Exploring System Noise, η_0, for Usage in COM

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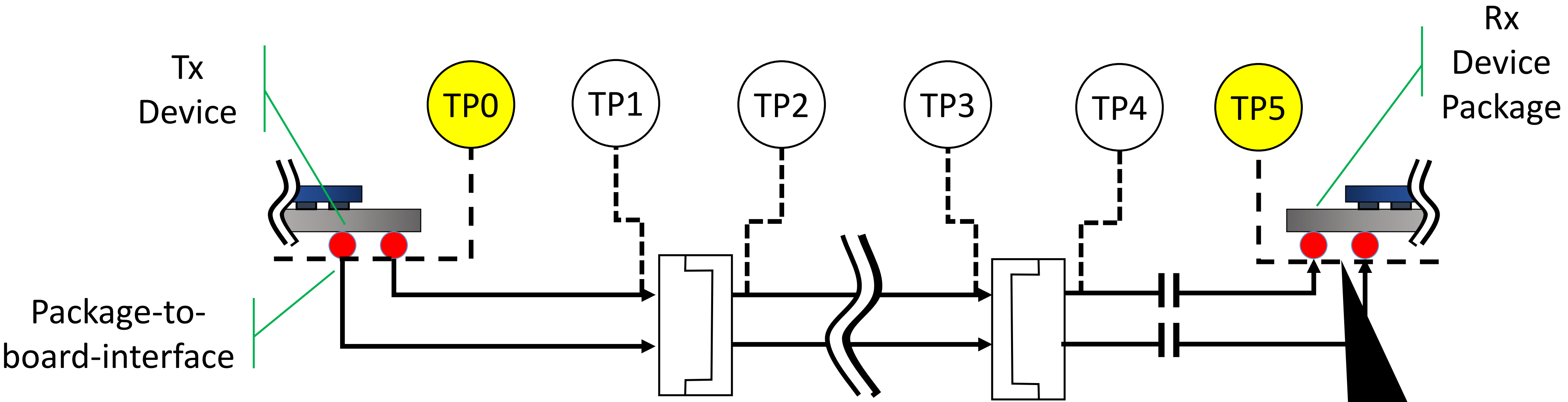
η_0 may be defined at the pins of the receiver



It may be the system noise not included in the Tx, Rx, or any noise induced by the Rx parent device.

… At least that is what was measured during the .3bj project

η_0 defined here

Background

The inclusion of system noise was indicated on slide 7 of the original COM proposal mellitz_01_0712, *"Time-Domain Channel Specification: Proposal for Backplane Channel"*

- ❑ It was broadband gaussian source called σ_r .
- ❑ It was originally located after the Rx package but before the CTLE

Measurement was provided in ran_02_0712, “Considering Alien Noise”

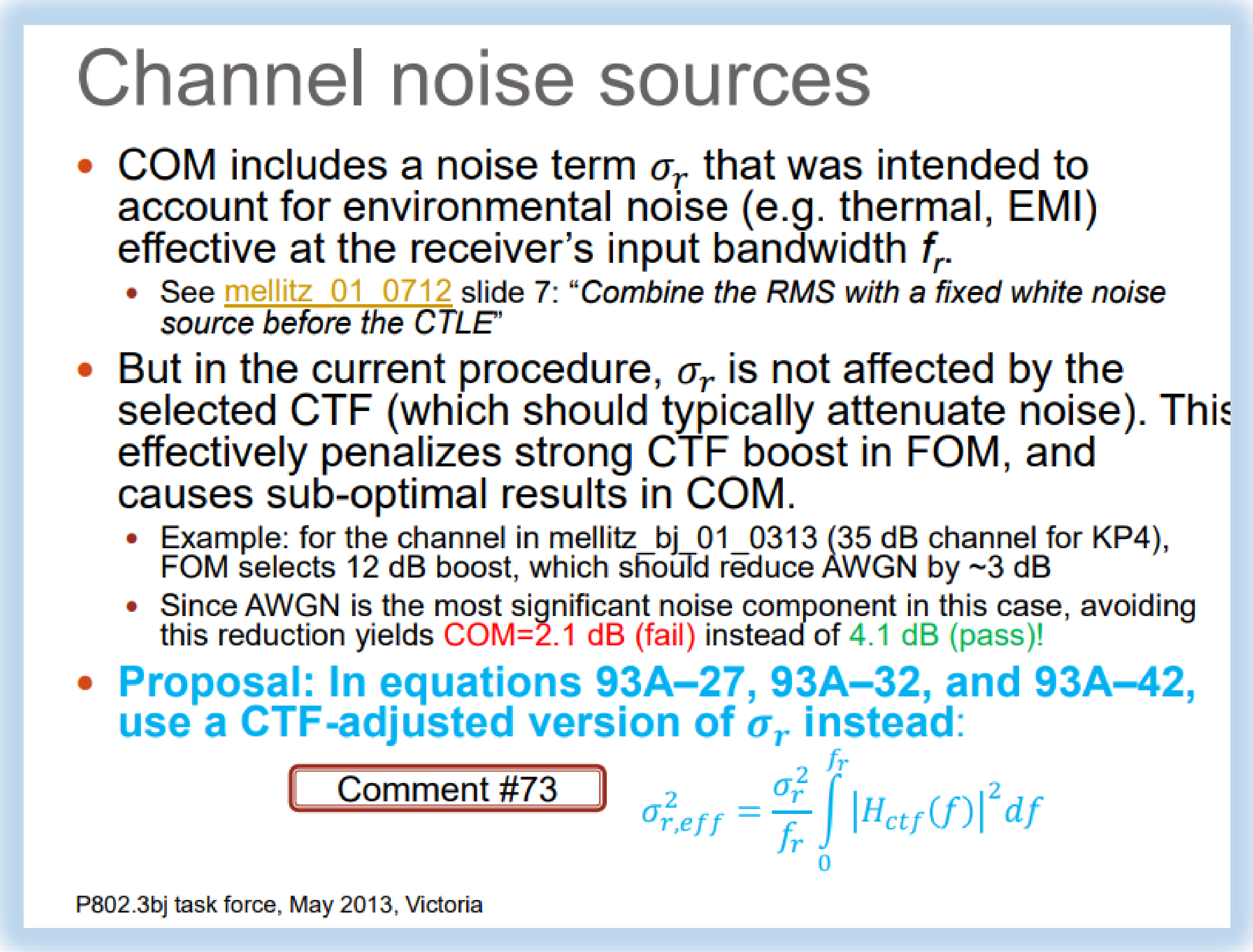
- Approximately 1 mV of signal was suggested
- As a result 1 mv σ_r was first introduced in IEEE P802.3bj™/D1.4, 21st February 2013
- EMI inducted noise on well design systems was ruled out from experiments proximally inducing highly tuned EMI noise near differential signals
- This is when we started considering the σ_r “alien noise”
- 5.2e-8 V^2 /GHz adopted for η_0 in IEEE P802.3bj™/D2.3, 11th October 2013 based on ½ mV or ”alien” or “environmental” noise

Question to consider at this point

- Is all noise which is not “alien” considered to be part the 3 dB COM limit?

First introduction for the concept of η_0

- The concept behind η_0 was introduced in ran_3bj_01a_0513
- It was considered "environmental noise"
- Question to come back to
  - Is all noise which is not "alien" or "environmental" considered to be part the 3 dB COM limit?



For now, let σ_m be the RMS of environmental noise

$$\sigma_m = \sqrt{\int_0^{f_r} \eta_{0\,df}} \quad , \qquad Where\ \Delta f\ and\ f_r, the\ receiver\ bandwidth, are\ in\ GHz$$

- For IEEE802.3by, .3by, and.3bm
  - Given f_r= 19.3359 GHz & η_0=5.2e-8 V^2/GHz σ_m=1.2 mV
- IEEE802.3cd
  - Given f_f= 19.9219 GHz & η_0=1.64e-8 V^2/GHz σ_m =0.57 mV
- Presently for 100 G IEEE8.3ck
  - Given f_r= 53.125 GHz & η_0=8.2e-9 V^2/GHz σ_m.57 mV
- This suggests the noise is broadband and limited to the receiver bandwidth
  - The implication is infinite bandwidth would be infinite noise

η_0 is results in σ_N

- σ_N is part of the noise budget used to compute COM
- The system noise is filtered by the Rx and CTF filters to create an broadband AWGN which is convolved with all the other noise sources (Annex 93A)

$$\sigma_N^2 = \eta_0 \int_0^{\infty} \left| H_r(f) H_{ctf}(f) \right|^2 df \qquad (93A\text{–}35)$$

- η_0 at 8.2e-9 V^2/GHz can account for up to 2 dB of COM 100 Gb/s PAM4 for our 28 dB channels!!!
- Maybe we should revisit η_0
  - See wu_3ck_adhoc_01_022719.pdf

Revisiting η_0 with respect to packages

$H_{21}^{(rp)}$

$$\sigma_N^2 = \eta_0 \int_0^\infty |H_r(f) H_{ctf}(f)|^2 df \qquad (93A\text{–}35)$$

- To be consistent with slide 2 maybe the package receiver response, $H_{21}^{(rp)}$, should be included.
- Perhaps this was missing in the original Annex 93A
- If the package was included here, COM values would rise a little

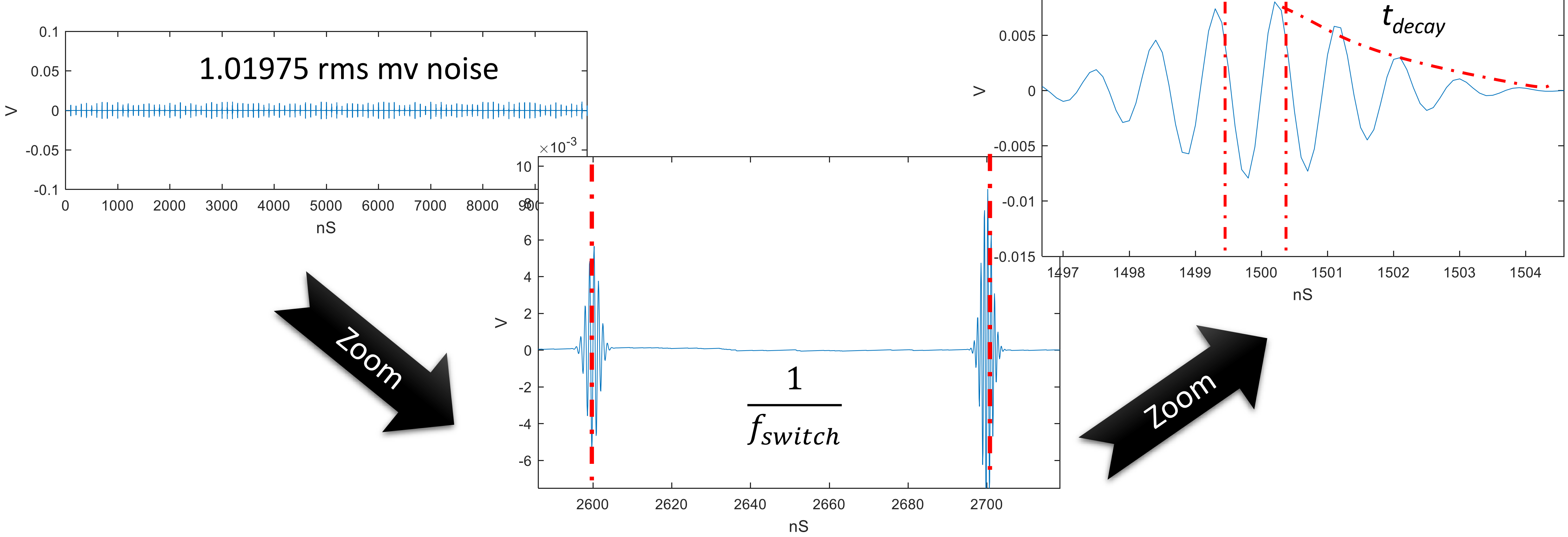
System noise may be dominated by power delivery

- Power supply noise on a differential line can be modeled as
  - A low frequency sawtooth wave and
  - A higher frequency sine wave enveloped with decaying exponentials at the sawtooth transitions
- The higher frequency proportion is likely caused by random nature of system di/dt loading at the inductor switching transistor in a power supply.
- Tact
  - Experiment to recreate the 1 mv RMS
  - Propose a waveform which might be represented of a mV RMS system noise
  - Determine the power spectral density
  - Propose a filter added to equation 93A-35 for the system noise power spectral density, $H_{sy}(f)$

Simple noise model

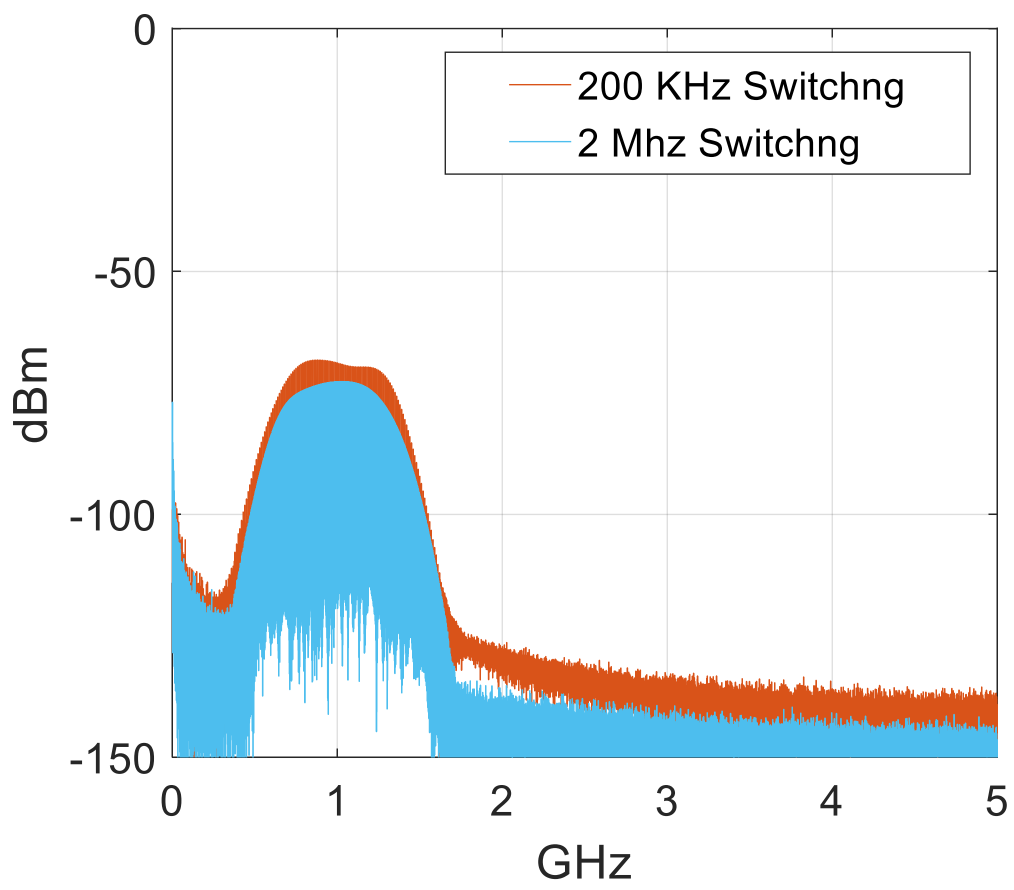
Each switch cycle has this form where Rv1, Rv2, and Rv3 are randomizing variables modeling load variations

$$\eta(t) = e^{\left(\frac{t}{t_{decay*Rv1}}\right)^{2}} \sin\left(2\pi \frac{t}{t_{spike*Rv2}}\right) + \text{sawtooth}(2\pi f_{switch} t * Rv3)$$



Power Spectral Density (PSD) results

- ❑ For
- ❑ t_{switch} = 200 KHz and 2 MHz
- ❑ t_{spike} = 1 ns (f_{spike} = 1 GHz)
- ❑ t_{delay} = 2 ns



Now we add to the plot: an η_0 PSD filter estimate (adjusted for 1 mV RMS of the original signal)

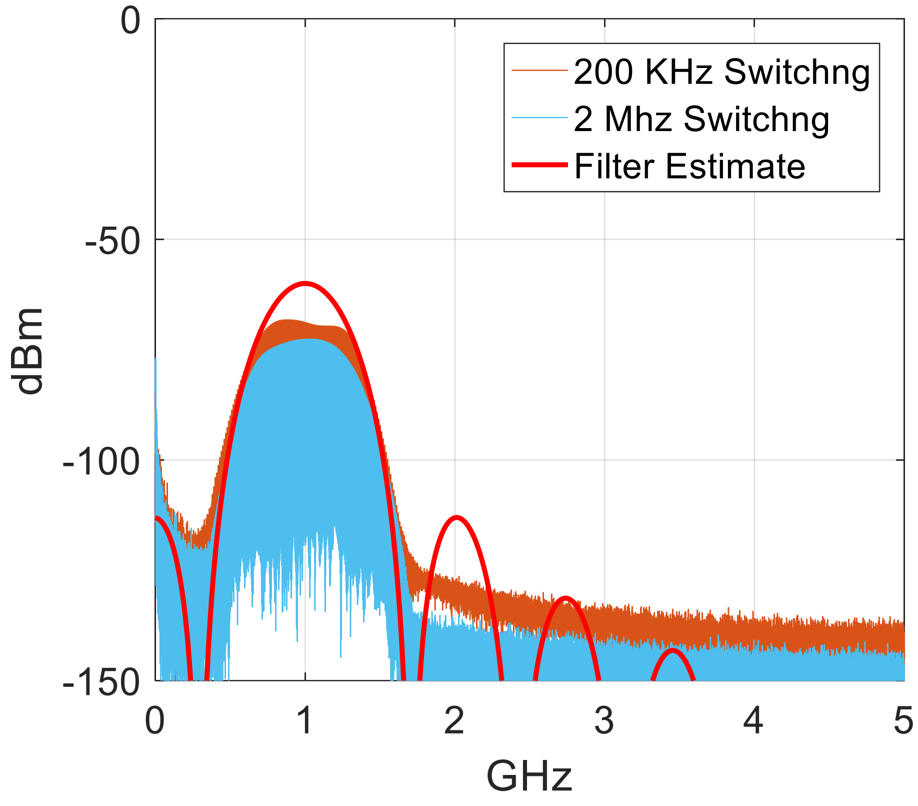
Filter estimate by comparing to PSD of the noise

$$H_e(f) = sinc\left(\frac{f - f_{spike}}{f_{spike}}\sqrt{2}\right)^2$$

$$\eta_0 = \frac{\sigma^2}{\sum_0^{f_b} sinc\left(\frac{f - f_{spike}}{f_{spike}}\sqrt{2}\right)^2 \Delta f}$$

η_0 =2.1238e-06 V^2/GHz

assuming σ of 1 mV RMS and f_{spike} = 1 GHz



Recommendation, if slide 2 is what we intend

Use η_0= 2.1238e-06 V^2/GHz for 1mV system noise

Use η_0= 5.3096e-07 V^2/GHz it we assume for ½ mV system noise

…but add system noise filter, $H_{sy}(f)$, to equation (93A-35)

$$H_{sy}(f) = sinc\left(\frac{f - f_{spike}}{f_{spike}}\sqrt{2}\right)^2$$, where f_{spike}=1 GHz

$H_{sy}(f) H_{21}^{(rp)}$

$$\sigma_N^2 = \eta_0 \int_0^{\infty} |H_r(f) H_{ctf}(f)|^2 df \qquad (93A\text{–}35)$$

Moving Forward

- ❑ Agree on what η_0 is
  - System noise allocation or
  - Standard receiver noise all can agree upon or
  - A combination or
  - Something else
- ❑ If it is a system noise budget
  - Use the $H_{sy}(f)$ recommendation as a starting point
  - Power spectral density (PSD) measurement of system noise, σ, would be useful
  - PSD and σ are not trivial measurements!
    - Instrument ground common mode noise can be an error term
    - Self-device noise is an error term which needs to be removed
      - This noise is already included in SNDR and RITT
    - Sufficient loading activity in the rest of the system is required

Thank You!

Reference

Johnson (Thermal) Noise for Resistance

$$P_{dbW} = 10\ log10(k_B T_k) + 10\ log10(\Delta f)\ ,\ in\ {}^{w}/_{\Delta f}$$

$$k_b = 1.38064852\text{e}{-}23\ \text{J}/T_k$$

$$T_k = degrees\ K = 273.15 + degrees\ C$$

$$\Delta f = frequency\ span,\ 1\ GHz = 1e9\ Hz$$

$$R = 100\ \Omega$$

Johnson noise in term of V^2/GHz is

$$\eta_{0jn} = 10^{\frac{P_{dbW}}{10}} R\,\Delta f = 10^{\frac{P_{dbW}}{10}}\,100\,(1e9),\quad {}^{V^2}/_{GHz}$$

$$\eta_{0jn} = 3.9922e - 10\ \ {}^{V^2}/_{GHz}\ @\ 16^{o}\ C$$

$$\eta_{0jn} = 5.1519e - 10\ \ {}^{V^2}/_{GHz}\ @\ 100^{o}\ C$$