UNIVERSITY OF BIRMINGHAM

MICROWAVE INTEGRATED SYSTEMS LABORATORY

School of Electronic, Electrical and Computer Engineering

Tracking of Fluctuating Targets Using Stroboscopic Sampling

A. Bystrov and M. Gashinova

Presenter: Dr Alex Bystrov
a.bystrov@bham.ac.uk

CoSeRa 2013
17-19 September 2013
Bonn, Germany

Presentation Outline

- *Introduction.*
  - *Hardware limitations in case of UWB signals.*
  - *Methods of signal sampling.*
  - *Stroboscopic sampling.*
- *Analysis of stroboscopic rangefinder accuracy.*
  - *Principles of range measurement.*
  - *Distortion of signal envelope due to amplitude fluctuations.*
  - *Tracking error.*
- *Suggested Pseudo random stroboscopic sampling.*
  - *Description of the method.*
  - *Results and discussion.*
- *Conclusions.*

Introduction

Hardware limitation in case of UWB signals

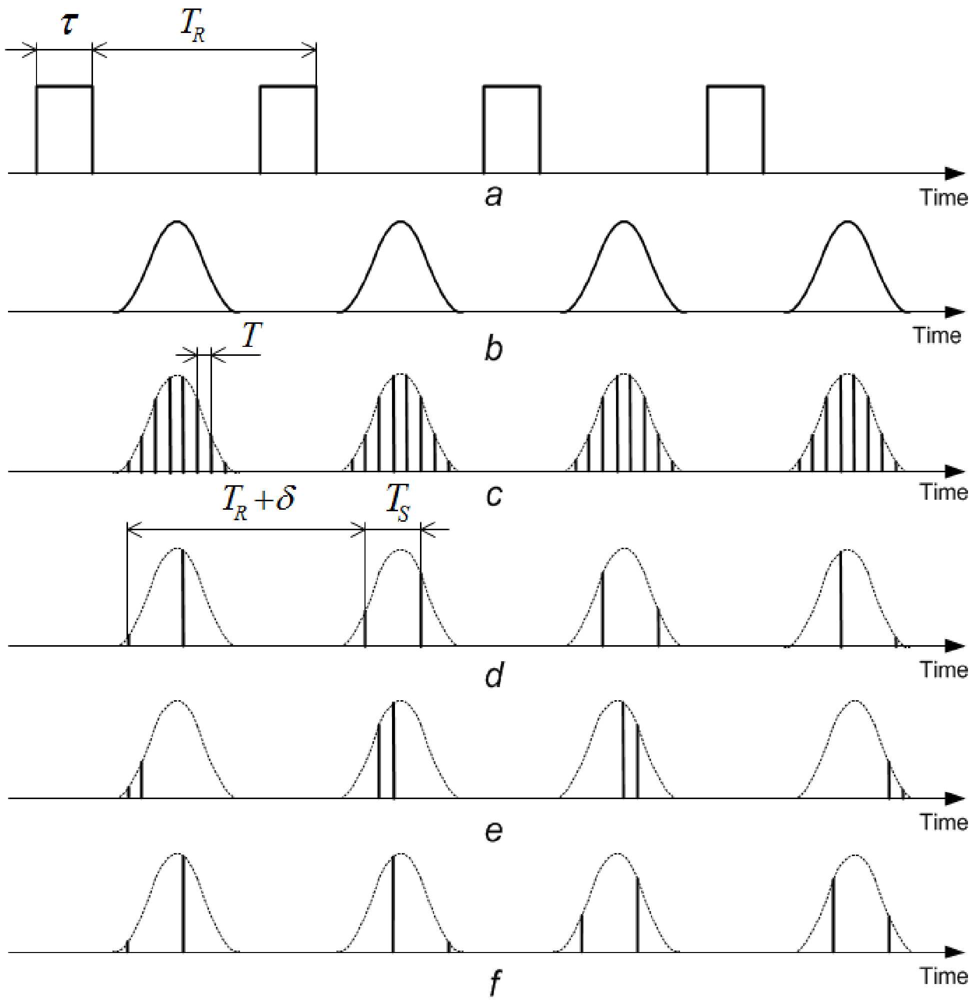
- The report examines the processing of radar signals in digital radar rangefinders.
- Due to wide spectral range of UWB signals, their Nyquist rates may exceed the specifications of the best analogue-to-digital converters (ADC).
- The considered method of ***stroboscopic sampling*** allows overcoming this limitation.
- A suggested pseudo random modification of the ***stroboscopic sampling*** method improves the accuracy of range measurement in the case of target amplitude fluctuations.

Signal Sampling Methods

In order to increase radar system performance special sampling methods are used:

- parallel sampling and parallel data processing
  leads to significantly higher hardware costs;
- low-digit (including binary) signal quantisation
  increases instrumental errors;
- Under-sampling, i.e. the sampling below the Nyquist frequency, including ***stroboscopic sampling*****.**

Signal Sampling Methods



Signal representation in the impulse radar

a Transmitted train of pulses
b Received pulses
c Real-time sampling
d Stroboscopic sampling (also known as equivalent time sampling or sequential sampling)
e Series-parallel sampling
f Pseudo random sampling

τ - pulse width,
T - real-time signal sampling interval (sampling at the Nyquist rate),
T_S - stroboscopic sampling interval;
T_R – pulse repetition interval;
δ - samples offset

Stroboscopic Sampling

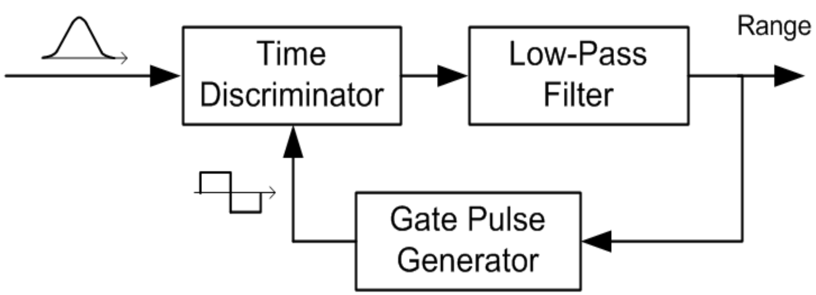
- Allows increasing the number of samples on a signal by their small offset $\delta = T_S / N$ from one pulse repetition interval to another, where N is the number of transmitted pulses needed to build the signal profile.
- Achieves a higher accuracy range measurement with lower sampling rate. In the limiting case ADC only needs to take one sample every pulse repetition interval so need for high speed ADC is avoided.
- The implementation of stroboscopic sampling does not require additional hardware.
- These are achieved in exchange for N times increased duration of distance measurement.

Number of samples per each signal in one pulse repetition interval $n_S = 2\tau / T_S$

Total number of samples per signal during one cycle of stroboscopic sampling $n = n_S N = 2\tau / \delta$

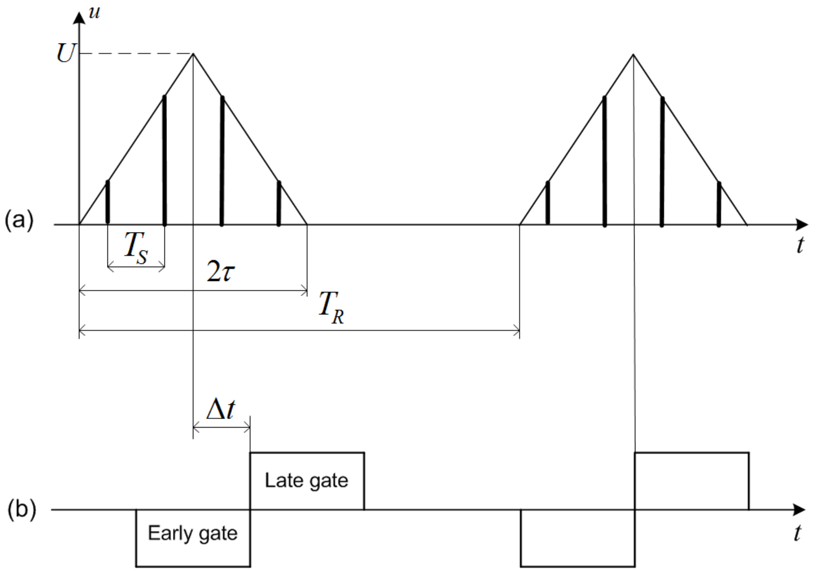
Radar Rangefinder Accuracy

Principles of Range Measurement



Rangefinder block diagram

A rangefinder provides the distance to the target.
Range tracking is carried out by the direct matching of a range gate position to the delayed echo pulse.



Signal processing in a range finder with a split gate time discriminator:
(a) – sampled signal,
(b) – early and late gates

Deviation of the pair of gates from the proper tracking position increases the signal energy in one gate and decreases it in the other, producing the error signal, which adjusts the pair of gates so as to establish equilibrium

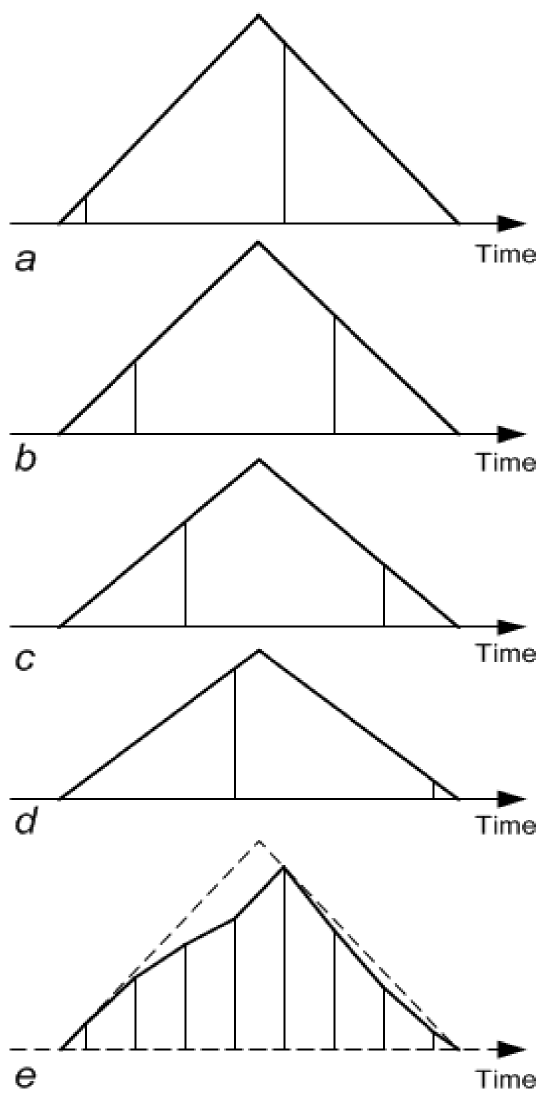
Distortion of Signal Envelope

During stroboscopic sampling the samples relating to different parts of the signal are taken at different pulse repetition intervals

The fluctuations in signal amplitude leads to distortion of a signal envelope

The output signal of time discriminator is different from zero even if tracking error is zero

Lower tracking accuracy



Target amplitude fluctuations:

a 1st period
b 2nd period
c 3rd period
d 4th period
e Restored signal envelope

Tracking Error

- Output signal of time discriminator in stroboscopic method at zero error:

$$Q_S(0) = -\sum_{j=0}^{N-1}\left\{\sum_{i=0}^{(n_S/2)-1} u(jT_R + iT_S + j\delta) - \sum_{i=n_S/2}^{n_S-1} u(jT_R + iT_S + j\delta)\right\}$$

where ***j*** – pulse repetition interval and ***i*** – number if signal sample.

- The simplified expression $$Q_S(0) = -\sum_{j=0}^{N-1} a_j\left(\sum_{i=0}^{(n_S/2)-1} u_{ij} - \sum_{i=n_S/2}^{n_S-1} u_{ij}\right)$$

whe u_{ij} - signal envelope a a_j - random amplitude fluctuations

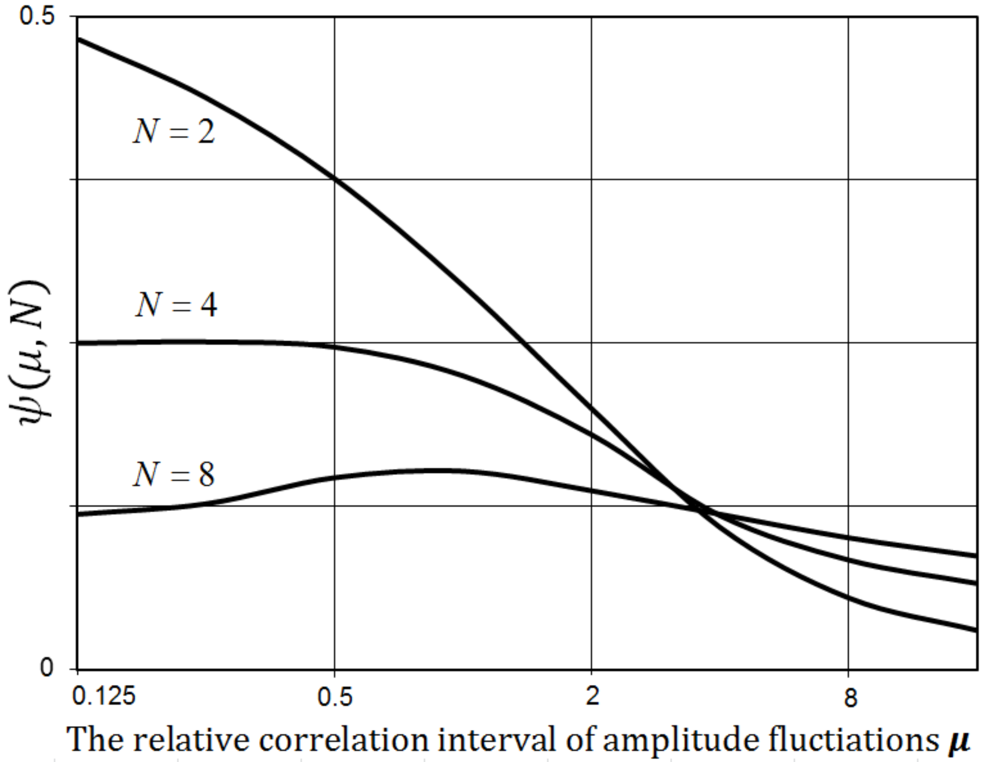
- The variance of tracking error due to target amplitude fluctuations at the output of time discriminator $$\boxed{\sigma_{a\_out}^2 = 4\sigma_a^2\tau^2 k_{dS}^2 \psi(N,\mu) / n_S^2 \propto N^2\psi(N,\mu)}$$

where σ_a^2 - variance of amplitude fluctuations,

k_{dS} - discriminator gain,

$\psi(N,\mu)$ - describes the dependence of the tracking error on the number of transmitted pulses used to build the signal profile and on the relative correlation interval of amplitude fluctuations $\mu = \tau_a / T_R$

Tracking Error



Influence of target amplitude fluctuation on the characteristics of time discriminator in case of maximum error (when n_S=1)

If $\tau_a >> T_R$ (Swerling I target fluctuation model), the signal can be considered non-fluctuating and $\psi(N, \mu) \approx 0$

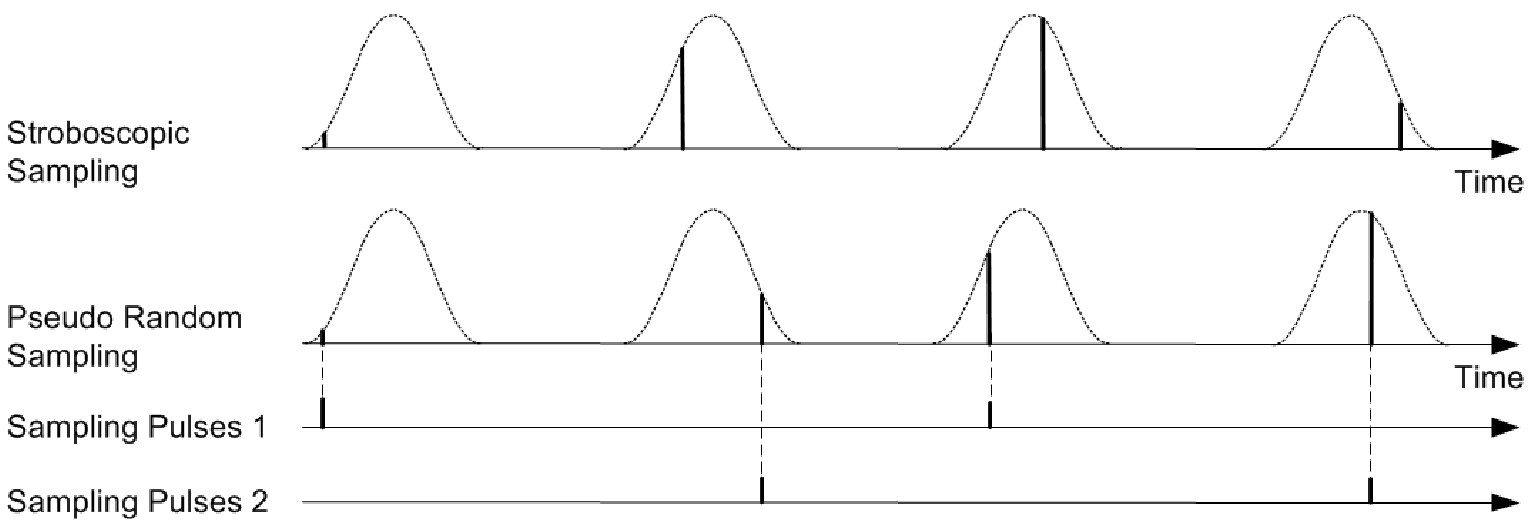
In case of small values of $\boldsymbol{\mu}$ the samples in the adjacent pulse repetition intervals are not correlated (Swerling II model) and $\psi(N, \mu) \approx 1/N$

To reduce the influence of target amplitude fluctuations, N should be reduced i.e. should be decreased the time during which the distance is measured. In this case the sampling frequency must be increased to maintain the same tracking accuracy.

Pseudo Random Stroboscopic Sampling

Pseudo Random Sampling

- The impact of amplitude fluctuations on the accuracy of range measurement can be reduced by a random distribution of samples on the duration of the signal.
- In pseudo random sampling method the signal samples shift in the adjacent periods in the opposite directions.
- Two sequences of sampling pulses are used: odd samples are taken from the first sequence of sampling pulses, even samples - from the second sequence.



UNIVERSITY OF BIRMINGHAM

Tracking Error (Pseudo Random Sampling)

- Output signal of time discriminator in stroboscopic method at zero error:

$$Q_S(0) = -\sum_{j=0}^{N-1}\left\{\sum_{i=0}^{(n_S/2)-1} u(jT_R + iT_S + j\delta) - \sum_{i=n_S/2}^{n_S-1} u\left[jT_R + iT_S + (N/2 - j)\delta\right]\right\}$$

where j – pulse repetition interval and i – number if signal sample.

- The simplified expression $Q_S(0) = -\sum_{j=0}^{N-1} a_j \left(\sum_{i=0}^{(n_S/2)-1} u_{ij} - \sum_{i=n_S/2}^{n_S-1} u_{i,(N/2)-j}\right)$

where u_{ij} signal envelope and a_j random amplitude fluctuations

- The variance of tracking error due to target amplitude fluctuations at the output of time discriminator

$$\boxed{\sigma^2_{a\_out} = 4\sigma_a^2 \tau^2 k_{dS}^2 \varphi(N,\mu) / n_S^2 \propto N^2 \varphi(N,\mu)}$$

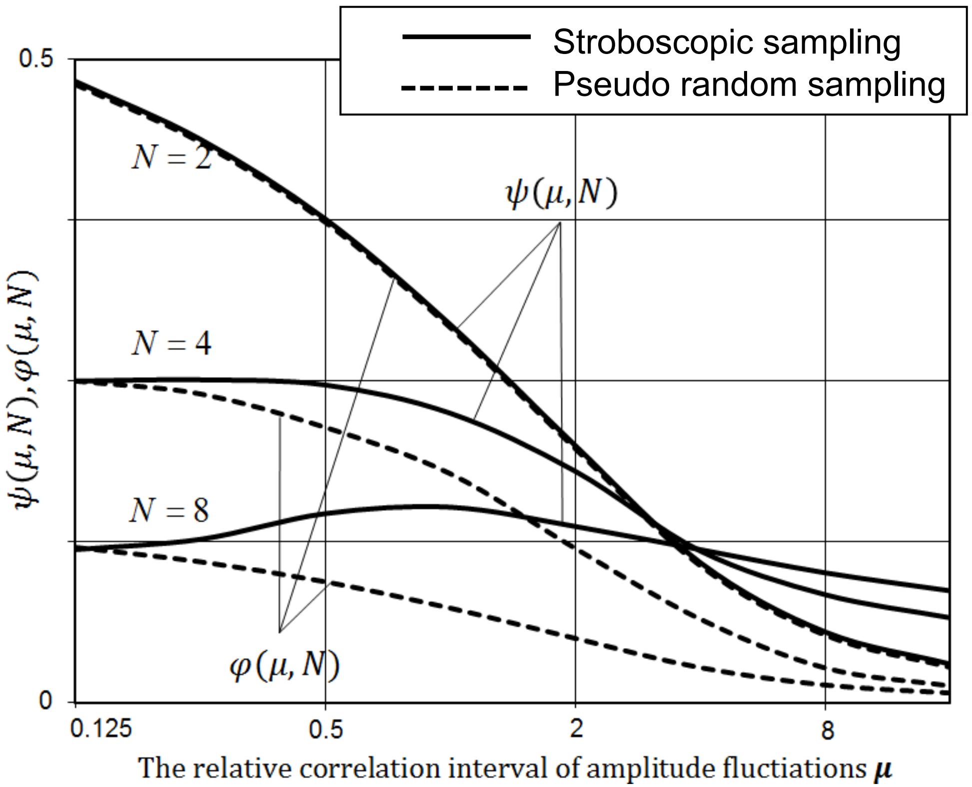
where σ_a^2 - variance of amplitude fluctuations,

k_{dS} - discriminator gain,

$\varphi(N,\mu)$ - describes the dependence of the tracking error on the number of transmitted pulses used to build the signal profile and on the relative correlation interval of amplitude fluctuations $\mu = \tau_a / T_R$

UNIVERSITY OF BIRMINGHAM

Tracking Error



Influence of target amplitude fluctuation on the characteristics of time discriminator in case of maximum error (when n_S=1)

The proposed method of pseudo random stroboscopic sampling provides significantly smaller variance of time discriminator output error than the common method.

If $n_S = 1$ and $N \geq 4$, the power gain at μ =0.5 is approximately 1.2-1.4 times (0.8-1.5 dB), while at μ =2 it is 1.5-2.5 times (1.8-4 dB).

If measurement is based on several pulse repetition intervals, then random sampling may have advantages over uniform. This is especially true when the fluctuations are high.

Conclusions

- The report analyses the tracking error of a digital radar rangefinders, caused by signal amplitude fluctuations .
- The expressions were obtained for the random error of tracking in the radar rangefinder with the stroboscopic signal sampling.
- A modification of the stroboscopic sampling method with pseudo random distribution of samples on the duration of the signal was suggested.
- The results of simulation show that the proposed method allows reducing a random error of tracking, caused by the amplitude fluctuations of a signal.
- This method is efficient in comparison with the conventional method in case of low sampling frequency (one or two samples on a signal duration).

Thank you