10GBASE-T
Cable characteristics, front-end solutions, and precoders

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  - Proposal: adopt three fixed IIR precoding responses "short", "medium", and "long" as a baseline set of fixed precoding responses.

Cabling characteristics

Strive for more clarity and conciseness

10GBASE-T cabling characteristics: proposed description

Cable insertion loss (IL_{CABLE}) --> squared magnitude of cable transfer function

f in MHz, ℓ in meter

$$IL_{CABLE}(f) = 1.05\left(ILa\sqrt{f} + ILb\,f + ILc/\sqrt{f}\right)\ \text{[dB/100m]} \rightarrow \left|G_{CABLE}(f,\ell)\right|^2 = 10^{-(\ell/100)\times IL_{CABLE}(f)/10}$$

Insertion loss of four connectors ($IL_{4\,CONN}$) --> squared magnitude of link-segment transfer function

$$IL_{4CONN}(f) = 4\times 0.02\sqrt{f}\ \text{[dB]} \rightarrow \left|G_{LINK\ SEG}(f,\ell)\right|^2 = \left|G_{CABLE}(f,\ell)\right|^2 \times 10^{-IL_{4CONN}/10}$$

Power-sum ANEXT loss (PSL_{ANEXT}) --> power-sum ANEXT coupling function

not in Draft 1.4

$$PSL_{ANEXT}(f) = \begin{cases} X1 - 10\log_{10}(f/100) & 1 \le f \le 100 \\ X1 - 15\log_{10}(f/100) & 100 \le f \le 500 \end{cases}\ \text{[dB]} \rightarrow C_{PSANEXT}(f,\ell) = 10^{-PSL_{ANEXT}(f)/10} \times \left(1 - \left|G_{CABLE}(f,\ell)\right|^4\right)$$

Power-sum equal-level AFEXT loss ($PSL_{ELAFEXT}$) --> power-sum AFEXT coupling function

$$PSL_{ELAFEXT}(f) = X2 - 20\log_{10}(f/100)\ \text{[dB]} \rightarrow C_{PSAFEXT}(f,\ell) = 10^{-PSL_{ELAFEXT}(f)/10} \times (\ell/100) \times \left|G_{CABLE}(f,\ell)\right|^2$$

Cabling	Max. cable length	IL at 250 MHz	ILa	ILb	ILc	PSANEXT const_avg X1	PSELAFEXT const_avg X2
Cat 6	55 m	20.3 dB	1.82	0.0169	0.25	47 + 2.5 dB	33.6 + 2.5 dB
Class E	100 m	35.9 dB	1.82	0.0169	0.25	62 + 2.5 dB	37 + 2.5 dB
Class F*	100 m	33.8 dB	1.80	0.0100	0.20	60 + 2.5 dB	37 + 2.5 dB

* = augmented Cat 6

Derivation of expected NEXT coupling function

The transfer function from transmitted signal to received NEXT signal is given by

$$G_N(f,\ell) = \frac{U_N(f, x=0)}{U_T(f, x=0)} = \int_{x=0}^{\ell} j2\pi f \; c_N(x) e^{-2x\gamma(f)} dx \;\; ,$$

where $c_N(x)$ is a real-valued spatial function determining the NEXT coupling between cable pairs, and $\gamma(f)$ is the complex-valued propagation function of the cable. We call the expected squared magnitude of $G_N(f,\ell)$ the *expected NEXT coupling function*:

$$C_N(f,\ell) = E\left\{ \left| \frac{U_N(f, x=0)}{U_T(f, x=0)} \right|^2 \right\} = \int_{x_1=0}^{\ell} \int_{x_2=0}^{\ell} 4\pi^2 f^2 E\{c_N(x_1) c_N(x_2)\} e^{-2x_1\gamma(f)} e^{-2x_2\bar{\gamma}(f)} dx_1 dx_2$$

For random *white Gaussian coupling* (WGC)

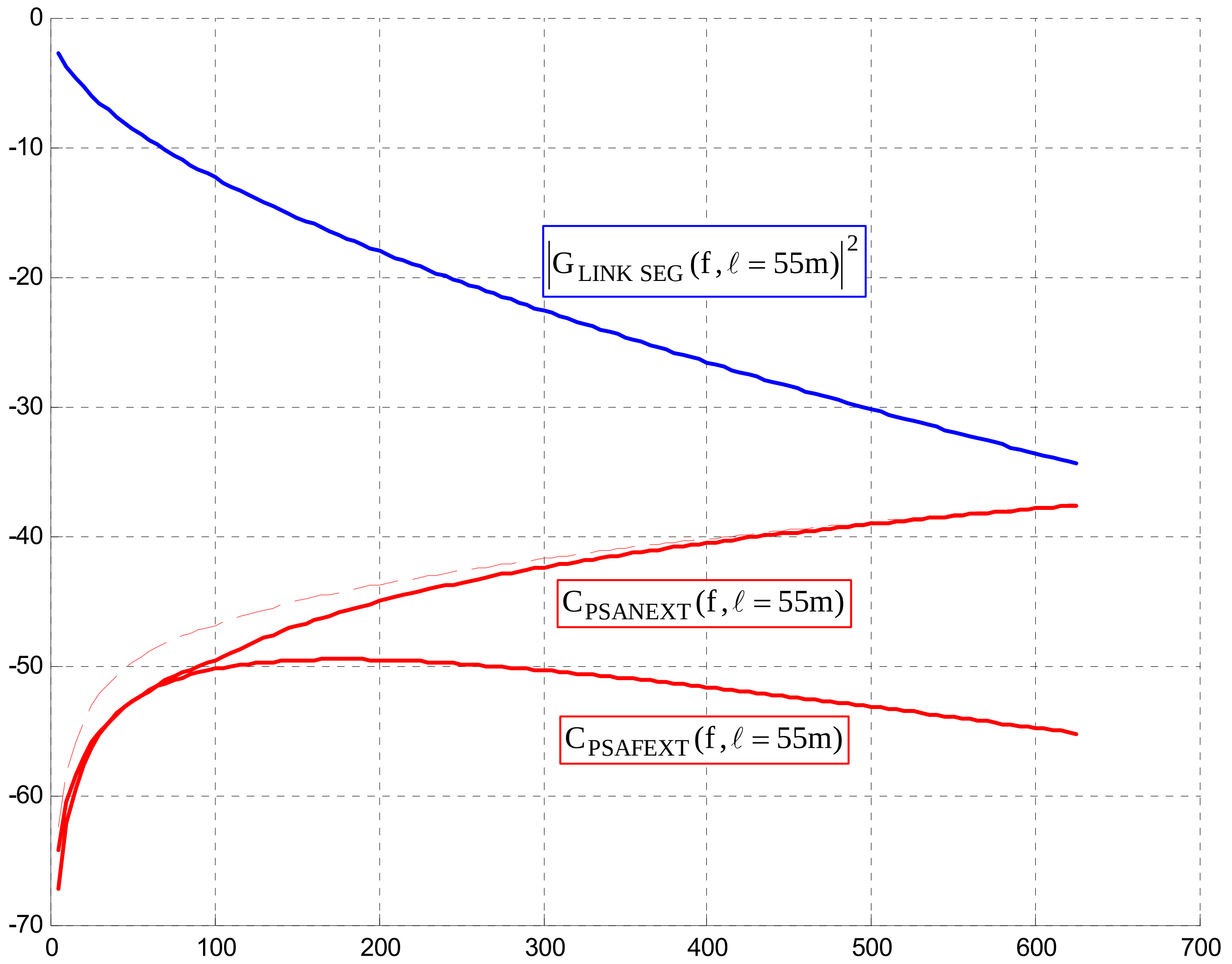
$$E\{c_N(x) c_N(x+y)\} = C_N^0 \delta(y) \;\; .$$

Let $\mathrm{Re}\{\gamma(f)\} = \gamma_R(f)$. Then

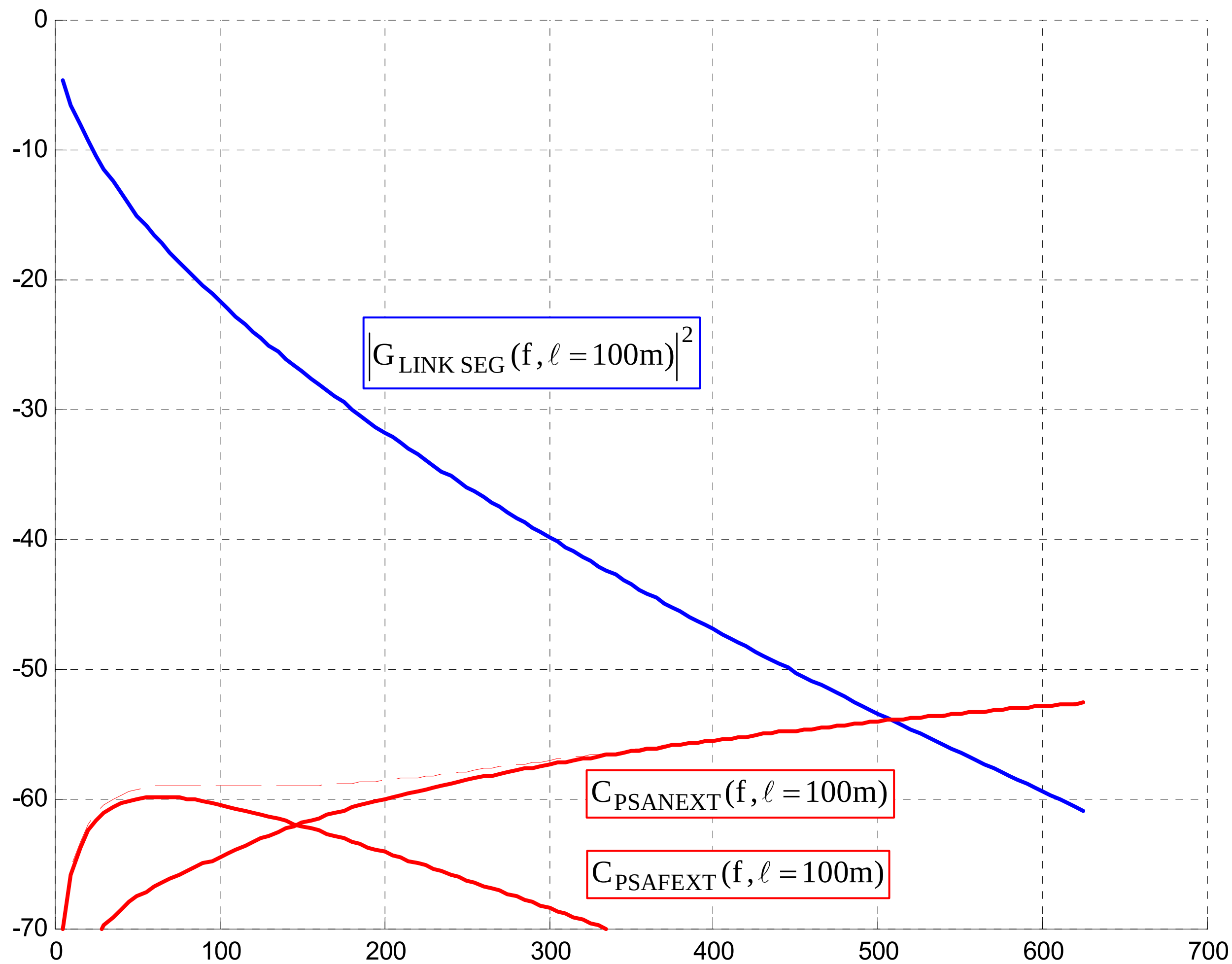
$$C_N(f,\ell) = 4\pi^2 f^2 C_N^0 \int_{x=0}^{\ell} e^{-4x\gamma_R(f)} dx = \frac{\pi^2 f^2 C_N^0}{\gamma_R(f)} \left(1 - e^{-4\ell\gamma_R(f)}\right) = C_N(f,\infty) \left(1 - |G_C(f,\ell)|^4\right).$$

Source: G. Ungerboeck, private notes, ca. 1995

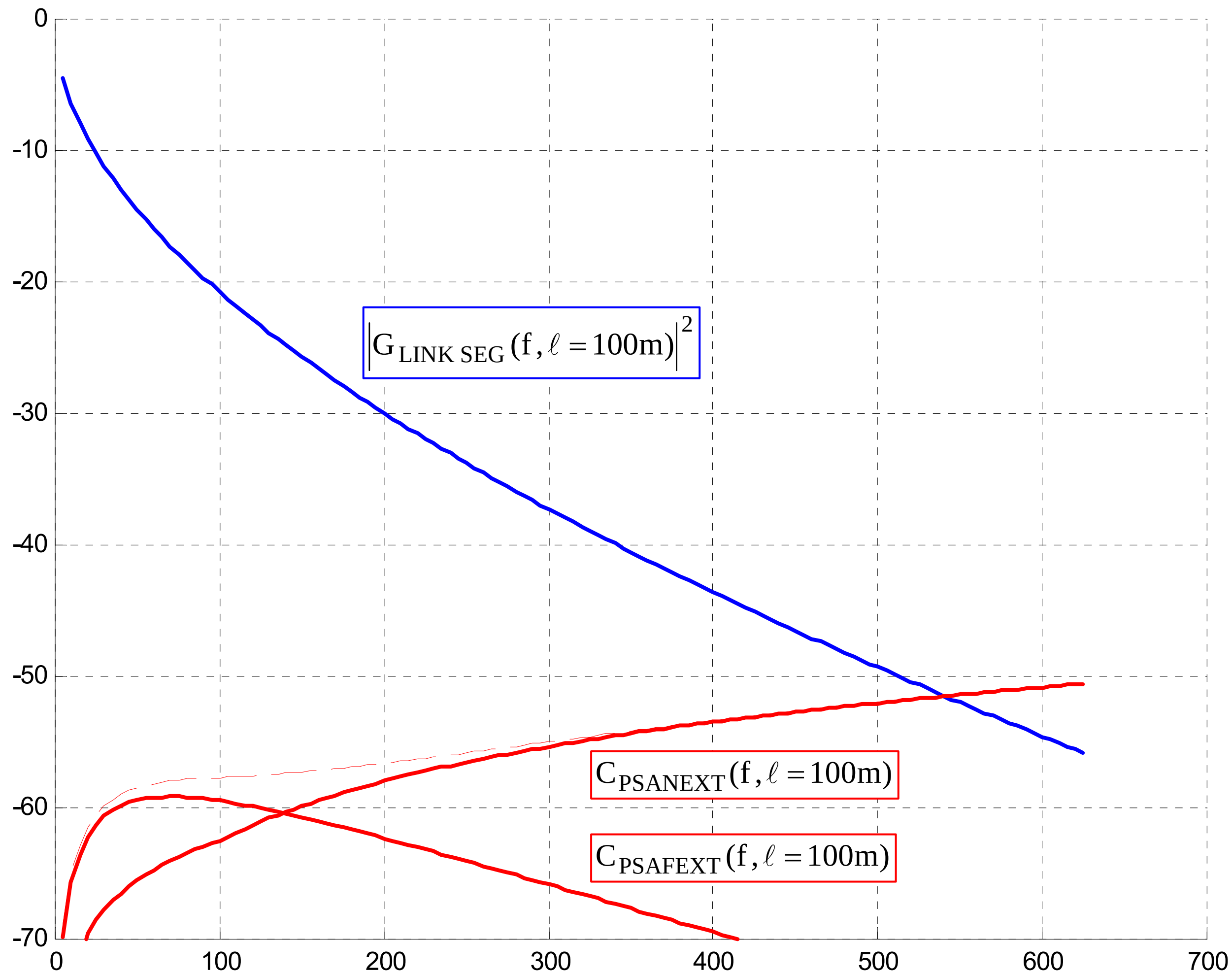
10GBASE-T cabling characteristics: Cat 6



10GBASE-T cabling characteristics: Class E



10GBASE-T cabling characteristics: Class F



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Cable characteristics: discussion & proposal

Section 55.7 can be improved by presenting cable / link attenuation-related properties first by length-independent "loss" quantities in dB, e.g.,

$IL_{CABLE}(f)$, $IL_{4CONN}(f)$, … $PSL_{ANEXT}(f)$, $PSL_{ELAFEXT}(f)$ …

and then expressing length-dependence in the corresponding squared-magnitude or power-coupling functions, e.g.,

$|G_{CABLE}(f,L)|^2$, … $C_{PSANEXT}(f,L)$, … .

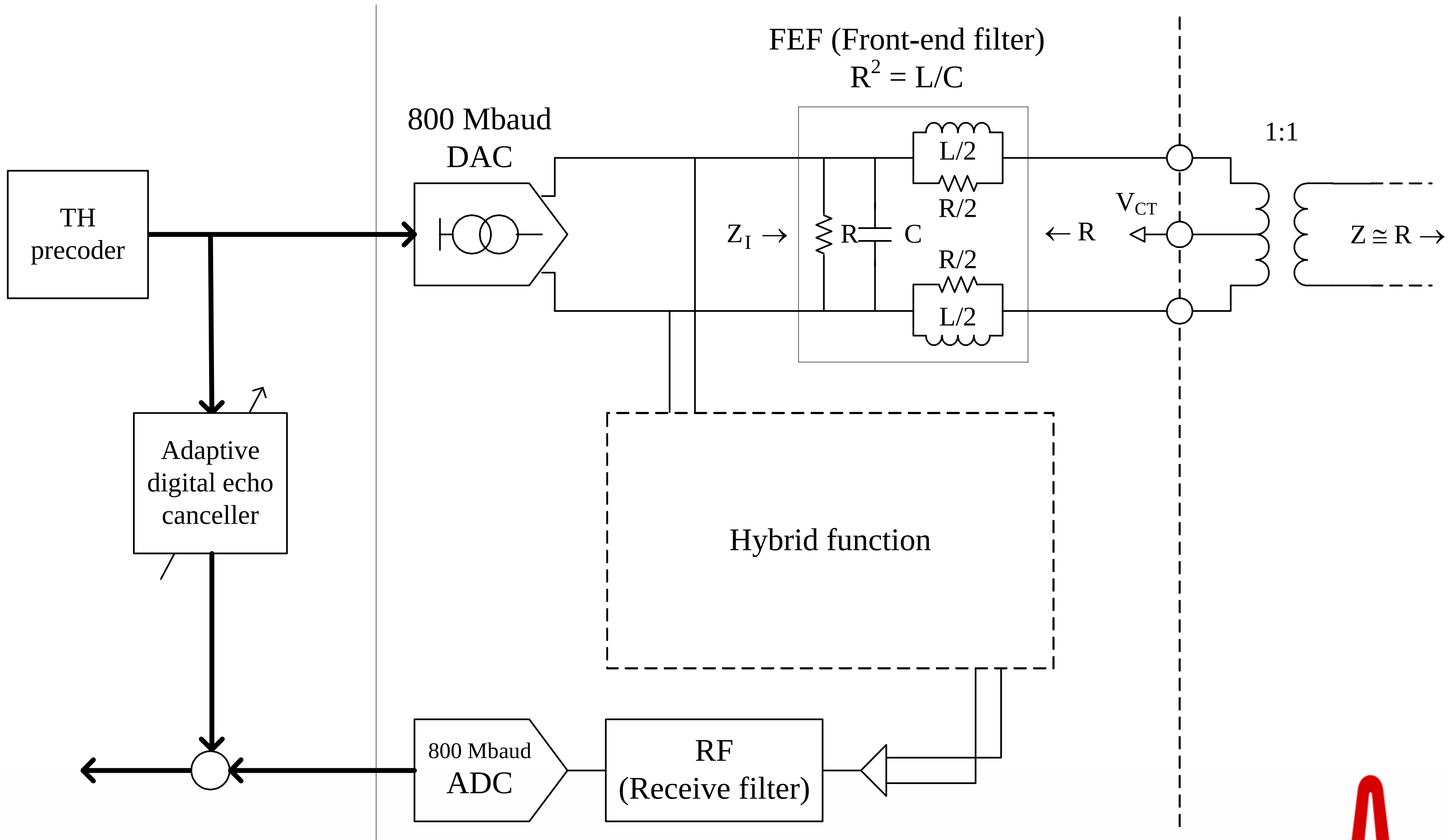
All cable-type dependent (Cat 6, Class E, Class F) parameters can be given in a single table, as has been shown.

Transmitter front-end solutions

“Baseline” approach and “preferred” approach

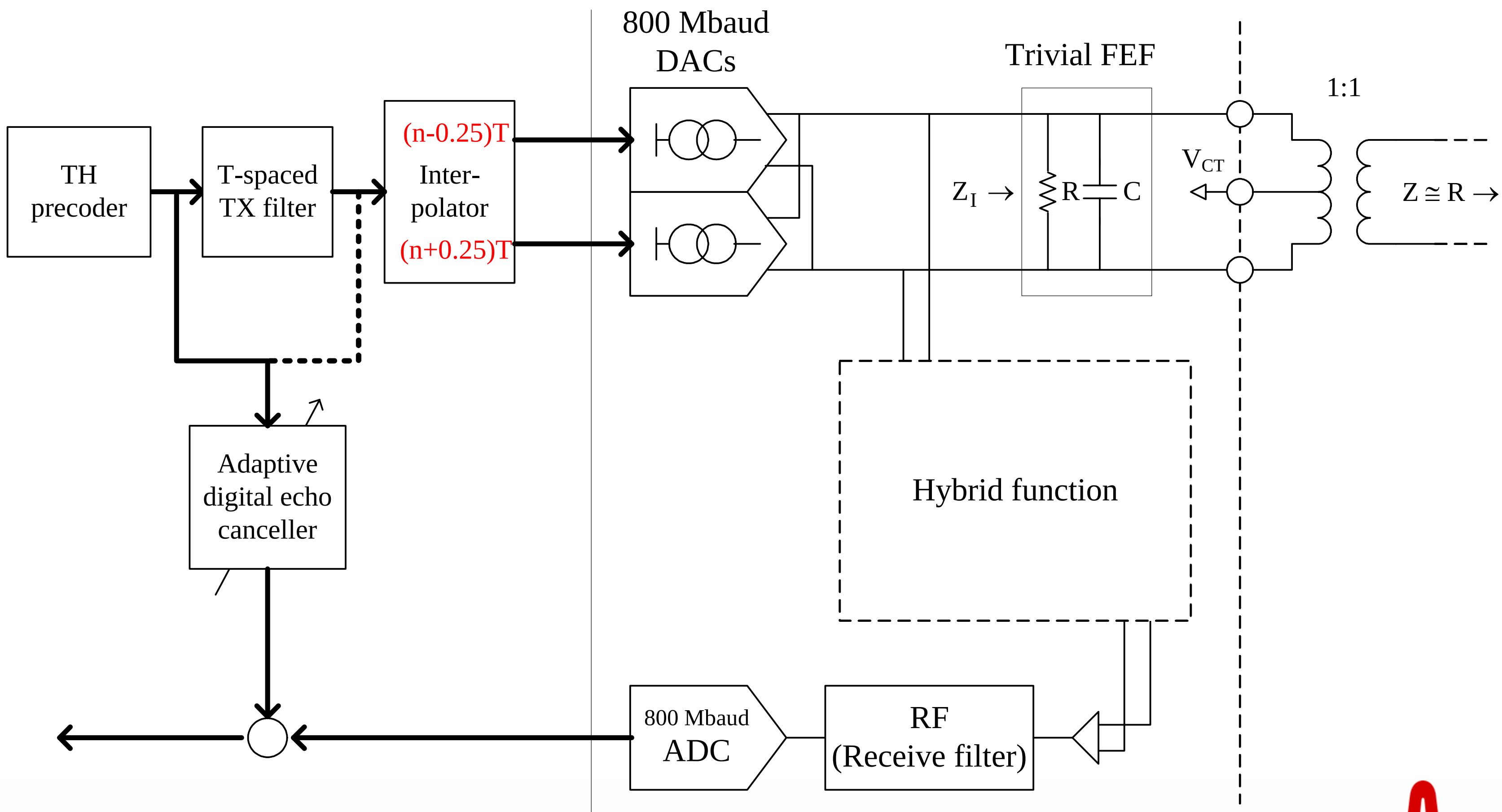
Transmitter front-end: “baseline” approach

No digital filtering, T-spaced DAC, front-end filter with frequency-dependent input impedance Z_I and constant output impedance R



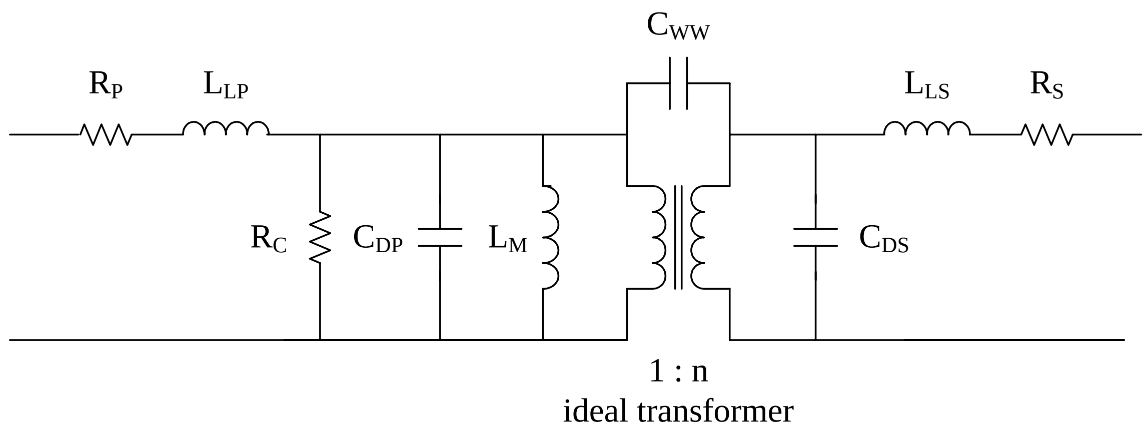
Transmitter front-end: “preferred” approach

Digital TX-filtering & T/2-interpolation, T/2-overlapping DACs, trivial front-end filter



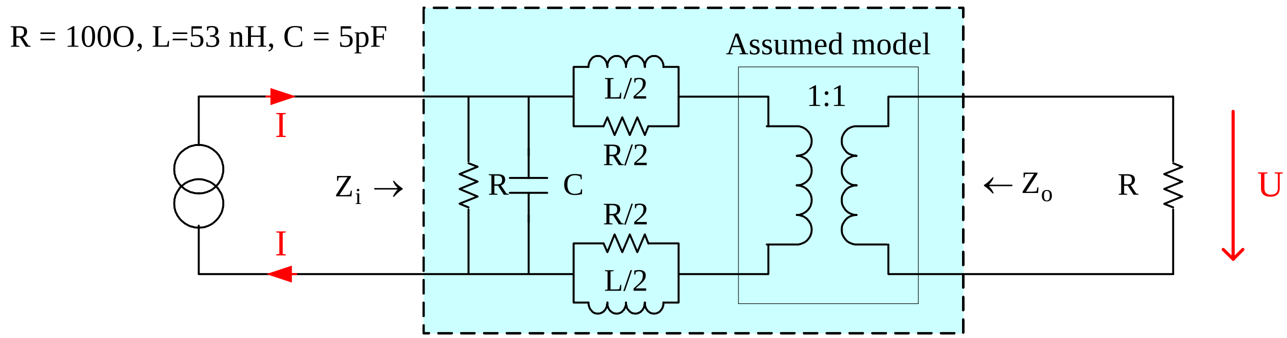
Transformer equivalent circuit

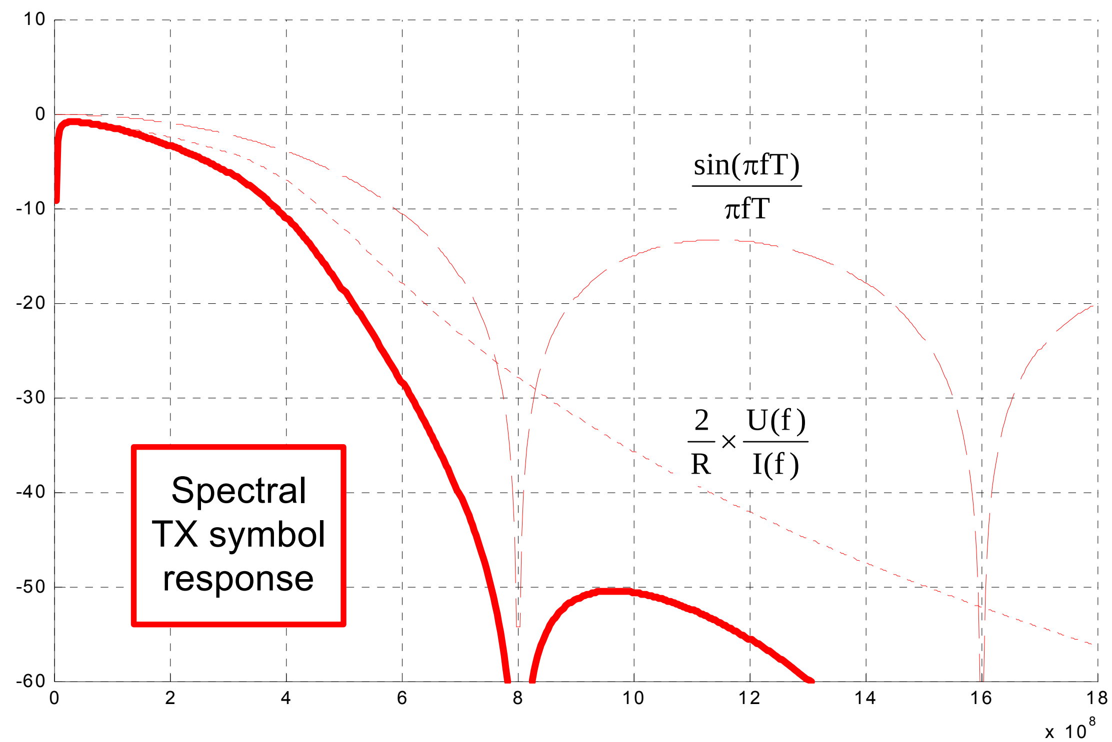
From "Introduction to Transformer Magnetics", White Paper G022.A (7/99)
www.pulseeng.com



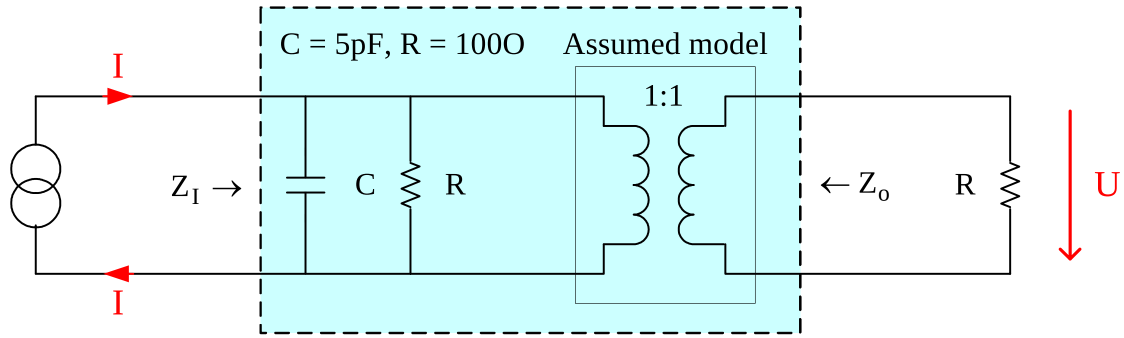
		Assumed model parms
n ……..	secondary-to-primary windings ratio	1
$R_{P/S}$ ….	primary/secondary winding resistance	2O
$L_{LP/S}$ ….	primary/secondary leakage inductor	50nH
R_C ….	core loss resistance	1000O
$C_{DP/S}$ ….	primary/secondary distributed capacitance	3pF
L_M ….	main inductance	2000nH
C_{WW} ….	inter-winding capacitance	*(has no effect for n=1)*

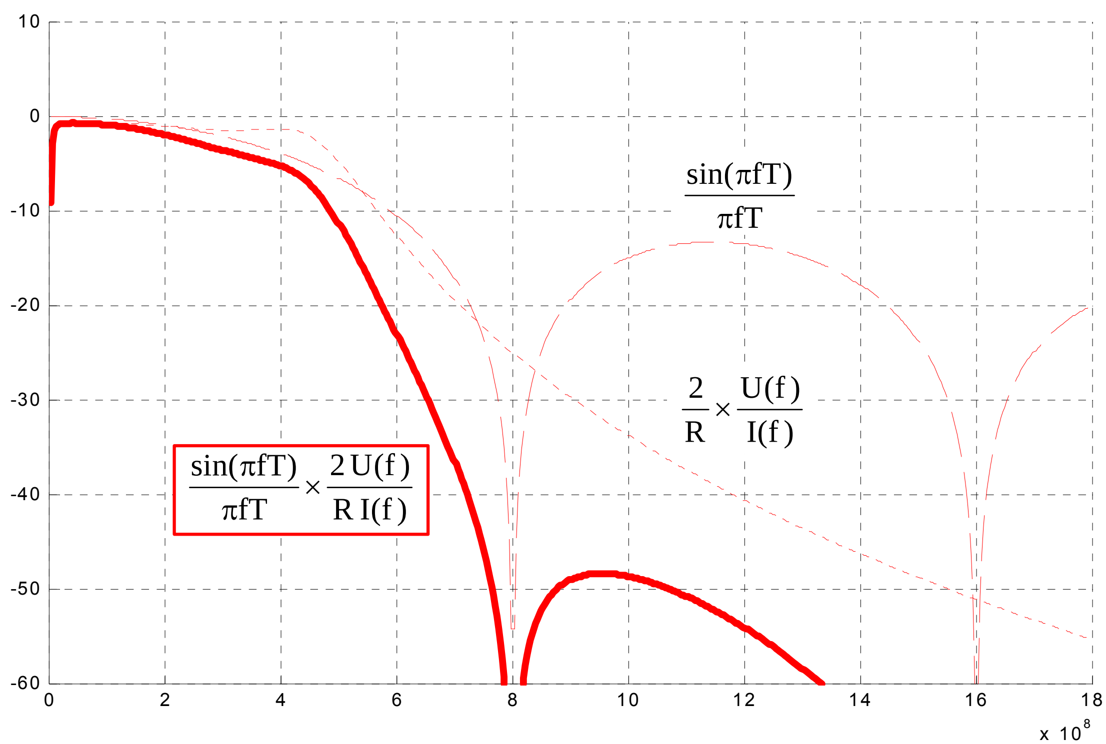
Baseline approach: analog front end



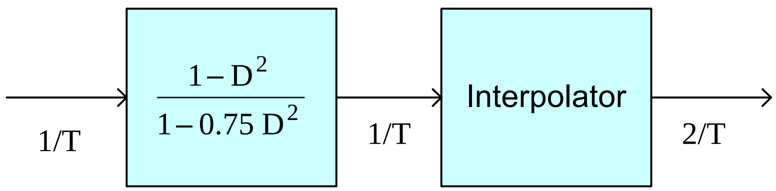


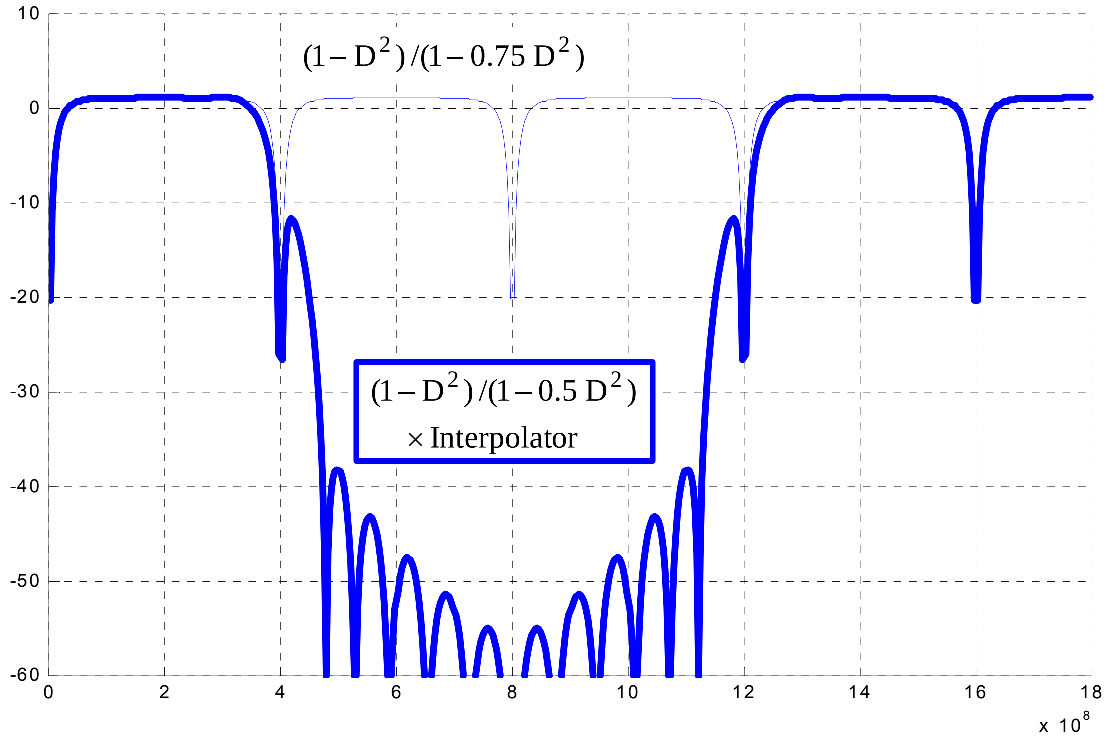
Preferred approach: analog front end





Preferred approach: digital TX filter & interpolator





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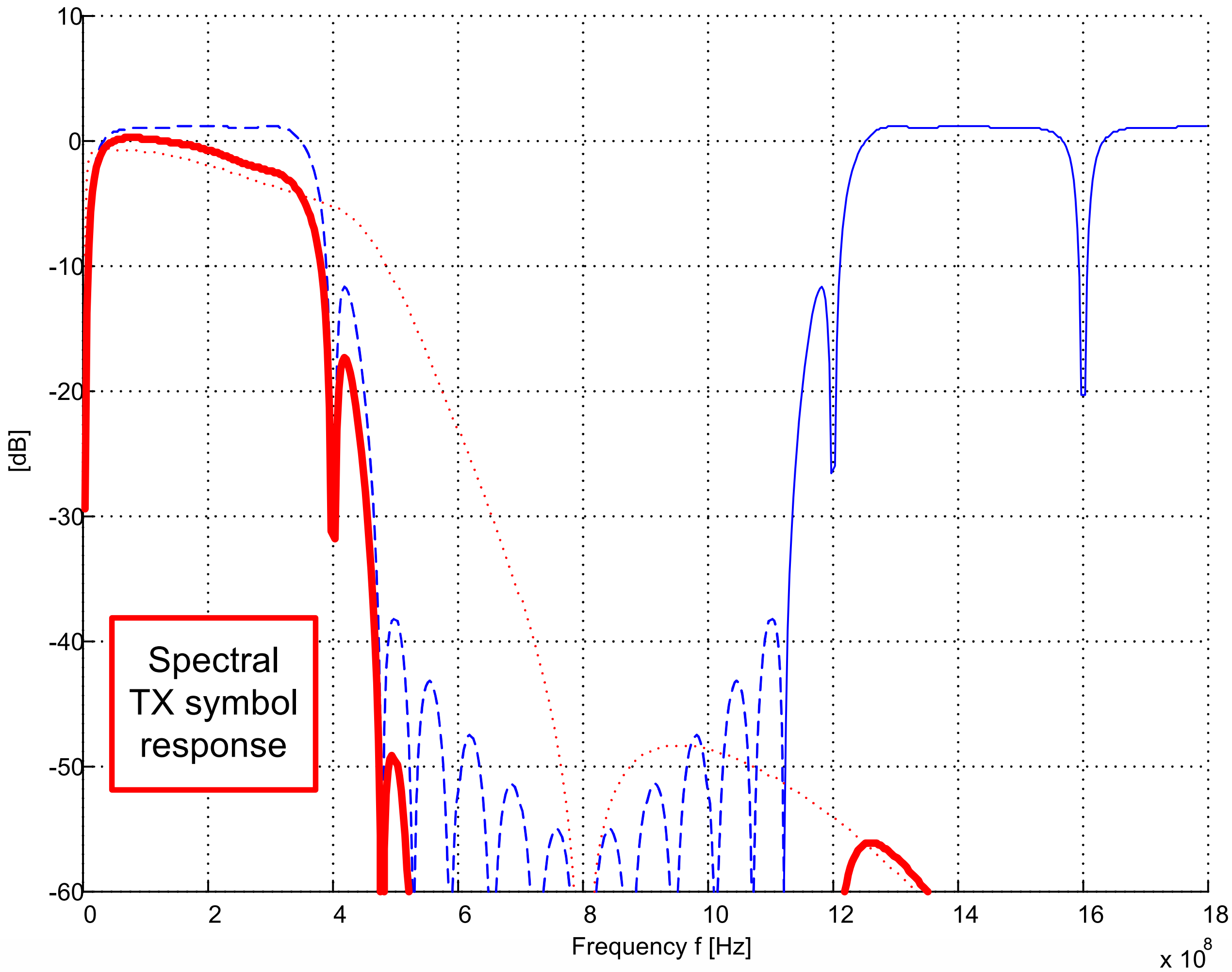
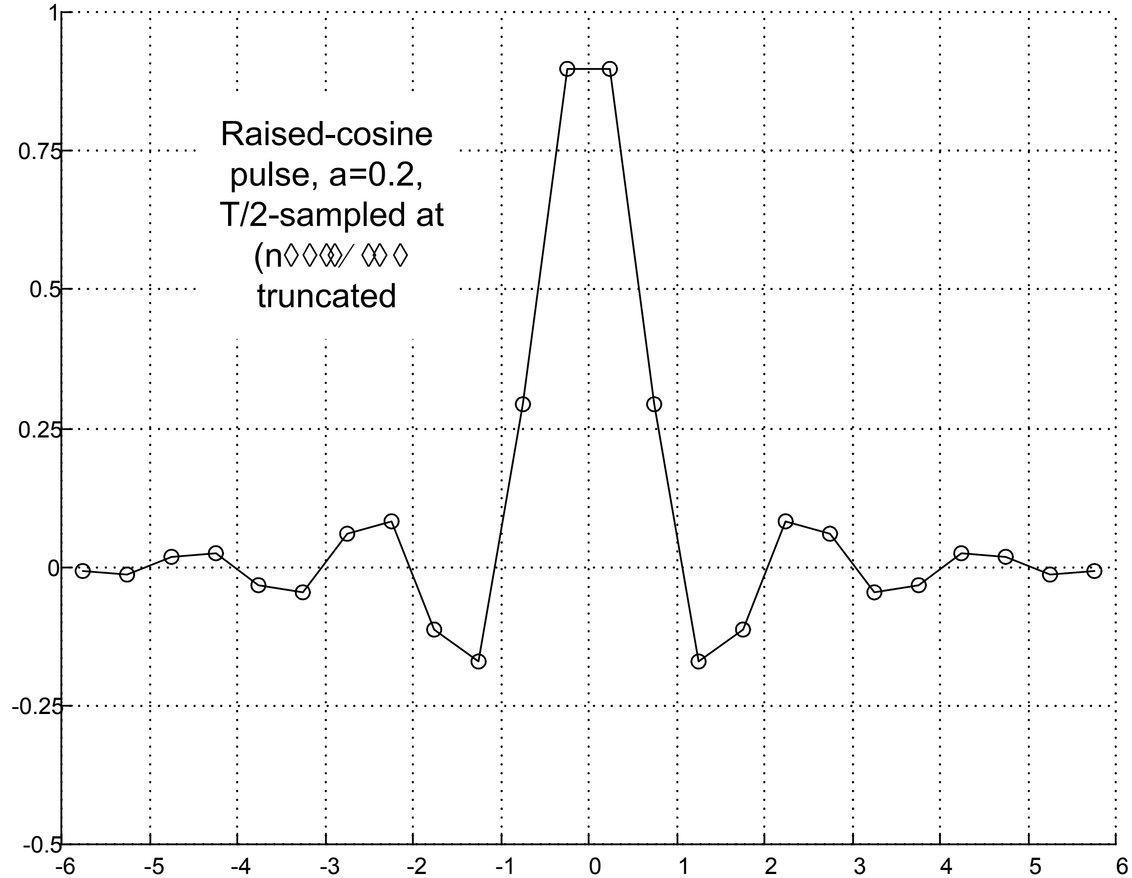
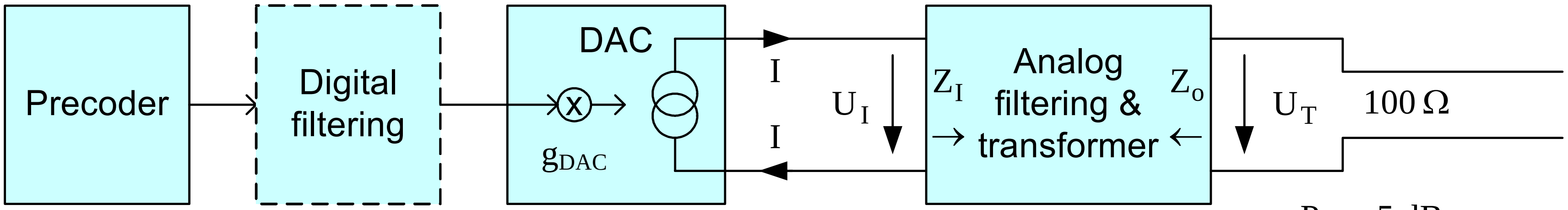
Preferred approach: digital & analog front-end



Preferred approach: interpolation coefficients



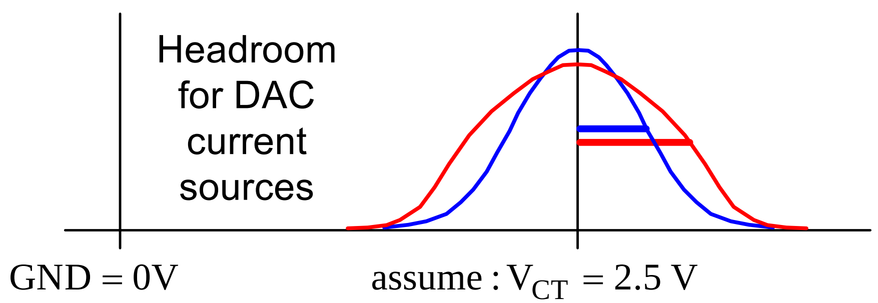
Comparison: baseline approach and preferred approach



$$P_T = 5\ \text{dBm}:$$
$$U_T = 562.3\ \text{mV}_{rms}$$

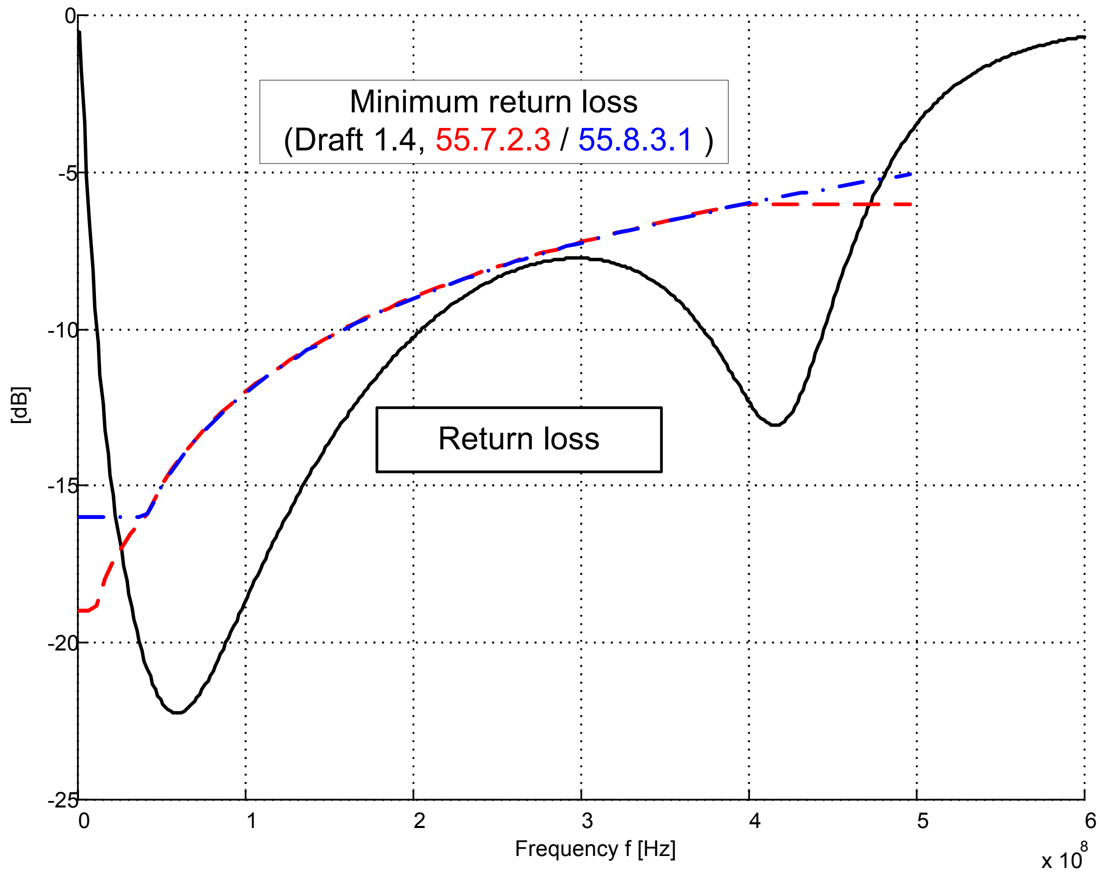
$$\text{Baseline approach}: \quad I = 15.9\ \text{mA}_{rms},\ U_I = 891.1\ \text{mV}_{rms,diff} \ \triangleq\ V_{CT} \pm 445\text{mV}_{rms}$$

$$\text{Preferred appraoch}: \quad I = 12.7\ \text{mA}_{rms},\ U_I = 630.7\ \text{mV}_{rms,diff} \ \triangleq\ V_{CT} \pm 315.3\text{mV}_{rms}$$

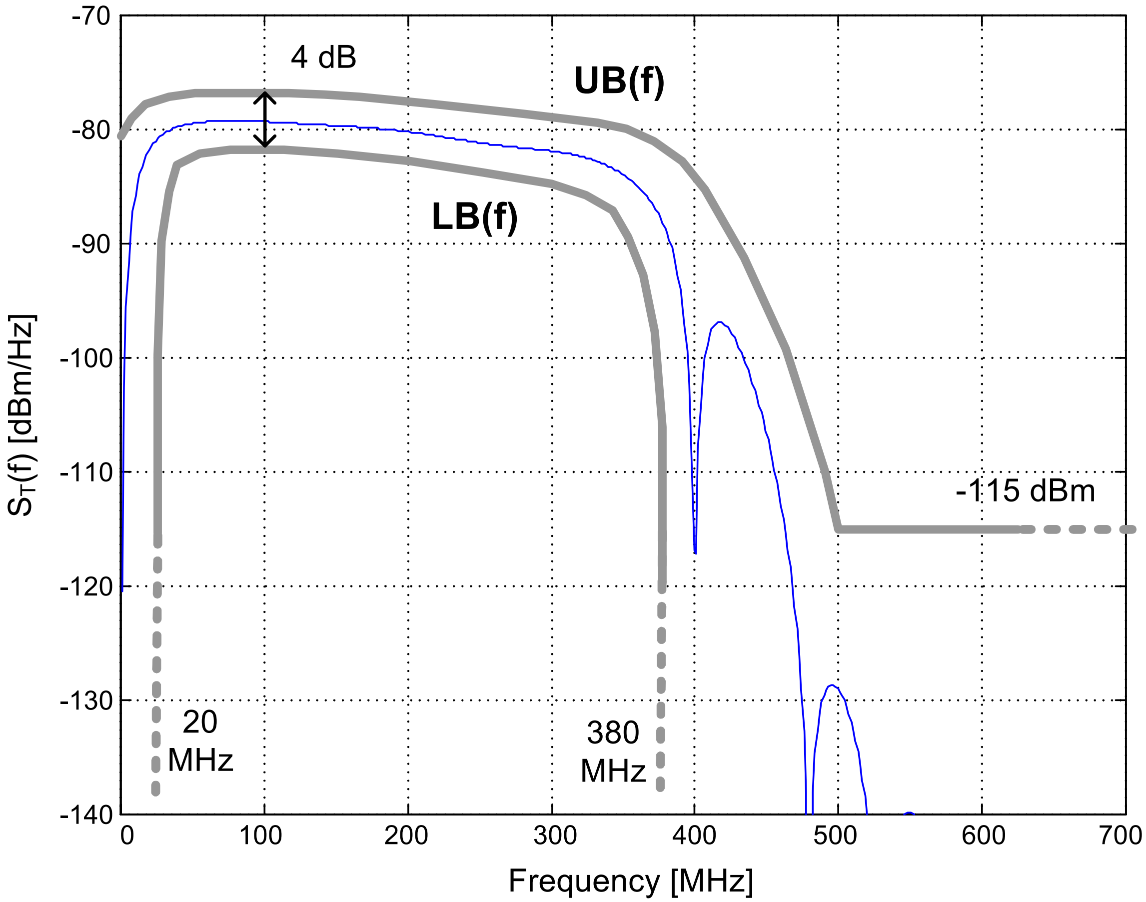


Preferred approach has lower (-3 dB) rms-voltage at DAC outputs than baseline approach, but (presumably) higher peak-to-average ratio.

Preferred approach: return loss



Proposed transmit PSD specification



The transmit PSD shall (a) be bounded by LB(f) and UB(f), and (b) exhibit spectral nulls at f = 0 and 400 MHz.

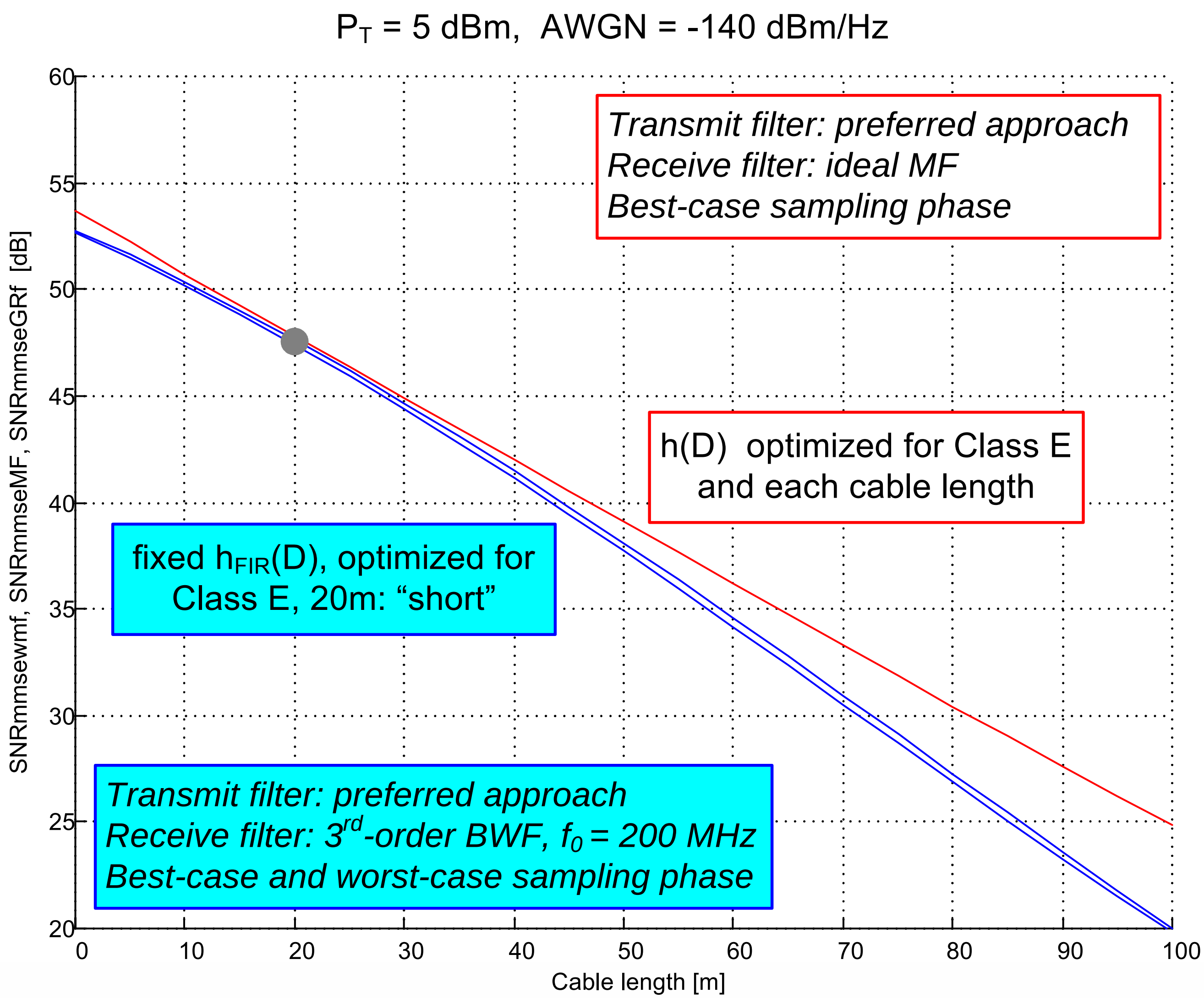
Transmitter front-end solutions: discussion & proposal

- Tighter TX PSD specification is needed than currently provided in Draft 1.4 in order to use transmit signal power efficiently, permit operation with a few fixed precoders, and generally facilitate interoperability .
- Excess bandwidth wastes signal energy and leads to sampling phase dependence in the receiver. Hence: ≈zero excess bandwidth with spectral null at 1/2T is desired; also there shall be a spectral null at dc.
- To achieve the desired TX PSD characteristics, digital filtering and 2x oversampling is needed. However, this leads to higher PAR.
- Without digital filtering and oversampling, substantial analog filtering must be used. Non-constant filter input impedance causes a PAR problem, too!
- With digital filtering, oversampling, and trivial analog filtering, the PAR-related problem appears to be comparable, and at least is not significantly worse.

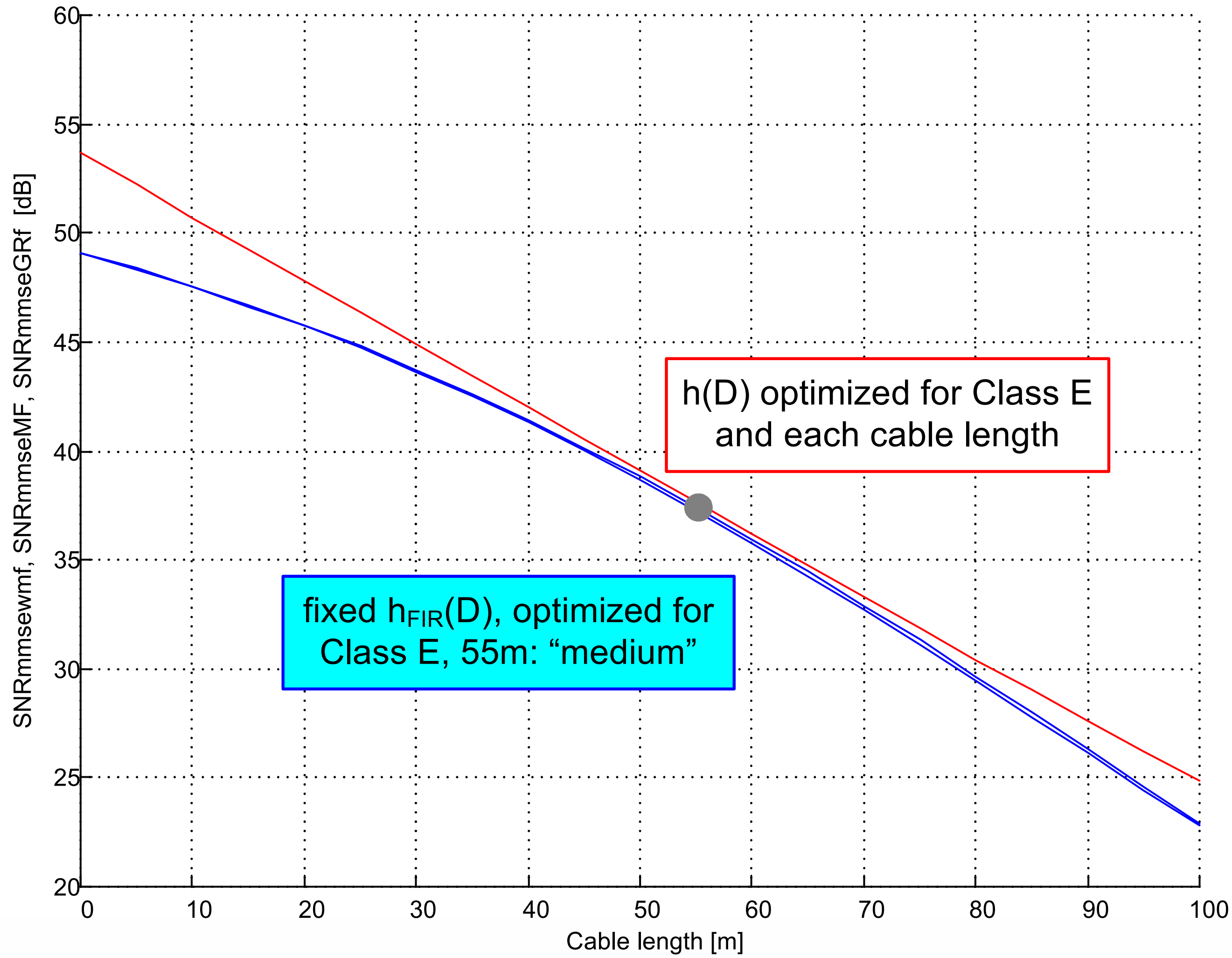
Decision-point SNR versus cable length and precoder functions

Towards set of fixed IIR precoder functions
"short", "medium", "long"

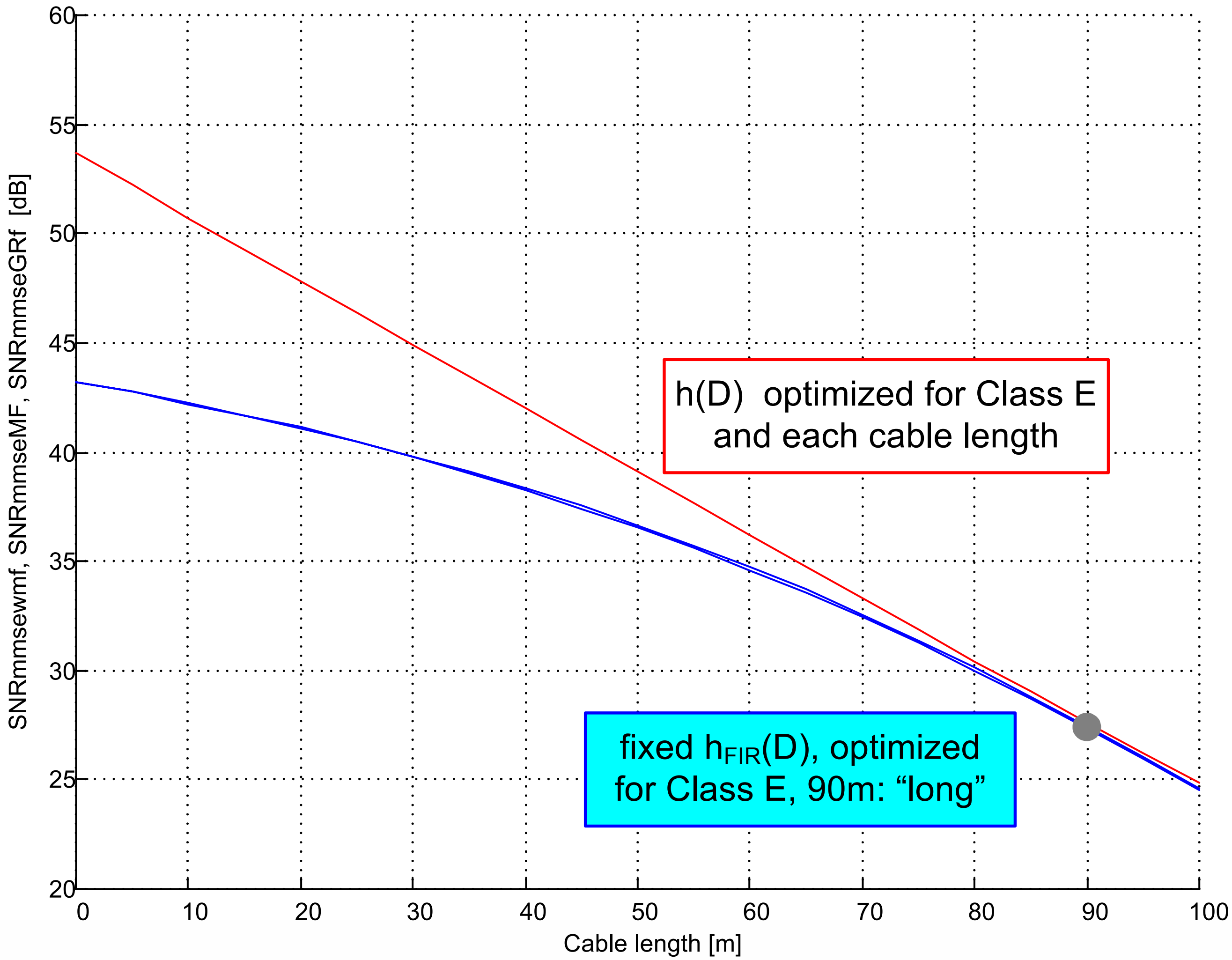
DP-SNR versus cable length: Class E



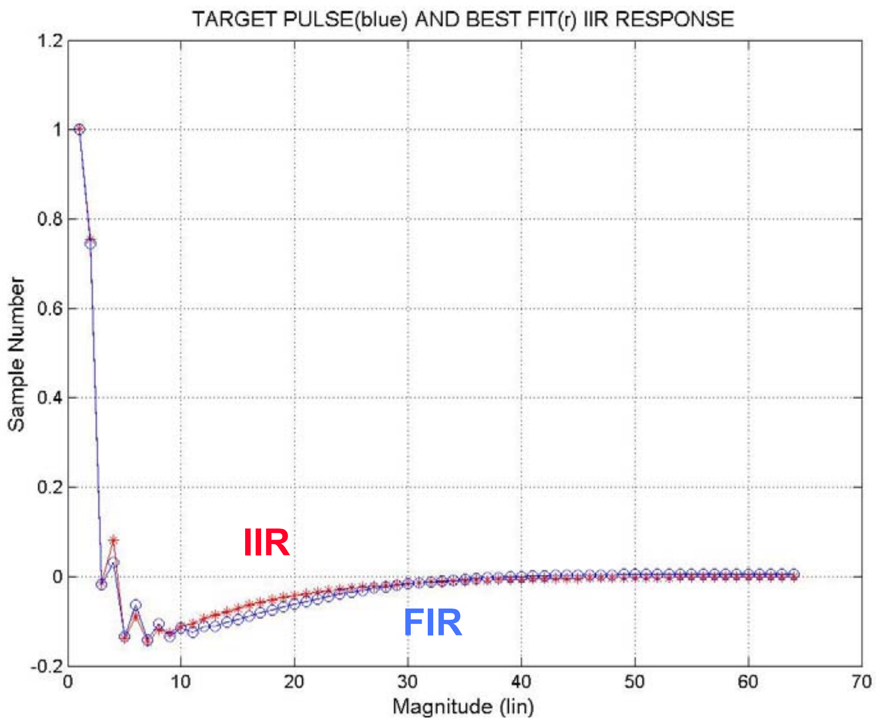
DP-SNR versus cable length: Class E

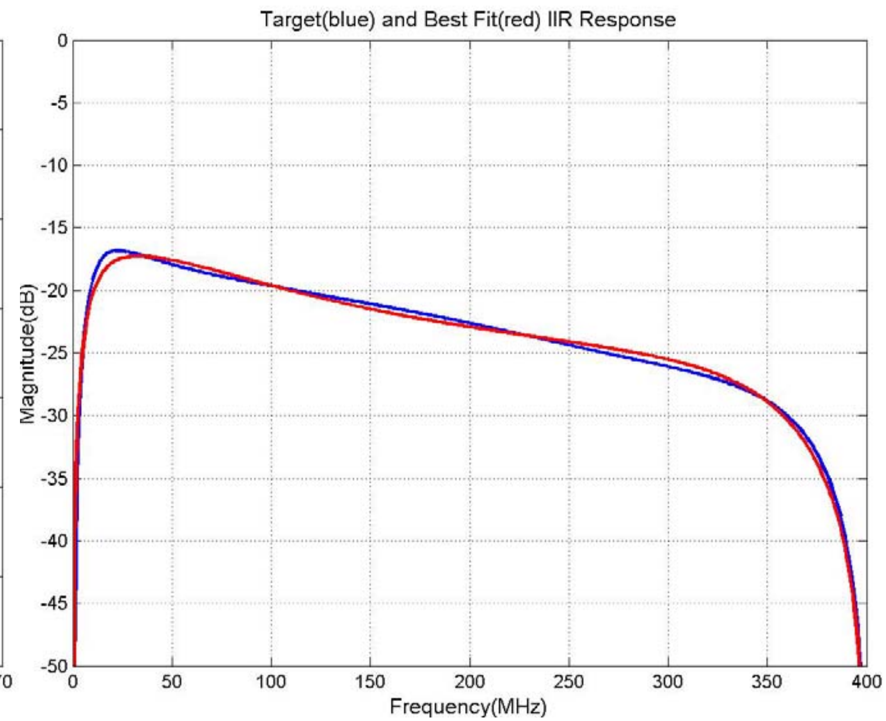


DP-SNR versus cable length: Class E

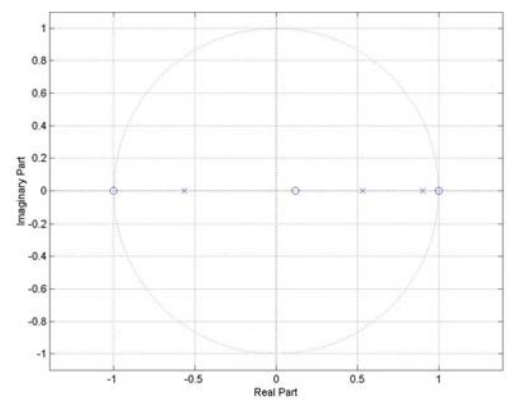


Precoder function optimized for Class E, 20m: "short"





$$h_{IIR}(D) = \frac{(1+D)(1-D)(1+b_1 D)}{(1+a_1 D + a_2 D^2)(1+a_3 D)}$$



b_1= -0.117209
a_1=-1.435716
a_2= 0.481075
a_3=-0.117209

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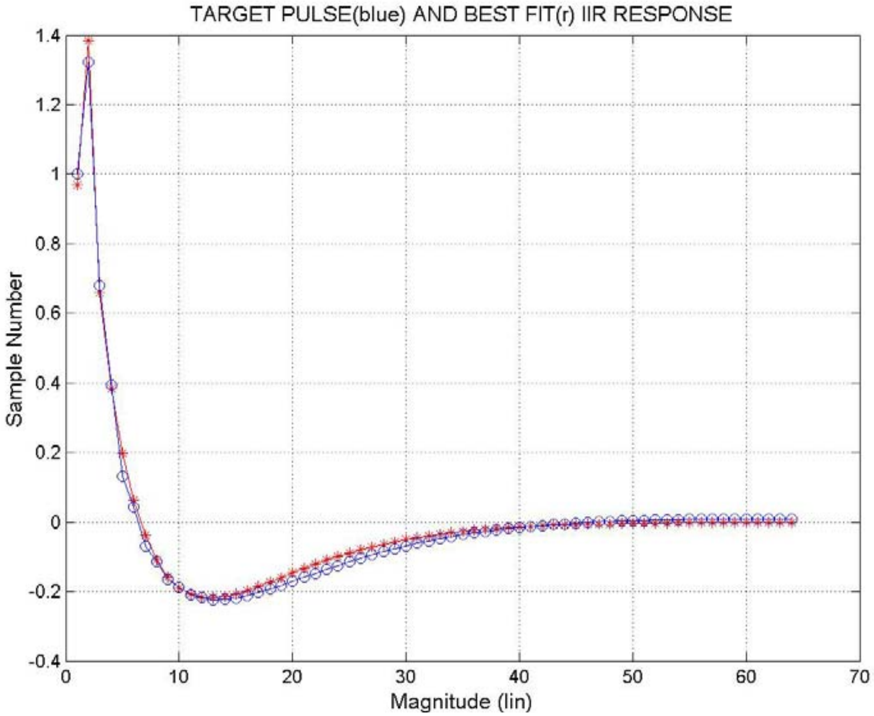
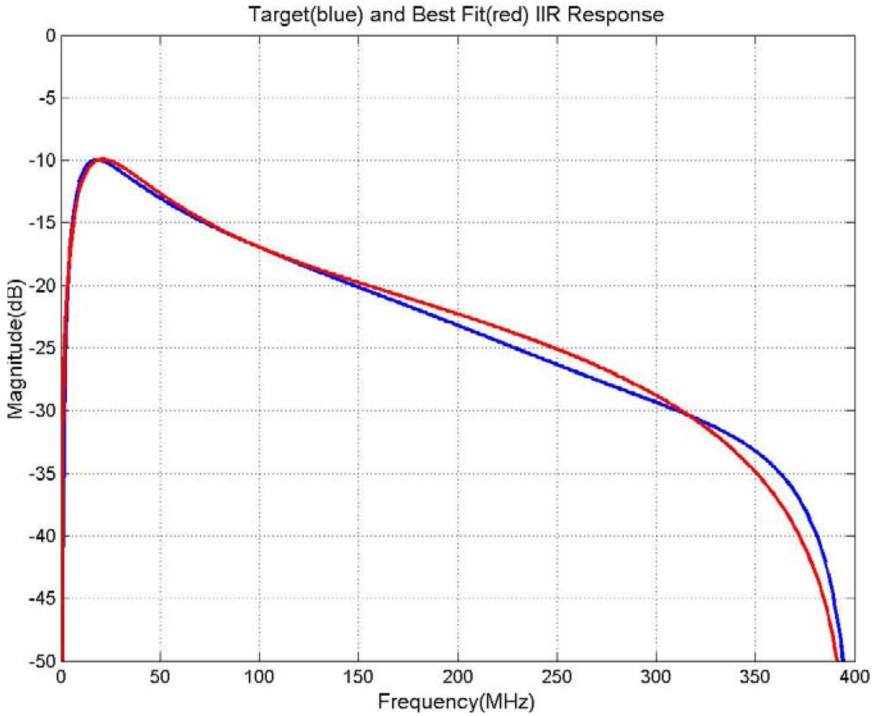
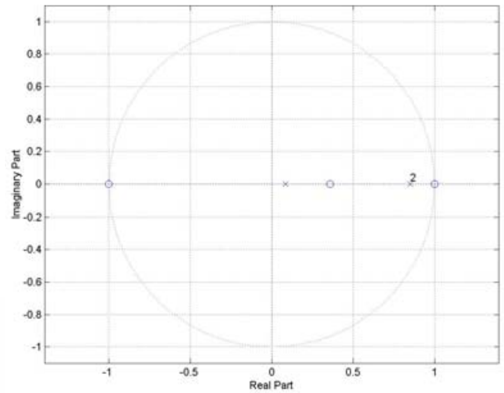
Precoder function optimized for Class E, 55m: “medium”



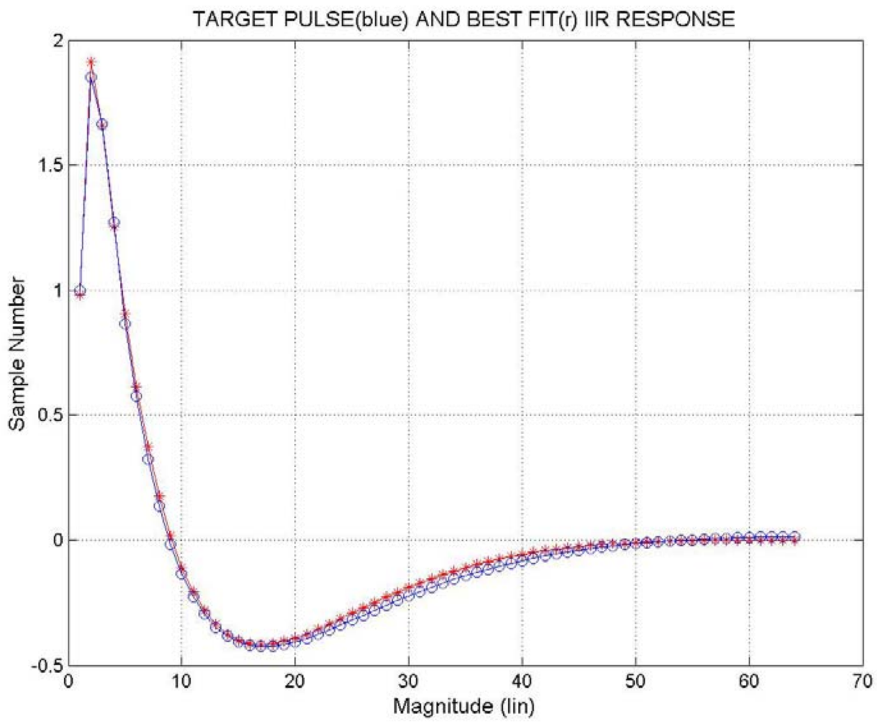


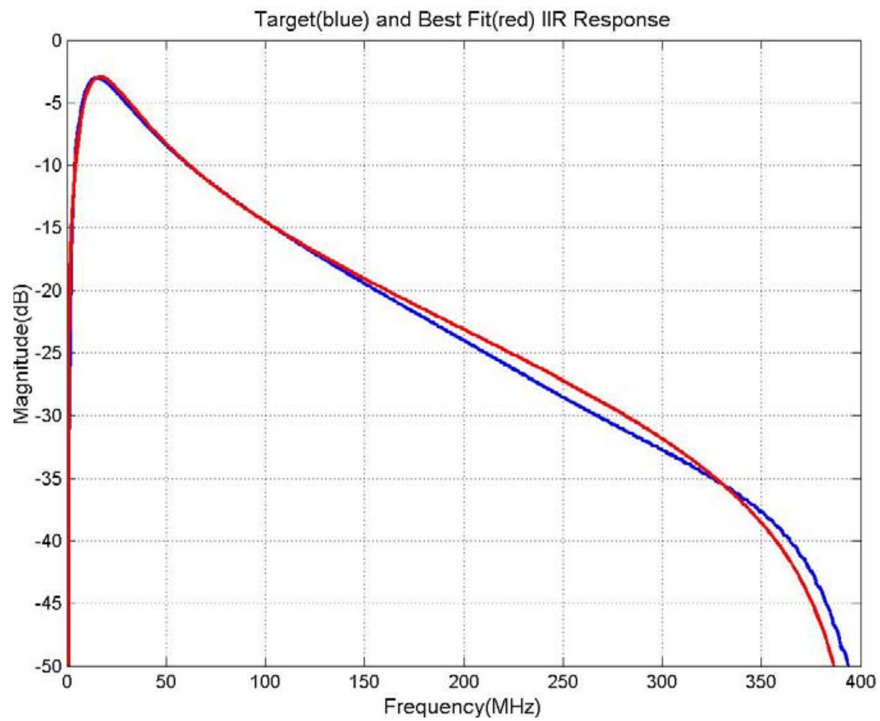
$$h_{IIR}(D) = \frac{(1+D)(1-D)(1+b_1 D)}{(1+a_1 D + a_2 D^2)(1+a_3 D)}$$



b_1= -0.358981
a_1=-0.935808
a_2= 0.072732
a_3=-0.849892

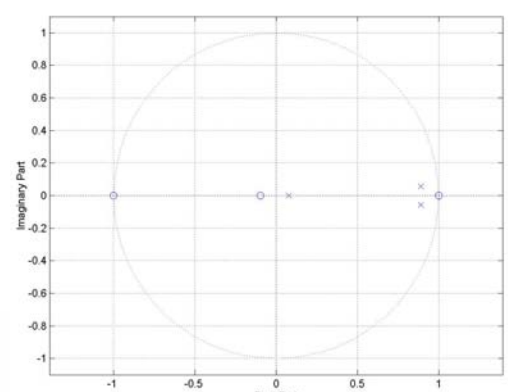
Precoder function optimized for Class E, 90m: "long"



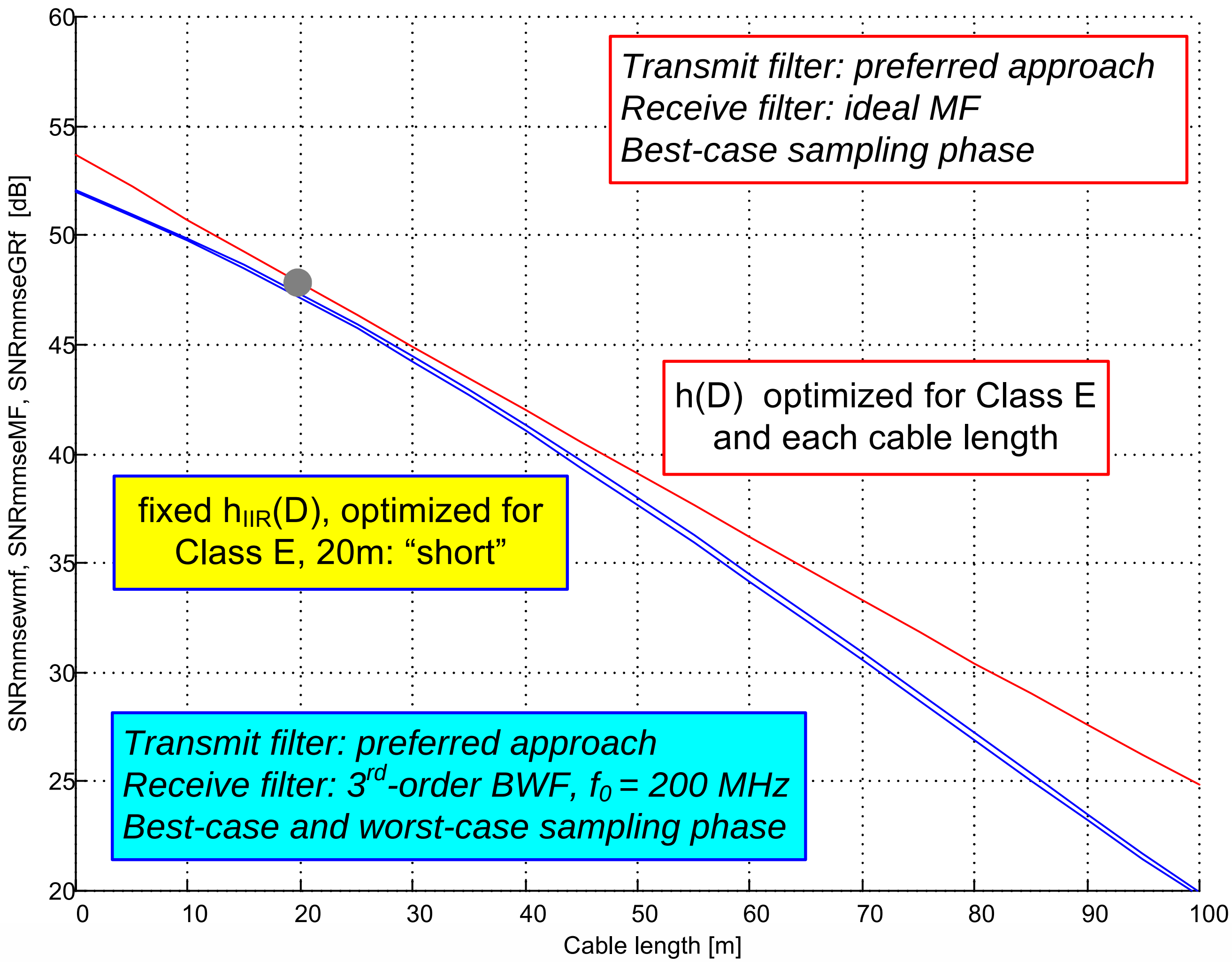


$$h_{IIR}(D) = \frac{(1+D)(1-D)(1+b_1 D)}{(1+a_1 D + a_2 D^2)(1+a_3 D)}$$

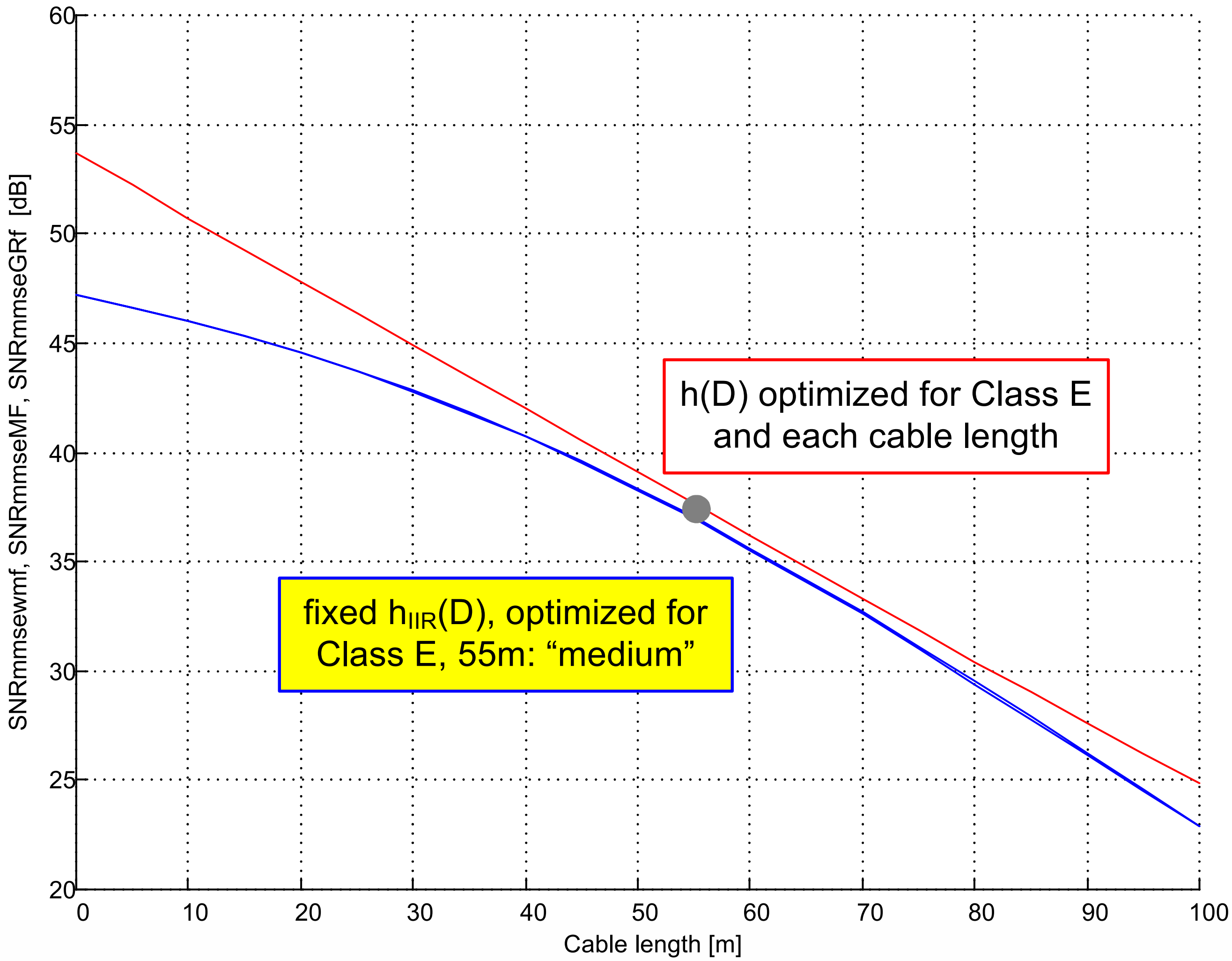
b_1= 0.098998
a_1=-1.777232
a_2= 0.792741
a_3=-0.075043



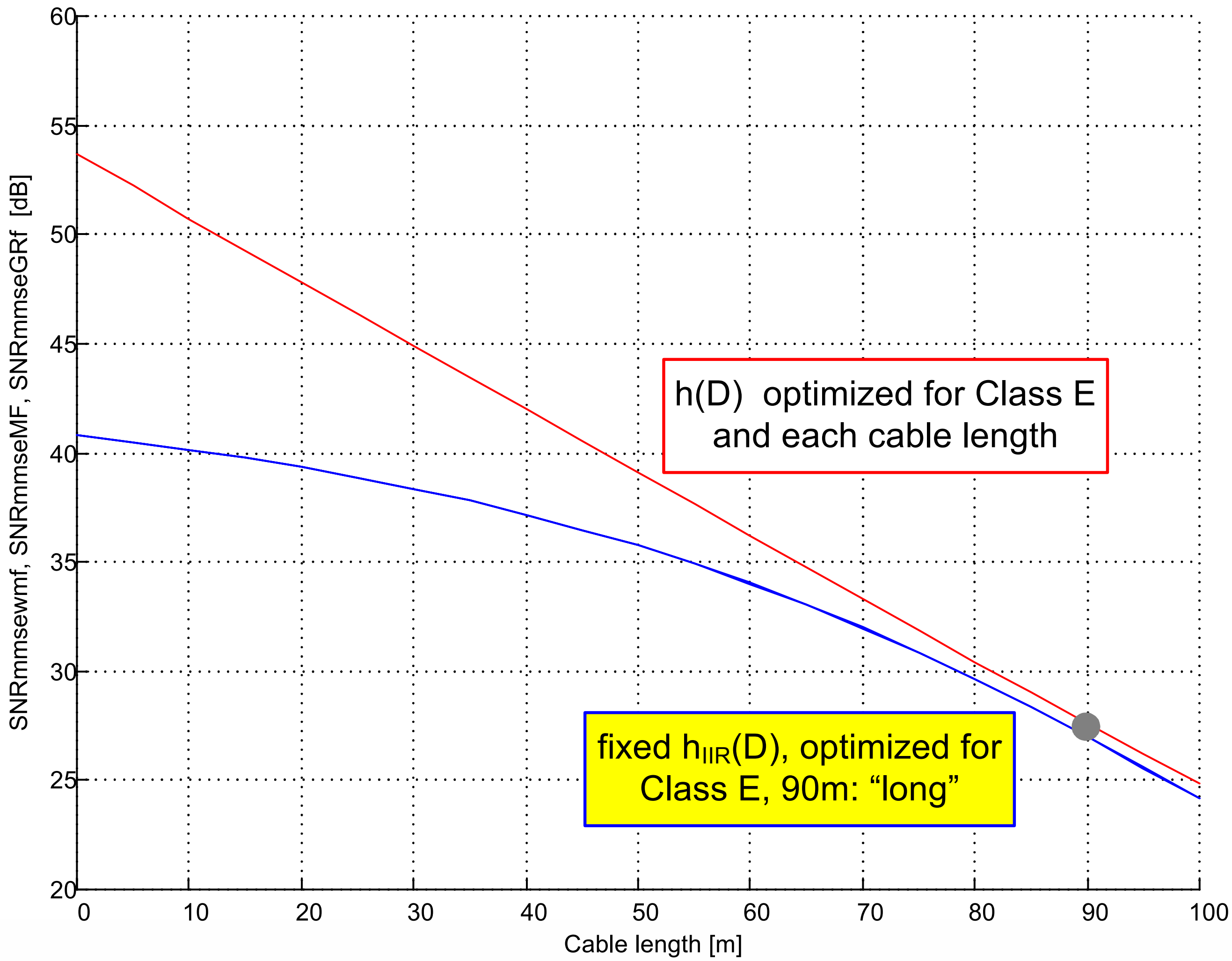
DP-SNR versus cable length: Class E



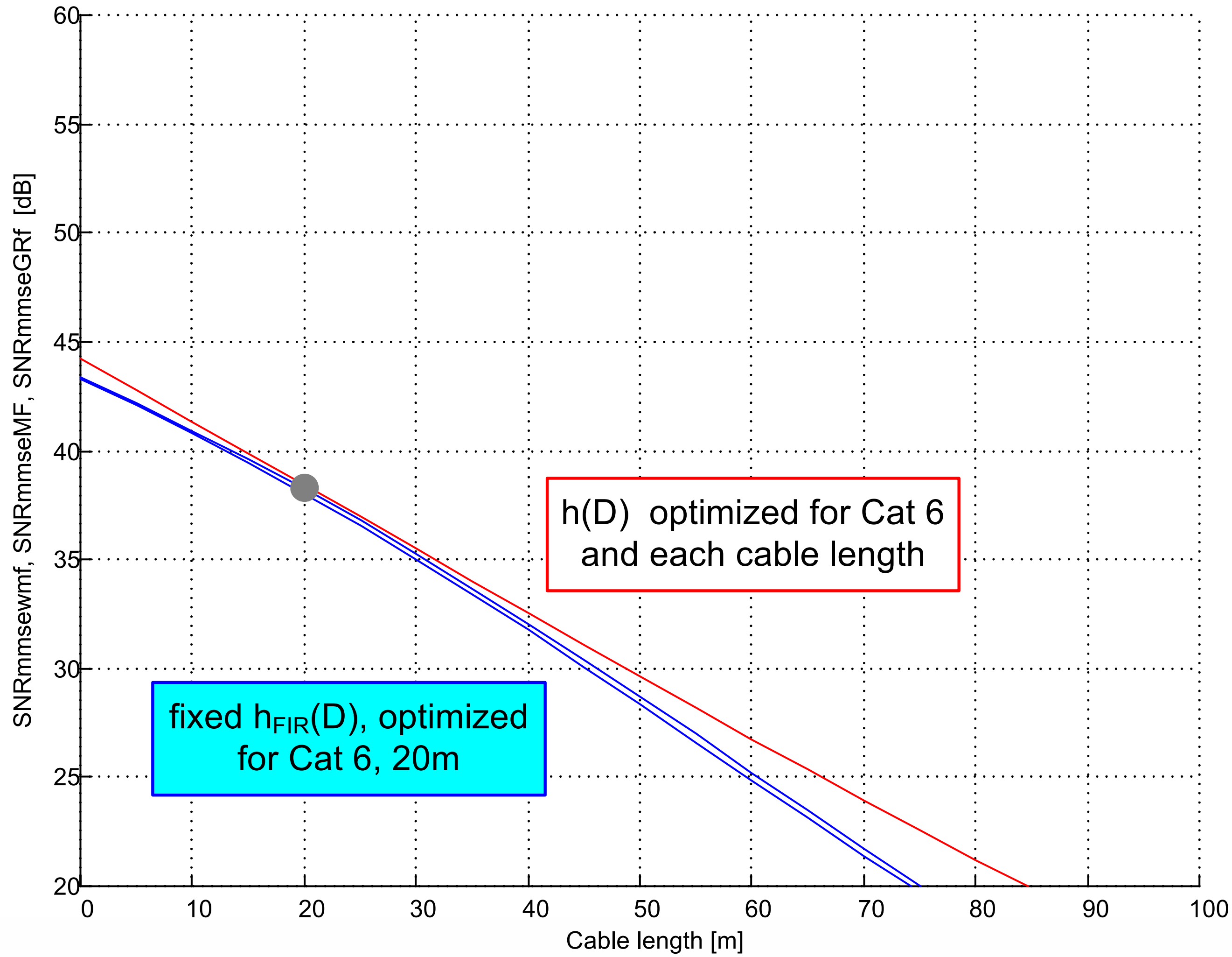
DP-SNR versus cable length: Class E



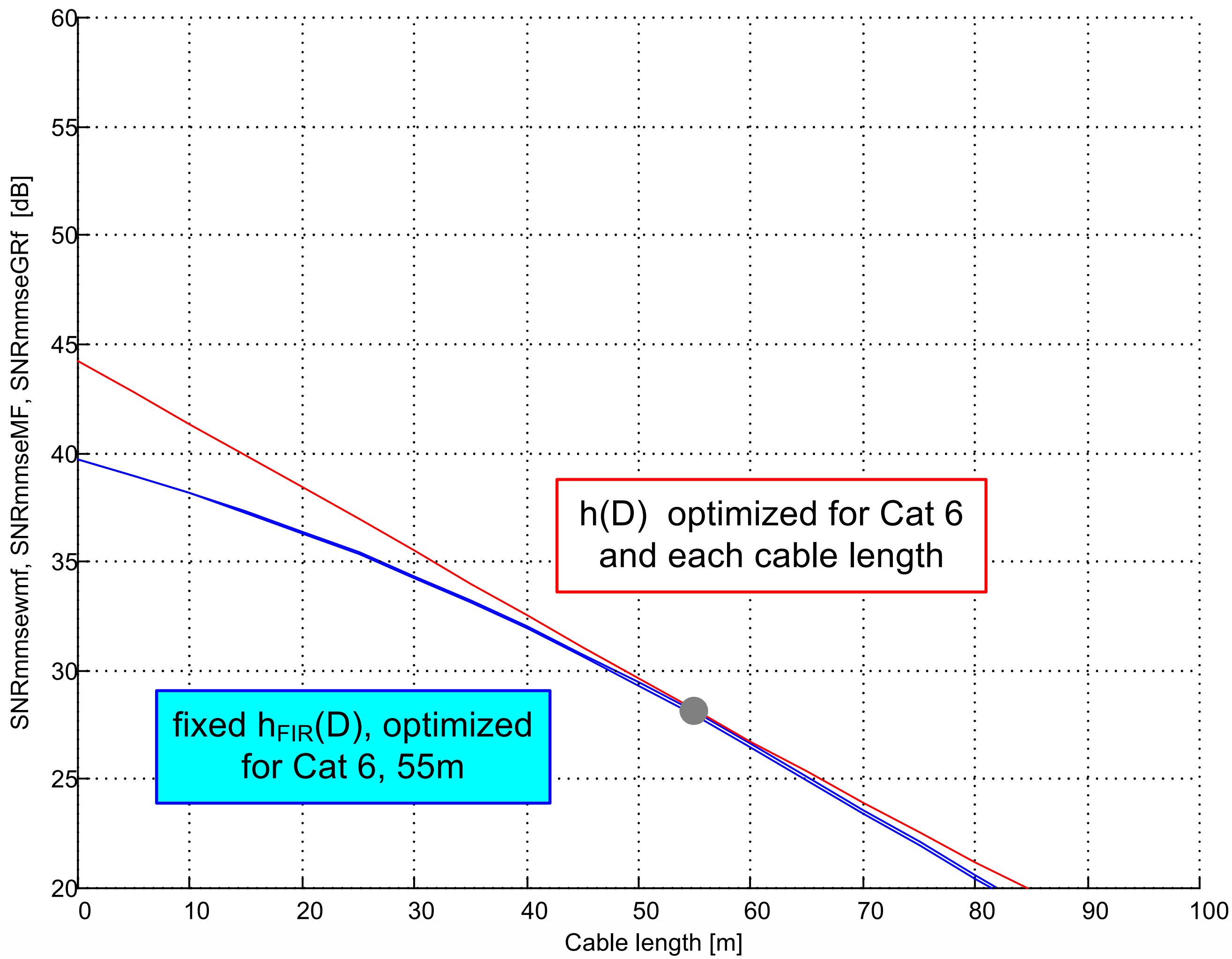
DP-SNR versus cable length: Class E



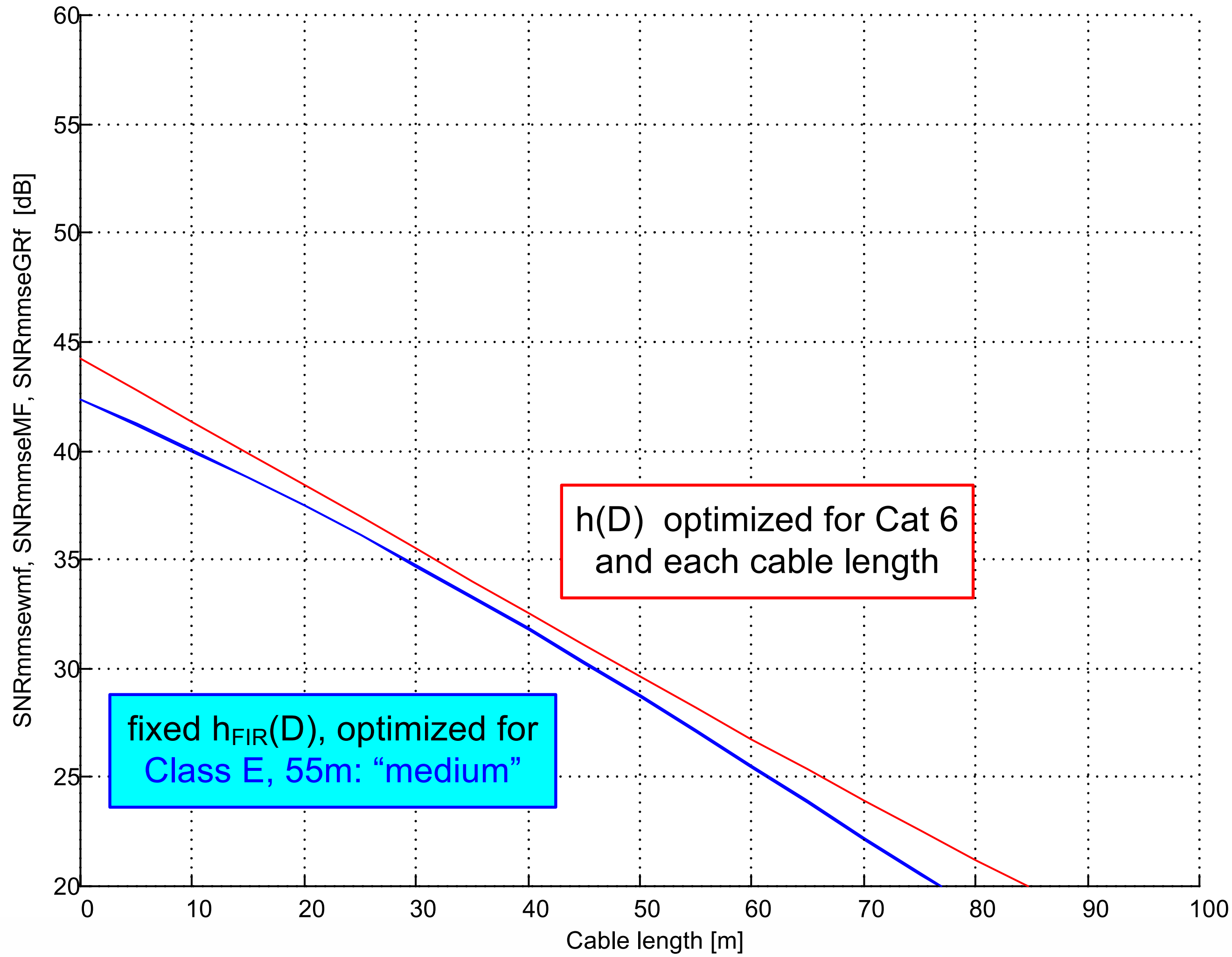
DP-SNR versus cable length: Cat 6



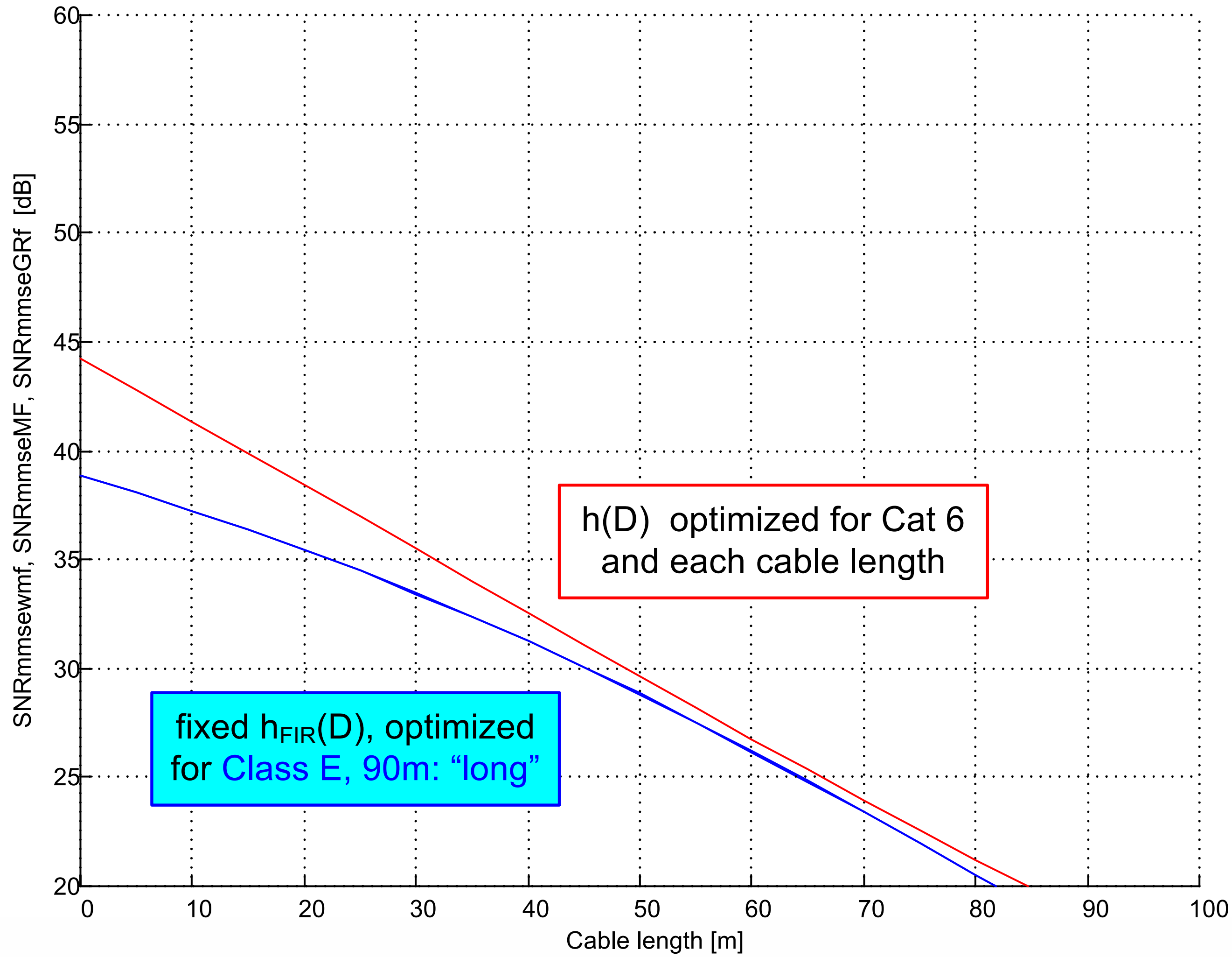
DP-SNR versus cable length: Cat 6



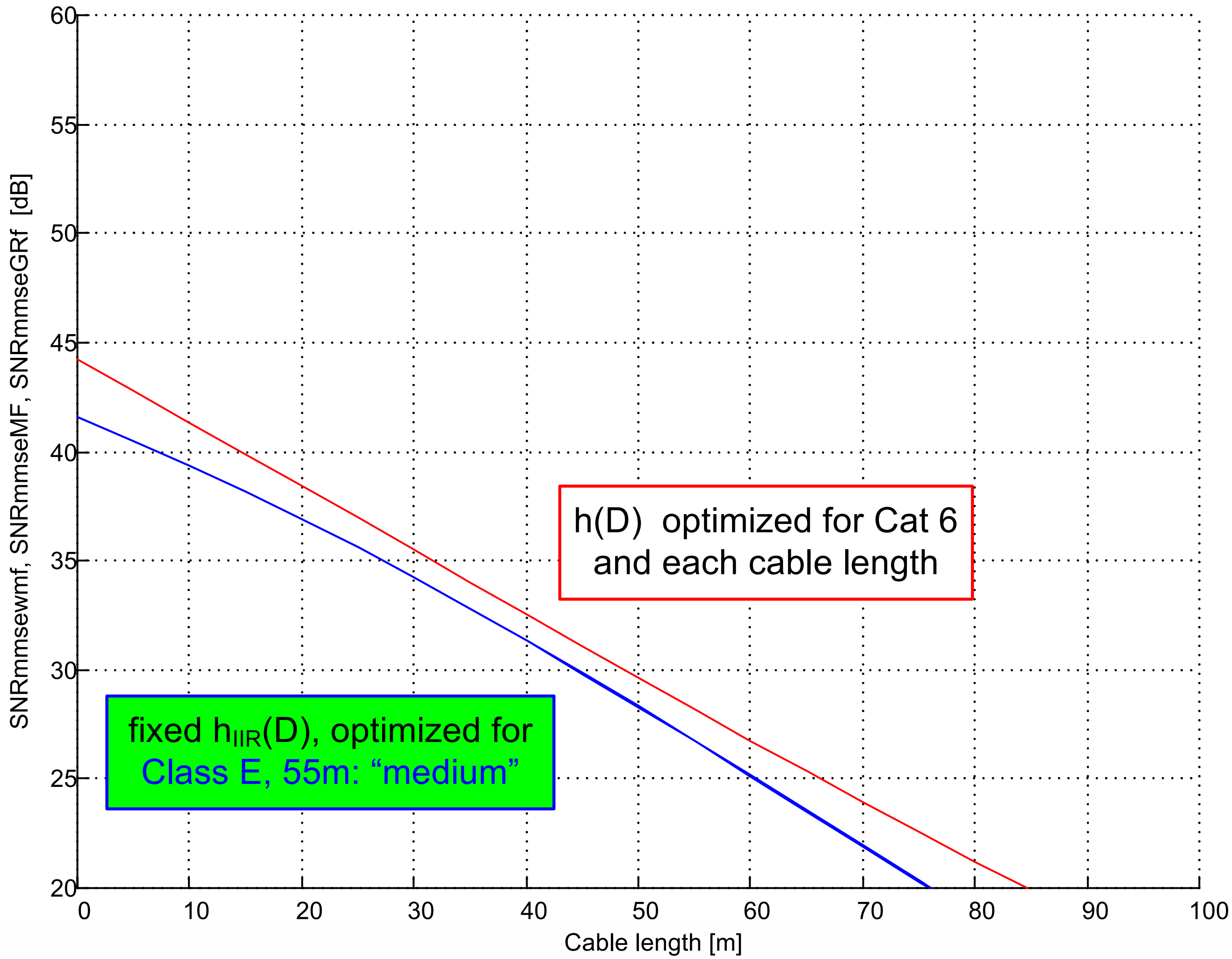
DP-SNR versus cable length: Cat 6



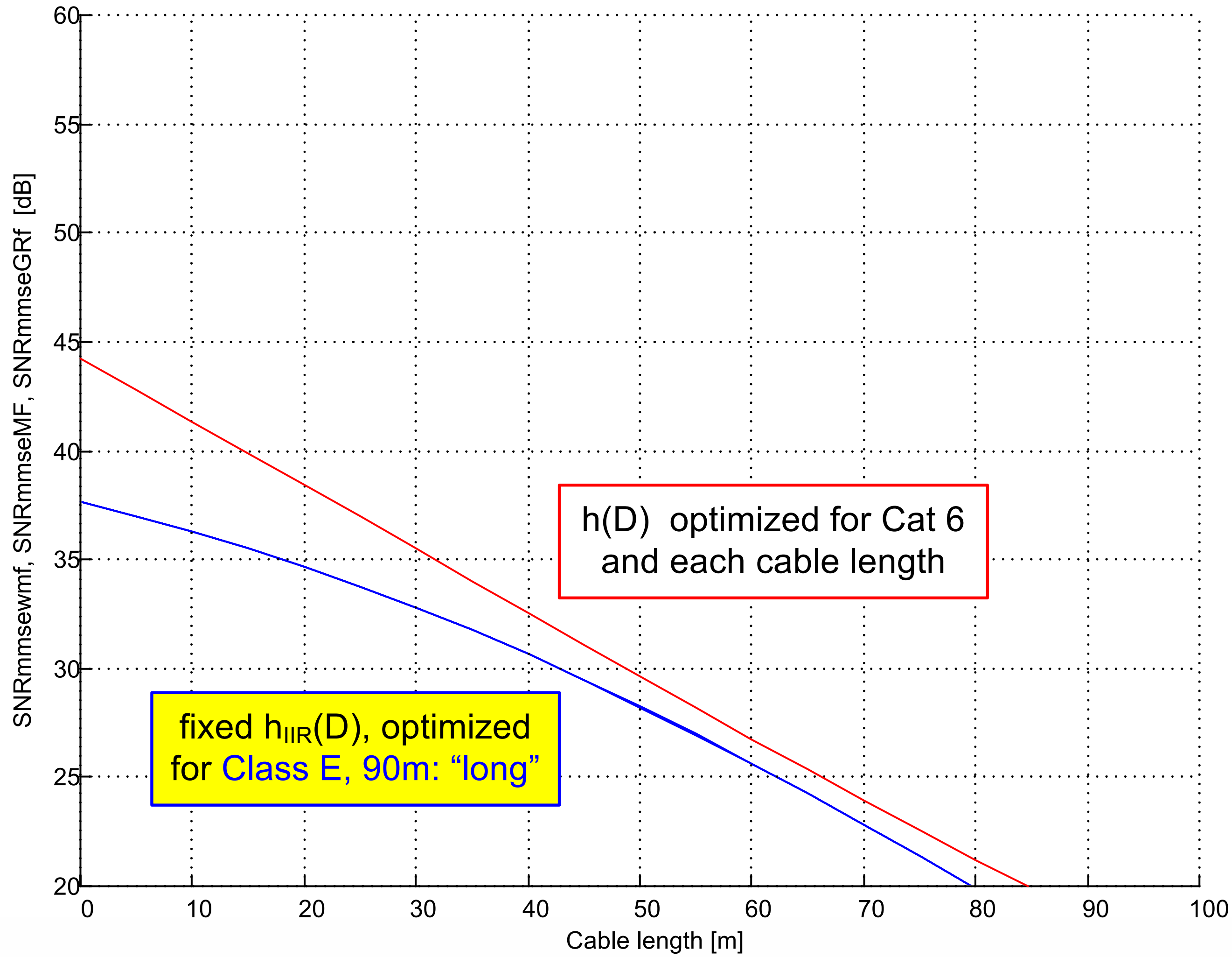
DP-SNR versus cable length: Cat 6



DP-SNR versus cable length: Cat 6



DP-SNR versus cable length: Cat 6



DP-SNR and precoders: discussion & proposal

- For Cat 6, Class E, and Class F cables, we found three precoders sufficient to approach *Salz* performance to within 1 dB in all cases, provided the TX PSD is well defined.
- The FIR responses “short”, “medium”, and “long” can accurately be approximated by IIR responses with three zeros and three poles. This causes only fraction-of-dB DP-SNR losses.
- Low-order IIR responses lead to significant hardware savings.
- Proposal: adopt the IIR responses “short”, “medium”, and “long” as baseline set of fixed precoding responses.
- Further studies of DP-SNR sensitivity under various link segment conditions are needed.