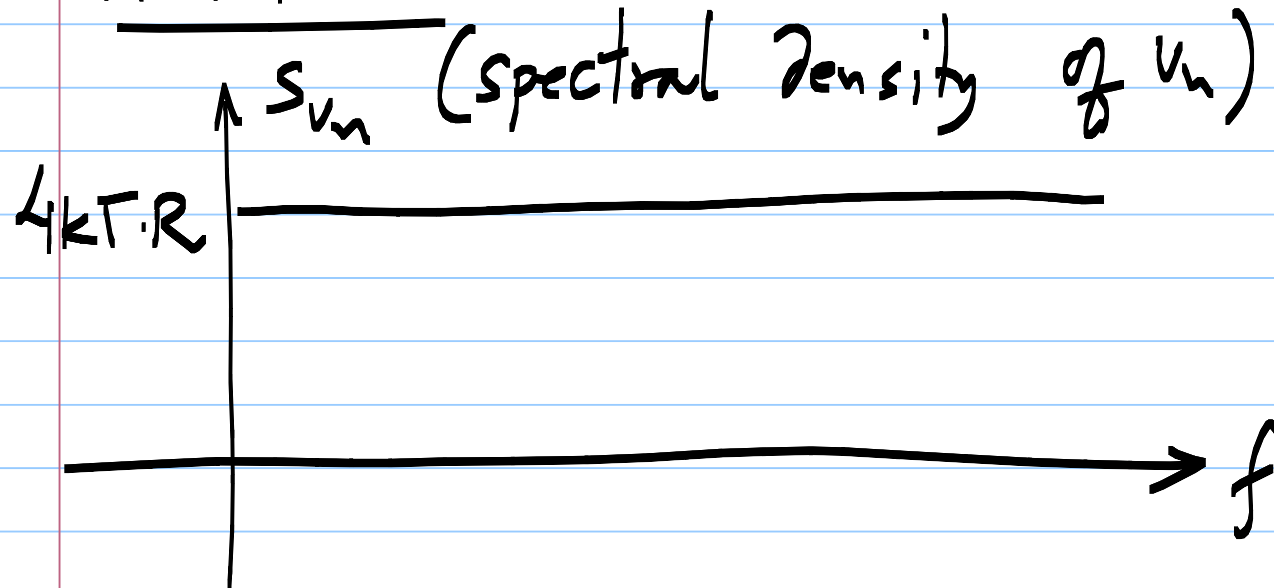
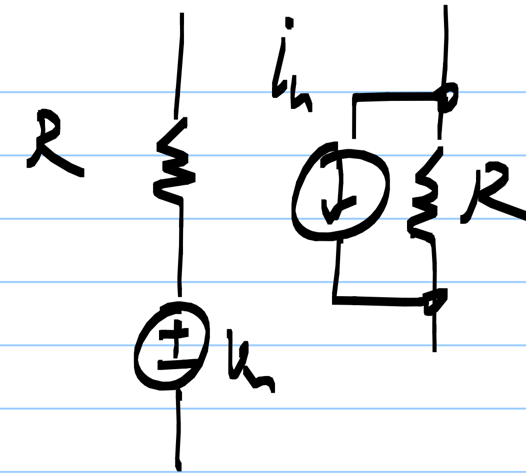
Resistor

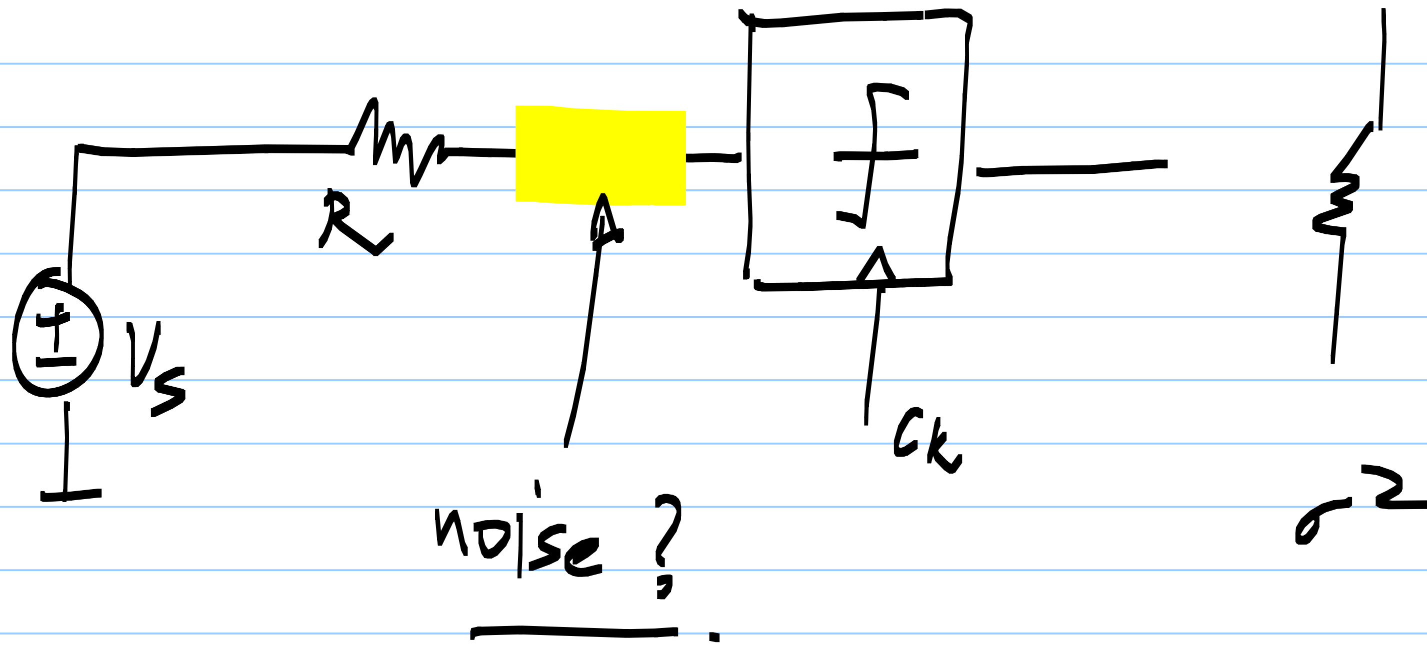


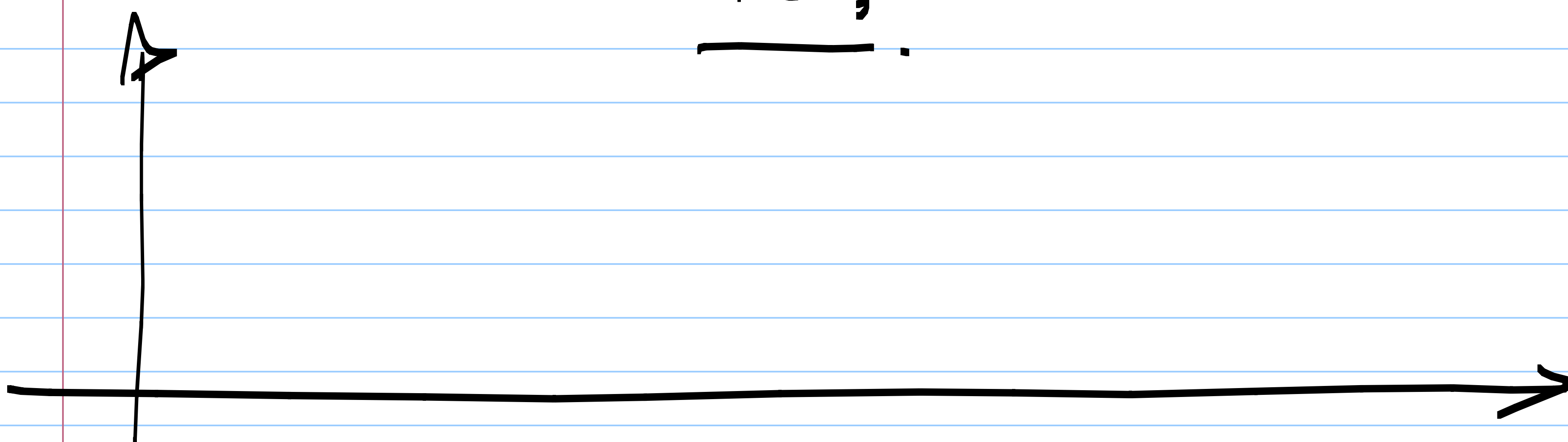


k: Boltzmann's constant : 1.38×10^{-23} J/K

T: absolute temp. 300K

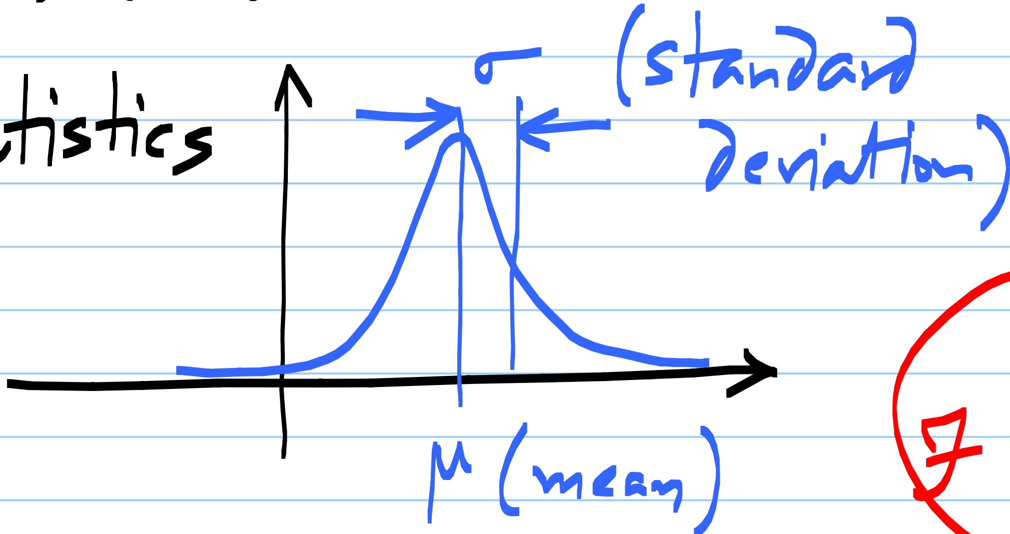
kT: (Energy) : 4×10^{-21} J


R
Vs
noise ?
ck
σ2



Random variable x

statistics

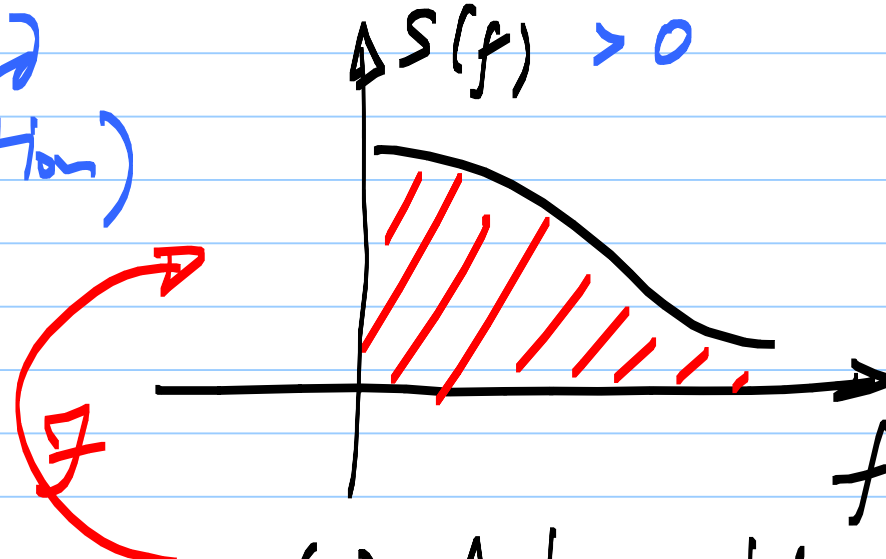


σ^2: variance

$E(X)$

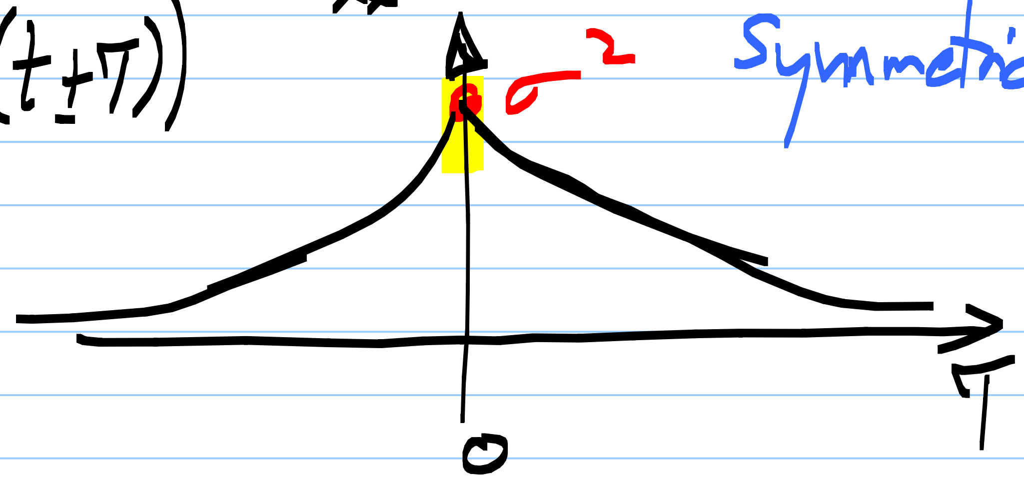
$E\left(\left(X - E(X)\right)^2\right)$

Spectral density



$R_{xx}(\tau)$ Autocorrelation

$E\left(x(t) \cdot x(t+\tau)\right)$



Variance $\int_0^\infty S_x(f)\,df$ Spectral density

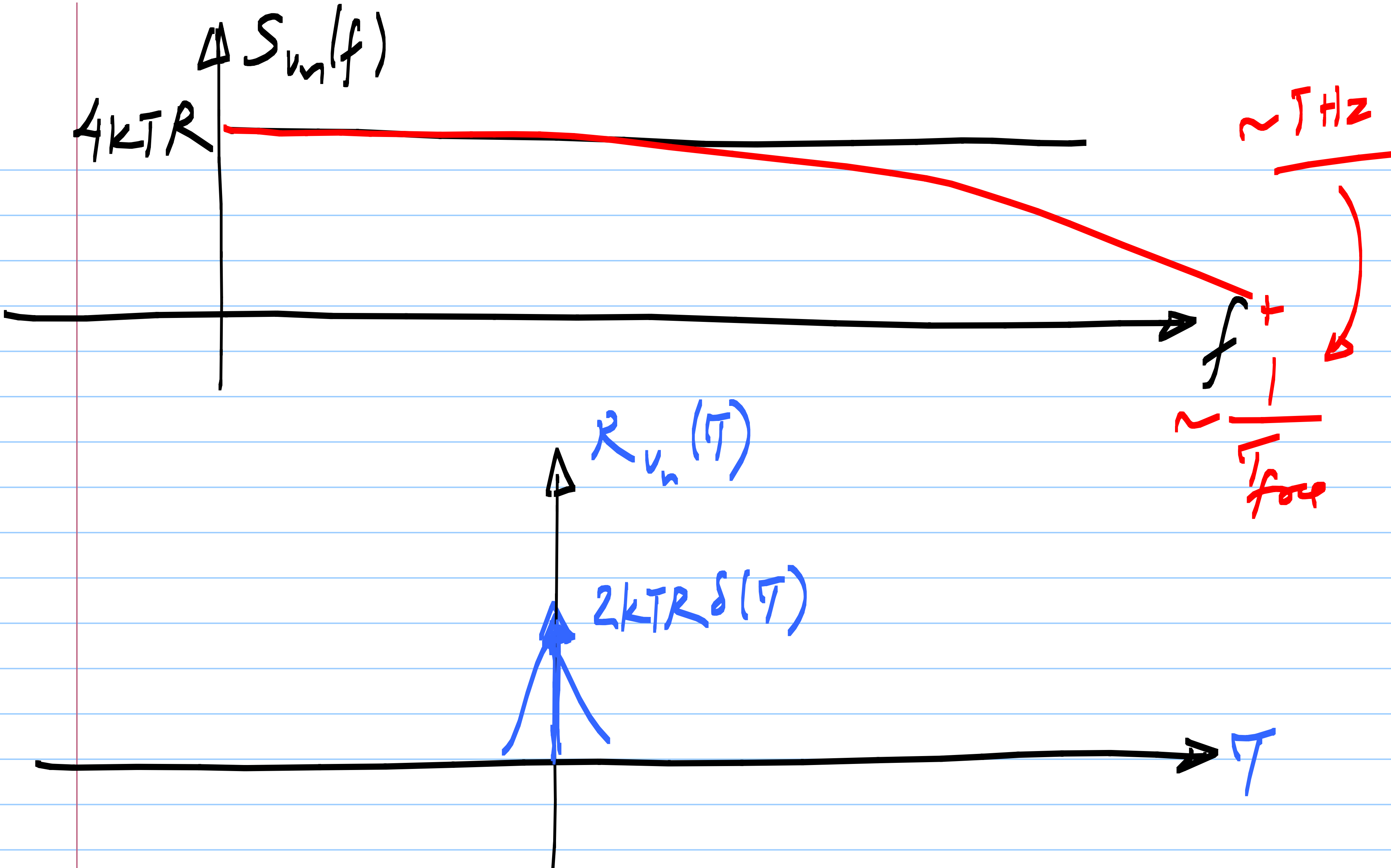
σ_x^2 $S_x(f)$

Fourier transform

Zero-mean Gaussian random noise $R_{xx}(0)$

Autocorrelation $R_{xx}(\tau)$

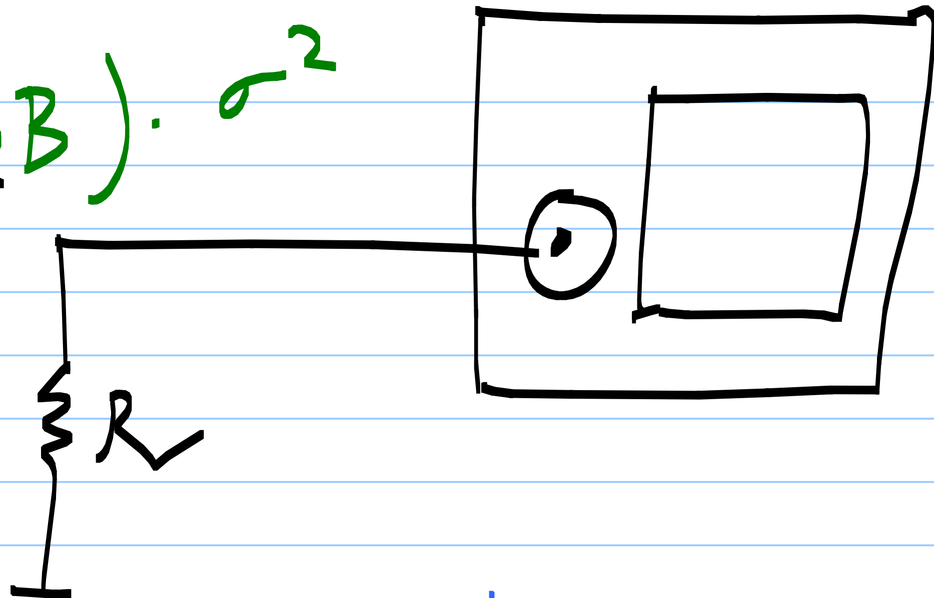
Uniform distribution

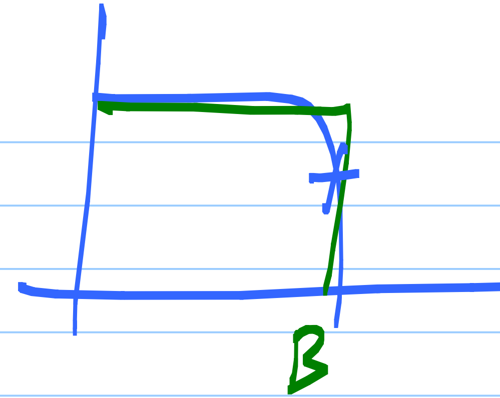


$S_{v_n}(f)$
4kTR
~THz
f
~1/τ_free
$R_{v_n}(\tau)$
2kTR δ(τ)
τ

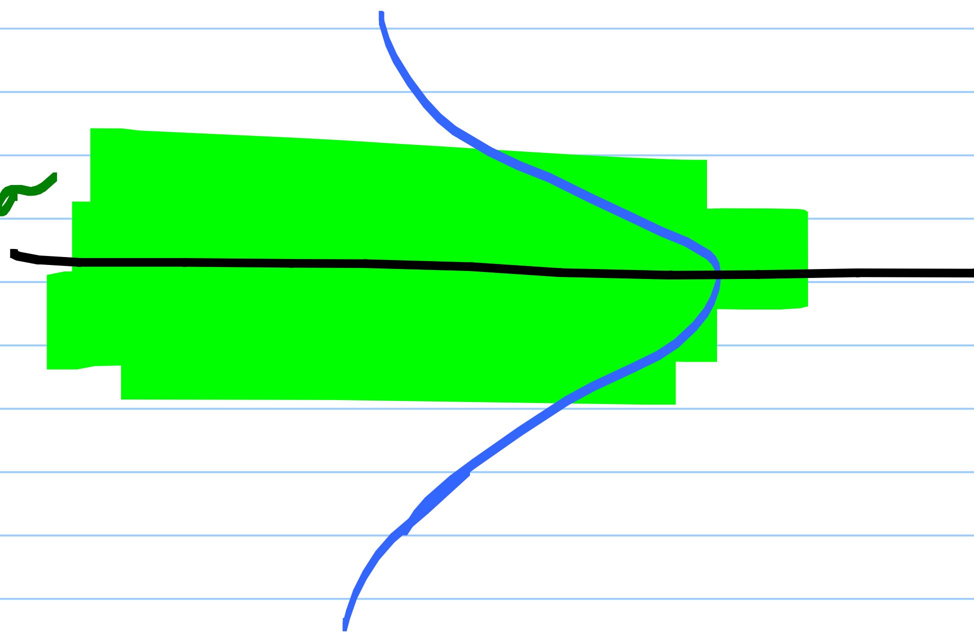
$S_v(f)$

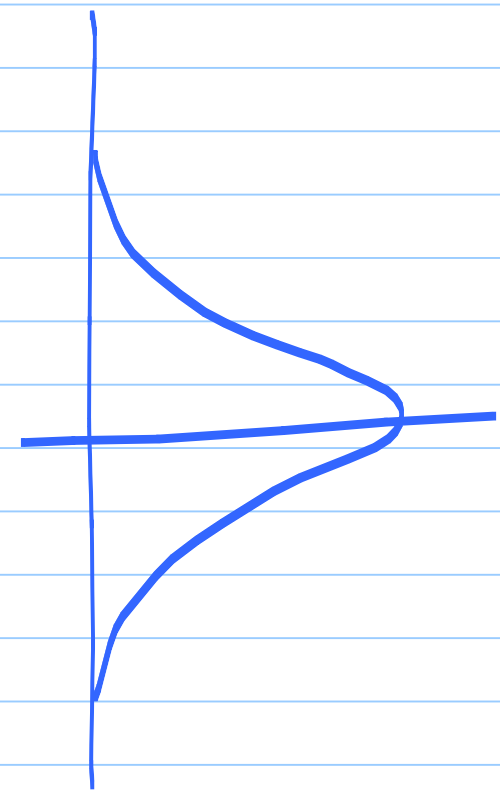
$(4kTR \cdot B) \cdot \sigma^2$

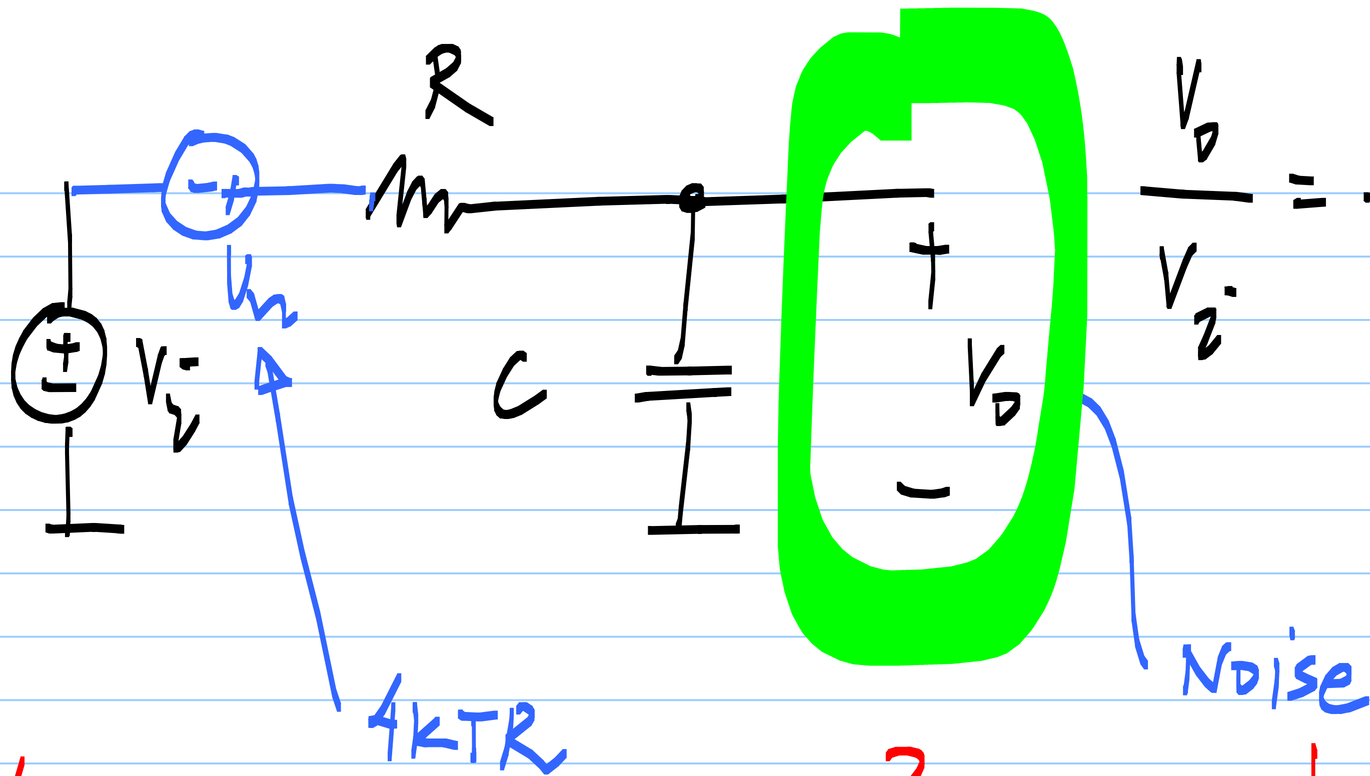




$\sqrt{4kTRB} : \sigma$

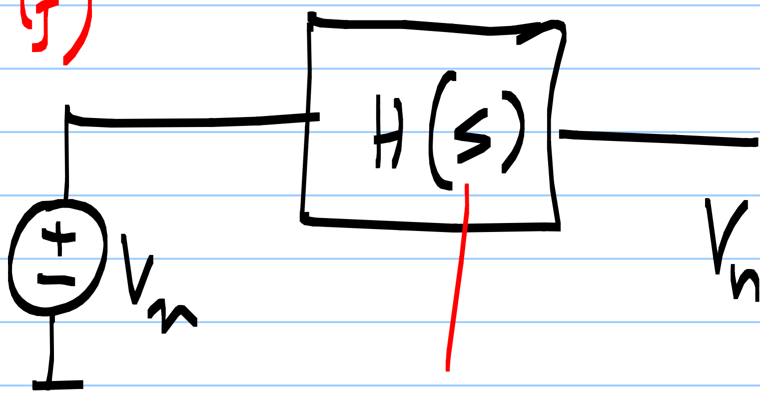






$$\frac{V_o}{V_i} = \frac{1}{1+sCR}$$

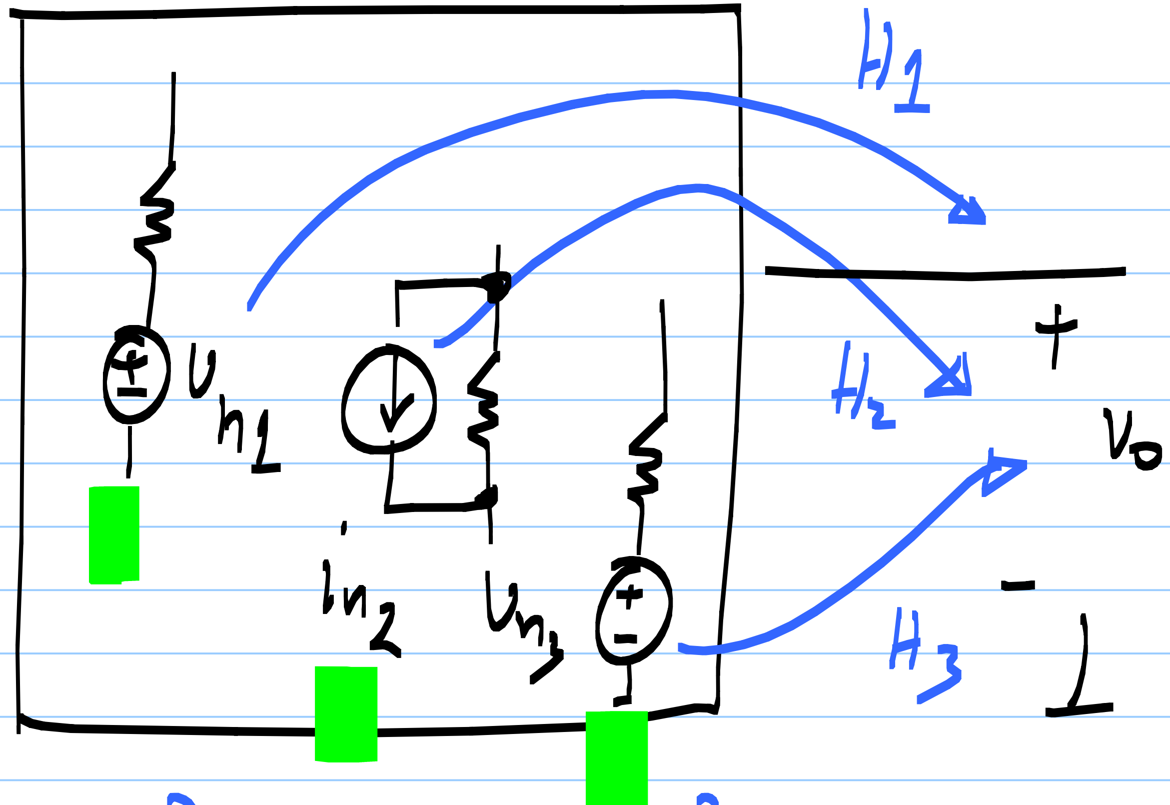
$S_{V_n}(f)$



?

$S_{V_n}(f) \cdot \left| H(j2\pi f) \right|^2$

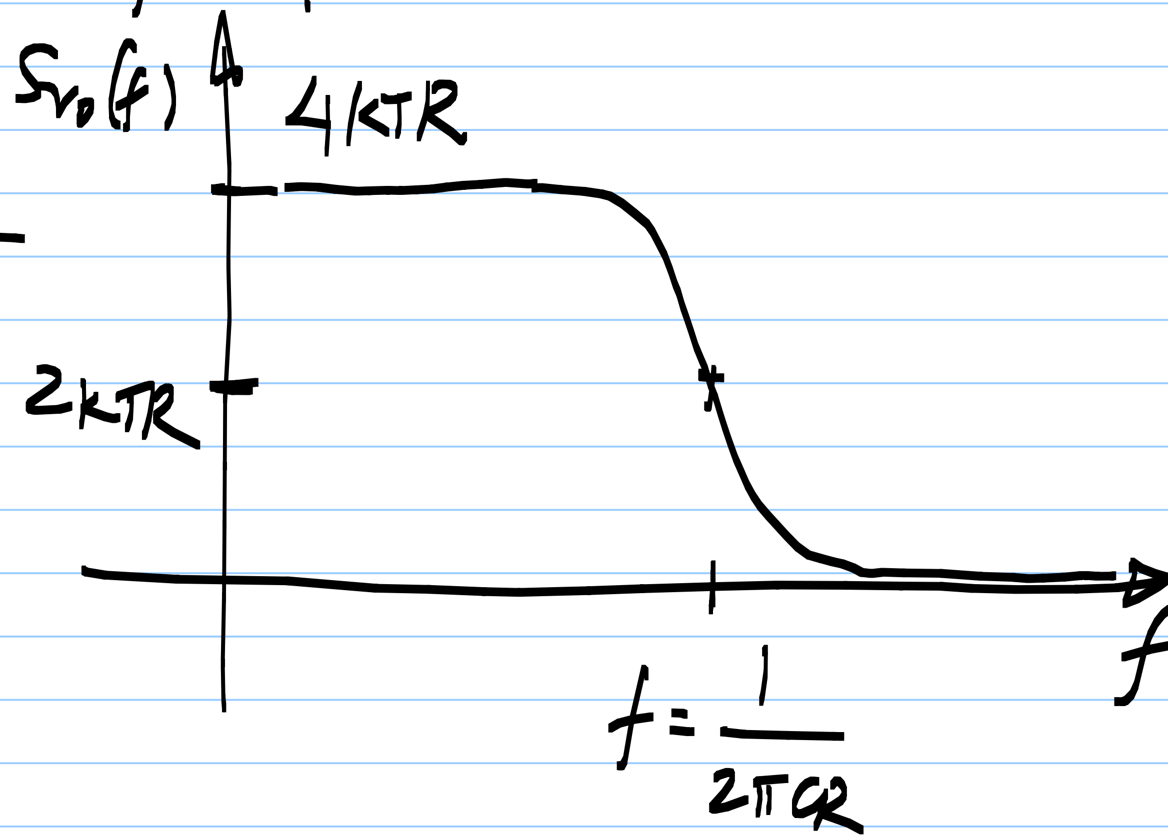
$V_n(s) \cdot H(s)$



$$S_{v_{n_1}} \cdot |H_1|^2 + S_{i_{n_2}} |H_2|^2 + S_{v_{n_3}} |H_3|^2 = S_o(f)$$

$$4kTR \left| \frac{1}{1 + j2\pi f C R} \right|^2 = S_{V_o}(f)$$

$$\frac{4kTR}{1 + \underbrace{4\pi^2 f^2 C^2 R^2}}$$



$$\int_0^\infty \frac{4kTR}{1 + (2\pi f CR)^2} \, df$$

$$x = 2\pi f CR$$

$$df = \frac{dx}{2\pi CR}$$

$$\frac{4kTR}{2\pi CR} \int_0^\infty \frac{1}{1 + x^2} \, dx$$

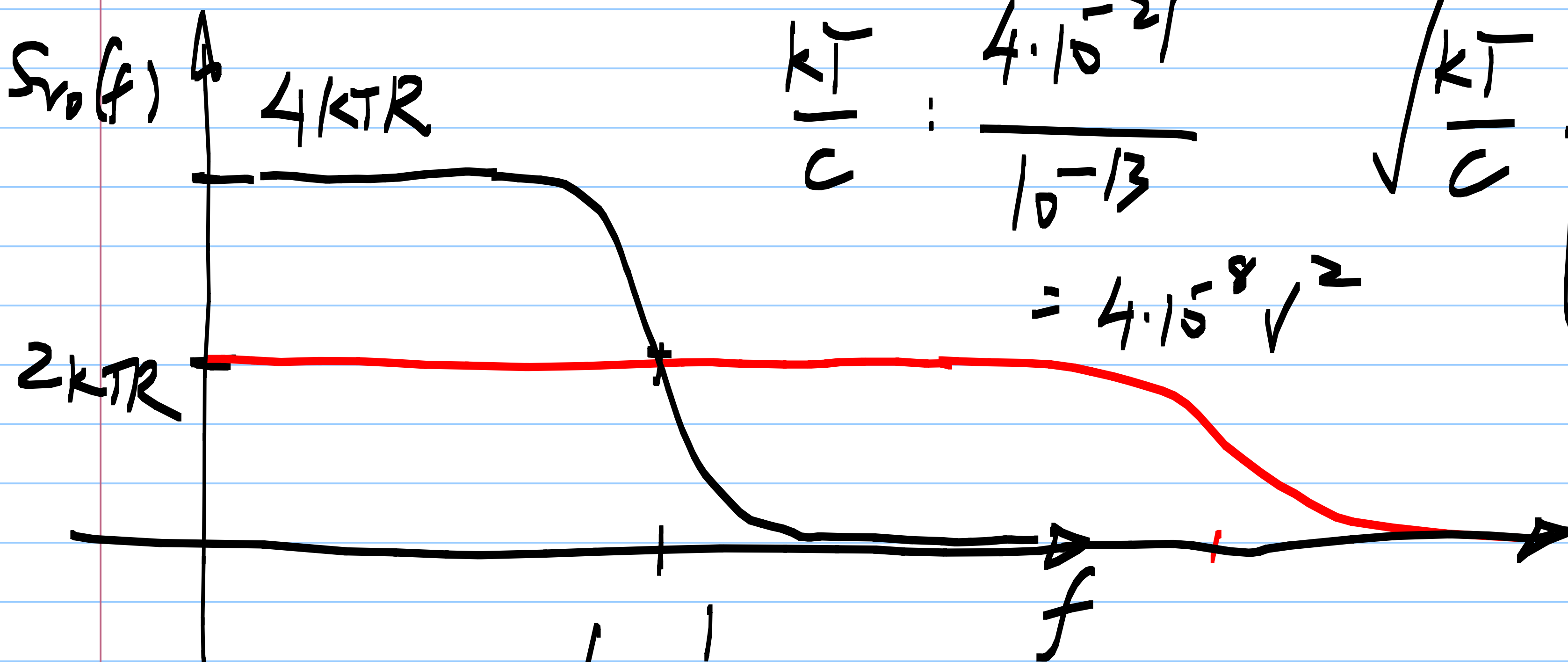
$$\frac{4kTR}{2\pi CR} \cdot \frac{\pi}{2} = \frac{kT}{C}$$

$$C = 100fF$$

$$\frac{kT}{C} : \frac{4 \cdot 10^{-21}}{10^{-13}} = 4 \cdot 10^{-8} V^2$$

$$\sqrt{\frac{kT}{C}} : 2 \cdot 10^{-4} V$$

$$\boxed{0.2mV}$$



$$f = \frac{1}{2\pi CR}$$

v_n : resistor noise : V (volts) $\int df$

$4kTR$: S_{v_n} : V^2/Hz $\xrightarrow{\quad}$ V^2

i_n : resistor noise $\int df$

$4kT/R$: S_{i_n} : A^2/Hz $\xrightarrow{\quad}$ A^2

$R = 1k\Omega$

$\underbrace{4kT}_{4 \cdot 10^{-21} J} R$: $16 \cdot 10^{-18}\ V^2/Hz$ | $4 \cdot 10^{-9}\ V/\sqrt{Hz}$

$4\ nV/\sqrt{Hz}$

$$4kTR \cdot B = \sigma^2$$

$$\underbrace{\sqrt{4kTR}}_{V/\sqrt{Hz}} \cdot \sqrt{B} = \sigma$$