A Fully Integrated 0.5-7Hz CMOS Bandpass Amplifier.

Alfredo Arnaud Maceira
Carlos Galup Montoro

[1] GME –IIE, Facultad de Ingeniería, Universidad de la República , Montevideo – Uruguay.
[2] LCI, Dep. de Engenharia Eletrica,Universidade Federal de Santa Catarina - Brazil.

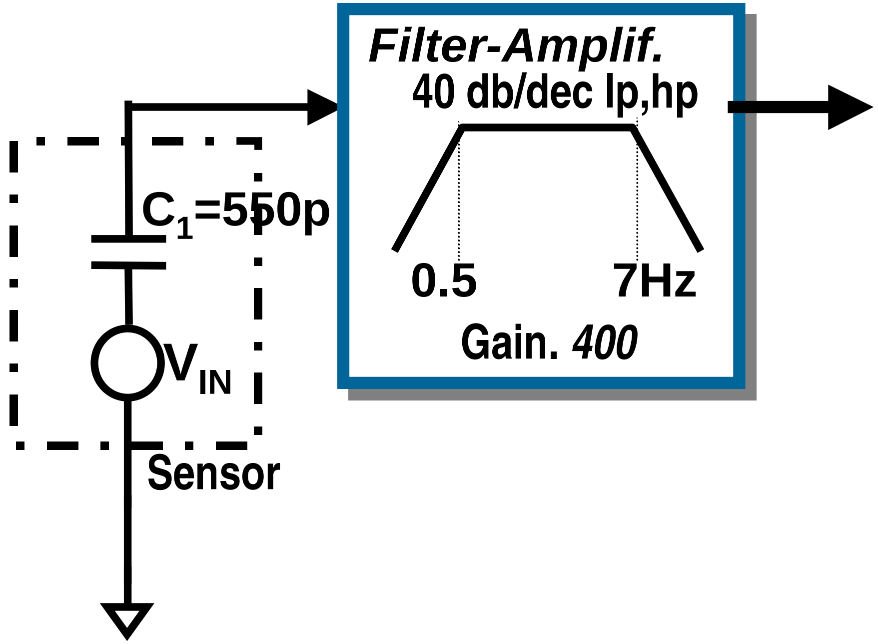
Case of study: *Signal conditioning circuit for a piezoelectric accelerometer which is part of a rate adaptive pacemaker.*

Objective:

1st - To realize the co... g external element...

2º - To reduce as mu... n, area, and noise.

First stage of the signal chain: 2nd order bandpass amplifier.



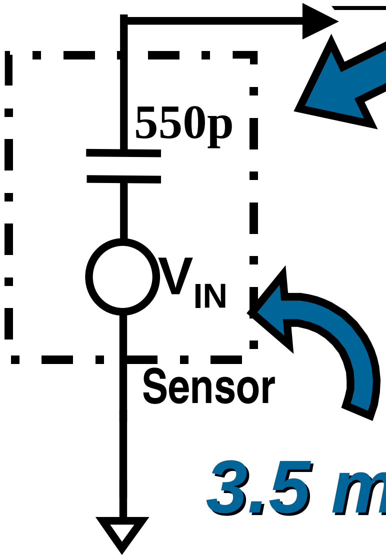
Contents: A Fully Integrated 0.5-7Hz CMOS Bandpass Amplifier.

- Circuit specifications, analysis and dificulties.
  - Series-Parallel OTAs with very low transconductance and extended linear range.
    - Bandpass-amplifier architecture and measurements.
      - Conclusions.

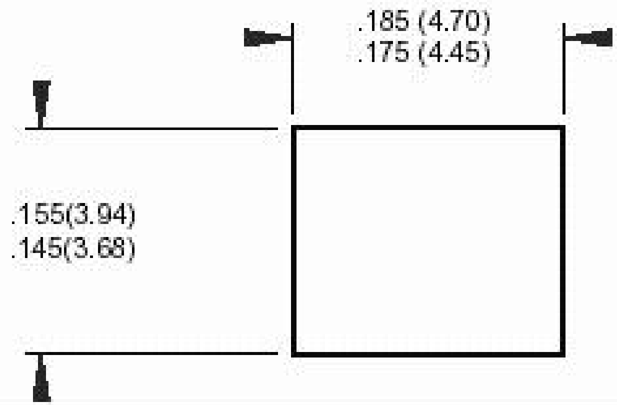
Circuit Specifications

Specifications: Sensor.

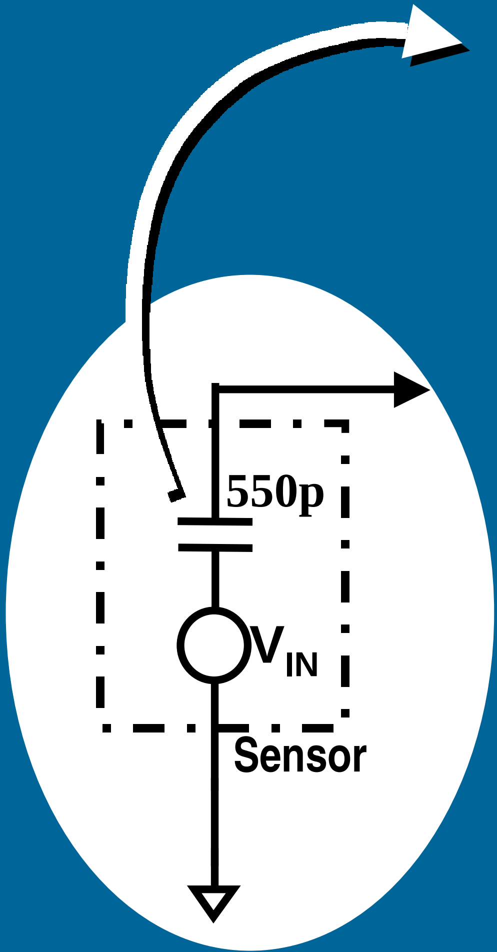
Specs.	Min.	Typ.	Max.
Charge Sensitivity [pC/g]	1.4	1.9	2.4
Capacitance		550 pF	
Transverse Response			5%
Resistance (25ºC)	10GΩ		
Resistanc[illegible]	100[illegible]		
Mechanic[illegible]		9kHz	



3.5 mV/g



580MΩ at 0.5Hz!



Some kind of virtual ground or DC bias is required!

Specifications: *System.*

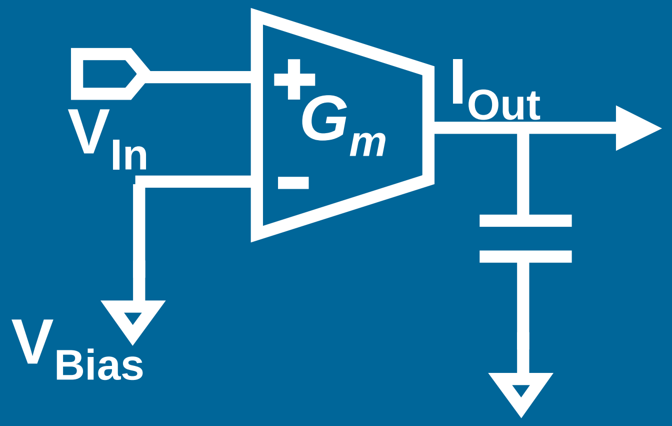
Specification	Range
Supply Voltage	**2.8 - 2.0 V**
Accelerations range	**0.007 - 0.34 g_{peak}**
Input Voltage Range	**(24 μV_{peak} - 1.2 mV_{peak}) $\pm$ 3.5mV gravity step**
Current Consumption	**< 2μA**
Frequency Response.	**Bandpass 0.5-7Hz, 40 dB/dec**
Input Noise.	**< 12μV_{rms}**
Input Offset.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

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.*

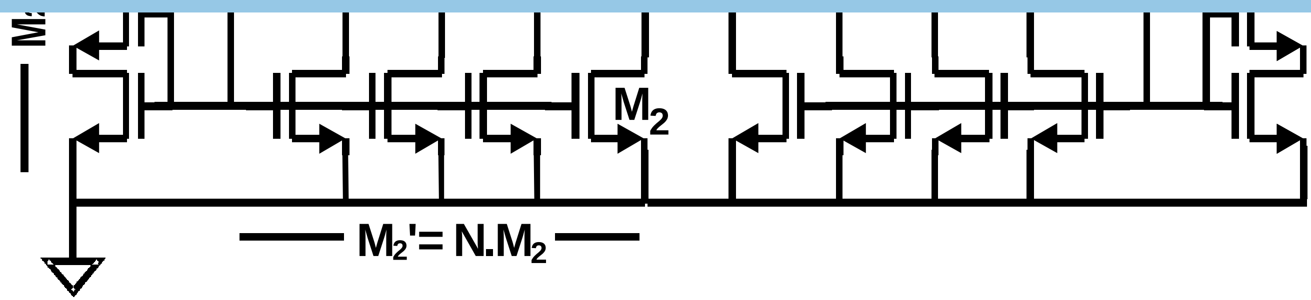


Extremely low transconductors or large capacitors are required for low frequency filters.

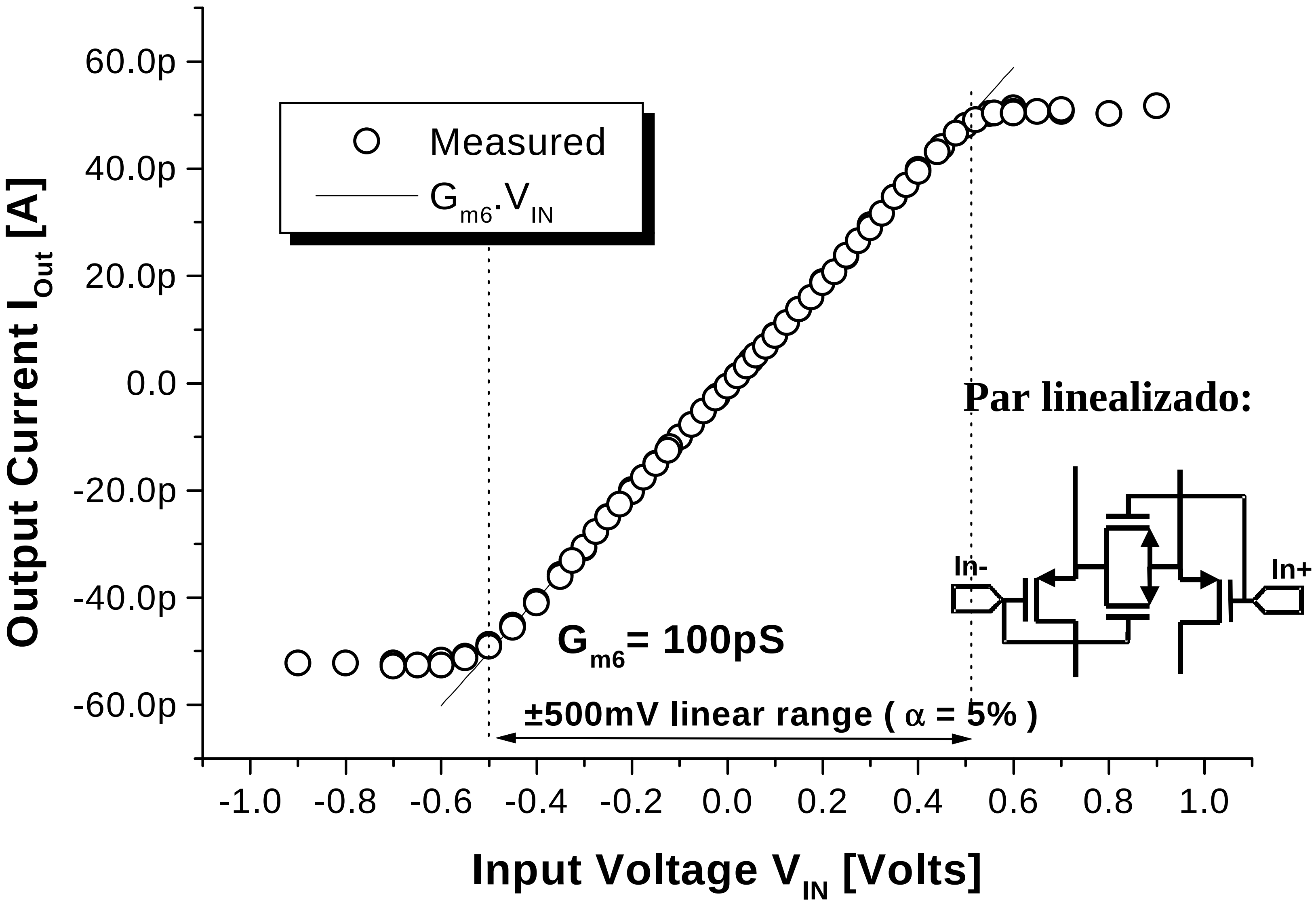
Series-Parallel division OTAs:

OTAs: *Basic Series-Parallel OTA.*

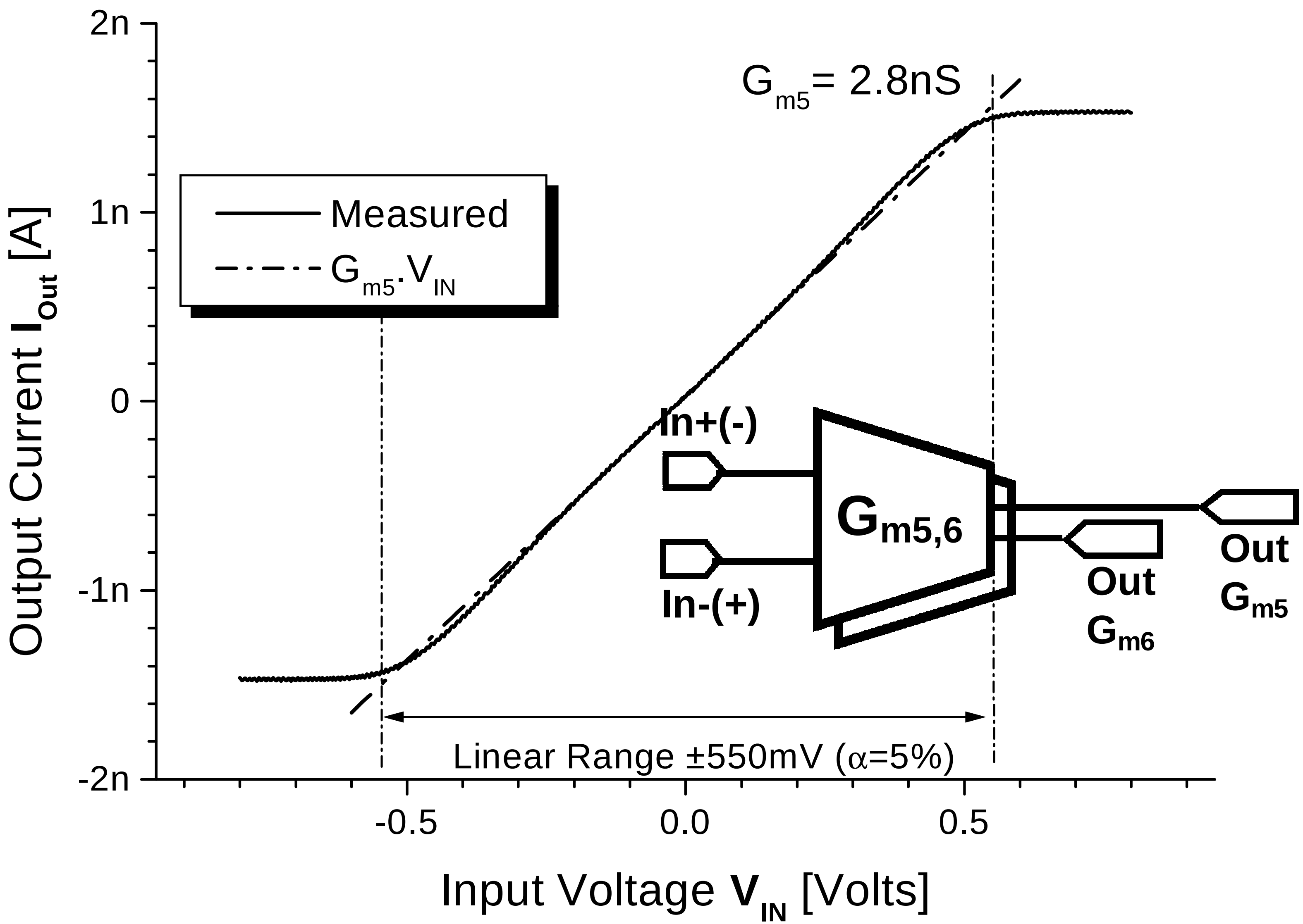
- **Very simple circuit ⇒ less area, power consumption.**
- **Do not introduce much excess noise or offset.**
- **Easy to reuse layout.**
- **Fabricated and tested OTAs up to 35nS (30GΩ) and 1V linear range.**



OTAs: Example G_{m6} = 100pS (10GΩ)



OTAs: *Example $G_{m5} = 2.58nS$ (380MΩ)*

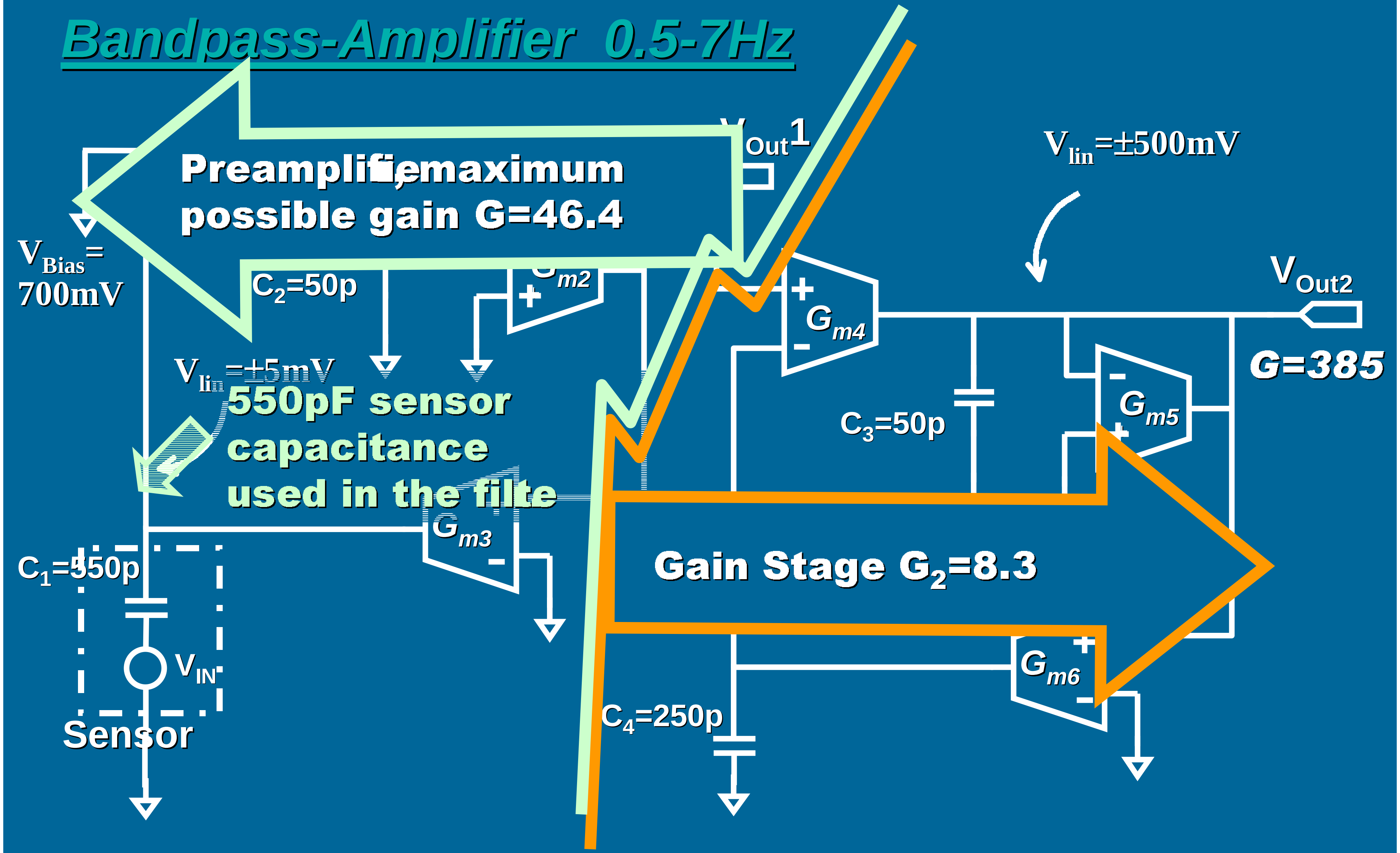


OTAs: Measured/estimated characteristics.

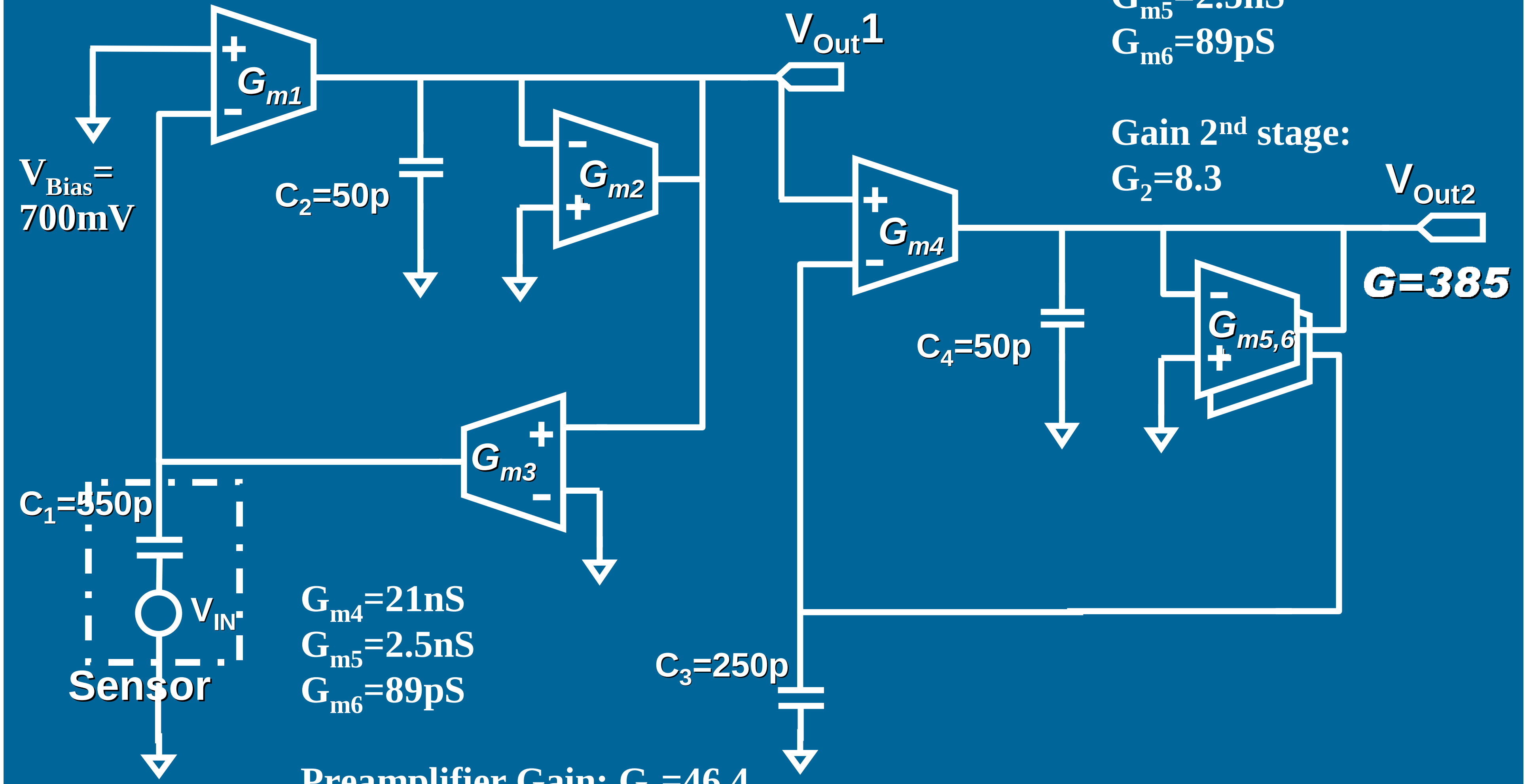
OTA	Transc.[a]	Linearity V_{Lin} [mV]	Input noise. [μV_{rms}] [a]	Input Offset σ_{Voff} [mV]	Current Cons.[nA]	Area [mm^2]
G_{m1}	110(110)nS	60	5 (4)	1.1	14	.019
G_{m2}	2.35(2.58)nS	150	42	4.4	43	.040
G_{m3}	35(33)pS	150	163(130)	2.1	42	.092
G_{m4}	21nS	150			47	.051
G_{m5}	2.4(2.8)nS	500		9.1	44	.18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

0.5-7Hz Filter-Amplifier

Bandpass-Amplifier 0.5-7Hz



Bandpass-Amplifier 0.5-7Hz



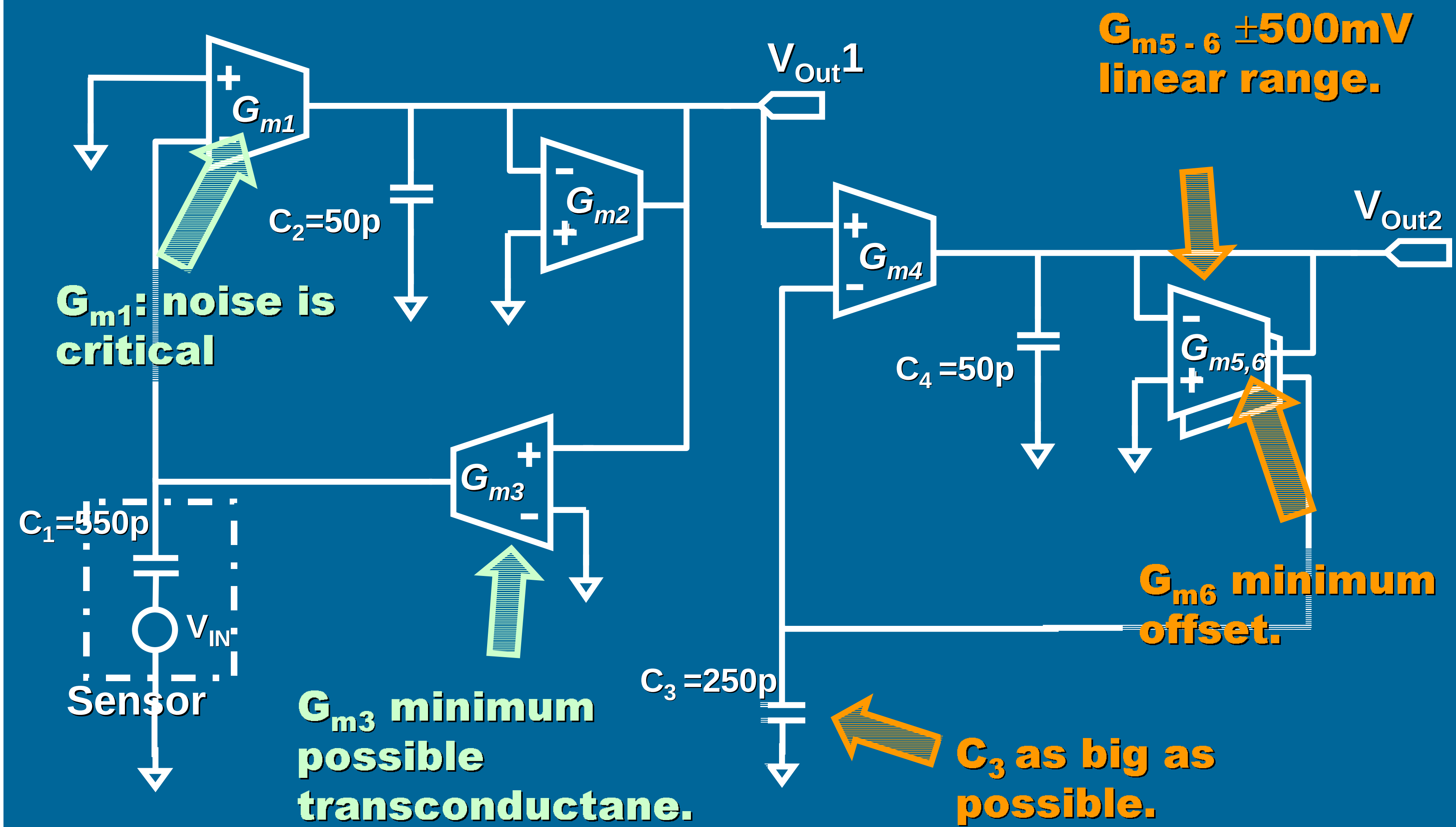
G_{m4}=21nS
G_{m5}=2.5nS
G_{m6}=89pS

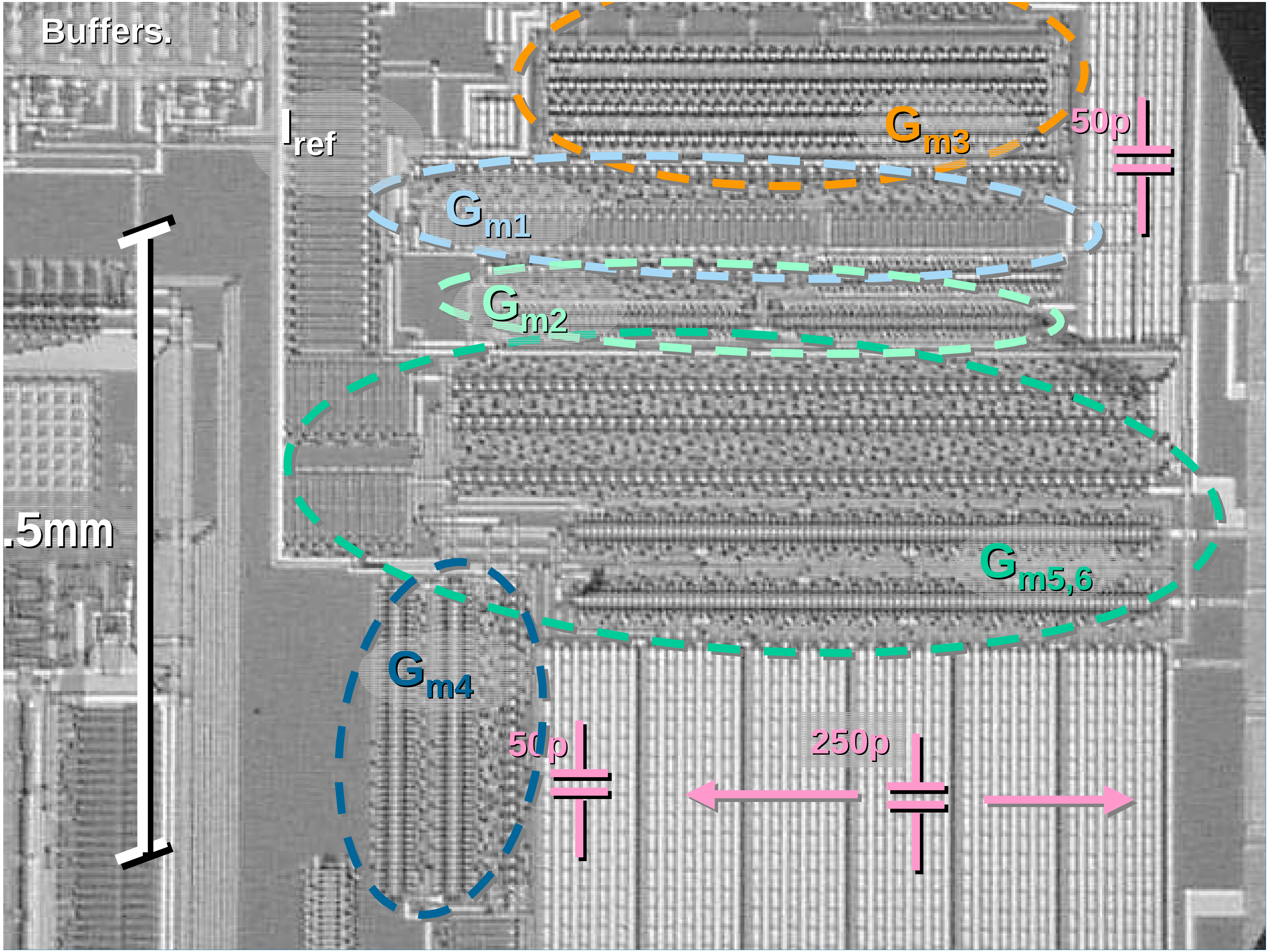
Gain 2[nd] stage:
G_2=8.3

G_{m4}=21nS
G_{m5}=2.5nS
G_{m6}=89pS

Preamplifier Gain: G_1=46.4

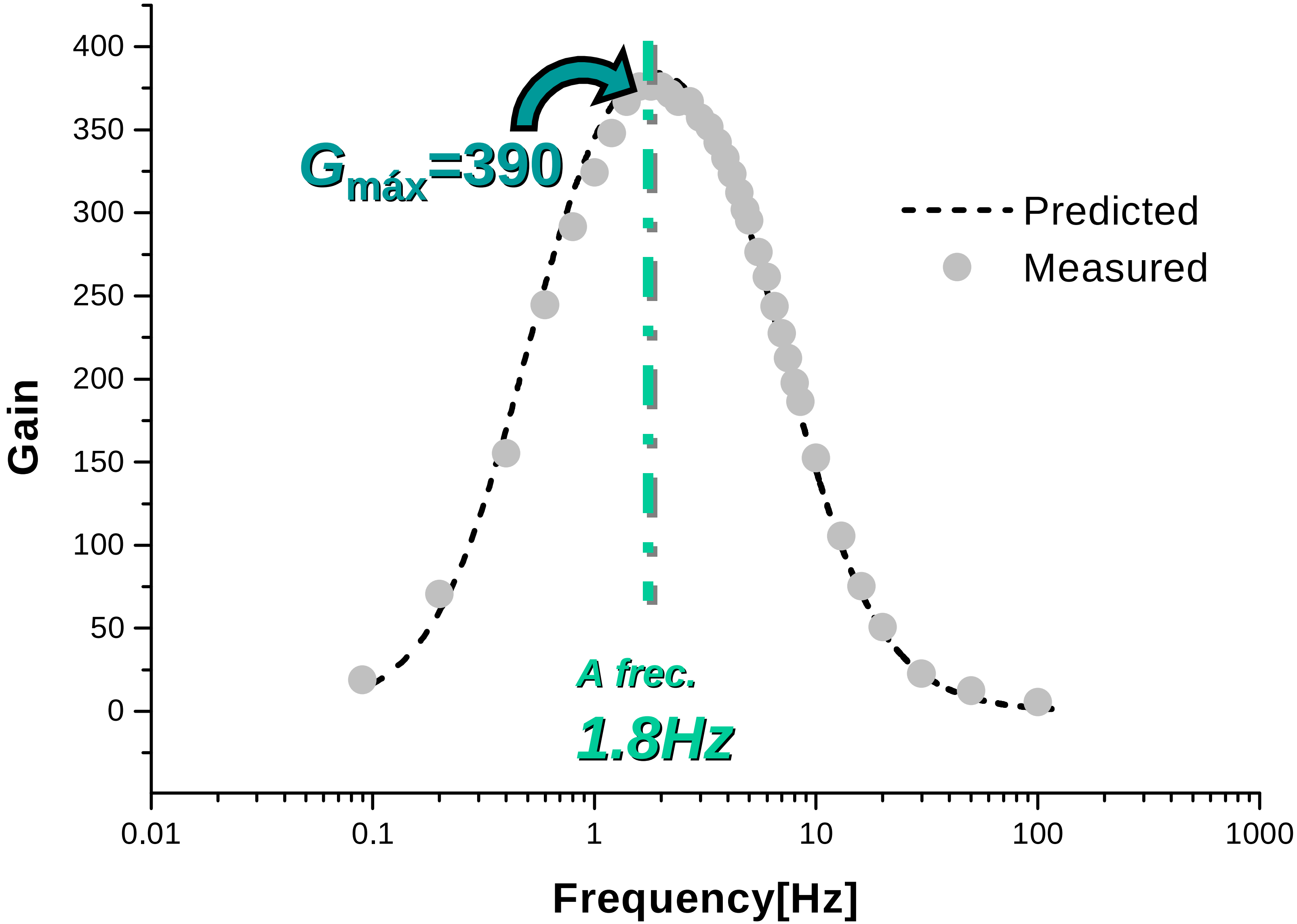
Bandpass-Amplifier 0.5-7Hz : Critical aspects.





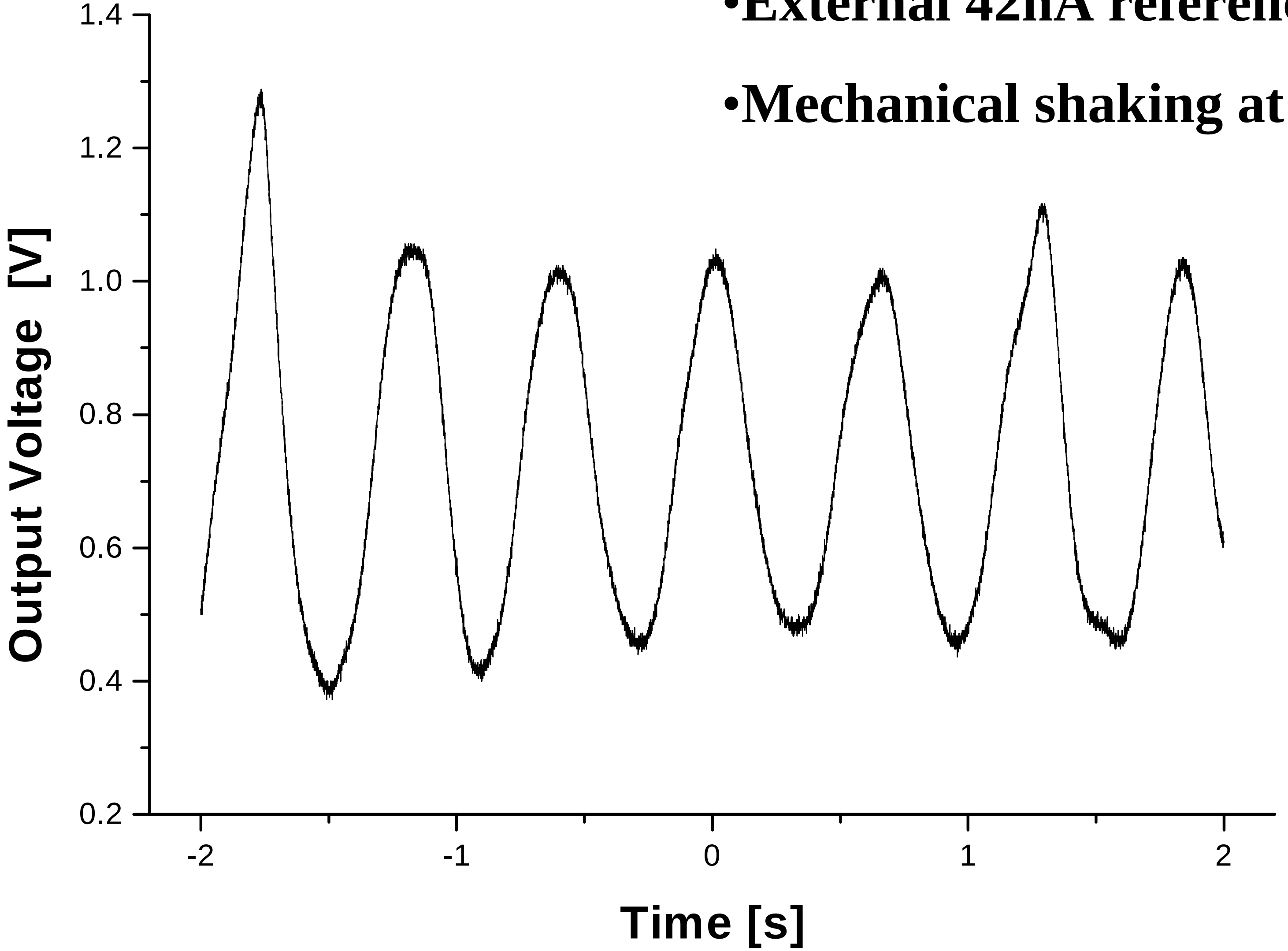
Buffers.
I_{ref}
G_{m3}
50p
G_{m1}
G_{m2}
.5mm
$G_{m5,6}$
G_{m4}
50p
250p

Bandpass Measurements: Gain - Frequency.



Measurements: *Qualitative response w/sensor.*

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



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

Specificatio	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	$18\mu V$

Concusions:

Series-parallel Division OTAs:

- **Excelent trade-off solution regarding linearity, noise, occupied area, power consumption.**

Filter Design:

- **0.5-7Hz, 40db/Dec, Gain 400, bandpass filter has been presented.**
- **Remarkable low power consumption, and input noise.**

No external elements have been employed!