A Fully Integrated Activity Sensing CMOS Circuit for Rate-Adaptive Pacemakers.

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Objective: A circuit to sense patient's physical activity in rate-adaptive pacemakers.

Contents:

- Circuit specifications, analysis and dificulties.
  - Series-Parallel division applied to OTAs with very low transconductance and extended linear range.
- 0.5 - 7Hz, G=400, bandpass-amplifier architecture and measurements.
  - Activity estimation measuremnts.
- Conclusiones.

Circuit Specifications

Case of study: ***Signal conditioning circuit for a piezoelectric accelerometer which is part of a rate adaptive pacemaker.***

Based on Piezoelectric accelerometer.

Objective:

1st - To realize the Hz-order continuous-time circuit without using external elements.

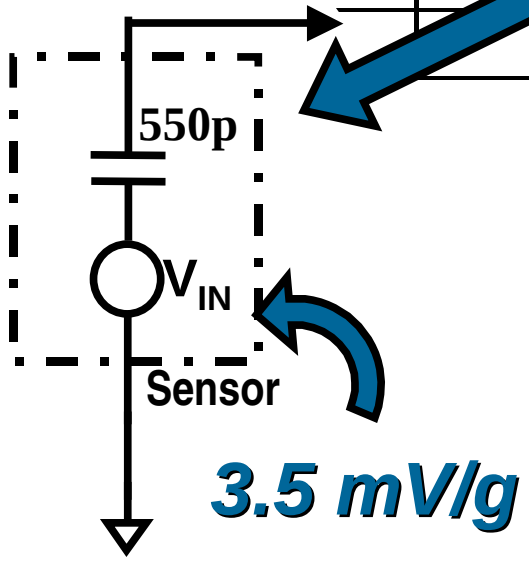
2nd - To reduce as much as possible power consumption, area, and noise.

Specifications: ***System.***

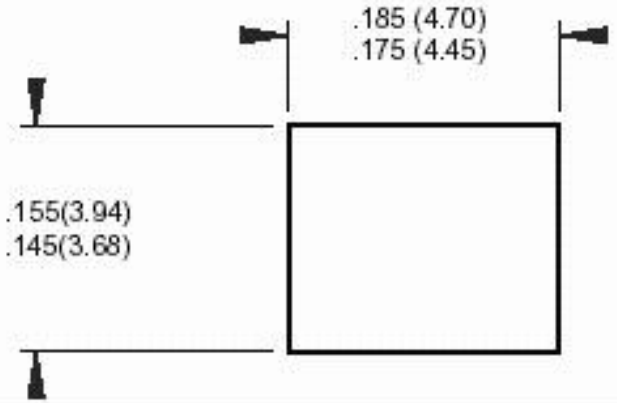
Specification	Range
Supply Voltage	**2.8 - 2.0 V**
Accelerations range	**0.007 - 0.34 g_{peak}**
Input Voltage Range	**(24 μV_{peak} - 1.2 mV_{peak}) $\pm$ 3.5mV gravity step**
Current Consumption	**< 2μA**
Frequency Response.	**Bandpass 0.5-7Hz, 40 dB/dec**
Input Noise.	**< 12μV_{rms}**
Input Offset.	**< 13μV**
Gain.	**400**
Others	**No external elements (i.e. R, C)**
	Relaxed tolerance in transfer function

Specifications: Sensor.

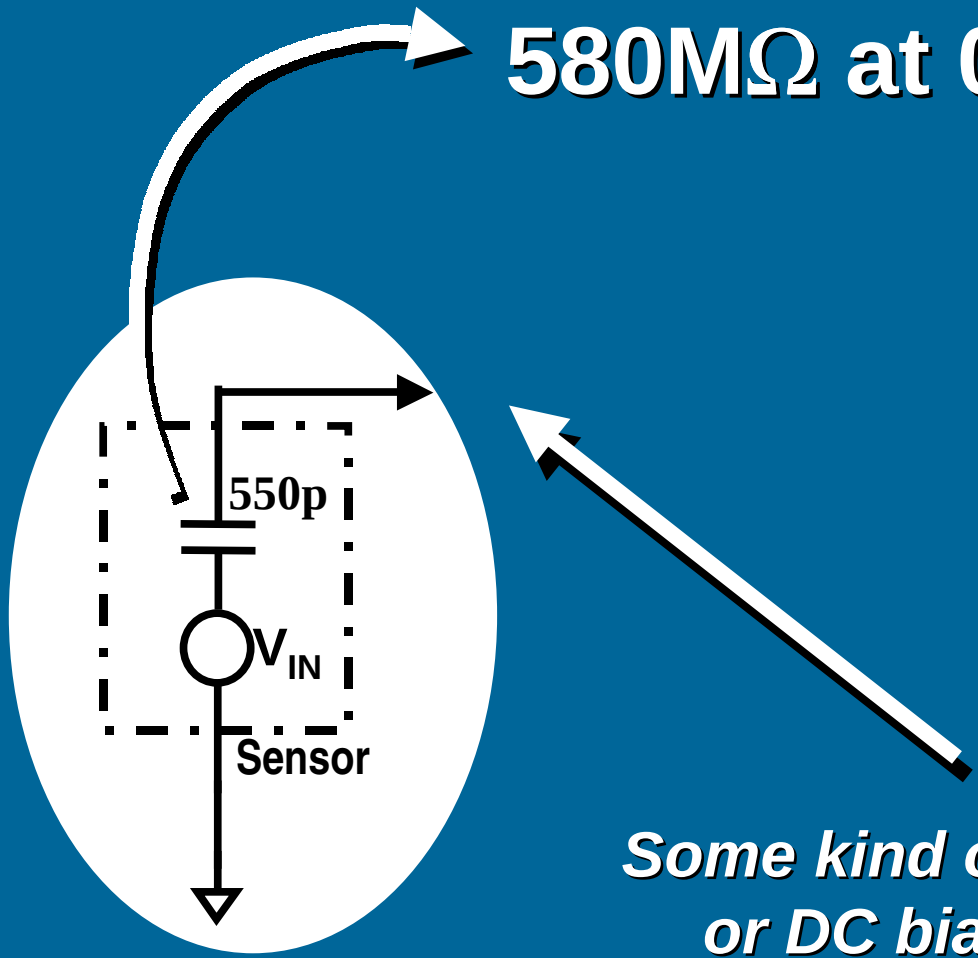
Specs.	Min.	Typ.	Max.
Charge Sensitivity [pC/g]	1.4	1.9	2.4
Capacitance		550 pF	
Transverse Response			5%
Resistance (25ºC)	10GΩ		
Resistanc	100		
Mechanic		9kHz	



3.5 mV/g



580MΩ at 0.5Hz!



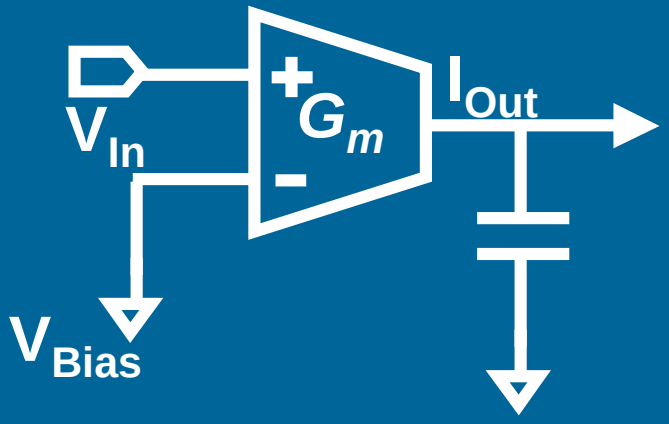
Some kind of virtual ground or DC bias is required!

Main chalenges:

- Transducer with a very high output impedance.
- Small signal inmerse in much higher gravity steps.
- Low noise, micropower.

- Sub-Hz filter without the aid of external resistors or capacitors.

Selected Circuit Techique: *G_m-C continuous -time.*



Extremely low transconductors or large capacitors are required for low frequency filters.

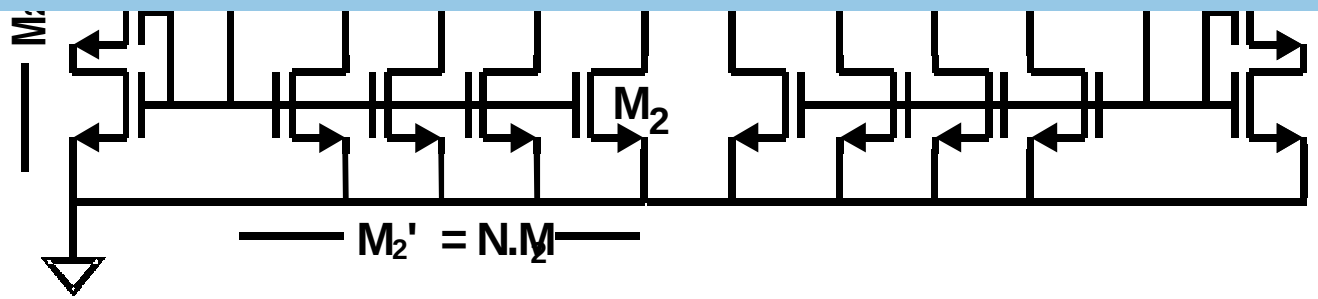
KEY TECHNIQUE:

Series-Parallel division OTAs:

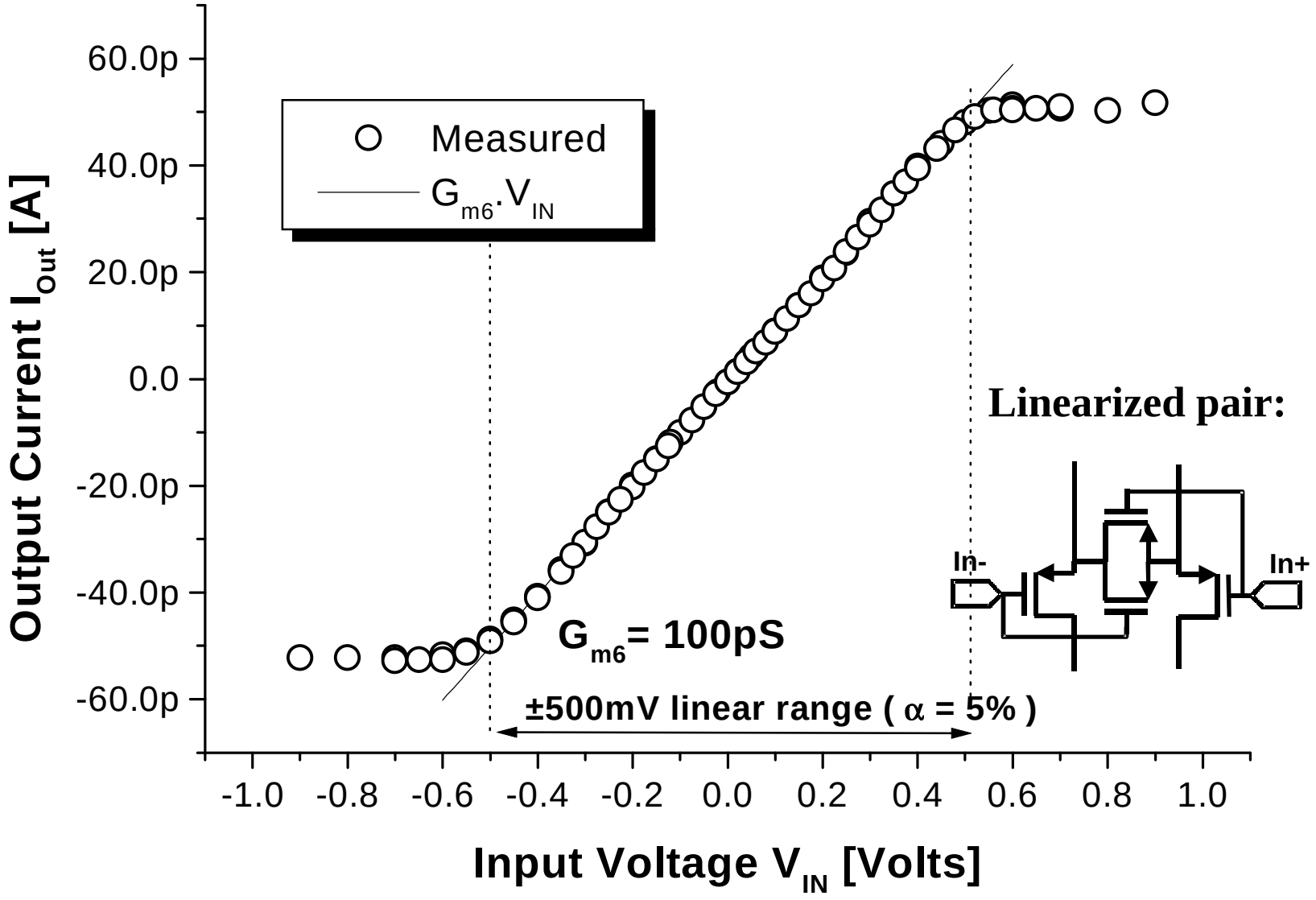
OTAs: *Basic Series-Parallel OTA.*

- **Very simple circuit ⇒ less area, power consumption.**
- **Do not introduce much excess noise or offset.**
- **Easy to reuse layout.**

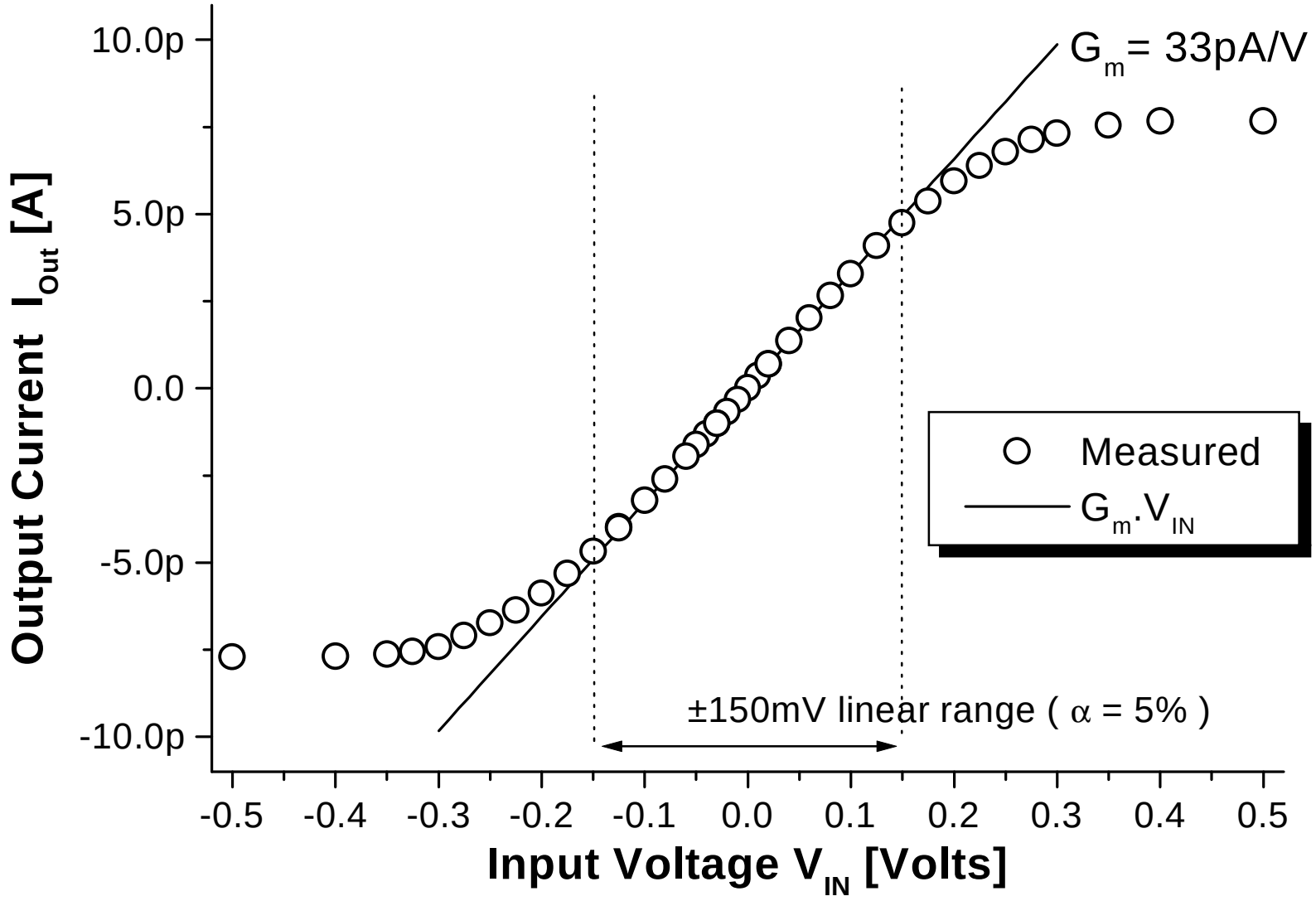
- **Fabricated and tested OTAs up to 35nS (30GΩ) and 1V linear range.**



OTAs: Example G_{m6} = 100pS (10GΩ)



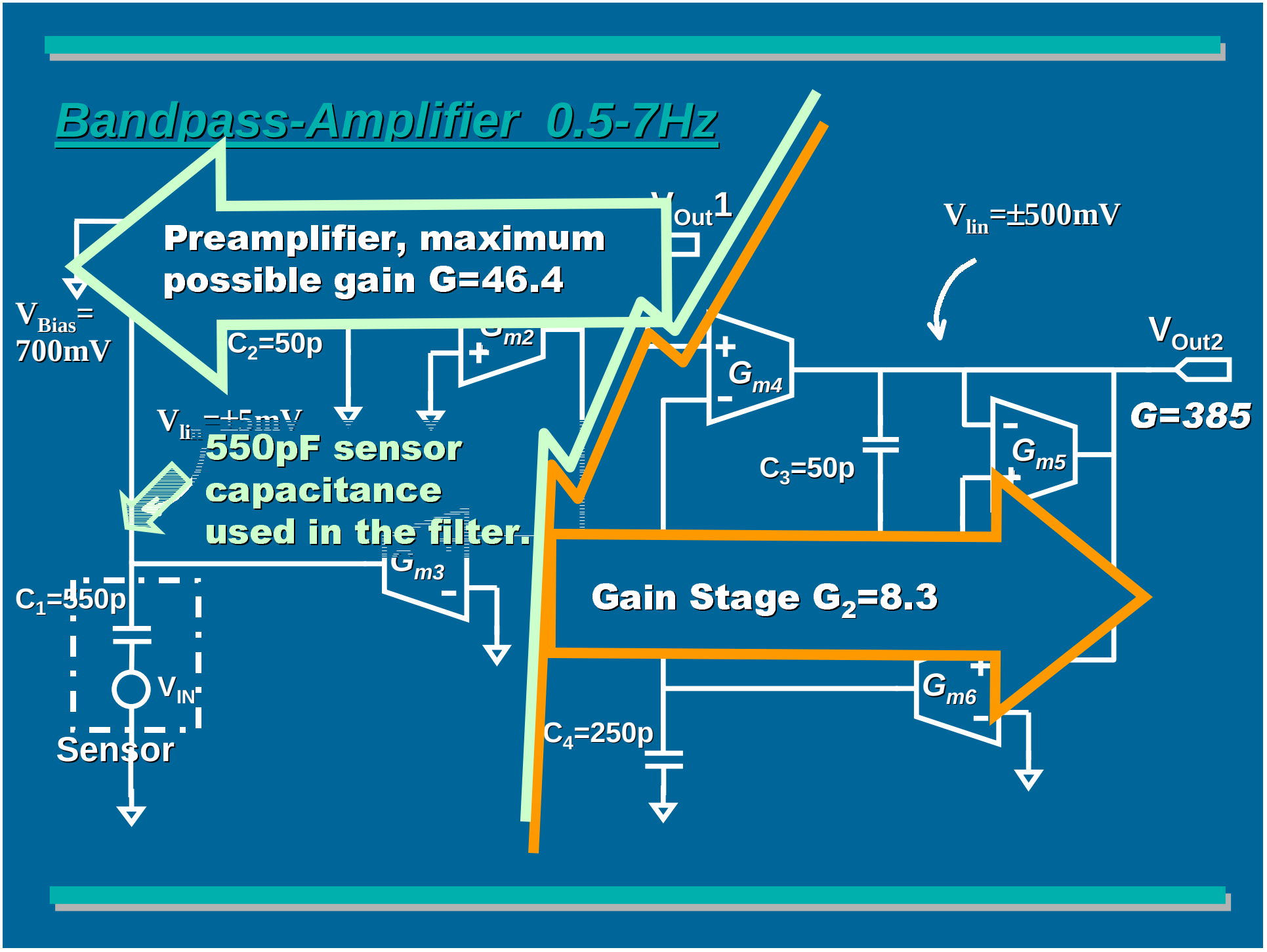
OTAs: Example G_{m3} = 35pS (30GΩ !!)



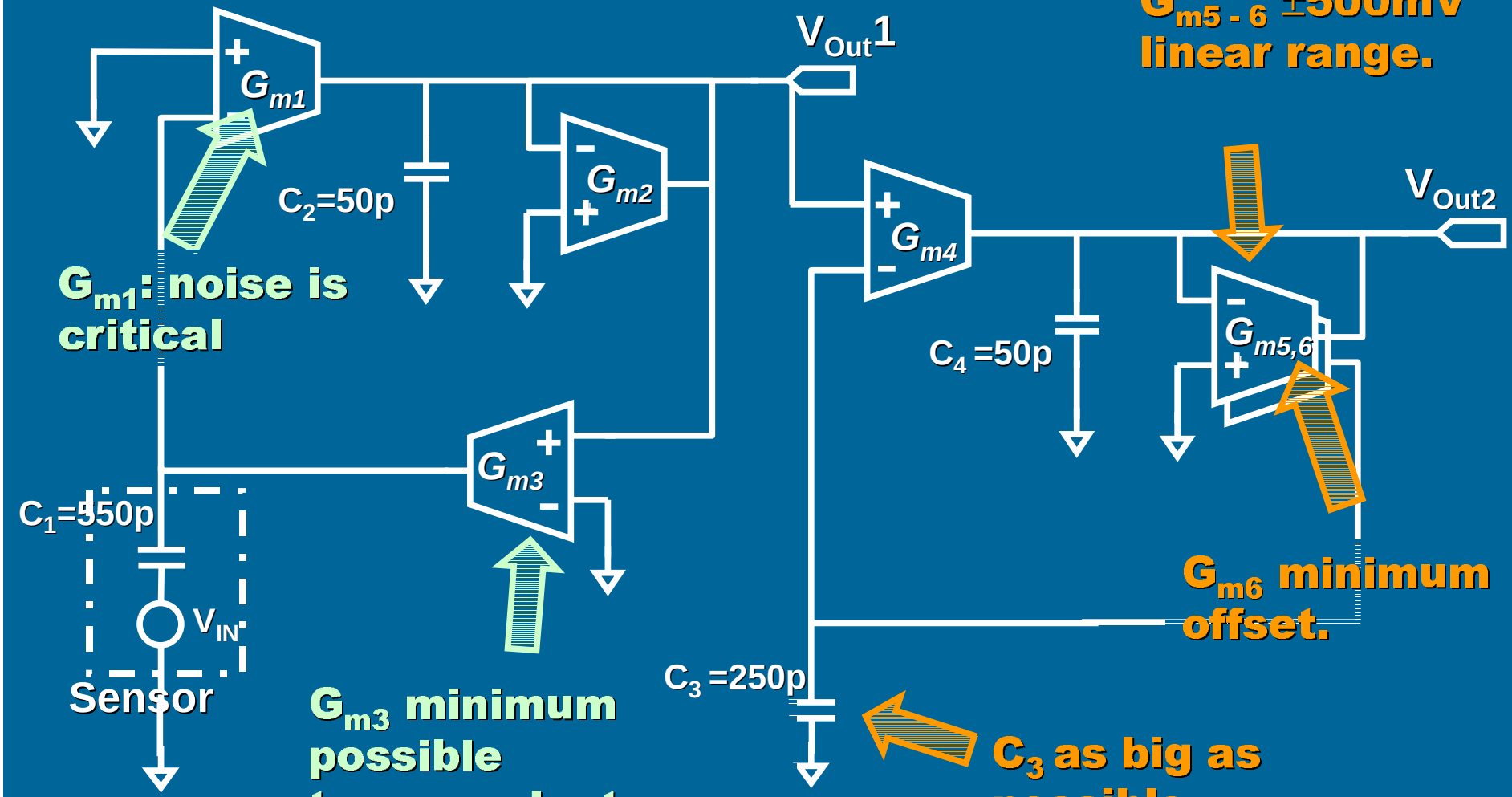
OTAs: Measured/estimated characteristics.

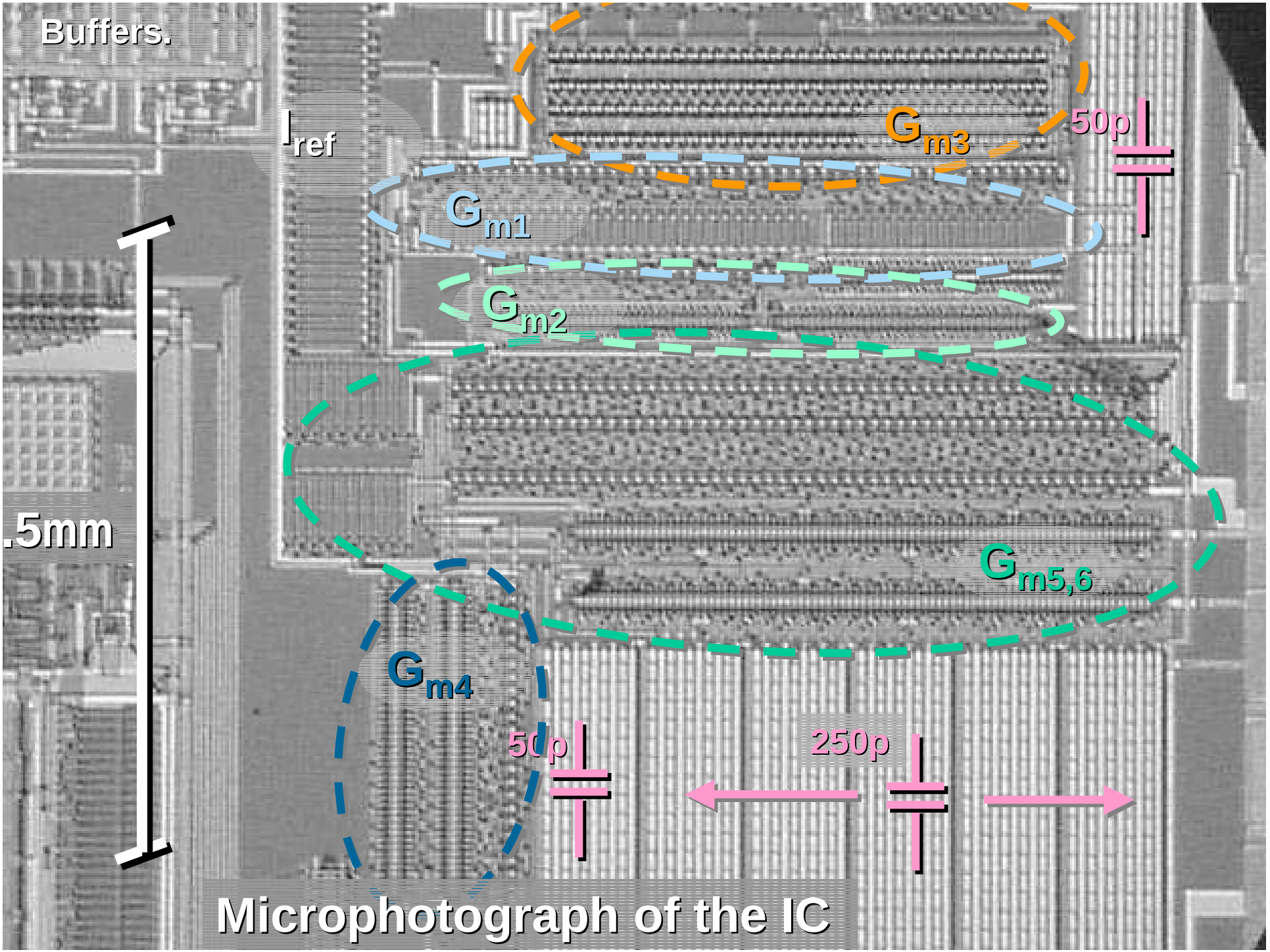
OTA	Transc.[a]	Linearity V_{Lin} [mV]	Input noise. [μV_{rms}] [a]	Input Offset σ_{Voff} [mV]	Current Cons.[nA]	Area [mm^2]
G_{m1}	110(110)nS	60	5 (4)	1.1	14	.019
G_{m2}	2.35(2.58)nS	150	42	4.4	43	.040
G_{m3}	35(33)pS	150	163(130)	2.1	42	.092
G_{m4}	21nS	150			47	.051
G_{m5}	2.4(2.8)nS	500		9.1	44	.18
G_{m6}	89(100)pS	500		6.8		

0.5-7Hz Filter-Amplifier


Bandpass-Amplifier 0.5-7Hz
Preamplifier, maximum possible gain G=46.4
$V_{Out}1$
V_{lin}=±500mV
V_{Bias}= 700mV
C_2=50p
G_{m2}
G_{m4}
V_{Out2}
G=385
V_{lin}=±5mV
550pF sensor capacitance used in the filter.
C_3=50p
G_{m5}
G_{m3}
C_1=550p
Gain Stage G_2=8.3
G_{m6}
V_{IN}
C_4=250p
Sensor

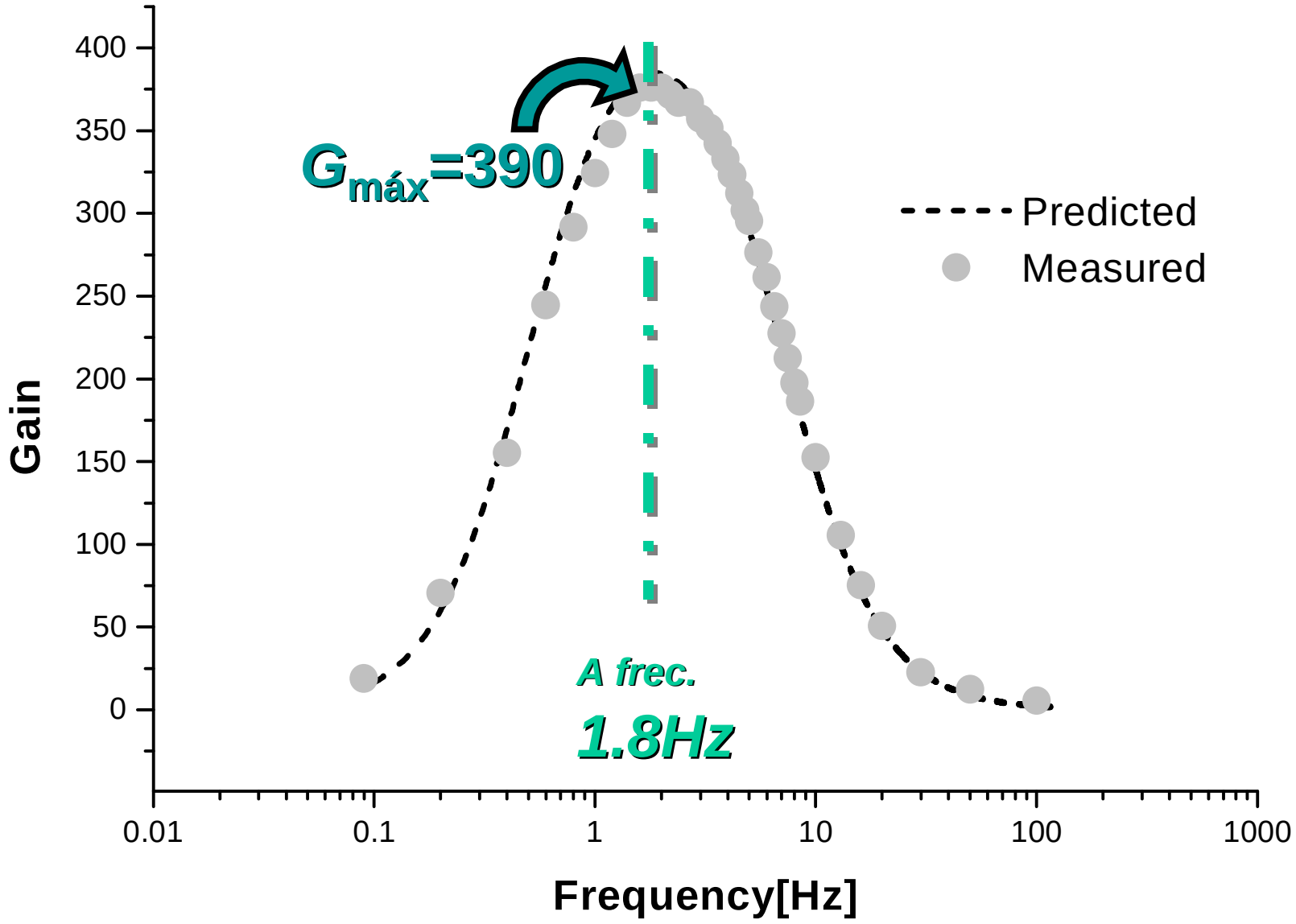
Bandpass-Amplifier 0.5-7Hz : Critical aspects.





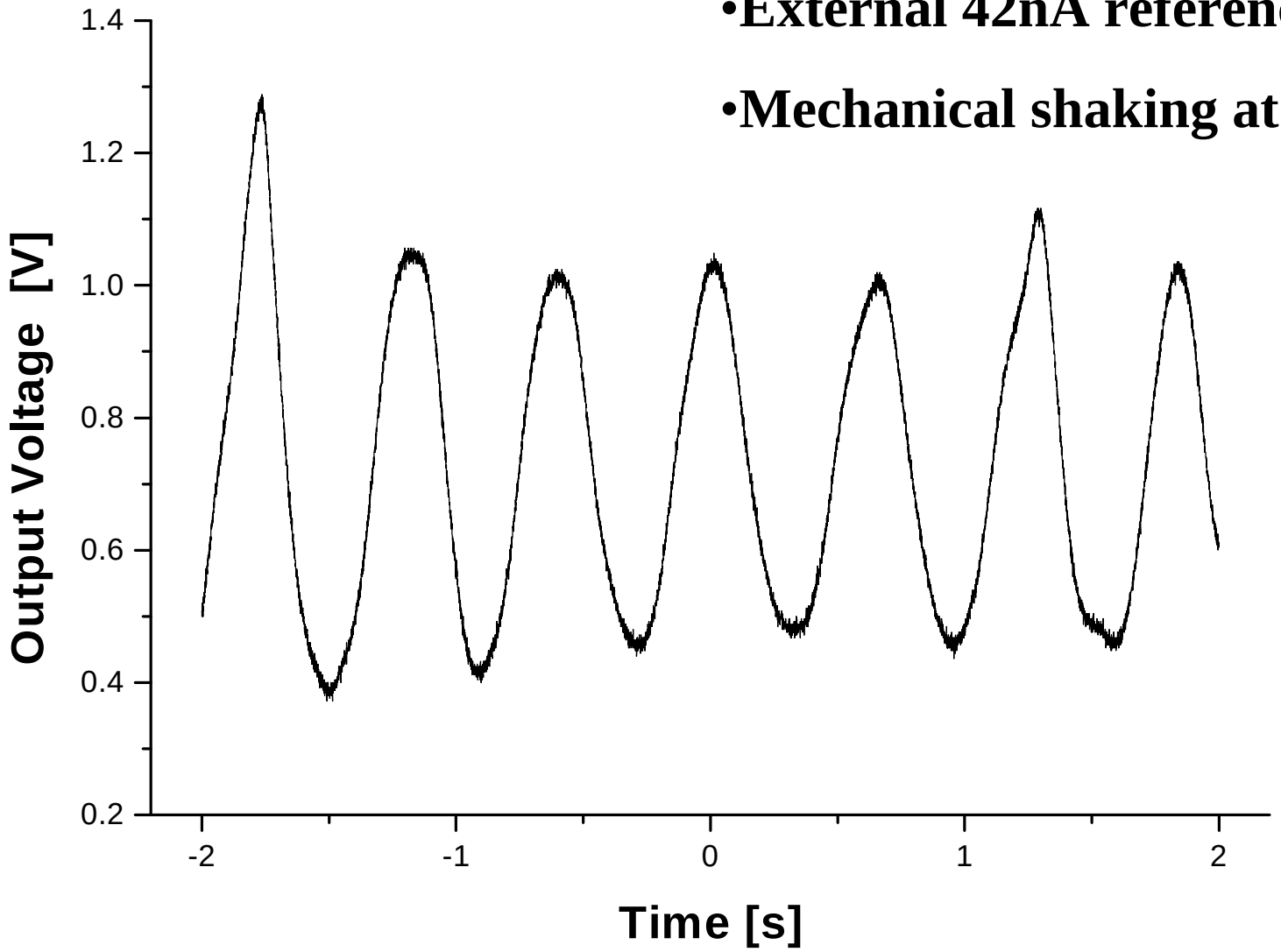
Microphotograph of the IC

Bandpass Measurements: Gain - Frequency.



Measurements: *Qualitative response w/sensor.*

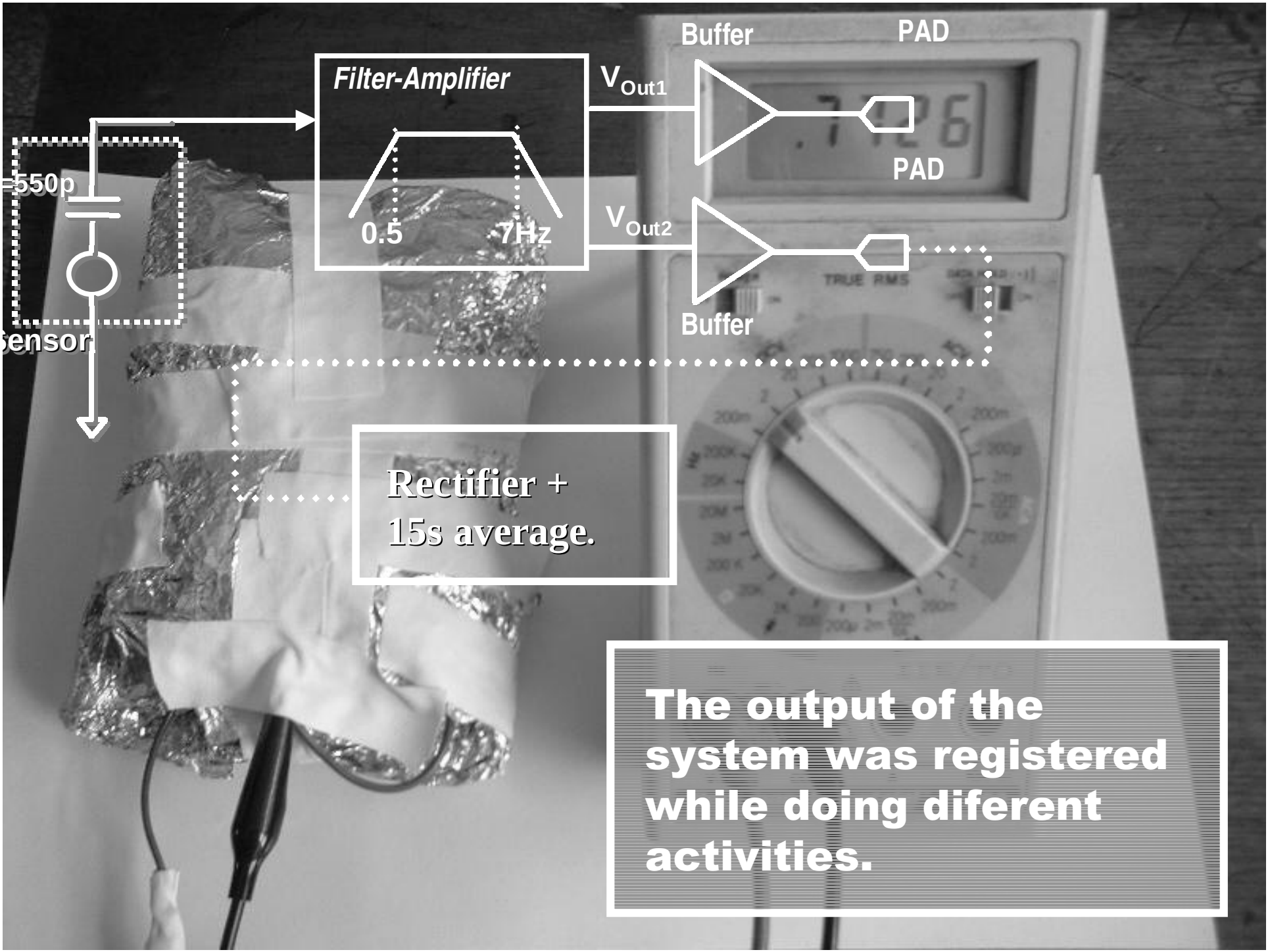
- **External 42nA reference current**
- **Mechanical shaking at approx. 2Hz**



Filter-Amplifier Measurements: ***Characteristics.***

Specification.	Measured Value.
Pass-band frequency	40db/dec 0.5-7Hz
Gain	390
Input noise	$2.1\mu V_{rms}$
Supply voltage	2.0 - 2.8 V
Current Consumption	230nA
Area	$0.78mm^2$
Input Offset	18μV

Physical Activity Sensing


Buffer
PAD
Filter-Amplifier
V_{Out1}
PAD
=550p
0.5
7Hz
V_{Out2}
Buffer
sensor
Rectifier +
15s average.
The output of the system was registered while doing diferent activities.

System Output: ***Measurement at at different activities.***

Physical Activity	System Output
Sleeping	0 mV
Working on a Computer	30 mV
Walking (slow)	44 mV
Walking (normal)	86 mV
Walking (fast)	210 mV
Climbing up stairs	95 mV
Going down stairs	82 mV
Climbing up stairs (fast)	200 mV
Running (10km/h)	423 mV

Conclusions

Conclusions: A comparative survey *.

** (Includes integrated rectifier)*

Circuit Description.	Technique	Discrete Elements	Input Noise	Gain	Current Consumption	Supply Voltage	Area [mm²]
(#1) 0.5-7Hz 2nd. order bandpass + rectifier + time averaging	G_m-C using series-parallel division OTAs	**no**	**2-4μV_{rms}**	**400**	**300nA**	**2-2.8V**	**1.2**
(#2) - 0.5-7Hz 1st. order bandpass + rectifier + time averaging.	...nuous-time ...niques	**10**	**18μV_{rms}**	**2900**	**3μA**	**2-2.8V**	**1.82**
(#3) - 0.5-7Hz 1st order bandpass + rectifier.	...ched ...tors	**2 for time averaging**					
(#4) - 6th order, 2.4Hz lowpass filter.					**3.3μA**	**3V**	**1**
(#5) - 3rd. Order bandpass filter 110Hz.						**2-2.8V**	**1.9**

(#5) Lentola et al. TCAS-II, 2003. (Cardiac sensing channel.)

(#1) ... work

(#3) GME - IIE, 2000

(#4) Solis-Bustos et al. TCAS-II, 2000.

Concusions:

Series-parallel Division OTAs:

Filter Design:

System Level:

- **Physical activity measurement circuit:**

  ⇒ **Improves previous results. (power-noise-sensitivity)**

  ⇒ **Apt to use in modern rate-adaptive pacemakers.**

No external elements have been employed!