Annex 191B: apply the 15 MHz HPF to all TX SNDR measurements, with or without PoC (Np = 300 retained)

Saket Sakunia, Wyant Chan, Ragnar Jonsson

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Comments on D2.3: 191.6.2.5, 191B.1 - 191B.6 (PICS)

Background: transmitter linearity and Annex 191B in D2.3

- 191.6.2.5: TX linearity in test mode 4 (PRBS13Q, MultiG), test fixture 1, SNDR per 120D.3.1.2 / 120D.3.1.6
  - limits: 36 dB (10G), 33 dB (5G), 30 dB (2.5G)
  - "Annex 191B describes an additional High Pass Filter to be applied to the measured data when the DUT includes any low frequency high pass filtering (e.g. PoC/PoDL)"

- Annex 191B (normative), introduced to remove baseline wander (BLW) from PoC/PoDL networks (corners ~1-5 MHz)
  - 191B.2: required only when a low-frequency high-pass network is present; may be omitted otherwise; presence identified "by visible baseline wander" or from DUT knowledge
  - 191B.3: 1st-order HPF, fHPF = 15 MHz, on the captured MDI waveform, before the linear fit of 120D.3.1.6
  - 191B.4: group delay accounted for in alignment; Np = 300
  - 191B.5: report whether the HPF was applied; PICS HPFS optional (O)

- This contribution proposes: fHPF = 15 MHz for ALL SNDR measurements, with or without PoC; Np = 300 is retained (supporting data in this contribution)
  - data and analysis shown for 10G (PAM4, 36 dB): highest limit and longest PoC/PoDL tail in UI (worst case); at 5G / 2.5G the same tail is 2x / 4x shorter in UI and the limits are lower

Issue with the current text

- D2.3: the Annex 191B HPF is applied only when the DUT includes a low-frequency high-pass network (PoC/PoDL) (191.6.2.5, 191B.2)
  - Test equipment manufacturer has to add a test option: SNDR with HPF (PoC/PoDL present) and without HPF (not present)
  - and select the option per DUT (knowledge of the DUT / fixture), record it and the reason (191B.5), and handle the optional PICS item HPFS
- Proposed: apply the 15 MHz HPF to all TX SNDR measurements, with or without PoC/PoDL
  - one test procedure for every DUT: no option to add, no selection, nothing to justify
  - negligible effect on a DUT without PoC/PoDL (measured at 10G, Np = 300: -0.10 dB)
  - Np = 300 is retained (supporting data in this contribution)

Proposed changes

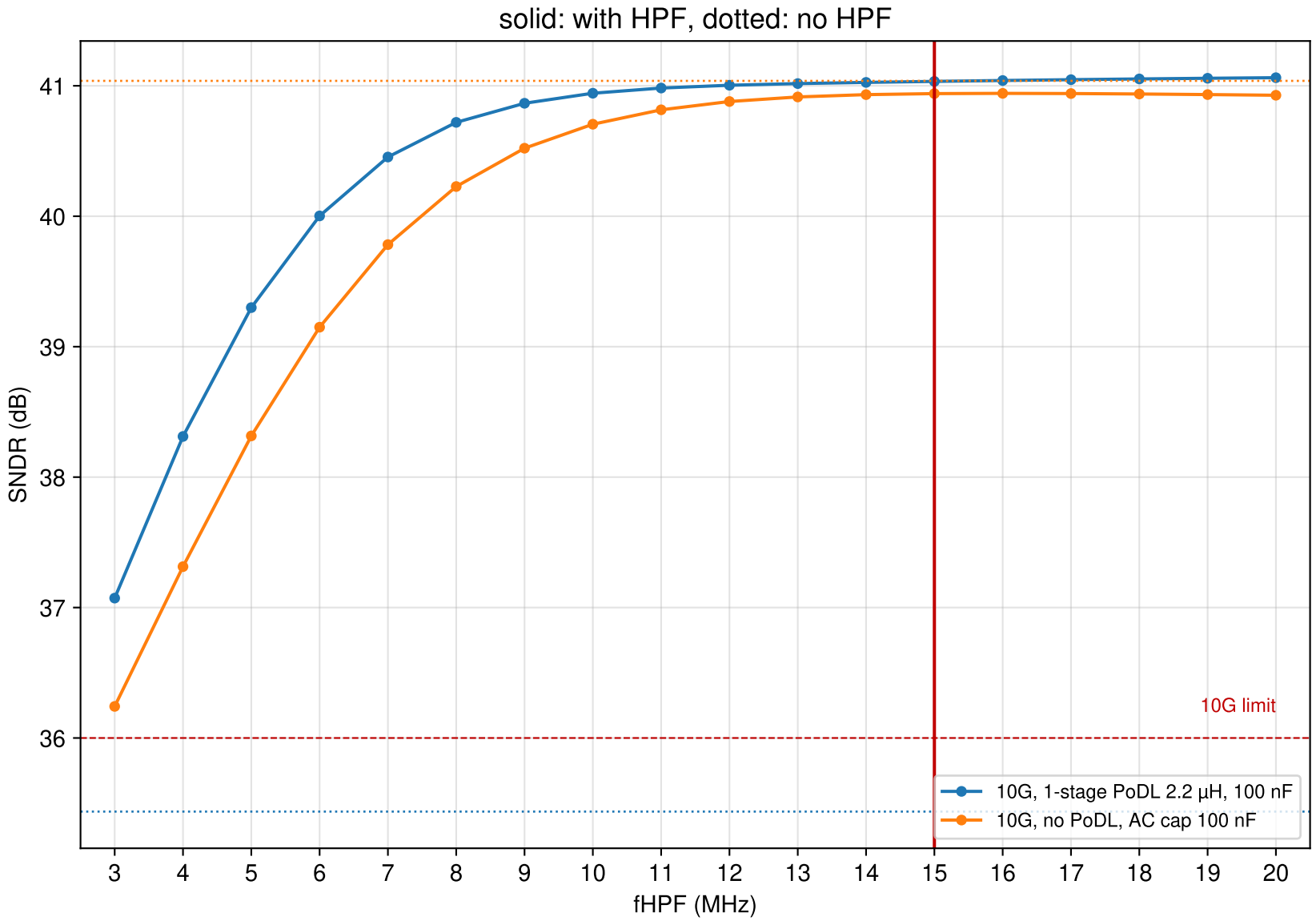
	D2.3	Proposed
Applicability (191B.2)	only with a LF high-pass network (PoC/PoDL), "visible BLW"	all TX SNDR measurements (191.6.2.5), with or without PoC/PoDL
HPF (191B.3)	1st order, fHPF = 15 MHz	unchanged: 1st order, fHPF = 15 MHz
Np (191B.4 b)	300	300 (no change)
Reporting (191B.5)	HPF applied yes/no + justification	fHPF and Np (no applicability decision)
PICS	HPFS: O	HPFS: M (or deleted)
191.6.2.5	HPF "when the DUT includes" LF high pass	HPF of Annex 191B applied to all measurements

Why apply fHPF = 15 MHz to all measurements

- One SNDR definition for every DUT and every lab
- Removes the dependence on fixture / AC-coupling / balun low-frequency response
- Negligible effect on a DUT without PoC (see measured summary)
  - 15 MHz is 0.27 % of the 10G symbol rate (5.625 GBd)
  - the fit models the HPF response as part of the pulse response (it is linear and time-invariant); only the part of the tail beyond Np is counted as error
  - HPF time constant: tau = 10.6 ns = 60 UI at 10G: Np = 300 covers 5 tau
- Trade-off: transmitter impairments below 15 MHz are not counted
  - these are outside the band of interest of the PHY (link partner EC/BLW correction) and are not measurable consistently in the presence of PoC/PoDL anyway

Measured: SNDR vs fHPF at Np = 300

Measured TM4 waveforms at the MDI, with and without PoDL; 10G PAM4, 32 samples/UI, Dp = 6

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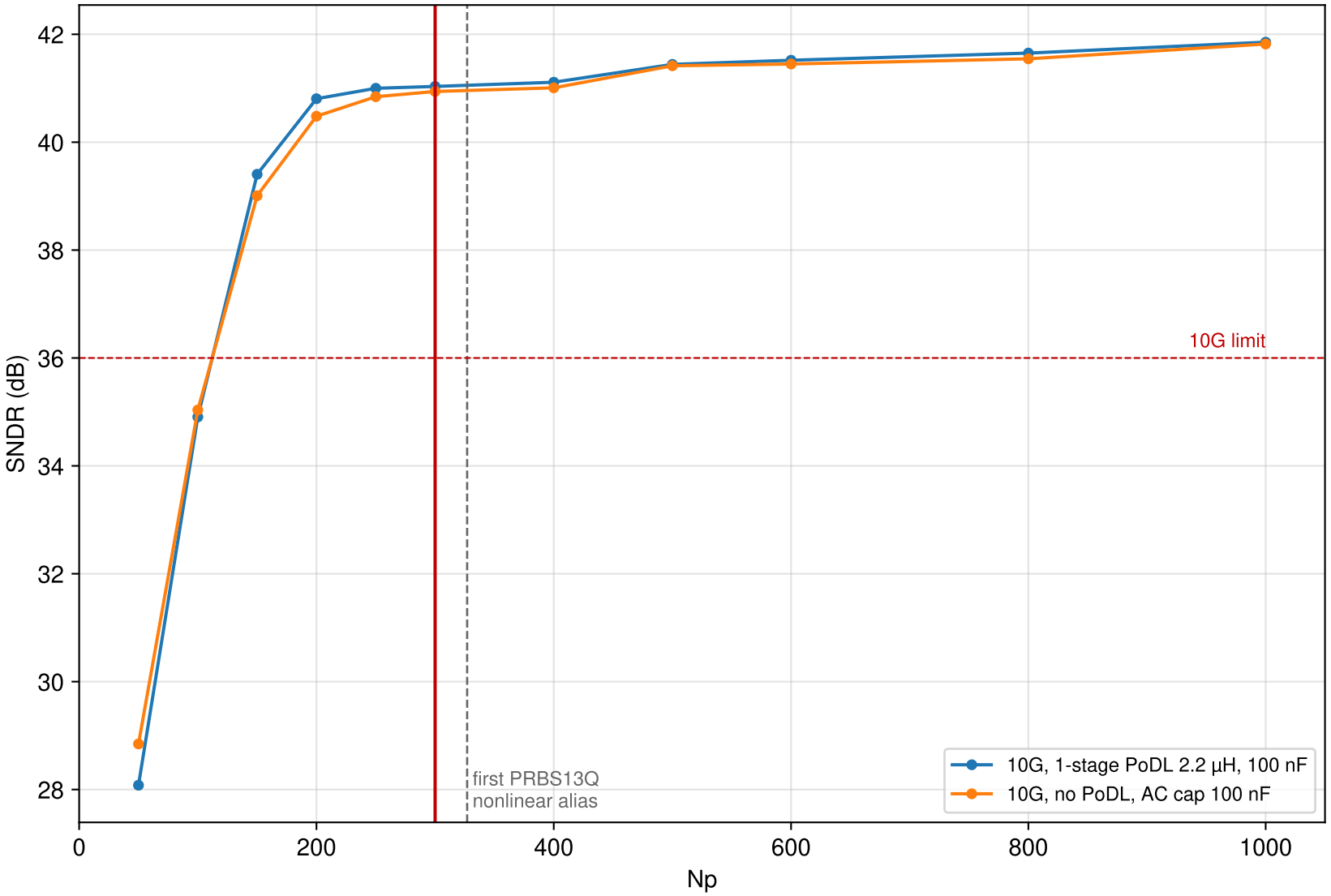
SNDR at Np = 300:

10G, 1-stage PoDL 2.2 µH, 100 nF
   no HPF  35.44 dB
   15 MHz  41.03 dB
10G, no PoDL, AC cap 100 nF
   no HPF  41.04 dB
   15 MHz  40.94 dB
```

- 12 - 20 MHz: SNDR flat within 0.1 dB, with and without PoDL
- Below ~8 MHz the HPF tail extends beyond Np = 300 and SNDR drops, also without PoDL

Measured: SNDR vs Np at fHPF = 15 MHz

Measured TM4 waveforms at the MDI, with and without PoDL; 10G PAM4, 32 samples/UI, Dp = 6

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SNDR at fHPF = 15 MHz:

10G, 1-stage PoDL 2.2 µH, 100 nF
   Np 300  41.03 dB
10G, no PoDL, AC cap 100 nF
   Np 300  40.94 dB
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- Np = 300 is on the plateau, with and without PoDL
- Slow rise beyond Np = 327: PRBS13Q nonlinear products alias into a longer fit

Measured summary: D2.3 rules vs proposed rules

Measured TM4 waveforms at the MDI, same TX design, with and without PoDL; Np = 300, Dp = 6

Case	no HPF, Np 300 (D2.3 without PoC)	15 MHz, Np 300 (proposed)	15 MHz vs no HPF	Limit
10G, 1-stage PoDL 2.2 µH, 100 nF	35.44 dB	41.03 dB	+5.60 dB	36 dB
10G, no PoDL, AC cap 100 nF	41.04 dB	40.94 dB	-0.10 dB	36 dB

Key measured findings

- Without PoC/PoDL, the 15 MHz HPF has a negligible effect (Np = 300)
  - SNDR change -0.10 dB (10G), +0.10 dB (2.5G)
- With PoC/PoDL and no HPF, SNDR is set by the PoDL network, not by the transmitter
  - same TX design: 35.4 dB with PoDL vs 41.0 dB without; the PoDL case fails the 36 dB limit
  - with the HPF: +5.6 dB vs no HPF (Np 300)
- With fHPF = 15 MHz and Np = 300, the PoDL case gives the same SNDR as the DUT without PoDL
  - 10G: 40.94 .. 41.03 dB -> SNDR reflects the transmitter
- Np = 300 is retained
  - the PoC/PoDL tail beyond 300 UI is small once the 15 MHz HPF is applied
  - a longer fit (Np > 327) would absorb PRBS13Q nonlinear products and over-estimate SNDR

Proposed text changes (D2.3)

Proposed remedy text (editorial licence granted)

191.6.2.5	... according to the test definition in 120D.3.1.2, with the high-pass filter specified in Annex 191B applied to the measured data. [delete: "Annex 191B describes an additional High Pass Filter to be applied to the measured data when the DUT includes any low frequency high pass filtering (e.g. PoC/PoDL)."]
191B.1	First paragraph: replace "when the device under test (DUT) or test configuration includes ... networks." with ". The HPF is applied to all transmitter linearity measurements, whether or not the DUT or test configuration includes a network with a low-frequency high-pass characteristic (e.g. PoC/PoDL bias-tee networks)."
191B.2	Replace with: "The procedure of this annex shall be applied to all transmitter SNDR measurements specified in 191.6.2.5." Delete the conditions on the presence of a low-frequency high-pass network and "visible baseline wander".
191B.3	"A first-order high-pass filter with fHPF = 15 MHz shall be applied to the captured MDI waveform for all SNDR measurements, with or without PoC/PoDL, before the linear fit of 120D.3.1.6."
191B.4 b)	No change: Np = 300 is retained (see measured SNDR vs Np).
191B.5	Report fHPF and Np used; delete the reporting of whether the filter was applied and why.
191B.6 PICS	HPFS: change Status O -> M (or delete the item); update STF1/STF2 to reference all SNDR measurements.

Annex 191B with the proposed changes (1/4)

Full D2.3 text; inserted text in blue underlined, deleted text in red struck through

191.6.2.5 Transmitter linearity

Transmitter linearity is specified with the transmitter in test mode 4, transmitting in MultiG mode, and using the transmitter test fixture 1 shown in Figure 191–39 for -T1 and Figure 191–40 for -V1, according to the test definition in 120D.3.1.2~~. Annex 191B describes an additional High Pass Filter to be applied to the measured data when the DUT includes any low frequency high pass filtering (e.g. PoC/PoDL)~~, with the high-pass filter specified in Annex 191B applied to the measured data.

The ideal PAM4 level of 1/3 should be used for effective symbol levels of ES1 and ES2 for a 10G+100MBASE-T1/V1 PHY. For 5G+100MBASE-T1/V1 or 2.5G+100MBASE-T1/V1 PHYs, only levels corresponding to PAM2 modulation (–1 and +1) are relevant and ES1, ES2 and levels at ±1/3 are not applicable in the calculation of signal-to-noise-and-distortion ratio (SNDR). The transmitter SNDR distortion, as specified in 120D.3.1.6, shall exceed 36 dB in 10G+100MBASE-T1/V1, 33 dB in 5G+100MBASE-T1/V1, and 30 dB in 2.5G+100MBASE-T1/V1 modes.

Annex 191B (normative)

High-Pass Filter for SNDR Testing with Low-Frequency High-Pass Networks

191B.1 Introduction

This annex specifies the high-pass filter (HPF) to be applied to the captured MDI waveform during the transmitter linearity test defined in 191.6.2.5 ~~when the device under test (DUT) or test configuration includes any network that introduces a low-frequency high-pass characteristic to the signal path. Examples include, but are not limited to, Power over Coax (PoC) and Power over Data Line (PoDL) bias-tee networks~~. The HPF is applied to all transmitter linearity measurements, whether or not the device under test (DUT) or test configuration includes a network that introduces a low-frequency high-pass characteristic to the signal path, such as Power over Coax (PoC) and Power over Data Line (PoDL) bias-tee networks. Low-frequency high-pass networks introduce slow baseline wander (BLW) in the captured MDI waveform. Without compensation, this BLW is misclassified as distortion or noise in the SNDR calculation defined in 191.6.2.5.

The transmitter SNDR distortion is defined as: $SNDR = 10 \log_{10} \frac{\sigma_p^2}{\sigma_e^2 + \sigma_n^2}$

Annex 191B with the proposed changes (2/4)

Full D2.3 text; inserted text in blue underlined, deleted text in red struck through

This causes the measured SNDR to underestimate the true transmitter performance. A 1st-order HPF applied to the captured MDI waveform removes the BLW contribution before the linear-fit estimation, restoring an accurate SNDR measurement. The corner frequency is chosen to be sufficiently above the typical low-frequency high-pass corner of PoC and PoDL networks (typically 1 MHz to 5 MHz) while preserving the signal band used in the SNDR computation per 120D.3.1.6. Applying the HPF to all measurements gives one test procedure for every DUT, independent of the presence of such a network; the effect on a DUT without a low-frequency high-pass network is negligible.

191B.2 Applicability

~~This annex is required when the DUT or test configuration includes any network that introduces a low-frequency high-pass transfer to the signal path, such as a PoC or PoDL bias-tee. It may be omitted when no such network is present or it is bypassed or disabled. The presence of a low-frequency high-pass may be identified by visible baseline wander in the captured MDI waveform or by knowledge of the DUT or fixture configuration.~~

The procedure of this annex shall be applied to all transmitter SNDR measurements specified in 191.6.2.5, whether or not the DUT or test configuration includes a PoC or PoDL bias-tee or any other network that introduces a low-frequency high-pass transfer to the signal path.

191B.3 HPF specification

~~When a low-frequency high-pass network is present, the~~ The following HPF shall be applied to the captured MDI waveform for all SNDR measurements, with or without PoC/PoDL, before the linear-fit pulse-response estimation defined in 120D.3.1.6.

Filter type: high-pass, corner frequency: fHPF = 15 MHz, filter order: 1st order

191B.4 Constraints

The following constraints shall apply when using the HPF per this annex:

a) Group delay introduced by the HPF shall be accounted for in symbol timing alignment prior to linear-fit estimation per 120D.3.1.6.

b) Np = 300 shall be used for the linear-fit estimation per 120D.3.1.6.

Annex 191B with the proposed changes (3/4)

Full D2.3 text; inserted text in blue underlined, deleted text in red struck through

191B.5 Reporting

The following information should be recorded: ~~whether HPF compensation was applied and the reason (e.g., PoC present, PoDL present, or other low-frequency high-pass network identified)~~ the HPF corner frequency fHPF and the value of Np used for the linear-fit estimation.

191B.6 Protocol implementation conformance statement (PICS) proforma for Annex 191B, High-Pass Filter for SNDR Testing with Low-Frequency High-Pass Networks[8]

191B.6.1 Introduction

The supplier of a protocol implementation that is claimed to conform to Annex 191B, High-Pass Filter for SNDR Testing with Low-Frequency High-Pass Networks, shall complete the following protocol implementation conformance statement (PICS) proforma.

A detailed description of the symbols used in the PICS proforma, along with instructions for completing the PICS proforma, can be found in Clause 21.

191B.6.2 Identification

191B.6.2.1 Implementation identification

Supplier[1]
Contact point for inquiries about the PICS[1]
Implementation Name(s) and Version(s)[1,3]
Other information necessary for full identification—e.g., name(s) and version(s) for machines and/or operating systems; System Name(s)[2]

NOTE 1—Required for all implementations.

NOTE 2—May be completed as appropriate in meeting the requirements for the identification.

NOTE 3—The terms Name and Version should be interpreted appropriately to correspond with a supplier's terminology (e.g., Type, Series, Model).

Annex 191B with the proposed changes (4/4)

Full D2.3 text; inserted text in blue underlined, deleted text in red struck through

191B.6.2.2 Protocol summary

Identification of protocol standard	IEEE Std 802.3dm-202x, Annex 191B, High-Pass Filter for SNDR Testing with Low-Frequency High-Pass Networks
Identification of amendments and corrigenda to this PICS proforma that have been completed as part of this PICS	
Have any Exception items been required? No [ ] Yes [ ] (See Clause 21; the answer Yes means that the implementation does not conform to IEEE Std 802.3dm-202x.)	
Date of Statement	

191B.6.2.3 Major capabilities/options

Item	Feature	Subclause	Value/Comment	Status	Support
HPFS	High-Pass Filter for SNDR Testing	191B.2		~~O~~ M	Yes [ ] ~~No [ ]~~

191B.6.2.4 PICS proforma tables for High-Pass Filter for SNDR Testing with Low-Frequency High-Pass Network

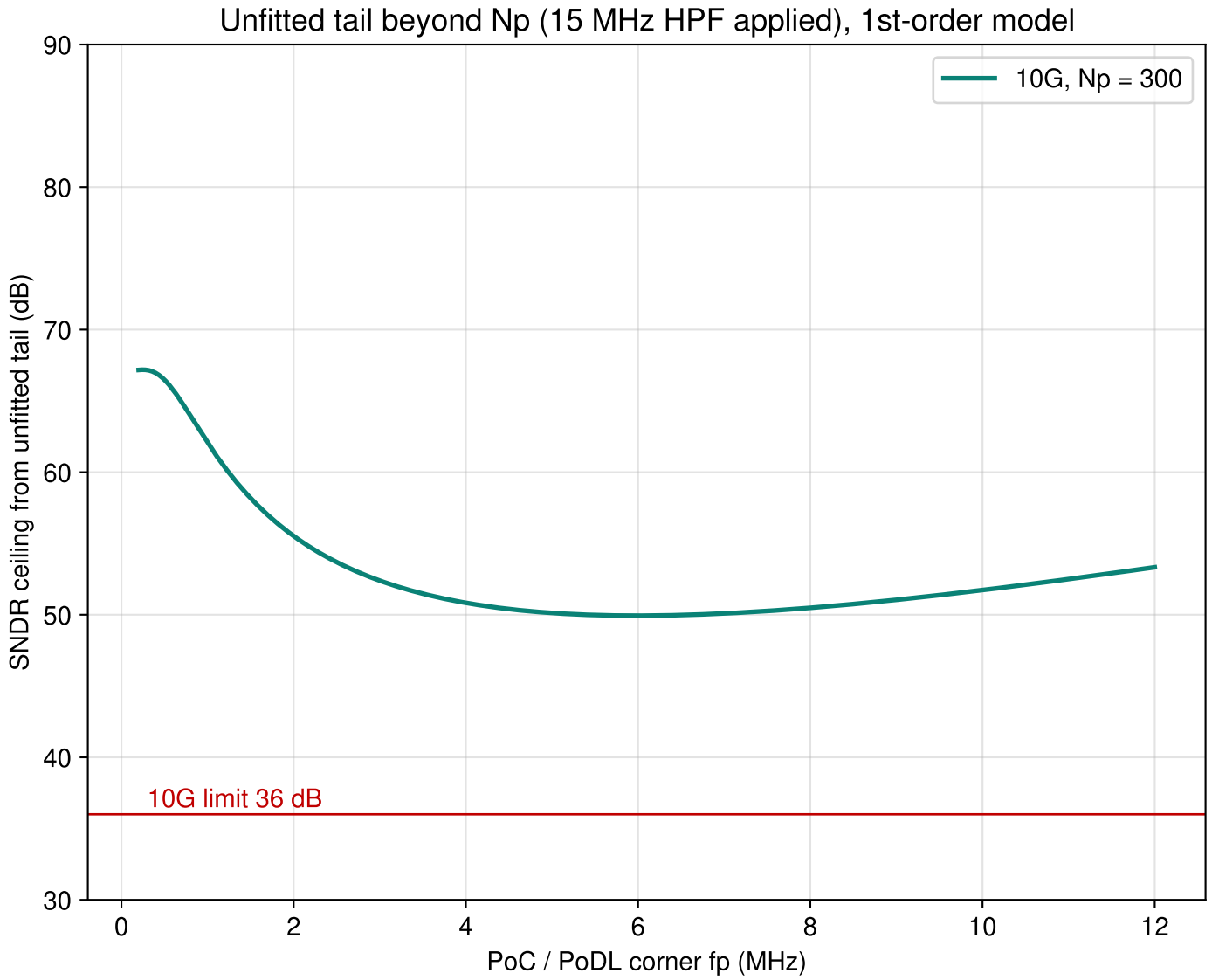
Item	Feature	Subclause	Value/Comment	Status	Support
STF1	HPF shall be applied to the captured MDI waveform for all SNDR measurements	191B.3		M	Yes [ ]
STF2	HPF constraints shall apply	191B.4		M	Yes [ ]

[8]Copyright release for PICS proformas: Users of this standard may freely reproduce the PICS proforma in this annex so that it can be used for its intended purpose and may further publish the completed PICS.

Backup

Np = 300: residual PoC/PoDL tail after the 15 MHz HPF is small

PoC/PoDL pole fp (= R/2πL) cascaded with the 1st-order HPF fh: H = s/(s+a) · s/(s+b), a = 2πfp, b = 2πfh



Tail beyond Np, slow pole (fp < fh):

$$p(n) \approx T\frac{a^2}{b-a}e^{-nT/\tau_a}, \quad \tau_a = 1/a$$

$$\sigma^2_{tail} \approx \sigma^2_x \sum_{n>N_p} p(n)^2 \propto e^{-2N_pT/\tau_a}$$

fp	L (R = 50 Ω)	τa at 10G
1.7 MHz	4.7 µH	527 UI
3.6 MHz	2.2 µH	249 UI
5.0 MHz	1.6 µH	179 UI

- Np = 300 UI = 53 ns at 10G; single-pole worst case (fp ≤ 8 MHz): ceiling ≥ 50 dB -> ≤ 0.5 dB on 41 dB

- Real networks are better (measured summary): PoC/PoDL cases at Np = 300 match the no-PoDL DUT

- Fit over-parameterisation: residual scaled by 1-(Np+Dp+1)/8191 -> +0.17 dB at Np = 300