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Radio Frequency over Glass Fiber-to-the-Home Specification

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TABLE OF CONTENTS

1.0 SCOPE AND DEFINITIONS....................2

2.0 NORMATIVE REFERENCES....................5

3.0 INFORMATIVE REFERENCES....................6

4.0 REFERENCE ARCHITECTURE....................7

5.0 SYSTEM SPECIFICATIONS....................9

6.0 DOWNSTREAM R-ONU SPECIFICATIONS....................11

7.0 UPSTREAM R-ONU SPECIFICATIONS....................12

8.0 R-ONU POWER....................18

9.0 PHYSICAL AND ENVIRONMENTAL....................18

10.0 IMPLEMENTATION NOTES....................22

11.0 APPENDIX A: SYSTEM LOSS SPECIFICATION....................25

12.0 APPENDIX B: UPSTREAM RECEIVER....................28

13.0 APPENDIX C: FM SPECIFICATION CLARIFICATION....................28

1.0 SCOPE AND DEFINITIONS

1.1 Scope

This document defines a fiber-to-the-home system optimized for compatibility with hybrid fiber-coax (HFC) plant, using the same end equipment at both the home and at the headend or hub. The RFoG system is defined to begin where the plant becomes passive, extending from that point to the home. This interface is referred to as the Optical Hub. There are many possible variations on the structure of the optical hub, depending on the needs of the system. The RFoG system is defined to terminate at the subscriber-side interface of an RFoG Optical Network Unit (R-ONU) at the home.

The specifications in this document apply to the R-ONU and are designed to allow interoperability between R-ONUs from various manufacturers.

The following system parameters and devices are NOT specified by this document:

- Downstream transmitter and optical amplifier
- Upstream receiver
- System carrier-to-noise and distortion

Additionally, the following items are not specified for the R-ONU. The user is cautioned that there may well be variations between manufacturers.

- Physical mounting arrangement
- Weight
- Fiber management
- Element management
- Service disconnect
- Extended reach
- The optical front-end need not reject a 1577 nm 10G-EPON or a 1577 nm XG-PON downstream carrier

This document contains specifications for systems that use amplitude modulation (AM) in the upstream path and systems that use frequency modulation (FM) in the upstream path. Unless otherwise noted, this document details the requirements for AM systems. The sections that apply specifically to FM systems are so noted and do not apply to AM systems. Portions of the AM specifications that do not apply to FM systems are also noted. AM and FM systems cannot be mixed in the same optical distribution network (ODN).

1.2 Acronyms

CNR	Carrier-to-Noise Ratio
NPR	Noise Power Ratio
ODN	Optical Distribution Network
OMI	Optical Modulation Index
ONU	Optical Network Unit
RFoG	RF over Glass
R-ONU	RFoG Optical Network Unit
SBS	Stimulated Brillouin Scattering
WDM	Wave Division Multiplexer

1.3 Definitions

Noise Power Ratio: The ratio of the signal power density to the power density of the combined noise and intermodulation distortion in the channel. Essentially, NPR is the depth of notch. The signal power density is defined with the entire passband filled with energy. The power density of the noise and intermodulation distortion shall be measured by removing signal power from a range of frequencies with a notch filter while maintaining constant total signal power at the DUT input.

Nominal: Specifications or values in this document that have the word "nominal" in them are approximate and designate a suggested or theoretical value. Items noted with the word "nominal" are not normative requirements.

Optical Modulation Index (OMI): The amount that the instantaneous power of the optical carrier varies around the average power of that optical carrier. In this specification, OMI is used only for the amplitude modulation of an optical carrier by an RF signal and is generally expressed as a percent. OMI is defined to be 100% when the peak of a single sine wave that is amplitude modulated onto an optical carrier modulates the instantaneous power of that carrier from zero power to twice the average power.

Figure 1 shows the relationship between the laser optical power and the modulating current.

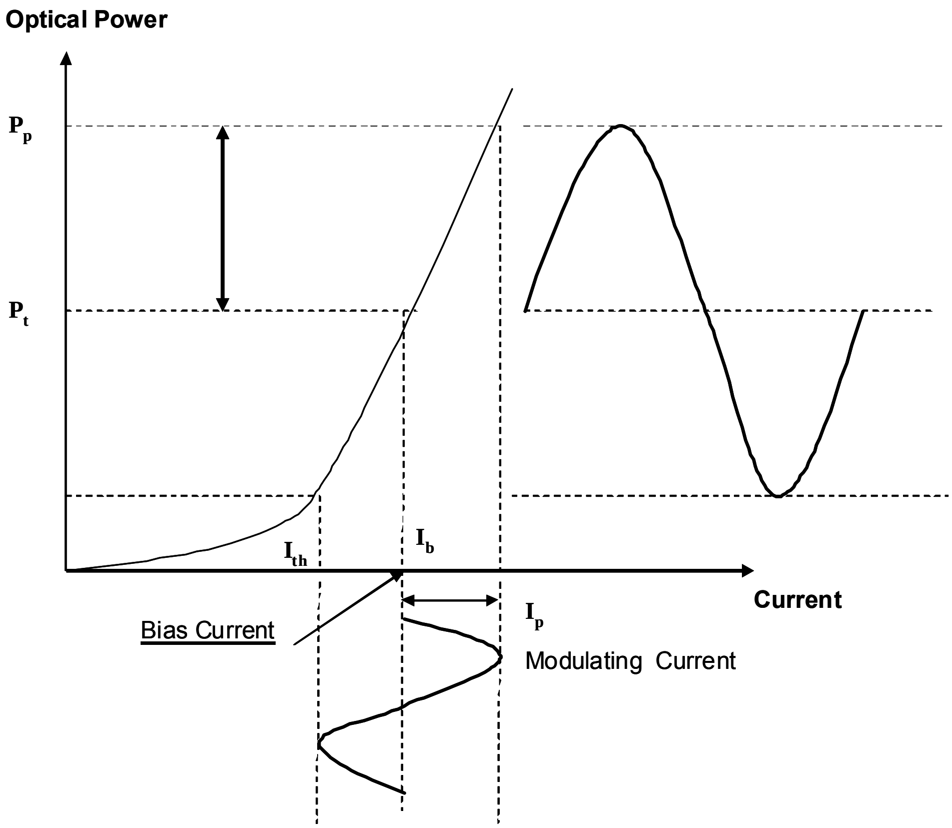

Figure 1: OMI Definition

In the optical domain, the OMI is defined as:

OMI = (Pp – Pt) / Pt, where

- Pp is the peak optical output power of the laser
- Pt is the optical power at the bias current

In the electrical domain, the OMI is defined as:

OMI = Ip / (Ib – Ith), where

- Ith is the threshold current of the laser
- Ib is bias current
- Ip is the peak modulating current

The optical and electrical definitions are equivalent.

The definition of OMI involves the peak of the signal and is easiest to measure with a simple sinusoidal signal. The OMI of any other modulating signal, m(t), is defined to be the OMI that would be produced if a single sine wave of identical average RF power to m(t) were modulated onto the optical carrier. In other words, with a complex modulating signal, the exact peak is no longer referenced. The average power of the complex signal is measured and is said to have the same OMI as would be produced if that signal were replaced with a sine wave of equivalent average power.

OMI should always be measured with a CW carrier that has the same average power as the desired signal.

Unless specified as a per-channel value, OMI always refers to the modulation index of the entire RF signal.

Optical Power: Unless otherwise specified, "optical power" refers to the average power of an optical carrier. If the optical power is gated on and off, the optical power is defined as the average power during the burst, not including turn-on and turn-off transitions. Optical power measurements shall be averaged sufficiently to assure that any changes to content that is modulated onto the laser does not affect the measurement.

2.0 NORMATIVE REFERENCES

The following documents contain provisions, which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreement based on this standard are encouraged to investigate the possibility of applying the most recent editions of the documents listed below.

- 47CFR15.109: 2005 Radio Frequency Devices, Unintentional Radiators, Radiated Emission Limits
- 47CFR76.605(12) 2004, Code of Federal Regulations, Multichannel Video and Cable Television Service, Technical Standards
- 47 CFR76.609(h): 1993 Code of Federal Regulations, Multichannel Video and Cable Television Service, Measurements
- 47CFR76.614: 2000 Code of Federal Regulations, Multichannel Video and Cable Television Service, Cable Television System regular monitoring
- ANSI C63.4, 2003-2009 Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9 kHz to 40 GHz
- ANSI/SCTE 01 2006 - Specification for "F" Port, Female, Outdoor
- ANSI/SCTE 02 2006 - Specification for "F" Port, Female, Indoor
- ANSI/SCTE 81 2007 - Surge Withstand Test Procedure

- ANSI/SCTE 119 2006 - Measurement Procedure for Noise Power Ratio
- GR-326-CORE, Issue 4, Generic Requirements for Single-Mode Optical Connectors and Jumper Assemblies
- GR-3120-CORE, Issue 2, Generic Requirements for Hardened Fiber Optic Connectors (HFOCs) and Hardened Fiber Optic Adapters (HFOAs)
- IEEE C62.41-1991, IEEE Recommended Practice for Surge Voltages in Low-Voltage AC Power Circuits
- ITU-T G.652d, Characteristics of a Single-Mode Optical Fibre Cable
- TIA-604-3-B FOCIS-3, Fiber Optic Connector Intermateability Standard, Type SC and SC-APC

3.0 INFORMATIVE REFERENCES

The following documents may provide valuable information to the reader but are not required when complying with this standard.

- ANSI/SCTE 96 2008 - Cable Telecommunications Testing Guidelines
- GR-49-CORE, Issue 2, Generic Requirements for Outdoor Telephone Network Interface Devices
- GR-487-CORE, Issue 3, Generic Requirements for Electronic Equipment Cabinets
- IEEE Standard 802.3-2008, Carrier sense multiple access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications (Includes the EPON standard). See also subsequent corrigenda.
- IEEE Standard 802.3av-2009, IEEE Standard for Information Technology-Part 3: Amendment 1: Physical Layer Specifications and Management Parameters for 10Gb/s Passive Optical Networks, October 2009
- ITU-T G.984, Gigabit-capable passive optical networks (GPON)
- ITU-T G.987, 10-Gigabit-capable passive optical network (XG-PON) systems
- ITU-T G.652, Characteristics of a single-mode optical fibre cable
- ITU-T G.657, Characteristics of a bend-loss insensitive single-mode optical fibre and cable for the access network
- Multimedia over Coax Alliance (MoCA), http://www.mocalliance.org

4.0 REFERENCE ARCHITECTURE

Reference architectures for the RFoG system and for the R-ONU are shown in this section. The terminology R-ONU, for RFoG Optical Network Unit, is used to differentiate the RFoG ONU from ONUs adhering to other specifications, which typically include a digital transmitter and receiver independent of any RF components. This reference architecture comprises the minimum commonality of the system. Nothing precludes a vendor from offering additional features, but they may or may not be compatible with components from other vendors. Compatibility is limited to the issues covered in this document.

4.1 System

Figure 2 illustrates the reference architecture of the system. In the reference architecture, the optical hub, the start of the RFoG system, comprises a downstream optical transmitter operating nominally on 1550 nm, optical amplification and splitting as appropriate, and an upstream optical receiver which receives upstream optical signals on λ_{up} nm (defined below), and converts them to RF form. The wave division multiplexer used to combine and separate the two wavelengths is part of the ODN, consistent with the ODN definition in EPON and GPON.

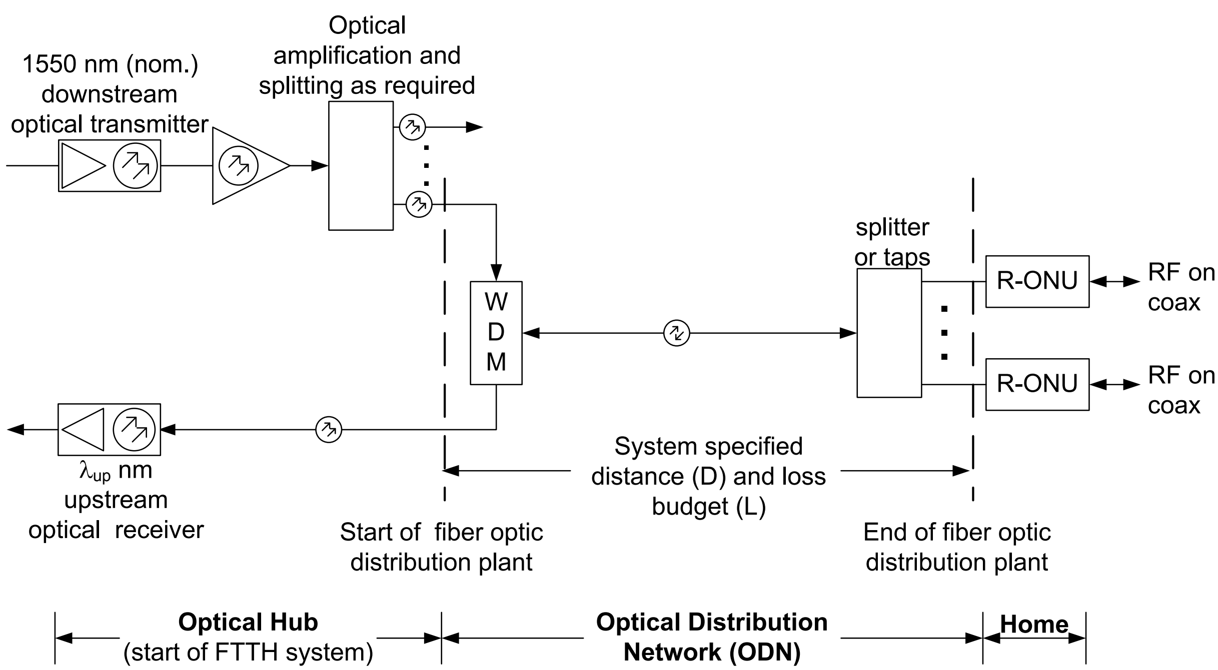

Figure 2: RFoG Reference Architecture

The Optical Hub may take on many other forms according to the needs of the system. For example, it may comprise only optical amplification and splitting in the downstream direction, with optical combining and demodulation followed by digital conversion in the upstream direction. The form of the optical hub is not controlled by this document. Specifications contained herein apply only between the start of the optical distribution network (ODN) and the RF coax output from the R-ONU. The system designer is responsible for making sure that the effects of any signal degradation at the Optical Hub or upstream of it, are properly accounted in the network design. Upstream system performance will vary by choice of Upstream Optical Receiver hardware. Receiver noise performance and technology choice determines interoperability. The ODN is defined to start at the input to the WDM at the optical hub and to end at the pigtail on the R-ONU at the home.

The ODN is shown with a single point splitter. However, the ODN may also be implemented as a series of optical taps or as a multi-layer splitter, such as a 1:4 split followed by a set of 1:8 splitters at a different location. So long as the maximum distance, loss budget, and split ratio are respected, the architecture of the splitting is at the discretion of the operator.

4.2 RFoG Optical Network Unit (R-ONU)

Figure 3 illustrates the ONU reference architecture. The ONU comprises a wave division multiplexer (WDM) which separates the downstream optical signal at 1550 nm nominal and the upstream optical signal at λ_{up} nm. The downstream receiver recovers RF downstream signals from the 1550 nm (nominal) downstream optical carrier and supplies them to the output via a diplexer.

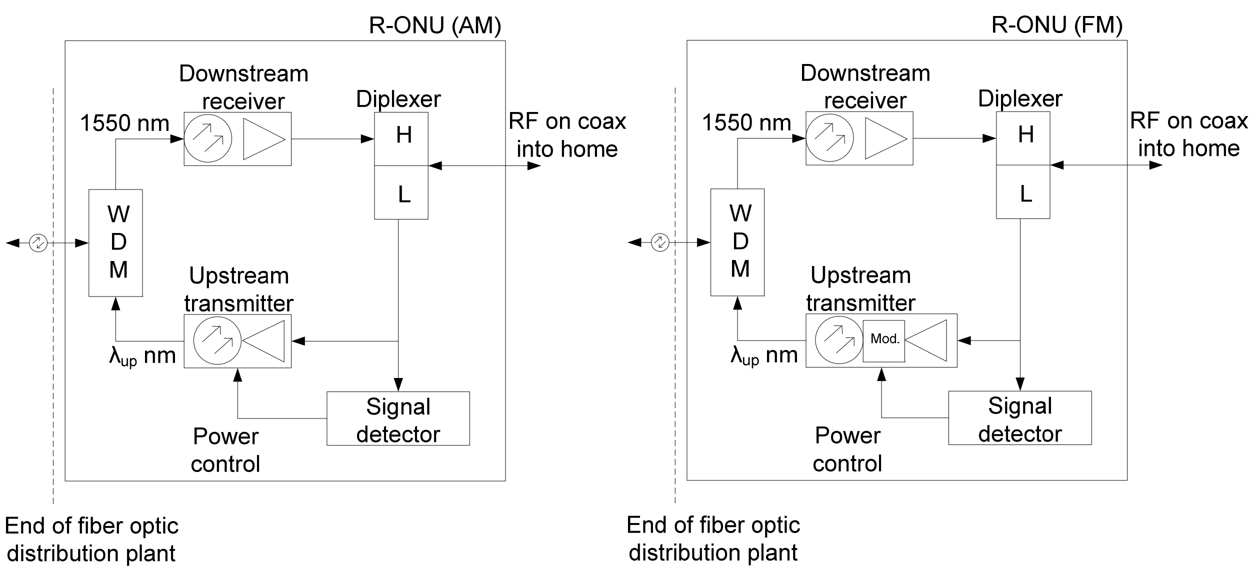

Figure 3: RFoG ONU Reference Architecture

The low port of the diplexer supplies upstream signals to an upstream transmitter whose output is at λ_{up} nm. It also supplies signals to a signal detector, whose job it is to turn on the upstream transmitter when RF signals in the upstream band are detected at a level exceeding a specified minimum threshold.

4.3 Upstream Wavelength, λ_{up}

The specification permits either of two upstream wavelengths λ_{up}. One permitted wavelength is 1310 nm nominal, and the other is 1610 nm nominal. Use of 1610 nm permits an optional overlay of an RFoG system with either an IEEE 802.3-2008 / IEEE 802.3av-2009 (EPON) system or an ITU G.984 / ITU G.987 (GPON) system, both of which use 1310 nm or lower wavelengths for upstream data communications. Both upstream wavelengths will work with the same physical network. Note that if the 1310 nm upstream wavelength is used for RFoG, then neither EPON nor GPON will coexist in the same physical passive optical network.

For compatibility with 10G-EPON or XG-PON systems, the 1610 nm upstream option may be used, but will need an external optical trap at 1577 nm (nominal) to eliminate that downstream carrier. Alternatively a manufacturer may offer an R-ONU with a built-in optical trap, or the operator may choose to deploy RFoG and 10G-EPON or XG-PON on separate networks with co-located splitting.

5.0 SYSTEM SPECIFICATIONS

The Optical Distribution Network shall meet the requirements in Table 1.

Table 1: ODN Specifications

Specification	Value
Operating distance, optical hub to R-ONU (D) for 1:32 split ratio [1,2]	0 - 20 km
Highest loss budget under which the system must operate (L)	25 dB [3]
Lowest loss budget under which the system must operate	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.
Assumed optical fiber type	ITU G.652 B or later, or ITU G.657

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. See Section 11.0, "Appendix A: System Loss Specification" for a discussion.

The crossover between upstream and downstream RF frequencies shall meet the requirements of one of the options in Table 2. The frequencies given in Table 2 are the values that the R-ONU must be specified to support. The inequalities are given to allow for R-ONU implementations that are manufacturer-specified to include a maximum upstream and/or minimum downstream frequency that provides a wider passband than the listed value.

Table 2: RF Frequencies

Option	Maximum Upstream Frequency $F_{US\text{-}Max}$	Minimum Downstream Frequency $F_{DS\text{-}Min}$
Option 42/54	≥ 42 MHz	≤ 54 MHz
Option 65/85	≥ 65 MHz	≤ 85 MHz
Option 85/105	≥ 85 MHz	≤ 105 MHz

6.0 DOWNSTREAM R-ONU SPECIFICATIONS

The R-ONU shall meet all the requirements in Table 3.

Table 3: Downstream R-ONU Specifications

Specification	Value
Optical carrier wavelength [1]	1540-1565 nm
Received optical power over which RF output level, tilt, and frequency response specifications must be met	-6 to 0 dBm
Received optical power over which there shall be no optical power alarms and the RF output shall be present	-13 to +1 dBm
Output impedance	75 ohms
RF output reference level as measured with a CW test signal at 860 MHz, OMI = 3.5% [2]	+17 ±3 dBmV
Output tilt (F_{DS-Min} to 1002 MHz)	+5 ±2 dB
Frequency response	±2 dB deviation from tilt, F_{DS-Min} to 1002 MHz. Response may drop an additional 2 dB from 860-1002 MHz

Note 1: See Section 10.0, "Implementation Notes" for comments on 10 Gb/s compatibility.

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.

7.0 UPSTREAM R-ONU SPECIFICATIONS

7.1 Amplitude Modulation Solution

7.1.1 Wavelength and Power

Two wavelength options are provided in the upstream direction. The upstream wavelength may be 1310 nm for maximum cost effectiveness, or 1610 nm in order to allow the same PON to be used for RFoG and GPON or EPON applications. The upstream band must be specified in purchase documents, and a corresponding WDM and upstream receiver must be used at the Optical Hub.

The R-ONU shall meet all the requirements in Table 4.

Table 4: AM Upstream R-ONU Specifications Specific to Wavelength and Power

	λ_{up} =1310 nm		λ_{up} =1610 nm		
	P_{up} = 1.5 dBm	P_{up} = 3 dBm	P_{up} = 1.5 dBm	P_{up} = 3 dBm	P_{up} = 6 dBm
Application	Secondary wavelength, only for systems not needing compatibility with EPON or GPON		Primary wavelength, compatible with EPON or GPON.[1]		
Optical output power, standard temperature range	+1.5 ±1.0 dBm	+3.0 ±1.0 dBm	+1.5 ±1.0 dBm	+3.0 ±1.0 dBm	+6.0 ±1.0 dBm
Optical output power, extended temperature range	+1.5 ±1.5 dBm	+3.0 ±1.5 dBm	+1.5 ±1.5 dBm	+3.0 ±1.5 dBm	+6.0 ±1.5 dBm
Maximum "off state" optical power	-30 dBm		-30 dBm		
Wavelength tolerance (includes effects of temperature)[2]	±50 nm		±10 nm		
Coexistence with EPON or GPON	None		All specifications must be met when the same fiber is carrying either EPON or GPON signaling.[1]		

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 (see Section 10.0, "Implementation Notes" for more information).

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."

7.1.2 Input Level and Response

Table 5 details the RF performance characteristics of the R-ONU. The R-ONU shall meet all the requirements in Table 5.

Table 5: AM Upstream R-ONU Input Level and Response Specifications

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

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 EINC over the return band of 5 to 42 MHz of no greater than 2.5 pA√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.

7.1.3 Turn-On and Turn-Off Characteristics

The R-ONU shall meet the turn-on and turn-off characteristics specified in Table 6. The characteristics are illustrated in Figure 4. The turn-on and turn-off characteristics shall be tested with a single continuous wave (CW) RF carrier.

Table 6: R-ONU Turn-On and Turn-Off Specifications

Interval	Specification	Value
N/A	Power at which R-ONU shall not turn on	≤ +7 dBmV
N/A	Power at which R-ONU shall turn on [1]	≥ +16 dBmV
N/A	Power at which R-ONU should turn on [1]	≥ +13 dBmV
N/A	Power of “on” level at which R-ONU laser should not turn on with pulsed on/off RF input (50% duty cycle, 100 ns period)	≤ +10 dBmV
N/A	Power of “on” level at which the R-ONU laser should turn on within time T1 (defined below and in Figure 4), when tested using a continuous 50% duty cycle pulsed on/off RF input, 50 ns on and 50 ns off.	≥ +16 dBmV
N/A	Power at which R-ONU shall not turn off [2]	≥ +1 dBmV
N/A	Power at which R-ONU should not turn off [2]	≥ -2 dBmV
N/A	Power at which R-ONU shall turn off	≤ -8 dBmV

T1: Don’t turn on too late	Maximum time from application of RF to 90% optical power (read to late-side mask)	1.3 µs
T2: Don’t turn on too fast	Minimum 10-90% optical power rise time (read from late-side mask 10% to early-side mask 90%)	100 ns
T3: Don’t turn on too slow	Maximum optical power rise time (read from early-side mask 10% to late-side mask 90%). If there is overshoot on the optical power, use the value after the overshoot has dissipated.	1.0 µs
Don’t turn on by mistake	Power at which a single isolated pulse ≤ 90 nanoseconds long should not turn on the laser	≤ +65 dBmV
T11: Don’t turn off too late	Maximum time from removal of RF (defined as RF dropping to -8 dBmV) to the time the optical carrier falls to 10% of its steady-state amplitude (read to late-side mask)	1.6 µs
T12: Don’t turn off too fast	Minimum 90-10% optical power fall time	100 ns
T13: Don’t turn off too slow	Maximum 90-10% optical power fall time	1.0 µs
T14: Don’t turn off by mistake	When turn-off threshold is > -2 dBmV, the R-ONU shall not drop laser power below 90% for a sudden drop in RF input power to ≤ -8 dBmV that lasts ≤ 600 ns. For the same turn-off threshold, the R-ONU may allow the laser power to remain above 90% for a sudden drop in RF input power to ≤ -8 dBmV that lasts > 600 ns. When turn-off threshold is ≤ -2 dBmV, the R-ONU shall not drop laser power below 90% for a sudden drop in RF input power to ≤ -8 dBmV that lasts ≤ 400 ns. For the same turn-off threshold, the R-ONU may allow the laser power to remain above 90% for a sudden drop in RF input power to ≤ -8 dBmV that lasts > 400 ns. [3]	N/A
Should Maintain Turn On with Ramp Up Input	Upon reaching 90% optical power during turn on, subsequent time during which optical power should not drop below 90% of its steady-state amplitude	≤ 12 µs

Should Reach and Maintain Steady-State Stability Upon Turn On	Maximum time after application of a valid turn on RF input in which optical modulator should achieve and maintain RF signal level stability within ±0.1 dB, observed at the output of a reference optical-to-electrical converter (also reach and maintain NPR required performance)	1.3 μs

Note 1: To allow flexibility in the laser activation implementation and provide greater noise immunity in the RFoG system, the "shall turn on" level may be increased by up to 3 dB relative to the "should turn on" level. This will delay the absolute start of laser activation by less than 1/3 of a symbol period.

Note 2: To allow flexibility in the laser de-activation implementation and provide greater noise immunity in the RFoG system, the "shall not turn off" level may be increased by up to 3 dB relative to the "should not turn off" level.

Note 3: For a sudden drop in RF input power to -8 dBmV, a valid input signal will remain below the higher threshold (+1 dBmV) for more time than below the lower threshold (-2 dBmV).

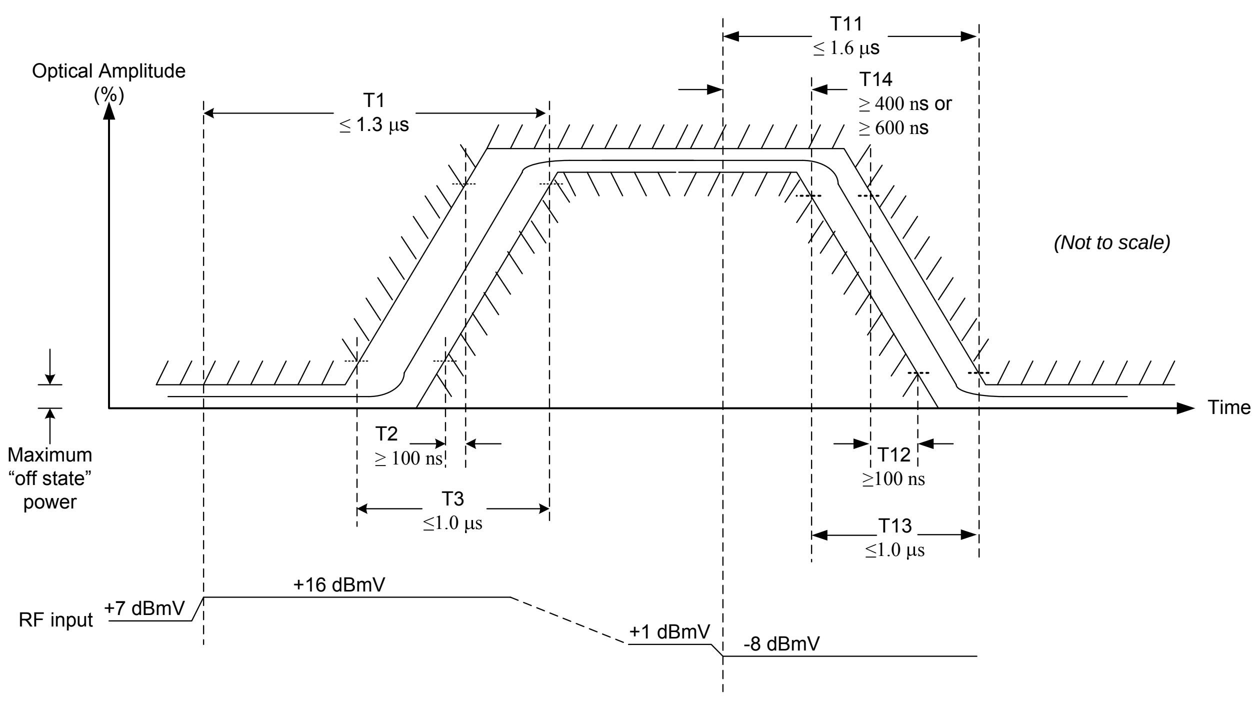

Figure 4: R-ONU Turn-On and Turn-Off Diagram

Note that the turn-on and turn-off characteristics shown in Figure 4 apply for transitions between any RF power within the “Off” power range and any RF power within the normal operating range of the R-ONU.

7.2 Frequency Modulation Solution

An alternative upstream technology using Frequency Modulation is specified in this section. The FM solution shall meet the specifications of Section 7.1, “Amplitude Modulation Solution” except where noted in this section. The upstream link gain is fixed (not a function of link loss) by frequency modulating/demodulating an RF carrier with the upstream RF signals.

The R-ONU shall meet all the requirements in Table 6.

See Section 13.0, “Appendix C: FM SPECIFICATION CLARIFICATION” for clarification of FM specifications.

Table 7: FM Upstream R-ONU Specifications

Specification	Value
Upstream Link Gain (R-ONU input to Receiver output)	-10.0 ± 1.0 dB
Nominal RF input level per channel (upstream RF into R-ONU	+30 dBmV per carrier
FM Center Frequency	1.250 ± 0.001 GHz
Frequency Modulator Sensitivity	400 ± 23 MHz/V
Optical output - unmodulated	3.0 ± 0.5 dBm
Peak Optical Modulation Index, nominal	1.28
Upstream spurious output in the downstream band (measured at nominal upstream input +10 dB)	< -55 dBc
Upstream spurious output above the downstream band (measured at modulator center frequency with no modulation) [1]	< -15 dBmV
Laser shutoff threshold due to excessive RF input level	>50 dBmV
System Noise Power Ratio (NPR) [2]	>28 dB between -31 and -50 dBmV/Hz input

Note 1: For FM systems that employ the MoCA home entertainment network standard, an external filter at the chosen MoCA frequency will improve rejection of unwanted signals.

Note 2: 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 26 dB total loss at 1610 nm. For FM systems, this specification supersedes the NPR test in Section 7.1.2, "Input Level and Response."

8.0 R-ONU POWER

The R-ONU shall be powered from 12 Vdc (nominal) and shall meet the requirements in Table 8. The R-ONU shall operate correctly when presented with the maximum specified input voltage ripple. Standby battery power is not required, but may be provided in an external power supply if desired.

Table 8: R-ONU Powering Specifications

Specification	Value
Operational Input Voltage Range	+10.5 to 18.0 volts dc (12 V nominal)
Input Current	400 mA max
Input Voltage Ripple, 50-120 Hz	500 mV_{RMS}
Input Voltage Ripple, 121 Hz - 1 MHz	500 mV_{p-p}
Power Connection Method	F connector combined with RF. Center conductor to be positive with respect to ground. [1]

Note 1: Additional power connection methods MAY be supplied, but this one MUST be supplied.

9.0 PHYSICAL AND ENVIRONMENTAL

9.1 R-ONU Common Requirements

The requirements in this section apply to all R-ONUs.

9.1.1 Marking

R-ONUs that do not meet the R-ONU Extended Temperature Range specification in Section 9.2, "R-ONU Outdoor Requirements" must be specified with the statement "Standard Temperature Only" and the products must be prominently and permanently labeled "For 0 to +50º C use only."

9.1.2 Operating Temperature

The R-ONU must meet all specifications when operated in an ambient temperature ranging from 0 to +50 degrees Celsius (+32 to +122 degrees Fahrenheit).

9.1.3 Operating Relative Humidity

The R-ONU must meet all specifications when operated in relative humidity from 5 to 95%, non-condensing.

9.1.4 Cooling and Ventilation

If a heat sink is be used, it should not be positioned on or as part of the back of the unit to avoid issues with mounting and dissipating heat from the back of the unit

9.1.5 Surge Withstand, AC Power Adapter Included

When the AC power adapter is provided with the R-ONU, the adapter and R-ONU shall meet all specifications after the adapter and R-ONU are subjected to surges in accordance with ANSI/SCTE 81 2007. At a minimum, tests shall include the IEEE C62.41-1991 Category A-3 Ring Wave, 6KV, 200A on all coaxial ports, and IEEE C62.41-1991 Category B-3 Combination Wave 6KV, 3KA at the AC side of the power supply while the R-ONU is connected to the low voltage side of the power adapter.

9.1.6 Surge Withstand, AC Power Adapter Not Included

When the AC power adapter is not provided with the R-ONU, the R-ONU shall meet all specifications after the R-ONU is subjected to surges in accordance with ANSI/SCTE 81 2007. At a minimum, tests shall include the IEEE C62.41-1991 Category A-3 Ring Wave, 6KV, 200A on all coaxial ports.

9.1.7 Indicators

The R-ONU shall provide visual indication of the presence of DC power and of downstream optical power.

The visual indication of downstream optical power must be on at levels above -13 dBm.

9.1.8 RFI integrity

The shielding integrity of an R-ONU when measured in accordance with 47CFR76.609(h) shall be such that measured values comply with limits set forth in 47CFR76.605(12) and 47CFR76.614. Unintentional emissions greater than 400 MHz when measured in accordance with ANSI C63.4, 2003-2009 shall comply with limits appearing in 47CFR15.109. The test shall be made with the exciting signal modulating the downstream optical transmitter to +3.5% OMI and the optical signal level at the R-ONU shall be 0 dBm. The RF output shall be terminated with a 75 ohm terminator.

9.1.9 Coaxial Ports

All coaxial ports on the R-ONU shall be type F and shall conform to the requirements of ANSI/SCTE 02 2006 (Specification for “F” Port, Female, Indoor). Optionally, for improved moisture rejection, the coaxial ports of the R-ONU should be designed to meet the requirements of ANSI/SCTE 01 2006 (Specification for “F” Port, Female, Outdoor).

9.1.10 Optical Connector

Acceptable R-ONU optical interfaces shall be based on the SC/APC single-mode connector using either (a) or (b), as follows:

a) Standard SC/APC connectors, as defined by

    i) Intermateability: TIA/EIA FOCIS 3 (TIA/EIA-604-3B)

    ii) Geometry, Loss, Reflectance: GR-326CORE, Issue 4, Feb 2010

b) Hardened fiber optic connectors (HFOCs) based on and which can mate to the SC/APC connector , as defined by appropriate sections of GR-3120, Issue 2, April 2010.

Both standard SC/APC connectors and hardened (weather-resistant) connectors are acceptable optical interfaces. The choice of connector interface (non-hardened or hardened) will depend on the intended deployment scenario for the R-ONU. Standard connectors generally require some measure of environmental protection, whereas hardened connectors generally do not. Intermateability between standard SC/APC connectors and hardened connectors permits standard SC/APC connectors to be used inside of the R-ONU while, with the proper bulkhead adapters, standard or hardened connectors may be connected from outside.

9.1.11 Shock

The R-ONU shall meet all specifications after being subjected to three drops from a height of three feet onto concrete, once in each axis. Connector damage is allowed, but the R-ONU must meet all specifications after damage is repaired.

9.2 R-ONU Outdoor Requirements

9.2.1 Housings for R-ONU Protection

R-ONUs may be deployed inside weather-resistant housings for the purpose of environmental/physical protection as well as to store cable slack, prevent tampering, facilitate access for network testing and the like. Housings used for this purpose should follow these guidelines:

Minimum Features:

- The housing should be designed to prevent the ingress of water, wind-driven rain, sand and dust, according to Telcordia GR-487 CORE section 3.31.1 “Wind-driven Rain” and Telcordia GR-49 section 5.9, “Sand and Dust”

- The standard entry/exit port size should accommodate optical drop cables as well as electrical power, optical, coaxial and twisted pair cables run to/from the customer premises.

- The housing should allow for a minimum bend radius of 10x the cable outside diameter, or as recommended by the cable manufacturer.

- Any metallic housing should provide suitable means for grounding and bonding of the R-ONU, cable shielding and other devices according to building codes and manufacturer recommendations.

- The housing should provide a suitable means (such as a backplane or substrate) for mounting and securing the R-ONU.

Additional Features:

- The housing may permit storage of drop cable slack.

- The housing may support pigtail splicing and/or optical adapters necessary to interconnect the drop cable and the R-ONU or inside optical cables to the drop or R-ONU.

- The housing may allow for coaxial splitters, power inserters and similar devices needed to complete the installation.

9.2.2 Outdoor Temperature

Unless the climate is moderate, an R-ONU used for outdoor operation should also comply with the R-ONU Extended Temperature Range in Section 9.3, “R-ONU Extended Temperature Range”.

9.3 R-ONU Extended Temperature Range

An R-ONU specified as meeting the extended temperature range must meet all specifications when operated in an ambient temperature ranging from -40 to +60 degrees Celsius (-40 to +140 degrees Fahrenheit).

10.0 IMPLEMENTATION NOTES

1. It is possible that, on the same PON or a group of PONs combined to one upstream optical receiver, a cable modem in one home will transmit at the same time a set top transmits in another home. If this happens, two optical transmitters will turn on at the same time. If they happen to be close enough in wavelength, it is possible that the two will generate mutual interference at the upstream receiver, and neither transmission may get through.

2. When an AM return is used, cable modems preferably should be restricted by the CMTS such that only one cable modem in a headend optical receiver group is transmitting at any given time. If several ODNs are combined to a single optical receiver, then the restriction should apply to all cable modems in the combined group. When an FM return is used, cable modems MUST be restricted by the CMTS such that only one cable modem in a headend optical receiver group is transmitting at any given time. This restriction may be accomplished by operating all modems from a common scheduler in the CMTS. A single cable modem may transmit on multiple bonded channels if desired.

3. For RFoG operation with burst profiles using 64-QAM modulation, preamble lengths of 32 symbols or more may be required. For lower orders of modulation, shorter preambles may work acceptably, but the CMTS vendor should be consulted. If CMTS default values of preamble length are to be changed, the CMTS vendor should be consulted.

4. With an RFoG system, DOCSIS operation should use DOCSIS 2.0 or 3.0 in order to provide opportunity to take advantage of higher order constellations, the 5.12 Msps symbol rate, and other DOCSIS 2.0 or 3.0 mechanisms. DOCSIS upstream operation should use an upstream symbol rate of 1280 ksps or greater.

   Standard practice of operating SCTE 55-1 upstream OOB uses the symbol rate of 128 ksps, and standard practice of operating SCTE 55-2 upstream OOB uses the symbol rate of 772 ksps even though SCTE 55-1 and 55-2 allow for other options. Therefore, with an RFoG system, SCTE 55-1 systems should operate with an upstream symbol rate of 128 ksps, and SCTE 55-2 systems should operate at 772 ksps.

To assure proper operation of the R-ONU, the operating level of the SCTE 55-1 or SCTE 55-2 signal at the R-ONU should be equal to the level of a DOCSIS channel.

5. If an upstream wavelength of 1310 nm is chosen, then it will not be possible to share the physical passive optical network with either an EPON or GPON standard network, as EPON and GPON both use 1310 nm for upstream signaling.

6. 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.

7. Blocking filters may also be required if an optical carrier at 1530 nm is used in the same fiber.

8. The minimum loss budget for any PON is set as 5 dB less loss than the maximum loss budget. The primary purpose is to minimize the variation in upstream performance. In mixed RFoG and PON systems, there is an additional consideration of crosstalk from the PON into RFoG. If loss must be added to an RFoG system, it may be added in the RFoG system only in the upstream signal path. The downstream may be accommodated by simply supplying a lower amplitude 1550 nm downstream optical carrier. For mixed RFoG and PON systems, additional loss will need to be added in the PON interface. See Figure 5 for an explanation of where to add attenuation in order to place the entire plant within specification. Note that WDM loss is included in the system loss budget. Also note that Figure 5 covers two cases, with and without an xPON (either EPON or GPON). The 1310 nm wavelength (if used) is handled in different ways with and without xPON.

9. The upstream channel capacity is assumed to be four 6.4 MHz wide DOCSIS channels, as shown in Table 5: AM Upstream R-ONU Input Level and Response Specifications. Table 5 also states the “Nominal RF input level per channel” and the “OMI at total power.” Note that the per-carrier level is 6 dB lower than the total power level. This accounts for the assumption that the system is loaded with four channels. The link loss and performance assumptions are based on four-channel operation. One could design the system for operation with fewer channels, which would result in a higher OMI and CNR for each channel, but less channel capacity for the system. Or, one could design the system for operation with more channels, which would result in a lower OMI and CNR for each channel, but allow for more capacity in the system. The “Nominal channel capacity” and “Nominal RF input level per channel” are not mandatory specifications. The “OMI at total power” specification is a normative requirement. However, one must be careful to not deviate too far from the Nominal RF input level per channel specification or the turn-on and turn-off thresholds of the R-ONU may not operate correctly with the actual channel level.

10. The Turn-On and Turn-Off Characteristics specified in Section 7.1.3, “Turn-On and Turn-Off Characteristics” are measured with a CW signal. The actual laser turn-on and turn-off times will be different when the R-ONU is fed actual DOCSIS traffic. When consecutive bursts from different cable modems behind different R-ONUs exist with the minimum guard times allowed in the DOCSIS 3.0 specification, the specifications in Section 7.1.3 allow a second R-ONU to turn on before the first R-ONU is off, thus allowing for the possibility of optical beat interference.

11. The CMTS or other long loop AGC controller will command the upstream RF transmitters in the premise to raise or lower their transmit level until the proper level is achieved at the input to the CMTS or other controller. It is important to align the RFoG upstream network such that the RF level into the R-ONU is at the proper level when the input to the CMTS or other controller is also at the proper level.

    For AM systems, it is recommended that the alignment be conducted on an R-ONU with high optical loss between it and the upstream receiver because R-ONUs that feed high optical loss budgets will require high RF input levels to compensate. As a result, R-ONUs with lower optical loss budgets will be driven with lower RF levels. If alignment were instead conducted on an R-ONU with a low optical loss budget, the RF input to R-ONUs with a high optical loss budget will have their upstream transmitters driven into clipping. R-ONUs with a high optical loss budget will have lower than average NPR at the nominal RF input level but will be driven by higher than nominal RF levels. R-ONUs with a low optical loss budget will have a higher than average NPR at the nominal RF input level but will be driven by lower than normal RF levels.

    FM systems have a fixed gain from R-ONU input to upstream receiver output regardless of optical link loss and are not subject to the considerations for AM systems mentioned in the previous paragraph.

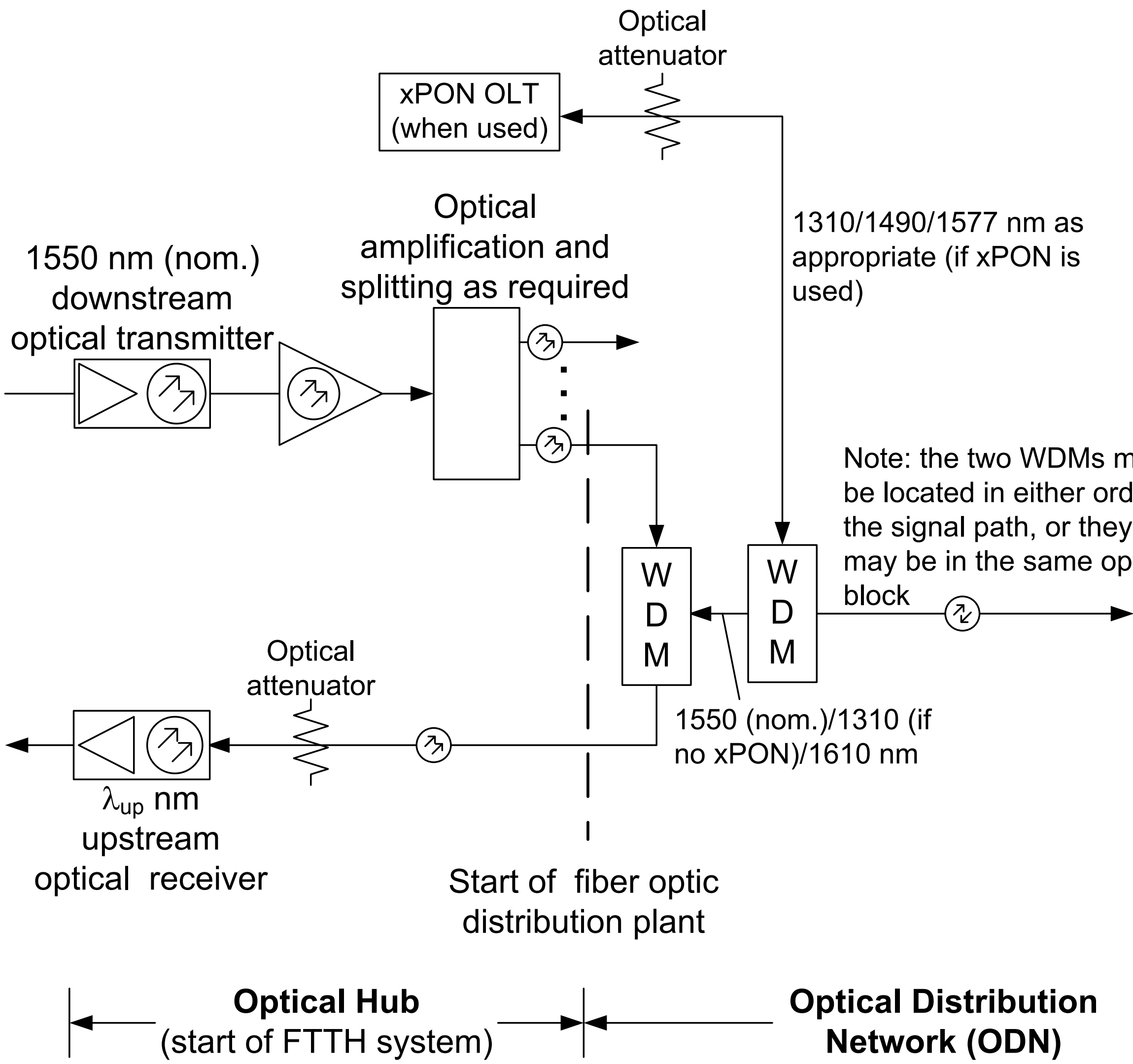

Figure 5: Placement of attenuators when system loss is too low

11.0 APPENDIX A: SYSTEM LOSS SPECIFICATION

The RFoG system must operate with a system loss in either direction of at least 25 dB. Note from Figure 2 that this loss is defined from the input to the WDM that combines the upstream and downstream optical signals, to the input of any R-ONU. The RFoG system may work at higher loss levels. This section is intended to provide guidance concerning the loss that can be tolerated. Both upstream and downstream directions must be considered, as either may be the limiting factor. Besides other considerations, one may want to keep in mind an ultimate conversion or overlay (to coexist with RFoG) to some other form of PON, looking at the loss budgets it will tolerate. One factor to be considered in an overlay would include additional system loss due to added WDM devices (added to or substituted for the original devices) and the potential impact on both the RFoG and PON system.

11.1 Downstream Considerations

In the downstream direction, the maximum loss tolerable is determined by the minimum optical signal needed at the R-ONU, and by the maximum launch signal at the headend. The maximum launch signal is usually set by SBS (Stimulated Brillouin Scattering) limitations in the fiber. When setting optical power into the fiber, it is very important to assure that the optical power meter is properly calibrated and adjusted to measure 1550 nm signals. If the optical power into the fiber is too high, SBS may result. With the current state of the art, the minimum received optical power at the R-ONU that produces a satisfactory carrier-to-noise ratio (C/N) is about -5 dBm for analog channels. Common practice is to operate analog carriers with an optical modulation index (OMI) into the optical transmitter of 3.5% per carrier, and this is assumed. Digital carriers (256-QAM) are by convention operated -6 dB from analog carriers, and when all-digital transmission is used, lower optical levels will usually produce satisfactory results. Thus, the minimum optical input of -5 dBm applies when analog carriers are transmitted, but if all-digital transmission is used, lower levels may be used without violating this standard.

Using conventional HFC optical transmitters, the maximum launch power into a long fiber might be +16 dBm, resulting in a tolerable loss budget of 16 - (-5) = 21 dB, less than required. However, there are several things an operator can do in order to improve the loss budget:

1. Many optical transmitters today employ SBS-mitigating strategies, resulting in higher output power without encountering the SBS threshold. Typically the SBS threshold might be raised by up to 4 dB, just getting to the 25 dB loss budget.
2. Shorter lengths of fiber permit higher launch powers. For example, if the distance from the headend to the splitter is 5 km, then the launch power can be approximately 4 dB higher than the launch power for a 20 km PON. (Note that in calculating the effect on SBS, one need only include the fiber distance to the first split, as power usually will drop enough at that point to not be much of a problem. Also, note that the PON is defined to include the WDM, and typically the WDM is located so close to the transmitter that the launch power contributing to SBS is the optical power after the loss of the WDM. Thus, the power you would use in calculating SBS effects will be 1 dB or so lower than the actual launch power, reduced by the loss in the WDM.)
3. Newer fiber types offer improved SBS limitation, so if you are installing new fiber from the headend, you may want to consider using this fiber in order to improve performance.

Note that at higher optical power levels there may be additional safety regulations which must be observed. Also, there are additional possibilities for damage to connectors and other components. A service provider contemplating operation at higher optical levels must be cognizant of these issues.

Of course, if digital-only transmission is planned over the RFoG network, then the optical power at the R-ONU may be lower, and the above considerations modified accordingly. In this case it may be possible to reduce the optical power by 3-5 dB compared with that needed if analog signals are carried. Such operation does not represent a violation of this standard.

11.2 Upstream Considerations

In the upstream direction, the maximum tolerable loss is determined by the launch power of the R-ONU, the type of modulation of the upstream carriers, the number of upstream carriers, and the sensitivity of the upstream receiver. Note that the tolerable upstream loss budget is different from the calculation of upstream levels from the RF sources in the home. Once the upstream optical loss is set for a particular PON, the expected receive level at the headend must be chosen such that the OMI of the upstream transmitter is "correct," as defined elsewhere in this document.

As an example, consider an upstream minimum launch power of +2 dBm, four 64-QAM signals, and a receiver that can provide 28 dB C/N (the minimum considered acceptable for 64-QAM) at an input level of -23 dBm. This yields a maximum system loss of 25 dB as suggested. There may be some ways to improve the loss, however:

1. Some manufacturers are providing optical receivers with greater sensitivity.
2. If you only plan to operate two upstream carriers rather than four, you might be able to design for 3 dB higher OMI at the R-ONU, improving your loss budget.
3. Some vendors are proposing optical amplifiers that can be strategically placed in the plant.
4. Use of the higher-powered 1610 nm option will permit more system loss.

You may decide to use some combination of these methods to allow for optically combining two upstream PONs, thus saving upstream receivers. But you must allow for a number of possible degrading issues:

1. System loss may turn out to be higher than anticipated after a break that is repaired under adverse conditions. Standard design techniques provide a "repair margin" (at least 1 dB and up to 3 dB) to allow for this. This means that 25 dB available loss would allow the designer 24 dB of day-one loss.

2. There could be up to 1 dB degradation in optical budget due to dispersion issues in the plant.
3. There can be several decibels of variation in OMI at the home, depending on actual losses in the system, receiver output, loss between the receiver and the CMTS, accuracy of the CMTS level setting, etc.

12.0 APPENDIX B: UPSTREAM RECEIVER

This section describes a receiver that, when used, should provide proper operation of the RFoG network for an AM system. Table 9 is set up assuming that one will operate DOCSIS 3.0 modems with four simultaneous upstream carriers from one home, using the highest density modulation formats permitted under the DOCSIS 3.0 specification. This section is for informational purposes only and is not normative.

Table 9: Upstream Receiver Performance (Informative Only)

Specification	Value
Minimum optical input level	-21 dBm
Detector responsivity (1310nm and 1610nm)	≥ 0.8 A/W
Frequency response	±1 dB, 5 to $F_{US\text{-}Max}$ MHz
RF output level (OMI= 17.5%, Popt,in= -21dBm)	≥ 10 dBmV
Equivalent input noise current density[1]	≤ 2.5 pA/√Hz

Note 1: The stated performance represents a typical receiver. To obtain the 25 dB loss budget required inTable 1 with 1.5 dBm and 3.0 dBm transmitters, the receiver sensitivity will need to go as low as -25 dBm. This will require receivers with more gain and less noise. Current technology enables receivers with equivalent input noise current density less than 1.0 pA/√Hz.

13.0 APPENDIX C: FM SPECIFICATION CLARIFICATION

The R-ONU and Upstream Optical Receiver of an FM RFoG System include a frequency modulator and frequency demodulator respectively. Refer to Figure 6 for the following discussion.

13.1 R-ONU

Just as with an AM R-ONU, the upstream RF signals enter the unit from the home coaxial network and are split from the downstream signals with an RF diplexer. These upstream signals are amplified and input to a frequency modulator (point A). With no upstream input, the output of the Modulator is a CW tone at the specified FM Center Frequency. Deviation around this center frequency is at the rate of the amplified upstream RF signals. The amount of deviation is a function of the Frequency Modulator Sensitivity and the amplified upstream RF level. The resulting signal exits the frequency modulator (point B) and amplitude modulates the following laser transmitter at the specified OMI.

13.2 Upstream Optical Receiver

The modulated light from the FM R-ONU travels upstream in the optical network, is split off at the headend/hub with a WDM filter, and is input to the Upstream Optical Receiver (FM) module. The FM RF signal is demodulated from the light with a photodiode, amplified, and input to a frequency demodulator (point C). The demodulator output is the upstream RF signals that were input to the R-ONU at the home (point D).

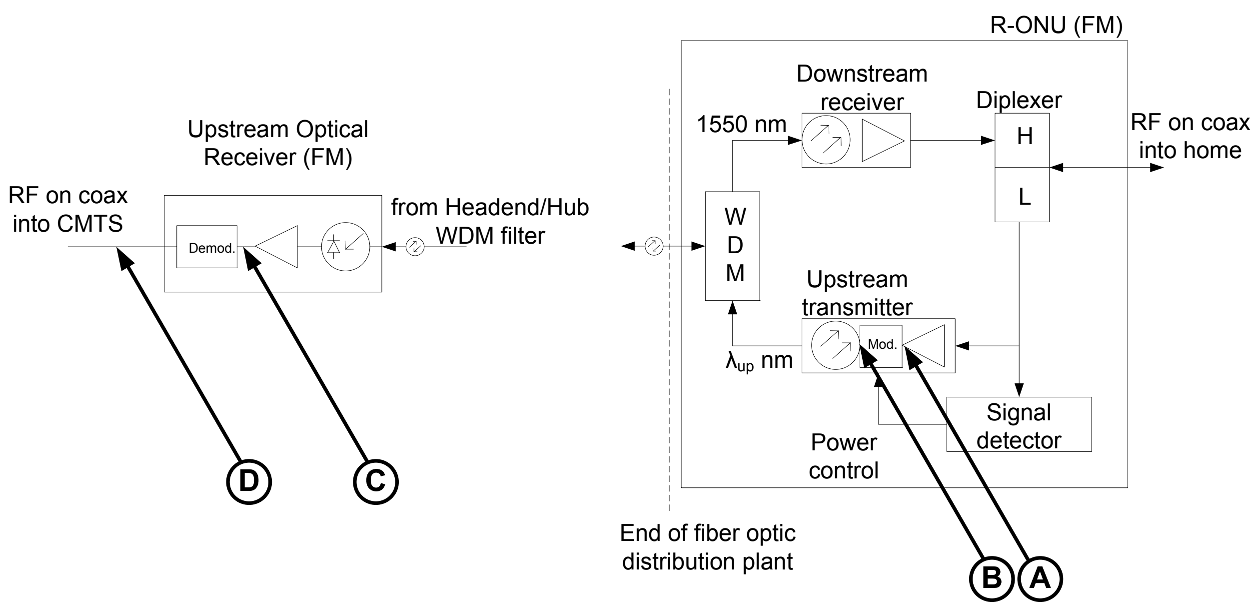

Figure 6: FM RFoG System Signal Diagram

13.3 Frequency Modulator Sensitivity (MHz/V)

A basic understanding of FM theory is required to appreciate this specification. FM signals are typically characterized with a value for modulation index as given in the following equation:

$$\beta = \frac{(k_v \bullet v_{\text{mod}})}{f_{\text{mod}}}$$

where:

$\beta =$ modulation index
$k_v =$ tuning sensitivity
$v_{\text{mod}} =$ modulating signal voltage
$f_{\text{mod}} =$ modulating signal frequency

Specific values of modulation index are easily identified using what is commonly described as “the Bessel Null method.” When viewed with a spectrum analyzer, an FM signal appears to be made up of many tones, with one tone at the FM center frequency. At a modulation index of 2.41, the center frequency tone amplitude is nulled (drastically reduced).

An appropriate example will help clarify the choice of this specification value.

Assume the frequency modulator is designed to have a modulation index of 2.41 at 7.5 MHz with an R-ONU input level of 30.09 dBmV. Viewing the RF spectrum at either point B or C will show an easily recognized null of the center frequency under these conditions. Using the equation above and converting the input level to peak voltage, the tuning sensitivity of the modulator becomes 400 MHz/Volt.

An actual plot of the resulting frequency modulator output signal is shown in Figure 7. This is taken with an R-ONU input noise pedestal from 5-42 MHz at -37 dBmV/Hz. At this nominal input level, the 20 dB bandwidth is +/- 100 MHz.

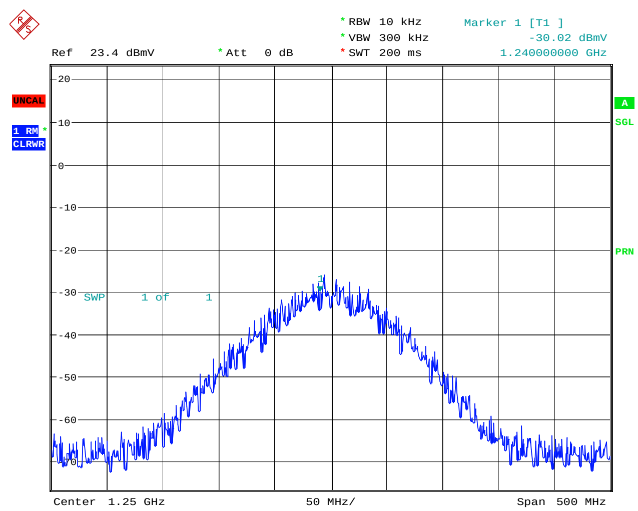

Figure 7: Spectrum analyzer plot of the Frequency Modulator output signal

13.4 Upstream Link Gain (dB) (R-ONU input to Receiver output)

One of the characteristics of an FM system is that the output level of the FM receiver does not depend on the input level. Therefore, loss variations of the optical network are ignored and as a result, the receiver output level is directly related to R-ONU input level. Since the modulator sensitivity is fixed, the demodulator design determines the output level relative to the R-ONU input level, and is expressed as a link gain specification.

13.5 Peak Optical Modulation Index

Sensitivity to non-linearities associated with laser clipping (exceeding 100% OMI, equivalent to 1.0 in decimal form) is minimal due to the information being contained in frequency deviation. As a result, it is possible to operate an FM system above 100% OMI. Measurement is done in a similar manner as with values below 100%, but care must be taken to account for peak values of light relative to the average. Additionally, this measurement is made with no input modulation on the FM carrier.

13.6 Nominal RF input level per channel (upstream RF into R-ONU)

This is the optimal drive level to the upstream transmitter residing within the R-ONU. The actual level out of the cable modem in the home is adjusted by the CMTS such that the required CMTS upstream input is met. Therefore, it is important to know the loss between the R-ONU input and the CMTS input. In an FM implementation, the link gain of the upstream path is fixed (independent of optical loss). Adjustment of the R-ONU upstream input level is done by either changing the RF attenuation between the upstream receiver and the CMTS upstream input, or changing the required CMTS input level. The cable modem output level is directly adjusted by the CMTS to compensate for different RF loss values in the home.

For example, see Figure 8. Assume:

CMTS required input level per channel	0 dBmV
RF attenuation between the upstream receiver and CMTS input port	20 dB
Upstream link gain	-10 dB
Home RF attenuation between modem and R-ONU RF port	10 dB
Resulting modem upstream output level per channel	40 dBmV

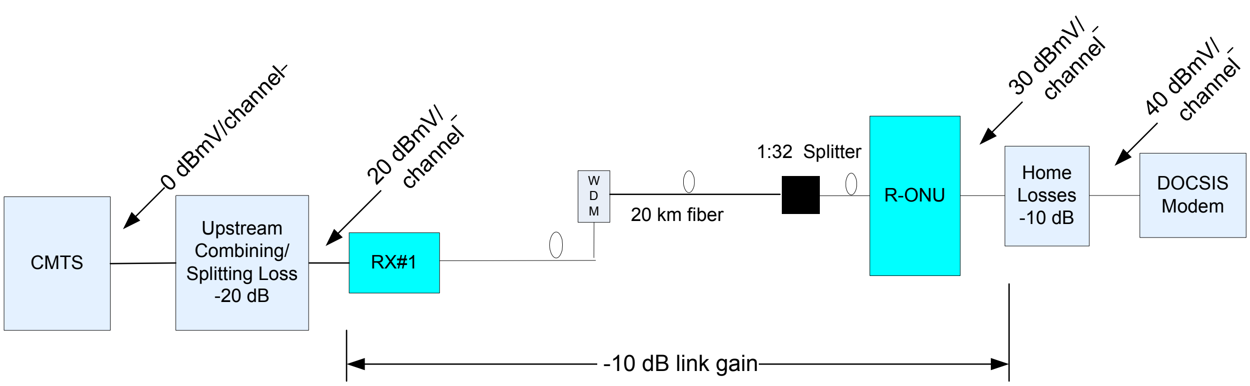

Figure 8: Example of FM system link gain

In an AM implementation, the link gain varies as a function of optical link loss. Adjustment of the Receiver output level must be made to optimize the R-ONU input level for the expected optical loss range. Sufficient dynamic range must be available to accommodate this variability.

13.7 System Noise Power Ratio (NPR)

This is an overall system performance specification. It covers both the R-ONU and Upstream Receiver along with a specified length of fiber and total optical loss budget. In an FM solution, specification of just the R-ONU NPR performance would require an ideal Upstream Receiver containing an FM demodulator which is not readily available.

The level is chosen to support adequate 64QAM performance over the specified dynamic range.