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Temporal Characteristics of CSR Emitted in Storage Rings – Observations and a Simple Theoretical Model

P. Kuske, BESSY

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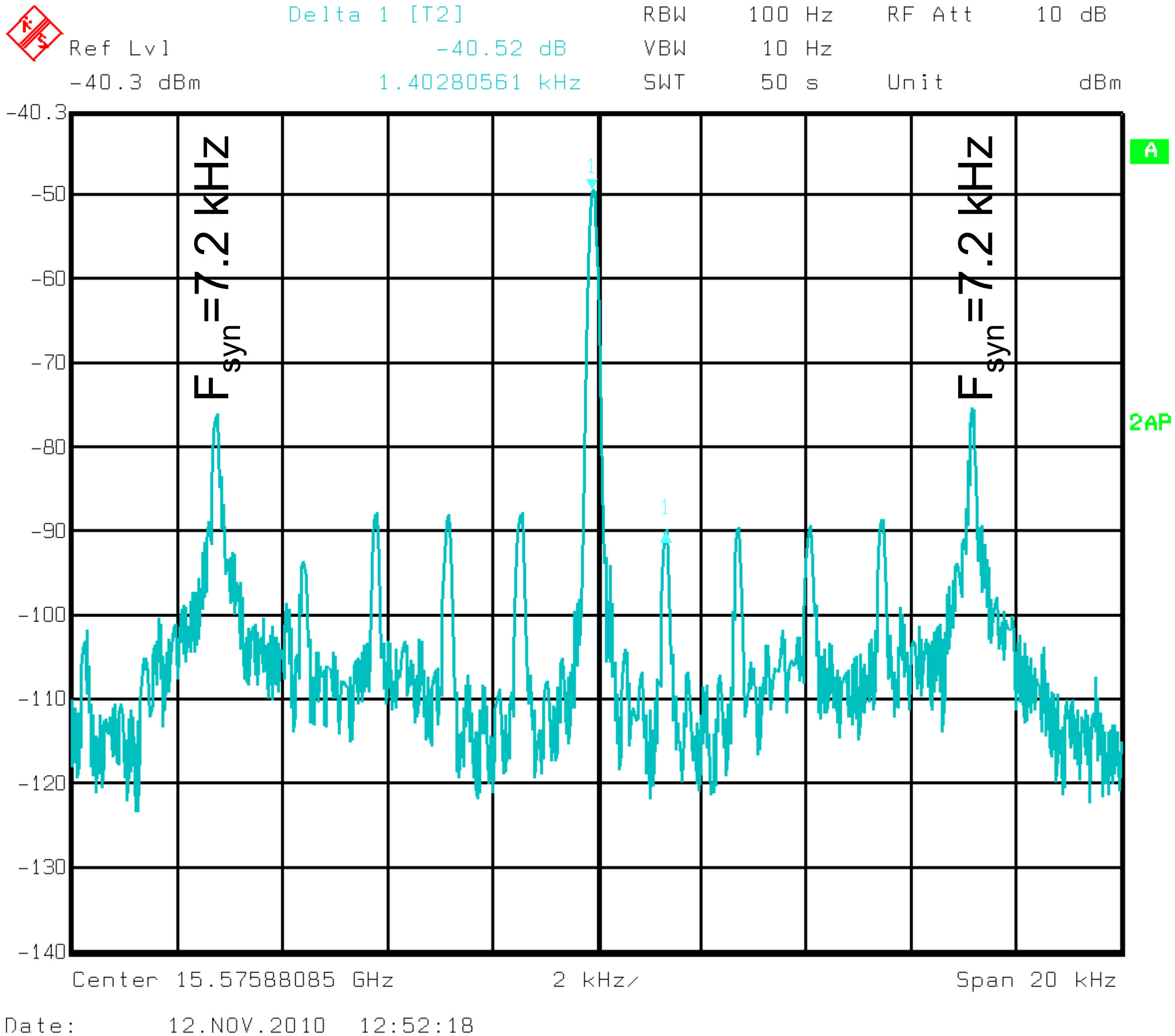

Pick-up signal of a single bunch with 8 mA observed at 15.6 GHz

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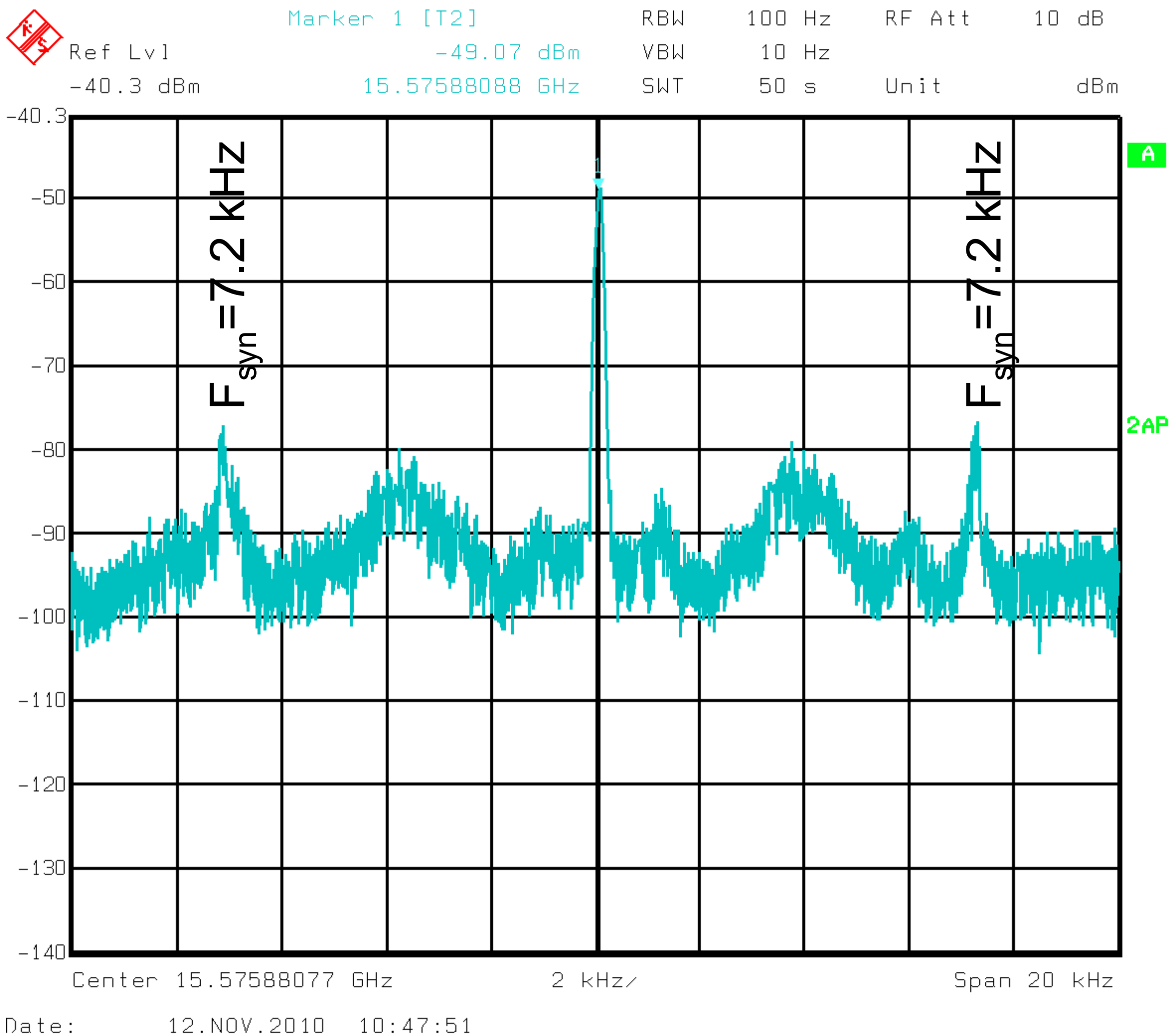

Pick-up signal of a single bunch with 15.7 mA observed at 15.6 GHz

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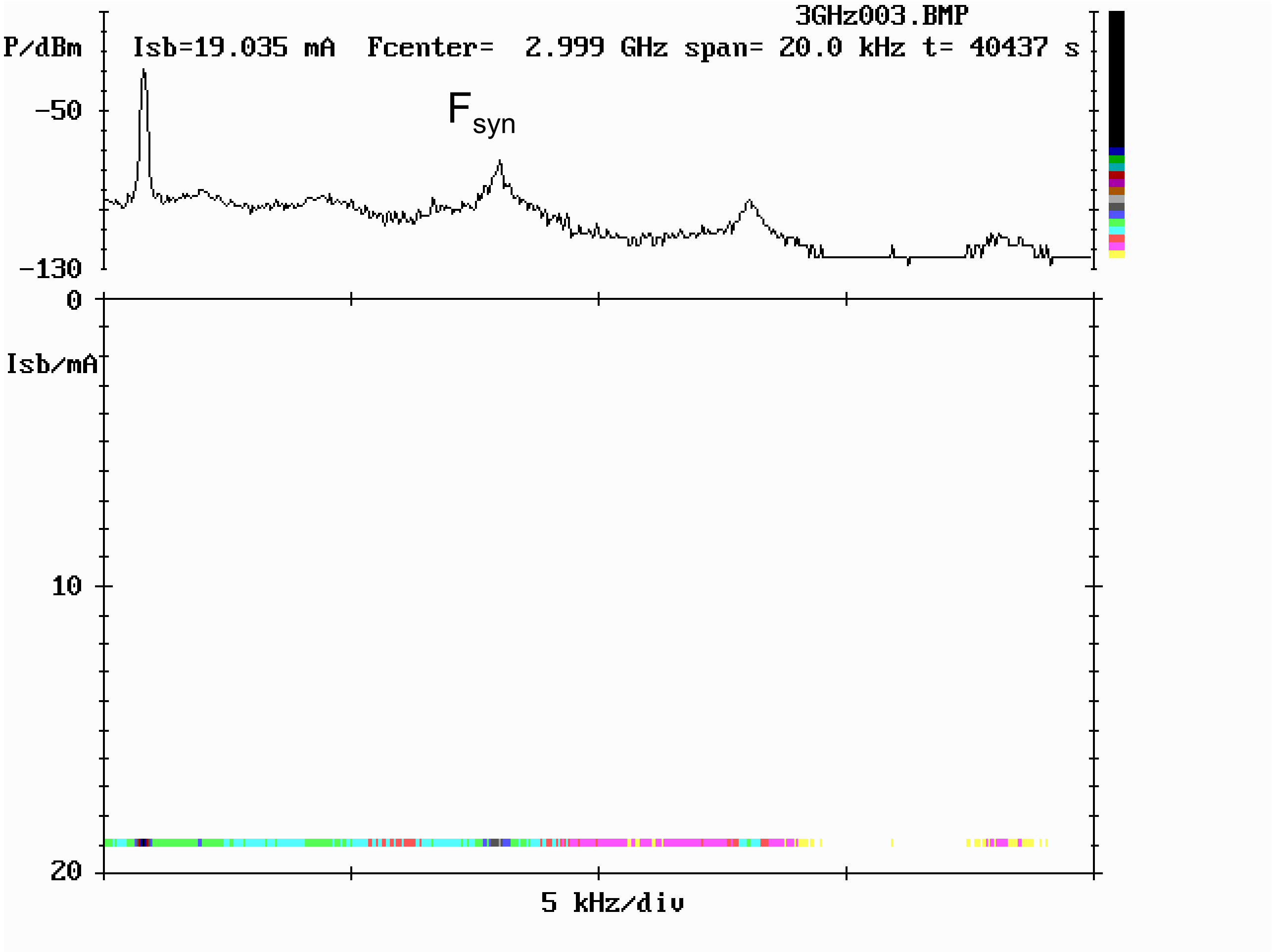
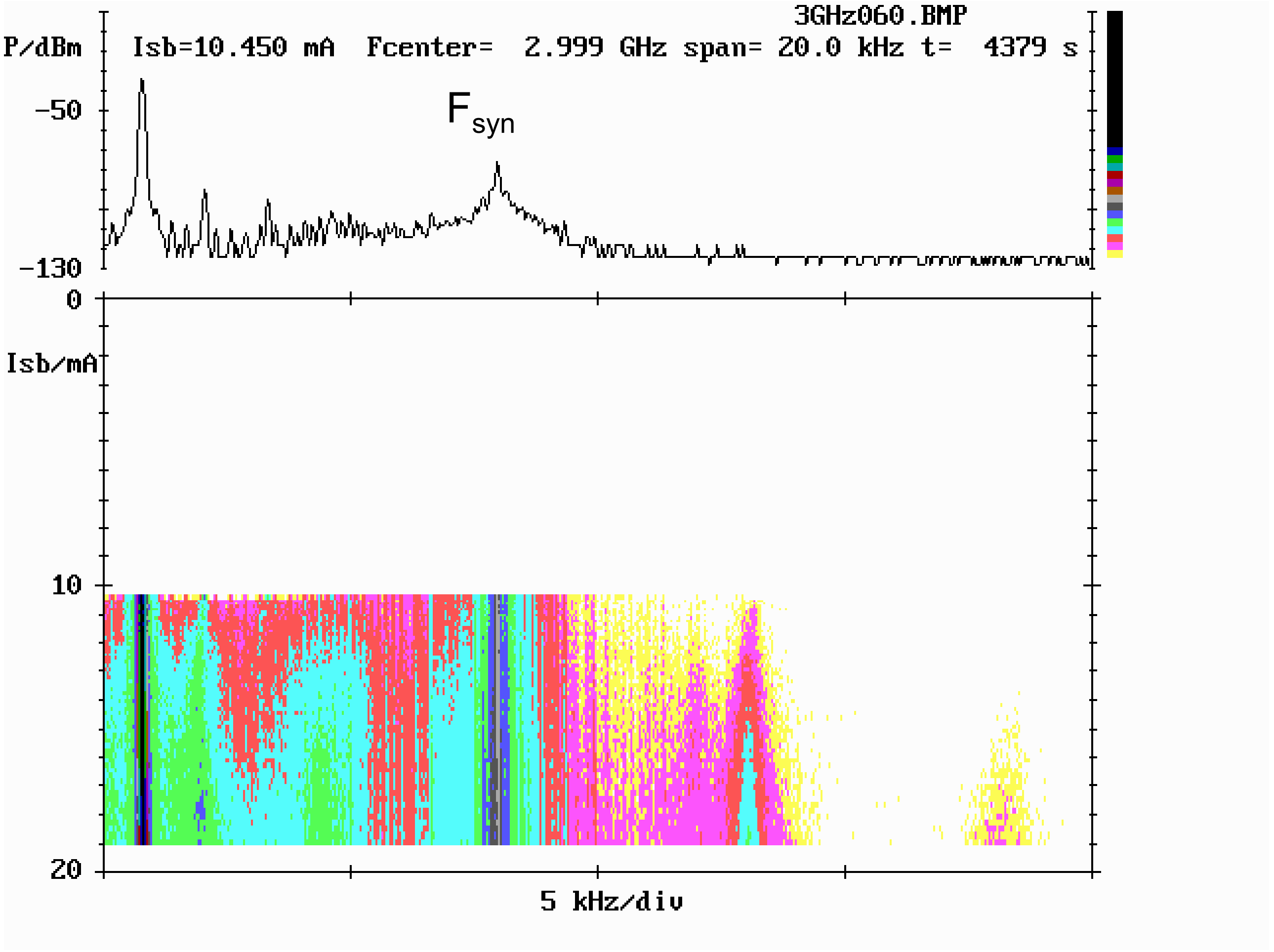


stripline signal of a single bunch observed at 3 GHz



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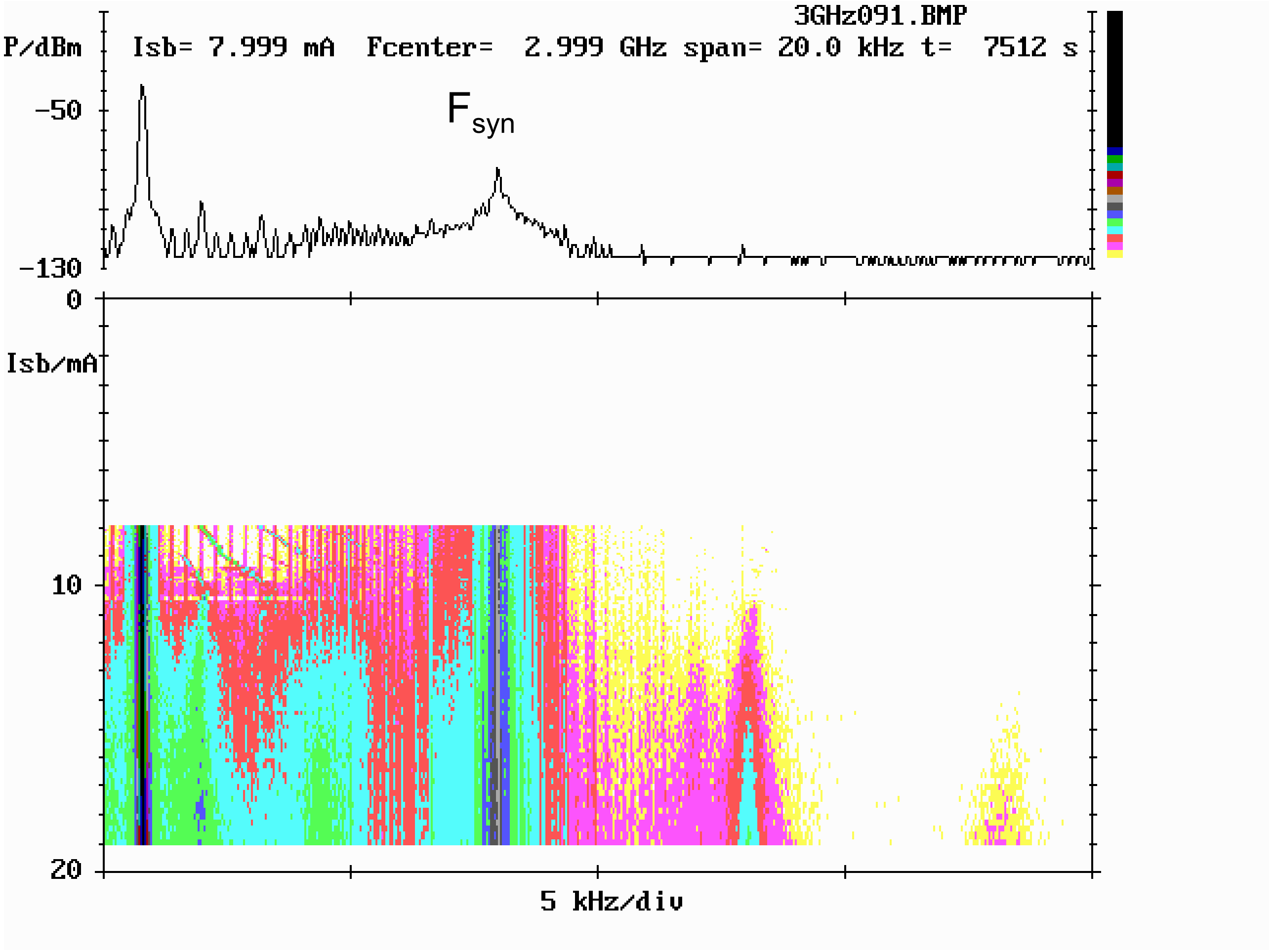

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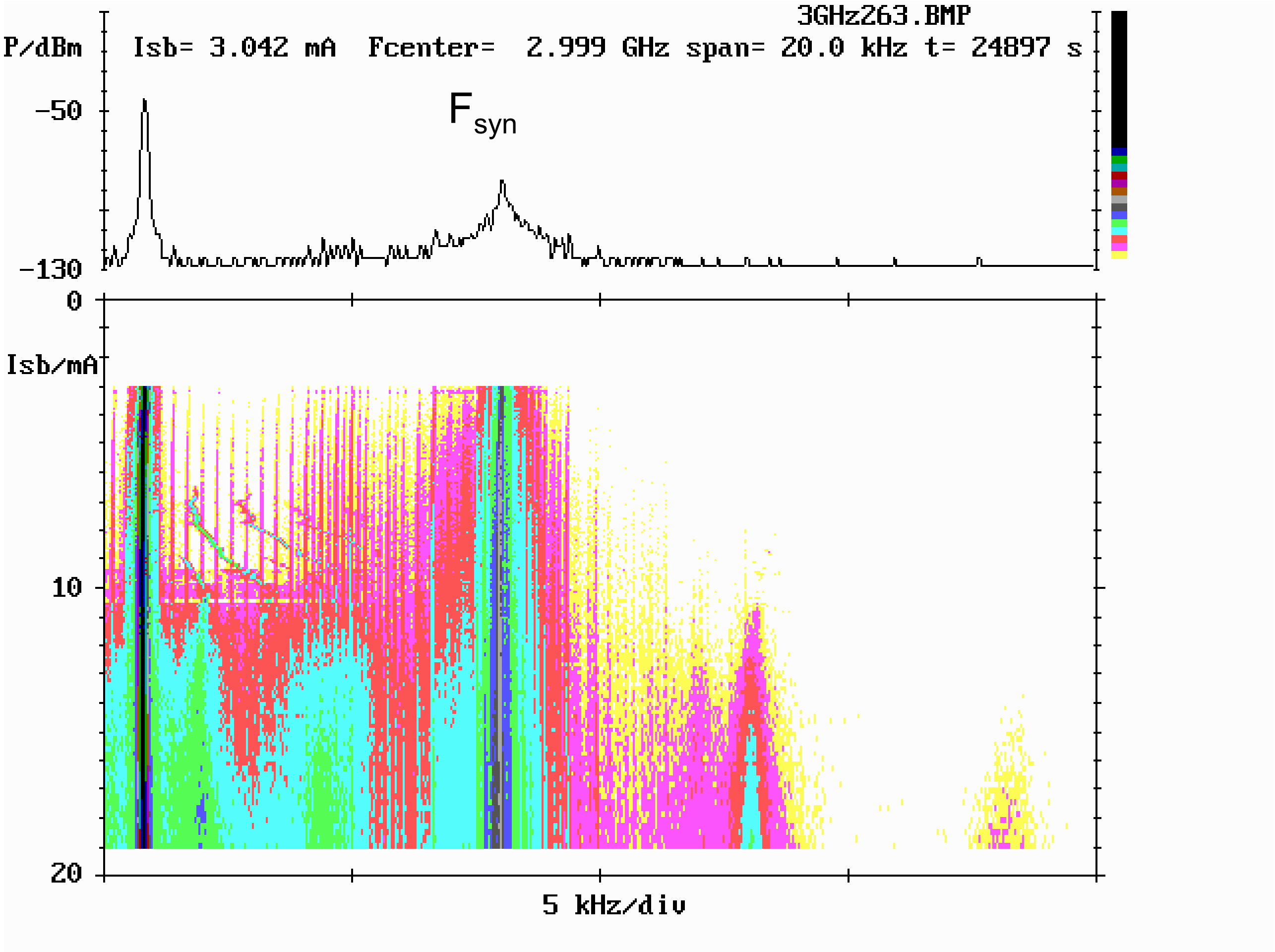

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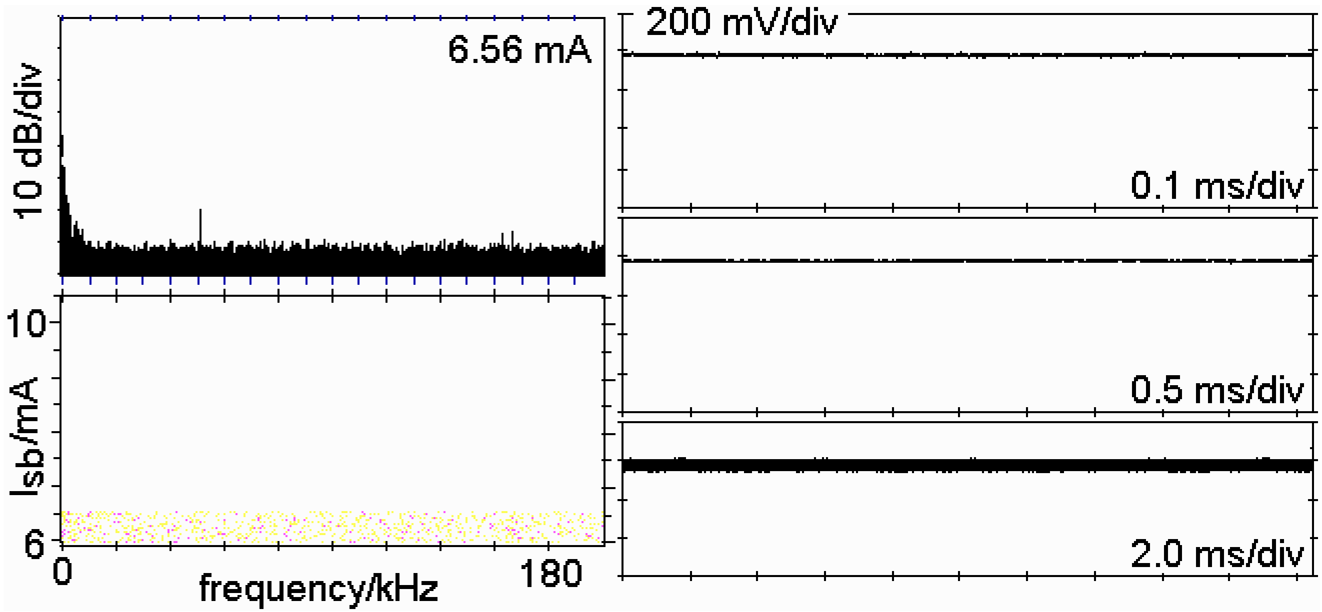
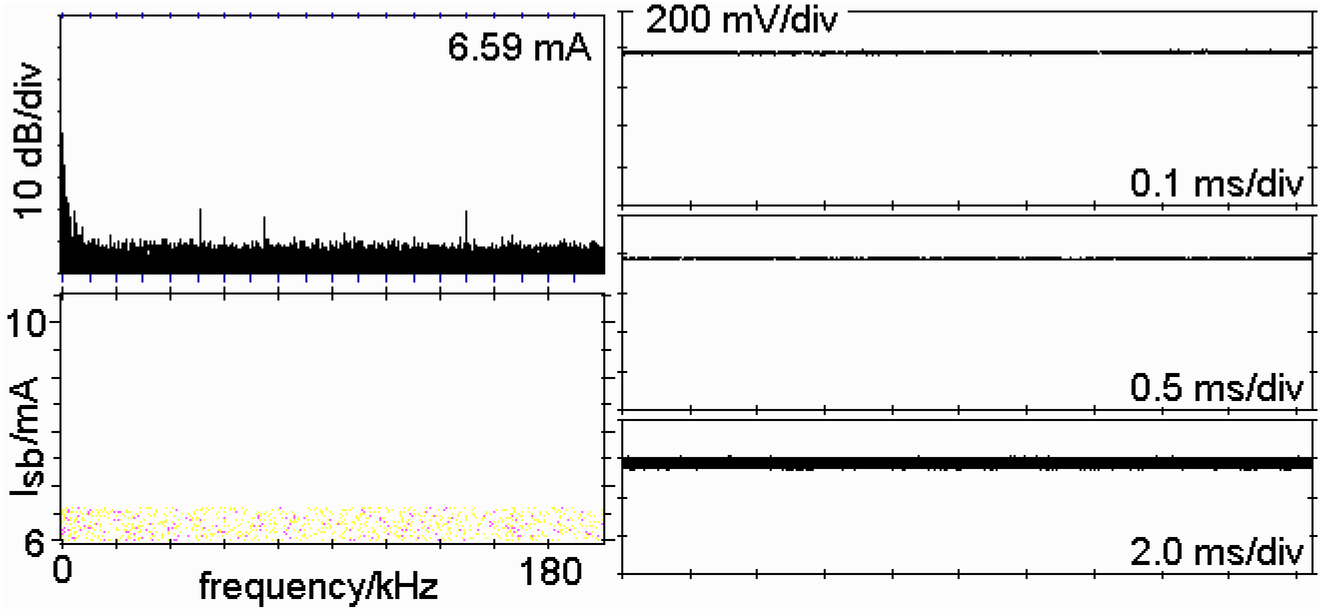


single bunch CSR signal observed between 100 GHz and 1 THz



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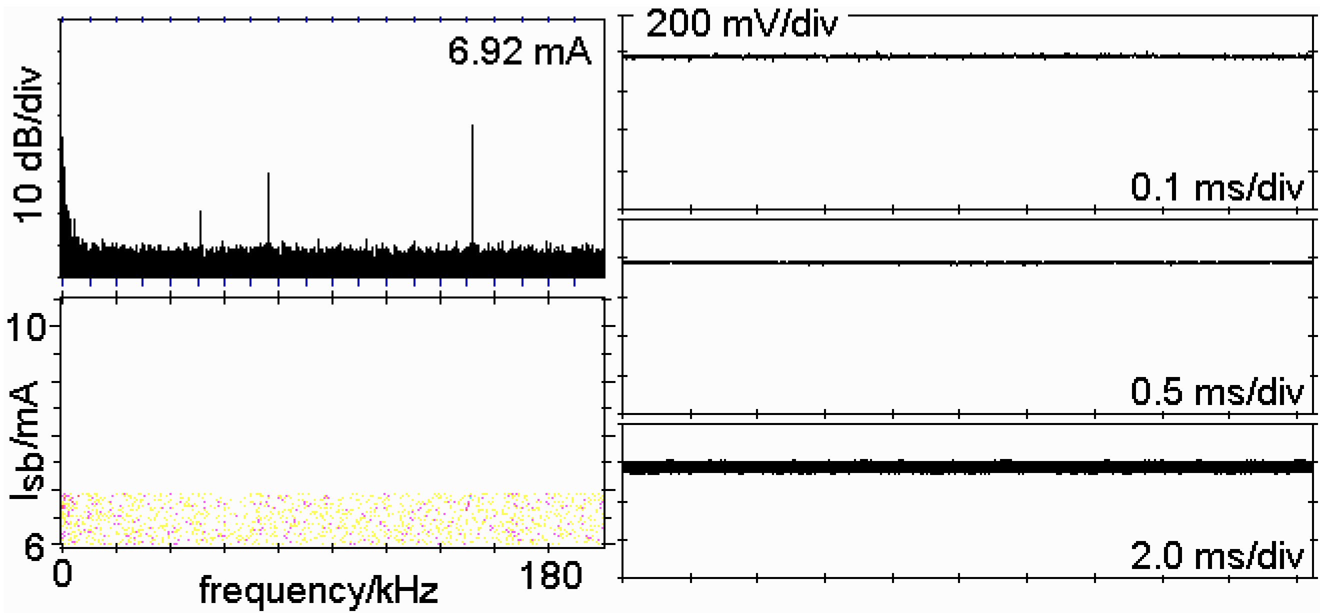

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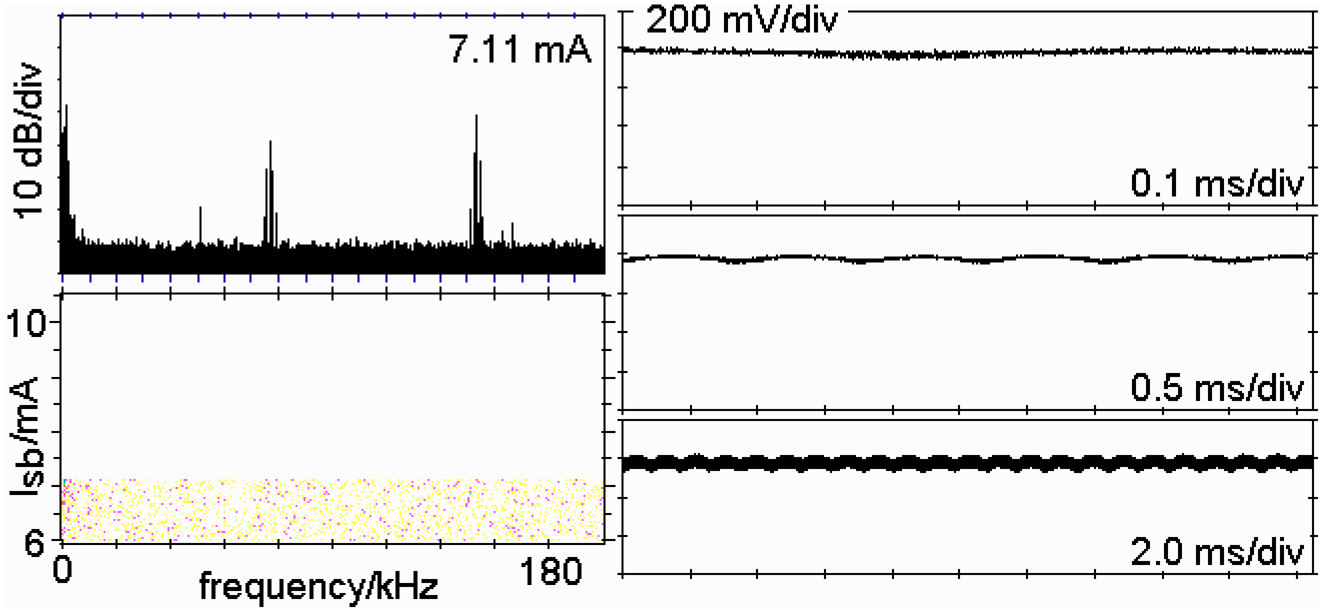

single bunch CSR signal observed between 100 GHz and 1 THz

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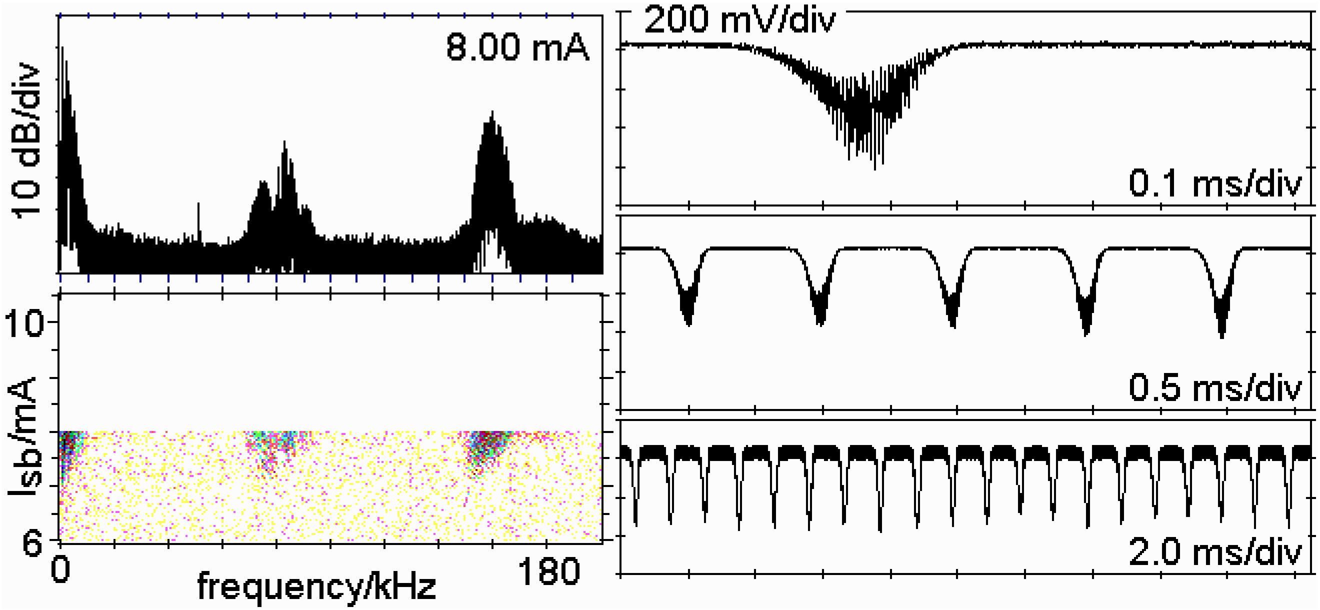

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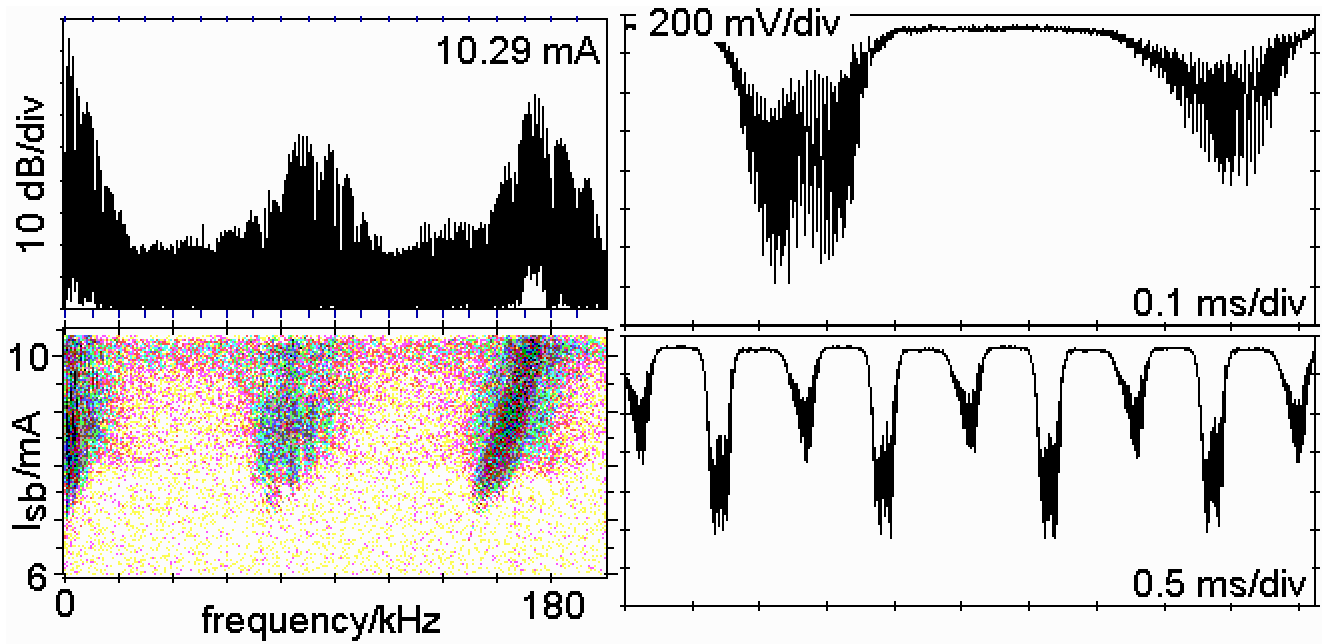
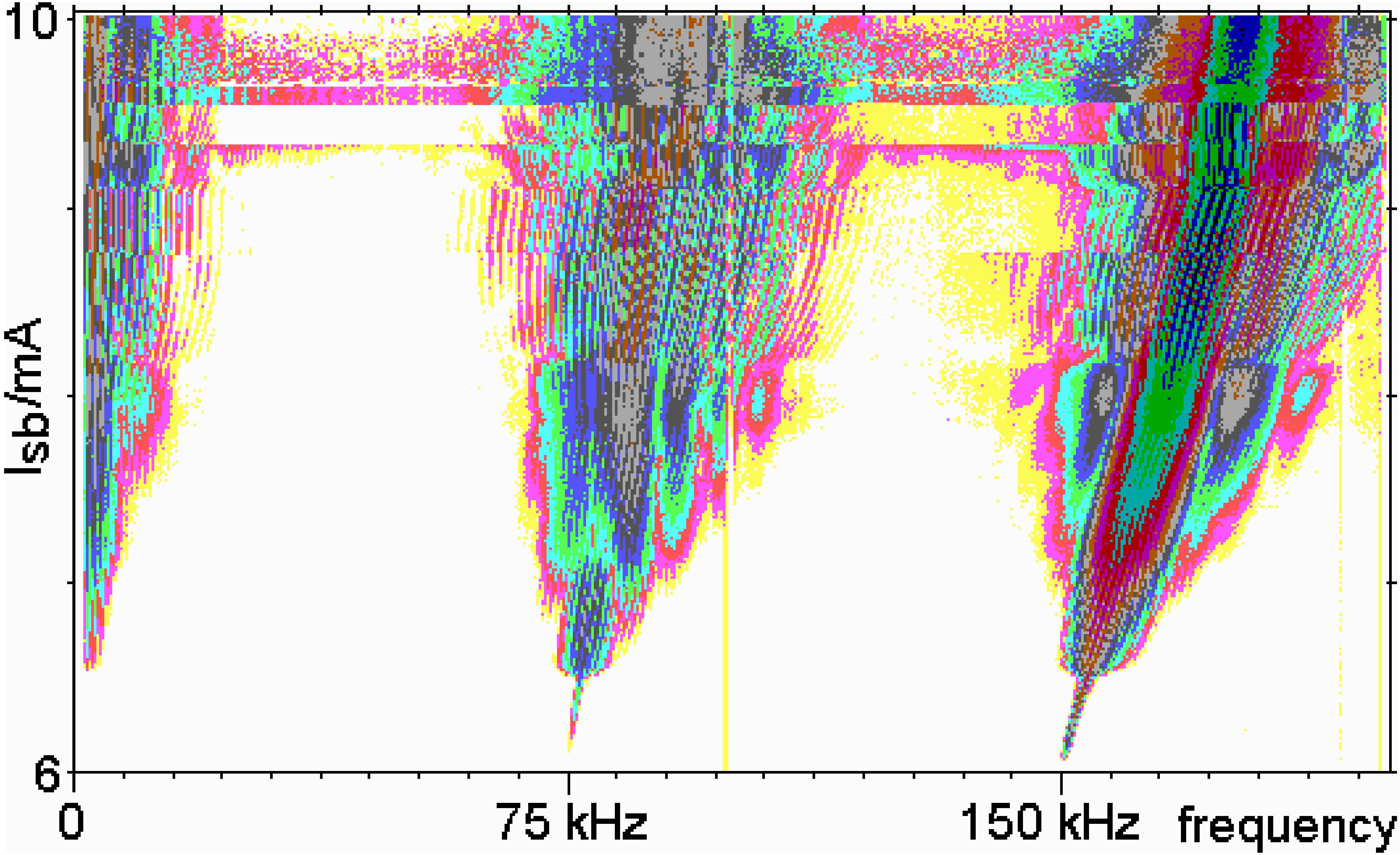


single bunch CSR signal observed between 100 GHz and 1 THz

II. CSR-Observations at BESSY II with 4 sc IDs in operation

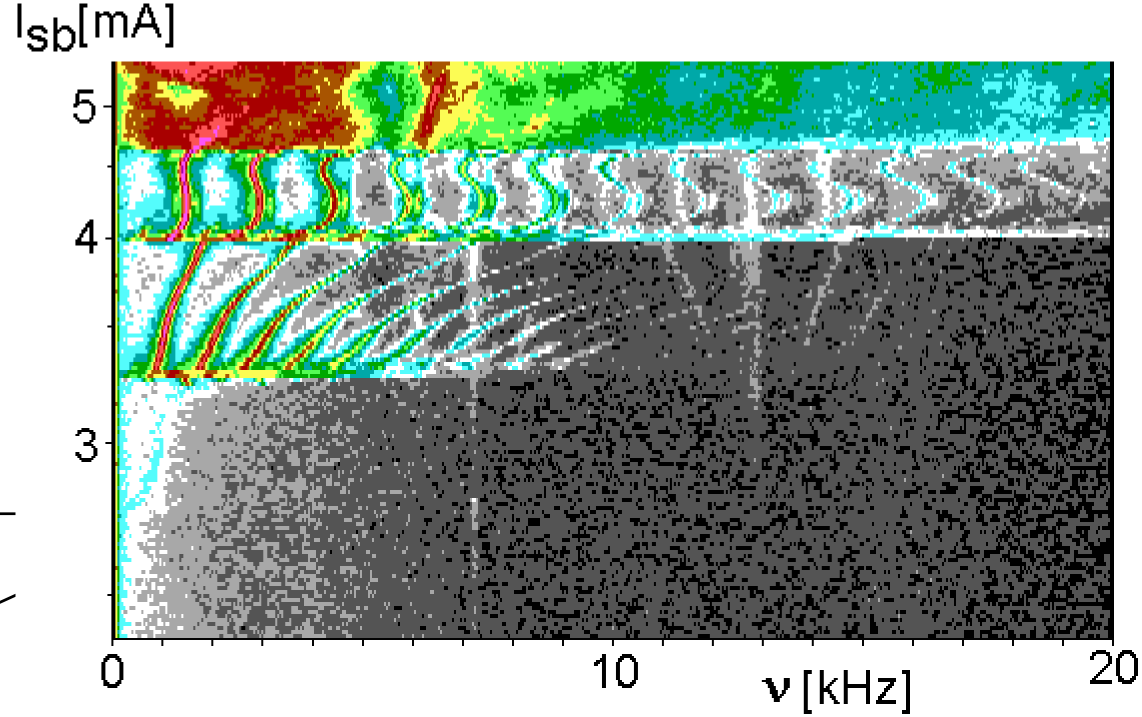


time dependent CSR-bursts observed in frequency domain:

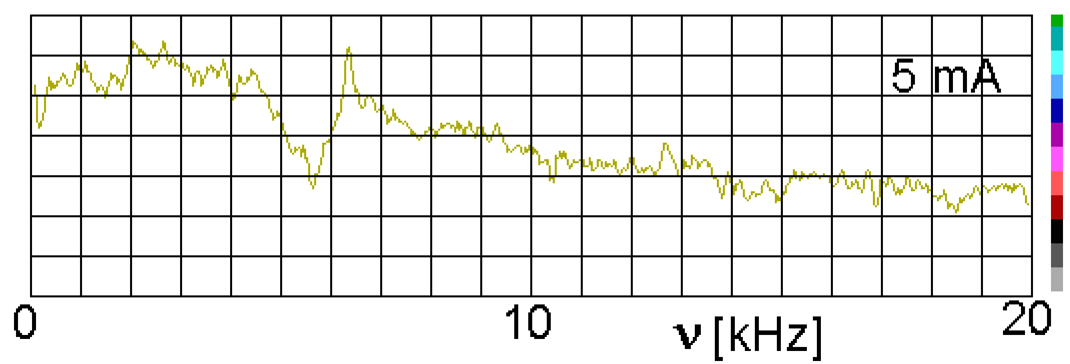
σ_0=14 ps, nom. optics, with 7T-WLS

CSR-bursting threshold

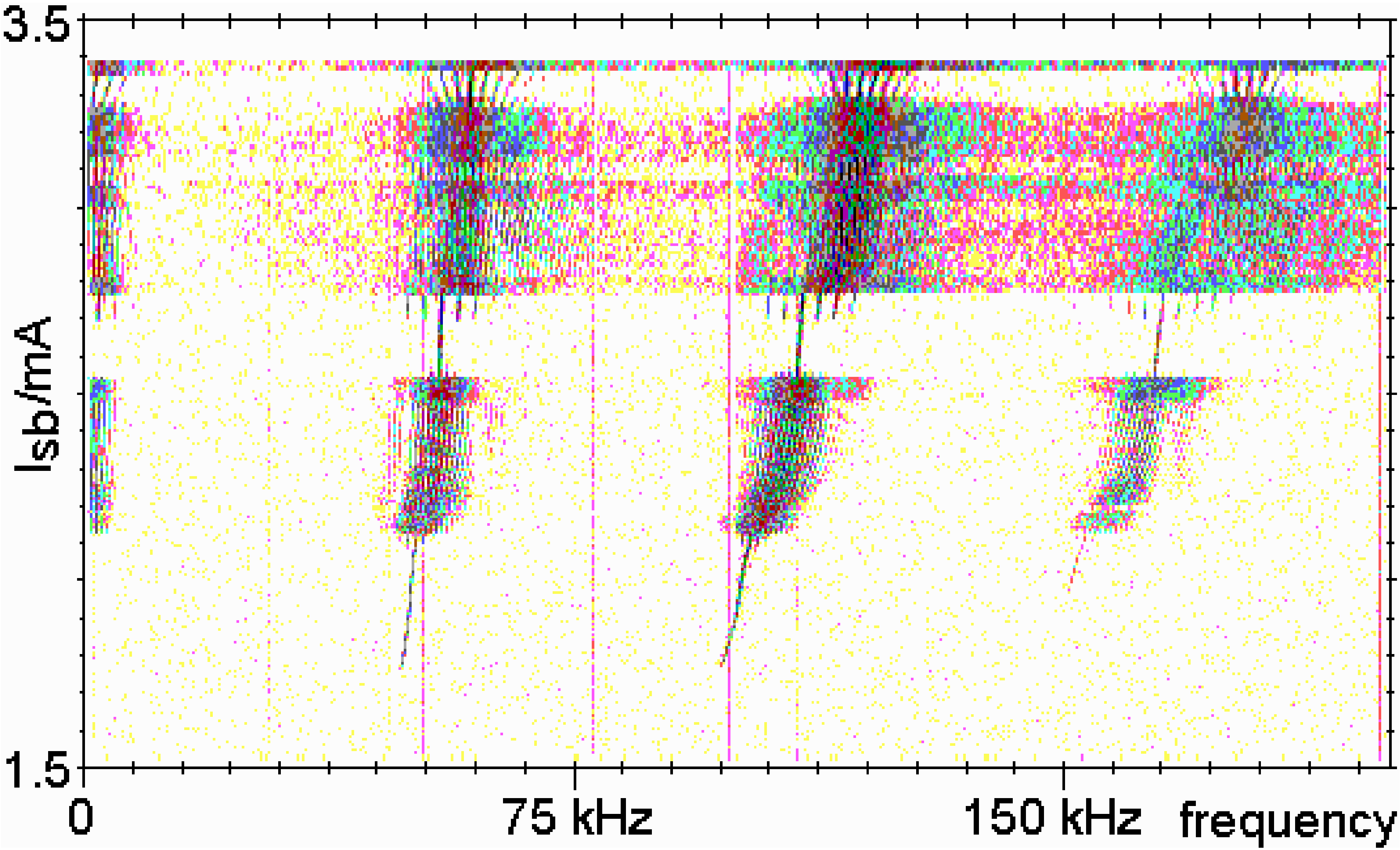
Stable, time independent CSR

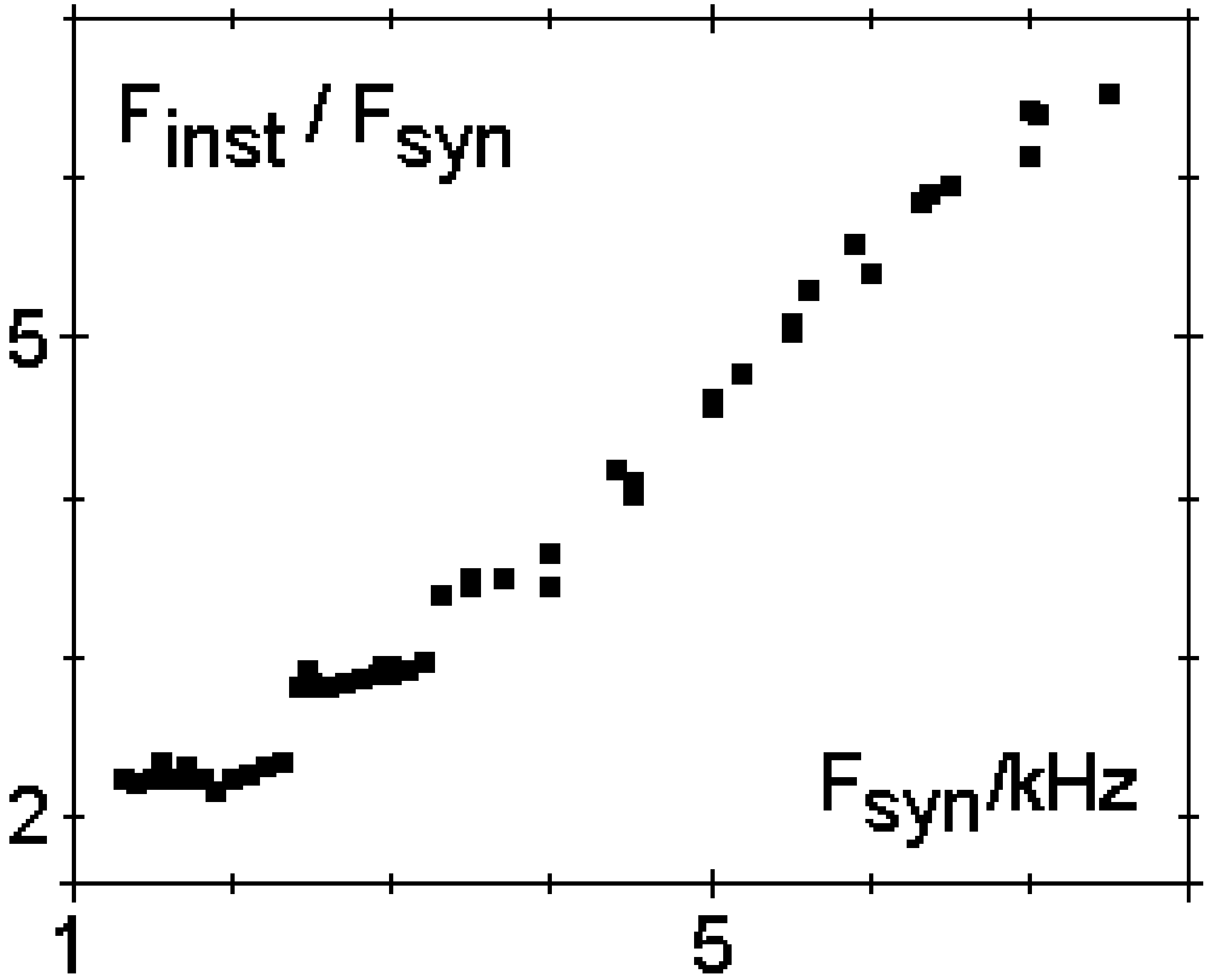


Spectrum of the CSR-signal:



II. CSR-Observations at BESSY II without sc IDs




Finst / Fsyn
Fsyn/kHz
5
2
1
5

III. 2 Vlasov-Fokker-Planck-Equation (VFP)

$$q = z / \sigma_z \qquad p = -\Delta E / \sigma_E \qquad \tau = \omega_s t$$

$$\frac{\partial f}{\partial \tau} + p \frac{\partial f}{\partial q} - \left[q + F_c(q, \tau, f) \right] \frac{\partial f}{\partial p} = \frac{2}{\omega_s t_d} \frac{\partial}{\partial p} \left(pf + \frac{\partial f}{\partial p} \right)$$

(M. Venturini)

RF focusing — Collective Force — Damping — Quantum Excitation

solution for $f(q, p, \tau)$ can become < 0, avoided with larger grids and smaller time steps

Ansatz – "wave function" approach: Distribution function, $f(q, p, \tau)$, expressed as product of amplitude function, $g(q, p, \tau)$: $f = g \cdot g$

$$\frac{\partial g}{\partial \tau} + p \frac{\partial g}{\partial q} - \left[q + F_c(q, \tau, g^2) \right] \frac{\partial g}{\partial p} = \frac{2}{\omega_s t_d} \frac{\partial}{\partial p} \left(pg + 2 \frac{\partial g}{\partial p} \right)$$

$\boldsymbol{f}(q, p, \tau)$ >= 0 and solutions more stable

numerical solution based on: R.L. Warnock, J.A. Ellison, SLAC-PUB-8404, March 2000
M. Venturini, et al., Phys. Rev. ST-AB 8, 014202 (2005)
S. Novokhatski, EPAC 2000 and SLAC-PUB-11251, May 2005

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solved as outlined by Venturini (2005): function, $g(q, p, \tau)$, is represented locally as a cubic polynomial and a time step requires 4 new calculations over the grid

distribution followed over 200 T_{syn} and during the last 160 T_{syn} the projected distribution $\rho(q)$ is stored for later analysis: determination of the moments and FFT for the emission spectrum

grid size 128x128 and up to 8 times larger, time steps adjusted and as large as possible

Energy	E	1.7 GeV
Natural energy spread	σ_ε/E	$7\cdot10^{-4}$
Longitudinal damping time	τ_{lon}	8.0 ms
Momentum compaction factor	α	$7.3\ 10^{-4}$
Bunch length	σ_o	10.53 ps
Accellerating voltage	V_{rf}	1.4 MV
RF-frequency	ω_{rf}	$500\cdot2\pi$ MHz
Gradient of RF-Voltage	$\partial V_{rf}/\partial t$	4.63 kV/ps
Circumference	C	240 m
Revolution time	T_o	800 ns
Number of electrons		$5\cdot10^{6}$ per μA

F_{syn} = 7.7 kHz

~60 T_{syn} per damping time

M. Venturini, et al., Phys. Rev. ST-AB 8, 014202 (2005)

Theoretical Results
Comparison with other Theories and Simulations

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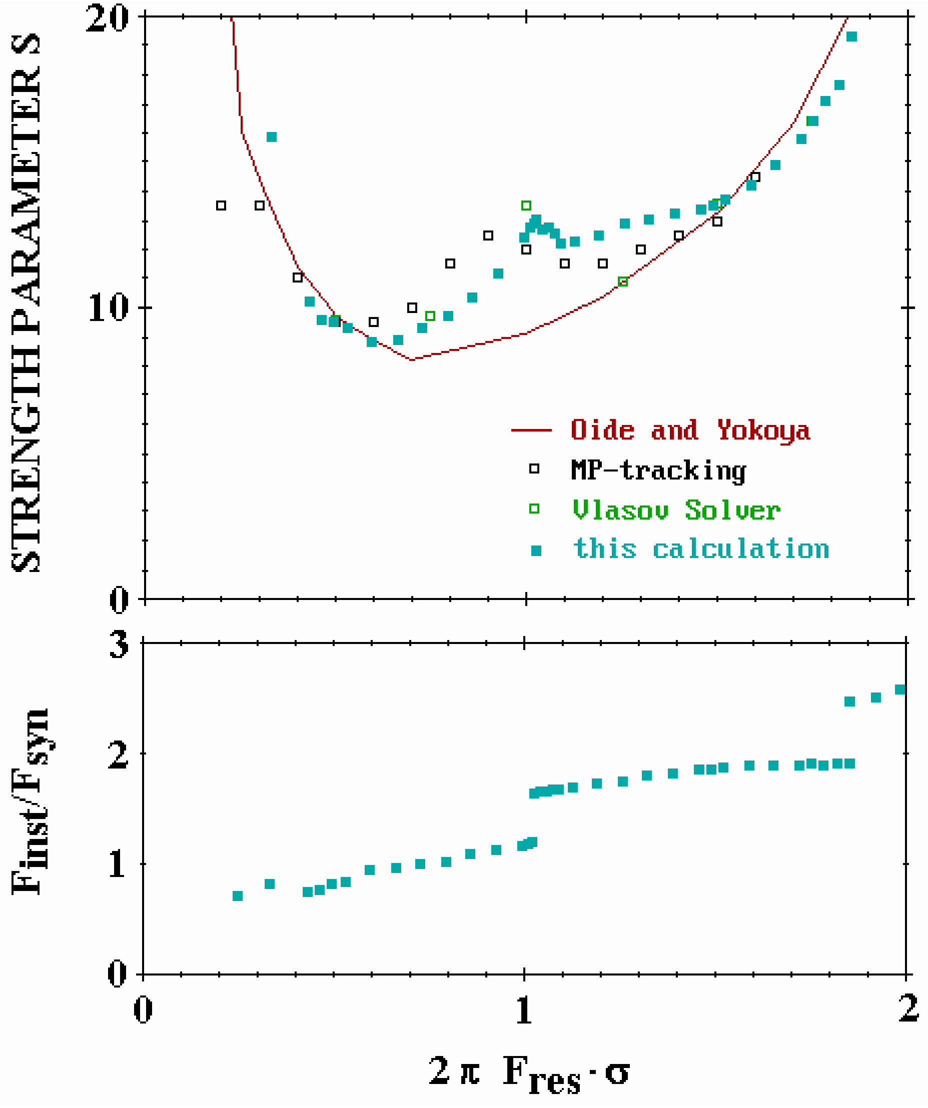

K. Oide, K. Yokoya, „Longitudinal Single-Bunch Instability in Electron Storage Rings“, KEK Preprint 90-10, April 1990
K.L.F. Bane, et al., „Comparison of Simulation Codes for Microwave Instability in Bunched Beams“, IPAC’10, Kyoto, Japan and references there in

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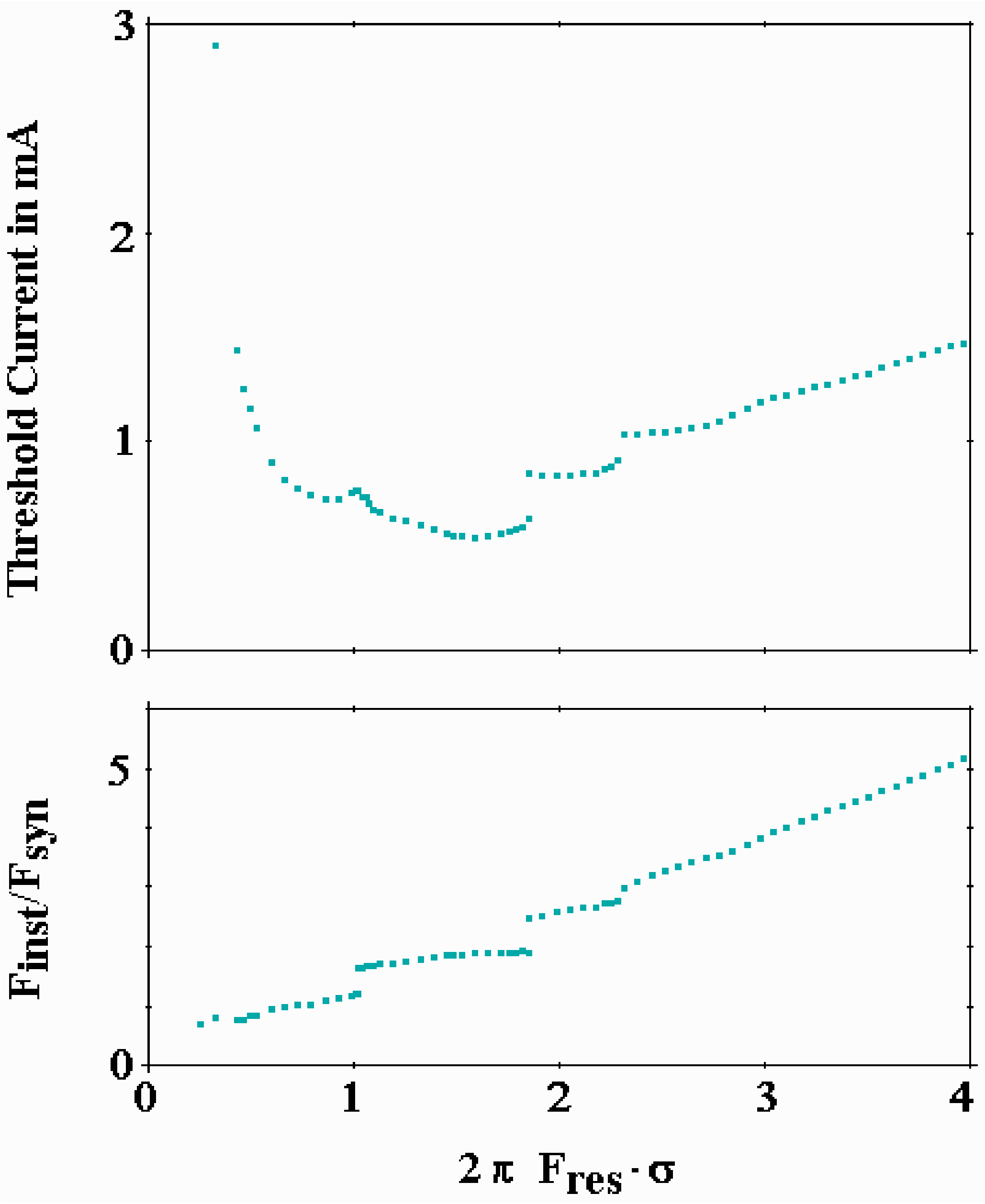


broad band resonator with:

R_s=10 kΩ, Q=1 and F_{res} variable

solution of VFP-equation: $f(q,p,\tau)$

line density:

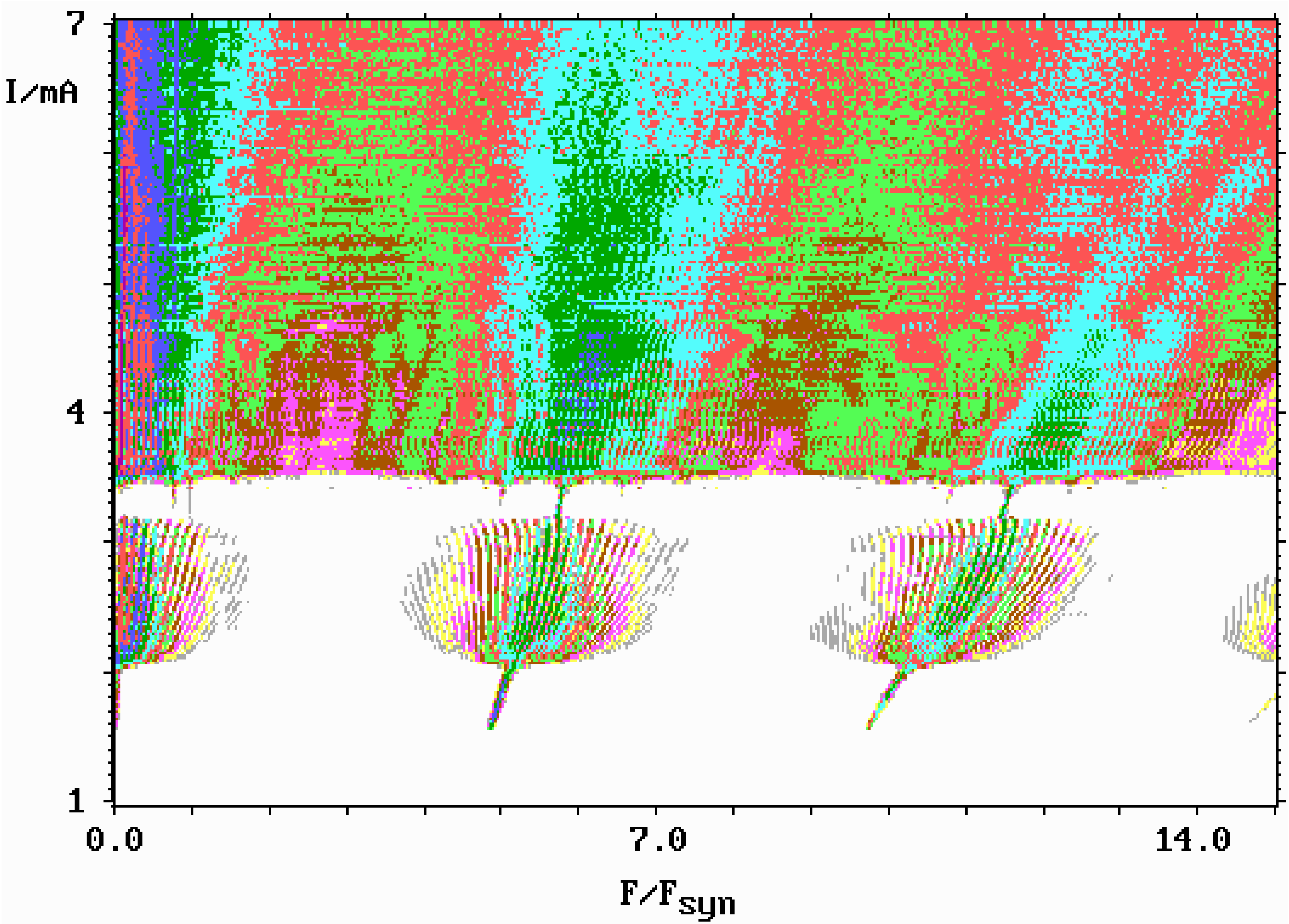
$$\rho(q,\tau)=\int_{-\infty}^{\infty} f(q,p,\tau)dp$$

instantaneous coh. syn. radiation:

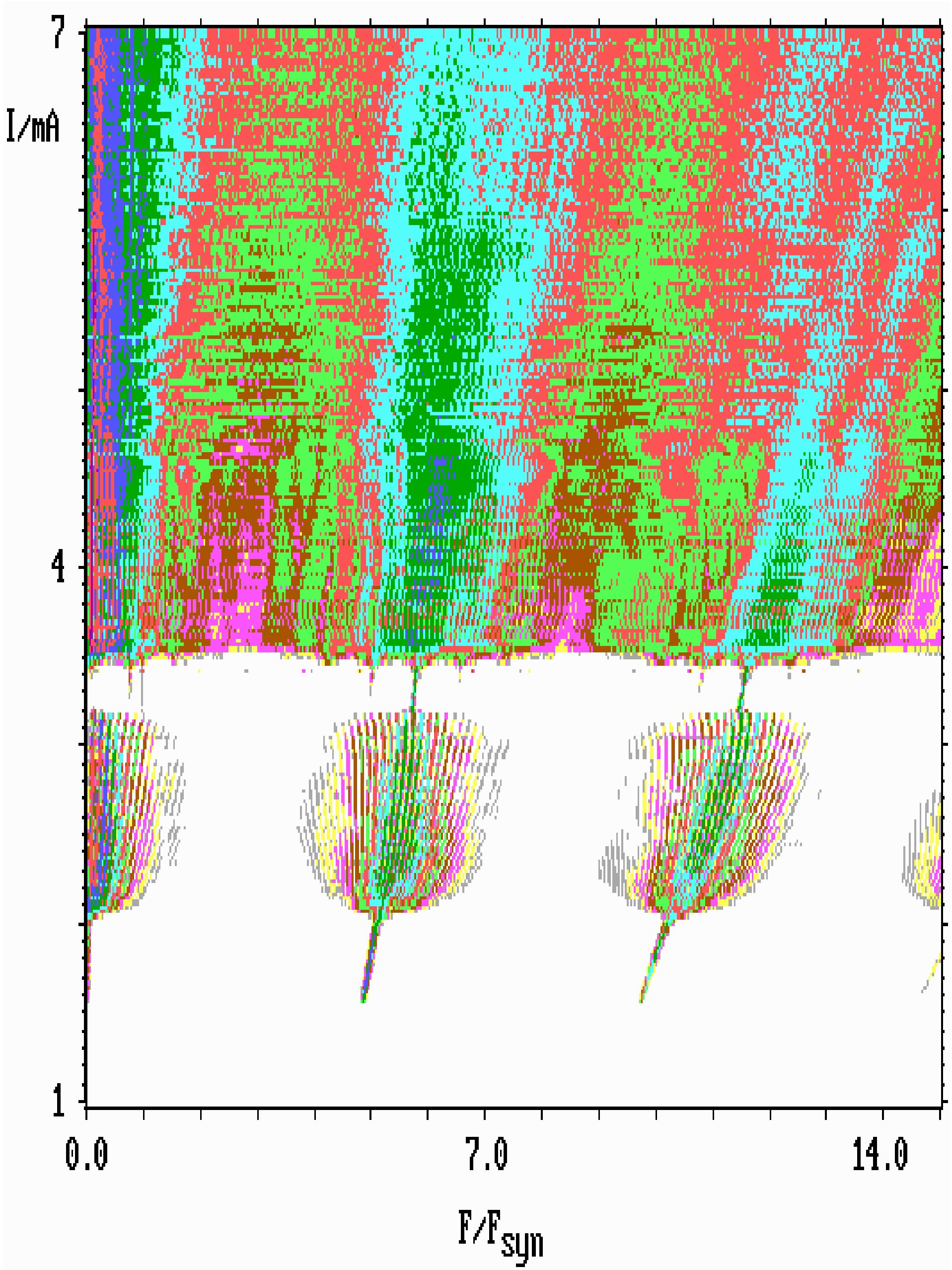
$$P_{coh}(\omega,\tau)\sim\left|\int_{-\infty}^{\infty}\rho(q,\tau)\cdot e^{-i\omega q}dq\right|^2$$

time dependent CSR-power:

$$P_{coh}^{tot}(\tau)=\int_{cutoff}^{\infty}P_{coh}(\omega,\tau)d\omega$$



BBR: R_s=10 kΩ, F_{res}=40 GHz, Q=1; R= 850 Ω and L /ω_0 =0.2 Ω



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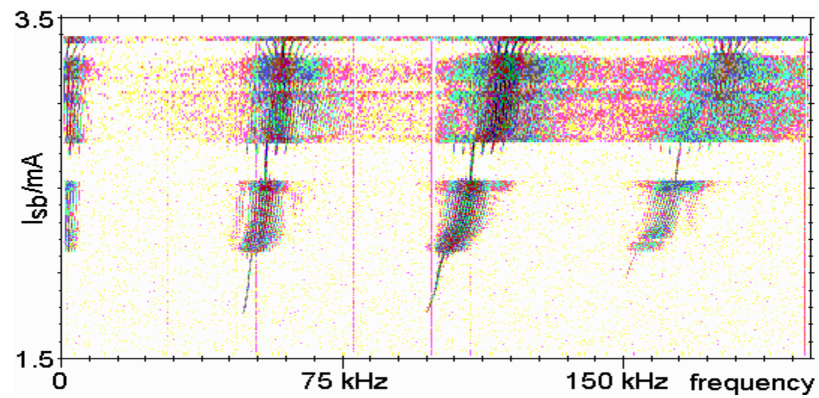

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a simple BBR-model for the impedance combined with the low noise numerical solutions of the VFP-equation can explain many of the observed time dependent features of the emitted CSR:

- typically a single (azimuthal) mode is unstable first
- frequency increases stepwise with the bunch length
- at higher intensity sawtooth-type instability (quite regular, mode mixing)
- at even higher intensitiy the instability becomes turbulent, chaotic, with many modes involved

Oide‘s and Yokoya‘s results are only in fair agreement with these calculations

simulation can serve as a benchmark for other theoretical solutions

need further **studies with more complex assumption on the vacuum chamber impedance**

Acknowledgement

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