Additive phase-noise in frequency conversion in LLRF systems

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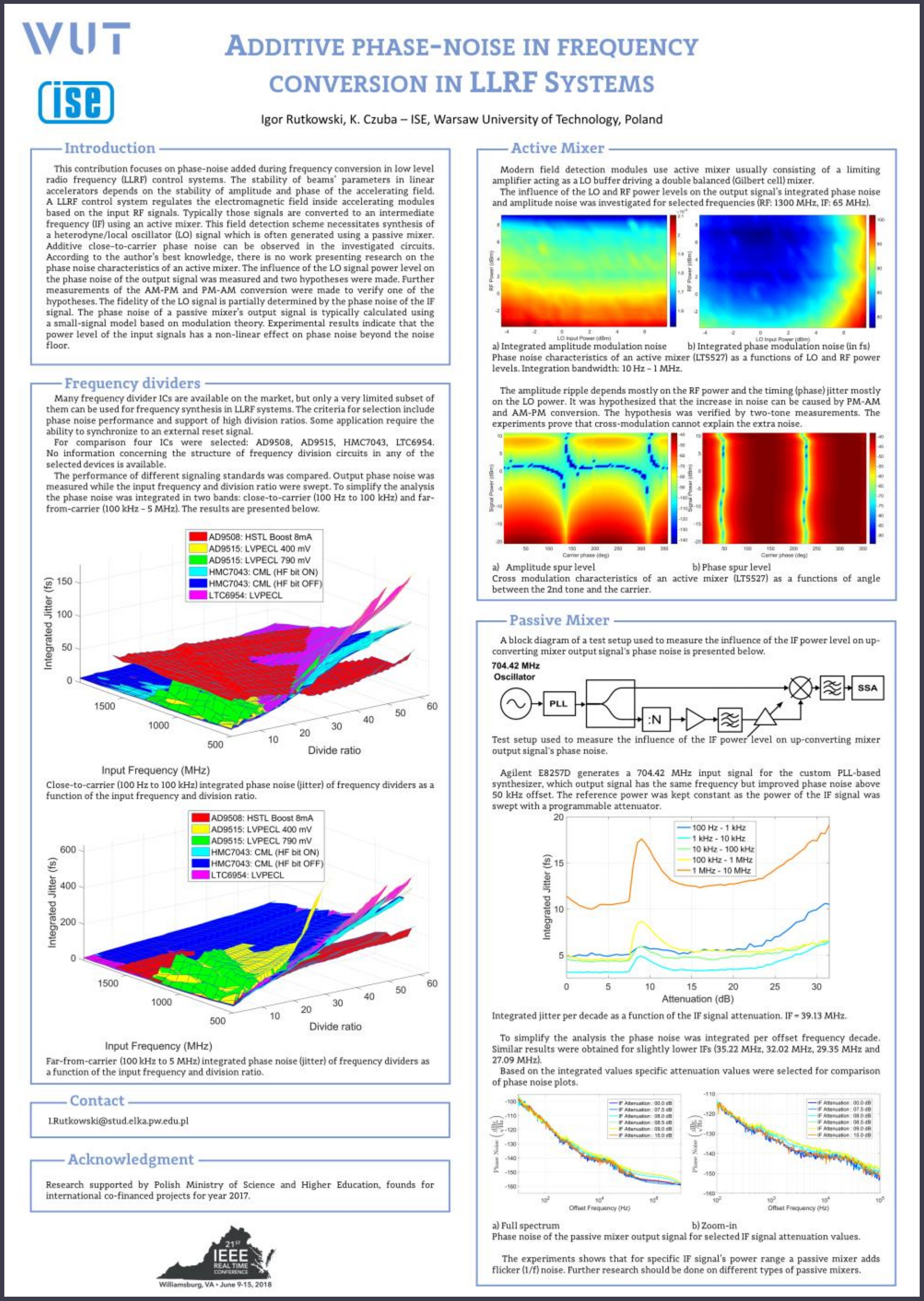
ABSTRACT

FREQUENCY DIVIDERS



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Introduction

This contribution focuses on phase-noise added during frequency conversion in low level radio frequency (LLRF) control systems. The stability of beams' parameters in linear accelerators depends on the stability of amplitude and phase of the accelerating field. A LLRF control system regulates the electromagnetic field inside accelerating modules based on the input RF signals. Typically those signals are converted to an intermediate frequency (IF) using an active mixer. This field detection scheme necessitates synthesis of a heterodyne/local oscillator (LO) signal which is often generated using a passive mixer. Additive close-to-carrier phase noise can be observed in the investigated circuits. According to the author's best knowledge, there is no work presenting research on the phase noise characteristics of an active mixer. The influence of the LO signal power level on the phase noise of the output signal was measured and two hypotheses were made. Further measurements of the AM-PM and PM-AM conversion were made to verify one of the hypotheses. The fidelity of the LO signal is partially determined by the phase noise of the IF signal. The phase noise of a passive mixer's output signal is typically calculated using a small-signal model based on modulation theory. Experimental results indicate that the power level of the input signals has a non-linear effect on phase noise beyond the noise floor.

Frequency dividers

Many frequency divider ICs are available on the market, but only a very limited subset of them can be used for frequency synthesis in LLRF systems. The criteria for selection include phase noise performance and support of high division ratios. Some application require the ability to synchronize to an external reset signal.

For comparison four ICs were selected: AD9508, AD9515, HMC7043, LTC6954. No information concerning the structure of frequency division circuits in any of the selected devices is available.

The performance of different signaling standards was compared. Output phase noise was measured while the input frequency and division ratio were swept. To simplify the analysis the phase noise was integrated in two bands: close-to-carrier (100 Hz to 100 kHz) and far-from-carrier (100 kHz – 5 MHz). The results are presented below.

Close-to-carrier (100 Hz to 100 kHz) integrated phase noise (jitter) of frequency dividers as a function of the input frequency and division ratio.

Far-from-carrier (100 kHz to 5 MHz) integrated phase noise (jitter) of frequency dividers as a function of the input frequency and division ratio.

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Active Mixer

Modern field detection modules use active mixer usually consisting of a limiting amplifier acting as a LO buffer driving a double balanced (Gilbert cell) mixer.

The influence of the LO and RF power levels on the output signal's integrated phase noise and amplitude noise was investigated for selected frequencies (RF: 1300 MHz, IF: 65 MHz).

a) Integrated amplitude modulation noise b) Integrated phase modulation noise (in fs)
Phase noise characteristics of an active mixer (LT5527) as a functions of LO and RF power levels. Integration bandwidth: 10 Hz – 1 MHz.

The amplitude ripple depends mostly on the RF power and the timing (phase) jitter mostly on the LO power. It was hypothesized that the increase in noise can be caused by PM-AM and AM-PM conversion. The hypothesis was verified by two-tone measurements. The experiments prove that cross-modulation cannot explain the extra noise.

a) Amplitude spur level b) Phase spur level
Cross modulation characteristics of an active mixer (LT5527) as a functions of angle between the 2nd tone and the carrier.

Passive Mixer

A block diagram of a test setup used to measure the influence of the IF power level on up-converting mixer output signal's phase noise is presented below.

Test setup used to measure the influence of the IF power level on up-converting mixer output signal's phase noise.

Agilent E8257D generates a 704.42 MHz input signal for the custom PLL-based synthesizer, which output signal has the same frequency but improved phase noise above 50 kHz offset. The reference power was kept constant as the power of the IF signal was swept with a programmable attenuator.

Integrated jitter per decade as a function of the IF signal attenuation. IF = 39.13 MHz.

To simplify the analysis the phase noise was integrated per offset frequency decade. Similar results were obtained for slightly lower IFs (35.22 MHz, 32.02 MHz, 29.35 MHz and 27.09 MHz).

Based on the integrated values specific attenuation values were selected for comparison of phase noise plots.

a) Full spectrum b) Zoom-in
Phase noise of the passive mixer output signal for selected IF signal attenuation values.

The experiments shows that for specific IF signal's power range a passive mixer adds flicker (1/f) noise. Further research should be done on different types of passive mixers.

M I X E R S

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