Master Thesis at the Department of Information Technology and Electrical Engineering

Autumn Semester 2025

# Analog waveform generation for future Point-of-Care Dielectrophoretic devices

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| Start: | September 1, 2025 |
| Due: | TBD |

# 1 Introduction

## 1.1 Dielectrophoresis

Dielectrophoresis (DEP) is a powerful, label-free technique for manipulating dielectric particles using non-uniform electric fields. When exposed to non-uniform fields, a dipole moment is induced on the particle, which becomes polarized [1] (see Fig. 2). Consequently, depending on the relative permittivity (dielectric constant) of the particle and the surrounding medium, two effects can take place:

- Positive DEP (pDEP): The particle moves toward regions of stronger electric field (if it's more polarizable than the medium).
- Negative DEP (nDEP): The particle moves toward weaker field regions (if it's less polarizable than the medium).

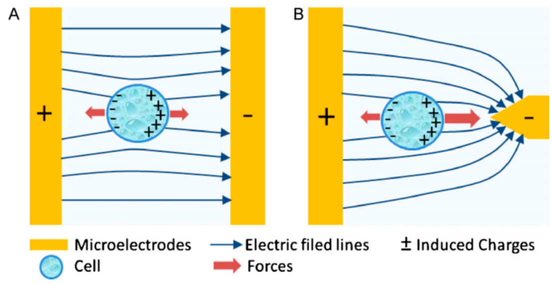


Figure 1: Principle of pDEP: dielectric particle immersed in a non-uniform static electric field (figure taken from: Zhang et al. [2])

While non-uniform DC electric field can be used, time-varying (AC) electric fields are the most common choice, which results in a net-force being a function of:

- the permittivity of the medium
- particle radius
- root-mean-square electric field
- a complex function of the particle and medium permittivity (and frequency)

Commonly, a sinusoidal signal is preferred (i.e., single frequency stimulus).

## 1.2 DEP for particle sorting

DEP has been employed for multiple applications, such as **particle sorting**, enabling the sorting of particles according to their size, shape, and dielectric properties [3, 4].[1]

One possible design topology for DEP particle sorting is based on inter-digitated electrodes. Such electrodes are integrated as part of a microfluidic chamber, which flows particles in an electrolytic solution. Fig. 2 shows one example of such a device. An AC voltage is applied to such electrodes (20 Vpp at 1 MHz [2]) to generate the time-varying electric field inside of the fluidic chamber.

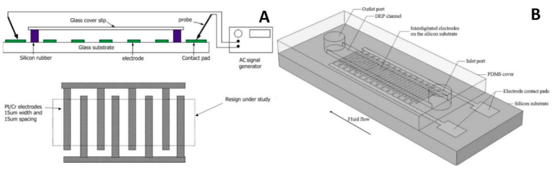


Figure 2: DEP with inter-digitated electrodes (image taken from [2]).

A more advanced and promising approach is offered by **microfabricated 3D pillars**. The generation of DEP forces using planar electrodes is limited by the confinement of the electric field to regions close to the electrode surface (especially in physiologic high-salinity media where the voltage amplitude must be restricted to prevent water electrolysis and bubble formation). In contrast, three-dimensional electrodes can generate localized DEP forces at lower applied voltages (a few tens of volts) and support higher sorting throughput, as they produce a uniform electric field across the entire channel thickness.

The Laboratory of Life Sciences Electronics at EPFL pioneered the design of new microstructures for DEP-based applications [5] (see Fig. 3). This project aims to advance the interfacing and use of these microstructures for DEP.

## 1.3 Challenges for signal generation

DEP-based particle manipulation is a widely researched technique. Yet, it is often based on *bulky equipment with a limited number of output channels*, hampering its use outside of dedicated research laboratories. The 3D-micropillar system is also currently operated with a benchtop instrumentation, generating sinusoids at up to 10 MHz and 10 Vpp. The availability of compact, portable, programmable DEP devices can enable a more widespread use in general biology or chemical labs. *This project aims to advance the DEP control signal generation, to enable standalone integration in an ultra-portable solution.*

[1] Since dielectric properties are frequency-dependent, DEP can be used to selectively manipulate different particles by tuning the field frequency.

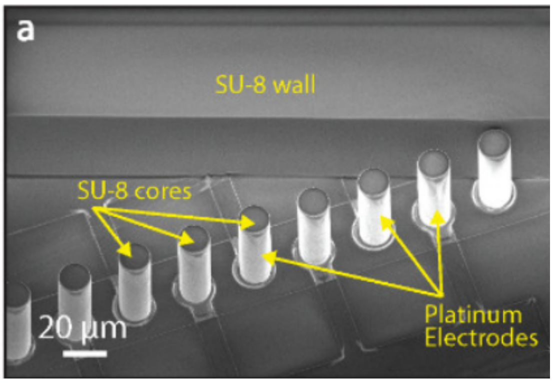


Figure 3: 3D electrodes for DEP (image taken from [5]).

### 1.3.1 Signal generation systems

The work of [6] is another example of a benchtop-instrumentation-based setup. A function/arbitrary waveform generator (33220A LXI, Agilent technologies) is coupled with an amplifier (A400DI, FLC Electronics; covering from DC to 500 kHz, 150mA full scale, fixed gain 20x), to deliver ≈80 Vpp over the investigated frequency range (30 kHz – 1 MHz).

The work of [7] is an initial attempt at implementing a microcontroller-based signal generation, using an ATMEGA connected to a custom signal-generator in the frequency range of 100 Hz to 100 kHz.

In [8], DEP sinusoidal signals were generated starting from a square-wave generator (LTC6902), followed by a power driver to increase current output capabilities (boosting up to 4A) and a class-E amplifier (LC topology). This design resulted in 4 channels, with 90deg phase shift, operating at 1 MHz and 1-15 Vpp.

The ADEPT platform [9, 10] is a representative portable system built around an Arduino Mega, which was also open sourced: `https://github.com/on6315/ADEPT_DEP_Module/tree/main`. The system connects to 6 microelectrodes and can provide three alternative (multiplexed) signals: GND, a fixed DC value, or a mix of sinusoids (5V, 0 – 12.5 MHz). Both frequency and phase shift can be tuned for each electrode. The design is based on a direct digital synthesizer (DDS) (AD9913), which generates the control signal with variable frequency and phase. The current output signal of the DDS is converted to a voltage output signal using a differential opamp configuration. An amplifier stage with digital potentiometers follows it to vary the amplitude of the control signal. An Arduino Mega is used to control the frequency (10 Hz – 30 MHz with a step size of 0.058 Hz), phase (0° to 360° with a phase tuning resolution of 0.022°) and amplitude (0 – 20 Vpp) of the output signal.

This project aims to provide a more advanced solution, further expanding the voltage range, frequency range, and number of channels of these prior designs.

## 2 Project Description

This project is in collaboration with the Laboratory of Life Sciences Electronics at EPFL, making use of the DEP system based on 3D micropillars.

The student will design a new compact solution to generate the control signals of the DEP platform. The design will feature:

- at least 6 independent signal channels
- covering a frequency range from 10 kHz to 30 MHz (ideally up to 50 MHz)
- covering a voltage range from 1V to 40 V

A microcontroller-based approach with a DDS will be considered as a starting point (e.g. taking inspiration from the ADEPT system).

- **Task I - Literature review:** The project will start by performing a literature review on DEP systems. The goal is to get acquainted with the most common approaches of signal generation for DEP. The student is expected to prepare a presentation with the findings and a proposal for system/circuit topology to be implemented.
- **Task II - Electromagnetic simulations:** considering the DEP system under test (based on 3D micropillars), the aim of this task is to characterize the signal propagation through the traces. In particular, the goal is to understand how much voltage drop is present along the metal traces, supporting the design of new and optimized electrodes structures at EPFL.
- **Task III - Circuit and system design:** Design the circuit for sinusoid generation (with the aid of analog circuit simulations, when needed).
- **Task IV - Firmware development:** This task develops the firmware of the microcontroller to enable real-time adjustment of measurement parameters. A simple user-interface (e.g. via UART from the laptop) will also be implemented.
- **Task V - Validation in DEP experiments:** The developed system will be used to perform DEP particle separation experiments at EPFL.
- **Task VI - quadrature signals (optional):** This task aims to expand the capabilities of the developed system in terms of phase alignment of different channels. The students will adapt the design to enable the generation of 4 signals in quadrature. Such design improvement will also enable electro-rotation applications [11].
- **Task VII - Report and Presentation work:** Work on the final report and presentation for the group.

## 3 Milestones

1. **M1:** Presentation about SoA findings.
2. **M2:** Signal propagation characterization via em simulations.
3. **M3:** Circuit topology defined.
4. **M4:** Circuit implemented and characterized.
5. **M6:** DEP experiments with the designed circuit.
6. **M7:** Presentation and final Report.

## 4 Project Realization

### 4.1 Project Plan

Within the first week of the project, you will be asked to prepare a project plan. This plan should identify the tasks to be performed during the project and sets deadlines for those tasks. The prepared plan will be a topic of discussion of the first week's meeting between you and your advisers. Note that the project plan should be updated constantly depending on the project's status.

### 4.2 Meetings

Weekly meetings and reports must be held. The exact time and location of these meetings will be determined within the first week of the project in order to fit the student's and the assistant's schedule. These meetings will be used to evaluate the status and progress of the project. Besides these regular meetings, additional meetings can be organized to address urgent issues as well.

### 4.3 Report

Documentation is an important and often overlooked aspect of engineering. One final report has to be completed within this project. The common language of engineering is de facto English. Therefore, the final report of the work is preferred to be written in English. Any form of word processing software is allowed for writing the reports, nevertheless, the use of LaTeX with Tgif[2] or any other vector drawing software (for block diagrams) is strongly encouraged by the IIS staff.

[2] See: `http://bourbon.usc.edu:8001/tgif/index.html` and `http://www.dz.ee.ethz.ch/en/information/how-to/drawing-schematics.html`.

**Final Report** The final report has to be presented at the end of the project and a digital copy needs to be handed in. Note that this task description is part of your report and has to be attached to your final report.

### 4.4 Presentation

There will be a presentation (15 min for the semester thesis, and 20 min for the MS thesis presentation followed by 5 min Q&A) at the end of this project in order to present your results to a wider audience. The exact date will be determined towards the end of the work.

## References


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Zurich, July 15, 2025 Prof. Dr. Luca Benini