WHAT IS RFoG?

WHY AND WHERE IS THIS TECHNOLOGY A CONSIDERATION?
• RFoG could be considered the “deepest fiber” version of HFC
• RFoG pushes fiber to the side of the home, then uses the existing drop to distribute signals in the home
• It is often considered a “bridging” architecture, enabling operators to use the same headend/back office structure in a FTTH environment
RFoG STANDARD

Society of Cable Telecommunications Engineers

ENGINEERING COMMITTEE
Interface Practices Subcommittee

AMERICAN NATIONAL STANDARD

ANSI/SCTE 174 2010

Radio Frequency over Glass
Fiber-to-the-Home Specification
RFoG ONU STRUCTURE (AM)

R-ONU (AM)

Downstream receiver

1550 nm

Diplexer

H

RF on coax into home

L

WD M

Upstream transmitter

\( \lambda_{up} \) nm

Power control

Signal detector

End of fiber optic distribution plant
RFoG ONU STRUCTURE (FM)
### ODN SPECIFICATIONS

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating distance, optical hub to R-ONU (D) for 1:32 split ratio (^{1,2})</td>
<td>0 - 20 km</td>
</tr>
<tr>
<td>Highest loss budget under which the system must operate (L)</td>
<td>25 dB (^{3})</td>
</tr>
<tr>
<td>Lowest loss budget under which the system must operate</td>
<td>5 dB lower than the highest loss. If the system design has even less loss (e.g., if the split ratio is low) then the system design must make up the loss. See Section 10.0, “Implementation Notes” for a discussion of the minimum loss budget.</td>
</tr>
<tr>
<td>Assumed optical fiber type</td>
<td>ITU G.652 B or later, or ITU G.657</td>
</tr>
</tbody>
</table>

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**Note 1** Longer distances may be possible, but the designer should keep the distance limits of EPON and GPON in mind if migration to either standard is contemplated.

**Note 2** Any ratio may be used so long as the total loss budget is respected. Depending on the splitting architecture, Stimulated Brillouin Scattering (SBS) may limit operation to a lower split ratio (See Section 11.1, “Downstream Considerations” for more information). Typical PON implementations normally use split ratios of 32 and, rarely, 64, limited by available optics, so using a higher split ratio may make use of those standards infeasible unless an intermediate interface is used.

**Note 3** The system must operate with losses up to and including 25 dB. Design and operation with loss budgets greater than 25 dB is optional.
<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical carrier wavelength</td>
<td>1540-1565 nm</td>
</tr>
<tr>
<td>Received optical power over which RF output level, tilt, and frequency response specifications must be met</td>
<td>-6 to 0 dBm</td>
</tr>
<tr>
<td>Received optical power over which there shall be no optical power alarms and the RF output shall be present</td>
<td>-13 to +1 dBm</td>
</tr>
<tr>
<td>Output impedance</td>
<td>75 ohms</td>
</tr>
<tr>
<td>RF output reference level as measured with a CW test signal at 860 MHz, OMI = 3.5%</td>
<td>+17 ±3 dBmV</td>
</tr>
<tr>
<td>Output tilt (F_{DS-Min} to 1002 MHz)</td>
<td>+5 ±2 dB</td>
</tr>
<tr>
<td>Frequency response</td>
<td>±2 dB deviation from tilt, F_{DS-Min} to 1002 MHz. Response may drop an additional 2 dB from 860-1002 MHz</td>
</tr>
</tbody>
</table>

**Note 1** Compatibility with 10 Gb/s PONs is optional due to the cost of blocking the 1577 nm downstream data wavelength. An R-ONU manufacturer may choose to support it, or an external blocking filter may be used, or a separate 10 Gb/s PON may be made available at the same splitting location.

**Note 2** At optical powers below -6 dBm, AGC may not be effective. Thus, the RF output level is allowed to decrease 2 dB for every 1 dB decrease in optical power. At -13 dBm optical power, the RF output level may be as low as +3 ±3 dBmV for an OMI of 3.5%. This specification does not prohibit implementations that maintain the +17 dBmV RF output reference level at optical powers below -6 dBm.
### UPSTREAM ONU WAVELENGTH AND POWER SPECS

<table>
<thead>
<tr>
<th></th>
<th>$\lambda_{up} = 1310$ nm</th>
<th>$\lambda_{up} = 1610$ nm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Application</strong></td>
<td>Secondary wavelength, only for systems not needing compatibility with EPON or GPON.</td>
<td>Primary wavelength, compatible with EPON or GPON.¹</td>
</tr>
<tr>
<td><strong>Optical output power, standard temperature range</strong></td>
<td>+1.5 ±1.0 dBm</td>
<td>+3.0 ±1.0 dBm</td>
</tr>
<tr>
<td><strong>Optical output power, extended temperature range</strong></td>
<td>+1.5 ±1.5 dBm</td>
<td>+3.0 ±1.5 dBm</td>
</tr>
<tr>
<td><strong>Maximum “off state” optical power</strong></td>
<td>-30 dBm</td>
<td>-30 dBm</td>
</tr>
<tr>
<td>**Wavelength tolerance (includes effects of temperature)**²</td>
<td>±50 nm</td>
<td>±10 nm</td>
</tr>
<tr>
<td><strong>Coexistence with EPON or GPON</strong></td>
<td>None</td>
<td>All specifications must be met when the same fiber is carrying either EPON or GPON signaling.¹</td>
</tr>
</tbody>
</table>

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**Note 1**
This does not necessarily include 10 Gb/s systems unless the R-ONU manufacturer claims coexistence with 10 Gb/s systems. Otherwise, coexistence with 10 Gb/s systems may require a blocking filter.

**Note 2**
The wavelength must be within the wavelength tolerance specified when the R-ONU is operated over the entire Operating Temperature range specified in Section 9.0, “Physical and Environmental.” If the unit is not labeled, for standard temperature use as specified in Section 9.1.1, “Marking,” the wavelength tolerance specification must be met across the extended temperature range specified in Section 9.3, “R-ONU Extended Temperature Range.”
## ONU Input and Response Specs

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal channel capacity¹</td>
<td>Four 6.4 MHz wide channels</td>
</tr>
<tr>
<td>Nominal RF input level per channel (upstream RF into R-ONU)¹</td>
<td>+33 dBmV per carrier</td>
</tr>
<tr>
<td>Frequency response</td>
<td>±2 dB, 5 to F_{US-Max} MHz</td>
</tr>
<tr>
<td>OMI at total power, over full rated temperature range²</td>
<td>35% ±3 dB @ carrier amplitude of +39 dBmV</td>
</tr>
<tr>
<td>Noise Power Ratio (NPR)³</td>
<td>≥ 38 dB over a ≥ 10 dB dynamic range</td>
</tr>
<tr>
<td>Maximum power level (total power, continuous, no damage)</td>
<td>+60 dBmV</td>
</tr>
</tbody>
</table>

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**Note 1**
The Nominal channel capacity is used to derive the Nominal RF input level per channel specification and to estimate the performance of an upstream channel in a typical deployment. These values are suggested and are not mandatory. R-ONUs should function with higher channel loads, but performance may be reduced. See Section 10.0, “Implementation Notes” for guidance on channel characteristics and additional considerations.

**Note 2**
The OMI is measured with a CW carrier inserted at the specified carrier amplitude. The specified OMI and carrier amplitude are the recommended design level for total composite RF power at the R-ONU coaxial port when fully loaded. If four channel operation is assumed, the level of each channel at the R-ONU coaxial port will be 6 dB lower. See Section 10.0, “Implementation Notes” for guidance on channel characteristics. This OMI is specific to Amplitude Modulated solutions and may be different for alternative technology choices such as Frequency Modulation, for lasers incorporated into the ONU.

**Note 3**
R-ONU upstream NPR cannot easily be measured in a link with high optical loss. To measure NPR, it is necessary to use a link with relatively low optical loss. The noise loading for the NPR test shall be 37 MHz of broadband noise from 5 MHz to 42 MHz with a nominally centered notch. NPR shall be tested with 20 km of fiber and additional attenuation resulting in -10 dBm optical power into the test receiver. The test receiver shall have an E{\text{IINC}} over the return band of 5 to 42 MHz of no greater than 2.5 pA\text{Hz} and two tone IM2 and IM3 products better than -60 dBc @ 20% OMI per tone and 0 dBm total optical received power. The test setup should have the optical attenuation placed between the transmitter and the fiber.
ADVANTAGES AND CHALLENGES OF RFoG
Advantages
- No actives in the field
- No power supplies to maintain
- Reduced operating cost
- Reliable
- Excellent signal quality in downstream
- Initiates fiber to the home while using existing headend/back office structure

Disadvantages
- Relatively high cost/sub to construct
- Fiber drop practices still being refined
- OBI can be a concern unless properly managed
OBI
OPTICAL BEAT INTERFERENCE

• OBI occurs when two or more optical signals are present on a fiber and are very close in wavelength
• It causes severe degradation in signal quality while both optical signals are present
• Upstream OBI is a product of 2 ONU’s transmit simultaneously and their optical wavelengths are very close together
• Downstream OBI will exist in a multi-wavelength forward environment
  — Multiple forward RFoG transmitters
  — RFoG sharing fiber with other architectures
OPTICAL BEAT INTERFERENCE
We typically describe optical signals in terms of wavelength (i.e. 1611nM).

That signal could also be described in terms of frequency, much like RF signals.

The frequency is equal to the speed of light ($3 \times 10^8$ M/S) divided by the wavelength (M/Cycle).

When two optical signals arrive at a photodiode simultaneously, the photodiode will generate an RF tone at the difference frequency of the incident signals.

Four Wave Mixing (FWM) can create optical beats capable of generating OBI in multiwave downstream applications.

If the frequency difference of the incoming signals is in the range of our modulation spectrum, destructive interference results:
- (54-1002MHz for downstream)
- (5-42 MHz upstream)
EYE PATTERN OF PCM DIGITAL SIGNAL WITH NO OBI
SAME SIGNAL WITH OBI
• Upstream OBI will occur when two or more transmitters are “on” at the same time with wavelengths within 2GHz of each other.
  — Will be measurable if incident wavelengths are within 2GHz of one another
  — Will become very severe if wavelengths are 50MHz or closer
  — Wavelength accuracy of standard DFB 1611 laser is ± 3nM
  — ± 3nM translates to ±350 GHz
  — Wavelength drift over temperature is .08nM/°C (9.3GHz)
  — Temperature changes with on/off status of laser
  — This means that ONU’s can drift into/out of OBI condition dynamically
• Will occur only in a multi-wavelength environment
  — Single fiber with multiple forward RFoG wavelengths
  — Single fiber with other PON systems
  — Is mitigated by good wavelength planning as well as optical launch power management
APPLYING RFoG IN TODAY’S HFC NETWORKS
Today, RFoG is primarily a greenfield architecture.

- It is a convenient way to build fiber to the home and leverage the existing HFC back office.
- RFoG equipment is being developed and refined as acceptance grows.
- RFoG can coexist alongside other optical technologies such as ePON and GEPON as well as other RFoG paths.
- In such multi-wave situations, care must be exercised in designing and applying optical signals.
BASIC MULTI-WAVE OPTICS

• Some new things to consider..
  — Chromatic Dispersion
  — Raman Scattering
  — Cross-phase Modulation (XPM)
  — SBS
  — 4 Wave Mixing
In Direct Modulation Style transmitters, modulation causes laser to emit energy over a range of wavelengths (colors). Dispersion describes the phenomenon in which those colors travel at different speeds through the fiber. Legacy Direct Modulation transmitters commonly used 1310 as their nominal wavelength. 1310 happens to be the zero dispersion point of the typical CATV deployed fiber, so dispersion was not a serious concern. Moving to wavelengths outside 1310 is desirable in multi-wave applications as energy at the zero dispersion point will cause degradation in the system performance. The actual zero dispersion point of fiber varies from 1300 to 1325nM. Multi-wave applications moved away from 1310 to avoid the zero dispersion point, thus making dispersion a consideration.
EFFECTS OF CHROMATIC DISPERSION

Input Pulse

Signal To Noise (SNR)
Bit Error Ratio (BER)

Output Pulse
CROSS PHASE MODULATION (XPM)

1. As a signal propagates
   a. Leading edge will experience an increase in refractive index
   b. Trailing edge sees a decrease in refractive index.

2. When two or more λs share a fiber, the modulation of the refractive index affects all signals.

3. XPM creates Cross intensity modulation of optical signals and thus, cross amplitude modulation of the RF Signals being carried!
STIMULATED RAMAN SCATTERING

- A phenomenon in fiber whereby one Optical Signal can act as a “pump” so as to provide gain (either positive or negative) to other signals sharing the fiber, leading to cross talk among the RF signals after detection.
- Lightwave Signal interacts with vibrating molecules in the fiber. Light is then scattered in all directions.
- SRS Crosstalk varies with wavelength spacing.
- Pump $\lambda$ is shorter than Victim $\lambda$. Gain is positive.
- Pump $\lambda$ is longer than Victim $\lambda$. Gain is negative.
SRS gain typically changes with the polarization states of launched light.
XPM & SRS

Access and Transport
STIMULATED BRILLOUIN SCATTERING (SBS)

- Occurs when too much power is launched into a fiber at a single $\lambda$.
- Is primarily a concern of externally modulated lasers as the optical power is very focused on a narrow range of wavelengths.
- Some of the energy from fiber molecules is transmitted as forward wave. Remainder is translated into an acoustic wave that propagates through the material back toward the source.
- Acoustic waves modulate the index of refraction causing the main light wave to alternately slow down and speed up, causing the detected signal to have increased distortions.
- Reflected signal is re-reflected and due to it’s random nature shows up as noise at the detector……typically below 60 MHz.

![Graph showing noise floor with SBS and typical noise floor]

Degrades:
- CSO
- CTB
- CNR
REGULAR (EVEN) WAVELENGTH SPACING
REGULAR (EVEN) WAVELENGTH SPACING
RFoG TYPICAL ARCHITECTURE

Max Launch Governed by SBS Suppression Limit

Splitter Input Range: 11.5 – 17.5dBm

17dB Loss

2KM Max (0.5dB Loss)

-6dBm Minimum
# RFOG Optical Budgeting

## Downstream

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch Power</td>
<td>18</td>
</tr>
<tr>
<td>ONU Input</td>
<td>-6</td>
</tr>
<tr>
<td>Splitter-ONU Loss</td>
<td>0.5</td>
</tr>
<tr>
<td>Splitter Loss</td>
<td>17</td>
</tr>
<tr>
<td>Loss Total</td>
<td>17.5</td>
</tr>
<tr>
<td>Headend-Splitter Budget</td>
<td>6.5</td>
</tr>
<tr>
<td>Headend-Splitter Distance (KM)</td>
<td>26</td>
</tr>
</tbody>
</table>
### Upstream RFOG Optical Budgeting

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch Power</td>
<td>6</td>
</tr>
<tr>
<td>Total Optical Path Loss</td>
<td>24</td>
</tr>
<tr>
<td>Receiver Input</td>
<td>-18</td>
</tr>
</tbody>
</table>
**UPSTREAM CONSIDERATIONS**

- Upstream signals encounter significant losses including those of distribution splitter or couplers
- Input to headend RX may be lower than in classic node
- Special low noise photodetectors (0.8 µA/\sqrt{Hz}) have been built into upstream receivers to aid in producing good quality RF
SOLUTION FOR TODAY ..... 

STEPPING STONE TO TOMORROW
RFOG WITH PON

1550 nm (nom.)
downstream optical transmitter

Optical attenuation

Optical attenuation

xPON OLT
(when used)

1310/1490/1577 nm as
appropriate (if xPON is
used)

1550 (nom.)/1310 (if
no xPON)/1610 nm

WDM

Start of fiber optic
distribution plant

WDM

Optical attenuator

Optical Hub
(start of FTTH system)

Optical Distribution
Network (ODN)

Optical Hub
(start of FTTH system)

Optical Distribution
Network (ODN)

Note: the two WDMs may
be located in either order in
the signal path, or they
may be in the same optical
block.