Incab

OPGW Engineering 101 – Design Factors & Best Practices

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Registered Continuing Education Program

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PURPOSE STATEMENT/COURSE DESCRIPTION

OPGW ENGINEERING 101 will teach you the advantages and disadvantages of the three basic design types of OPGW used today. You will also learn the "best practices" for each type. We will continue with the trade-offs between fiber count, diameter, and fault current capacity. This will then segue into the details of how the required fault current capacity should be determined by a utility along with how it is then computed by a cable manufacturer for a cable design. We will review why it is not a good idea to require that the capacity be comparable to that of a conventional (that is, non-fiber optic), commonly-used overhead groundwire. We will finish by discussing lightning performance.

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LEARNING OBJECTIVES

After this class you will be able to:

1. Explain the basic construction elements of the three design types of OPGW used today:
   - Center Tube (with stainless steel buffer tubes)
   - Aluminum Pipe (with plastic buffer tubes)
   - Stranded Stainless Steel Tube
2. Explain the advantages and disadvantages of each design type.
3. Describe today's "best practices" in the design and manufacturing of each design type.
4. Cite the three most important design parameters for any type of OPGW: fiber count, diameter, and fault current capacity.
5. Explain how the required fault current capacity should be determined.
6. Describe how cable fault current capacity should be computed.
7. Explain why one should not use a conventional overhead groundwire as the basis for their OPGW's fault current capacity.
8. Discuss lightning performance for OPGW.

Learning Hub

INCABAMERICA.COM

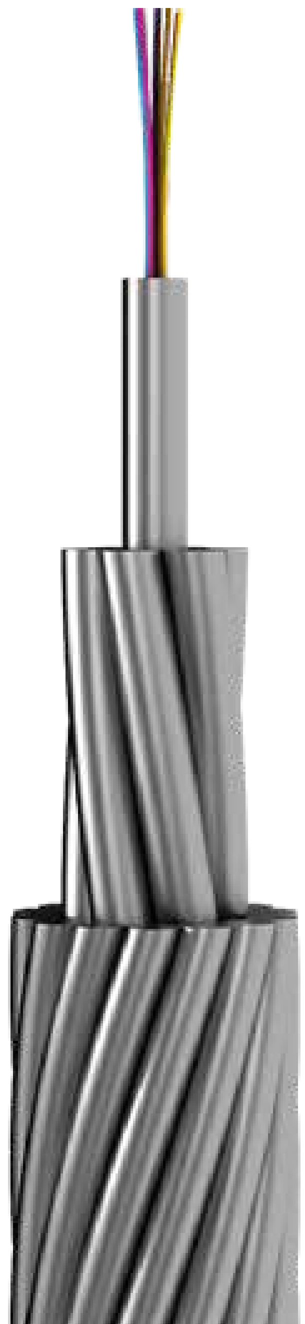
Webinar Rules

- Introduction and sound check
- Presentation: 50 min
- Use chat for questions during presentation
- Q&A (NB! Technical questions only): 10 min
- Let's start!

OPGW

OPTICAL GROUND WIRE

- Optical Ground Wire or «OPGW»
  - Per IEEE 1138-2021 (USA and some countries)
    - Note: Replaced the 2009 version
  - Per IEC 60794-4-10 (Many other countries)
- Function
  - The primary function of OPGW is to be a shield wire for a transmission line:
    - A. To protect the phase conductors from lightning, and
    - B. To provide a path for fault current
  - The secondary function of OPGW is to house optical fiber for data and communications



Review

FIBER & FIBER OPTIC CABLE BASICS

- Let’s start by talking about the fiber and loose tubes.
- These are the same whether they are in OPGW or in ADSS.

Review - Fiber & Fiber Optic Cable Basics

FIBER

- **"Low Water Peak" SM**
  — ITU-T G.652D
  — Corning SMF family
  — Generally splice compatible
  — Good for about 60-90 miles

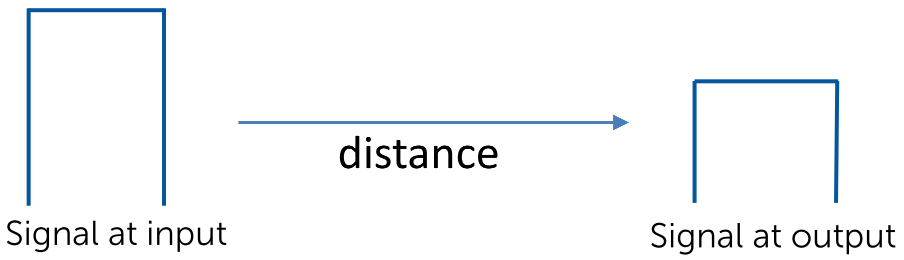
Overwhelmingly most commonly used fiber type!

- **Non-Zero Dispersion Shifted (NZDS)**
  — ITU-T G.655
  — Corning LEAF and OFS TrueWave RS ZWP
  — Generally not splice compatible
  (the «progressive lenses» analogy)
  — Good for up to about 250 miles
  — A must when using DWDM to boost bandwidth

Review - Fiber & Fiber Optic Cable Basics

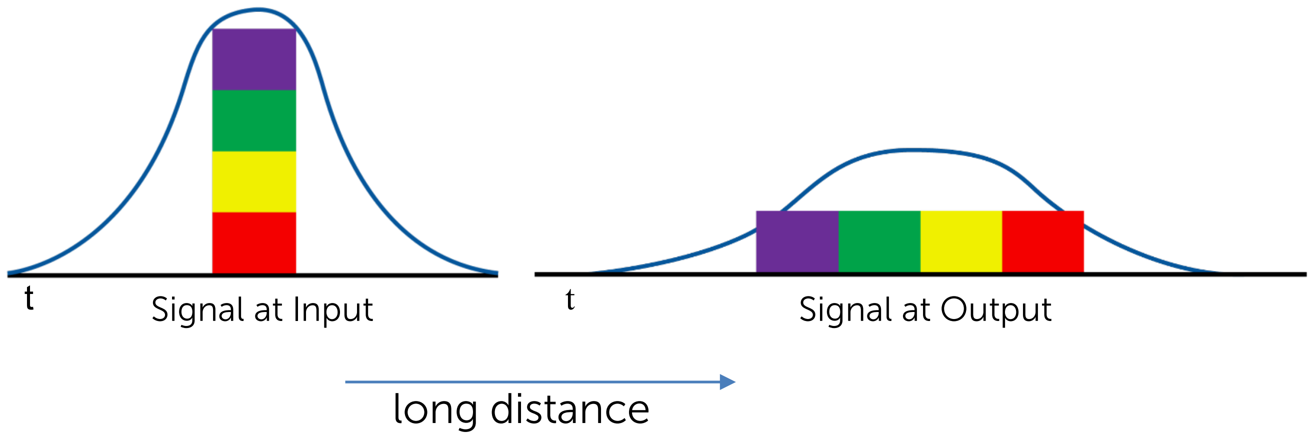
FIBER — PERFORMANCE SPECIFICATIONS

Attenuation: The loss of power over distance (dB/km)



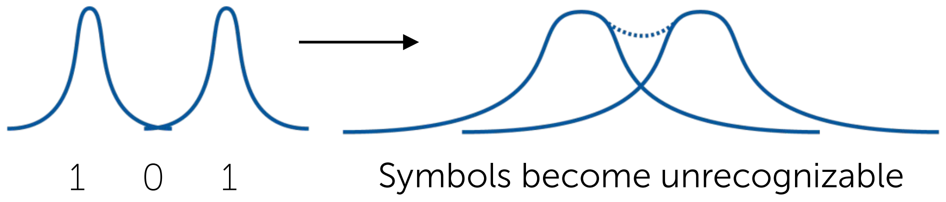
The single most important fiber performance spec for the user

(Chromatic) Dispersion: Corruption ("spreading out") of a signal over distance due to component wavelengths travelling at different speeds



Dispersion

As a pulse travels down a fiber, dispersion causes pulse spreading.
This limits the distance and the bit rate of data on an optical fiber.



Review - Fiber & Fiber Optic Cable Basics

FIBER — PERFORMANCE SPECIFICATIONS

- **Attenuation limits should be specified as "maximum, individual, after cabling"**
  — Bi-directional average for each and every fiber (but…)
  — Limits apply to each fiber (vs. averaging across a reel)
  — Limits apply to finished cable (vs. bare fiber specs)
  — Measured in dB/km at 1310 and 1550, plus 1625 nm is good to know

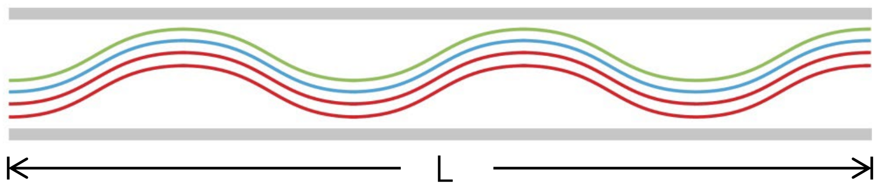
- **Recommended limits**
  — Standard fiber: 0.34, 0.20, 0.22
  — NZDS fiber: 0.22, 0.24

- **What about other fiber types?**
  — Multimode fiber is available for special applications: 62.5 micron (USA) and 50 micron (especially for sensing)
  — There's growing interest in G654 fiber, and it may supersede both standard SM fiber and NZDS fiber.

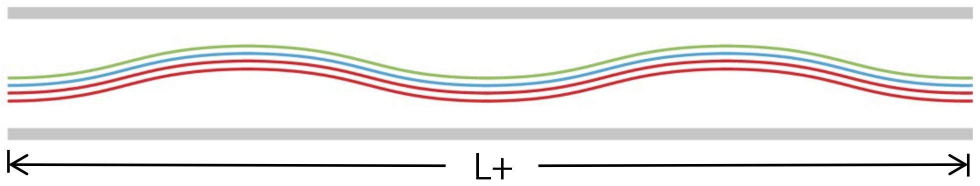
Review - Fiber & Fiber Optic Cable Basics

Protecting the fiber — loose tubes

- Loose tubes allow the fibers to move in response to changes in elongation which result from changes in temperature plus ice and wind loading



Loose Tube – No Tension



Loose Tube – Elongated By Tension

- Fibers laid in sinusoidal shape

  $\frac{L_{fibers}}{L_{tubes}} \approx 1.0025$ (or more)

- Fibers begin to straighten out

  $\frac{L_{fibers}}{L_{tubes}}$ ⇒ lowers, until it is 1
  ⇒ Then there is strain on the fibers

- EFL = Excess Fiber Length = the "extra" fiber per unit length of tube or cable (from stranding)
  General Rule: Higher is better ("No strain = No problem")

  Stranding a tube increases "EFL" because of the helix imparted to it (≈2.5% to EFL)

Distance required to complete 1 revolution of a tube around the diameter of what's underneath (typically, the center element)

- Zero Fiber Strain Margin = the point where the fibers begin to experience strain. Expressed in %RBS

Review - Fiber & Fiber Optic Cable Basics

Protecting the fiber — loose tubes, inferences

- If a tube is «overfilled», then the fibers will not have the sinusoidal shape they should have and they will also lose the ability to move freely

    ➔ Not good!

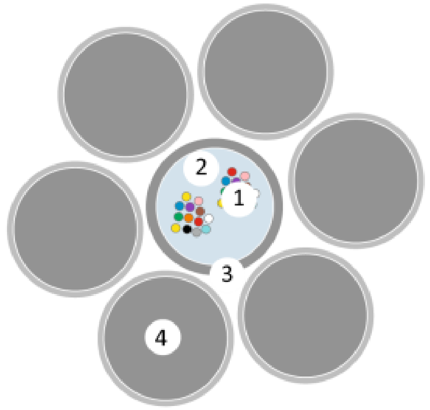
- «Bundling» or «binder threads» can reduce freedom of movement, but splicing techs often prefer these over ring or band marking
  — Today's manufacturing processes yield EFL that is:
    * Consistent. Each fiber has the same amount of EFL
    * Well-coordinated. All fibers "in phase"
      ➔ So, bundling does work well…the bundle itself moves as a unit

OPGW – Today's Designs

THE THREE TYPES USED TODAY

Center Tube Designs

a.



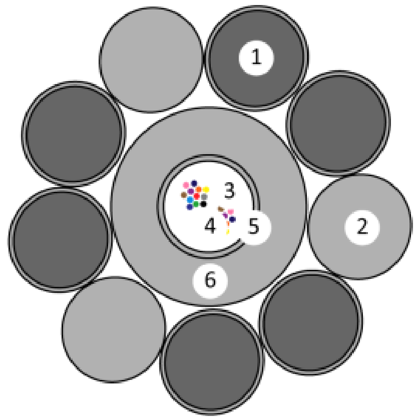
OPGW C

DESIGN:

1. Optical fiber Corning® SMF-28® Ultra
2. Stainless steel tube filled with water-blocking gel

3. & 4. Stranded wires (aluminum-clad steel (ACS) wires and/or aluminum alloy wires)

b.

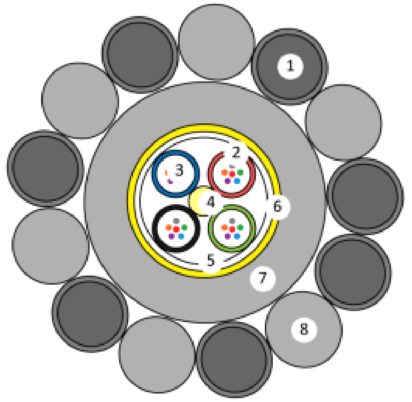


OPGW CA

DESIGN:

1. Aluminum-clad steel wire
2. Aluminum alloy wires
3. Water-blocking gel
4. Optical fiber Corning® SMF-28® Ultra
5. Stainless Steel Loose Tube (SSLT)
6. Aluminum cladding applied to SSLT

Aluminum Pipe Design

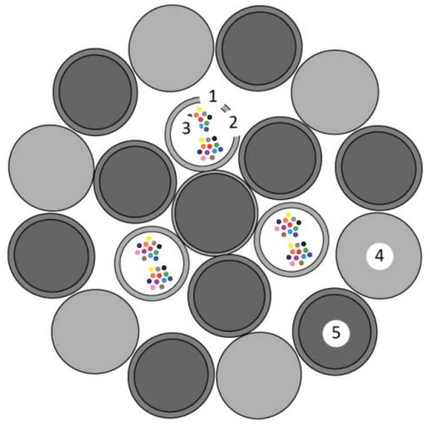


OPGW AP

DESIGN:

1. Aluminum-clad steel wire
2. Gel-filled plastic buffer tube
3. Optical fiber Corning® SMF-28® Ultra
4. Central strength member FRP
5. Water-swellable tape
6. Thermal barrier
7. Aluminum pipe
8. Aluminum alloy wire

Stranded Design



OPGW S

DESIGN:

1. Stainless Steel Loose Tube (SSLT)
2. Water-blocking gel
3. Optical fiber Corning® SMF-28® Ultra
4. Aluminum alloy wires
5. Aluminum-clad steel (ACS) wire

OPGW – Today's Designs

THE THREE TYPES USED TODAY

- Each design type has its advantages and disadvantages
- No one of them is categorically better than the other two

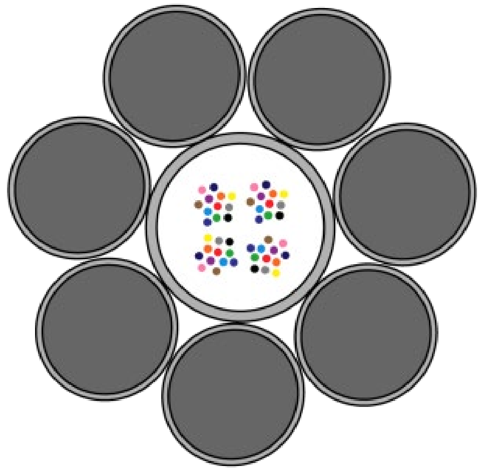
Let's look at each…

OPGW

CENTER TUBE DESIGN

- **Advantages**
  - Loose tube construction
  - Stainless steel tube provides superior protection for the fibers
  - Small diameters = mechanically and electrically efficient
  - Cost effective
- **Disadvantages**
  - Lowest “zero fiber strain margin” (40 – 50% RBS) could mean reduced reliability (especially if fiber strain > 0.2%) (NESC Rule 250B)
  - Perceived to be more difficult to splice prep the SSLT
  - Lower flexibility and higher susceptibility to being deformed or crushed
  - Often requires anti-rotation device (ARD), larger blocks, and pulling restrictions (angles and/or maximum length)
  - Lower available fiber counts (48 to at most 96)

OPGW C



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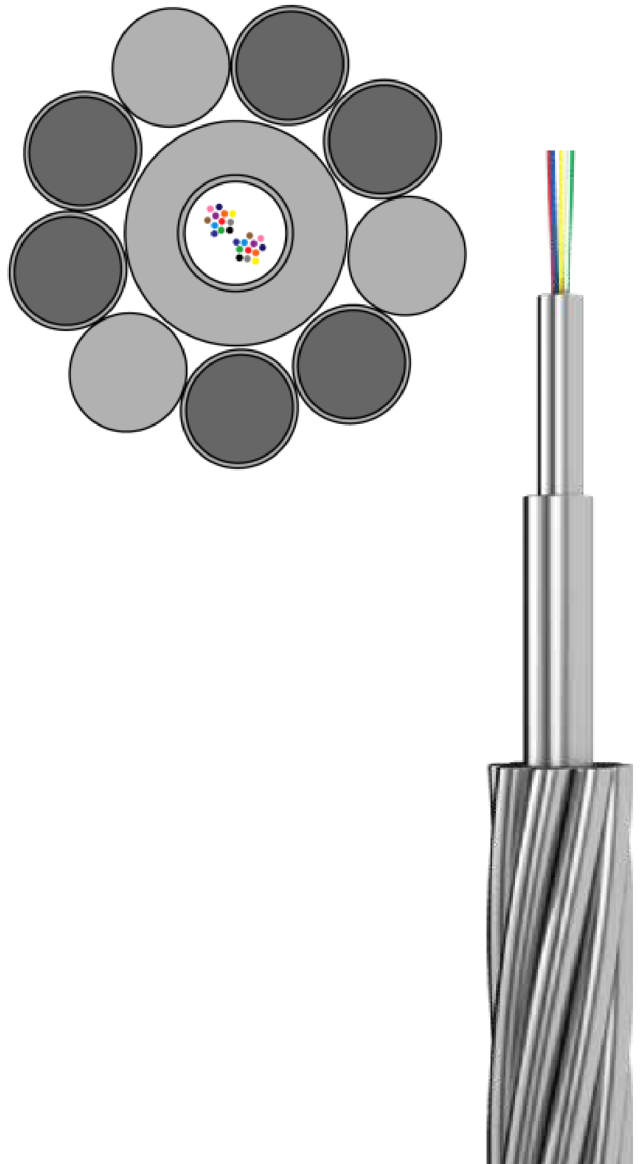
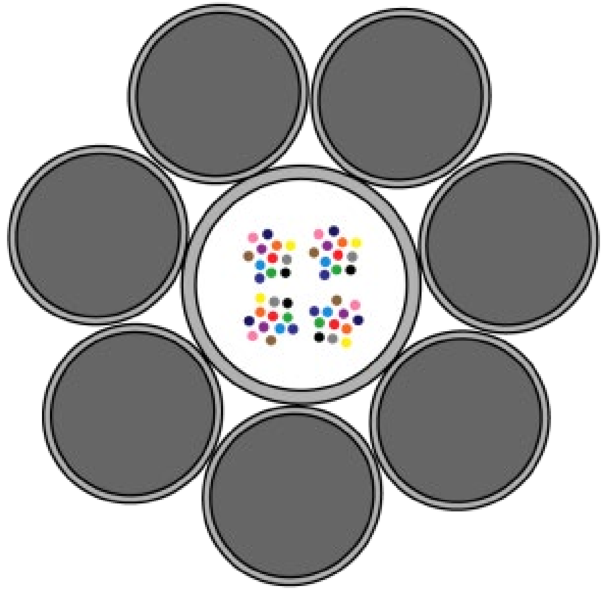
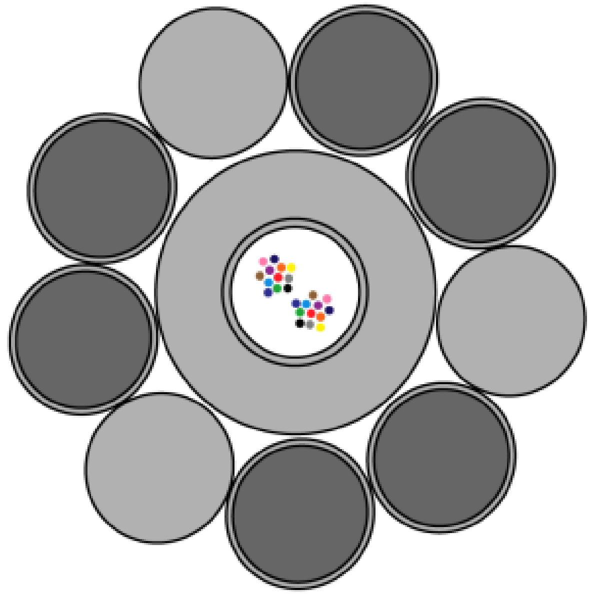


Center tube design
BEST PRACTICES

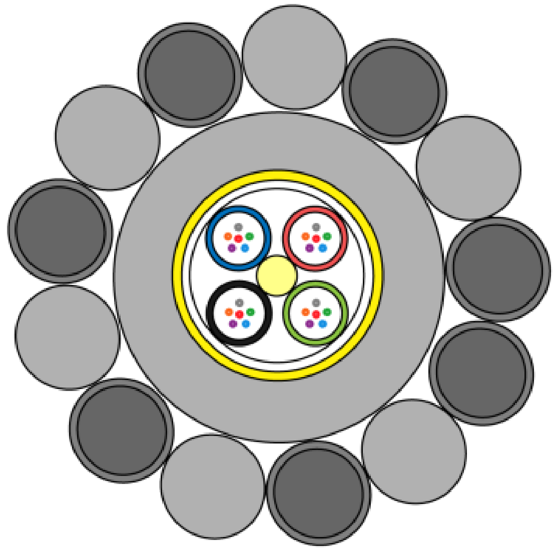
- Need "enhanced" (extra) Excess Fiber Length (EFL) in the tubes in order to boost the zero fiber strain margin (Need ≈ 0.4%)
- Aluminum-cladding is preferred to an aluminum pipe because the optical unit then acts as a single, integrated element
- In-line EFL control to enhance and precisely control EFL plus eddy current testing to ensure 100% perfect tube
- Gel formulated for use in laser-welded stainless-steel loose tubes (increased temperature and "hydrogen scavenging" means slight tint)
- Color-coded bundling threads <u>plus</u> ring marking to facilitate splicing preparation ("belt and suspenders")
- Conservative wire lay length and preform for good fit





OPGW
ALUMINUM PIPE DESIGN

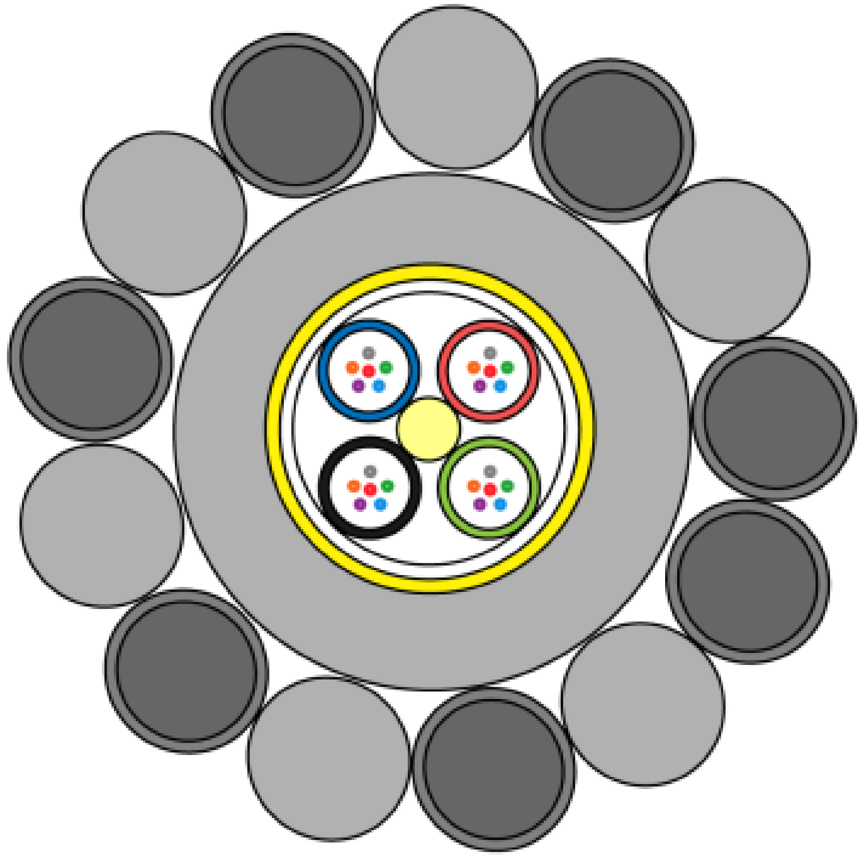
OPGW AP



- **Advantages**
  - — Loose tube construction
  - — Perceived easier to splice prep plastic buffer tubes versus SSLT's
  - — Aluminum pipe has excellent electrical properties
- **Disadvantages**
  - — Medium "zero fiber strain margin" (50 – 60% RBS at best)
  - — SSLT's protect fibers better than plastic tubes
  - — Aluminum pipe is relatively inflexible and susceptible to being deformed or crushed, especially during pull-in
  - — Always requires anti-rotation device (ARD), larger blocks, and pulling restrictions
  - — Aluminum pipe can corrode in some environments
  - — Expense of extra manufacturing steps (tubes + core + pipe)

Aluminum pipe design
BEST PRACTICES

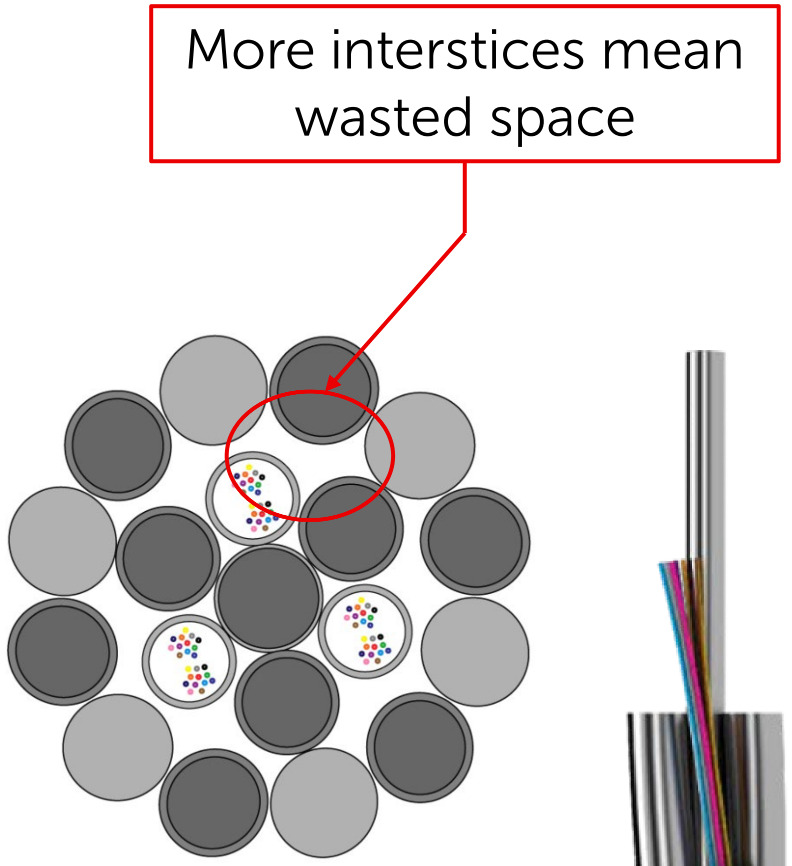
- PBT plastic is best for the tubes, and they should be reverse-oscillating lay (ROL, a.k.a "SZ") stranded with conservative lay length
- Long-term reliability is assured if both a thermal barrier and a water absorbing medium are included
- Extruded aluminum pipe is preferred (vs. welded)
- Conservative wire lay length and preform for good fit



OPGW
FULLY STRANDED DESIGN

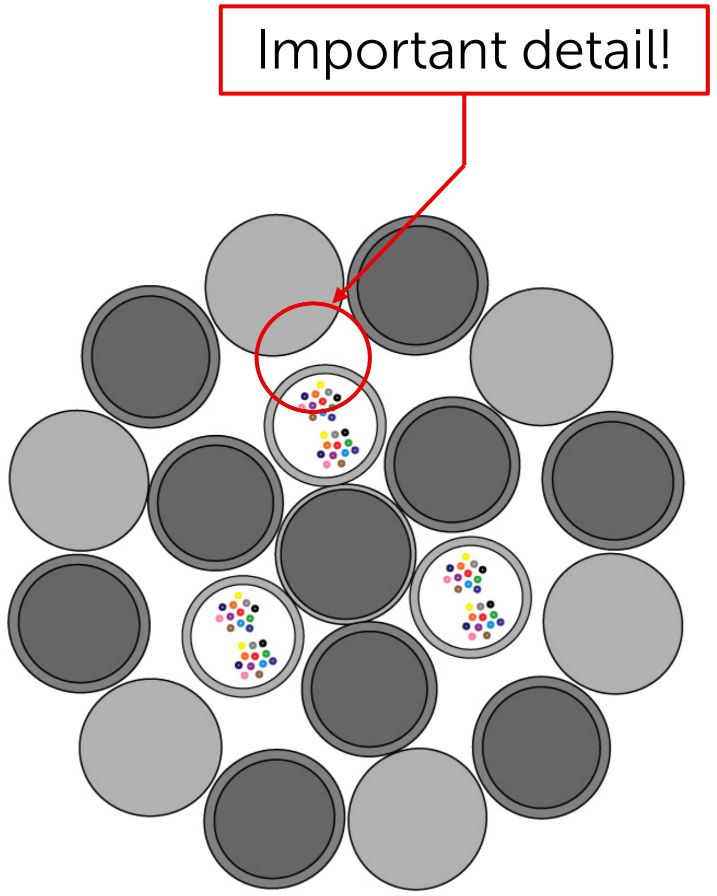
OPGW S

- **Advantages**
  - Loose tube construction with highest zero fiber strain margin (≥ 80% RBS) = enhanced optical reliability (NESC 250C&D)
  - Stainless steel tubes provide superior protection for the fibers
  - Looks and handles more like traditional OHGW or conductor
  - More flexible and crush resistant
  - No anti-rotation device (ARD) required during stringing
  - Longer pulls through more angles may yield fewer splice points
- **Disadvantages**
  - Not as mechanically and electrically efficient
  - Perceived to be more difficult to splice prep SSLT



Fully stranded design
BEST PRACTICES

- Slightly undersize SSLTs adjacent to ACS and/or AY wires get greater protection from crushing forces (“bridge effect”)
- In-line EFL control plus eddy current testing
- Gel formulated for use in laser-welded stainless-steel loose tubes (“hydrogen scavenging” + higher temperature means slight tint)
- Color-coded bundling threads + ring marking to facilitate splicing preparation
- Conservative wire lay length and preform for good fit



OPGW Design Considerations

CHOOSING DESIGN PARAMETERS

- For any type of OPGW, the three most important design parameters are:
  - Fiber Count
  - Max. Diameter Requirement
  - Fault Current Carrying Capacity

- These three factors interplay with one another to determine the final size and mechanical/ electrical properties of a cable design
  - They create significant trade-offs! Consider:
    - Want a small diameter
    - Higher fault current = more metal = larger diameter
  - Cost is a trade-off too

OPGW Design Considerations
FIBER COUNT

- 48 is still the most widely used fiber count, but…
  — 72 and 96 also very common, plus a good quantity of 144
  — Limited quantities of others, especially those below 48
- What about the fiber count in each tube?
  — 24 or 48 are the most common, by far
  — Tube counts of 1 or 2 are the most common

  — Note: Contrast with dielectric cables: 12 or 24 fibers/tube are the most common with 4 tubes or more per cable
    - Requires some "reorganization" in splice enclosures when splicing OPGW to dielectric cable
    - Requires attention to detail when recording network layout

OPGW Design Considerations
FIBER COUNT

- Each tube size has a maximum fiber count
  — Good design maximizes the zero fiber strain margin (ZFSM) point and conversely minimizes fiber strain at maximum rated design tension (MRDT) (ideally, 0 strain at MRDT)

  Tip: Poor optical unit design (low EFL, overfilled tubes, etc.) will show up as low ZFSM and/or strain at MRDT, but you often have to request these specifications

- Tube size is limited by
  — Al Pipe type: space inside pipe
  — Stranded SSLT type: size of adjacent wires
  — Center SSLT type: maximum SSLT size

OPGW Design Considerations

CHOOSING DIAMETER

- Usually, the smaller the better, but…
  — Limits maximum fiber count
  — Limits fault current capacity too

- Incab typical range:
  — 0.364”– 0.787”
  — Most common: 0.465”- 0.646”
  — Larger is possible with added layers (increased cost!)

- Larger diameters impact on structure loading:
  — Increases cable cost, plus…
  — Shorten reel lengths (more set-ups and splices?)
  — May increase hardware cost too

OPGW Design Considerations
FAULT CURRENT

- Designing for fault current has two sides:

  1. The required fault current capacity
     ➔ Determined by the utility

  2. The cable fault current rating
     ➔ Determined by the cable manufacturer

  Let's look at these…

  (Note: We have a webinar with a "deep dive" on fault current.)

OPGW Design Considerations
FAULT CURRENT

Utility Side

I^2t

- kA squared X duration in seconds
- Current (kA) – Expected fault current (1 phase or 3?)
- Duration – Expected clearing time
  - Single contingency: 4-6 cycles (highest risk)
  - Allow for re-close: 8-12 cycles
  - Back-up protection: 22-30 cycles (most conservative)

Manufacturer Side

Temperature delta is the single most important variable in computing fault current capacity!

- 210°C (410°F) standard maximum final (hottest part of cable, NOT coolest!)
- Initial cable temperature, NOT the ambient air temperature! 40°C = 104°F is typical, because it's a realistic CABLE temp on a summer day
- IEEE 738 methodology

Determining your Fault Current requirement is a function of your design philosophy:

➔ *How much risk is acceptable to you and your utility?*

OPGW Design Considerations

CONVENTIONAL CABLES' RATINGS

- You may wonder why you just can't say, "Equivalent to 3/8" EHS, 7#8 ACS, or some other conventional cable?"

- Reason #1 – Lacks precision, is too vague
  — There's no published fault current capacities for conventional cables
  — The published data for R_{ac} is only up to 75°C and shows a non-linear increase
  — What upper temperature limit do you use?
    * Much higher than 210°C is possible! (because no optics/optical unit and no AY wire)

- Reason #2 – Capacities are too low for today's power grid
  — These cables adopted around 100 years ago, and demand on our grid was much less than it is today
  — Make some assumptions, and you'll find:
    3/8 ≈ 10 - 16 and 7#8 ≈ 27 - 39 (kA^2s) 🡐 Quite low for today's grid!

OPGW Design Considerations

LIGHTNING PERFORMANCE

- Incab believes that if you design well for fault current, then good lightning performance will follow too

- There are no agreed upon guidelines for lightning design, but we will share our observations and experience on the next slide

(Note: We have a webinar with a "deep dive" on lightning and lightning performance.)

OPGW Design Considerations

LIGHTNING PERFORMANCE

- Our observations and experience:

  — Size matters. A larger wire is less likely to be burned through than a smaller one

  * In response, some utilities have adopted minimum wire sizes
  * Most common is 2.9 – 3.0 mm, but these are arbitrarily chosen (i.e. not based on data)
  * Empirically citing experience with #8 (3.26 mm) makes sense
    (But remember that this increases the size, weight and cost of the cable)

  — Material matters. ACS is better than AY (but, galvanized is best)

  * Some utilities require all-ACS outer layer (again, consider the trade offs)

  — Wire count matters too

  * X energy (1C = 1A·s) will burn Y wires. Y of 12 is better than Y of 8

  — There's a correlation with wire count and overall diameter too. Perhaps greater arc area is a factor.

OPGW Design Considerations
LIGHTNING PERFORMANCE

In addition to the preceding, we note that

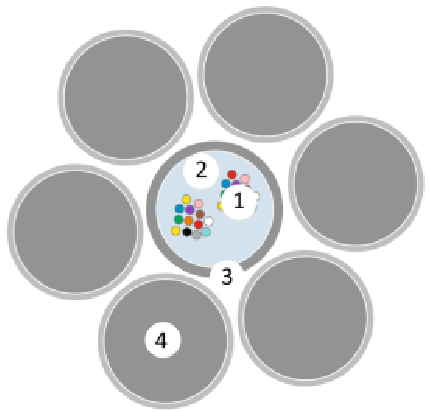
- Low footing resistance correlates with low incidents of lightning damage
  — Strikes more likely to hit at or near a structure where the cable has added protection

And, you may be wondering: What about the design type itself? Is it a factor?

OPGW Design Considerations

DOES DESIGN TYPE AFFECT PERFORMANCE?

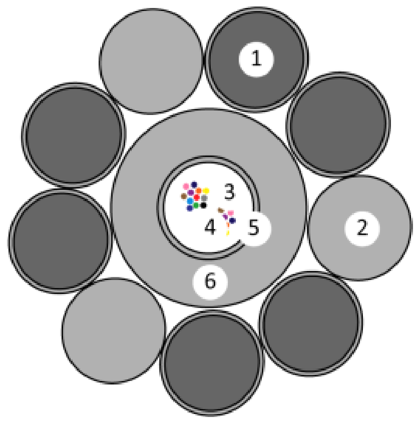
Answer: It is a factor. Should be viewed in light of factors and trade-offs already mentioned (size, material, cost, etc.). ➔ Rough guidelines are:



OPGW C — Good

DESIGN:

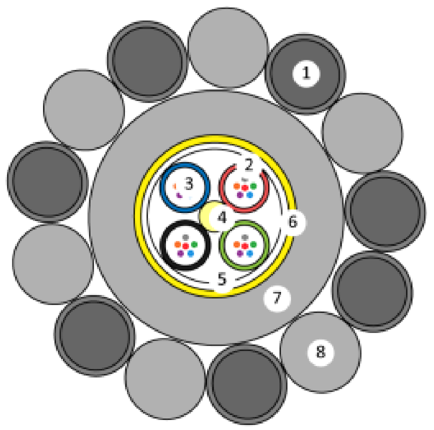
1. Optical fiber Corning SMF-28 Ultra
2. Stainless steel tube filled with water-blocking gel
3. & 4. Stranded wires (aluminum-clad steel (ACS) wires and/or aluminum alloy wires)



OPGW CA — Good

DESIGN:

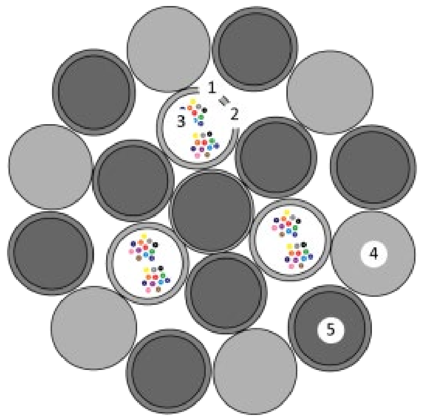
1. Aluminum-Clad Steel Wire 20SA
2. Aluminum alloy wire
3. Water-blocking gel
4. Optical fiber Corning SMF-28 Ultra
5. Stainless Steel Loose Tube (SSLT)
6. Aluminum jacket



OPGW AP — Better

DESIGN:

1. Aluminum-Clad Steel Wire 20SA
2. Gel filled loose tube
3. Optical fiber Corning SMF-28 Ultra
4. Central strength member FRP
5. Water-swellable tape
6. Thermal barrier
7. Aluminum pipe
8. Aluminum alloy wire



OPGW S — Best

DESIGN:

1. Stainless Steel Loose Tube (SSLT)
2. Water-blocking gel
3. Optical fiber Corning SMF-28 Ultra
4. Aluminum alloy wire
5. Aluminum-Clad Steel Wire 20SA

The Configurator™: ACES

ADVANCED CABLE ENGINEERING SYSTEM

- Our Advanced Cable Engineering System (ACES) is a unique software tool to help engineers select the optimal OPGW / ADSS design along with the associated accessories, including dead ends, suspensions, down leads, splice enclosures, and dampers

- ACES will also help engineers and planners prepare cost estimates, generate a complete bill of materials, determine reel lengths, and plan logistics

optimal cable selection

cost estimates

specifications generation

design calculations

ACES was developed by Incab in partnership with Preformed Line Products, and we very much appreciate their assistance.

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Incab

Thank you!

QUESTIONS?

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