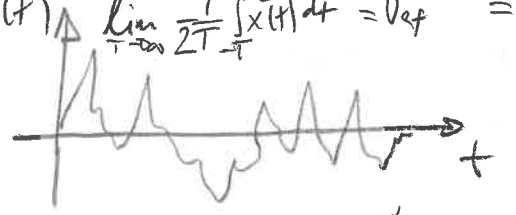
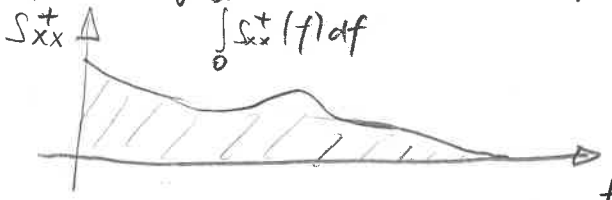
Šum

Je naključen signal.

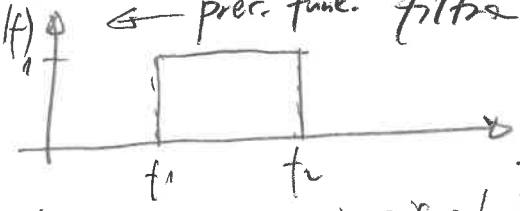


$$\lim_{T\to\infty}\frac{1}{2T}\int_{-T}^{T}x^2(t)\,dt = V_{ef}^2 =$$

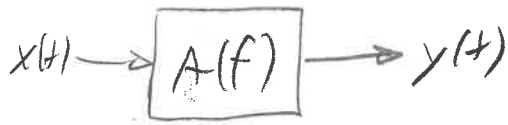
Opišemo ga z enostranskim spektrom moči:



Če tak signal pošljemo skozi idealen filter s karakteristiko:

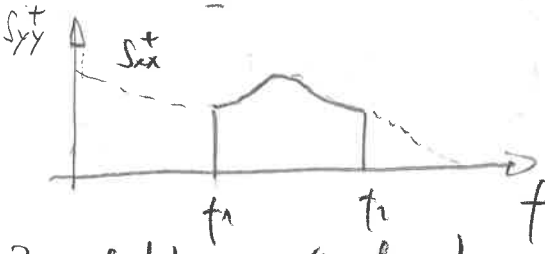


← prev. funk. filtra



dobimo nov šumni signal $y(t)$. Spektar $y(t)$ je

$$S_{yy}^+(f) = S_{xx}^+(f)\cdot|A(f)|^2$$



Spekter se preoblikuje s kvadratom ojačenja.

Z efektivno vrednostjo $y(t)$ velja

$$y_{RMS}^2 = \lim_{T\to\infty}\frac{1}{2T}\int_{-T}^{T}|y(t)|^2\,dt = \int_0^\infty S_{yy}^+(f)\,df = \int_{f_1}^{f_2} S_{xx}^+(f)\,df$$

Vrste šuma

Termični šum (Johnson-Nyquistov šum)

Naključno gibanje nosilcev naboja v prevodniku - vir se upornosti v vezju

$$S_{mnTHI}^+(f) = \frac{4hf}{R\left(e^{\frac{hf}{kT}}-1\right)}$$

Šumni ok

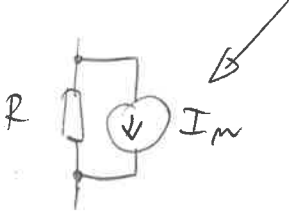
h.. Planckova konstanta $6.626\cdot10^{-34}\ m^2kg/s$

k.. Boltzmannova konstanta $1.381\cdot10^{-23}\ m^2kg/s^2K$

Pri temperaturah, pri katerih delujejo vezja je $\frac{kT}{h} \approx 2\cdot1.10^{10}\,Hz/K\cdot T \approx 6{,}3\ THz$ za $300K$

in lahko še frekvenco do ~6 THz uporabimo

$$S_{mnTHI}^+(f) = \frac{4kT}{R}\quad [A^2/Hz]$$ gostota moćnostnega spektra šumnega toka



$V_n = RI_n$

$$S_{mnTHV}^+(f) = 4kTR$$

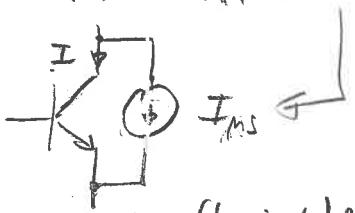
Odvisen od temperature.

Šumi Šum (shot noise)

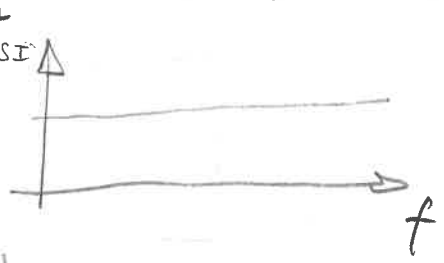
Pojavi se v polprevodnikih v katerih teče tok. Vzrok je šumnost nabojev (elektroni in vrzeli imajo končno velik naboj).

$$S^{+}_{mn\,SI}(f) = 2qI$$

q.. naboj elektrona $1.602 \cdot 10^{-19}$ As
I.. tok v polprevodniku



V prevodnikih (kovinah) ga ni.



Odvisen od toka

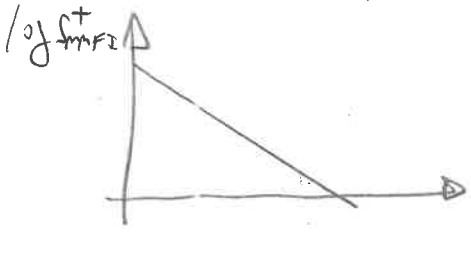
1/f Šum (flicker noise)

Diode, BJT, ogljikovi plastni upori, MOSFET, ...

$$S^{+}_{mnFI} = \frac{K_f I^{A_f}}{f}$$

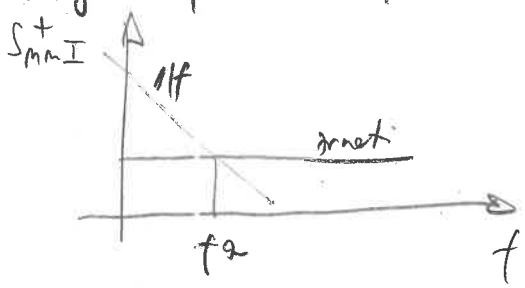
K_f, A_f .. koeficienta

Odvisen od toka



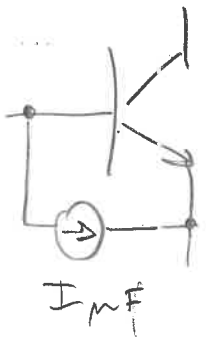
Problematičen pri nizkih frekvencah, oscilatorji - modulacija nosilca - fotni šum.

Vogalna frekvenca, ko šumni šum prevlada nad 1/f šumom.



$$f_g = \frac{K_f I^{A_f - 1}}{2q}$$

dioda, $I = 1\,mA$, $A_f = 1$
$K_f = 20 \cdot 10^{-18}\,A$
$f_g = 62\,Hz$



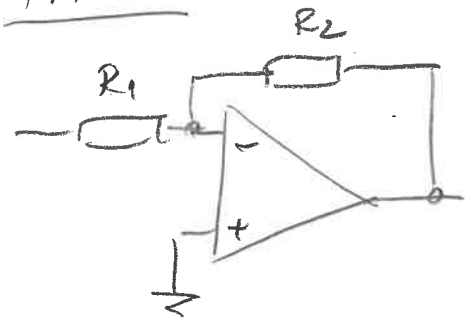
Računanje s šumom

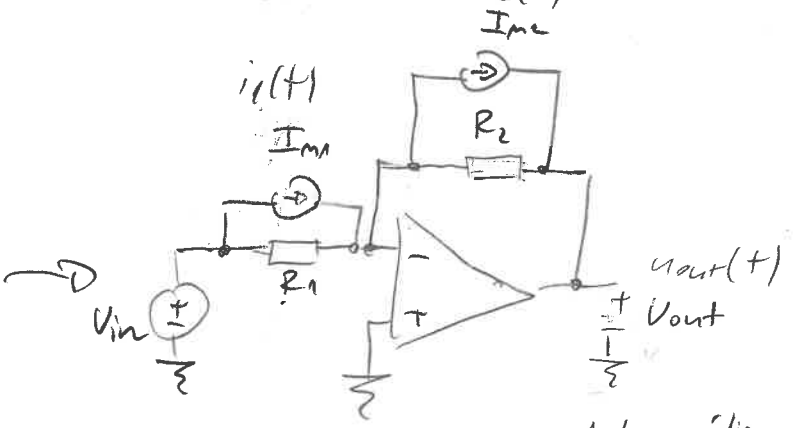
Šumni signal $x(t) = a(t) + b(t)$; spektri S_{xx}^+, S_{aa}^+, S_{bb}^+

Če sta $a(t)$ in $b(t)$ nekorelirana (običajno so šumni viri v vezjih nekorelirani), velja

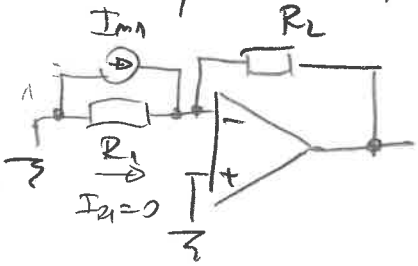
$S_{xx}^+(f) = S_{aa}^+(f) + S_{bb}^+(f)$ — seštevajo se močnostni spektri

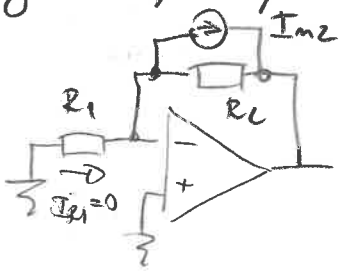
Primer:





superpozicija, šum je majhen signal – povezje je kot majhen signal





$\frac{V_{out1}}{R_2} + I_{n1} = 0$ → obj. $H(j\omega)$

$V_{out1} = -R_2 I_{n1}$

$S_{nnTHIR1}^+ = \frac{4kT}{R_1}$

$S_{nnVout1}^+ = |-R_2|^2 \cdot \frac{4kT}{R_1}$

$\frac{V_{out2}}{R_2} - I_{n2} = 0$ → obj. $H(j\omega)$

$V_{out2} = R_2 I_{n2}$

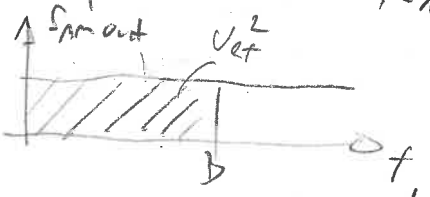
$S_{nnTHIR2}^+ = \frac{4kT}{R_2}$

$S_{nnVout2}^+ = |R_2|^2 \cdot \frac{4kT}{R_2}$

$$S_{nnVout}^+ = S_{nnVout1}^+ + S_{nnVout2}^+ = 4kTR_2^2\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = 4kTR_2\frac{R_1+R_2}{R_1}$$

300k, $R_1 = 100k\Omega$, $R_2 = 1M\Omega$

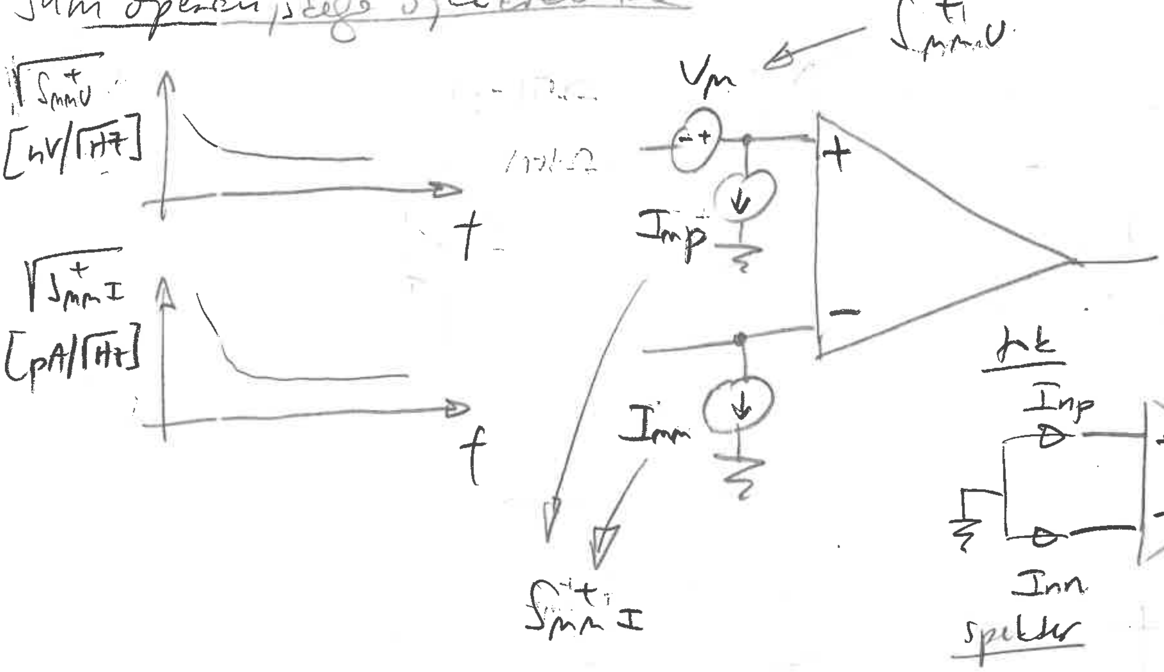
$S_{nnout}^+ = 0.18 \cdot 10^{-12}\ V^2/Hz$



Instrument s pasovno širino 1kHz bi pokazal ef. vrednost

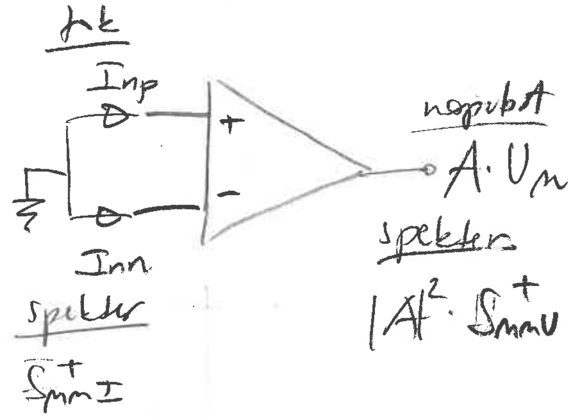
$V_{ef} = (S_{nnout}^+ \cdot B)^{1/2} = 13.5\ \mu V$ $\quad B = 100kHz \rightarrow 135\ \mu V$

Šum operacijskega ojačevalnika



MOS, JFET op.oj.

$I_{np} = I_{nn} = 0$

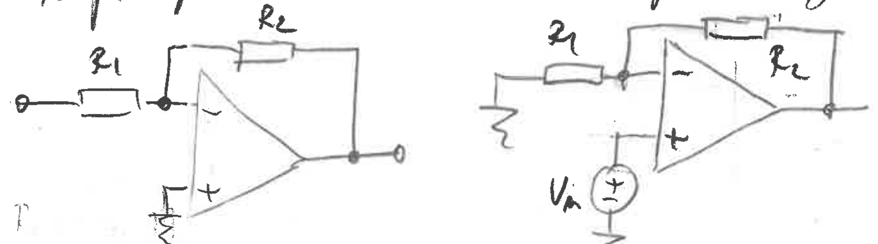


Primer:

$$\sqrt{S^{+}_{nn U}} = 100\,nV/\sqrt{Hz} \qquad S^{+}_{nn U} = 10 \cdot 10^{-15}\,V^2/Hz$$

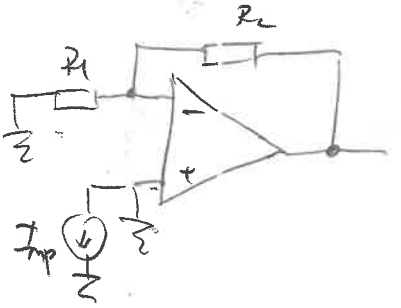
$$\sqrt{S^{+}_{nn I}} = 0.03\,pA/\sqrt{Hz} \qquad S^{+}_{nn I} = 9 \cdot 10^{-28}\,A^2/Hz$$

≈ predpostavimo konstantne spektralne gostote moči

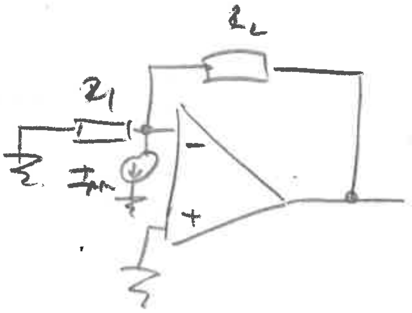


V_n se prenese kot V_{offs}

$$V_{out\,V_n} = \underbrace{\left(1 + \frac{R_2}{R_1}\right)}_{11 \to \text{oj.}} V_n$$



$V_{out\,I_{np}} = 0 \cdot I_{np}$ → oj.



$V_{out\,I_{nn}} = R_2 \, I_{nn}$ → oj.

Prispevek op.oj. k šumu:

$$S^{+}_{nn\,out\,V_n} = \left(1 + \frac{R_2}{R_1}\right)^2 S^{+}_{nn U} = 1.210 \cdot 10^{-12}\,V^2/Hz$$

$$S^{+}_{nn\,out\,I_{nn}} = R_2^2 \, S^{+}_{nn I} = 9.000 \cdot 10^{-16}\,V^2/Hz$$

$$S^{+}_{nn\,out\,oj.} = S^{+}_{nn\,out\,V_n} + S^{+}_{nn\,out\,I_{nn}} = 1.2119 \cdot 10^{-12}\,V^2/Hz$$

Z instrumentom $B = 1\,kHz$ bi namerili

$$V_{ef} = \sqrt{(S^{+}_{nn\,out\,R} + S^{+}_{nn\,out\,oj.}) \cdot B} = 37.3\,\mu V$$