OPTICAL INFRASTRUCTURE UNVEILED

THE REAL GUIDE to TIER-1 TELEOM OPERATORS

(FROM FIELD TO CORE)

- ✓ **RIGHT** SCREWS
- ✓ **REAL** CONFIGURATIONS
- ✓ **TIER-1** STANDARDS

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Optical Infrastructure Without Secrets

The Real-World Guide of Tier-1 Carriers

From Component to Operation -- Architecture, Vendors, and Procedures for Telecommunication Networks

Made for: Planning Engineers, OSP Designers, Field Engineering Teams, NOC Level 3, Datacenter Providers.

Differential: This book does not teach optical fiber theory. It teaches exactly which screw to use on the (Vivo, TIM, Claro) utility pole, which configuration template to use to interoperate a Cisco ASR9k router with a Huawei MA5800 OLT, and which acceptance test procedure (ATP) is required by a hyperscaler (Google/Meta) for dark fiber leasing.

Complete Table of Contents

Volume I: The Physical Layer (Infrastructure and Outside Plant)

Chapter 1: Component Details -- The Bill of Materials (BOM) of a Tier-1 Carrier

- 1.1 Optical Fibers: G.652.D (SMF-28 Ultra) vs. G.657.A1/A2 (Flexibility for FTTH). Attenuation (IL) and reflectance (ORL) specifications accepted by Anatel and major carriers.
- 1.2 Cables: Types, construction, and suppliers (Furukawa, Prysmian, Corning).
    - Loose Tube Cables with gel vs. dry water-blocking tape.
    - Ribbon Cables for high density (3456 fibers).
- 1.3 Connectors and Adapters: FC/APC vs. SC/APC vs. LC/UPC. Polish standards. Why Claro requires APC for all outside plant.
- 1.4 Optical Patch Cords (Jumpers): Delivery mode (simplex, duplex, fan-out). Tensile and minimum bend radius specifications.
- 1.5 Splice Closures (CDE/CEOs): IP68 sealing, tray organization.
- 1.6 Ducts and Underground: 40mm, 50mm, and 100mm conduits. Microducts for blow fiber.

Chapter 2: Field Tools and Instrumentation

- 2.1 Fusion Splicers: Fujikura 70S (single) vs. Fujikura 90R (mass fusion). Calibration parameters and arc adjustment.
- 2.2 Light Sources and Power Meters: Referencing procedure (0dB) for accurate loss measurement.
- 2.3 OTDR: Pulse width and averaging time configuration for long-haul vs. PON network event identification.
- 2.4 Live Fiber Identifiers: Identification technique without traffic interruption.

Chapter 3: Installation Procedures -- Step by Step

- 3.1 Cable Opening: Ring-cut technique for ribbon vs. loose tube cables without damaging fibers.
- 3.2 Tray Organization: Minimum bend radius (30mm for G.652.D, 15mm for G.657.A2).
- 3.3 Splicing: Acceptable loss table (<0.05dB for same manufacturer, <0.1dB for different manufacturers).
- 3.4 Aerial Installation (Poles): Minimum height, messenger (ACSR), and pole sharing protocols with utility companies.
- **Volume II: Active Architecture and Vendors**
- **Chapter 4: The Core (Backbone) -- DWDM Transport**

- 4.1 Architecture: Reconfigurable Optical Add-Drop Multiplexer (ROADM) with flexible grid (Flex-Grid).
- 4.2 Vendors:
    - **Nokia (Alcatel-Lucent):** 1830 PSS (Photonic Service Switch) family. Supervision (GCC/SCC) and optical amplifier (EDFA/Raman) configuration.
    - **Cisco:** NCS 2000 Platform. Interoperability with third-party transponders.
    - **Huawei:** OSN 9800 Platform. Security procedures to prevent backdoors in critical networks (NATO/ABIN standard).
- 4.3 Transponders and Muxponders: 100G/400G/800G. Modulation (QPSK, 16QAM). FEC (Forward Error Correction) -- how to gain 2dB of budget by adjusting FEC.
- **Chapter 5: Access (FTTH) -- GPON/XGS-PON Architecture**
- 5.1 Standards: G.984 (GPON) vs. G.9807 (XGS-PON). Split ratio (1:64 vs 1:128).
- 5.2 OLTs (Optical Line Terminal):
    - **Huawei MA5800-X17/X15:** DBA (Dynamic Bandwidth Allocation) and VLAN mapping configuration.

    - **Nokia (Alcatel) 7360 ISAM FX:** Traffic profile configuration for residential vs. business.
    - **ZTE C300/C600:** PON port unlocking procedures.
- 5.3 ONTs/ONUs: Provisioning via OMCI. RF overlay standards for TV (CATV).
- **Volume III: Operation, Configuration, and Acceptance**
- **Chapter 6: Edge Router Configuration**
- 6.1 **Juniper MX Series (MX204, MX10003):** BGP configuration for traffic exchange with IXPs (PTT.br, FTS).
- 6.2 **Cisco ASR 9000 Series:** IOS-XR configuration, QoS policies to differentiate video traffic (Netflix/YouTube) from data.
- 6.3 **MikroTik for Regional Providers:** CHR (Cloud Hosted Router) and CCR1072. Myth-busting: when it replaces a Cisco or Nokia (and when it doesn't).
- **Chapter 7: Acceptance Test Procedures (ATP)**
- 7.1 Continuity and Loss Test (ILM): 3-jumper method (A/B/C). Tolerances.
- 7.2 Reflectometry (OTDR): Event analysis -- how to interpret a "gainer" (negative event) and when it indicates a poorly executed splice or mode field mismatch.

- 7.3 Chromatic Dispersion (CD) and Polarization Mode Dispersion (PMD) Testing: Mandatory for links above 100G.
- 7.4 Stress Test (Pulling): Certification that the fiber withstood installation without micro-bends.
- **Chapter 8: Security and Best Practices for Carriers**
- 8.1 Grounding: Grounding schemes for cables with steel wire armor (SWA). Lightning protection in splice closures.
- 8.2 Duct Space Management: The 40% rule (NBR 14565).
- 8.3 Documentation and GIS: Fiber naming standard (F.O. XX-YY-ZZ). Integration with inventory systems (Netcracker, Carrier OSS).

Happy reading!!!

Volume I: The Physical Layer (Infrastructure and Outside Plant)

Chapter 1: Component Details -- The Bill of Materials (BOM) of a Tier-1 Carrier

1.1 Optical Fibers: Fundamentals, Types, Specifications, and Selection Criteria

1.1.1 What is an optical fiber and why did it revolutionize telecommunications

To understand the choice of components, it is first necessary to understand what an optical fiber is and why it has become the predominant transmission medium in the world. An optical fiber is a filament of extremely high-purity glass, composed essentially of silica, with an approximate diameter of 125 micrometers. To give you an idea, a human hair has a diameter between 50 and 100 micrometers. The optical fiber is, therefore, thinner than a human hair, but has the capacity to transport information at speeds exceeding 800 gigabits per second on a single channel, and tens of terabits per second when multiple channels are combined in DWDM systems.

The history of optical fiber dates back to the 1960s, when researchers Charles Kao and George Hockham, working at the Standard Telecommunication Laboratories in England, demonstrated that signal loss in glass fibers could be reduced to practical levels for telecommunications. Before their discoveries, existing glass fibers had losses exceeding 1000 decibels per kilometer, rendering them useless for any practical application beyond a few meters. Kao and Hockham proposed that the loss was caused by impurities in the glass, mainly iron, copper, and hydroxyl ions, and that removing these impurities could reduce loss to around 20 decibels per kilometer. In 1970, Corning Glass Works in the United States produced the first optical fiber with loss below 20 decibels per kilometer, ushering in the era of optical communications. Charles Kao received the Nobel Prize in Physics in 2009 for his fundamental contributions.

The modern optical fiber is composed of three concentric layers, each with a specific function. The **core** is the central region, where light actually travels. It has a diameter of 8 to 10 micrometers for single-mode fibers, or 50 to 62.5 micrometers for multimode fibers, and is made of silica glass doped with germanium to increase its refractive index.
The **cladding** surrounds the core and has a diameter of 125 micrometers. It is made of pure silica or fluorine-doped silica to have a slightly lower refractive index than the core. The difference in refractive indices between the core and cladding is what confines the light to the core through total internal reflection. When light tries to exit the core into the cladding, it encounters a refractive index barrier and is reflected back into the core. This principle, known as total internal reflection, is the same that makes a beam of light propagate through a water jet from a luminous fountain. The **primary coating** is the outer layer, made of acrylic or polyester, which protects the glass against moisture, abrasion, and mechanical impacts. It has a diameter of 250 micrometers and is only removed at the time of splicing or connection. The bare fiber, without the primary

coating, cannot be touched with bare hands because the skin's oils cause micro-cracks that can lead to fracture.

1.1.2 Why are there different types of optical fiber

The evolution of telecommunications networks brought different needs that a single type of fiber could not meet. The main variables that differentiate fiber types are chromatic dispersion, polarization mode dispersion, attenuation, and bend sensitivity. Each application—whether a 10,000-kilometer submarine backbone, an 80-kilometer metropolitan network, or a few-kilometer FTTH access network—imposes different requirements.

Chromatic dispersion is the phenomenon where different wavelengths of light travel at slightly different speeds in the fiber. This occurs because the refractive index of glass varies with wavelength. In high-speed systems, like 100G and 400G, chromatic dispersion can cause bits to spread out in time and overlap, causing errors. The parameter measuring chromatic dispersion is the dispersion coefficient, expressed in picoseconds per nanometer per kilometer. The lower this coefficient, the greater the distance the signal can travel without needing compensation.

Attenuation is the loss of signal power as light travels through the fiber. It is caused by absorption and scattering. Absorption occurs when light interacts with impurities in the glass, such as hydroxyl ions that cause an absorption peak at 1380 nanometers. Rayleigh scattering is a fundamental phenomenon where light is scattered by fluctuations in the density of the glass, and it is the main source of attenuation at wavelengths of interest for telecommunications. Attenuation decreases as the wavelength increases, up to about 1600 nanometers, where absorption by molecular vibrations of silica begins to dominate.

Bend sensitivity is the tendency of the fiber to lose signal when bent. In standard fibers, a sharp bend causes part of the light that should be confined in the core to escape into the cladding and be lost. Bend-insensitive fibers, like G.657, were developed specifically for applications where space is limited, such as inside homes and tight splice closures.

1.1.3 G.652.D Fiber: the backbone of backbone networks

The G.652.D fiber is, by far, the most widely deployed type in the world for backbone, metropolitan, and most long-distance applications. It is defined by the ITU-T G.652 recommendation, which establishes the characteristics of a non-dispersion-shifted single-mode fiber. The letter D at the end indicates the most recent version, which eliminates the absorption peak at 1380 nanometers, allowing the use of the entire spectrum from 1260 to 1625 nanometers.

The technical characteristics of G.652.D fiber are rigorously specified by manufacturers and verified by carriers at the time of purchase. The core diameter is 8.2 to 9.5 micrometers, with a typical value of 9.2 micrometers. The cladding diameter is 125 ± 1 micrometer. The primary coating diameter is 245 ± 10 micrometers. Maximum attenuation at 1310 nanometers is 0.35 decibels per kilometer, and at 1550 nanometers is 0.25 decibels per kilometer. The chromatic dispersion coefficient at 1550 nanometers is approximately 17 picoseconds per nanometer per kilometer. The zero dispersion wavelength, where chromatic dispersion is null, is at 1310 nanometers.

What makes G.652.D so versatile is the combination of low attenuation at 1550 nanometers, which is the operating window for EDFA amplifiers, with moderate chromatic dispersion that can be electronically compensated in modern systems. Furthermore, the elimination of the absorption peak at 1380 nanometers allows the use of CWDM systems in the S-band, between 1460 and 1530 nanometers, for lower-cost applications where DWDM is overkill.

The suppliers approved by Brazilian carriers for G.652.D fiber are Corning, with its SMF-28 Ultra product; Furukawa, with its LWP product; and Prysmian, with its E-SMF product. Each of these products meets the G.652.D recommendation, but there are slight differences in the mode field diameter that affect splice loss when fibers from different suppliers are spliced.

The **mode field diameter (MFD)** is a measure of the effective diameter of the light mode traveling through the core. It is slightly larger than the physical core, because part of the light propagates in the cladding. For G.652.D, the typical MFD at 1310 nanometers is 9.2 micrometers, with a tolerance of plus or minus 0.4 micrometers. When fibers from different suppliers are spliced, if one has an MFD of 8.8 micrometers and the other has 9.6 micrometers, the incompatibility causes loss due to mismatch of up to 0.3 decibels. This is why carriers like TIM standardize on a single supplier per project and maintain reserve cable stocks from the same production batch.

1.1.4 G.657.A2 Fiber: the bend-insensitive fiber for FTTH

The G.657 fiber was developed specifically to meet the needs of FTTH access networks, where fibers are installed in tight spaces inside homes, building risers, and congested splice closures. The ITU-T G.657 recommendation defines single-mode fibers with reduced bend sensitivity, allowing much smaller bend radii than G.652.D.

G.657 is divided into two main categories. G.657.A1 allows a bend radius of 10 millimeters, and is essentially a G.652.D with improved bend performance. G.657.A2 allows a bend radius of 7.5 millimeters, and is the most suitable for applications where space is extremely tight. There is also G.657.B3, which allows a bend radius of 5 millimeters, used in special applications like residential drop cables that need to go around wall corners.

The G.657.A2 fiber, marketed as ClearCurve by Corning and EliteBend by Furukawa, maintains the same attenuation characteristics as G.652.D, but with much higher tolerance to bends. While G.652.D starts losing significant signal when bent with a radius below 30 millimeters, G.657.A2 maintains loss below 0.1 decibel even with a radius of 15 millimeters, and can be bent up to 7.5 millimeters in temporary situations without permanent damage.

The mechanism that allows this bend insensitivity is a modification in the refractive index profile. In G.652.D, the core refractive index is uniform and the cladding is uniform, forming a step. In G.657.A2, there is a low-index ring around the core that creates an additional barrier to light escape when the fiber is bent. This ring, called a trench, confines the light even in sharp bends.

The application of G.657.A2 in carrier networks follows a rule of thumb established by Vivo: every aerial cable, internal jumper, cord that will be frequently handled, and fiber that will be installed inside buildings must use G.657.A2 fiber. Buried cables and cables in ducts, which do not experience sharp bends during operation, can use G.652.D, which costs about 30 percent less.

1.1.5 Attenuation and reflectance specifications: what Anatel and carriers require

Attenuation, or loss, is the reduction in signal power as light travels through the fiber. It is expressed in decibels per kilometer and is the most basic specification for any network project. Anatel does not set direct limits for attenuation in private networks, but carriers incorporate into their projects the values defined by ITU-T standards and manufacturers.

For G.652.D fiber, the maximum attenuation at 1310 nanometers is 0.35 decibels per kilometer, and at 1550 nanometers is 0.25 decibels per kilometer. These are the values guaranteed by manufacturers upon delivery. During the fiber's lifespan, attenuation can increase due to aging, hydrogen exposure, or mechanical damage. Therefore, carriers require a safety margin: in projects, they use values of 0.30 decibels per kilometer at 1310 nanometers and 0.22 decibels per kilometer at 1550 nanometers to calculate the optical budget, leaving a reserve for aging.

Reflectance, or optical return loss, is the amount of light reflected back to the source at each connection or splice point. In high-power systems like PON and DWDM networks, reflectance is critical because the reflected light returns to the laser and interferes with its operation, causing instabilities that can affect the entire network. Return loss is expressed in decibels, and the higher the value, the better.

For connectors with APC polish, typical return loss is greater than 50 decibels. For connectors with UPC polish, it is greater than 40 decibels. Anatel does not set limits, but carriers impose their own standards in their engineering manuals. Claro, for example, requires that all outside plant connectors have return loss greater than 50 decibels, which is only achieved with APC polish. Internal connectors, in active equipment, can have return loss greater than 40 decibels with UPC polish.

1.1.6 Fiber reception and inspection procedure: step by step

When a batch of fiber optic cables arrives at the carrier's warehouse, a rigorous inspection procedure is executed before the cables are accepted and stored. This procedure varies between carriers, but TIM's standard, documented in its supply manual, is an example of industry practice.

The first step is **document verification**. The responsible engineer checks if the invoice matches the purchase order: number of reels, fiber type, fiber count per cable, and length of each reel. Then, they verify that each reel is accompanied by the factory test report, a document containing the results of tests performed by the manufacturer.

The factory test report must contain at least: the manufacturing batch number; the fiber type according to ITU-T; the attenuation measured at 1310, 1383, 1550, and 1625 nanometers; the cut-off wavelength; the mode field diameter; the chromatic dispersion coefficient; the polarization mode dispersion coefficient; and the result of the tensile test. The tensile test, or proof test, is a factory process where the fiber is subjected to a tension of 100 kpsi, about 700 megapascals, to ensure there are no latent cracks. If the factory test report is missing or incomplete, the reel must be rejected immediately.

The second step is **visual inspection of the reels**. The engineer examines each reel for transport damage. The cable's outer jacket must have no dents, cuts, or deformations indicating impact. The cable ends must be sealed with heat shrink caps or protective tape. If the jacket is damaged or the ends are not sealed, the reel must be returned because moisture may have penetrated and compromised the internal fibers. Moisture causes two problems: first, water can freeze in cold climates, expanding and damaging the fiber; second, water reacts with the primary coating, releasing hydrogen which increases attenuation at 1383 and 1550 nanometers.

The third step is **sampling for continuity testing**. The engineer selects one reel per batch for continuity testing with an OTDR. The test consists of splicing a pigtail to one end of the cable and performing an OTDR trace from start to finish. The measured attenuation must be within the values specified in the factory test report, with a 10 percent tolerance. If the attenuation is above the specified value, the entire batch may be rejected or subjected to additional testing.

The fourth step is **storage**. Approved reels are stored in a dry, covered location with controlled temperature between 10 and 40 degrees Celsius. The reels are placed on wooden pallets to avoid contact with the floor, and are protected from direct sunlight, which can degrade the primary coating. Each reel receives an identification label with the purchase order number, batch number, fiber count, and length.

1.2 Optical Cables: Types, Construction, Suppliers, and Selection Criteria

1.2.1 The evolution of optical cables and why different constructions exist

The optical cable is the structure that transforms the fragile fiber into a robust product capable of being installed in ducts, buried in the ground, or suspended from poles. The evolution of optical cables followed the evolution of networks: from the first long-distance networks with loose tube and gel cables, to high-density ribbon cables, and to access networks with dry ribbon and microduct cables.

The function of the cable is to protect the fibers against three types of aggression: mechanical, environmental, and chemical. Mechanical aggression includes tension during installation, compression by other cables or vehicles in underground ducts, and impact. Environmental aggression includes moisture, temperature variations, and ultraviolet radiation. Chemical aggression includes contact with solvents, oils, and chemicals present in the soil.

Each type of cable construction is optimized for a specific set of aggressions and for an installation method. The **loose tube cable with gel** is the most versatile and most used in buried backbone because the gel protects the fibers against moisture and allows them to move freely within the tube when the cable is pulled. The **ribbon cable** is used in high-density applications because it maximizes the number of fibers within a given cable diameter. The **dry ribbon cable** eliminates the gel to reduce preparation time in the field. The **ADSS cable** is used in aerial installations because it is completely dielectric, avoiding electrical hazards.

1.2.2 Loose tube cable with gel: detailed construction, applications, and procedures

The loose tube cable with gel is the oldest construction and still the most widely used for buried backbone and urban ducts. Its construction is an engineering feat that combines multiple layers of protection to ensure the integrity of the fibers for decades.

At the center of the cable is the **central strength member (CSM)** . This element is a steel or fiberglass rod that withstands tension during installation. In cables that cannot contain metals, like ADSS, the central element is fiberglass or aramid. The diameter of the central element varies according to the cable's capacity, typically between 2 and 5 millimeters.

Around the central element, **loose tubes** are helically stranded. Each tube is a plastic tube, usually PBT or polybutylene terephthalate, with an internal diameter of 1.5 to 2.5 millimeters. Inside each tube, 12 to 36 fibers are inserted, depending on the design. The fibers are loose inside the tube, without fixation, and the empty space is filled with a thixotropic gel. This gel has special rheological properties: at rest, it behaves like a solid, keeping the fibers immobile; when subjected to mechanical stress, such as tension during installation, it liquefies, allowing the fibers to move and preventing the force from being transferred to them.

The number of tubes varies according to the cable's capacity. A 144-fiber cable might have 6 tubes of 24 fibers each, or 12 tubes of 12 fibers each. The tubes are identified by colors, following an international standard: blue, orange, green, brown, gray, white, red, black, yellow, violet, pink, and light blue. The color sequence is repeated as necessary.

Over the stranded tubes, layers of polyester or polypropylene tape are applied to keep the structure together and provide additional protection. Next, if the cable is armored, a corrugated steel tape armor is applied. The armor is a steel tape with a thickness of 0.15 to 0.25 millimeters, wound spirally around the core. The armor protects against rodents, which can gnaw through the plastic outer jacket, and against impacts. In cables installed in ducts shared with power cables, the armor also serves as grounding.

The **outer jacket** is made of high-density polyethylene (HDPE), with a thickness of 1.5 to 3 millimeters. HDPE is resistant to abrasion, ultraviolet radiation, and most chemicals found in the soil. The color of the outer jacket varies according to the application: black for buried or in-duct cables; yellow for ADSS aerial cables; green for FTTH access cables.

The procedure for opening a loose tube cable with gel is an operation that requires precision and patience. The technician uses a **ring cutter**, like the Miller L-8677, adjusting the blade depth to cut only the outer jacket without reaching the internal tubes. The cutter is rotated around the cable at two points separated by about 50 centimeters. Then, a longitudinal cut is made between the two rings, and the outer jacket is removed with a jacket puller. If there is armor, an **armor cutter** like the Miller RA-2 is used, rotating it around the armor to cut it in a spiral. The armor is then removed with needle-nose pliers, taking extreme care that the sharp edges do not contact the tubes.

With the outer jacket and armor removed, the loose tubes are exposed. The technician identifies each tube by the color of its identification tape or by the print on the tube's jacket. The central strength member is cut about 5 centimeters from the entry point into the splice closure. This element will be fixed to the closure's clamp to transfer cable tension to the closure.

Cleaning the gel is the most tedious and most critical step. The technician uses disposable lint-free wipes moistened with 99 percent isopropanol. The wipe is passed along the tube in a single direction, from base to tip, removing all visible gel. Never move the wipe back and forth, as this would deposit the gel back onto the surface. After external cleaning, the technician uses a ring stripper to remove about 5 centimeters of the tube at the end, exposing the fibers with their 250-micrometer primary coating. The fibers are then cleaned again with an isopropanol wipe to remove any gel residue that may have adhered to the primary coating.

1.2.3 Loose tube cable with dry water-blocking tape: the gel-free alternative

In recent years, carriers have been migrating to loose tube cables with dry water-blocking tape, especially for applications where installation speed is critical. This construction was developed by Corning in the late 1990s and has been refined by other manufacturers since then.

In the dry tape construction, the gel is replaced by **superabsorbent yarns** and polyester tapes that expand upon contact with water. The superabsorbent yarns are made of a polymer that can absorb up to 100 times its weight in water, forming a physical gel that blocks moisture migration. The polyester tapes serve as an additional barrier and as a separation element between layers.

The great operational advantage of dry tape is the elimination of the gel. There is no need for solvent cleaning, which reduces cable opening time from about 15 minutes to less than 5 minutes per tube. Additionally, there are no chemical residues to dispose of, which is a significant environmental advantage. The disadvantage is that dry tape cables are slightly more expensive, about 5 to 10 percent, and require extra care during installation because the superabsorbent yarns can get tangled with the fibers if the cable is opened abruptly.

The procedure for opening a dry tape cable is similar to that for a gel cable, but with important differences. After removing the outer jacket and armor, if present, the technician finds the superabsorbent yarns that must be cut flush with the entry point of the splice closure. The loose tubes contain no gel, so they can be handled immediately. Fiber cleaning is still necessary, but only with isopropyl alcohol on a dry wipe, without the need to remove gel residues. The total time to open a 144-fiber dry tape cable can be 10 to 15 minutes, compared to 30 to 40 minutes for a gel-filled cable.

1.2.4 Ribbon cable for high density: when and how to use it

The ribbon cable is the choice for projects requiring high fiber density in a single duct. It is used by carriers like TIM in the backbone rings of São Paulo and Rio de Janeiro, where duct scarcity demands maximum compactness.

In the ribbon construction, fibers are arranged in parallel ribbons of 12 or 24 fibers. The ribbons are formed by gluing the fibers side-by-side with a resin that maintains constant spacing. A 12-fiber ribbon has a typical width of 3.5 millimeters and a thickness of 0.3 millimeters. The ribbons are then stacked inside a central tube or in multiple tubes, depending on the capacity.

A high-density ribbon cable can contain hundreds or even thousands of fibers. The densest commercially available cable has 6912 fibers, with 288 ribbons of 24 fibers each. This cable has a diameter of about 30 millimeters and is used on ultra-high capacity routes, such as connections between hyperscaler data centers.

The advantage of the ribbon cable is the possibility of **mass fusion**, where all fibers of a ribbon are spliced simultaneously. This drastically reduces splicing time. A mass fusion splicer like the Fujikura 90R splices a 12-fiber ribbon in