NORTHWIRE INC

WHITE **PAPER**

Key Considerations in the Design and Manufacture of Medical Cables

2025

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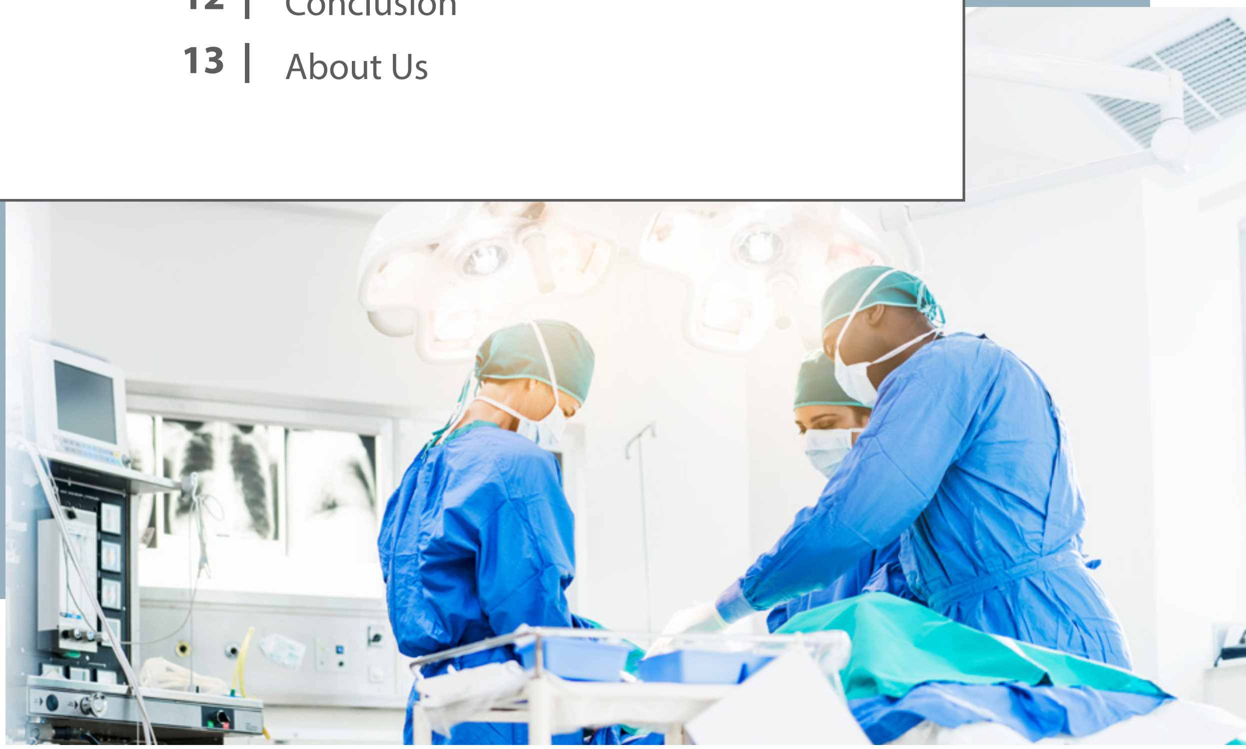
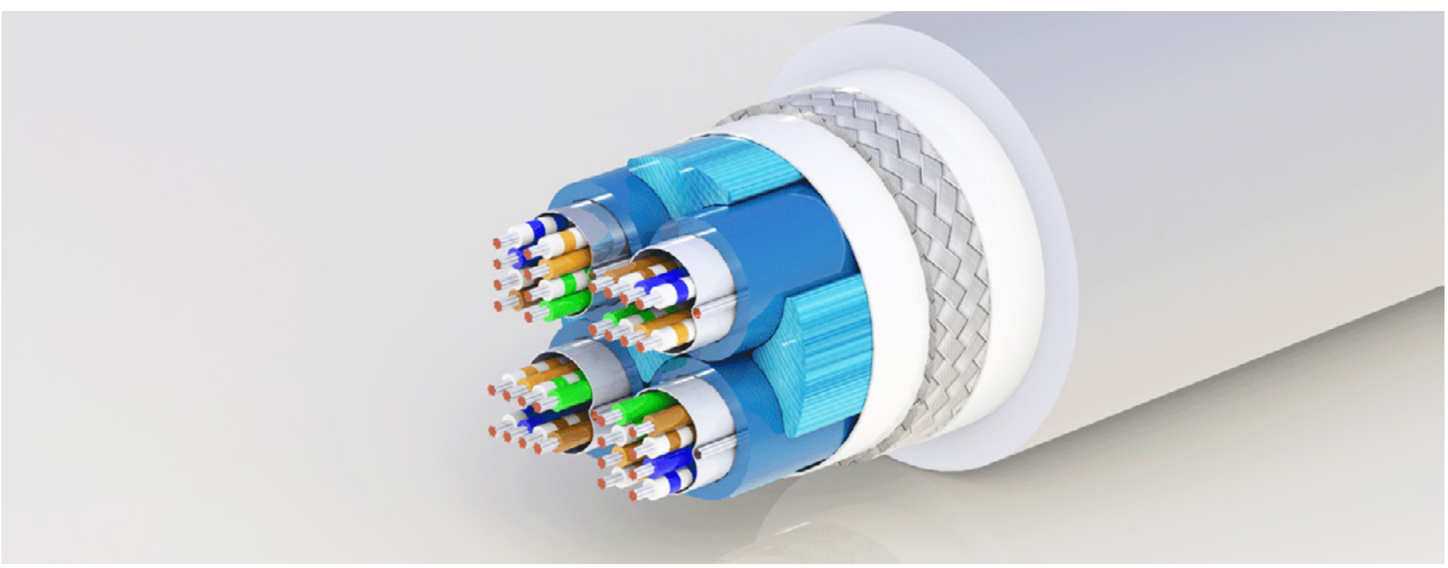


Introduction

Medical cables are critical components in a wide range of diagnostic, therapeutic, and surgical devices. Their performance directly impacts patient safety, device reliability, and clinical workflows. This white paper outlines the key considerations in the design and manufacture of raw medical cable, specific to connector considerations and cable assemblies, providing a practical guide for OEMs, engineers, and regulatory professionals involved in medical device development.

This paper will take a "copper-up" approach to medical cable design considerations. That is, it will follow much the same flow as the manufacture of the cables themselves, looking at many aspects of electrical, mechanical, and regulatory requirements relating to:

- **Copper** – size, strand count, strand configuration, plating
- **Insulation** – material, thickness, color, striping
- **Other components** – thermocouples, fiber optics, tubes, strength members, fillers, tapes, shields
- **Component layout** – twisted pairs, triads, sub-bundles (sub-jacketed or not)
- **Jacket** – material, thickness, color, extrusion type, surface finish



Copper

The fundamental function of almost any cable is to transmit electrical power and/or signal from one point to another.

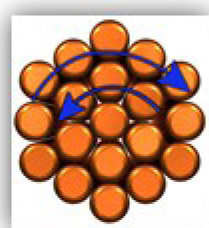
To determine the gauge size or circular area required, there are well-proven programs, formulas, and look-up tables that utilize the relevant factors of current, voltage, temperature, and cable length. Where many of these long-standing methods can fall short, however, is in applications with very narrow pulses (very low duty cycle) and very high voltages, such as those being employed in the rapidly growing area of Pulsed Field Ablation (PFA) devices. These may require a more detailed look at the pulse characteristics and more thorough verification testing.

Copper Construction

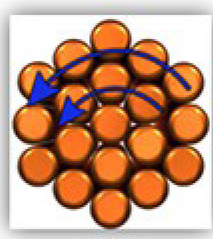
After determining the wire gauge or circular area, there may be more copper construction options to consider. This can include the number of strands and the layout of those strands – concentric, semi-concentric, unilay, bunched, or rope lay. There may even be options for the lay length within any of these various constructions.

Generally, higher strand counts offer more flexibility and lower impact of the skin effect at high frequencies, but higher strand count also brings a higher price tag.

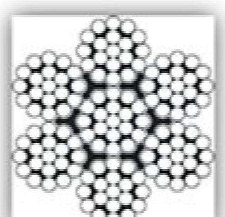
Bunched



Concentric



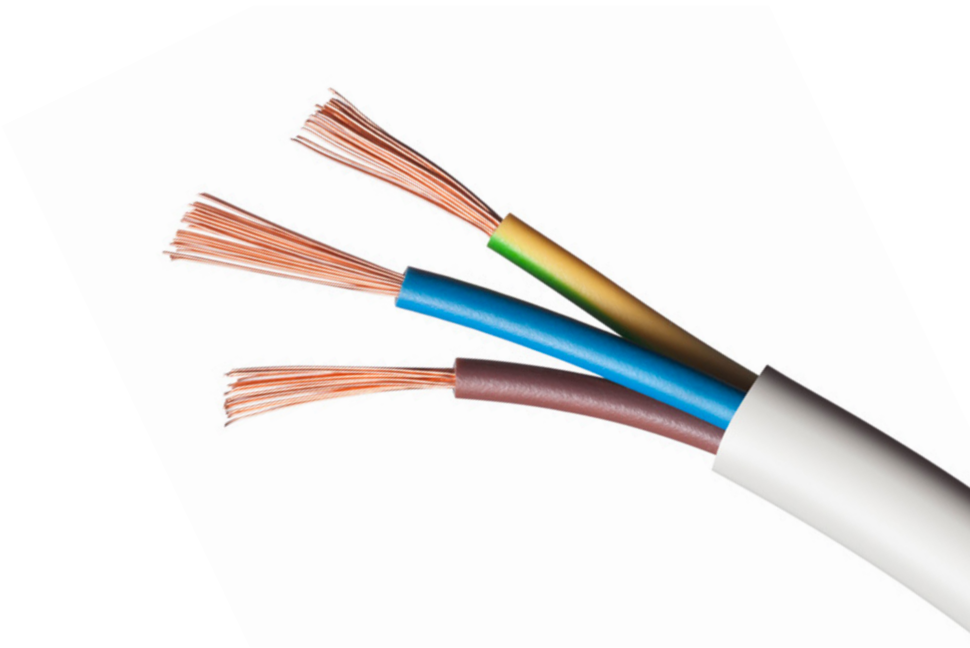
Unilay



Rope Lay

Choosing the optimal copper construction can include key considerations of:

- Flexibility
- Flex life
- Cost
- Outer diameter (OD)
- Strip-ability
- IPC-620 classification
- Signal type and frequency
- Tensile strength
- DC resistance



Copper plating options include:

- Nickel plating
- Silver plating
- Tin plating
- No plating (bare copper)

Silver plating offers advantages of high conductivity and excellent solderability, but at the highest price of the four. Bare copper offers the lowest cost but the highest susceptibility to oxidation and corrosion.

Stranded copper conductors are, by far, the most common type of conductors used in medical cables. There are, however, other less common types including alloys, and tinsel wire.

Insulation

Beyond electrical isolation, insulation helps with signal integrity in high-frequency cables by minimizing electromagnetic interference (EMI) and crosstalk. Insulation also provides mechanical protection—protecting the wire from abrasion, moisture, chemicals, and thermal extremes.

Key considerations for wire insulation include:

- **Dielectric strength/wall thickness** – influences capacitance/impedance, overall cable OD
- **Flexibility/shore hardness** – especially in high conductor count composite cables
- **Temperature stability** – for soldering, for high-temperature sterilization
- **Strip-ability** – IPC-620 compliance, automated cut/strip operations
- **Chemical resistance** – for applications with exposed inners

Common Thermoplastics for wire insulation include:

- **Fluoropolymers** – ECTFE (Halar), ETFE (Tefzel), PFA, PVDF, FEP (solid and foamed)
- **Polyamide** – Nylon 6, Nylon 66, Nylon 12
- **Polyester** – TPES (Hytrel)
- **Polyolefin (solid and foamed)** – PPE, HDPE, LDPE, LLDPE, MDPE, PP, FRPP
- **Polyvinyl Chloride** – Flexible, Semi-Conductive, Semi-Rigid
- **Thermoplastic Elastomer** – TPR (Elexar), TPV (Santoprene)
- **Silicone Rubber and alternatives** – BioCompatic® TPE (silicone alternative)

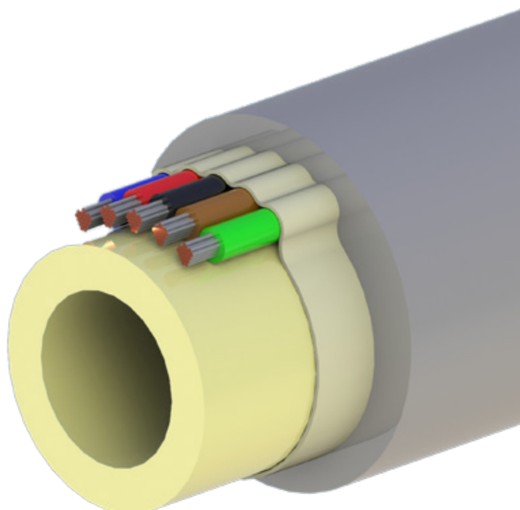
Other Components

Nearly every medical cable contains components beyond just the inner copper conductors and outer jacket.

Coaxial Conductors
Coaxial conductors are common, particularly in high frequency/imaging applications.

Fiber optic components
Multi-mode, single-mode, and plastic optical fiber (POF) are included to support high data rate transmission or illumination of surgical sites.

Fluidic Tubes
Fluidic tubes made of various materials - for low- or high-pressure gases or liquids – can be cabled together with inner conductors and various other components and encompassed in a single jacketed cable. This single-cable approach can really streamline interconnect applications that might otherwise have one or more tubes separate from the composite cable. In the cable assembly, the tube(s) can either be integrated into the distal device and/or proximal connector or break out at some point along the cable assembly for a separate tube connection.



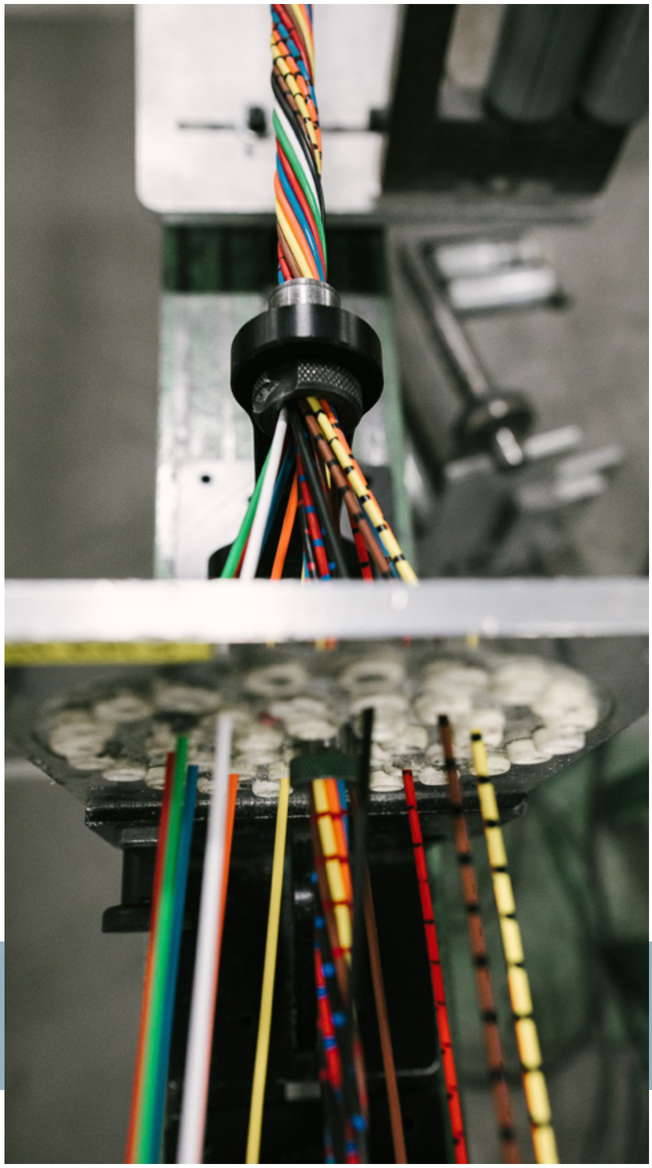
Cable Shielding
The four main types of cable shielding are foil, spiral serve, braid, and conductive polymers. It's common for complex cables to contain multiple shields over twisted pairs, over various sub-bundles, and even one shield directly over another (i.e. braid over foil). Further details on shielding are included later in the paper.

Tapes and Fillers
Tapes and fillers are used in almost every composite medical cable to ensure roundness, reduce internal friction - increase flexibility, group sub-bundles, and provide easier removal of jacket (ROJ) during cable assembly.

Layout/Construction

With all the various key cable components identified and individually designed, the Cable Design Engineer will layout the components in the final cable design. This is most commonly depicted as a single, 2-dimensional cable cross-section. It is important to remember that cables are 3-dimensional, and this cross-section will vary along the length of the cable, particularly when the cable contains twisted pairs, triads, or sub-bundles with multiple components.

Each of these elements is cabled, or twisted, together and then twisted as a sub-bundle into the final cable core. A particular conductor within a sub-bundle could be near the outer cable jacket at one point along the cable, and near the center of the cable at another point, and in any position around the 360-degree circle of its bundle at any point along the cable.



The component placement, twist rates/lay lengths , and overall layout have a significant influence on both electrical and mechanical performance. For instance, crosstalk, EMI/EMC, and flexibility are influenced by the cable layout. Static and kinetic friction between adjacent components are a big contributor to a cable's flexibility (or lack thereof). Designers choose from a variety of different fillers and tapes to address this.

Shielding

Effective electromagnetic interference (EMI) shielding in cables is crucial for maintaining signal integrity and ensuring compliance with electromagnetic compatibility standards.

Key considerations for shielding include:

- Frequency and strength of electromagnetic fields (susceptibility or emissions)
- Percent of coverage desired
- Flexibility
- Physical protection
- OD
- Weight
- Termination/grounding
- Cost

Foil shields are lightweight and cost-effective. They provide 100% coverage, so they are generally effective for RF and microwave frequencies. Their disadvantages, however, are that they decrease flexibility, are limited in the amount of current they can transmit, and are difficult to terminate. They often require a drain wire to increase the amount of current they can transmit and for ease of termination.

Spiral/serve shields offer the highest flexibility and some physical protection. They are more costly than Aluminum foil tapes, but cheaper than braided shields. Serve shields are the most prone to developing a shield gap, particularly in applications where the cable undergoes static or dynamic bending while transmitting.

Designers should consider the highest frequencies the cable will be subjected to – whether susceptibility or emissions, or both – and adhere to best design practices, such as the 1/20th of a wavelength rule to ensure optimal shielding performance.

Braided shields are also somewhat prone to shield gaps if a tight bend radius is required, but less prone than serves. Braided shields offer the highest level of physical protection.

Conductive polymers are much less common than the aforementioned 3 types of metal shielding. But conductive polymers play a critical role in cables with very low noise requirements, including shielding from triboelectric noise.

Jacket

Designing the jacket for a medical cable requires careful evaluation of several critical factors to ensure safety, durability, and compliance with medical standards. Since the jacket is the cable's interface to the outside world, it is often considered the most important element of a medical cable.

Key considerations when designing the jacket for a medical cable include:

Biocompatibility: Materials must be non-toxic and safe for patient contact, adhering to standards like ISO 10993-5:2009 and ISO 10993-10:2021and FDA regulations. Medical-grade materials such as silicone and BioCompatic® (TPE), and polyurethane are commonly used for their biocompatibility.

Chemical Resistance: The jacket must withstand exposure to cleaning agents and disinfectants without degrading. Materials like BioCompatic® and silicone offer excellent resistance to various sterilization methods, including autoclaving, ethylene oxide, and gamma radiation.

Flexibility and Durability: The cable must endure repeated flexing and mechanical stresses. Balancing flexibility with mechanical strength is crucial. For instance, polyurethane provides durability but may be less flexible than BioCompatic®.

Sterilization Compatibility: The jacket material should tolerate the specific sterilization methods it will undergo. BioCompatic®, for example, withstands numerous autoclave cycles, making it suitable for reusable devices, at a price point much lower than silicone.

Environmental Resistance: Consideration of the operating environment is essential. The material should resist factors like temperature extremes and moisture to maintain performance over time.

BioCompatic®

USP Class VI Silicone Alternative Cable Jacketing Material

Aesthetic and Tactile Properties: For the medical professionals using the cables, look and feel are arguably the most important aspects. Aesthetics create the user's perception of the quality of the cable. For instance, a surgeon, nurse, or O.R. technician will discard a device if there is something concerning about the appearance of the cable, even for just slight color variation.

Aesthetic characteristics can be difficult to specify, so they often aren't specified in great detail. Therefore, it is incumbent on the cable manufacturer to really understand the details, and importance, of these aspects of medical cables.

A level of aesthetics that might be readily acceptable in an industrial cable or consumer cable can be very unacceptable in a medical cable. It is advantageous to choose a manufacturer with decades of experience in custom medical cables and a strong track record of exceptional medical-grade quality and consistency.

Selecting the appropriate jacket material involves balancing these factors to meet the specific requirements of the medical device, ensuring functionality, safety, and compliance with regulatory standards.

Conclusion

The design and manufacture of medical cables demand a precise, informed approach—where every component from the copper construction to the outer jacket plays a critical role in the cable's overall performance and compliance. By considering key factors such as copper construction, insulation materials, shielding techniques, component integration, and jacket properties, engineers can create solutions that not only meet but exceed the rigorous demands of medical applications.

Northwire has been partnering with leading global medical device OEMs and their contract manufacturers for decades to design, manufacture, and test high-quality medical cable and cable assemblies for a vast spectrum of healthcare applications.

Our medical cables are manufactured under strict quality standards, ensuring reliability and patient safety.

Northwire is ISO 13485:2016 certified and compliant to USP Class VI, ISO 10993-5:2009 and ISO 10993-10:2021, and RoHS3 standards.

About Us

Northwire is a leading designer and manufacturer of custom cables, cable assemblies, and wire solutions for demanding applications across various industries, including aerospace, defense, medical, industrial, and automation. With a strong focus on engineering excellence, Northwire specializes in developing high-performance, durable, and reliable interconnect solutions tailored to meet stringent environmental, electrical, and mechanical requirements.

As a subsidiary of the LEMO Group, Northwire leverages advanced technology, rapid prototyping, and in-house testing to ensure compliance with industry standards such as UL and RoHS/REACH. We are Quality Management System certified to ISO 9001:2015, AS9100 D, ISO 13485:2016, and ISO 17025:2017 as a CSA Group quality testing facility. Our company is committed to providing customers with custom-engineered solutions, short lead times, and exceptional support, helping to optimize performance, cost efficiency, and long-term reliability.

With a customer-centric approach, Northwire offers direct collaboration with design engineers, enabling seamless integration of cables and assemblies into complex systems. Whether for mission-critical aerospace applications or high-flex industrial automation, Northwire delivers innovative and tailored cable solutions that meet the evolving demands of modern industries.

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