Plastic Fiber Active Optical Cables (AOCs) for UHD Video
## Trends in Display Technology

<table>
<thead>
<tr>
<th>Year</th>
<th>Resolution</th>
<th>Color Gamut</th>
<th>Color Depth</th>
<th>Frame Rate</th>
<th>Dimension</th>
<th>Transmission Speed</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950 ~</td>
<td>535line</td>
<td>BT.1700</td>
<td>-</td>
<td>30fps</td>
<td>2D</td>
<td>10MHz</td>
<td>RCA cable</td>
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<tr>
<td>1990</td>
<td>720x480</td>
<td>BT.601</td>
<td>8bits</td>
<td>30fps</td>
<td>2D</td>
<td>0.25Gbps</td>
<td>HDMI cable</td>
</tr>
<tr>
<td>2005</td>
<td>1920x1080</td>
<td>BT.709</td>
<td>10bits~16bits</td>
<td>60fps</td>
<td>3D (w.glass)</td>
<td>1Gbps</td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>4K</td>
<td>xvYCC, BT.2020</td>
<td>10bits~16bits</td>
<td>60fps</td>
<td>3D</td>
<td>10Gbps</td>
<td></td>
</tr>
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<td>2015</td>
<td>8K</td>
<td>xvYCC, BT.2020</td>
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<td>60fps</td>
<td>3D</td>
<td>18 Gbps</td>
<td>Optical cable</td>
</tr>
<tr>
<td>2020</td>
<td>4K</td>
<td>xvYCC, BT.2020</td>
<td>10bits~16bits</td>
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<td></td>
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</table>

- **HDMI 2.1** will reach 48 Gb/s for 8K video
- Proprietary links inside HDTVs expected to exceed 100 Mb/s

Source: Prof. Y. Koike, Keio University
Limitations of Copper Cables

Bandwidth

• For HDMI 2.0, (18 Gb/s) copper cables are quite practical and retain good flexibility up to ~5 meters
• For HDMI 2.1 (48 Gb/s) max length is expected to be ~2 meters
• Active copper cables are already widespread

Other problems

• Longer copper cables rapidly become quite large, heavy, and stiff
• More difficulty with non-latching connectors
• More difficulty in pulling behind walls

Optical implementations of HDMI 2.0 already widely used in commercial and school installations (10 -100 meters)

Optical HDMI not yet a factor in residential – but it will be!
Solution: Active Optical Cables

Advantages of AOCs

- supports much longer distances than copper
- cable reminds small and flexible
- no need to keep exposed optical connectors clean as with passive fibers
- uses standard electrical port - no dedicated optical port needed
Construction of GI-POF HDMI AOC

- fully ribbonized cable elements
- mechanical durability of POF simplifies construction of fiber/copper hybrid cables
- low-cost, non-hermetic OSA with chip-on-board mounting of VCSELs and PDs
Patented monolithic GigaPOF® ribbon is easy to terminate

- Terminate multiple fibers as a single unit
- No need to strip overcladding to terminate fiber
- 100% passive alignment of fiber to OSA

GigaPOF® Monolithic Ribbon Patent #9046670

Reduces fiber termination costs
Award-Winning Plenum HDMI 1.4 and 2.0 AOCs

InfoComm “Best New AV Accessory”

Commercial Integrator “25 Best of 2013”

EC&M “2014 Product of the Year”

• installed in ~ 100,000 video links in North America
• first large-scale use of GI-POF worldwide
• most volume now migrated to HDMI 2.0 product
Long HDMI Link Alternatives

- Simple “plug ‘n play” install
- No external power needed
- Fewer device incompatibilities

- Complex installation
- Extenders need external power
- Many potential incompatibilities
- Relatively expensive
DisplayPort AOCs

- DP 1.2 AOCs support up to 32.4 Gb/s data rate (8.1 Gb/s per channel)
- technically most robust solution for 4K/60 4:4:4 video
- but does not support HDCP 2.2
- DP 1.4 will support up to 32.4 Gb/s data rate (8.1 Gb/s per channel), and will also support HDCP 2.2

- much smaller volume than HDMI AOCs so far
- opportunities coming in AR/VR systems, gaming, and digital signage
What’s Next for UHD AOCs?

**Higher bandwidths**
- 48 Gb/s for HDMI 2.1
- Links between TV processing units and display likely to exceed Gb/s in near future
- Methods to achieve higher bandwidth are well known, no different between POF and glass fibers

**Short distances and consumer environments**
- ProAV - semi-skilled commercial installations, usually dragged through conduit and inside walls and ceilings
- With HDMI 2.1 and TV links, AOCs will extend down to consumer electronics - no control over abuse of cables
- Glass fiber cables can tolerate this abuse on a short-term basis, but fail over time
- New applications not only require better durability, but also more cost sensitive

AOCs will need to tolerate kinks, pinches and knots on a permanent basis. Much lower assembled costs needed in consumer markets.
GigaPOF® is immune to static fatigue failures

**Glass fibers suffer from static fatigue**

- When fiber is bent, material stretches on one side, compresses on the other
- Strain makes it easier to nucleate cracks
- Over time, cracks form spontaneously; time to cracking failure is related to fiber bend radius
- When fiber pushes against other elements, bend radius can be sharper than cable bend radius
- High speed copper cables are also vulnerable to strains that affect pitch of twisted wire pairs
- When fiber pushes against other elements, bend radius can be sharper than cable bend radius

**Plastic fibers are immune to static fatigue**

- Polymer molecules can creep past each other over time, relaxing strain
- Polymer fibers take a “set”, but they don’t crack
- So, polymer fiber cables can withstand pinches, knots and kinks permanently

Source: Corning, Inc.
Material choices are critical for ultra-durable POF

• Chromis started by making POF using only the PBVE (CYTOP) homopolymer, and an index-raising dopant

• dopant solubility and Tg depression limits NA practically to 0.18 or less using only dopant and PBVE homopolymer

• bend tolerance of ~1 mm requires NA ~ 0.23.

• this requires use of lower-index polymers as cladding materials

Copolymers for ultra-durable POF

• by co-polymerization of PBVE with other monomers, we can make polymers that enable fibers with a much higher NA, and/or higher Tg
Innovative optical engine optimized for GigaPOF®

- prism- and lens-free optical sub-assembly design
- attaches to PCB as single unit with solder reflow
- shaped for Chromis monolithic GigaPOF® ribbon
- cheaper to make than traditional optical engines

GigaPOF® Monolithic Ribbon

Lower AOC bill of materials and assembly costs
Ease of Assembly

Monolithic POF Ribbon
• Terminates as single unit
• Guillotine cut and plug in to OSA

Use simplified OSA
• Attaches to PCB as single unit w. solder reflow
• Shaped to accept monolithic ribbon
• No lenses or hermetic seal

Keep Channel Count Low
• \( \sim 25 \text{ Gb/s} \) each channel, not \( 10 \text{ Gb/s} \)
• 2-4 fibers vs. 6-12
Requirements for Consumer POF Cables

Ease of assembly

- Millions of units per month required
- Assembly by unskilled operators with high turnover
- Most steps must be automated

Durability

- Optical ends protected against dust and contamination
- 1-2 mm permanent bending, knots, etc.

Low cost

- USD $100 active cables are OK in pro A/V
- Consumer cables need to wholesale below USD $20
- Highly automated assembly
- High volume partnerships with makers of ICs, VCSELs
GigaPOF® pathway to optical performance at copper cost

Graded-Index Polymer Optical Fiber (Chromis GigaPOF® GI-POF)

+ Patented monolithic GigaPOF® ribbon

+ Lens- and prism-free optical engine that mounts by solder reflow

Innovative technology cuts bill of materials and assembly costs to make inexpensive AOCs possible

GigaPOF® Salus Series Plenum HDMI 2.0 AOC
Conclusions

HD video cables represent a good opportunity for POF

Professional video AOCs have been the first market for GI-POF

8K standards represent the possibility to greatly expand this

- HDMI 2.0 takes special efforts not to require higher-bandwidth cables
- HDMI 2.1 and later standards will be unable to avoid improved cables
- POF has unique virtues for a multi-gigabit consumer cable
- Heroic strides in cost reduction will be needed for success – but POF enables these