1. Super-PON PMD Proposal

1.1. Super-PON Overview

The name Super-PON indicates a set of physical layer specifications and management parameters for optical subscriber access networks supporting point-to-multipoint operations using wavelength division multiplexing over an increased-reach (up to at least 50 km) passive optical network (PON). The defining element of a Super-PON optical distribution network (ODN) is the presence of a passive wavelength router that determines the channels supported by the ODN.

The Super-PON objectives are:

a) Preserve the Ethernet frame format utilizing the Ethernet MAC;
b) Support a BER of better than or equal to 10^{-12} at the MAC/PLS service interface (or the frame loss ratio equivalent);
c) Support a passive point-to-multipoint ODN with a reach of at least 50 km with at least 1:64 split ratio per wavelength pair;
d) Support at least 16 wavelength pairs for point-to-multipoint PON operation;
e) Support the MAC data rate of 10Gb/s downstream;
f) Support the MAC data rates of 2.5Gb/s and 10Gb/s upstream;
g) Leverage existing EPON PCS and PMA to support the above MAC data rates; and
h) Support tunable transmitters.

Figure 1 shows an exemplary structure of a Super-PON network.

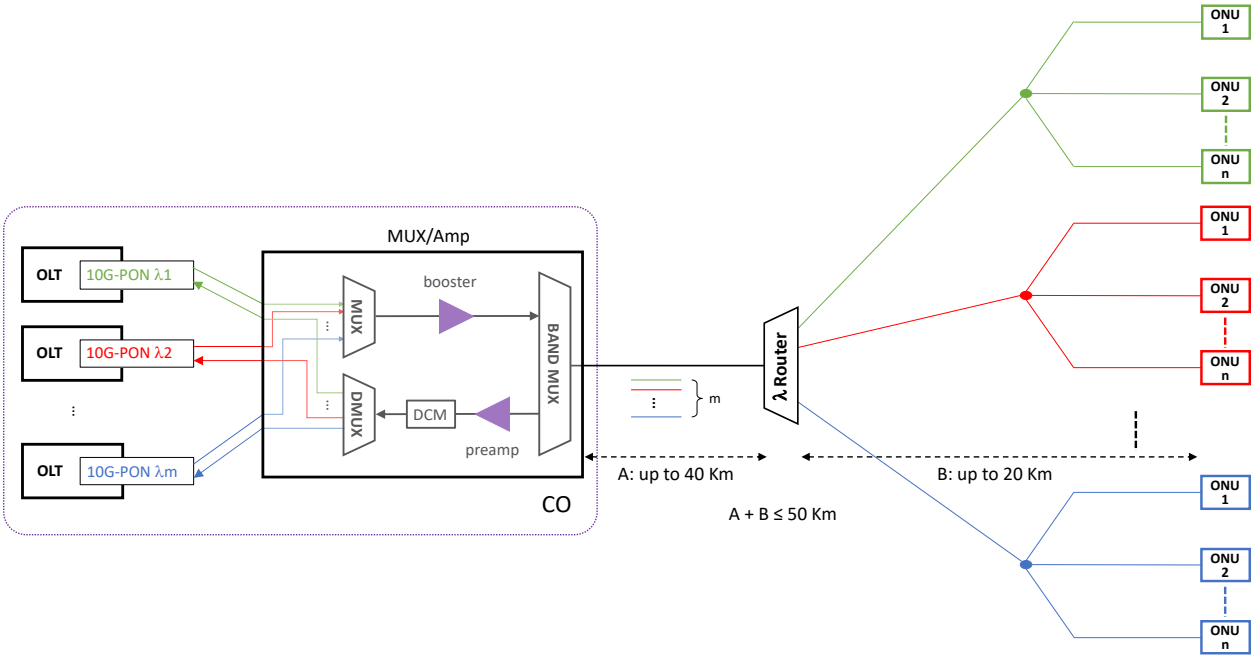

Figure 1 - Example of Super-PON Network

As shown in Figure 1, the OLT PMDs are full duplex, while the ONU PMDs are bidirectional. The wavelength pairs defining the Super-PON channel plan are shown in Table 2.

On the downstream direction, the downstream wavelengths belonging to the channels used by the m OLTs are multiplexed, amplified and finally multiplexed with the upstream wavelengths in order to get to the ODN fiber. In the ODN, these wavelengths are routed by the remote wavelength router over its physical ports. Each wavelength reaches a power splitter and then the ONUs served by the origin OLT. The point of attachment to the ODN determines the specific wavelength pair an ONU uses to operate.

On the upstream direction, an ONU transmits using the upstream wavelength belonging to the channel selected by the OLT to which it is connected. The upstream wavelengths are multiplexed by the wavelength router toward the Central Office (CO). In the CO, the upstream wavelengths are separated from the downstream ones, pre-amplified, processed by a dispersion compensation module (DCM), if needed, and finally demultiplexed for delivery to the appropriate OLT port.

Each OLT port operates over a specified channel determined by the operator in a CO, therefore it is assumed that OLT PMDs support a single channel. ONUs operate over the channel determined by their point of attachment to the ODN. On the receiving side, Super-PON ONUs use a broadband receiver. On the transmitting side, a variety of implementations is possible for ONUs,

from ONUs supporting a single channel, to fully tunable ONUs able to support all channels, going through partially tunable ONUs able to support a contiguous subset of the defined channels.

1.2. PMD Specification Method

The Super-PON PMD sublayer is defined using the 'black link' approach at the reference points shown in Figure 2.

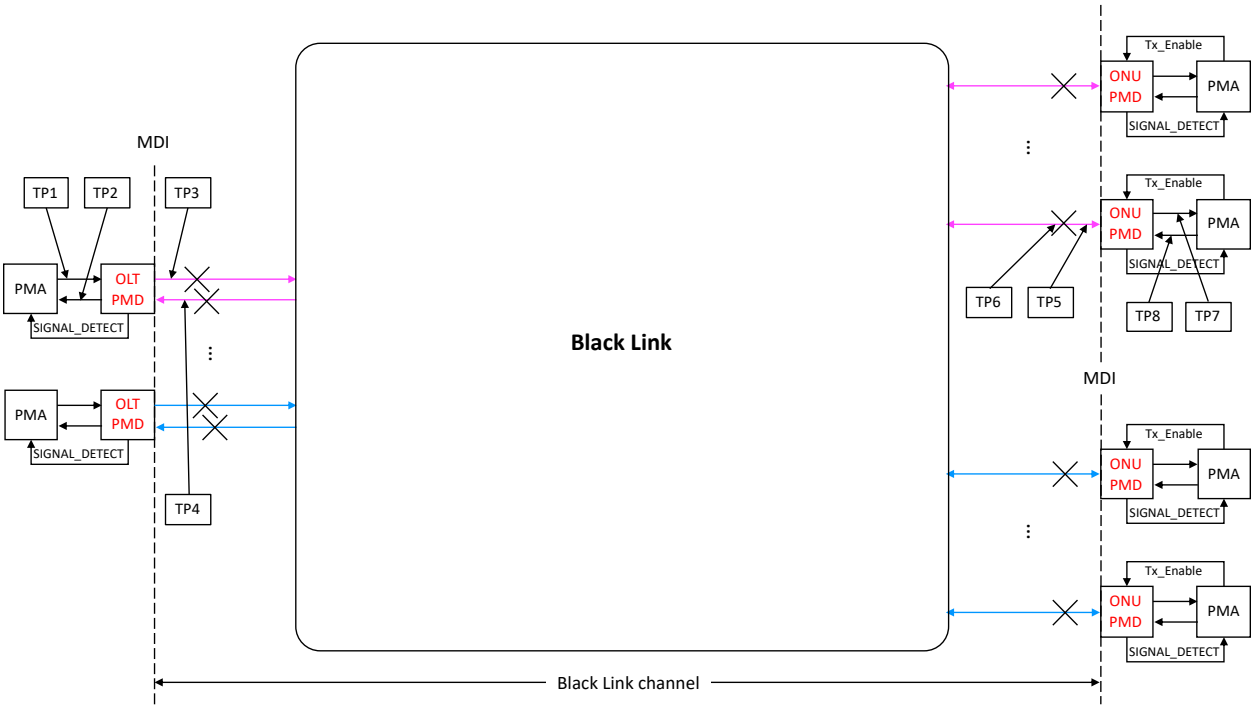

Figure 2 - Super-PON PMD Test Points

Test points TP1, TP3, TP5, and TP7 refer to the downstream channel, while test points TP8, TP6, TP4, and TP2 refer to the upstream channel. In the downstream channel, TP3 and TP5 are compliance points, while in the upstream channel TP6 and TP4 are compliance points. TP1, TP2, TP7, and TP8 are reference points for use by implementers.
An example of black link implementation is described in Annex 1.

1.3. PMD Naming

Super-PON PMD naming conforms to the following convention, with individual elements shown in Table 1:

r_1/r_2GBASE-SPg-dab

Table 1 - Super-PON PMD Naming Convention

Parameter	Explanation	Allowed Values
r_1	PMD downstream rate class (in Gb/s)	10
r_2*	PMD upstream rate class (in Gb/s)	2.5, 10
G	PMD operates at Gigabit rates	
BASE	PMD uses a baseband signal	
SP	PMD is of Super-PON P2MP type	
g	PMD generation class	1, 2
d	PMD direction class	D, U
a	PMD first transmit channel supported	0 to F#
b+	PMD last transmit channel supported	0 to F#

* If r_1 is equal to r_2 (i.e., the PMD is symmetric), r_2 is omitted.
+ If a is equal to b (i.e., the PMD supports a single channel), then b is omitted. It is assumed that type D PMDs support a single channel.
# See Table 2.

For example, using this convention:
- a generation 1 10G symmetric OLT PMD supporting only transmit channel 3 is identified as 10GBASE-SP1-D3;
- a generation 1 10G symmetric ONU PMD supporting transmit channels 2 to D is identified as 10GBASE-SP1-U2D;
- a generation 1 10G/2.5G asymmetric ONU PMD supporting transmit channels 2 to 6 is identified as 10/2.5GBASE-SP1-U26;
- a generation 1 10G/2.5G asymmetric ONU PMD supporting only transmit channel 4 is identified as 10/2.5GBASE-SP1-U4.

1.4. Channel Plan

The Super-PON channel plan is shown in Table 2.

Table 2 - Super-PON Channel Plan

	Generation 1				Generation 2			
	L-band 1 (downstream)		C-band 1 (upstream)		L-band 2 (downstream)		C-band 2 (upstream)	
Channel	Frequency (THz)	Wavelength (nm)	Frequency (THz)	Wavelength (nm)	Frequency (THz)	Wavelength (nm)	Frequency (THz)	Wavelength (nm)
0	187.613	1597.93	192.000	1561.42	189.807	1579.46	194.193	1543.78
1	187.711	1597.10	192.100	1560.61	189.906	1578.64	194.294	1542.98
2	187.809	1596.27	192.200	1559.79	190.004	1577.82	194.396	1542.18
3	187.906	1595.44	192.300	1558.98	190.103	1577.00	194.497	1541.38
4	188.004	1594.61	192.400	1558.17	190.202	1576.18	194.598	1540.57
5	188.102	1593.78	192.500	1557.36	190.301	1575.36	194.699	1539.77
6	188.200	1592.95	192.600	1556.56	190.400	1574.54	194.800	1538.97
7	188.297	1592.12	192.700	1555.75	190.499	1573.73	194.901	1538.18
8	188.395	1591.30	192.800	1554.94	190.597	1572.91	195.003	1537.38
9	188.493	1590.47	192.900	1554.13	190.696	1572.09	195.104	1536.58
A	188.590	1589.65	193.000	1553.33	190.795	1571.28	195.205	1535.78
B	188.688	1588.83	193.100	1552.52	190.894	1570.47	195.306	1534.99
C	188.786	1588.00	193.200	1551.72	190.993	1569.65	195.407	1534.19
D	188.883	1587.18	193.300	1550.92	191.092	1568.84	195.508	1533.40
E	188.981	1586.36	193.400	1550.12	191.191	1568.03	195.609	1532.61
F	189.079	1585.54	193.500	1549.32	191.289	1567.22	195.711	1531.82

1.5. Supported Combinations of OLT and ONU PMDs

Recommended pairings of OLT PMDs with ONU PMDs are shown in Table 3.

Table 3 - OLT and ONU Pairings

		ONU PMDs	
		10GBASE-SP1-Uyz	**10/2.5GBASE-SP1-Uyz**
OLT PMDs	**10GBASE-SP1-Dx**	10G/10G*	N/A
	10/2.5GBASE-SP1-Dx	N/A	10G/2.5G*
* For the pairing to work, channel x shall belong to the channel interval {y, z}.			

1.6. PMD to MDI Optical Specifications for OLT PMDs

Table 4 - OLT Transmit Characteristics

Parameter	10GBASE-SP1-Dx	10/2.5GBASE-SP1-Dx	Unit
Signaling speed (range)	10.3125 ± 100 ppm		GBd
Channel wavelengths	x=0: 1597.93 ± 0.10 x=1: 1597.10 ± 0.10 x=2: 1596.27 ± 0.10 x=3: 1595.44 ± 0.10 x=4: 1594.61 ± 0.10 x=5: 1593.78 ± 0.10 x=6: 1592.95 ± 0.10 x=7: 1592.12 ± 0.10 x=8: 1591.30 ± 0.10 x=9: 1590.47 ± 0.10 x=A: 1589.65 ± 0.10 x=B: 1588.83 ± 0.10 x=C: 1588.00 ± 0.10 x=D: 1587.18 ± 0.10 x=E: 1586.36 ± 0.10 x=F: 1585.54 ± 0.10		nm
Side-mode suppression ratio (SMSR) (min)	35		dB
Average launch power (max)	2		dBm
Average launch power (min)	-3		dBm
Average launch power of OFF transmitter (max)	-39		dBm
Extinction ratio (min)	8.2		dB
$RIN_{15}OMA$ (max)	-120		dB/Hz
Transmitter and dispersion penalty (TDP) @ 0 to 1000 ps/nm residual CD	0*		dB
Optical return loss tolerance (max)	15		dB
Transmitter reflectance (max)	-10		dB
Transmitter eye mask definition {X1, X2, X3, Y1, Y2, Y3}	{0.25, 0.4, 0.45, 0.25, 0.28, 0.4}		UI
* A negative chirp transmitter is assumed, which results in a negative dispersion penalty in the positive dispersion region.			

Table 5 - OLT Receive Characteristics

Parameter	10GBASE-SP1-Dx	10/2.5GBASE-SP1-Dx	Unit
Signaling speed (range)	10.3125 ± 100 ppm	2.578125 ± 100 ppm	GBd
Channel wavelength range	1549.24 to 1561.50		nm
Bit error ratio (max)	10^{-3}		
Average receive power (max)	-6	-6	dBm
Damage Threshold	-5	-5	dBm
Receiver sensitivity (max)	-28	-30	dBm
Receiver reflectance (max)	-12	-12	dB
Signal detect threshold (min)	-45	-45	dBm
Stressed receiver sensitivity (max)	-27	-29.5	dBm

1.7. PMD to MDI Optical Specifications for ONU PMDs

Table 6 - ONU Transmit Characteristics

Parameter	10GBASE-SP1-Uyz	10/2.5GBASE-SP1-Uyz	Unit
Signaling speed (range)	10.3125 ± 100 ppm	2.578125 ± 100 ppm	GBd
Channel wavelengths: All channels included between y and z. When only y, the identified single channel.	y or z = 0: 1561.42 ± 0.08 y or z = 1: 1560.61 ± 0.08 y or z = 2: 1559.79 ± 0.08 y or z = 3: 1558.98 ± 0.08 y or z = 4: 1558.17 ± 0.08 y or z = 5: 1557.36 ± 0.08 y or z = 6: 1556.56 ± 0.08 y or z = 7: 1555.75 ± 0.08 y or z = 8: 1554.94 ± 0.08 y or z = 9: 1554.13 ± 0.08 y or z = A: 1553.33 ± 0.08 y or z = B: 1552.52 ± 0.08 y or z = C: 1551.72 ± 0.08 y or z = D: 1550.92 ± 0.08 y or z = E: 1550.12 ± 0.08 y or z = F: 1549.32 ± 0.08		nm
Side-mode suppression ratio (SMSR) (min)*	38	38	dB
Average launch power (max)	see Figure 3	see Figure 4	dBm
Average launch power (min)	see Figure 3	see Figure 4	dBm
Transmitter and dispersion penalty (TDP) @ -450 ps/nm residual CD @ +450 ps/nm residual CD @ +900 ps/nm residual CD	 1 1 N/A	 0.5 0.5 0.5	dB
Average launch power of OFF transmitter (max)	-45	-45	dBm
Extinction ratio (min)	see Figure 3	see Figure 4	dB
$RIN_{15}OMA$ (max)	-128	-128	dB/Hz
Optical return loss tolerance (max)	15	15	dB
Transmitter reflectance (max)	-10	-10	dB
Transmitter eye mask definition {X1, X2, X3, Y1, Y2, Y3}	{0.25, 0.4, 0.45, 0.25, 0.28, 0.4}		UI
Turn-on time (max)	128		ns
Turn-off time (max)	128		ns
* It is assumed the SMSR is measured with only the DC laser bias (no data modulation).			

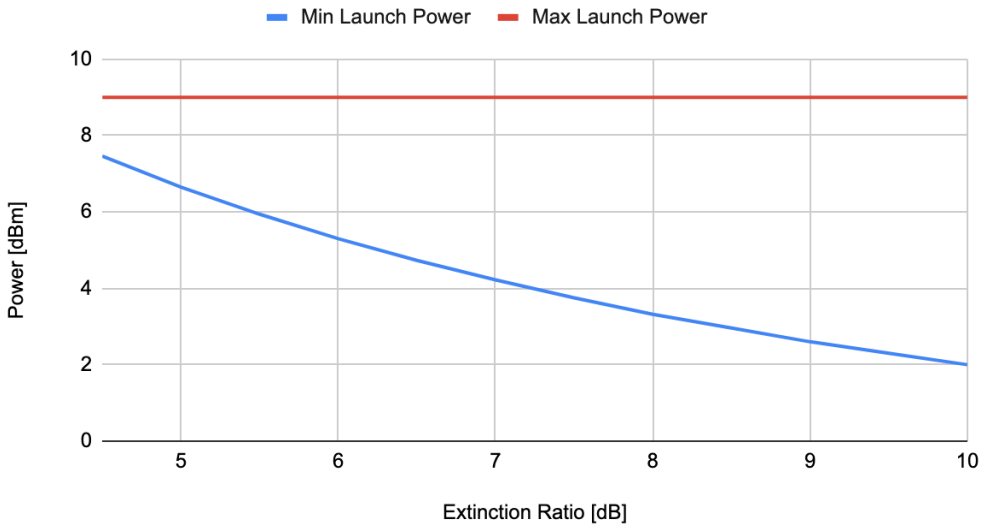

Figure 3 - Acceptable ONU Launch Power at 10Gb/s

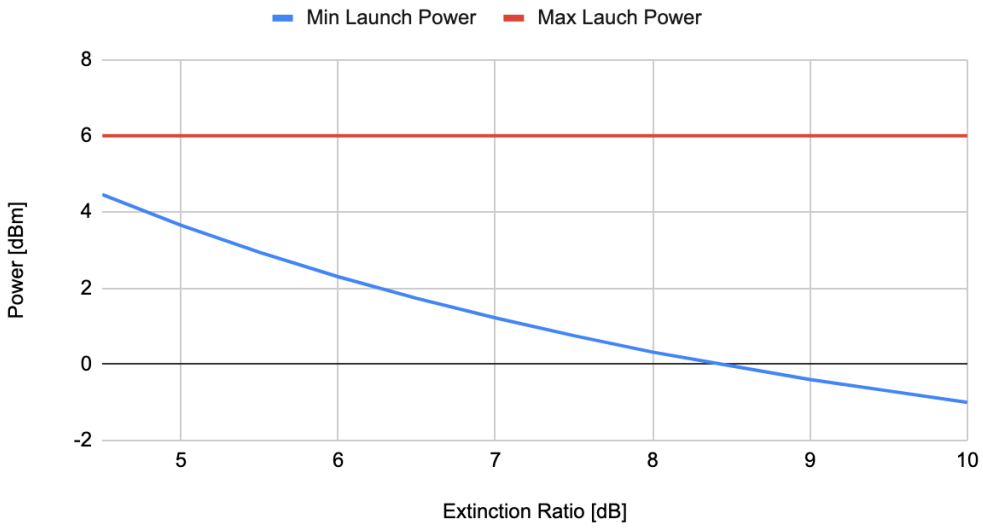

Figure 4 - Acceptable ONU Launch Power at 2.5Gb/s

Table 7 - ONU Receive Characteristics

Parameter	10GBASE-SP1-Uyz	10/2.5GBASE-SP1-Uyz	Unit
Signaling speed (range)	10.3125 ± 100 ppm		GBd
Channel wavelength range	1585.44 to 1598.03		nm
Bit error ratio (max)	10^{-3}		
Average receive power (max)	-8		dBm
Damage Threshold	-2		dBm
Receiver sensitivity (max)	-29		dBm
Receiver reflectance (max)	-12		dB
Signal detect threshold (min)	-44		dBm
Stressed receiver sensitivity (max)	-29		dBm

1.8. Black Link Specification

Table 8 - Optical Path OLT to ONU, 10Gb/s

Parameter	OLT to ONU, 10Gb/s	Unit
Maximum ripple		dB
Maximum (residual) chromatic dispersion		ps/nm
Minimum (residual) chromatic dispersion		ps/nm
Minimum optical return loss		dB
Maximum discrete reflectance		dB
Maximum differential group delay		ps
Maximum inter-channel crosstalk		dB
Maximum interferometric crosstalk		dB
Maximum optical path OSNR penalty		dB

Table 9 - Optical Path ONU to OLT, 10Gb/s

Parameter	ONU to OLT, 10Gb/s	Unit
Maximum ripple		dB
Maximum (residual) chromatic dispersion		ps/nm
Minimum (residual) chromatic dispersion		ps/nm
Minimum optical return loss		dB
Maximum discrete reflectance		dB
Maximum differential group delay		ps
Maximum inter-channel crosstalk		dB
Maximum interferometric crosstalk		dB
Maximum optical path OSNR penalty		dB

Table 10 - Optical Path ONU to OLT, 2.5Gb/s

Parameter	ONU to OLT, 2.5Gb/s	Unit
Maximum ripple		dB
Maximum (residual) chromatic dispersion		ps/nm
Minimum (residual) chromatic dispersion		ps/nm
Minimum optical return loss		dB
Maximum discrete reflectance		dB
Maximum differential group delay		ps
Maximum inter-channel crosstalk		dB
Maximum interferometric crosstalk		dB
Maximum optical path OSNR penalty		dB

Annex 1 (Informative)

Figure 5 shows an example of Super-PON black link implementation, able to satisfy the Super-PON objectives.

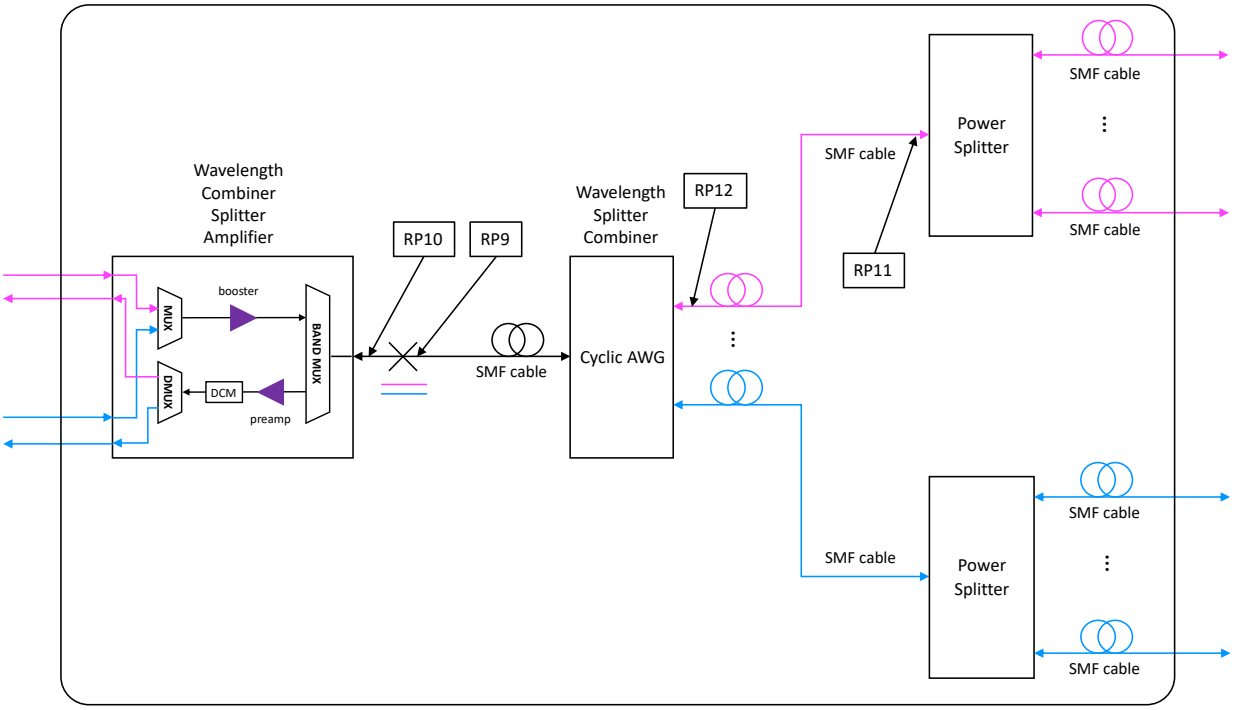

Figure 5 - Example of Black Link Implementation

Reference points RP9 and RP11 refer to the downstream channel, while test points RP12 and RP10 refer to the upstream channel.