SoC-based Phase Sensitive Detector for Magnetic Induction Tomography

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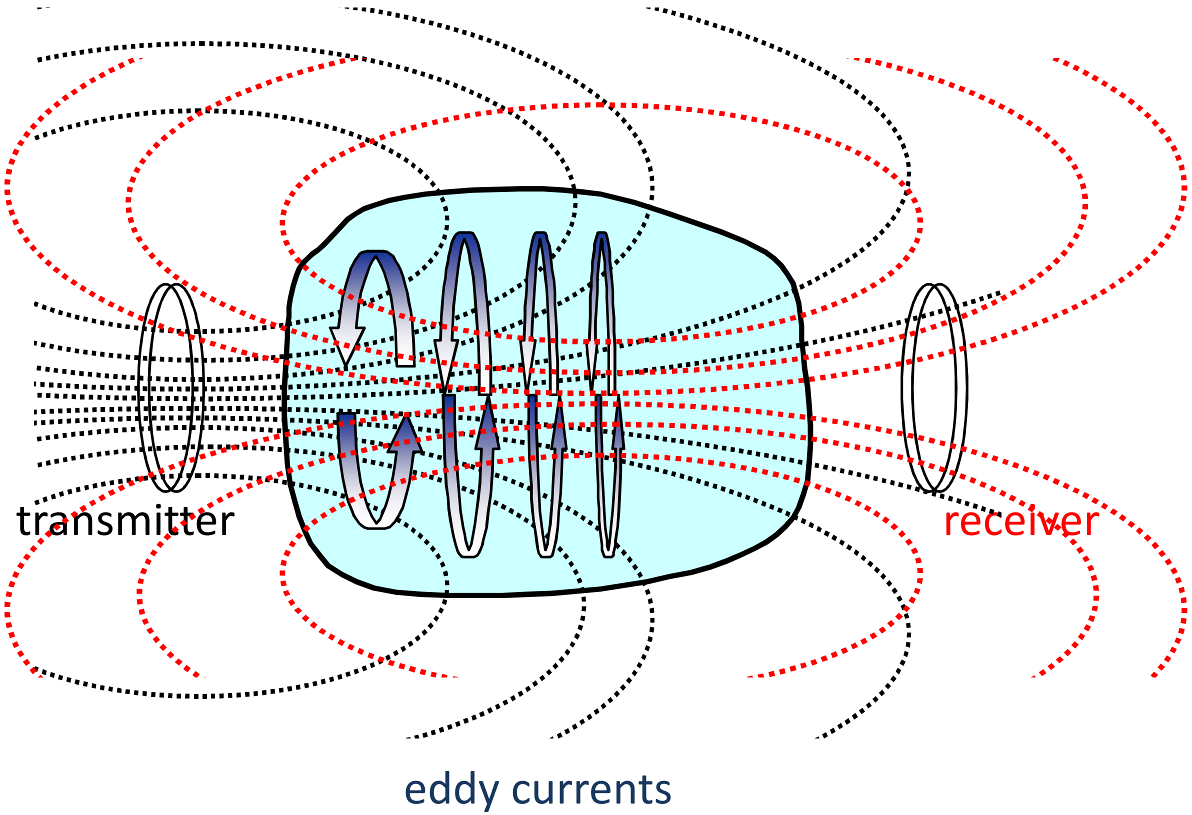
Introduction

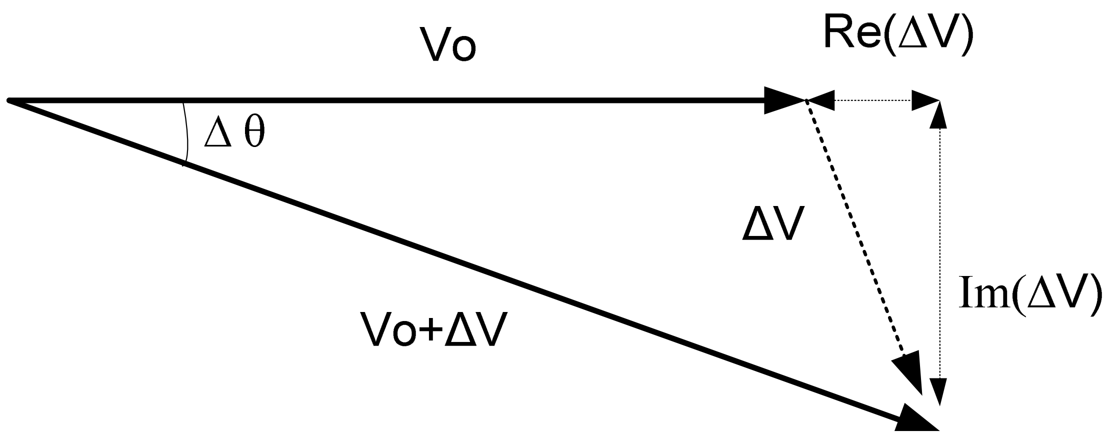
- Magnetic Induction Tomography (MIT)
- Measurement Problem
- Phase Measurement for MIT
- System-on-Chip
- Results
- Applications

Magnetic Induction Tomography



The MIT Signal

Primary and secondary magnetic fields detected – primary signal Vo, secondary signal ΔV



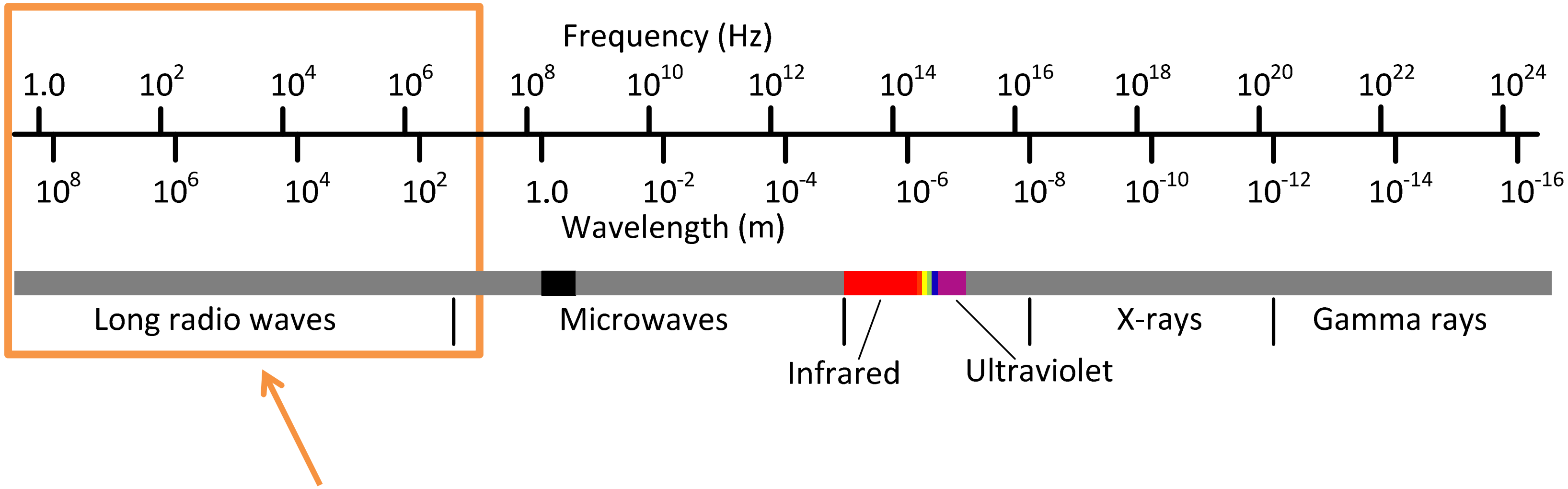
Phase Δθ → conductivity

$$Im(\Delta V) \propto \omega\sigma$$

Amplitude → permittivity, permeability

$$Re(\Delta V) \propto \omega^2 \epsilon_r \epsilon_0$$

Electromagnetic Spectrum

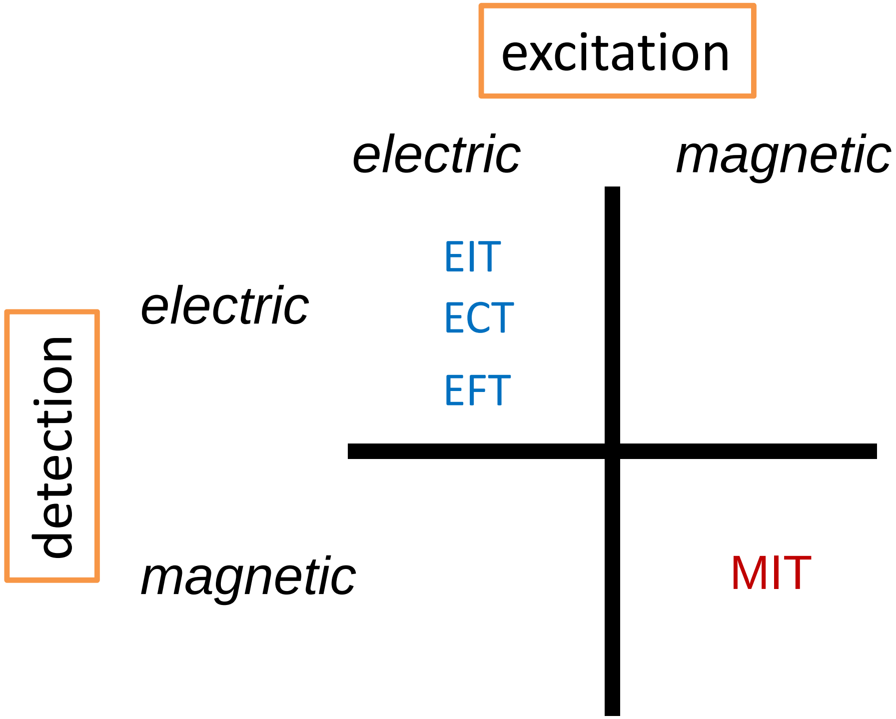


Electromagnetic Tomographies

EIT, ECT, EFT, MIT

Imaging of the electrical properties of objects

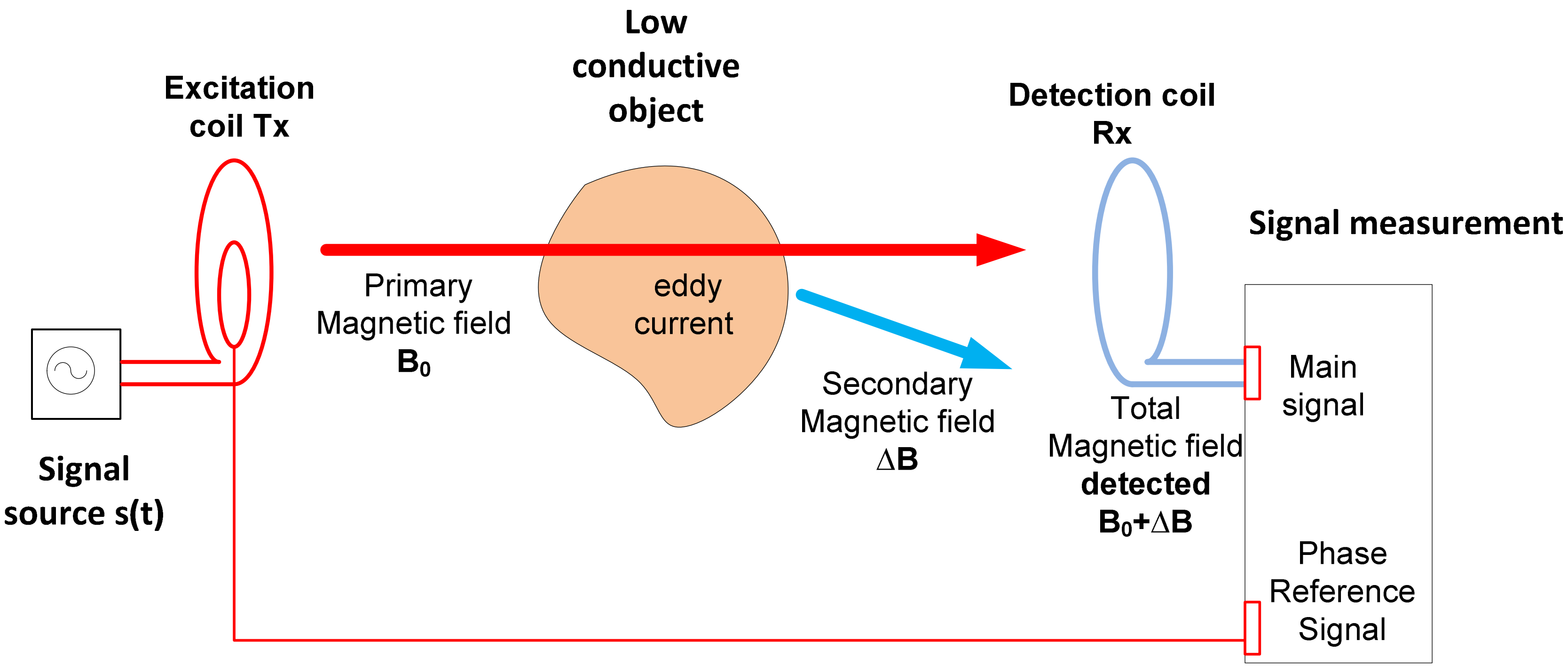
Electromagnetic Tomographies



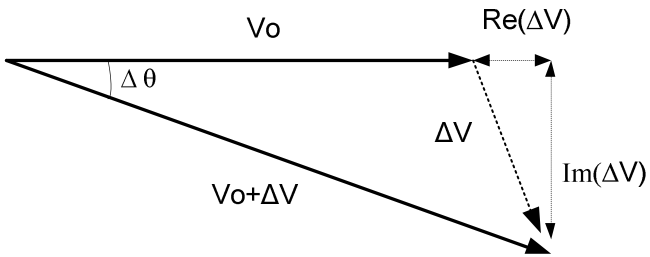
Magnetic Induction Tomography (MIT)

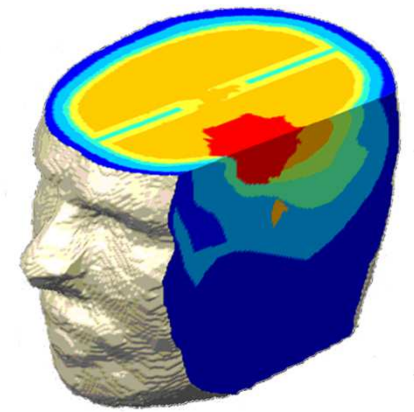
Coils, Non-contact – apply magnetic field, detect magnetic field
Measures conductivity σ, permittivity ε, permeability μ

A single channel MIT system



The MIT Signal and Phase Precision





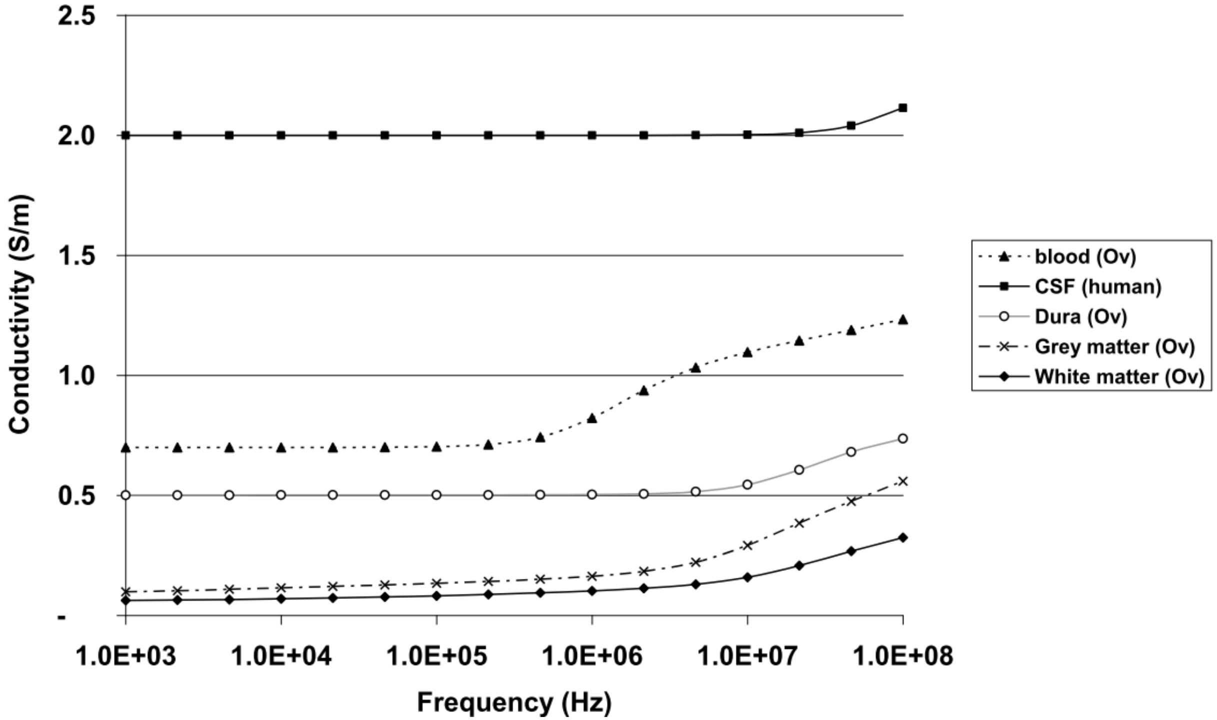
From modelling study [1)]

Large peripheral stroke	- 70m° maximum
Small peripheral	- 14m° maximum
Small deep	- 4m° maximum

Phase measurement precision required **1m° or better**

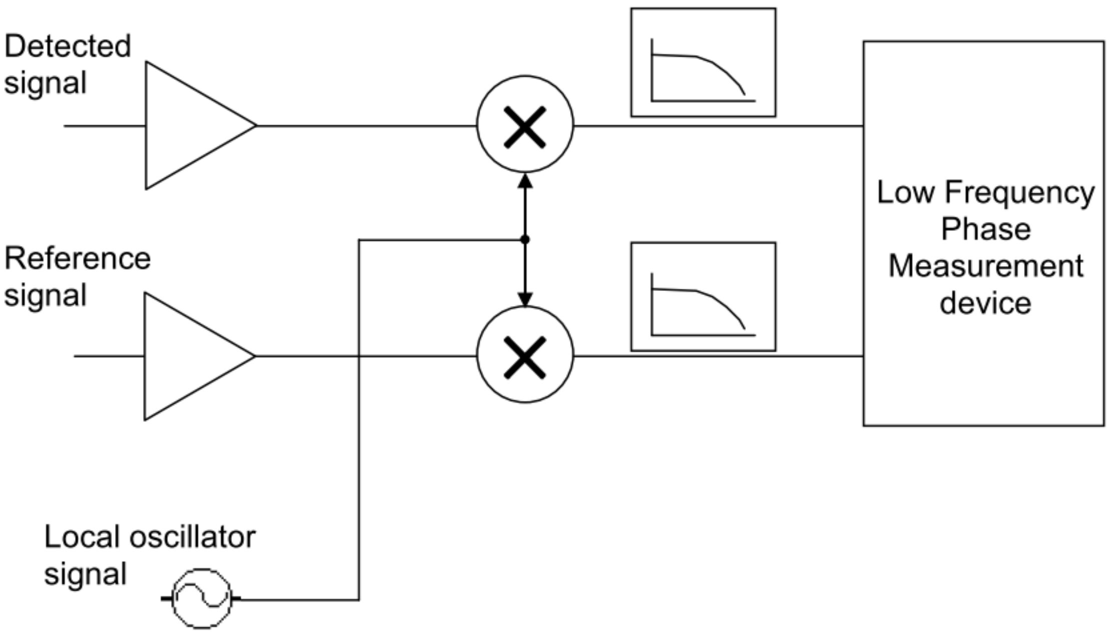
[1)] ***"Detection of haemorrhagic cerebral stroke by magnetic induction tomography: FE and TLM numerical modelling ",* M. Zolgharni, P.D. Ledger, D.W. Armitage, H. Griffiths and D.S. Holder,** 2008 Electrical Impedance Tomography Conference, **Dartmouth** College, Hanover, USA

Conductivity of biological tissue



Phase Measurement

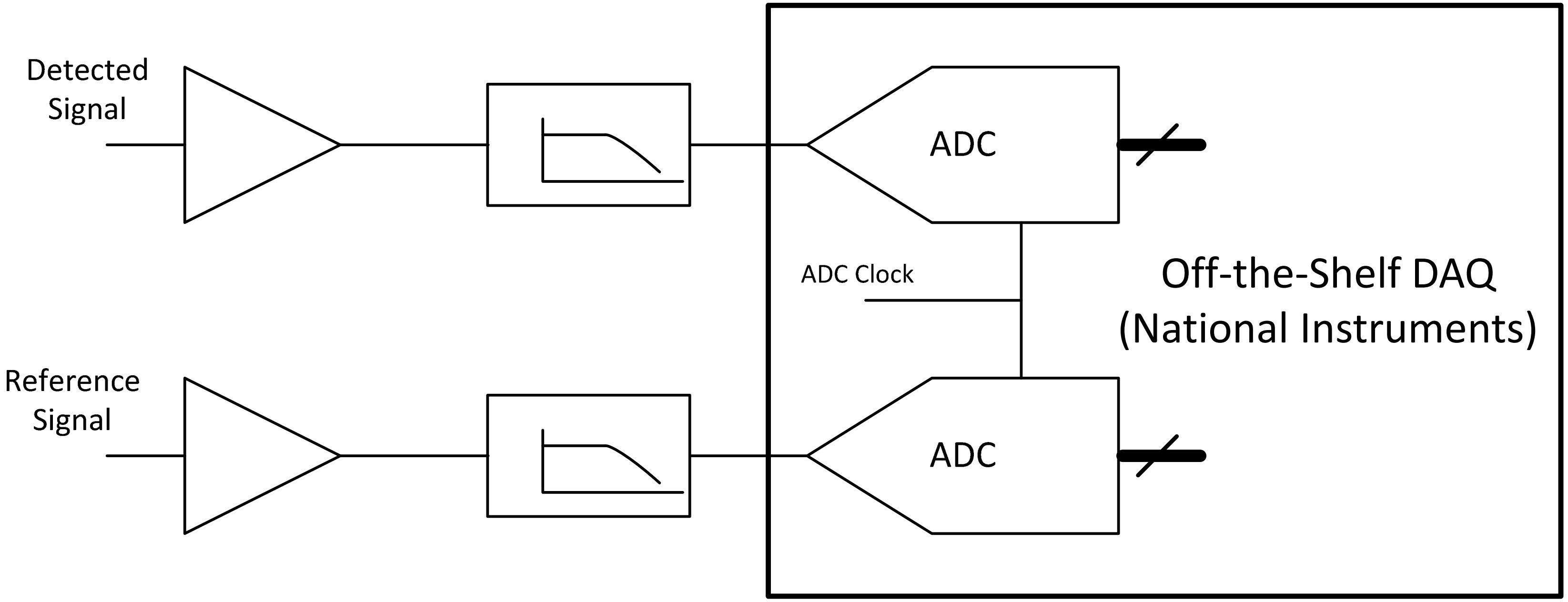
At low Frequency



- Linear Phase Detector
- Lock-in Amplifier
- XOR-based

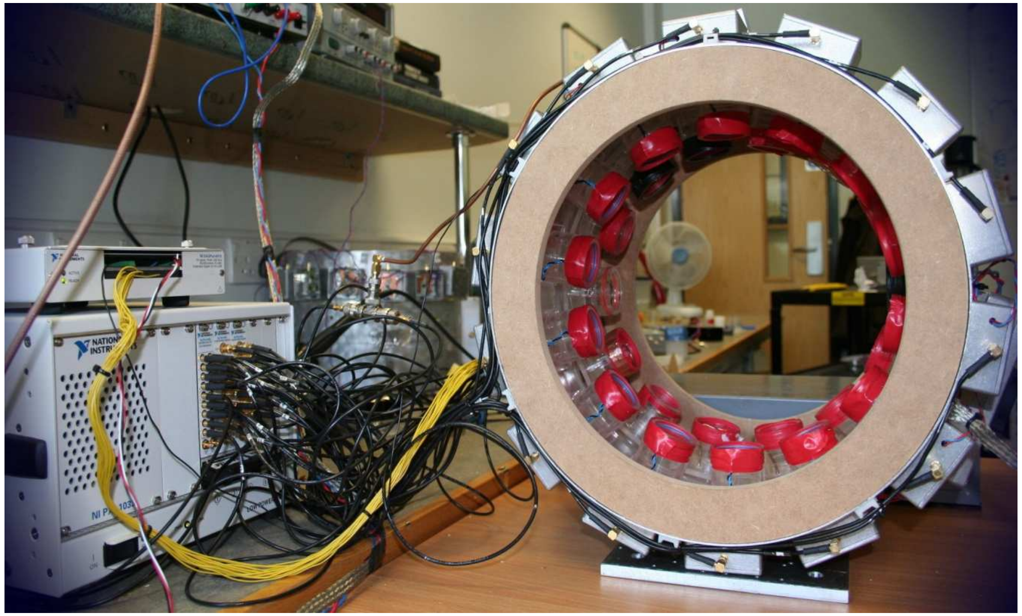
Phase Measurement

Direct conversion



Direct Conversion Systems

Cardiff MkII MIT System



- 12-bit ADC resolution
- 60MS/s Sample rate
- Measurement time: 16ms

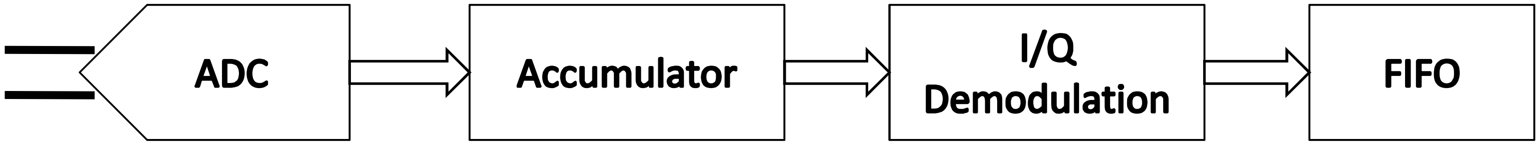
- 2^{20}-point DFT implemented in LabView and running on a GPU

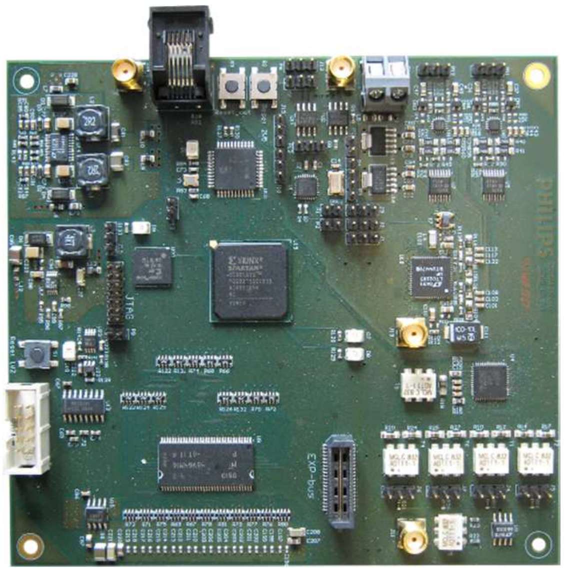
Performance:

- < 1m° phase precision @ full-scale input
- 466ms/channel measuring & processing time
  - 400ms transfer time
  - ~50ms processing time (GPU)

FPGA-based Direct Conversion

- Single signal cycle averaging with 12x oversampling
- I/Q demodulation
- I and Q results stored in FIFO buffer



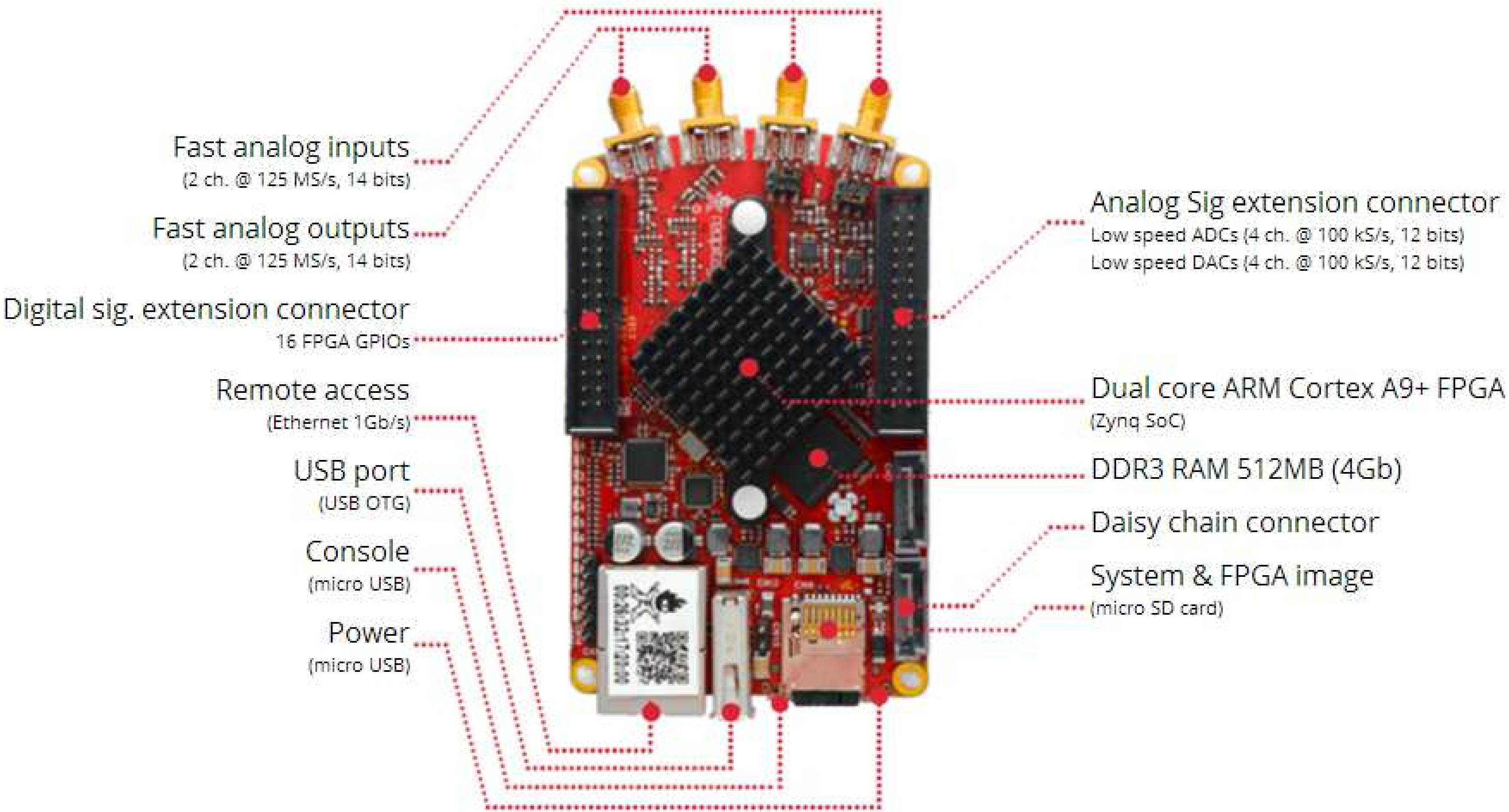


- 14-bit ADC resolution
- 120MS/s Sample rate
- Measurement time: 16ms

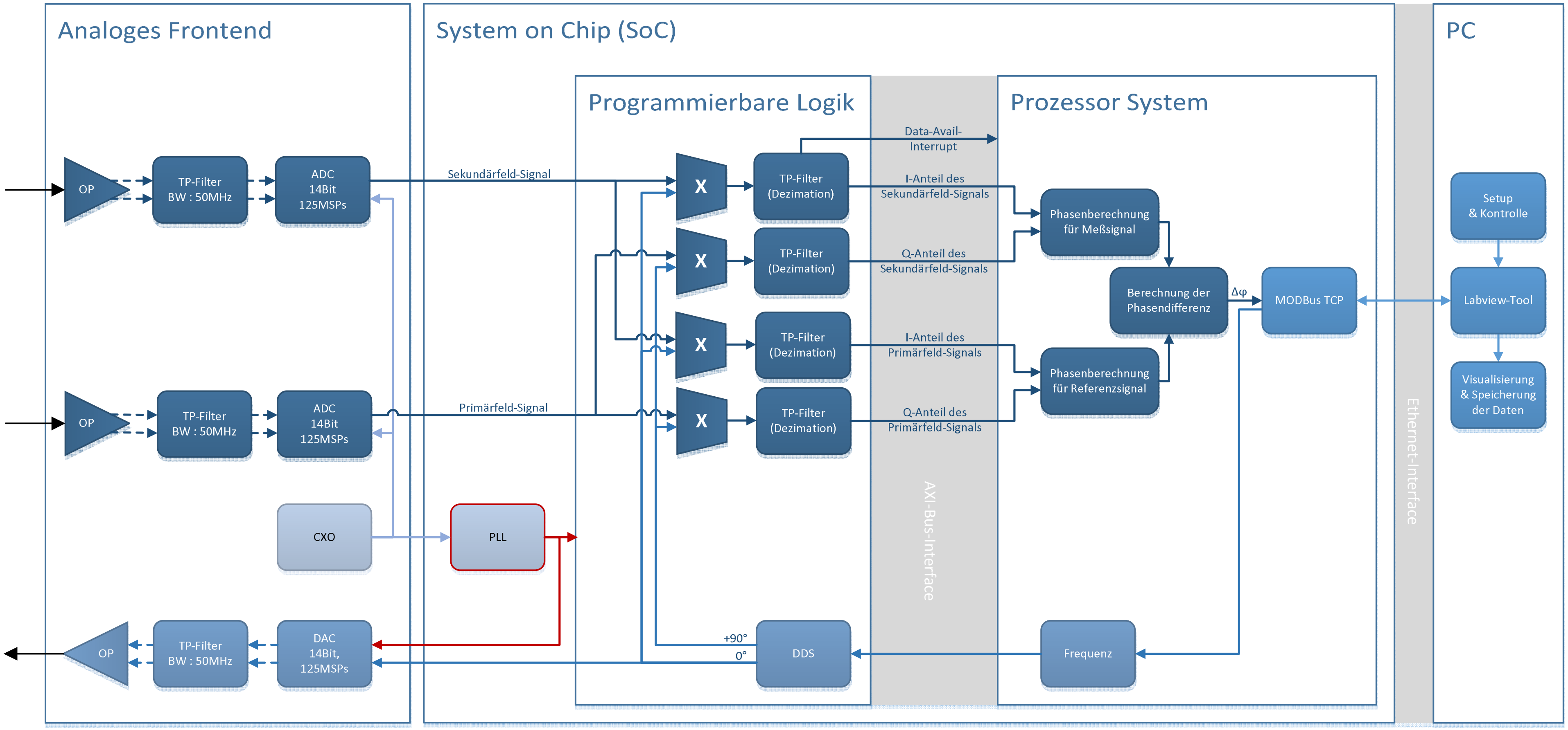
Performance:

- < 1m° phase precision @ full-scale input
- 16.6ms/channel measuring & processing time
  - 0.4ms transfer time
  - 167ns processing time (FPGA)

Red Pitaya FPGA Board

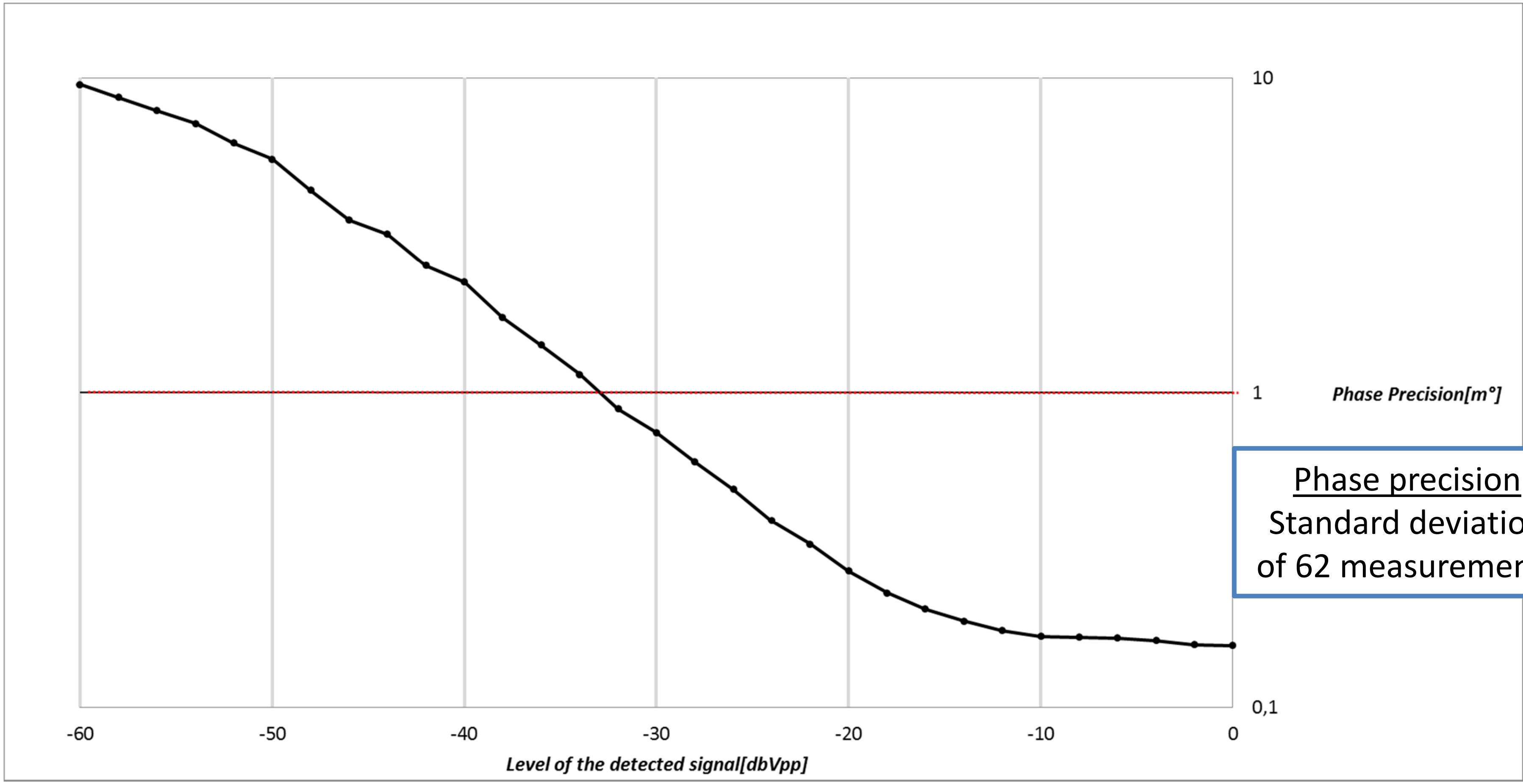


System Overview



Sample rate: 125MS/s; Full-scale input: $2V_{pp}$; Bandwidth = 50MHz

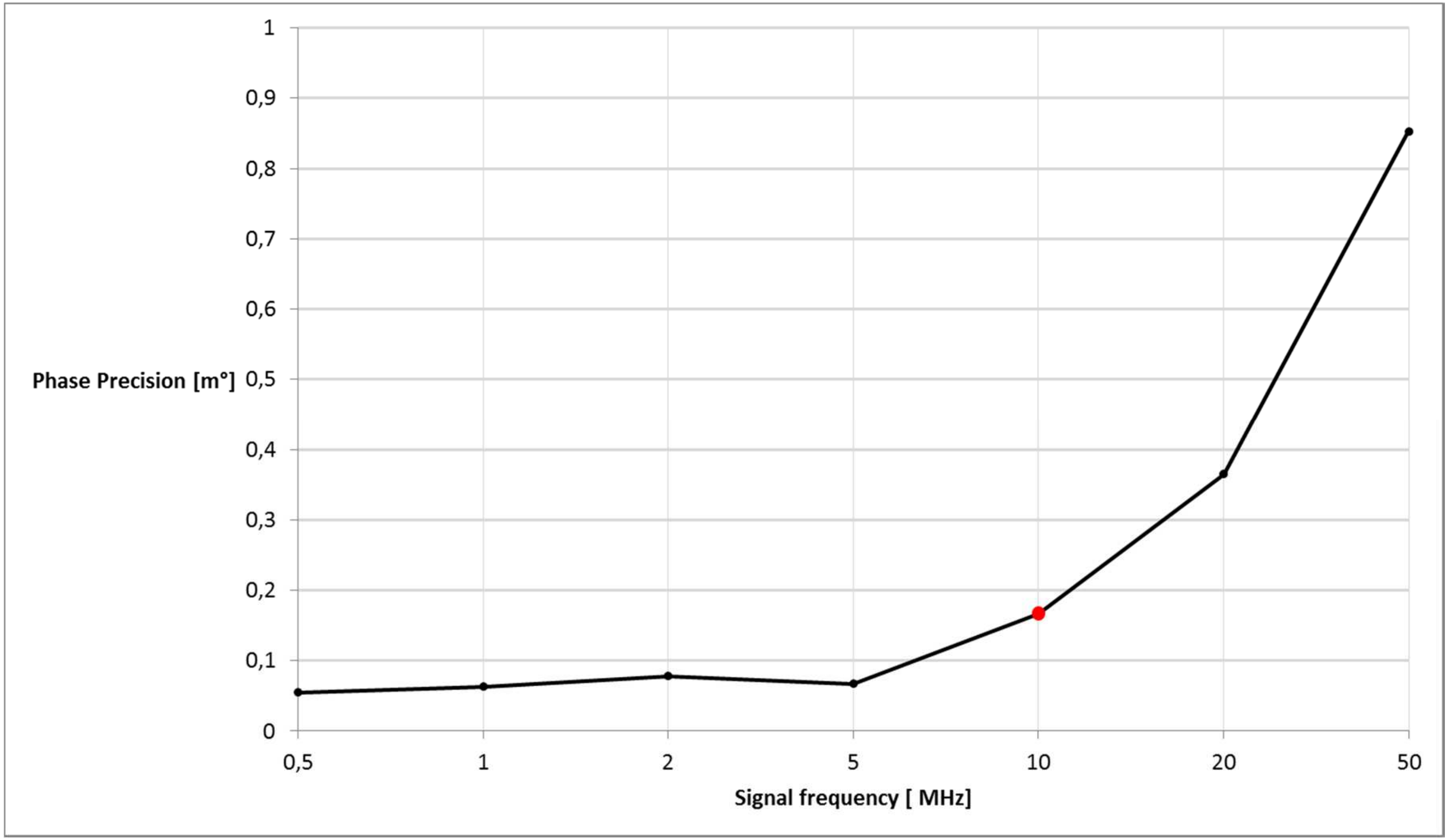
Results
Phase Precision vs. Signal Amplitude



Phase precision
Standard deviation of 62 measurements

$$V_{ref} = 1V_{pp}; V_{signal} = 1mV_{pp} - 1V_{pp}; f = 10MHz; Measurement\ time = 16{,}67ms$$

Results
Phase Precision vs. Frequency



$$V_{ref} = 1V_{pp}; V_{signal} = 1mV_{pp} - 1V_{pp}; f = 10MHz; Measurement\ time = 16{,}67ms$$

Comparison

	MkII Digitizer	FPGA-based	Red Pitaya
Sample Rate	60MSps	120MSps	125MSps
ADC Resolution	12-bit	14-bit	14-bit
Acquisition	17.47ms	17.47ms	16.67ms
Phase precision	0.7 – 60m°	0.36 – 342m°	0.16 – 9.5m°
Phase drift	3m°	3.2m°	tbd
Phase linearity	0.9999	0.9999	tbd
Gain stages	1, 6, 30, 120	1	1

Applications

<u>MIT in process monitoring</u>

Multiphase flows

Glass production

Metal production

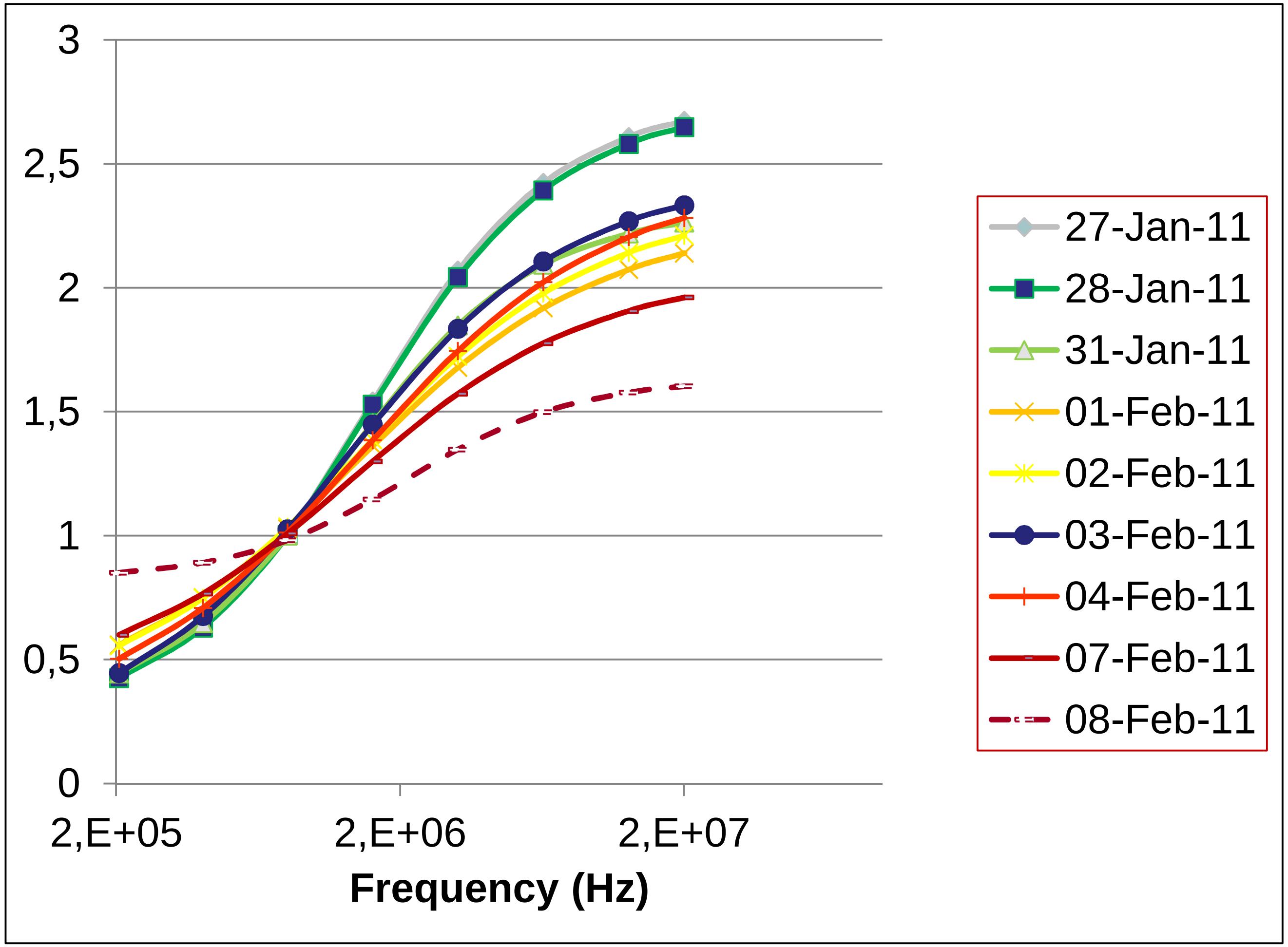
<u>Magnetic Induction Spectroscopy</u>

Non-destructive testing of biological tissues

<u>MIT medical applications</u>

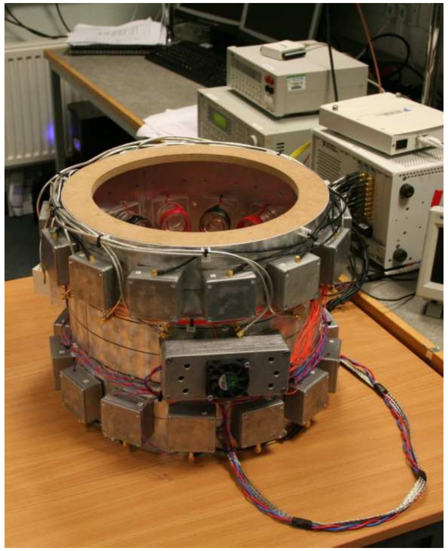
Cerebral haemorrhage detection

Non-destructive testing of biological tissues



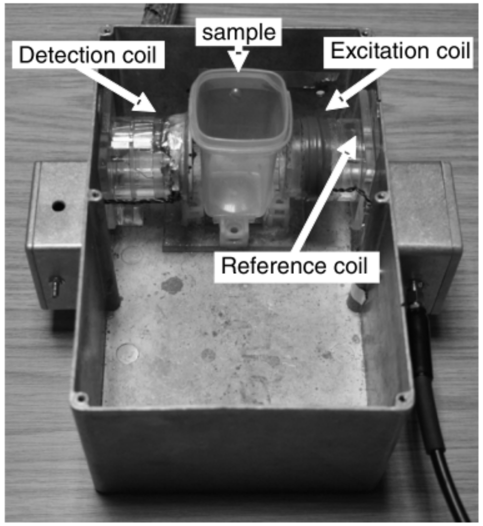
MIT Systems

Cardiff Mk IIa



Cardiff Mk IIb

Cardiff Mk IIc



Single Channel

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