Sharper Images with Smart Sound: Optimized Chirp Signals for Scanning Acoustic Microscopy

Signal Design and Pulse Compression for High-Resolution Ultrasonic Imaging

Type of Thesis: Diploma, master, bachelor, student thesis

Suitable for: computer science, Robotics

Motivation & Background:

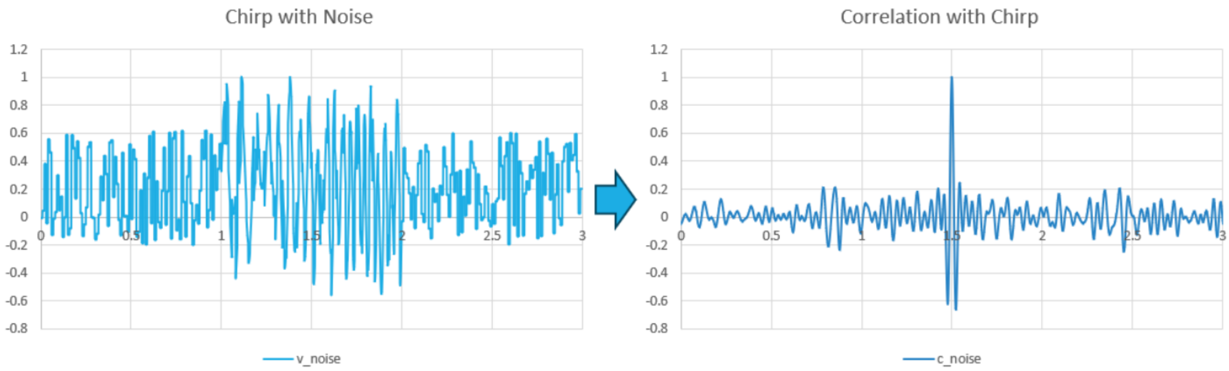
Ultrasound is widely used in medical diagnostics and non-destructive material testing. Modern ultrasonic systems increasingly incorporate advanced signal processing techniques originally developed in **communications engineering**, enabling improved image quality and measurement sensitivity. Many of these developments were pioneered in medical imaging systems and are now gradually being transferred to other ultrasonic platforms.

One such platform is **Scanning Acoustic Microscopy (SAM)**, which allows high-resolution imaging of internal structures in microelectronic devices, advanced materials, and biological samples. SAM systems often operate at very high ultrasonic frequencies to achieve micrometer-scale spatial resolution.

However, conventional **short-pulse excitation** reaches fundamental limitations at high frequencies. To achieve sufficient axial resolution, the acoustic pulses must become increasingly short. Short pulses contain less energy, resulting in lower acoustic amplitudes and reduced signal-to-noise ratio (SNR). At the same time, acoustic attenuation in materials increases strongly with frequency—often proportional to the square of the frequency—requiring higher signal energy to maintain image quality.

This trade-off between **resolution, attenuation, and signal energy** limits the performance of classical pulse-based SAM systems.

A promising solution is the use of **pulse compression techniques**, which are widely used in radar and communication systems. The key idea is to transmit a longer signal that contains more energy and then reconstruct a short effective pulse through signal processing at the receiver.



One particularly versatile approach uses **chirp signals**, in which the excitation frequency is swept over time. Chirp signals allow:

- efficient transmission of high signal energy

- flexible control of the frequency bandwidth
- improved signal-to-noise ratio after pulse compression
- potential bandwidth extension of ultrasonic transducers through tailored amplitude shaping

By combining optimized excitation signals with appropriate signal processing techniques, it may be possible to significantly improve the performance of scanning acoustic microscopy systems.

Goals & Objectives:

The primary goal of this thesis is to **develop and evaluate optimized chirp excitation signals for high-resolution imaging of microelectronic samples using Scanning Acoustic Microscopy (SAM).**

To achieve this, both the **transmitted excitation signal** and the **receiver signal processing chain** must be investigated and optimized together.

The work will focus on:

- Design and simulation of chirp excitation signals with different bandwidths and modulation characteristics
- Evaluation of pulse compression techniques for ultrasonic imaging
- Investigation of the interaction between excitation signal design and signal reconstruction algorithms
- Experimental validation of the optimized approach using SAM measurements on microelectronic samples

A key aspect of the work is identifying and exploiting **cross-dependencies between signal excitation and receiver processing**, enabling improved image quality and signal-to-noise ratio.

Milestones:

M1: Literature review on pulse compression techniques, chirp signals, and their applications in radar, communications, and ultrasonic imaging.

M2: Development and implementation of the signal processing chain for pulse compression using simulated signals.

M3: Design of candidate excitation signals and simulation-based evaluation of their performance.

M4: Integration of the excitation signals into the experimental SAM setup and validation of the signal processing chain with first measurements.

M5: Acquisition of experimental data using different chirp signal configurations.

M6: Data analysis to identify dependencies between transducer characteristics, excitation signals, and reconstruction algorithms.

M7: Definition and experimental validation of optimized excitation signals for improved SAM imaging performance.

Character of the work:

20 % Literature review and concept development, 40 % Signal design, simulation, and algorithm development, 40 % Experimental work and data evaluation

Supervision & Workflow:

- Meetings: weekly meetings between student and supervisor to evaluate status and progress and identify need for support; time and location (also possibly online) will be determined at the beginning of the work; additional meetings for any necessity are highly encouraged

- Lab works: The project pursues several works in the lab, which requires a reliable and structured workflow. Furthermore, the student will get a safety briefing for the house and the lab and the clean room.
- Weekly reports: The student is required to write a weekly report at the end of each week and to send it to his advisors or document it in git. The idea of the weekly report is to briefly summarize the work, progress, and any findings made during the week, to plan the actions for the next week, and to bring up open questions and points. The weekly report is also an important means for the student to get a goal-oriented attitude to work.
- Mid-term presentation: Students are encouraged to give a mid-term presentation as a preparation for the final presentation of the thesis. This is an opportunity to discuss the results with a broader audience and get important feedback on the current state of the work.

Technical Details:

- A **commercial Scanning Acoustic Microscope (SAM)** is available and can be used to experimentally test the developed excitation signals and the corresponding signal processing chain.
- The work can build upon an **existing Python-based simulation framework** that allows simulation of ultrasonic wave propagation with arbitrary excitation signals.
- The thesis combines **signal design, numerical simulation, and experimental validation** using the SAM platform.
- Basic experience with **Python, signal processing, or data analysis** is required.

Supervisor: Dipl.-Ing. Emanuel Leipner