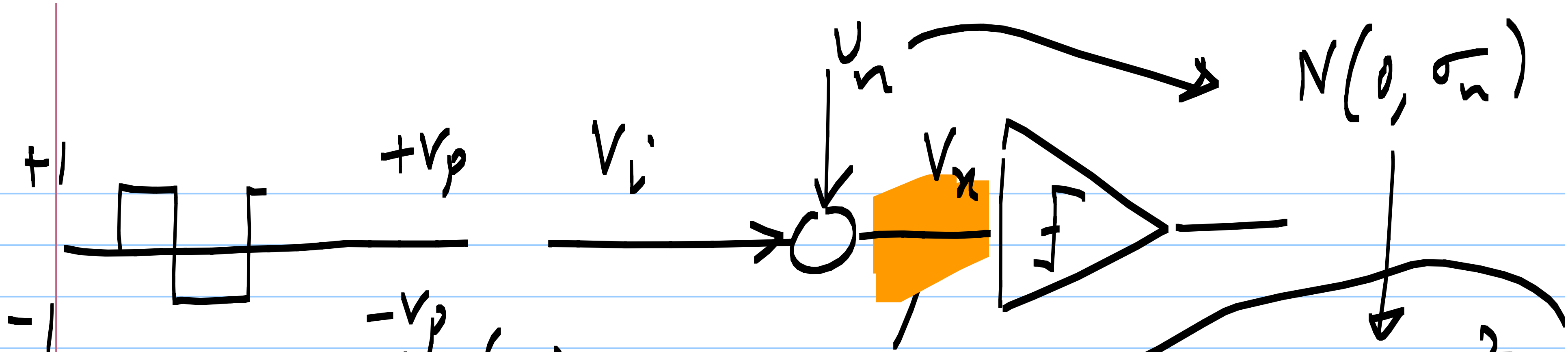
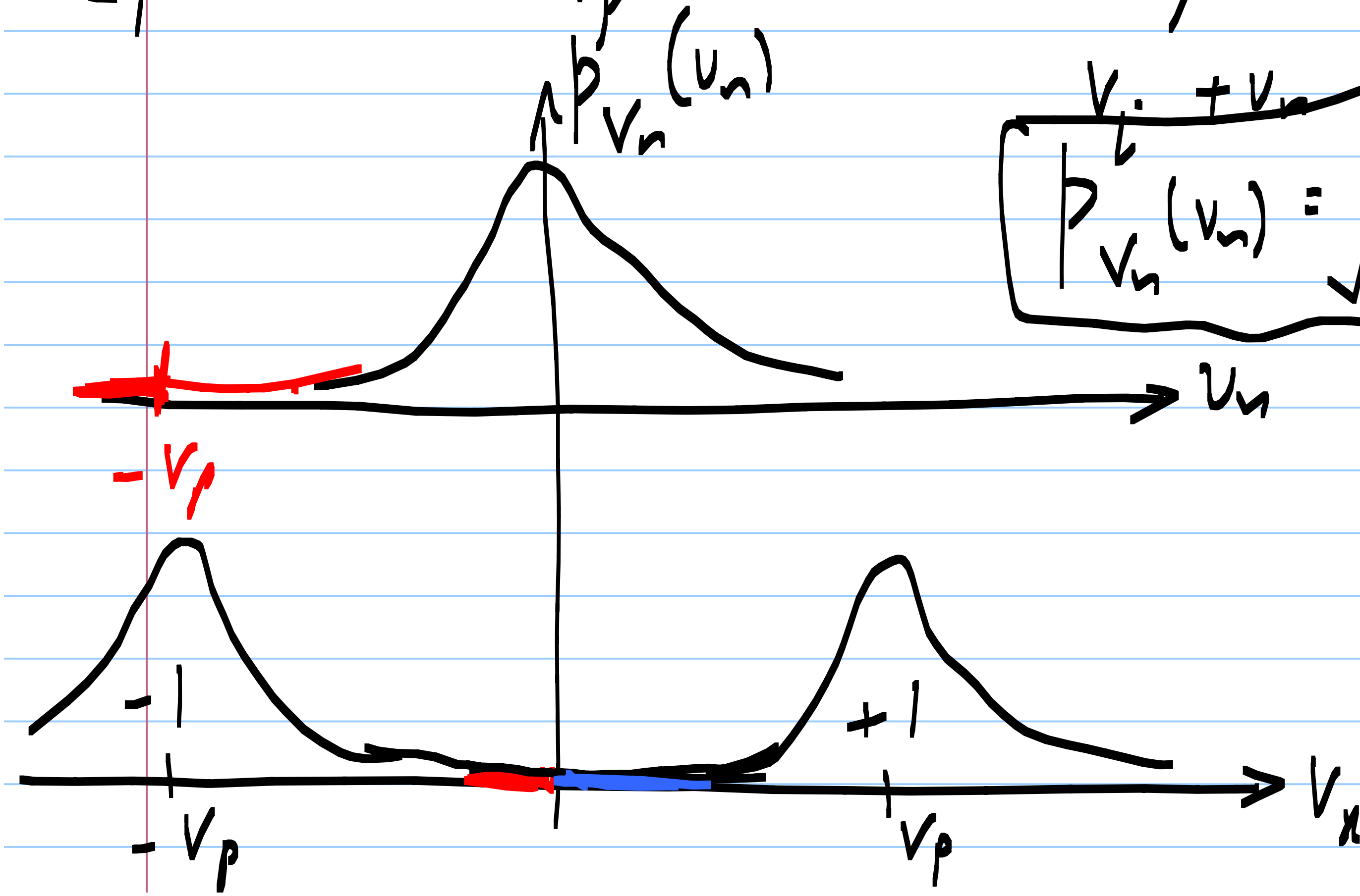


$$p_{V_n}(v_n) = \frac{1}{\sqrt{2\pi}\cdot\sigma}\exp\left(-\frac{v_n^2}{2\sigma^2}\right)$$



$$P(+1)\int_{-\infty}^{-V_p} p_{V_n}(v_n)\cdot dv_n$$

$$P(-1)\int_{V_p}^{\infty} p_{V_n}(v_n)\,dv_n$$

$$BER = \underbrace{\int_{V_p}^{\infty} p_{V_n}(v_n) \cdot dv_n}$$

$$p_{V_n}(v_n) = \frac{1}{\sqrt{2\pi}\,\sigma} \exp\left(-\frac{v_n^2}{2\sigma^2}\right)$$

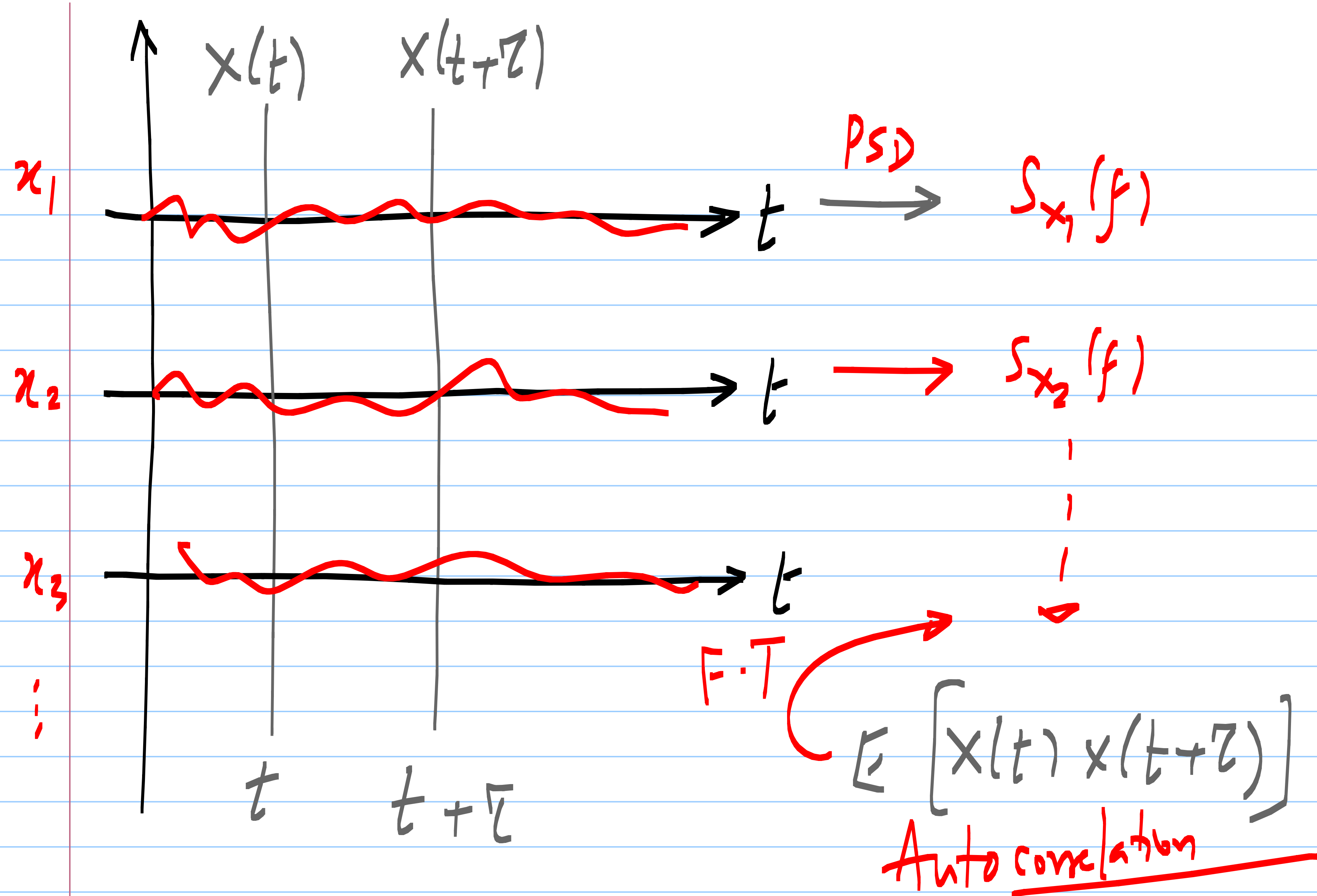
$$= Q\left(\frac{V_p}{\sigma}\right)$$

$Q(3) \simeq 10^{-3}$

$Q(6) \simeq 10^{-9}$

$Q(7) \simeq 10^{-12}$

$Q(8) \simeq 10^{-15}$

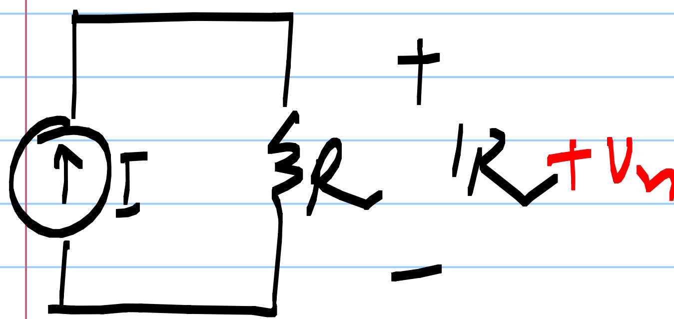

x(t)
x(t+τ)
x_1
x_2
x_3
t
t
t
t
t+τ
PSD
$S_{x_1}(f)$
$S_{x_2}(f)$
F.T
E[x(t) x(t+τ)]
Autocorrelation

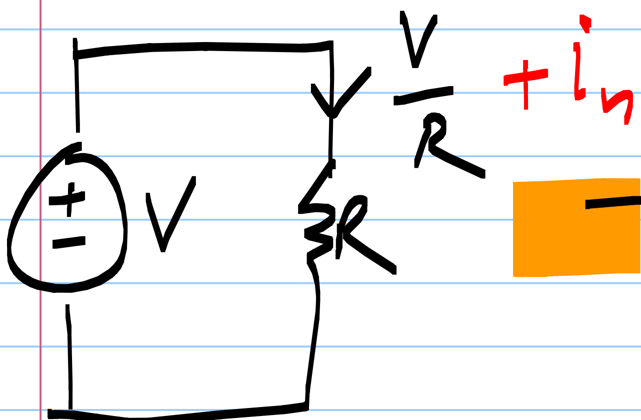
$$E[x(t)\,x(t+\tau)] = R_x(\tau) \overset{F.T}{\longleftrightarrow} S_x(f)$$

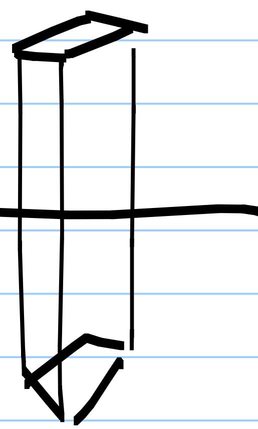
$$\sigma_x^2 = E[x^2(t)] = R_x(0) \longleftrightarrow \int_{-\infty}^{\infty} S_x(f)\,df$$

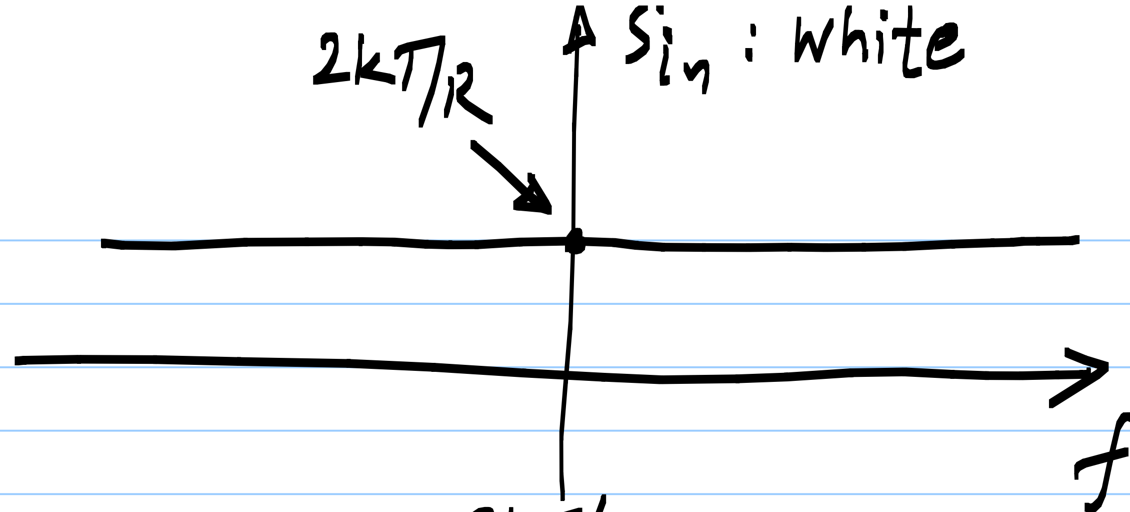
Variance

Resistor noise

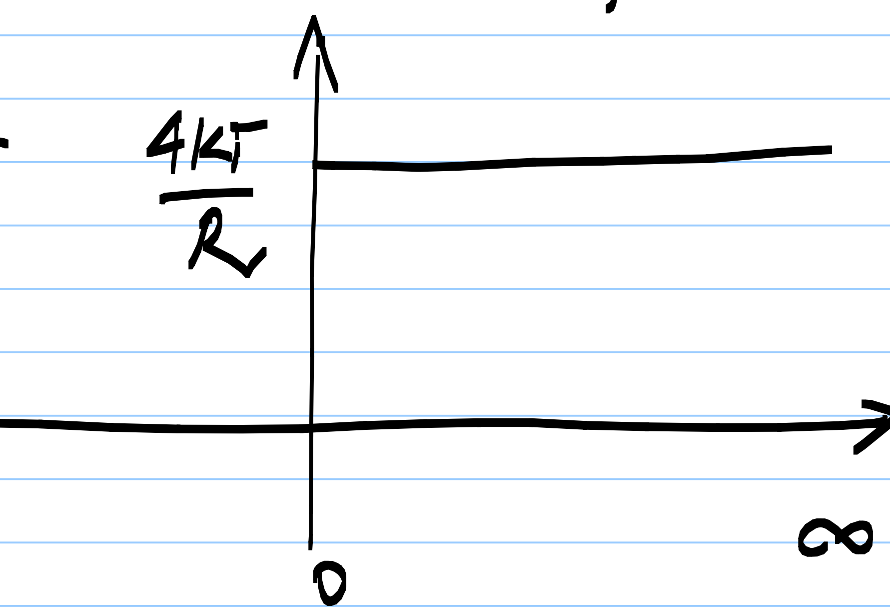








S_{i_n} : $2kT/R$ $\quad \infty \leq f \leq \infty$



S_{i_n} : $\frac{4kT}{R}$ $\quad 0 \leq f \leq \infty$

$$\frac{4}{R}$$

$kT: 4\times10^{-21}\ J$

$$\frac{1}{\exp\left(\frac{h\nu}{kT}\right) - 1}$$

$h\nu$ — Planck's constant, frequency

$\sim kT$ — Boltzmann's constant

$1.38\times10^{-23}\ J/K$

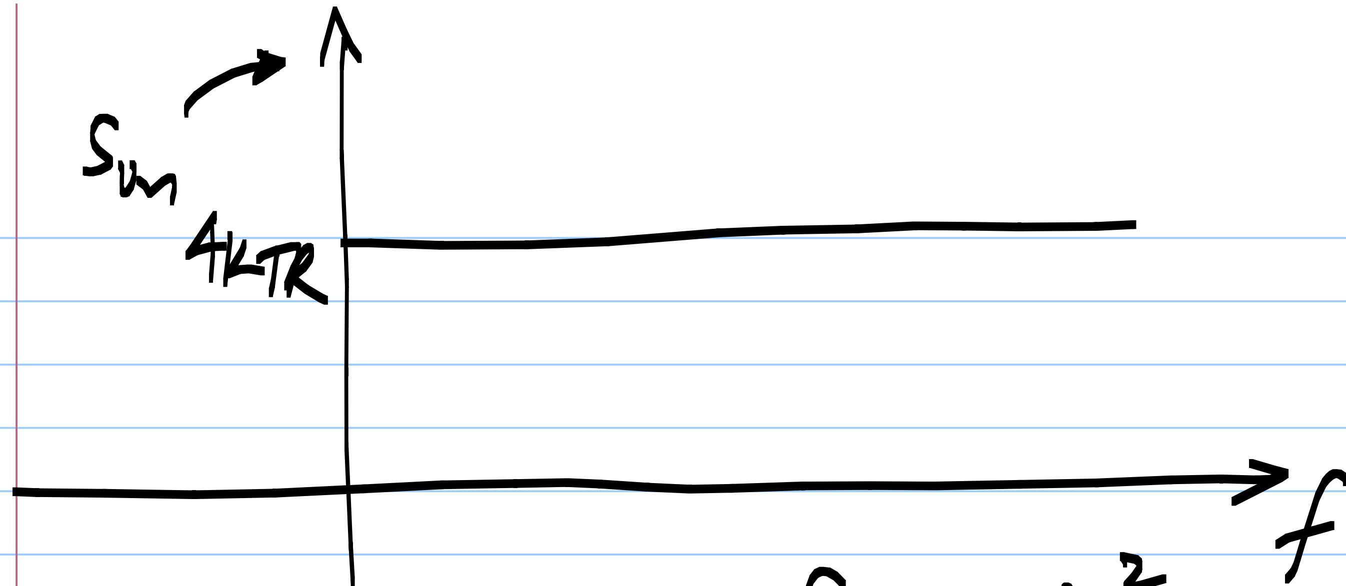
$300 K$

$h\nu \ll kT$

$$1 + \frac{h\nu}{kT}$$

$$\frac{4\times10^{-21}}{6.6\times10^{-34}} \sim 6\times10^{12}$$

6 THz



$T = 300\,K$

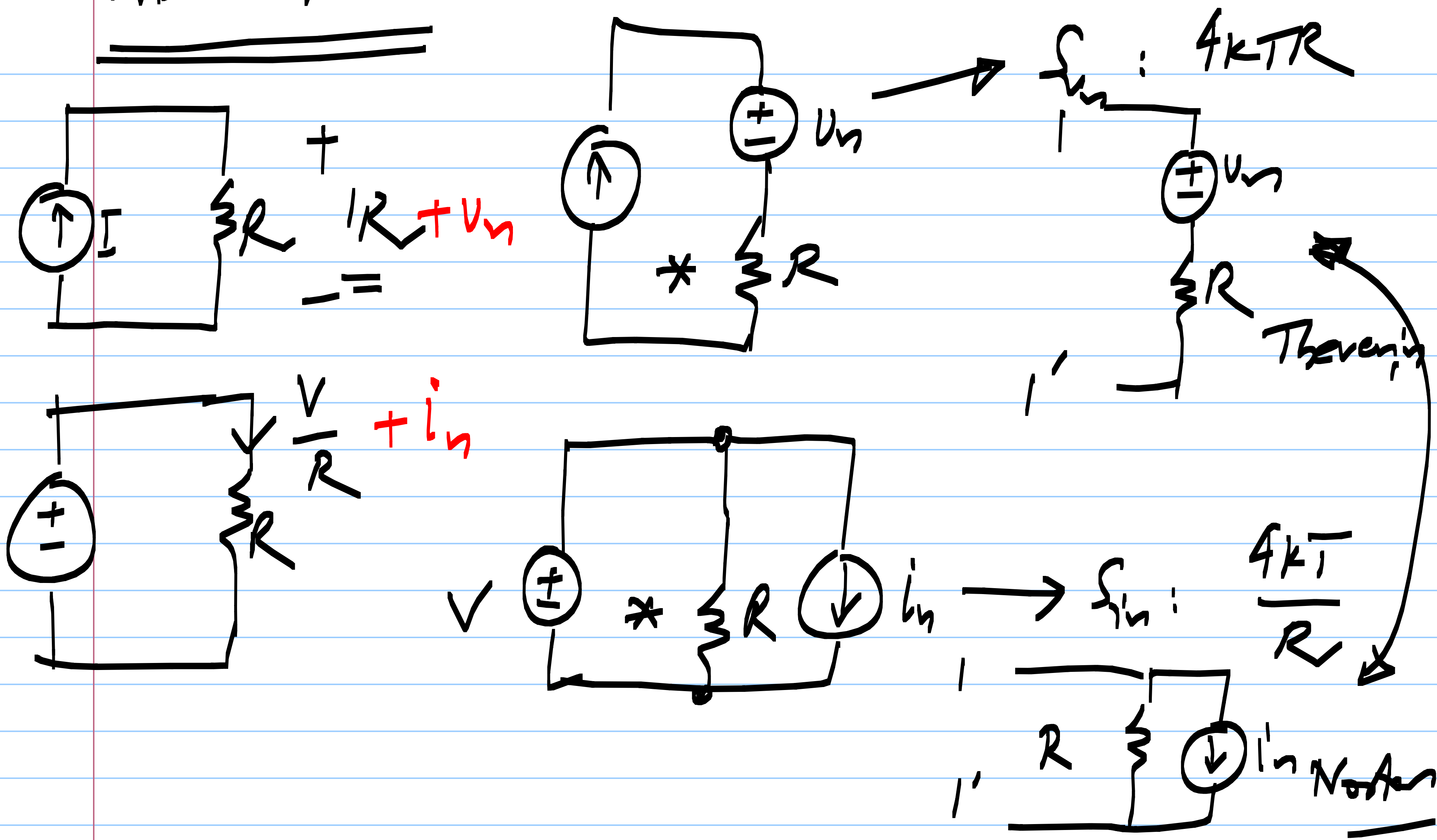
$R = 1\,k\Omega$

$S_{in}: \frac{4KT}{R} : \frac{A^2}{Hz} = \left(\frac{4\,pA}{\sqrt{Hz}}\right)^2$

$4nV/\sqrt{Hz}$

$S_{vn}: 4KTR : \frac{V^2}{Hz}$ $\left[16\times10^{-18}\,\frac{V^2}{Hz}\right]$ $\left[4\times10^{-9}\,\frac{V}{\sqrt{Hz}}\right]^2$

$$v_n = i_n \cdot R$$



$$v_n = i_n \cdot R$$

Random process

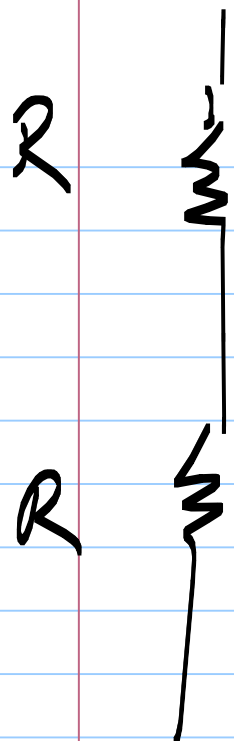
$$S_{v_n} = S_{i_n} \cdot R^2$$

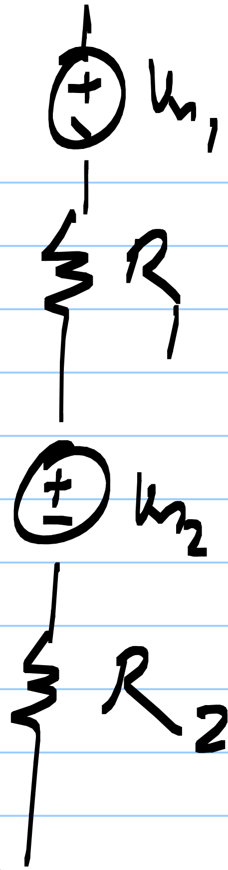
$$\sigma_{v_n}^2 = \sigma_{i_n}^2 \cdot R^2$$

$$\sigma_{v_n} = \sigma_{i_n} \cdot R$$

$$4kTR = \left(\frac{4kT}{R}\right) \cdot R^2$$

$$R_{v_n}[\tau] = R_{i_n}[\tau] \cdot R^2$$

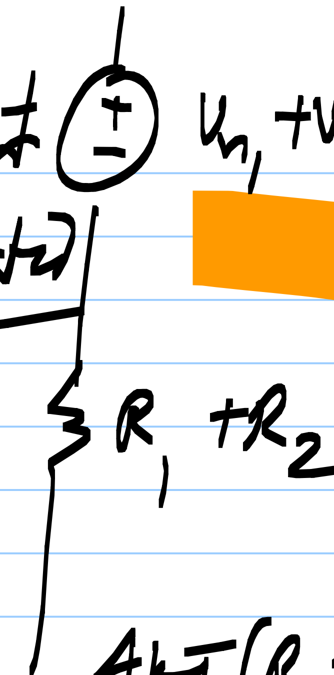




v_{n_1} : $4kTR_1$

v_{n_2} : $4kTR_2$

Noise from different resistors: uncorrelated

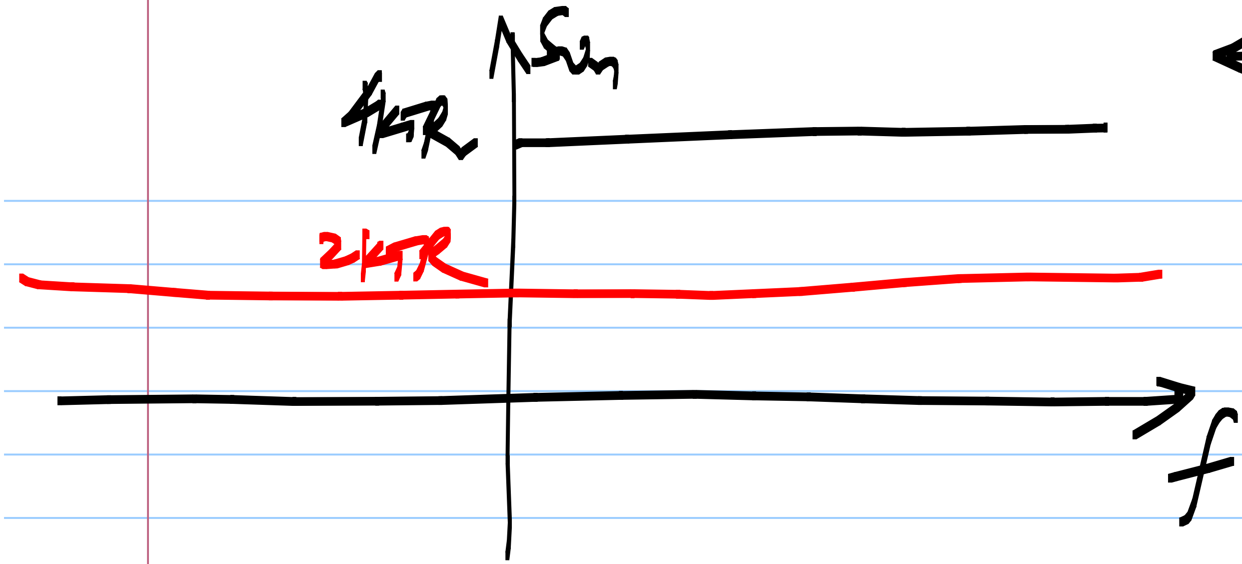


$v_{n_1} + v_{n_2}$

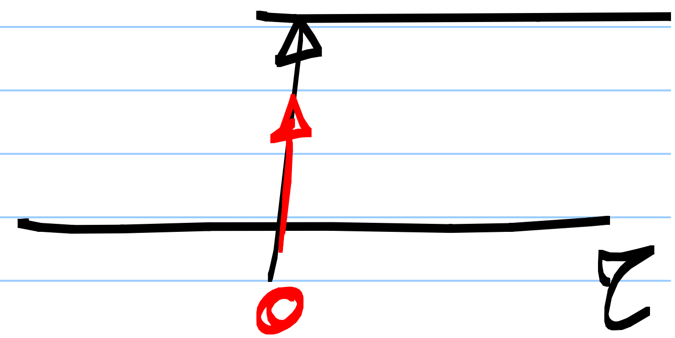
$4kT(R_1 + R_2)$

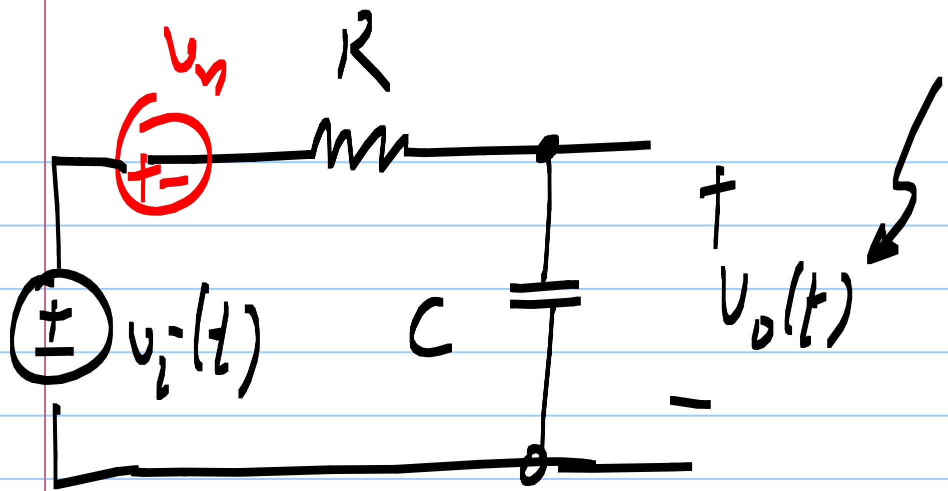
$$E[(x_1 + x_2)^2] = E[x_1^2] + E[x_2^2] + 2E[x_1 x_2]$$

Correlation



$$\longleftrightarrow R_{v_n}[\tau] = 2kTR \cdot \delta(\tau)$$





Transfer fn: $\frac{V_o}{V_n}$

$$S_{v_o} = S_{v_n} \cdot \left| \frac{V_o}{V_n} \right|^2 \xrightarrow{\int_0^\infty df} \sigma_{v_o}^2$$