



Center for the Advancement of Natural Discoveries using Light Emission

SYNCHROTRON RESEARCH INSTITUTE

The Phase Spectrum of RF Distortion

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INTRODUCTION

Goal



Determine the phase position and duration of a bunch, as well as the phase distortion of the electrons



Nondestructive and online measurement method is proposed

The method is based on the known effect of disturbance of the field of an electromagnetic wave in a cavity by the field of electron bunch.



Result



The phase spectrum of disturbed signal can be used to determine the phase position and duration of accelerated bunches

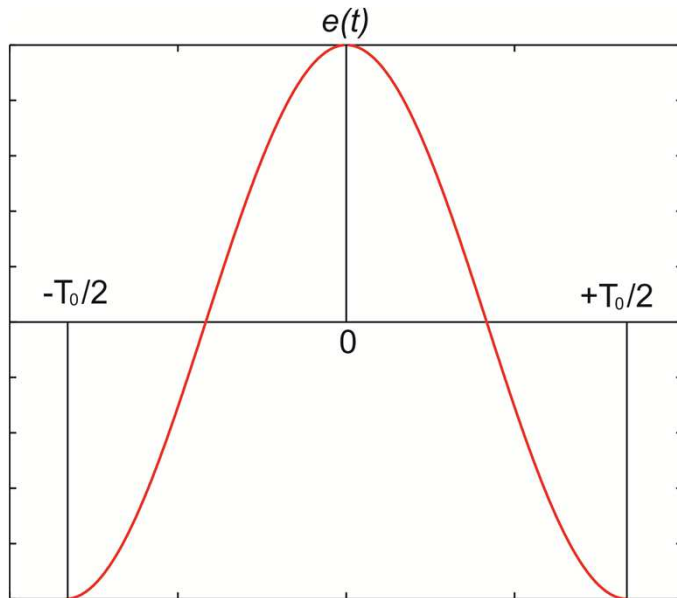
Measurement scheme

E. Begloyan, E. Gazazyan, E.Laziev, G. Oksuzyan et al. *Determination of the Phase of a Periodic Perturbation of a Harmonic Signal*, FEL-99 Proceedings, Hamburg, II-61-II-62, (1999)

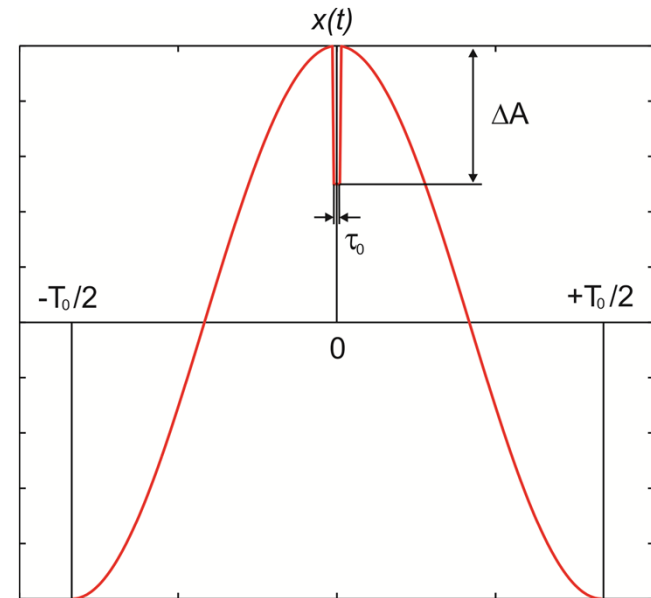
METHOD DESCRIPTION

Cosine wave fragment $e(t)$

Amplitude: $A_0=1$, Period: T_0



Influence of electron bunch \rightarrow $x(t)$ signal



Signal as a segment of cosine wave with $(2n+1)$ periods

$$E(t) = \sum_{j=1}^n e(t - jT_0) + e(t) + \sum_{j=1}^n e(t + jT_0)$$

Kick with amplitude $-\Delta A$ and duration $\tau_0 \ll T_0$.
For $(2n+1)$ periods

$$X(t) = \sum_{j=1}^n e(t - jT_0) + x(t) + \sum_{j=1}^n e(t + jT_0)$$

METHOD DESCRIPTION

The difference between this new signal and initial cosine wave train signal will be

$$\boxed{X(t) - E(t) = x(t) - e(t)} \xrightarrow{t \rightarrow \omega} \boxed{S_X(\omega) - S_E(\omega) = S_x(\omega) - S_e(\omega)}$$

The position of cosine wave perturbation can be determined by calculating the difference spectrum of perturbed and initial cosine wave signals. This assumption is also true in multibunch case.

Numerical calculations

Fourier transform
$$F(k) = \int_{-\infty}^{+\infty} f(t) e^{-2\pi i k t} dt$$

We consider discrete function

$$f(t) \rightarrow f(t_k), \quad f_k \equiv f(t_k)$$

$$t_k = k\Delta, k = 0, \dots, N-1$$

Discrete Fourier Transform

$$F_n = \sum_{k=0}^{N-1} f_k e^{-2\pi i n k / N}$$

$(\omega, |F_n|)$ - amplitude spectrum

$(\omega, \arg(F_n))$ - phase spectrum

When $\tau_0 \ll T_0$ the phase spectrum should be considered for the difference spectrum calculations

NUMERICAL CALCULATION RESULTS

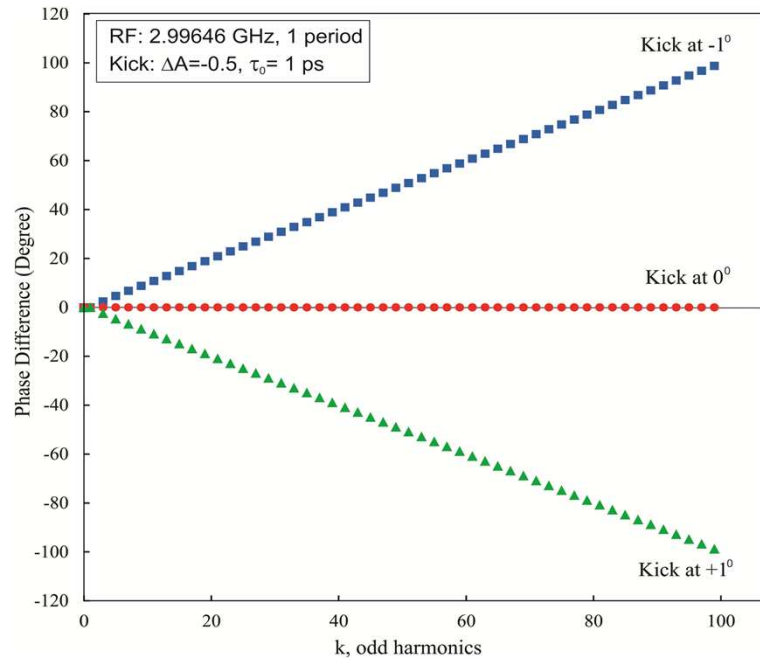
AREAL (Frequency of accelerating field 2.99646 GHz)

Single bunch

Kick position: 0° and $\pm 1^\circ$, $(t_0 = 0, \pm \frac{T_0}{360})$

Amplitude: $\Delta A = -0.5$

Duration: $\tau_0 = 1 \text{ ps}$

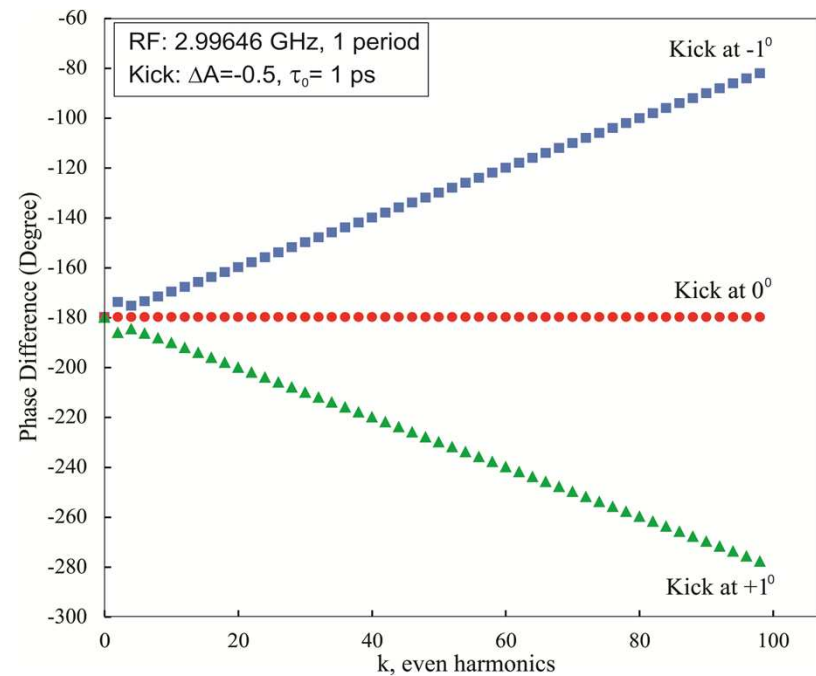


Multibunch (50 MHz, 16 pulses)

Kick position: $t_j = \sum_{j=1}^7 t_0 \pm j(60T_0)$

Amplitude: $\Delta A = -0.5$

Duration: $\tau_0 = 1 \text{ ps}$



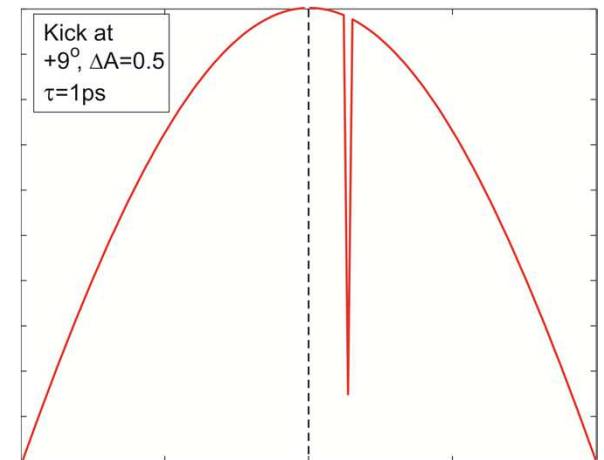
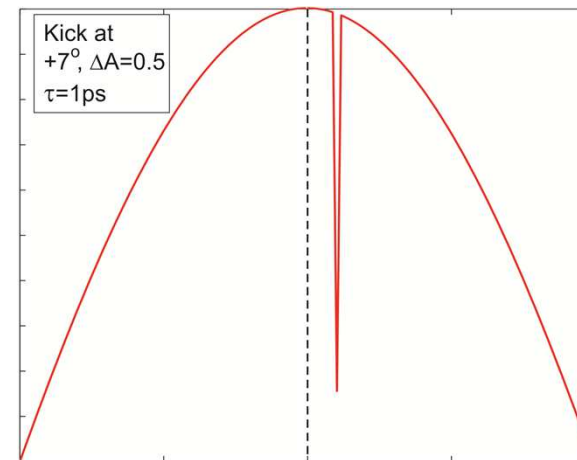
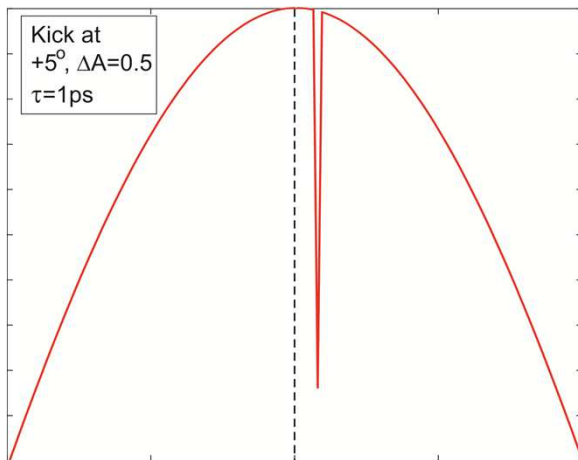
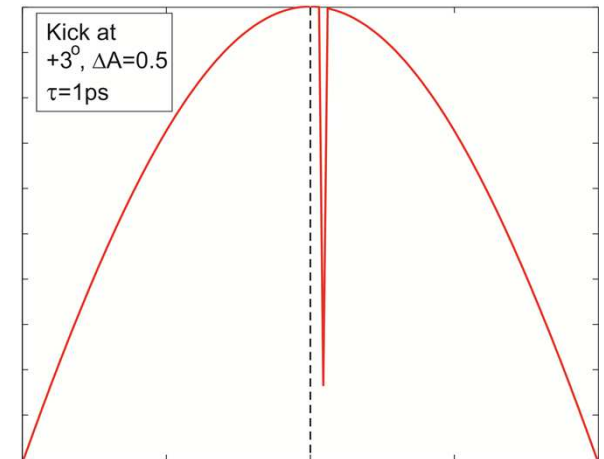
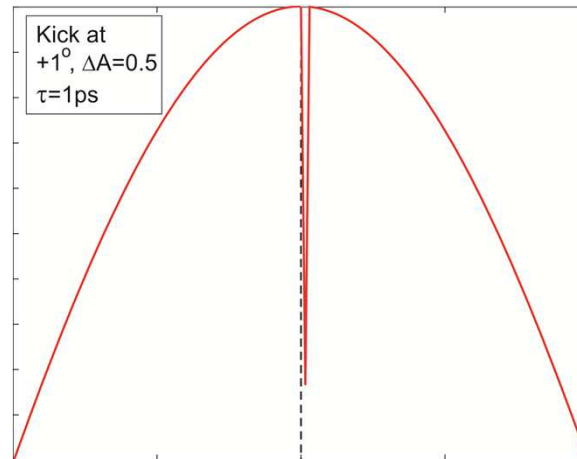
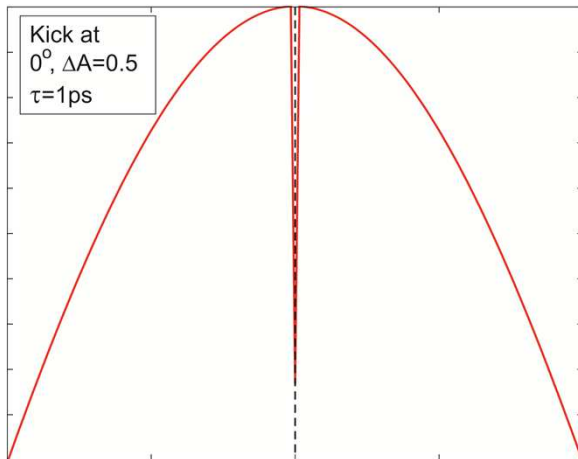
NUMERICAL CALCULATION RESULTS

The impact of kick position

$$\Delta A = -0.5$$

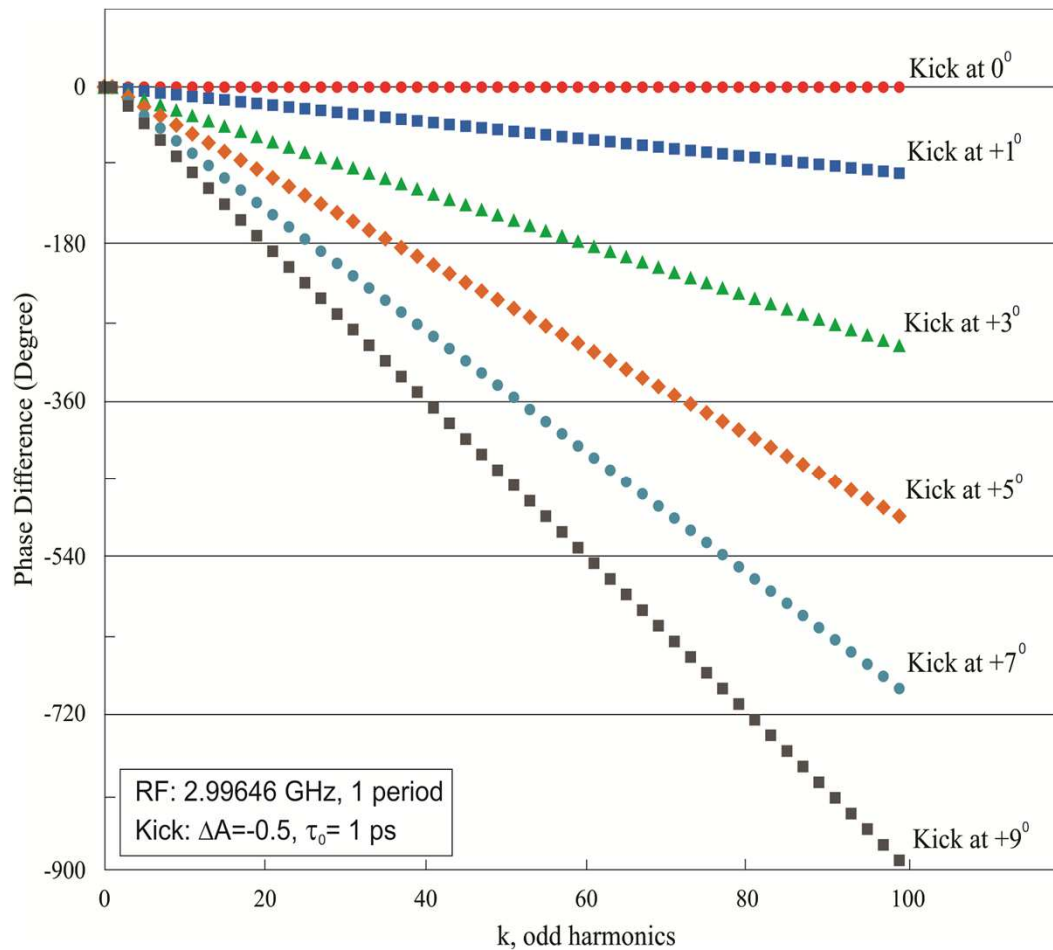
$$\tau_0 = 1 \text{ ps}$$

Kick at $0^\circ, +1^\circ, +3^\circ, +5^\circ, +7^\circ$ and $+9^\circ$



NUMERICAL CALCULATION RESULTS

The impact of kick position



- The dependence of phase difference on harmonic number is linear
- The value of difference phase has strong dependence on kick position.



The bunch position in respect to electromagnetic wave can be found by measuring the difference phase.

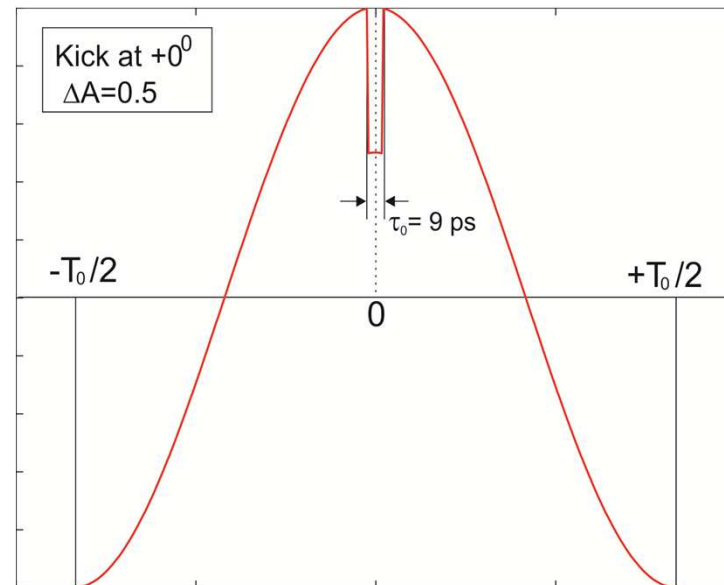
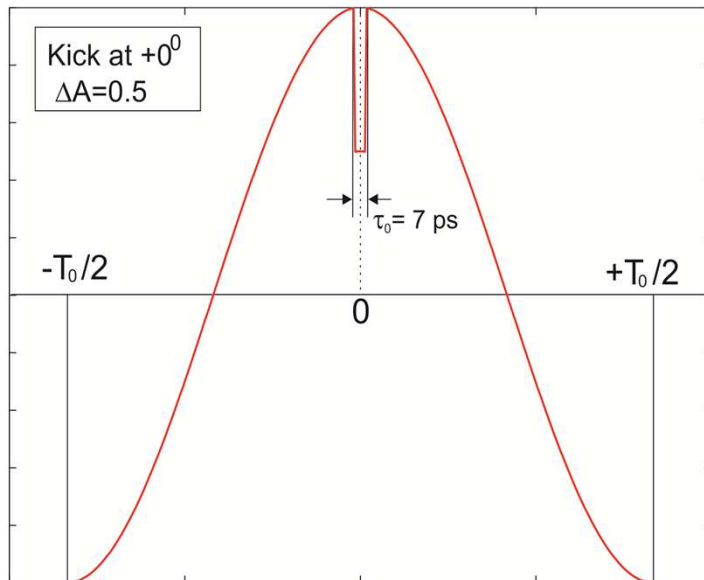
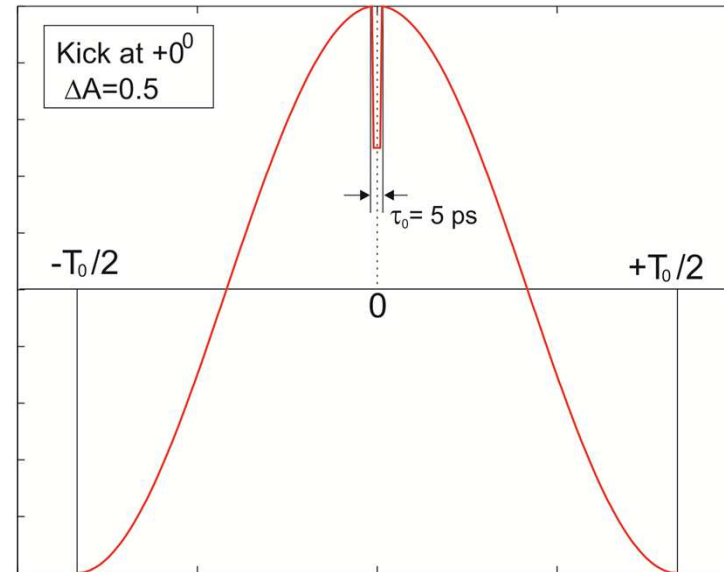
NUMERICAL CALCULATION RESULTS

The impact of kick duration

Kick position: 0°

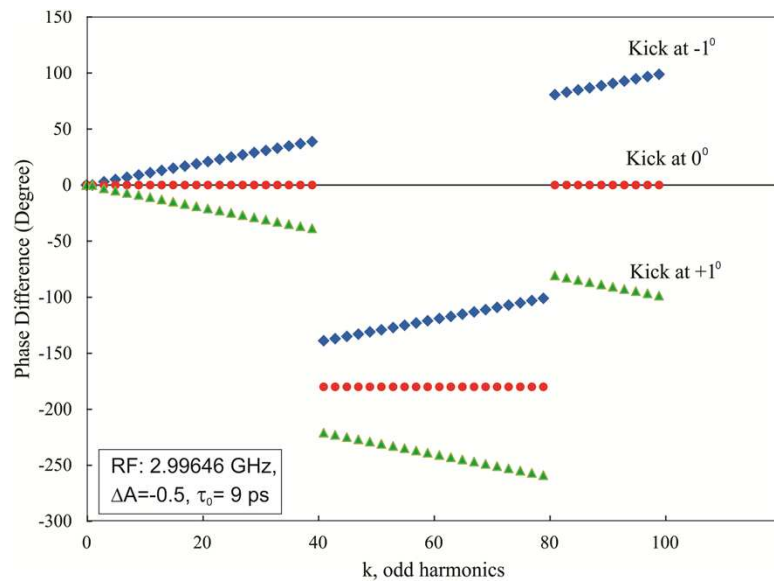
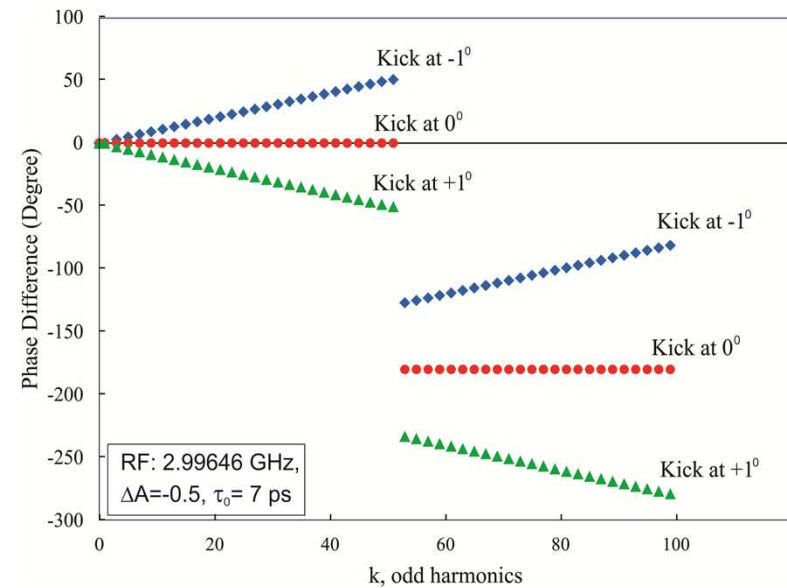
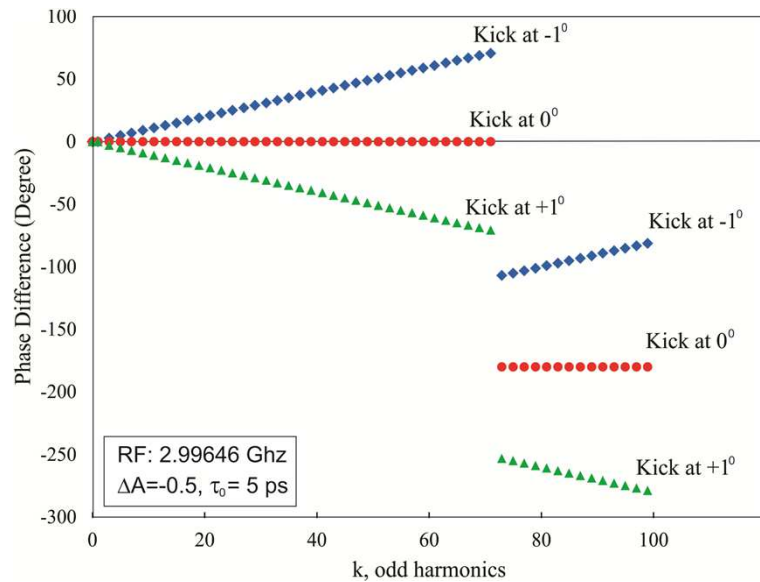
Amplitude: $\Delta A = -0.5$

Duration: $\tau_0 = 5, 7 \text{ and } 9 \text{ ps}$



NUMERICAL CALCULATION RESULTS

The impact of kick duration

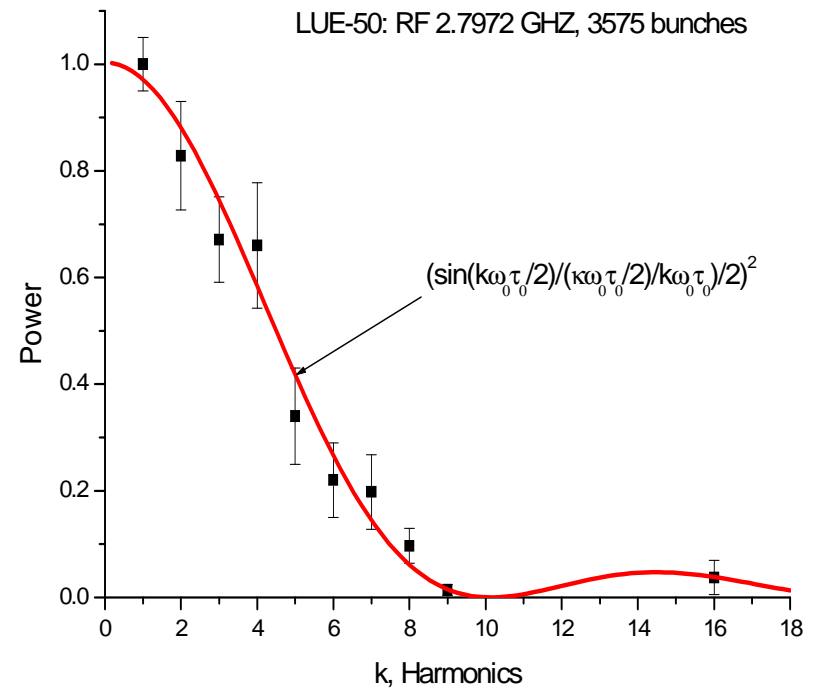
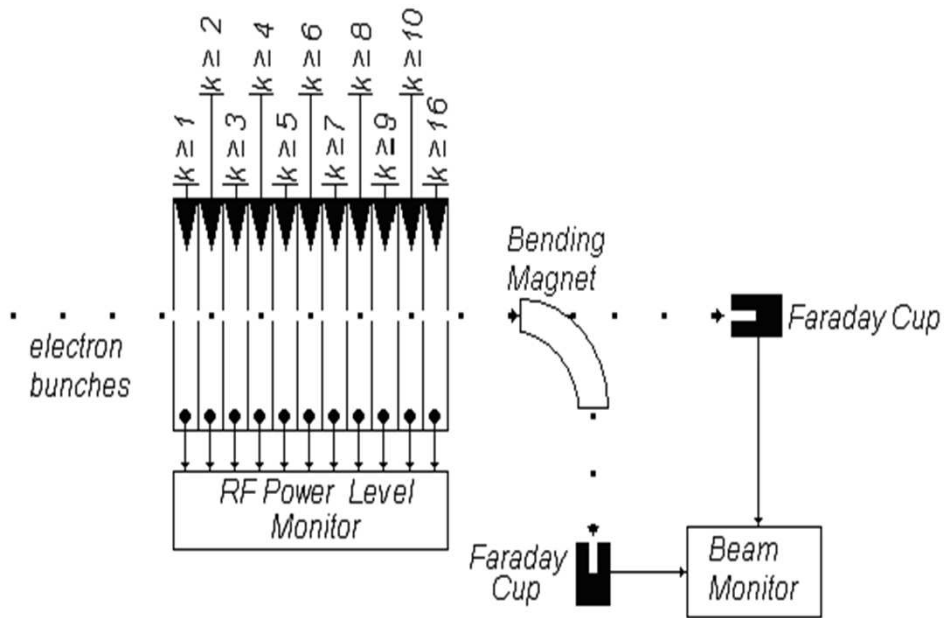


The difference phase spectrum also contains information concerning to the duration of the kick τ_0

SUMMARY

- The phase position of accelerated bunches can be measured by calculating the phase spectrum of disturbed signal.
- The difference phase spectrum is linearly dependent on the number of harmonics.
- The angle of inclination from the line is determined only by the phase position of accelerated bunches. Thus the possibility of measuring the phase position of the bunch in the accelerating electromagnetic waves in the microwave range ($k \leq 30$) is confirmed.
- The difference phase spectrum contains information about bunch duration

LUE-50 Results



LUE-50 Results

LUE-50: RF 2.7972 GHz, 3575 bunches

