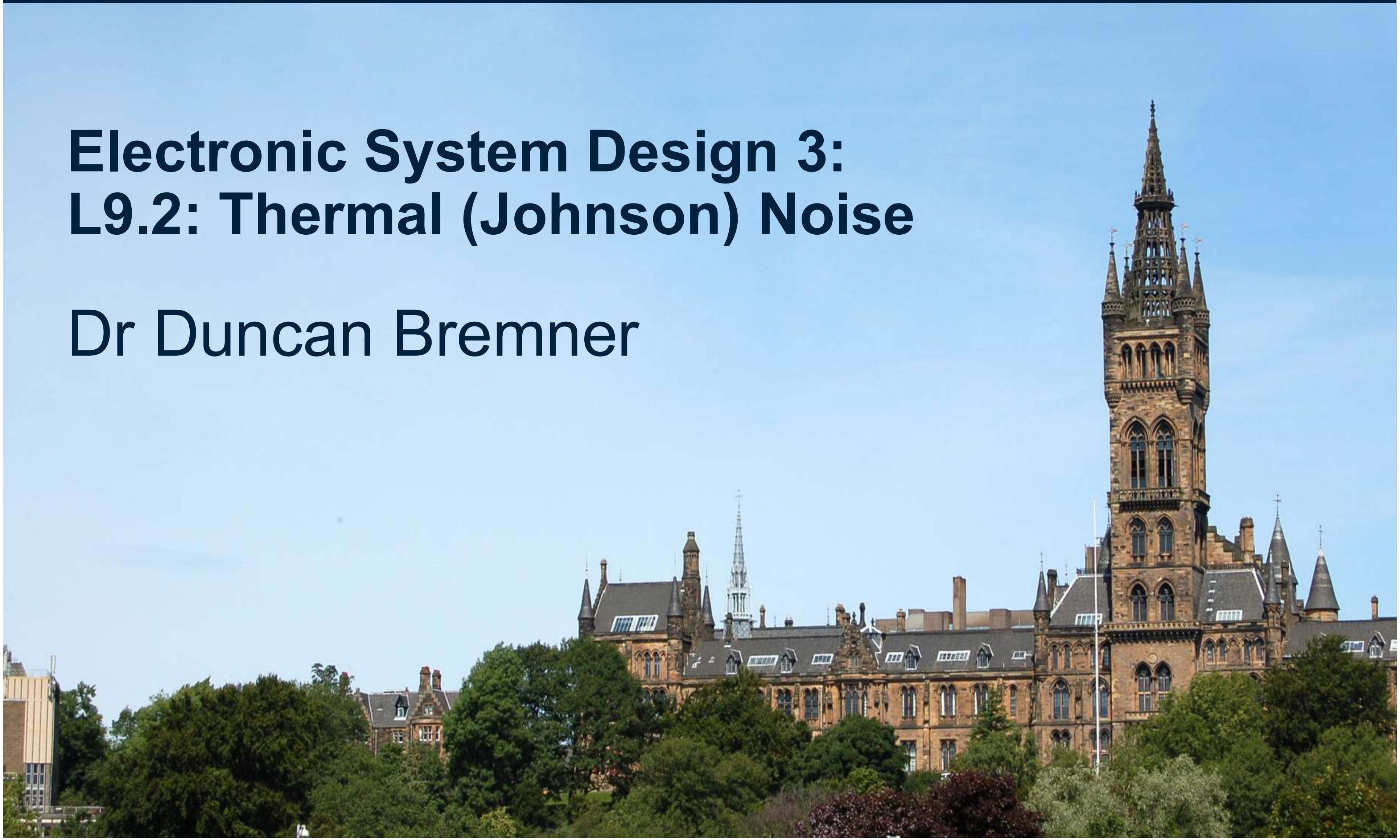
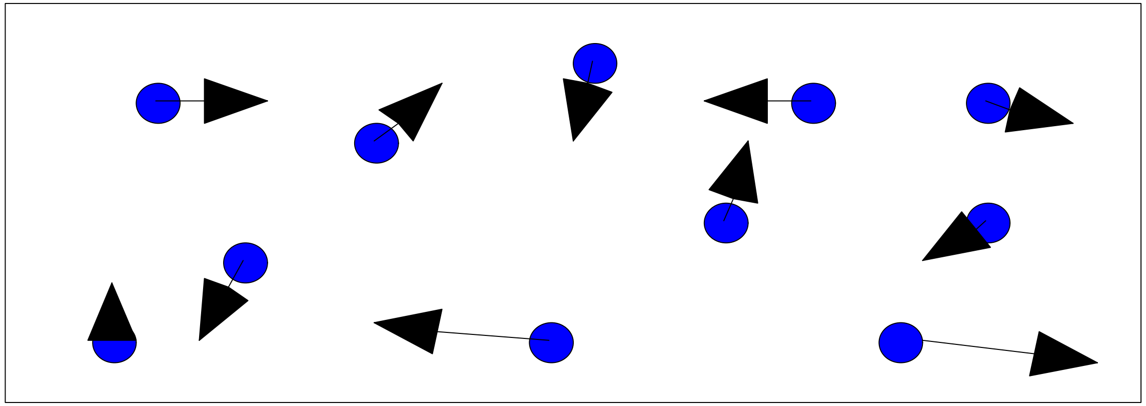
Electronic System Design 3:
L9.2: Thermal (Johnson) Noise

Dr Duncan Bremner



Thermal Noise



Electrons in a resistor are in a state of constant, random motion

=> Randomly varying currents flowing throughout the resistor

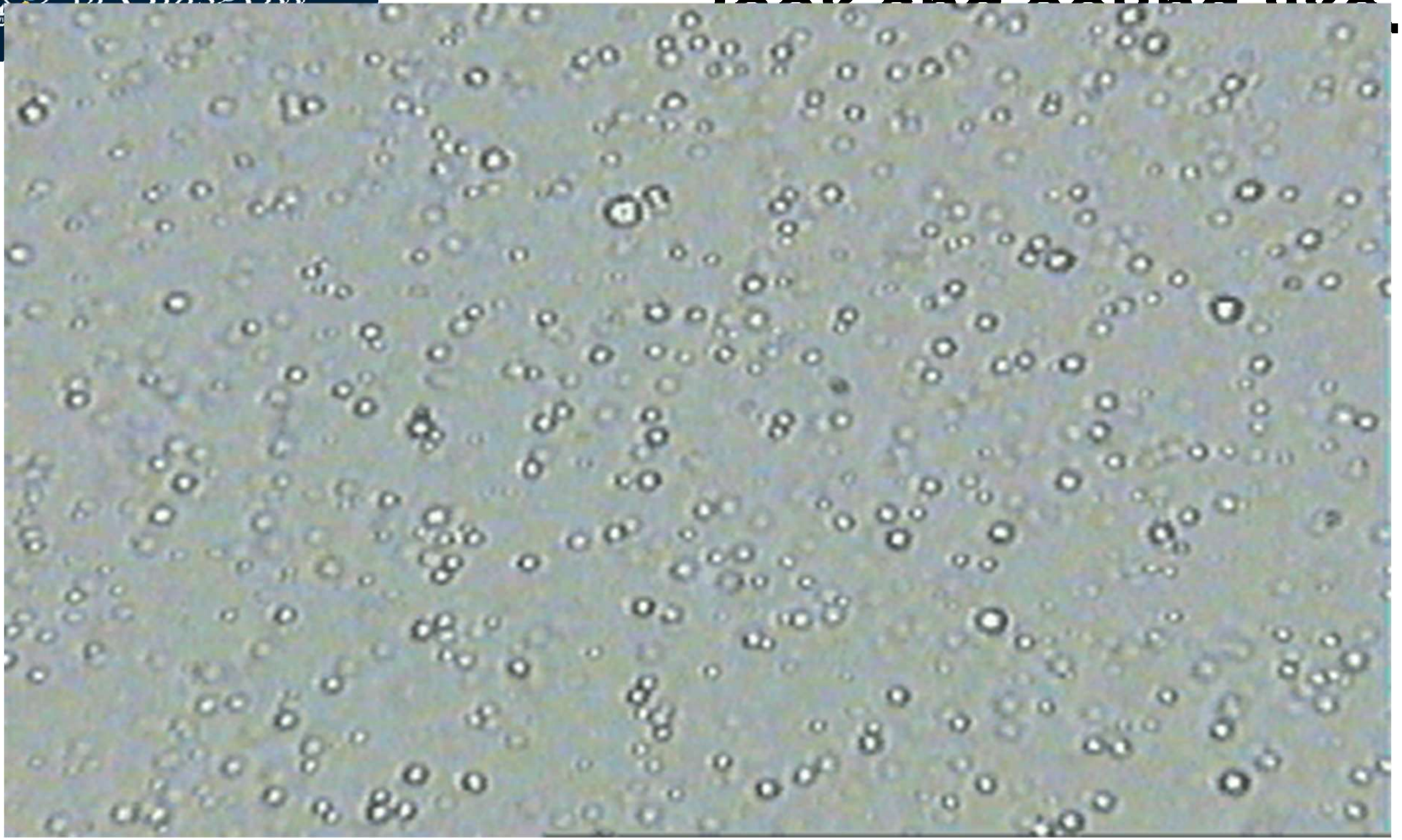
=> Random time-varying voltage across the resistor

Thermal motion:

Hotter => Electrons move more -> Bigger voltage

Thermal noise would be zero at 0K, so **never is**

This is what dancing electrons look and sound like….



http://www.cabrillo.edu/~jmccullough/Videos/index.html

Thermal Noise

Random voltage, so use statistics to characterise.

- Lots of electrons moving
  (~ 10^{20} / mm^3, 4 x 10^4 in a 1μm^3 resistor)

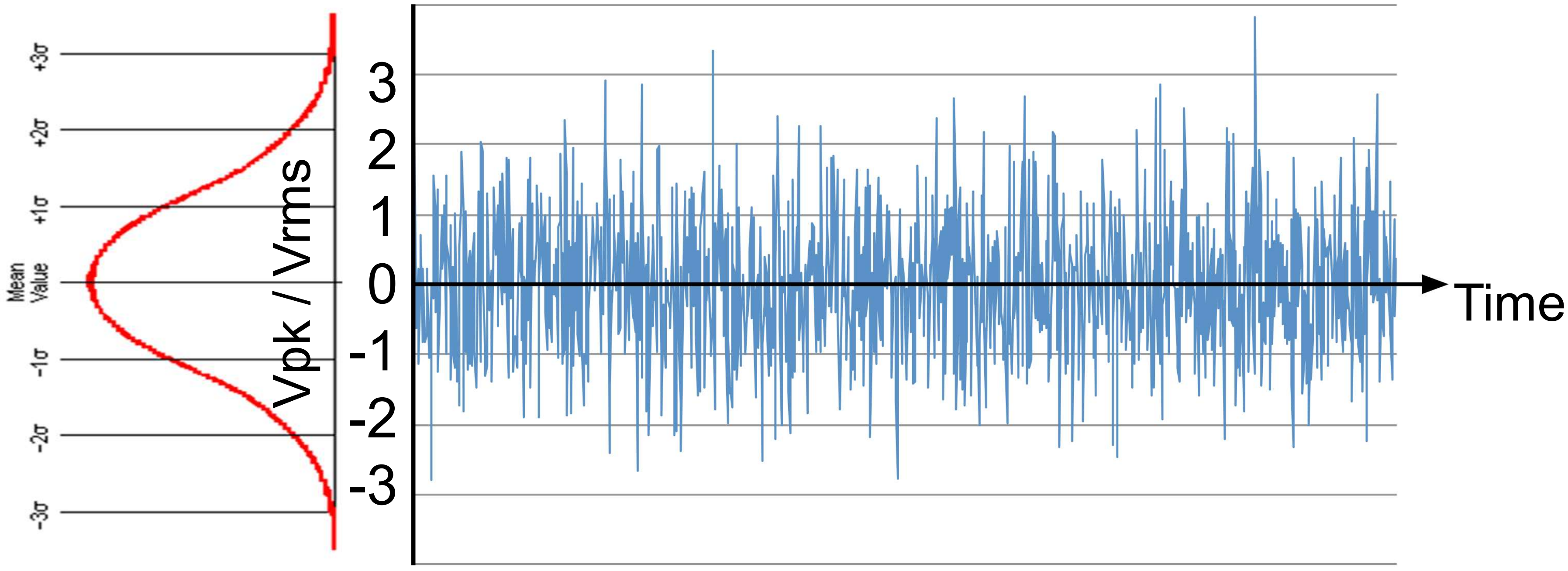
- Moving very fast (~10^{12} collisions / second / electron)
  => Statistics are Very Accurate

- Noise looks the same whenever it is measured (for constant temperature, bandwidth etc.) ("Statistically Stationary"): Characterise using time averages

Thermal Noise

Noise voltage may be +ve, -ve or 0: Average is 0

=> Measure RMS voltage.



Hint: Peak value is about 3x the rms

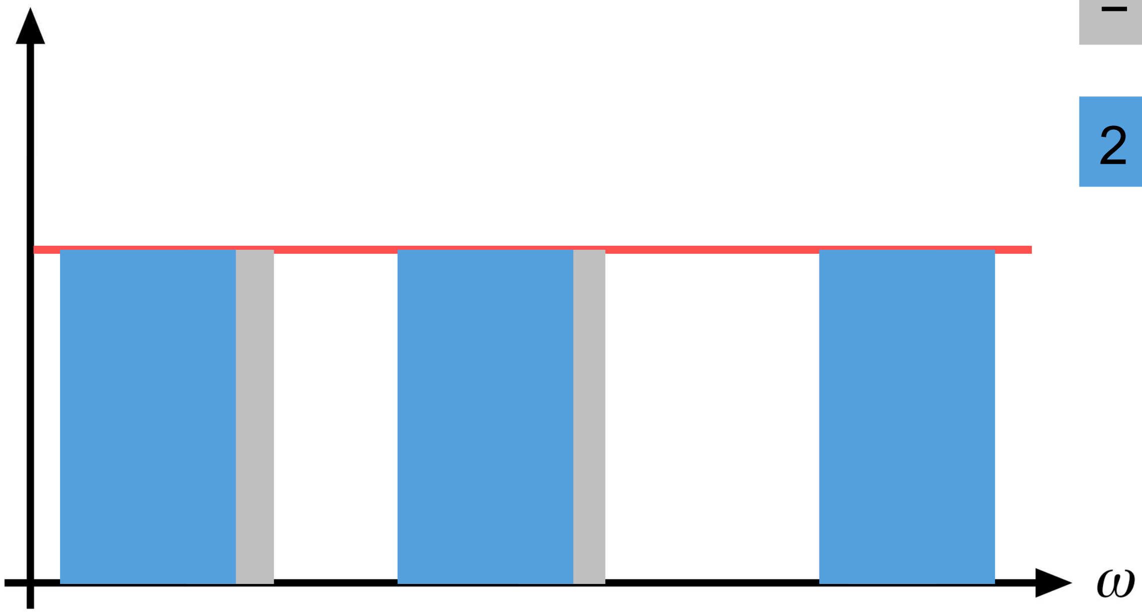
-> 99.7% probability that Vpeak <= 3*Vrms

Thermal Noise: Frequency spectrum

- Thermal noise is generated at all useful frequencies

- Thermal noise has the same RMS amplitude at all frequencies < $6\cdot10^{12}$ Hz if measured with the same bandwidth

$V_{RMS}(\omega)$ Over constant bandwidth, B

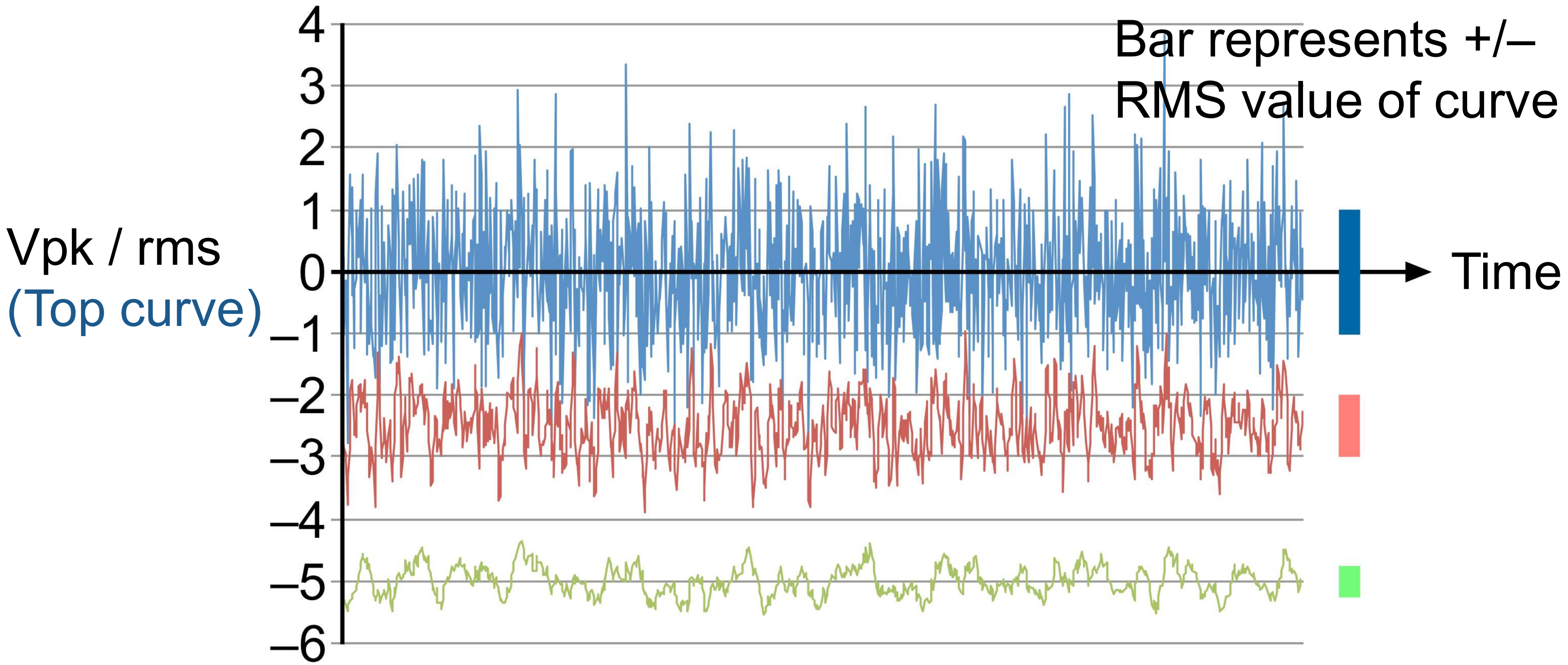


= same noise voltage (Vn)

2 x bandwidth = $\sqrt{2}\,.(Vn)$

Thermal Noise

RMS thermal noise **does** depend on the bandwidth used



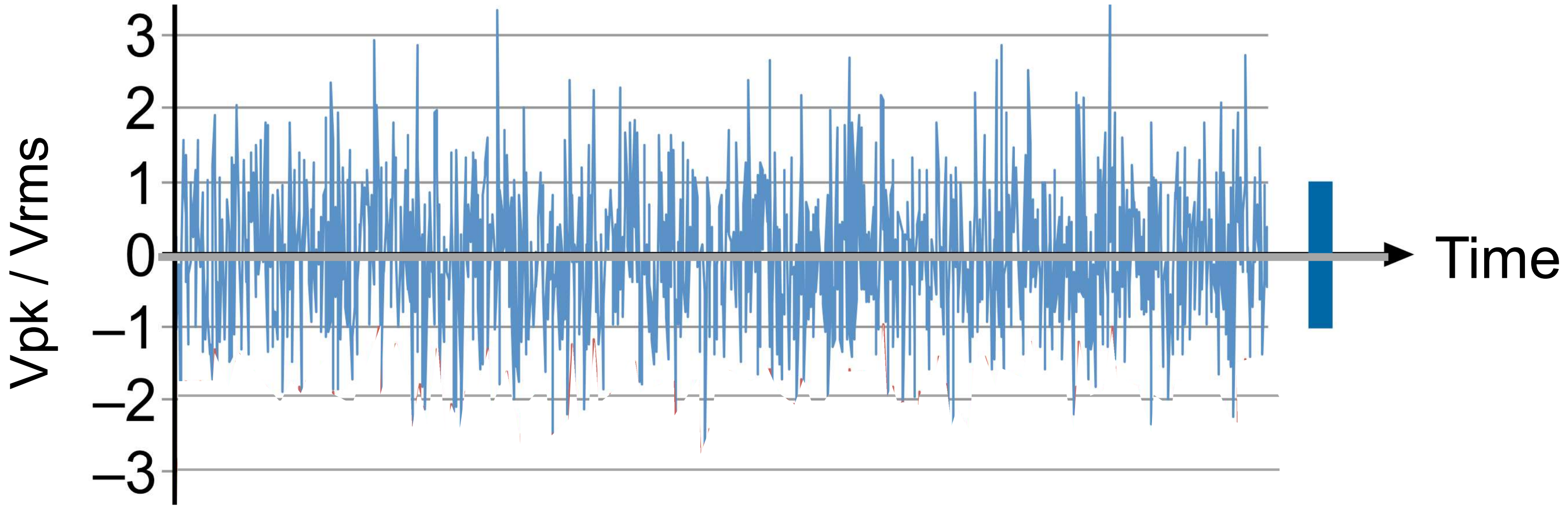
Each curve has ¼ of the bandwidth of the previous curve

Amplitude x2 if bandwidth x4 (statistics!)

Lowpass filter

Thermal Noise

RMS thermal noise **does** depend on the bandwidth used

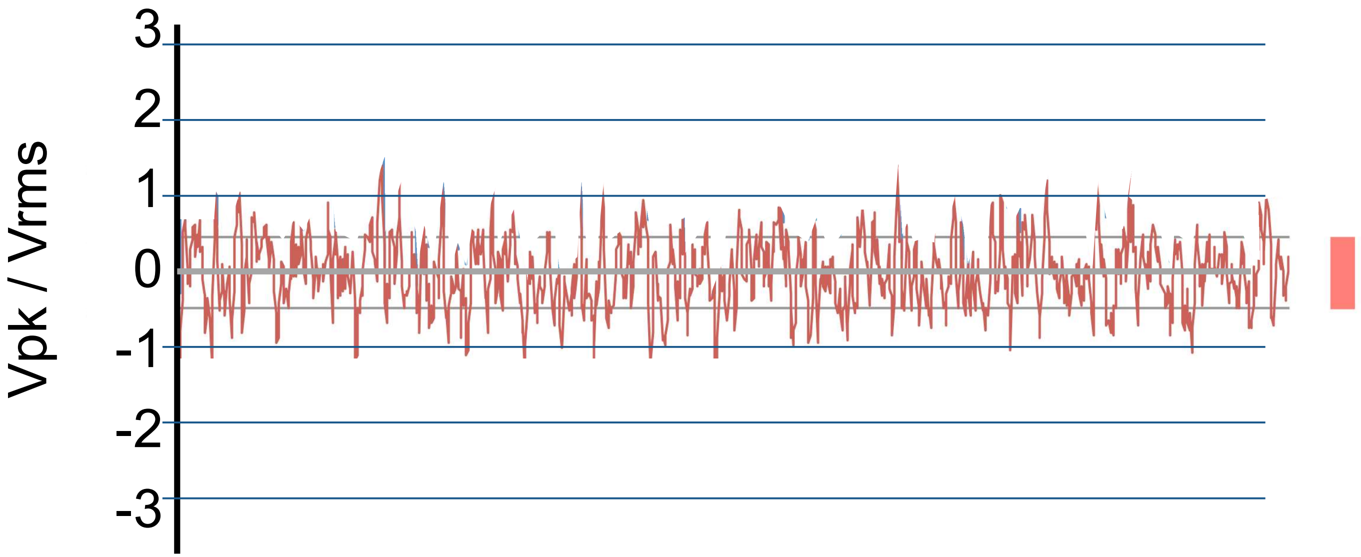


Each curve has ¼ of the bandwidth of the previous curve

Amplitude x0.5 if bandwidth x0.25 (statistics!) Lowpass filter

Thermal Noise

RMS thermal noise **<u>does</u>** depend on the bandwidth used



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Amplitude x0.5 if bandwidth x0.25 (statistics!) (Lowpass filter)

Thermal Noise

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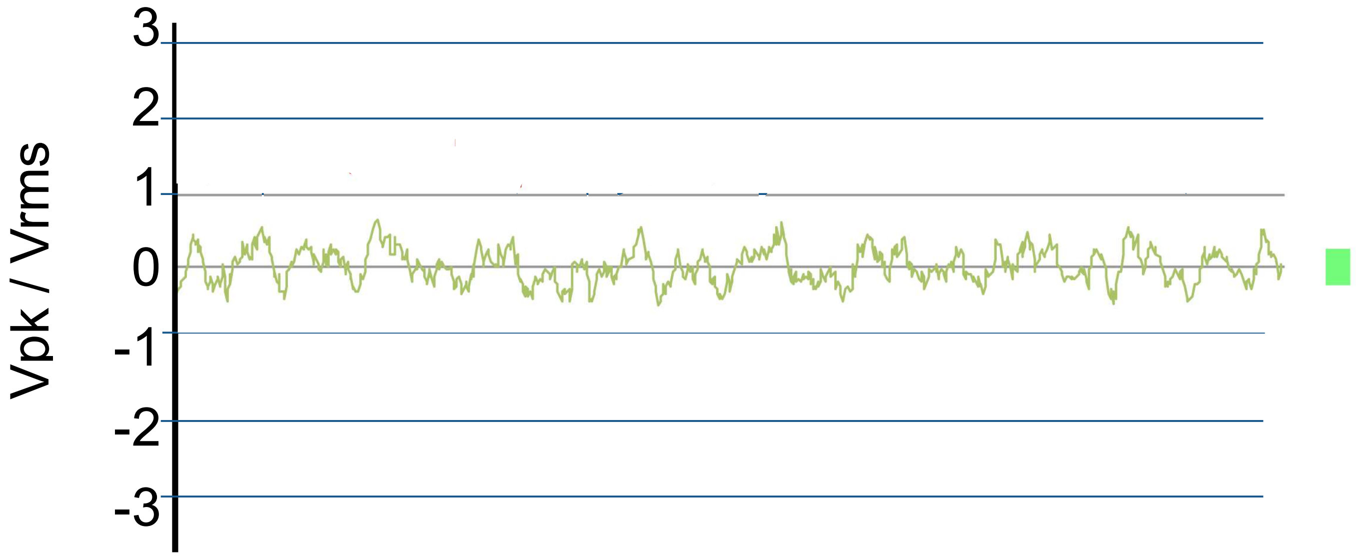

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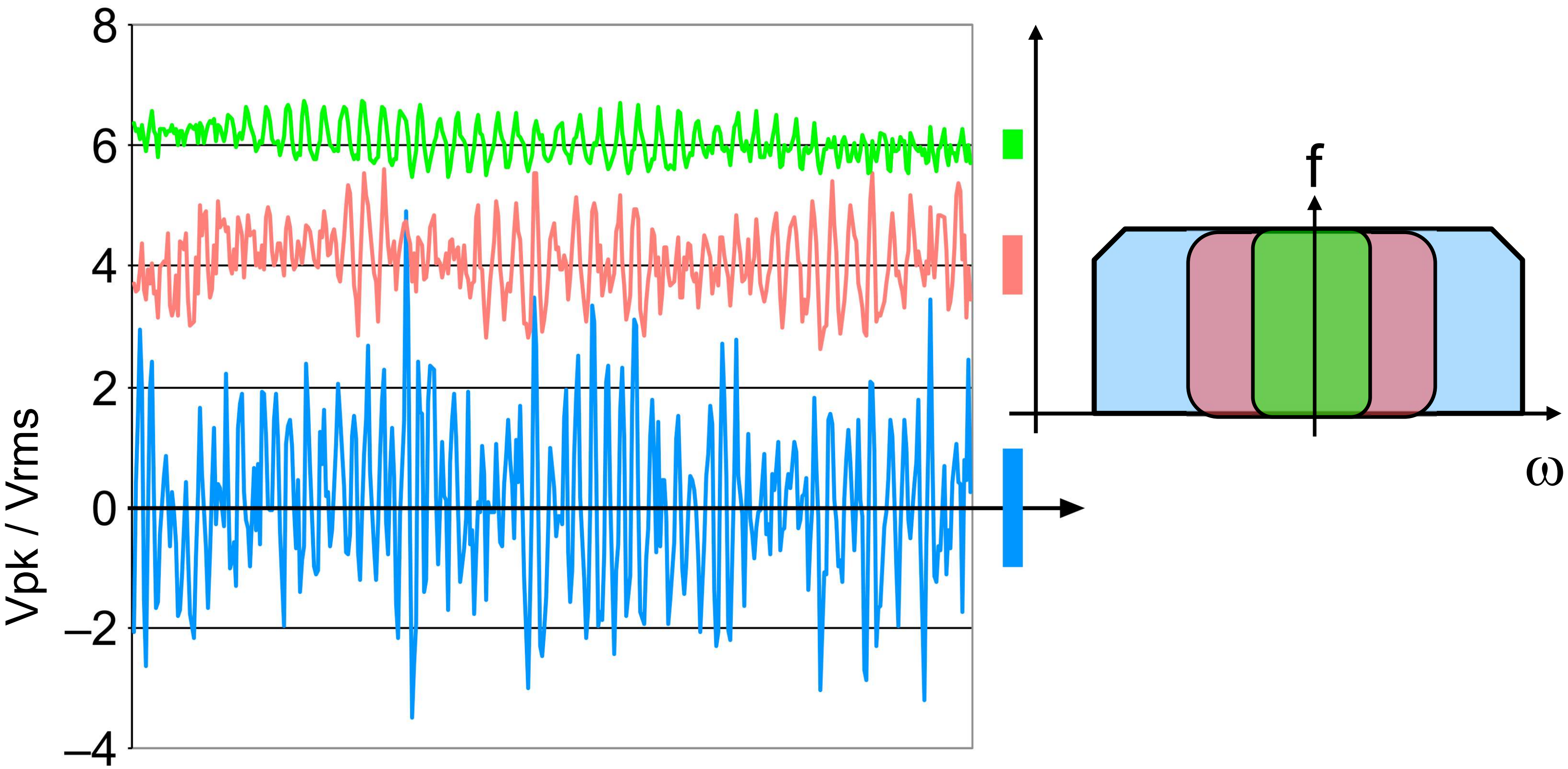
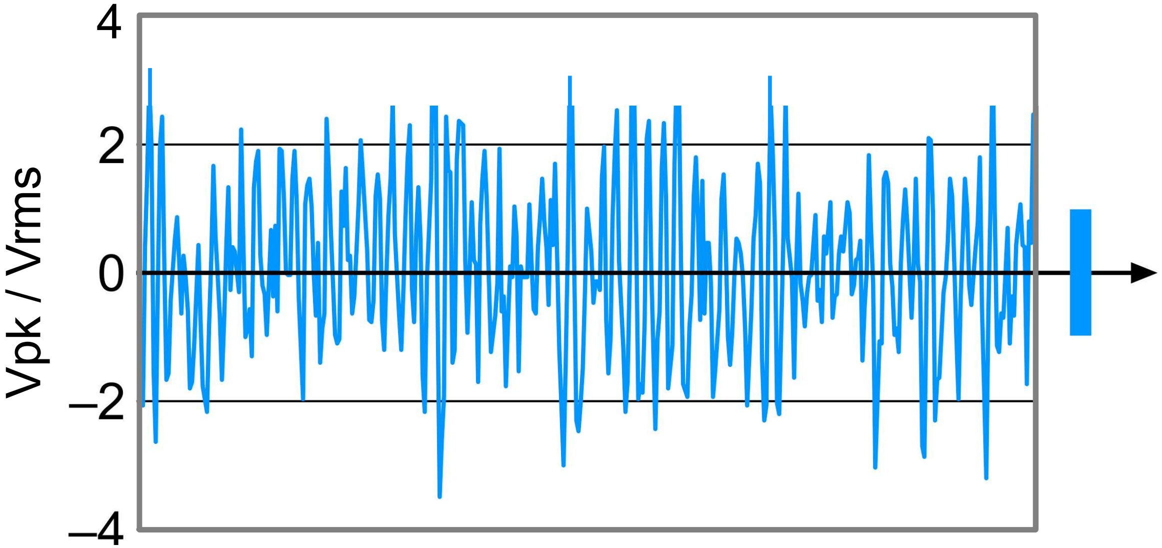
Lowpass filter

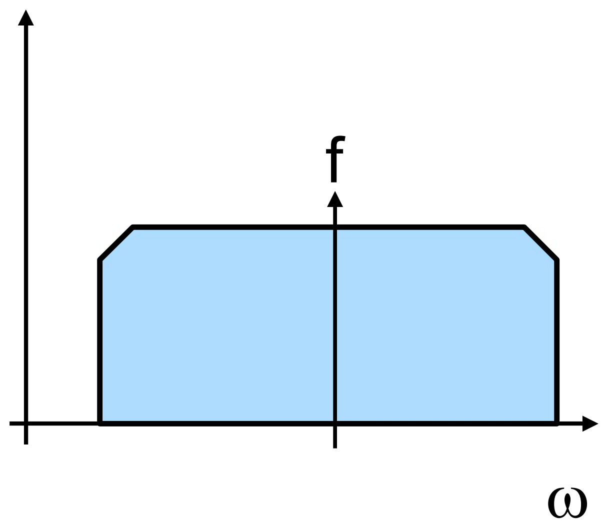
Thermal noise



Bandpass filtering has the same effect (note average frequency is the same but narrow bandwidth signal is more coherent)

Thermal noise





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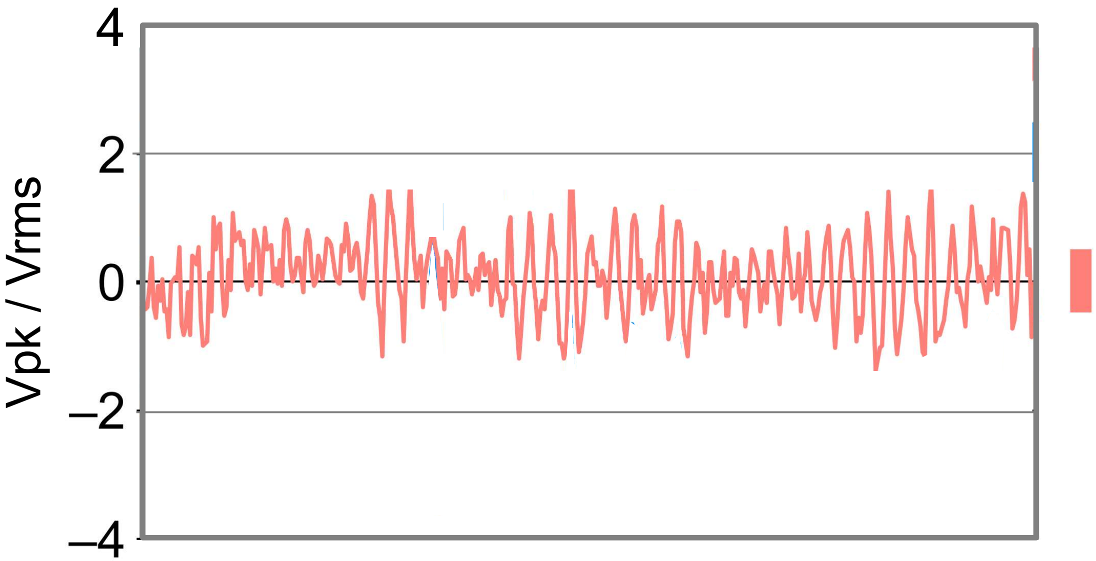

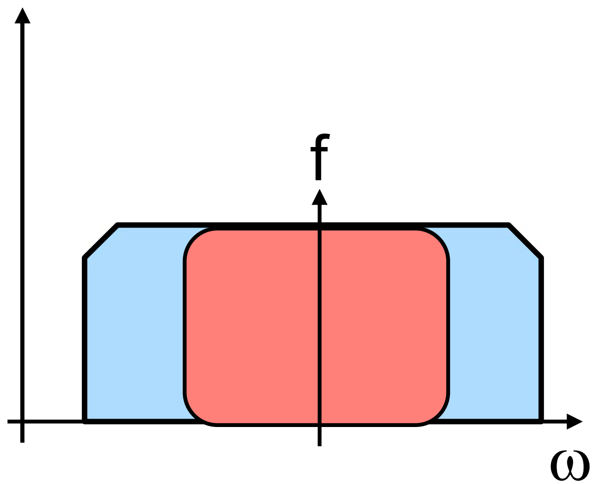

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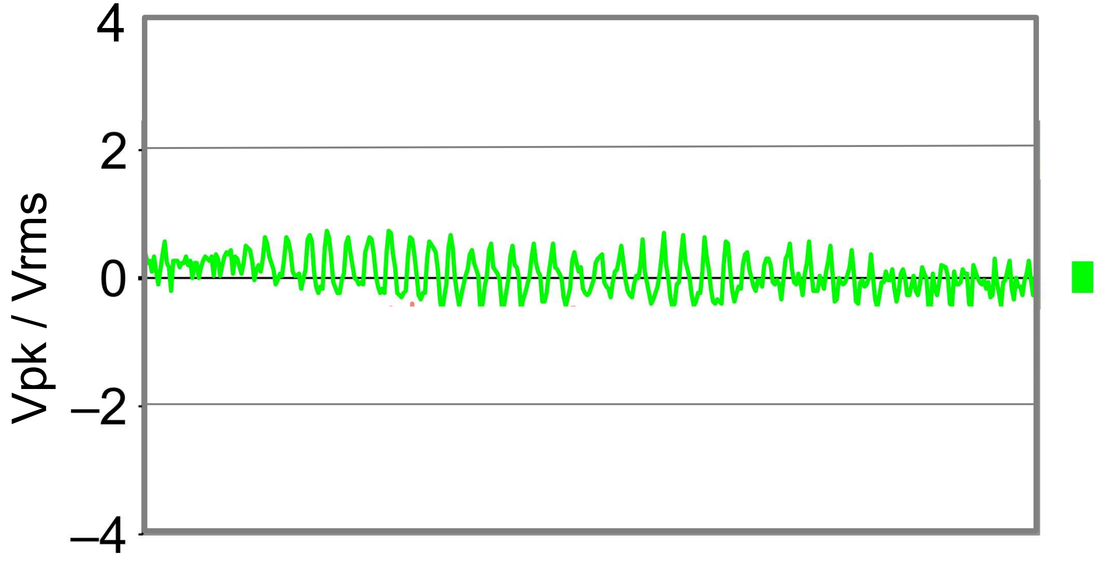

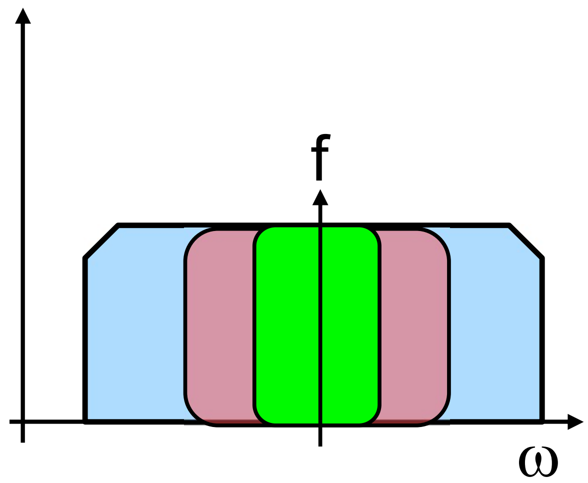

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University of Glasgow
Thank you
谢谢
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