CTLE for the C2M reference receiver

(supporting comment 127)

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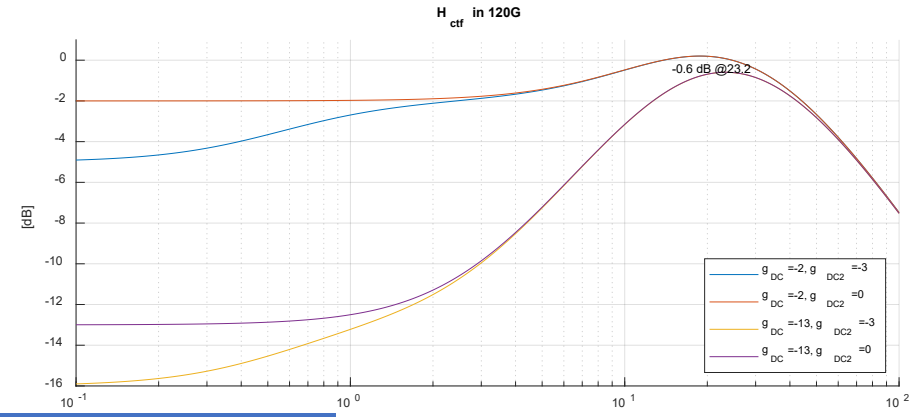
Outline

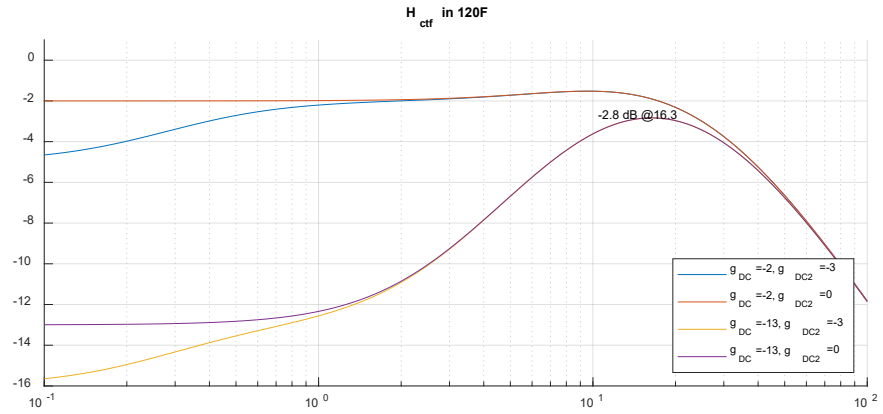
- Examine the reference CTLE model in 120G (C2C)
- Compare to 120F (C2C)
- Compare to 120E (50G PAM4 C2M) and 83E (25G NRZ C2M)
- Consider differences, and why should we care
- Proposal for change, with some results

A look at Annex 120G CTLE

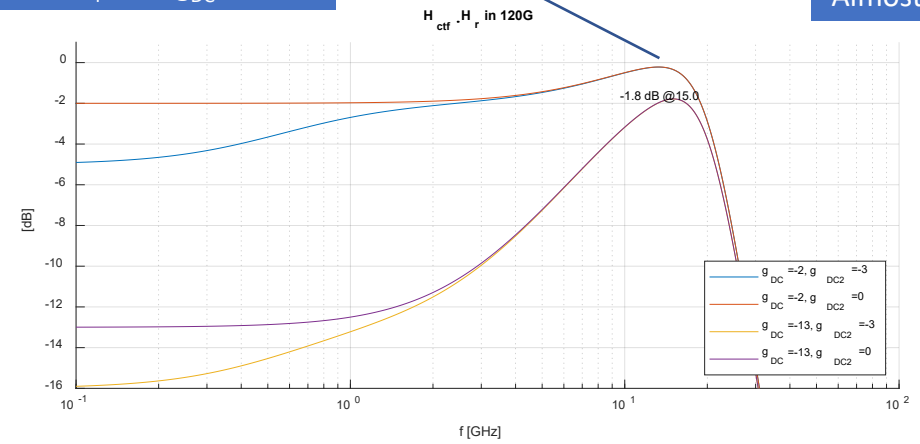
- CTLE transfer functions in annex 120G are based on Annex 93A (COM) equations, but with unusual parameters
  - In other places where these equations are used, we have $f_{p1}=f_z$, and $f_{p2}=f_b$
  - In 120G, these four parameters are different from each other
- The resulting CTLE is not passive (peak > 0 dB) for some values of g_{DC} (e.g. 0 dB)
  - With g_{DC} = -2 dB, after the specified H_r transfer function, the peak close to 0 dB (but not exactly)
  - But with lower values of g_{DC} the peak drops below 0 dB (down to -1.8 dB)
- The reason for this choice of parameters is unclear
  - Limiting max g_{DC} to -2 dB seems to be an attempt to hit 0 dB – it has been changed across drafts (not stated explicitly)
  - It is not claimed to be optimal or to match reasonable implementations
- All resulting settings have some peaking and negative DC gain
  - Unlike other places that use COM equations

CTLE curves in 120G (host output) vs. 120F

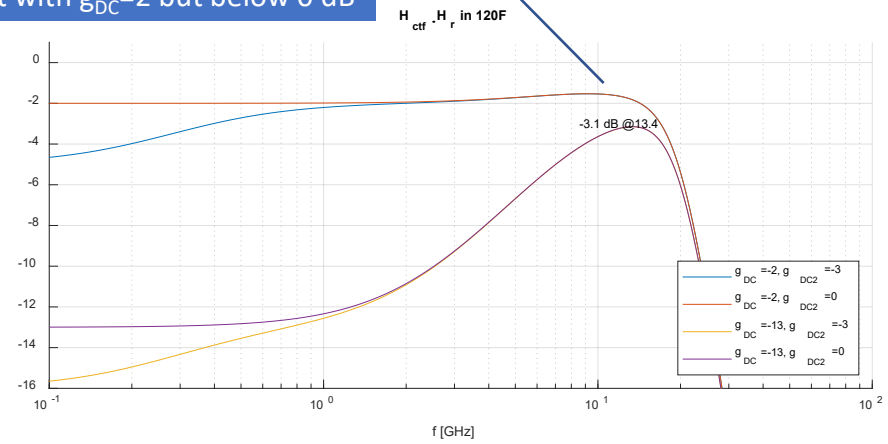




Up to 0 dB after H_r with g_{DC}=2



Almost flat with g_{DC}=2 but below 0 dB



Note that for minimum g_{DC}, the peaking frequencies in 120F and 120G are very close, but the peaks are different

CTLE curves in previous C2M annexes

120E used equations which create zeros/poles equivalent to typical COM CTLEs, but with a gain factor G to make all curves touch 0 dB

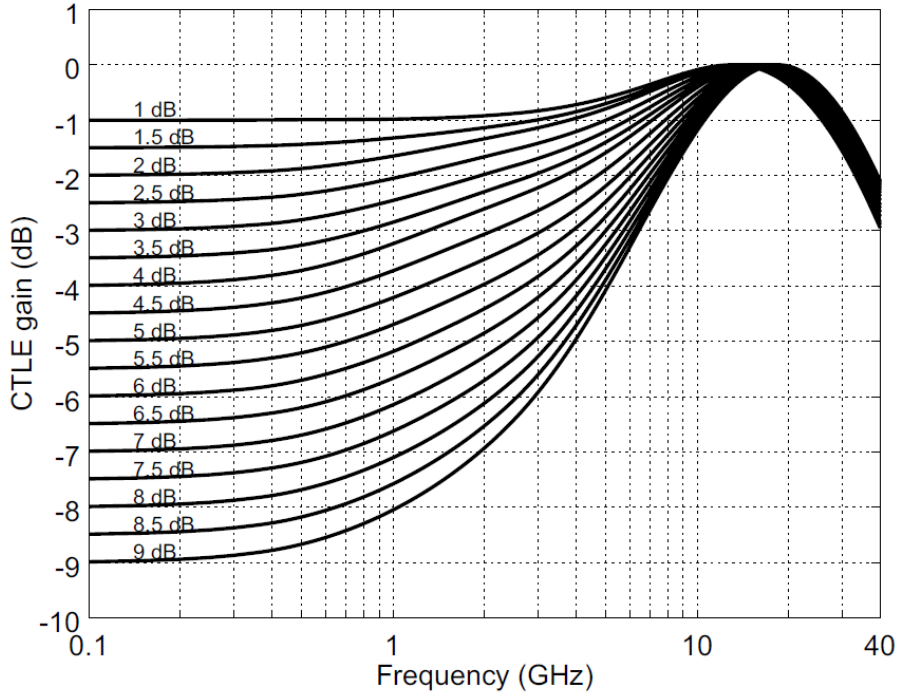


Figure 120E–9—Reference continuous time linear equalizer (CTLE) characteristic

83E used somewhat different poles and zeros but also made all curves touch 0

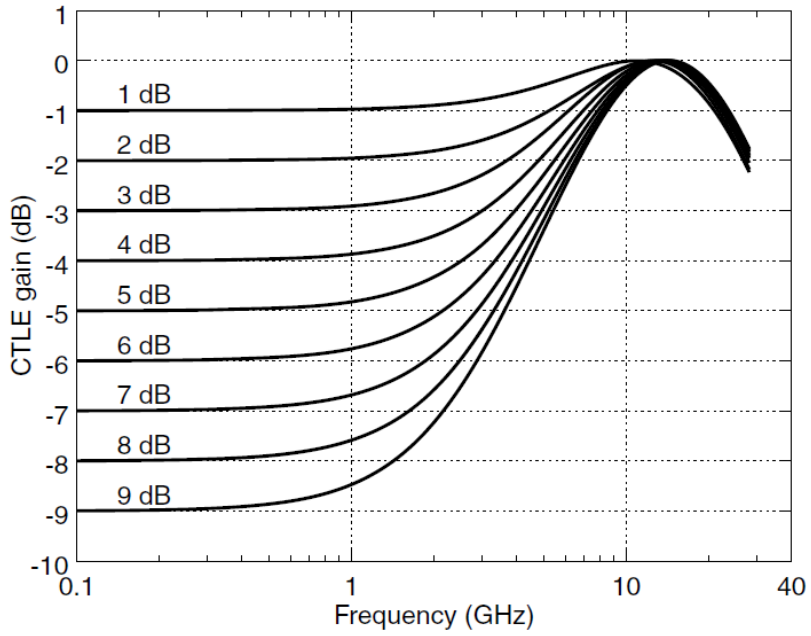


Figure 83E–10—Selectable continuous time linear equalizer (CTLE) characteristic

Note that in both cases there is no “flat” setting
(and the reference receiver has no DFE – may be related)

120G is a new beast

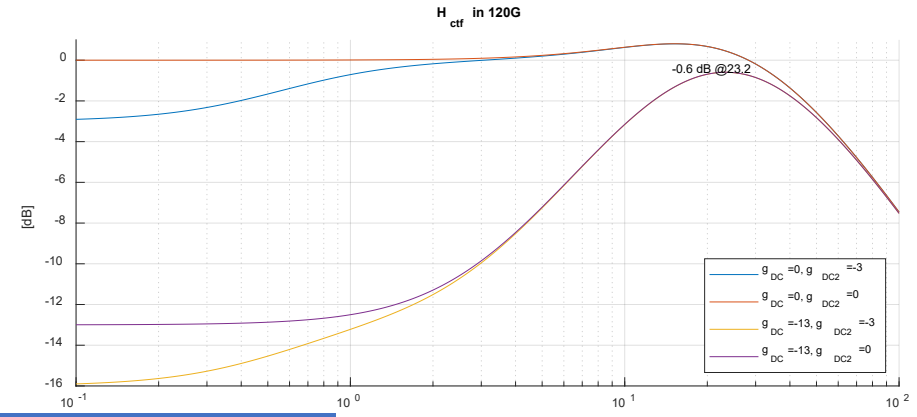
- The reference receiver includes a DFE, and a bandwidth limiting filter H_r, like C2C reference receiver (and unlike previous C2M)
  - The DFE has c(1) with minimum value of 0.1
- It requires limitations on values of g_{DC} to prevent positive gain
- CTLE Transfer functions do not touch 0 dB in all cases
  - No normalization factor
  - This means the definition of EH has changed from what it was in 120E/83E – where normalization factor was always applied

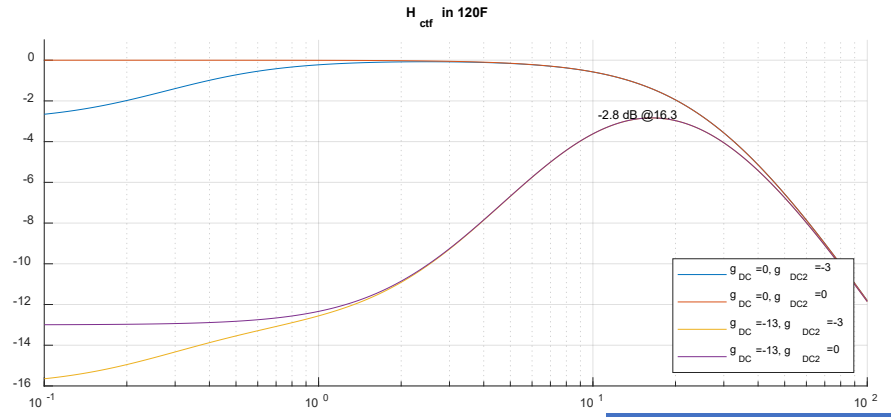
Why should we care?

- Uniformity is better in a standard
- It is likely a better match to module and host capabilities (e.g. it is hard to avoid having some settings with no peaking)
- There may be cases (like hosts with very short traces) that with nonzero peaking create very small, or negative DFE taps, but these are not allowed.
  - These hosts might need negative pre-emphasis to pass the test (not a typical design)
  - But modules probably don’t need this “tweak”
- It is expected to improve EH results and enable reducing max Vdiff-pTp to 600 mV.

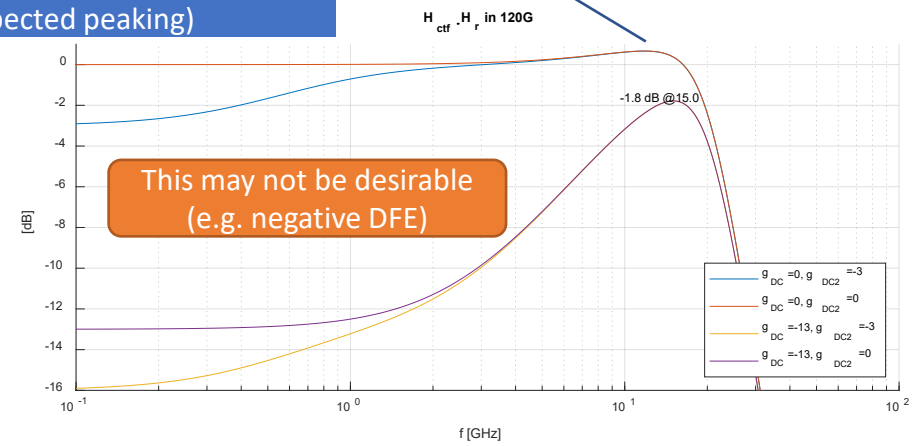
What if we just use g_{DC}=0 for host output?

This is not proposed – just showing the effect on the two models



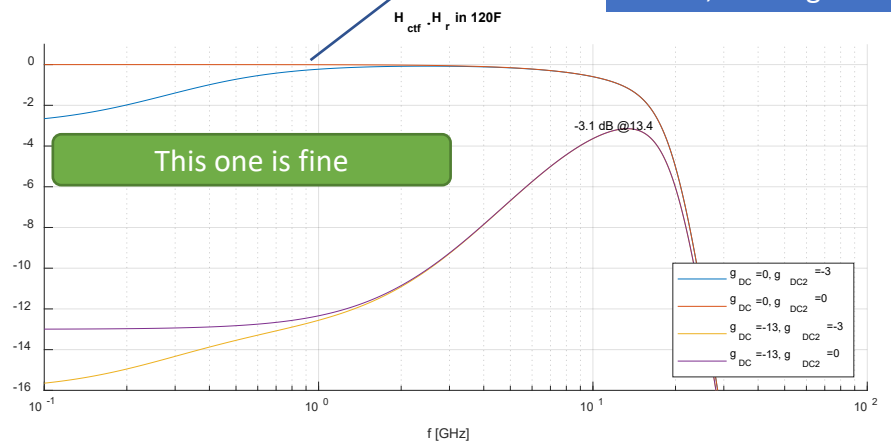


Goes above 0 dB even after H_r (unexpected peaking)



This may not be desirable (e.g. negative DFE)

Flat, starting at 0 dB



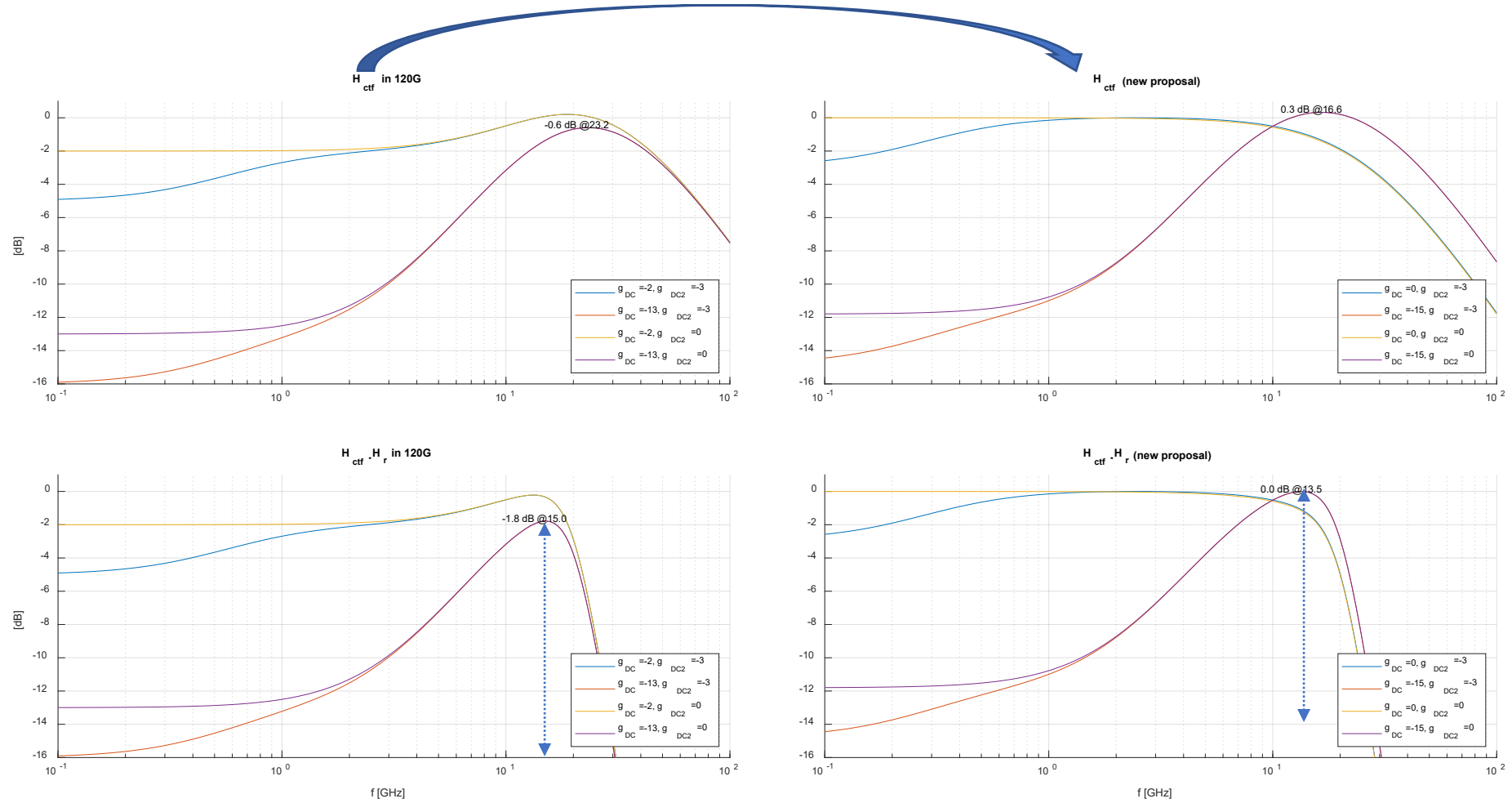
This one is fine

Outline of proposal

- Change the CTLE parameters to be equal to the ones defined in 120F (C2C)
- Modify g_{DC} ranges:
  - Enable g_{DC} up to 0 dB to ensure negative DFE will not be needed
  - Keep maximum boost requirements as they are. This requires reducing the minimum g_{DC} by 2 dB.
  - Keep the dependence of g_{DC} range on g_{DC2} (to reduce the number of combinations)
- Additionally, add a normalization factor to make all curves touch 0 dB (as in 120E, 83E)
  - This will apply positive gain in all cases where $g_{DC}<0$
  - And will likely somewhat improve EH results

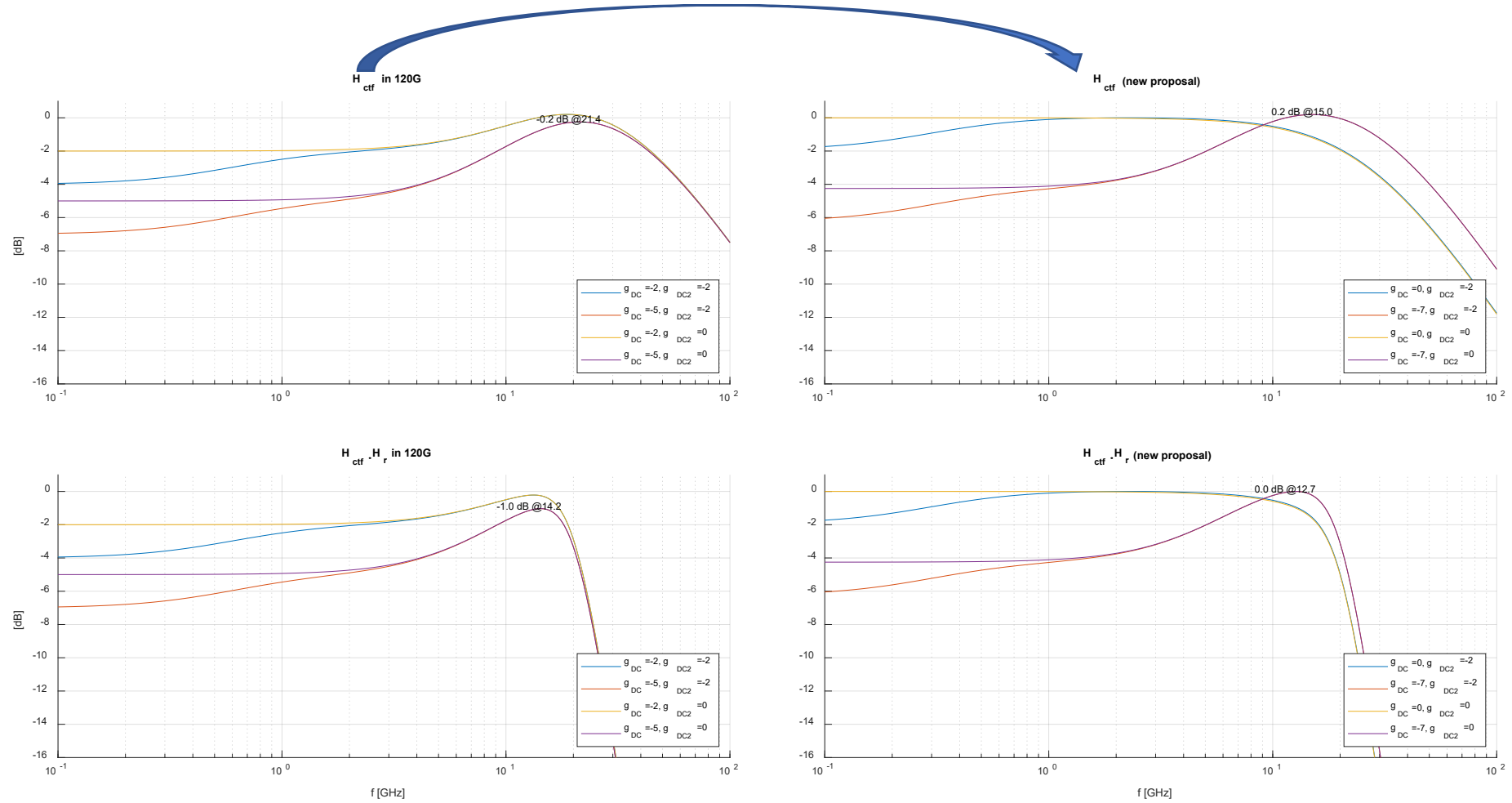
Some results of the proposed change

Host output (TP1a)

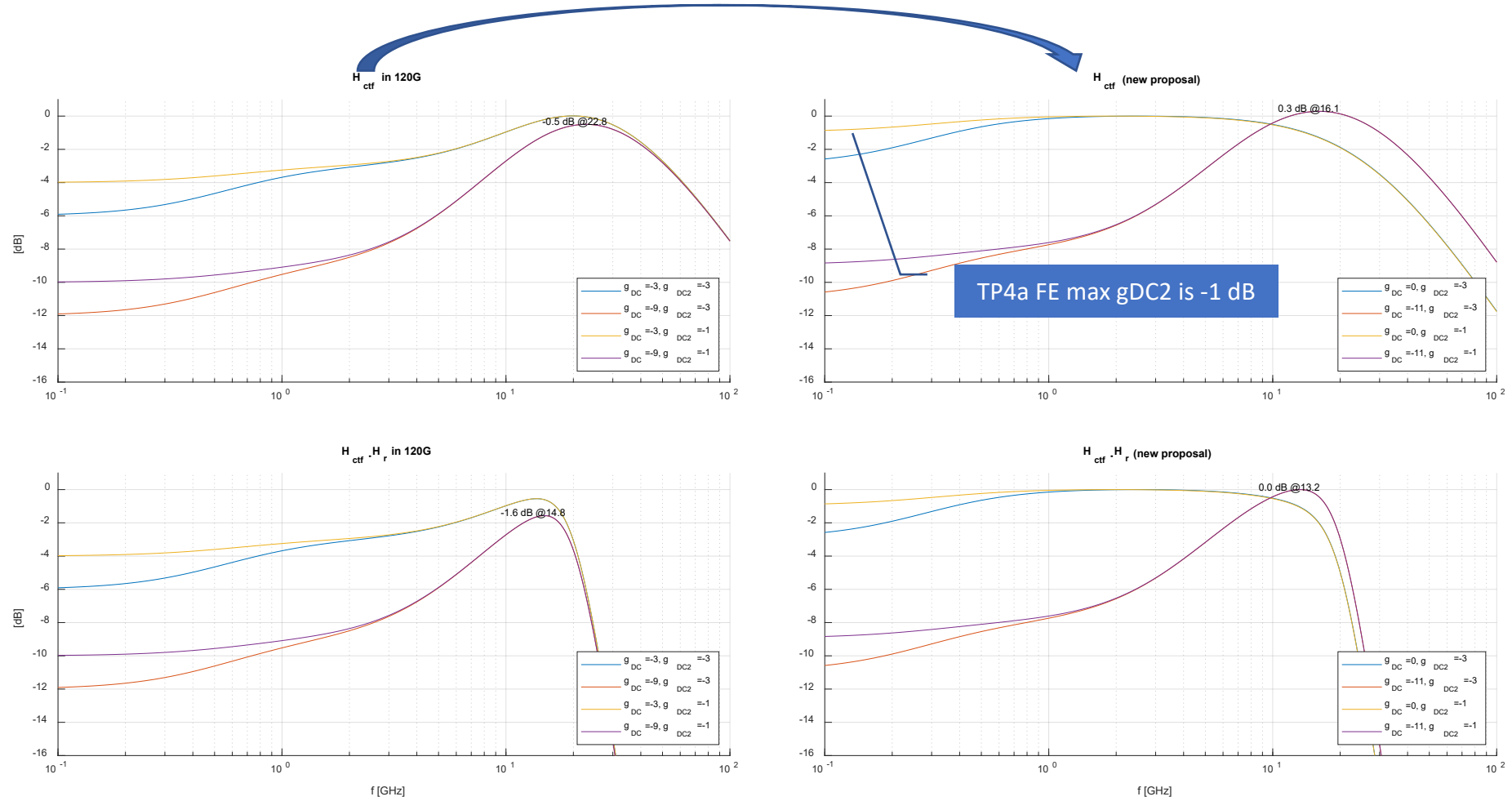


Maximum boost (peak gain minus DC gain) is about the same

Module output (TP4 near-end)



Module output (TP4 far-end)



It may not be necessary to allow g_{DC}=0 in this case

Proposal details

- Bring 93A.1.4.3 (Receiver equalizer) into the draft, and change Equation 93A–22 to include an additional factor G:

$$H_{ctf}(f) = G\frac{\left(10^{\frac{g_{DC}}{20}} + j\frac{f}{f_z}\right)\left(10^{\frac{g_{DC2}}{20}} + j\frac{f}{f_{LF}}\right)}{\left(1 + j\frac{f}{f_{p1}}\right)\left(1 + j\frac{f}{f_{p2}}\right)\left(1 + j\frac{f}{f_{LF}}\right)} \qquad (93A-22)$$

- Add text after the equation:
  "Where G is a gain factor, whose value depends on the variable norm_ctle as follows:
  - If norm_ctle is 1, G is set based on g_DC, f_z, g_DC2, f_LF, f_p1, and fp2, such that the maximum of $H_{ctf}(f) \cdot H\_r(f)$ across f is equal to 1.
  - If norm_ctle is 0 or is not provided by the clause that invokes this method, G is set to 1."

- In Annex 120G:
  - Apply changes to Table 120G–12 parameters as shown in the next slide.
  - Add the parameter norm_ctle with value 1 (in the table or in the text of 120G.5.2).

Table 120G – 12 changes

Table 120G–12—Eye opening reference receiver parameter values

Parameter	Symbol	Value	Units
Receiver 3 dB bandwidth	f_r	$0.75 \times f_b$	GHz
Continuous time filter, DC gain for TP1a Range for $g_{DC2} = 0$ Range for $-1 \le g_{DC2} < 0$ Range for $-2 \le g_{DC2} < -1$ Range for $-3 \le g_{DC2} < -2$ Step size	g_{DC}	~~–2~~ to –9 –2 to –12 –4 to –12 –6 to ~~–13~~ -15 1.0	dB
Continuous time filter, DC gain 2 for TP1a Minimum value Maximum value Step size	g_{DC2}	–3 0 0.5	dB
Continuous time filter, DC gain for TP4 near-end Minimum value Maximum value Step size	g_{DC}	~~–5~~ -7 ~~–2~~ 0 1.0	dB
Continuous time filter, DC gain 2 for TP4 near-end Minimum value Maximum value Step size	g_{DC2}	–2 0 0.5	dB
Continuous time filter, DC gain for TP4 far-end Minimum value Maximum value Step size	g_{DC}	~~–9~~ -11 –3 1.0	dB
Continuous time filter, DC gain 2 for TP4 far-end Minimum value Maximum value Step size	g_{DC2}	–3 –1 0.5	dB
Continuous time filter, zero frequency for $g_{DC} = 0$	f_z	~~12.58~~ $f_b/2.5$	GHz
Continuous time filter, pole frequencies	f_{p1} f_{p2}	~~20~~ $f_b/2.5$ ~~28~~ f_b	~~GHz~~ GHz
Continuous time filter, low-frequency pole/zero	f_{LF}	f_b/~~40~~ 80	GHz

Planned next steps

- Run EH/VEC simulations on candidate channels with/without the proposed change, and provide results
  - Pointing out candidate channels would be appreciated
  - If anyone has an automated test suite for this, help would be appreciated

Straw poll

- For the reference CTLE of Annex 120G:
  A. I would support the proposed change if it does not degrade VEC/EH compared to the current parameters.
  B. I would support the proposed change if it improves VEC/EH compared to the current parameters, and change the max VEC / min EH accordingly.
  C. I am interested in the proposed change but some modifications are required.
  D. I would not support any change.
  E. I need more information.
  F. I don’t have an opinion.
- (choose one)