Data analysis of measurements of beam stability threshhold with antidamper induced instability in the presence of octupole non-linearity, March 30, 2019

Prev. scope attenuator at 16dB

					another injection			
no octupoles	I_b mA	1.95	1.7	1.15	0.75	2.0	0.9	0.75	2.4
	δ mm	0.122	0.12	0.114	0.114	0.123	0.114	0.113	.126
	Atten Hex, 0.5dB	18	10	0C	4	10	8	4	14
	comm	small loss	25% loss	25%	50%	55%	15%	60%	30%

~~Octupoles~~ 10dB = 20units = 14Hex	I_b mA	2.1	2.7	2.8	2.4	1.7	1.6	0.75
	δ mm	0.109	.113	.114	.112	.107	.105	.094
	Atten (-10dB) Hex 0.5dB	20-10dB	20	22	20	20	20	10
	loss	70%	70%	70%	70%	70%	50%	70%

Octupoles 2A	I_b mA	1.36	0.7	2.50	1.9	1.2	0.9	2.7	1.3
	δ mm	.169	.150	.168	.167	.163	.163	.17	.163
	Atten (-6dB) Hex 0.5dB	10	2	1C	18	14	10	1C	12
	loss	70%	90%	10%	35%	10%	10%	30%	50%

Octupoles 0A	I_b mA	3.2	2.8	1.4	3.0	1.3
	δ mm	.174	.17	.168	.173	.173
	Atten -6dB	2C	28	1C	28	1C
	loss	10%	50%	60%	60%	60%

Obs.1. $I_b = 2.7$, $\delta = .17$, att = 24, 65% oct = 0

Obs.2. $I_b = 2.6$, $\delta = .169$, att = 18, 50% oct = 2A

Growth times for zero and 2 A octupole curernts are 195 and 64 turns, respectively. Beam currents are 2.7 and 2.6 mA.

$$R := \begin{pmatrix} 2.7 & 2.6 \\ 2\cdot 16+4 & 1\cdot 16+8 \\ 195 & 64 \end{pmatrix}$$

- I beam [mA]
- Attenuation [hex] 0.5 dB/bit

$\kappa_G := 0.023$

$k := 0 .. 1$

$$g_k := \kappa_G \cdot R_{0,k} \cdot 10^{-\frac{R_{1,k}}{20}\cdot 0.5}$$

$(g_k \cdot R_{2,k}) =$

1.524
0.961

Octupoles at 0 A

$$O0 := \begin{pmatrix} 3.2 & 2.8 & 1.4 & 3.0 & 1.3 \\ 0.174 & 0.17 & 0.168 & 0.173 & 0.173 \\ 2\cdot 16+12 & 2\cdot 16+8 & 1\cdot 16+12 & 2\cdot 16+8 & 1\cdot 16+12 \\ 10 & 50 & 60 & 60 & 60 \end{pmatrix}$$

I beam [mA]
σ_x [mm]
Attenuation [hex] 0.5 dB/bit
Loss [%]

Octupoles at 2 A

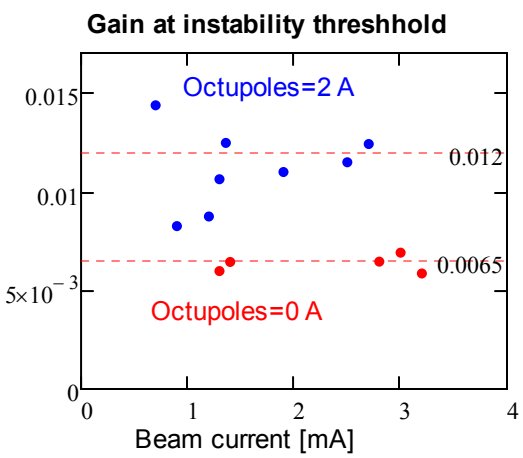
$$O2 := \begin{pmatrix} 1.36 & 0.7 & 2.5 & 1.9 & 1.2 & 0.9 & 2.7 & 1.3 \\ 0.169 & 0.15 & 0.168 & 0.167 & 0.163 & 0.163 & 0.17 & 0.163 \\ 1\cdot 16+0 & 0\cdot 16+2 & 1\cdot 16+12 & 1\cdot 16+8 & 1\cdot 16+4 & 1\cdot 16+0 & 1\cdot 16+12 & 1\cdot 16+2 \\ 70 & 90 & 10 & 35 & 10 & 10 & 30 & 50 \end{pmatrix}$$

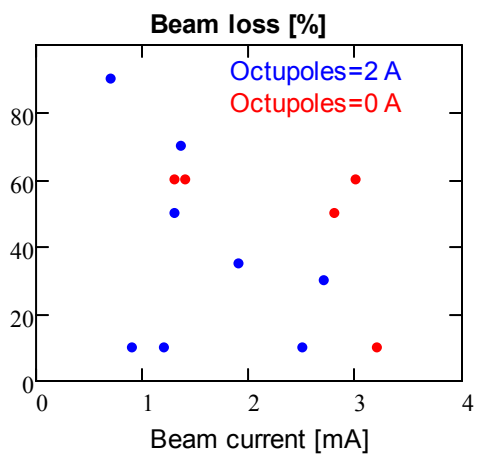
$k0 := 0 .. cols(O0) - 1$

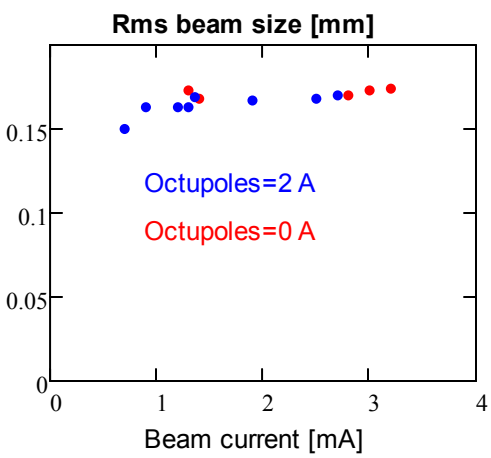
$$g0_{k0} := \kappa_G \cdot O0_{0,k0} \cdot 10^{-\frac{O0_{2,k0}}{20}\cdot 0.5}$$

$k2 := 0 .. cols(O2) - 1$

$$g2_{k2} := \kappa_G \cdot O2_{0,k2} \cdot 10^{-\frac{O2_{2,k2}}{20}\cdot 0.5}$$







$$O0 = \begin{pmatrix} 3.2 & 2.8 & 1.4 & 3 & 1.3 \\ 0.174 & 0.17 & 0.168 & 0.173 & 0.173 \\ 44 & 40 & 28 & 40 & 28 \\ 10 & 50 & 60 & 60 & 60 \end{pmatrix}$$

$$O2 = \begin{pmatrix} 1.36 & 0.7 & 2.5 & 1.9 & 1.2 & 0.9 & 2.7 & 1.3 \\ 0.169 & 0.15 & 0.168 & 0.167 & 0.163 & 0.163 & 0.17 & 0.163 \\ 16 & 2 & 28 & 24 & 20 & 16 & 28 & 18 \\ 70 & 90 & 10 & 35 & 10 & 10 & 30 & 50 \end{pmatrix}$$

Analysis of instability induced by the antidamper

$M0 :=$ ...\tek0001ALL.csv

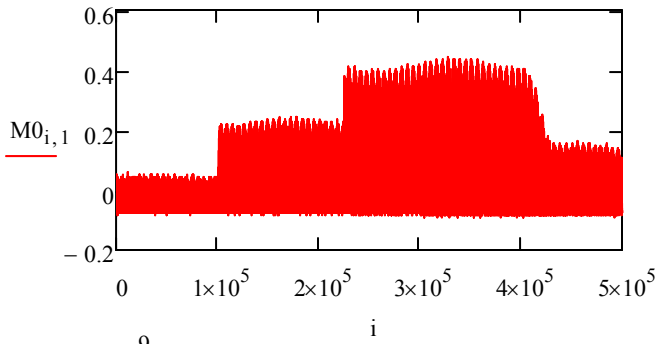
$Nd := rows(M0)$

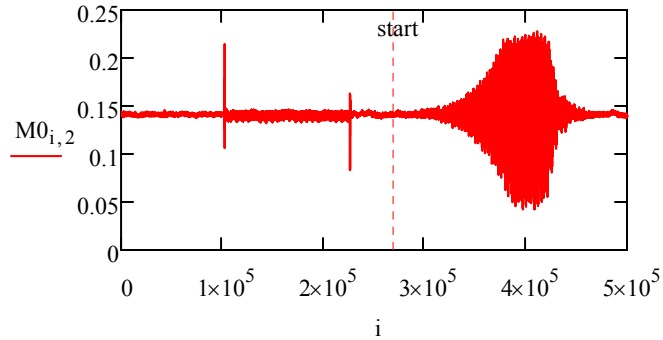
$start := 270000$

$i := 20, 40 .. \frac{Nd}{2}$

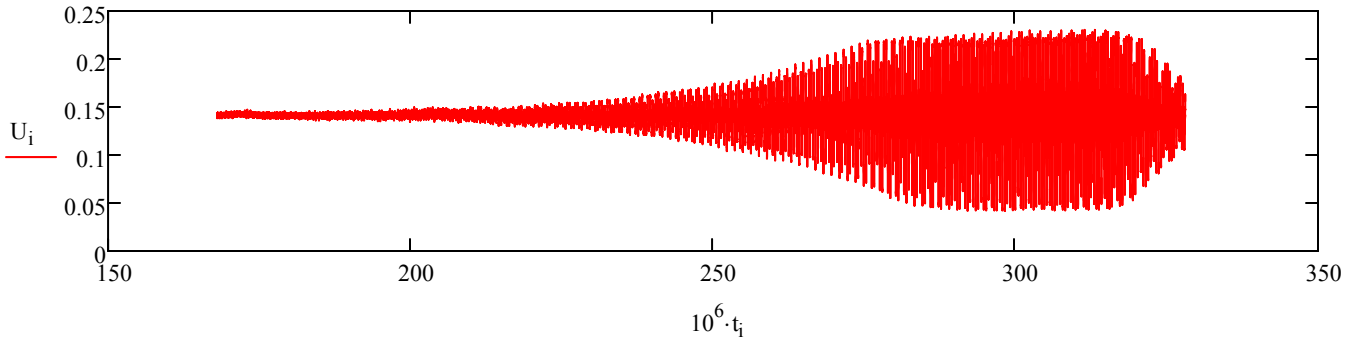
$Nd = 1 \times 10^6$

$\frac{M0_{1020,0} - M0_{20,0}}{1000} \cdot 10^9 = 1$ ns



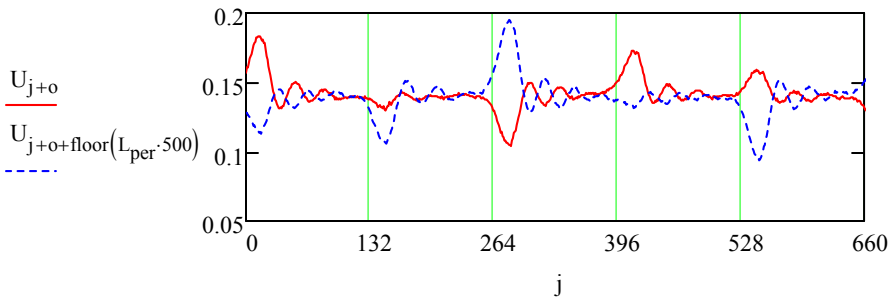


$\Delta t := 1 \cdot 10^{-9}$ s $\quad ofs := start \quad i := 0 .. 160000 \quad t_i := M0_{ofs+i,0} \quad U_i := M0_{ofs+i,2}$



$L_{per} := 133.18 \quad o := 90193 \quad j := 0 .. 1000 \quad \frac{o}{L_{per}} = 677.226 \quad f_0 := \frac{1}{\Delta t \cdot L_{per}} = 7.509 \times 10^6$

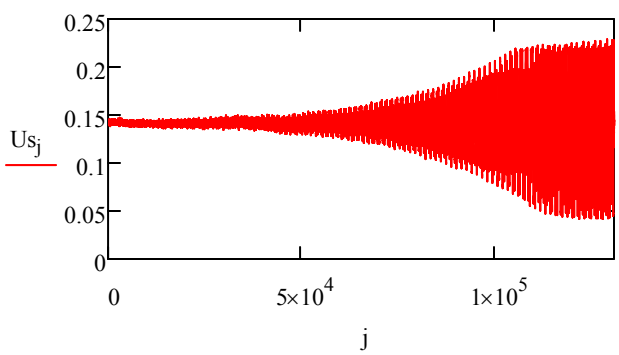
$f_0 \cdot 10^{-6} = 7.509$ MHz

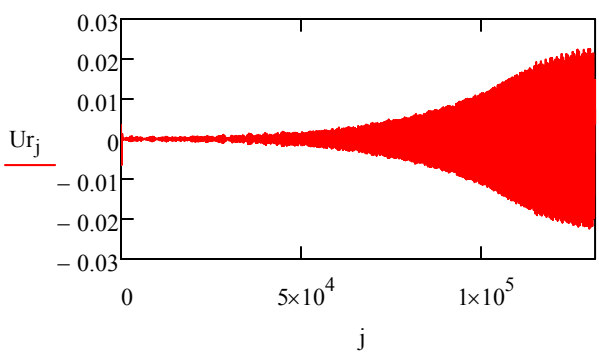


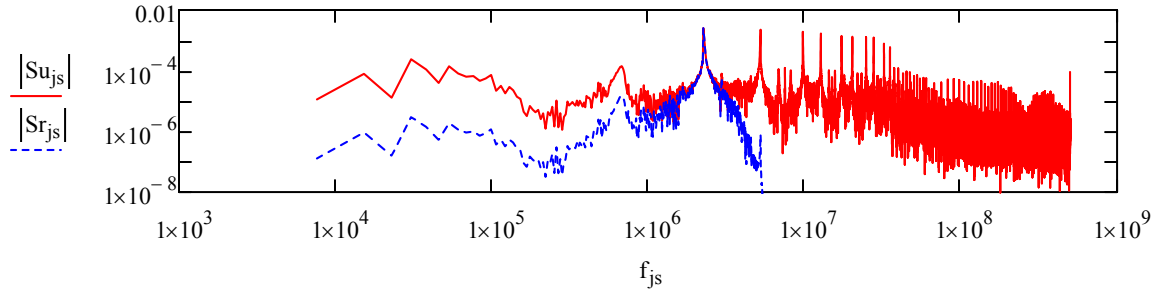
$Ns := 128 \cdot 1024 \quad j := 0 .. Ns - 1 \quad Us_j := U_{j+2000} \quad js := 0 .. \frac{Ns}{2} \quad \Delta f := \frac{1}{\Delta t \cdot Ns}$

$\nu := 0.3002 \quad \sigma_f := f_0 \cdot 0.1 \quad Su := FFT(Us) \quad Su_0 := 0 \quad f_{js} := js \cdot \Delta f \quad f_\beta := \nu \cdot f_0 \quad Sr_{js} := Su_{js} \cdot \exp\left[-\frac{(f_{js} - f_\beta)^2}{2 \cdot \sigma_f^2}\right]$

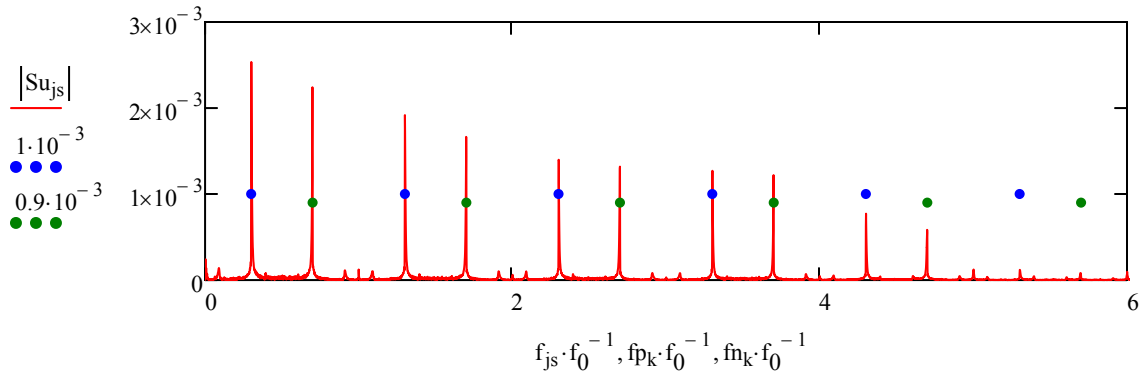
$Ur := IFFT(Sr)$

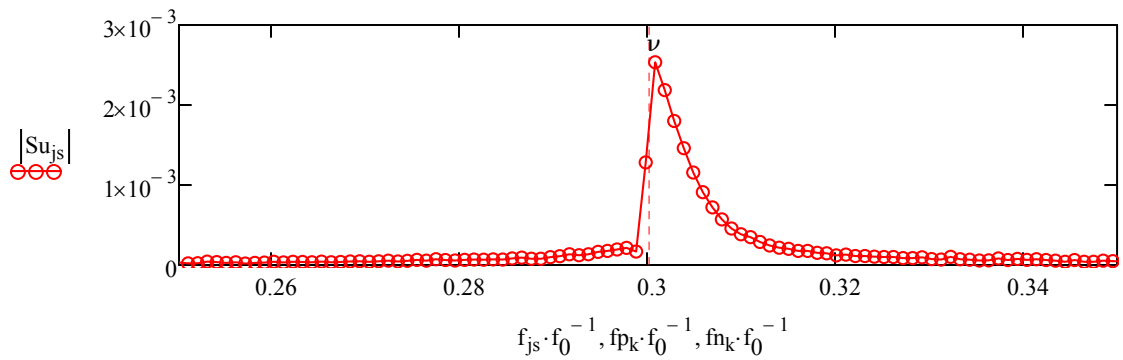




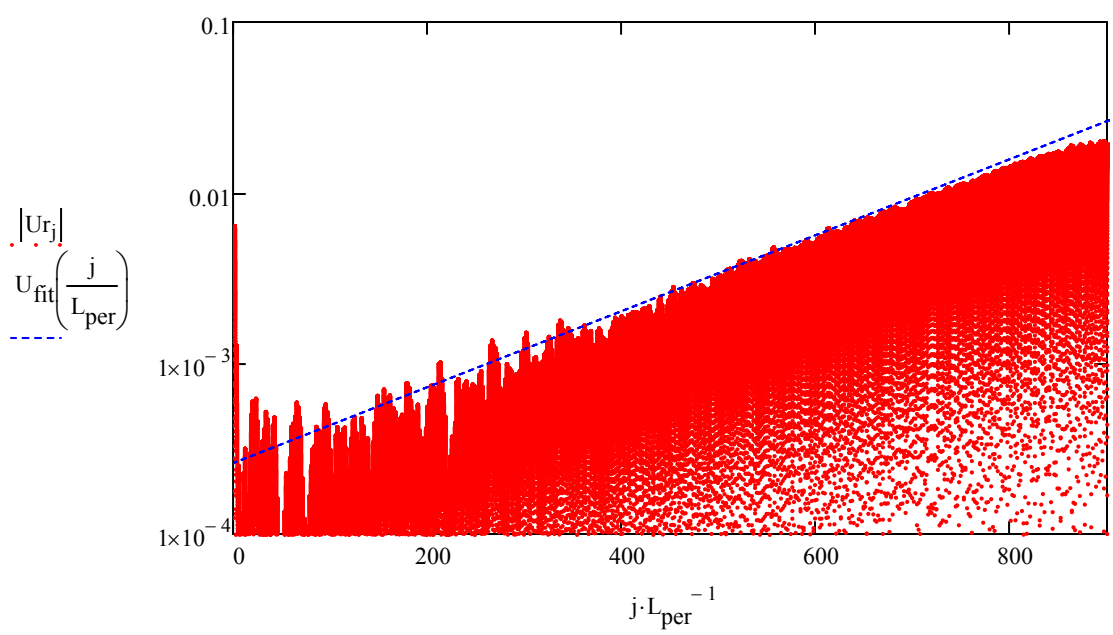


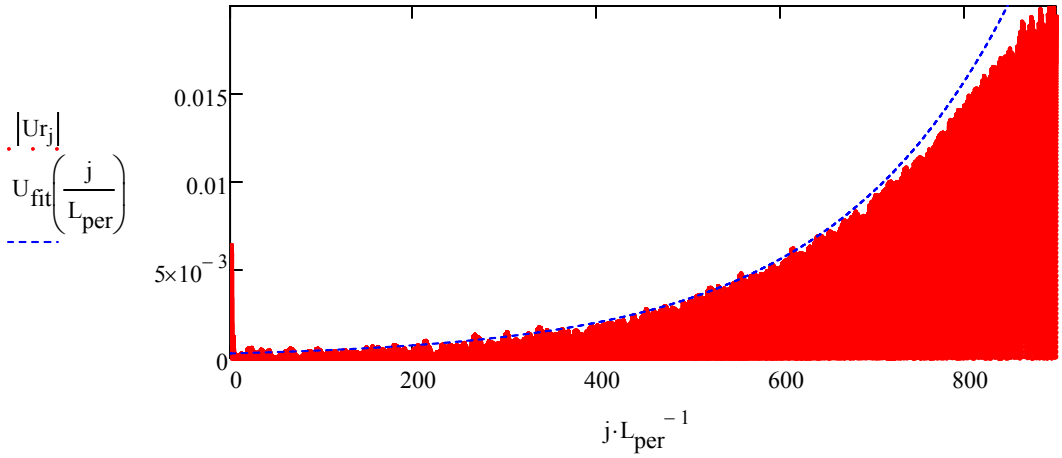
$k := 0 .. 10$ $\quad fp_k := f_0 \cdot (\nu + k)$ $\quad fn_k := f_0 \cdot (k - \nu + 1)$

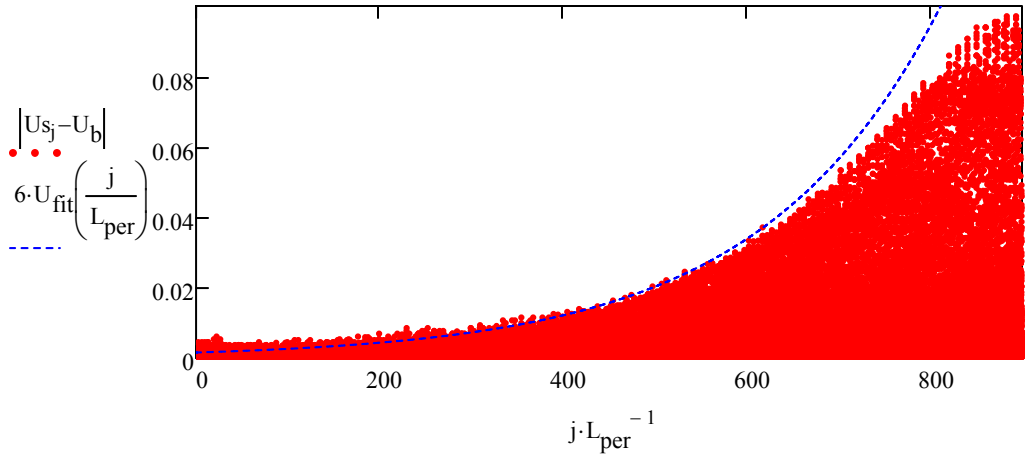


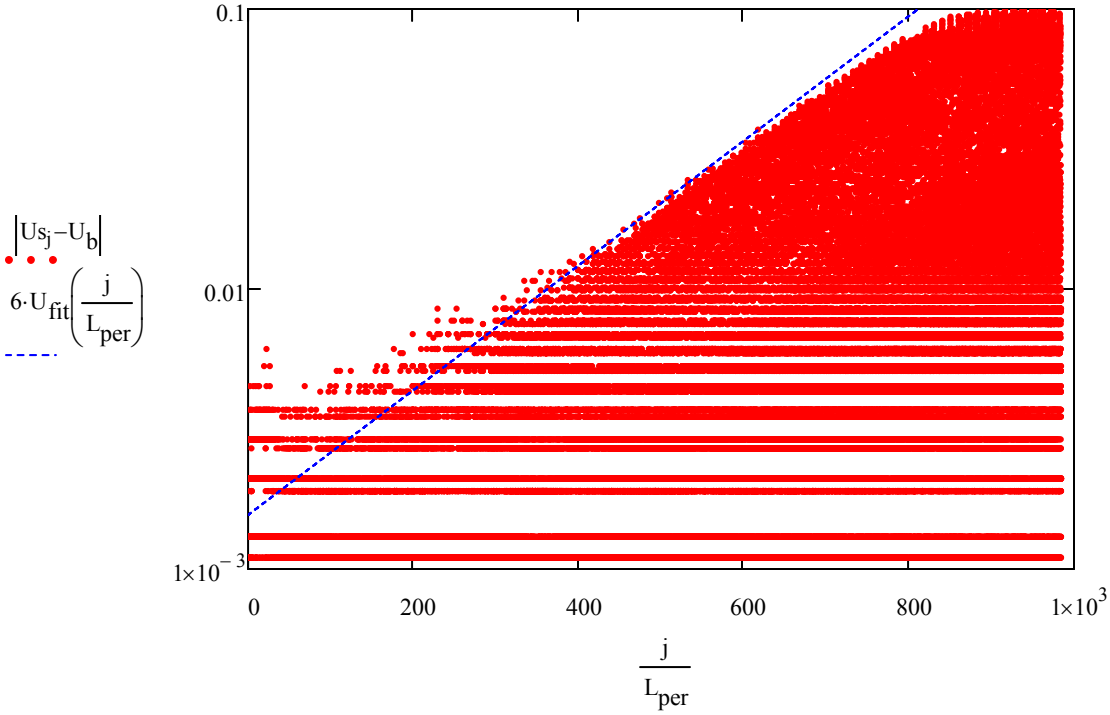


$n_{inst} := 195$ $\quad U_{fit}(n) := 0.00026 \cdot \exp\left(\frac{n}{n_{inst}}\right)$ $\quad U_b := \frac{1}{Ns} \cdot \left(\sum_j Us_j\right)$ $\quad U_b = 0.141$

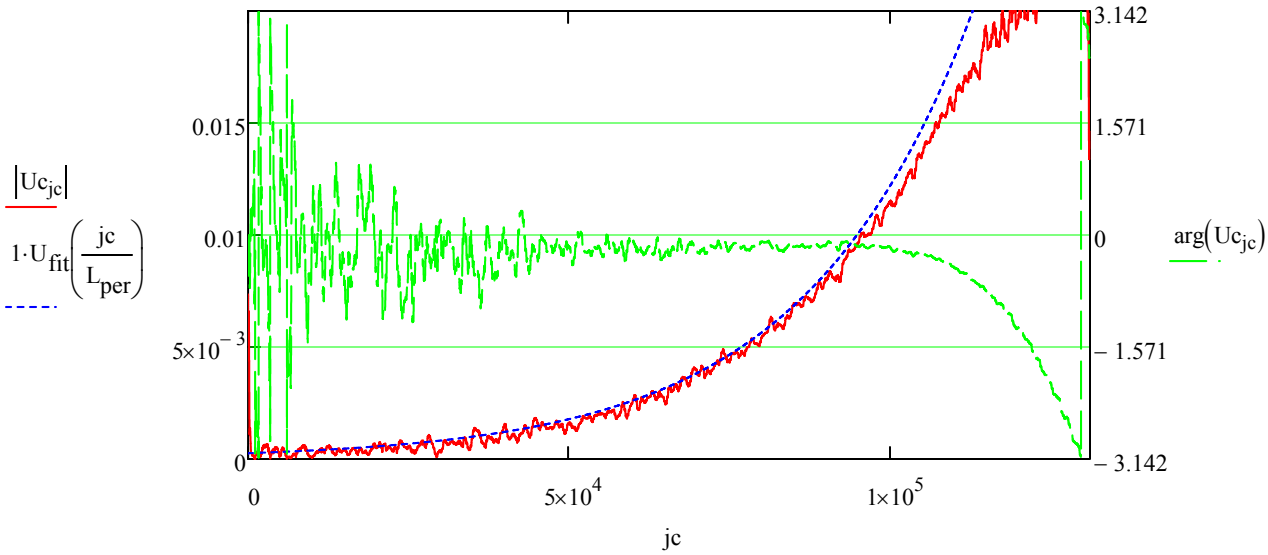



$|Ur_j|$
$U_{fit}\left(\frac{j}{L_{per}}\right)$
0.015
0.01
5×10^{-3}
0
0
200
400
600
800
$j\cdot L_{per}^{-1}$


$|Us_j - U_b|$
$6\cdot U_{fit}\left(\frac{j}{L_{per}}\right)$
0.08
0.06
0.04
0.02
0
0
200
400
600
800
$j\cdot L_{per}^{-1}$

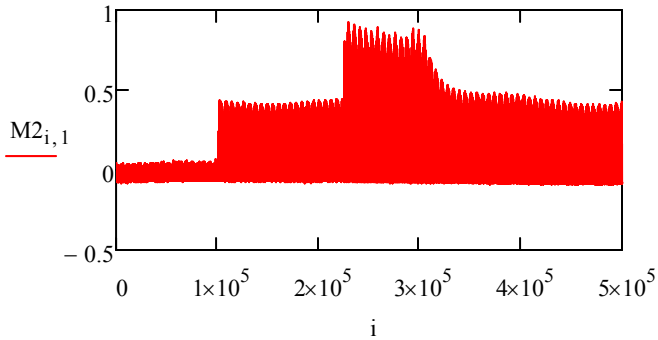

$|Us_j - U_b|$
$6\cdot U_{fit}\left(\frac{j}{L_{per}}\right)$
0.1
0.01
1×10^{-3}
0
200
400
600
800
1×10^{3}
$\frac{j}{L_{per}}$

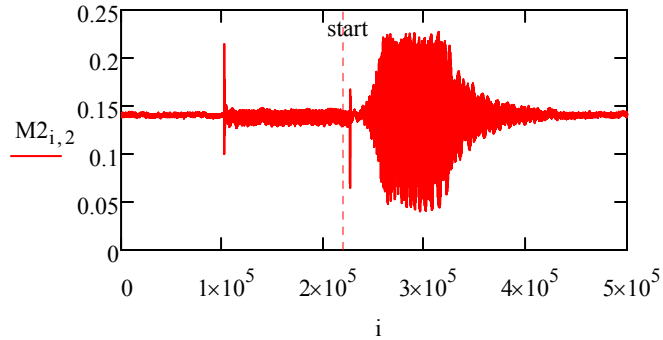
$\nu := 0.3002$ $\quad jc := 0 .. Ns - 1 - 111 \quad Uc_{jc} := \left(Ur_{jc} + i \cdot Ur_{jc+111}\right) \cdot \exp\left(2i \cdot \pi \cdot f_0 \cdot \nu \cdot \Delta t \cdot jc + i \cdot 1\right) \quad \frac{L_{per}}{\nu} = 443.638$



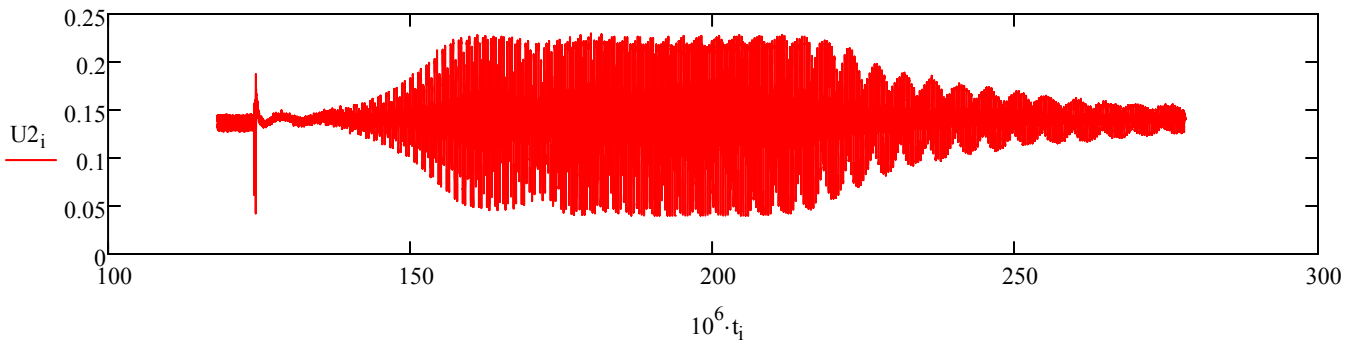
$M2 :=$ ...\tek0002ALL.csv $\quad Nd := \mathrm{rows}(M0) \quad i := 20, 40 .. \frac{Nd}{2} \quad Nd = 1 \times 10^6$

$start := 220000 \quad \frac{M0_{1020,0} - M0_{20,0}}{1000} \cdot 10^9 = 1$ ns





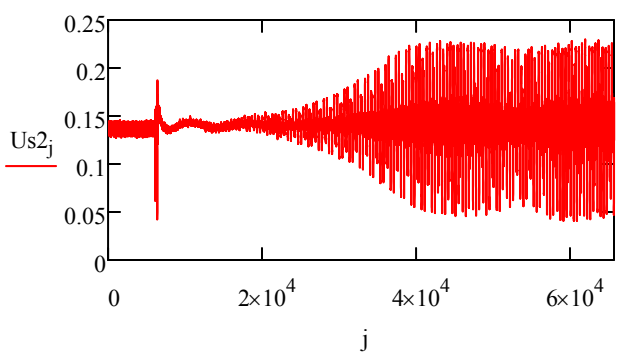
$ofs := start \quad i := 0 .. 160000 \quad t_i := M2_{ofs+i,0} \quad U2_i := M2_{ofs+i,2}$

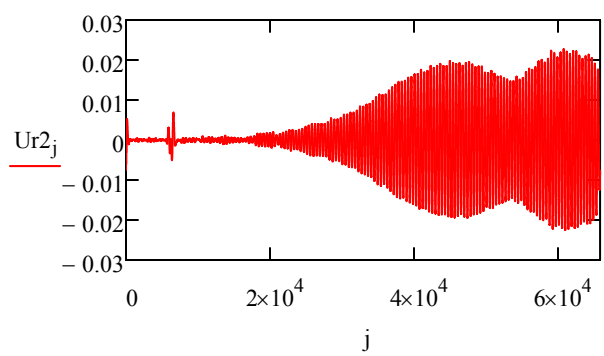


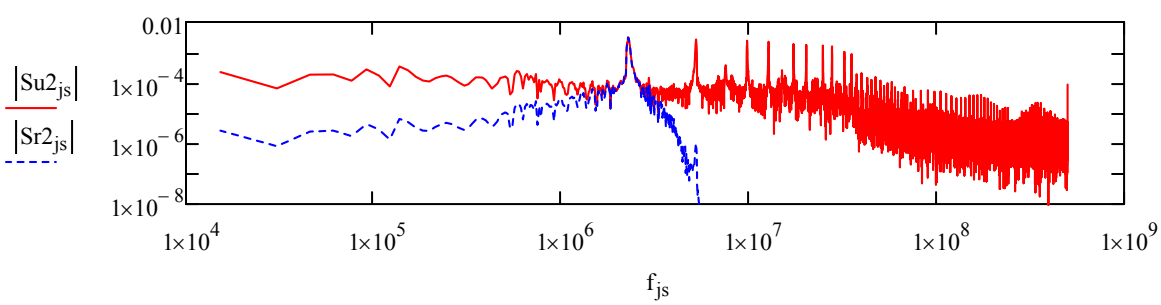
$Ns2 := 64 \cdot 1024 \quad j := 0 .. Ns2 - 1 \quad Us2_j := U2_{j+000} \quad js := 0 .. \frac{Ns2}{2} \quad \Delta f2 := \frac{1}{\Delta t \cdot Ns2}$

$\nu := 0.3002 \quad Su2 := \mathrm{FFT}(Us2) \quad Su2_0 := 0 \quad f_{js} := js \cdot \Delta f2 \quad f_\beta := \nu \cdot f_0 \quad Sr2_{js} := Su2_{js} \cdot \exp\left[-\frac{(f_{js} - f_\beta)^2}{2 \cdot \sigma_f^2}\right]$

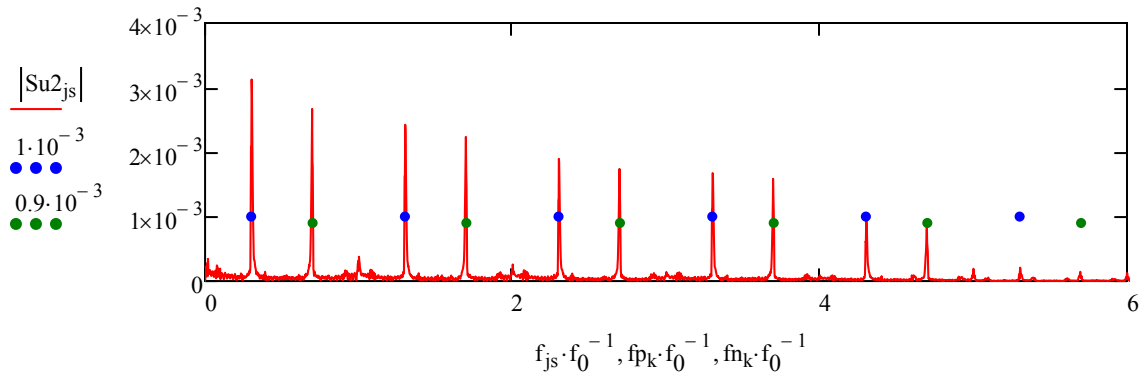
$Ur2 := \mathrm{IFFT}(Sr2)$



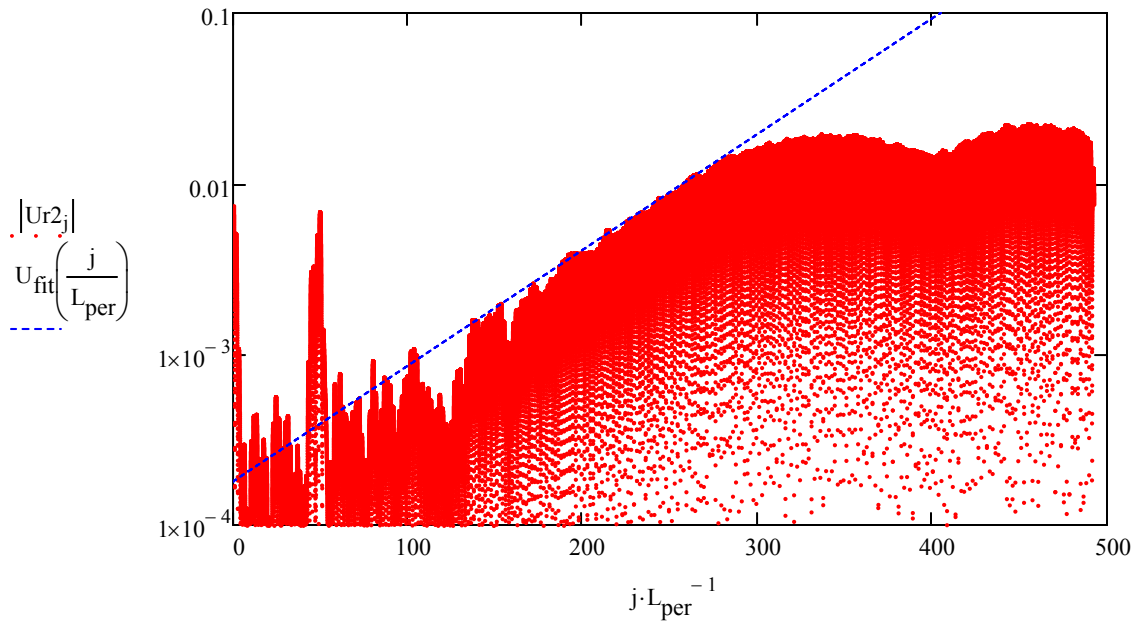


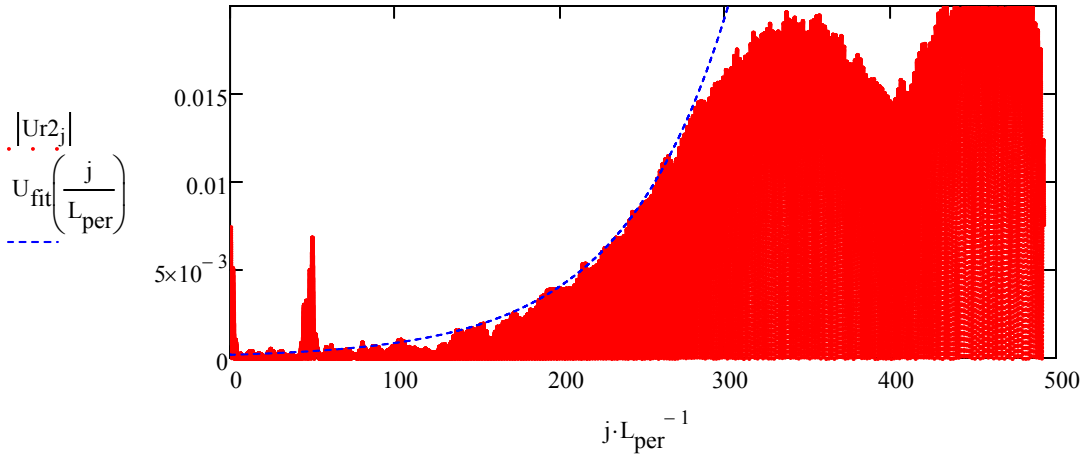


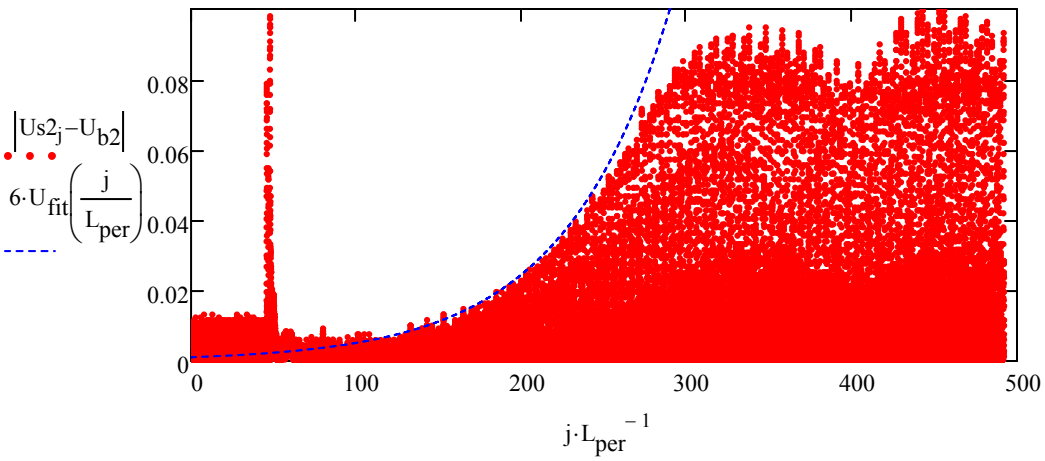
$k := 0 .. 10 \quad fp_k := f_0 \cdot (\nu + k) \quad fn_k := f_0 \cdot (k - \nu + 1)$

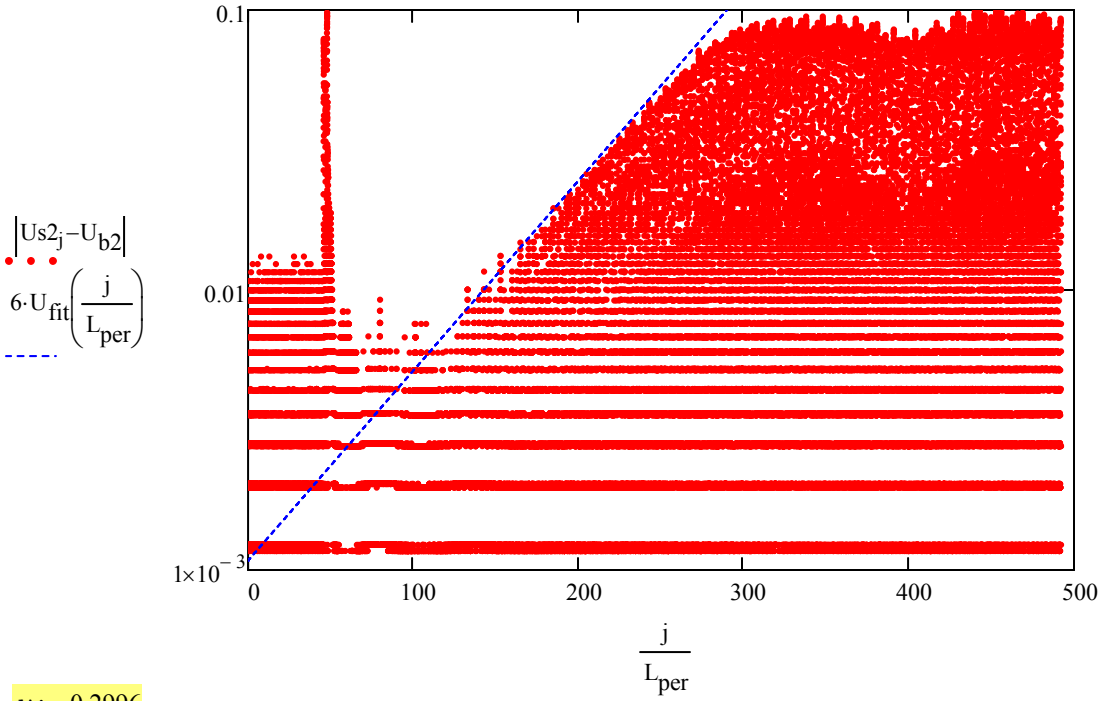


$n_{inst} := 64$ $\quad U_{fit}(n) := 0.00018\cdot\exp\left(\frac{n}{n_{inst}}\right)$ $\quad U_{b2} := \frac{1}{Ns2}\cdot\left(\sum_j Us2_j\right)$ $\quad U_{b2} = 0.14$

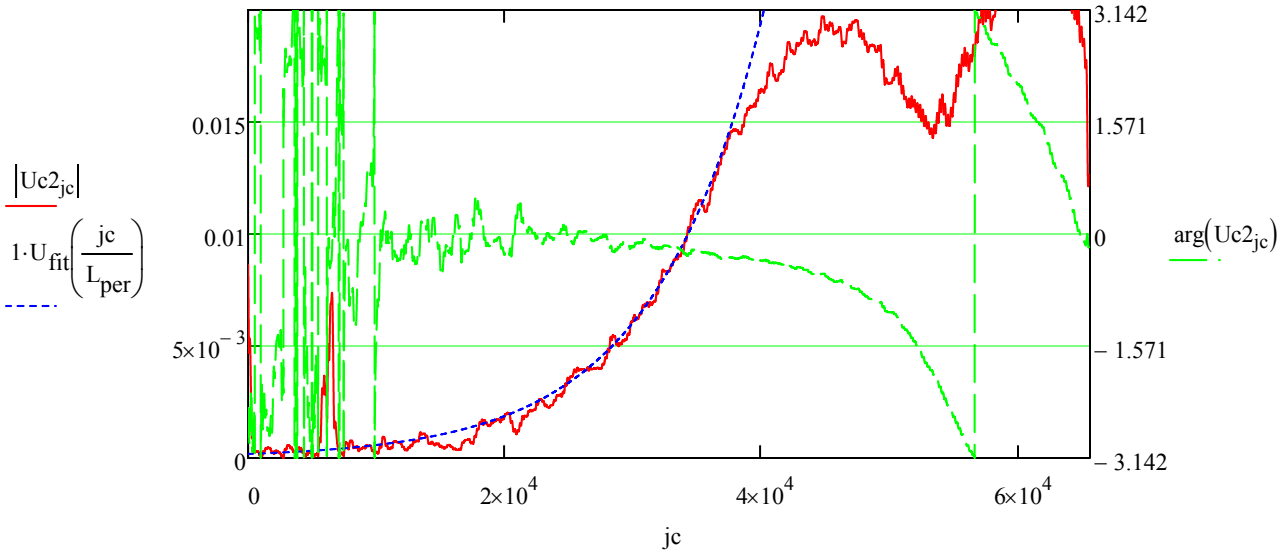








$\nu := 0.2996$ $\quad jc := 0 .. Ns2 - 1 - 111 \quad Uc2_{jc} := \left(Ur2_{jc} + i \cdot Ur2_{jc+111}\right) \cdot \exp\left(2i \cdot \pi \cdot f_0 \cdot \nu \cdot \Delta t \cdot jc + i \cdot 1.2\right) \quad \frac{L_{per}}{\nu} = 444.526$



Instability simulations

Generate initial distribution: $\sigma_0 := .08\cdot 8$ $\quad x_o := .0001$

$N_p := 1000$ $\quad n := 0 .. N_p - 1$ $\quad x0 := \mathrm{rnorm}(N_p, 0, \sigma_0) + x_o$ $\quad p0 := \mathrm{rnorm}(N_p, 0, \sigma_0)$

Betatron tune and it dependence on action

$\mu_0 := 2\cdot\pi\cdot 0.3$ $\quad d\mu dI := 0.005$ $\quad Apert := 3$

Feedback parameters

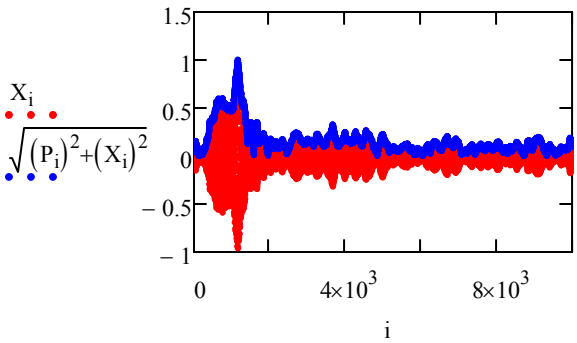
$g := -0.01$ $\quad \sigma_{bpm} := 0.01$ $\quad N_{turn} := 10000$

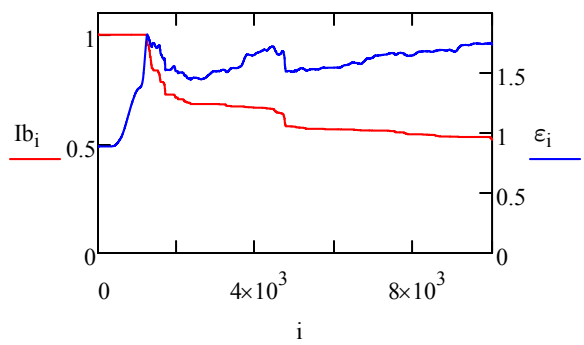
$i := 0 .. N_{turn} - 1$

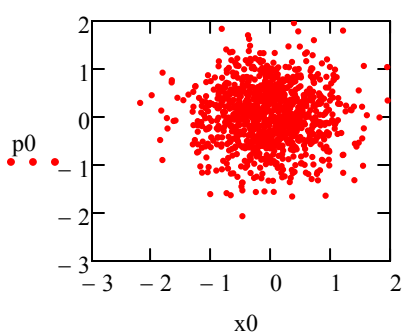
$r := \mathrm{Iter}(N_p, x0, p0)$

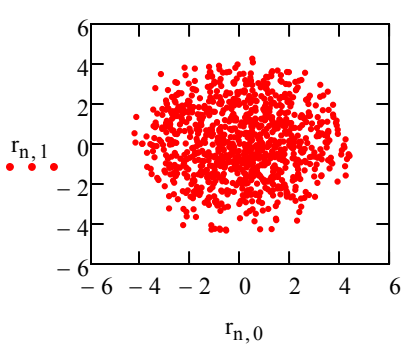
$X_i := r_{i+N_p, 0}$ $\quad P_i := r_{i+N_p, 1}$

$Ib_i := r_{i+N_p, 2}$ $\quad \varepsilon_i := r_{i+N_p, 3}$









$\mathrm{Iter}(N_p, x0, p0) :=$

$x \leftarrow x0$

$p \leftarrow p0$

for $n \in 0 .. N_p - 1$

$\quad \rho_n \leftarrow 1$

for $i \in 0 .. N_{turn} - 1$

$$P_i \leftarrow \frac{1}{N_p}\cdot\sum_{n=0}^{N_p-1}(p_n\cdot\rho_n)$$

$$X_i \leftarrow \frac{1}{N_p}\cdot\sum_{n=0}^{N_p-1}(x_n\cdot\rho_n)$$

$$Ib_i \leftarrow \frac{1}{N_p}\cdot\sum_{n=0}^{N_p-1}\rho_n$$

$$\varepsilon_i \leftarrow \sqrt{\frac{1}{N_p\cdot Ib_i}\cdot\sum_{n=0}^{N_p-1}\left[\left[(x_n - X_i)^2 + (p_n - P_i)^2\right]\cdot\rho_n\right]}$$

$\delta p \leftarrow g\cdot P_i$

$\Delta p \leftarrow \mathrm{rnorm}(1, 0, \sigma_{bpm})_0$

for $n \in 0 .. N_p - 1$

$\quad p_n \leftarrow p_n - \delta p + \Delta p$

$\quad \delta\mu_n \leftarrow d\mu dI\cdot\left[(x_n)^2 + (p_n)^2\right]$

$\quad c_n \leftarrow \cos(\mu_0 + \delta\mu_n)$

$\quad s_n \leftarrow \sin(\mu_0 + \delta\mu_n)$

$\quad xt_n \leftarrow x_n\cdot c_n + p_n\cdot s_n$

$\quad p_n \leftarrow -x_n\cdot s_n + p_n\cdot c_n$

$\quad x_n \leftarrow xt_n$

$\quad \rho_n \leftarrow 0$ if $x_n > Apert$

$r1 \leftarrow \mathrm{augment}(x, p, \rho, \rho)$

$r2 \leftarrow \mathrm{augment}(X, P, Ib, \varepsilon)$

$r \leftarrow \mathrm{stack}(r1, r2)$

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