

99. Physical Medium Attachment (PMA) Sublayer, Physical Medium Dependent (PMD) Sublayer, and Medium for Coaxial Distribution Networks, Type <EPoC_PMD_NAME>.....	5	2
		3
99.1 Overview.....	5	4
99.1.1 Terminology and Conventions.....	5	5
99.1.2 Goals and Objectives.....	5	6
99.1.3 Positioning of the PMA and PMD Sublayers within the IEEE 802.3 Architecture.....	5	7
99.1.4 PMA/PMD Block Diagram.....	6	8
99.2 PMA Functional Specification.....	6	9
99.2.1 PMA Service Interface.....	6	10
99.2.1.1 Delay Constraints.....	6	11
99.2.1.1.1 Relative Processing Delays.....	7	12
99.2.1.2 PMA_UNITDATA.request.....	7	13
99.2.1.3 PMA_UNITDATA.indication.....	7	14
99.2.1.4 PMA_SIGNAL.request.....	7	15
99.2.1.5 PMA_SIGNAL.indication.....	7	16
99.2.2 Downstream OFDM Numerology.....	7	17
99.2.2.1 Number of Channels, Channel size and Sampling Frequency.....	7	18
99.2.2.2 FFT size(s).....	7	19
99.2.2.3 Available Subcarriers.....	7	20
99.2.2.4 Cyclic prefix.....	7	21
99.2.2.5 Pulse Window Shaping (alpha and filter type).....	7	22
99.2.2.6 Guard Size.....	7	23
99.2.2.7 Cyclic Prefix Prepend.....	7	24
99.2.3 Upstream OFDMA Numerology.....	8	25
99.2.3.1 Number of Channels, Channel Size, and Sampling Frequency.....	8	26
99.2.3.2 Sub-Band width(s).....	8	27
99.2.3.3 FFT size(s).....	8	28
99.2.3.4 Subcarrier width.....	8	29
99.2.3.5 Number of Subcarriers.....	8	30
99.2.3.6 Subcarrier Group Size.....	8	31
99.2.3.7 Subcarrier Per Transmitter.....	8	32
99.2.3.8 Available Subcarriers.....	8	33
99.2.3.9 Cyclic prefix/Guard Size.....	8	34
99.2.3.10 Pulse Window Shaping (alpha and filter type).....	8	35
99.3 PMD Functional Specification.....	8	36
99.3.1 PMD Service Interface.....	8	37
99.3.1.1 Delay Constraints.....	8	38
99.3.1.1.1 Relative Processing Delays.....	9	39
99.3.1.2 PMD_UNITDATA.request.....	9	40
99.3.1.3 PMD_UNITDATA.indication.....	9	41
99.3.1.4 PMD_SIGNAL.request.....	9	42
99.3.1.5 PMD_SIGNAL.indication.....	9	43
99.3.2 PMD Transmit Function.....	9	44
99.3.2.1 Modulation Formats.....	9	45
99.3.2.1.1 Total Information Data Rate for OFDM Channels.....	9	46
99.3.2.2 Frequency Plan.....	9	47
99.3.2.2.1 FDD/TDD DS.....	9	48
99.3.2.2.2 TDD US.....	9	49
99.3.2.3 Carrier Muting.....	9	50
99.3.3 Downstream Transmitter Requirements.....	9	51
99.3.3.1 Transmit Power Requirements.....	9	52
99.3.3.1.1 OFDM Transmit Power Calculations.....	10	53
99.3.3.1.2 Transmit Power Step Size.....	10	54

99.3.3.1.3	PAPR	10	1
99.3.3.2	Fidelity Requirements	10	2
99.3.3.2.1	Spectral Nulling	10	3
99.3.3.2.2	Adjacent Channel Spurious Emissions	10	4
99.3.3.2.3	Spurious Emissions in the Frequency Range.....	10	5
99.3.3.2.4	Spurious Emissions During Burst On/Off Transients.....	10	6
99.3.3.2.5	Modulation Error Ratio.....	10	7
99.3.3.2.6	Filter Distortion.....	10	8
99.3.3.2.7	Carrier Phase Noise	10	9
99.3.3.2.8	Channel Frequency Accuracy.....	10	10
99.3.3.2.9	Modulation Rate Accuracy	10	11
99.3.3.2.10	Modulation Timing Jitter	11	12
99.3.4	Upstream Transmitter Requirements	11	13
99.3.4.1	CNU Transmitter Pre-Equalizer	11	14
99.3.4.2	CNU Transmit Power Requirements	11	15
99.3.4.2.1	OFDMA Transmit Power Calculations	11	16
99.3.4.2.2	Transmit Power Step Size.....	11	17
99.3.4.2.3	Transmit Power Requirements with Multiple Transmitters	11	18
99.3.4.2.4	PAPR	11	19
99.3.4.3	Burst Timing Ramp Up/Down.....	11	20
99.3.4.4	Upstream Frequency Agility and Range.....	11	21
99.3.4.5	CNU Transmitter Capabilities	11	22
99.3.4.6	CNU Transmitter Fidelity Requirements.....	11	23
99.3.4.6.1	Adjacent Channel Spurious Emissions	11	24
99.3.4.6.2	Spurious Emissions in the Upstream Frequency Range	11	25
99.3.4.6.3	Spurious Emissions During Burst On/Off Transients.....	12	26
99.3.4.6.4	Modulation Error Ratio.....	12	27
99.3.4.6.5	Carrier Phase Noise	12	28
99.3.4.6.6	Channel Frequency Accuracy.....	12	29
99.3.4.6.7	Modulation Rate Accuracy	12	30
99.3.4.6.8	Modulation Timing Jitter	12	31
99.3.4.6.9	Clock Recovery.....	12	32
99.4	PMD Receive Function.....	12	33
99.4.1	CNU Receive	12	34
99.4.1.1	Input Signal Characteristics at CNU Receiver	12	35
99.4.1.2	Tuner Frequency Range.....	12	36
99.4.1.3	Frame Error Rate	12	37
99.4.1.4	Input Return Loss.....	13	38
99.4.1.5	Input Impedance	13	39
99.4.1.6	Image Rejection Performance.....	13	40
99.4.1.6.1	Adjacent Channel.....	13	41
99.4.1.6.2	Non-Adjacent Channel	13	42
99.4.1.7	Multi-Channel Receiver Operation.....	13	43
99.4.1.8	Reconfiguration of CNU Receiver	13	44
99.4.1.9	PMD Transmit Enable Function (CNU).....	13	45
99.4.1.10	PMD Auto-Negotiation Function	13	46
99.4.2	CLT Receive	13	47
99.4.2.1	Input Signal Characteristics at CLT Receiver	13	48
99.4.2.2	CLT Tuner Frequency Range	13	49
99.4.2.3	CLT Frame Error Rate	13	50
99.4.2.4	Input Return Loss.....	13	51
99.4.2.5	Input Impedance	13	52
99.4.2.6	Image Rejection Performance.....	13	53
99.4.2.6.1	Adjacent Channel.....	14	54

99.4.2.6.2	Non-Adjacent Channel	14	1
99.4.2.7	Multi-Channel Receiver Operation.....	14	2
99.4.2.8	PMD Signal Detect	14	3
99.4.2.8.1	CNU PMD Signal Detect.....	14	4
99.4.2.8.2	CLT PMD Signal Detect.....	14	5
99.5	Definitions of Parameters and Measurement Methods	14	6
99.5.1	Insertion Loss?.....	14	7
99.5.2	Test Patterns.....	14	8
99.5.3	Frequency and Frequency Range Measurement.....	14	9
99.5.4	RF Power Measurements	14	10
99.5.5	Transmit Waveform and MER (Constellation diagram)	14	11
99.5.6	Transmit Penalty?	14	12
99.5.7	Receive Sensitivity	15	13
99.5.8	Stressed Receiver Conformance Test	15	14
99.5.9	Jitter Measurements	15	15
99.5.10	Transmitter On/Off Timing Measurements	15	16
99.5.11	Receiver Settling Timing Measurement	15	17
99.6	Environmental, Safety, and Labeling	15	18
99.6.1	General Safety.....	15	19
99.6.2	RF Safety	15	20
99.6.3	Installation	15	21
99.6.4	Environment.....	15	22
99.6.5	PMD Labeling?.....	15	23
99.7	Channel Characteristics	15	24
99.7.1	Coaxial Cabling Model.....	16	25
99.7.2	Coaxial Cable.....	16	26
99.7.3	Coaxial Connectors.....	16	27
99.7.4	Medium Dependent Interface (MDI).....	16	28
99.8	EEE Capability	16	29
99.9	TimeSync Capability	16	30
99.10	Protocol implementation conformance statement (PICS) proforma for Clause 100, Physical Medium Dependent (PMD) sublayer and medium for coaxial distribution networks, type EPoc_PMD_Name	16	31 32 33
			34
			35
			36
			37
			38
			39
			40
			41
			42
			43
			44
			45
			46
			47
			48
			49
			50
			51
			52
			53
			54

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54

99. Physical Medium Attachment (PMA) Sublayer, Physical Medium Dependent (PMD) Sublayer, and Medium for Coaxial Distribution Networks, Type <EPoC_PMD_NAME>

99.1 Overview

This clause describes the Physical Medium Attachment (PMA), the Physical Medium Dependent (PMD) sublayer, and Medium Dependent Interface (MDI) used with {EPoC_PMD_NAME} point-to-multipoint (P2MP) networks. These are passive or active multipoint coaxial distribution networks (CDN) that connect multiple DTEs using a single shared coaxial link. The architecture is asymmetric, based on a tree and branch topology utilizing passive or active coaxial splitters. This type of network requires that the Multipoint MAC Control sublayer exists above MAC instances, as described in {Clause 102}.

99.1.1 Terminology and Conventions

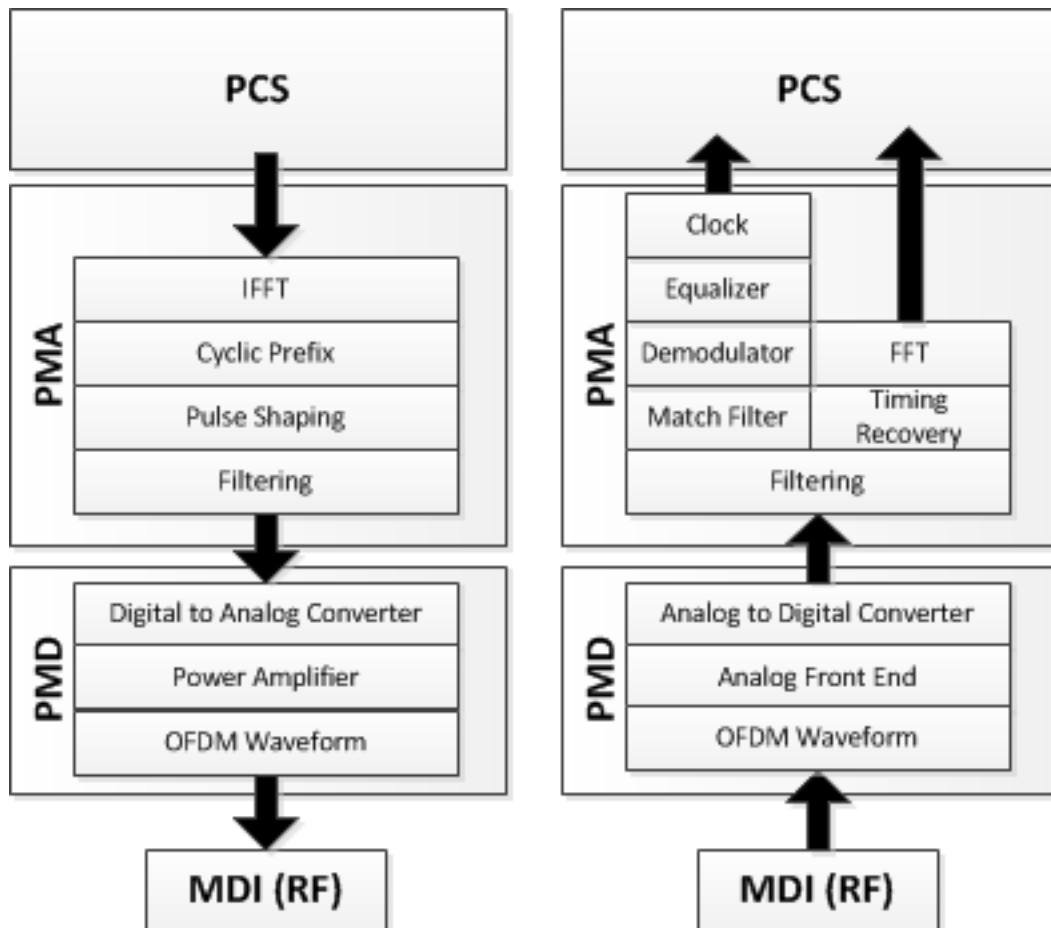
The notation used in the state diagrams in this clause follows the conventions in {21.5}. Should there be a discrepancy between a state diagram and descriptive text, the state diagram prevails. The notation ++ after a counter indicates it is to be incremented by 1. The notation — after a counter indicates it is to be decremented by 1. The notation -= after a counter indicates that the counter value is to be decremented by the following value. The notation += after a counter indicates that the counter value is to be incremented by the following value. Code examples given in this clause adhere to the style of the “C” programming language.

99.1.2 Goals and Objectives

99.1.3 Positioning of the PMA and PMD Sublayers within the IEEE 802.3 Architecture

99.1.4 PMA/PMD Block Diagram

Figure 1—PMA/PMD Block Diagram



This section might need to be expanded into much more detail than what was shown in 10G-EPON. What we need to show is interaction between PMD and PMA similar to Figure 95-3, but we can also show more details on internal PMD structure, relative to functional blocks etc.

99.2 PMA Functional Specification

99.2.1 PMA Service Interface

99.2.1.1 Delay Constraints

A critical subclause which provides delay constraints for PMD we specify for EPoC. Usually, we provide delay and variability (jitter) in here, expressed in units of TQ.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54

99.2.1.1.1 Relative Processing Delays

Requirements for messaging processing delay through the PMD

99.2.1.2 PMA_UNITDATA.request

Describes how the data is transferred from PMA (digital interface) into analog front-end

99.2.1.3 PMA_UNITDATA.indication

Describes how the data is transferred to PMA (digital interface) from analog front-end

99.2.1.4 PMA_SIGNAL.request

Describes how the PMA controls the transmitter state (on / off). It will be needed for burst mode transmission. We could also control the status of the auto-negotiation process, data rate control etc. To be discussed in more detail later.

99.2.1.5 PMA_SIGNAL.indication

Describes how the PMA learns about the incoming signal (presence of data). It will be needed for burst mode transmission and continuous mode transmission alike. Here, we will be also able to indicate whether the link is operating, in hunting mode, stable, etc.

99.2.2 Downstream OFDM Numerology

99.2.2.1 Number of Channels, Channel size and Sampling Frequency

99.2.2.2 FFT size(s)

99.2.2.3 Available Subcarriers

Total subcarriers available for payload after all of the overhead is accounted for.

99.2.2.4 Cyclic prefix

99.2.2.5 Pulse Window Shaping (alpha and filter type)

99.2.2.6 Guard Size

99.2.2.7 Cyclic Prefix Prepend

Describes the size and structure of the cyclic prefix

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54

99.2.3 Upstream OFDMA Numerology

1

2

3

4

99.2.3.1 Number of Channels, Channel Size, and Sampling Frequency

5

6

7

8

99.2.3.2 Sub-Band width(s)

9

10

11

12

99.2.3.3 FFT size(s)

13

14

15

16

99.2.3.4 Subcarrier width

17

18

19

20

99.2.3.5 Number of Subcarriers

21

22

23

24

99.2.3.6 Subcarrier Group Size

25

26

27

28

99.2.3.7 Subcarrier Per Transmitter

29

30

31

32

99.2.3.8 Available Subcarriers

33

34

Total subcarriers available for payload after all of the overhead is accounted for.

35

36

99.2.3.9 Cyclic prefix/Guard Size

37

38

39

40

99.2.3.10 Pulse Window Shaping (alpha and filter type)

41

42

43

44

45

99.3 PMD Functional Specification

46

47

99.3.1 PMD Service Interface

48

49

99.3.1.1 Delay Constraints

50

51

A critical subclause which provides delay constraints for PMD we specify for EPoC. Usually, we provide delay and variability (jitter) in here, expressed in units of TQ.

52

53

54

99.3.1.1.1 Relative Processing Delays

Requirements for messaging processing delay through the PMD

99.3.1.2 PMD_UNITDATA.request

Describes how the data is transferred from PMD (digital interface) into analog front-end

99.3.1.3 PMD_UNITDATA.indication

Describes how the data is transferred to PMD (digital interface) from analog front-end

99.3.1.4 PMD_SIGNAL.request

Describes how the PMD controls the transmitter state (on / off). It will be needed for burst mode transmission. We could also control the status of the auto-negotiation process, data rate control etc. To be discussed in more detail later.

99.3.1.5 PMD_SIGNAL.indication

Describes how the PMD learns about the incoming signal (presence of data). It will be needed for burst mode transmission and continuous mode transmission alike. Here, we will be also able to indicate whether the link is operating, in hunting mode, stable, etc.

99.3.2 PMD Transmit Function

99.3.2.1 Modulation Formats

Details the modulation formats that must be supported for each channel - PLC, Data, and pilots for DS and US (e.g.256QAM, 512QAM, 1024QAM etc.)

99.3.2.1.1 Total Information Data Rate for OFDM Channels

Describes the data capacity of the data and signaling channels

99.3.2.2 Frequency Plan

Range of transmitter frequencies

99.3.2.2.1 FDD/TDD DS

99.3.2.2.2 TDD US

99.3.2.3 Carrier Muting

99.3.3 Downstream Transmitter Requirements

99.3.3.1 Transmit Power Requirements

Transmit power requirements for the FCU, including range of reported transmit power per channel, step size of power commands, step size accuracy, and absolute accuracy of FCU.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54

99.3.3.1.1 OFDM Transmit Power Calculations	1
	2
	3
	4
99.3.3.1.2 Transmit Power Step Size	5
	6
	7
	8
99.3.3.1.3 PAPR	9
	10
	11
	12
99.3.3.2 Fidelity Requirements	13
	14
	15
	16
99.3.3.2.1 Spectral Nulling	17
	18
	19
	20
99.3.3.2.2 Adjacent Channel Spurious Emissions	21
	22
	23
	24
99.3.3.2.3 Spurious Emissions in the Frequency Range	25
	26
	27
	28
99.3.3.2.4 Spurious Emissions During Burst On/Off Transients	29
	30
	31
	32
99.3.3.2.5 Modulation Error Ratio	33
	34
Includes definitions and requirements	35
	36
99.3.3.2.6 Filter Distortion	37
	38
	39
	40
99.3.3.2.7 Carrier Phase Noise	41
	42
	43
	44
99.3.3.2.8 Channel Frequency Accuracy	45
	46
	47
	48
99.3.3.2.9 Modulation Rate Accuracy	49
	50
	51
	52
	53
	54

99.3.3.2.10 Modulation Timing Jitter

1

2

3

4

99.3.4 Upstream Transmitter Requirements

5

6

99.3.4.1 CNU Transmitter Pre-Equalizer

7

8

9

10

99.3.4.2 CNU Transmit Power Requirements

11

12

Transmit power requirements the CNU, including range of reported transmit power per channel, step size of power commands, step size accuracy, and absolute accuracy of CNU.

13

14

15

99.3.4.2.1 OFDMA Transmit Power Calculations

16

17

18

19

99.3.4.2.2 Transmit Power Step Size

20

21

22

23

99.3.4.2.3 Transmit Power Requirements with Multiple Transmitters

24

25

26

27

99.3.4.2.4 PAPR

28

29

30

31

99.3.4.3 Burst Timing Ramp Up/Down

32

33

34

35

99.3.4.4 Upstream Frequency Agility and Range

36

37

38

39

99.3.4.5 CNU Transmitter Capabilities

40

41

Describes what CNU capabilities the CNU must report to the FCU and OLT - TDD capable, for example

42

43

99.3.4.6 CNU Transmitter Fidelity Requirements

44

45

46

47

99.3.4.6.1 Adjacent Channel Spurious Emissions

48

49

50

51

99.3.4.6.2 Spurious Emissions in the Upstream Frequency Range

52

53

54

99.3.4.6.3 Spurious Emissions During Burst On/Off Transients

1
2
3

99.3.4.6.4 Modulation Error Ratio

4
5

99.3.4.6.5 Carrier Phase Noise

6
7
8

99.3.4.6.6 Channel Frequency Accuracy

9
10
11

99.3.4.6.7 Modulation Rate Accuracy

12
13
14

99.3.4.6.8 Modulation Timing Jitter

15
16
17

99.3.4.6.9 Clock Recovery

18
19
20

99.4 PMD Receive Function

21
22
23

99.4.1 CNU Receive

24
25
26

99.4.1.1 Input Signal Characteristics at CNU Receiver

Describes the characteristics of the input signal at the receiver(e.g, signal level, power spectral density (PSD) etc.),.

27
28
29

99.4.1.2 Tuner Frequency Range

30
31
32

99.4.1.3 Frame Error Rate

Specifies the downstream frame error ratio. From objectives: better than 10^{-6} at the MAC/PLS service interface. Complete details required (channel conditions, frame sizes, etc.).

33
34
35

36
37
38

39
40
41

42
43
44

45
46
47

48
49
50

51
52
53

54

99.4.1.4 Input Return Loss

1

99.4.1.5 Input Impedance

2

3

99.4.1.6 Image Rejection Performance

4

5

For example: Performance MUST be met with an analog or a digital signal at +10 dBc in any portion of the RF band.

6

7

8

9

99.4.1.6.1 Adjacent Channel

10

99.4.1.6.2 Non-Adjacent Channel

11

12

99.4.1.7 Multi-Channel Receiver Operation

13

14

Are there any requirements for multi-channel receiver requirements needed?

15

16

99.4.1.8 Reconfiguration of CNU Receiver

17

18

Specifies requirements for the CNU to dynamically change the receive channel parameters it is currently using. This could be used for modulation profiles, bit loading, etc.

19

20

21

99.4.1.9 PMD Transmit Enable Function (CNU)

22

23

Assuming burst mode transmission is done in upstream only

24

25

99.4.1.10 PMD Auto-Negotiation Function

26

27

This subclause will be brand new and will describe the process of auto-negotiating data rate across EPoC link

28

29

30

99.4.2 CLT Receive

31

32

99.4.2.1 Input Signal Characteristics at CLT Receiver

33

34

Describes the characteristics of the input signal at the receiver (e.g, signal level, power spectral density (PSD), .

35

36

37

99.4.2.2 CLT Tuner Frequency Range

38

39

99.4.2.3 CLT Frame Error Rate

40

41

Specifies the downstream frame error ratio. From objectives: better than 5×10^{-5} at the MAC/PLS service interface. Complete details required (channel conditions, frame sizes, etc.).

42

43

44

99.4.2.4 Input Return Loss

45

46

99.4.2.5 Input Impedance

47

48

99.4.2.6 Image Rejection Performance

49

50

Performance MUST be met with an analog or a digital signal at +10 dBc in any portion of the RF band.

51

52

53

54

99.4.2.6.1 Adjacent Channel

1

99.4.2.6.2 Non-Adjacent Channel

2

3

99.4.2.7 Multi-Channel Receiver Operation

4

5

Are there any requirements for multi-channel receiver requirements needed? Not defined yet.

6

7

99.4.2.8 PMD Signal Detect

8

9

Table similar to Table 95-4 will need to be specified in here, indicating when and how signal presence is detected and when it is not

10

11

12

99.4.2.8.1 CNU PMD Signal Detect

13

14

15

99.4.2.8.2 CLT PMD Signal Detect

16

17

18

19

20

21

99.5 Definitions of Parameters and Measurement Methods

22

23

10G-EPON spec contains several subclauses which are not going to be applicable to coaxial plant. The list below accounts for the subclauses most likely to apply to coaxial section, but also other (new) subclauses are possible, as long as TF agrees to their presence.

24

25

26

27

99.5.1 Insertion Loss?

28

29

Is this channel model defined

30

31

99.5.2 Test Patterns

32

33

34

35

99.5.3 Frequency and Frequency Range Measurement

36

37

38

39

99.5.4 RF Power Measurements

40

41

42

43

99.5.5 Transmit Waveform and MER (Constellation diagram)

44

45

46

47

99.5.6 Transmit Penalty?

48

49

50

51

52

53

54

99.5.7 Receive Sensitivity

1
2
3

99.5.8 Stressed Receiver Conformance Test

4
5

We will need to discuss whether such a test makes sense for RF devices.

6
7

99.5.9 Jitter Measurements

8
9

99.5.10 Transmitter On/Off Timing Measurements

10
11

Might be needed if transmitter is indeed switched on/off between bursts.

12
13

99.5.11 Receiver Settling Timing Measurement

14
15

Might be needed for CLT Rx, where bursts from individual CNU's are incoming time interleaved.

16
17

99.6 Environmental, Safety, and Labeling

18
19

10G-EPON spec contains several subclauses which are not going to be applicable to coaxial plant. The list below accounts for the subclauses most likely to apply to coaxial section, but also other (new) subclauses are possible, as long as TF agrees to their presence. The set below is a minimum set which has been used for PMD description in the past. This set is likely to be extended

20
21

99.6.1 General Safety

22
23

99.6.2 RF Safety

24
25

99.6.3 Installation

26
27

99.6.4 Environment

28
29

99.6.5 PMD Labeling?

30
31

99.7 Channel Characteristics

32
33

The channel is composed of coax, active components (amps,) and passive components (taps, etc). This should refer to the channel model appendix.

34
35

36
37

38
39

40
41

42
43

44
45

46
47

48
49

50
51

52
53

54

99.7.1 Coaxial Cabling Model

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54

99.7.2 Coaxial Cable

99.7.3 Coaxial Connectors

99.7.4 Medium Dependent Interface (MDI)

99.8 EEE Capability

This subclause might contain summary of the EEE capabilities for this PMD type. Given that it is a new PMD design, the suggestion is to in-build EEE capability from day one, rather than add it in a fashion similar to P802.3az project. This material will all be new in 802.3bn

99.9 TimeSync Capability

This subclause might contain summary of the TimeSync capabilities for this PMD type. Given that it is a new PMD design, we can embed TimeSync capability from day one. This involves primarily guaranteeing repeatable and stable delay as well as support for specific capability registers. See Clause 90 for more details.

99.10 Protocol implementation conformance statement (PICS) proforma for Clause 100, Physical Medium Dependent (PMD) sublayer and medium for coaxial distribution networks, type EPoc_PMD_Name

To be filled in once the main spec is ready (Clause 100 work is largely technically complete)