KOBE UNIVERSITY

Normally-Off Technologies for Healthcare Appliance

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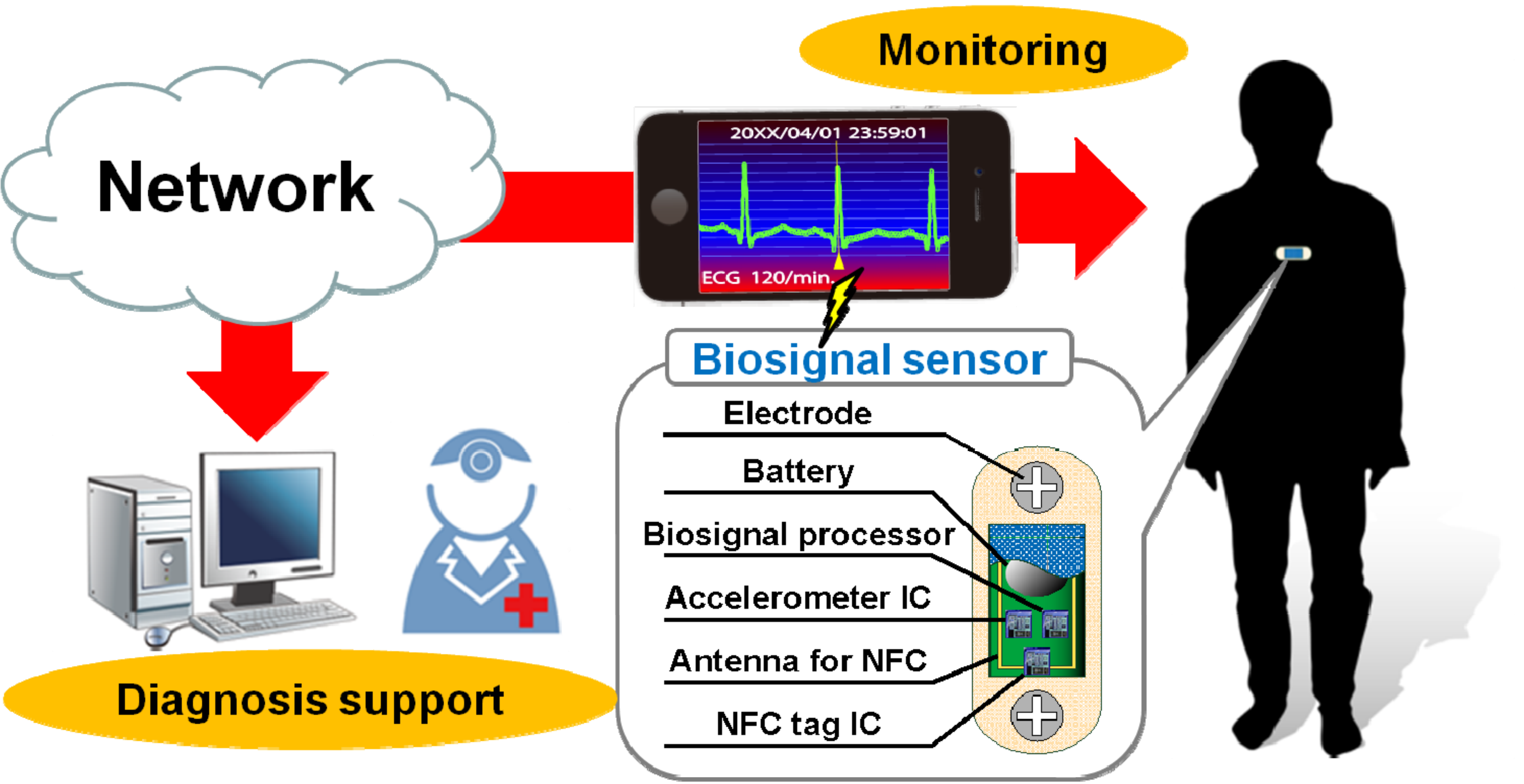
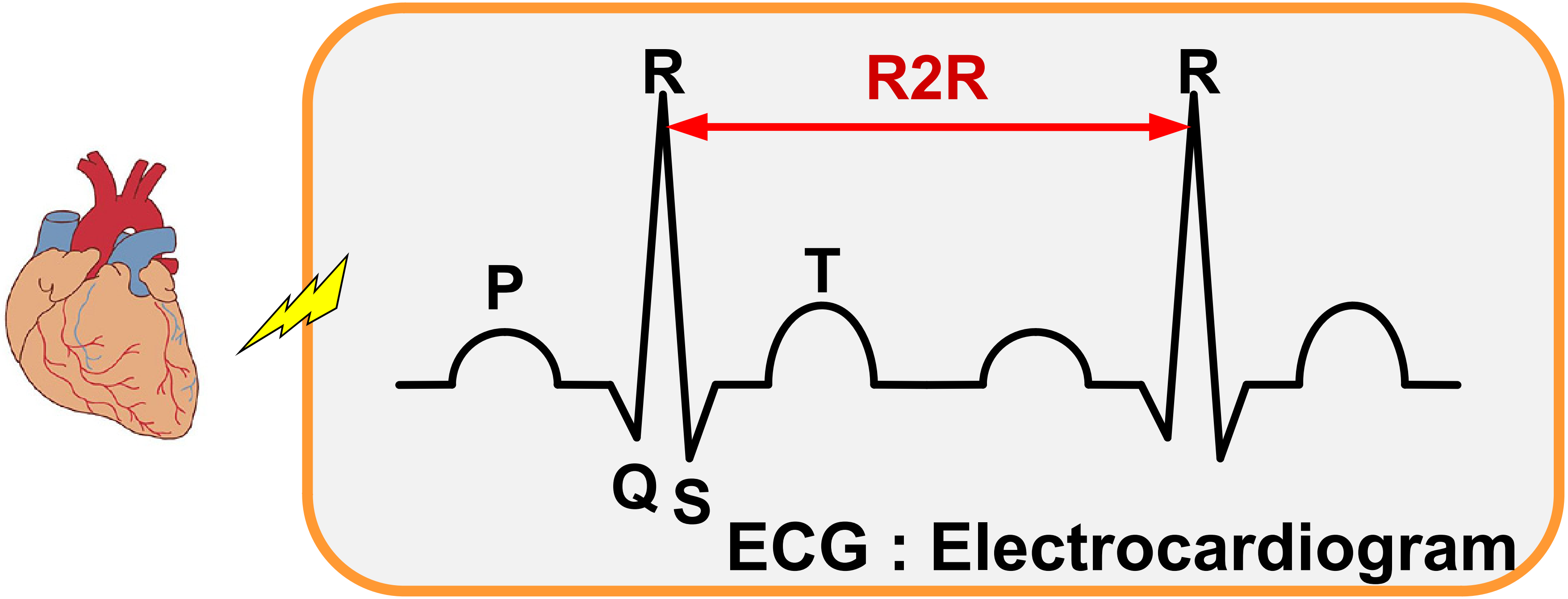
Wearable Healthcare System



Proposed LSI: IHR monitor

IHR (Instantaneous Heart Rate)

= 60 / (newest R2R interval [s]) [bpm]

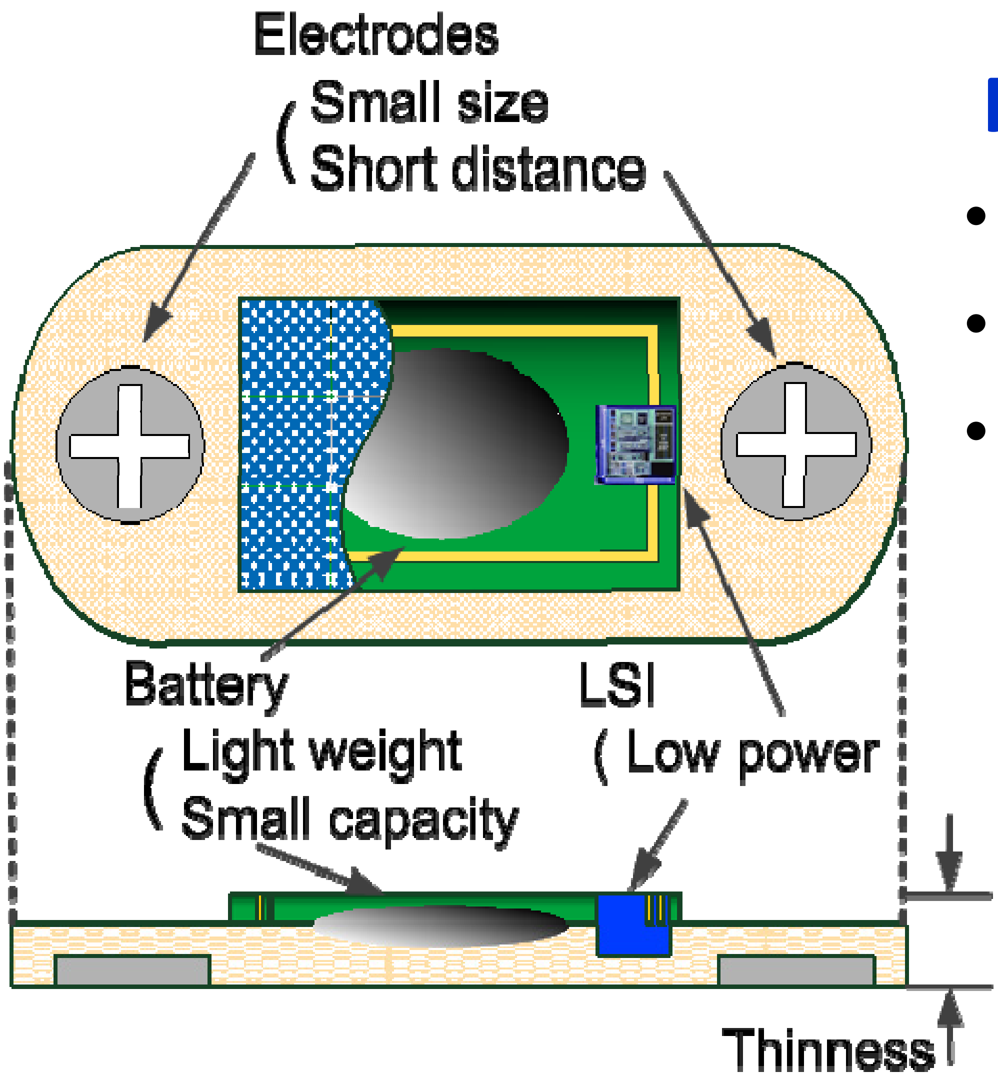


Applications :

✓ **Heart Rate Variability (HRV) analysis**

✓ **Exercise intensity estimation**

Constraints of Wearable Sensor



Requirement

- Small size
- Light weight
- Low cost

(Small size, Light weight:)
✓ Electrode
✓ Battery

Problems:
Current consumption (average, peak)
SNR degragetion

Normally-off strategy

- Wireless communication

  → Passive NFC (Near Field Communication)

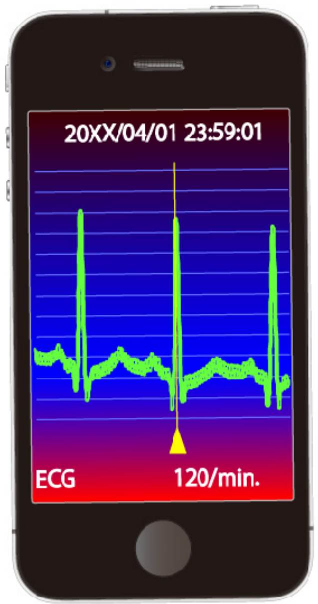
- Leakage current of data buffer

  → FeRAM

- Active current of analog front end

  → Low-cost amplifier and ADC
  with noise tolerant algorithm

Passive NFC tag IC usage



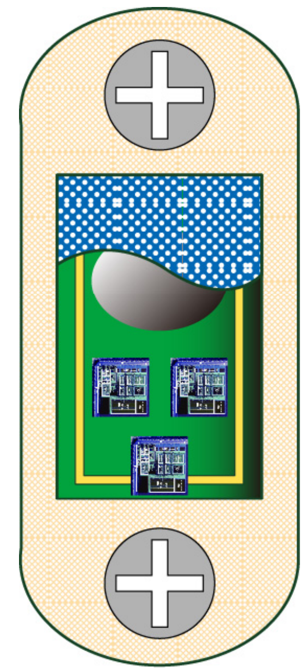
Smartphone
or
Reader/Writer

Program loading →

Parameter setting →

NFC

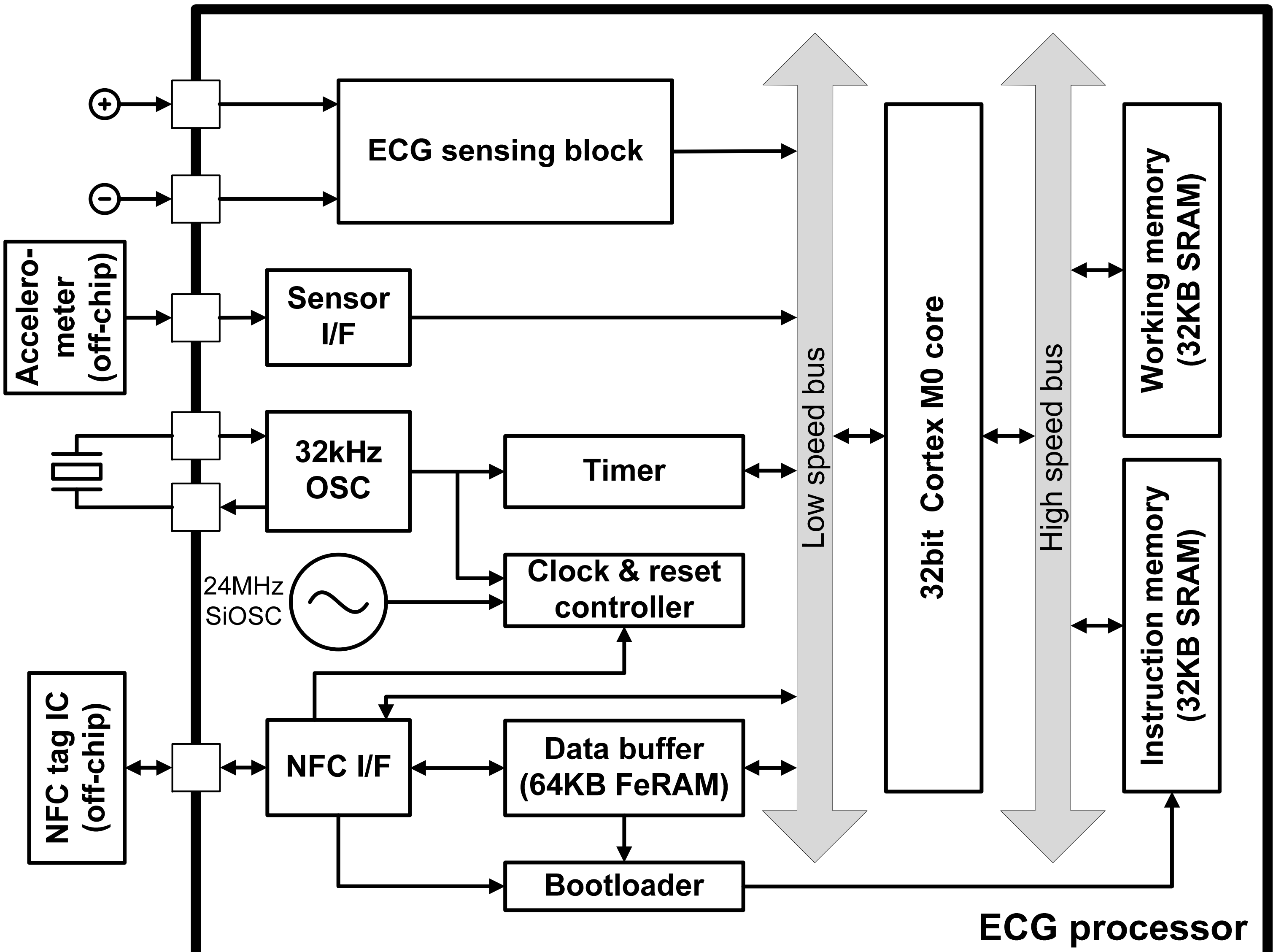
← Data gathering



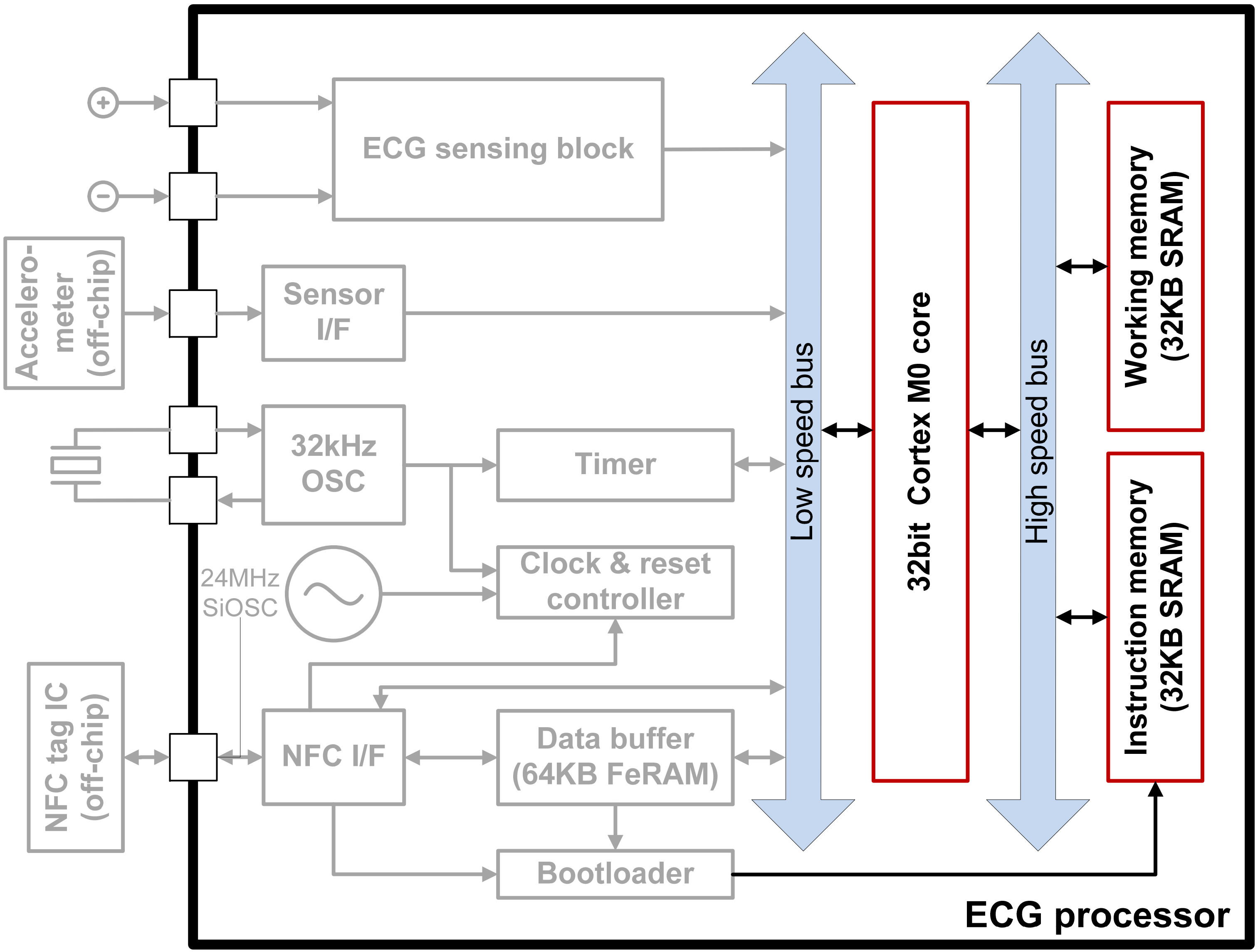
Wearable
sensor

Low speed, passive communication

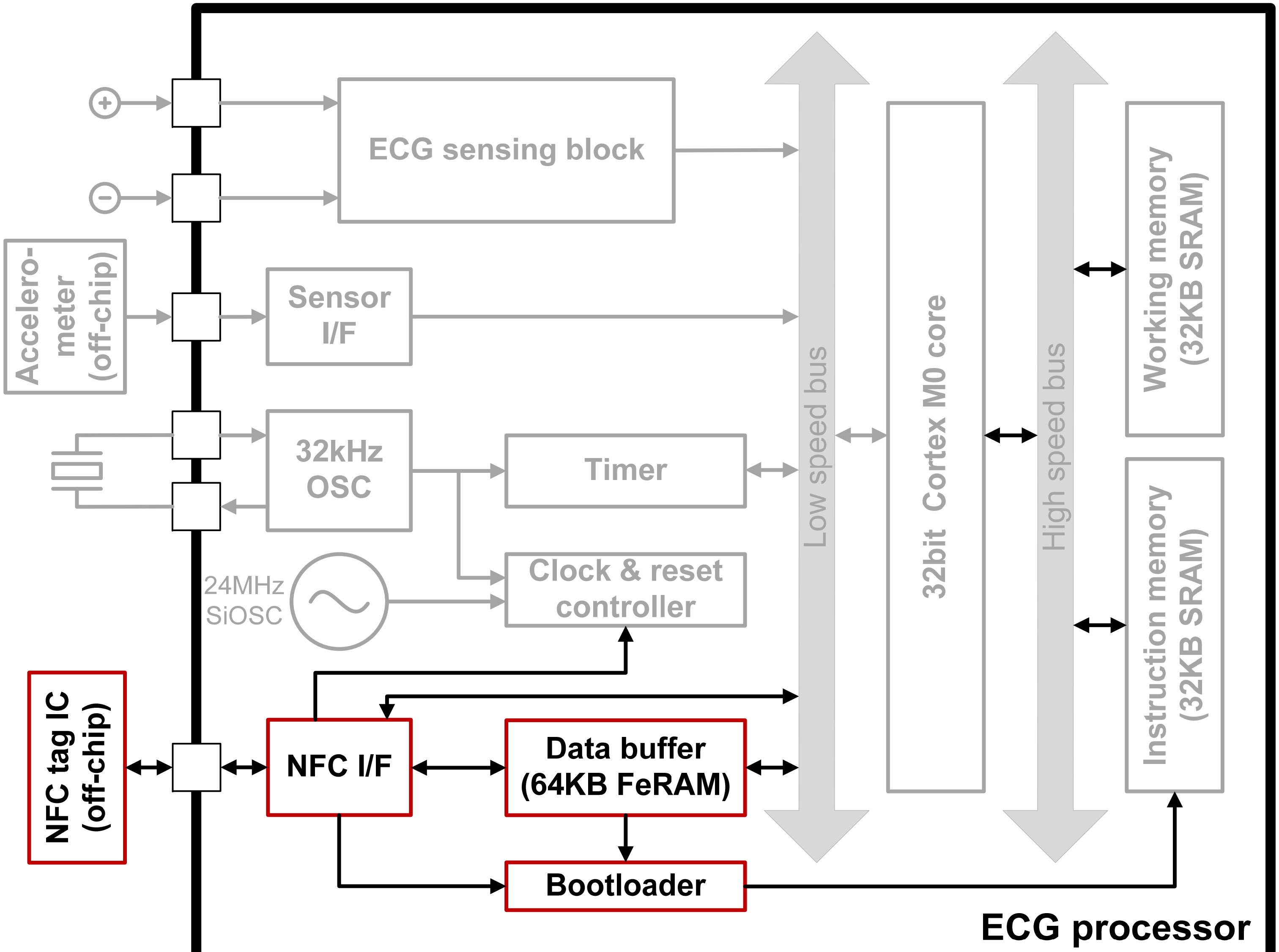
System Architecture



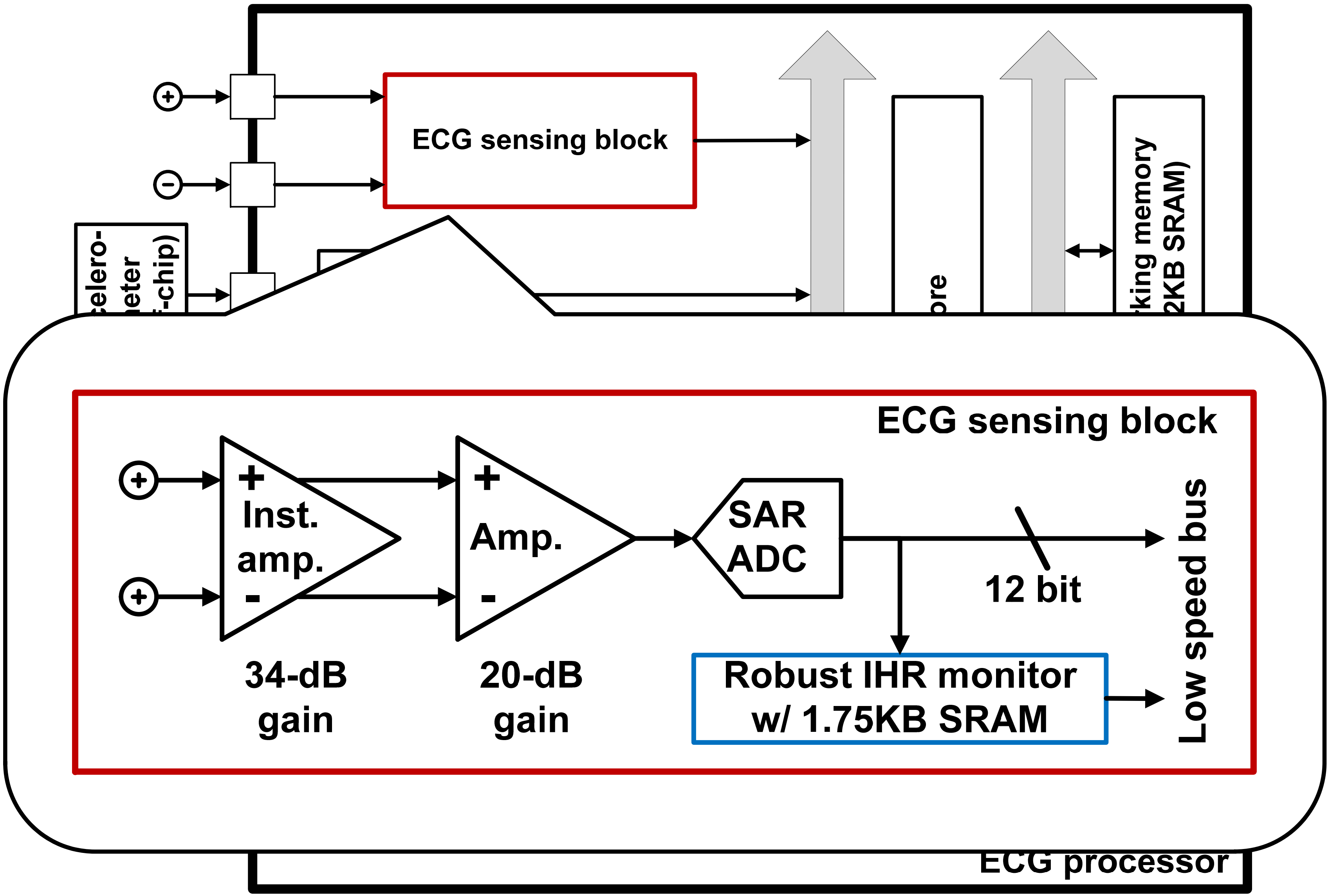
Cortex M0 core



Data Communication



Robust IHR Monitor



Noises in wearable ECG

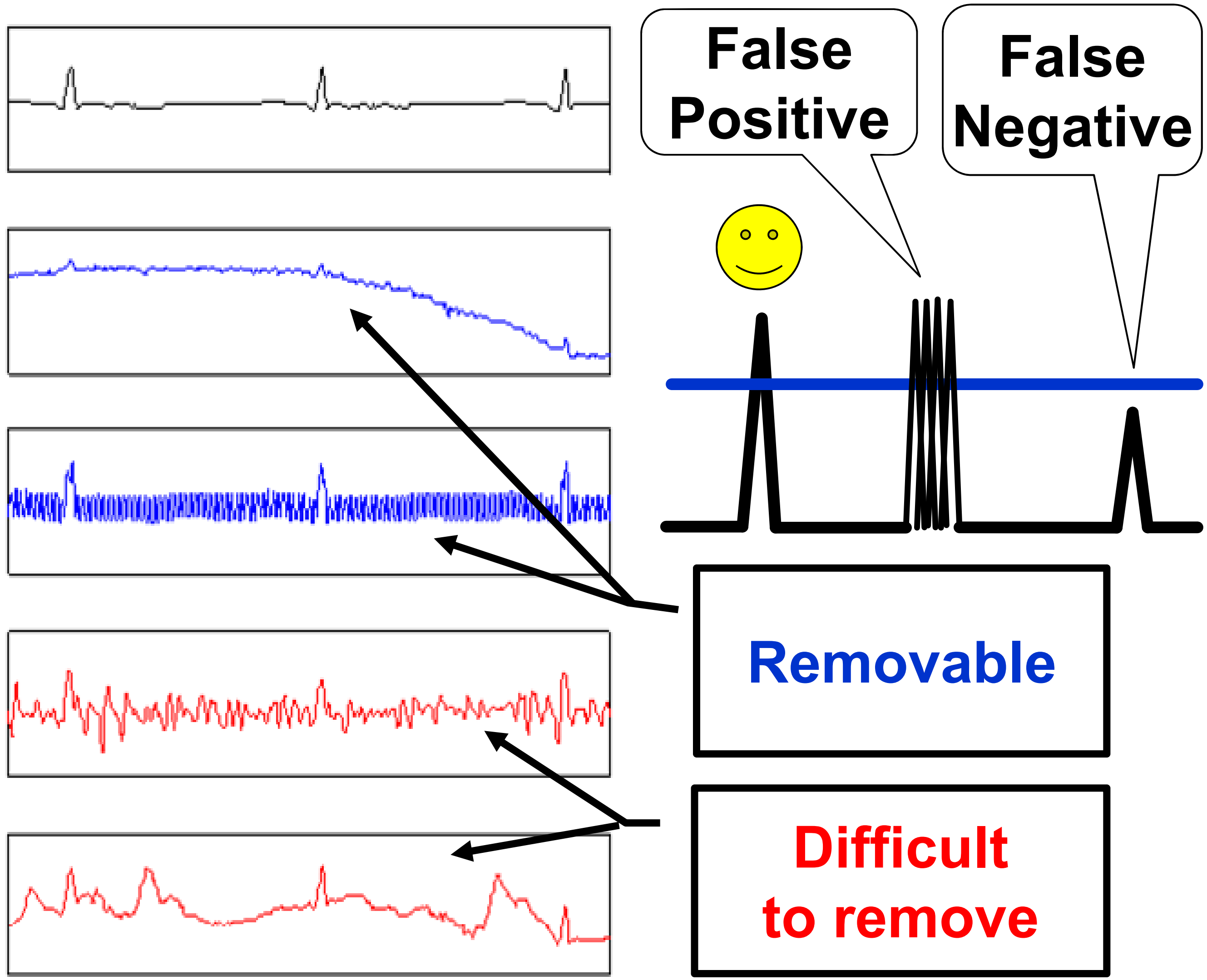
Clean ECG (10~30Hz)

Baseline drift (~3Hz)

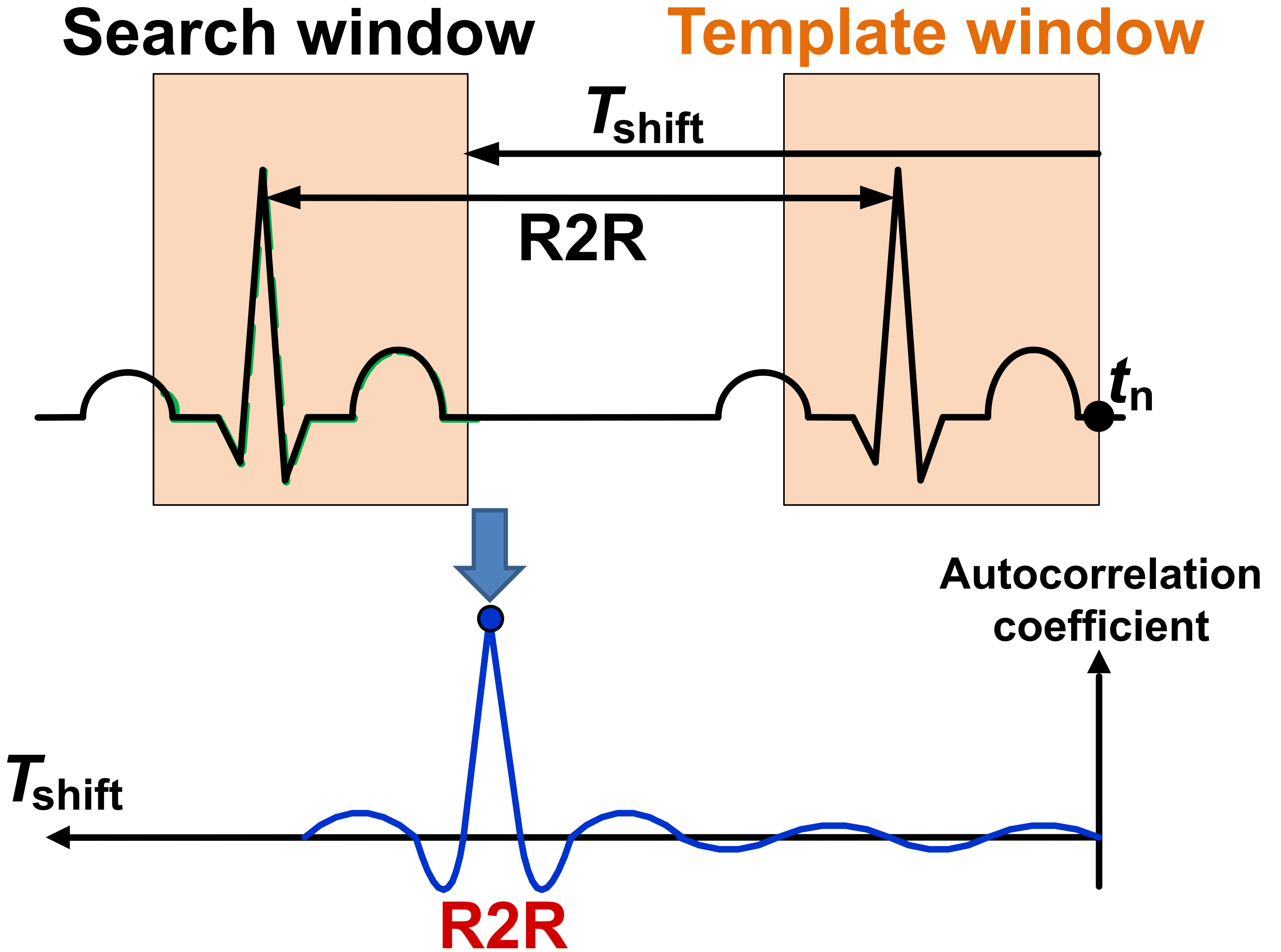
Hum noise (50,60Hz)

Muscle noise (10~1kHz)

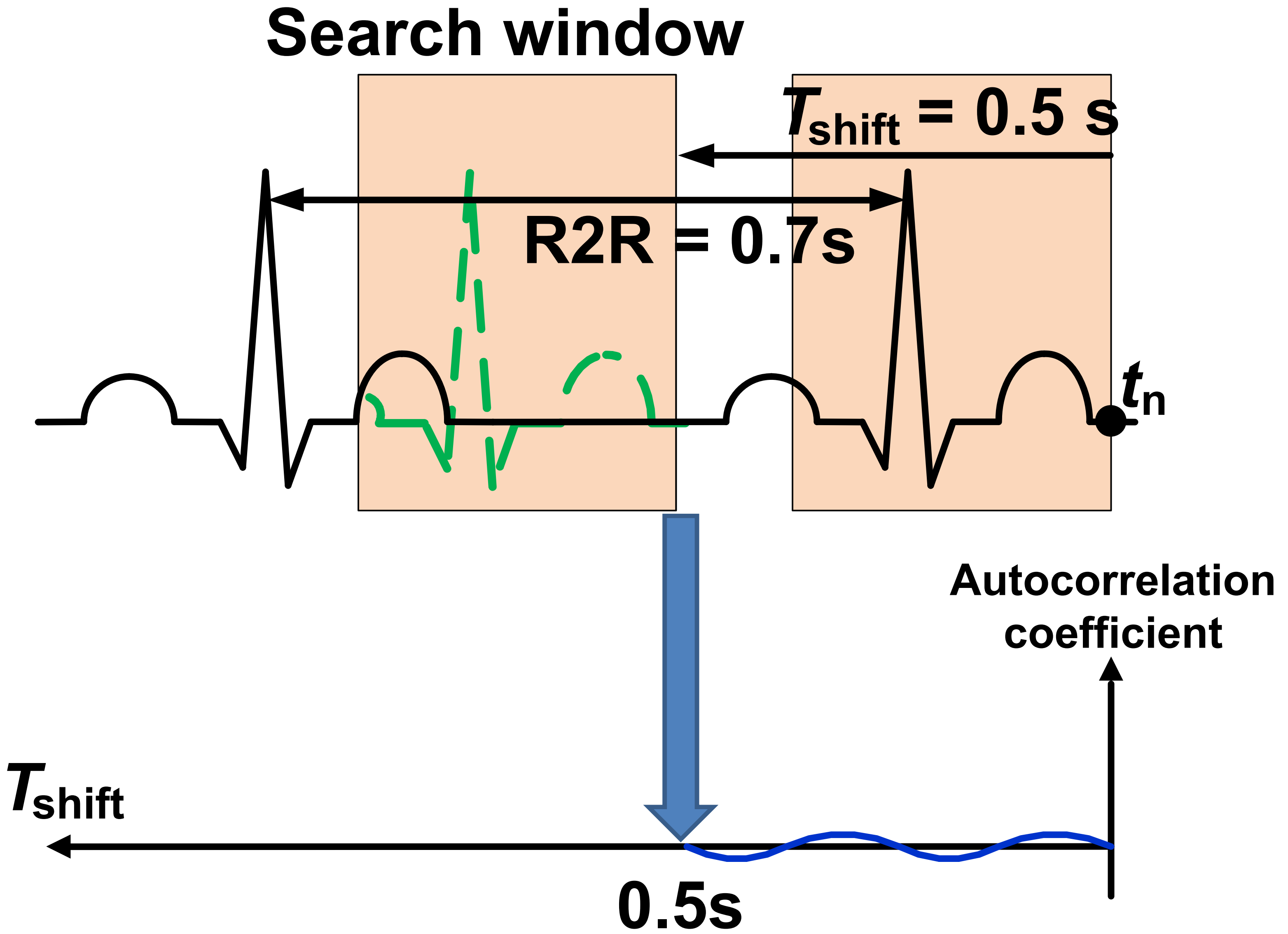
Motion artifact (5~20Hz)



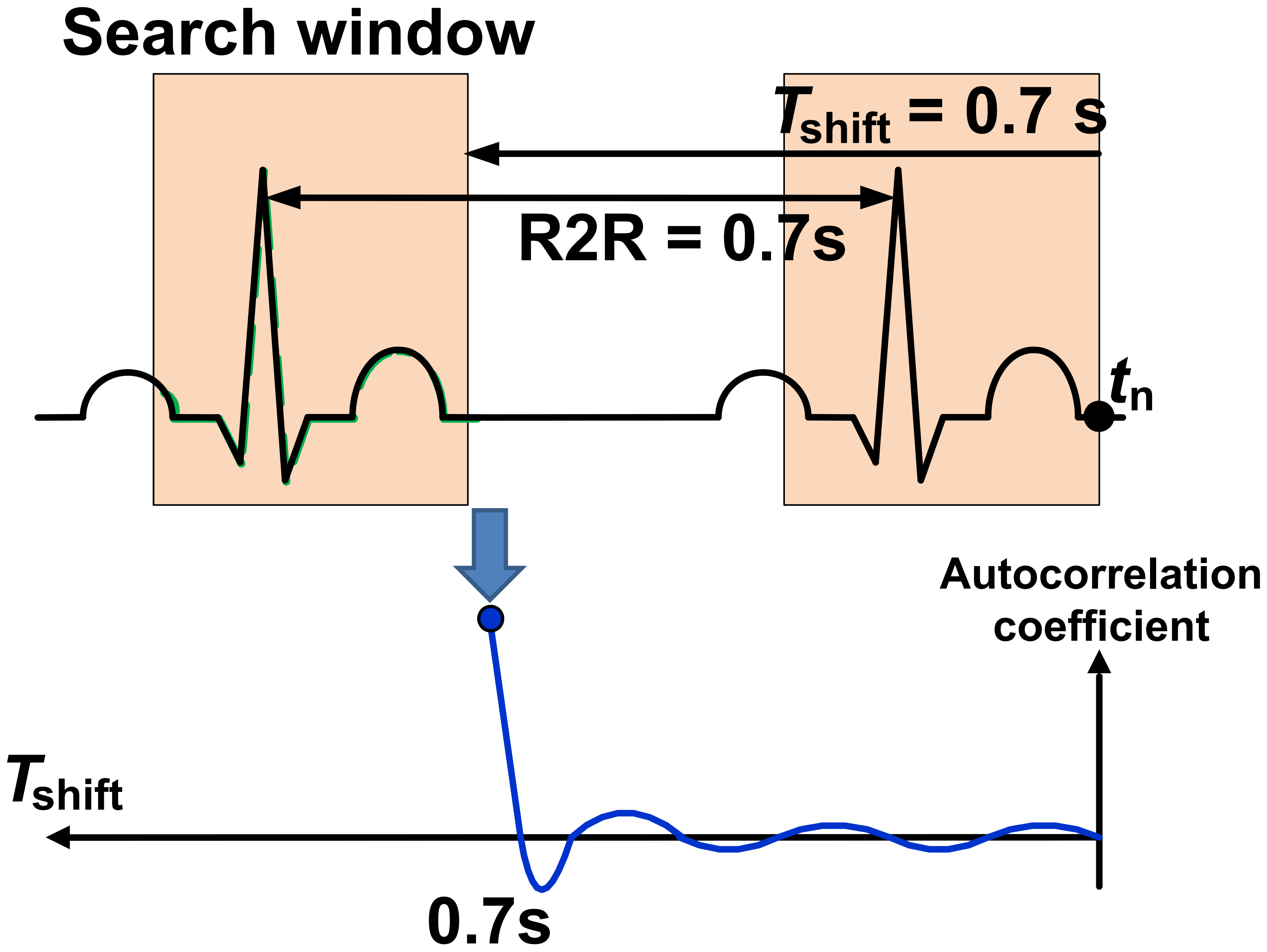
Short-Term Autocorrelation Algorithm



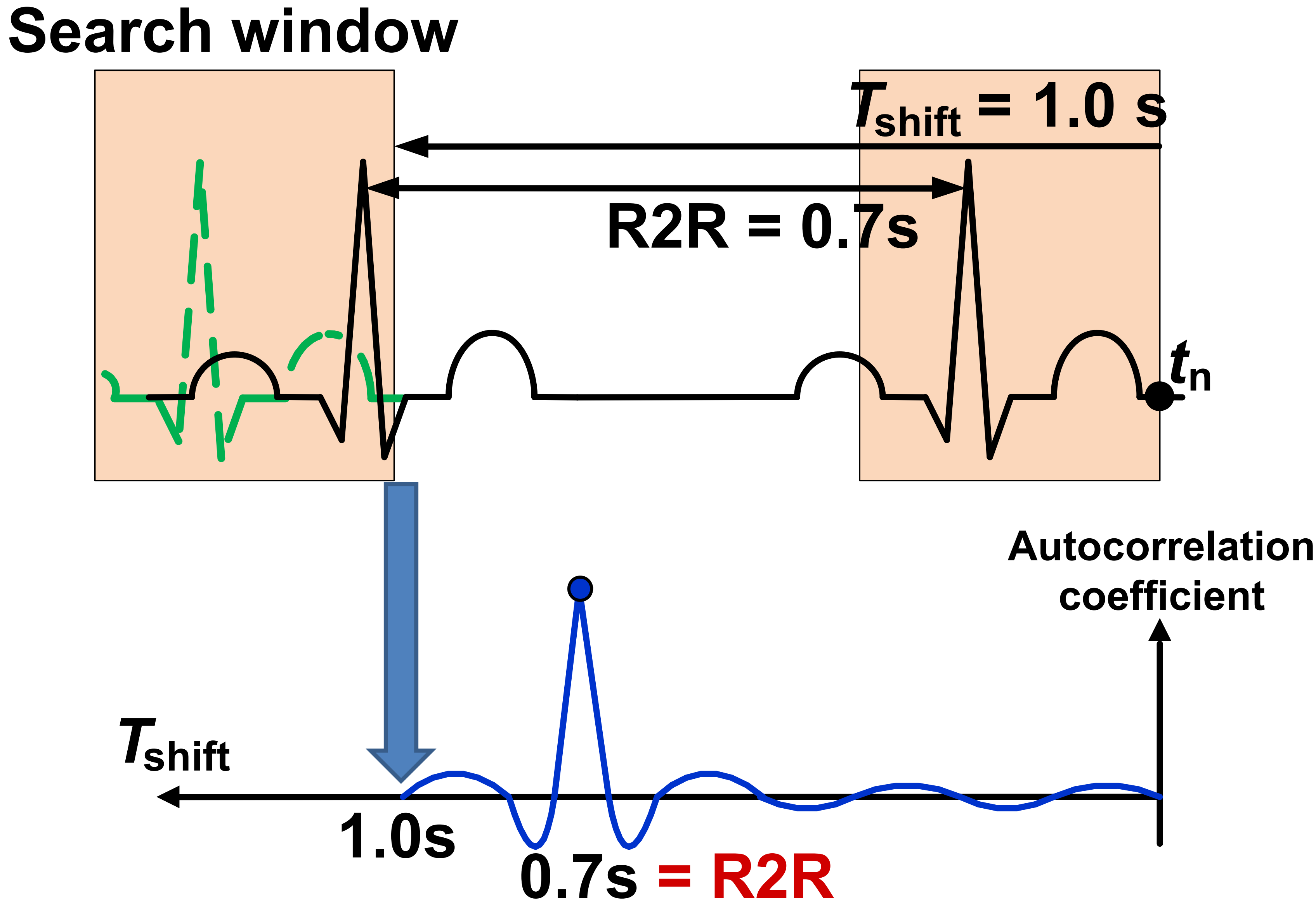
Short-Term Autocorrelation Algorithm



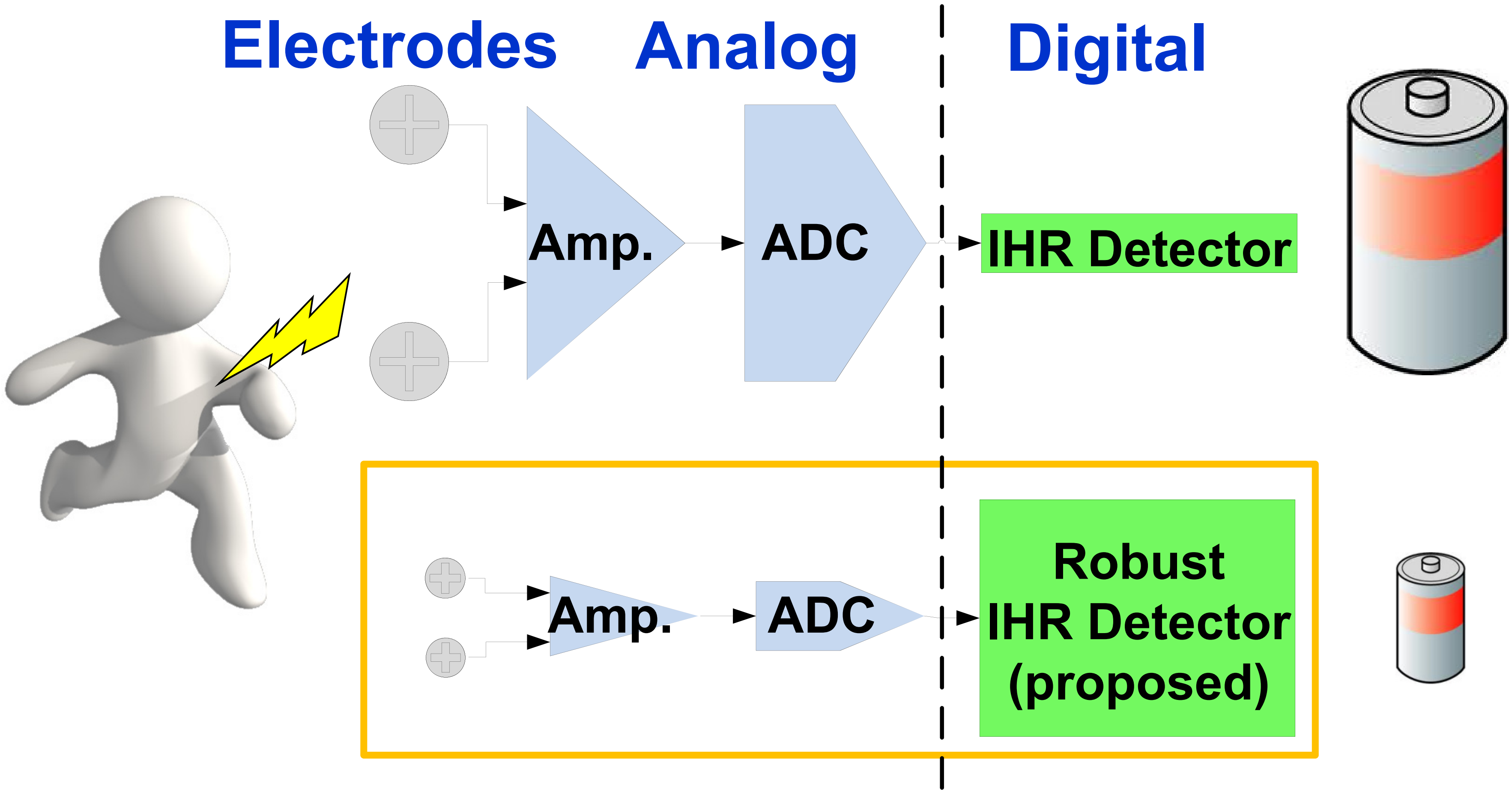
Short-Term Autocorrelation Algorithm



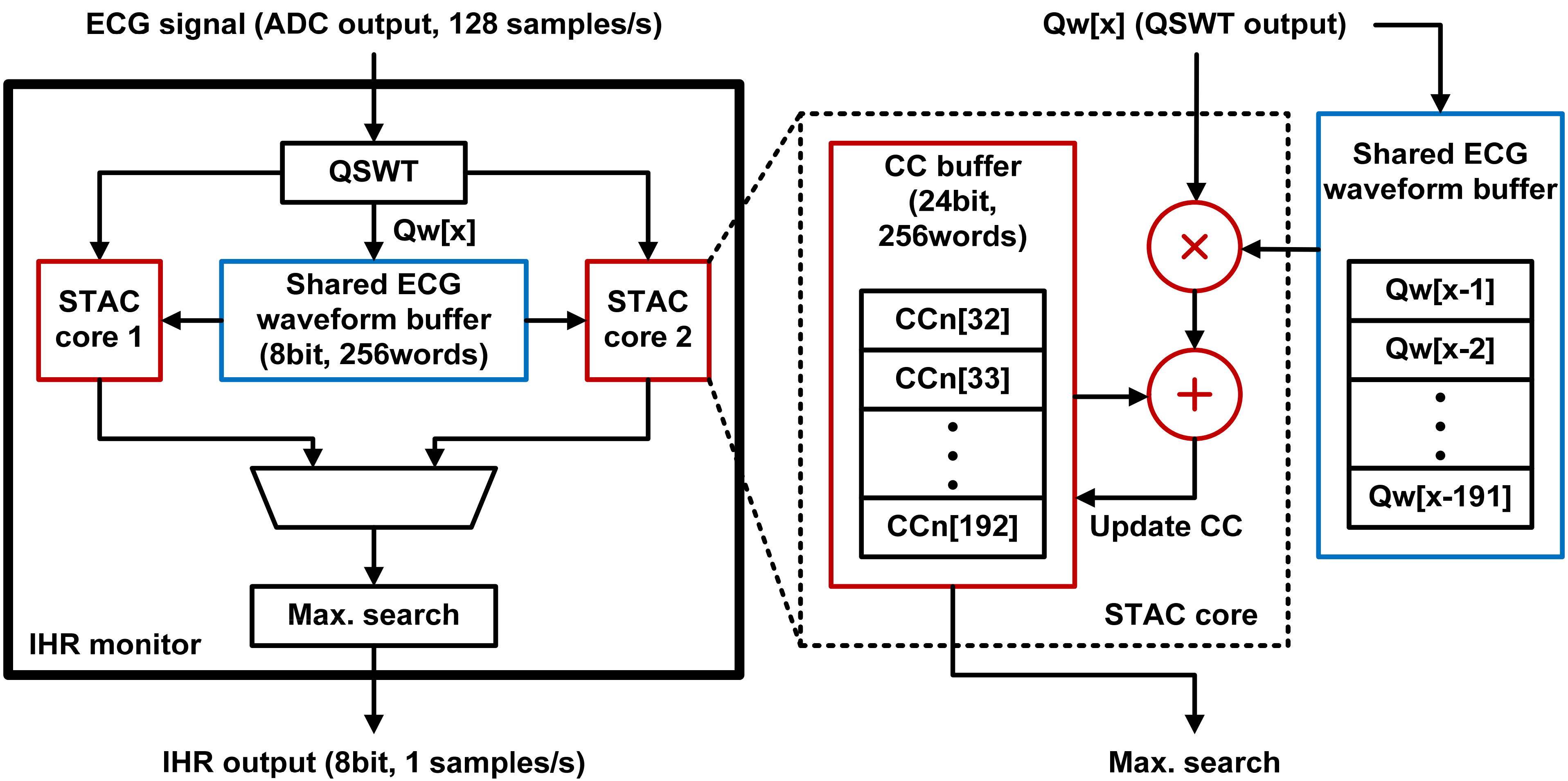
Short-Term Autocorrelation Algorithm



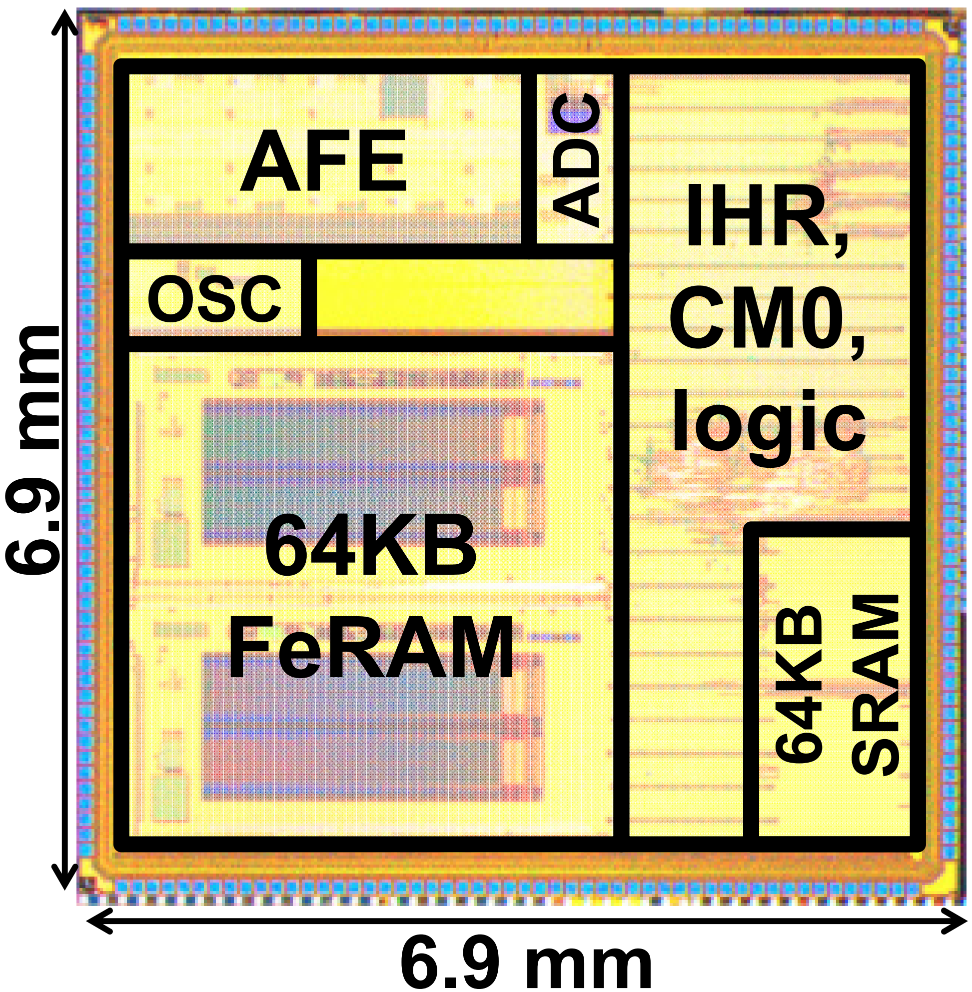
Our Approach for ECG Sensing



Architecture of IHR monitor

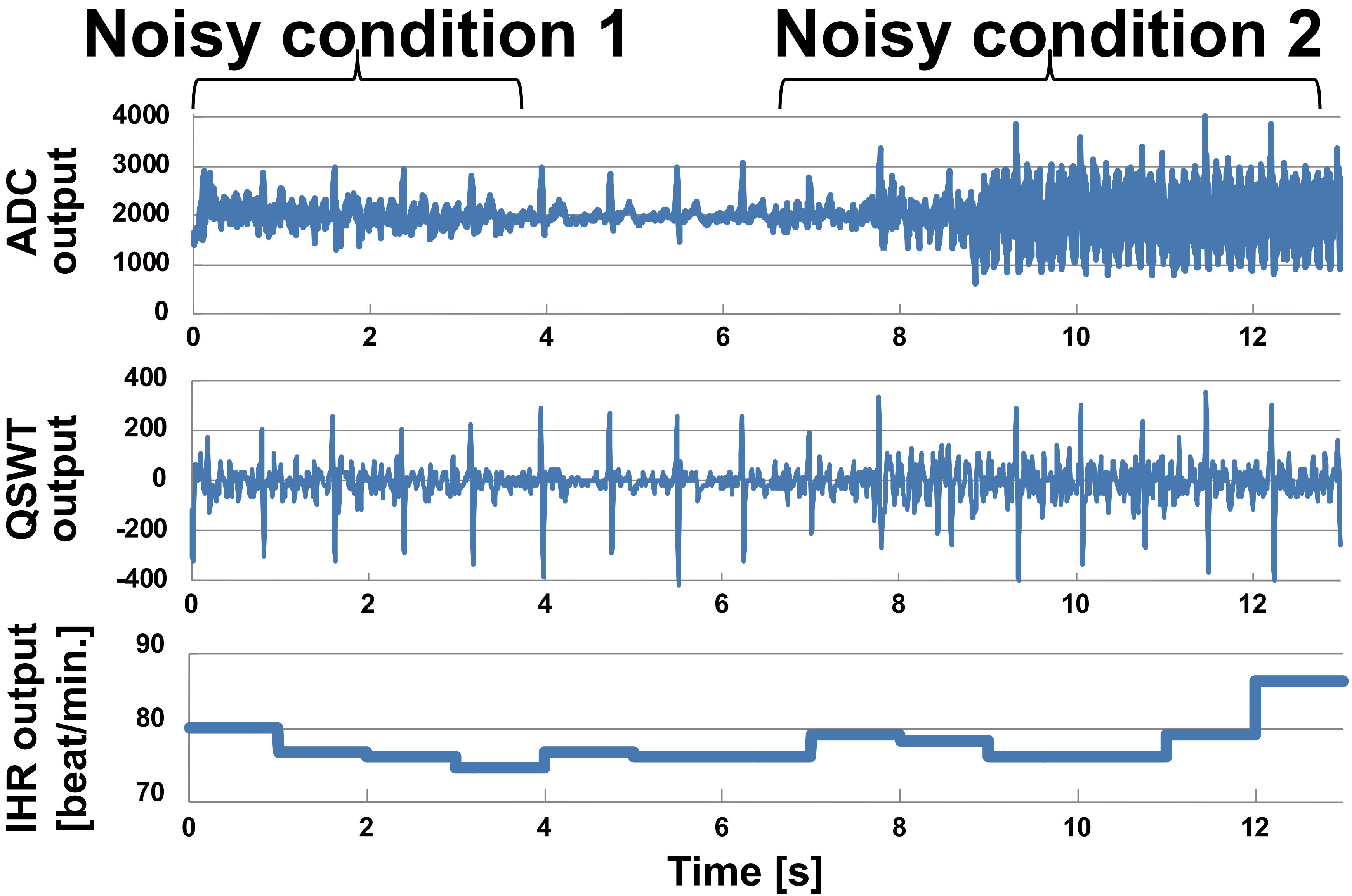


Die Micrograph and Specification

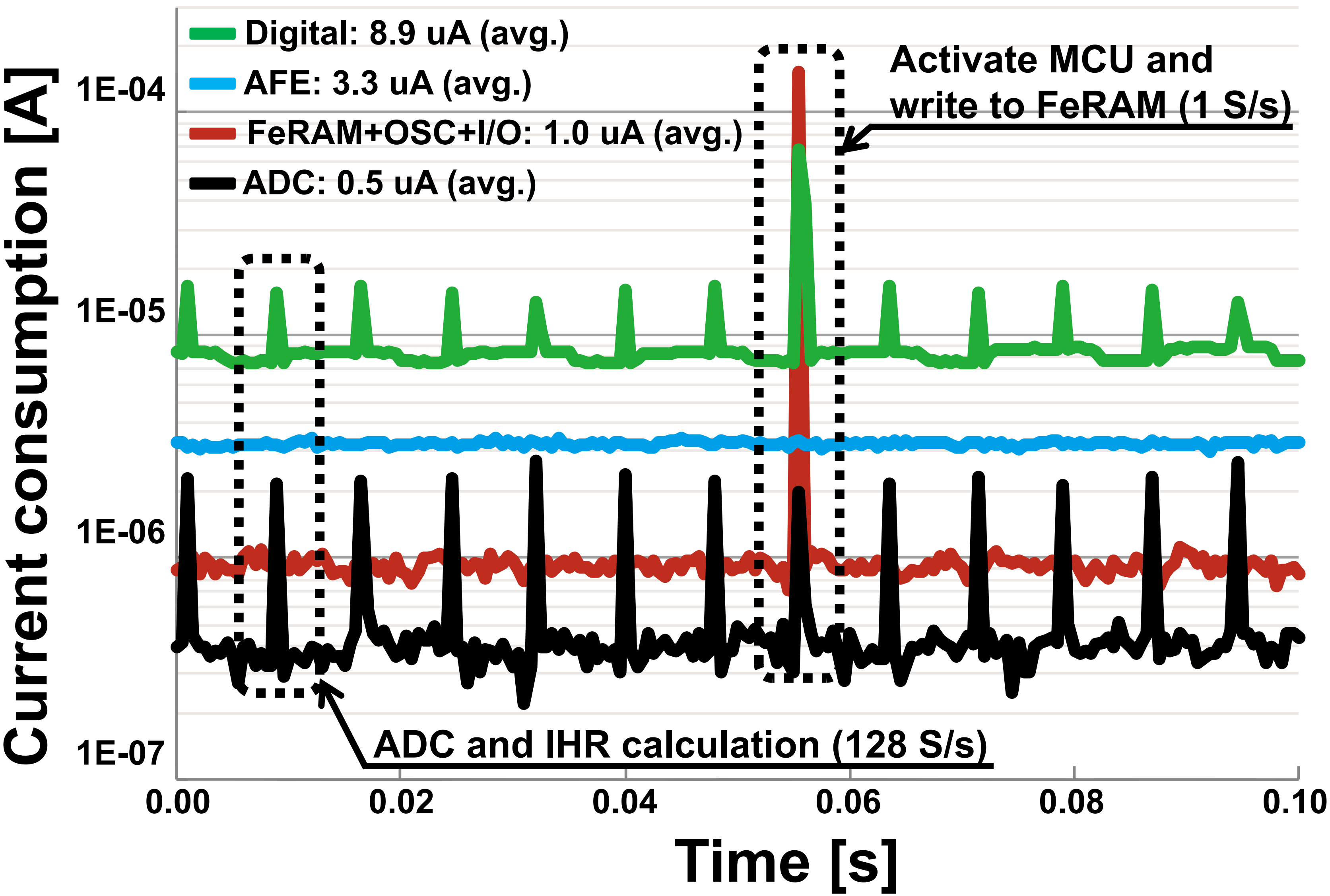


Technology		130-nm CMOS
Supply voltage		1.2V (Digital, SRAM, ADC, AFE)
		3.0V (FeRAM, 32kHz OSC, I/O)
Chip area		6.9 mm × 6.9 mm
Frequency		24 MHz (for MCU)
		32 kHz (for other blocks)
MCU		32-bit Cortex M0
On chip memory		64-KB FeRAM (for logging data
		64-KB SRAM (for MCU)
		1.75-KB SRAM (for IHR detecto
ADC	Resolution	12 bit
	Current	0.5 μA@128 S/s, 1.4 μA@1 kS/s
AFE	Gain	54 dB
	Bandwidth	0-100 Hz
	Current	3.4 μA
Total current		13.7 μA (for heart rate logging)

Measurement



Measurement



Comparison

	This work	ISSCC'12 [12]	VLSI'11 [13]
Technology	130 nm	130 nm	180 nm
Supply voltage	1.2V/3.0V	0.3-0.7V	1.2V
Frequency	24 MHz/32 kHz	1.7 MHz-2 kHz	1 MHz
MCU	Cortex M0 (32 bit)	8b RISC	n/a
On chip memory	129.75 kB	5.5 kB	46 kB
Total power for heart rate extraction	18.24 μW	19 μW	31.1 μW
Total current for heart rate extraction	**13.7 μA**	>27 μA	25.9 μA

Conclusion

- The low-power wearable sensor using normally-off strategy was presented
- The noise tolerant ECG processor chip was fabricated in 0.13μm CMOS
- The robust IHR monitor using short-term autocorrelation algorithm consumes 1.21μA
- The test chip totally consumes 13.7μA in IHR logging application

Acknowledgement

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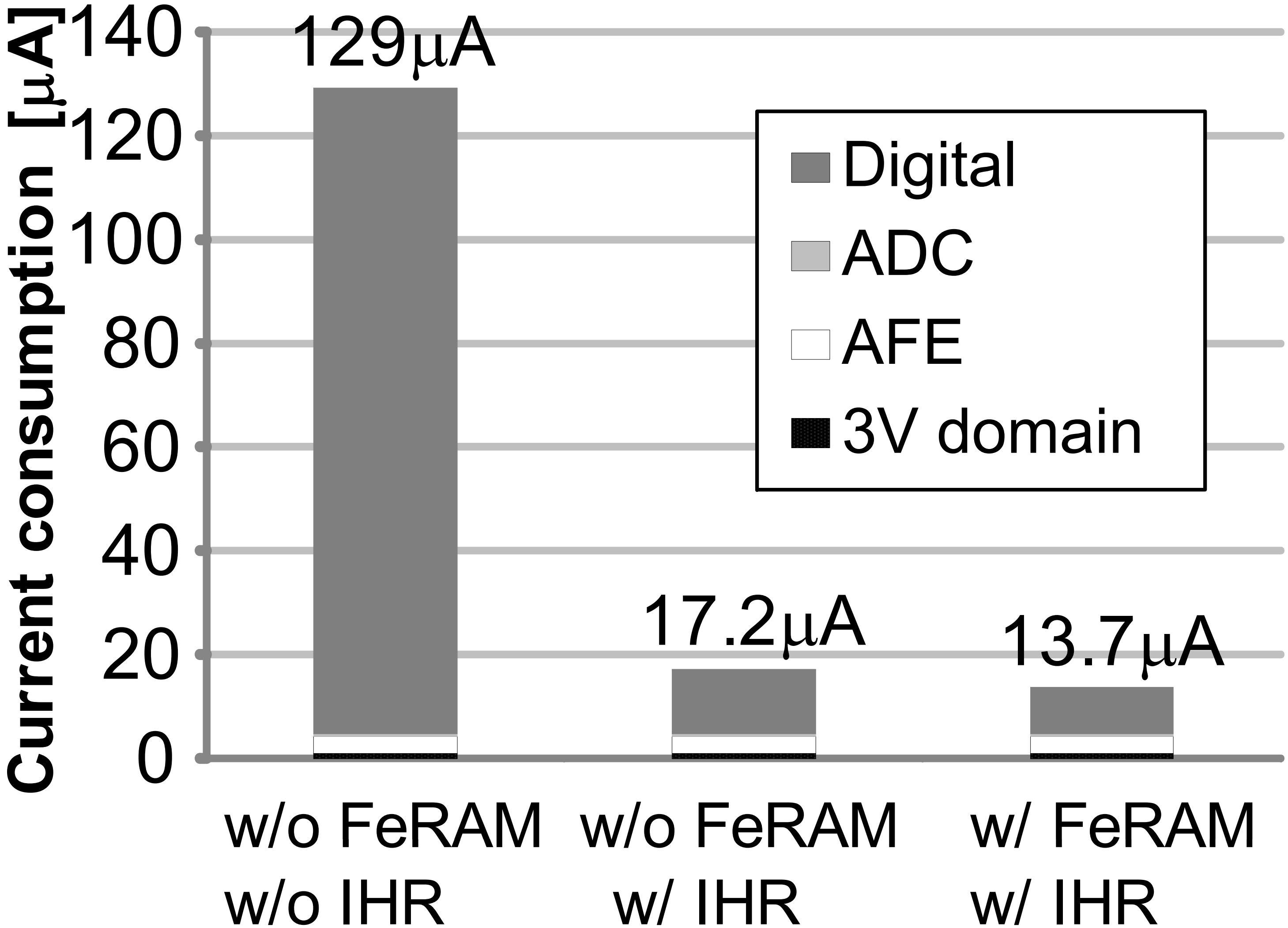
Thank you !

Performance Summary



Wavelet Transform (WT)

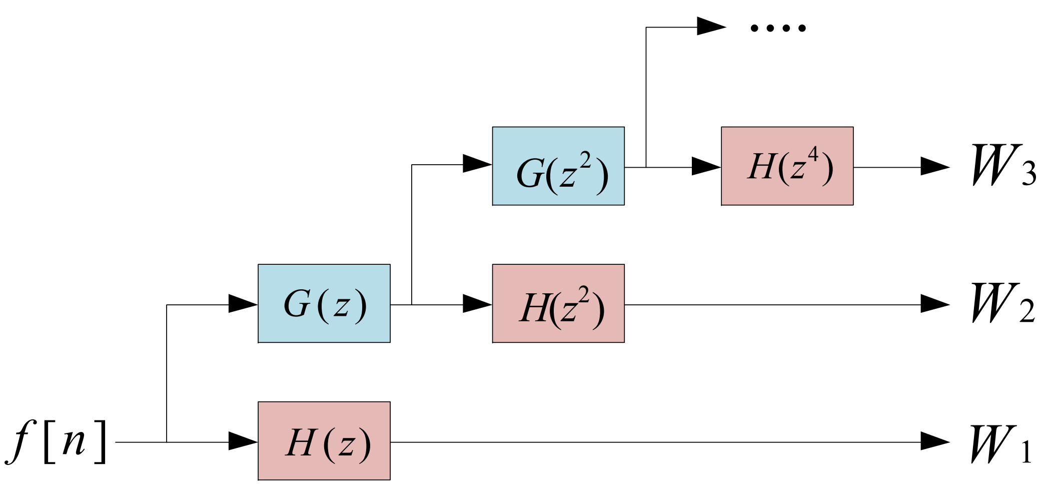
- **Both time and frequency analysis**

$$W_f(a,b) = \frac{1}{\sqrt{|a|}} \int_{-\infty}^{\infty} \overline{\psi\left(\frac{x-b}{a}\right)} f(x)dx$$

- **ψ : mother wavelet**

  (decide a kind of transform)

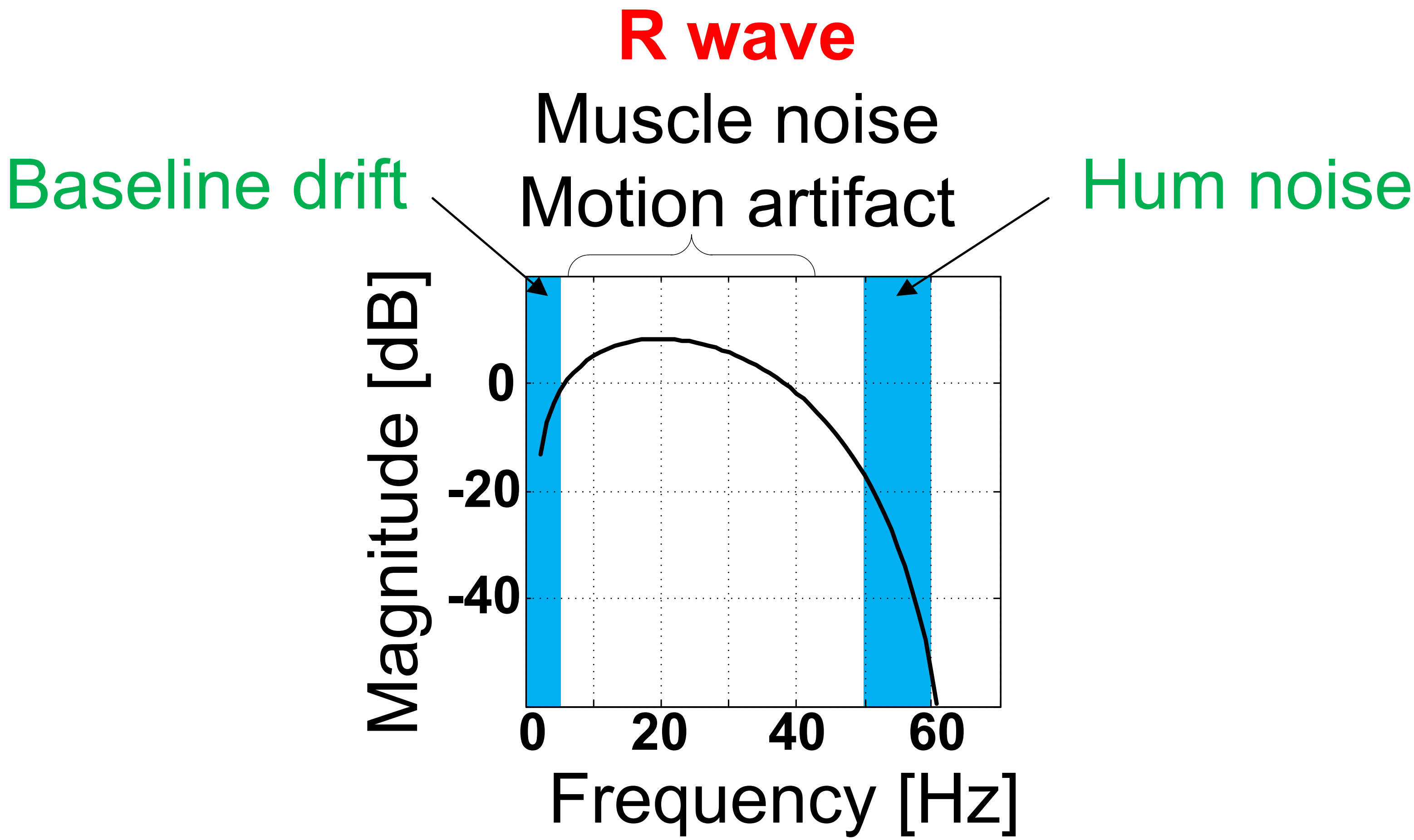
- **Discrete WT (DWT) consists of digital filters**



H : High pass filter
G : Low pass filter

Wavelet Transform

- **Sampling frequency = 128Hz**
- **A kind of Band Pass Filter (BPF)**



SNR

$$SNR = 10\log\frac{S}{N \times a^2}$$

S : The peak-to-peak amplitude of QRS complex
N : Frequency-weighted noise power
a : Scale factor

MIT-BIH NST : http://www.physionet.org/physiotools/wag/nst-1.htm