Time Domain Echo Metrics in 802.3cy D3.0

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Acknowledgements

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- Hossein Sedarat
- Ragnar Jonsson
- Natalie Wienckowski
- Erwin Koeppendoerfer
- Christian Neulinger
- Steve Carlson

All of you provided good input, knowledge, experience, and pieces of the puzzle to (hopefully) understand the role and applications of these metrics

Questions about Return Loss Specification in 802.cy

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- **Why do we need time domain responses at all?, Do they have significant impact on PHY parameters?**

? How do these work, and work as written?

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? What about the delay estimate?

? Are the echo specifications robust to automotive conditions and cable handling?

? Are they overly constraining? (not allowing for technology improvement)

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Why time domain echo responses at all?

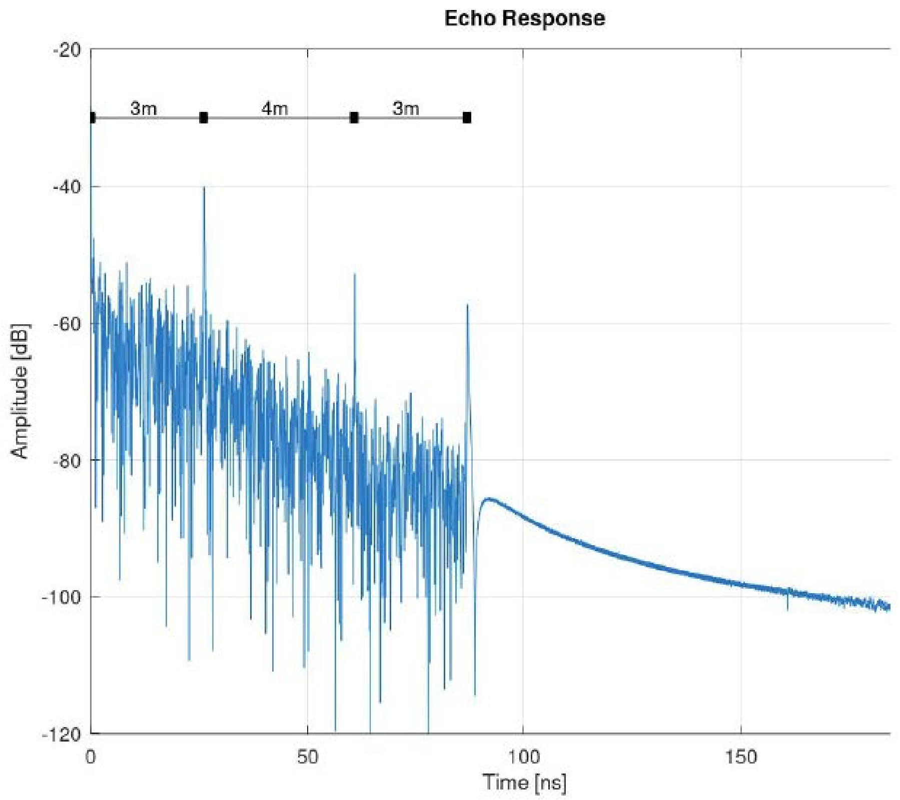
Echo response complexity grows based on time duration of the echo to be cancelled

Classic frequency-domain return loss specifications eliminate time-domain information by taking only the magnitude response

The majority of the echo impairment is generally not evenly distributed along the cable length

Dirty little secret – PHY designers almost always count on unspecified behavior of the echo response

Note – none of this matters on short cables (e.g., 1 to 2 meters for cy) where frequency-domain return loss is often most stressed



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PHY Design & Power Impacts of Echo

Attribute	Impact	Usual method to estimate
Overall magnitude of reflected symbol stream (e.g., peak voltage of aggregate response)	Front end receiver dynamic range (e.g., ADC bits)	Integrated over frequency domain
Magnitude of overall cancellation required	Complexity of echo cancellation	Integrated over frequency domain or simulated in time domain
Number of individual large-magnitude reflections ("major reflections")	Linearity and number of large dynamic range taps	Isolated over time domain*
Roughness of the underlying echo response ("micro reflection magnitude")	Magnitude of the continuous response	Isolated over time domain*
Time-distribution of the underlying echo response ("micro reflection tail")	Complexity of cancellation of the micro-reflections	Isolated over the time domain

*Note – in certain cases, particularly with small numbers of major reflections, the major and minor reflections can be separated from the magnitude frequency response, but never from the envelope of the magnitude or a "limit line"

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What REM does – First principles

- REM specifies the residual power outside of a limited number of point reflections
- REM takes a limited number of time-domain cancellation blocks and applies them where they best impact the echo response, minimizing the remaining echo energy
- REM considers the echo power reduction that can be achieved by removing a fixed number of echo taps, or any magnitude (subject to the dynamic range) anywhere in the time domain response
  - REM includes everything from the front end of the cable to the long tail of the reflection off the far-end termination

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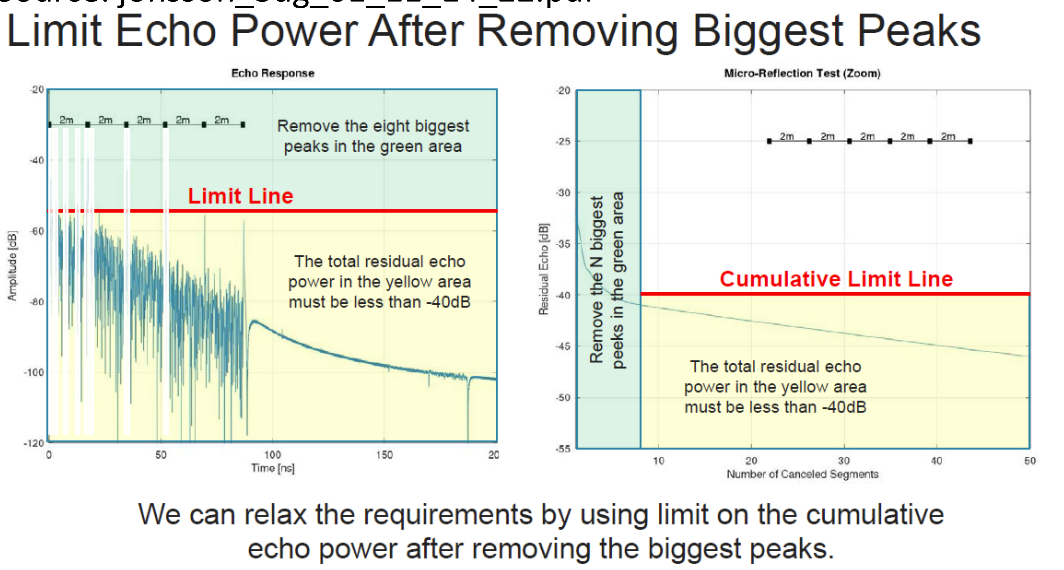

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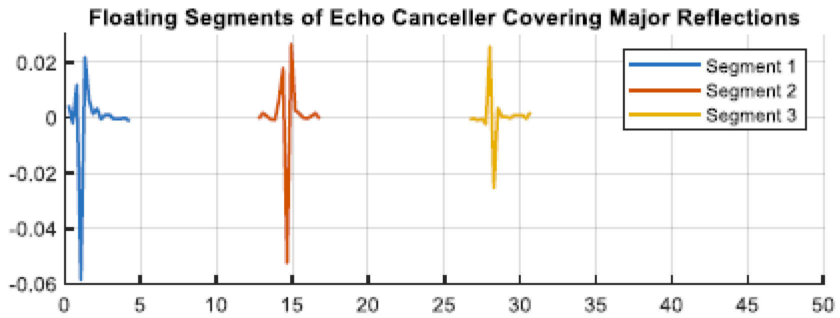


As written: the REM algorithm steps

Because these are new metrics, and because they require sensitive measurements, it is appropriate that the standard specify more about the computation than usual in 165.7.1.3.3

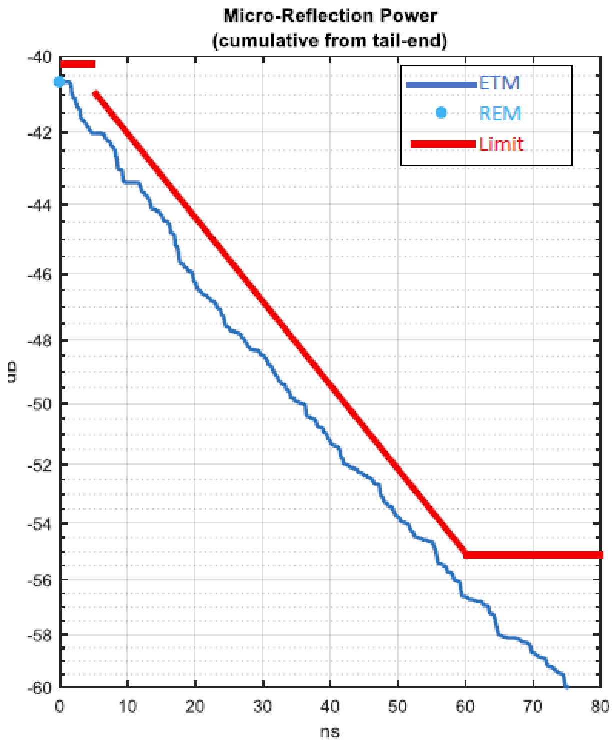
- STEPS 1 & 2 (a&b) compute the time domain echo response from VNA measurements
  - These are well-known techniques familiar to PHY modeling experts, but potentially unfamiliar to other experts. Other techniques could be used, computing from the frequency domain is often the most sensitive and can avoid errors in results
  - Personal experience has seen error buildup from noise in time domain measurements create “false micro reflections” at the levels needed
- STEP 3 divides the echo response into time domain segments and computes the power in each segment
  - The entire computed echo response is used, spanning 200 nsec
- STEP 4 excises the (*k*) largest segments, assuming they are cancelled (only k= $N_{discard}$ =16 is used)
- STEP 5 computes the remaining echo power after the *k* largest segments are removed
- Equation 165-35 checks the remaining echo power after removing the $N_{discard}$ (16) segments and compares it to a threshold which varies with the insertion loss.
  - The threshold varies from 30 dB reduction on lines with 10 dB or less loss at 4 GHz to 40 dB reduction on maximum insertion loss lines.

The REM provides for PHY designs suppressing echo 30 to 40 dB below the transmitted pulse without further assumptions or computation

- Designers may estimate further complexity for further reduction based on the bidirectional measurements

What ETM does – First principles

- ETM aims to measure the homogeneity of the echo underlying the largest peaks
  - Aimed at the question of whether the remainder of the line has "major reflections" or substantial changes in micro reflection levels
- ETM assumes the first 12 segments of the cable are cancelled, as well as the far-end reflection
  - The delay estimation is to remove the far end reflection
  - ETM then removes the next 6 largest segments wherever they may be
  - Total of 18 segments discarded vs. REM – but 12 are fixed at the front end
- ETM requires remaining echo power decay uniformly below a limit of 0.29 dB/nsec
  - ETM allows for the limit line to rise as the REM limit line rises for short lines
  - **Limit line flattens at about the round trip of 5.5 meters**



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As written: the ETM algorithm steps

While ETM is written for brevity in the same text as REM, it is explained here separately.

- STEPS 1 & 2 (a&b) compute the time domain echo response from VNA measurements as in REM – but the sensitivity is ESPECIALLY TRUE with the low-level micro reflections targeted by ETM

After STEP 2, ETM diverges from REM:

- STEP 6 (a&b) estimate the propagation delay from the end under test to the termination (The estimate is one way of making the estimate, more on the effect of errors later)

The following steps are performed for *m*=13 to the value of m corresponding to the round-trip delay (maximum delay line would be to *m*=307)

- STEP 7 excises the first *m* segments of the echo response and the “echo tail”, that part of the echo after the round-trip propagation delay estimate
  - NOTE- Since the minimum value of *m* evaluated is 13, this means that the first 12 segments are always excised. Empirically, a majority are usually in the top 16 for echo power
- STEP 3* computes the power in each segment of truncated and excised response from STEP 7
- STEP 4* excises the (k) largest segments from the truncated and excised response, assuming they are cancelled (only k= $N_{discard\_etm}$ = 6 is used)
  - ***NOTE –the segments excised change as you go through the line… Does this matter?***
- STEP 5* computes the remaining echo power after the 6 largest *remaining* segments are removed
- Equation 165-36 checks the remaining echo power after removing the $N_{discard\_etm}$ (6) segments and compares it to a threshold which varies with the insertion loss, and with the location along the line. This threshold decreases at a rate of about 1.6dB/m of cable at ¼ Nyquist (or 0.29dB/nsec according to Sedarat_3cy_02_0614.pdf)

On a maximum length line, the ETM ensures the gradual decay of the micro reflection response (according to the insertion loss) down to 16 dB below the REM limit. This can be used by PHY designers to budget additional echo cancellation on the micro reflections without worrying about larger, high-delay reflections

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Do we still need Frequency Domain?

Frequency domain return loss will still provide us essential information to compute the total returned echo power

- Frequency domain COULD be replaced by an additional time domain total power metric, but there is no good reason to do so

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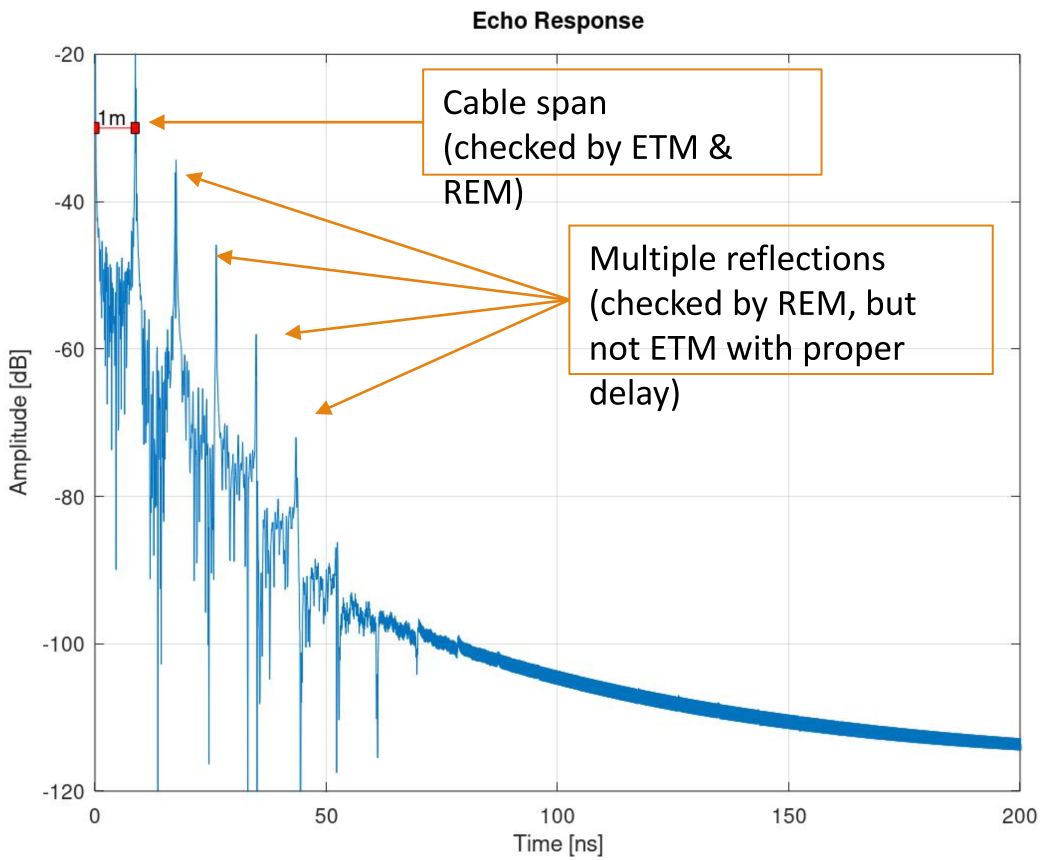
What about the delay estimate?

- In ETM, the delay estimate is used to cut off multiple reflections, either from the far-end termination/MDI or connections – REM does not truncate the response this way
- An error in estimating the cable propagation delay will change what part is cut off the end of the response (Only ETM, not REM needs the delay estimate)
- Overestimating the delay (less likely, since the minimum of 2 directions is taken) includes some of the far-end termination reflection
  - This makes the ETM worse, and pessimistic. It may matter on short lines
  - Unlikely to matter on lines longer than 5.5 meters due to flattening of the ETM threshold
- Underestimating the delay makes the ETM blind to defects near the far end of the cable
  - ETM from the opposite direction will also be blind to excess reflections near the end
  - REM likely doesn't catch it either
  - Frequency-domain return loss (from the reverse direction) will likely catch it, since such a segment needs to be pretty bad to matter on cables longer than 5.5 meters



1 meter cable – multiple reflections, (private communication, R. Jonsson)

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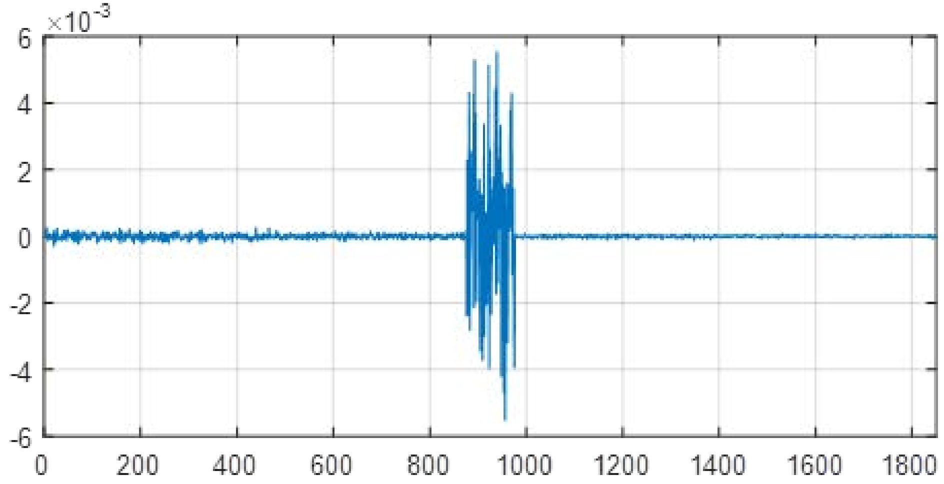
Robustness in Handling

What if point reflections due to handling or bad patch segments are used?

- REM would pass a cable with a bad patch provided the segments to be cancelled fit within the 16 ($N_{discard}$) cancelled segments, located anywhere
- While the sum of excluded segments in ETM and REM are similar, ETM fixes 12 of the excluded segments at the start of the cable, allowing only 6 segments for major reflections at points within the cable
  - Because connector reflections are unlikely to be centered fully within a segment, that means at least 4 segments are used for connectors
- ETM excludes a cable which might have additional major reflections or a bad patch within the span.

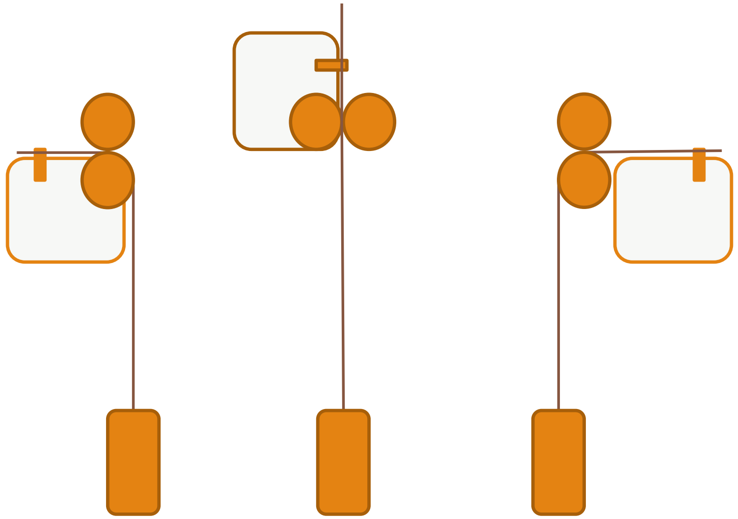
Response meant to fail ETM
(private communication, H. Sedarat)



Does this happen with normal handling?

- LAN cabling (PIMF) exhibits point reflections with bends and handling, but does automotive?
- Private discussions suggest this is a difference with automotive cabling met by practices and materials
  - Insulations are stiffer plastics
  - Shields are braids rather than metal foil
  - Bending for flexible cables are tested
  - Passing cables through a bulkhead requires a connector – not pulled through and around a corner which can bend the cable
  - Connectors are pre-terminated
- For results, see, Koeppendoerfer_3cy_01 06_07_22.pdf

THIS APPEARS TO BE AN ADVANTAGE TO AUTOMOTIVE CABLING



ISO-19642-2:2019 (E) Bending fixture (Koeppendoerfer_3cy_01 06_07_22.pdf)

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Do they provide room for technology improvement

REM only constrains the number of segments to be excluded and the residual energy outside those segments – should not constrain technology improvement

ETM constrains the distribution of the residual echo power based on an insertion loss model.

- This shows up as the fixed (0.29) dB/nsec slope of the ETM threshold in Equation 165-36
- When converted to dB/unit length, this is approximately equal to the worst-case link segment IL on 11 meters
- Lower loss per unit delay (unit length) cable may be penalized (metric is hardest at cold temperature)
  - Mitigated by ETM (& REM) threshold level reduction as insertion loss decreases, down to 10 dB IL @ 4 GHz (about ½ the worst-case IL)

BUT – it may not matter (thanks to Natalie for some good discussion)

- Unlike LAN cabling and IL spec, automotive specifications limit cable to no LARGER than ~ 26 AWG
- Link segment delay specification limits length
  - This limits utility of lower-loss cable to achieve longer reach with strict standards compliance
- As a result, there doesn't seem to be a gross mismatch, but experts should consider fine-tuning if needed (not only is the slope right, but, e.g., is 4 GHz the right frequency for IL adjustment?)

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Are the parameters optimal?
Are ETM and REM parameters consistent?

We have shown $N_{discard}$ (16) for REM and $N_{discard\_etm}$ + m_s (18) for ETM exclude similar numbers of segments, but not equal.

- Additionally, ETM fixes the first 12 at the end of the cable, and allows an effective increase in discarded segments down the cable (by allowing discarded segments to be reallocated as major reflections are passed)
- Results are similar, and ETM parameters are derived approximately

Threshold sensitivities for REM and ETM differ

- This is by design, are they the right levels? (different PHY designers have their own levels)

Is the 0.29dB/nsec slope of ETM the worst case we want to see for cabling?

- Remember, less insertion loss (better cables) could make ETM worse –is mitigation by the raising the threshold enough?
- Is 4 GHz the right frequency to sample insertion loss at to adjust this level?

Since ETM(m) is a *strictly decreasing* function of m, if ETM(m) passes for $m \leq m_e$, where the threshold goes flat, specification beyond $m = m_e$ should be unnecessary (simplifying things)

No conclusions here, but things to think about with your own expertise now that hopefully you know more of the issues and algorithms

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Now, we just have to capture the relevant parts in the standard….

THANK YOU!