Programmable THP Analysis and Implementation

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Agenda

- **Study SNR margin penalty for using fixed THP as defined in D1.4 vs. programmable THP for various noise scenarios**
  - 10GBASE-T ANEXT + 10GBASE-T AFEXT
  - 10GBASE-T ANEXT + 1000BASE-T AFEXT
  - 1000BASE-T ANEXT + 1000BASE-T AFEXT
  - Short vs. Long victim vs. disturber cables
  - Cat-6 vs. Cat-6A cabling environment

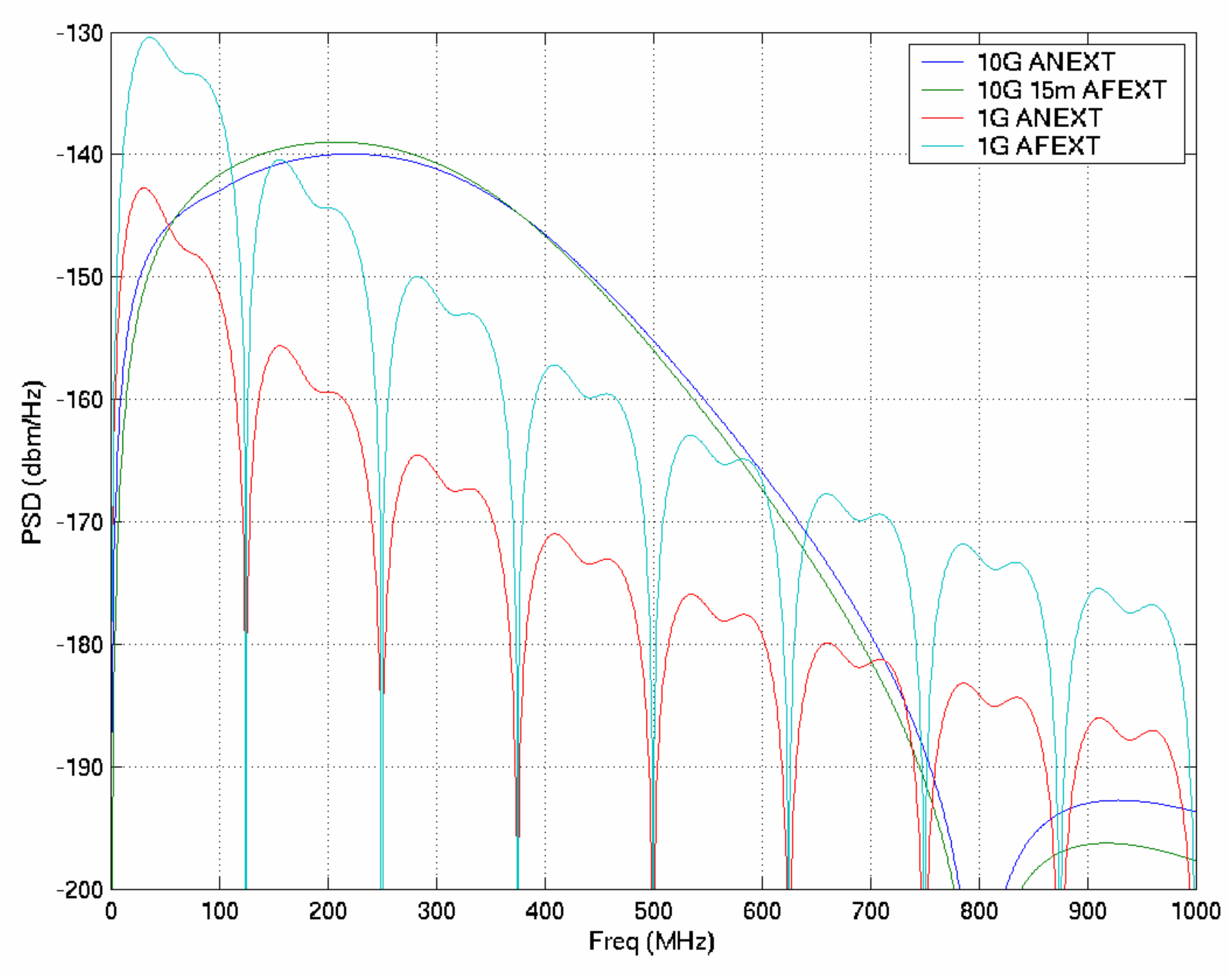
- **Study implementation issues for fixed vs. programmable THP**
  - Propose bit precisions for IIR/FIR programmable THP filters
  - Suggest implementation architecture for programmable FIR THP filter
  - Study datapath dimensioning for FIR/IIR precoders
- **Propose coeffcient exchange mechanism during startup**

SNR Penalty Study

- Salz analysis setup

- Link setup
  - Model2 victim with 55m ANEXT disturber + 15m AFEXT disturber
  - 55m Cat6a victim with scaled ANEXT and 100m ANEXT disturber + 15m AFEXT disturber
  - Model3 victim with 100m ANEXT disturber + 15m AFEXT disturber
  - All links are compliant with D1.4
- Transmit PSD
  - 10G victim transmits with 4.2dBm power
  - 10G disturber transmits with 5.2dBm power
  - 1G disturber transmit PSD compliant with Clause 40
- Power Backoff
  - 10G victim backoff is 10dB/0dB for Model2/Model3
  - 10G disturber backoff is 14dB/10dB/0dB for 15m/55m/100m
  - 1G disturber does not backoff
- When quoting the margin for a fixed IIR/FIR THP, we calculate the margin for all three coefficient sets (IIR or FIR) and we choose the best one. Note that the best precoder does not necessarily correspond to the precoder which is closest in cable length.

SNR Penalty Study
- PSD of noise sources



SNR Penalty Study

- Model 2/3, 10G ANEXT+10G AFEXT

Victim Model	10G ANEXT Length	Additional Noise	Optimum Salz Margin	Margin with fixed IIR THP	Margin with fixed FIR THP
Model2	100m	-140dBm/Hz (632uV rms)	-5.4dB	-7.0dB	-7.2dB
		-150dBm/Hz (200uV rms)	-4.9dB	-6.7dB	-7.0dB
Model2	55m	-140dBm/Hz (632uV rms)	0.7dB	-0.5dB	-0.7dB
		-150dBm/Hz (200uV rms)	2.3dB	0.7dB	0.4dB
Model3	100m	-140dBm/Hz (632uV rms)	0.4dB	-0.6dB	-0.8dB
		-150dBm/Hz (200uV rms)	3.0dB	1.4dB	1.1dB

SNR Penalty Study

- Model 2/3, 10G ANEXT+1G AFEXT

Victim Model	10G ANEXT Length	Additional Noise	Optimum Salz Margin	Margin with Fixed IIR THP	Margin with fixed FIR THP
Model2	100m	-140dBm/Hz (632uV rms)	-6.1dB	-7.5dB	-7.8dB
		-150dBm/Hz (200uV rms)	-5.8dB	-7.3dB	-7.6dB
Model2	55m	-140dBm/Hz (632uV rms)	0.0dB	-1.6dB	-1.4dB
		-150dBm/Hz (200uV rms)	1.3dB	-0.9dB	-0.2dB
Model3	100m	-140dBm/Hz (632uV rms)	-0.2dB	-1.0dB	-1.2dB
		-150dBm/Hz (200uV rms)	2.2dB	1.0dB	0.7dB

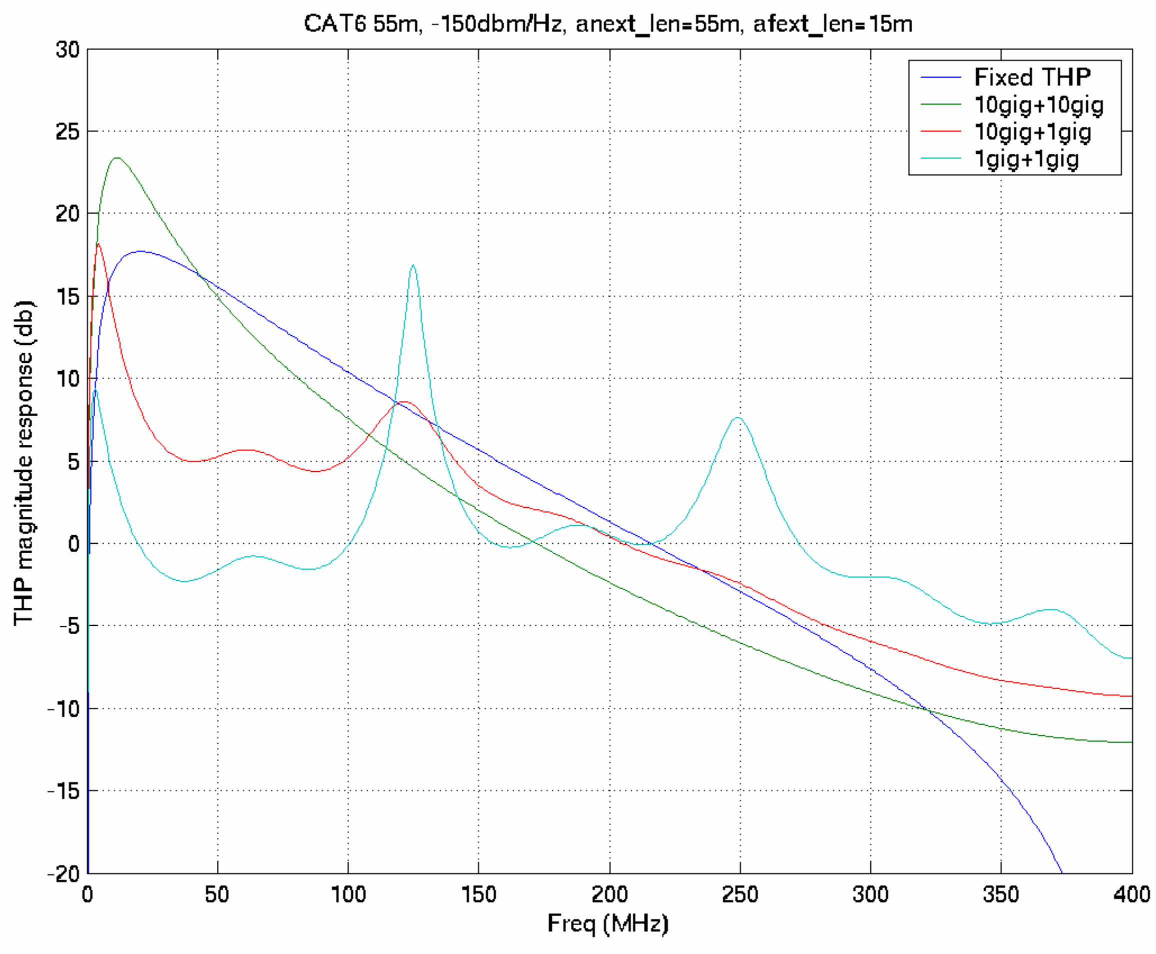
SNR Penalty Study

- Model 2/3, 1G ANEXT+1G AFEXT

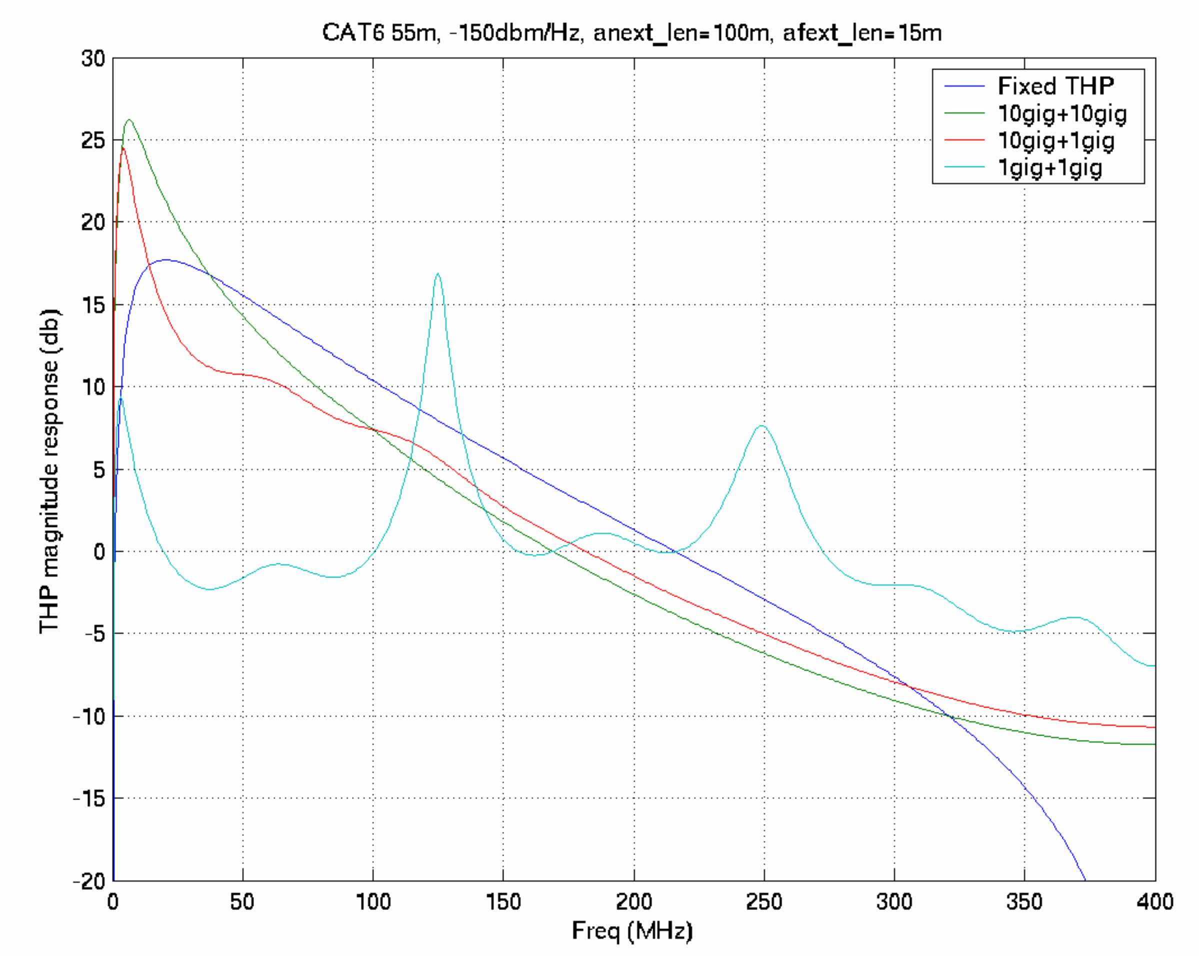
Victim Model	Additional Noise	Optimum Salz Margin	Margin with Fixed IIR THP	Margin with Fixed FIR THP
Model2	-140dBm/Hz (632uV rms)	2.2dB	-1.6dB	0.9dB
	-150dBm/Hz (200uV rms)	6.2dB	-0.9dB	3.2dB
Model3	-140dBm/Hz (632uV rms)	1.2dB	0.4dB	-0.1dB
	-150dBm/Hz (200uV rms)	6.6dB	5.0dB	4.5dB

SNR Penalty Study

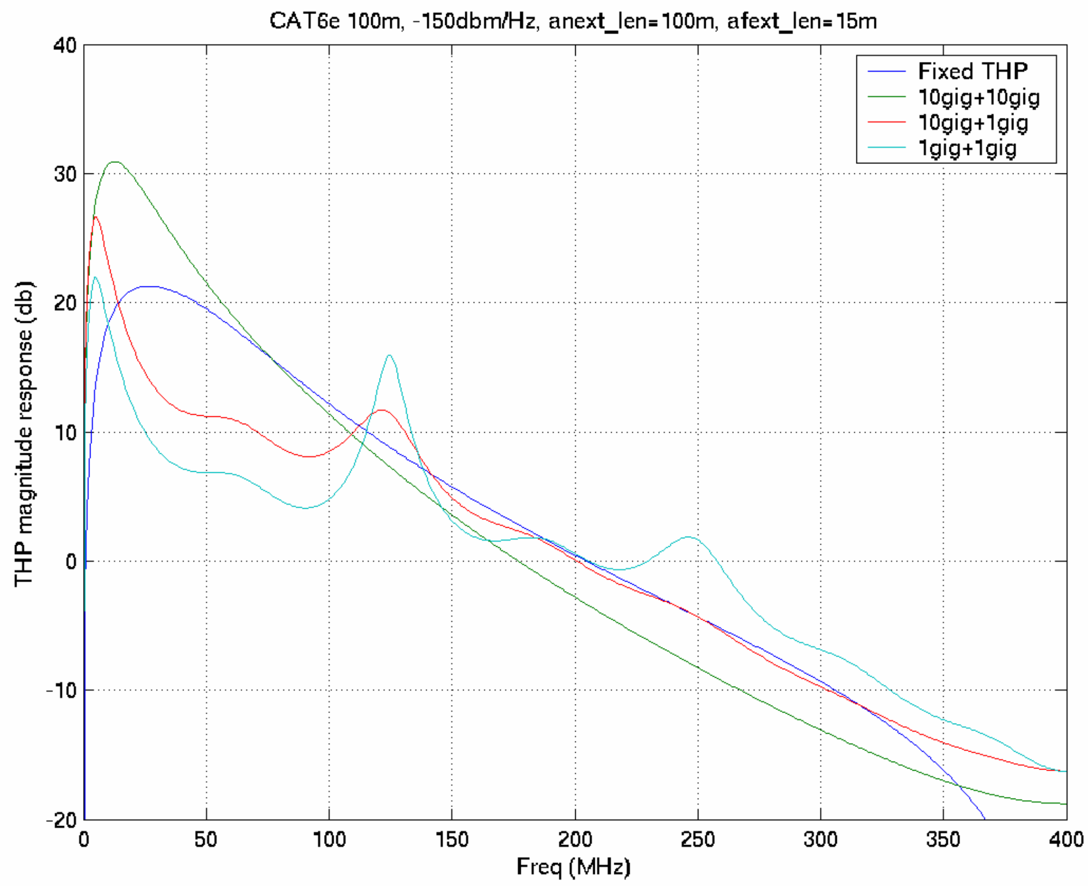
- Optimum THP desired responses (Model 2)



SNR Penalty Study
- Optimum THP desired responses (Model 2)



SNR Penalty Study
- Optimum THP desired responses (Model 3)



SNR Penalty Study

- Conclusions

- **SNR Penalty for fixed THP vs. programmable THP is**
  - Substantial
  - Unaffordable since it results in negative margins
  - Varies with dominant noise types, whether 1G or 10G, whether AFEXT or ANEXT
- **SNR Penalty for fixed THP vs. programmable THP is also dependent on receiver architectures**
  - Changes if fractionally spaced or T-spaced
  - Changes if pre-equalization is done prior to A/D
  - Changes with variations in receive filters and transformer cutoff frequencies for finite length THP filters.

Implementation of Programmable vs. Fixed THPs

- **In the extreme case, the implementation complexity of a programmable THP can be ~3X that of a single fixed THP, assuming the same data/coefficient precisions**
  - Complexity penalty declines as the number of fixed THPs increase
  - D1.4 already has 6 IIR fixed THPs and 9 FIR fixed THPs.

- **In the extreme case, the critical path complexity of a programmable THP can be ~2X that of a single fixed THP**
  - Critical path complexity difference between fixed and programmable also declines as the number of fixed THPs increase

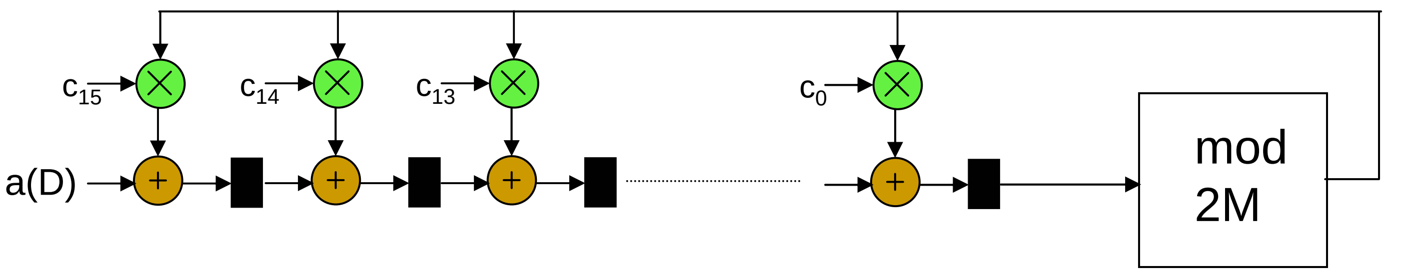
Mitigating Complexity Increases

- **Propose mitigating complexity increases by reducing the precision requirement of the programmable coefficients**
  - FIR coefficients vary from -2.0 to 1.9375 in steps of 0.0625
  - IIR coefficients vary from -4.0 to 3.9375 in steps of 0.0625
  - Both Vareljian's FIR coefficients and Ungerboeck's IIR coefficients can be represented with such precision with negligible change in desired response.

- **The critical path complexity of the IIR implementations remain the same as in ungerboeck_1_1104.pdf, slide 20**
  - 1 multiply + 4 add delay

- **The critical path complexity of an FIR implementation is less**
  - 1 multiply + 1 add delay

Implementing FIR THP (Transverse Form + delayed input)



Critical path delay = 1mult + 1add

Input a(D) incurs additional 16 cycle (20ns) latency wrt conventional implementation

Architecture can be easily “loop unfolded” to create any desired level of parallelization.

Precoder Dimensioning: FIR

- For an FIR precoder with N taps with range +/- L and input bounded to +/- 2M the absolute value of the output is always less that N*L*2*M.
- In our case N = 16 and L = 2 so in the worst case we need 5 bits more in the output of the FIR to be able to work without stability issues with ANY proposed precoder.
- We can reduce that by specifying in the standard that the sum of the absolute values of the FIR coefficients has to be smaller that 16 (> 8 for current values of the long coefficients in D1.4). This gets us to exactly the same bit widths that the ones needed for the fix FIR THP.
- If the FIR values are computed dynamically, we will need to do this checking and take appropriate action on chip. However a value of 16 should cover most cases of interest.

Precoder Dimensioning: IIR

- We can analyze the dynamic range at its output by replacing the IIR with an FIR that has its impulse response.
- If we do so, we see that the sum of the absolute values for the proposed IIR for 100m is 16.60. A similar analysis could be done for the other nodes in the filter.
- We can specify in the standard that valid filters will have coefficients such that the sum of the absolute values of its impulse response is less than 32. This would ensure that those filters will behave at the output like the one proposed.
- Similar derivations could be done for the other nodes in the filter.
- As IIR would very likely be pre computed off chip it should be straightforward to ensure compliance.

Programmability Proposal

- **Minor modifications to existing solution to:**
  - Allow the exchange of coefficients during startup.
  - Allow different coefficients for each pair.
- **While preserving existing support for fixed coefficients**

Programmability Proposal

- The startup is covered in the PHY control section of D1.4 (55.4.2.4) and in Figure 55-18.
- We propose to change the state machine such that:
  - The Master PHY starts transmitting and if in a given time it does not get signal from the slave it will try with another PBO/THP settings (We would use one existing fixed set of coefficients (FIR and IIR) for this).
  - The slave estimates selects a PBO/THP setting for transmission based on cable length estimation.
  - Then the PHYs exchange PBO/THP settings using the Info Fields and they converge to final settings. During this phase programmable coefficients per dimension are allowed.

Info Fields

- **Current Definition is as follows (From D1.4):**
  - Start of Frame Delimiter 4 bytes.
  - Current TX setting 1 byte (3x,3 bits PBO, 2 bits THP).
  - Next TX setting 1 byte (3x,3 bits PBO, 2 bits THP).
  - Requested TX setting 1 byte (3x,3 bits PBO, 2 bits THP).
  - Message field 1 byte.
  - SNR Margin 4 bits.
  - Transition Counter 12 bits.
  - Reserved Field 4 bytes.
  - CRC16 (2 bytes).

Proposed changes to Info Fields

- **The Info Field is extended with 16 bytes after the existing ones. CRC-16 is used to protect all of them.**
- **We can use one of the x bits to signal that we enable coefficient exchange. This bit is set to 0 until the PMA training update state is reached. At this point if the bit is set, the last 16 bytes are used to send the requested coefficients to the transmitter for one dimension. Subsequent frames will program all 4 dimensions. If the bit is not set, fixed coefficients would be used as per D1.4.**
- **2x bits can be allocated to specify the dimension for which the coefficients apply.**
- **For FIR the coefficients are sent in one byte (6 bits).**
- **For IIR the coefficients are sent in one byte (7 bits).**

Proposed Info Fields

- **Proposed definition is as follows:**
  - Start of Frame Delimiter 4 bytes.
  - Current TX setting 1 byte (3x,3 bits PBO, 2 bits THP).
  - Next TX setting 1 byte (3x,3 bits PBO, 2 bits THP).
  - Requested TX setting 1 byte (1 bit Coefficient Exchange Enabled,2bits Dimension,3 bits PBO, 2 bits THP).
  - Message field 1 byte.
  - SNR Margin 4 bits.
  - Transition Counter 12 bits.
  - Reserved Field 4 bytes.
  - Coefficients (valid if Coefficient Exchange Enable = 1) 16 bytes.
  - CRC16 (2 bytes).

Proposed Info Fields: Coefficient Details

- FIR
  - 6 bits per coefficient. Use one byte per coefficient (x,x,msb,…,lsb).
  - Coefficients start as in D1.4 from 1 to 16.
  - 16 bytes Dimension as specified by Dimension bits.
- IIR
  - 7 bits per coefficient. Use one bytes one for (x,msb,..lsb).
  - As there are 4 coefficients we would use 4 bytes starting with coefficient a1 and ending in coefficient a4. These would be the first 4 bytes in the coefficient field.

Summary

- **It has been shown that for certain impairments there may be a significant SNR loss if the coefficients are not dynamically adapted independently for all four dimensions.**
- **With minor modifications to existing Info Fields we can add THP programmability whilst preserving the existing approach of using fixed coefficients.**
- **Vendors can still use only fixed coefficients if they want to.**
- **The complexity increase is small (if any) relative to a (large) set of fixed precoder coefficients.**
- **It has been shown that 6 bit coefficients give good performance for the FIR precoder.**