Low noise, low power capacitive sensors for tagless indoor human localization and identification

Mihai Lazarescu, Luciano Lavagno
Politecnico di Torino
Dip. Elettronica e Telecomunicazioni
mihai.lazarescu@polito.it, luciano.lavagno@polito.it

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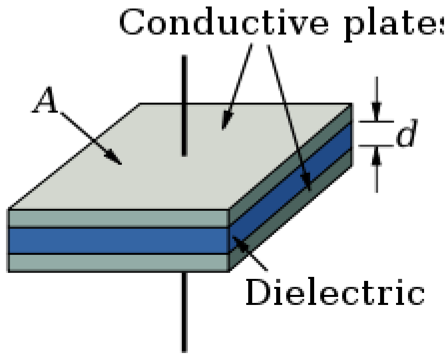
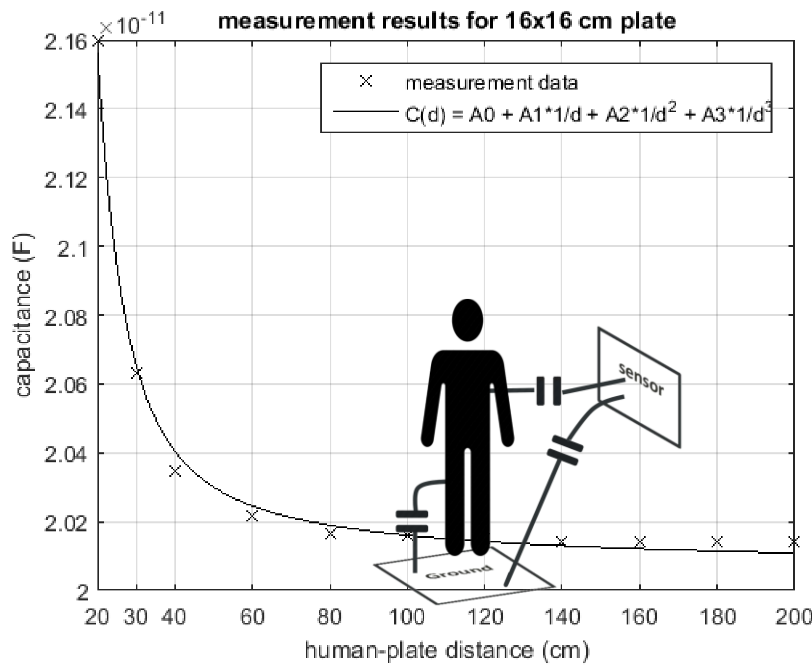
Why long-range indoor capacitive *sensing*?

- Enabler for many automation and monitoring applications
- Can be small, inexpensive, easy to install and operate
- Generally have low accuracy and low range
- Need very low noise measurement ($C \sim A / d^{2 \div 3}$)
- Sensor data post-processing
  - Improve SNR ($\Delta C < 0.01\%$)
  - Infer human identity, location and behavior

Measurement challenges

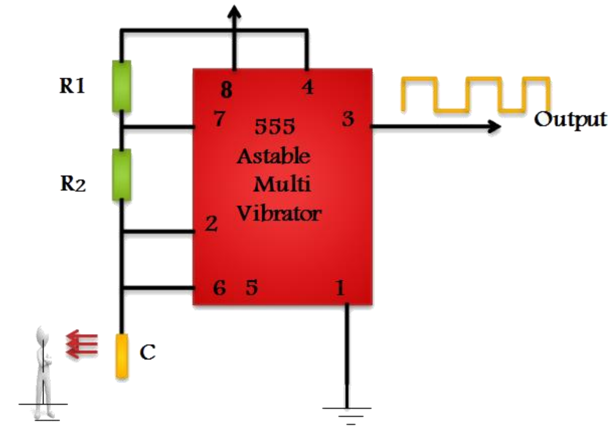
- Planar capacitors: √**A >> d**
  - C = ε **A / d**
- Load-mode sensors: **d >>** √**A**
  - C ~ **A / d**$^{2\div3}$
- d (meters) >> √A (tens of cm):
  - Very low ΔC (< 0.01%)
  - Very high sensitivity
  - Very high noise rejection

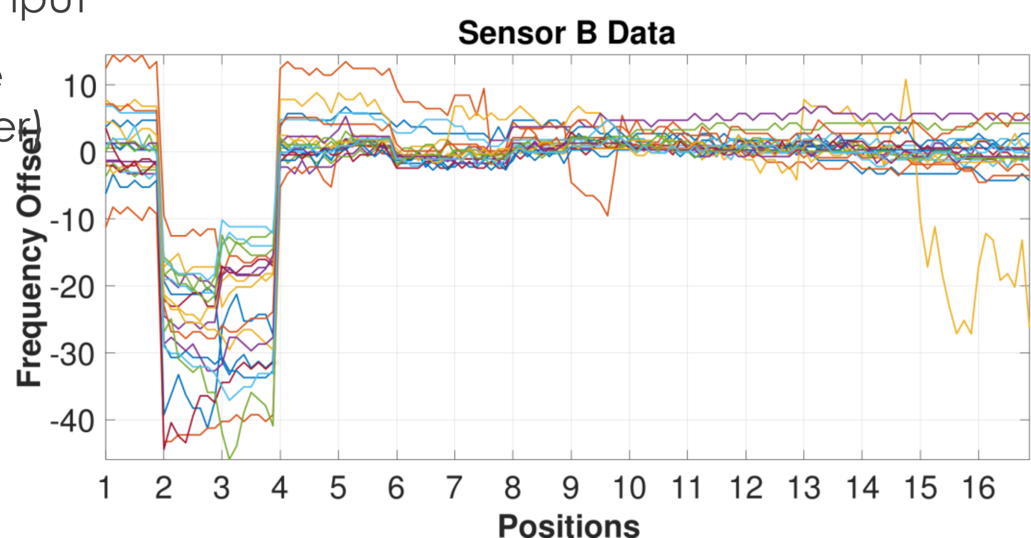




Single-plate threshold-based measurement front-end

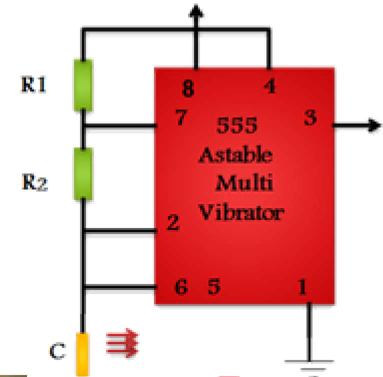
- C = Q / V
  - Control Q flow, set V thresholds
  - Measure f ~ 1 / time-to-V threshold
- Simple, cheap, low-power
- Low C, low I for kHz-range f (lower quantization noise)
  - Very high impedance input
  - Susceptible to EM noise (Vnoise => f value & jitter)
  - Susceptible to drift (low frequency noise)
  - Difficult noise filtering
- Low SNR overall





Main sources of noise

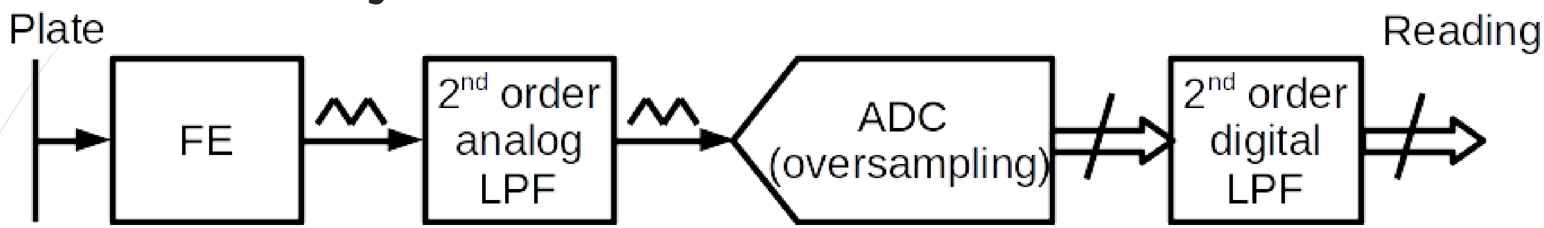
- Drift due to static charges (low frequency)
  - Change plate potential to environment
  - Variable with body movement, charge migration
  - Asymmetric influence on plate charge/discharge currents



From explainthatstuff.com

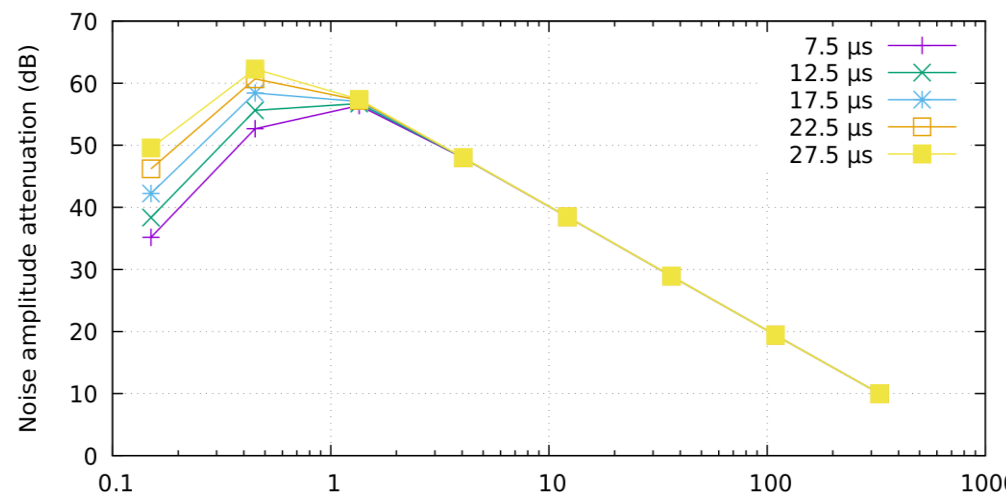
- Environmental noise (high freq.)
  - Jitter and reduced osc. Period (plate reaches unpredictably and earlier voltage thresholds)
- **Fix: 1.** voltage thresholds **2.** compensate current asymmetry

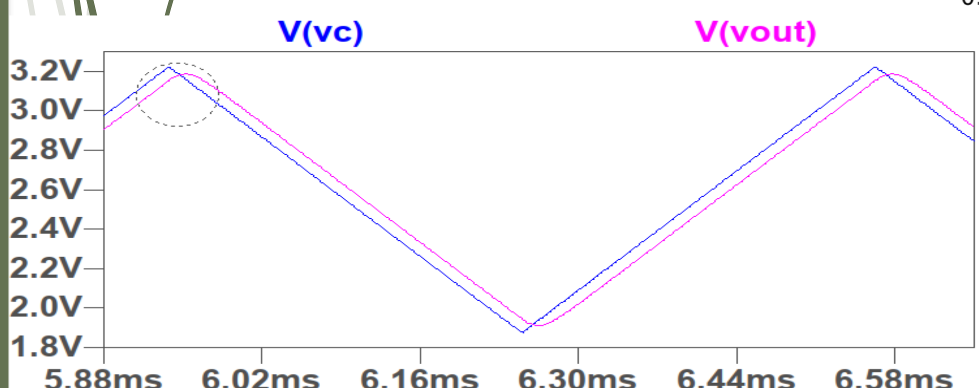
Drift rejection



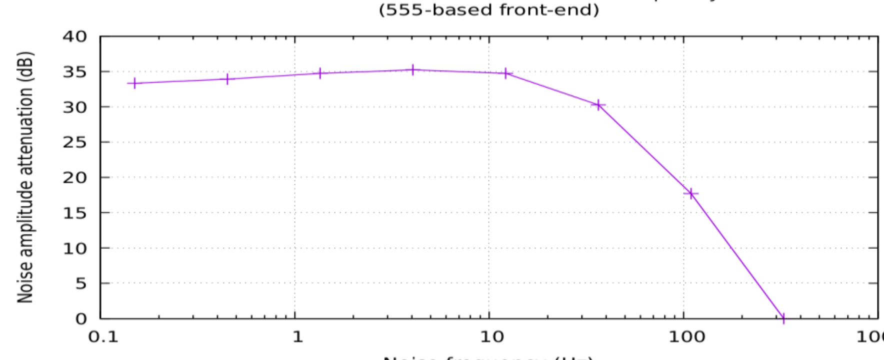
- Ignore non-linearities at ramp ends
- High attenuation for low frequencies (drift)
- Simulation noise at high attenuation

Noise attenuation function of noise frequency and measurement separation from ramp ends (with second order 20 kHz cutoff antialias filter)



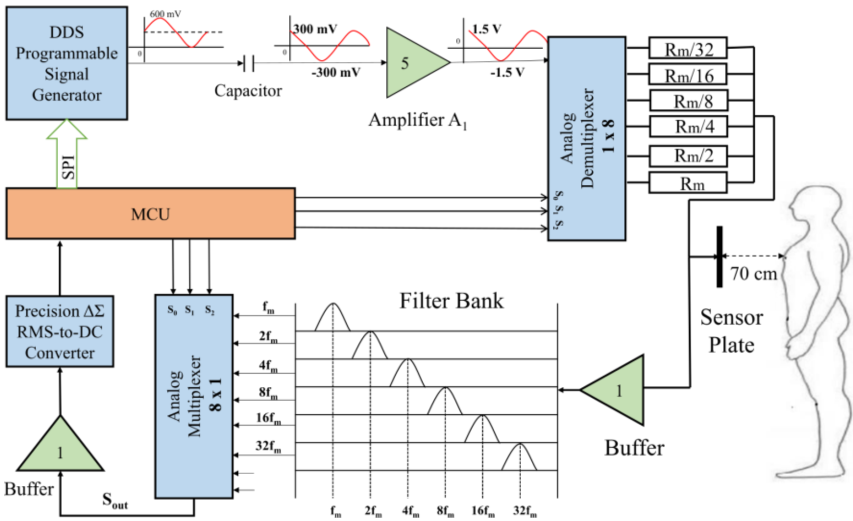


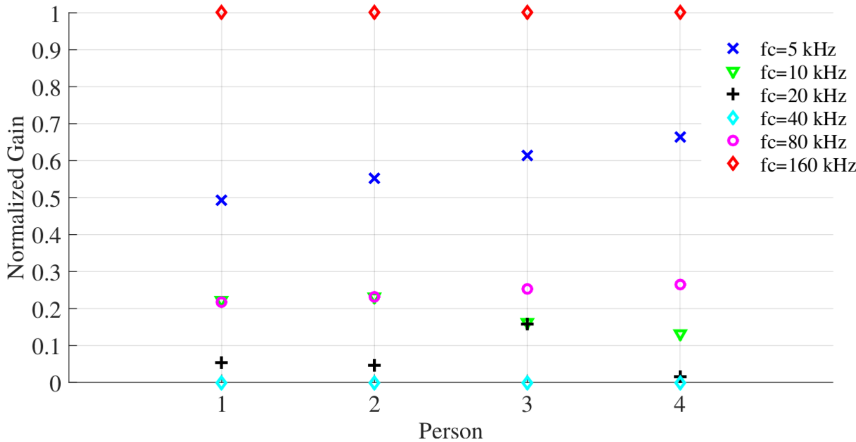
Noise attenuation function of noise frequency (555-based front-end)



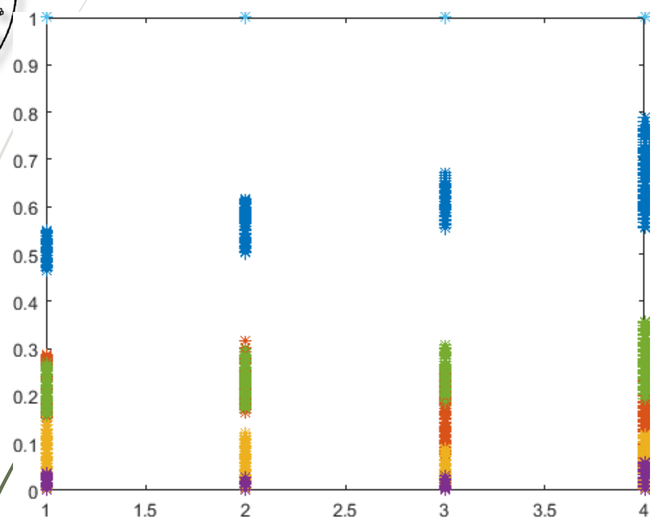
Human identification

- Measure the body-sensor capacitance at several frequencies at (almost) the same time
- Capacitance-frequency dependency pattern depends on body properties (tissue ratios, shape, …)
- Distinct patterns can identify persons from a limited pool
- Monitor passage through doors





Embedded low power Neural Network inference

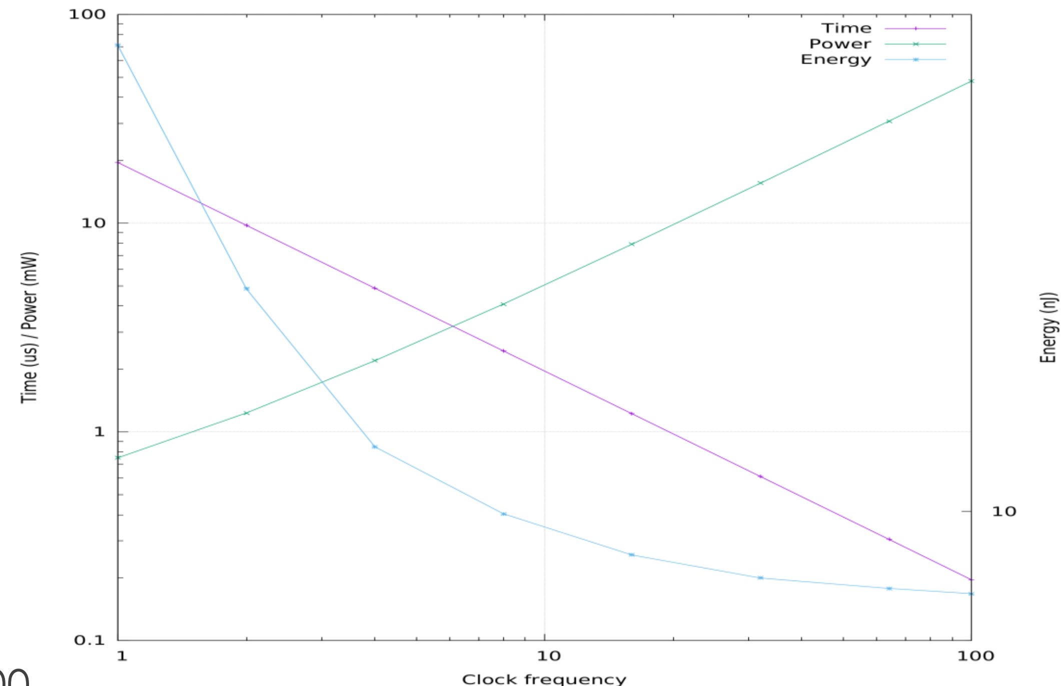


		Hidden Layer			
		1	2	3	4
Number of nodes in each layer	4	5,23 %	5 %	4,8 %	4,88 %
	8	4,93 %	4,9 %	4,9 %	4,91 %
	16	4,98 %	4,89 %	4,93 %	4,89 %
	32	4,94 %	4,85 %	4,86 %	4,85 %

- Noise-augmented data to 40,000 tuples: 28,000 training, 12,000 test
- Little degradation for small NNs on data augmented with noise
- 2 hidden layers with 8 neurons each for implementation exploration

Embedded low power Neural Network inference

- Lattice ICE40UP5K
  - 5280 LUT (32%)
  - 8 DSP (100%)
  - **277 µW static**
- Candidates (no DSP)
  - Microsemi AGLN250
    - 3000 LE
    - **24 µW static**
  - Microsemi M1AGL1000
    - 11000 LE
    - **53 µW static**



Conclusions

- Indoor low-cost low-power capacitive sensing may enable many smart applications
- Needs effective broadband noise reduction
- Low-power analog and digital processors (µP, FPGA, …)
- Low-power communication (used sparingly)
- Low-resource measurement and processing techniques

Thank you.

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