Results of heterodyne mixing of the emitted electric field of synchrotron radiation in the THz-regime

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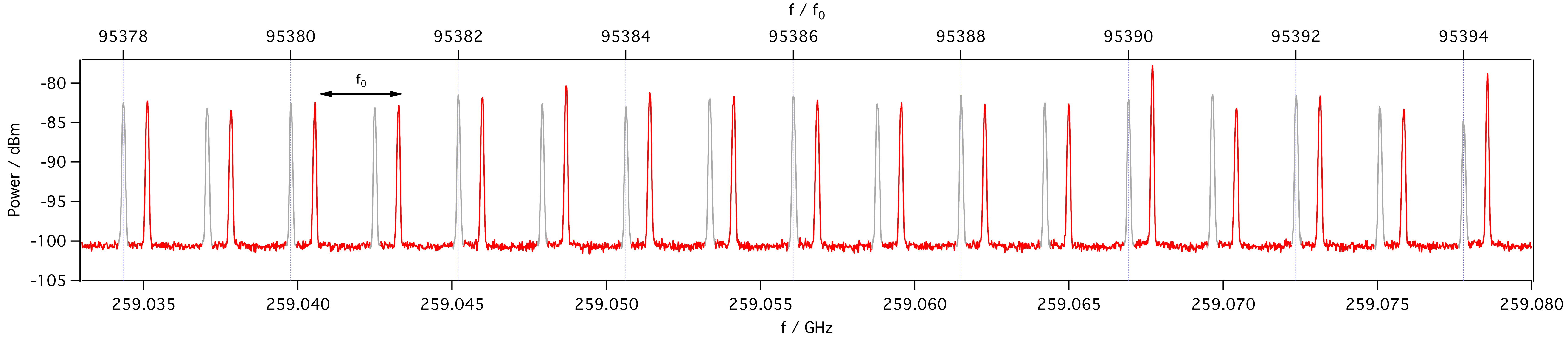
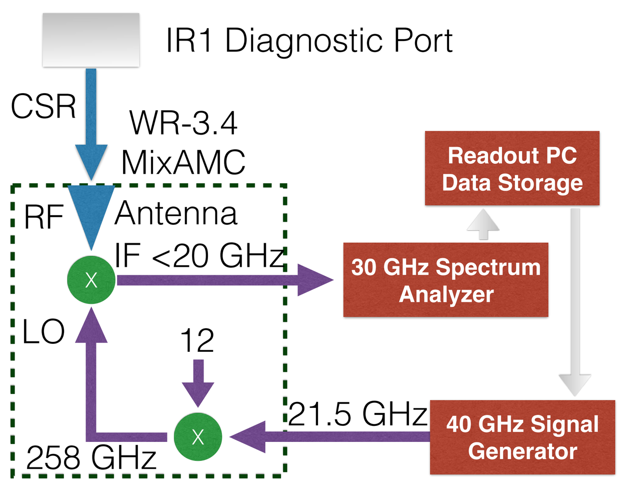
Abstract: Using heterodyne spectroscopy we observe the electric field of synchrotron radiation in the THz-Regime. Our measurements of the emitted coherent synchrotron radiation at 270 GHz reveal the discrete frequency harmonics around the 100'000 revolution harmonic of ANKA. We present the effects of the filling pattern structure in multi-bunch mode on the beam spectrum as well as measurements of the synchrotron frequency.

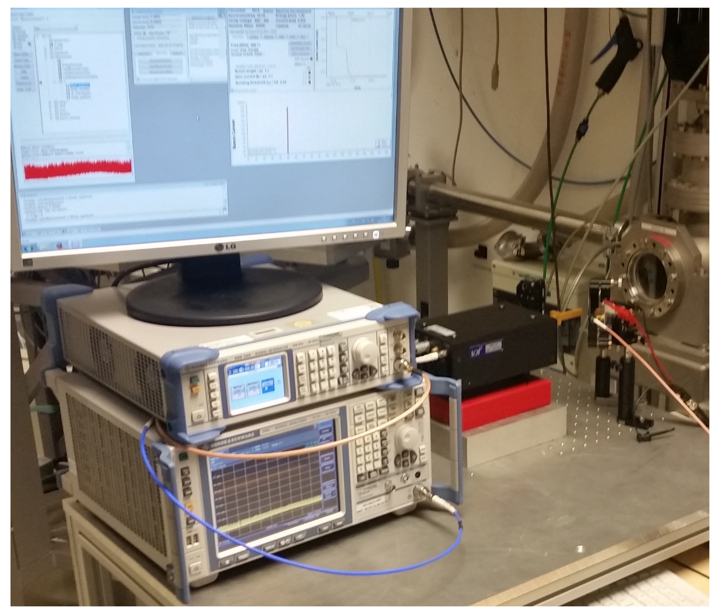
While the bandwidth of interferometers or grating spectrometers in the Terahertz regime are typically limited to some hundred Megahertz, heterodyne measurements can provide resolutions of better than 1 Hz. By mixing the electric field of the radiation into the baseband, off-the-shelf electrical spectrum analyzers can be used to measure coherent synchrotron radiation.

Synchrotron radiation in a storage ring is a frequency comb



Measurement Setup:





- Beam energy: 1.3 GeV
- Accelerator frequency: 499.715 MHz
- Revolution frequency: 2.715 MHz
- Synchrotron frequency: 7.5 kHz

- Mixer: VDI WR3.4SAX
- 220 GHz to 330 GHz
- 20 GHz IF bandwidth

Theory of repeated patterned emission

The time signal constitutetes from an infinite series of delta pulses convoluted by the filling pattern convoluted by the single pulse signal

$$s(t) = \text{Ш}_{T_0}(t) * s_F(t) * s_p(t)$$

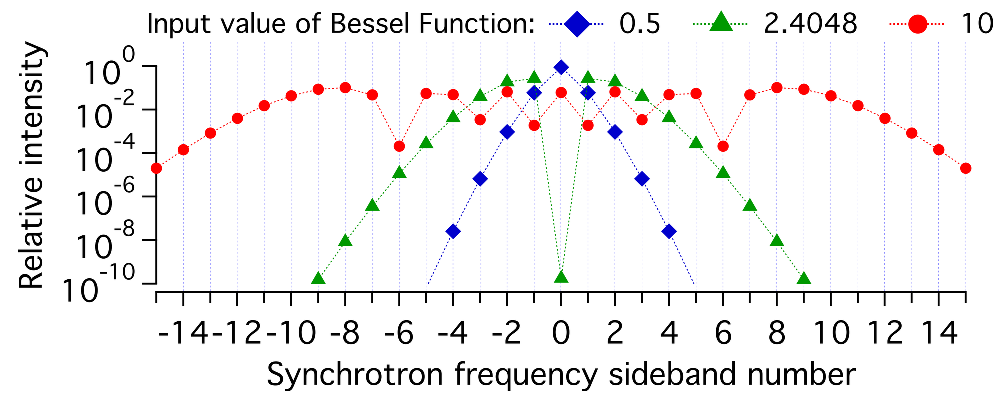
$$S(f) = \frac{1}{T_0} \text{Ш}_{\frac{1}{T_0}}(f) \times \text{DFT}\{s_F(t), f\} \times s_p(f)$$

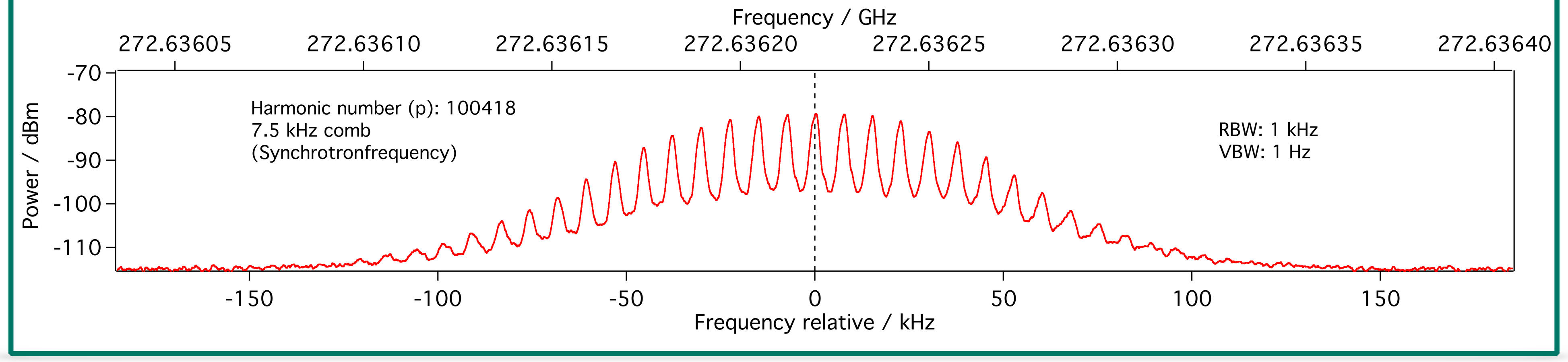
The Spectrum consists of a frequency comb with a line spacing of the repetition frequency, multiplied by the discrete Fourier transformation of the filling pattern and multiplied by the spectrum of a single pulse (broadband synchrotron spectrum)

Observed Synchrotron Oscillations

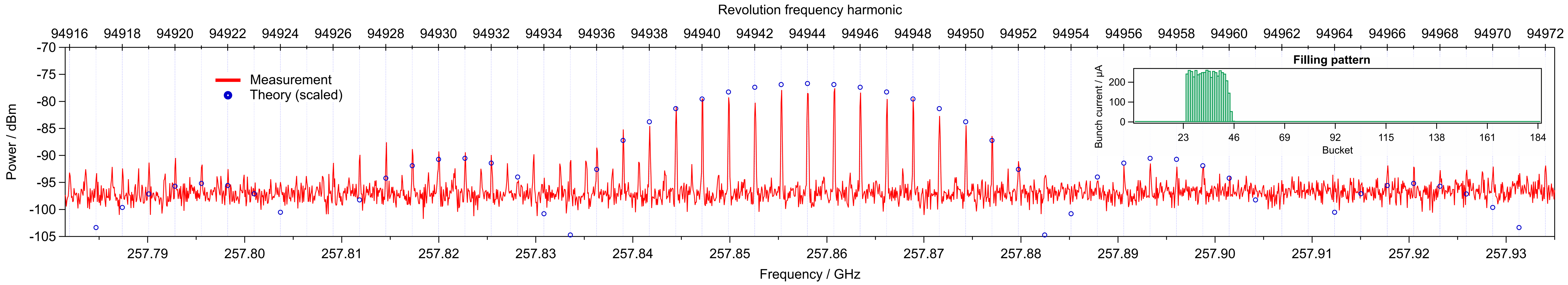
$$S(\omega) \propto \sum_{p,m=-\infty}^{\infty} j^{-m} J_m(p\omega_0\hat{\tau})\delta(\omega - p\omega_0 + m\omega_s)$$

- sidebands scale with Bessel functions
- visibility dependent on
  - observed frequency
  - synchrotron oscillation amplitude





Influence of filling pattern in multi-bunch fill:



See also:

J.L.Steinmann et al.,"Frequency comb spectrum of periodic patterned signals", submitted to Phys. Rev. Lett.
J.L.Steinmann et al.,"Non-interferometric Spectral Analysis of Synchrotron Radiation in the THz regime at ANKA" IPAC 2015, TUPWA043
J.L.Steinmann et al.,"Influence of Filling Pattern Structure on Synchrotron Radiation Spectrum at ANKA", IPAC 2016, WEPOW015

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