Characterisation of a multi-channel multiplexed EMG recording system: towards realising variable electrode configurations

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Introduction

First steps towards osseointegrated myoelectrically-controlled prostheses:

- Bone anchor conduit conveys EMG signals from implanted electrodes [1].
- In vivo selection of electrode configurations would improve signal-to-noise ratio (SNR) of EMG recordings [2]; optimal electrode configurations are not known before implantation.

The **CAPITel** system:

- **C**ontrol of **A**ctive **P**rostheses using **I**mplantable **Tel**emetry [3,4].
- Implantable EMG amplifier with a novel multiplexed frontend.
- In vivo selection of monopolar, bipolar or tripolar configurations.
- Designed using commercially available components for use in animal models.
- After further research design will be implemented as an ASIC.

Characterisation

System performance for bipolar configurations.

Input impedance *(figure 3)*

- Required to be > 1 MΩ (epimysial electrode impedance ~2.3 kΩ [2]).
- Z_{mean}: frontend impedance to ground (including MUX, BPF & ADC); average of 12 measurements between electrode connection pairs; one of the pair connected to ground.
- $Z_{short\text{-}circuit}$: impedance of the MUX; single measurement between 2 electrode inputs short-circuited through the MUX.

Frequency response *(figure 4)*

- Balanced bipolar sine-wave test-bench: 1 Hz – 10 kHz; Audacity DAW station; UR22mkII Steinberg audio interface; step-down transformer; 6 × ADC gain.
- DM input: approximates expected EMG
- CM input: as large as possible (limited by test-bench).
- SNR baseline noise: RMS voltage with input terminals shorted to reference.

Parameter	Design Critera	Experimental Outcomes
Recording channels	6	6 ADCs
Sampling frequency	> 1 kHz	2 kHz
Input impedance (Z_{mean})	> 1 MΩ	5.8±0.3 MΩ
Bandwidth	30 – 800 Hz	20 – 500 Hz
Gain (passband)	0 – 40 dB	6.8±0.1 dB
CMRR (passband)	40 dB	49.0±1.9 dB
SNR	> 30 dB	51.4±0.2 dB
Power consumption	< 100 mW	44 – 61.6 mW[a]

[a] 10Ω±1% resistor in series with the supply line: 5.5 V supply, 8 mA when idle, 11.2 mA during data transmission

In vivo EMG recordings

Figure 5 shows CAPITel EMG recordings compared against commercial BIOPAC MP150 recordings (EMG100C bioamplifiers, 100 Hz – 500 Hz bandpass, 1000 × gain, 2 kS/s) using a purpose-built switch arrangement [5] to realise the same configurations.

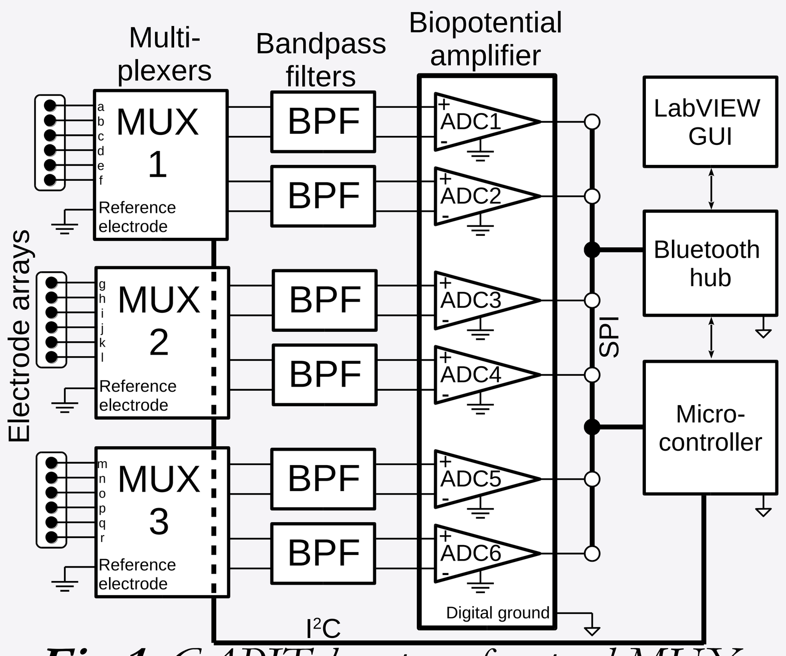


Fig 1: *CAPITel system: frontend MUXs; analogue BPFs; 6 channel ADC.*

Methods

- ADS1298 ADC biopotential amplifier core (6 channels, 16-bit resolution, 2 kS/s, variable gain, 500 Hz bandwidth).
- ADG2188 multiplexers (2 ADC channels per MUX, 8 × 8 array, 1 μA quiescent supply); reconfigure a 6-pole electrode array.
- Balanced differential analogue bandpass filters (30 – 800 Hz, 9 components per ADC channel); maximise SNR.
- MSP430FR2433 micro-controller (126 μA/MHz; SPI and I²C interface; 4 × 4 mm); communicates with the ADC, the MUX and transmits the digital output to a laptop.

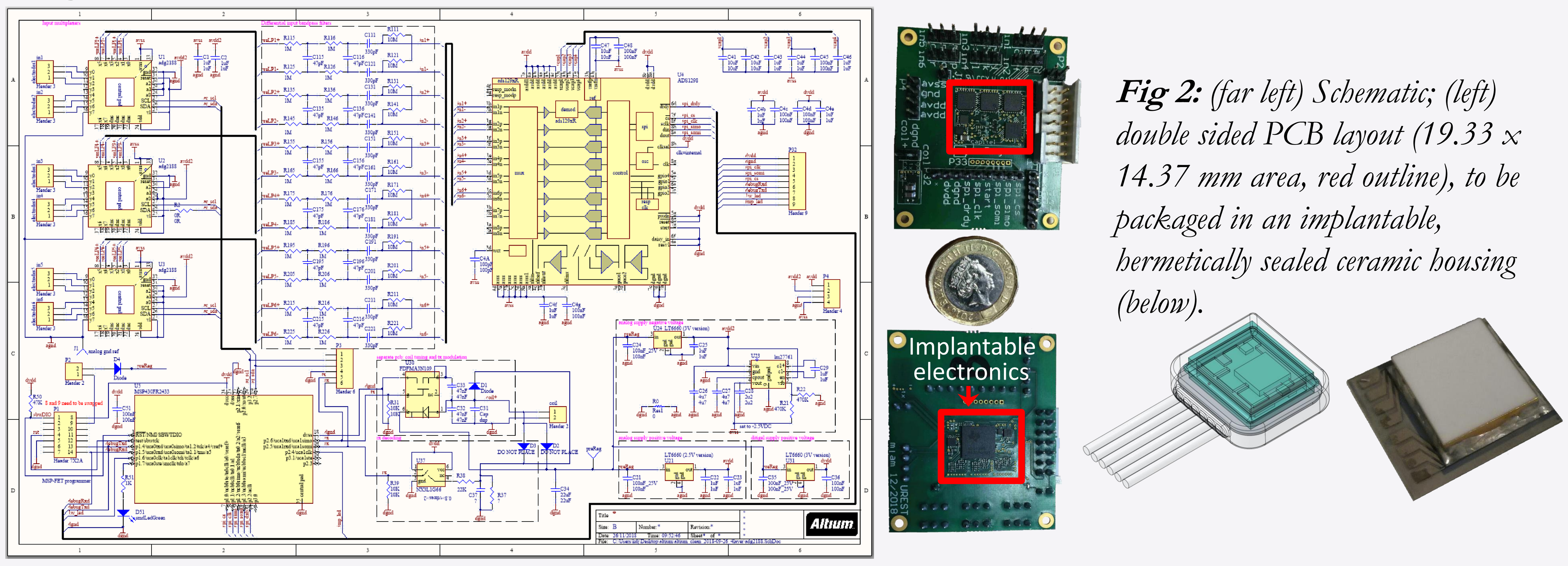


Fig 2: *(far left) Schematic; (left) double sided PCB layout (19.33 × 14.37 mm area, red outline), to be packaged in an implantable, hermetically sealed ceramic housing (below).*

Fig 3: *Input impedance and phase (Wayne Kerr 6500B impedance analyser; 20 Hz – 100 kHz range; 1 mA drive current).*

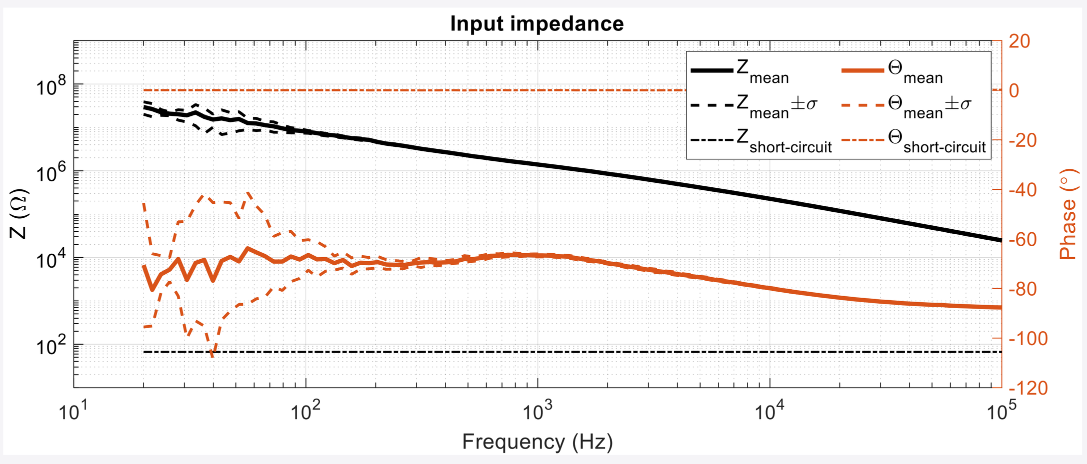
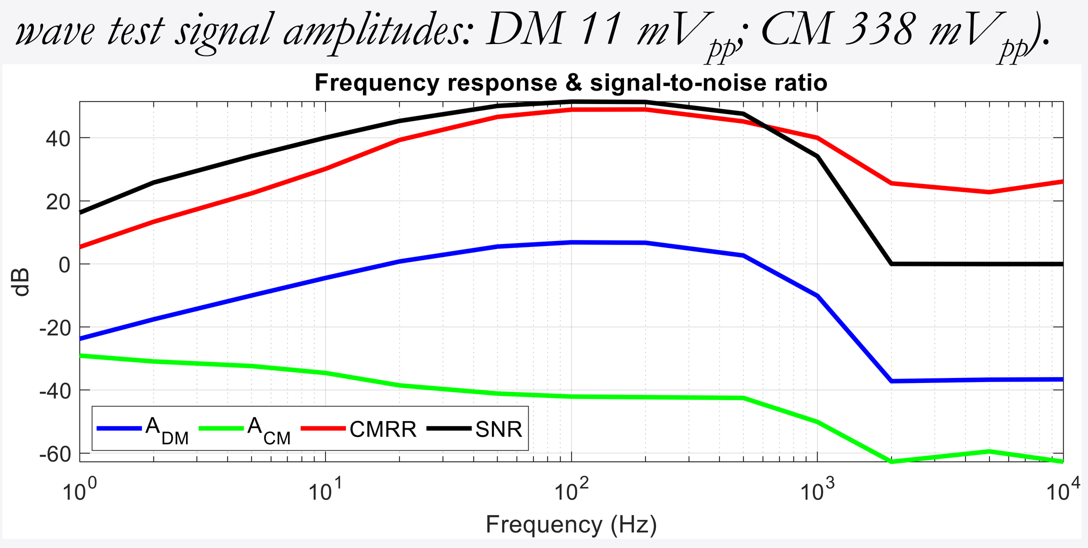


Fig 4: *Mean frequency response across 6 ADC channels (sine-wave test signal amplitudes: DM 11 mV_{pp}; CM 338 mV_{pp}).*



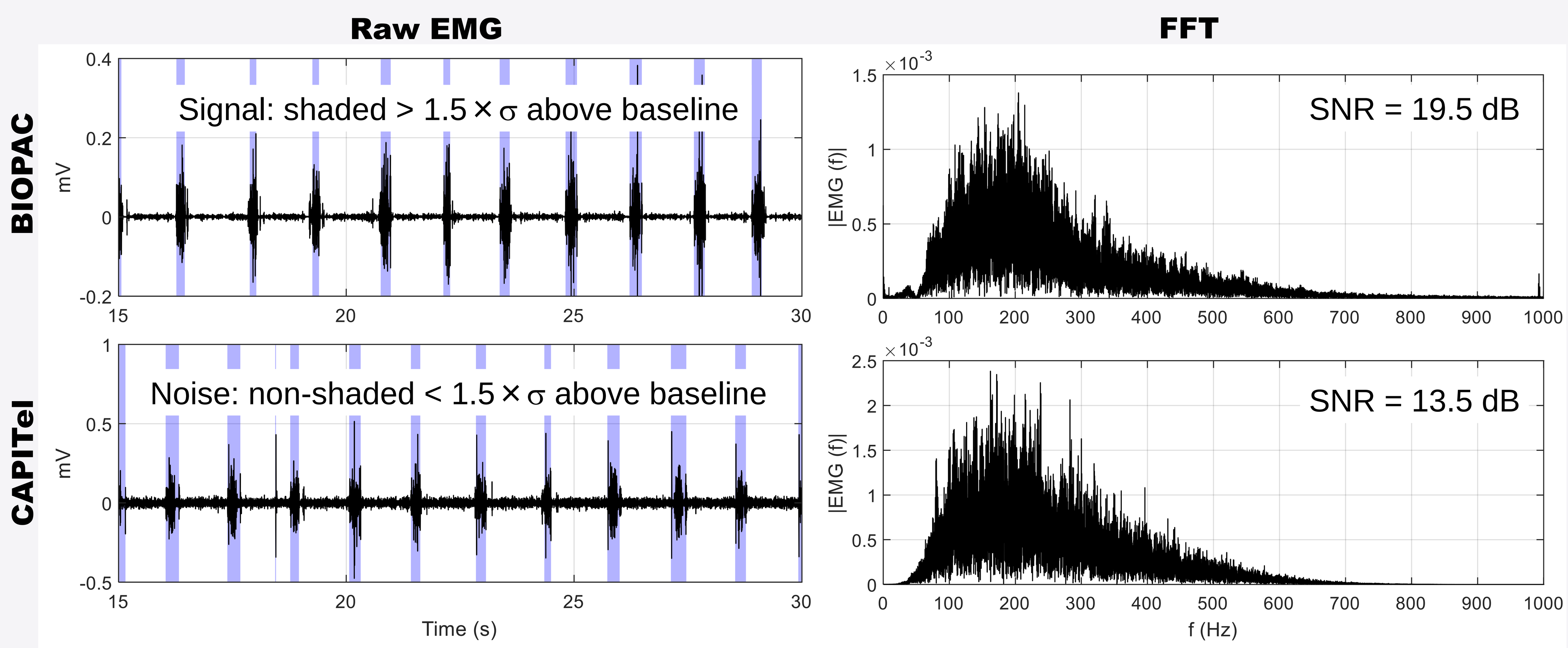
Discussion

Proof-of-concept achieved using standard PCB & commercially available components.

Frontend components decrease the system performance below that of the ADS1298, however such a payoff should not deter researchers from utilising encapsulated PCBs to develop implantable prototypes as the characterised system meets the design criteria.

CAPITel EMG recordings showed lower signal quality compared with BIOPAC recordings, nonetheless the signals appeared suitable for myoelectric control applications.

An implantable version of CAPITel (once encapsulated), should improve SNR & reduce implant-prosthesis connection complexity.



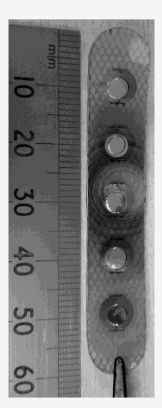


Fig 5: *(above) CAPITel and BIOPAC EMG recordings captured during walking from implanted epimysial electrodes (left) in an ovine model, in combination with a bone-anchor conduit (right) implanted trans-tibially. CAPITel recordings were post-processed (2nd order Butterworth BPF; 10 Hz – 500 Hz) for direct comparison.*

References

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Acknowledgements

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