
10GBASE-T

PCS details and Precoding

**IEEE P802.3an Task Force
Vancouver, January 26-28, 2005**

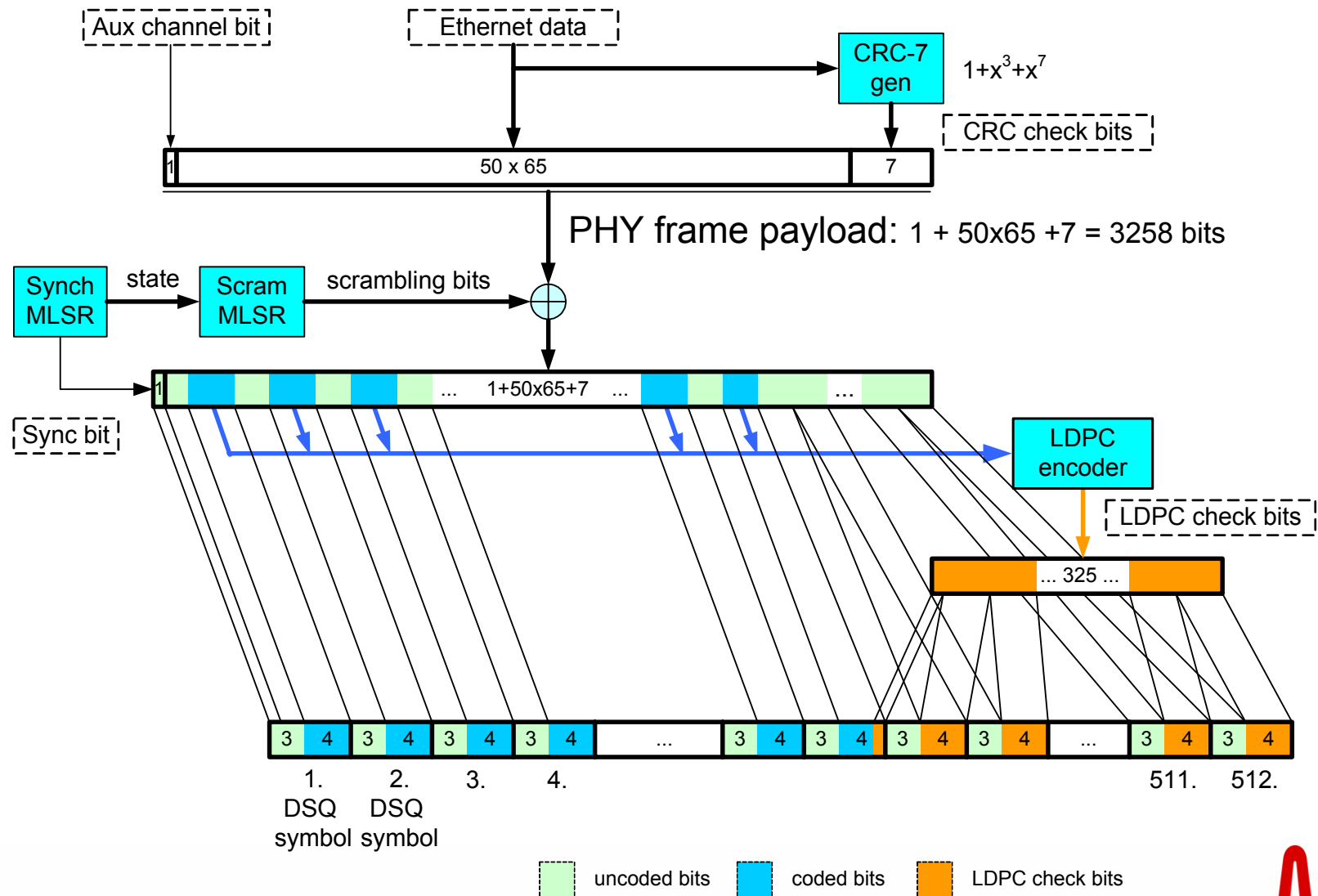
Gottfried Ungerboeck

CRC and Scrambling

- in which order?

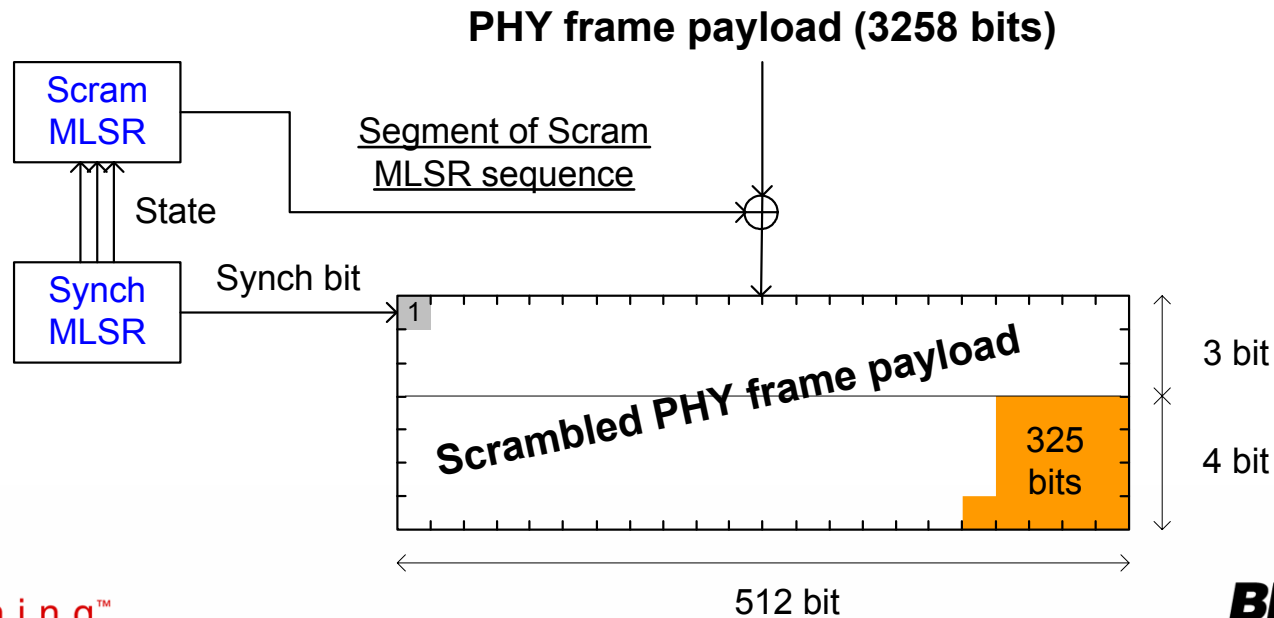
- what type of scrambling?

Composition of PHY frame: CRC, then cipher-stream scrambling



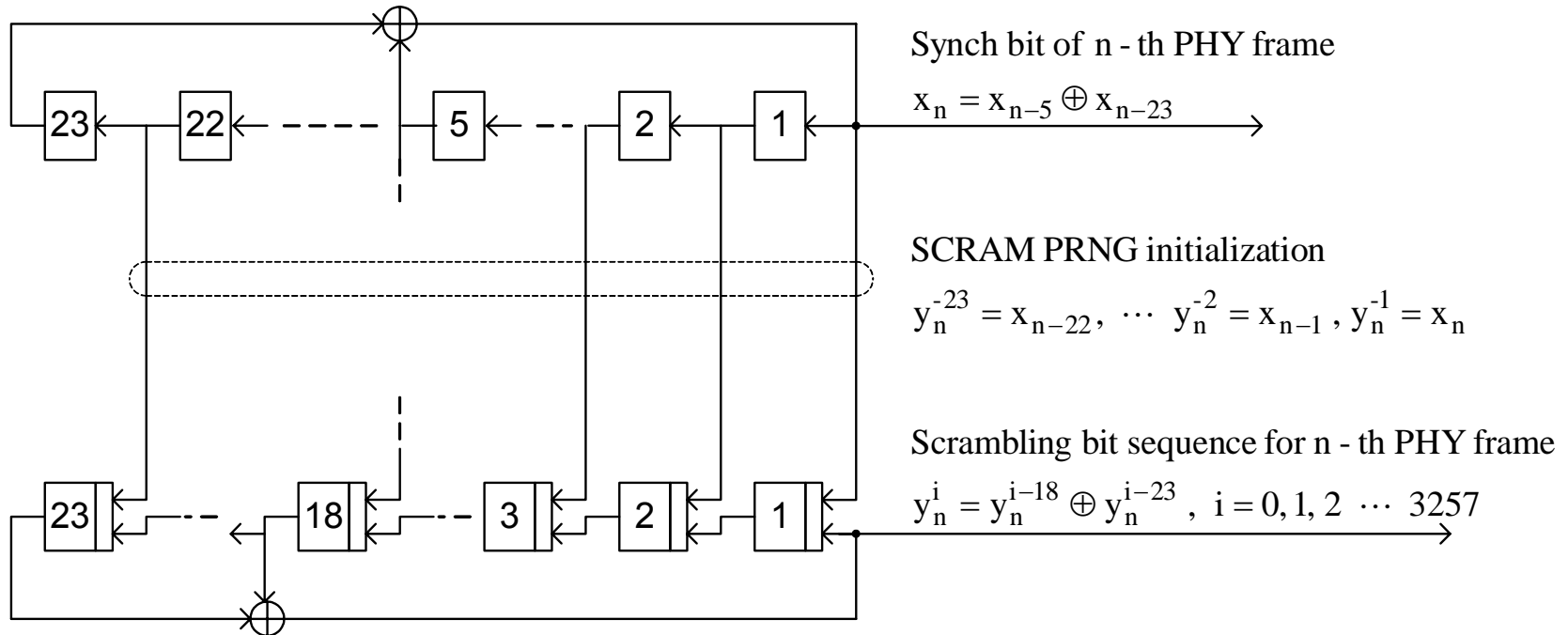
Synch bit and cipher-stream scrambling

- **Synch MLSR** generates one synch bit per PHY frame and transitions to new n-bit state. The synch bit is inserted into the PHY frame.
- **Scram MLSR** is initialized with n-bit state of Synch MLSR and generates a segment of the Scram MLSR sequence for cipher-stream scrambling.
- By proper design, the segments of the Scram MLSR sequence start at pseudo-random locations.



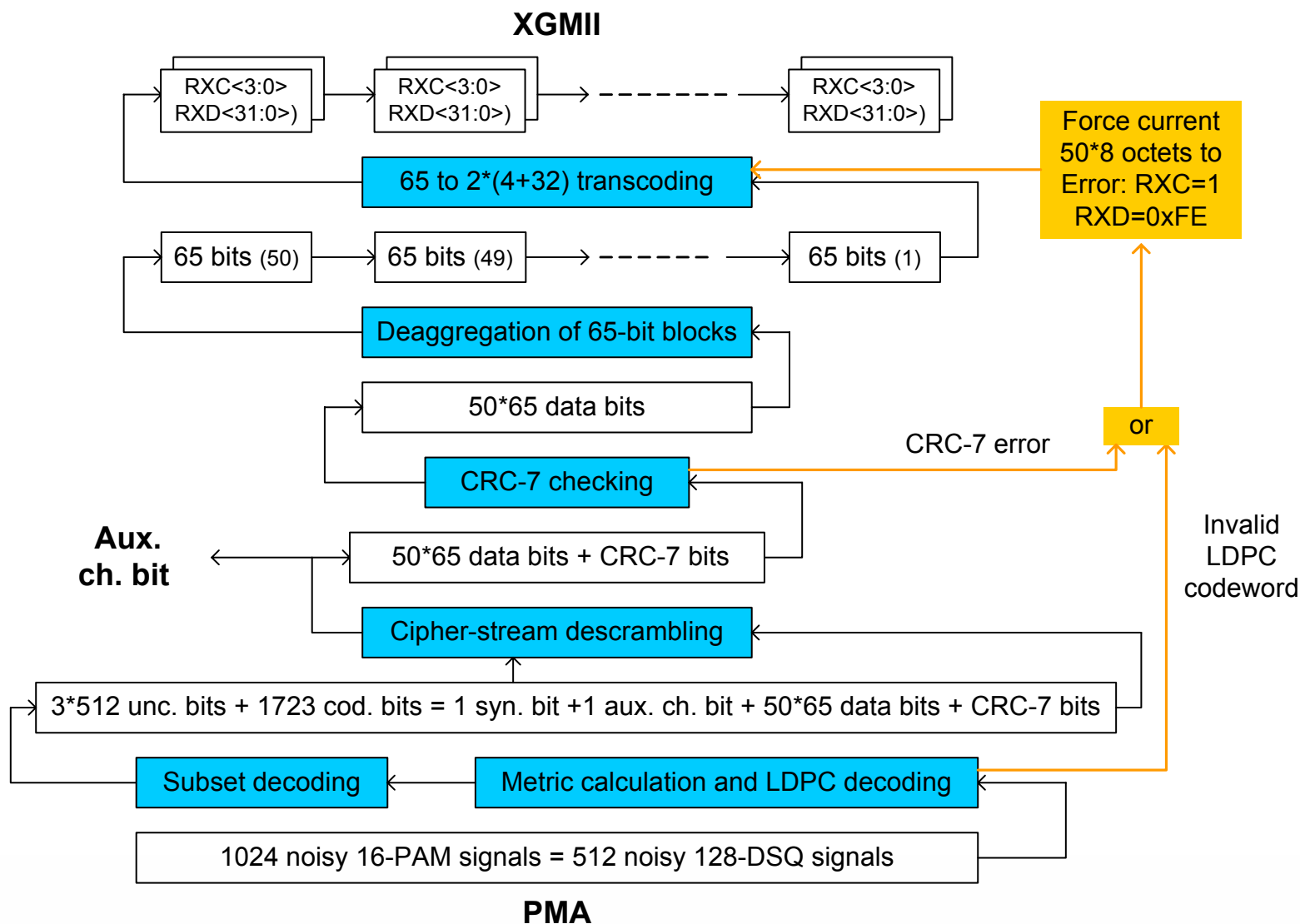
Synch MLSR and Scram MLSR generators

Synch MLSR $(1+x^5+x^{23})$

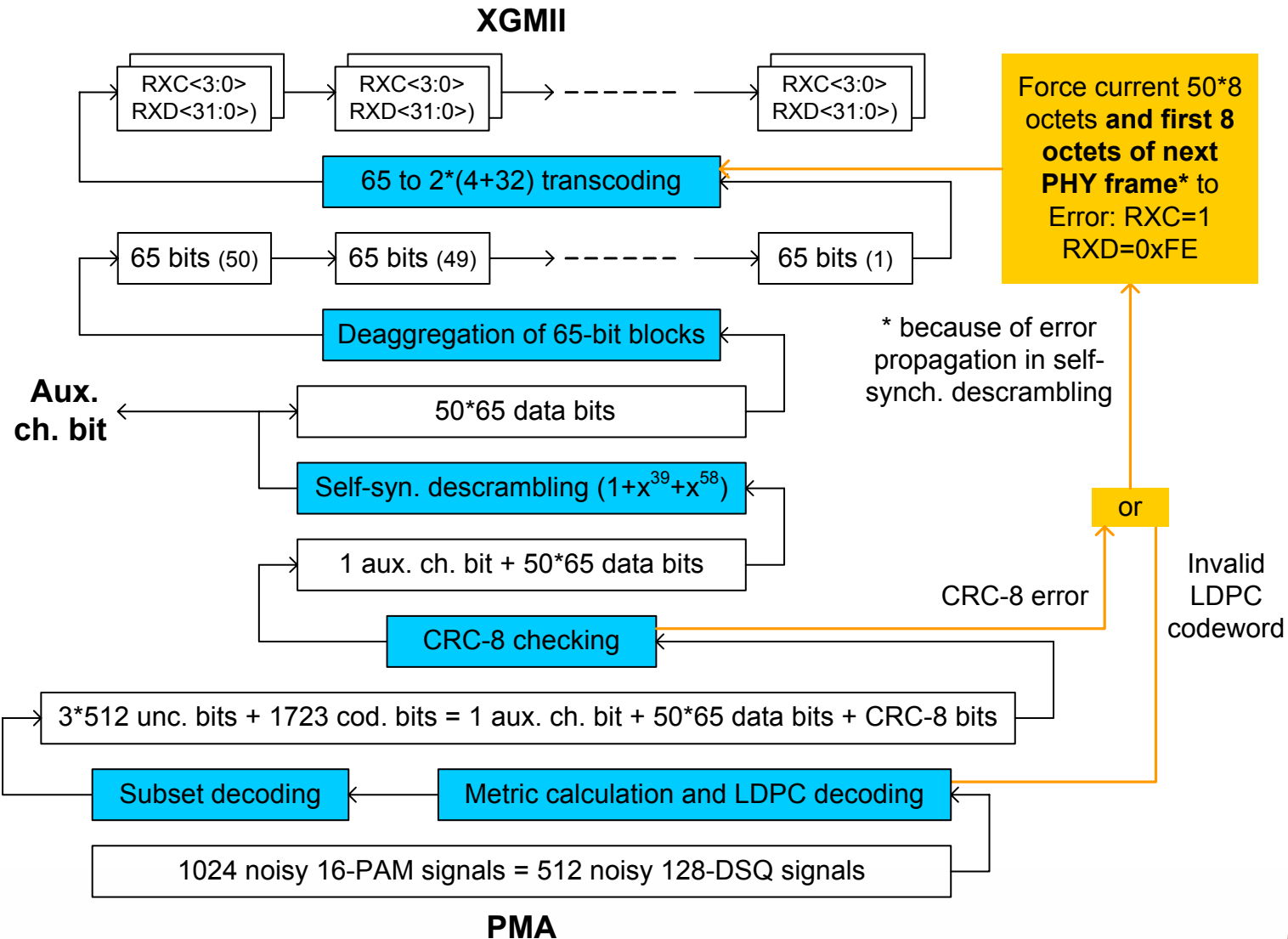


Scram MLSR $(1+x^{18}+x^{23})$

Receiver PCS functions: cipher-stream descrambling, then CRC-7 checking



Receiver PCS functions: CRC-8 checking, then self-synch descrambling



CRC and scrambling: conclusions

Option 1: (in transmitter) First CRC, then cipher-stream scrambling

- ☺ When PHY frame error is detected in receiver, at XGMII all octets of current PHY frame must be replaced by ERROR octets
- ☹ Requires (?) one synch bit in PHY frame → 7 bits available for CRC.

Option 2: (in transmitter) First self-synch scrambling, then CRC

- ☺ No synch bit required → 8 bits available for CRC
- ☹ When PHY frame error is detected in receiver, at XGMII all octets of current PHY frame and a few octets at beginning of next PHY frame must be replaced by ERROR octets.

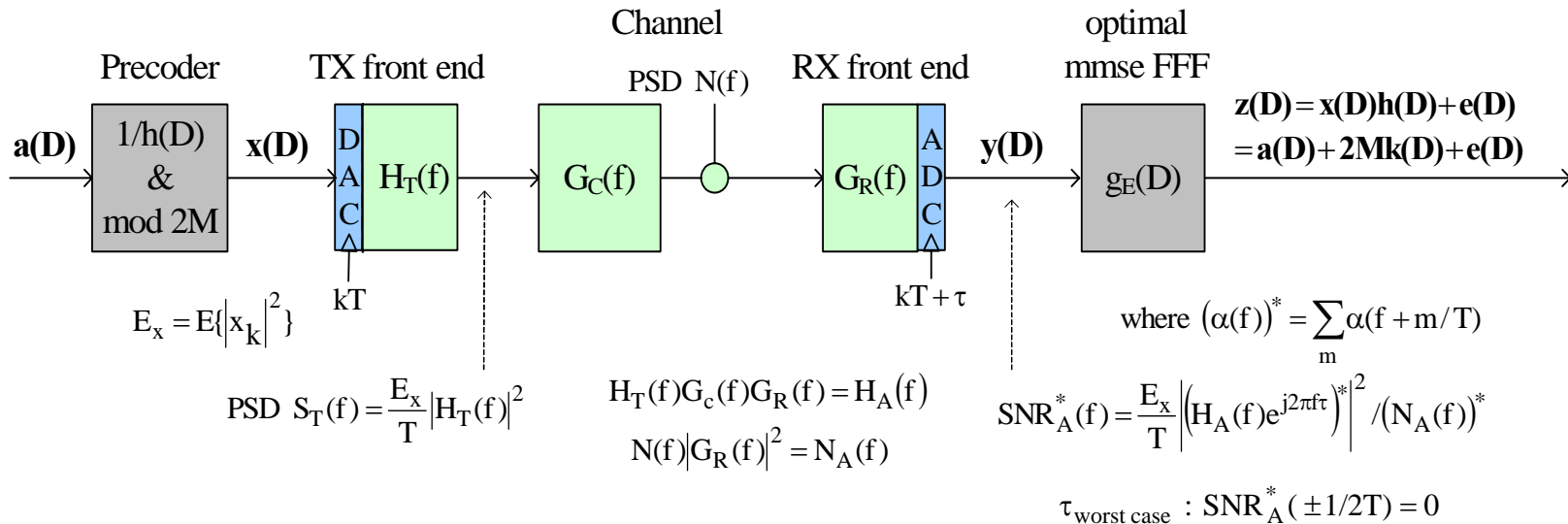
Differences in complexity are negligible.

(?) Cipher stream synchronization may be realized without synch bit by relying on PHY frame counting after start-up and/or signaling in auxiliary channel.

Precoding

- analytic relations
- fixed transmit and receive filters
- set of IIR precoders
- SNR vs cable length for Cable Model #2

Optimum precoding response and decision-point SNR



Optimum precoding response $h(D)$ for given $H_A(f)$, $N_A(f)$, and τ is obtained from

$$\text{SNR}_A^*(f) + 1 \xRightarrow{\text{spec. fac.}} \text{SNR}_{\text{mmse}} \bar{h}(D^{-1})h(D) \quad h(D) \text{ causal, monic, } D = e^{-j2\pi f T}$$

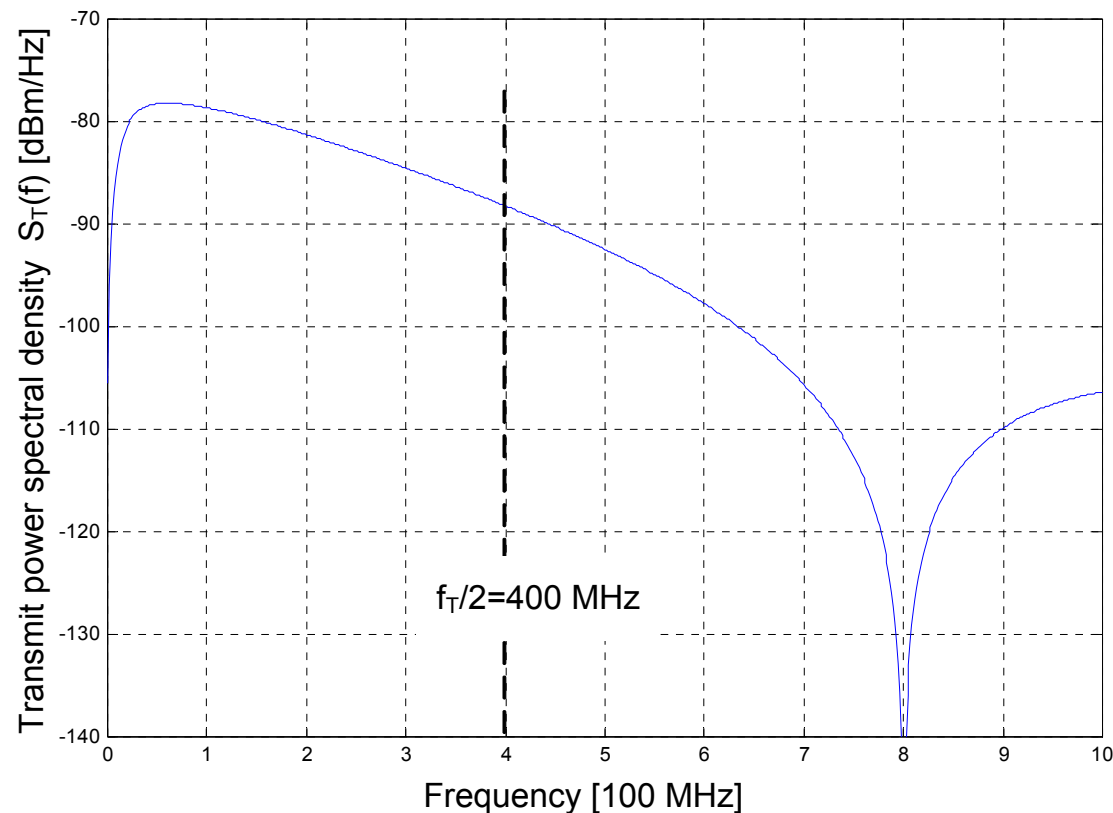
Decision - point SNR for given $H_A(f)$, $N_A(f)$, τ , and precoding response $h(D)$

$$\text{SNR}_{\text{mmse}} = \left[T \int_{-1/2T}^{1/2T} |h(e^{-j2\pi f T})|^2 / (\text{SNR}_A^*(f) + 1) df \right]^{-1}$$

TX front-end filtering and PSD $S_T(f)$

Modulation rate $f_T = 800$ Mbaud, $P_T = 5$ dBm

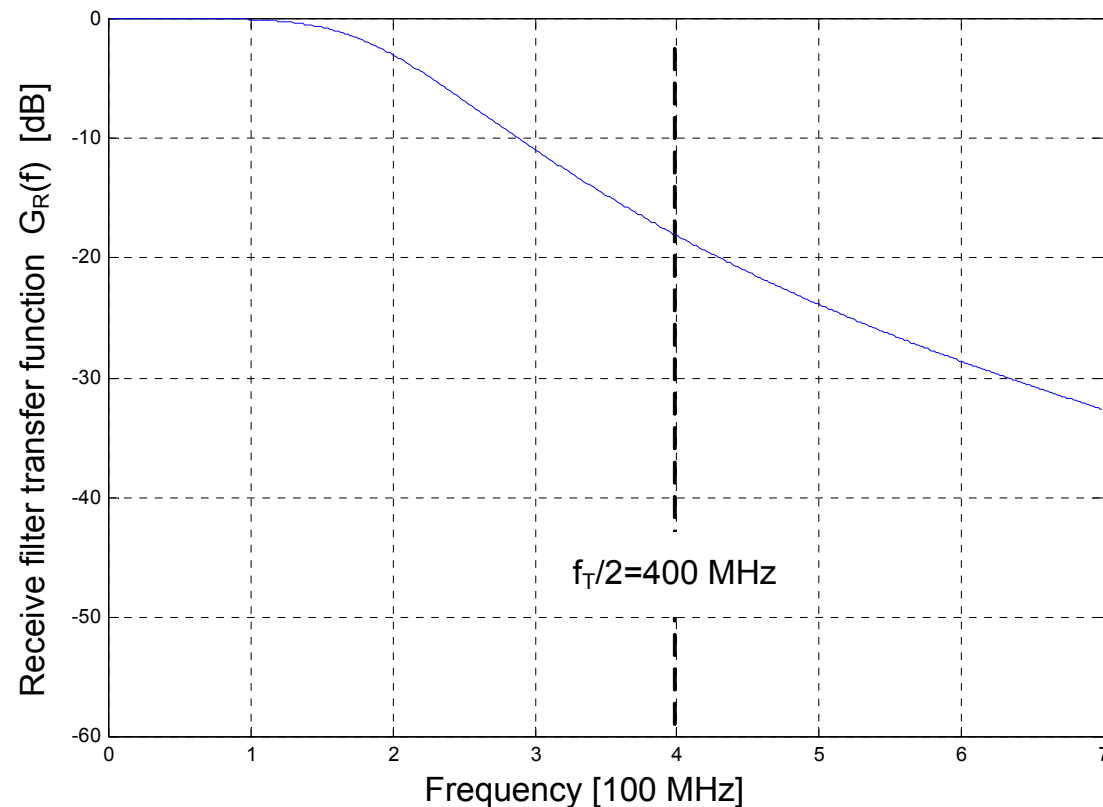
$$H_T(f) \propto \frac{\sin(\pi f T)}{\pi f T} \times \frac{j f / f_0}{1 + j f / f_0} \times \frac{1}{1 + j f / f_1}, \quad f_0 = 20 \text{ MHz}, f_1 = 200 \text{ MHz}$$



RX front-end filtering

Modulation rate $f_T = 800$ Mbaud, RF = 3rd order BWF

$$G_R(f) = \prod_{i=1}^N \frac{1}{a_i + jf/f_0}, \quad a_i = \exp\left(\frac{j\pi}{N}(i - (N+1)/2)\right), \quad N = 3, f_0 = 200 \text{ MHz}$$



IIR precoding responses $h_{\text{IIR}}(D)$

$$h_{\text{IIR}}(D) = \frac{1-D^2}{1+q_1D+q_2D^2+q_3D^3} = 1 - \frac{q_1D+(q_2+1)D^2+q_3D^3}{1+q_1D+q_2D^2+q_3D^3}$$

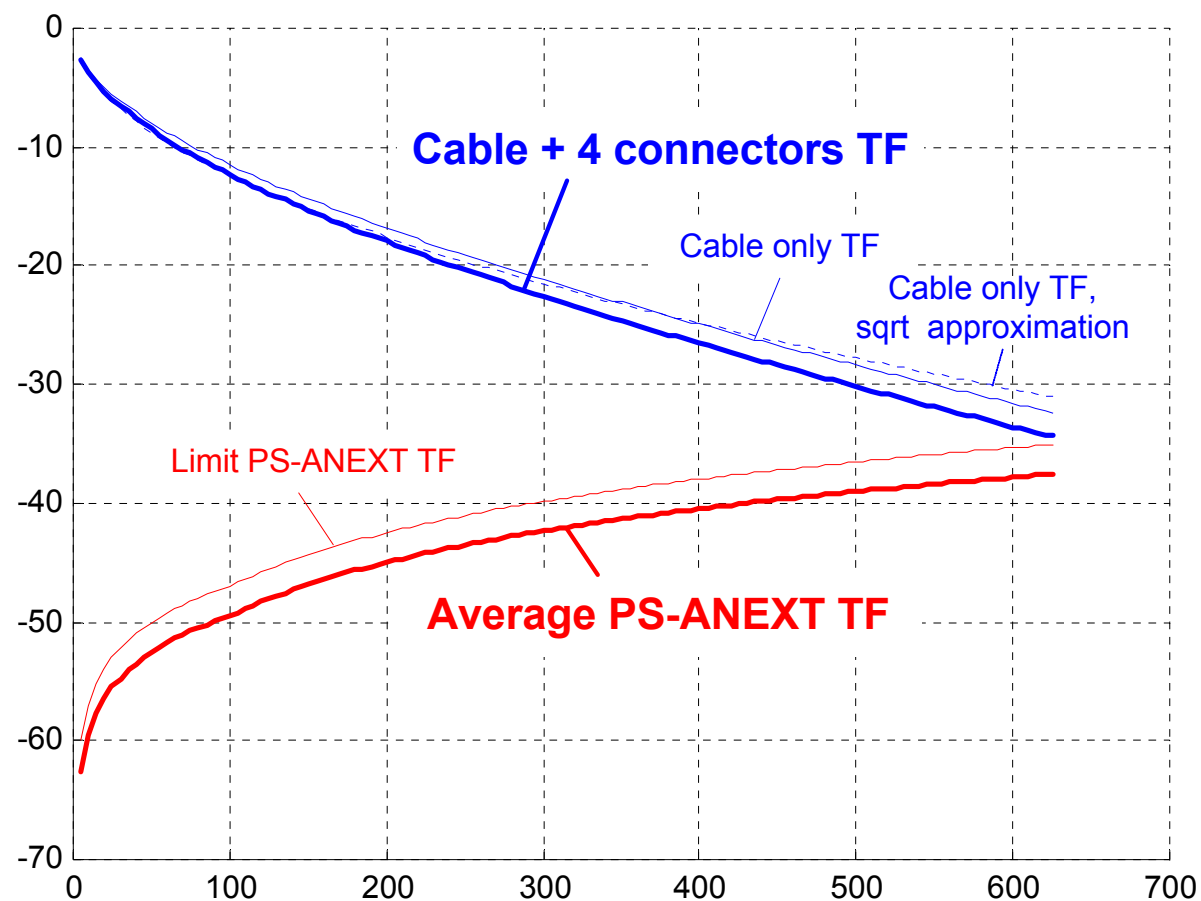
	Coeffs			Zeroes $\alpha_1 = 1, \alpha_2 = -1$		
	q_1	q_2	q_3	β_1	β_2	β_3
THPF #1	-141/64	104/64	-26/64	0.8916	0.6558+0.1600i	0.6558-0.1600i
THPF #2	-122/64	71/64	-12/64	0.9309	0.6785	0.2969
THPF #3	-98/64	36/64	0/64	0.9195	0.6117	0
THPF #4	-73/64	8/64	4/64	0.9356	0.3805	-0.1755

THP filters designed for variable-length cable model #3 (Ungerboeck_1_0704, Portland)

#1: 100 m, #2: 70 m, #3: 40 m, #4: 10 m

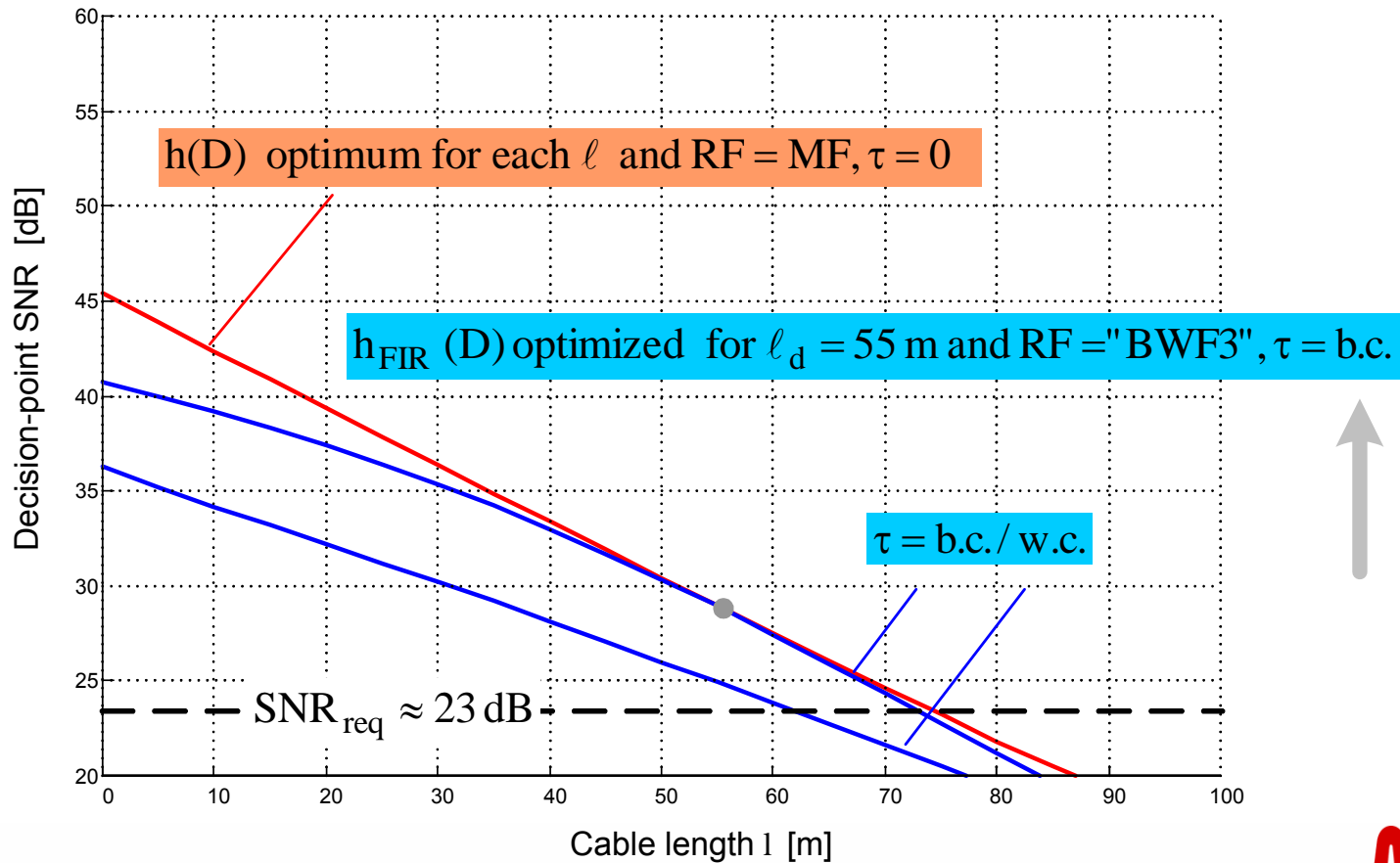
Decision-point SNR vs cable length shown for variable-length Cable Model #3 in ungerboeck_1_1104 (San Antonio). In the sequel we consider Cable Model #2.

Cable and PS-ANEXT transfer functions: Cable Model #2



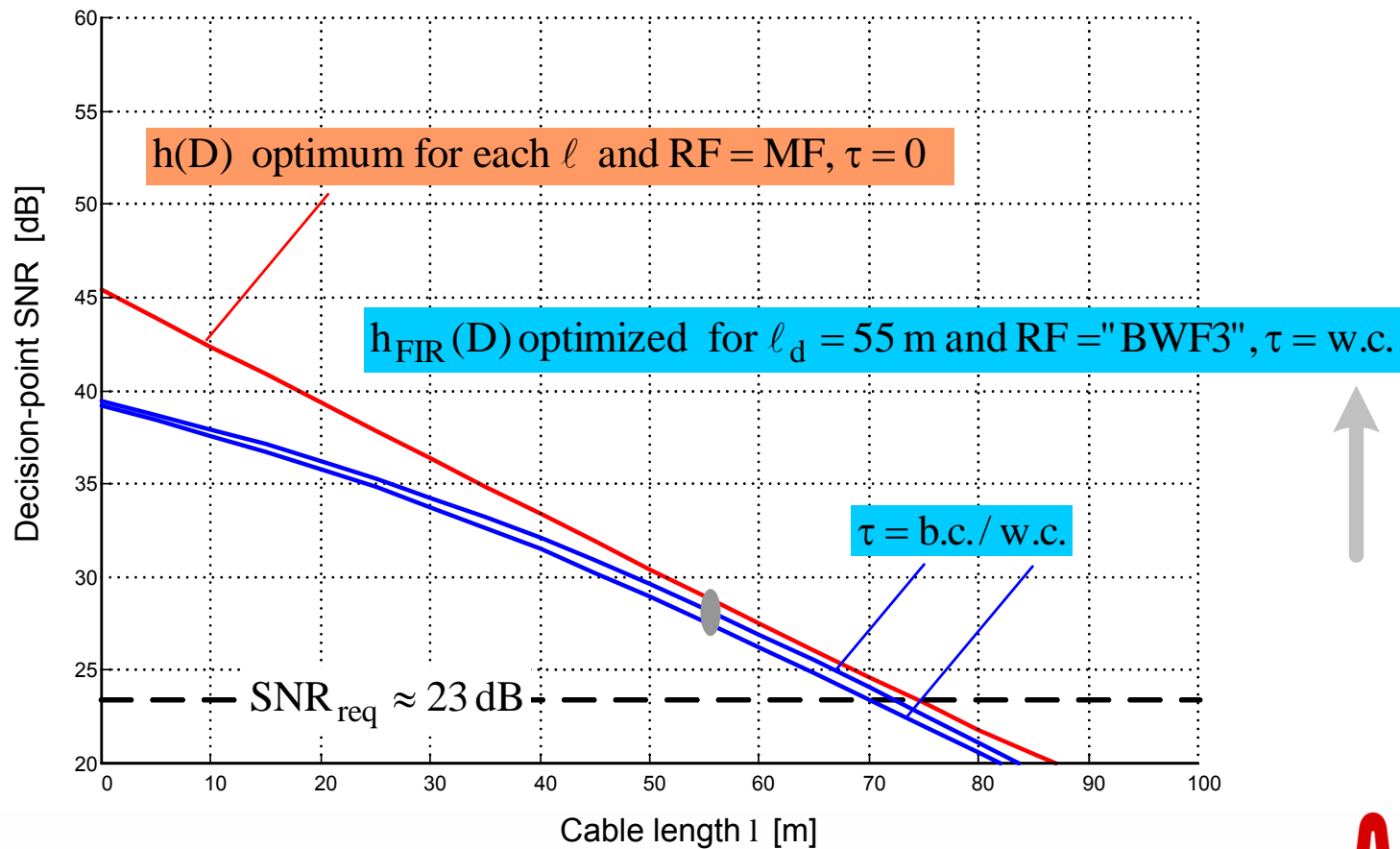
SNR vs. cable length

Variable-length Cable Model #2; $f_T = 800$ Mbaud; TF = "Sinx/xf0f1";
 $P_T = 5$ dBm; AWGN=-140 dBm/Hz; ANEXT ($P_T=5$ dB, $\ell=55$ m)



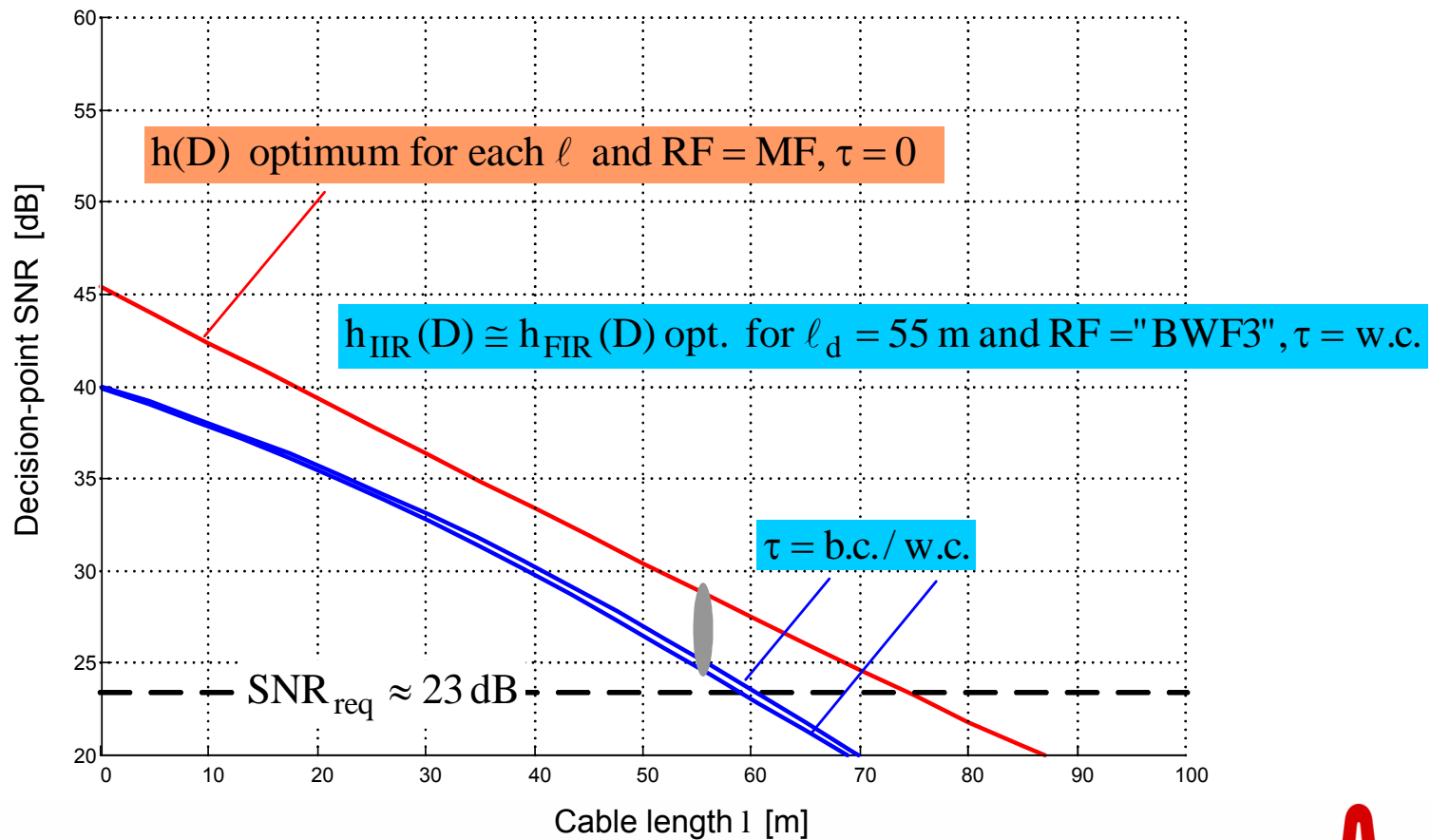
SNR vs. cable length

Variable-length Cable Model #2; $f_T = 800$ Mbaud; TF = "sinx/xf0f1";
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SNR vs. cable length

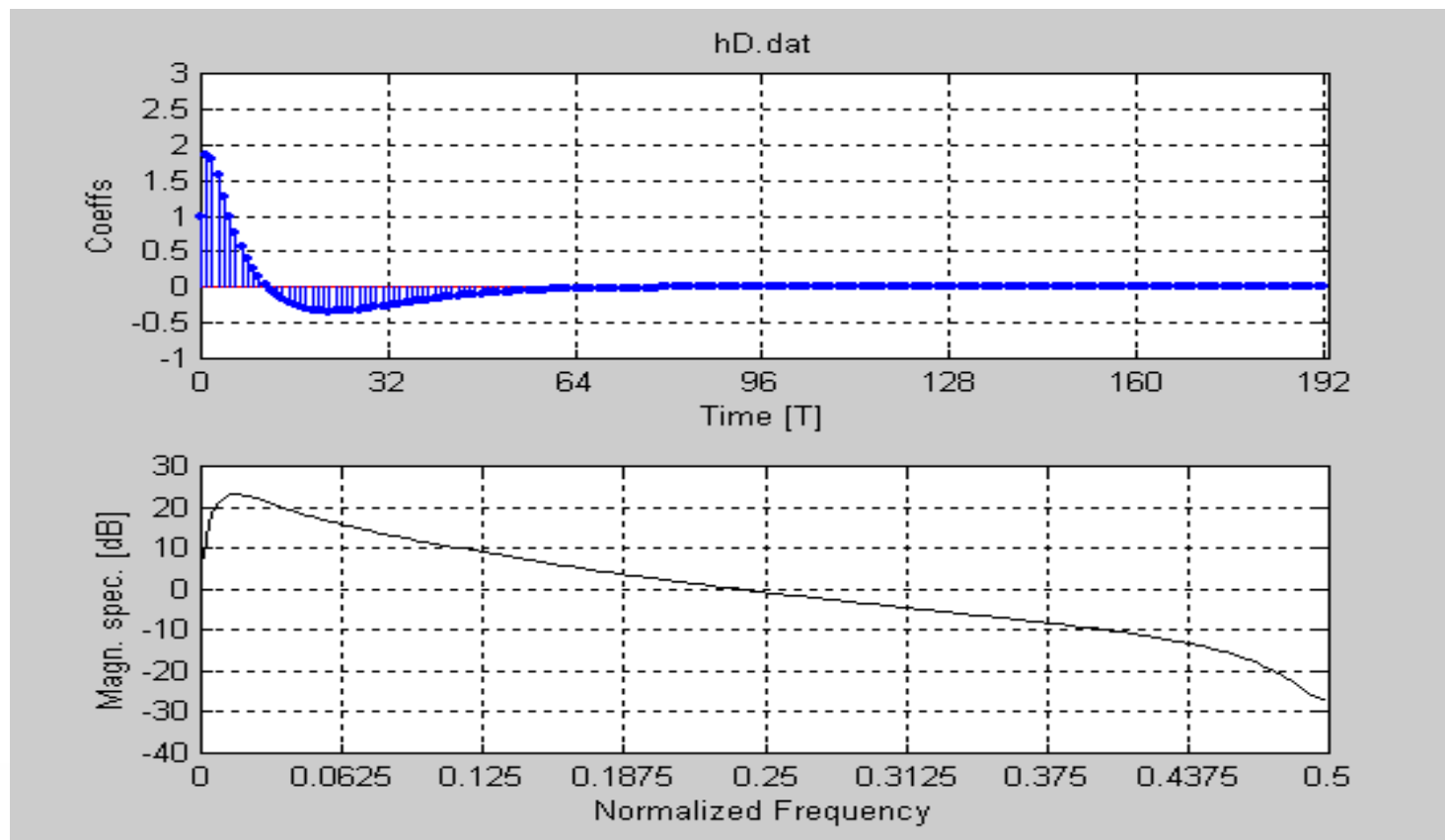
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Fixed $h_{\text{FIR}}(D)$

Variable-length Cable Model #2; $f_T = 800$ Mbaud; TF = "sinx/xf0f1";
 $P_T = 5$ dBm; AWGN=-140 dBm/Hz; ANEXT ($P_T=5$ dB, $\ell=55$ m)

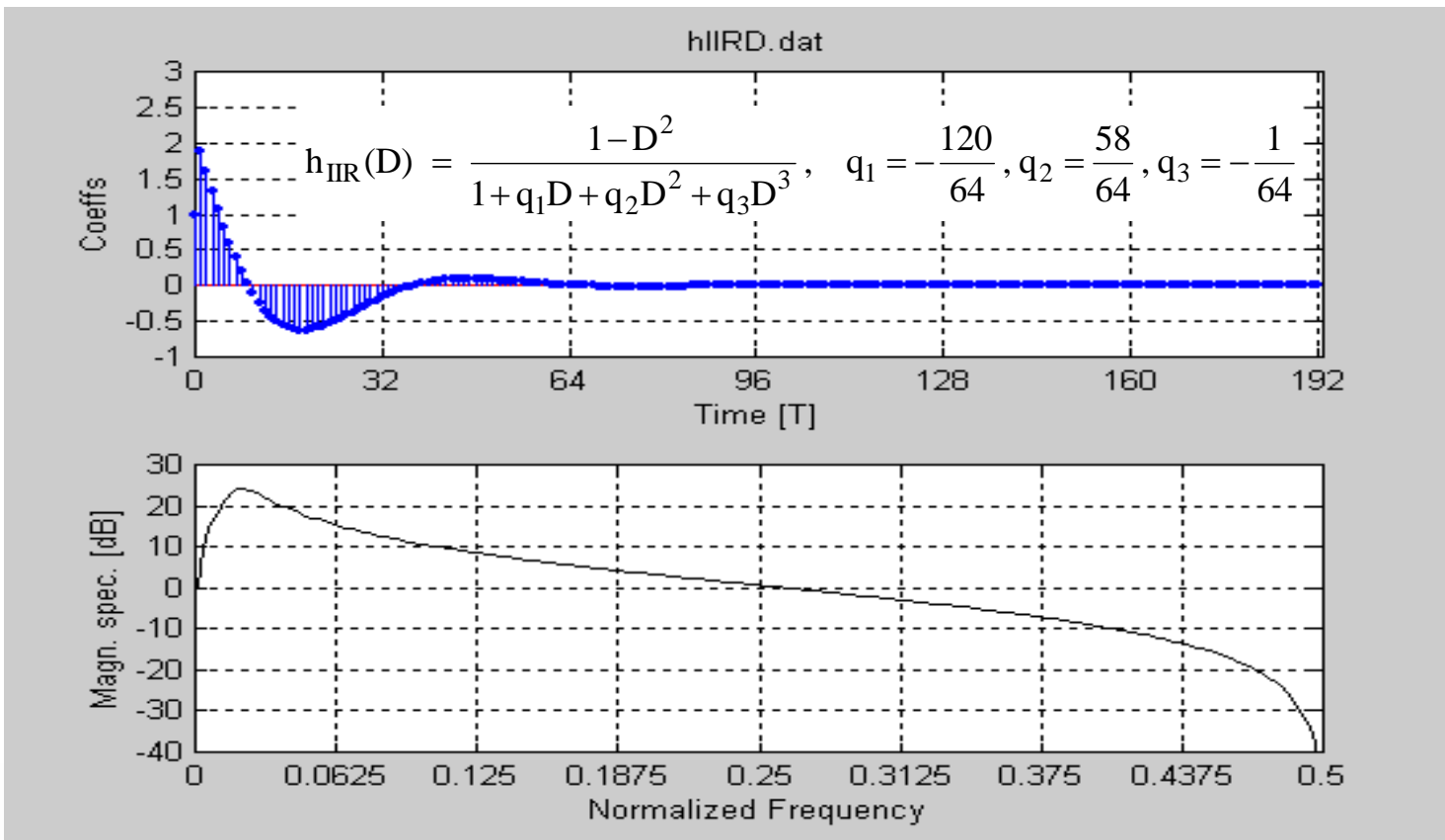
$h_{\text{FIR}}(D)$ optimized for $\ell_d = 55$ m and RF="BWF3", $\tau = \text{w.c.}$



Fixed $h_{\text{IIR}}(D)$

Variable-length Cable Model #2; $f_T = 800$ Mbaud; TF = "sinx/xf0f1";
 $P_T = 5$ dBm; AWGN=-140 dBm/Hz; ANEXT ($P_T=5$ dB, $\ell=55$ m)

$h_{\text{IIR}}(D) \cong h_{\text{FIR}}(D)$ optimized for $\ell_d = 55$ m and RF="BWF3", $\tau = \text{w.c.}$



Precoding: conclusions

- There exists sufficient evidence that a small number (4 - 8) of fixed precoding responses suffices to achieve near optimum performance for all cable types and lengths relevant for 10GBASE-T.
- Coarse approximations of FIR precoding responses by IIR response (as done by this author) have lead to significant decision-point SNR losses.
- Approximation of known good FIR responses by IIR responses with low degrees of the numerator and denominator polynomials requires further study.

Backup slide

Variable-length 10GBASE-T cable models (ungerboeck_1_0704.pdf)

Complex-valued cable-transfer function

$$G_C(f_{[\text{Hz}]}, \ell_{[\text{m}]}) = e^{-\ell \gamma(f)} \times 10^{-4 \times 0.02 \times \sqrt{f/10^6}/20}; \quad \gamma(f) = \sqrt{\frac{R_s \sqrt{jf/f_s} + j2\pi fL}{R_d + 1/j2\pi fC}}$$

\uparrow
propagation constant

4 connectors

skin effect

dielectric loss

$$f_s = 200\text{MHz}; L = 0.5\text{mH/m}, C = 50\text{pF/m}; Z_0 \cong \sqrt{L/C} = 100\Omega, v = 1/\sqrt{LC} = 200 \times 10^6 \text{m/s}$$

Expected alien-NEXT squared magnitude function

$$|G_A(f_{[\text{Hz}]}, \ell_{[\text{m}]})|^2 = 10^{-\left(\frac{X1 + 2.5 - S \times \log_{10} \sqrt{f/10^8}}{10}\right)} \times \left(1 - |G_C(f, \ell)|^4\right); S = \begin{cases} 10, & f \leq 10^8 \\ 15, & f \geq 10^8 \end{cases}$$

NEXT attenuation [dB]

dependence on length

Model #1 (Cat 7, shielded) , 100 m → cabtyp “**ClassF**” : $R_s=9.48 \Omega/\text{m}$, $R_d=1.7 \text{ m}\Omega/\text{m}$, $X1=60 \text{ dB}$

Model #2 (Cat 6, unshielded) , 55 m → cabtyp “**ClassEu**” : $R_s=9.85 \Omega/\text{m}$, $R_d=3.5 \text{ m}\Omega/\text{m}$, $X1=47 \text{ dB}$

Model #3 (Cat 6, shielded) , 100 m → cabtyp “**ClassEs**” : $R_s=9.85 \Omega/\text{m}$, $R_d=3.5 \text{ m}\Omega/\text{m}$, $X1=62 \text{ dB}$