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SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Access networks – Optical line systems for local and access networks

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10 Gigabit-capable passive optical networks (XG(S)-PON): Reach extension

Recommendation ITU-T G.9807.2

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Recommendation ITU-T G.9807.2

10 Gigabit-capable passive optical networks (XG(S)-PON): Reach extension

Summary

Recommendation ITU-T G.9807.2 outlines the architecture and interface parameters for 10 gigabit-capable symmetric passive optical network (XG(S)-PON) systems with extended reach using a physical layer reach extension device, such as a regenerator or optical amplifier in the fibre link between the optical line termination (OLT) and optical network unit (ONU). Wavelength converting, continuous mode, 1:N and combination type reach extenders (REs) are also described. The maximum reach is up to 60 km with loss budgets in excess of 28.5 dB being achievable in both spans.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T G.9807.2	2017-08-13	15	11.1002/1000/13294

Keywords

Reach extender; XG(S)-PON.

* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

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1 Scope

This Recommendation concerns 10 gigabit-capable symmetric passive optical network (XG(S)-PON) systems with optical link budgets up to the logical limits of the transmission convergence (TC) layer. It extends the capabilities of [b-ITU-T G.987.4], limited to asymmetric XG-PON, to XG(S)-PON, including its dual rate working capacity. The increased optical capability, which includes both increased overall fibre length and increased overall splitting ratio, is referred to in this Recommendation as "reach extension". The primary concerns addressed are the increase of the loss budget and the management of optical impairments.

This Recommendation considers mid-span extension, which uses an active extension node placed in the middle of the optical network. The recommended parameters for the optical distribution network(s) [ODN(s)] involved in this scheme are specified. Single-sided extension is considered as an improvement to the optical line terminal (OLT) interface.

The systems considered here must remain compatible with existing optical network units (ONUs). Furthermore, the approaches should maintain compatibility with existing OLTs to the maximum extent possible. It is recognized that some modification of the OLT equipment may be necessary, but this should be minimized.

Two system architectures are considered: optical amplification and opto-electronic regeneration. These can be viewed as providing reach extension at the physical layer. The key interfaces and functional blocks in each of these architectures are identified and specified.

Optionally, optical-electronic-optical (OEO) type reach extender (RE) units may support a burst mode (BM) to continuous mode (CM) conversion function, as specified in clause 6.2. In this case, it is also necessary to introduce a CM to BM conversion function before the S/R interface at the OLT.

Optionally, both optical amplifier (OA) and OEO type RE units may support the wavelength conversion (WC) function, as specified in clause 6.4. In case of WC-enabled RE units, it is also necessary to introduce a WC-function block before the S/R interface.

Optionally, combination RE units may support all the functions described in this Recommendation, and the G-PON RE functions described in [ITU-T G.984.6].

The optional support of a type B protection in RE units is described.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T G.652] Recommendation ITU-T G.652 (2016), *Characteristics of a single-mode optical fibre and cable*.

[ITU-T G.984.5] Recommendation ITU-T G.984.5 (2014), *Gigabit-capable passive optical networks (G-PON): Enhancement band*.

[ITU-T G.984.6]	Recommendation ITU-T G.984.6 (2008), *Gigabit-capable passive optical networks (GPON): Reach extension*.
[ITU-T G.987.2]	Recommendation ITU-T G.987.2 (2016), *10 Gigabit-capable passive optical networks (XG-PON): Physical media dependent (PMD) layer specification*.
[ITU-T G.987.3]	Recommendation ITU-T G.987.3 (2014), *10 Gigabit-capable passive optical networks (XG-PON): Transmission convergence (TC) layer specification*.
[ITU-T G.988]	Recommendation ITU-T G.988 (2012), *ONU management and control interface (OMCI) specification*.
[ITU-T G.694.1]	Recommendation ITU-T G.694.1 (2012), *Spectral grids for WDM applications: DWDM frequency grid*.
[ITU-T G.694.2]	Recommendation ITU-T G.694.2 (2003), *Spectral grids for WDM applications: CWDM wavelength grid*.
[ITU-T G.9807.1]	Recommendation ITU-T G.9807.1 (2016), *10-Gigabit-capable symmetric passive optical network (XGS-PON).*
[ITU-T L.313]	Recommendation ITU-T L.313/L.66 (2007), *Optical fibre cable maintenance criteria for in-service fibre testing in access networks*.

3 Definitions

See clause 3 of [ITU-T G.9807.1].

4 Abbreviations and acronyms

See clause 4 of [ITU-T G.9807.1] in addition to the following.

2R	Re-amplification, Reshaping
AOWC	All-Optical Wavelength Converter
ASE	Amplified Spontaneous Emission
BM	Burst Mode
CM	Continuous Mode
EONU	Embedded Optical Network Unit
LC	Local Controller
MCR	Mode-Coupling Receiver
OA	Optical Amplifier
OBF	Optical Bandpass Filter
OEO	Optical-Electronic-Optical
SOA	Semiconductor Optical Amplifier
WC	Wavelength Conversion
WLCH	Wavelength Channel
XGM	cross-Gain Modulation
XGS-PON	10-Gigabit-capable Symmetric Passive Optical Network
XG(S)-PON	10 Gigabit-capable (Symmetric) Passive Optical Network

5 Conventions

See clause 5 of [ITU-T G.9807.1].

6 Optical extension schemes and architectures

The basic PON architecture is shown in Figure 1. The OLT interfaces with multiple ONUs via the ODN. The OLT also provides interfaces to one or more service node interfaces (SNIs), as well as the management system. The ONU interfaces with various UNIs. The only interfaces of interest to this Recommendation are those that face the ODN. The XGS-PON physical medium dependent (PMD) specification (see Annex B of [ITU-T G.9807.1]) specifies the loss profile for the ODN to be 14~9 dB, 16~31 dB, 18~33 dB or 20~35 dB. The OLT-ODN and ONU-ODN interfaces for XGS-PON are specified in Annex B of [ITU-T G.9807.1]. Indeed, most ITU-compliant PONs deployed today adhere to these Recommendations.

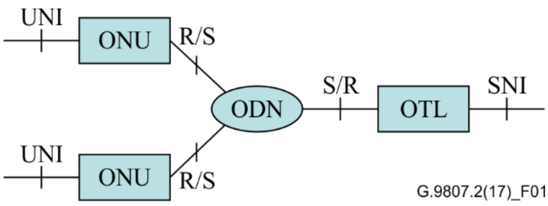


Figure 1 – Basic PON architecture

The architecture considered in this Recommendation is illustrated in Figure 2. A mid-span extender device is inserted between the ODN (compliant with existing PON Recommendations) and an optical trunk line (OTL), which is connected to the OLT. This architecture extends the reach of the PON by the length of the OTL, and may also increase the split ratio of the PON. However, it does require electrical power for the mid-span extender.

Since XG(S)-PON from the start enables the co-working of XG-PON and XGS-PON ONUs, dual rate operation for the upstream is mandatory.

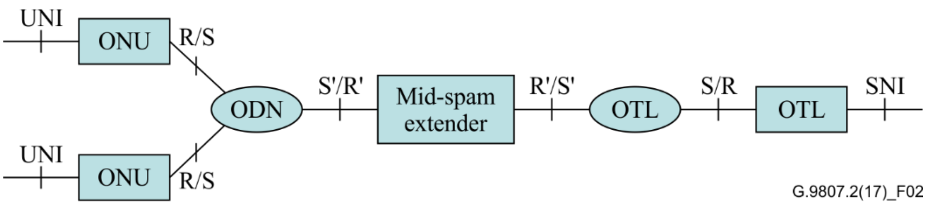


Figure 2 – Mid-span reach extension

An extended architecture considered in this Recommendation is presented in Figure 3. A WC-enabled RE-unit is inserted between the ODN (compliant with existing PON recommendations) and an optical trunk line (OTL), which is connected to the OLT. This architecture extends the reach of the PON by the length of the OTL, and may also increase the split ratio of the PON. Additionally, the WC-RE unit may aggregate several XGS-PON-class ODNs, enabled by the WDM over OTL to achieve more cost-efficient use of existing fibre infrastructure. The WC function block inserted before the S/R interface at the OLT performs adaptation between the WDM optical signals transmitted over the OTL and the OLT interfaces that are compliant with ITU-T G.9807-series Recommendations.

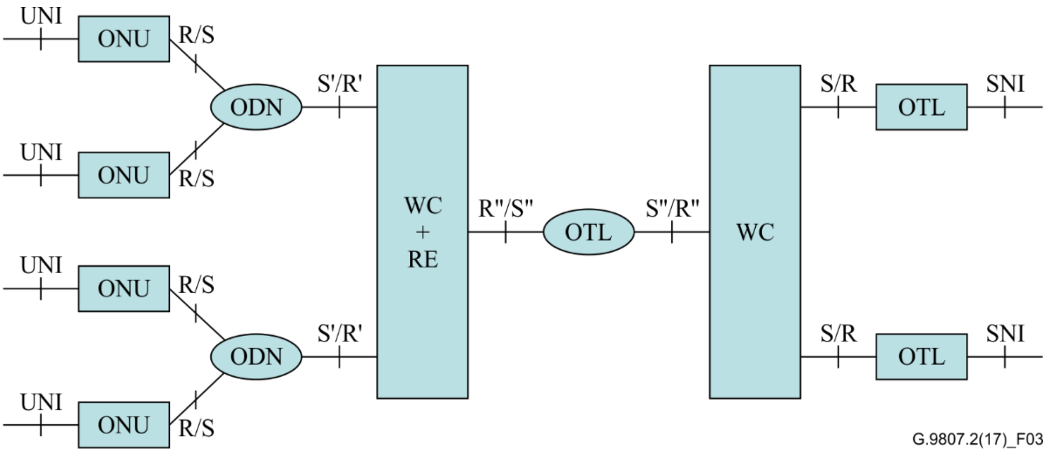


Figure 3 – Wavelength conversion reach extender architecture

An additional extended architecture considered in this architecture is shown in Figure 4. "BM-to-CM" means burst mode to continuous mode converter, and *vice versa*. A BM-to-CM converter is used at the remote PON RE to convert the bursty upstream signal into a conventional continuous mode signal. A CM-to-BM converter is theoretically present at the OLT location, although it will most likely be integrated into the OLT itself.

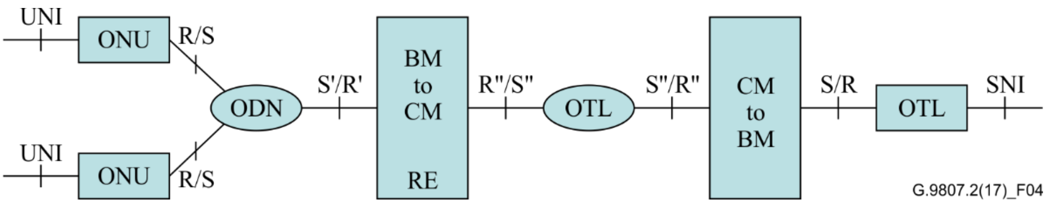


Figure 4 – BM-to-CM conversion reach extender architecture

An additional aspect of XG(S)-PON systems is their coexistence with the ITU-T G.984-series G-PON systems. The RE function can be combined to support both systems simultaneously, as shown in Figure 5. The "combo" RE fulfils the roles of both an ITU-T G.984.6 RE and an RE compliant with this Recommendation.

Furthermore, since XG(S)-PON systems can optionally also operate at the wavelength of G-PON that is defined under the name of "optional wavelength set", the combo REs would see 10 Gbit/s working on both wavelength pairs.

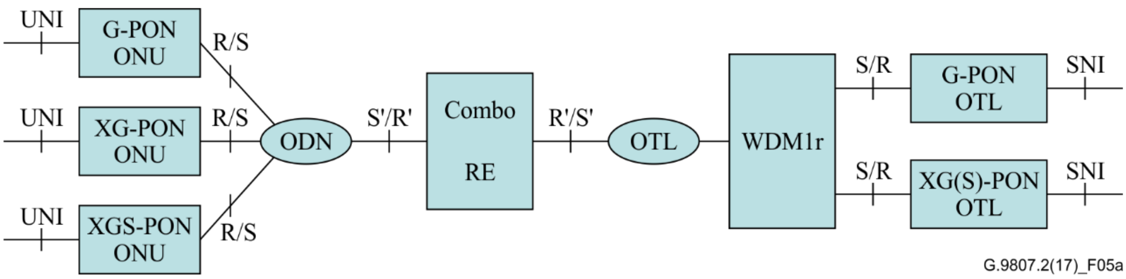


Figure 5(a) – Combination G-PON/XG(S)-PON reach extender

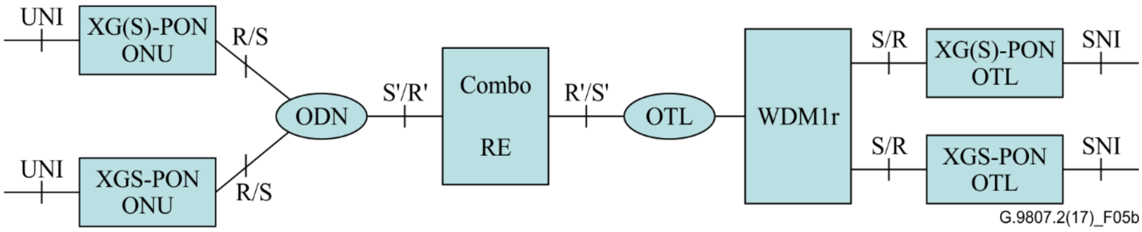


Figure 5(b) – Combination XG(S)-PON/XGS-PON reach extender

NOTE – In Figure 5(b), the combination of the XG(S)-PON and XGS-PON devices is enabled by the use of XGS-PON devices at the optional wavelength set in addition to XG(S)-PON devices operating at the basic wavelength set.

REs can also incorporate additional fanout within the RE, as shown in Figure 6. In this case, the RE has multiple S'/R' interfaces that are combined with the usual PON logical connectivity (downstream broadcast, upstream combining) to a single R'/S' interface. However, it is not the same as placing a splitter next to the RE, as the loss budget constraints would prevent this. A couple of physical methods to achieve this are described in clause 6.7. The motivation for such a scheme is to increase the sharing of the OLT port, OTL fibre and RE R'/S' interface over more ODNs. This can be particularly useful in the XG(S)-PON overlay application.

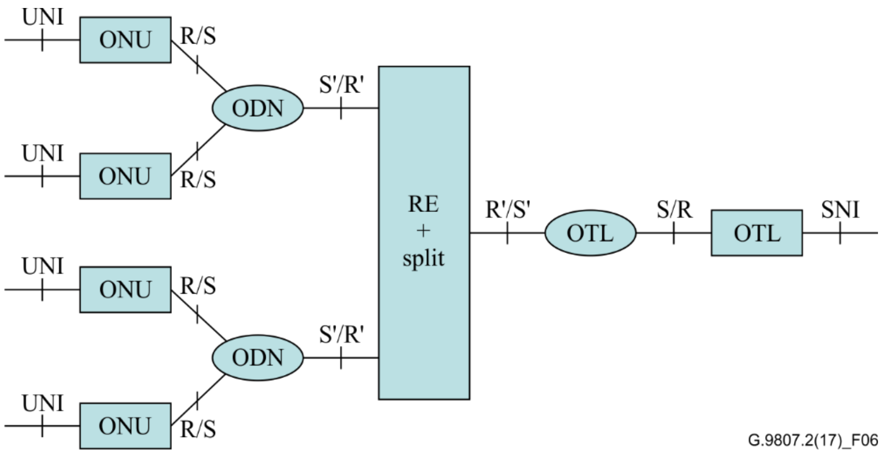


Figure 6 – Reach extender with additional fanout in the RE

The topology of REs is to allow point-to-multipoint connectivity between the RE and the OLT, as shown in Figure 7. In this case, the split optical trunk line (S-OTL) contains some passive that combines the output of several R'/S' interfaces into a single S/R interface to the OLT. The motivation here is similar to the previous case: to increase the sharing of the OLT interface. This method also allows for physically diverse placement of the subtending RE units. However, it does not increase the sharing of the RE R'/S' interfaces, and it then requires that the R'/S' interfaces must be able to operate in burst mode.

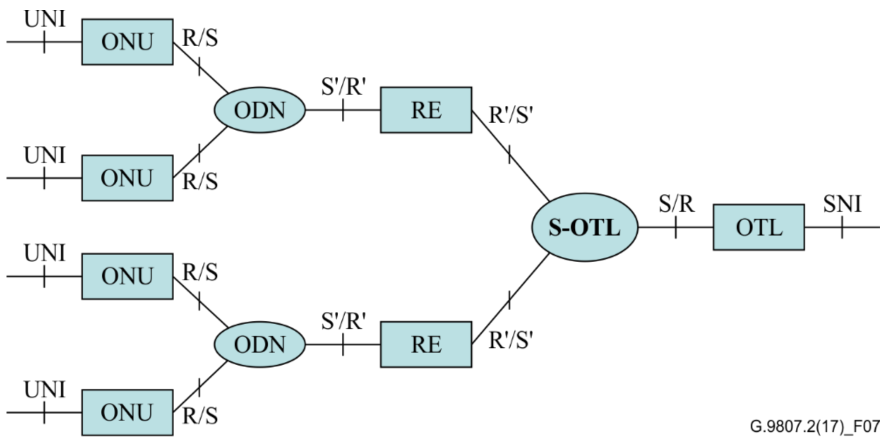


Figure 7 – Reach extender with a split optical trunk line

There are several ways to implement an optical RE. There are two general classes of extenders. The first is an optical amplifier (OA), shown in Figure 8a), which provides gain in optical power. The second is an OEO regenerator [Figure 8b)], which receives an optical signal, reshapes and retimes it in the electrical domain, and retransmits in the optical domain. Further hybrid schemes are possible, for example, to use optical amplification in the downstream and regeneration in the upstream, as shown in Figure 9a) or the reverse as shown in Figure 9b).

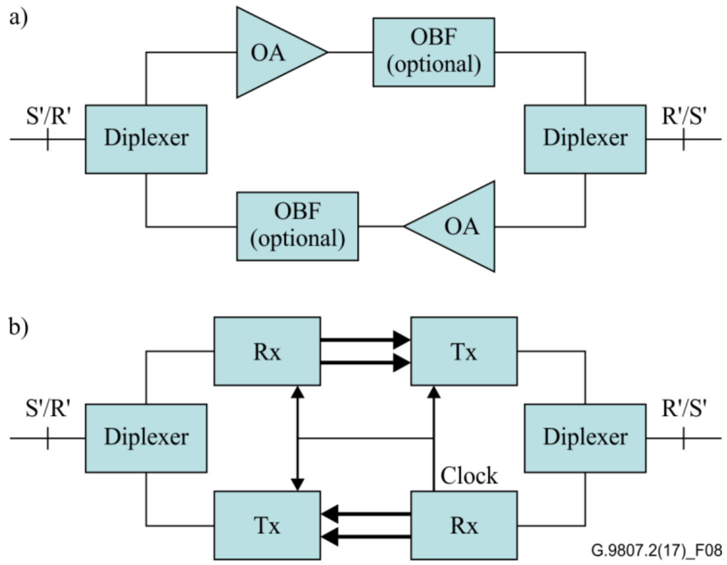


Figure 8 – The two basic extender architectures: Optical amplifier, repeater

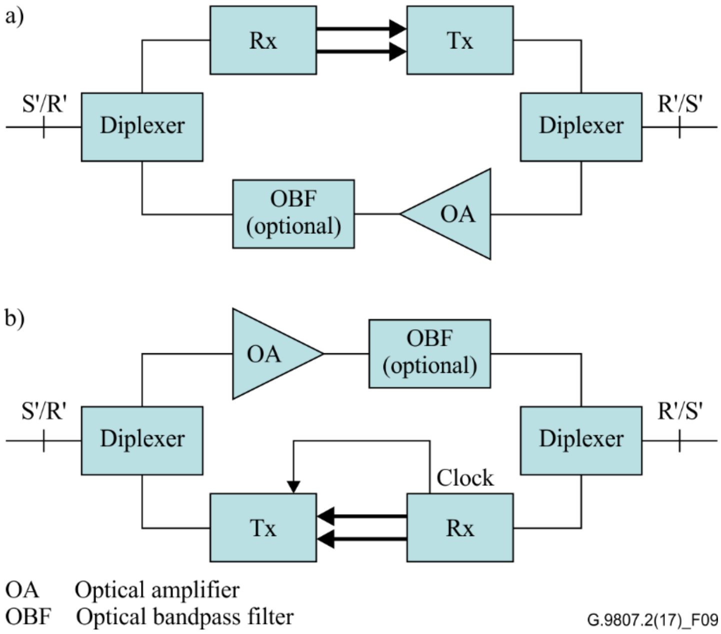


Figure 9 – Examples for hybrid extender architectures

6.1 OA-based reach extenders

REs based on optical amplifiers optionally may include optical bandpass filters (OBFs) in order to restrict the bandwidth of amplified spontaneous emission (ASE) generated by the optical amplifier, and thus reduce ASE-ASE beat noise and ASE-based power-offset (see Appendix I) in the optical receiver and achieve higher performance.

Due to the nature of OA-based REs, the application range (useable trunk and ODN loss range) varies according to the parameters of the optical amplifiers used. The vendor has to provide sufficient data showing the key parameters (e.g., maximum gain, minimum gain, and saturated output power), the application range and applicable penalties due to ASE.

As there is no signal regeneration provided by OA-based REs, ONU and OLT transmitters must provide a dispersion reach of up to 60 km.

An optical amplifier-based extender should include a complete embedded ONU (EONU) for management purposes, as shown in Figure 10. The EONU is connected internally by means of an optical tap coupler at the interface facing the OTL in order to keep the RE accessible, even if an optical amplifier fails.

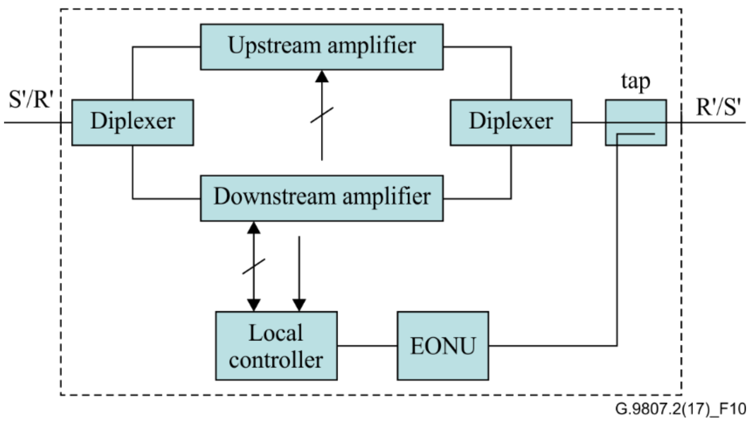


Figure 10 – OA-type reach extender with embedded ONU for management purposes

6.2 OEO-based reach extenders

The signals passing through the OEO extender are re-timed (2R regenerators are not specified by this Recommendation). The timing reference for this function is the downstream receiver of the extender (see Figure 11). This timing is used to drive both transmitters and as a reference for the other receiver. This arrangement is identical to that used in SDH regenerator devices.

The presence of an OEO-based extender may require extension of burst overhead, which is automatically handled by the OLT via physical layer operations, administration and maintenance (PLOAM) messages (refer to clause 8.5). As the increase of burst overhead is bandwidth relevant, upstream burst detection is supported by the aid of an EONU (see Figure 11) which is used for management (see clause 7.2). In addition to the managing functions, the EONU may analyse the downstream signal and read the BW map in order to calculate burst-timing. In this way, a reset signal to the upstream burst-mode receiver can be provided and the required burst overhead extension is kept to a minimum.

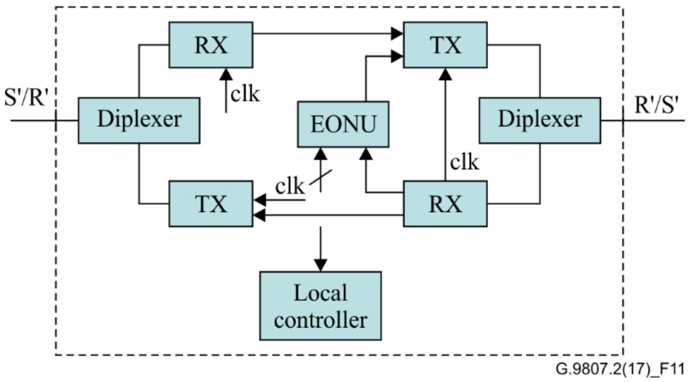


Figure 11 – OEO-type reach extender with EONU for management purposes

OEO-based REs should be enhanced to support dual rate operation. In the upstream, the RX near the S'/R' reference point should be capable of receiving both 2.5G and 10G burst signals. The TX near the R'/S' reference point should be capable of transmitting both 2.5G and 10G signals. When the recoding scheme of Appendix IV is employed in the RE, the TX near the R'/S' reference point should conduct such signal recoding and transmit 10G signals in continuous mode to the OLT.

The continuous mode OEO RE is a subtype of OEO RE. The S'/R' interface of CM OEO RE is the same as that of the OEO RE. In the CM RE, a BM-to-CM converter is used to convert the burst signal to a continuous signal. The downstream signal (denoted CMXGSPON_D) has a bit rate of 9.953 28 Gbit/s, and a frequency accuracy of 32 ppm in the worst case (where the OLT is in free running mode). The upstream signal (denoted CMXGSPON_U) has a bit rate of 9.953 28 Gbit/s or 2.488 32 Gbit/s (for XGS-PON and XG-PON, respectively), and a frequency accuracy of 32 ppm in the worst case (where the OLT is in free running mode). It must be noted, however, that the upstream signal is always synchronous with the downstream signal.

The CMXGSPON_U signal is composed of the regenerated upstream bursts and some stuffing signal inserted between the bursts. The stuffing signal is a bit pattern that is well balanced in order to avoid long CID. This continuous signal is transmitted by the R"/S" interface. The stuffing bit pattern is configured at both the transmitter and receiver. The means that such a configuration is for further study. The pattern is somewhat arbitrary; however, it does need to satisfy a few basic requirements to avoid impacting the physical layer: it should have approximately a 1:1 mark to space ratio, and it should have approximately a 50% transition density. The OEO RE regenerates the received data from ONUs, and therefore does not unscramble the data from the ONUs.

The upstream frame is depicted in Figure 12. It is important to note that the incoming upstream bursts each have a unique and independent bit clock phase. At its output, the BM-to-CM converter produces a signal that has a single continuous bit clock phase. Therefore, the BM-to-CM converter must buffer each incoming burst of data and re-time it with its output clock.

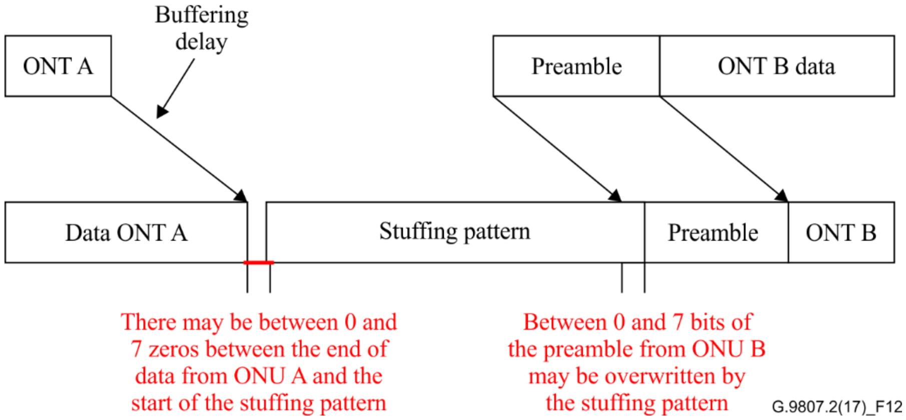


Figure 12 – Frame of the upstream CMXGSPON_U signal

Specific techniques for implementing BM-to-CM are beyond the scope of this Recommendation; however, there are a couple of basic methods for detecting the gaps between bursts. The following paragraphs provide some informative discussion of these methods.

Detecting the gap at the optical layer (fibre to PHY interface). On the OEO RE, the optical power is detected, and a control signal thatcan be used to control the insertion is generated accordingly.

Detecting the gap at the logical layer (PHY to TC interface). There are some regular patterns (typically the all zeroes pattern) in the burst gaps that can be detected and used to generate the control signal. Upon the completion of data synchronization, the receiver accepts the burst data while at the same time it is searching for the end of the burst. When it detects the burst termination by finding the expected pattern, it can reset the burst receiver. Detecting the beginning of bursts requires 32 bit pattern @2.48832 Gbit/s matching, except for cases where the receiver produces random data between bursts, in which case 96 bit patterns are required for a reliable result. Also, 96 bit pattern @2.48832 Gbit/s matching is required to detect the end of bursts for a reliable result (as the user's payload data is substantially random). These numbers of digits required are based on statistical calculations of the probability of missing a burst event or creating a false burst event. Shorter or longer pattern matching is possible, with the concomitant change in error probability.

The gap detector will require a logical buffer to store the upstream data to compensate for the nonzero response time of the gap detector, so as to avoid long gaps of all-zero data. However, the stuffing pattern is typically byte oriented, while the aligned bursts can be at any arbitrary bit timing. Therefore, in this case an integral number of 0 to 7 bits of zeroes should be expected at the end of each burst, and the last byte of the stuffing pattern will overwrite an integral number of 0 to 7 bits of the following burst's preamble.

The CM-to-BM converter can find the boundaries of the bursts using the logical layer detection method. Importantly, the pattern between the bursts is known to be filled with the stuffing pattern, and so the detection algorithm can be quite simple and should require only 32 bits of pattern matching to detect the start of burst, and 96 bits to detect the end of burst. The comment previously made on lengths of bit pattern matching applies here as well.

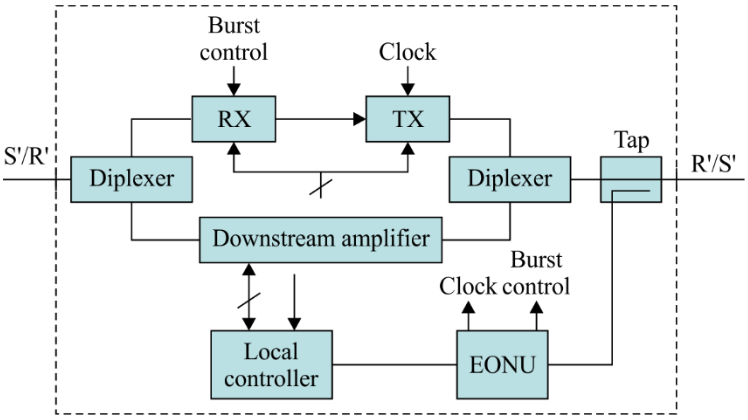
As with the ordinary OEO RE, the RE system clock is driven by the downstream signal, and the upstream signal from the ONUs is locked synchronously to the downstream signal that the RE sends to them. The frequency, jitter, and jitter tolerances of the OLT and ONU equipment are given in Annex B of [ITU-T G.9807.1].

The converted CM signal can optionally be transported over an OTN path. See Appendix IV for more information.

6.3 Hybrid architectures

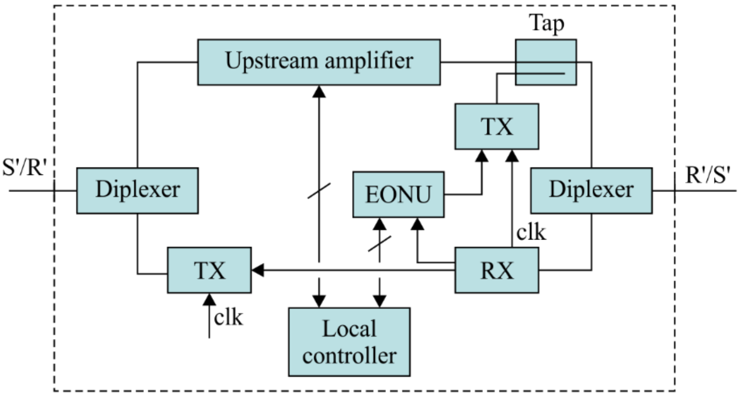
A hybrid architecture using an optical amplifier for the downstream requires a clock reference for the upstream burst-mode receiver and transmitter. This has to be provided by an EONU used for management (refer to clause 7.2). Possible hybrid extender architectures are shown in Figure 13.

a)

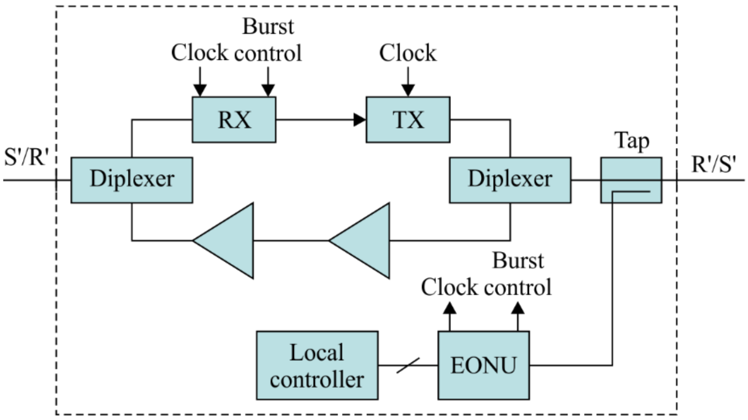


The RE upstream RX and TX should be enhanced as the same way in Clause 6.2 (OEO-based RE) to support upstream dual rate in XG(S)-PON.

b)



c)



The RE upstream RX and TX should be enhanced as the same way in Clause 6.2 (OEO-based RE) to support upstream dual rate in XG(S)-PON.

d)

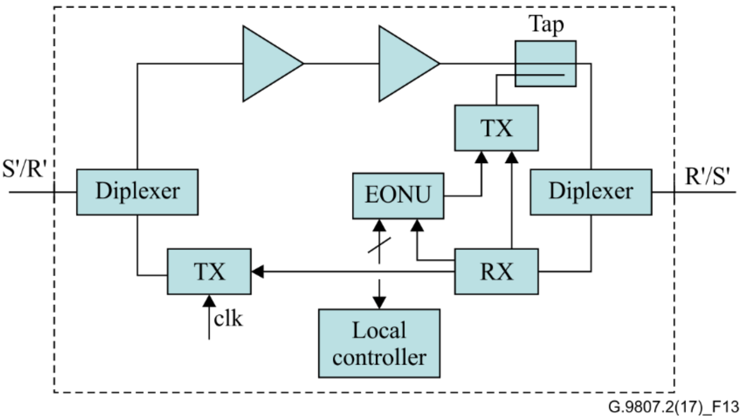


Figure 13 – Possible architectures for hybrid reach extenders

6.4 Wavelength conversion reach extenders

A WC-RE unit has the capability of performing the WC function in the upstream and downstream channel. The functional architecture of a WC-RE unit is presented in Figure 14. The WC function in the upstream channel converts λ_U to λ_{U_OTL} and the WC function in the downstream channel, converts λ_{D_OTL} to λ_D. The RE function could either be the OA or OEO type reach extension function as described in clauses 6.1 to 6.3.

The functional blocks in Figure 14 only represent logical functions, rather than a specific physical implementation. The functional blocks in Figure 14 can be implemented in a variety of ways; as a separate physical element, component, or subassembly performing the desired functions, including implementations whereby WC function may be implemented as an integral part of the existing elements of the RE unit, as discussed in Appendix V.

There are several optional elements in this architecture.

- In some implementations, the local controller (LC), used optionally in remotely managed RE units, may additionally need to control the WC function implementation, selecting the target transmission wavelength (in the case of WC-enabled OEO-type REs) or controlling the operating point for all optical wavelength converters (in the case of both OA-type and OEO-type REs equipped with WC function). The LC is served by an E-ONU, which in Figure 14 is connected to one of the outputs of the WC-RE. Other methods of connecting the E-ONU to the PON signal paths are possible, as well as providing protection for the management channel.
- One or two fibres can be employed for the OTL.
- In certain implementations of the RE unit, it may be also necessary to guarantee that the clock signal is exchanged between the upstream and downstream channels for proper bit alignment and phase detection.

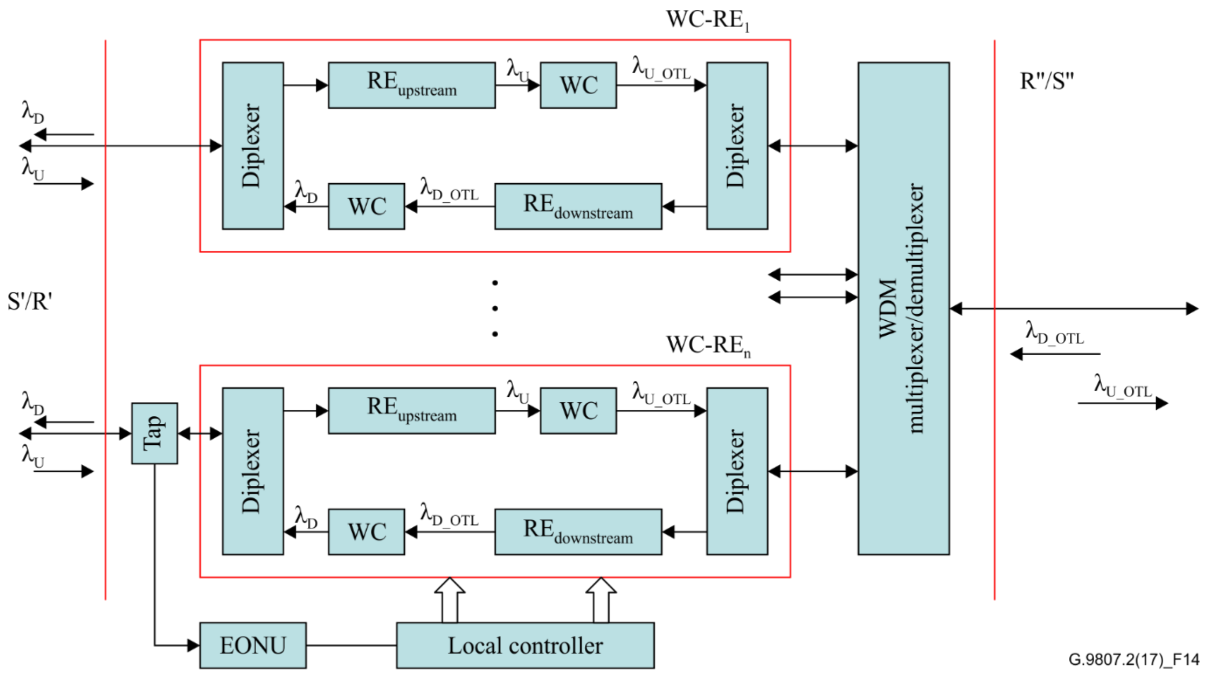


Figure 14 – Internal structure of a WC-RE unit with optional WC function shown for both upstream and downstream channels

6.5 Wavelength re-conversion at OLT

The OLT WC function block is required to ensure that the existing optical interfaces, which are compatible with Annex B of [ITU-T G.9807.1], at the OLT do not need to be redefined.

Figure 15 presents the functional architecture of the WC-OLT unit, with optional WC function implementation for both downstream and upstream channels. An optional management function based on an E-ONU function is also presented; however, since this equipment is likely to be located in the central office other management mechanisms may be used.

One or two fibres can be employed for the OTL.

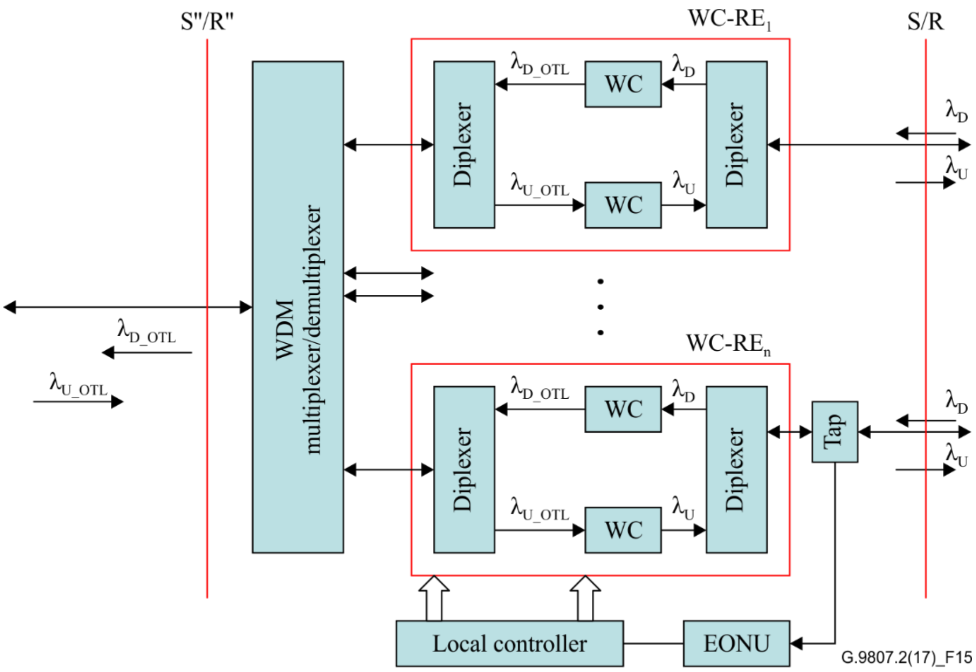


Figure 15 – Internal structure of a WC-OLT unit with optional WC functions shown for both upstream and downstream channels

The functional blocks in Figure 15 only represent logical functions, rather than a specific physical implementation. The functional blocks in Figure 15 can be implemented in a variety of ways as a separate physical element, component or subassembly performing the desired functions, including implementations, whereby WC function may be implemented as an integral part of the existing elements of an OLT unit, as discussed in Appendix V.

The WC function performs conversion of the frequency of the optical signal carried over OTL in downstream and upstream directions, adjusting it to the conditions required at the S/R and S"/R" interfaces. The WC function in an RE unit may also be implemented in a wavelength transparent way in downstream or upstream directions, depending on user requirements.

6.5.1 Operation of the WC function in the downstream channel

Implementation of the WC-OLT function in the downstream channel is optional and depends on the implementation of the WC function in the RE unit.

If the WC-OLT function is implemented, the optical signal received from the OLT at λ_D is converted into λ_{D_OTL}, which is then transmitted towards the WC-enabled RE over the OTL. In practice, that means that the optical signal received at λ_D, compliant with ITU-T G.9807-series Recommendations, can be converted into any wavelength λ_{D_OTL}.

Detailed information about the wavelength transparent WC function is provided in clause 8.6.

λ_{D_OTL} is defined in clause 8.6.

6.5.2 Operation of the WC function in the upstream channel

Implementation of the WC-OLT function in the upstream channel is optional and depends on the implementation of the WC function in the RE unit.

The optical signal received from the OTL at λ_{U_OTL} is converted into λ_U compliant with ITU-T G.9807-series Recommendations and then delivered to the OLT connected to the S/R interface of the WC function. This way, the WC function adapts the optical signal received from the ONU over the OTL into the existing OLT receiver that is compliant with Annex B of [ITU-T G.9807.1].

Detailed information about the wavelength transparent WC function is provided in clause 8.6.

λ_{U_OTL} is defined in clause 8.6.

6.6 Combination G-PON and XG(S)-PON reach extenders

The essential arrangement of a combo RE (plus the optional video overlay extender) is shown in Figure 16. This shows that all the externally observable characteristics of the G-PON extender and XG(S)-PON extender are supported, and are *functionally* separate. The simplest way to arrive at such a function is to implement the two REs separately, and to multiplex them using passive WDM filters specified in [ITU-T G.984.5]. Furthermore, this split enables either G-PON (ITU-T G.984 series) systems or XG(S)-PON systems [ITU-T G.9807.1] to be extended. However, as mentioned later, there are several levels of integration that can have benefits in higher optical performance or lower parts count and cost.

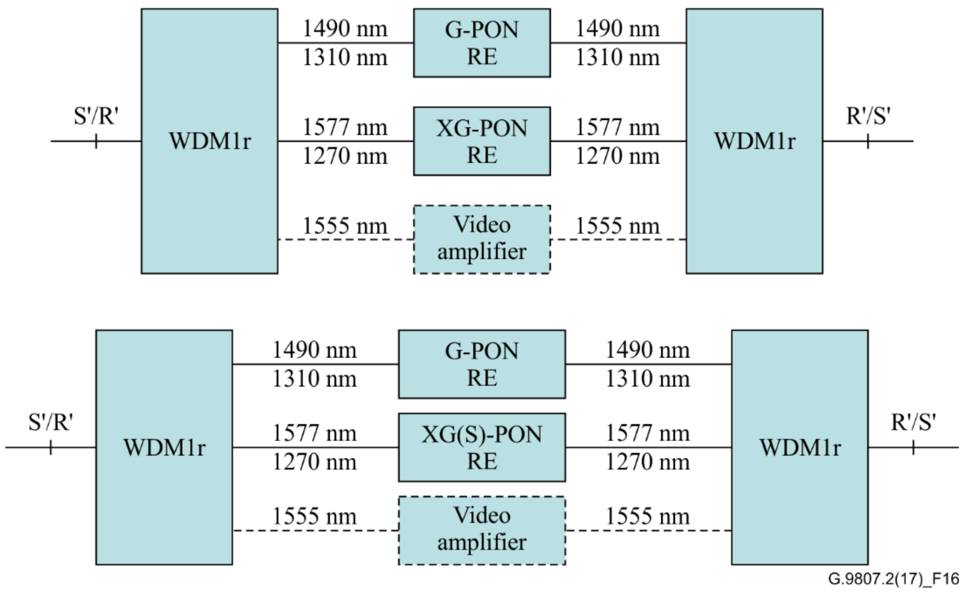


Figure 16 – Functional schematic of a combo reach extender

Figures 17 to 19 illustrate some possible implementations of combo REs that achieve some level of integration between the two RE functions. The first is that the WDM1 filters can be merged with the diplexing filters in the RE units themselves, as shown in Figure 17. This essentially utilizes not only the dual-fibre interface of the WDM1 as described in [ITU-T G.984.5], but also a dual-fibre interface for the G-PON as well.

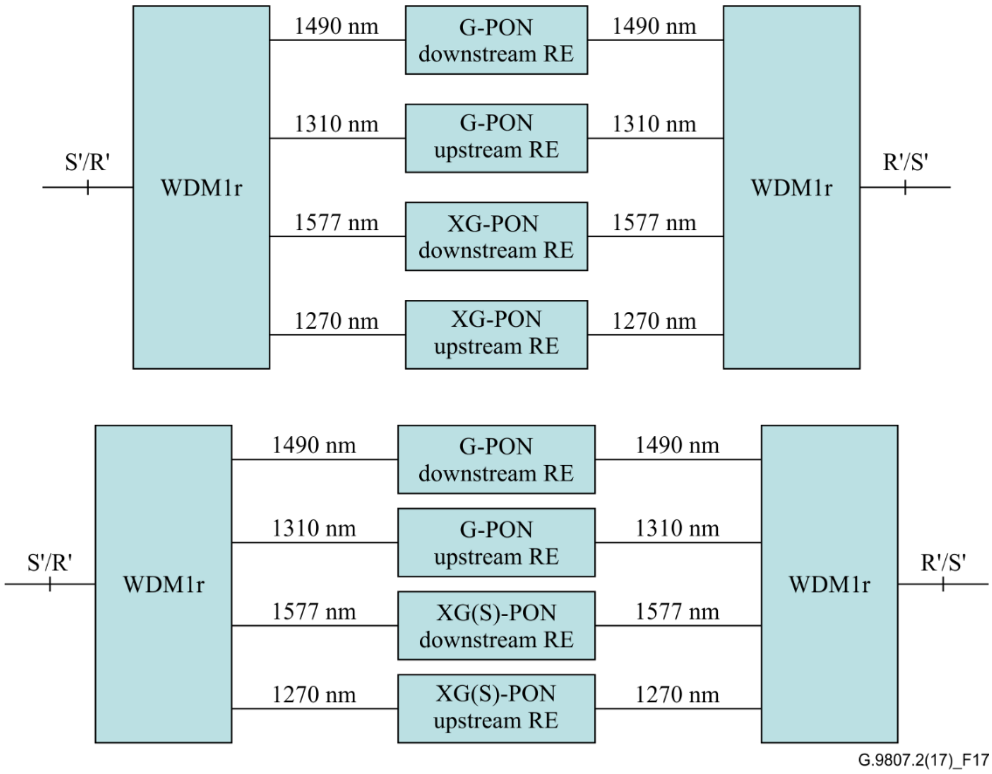


Figure 17 – Merging of the diplexer and WDM1 filter functions

The second is the merging of the downstream or upstream amplifier functions for both G-PON and XG(S)-PON, as shown in Figure 18. This is most possible with the upstream amplifiers, as the wavebands for the two systems are reasonably close together, and semiconductor optical amplifier (SOA) devices can be made with sufficient bandwidth. However, it is theoretically possible to do this with the downstream only, or with both directions (as shown). Note that in this case, the WDM filters and diplexers would likely be replaced or augmented with optical circulator devices.

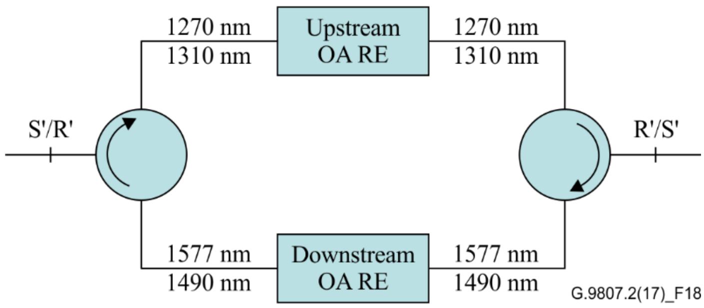


Figure 18 – Merging of the downstream and upstream amplifiers functions in a combo reach extender

The third aspect that can be merged is the common equipment functions of the RE equipment, including the controllers and power conversion or distribution functions. This is most likely in implementations that support multiple RE interfaces in a single unit, as shown in Figure 19. In this case, there is the possibility that the G-PON system and the XGS-PON system could be interconnected so that each could act as a back-up interface for the other. Alternatively, if the two systems are to be segregated, this can also be done, at the cost of additional protection interfaces for either system.

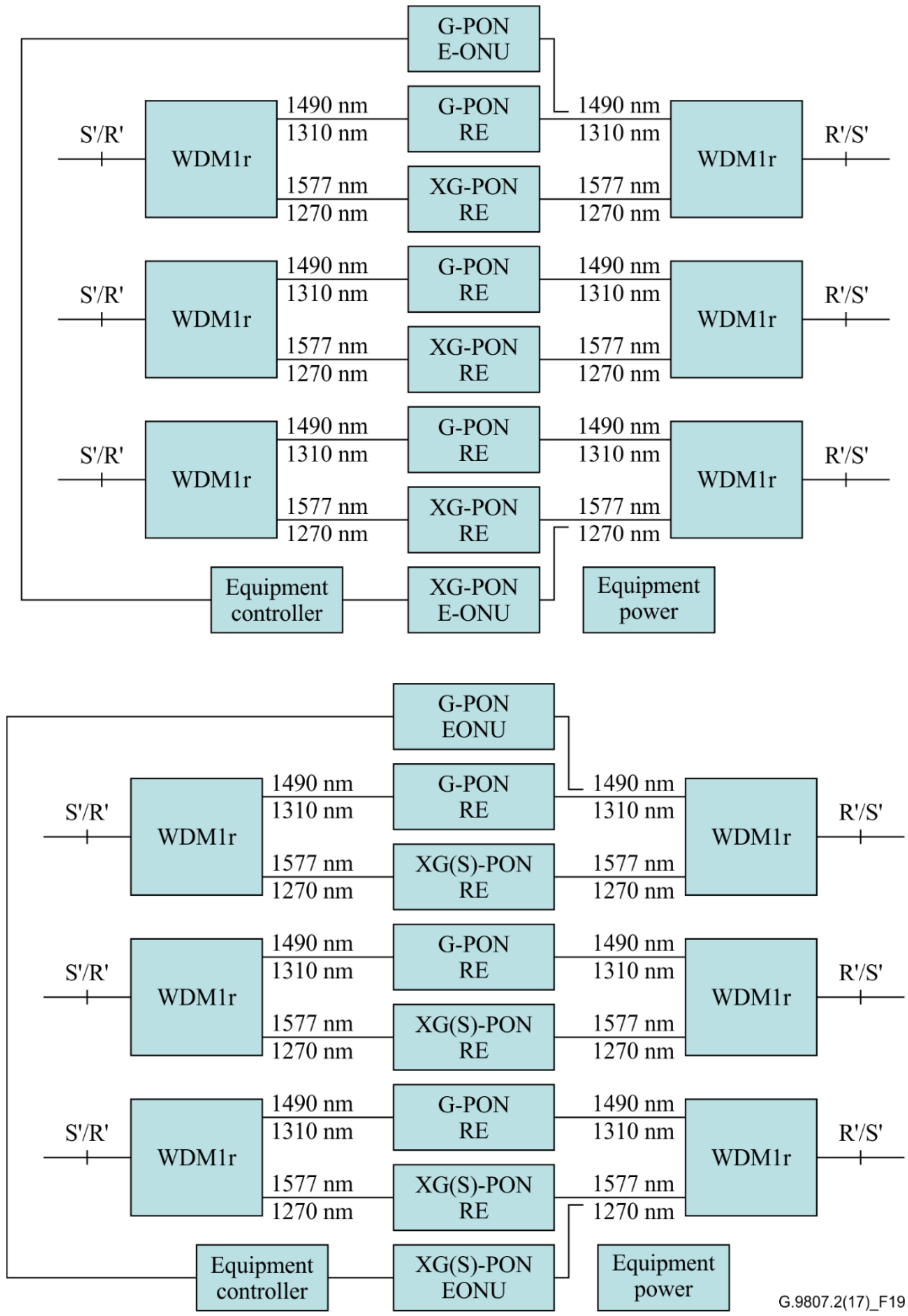


Figure 19 – Merging of the common equipment functions in a combo reach extender

6.7 Increased fanout reach extenders

As explained previously, it is in some ways desirable to increase the fanout of the RE function to improve sharing of the upstream devices. This section outlines two possible methods for achieving this. The first possibility is to employ an optical method, as shown in Figure 20. In the downstream direction, the RE function is implemented with a more powerful transmitter, and this would drive an optical splitter that feeds multiple S'/R' interfaces. In the example shown, this is an OEO-type, but an OA-type RE function is also possible. In the upstream direction, the multiple S'/R' ports are connected to a mode-coupling receiver (MCR) [b-Cheng]. The MCR allows the combination of the multiple single-mode inputs on to a single multimode receiver without intrinsic optical loss. In this way, the sensitivity of the RE S'/R' interface can be maintained.

The second possibility is to employ electrical splitting, as shown in Figure 21. In this case, several S'/R' interfaces are terminated using OLT-like transceivers, and the resulting electrical interfaces are connected to a single ONU-like transceiver. In the downstream, the signal is broadcast, and in the upstream, the signals are electrically combined (added). The downstream-derived clock is also distributed to all the functional blocks. Because the additional splitting and combining occur in the electrical domain after amplification has already taken place, the sensitivity of the S'/R' interfaces can be maintained.

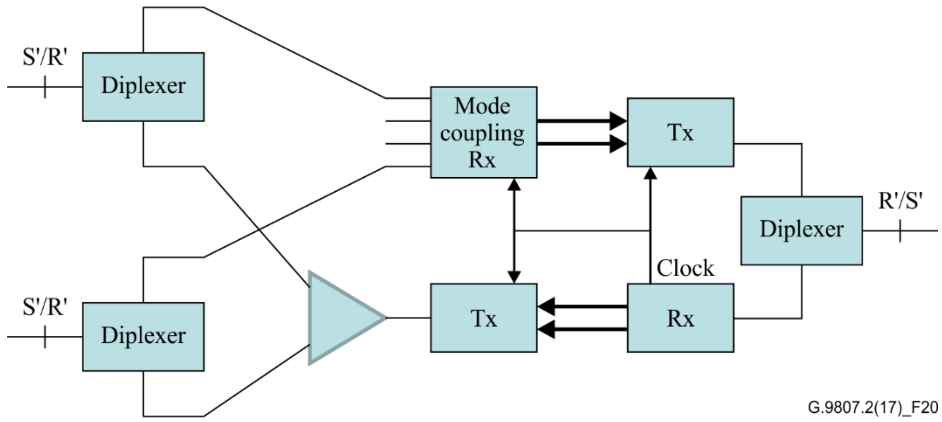


Figure 20 – RE fanout increased using mode-coupling receiver technology

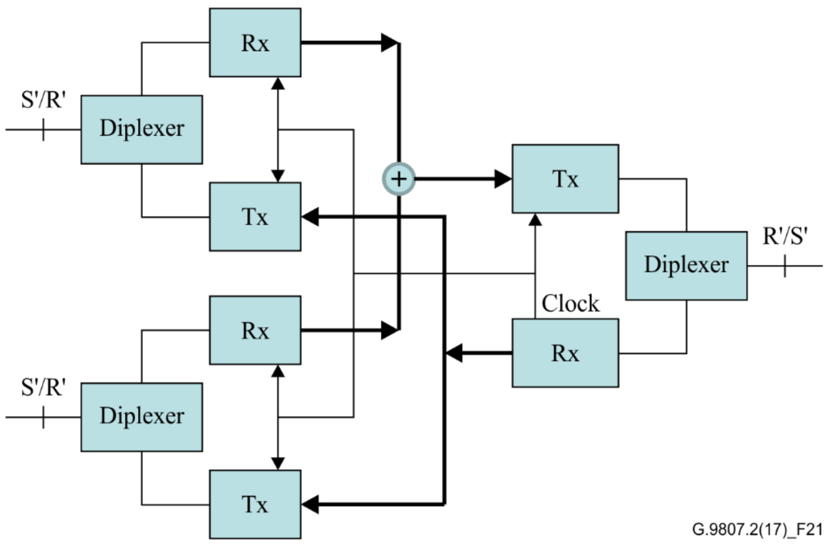


Figure 21 – RE fanout increased using electrical splitting technology

7 General requirements for XG(S)-PON reach extenders

7.1 Compatibility

The RE must be compatible with existing XGS-PON 9.953 28/9.953 28 Gbit/s ONU or XG-PON 9.953 28/2.388 32 Gbit/s ONU equipment and class N1 or N2 ODN. It is possible for the extender to support a more capable ODN, such as the class E1 or E2 defined in [ITU-T G.987.2].

The RE (and, if applicable, its associated wavelength converter or CM-to-BM converter located at the OLT) should be compatible with the existing OLT equipment to the maximum extent possible. There are physical factors that might make it difficult to support complete backward compatibility with the OLT, so some modification of the OLT may be necessary. However, it is envisaged that these modifications will be limited to parameter adjustments of the PMD and TC layers, and will not require wholesale hardware replacements.

7.2 Management

The RE must support full management of its configuration, performance monitoring and fault reporting. The scope of parameters under management depends on the extender type, and it may be that some of the OLT interface management features may not be supported in the extender.

The management of the extender should be provided using the OLT as a proxy. That is, the extender is considered to be an extension of the OLT network element, and no additional interface to the operator's management network will be provided.

For the mid-span extender, the simplest way to accommodate these requirements is to furnish the extender equipment with the functions of an EONU to the extent that a PLOAM and an ONU management and control interface (OMCI) channel can be established between the extender and the OLT. The attributes that are specific to extenders are described in [ITU-T G.988].

7.2.1 Provisioning and operation of reach extenders managed through EONU

The OLT CT will automatically discover the presence of EONU managed RE and take all necessary measures depending on the device performance, to enable a simple and hitless operation experience.

In the serial number field, the four most significant bits (MSBs) are the American Standard Code for Information Interchange- (ASCII-) coded alphanumeric label of the vendor, which only uses code points from 65 to 90, both in [ITU-T G.987.3] and [ITU-T G.9807.1]. This means that the leading bit of each byte is left unused so far.

Therefore in order to enable unambiguous identification of an EONU, the vendor identifier (ID) of the EONU should be the ordinary vendor ID plus 0x80 00 00 00.

7.2.2 Means to discover the ONU to RE-CT mapping

Several solutions to discover the ONU to RE-CT mapping have been identified. In order to cause no breach to interoperability, only one will be retained.

To cause as little disruption as possible, solutions rely on the basic principle of the OLT issuing a simultaneous specific bandwidth map to the ONU in parallel with a command for the RE to monitor what is going on, on its RE-CT detecting an upstream signal or a specific power level to be retrieved through OMCI messaging.

The details are for further study.

7.2.3 Reach extender-specific PLOAM messages

In the presence of REs, for field operations, in addition to the OC structure containing information valid on the OTL section of the PON, updates are needed to be able to retrieve accurate transmit optical level (TOL) information, corresponding to each ODN on each RE port.

Once this ONU mapping has been found according to the method defined in clause 7.2.2, since REs do not have the ability to change the frame-contained information, it must be periodically sent by the OLT through a clear broadcast PLOAM message for easy retrieval by an analyser used by field engineers, in order to pick up the TOL value corresponding to the actual path under test among those of the full list of RE-CTs.

Therefore the following PLOAM messages have been defined:

PLOAM message corresponding to message type ID 0xF0 in Table C.11.2 of [ITU-T G.9807.1]:

Octet	Content	Description
1-2	ONU-ID	0x03FF, Exclusively Broadcast.
3	Message type ID	0xF0, "ONU to RE Mapping".
4	SeqNo	Broadcast PLOAM sequence number
5	RE/ RE CT-Id	0xXYZTn where: Since only four ONUs can be mapped per message, XYZ indicate the rank of the message in the announcement needed for RE-Id n depending on the number of ONUs attached to the RE. T set to "1" indicates the last message for RE Id number n "n" is a 4 bit RE-Id as given in the wavelength channel (WLCH) of the OC structure.
6	Number of ONU for RE-Id "n"	0 – 254 Number of ONUs attached to the given CT 255 – reserved for the case of all ONU attached to a single RE
7-10	First ONU Vendor_ID	See clause C.11.2.6.1 of [ITU-T G.9807.1]
11-14	First ONU VSSN	See clause C.11.2.6.2 of [ITU-T G.9807.1]
15-18	Second ONU Vendor_ID	See clause C.11.2.6.1 of [ITU-T G.9807.1]
19-22	Second ONU VSSN	See clause C.11.2.6.2 of [ITU-T G.9807.1]
…		
31-34	Fifth ONU Vendor_ID	See clause C.11.2.6.1 of [ITU-T G.9807.1]
35-38	Fifth ONU VSSN	See clause C.11.2.6.2 of [ITU-T G.9807.1]
39-40	Padding	
41-48	MIC	Message integrity check, computed using the default PLOAM integrity key.

A cyclic broadcast PLOAM message sent in clear transmits the full set of TOL values on the PON for activated RE-CTs.

Combined with RE-CTs – ONU identity mapping, field engineers can retrieve the information applicable to the ODN segment they are operating on.

Note that detection of the RE bit set in the downstream frame OC structure will tell field engineers that the frame header TOL value cannot be used when working on an ODN section.

PLOAM message corresponding to message type ID 0xF1 of Table C.11.2 of [ITU-T G.9807.1]:

Octet	Content	Description
1-2	ONU-ID	0x03FF, exclusively Broadcast.
3	Message type ID	0xF1, "TOL & RE CT-Id mapping".
4	SeqNo	Broadcast PLOAM sequence number
5	RE/ RE CT-Id	0xN1
6-7	TOL – RE CT1	0x0000 Value of TOL field for RE/ RE CT Id 1 See TOL in clause C.10.1.1.1.3 of [ITU-T G.9807.1]

Octet	Content	Description
8	RE/ RE CT-Id 2	0xN2
9-10	TOL – RE CT2	0x0000 Value of TOL field for RE/ RE CT Id 2 See TOL in clause C.10.1.1.1.3 of [ITU-T G.9807.1]
…		
38	RE/ RE CT-Id 12	0xN12
39-40		0x0000 Value of TOL field for RE/ RE CT Id 2 See TOL in clause C.10.1.1.1.3 of [ITU-T G.9807.1]
41-48	MIC	Message integrity check, computed using the default PLOAM integrity key.

There can be one EONU per RE or alternatively one shared EONU can provide a management interface to multiple REs in a shelf (extender chassis).

The EONU should provide a dying gasp function.

7.3 Power

The exact requirements of RE powering lie outside the scope of this Recommendation. However, some generic comments on this issue are given here. The mid-span extender requires electrical power. This may be a practical difficulty when the extender is located in the field. Also, the power supply is usually designed to be resilient against transient failures of the primary power source. To reduce the size of the power backup equipment, the power consumption should be reduced as much as possible.

7.4 Optional enhancements

The following issues are of interest for RE technology, but are considered to lie outside the scope of this Recommendation.

Resilience in the presence of a RE may be required due to the extended reach. There are several functions that could be protected (e.g., OTL, RE optics, OLT optics). The type B protection scheme is considered in Appendix II.

8 Specifications for mid-span extenders

8.1 Optical trunk line

The optical parameters of the optical trunk line are given in Table 1.

Table 1 – Physical medium dependant layer parameters of OTL

Items	Unit	Specification			
Fibre type	–	[ITU-T G.652]			
ODN class		N1	N2	E1	E2
Attenuation range for the 1 260 nm to 1 280 nm range applicable for OEO type of extenders (Note 1)	dB	14-28.5	16-30.5	18-32.5	20-34.5
Maximum attenuation for the 1 260 nm to 1 280 nm range applicable for OA type of extenders (Note 2)	dB	29	31	33	35
Minimum attenuation for the 1 260 nm to 1 280 nm range applicable for OA type of extenders	dB	(Note 3)	(Note 3)	(Note 3)	(Note 3)
Attenuation range for the 1 575 nm to 1 581 nm range applicable for OEO type of reach extenders (Note 1)	dB	11-23	13-25	14.5-26.5	16-28

Table 1 – Physical medium dependant layer parameters of OTL

Items	Unit	Specification			
Maximum attenuation for the 1 575 nm to 1 581 nm range applicable for OA type of reach extenders (Note 2)	dB	23	25	26.5	28
Minimum attenuation for the 1 575 nm to 1 581 nm range applicable for OA type of reach extenders	dB	(Note 3)	(Note 3)	(Note 3)	(Note 3)
Attenuation range for C-band applicable for WC type of extenders (Note 1)	dB	14-28.5	16-30.5	18-32.5	20-34.5
Maximum attenuation for L-band applicable for WC type of extenders (Note 1)	dB	14-28.5	16-30.5	18-32.5	20-34.5
Maximum optical path penalty	dB	1			
Maximum fibre distance between S/R and R'/S' points	km	60 minus the distance used in the ODN			
Bidirectional transmission	–	1-fibre WDM			
Maintenance wavelength	nm	See [ITU-T L.313]			
NOTE 1 – For lower attenuation values, external optical attenuators can be used. NOTE 2 – May be varied depending on implementation. NOTE 3 – OA implementation-dependent; for low attenuation values, an appropriately designed OA type extender or external optical attenuators can be used.					

8.2 Optical trunk line interface (R'/S') and OLT interface (S/R)

The optical parameters of the R'/S' and S/R interfaces are given in Tables 2 and 3. The specifications for the OLT S/R interface are based upon the specifications of the S/R interface in Tables B.9-3 and B.9-4 of [ITU-T G.9807.1], with the noted exceptions. The specifications for the RE R'/S' interface are based upon the specifications of the R/S interface in Tables B.9-3 and B.9-4 of [ITU-T G.9807.1], with the noted exceptions.

Table 2 – Optical interface parameters of 9 953 Mbit/s downstream direction (OLT>Ext)

Items	Unit	OEO type	OA type
OLT transmitter			
All transmitter specifications in Table B.9-3 of [ITU-T G.9807.1] unless specified here		Same as Annex B of [ITU-T G.9807.1]	Same as Annex B of [ITU-T G.9807.1]
Extender receiver			
All receiver specifications in Table B.9-3 of [ITU-T G.9807.1] unless specified here		Same as Annex B of [ITU-T G.9807.1]	Same as Annex B of [ITU-T G.9807.1]
Maximum reflectance of equipment, measured at receiver wavelength	dB	Same as Annex B of [ITU-T G.9807.1]	NA
Bit error ratio	–	Less than 10^{-5}	NA

Table 2 – Optical interface parameters of 9 953 Mbit/s downstream direction (OLT>Ext)

Items	Unit	OEO type	OA type
Minimum sensitivity (back-to-back)	dBm	N1: –22 N2a: –22 N2b –15.5 E1: –21.5 E2a: –21 E2b: –14.5	N1: –22 N2a: –22 N2b –15.5 E1: –21.5 E2a: –21 E2b: –14.5 (Note 1)
Minimum overload	dBm	N1: –5 N2a: –5 N2b –0.5 E1: –4.5 E2a: –4 E2b: +0.5	N1: –5 N2a: –5 N2b –0.5 E1: –4.5 E2a: –4 E2b: +0.5 (Note 1)
NOTE 1 – The input power specifications into the OA-type extender at R'/S' interface is given in order to achieve a bit error ratio of 10^{-3} at the ONU. NOTE 2 – For WC-type reach extenders, the operating wavelength may be changed; see clause 8.6. NOTE 3 – For some optical wavelength converters, the non-return to zero (NRZ) data is inverted in the OTL section between the WC-RE and the WC-OLT. The configuration of data pattern inversion is for further study. NOTE 4 – Typical seed light sources have a spectral power density of 6 dBm/nm.			

Table 3a – Optical interface parameters of 9 953 Mbit/s upstream direction (Ext>OLT)

Items	Unit	OEO type	OA type
Extender transmitter			
All transmitter specifications in Table B.9-4 of [ITU-T G.9807.1] unless specified here	Mbit/s	Same as Annex B of [ITU-T G.9807.1]	NA
Mean launched signal power minimum	dBm	+4	(Note 1)
Mean launched signal power maximum	dBm	+9	(Note 1)
Maximum ASE output power in the 1 255 nm to 1285 nm band launched toward OLT relative to signal output power. Condition: –28 dBm signal input power at S'/R'.	dB	NA	7
Maximum ASE output power in the 1 200 nm to 1255 nm and the 1 285 nm to 1 400 nm band launched toward OLT relative to signal output power. Condition: –28 dBm signal input power at S'/R'.	dB	NA	–4

Table 3a – Optical interface parameters of 9 953 Mbit/s upstream direction (Ext>OLT)

Items	Unit	OEO type	OA type
Maximum ASE output power in the 1 400 nm to 1 600 nm band launched toward OLT. Condition: –23 dBm signal input power at 1490 nm at R'/S'.	dBm	NA	2
OLT receiver			
All receiver specifications in Table B.9-4 of [ITU-T G.9807.1] unless specified here		Same as Annex B of [ITU-T G.9807.1]	Same as Annex B of [ITU-T G.9807.1]
Bit error ratio	–	Less than 10^{-6}	NA
Maximum penalty due to ASE-related power bias at OLT receiver	dB	NA	0.5
Immunity against incident ASE power (optical power bias tolerance) in the 1 285 nm to 1 335 nm band at 0.5 dB additional penalty: ASE power relative to modulated signal power.	dB	NA	7 (Note 2)

NOTE 1 – Implementation-dependent. Values can be derived from the OA-type reach extender's gain specification and its allowed ODN attenuation range. Maximum and minimum signal output power may be determined from the following formulae:

$P_{out(max)}$ = +7 – min ODN attenuation + maximum gain

$P_{out(min)}$ = +2 – max ODN attenuation + minimum gain

NOTE 2 – ASE noise generated by the OA-type reach extender appears to the receiver as optical power bias (see Appendix I).

NOTE 3 – For WC-type reach extenders, the operating wavelength may be changed; see clause 8.6.

NOTE 4 – For some optical wavelength converters, the NRZ data is inverted in the OTL section between the WC-RE and the WC-OLT. The configuration of data pattern inversion is for further study.

Table 3b – Optical interface parameters of 2 488 Mbit/s upstream direction (Ext>OLT)

Items	Unit	OEO type	OA type
Extender transmitter			
All transmitter specifications in Table 9-4 of [ITU-T G.987.2] unless specified here	Mbit/s	Same as [ITU-T G.987.2]	NA
Mean launched signal power minimum	dBm	+2	(Note 1)
Mean launched signal power maximum	dBm	+7	(Note 1)
Maximum ASE output power in the 1 255 nm to 1 285 nm band launched toward OLT relative to signal output power. Condition: –28 dBm signal input power at S'/R'.	dB	NA	7
Maximum ASE output power in the 1 200 nm to 1 255 nm and the 1 285 nm to 1 400 nm band launched toward OLT relative to signal output power. Condition: –28 dBm signal input power at S'/R'.	dB	NA	–4

Table 3b – Optical interface parameters of 2 488 Mbit/s upstream direction (Ext>OLT)

Items	Unit	OEO type	OA type
Maximum ASE output power in the 1 400 nm to 1 600 nm band launched toward OLT. Condition: –23 dBm signal input power at 1 490 nm at R'/S'.	dBm	NA	2
OLT receiver			
All receiver specifications in Table 9-4 of [ITU-T G.987.2] unless specified here		Same as [ITU-T G.987.2]	Same as [ITU-T G.987.2]
Bit error ratio	–	Less than 10^{-6}	NA
Maximum penalty due to ASE-related power bias at OLT receiver	dB	NA	0.5
Immunity against incident ASE power (optical power bias tolerance) in the 1 285 nm to 1 335 nm band at 0.5 dB additional penalty: ASE power relative to modulated signal power.	dB	NA	7 (Note 2)
NOTE 1 – Implementation-dependent. Values can be derived from the OA-type reach extender's gain specification and its allowed ODN attenuation range. Maximum and minimum signal output power may be determined from the following formulae: $P_{out(max)}$ = +7 – min ODN attenuation + maximum gain; $P_{out(min)}$ = +2 – max ODN attenuation + minimum gain NOTE 2 – ASE noise generated by the OA-type reach extender appears to the receiver as optical power bias (see Appendix I). NOTE 3 – For WC-type reach extenders, the operating wavelength may be changed; see clause 8.6. NOTE 4 – For some optical wavelength converters, the NRZ data is inverted in the OTL section between the WC-RE and the WC-OLT. The configuration of data pattern inversion is for further study.			

8.3 Optical distribution network

The optical parameters of the optical distribution network are given in Table B.9-2 of [ITU-T G.9807.1].

8.4 Extender interface to optical distribution network (S'/R') and ONU interface (R/S)

The optical parameters of the S'/R' and R/S interfaces are given in Tables 4, 5a and 5b. The specifications for the RE S'/R' interface are based upon those of the S/R interface in Tables B.9-3 and B.9-4 of [ITU-T G.9807.1], with the noted exceptions. The specifications for the ONU R/S interface are based upon the specifications of the R/S interface in Tables B.9-3 and B.9-4 of [ITU-T G.9807.1], with the noted exceptions.

Table 4 – Optical interface parameters of 9 953 Mbit/s downstream direction (Ext>ONU)

Items	Unit	OEO type	OA type
Extender transmitter			
All transmitter specifications in Table B.9-3 of [ITU-T G.9807.1] unless specified here		Same as Annex B of [ITU-T G.9807.1]	NA
Mean launched power minimum	dBm	Same as Annex B of [ITU-T G.9807.1]	(Note 1)

Table 4 – Optical interface parameters of 9 953 Mbit/s downstream direction (Ext>ONU)

Items	Unit	OEO type	OA type
Mean launched power maximum	dBm	Same as Annex B of [ITU-T G.9807.1]	(Note 1)
Maximum ASE power in the 1 400 nm to 1 600 nm band launched toward ONUs relativeto the launched output signal power. Condition: –23 dBm signal input power at R'/S'.	dB	NA	5
Maximum ASE output power in the 1 200 nm to 1 400 nm band launched toward ONUs. Condition: –28 dBm 1270 nm signal input power at S'/R'	dBm	NA	9
ONU receiver			
All receiver specifications in Table 9-3 of [ITU-T G.9807.1] unless specified here		Same as Annex B of [ITU-T G.9807.1]	Same as Annex B of [ITU-T G.9807.1]
Additional penalty due ASE-related power bias at ONU receiver	dB	NA	0.5 dB
Immunity against incident ASE power (optical power bias tolerance) in the 1 400 nm to 1 600 nm band at 0.5 dB additional penalty: ASE power relative to signal power.	dB	NA	5 (Note 2)
NOTE 1 – Implementation-dependent. Values can be derived from the OA-type reach extender's gain and the OTL loss. Maximum and minimum signal output power may be determined by: $P_{out(min)}$ = OLT_Pout_min + minimum gain – OTL loss $P_{out(max)}$ = OLT_Pout_max + maximum gain – OTL loss As an option, the gain can be adjusted to optimize performance (ODN attenuation range). NOTE 2 – ASE generated by the OA extender appears to the receiver as optical power bias. See Appendix I.			

Table 5a – Optical interface parameters of 9 953 Mbit/s upstream direction (ONU>Ext)

Items	Unit	OEO Type	OA type
ONU transmitter			
All transmitter specifications in Table B.9-4 of [ITU-T G.9807.1] unless specified here		Same as Annex B of [ITU-T G.9807.1]	Same as Annex B of [ITU-T G.9807.1]
Dispersion range	ps/nm	Same as Annex B of [ITU-T G.9807.1]	0 to –420
Extender receiver			
All receiver specifications in Table B.9-4 of [ITU-T G.9807.1] unless specified here		Same as Annex B of [ITU-T G.9807.1]	Same as Annex B of [ITU-T G.9807.1]

Table 5a – Optical interface parameters of 9 953 Mbit/s upstream direction (ONU>Ext)

Items	Unit	OEO Type	OA type
Maximum reflectance of equipment, measured at receiver wavelength	dB	Less than –20	Less than –20
Bit error ratio	–	Less than 10^{-4}	NA
Consecutive identical digit immunity	Bit	Same as Annex B of [ITU-T G.9807.1]	NA
Jitter tolerance	–	NA	NA

Table 5b – Optical interface parameters of 2 488 Mbit/s upstream direction (ONU>Ext)

Items	Unit	OEO Type	OA type
ONU transmitter			
All transmitter specifications in Table 9-4 of [ITU-T G.987.2] unless specified here		Same as [ITU-T G.987.2]	Same as [ITU-T G.987.2]
Dispersion range	ps/nm	Same as [ITU-T G.987.2]	0 to –420
Extender receiver			
All receiver specifications in Table 9-4 of [ITU-T G.987.2] unless specified here		Same as [ITU-T G.987.2]	Same as [ITU-T G.987.2]
Maximum reflectance of equipment, measured at receiver wavelength	dB	Less than –20	Less than –20
Bit error ratio	–	Less than 10^{-4}	NA
Consecutive identical digit immunity	Bit	Same as [ITU-T G.987.2]	NA
Jitter tolerance	–	NA	NA

8.5 TC layer impacts

The introduction of an OEO RE into the PON signal path will cause some degradation of the total burst mode overhead. For most OEO type systems, the extender's own burst mode receiver must accomplish level or clock recovery. For some OA type systems, there may be a short time interval from when the burst first arrives at the OA to when the gain control mechanisms have stabilized. The extender essentially "consumes" an interval of the preamble pattern for its own adjustment before it can begin to transmit high-quality preamble upstream toward the OLT.

The OLT and ONU must compensate for this by allowing extra preamble pattern to be transmitted before each burst. The exact amount of extra preamble depends on the design of the extender, and is best determined during operation via the extender management channel. It is expected that REs would require no more preamble than an OLT receiver, and potentially less.

The basic procedure for network commissioning is as follows:

Step 1: The OLT broadcasts a Profile message (profile X) on the PON.

Step 2: The OLT activates the RE (i.e., ranges and establishes the OMCI channel).

Step 3: The OLT obtains via the OMCI the RE's preamble requirement.

Step 4: The OLT broadcasts a different profile message (profile Y) that includes the RE's extra preamble requirement. Note that the OLT will not command the RE to use the profile Y. Consequently, the RE will use profile X (with a normal preamble) and the ONUs will use profile Y (with the extended preamble).

Step 5: The OLT activates all the ONUs downstream of the extender now that the upstream channel has been properly aligned.

8.6 WDM wavelength allocation plan for OTL

The wavelength allocation plans for the OTL between the S"/R" and R"/S" interfaces are defined in this section. Since the various technical options have different requirements on the wavelength allocation, we arrive at several channel plans. Examples of the application of these plans are shown in Appendix V.

8.6.1 Transparent OTL wavelength allocation plan

The transparent OTL wavelength allocation plan is presented in Table 6. The basic design principle here is to use the usual 100 GHz or 50 GHz channel grid. This arrangement should facilitate forward compatibility with the maximal set of XG(S)-PON equipment.

Table 6 – Transparent OTL wavelength allocation plan for upstream and downstream channels

	Upstream		**Downstream**	
Minimum channel spacing	100 GHz	50 GHz	100 GHz	50 GHz
Minimum central frequency	234.3 THz 1 279.52 nm	234.3 THz 1 279.52 nm	189.7 THz 1 580.35 nm	189.65 THz 1 580.77 nm
Maximum central frequency	237.8 THz 1 260.69 nm	237.85 THz 1 260.43 nm	190.3 THz 1 575.37 nm	190.3 THz 1 575.37 nm
Spectral excursion	±20 GHz	±10 GHz	±20 GHz	±10 GHz
Total number of supported channels	36	72	7	14

8.6.2 Conventional OTL wavelength allocation plan

The conventional OTL wavelength plan is presented in Table 7. The basic design concept here is to use conventional wavelength assignments from [ITU-T G.694.1] or [ITU-T G.694.2]. In DWDM applications using two fibres, the C-band allocations are used for both transmission directions. In DWDM applications using a single fibre, the C-band is used for the upstream, and the L-band is used for the downstream.

Table 7 – The conventional OTL wavelength allocation plan

	CWDM option	DWDM options for upstream and two fibres downstream		DWDM options for single fibre downstream	
Minimum channel spacing	20 nm	100 GHz	50 GHz	100 GHz	50 GHz
Maximum central frequency	1471 nm	196.0 THz 1 529.55 nm	196.05 THz 1 529.16 nm	190.3 THz 1 575.37 nm	190.35 THz 1 574.95 nm
Minimum central frequency	1 611 nm	192.1 THz 1 560.61 nm	192.1 THz 1 560.61 nm	186.4 THz 1 608.33 nm	186.4 THz 1 608.33 nm
Spectral excursion	±6.5 nm	±20 GHz	±10 GHz	±20 GHz	±10 GHz
Total number of supported channels	18	40	80	40	80

8.6.3 Optically converted OTL wavelength allocation plan

The optically converted wavelength allocation plan is presented in Table 8. This wavelength plan is suitable for certain WC technologies that have a limitation in the change of wavelength. For this reason, the wavelength bands are placed close to (but not overlapping) the wavelength bands of XG(S)-PON.

Table 8 – The optically converted OLT wavelength plan

	Upstream		Downstream	
Minimum channel spacing	100 GHz	50 GHz	100 GHz	50 GHz
Minimum central frequency	231.30 THz 1 296.12 nm	231.25 THz 1 296.40 nm	190.7 THz 1 572.06 nm	190.65 THz 1 572.48 nm
Maximum central frequency	233.60 THz 1 283.36 nm	233.60 THz 1 283.36 nm	191.3 THz 1 567.13 nm	191.3 THz 1 567.13 nm
Spectral excursion	±20 GHz	±10 GHz	±20 GHz	±10 GHz
Total number of supported channels	24	48	7	14

Appendix I

Implications on OLT receivers due to insertion of OA type extenders

(This appendix does not form an integral part of this Recommendation.)

SOAs are presently the most practical gain element for implementing OA-type of extenders. The ASE generated by the SOA appears at the R/S interface as a broadband light source, which is converted by the photodetector section of the receiver to a DC bias current and a noise term in the electrical domain. This appendix describes the implications of this optical power bias for the receiver.

Figure I.1 illustrates the effect of the ASE-based DC bias current on the decision threshold at the upstream receiver's sensitivity limit and overload limit, respectively. A receiver will function correctly only if it can tolerate this DC bias current with a maximum 0.5 dB power penalty over its entire input range.

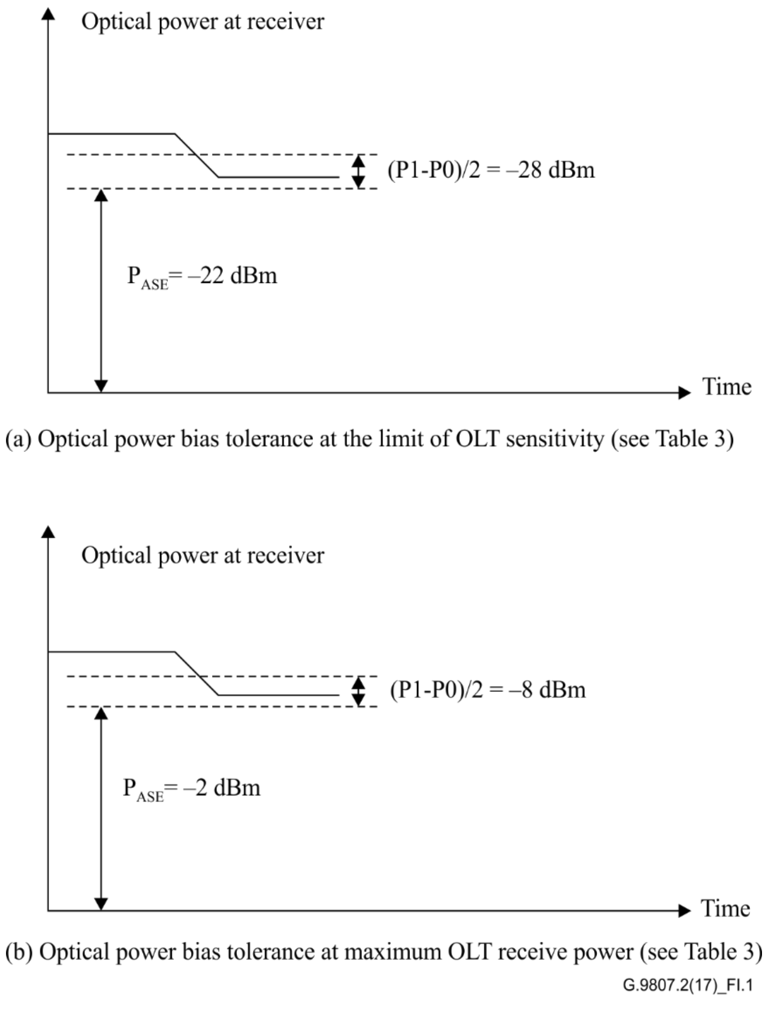


Figure I.1 – Optical power bias tolerance at the OLT upstream receiver

Generally, OLT receivers that are AC coupled and those that are DC coupled but readjust their decision thresholds at the beginning of each received burst will be tolerant of DC bias. XG(S)-PON OLT receiver implementations typically fall into one of these categories.

In both the upstream and downstream directions, a significant portion of the ASE power spectrum falls outside the nominal operating wavelength band of the OLT or ONU transmitter. The specifications given in Table 3 assume usage of an OBF to block upstream ASE directed to the OLT outside the operating band of the ONU transmitter. As an option, an OBF may also be used to block ASE directed towards ONU outside the operating band of the OLT transmitter.

OBFs improve performance by reducing ASE-ASE beat noise at the receiver and by relaxing the optical power bias tolerance requirements at the receivers.

Note that the excess backward ASE in upstream direction produced by the downstream OA need not be filtered out. The OBF should not interfere with video wavelengths, NGA wavelengths or supervisory wavelengths, since both OEO and OA extenders would likely use WDM technology to accommodate other wavelengths. In the following example, a video overlay signal at 1 550 nm operates in a region where an OA extender may produce a significant amount of ASE. As shown in Figure I.2, WDM1 would block 1 550 nm backward ASE from reaching the video OLT, and WDM2 would keep forward ASE at 1 550 nm away from the video receiver.

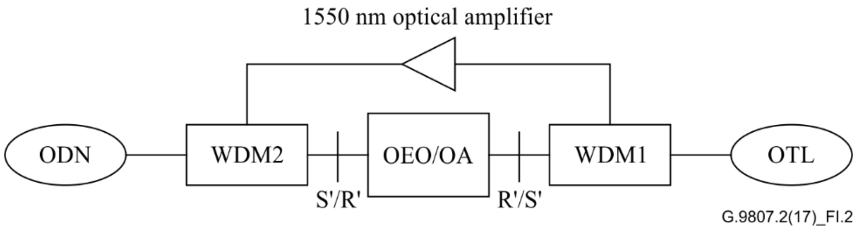


Figure I.2 – Forward and backward ASE filtering due to WDM overlay

Appendix II

Protection

(This appendix does not form an integral part of this Recommendation.)

II.1 Introduction

Protection architectures and solutions with XG(S)-PON REs are possible. However, XG(S)-PON reach extension can have an impact on reliability. Due to long link length, the risk of fibre damage is higher, and so in many cases the OTL might have to be protected.

On the other hand, XG(S)-PON reach extension enables OLT-geo-redundancy, which is not yet fully standardized. This geographic redundancy is also termed "dual homing". The control and signalling of the dual-homing schemes are for future study.

II.2 RE-independent type B protection

Figure II.1 gives an example of a protected reach extended XG(S)-PON. In this case, the OTL and mid-span REs are duplicated (protected), and the ODN implements the classical type-B 2:N splitting connection. In this scenario, the REs require a control input such that only the working RE transmits in the downstream, and the protecting RE suppresses its transmission. This can be accomplished most easily by constructing the RE such that if the signal from the OLT is suppressed, then the RE downstream output will also be suppressed.

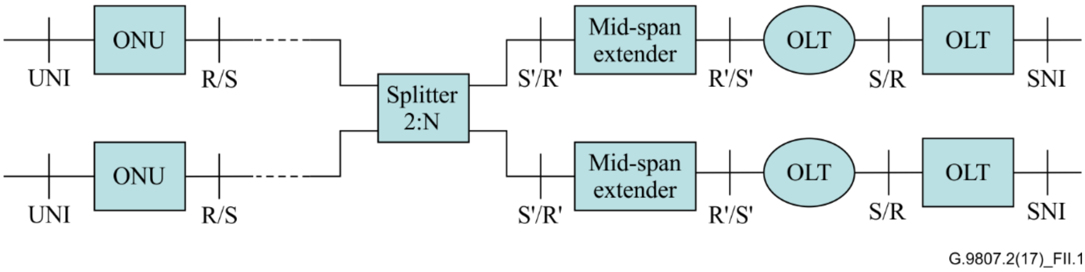


Figure II.1 – Reach extended XG(S)-PON, with geo-redundant OLT and trunk line protection

II.3 OEO extender-based type B protection

Figure II.2 shows the architecture of an OEO-based reach extended PON with a type B protection function. In this case, the type B 2:N junction point is inside the RE. The protection switch function is done by an integrated MUX module within the E-ONU MAC. Once the E-ONU is powered up, the inner MUX module, controlled by the EONU MAC, chooses to pass the signal from the Tx/Rx set at the R'/S' side connecting with the working OLT. Then the EONU registers to this OLT as well as all of the other downstream ONUs. Then the system enters the normal working state as usual.

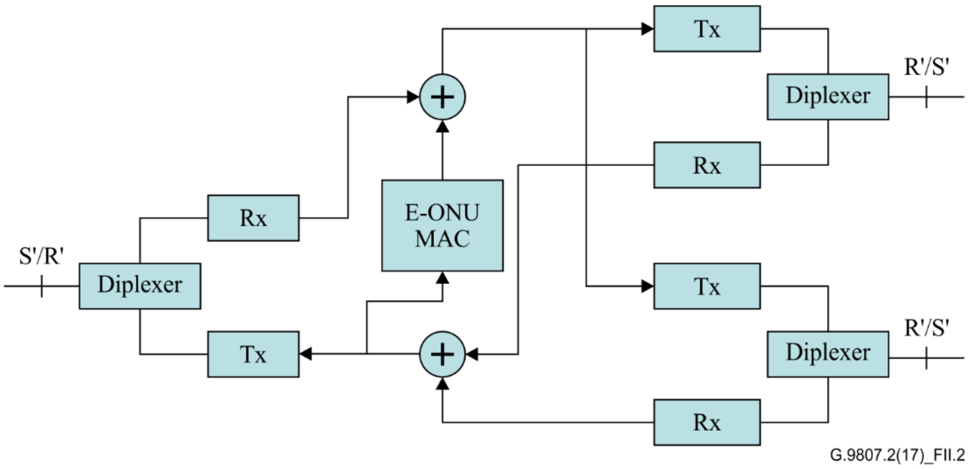


Figure II.2 – OEO-based LR PON with type B protection: integrated MUX module

II.4 OA-extender-based type B protection architecture

Figure II.3 shows the architecture of an OA-based LR PON with a type B protection function. In this case, the 2:N function is done by an external MUX module at the R'/S' side. Though the RE feature is implemented through an optical amplifier, it works in a similar way to the architecture shown in Figure II.2.

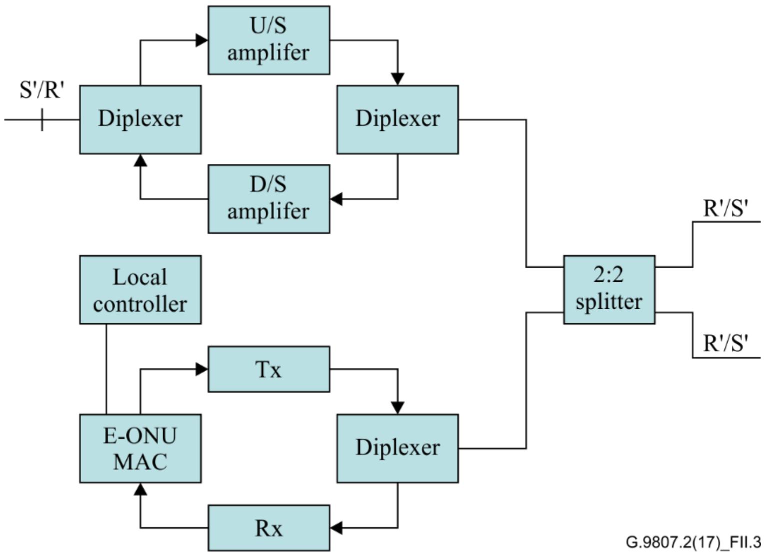


Figure II.3 – OA-based LR PON with type B protection: external MUX module

Appendix III

Optical time domain reflectometer

(This appendix does not form an integral part of this Recommendation.)

III.1 Introduction

Optical time domain reflectometer (OTDR) monitoring pulses may disturb the operation of the RE and, on the other hand, the presence of an RE blocks the propagation of the OTDR signals.

III.2 Solution

Figure III.1 gives one example of an extended XG(S)-PON equipped with OTDR blocking filters or bypass filters. In both cases, insertion loss of the blocking or bypass filters has to be accounted into the OTL or the ODN loss. In case of bypass, the reach limit of the OTDR in use requires consideration.

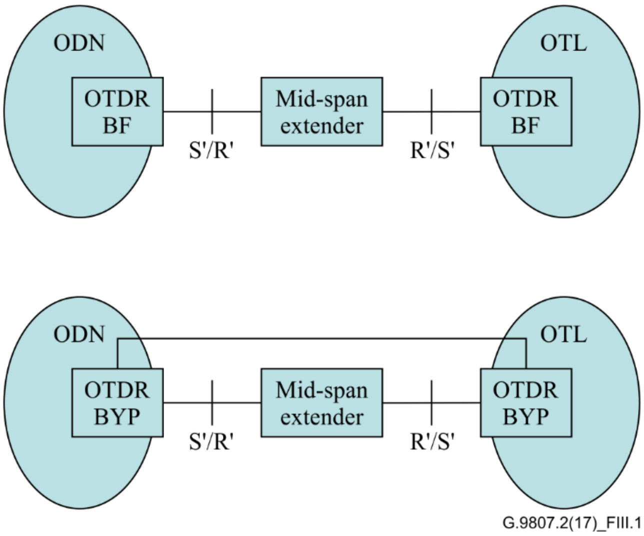


Figure III.1 – Reach extender with OTDR blocking filters (BF) and OTDR bypass (BYP) filters

Appendix IV

Transport of BM-to-CM converted signals over OTN

(This appendix does not form an integral part of this Recommendation.)

The use of BM-to-CM enabled RE functions opens a new possibility: transporting the resulting continuous mode signals over the optical transport network (OTN). The basic system arrangement is shown in Figure IV.1.

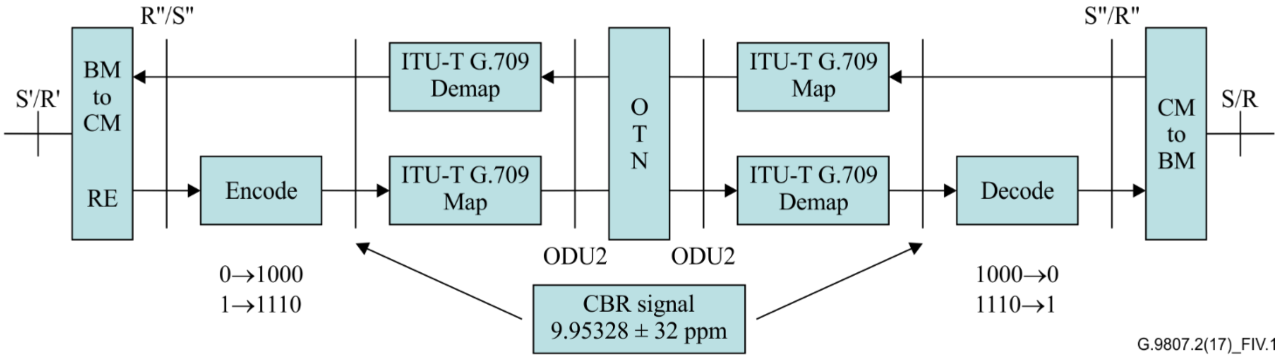


Figure IV.1 – The transport of BM-to-CM signals over OTN

In the downstream direction, the CM-to-BM unit performs a null function (i.e., the output of the OLT is already a continuous mode signal). The CMXGSPON_D signal is a 9.953 28 Gbit/s constant bit rate signal, and it has a frequency accuracy no worse than 32 ppm (corresponding to an OLT that is operating in free running mode, per Annex B of [ITU-T G.9807.1]). In fact, in normal operation, the frequency accuracy should be 4.6 ppm or better. [b-ITU-T G.709] describes how to map the CMXGSPON_D signal into an ODU2, and how to de-map (recover) the signal on the other side. The BM-to-CM unit performs a null function again, and merely passes the continuous mode signal on to the optical interface.

In the upstream, the BM-to-CM unit converts the upstream bursts into a continuous mode signal (CMXGSPON_U), as described in clause 6.2. The CMXGSPON_U signal is a 9.953 28 Gbit/s or 2.488 32 Gbit/s bit rate signal that is synchronous with the downstream signal and it has a frequency accuracy no worse than the downstream signal (per Annex B of [ITU-T G.9807.1]). A trivial encoding is used to convert this into a 9.953 28 Gbit/s signal (denoted CMXGSPON_U2). This encoding converts an input 0 into 1000, and an input 1 into 1110. The decoder performs the reverse conversion. [b-ITU-T G.709] describes how to map the CMXGSPON_U2 signal into an ODU2, and how to recover it on the other side. The CM-to-BM unit converts the upstream continuous mode signal back into a burst-like signal, and passes this to the OLT.

Appendix V

Possible realization of OA and OEO-based extenders using wavelength conversion

(This appendix does not form an integral part of this Recommendation.)

This appendix illustrates examples of several implementations of WC extenders.

V.1 A transparent wavelength plan extender realization

Figures V.1 and V.2 are schematic diagrams for examples of the optical WC RE and WC OLT, respectively, for a transparent WC design.

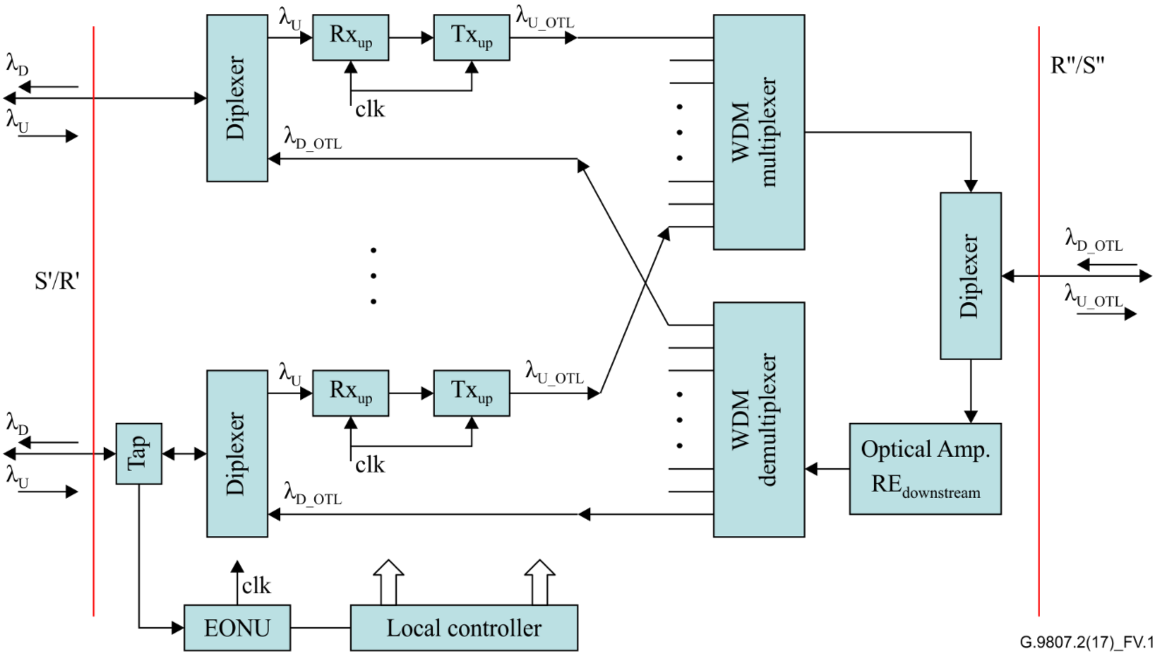


Figure V.1 – Example of a transparent wavelength conversion reach extender

The RE upstream Rx and Tx should be enhanced in the same way as in clause 6.2 (OEO-based RE) to support dual rate operation in the XG(S)-PON. In addition, the RE upstream Tx should also be able to convert the received upstream wavelength into a different one, to support wavelength multiplexing at the upstream WDM. Either coloured or tunable Tx technology can fulfil this function.

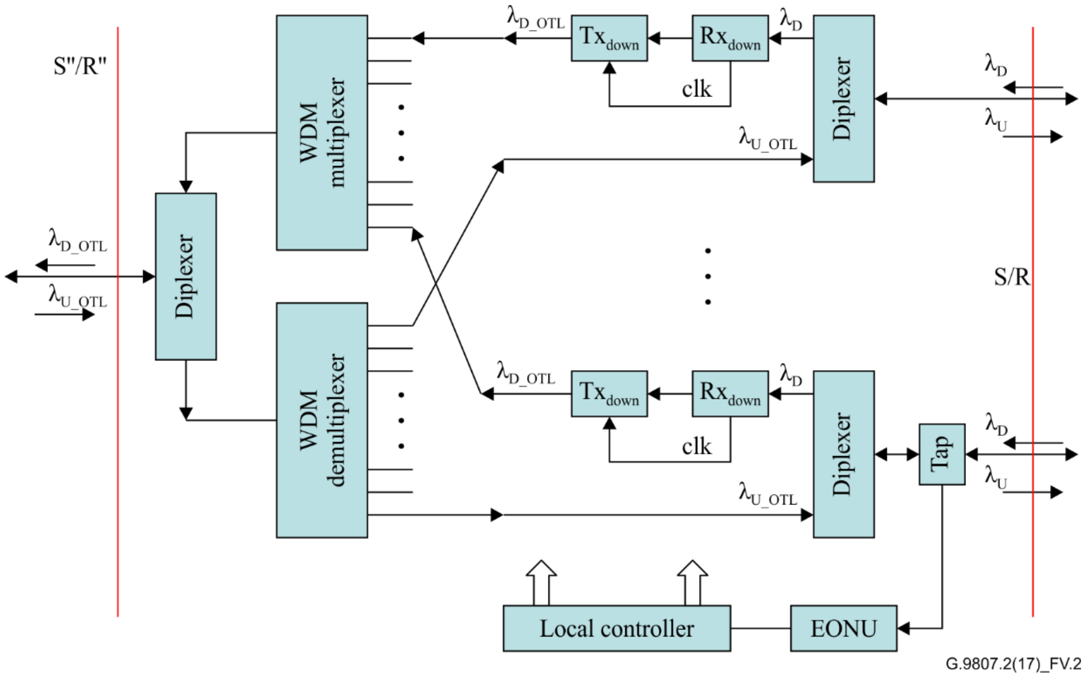


Figure V.2 – Example of a transparent wavelength conversion OLT

The chief advantage of the transparent WC system is that the wavelength re-conversion at the receiving end of the OTL is avoided. In the downstream, all that is needed at the RE is an optical amplifier. This is particularly advantageous in cases where this amplifier can handle all of the wavelength channels at once. In the upstream at the WC-OLT, just a passive WDM is used to direct the channels to the appropriate OLT port. On the transmitting end of the OTL, any means of WC is possible; in the example here, OEO conversion is used.

V.2 A conventional wavelength plan extender realization

Figures V.3 and V.4 are schematic diagrams for examples of the optical WC RE and WC OLT, respectively, for a conventional WC design. This is perhaps the most straightforward type of WC, where both directions of the PON signals are converted to the conventional ITU-T G.694-series wavelength options, and back again. This example shows OEO WC technology, but other types of conversion are possible. This example also shows the use of BM-to-CM conversion and re-conversion. This allows for the use of more common CM optics, but this is not essential.

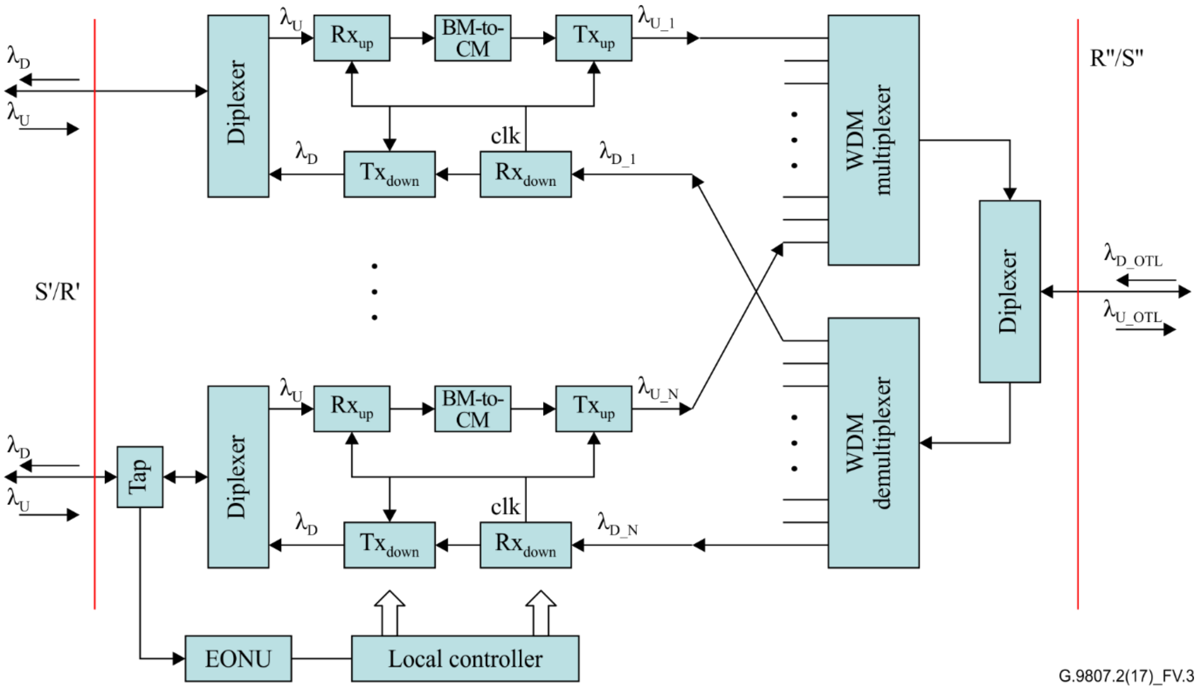


Figure V.3 – Example of a conventional wavelength conversion reach extender

The RE upstream RX and TX should be enhanced in a similar way to that in clause 6.2 (OEO-based RE) to support dual rate operation in the XG(S)-PON. In addition, the RE upstream TX should also be able to convert the received upstream wavelength into a different one, to support wavelength multiplexing at the upstream WDM. Either coloured or tunable TX technology can fulfil this function.

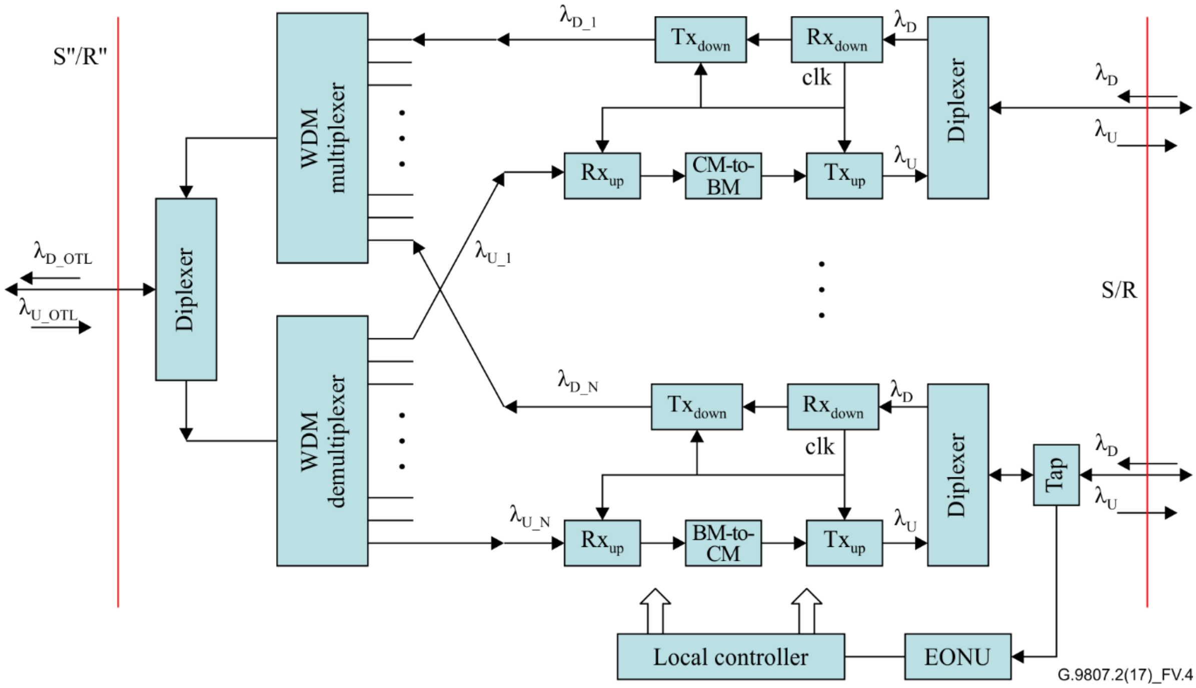


Figure V.4 – Example of a conventional wavelength conversion OLT

V.3 An OWC based extender realization

Figures V.5 and V.6 are schematic diagrams for examples of the optical WC RE and WC OLT, respectively, for an optical WC design. The main advantage of optical WC is that it can be independent of PON signal data rate and protocol format. From a certain point of view, this is more "passive" than other types of WC.

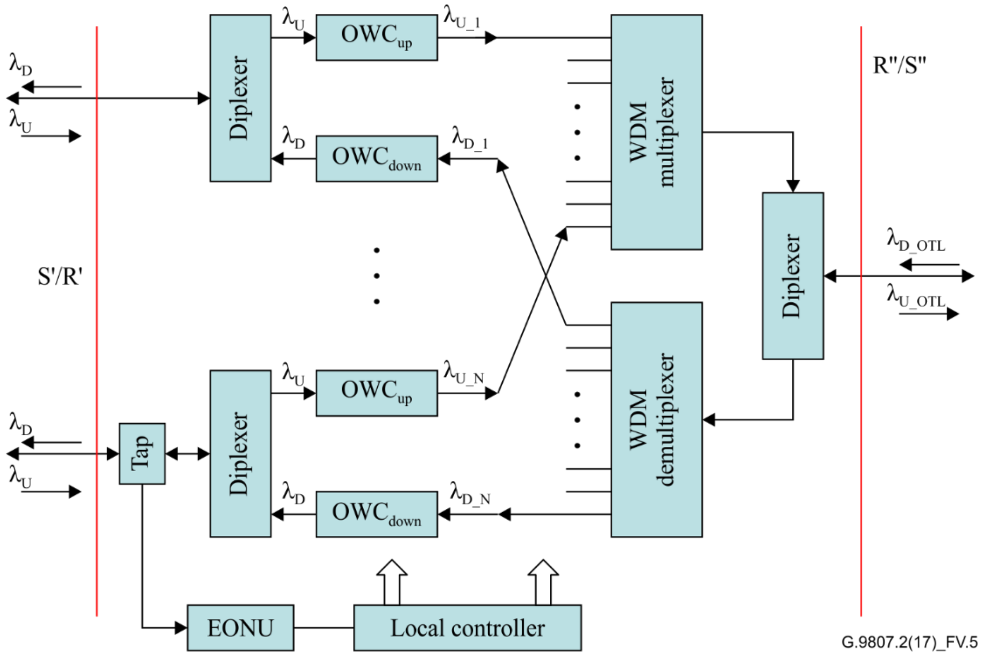


Figure V.5 – Example of an optical wavelength conversion reach extender

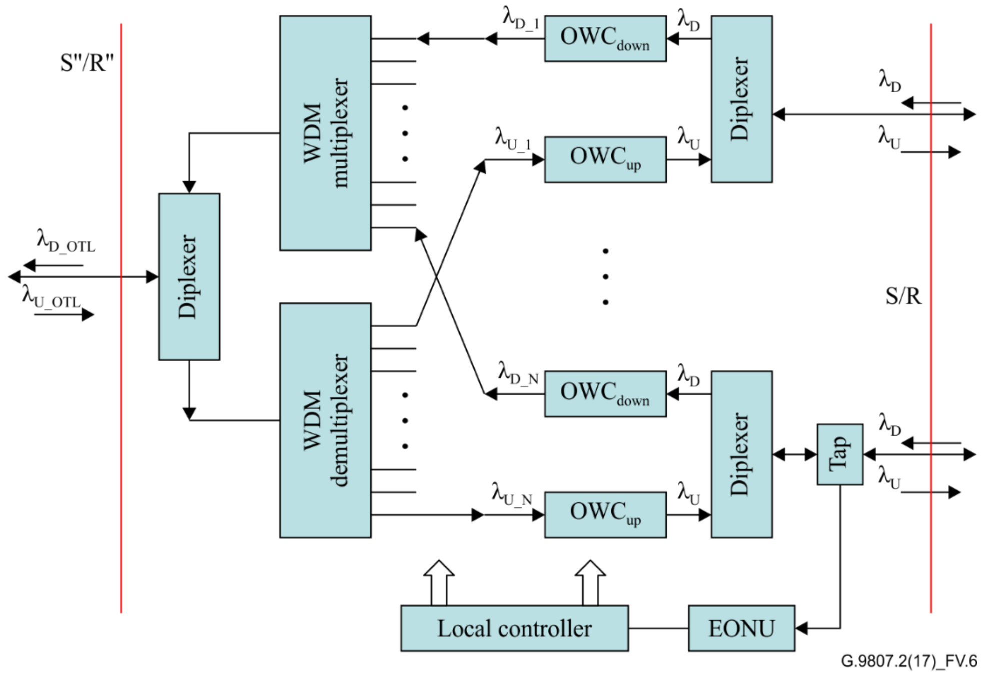


Figure V.6 – Example of an optical wavelength conversion OLT

One possible implementation of an optical wavelength converter is the so-called all-optical wavelength converter (AOWC) device. The AOWC device can be constructed from the following components:

- Input fibre, which guides input signal into AOWC;

- SOA based fibre-grating external-cavity laser, operating at wavelength λ_2, responsible for the WC function;
- Output fibre, which guides the wavelength-converted signal out of the AOWC unit.

The operating principle can be described as follows.

The input optical fibre guides the non-return to zero (NRZ) input signal at wavelength λ_1 into the SOA unit. The amplitude-modulated NRZ input signal at wavelength λ_1 is amplified and the output optical power at wavelength λ_2 is suppressed simultaneously by cross-gain modulation (XGM) effect. The output optical power at wavelength λ_2 is modulated by the input signal power and the input NRZ signal is wavelength converted from wavelength λ_1 to wavelength λ_2 with reversed digital levels (logical "1" is equivalent to low light level). The output fibre guides the wavelength-converted signal at wavelength λ_2 out of the AOWC. A WDM multiplexer/demultiplexer or arrayed waveguide grating (AWG) located outside the AOWC, acting as a wavelength selective filter, blocks the input signal at wavelength λ_1 and only allow the wavelength-converted signal at wavelength λ_2 to pass through.

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