Noise calibration for interference tolerance tests

(comments #207 and #209)

Adam Healey

Broadcom Inc.

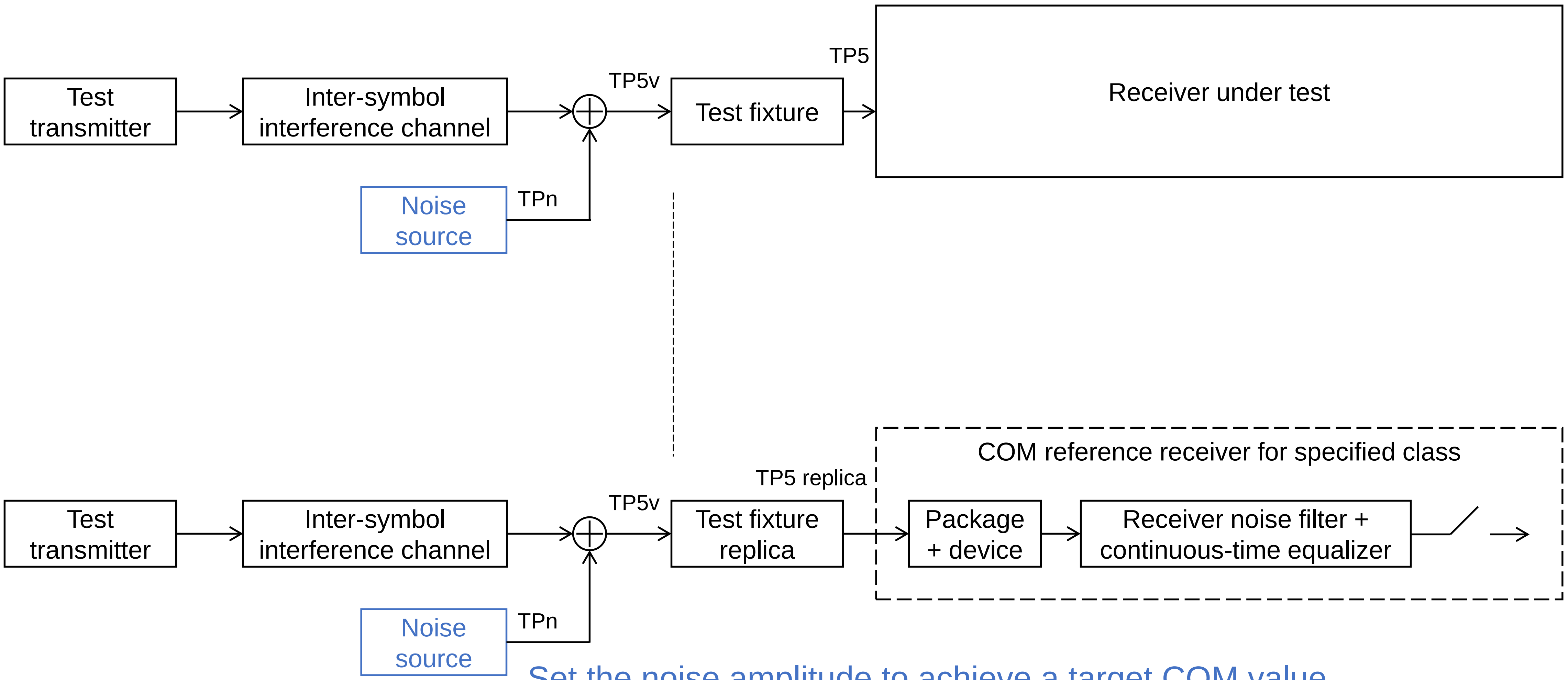
IEEE P802.3dj Task Force

November 2024 (r0)

Problem statement

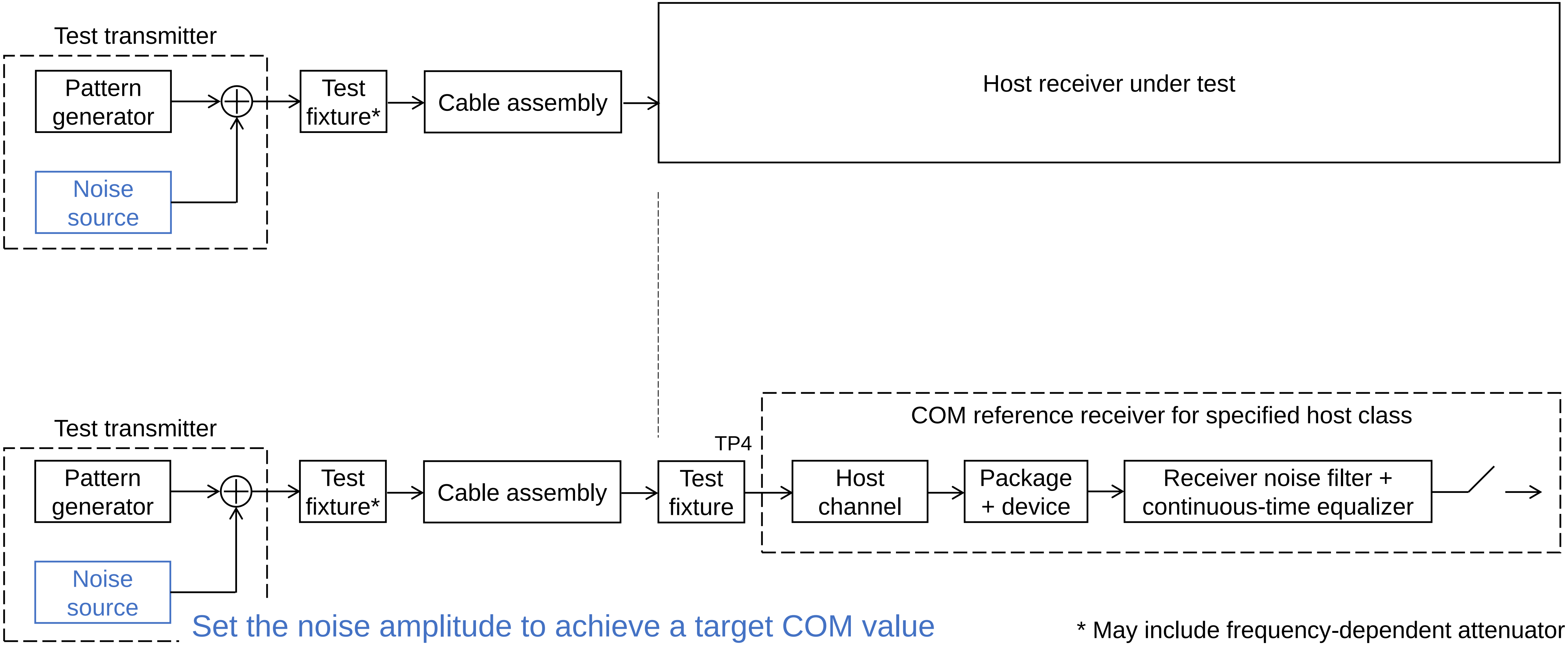
- Interference tolerance tests defined in 178.9.3.3 and 179.9.5.3.3 include noise calibration procedures based on Channel Operating Margin (COM)
- The noise calibration procedures were developed for Annex 93A COM
- Clauses 178 and 179 use the COM calculation defined in Annex 178A
- These noise calibration procedures need to be updated accordingly

Clause 178 noise calibration



Set the noise amplitude to achieve a target COM value

Clause 179 noise calibration



Set the noise amplitude to achieve a target COM value

* May include frequency-dependent attenuator

Treatment of noise in Annex 178A COM

- Noise power spectral density (and, equivalently, its autocorrelation function) is considered during equalizer optimization

$$S_n(\theta) = S_{rn}(\theta) + \sum_{k=1}^{K-1} S_{xn}^{(k)}(\theta) + S_{tn}(\theta) + S_{jn}(\theta)$$

Combined noise power spectral density

Noise due to transmitter jitter
(based on jitter measured from test transmitter)

Transmitter output noise
(based on SNDR measured from test transmitter)

Crosstalk
(based on test channel)

Receiver input noise
(parameter of the reference receiver)

- It is also included in the Gaussian noise term used for the calculation of COM

$$\sigma_G^2 = f_b \int_{-\pi}^{\pi} \left[S_{tn}(\theta) + S_{jn}^{(RJ)}(\theta) + S_{rn}(\theta) \right] \left| H_{rxffe}(\theta) \right|^2 d\theta$$

Augment the noise power spectral density – Clause 178

$$S_n(\theta) = S_{rn}(\theta) + \sum_{k=1}^{K-1} S_{xn}^{(k)}(\theta) + S_{tn}(\theta) + S_{jn}(\theta) + S_{in}(\theta)$$

Add new term for "interference noise"

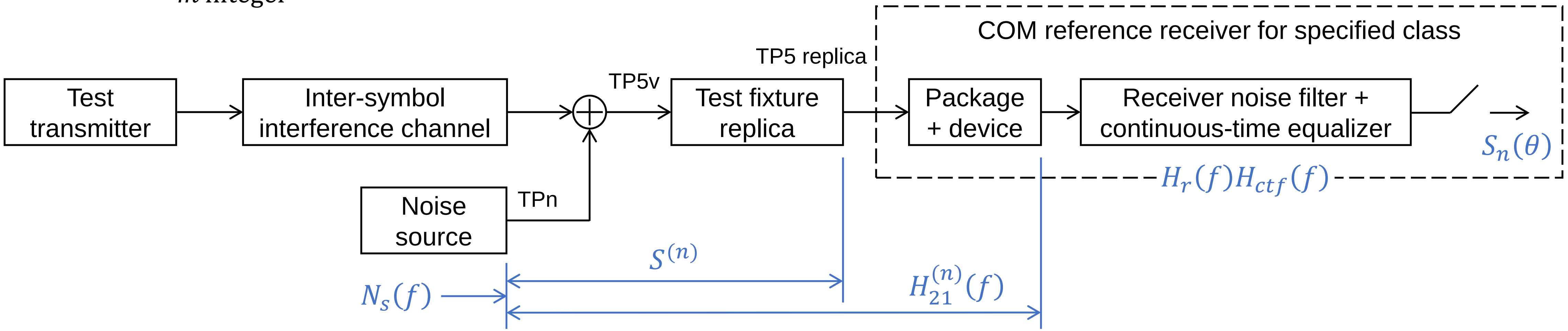
$$N_{in}(f) = N_s(f)\left|H_{21}^{(n)}(f)H_r(f)H_{ctf}(f)\right|^2$$

$N_s(f)$ is the 2-sided noise power spectral density at the output of the noise source

$H_{21}^{(n)}(f)$ is the voltage transfer function for the noise path which is derived from measured s-parameters from TPn to TP5 replica $S^{(n)}$ in cascade with the reference package and device models

$$S_{in}(\theta) = \sum_{m\ \text{integer}} N_{in}\left(\frac{\theta + 2\pi m}{2\pi T_b}\right)$$

Sample the noise at T_b-spaced intervals



Augment the noise power spectral density – Clause 179

$$S_n(\theta) = S_{rn}(\theta) + \sum_{k=1}^{K-1} S_{xn}^{(k)}(\theta) + S_{tn}(\theta) + S_{jn}(\theta) + S_{in}(\theta)$$

$S_{tn}(\theta)$ is based on the measured SNDR of the test transmitter with the noise source "off"

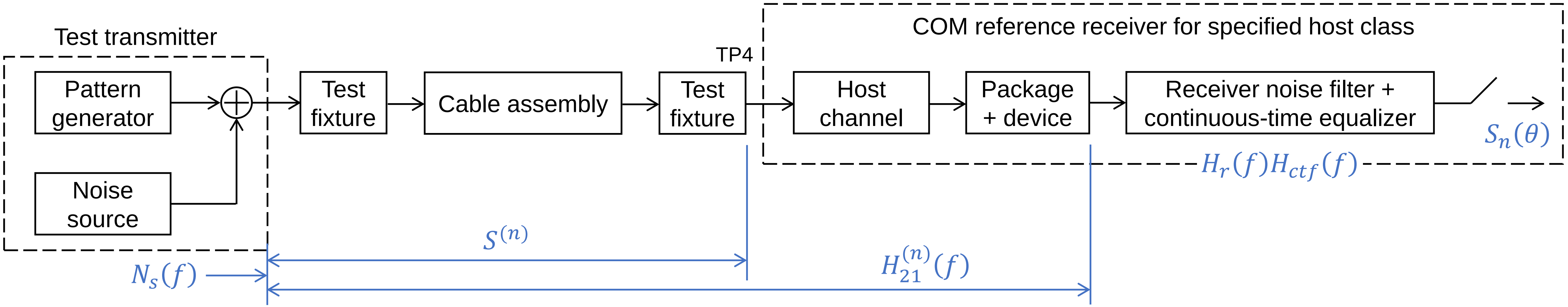
$$N_{in}(f) = N_s(f)\left|H_{21}^{(n)}(f)H_r(f)H_{ctf}(f)\right|^2$$

$N_s(f)$ is the 2-sided noise power spectral density measured at the output of the test transmitter

$H_{21}^{(n)}(f)$ is the voltage transfer function for the noise path which, in this case, is the same as the victim signal path

$$S_{in}(\theta) = \sum_{m \text{ integer}} N_{in}\left(\frac{\theta + 2\pi m}{2\pi T_b}\right)$$

Sample the noise at T_b-spaced intervals



Noise source power spectral density

- The noise power spectral density at the output of the noise source (or test transmitter) must meet certain requirements
- This permits the use of an assumed noise source power spectral density $N_s(f)$ for the calculation of COM

Assumptions about $N_s(f)$ that may be used in the calculation of COM

Clause 178	Clause 179
Power spectral density is uniform over the interval $[-f_b/2, f_b/2]$ $$N_s(f) = \sigma_{ns}^2/f_b \qquad -f_b/2 \le f \le f_b/2$$	High-pass filter applied to a power spectral density that is uniform over $[-f_b/2, f_b/2]$ $$N_s(f) = \left(\frac{\sigma_{ns}^2}{\beta f_b}\right)\frac{\left(f/f_{hp}\right)^2}{1+\left(f/f_{hp}\right)^2} \qquad -f_b/2 \le f \le f_b/2$$ $$\beta = 1 - \frac{2f_{hp}}{f_b}\tan^{-1}\left(\frac{f_b}{2f_{hp}}\right)$$

- It is also possible for the power spectral density to be measured and used in the COM calculation (for higher calibration accuracy)

Proposed noise calibration procedure

1. Measure the s-parameters $S^{(n)}$ of the path from the output of the noise source (or test transmitter) to the specified reference point
2. Choose σ_{ns}^2 and compute the corresponding noise power spectral density $N_s(f)$ as defined on slide 8 [a]
3. Compute COM as specified in Annex 178A with additional noise term $S_{in}(\theta)$ defined on slide 6 for Clause 178 or on slide 7 for Clause 179 and with the adjustment to the equation for σ_G^2 shown below

$$\sigma_G^2 = f_b \int_{-\pi}^{\pi} \left[S_{tn}(\theta) + S_{jn}^{(RJ)}(\theta) + S_{rn}(\theta) + S_{in}(\theta) \right] \left| H_{rxffe}(\theta) \right|^2 d\theta$$

4. Repeat steps 2 and 3 until a value for σ_{ns}^2 is found that produces the target COM
5. Configure the noise source (or test transmitter) so that the noise power measured at its output is σ_{ns}^2 [b]

[a] A measured noise power spectral density $N_s^{(meas)}(f)$ may also be used but it must be converted to a 2-sided density via the expression $N_s(f) = N_s^{(meas)}(|f|)/2$ and the corresponding value of σ_{ns}^2 is the integral of $N_s(f)$

[b] If an assumed noise power spectral density is used, the limits of integration for the measurement of σ_{ns}^2 should be 0 to $f_b/2$

Summary and proposal

- This contribution proposes a noise calibration procedure for interference tolerance testing
- It is aligned with the Annex 178A definition of COM
- It enables use of measured noise power spectral densities for improved calibration accuracy