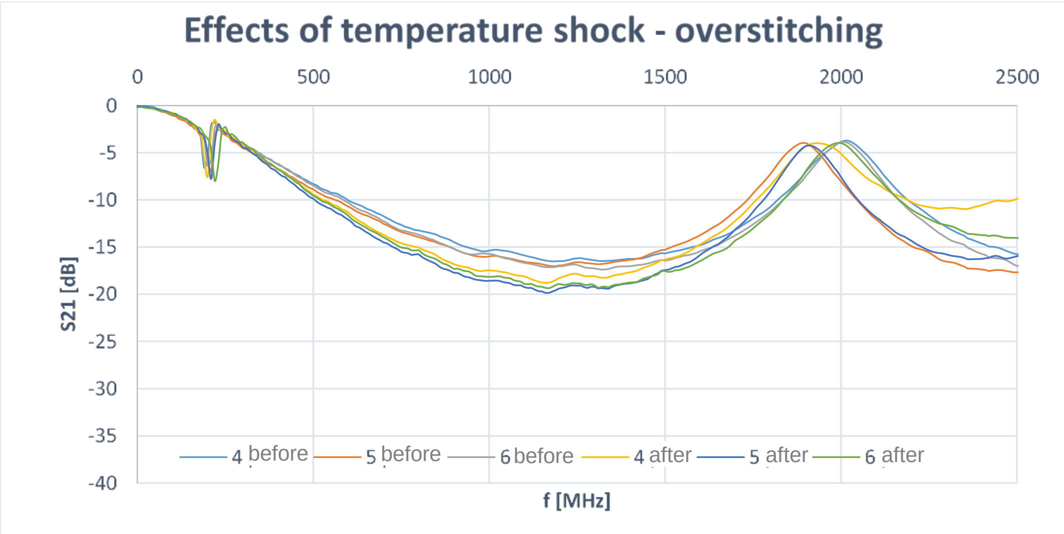
4. Embroidered antennas

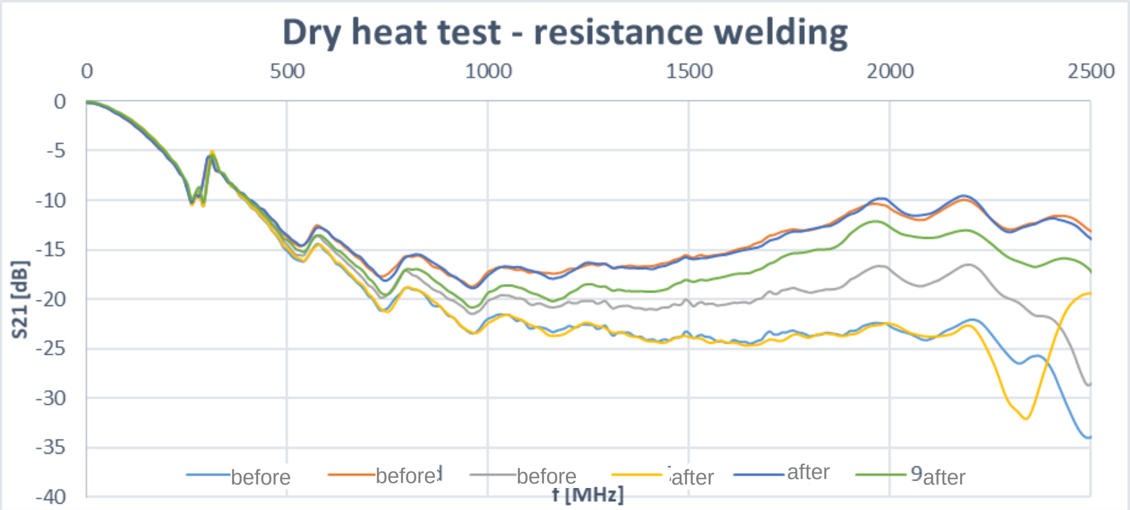
- Different contacting methods (sewing, soldering, resistance welding, ultrasonic welding and glueing) for embroidered antennas and their resistance to stress tests (dry heat, wet heat, temperature shock tests and washing tests) were tested.
- The best results achieved by soldering and sewing.

The contact formed by sewing (overstitching)



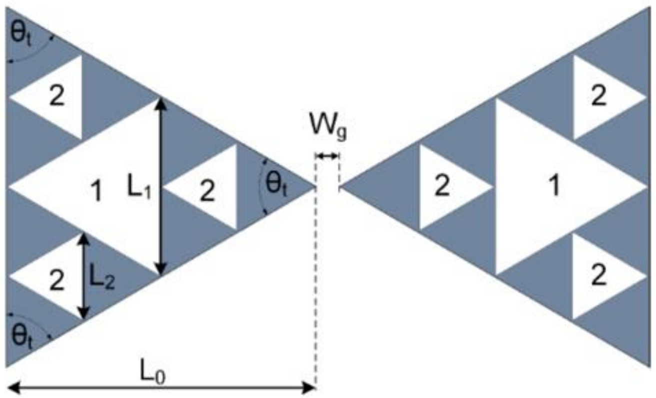
The contact formed by resistance welding



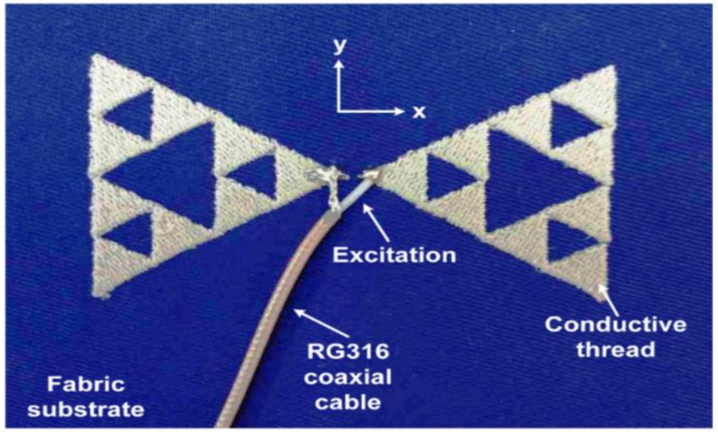


attenuation values over 10 dB.

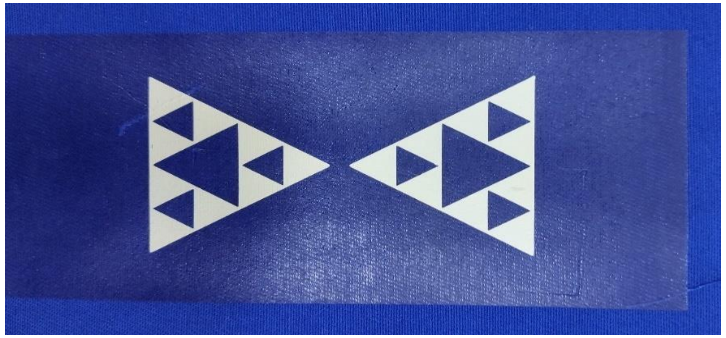
4. Embroidered antennas



Geometric arrangement of bowtie antenna

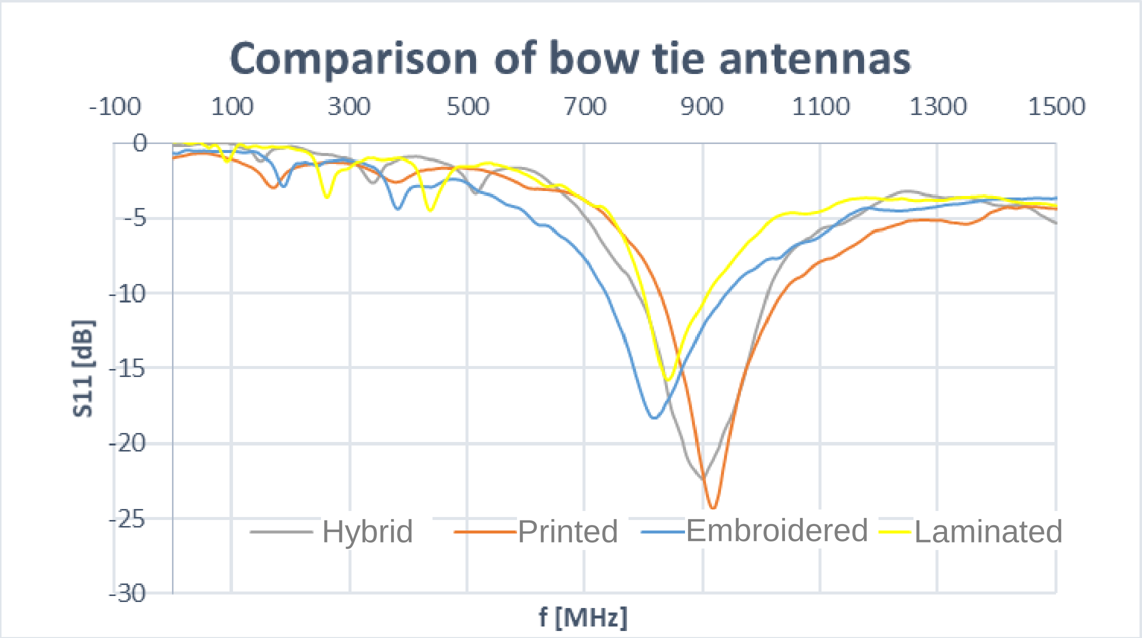


Realized bowtie antenna – embroidered

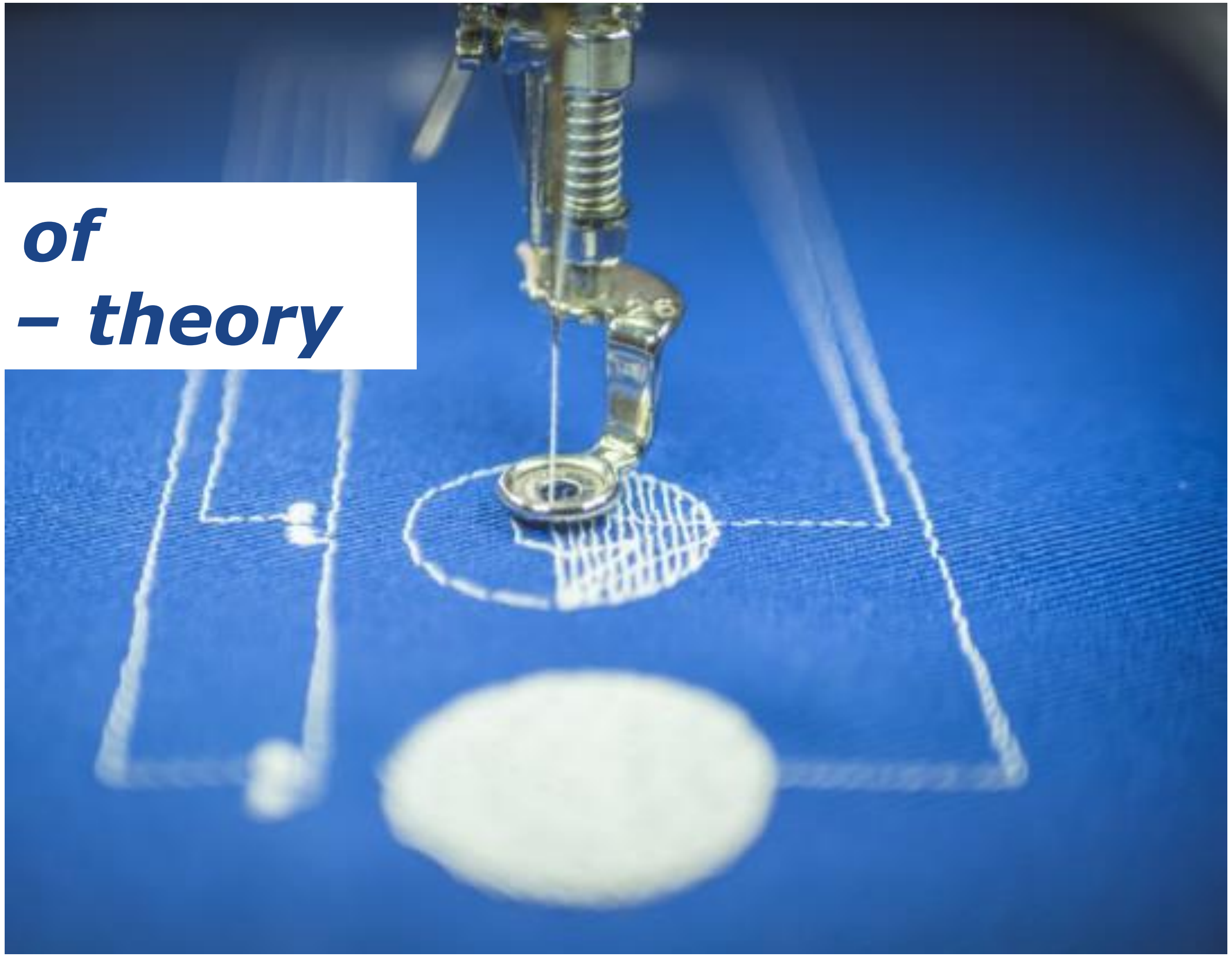


Realized bowtie antenna – printed/laminated (Intexar)

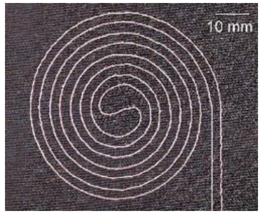
Parameters	Bow tie
L_0 (mm)	50
L_1 (mm)	24
L_2 (mm)	10
w_g (mm)	3
θ_t (deg)	60



5. Design and digitizing of technical embroidery – theory



5. Design and digitizing of technical embroidery

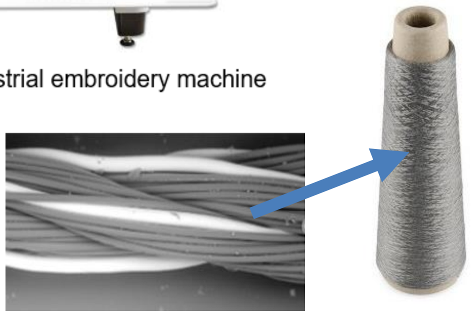


Need to have:

1. Design of pattern to be embroidered
2. SW for embroidery digitization
3. Embroidery machine
4. Conductive thread compatible with embroidering machine

a) hobby embroidery machine

b) semi-industrial embroidery machine

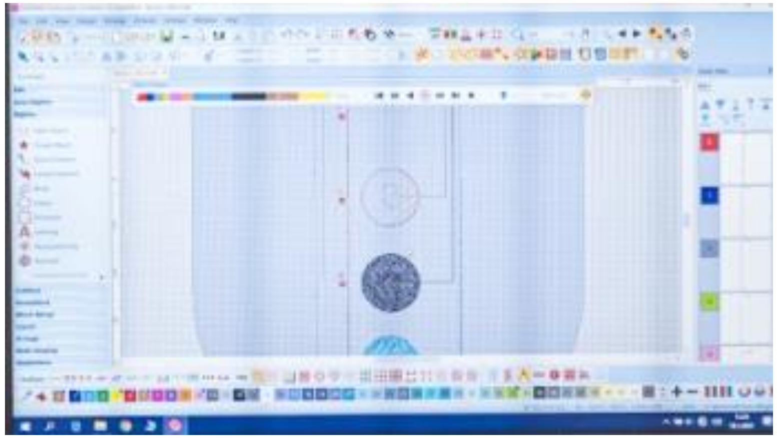


Significant difference between technical embroidery and conventional decorative embroidery

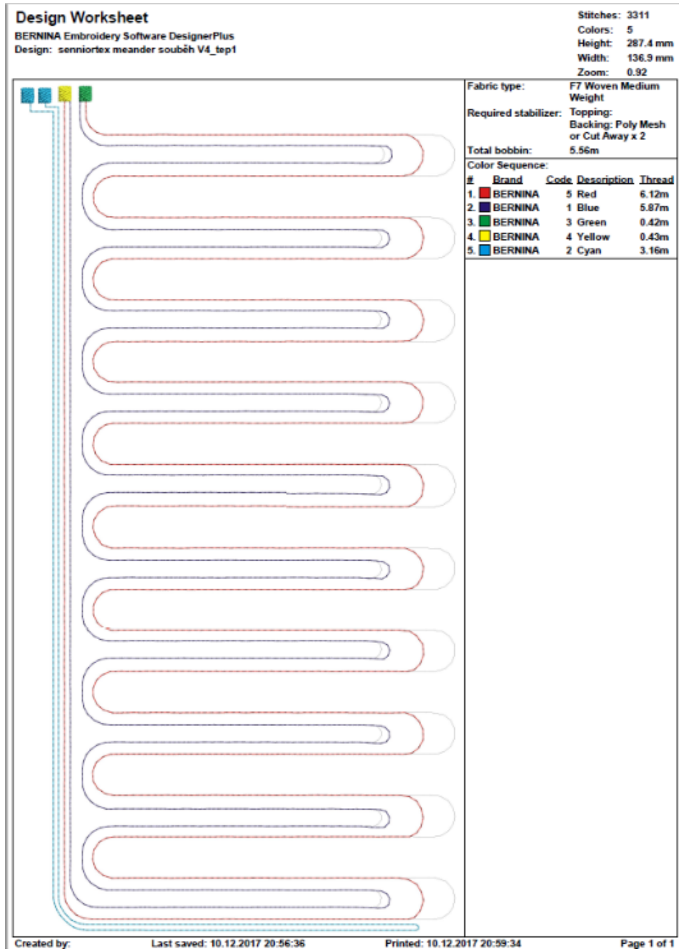
To have the knowledge for technical embroidery !!!

- Automatic embroidery machines embroider in XY coordinates.
- The embroidery and the order of its embroidery, the length and types of stitches, the colour (types) of thread used are programmed in CAD software for embroidery machines.

Embroidery machine Bernina 790

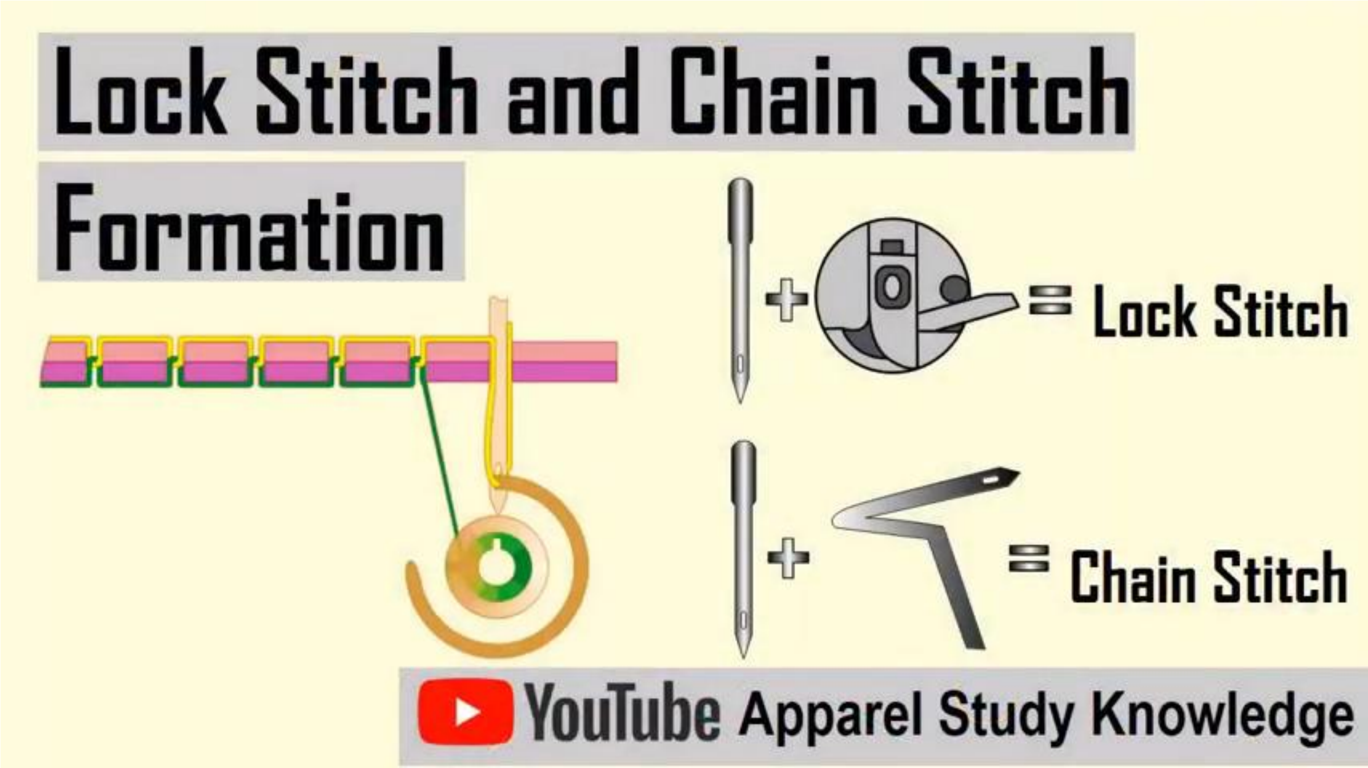


SW environment for embroidery design for Bernina machine

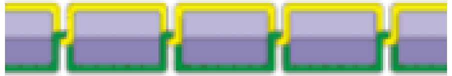


Embroidery design for heated textiles with integrated thermometer.

5. Embroidered conductive fabrics



Lock stitch formation- Video



The final length of the upper and lower sewing thread depends on the stitch tightening. The length of the forward and reverse stitching is not the same!

Ranking of textile techniques according to the conductive thread load

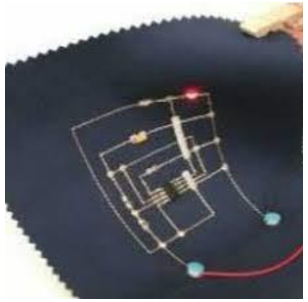
1. Embroidering (the most stressful)
2. Knitting
3. Weaving (insertion of conductive threads into the warp)
4. Wire laying technology

Decorative embroidery
- Precise reproduction of an image or text.
- Visual impression.
- Touch features.
- Smoothness.
- Usually many colour threads and different stitches types.

vs.

Technical embroidery
- Functionality – defined and reproducible electrical parameters.
- Reliability during use and maintenance (keeping the continuity without any thread breakage).
- Usually only a few different threads.
- Conductive threads can be top as well as bobbin thread.

Decorative embroidery



Technical embroidery

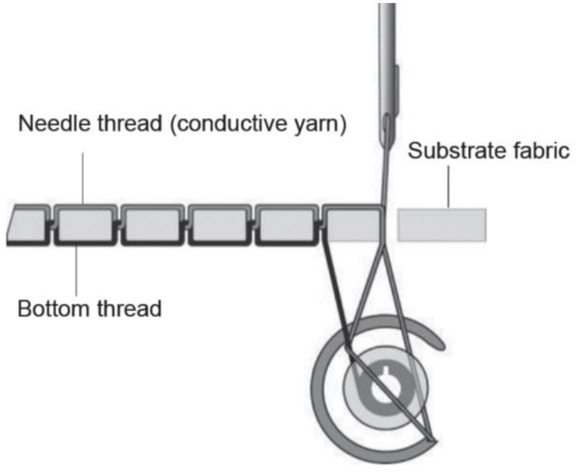
5. Design and digitizing of technical embroidery

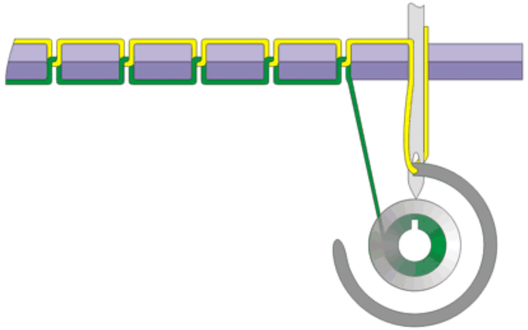
Principle and equipment is similar, but:

- Technical embroidery have to create continuous conductive path without any interruptions.
- Thread breakage in one conductive path is not permitted (not an issue in decorative embroidery).
- The length of path is important.
- Longer path – higher electrical resistance.
- Longer path – higher thread consumption, higher cost.
- Direction of embroidery have to be also considered - when embroidering an equally designed pattern in different directions, different thread consumption may occur due to the inaccuracy of the motors in the sliding embroidery module (pantograph). It results in a different electrical resistance.
- Fineness of the thread (the optical diameter of the thread) is important for filling the areas.
- Embroidering speed should be lower for technical embroidery (recommended 300-400 stitches per minute). At high embroidery speeds, the structure of the conductive threads may be damaged, and the conductive micro-wires may break.

The quality of embroidery depends on:

- **Choice of the textile substrate** (ideally twill or dense plain weave).
- **Thread** (yarn) - optical diameter, structure, composition.
    - Top (needle) thread.
    - Bottom (bobbin) thread.
- Use/non-use of **stabilizer** (backing) - It is used to support the fabric during the stitching process to keep puckering or stretching from occurring.
- Choice of embroidery machine and embroidering parameters (mainly the speed).
- **Machine embroidery needle** (type, dimensions, surface).





5. Design and digitizing of technical embroidery

Three independent steps:

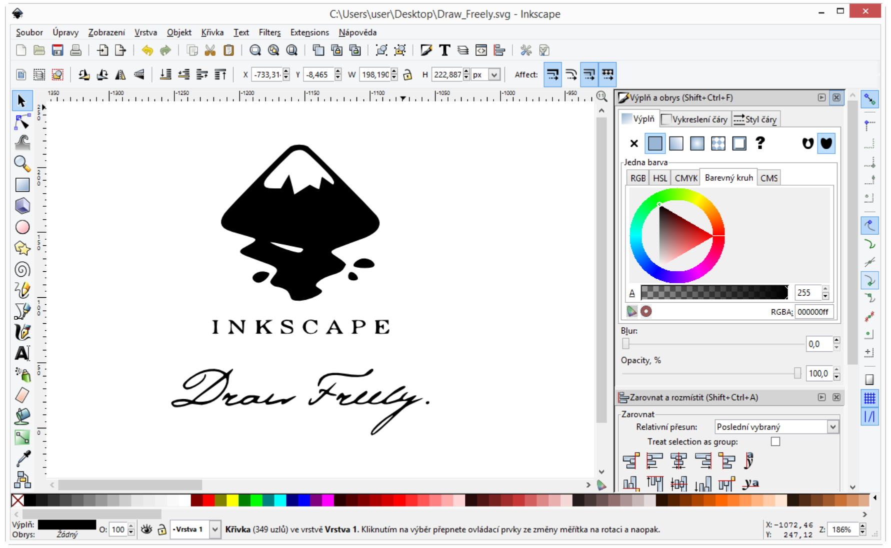
1. Idea of the pattern to be embroidered – hand sketch, picture.
2. Design the pattern in 2D vector graphics with precise dimensions based on required electrical function.
3. Digitizing of vector graphics – transfer vector graphics to file format compatible with particular embroidery machines.

Embroidery Stitch File Format	Embroidery Machine Brand
.ART	Bernina
.PES / .PEC	Brother / Baby Lock / Deco
.DST	Tajima / Barudan
.EXP	Melco / Bravo
.SEW / .JEF	Janome
.VP3 / .HUS / .VIP	Husqvarna /Viking

5. Design and digitizing of technical embroidery

Embroidery design

- The basis of any technical embroidery is its graphic design.
- Graphical design allows to transfer the idea to 2D vector graphics.
- Many existing vector graphics programs can be used:
    - Universal vector graphic SW – CorelDRAW, Adobe Illustrator, Visio,…
    - Proprietary SW - special SW supplied with the specific embroidery machine according to the manufacturer.
    - Free vector graphic SW – Inkscape, LibreOffice Draw, etc.



https://inkscape.org/release/inkscape-1.1.2/

- Selected SW for graphic design for technical embroidery - Inkscape.

5. Embroidery digitizing

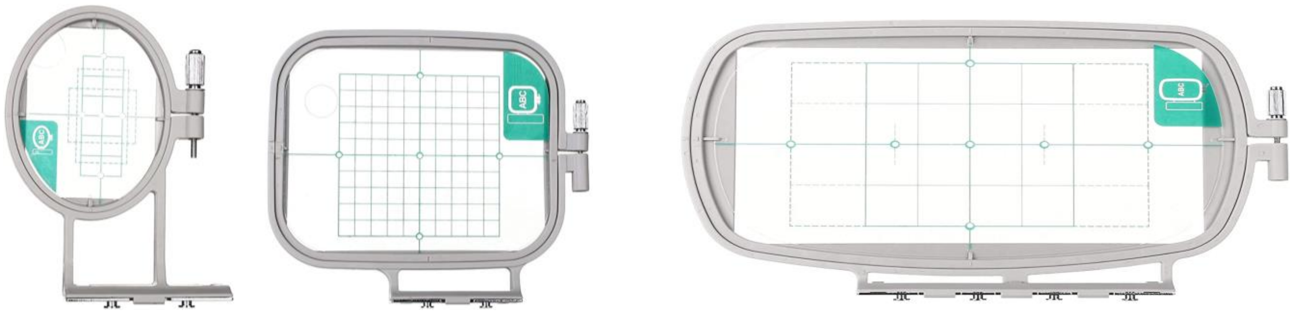
Converting vector graphics to embroidery formats.

- Many existing digitizing programs can be used (output file format have to be compatible with particular embroidering machine):
  - Universal SW – Hatch, Embird, My Editor, Ink/Stitch, Embroidermodder, SophieSew, TrueSizer, etc.
  - Proprietary - supplied with the specific embroidery machine (Brother PE-Design, Bernina Artlink, ZSK IDS, Tajima DG, …).

- Selected SW for digitizing the vector graphics - **InkStitch.**
  - An open-source machine embroidery design platform based on Inkscape (add-on to Inkscape).
  - This add-on focuses on converting vector graphics to embroidery formats. A file can be generated in a format that is compatible with the selected embroidery machine.

https://inkstitch.org/

- The basis of technical embroidery is its graphic design.
- Keep in mind during the preparation of vector graphics design:
  - Structure of the designed electrical circuit – **no crossing of conductive threads** is generally allowed (risk of short circuit).
  - **No interruptions in embroidered pattern** are allowed – risk of loosing connection when connecting two conductive threads in pattern.
  - The technological limitation of embroidery – **resolution of embroidery** (minimum line spacing).
  - The technological limitation of embroidery – **maximum size of the embroidery frame**.



5. Embroidered conductive fabrics

Advantages

- Any two-dimensional conductive pattern can be quickly created.
- Easy customization, quick machine reconfiguration (digital embroidery).
- It is possible to use multiple threads at once during one embroidery.
- It is possible to stitch over each other (e.g. to form non-conductive insulating bridges).

Disadvantages

- Functional embroidery is slow compared to other knitting and weaving technologies.
- Of all the production methods, embroidery is the most stressful for the conductive threads (high friction forces in the eye of the sewing needle, high tensile forces of the hook, large thread bends during sewing).
- The embroidery is less abrasion resistant and has less resistance to washing.

6. Design and digitizing of technical embroidery – practical examples

6. Design and digitizing of technical embroidery – practical examples

- Focuses on the most common shapes and basic patterns in technical embroidery. The embroidery design in Inkscape will be shown in 3 examples.

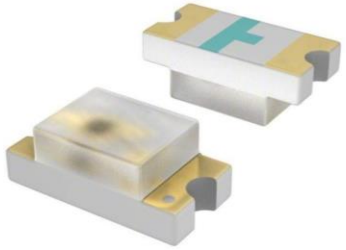
  a) **Contact pads for small electronic components**

  b) **Contact pads of larger dimensions** (connection of battery, removable connectors like snap fasteners, etc.)

  c) **Contact pads with parallel conductive paths** – to design the continuous pattern.

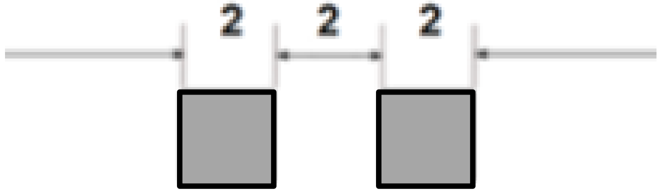
A) Contact pads for small electronic components

- Contact pads used for placement and interconnection of SMD (Surface Mount Device) electronic components like:
  - Light Emitting Diodes (LEDs)
  - Resistors/Capacitors
  - Sensors

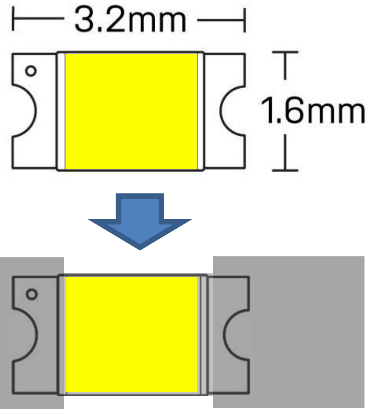


Necessary to design 2 pads with proper dimensions and defined distance between pads
(for SMD with dimensions 1206):

- Pads dimensions **2x2 mm**
- Gap between pads **2 mm**

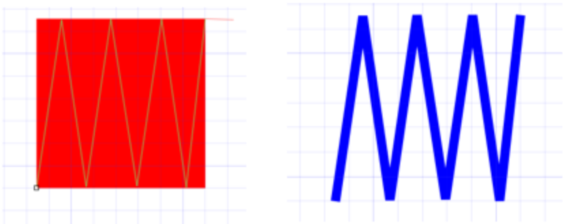


Contact pad design for SMD LED 1206 (dimensions in millimeters).



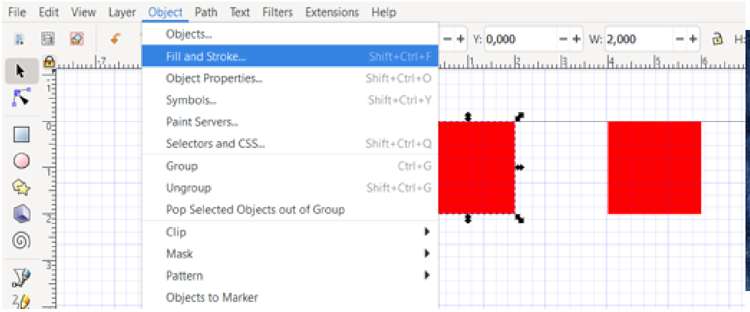
6. Basic patterns for technical embroidery

- **First method** - manual hatching method
  - Smaller amount of thread, lower thread consumption, freedom in filling design.
  - No significant increasing the dimensions of the embroidered object, which could cause a short circuit of the electrical circuit.
  - Design takes more time.



Realization of a planar object using manual hatching by Inkstitch

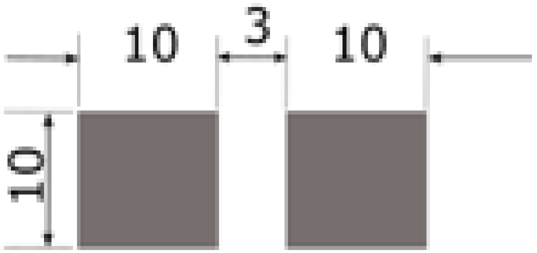
- **Second method** - flat shape filling method
  - Higher consumption of thread – dense filling.
  - Dimensions of the embroidered object are larger than was given in the graphic design.
  - Embroidering creates elevated areas.
  - Higher deformation of textile substrate.



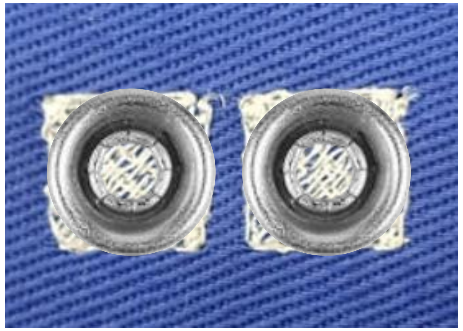
Fill and *Stroke* options

B) Contact pads of larger dimensions

- Typical design for detachable connectors like snap fasteners.
- In this case two **contact pads with 10 x 10 mm** dimensions are implemented.
- The **gap of 3 mm** is between the pads.



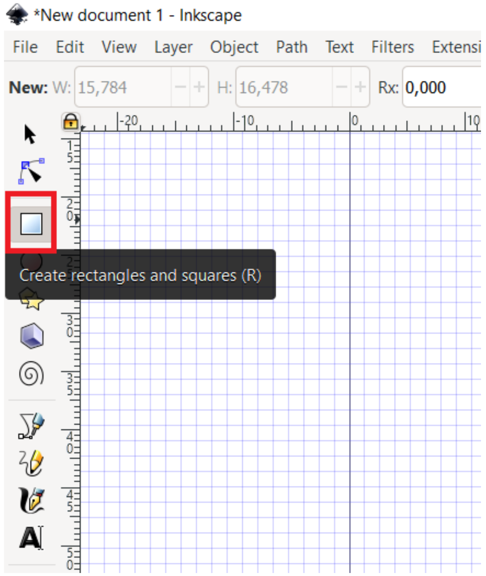
A pair of contact pads design for snap fasteners.

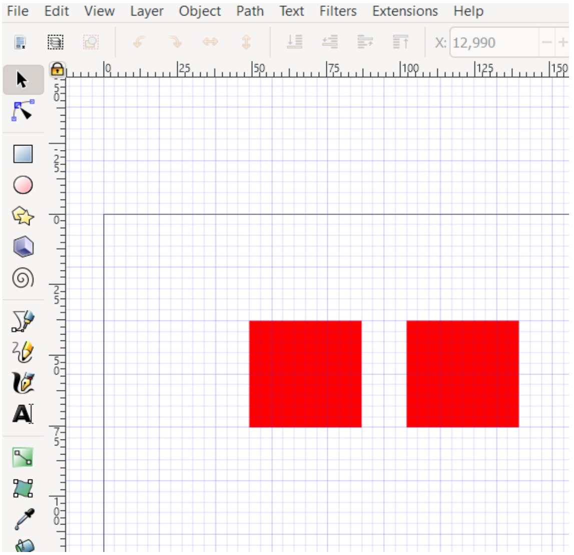


An example of snap fasteners on embroidered pads (snap fastener Roland baby, diameter 10 mm).

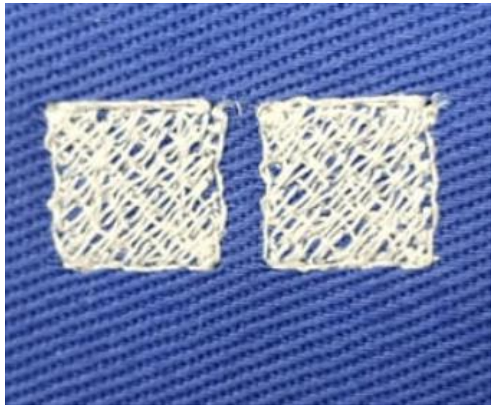
B) Contact pads of larger dimensions

- It is necessary to properly set the parameters of filling.
- The knowledge of thread diameter is essential (in case of hybrid conductive thread usually the optical diameter is around 0.23 mm).





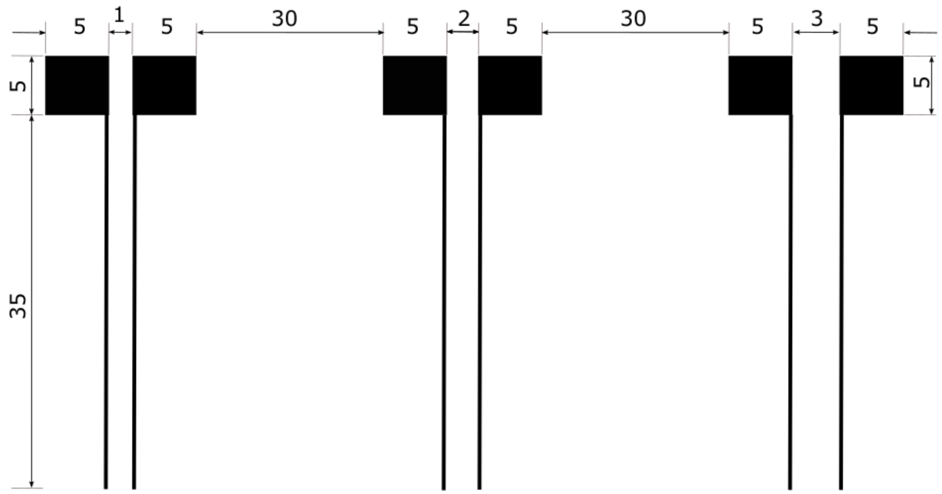
Design of contacting pads of larger dimensions.



Stroke	
Running stitch	2 mm
AutoFill	
Running stitch	2 mm
Angle of lines of sitches	45 deg
Spacing between rows	0.5 mm

C) Contact pads with parallel conductive paths

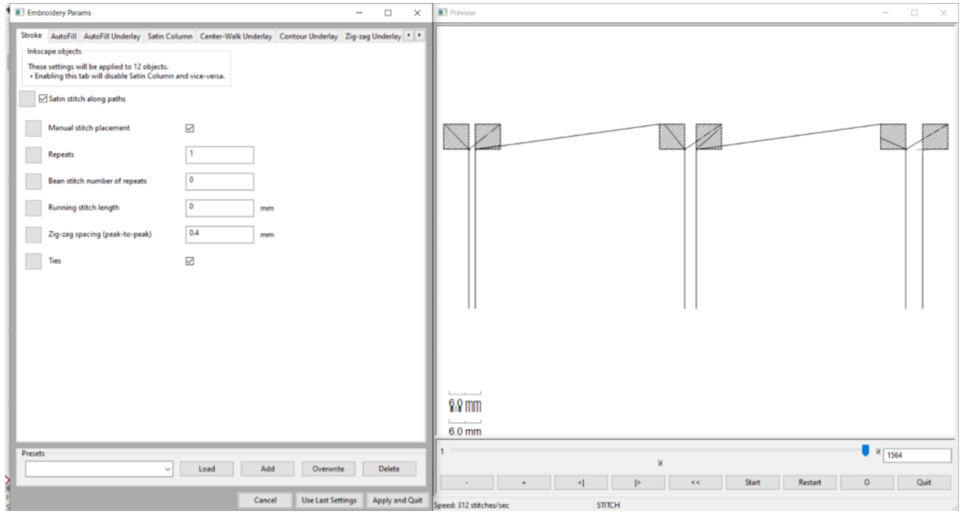
- Typical design for the verification of **embroidery resolution** (minimum line spacing).
- Parallel paths where embroidered threads are spaced 1, 2, and 3 mm apart.
- The purpose of this example is to draw attention to the need for a **sufficient distance** when **embroidering parallel conductive paths**.
- In the case of an insufficient distance the undesired connection of threads can occurs - **short-circuit**.
- In case of inappropriate order of individual paths there is a **risk of disconnection of the circuit**.



Parallel conductive paths.

C) Contact pads with parallel conductive paths

- It is recommended **to draw the pattern exactly in the order** in which it should be embroidered.
- It is advisable to choose a **minimum distance** of parallel paths of **2 mm** to maintain the gap between them and **eliminate the risk of short circuit**.
- When embroidered at a distance of 1 mm, there can be an undesired interconnection of parallel paths (depends on thread diameter, embroidering direction, embroidering machine setting).

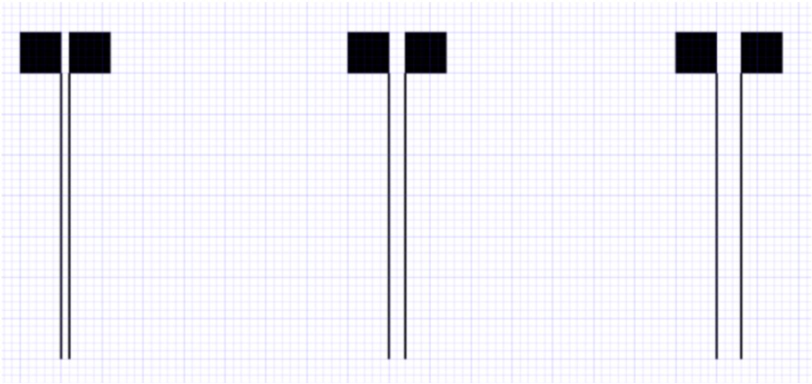


Setting InkStitch parameters.

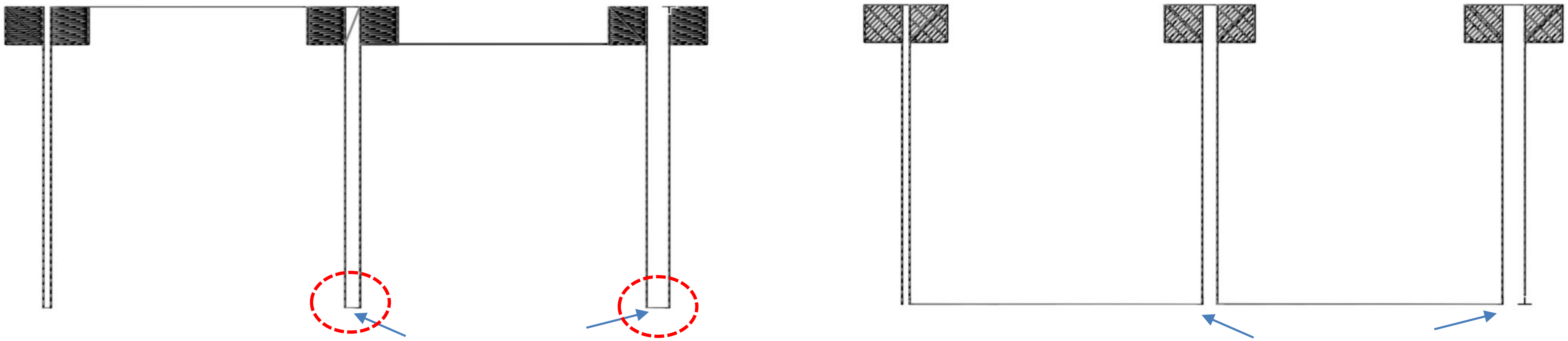
Stroke	
Running stitch	2 mm
AutoFill	
Running stitch	2 mm
Angle of lines of sitches	45 deg
Spacing between rows	0.5 mm

Embroidered pattern.

C) Contact pads with parallel conductive paths



Design of individual patterns.



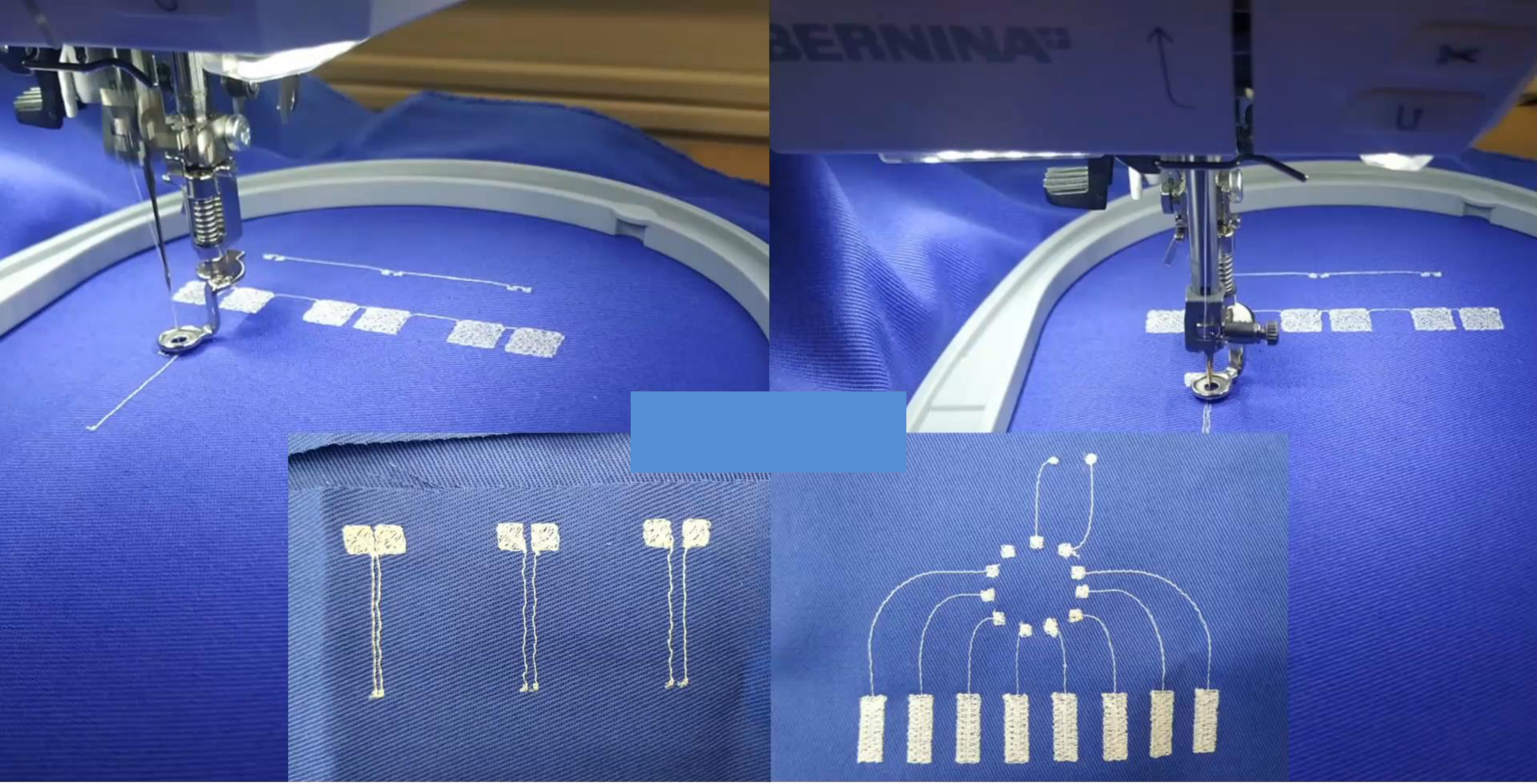
Optimized order of individual patterns:

Inappropriate order of individual patterns:

Trims (risk of short circuit)

Trims (reduced risk of short circuit during trimming)

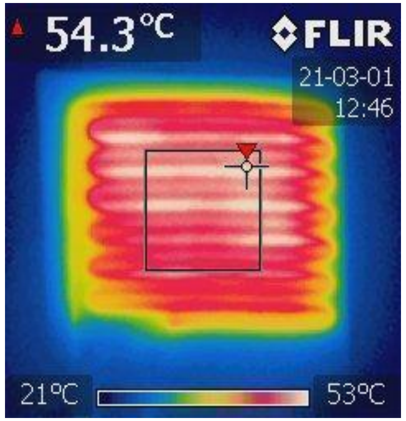
7. Demonstration videos



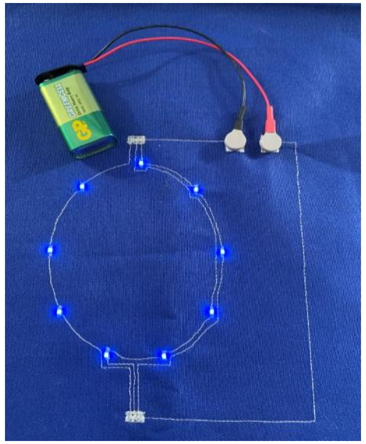
The Case 2 shows design and digitizing of technical embroidery

- Within our course Flexible electronics technology the following 3 examples were practically realized by students:

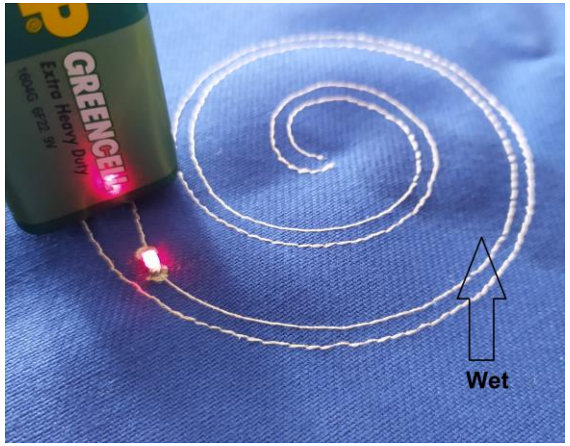
  - **Case 3: Textile Based Heating Element -** emphasis on a precise and defined value of electrical resistance. [Video 1]
  - **Case 4: Illuminated fabrics -** emphasis on continuous conductive path of complex shape and preparation of contact plates for SMD. [Video 2]
  - **Case 5: Textile based water leak sensor on fabric -** emphasis on a precise and defined gap between the conductive paths. [Video 3]



Textile Based Heating Element



Illuminated fabrics



Textile based water leak sensor

Thank you for your attention

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