Dynamically Biased 1 MHz Low-pass Filter with 61 dB peak SNR and 112 dB Input Range

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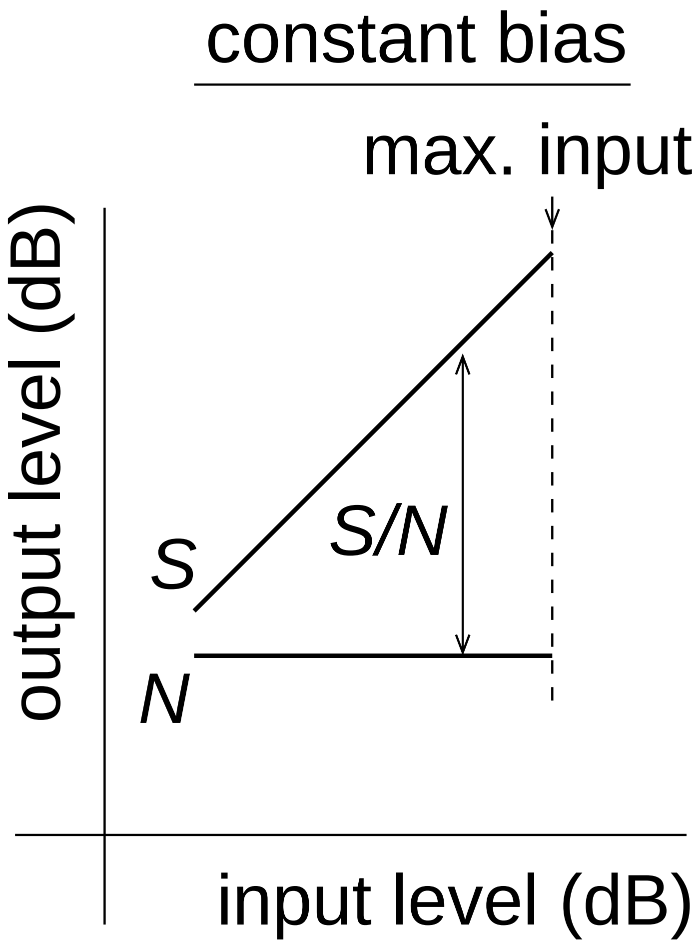
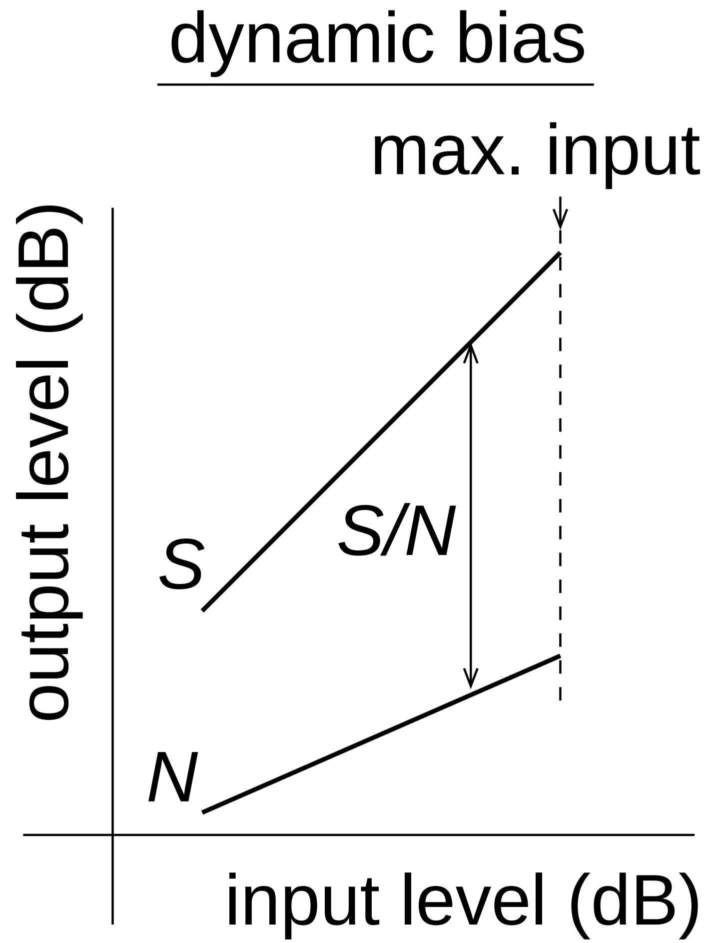
Motivation



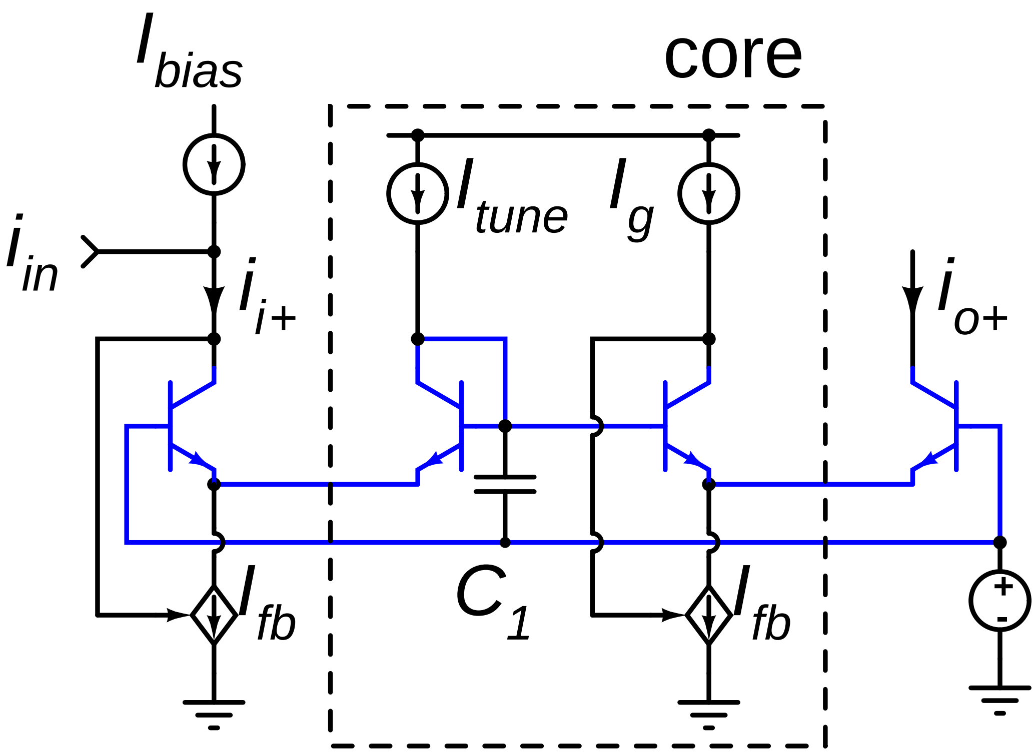


- Dynamically biased current mode filter:
  - 112 dB input range (THD $<$ -40 dB).
  - Quiescent power consumption of 575 μW.

Outline

- Principle of distortionless dynamic biasing.
- Third-order Butterworth filter.
- Measurement results.
- Comparison.
- Conclusions.

First order log-domain filter



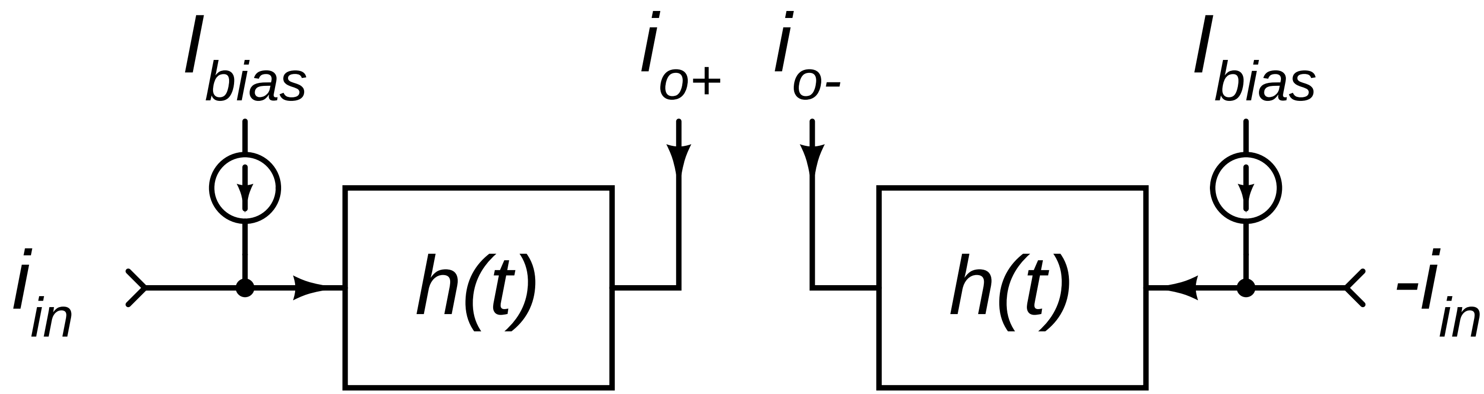
- Linear from i_{i+} to i_{o+}

$$\frac{I_{o+}(s)}{I_{i+}(s)} = \frac{I_g/I_{tune}}{1 + sC_1V_t/I_{tune}}$$

[Punzenberger & Enz '97]

- Output noise $\sim I_{bias} + kI_{bias}^2$; Power diss. $\sim I_{bias}$.
- $I_{bias} \downarrow \Rightarrow$ Output noise $\downarrow$ & Power dissipation $\downarrow$.
- But, filtered $I_{bias}(t)$ appears at the output.

Pseudo-differential operation

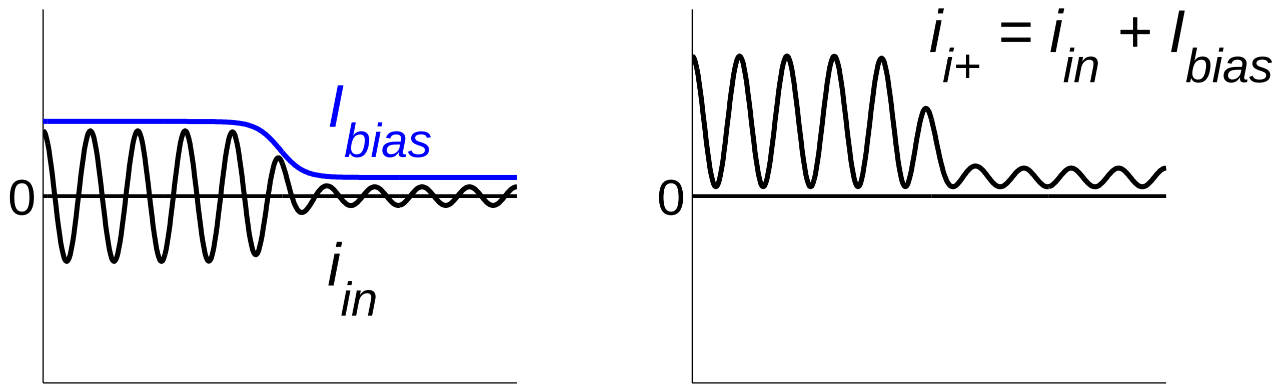


$$i_{o+} = (i_{in} + I_{bias}(t)) * h(t) \qquad i_{o-} = (-i_{in} + I_{bias}(t)) * h(t)$$

$$\boxed{i_{out} = i_{o+} - i_{o-} = 2i_{in} * h(t)}$$

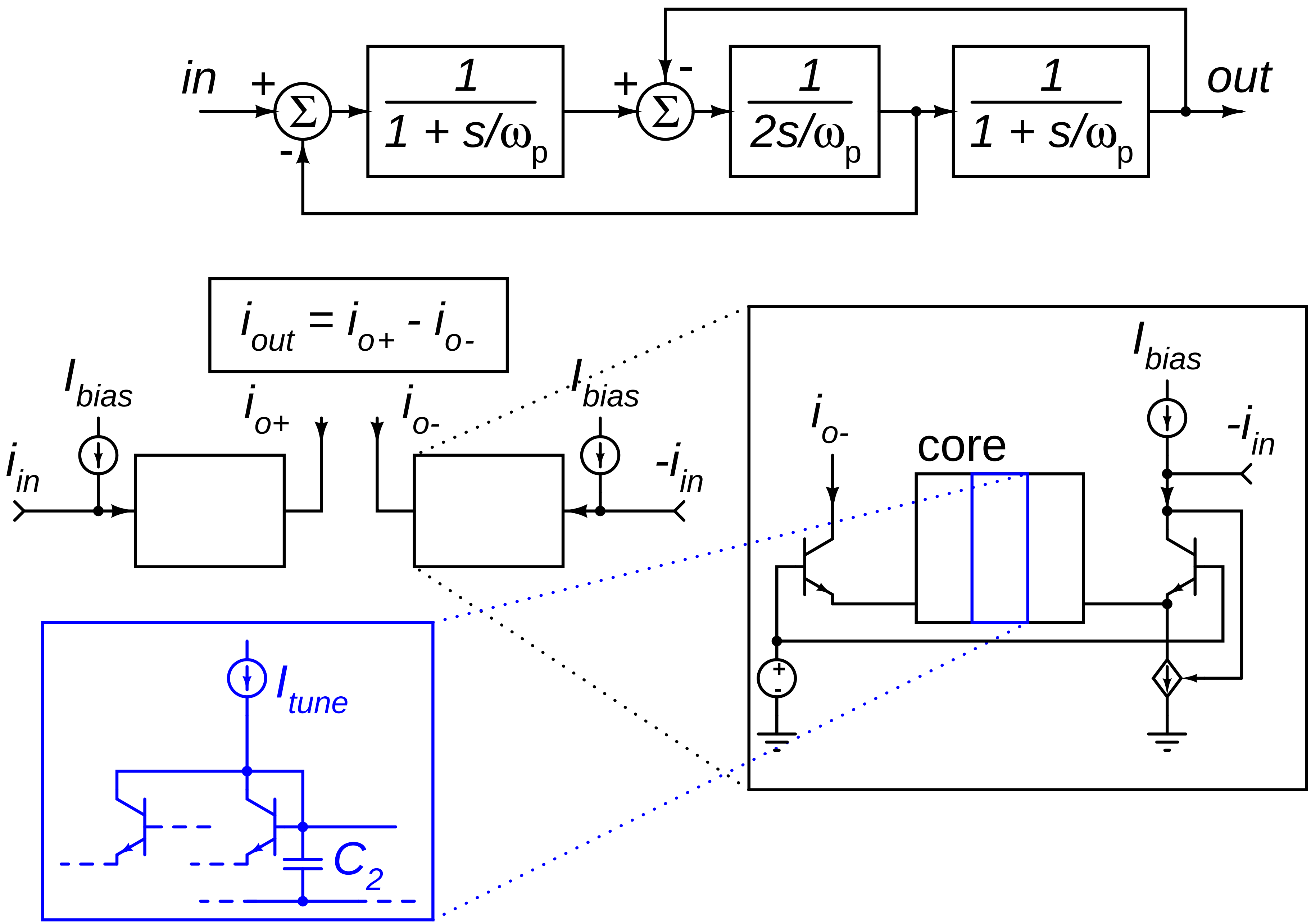
- Large signal linearity $\Rightarrow$ cancellation of I_{bias}.

Dynamic biasing

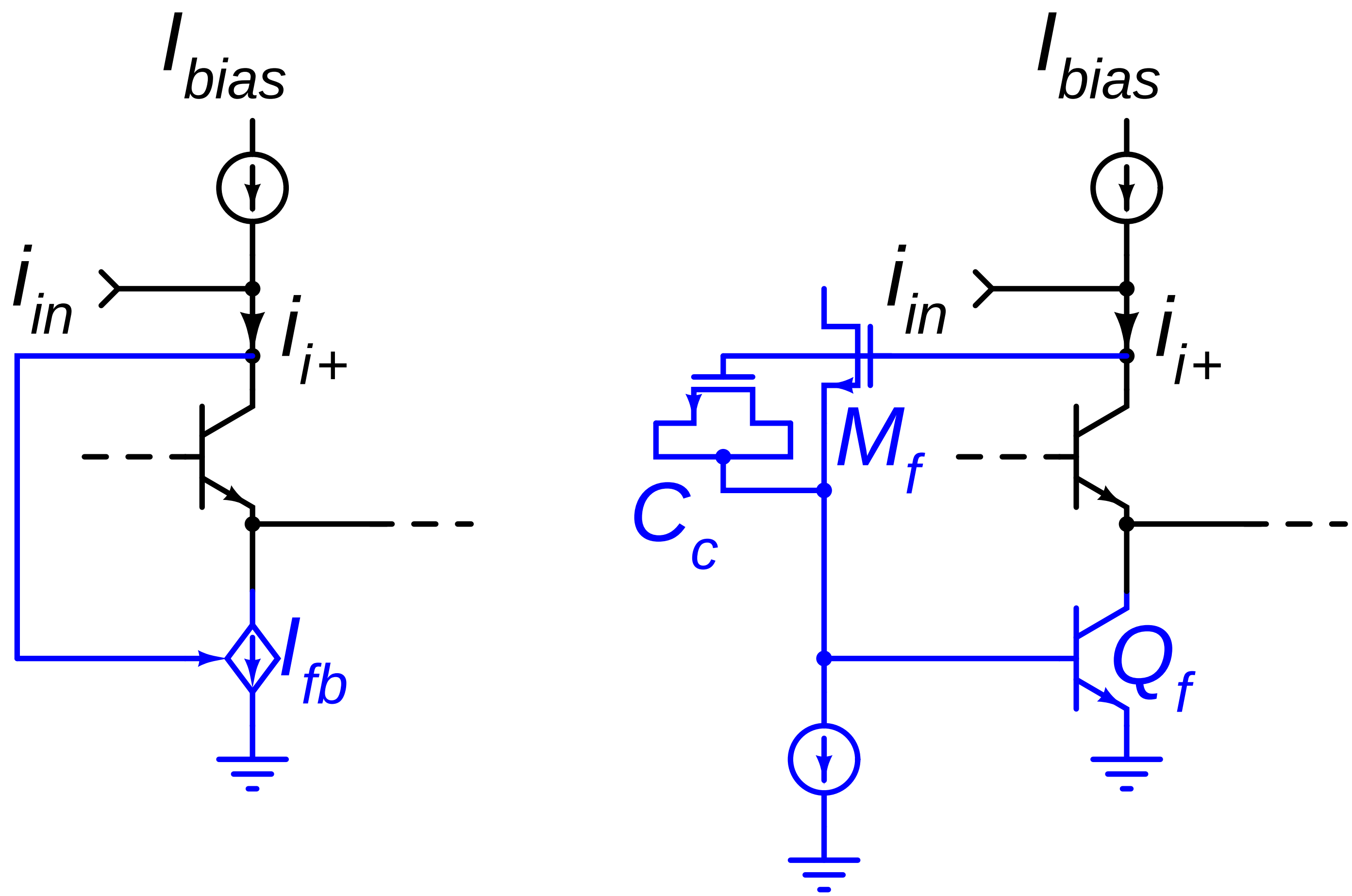


- Decrease I_{bias} for small input amplitudes.
- SNR improvement for small signals while maintaining linearity and time-invariance.
- Output noise depends on *total* input signal.

Third-order Butterworth filter

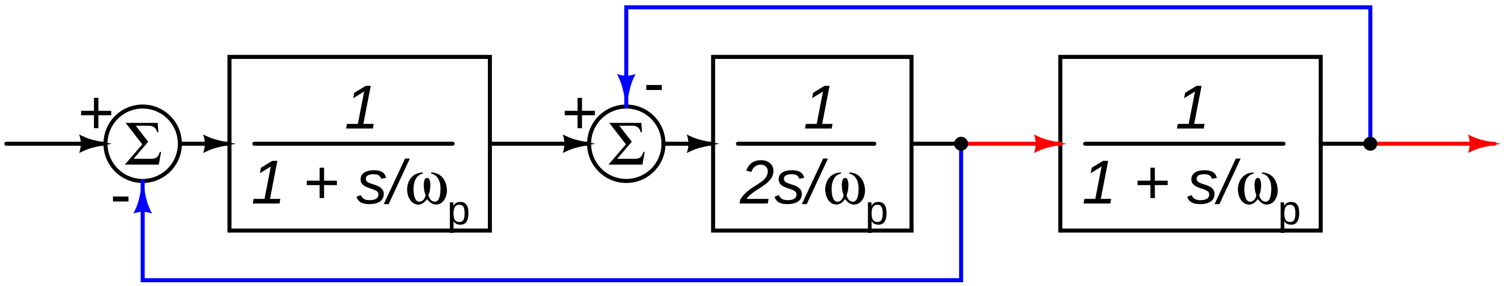


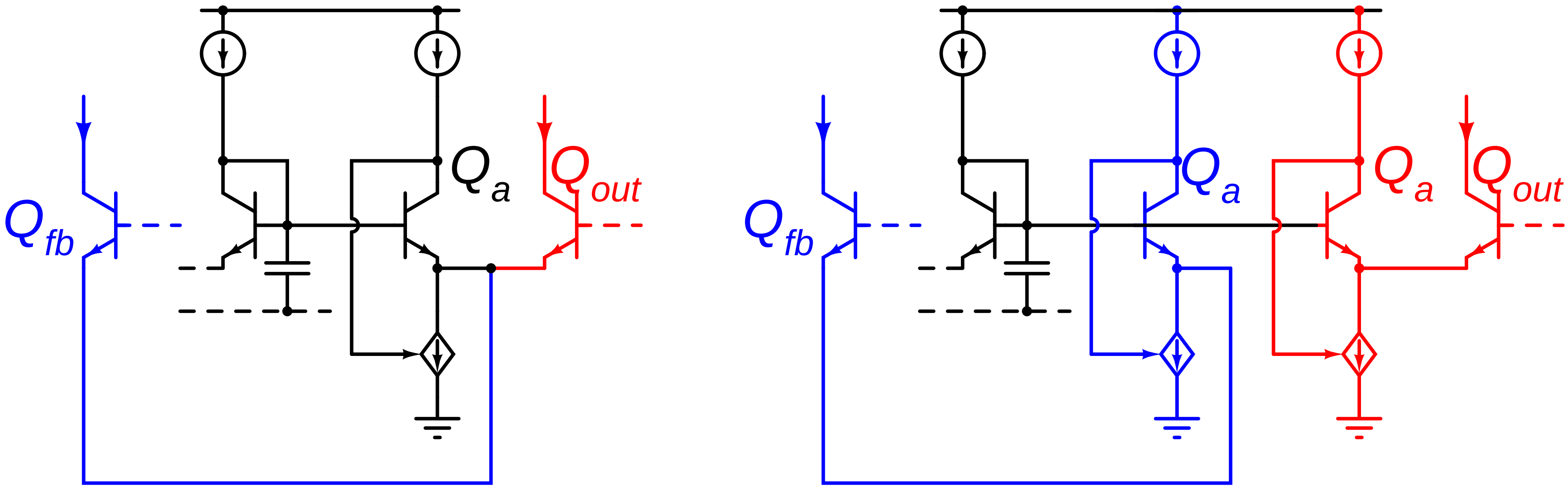
Minimizing distortion due to Early effect



- Large g_m for I_{fb} to reduce distortion due to Early effect.
- C_c: pole-zero compensation.

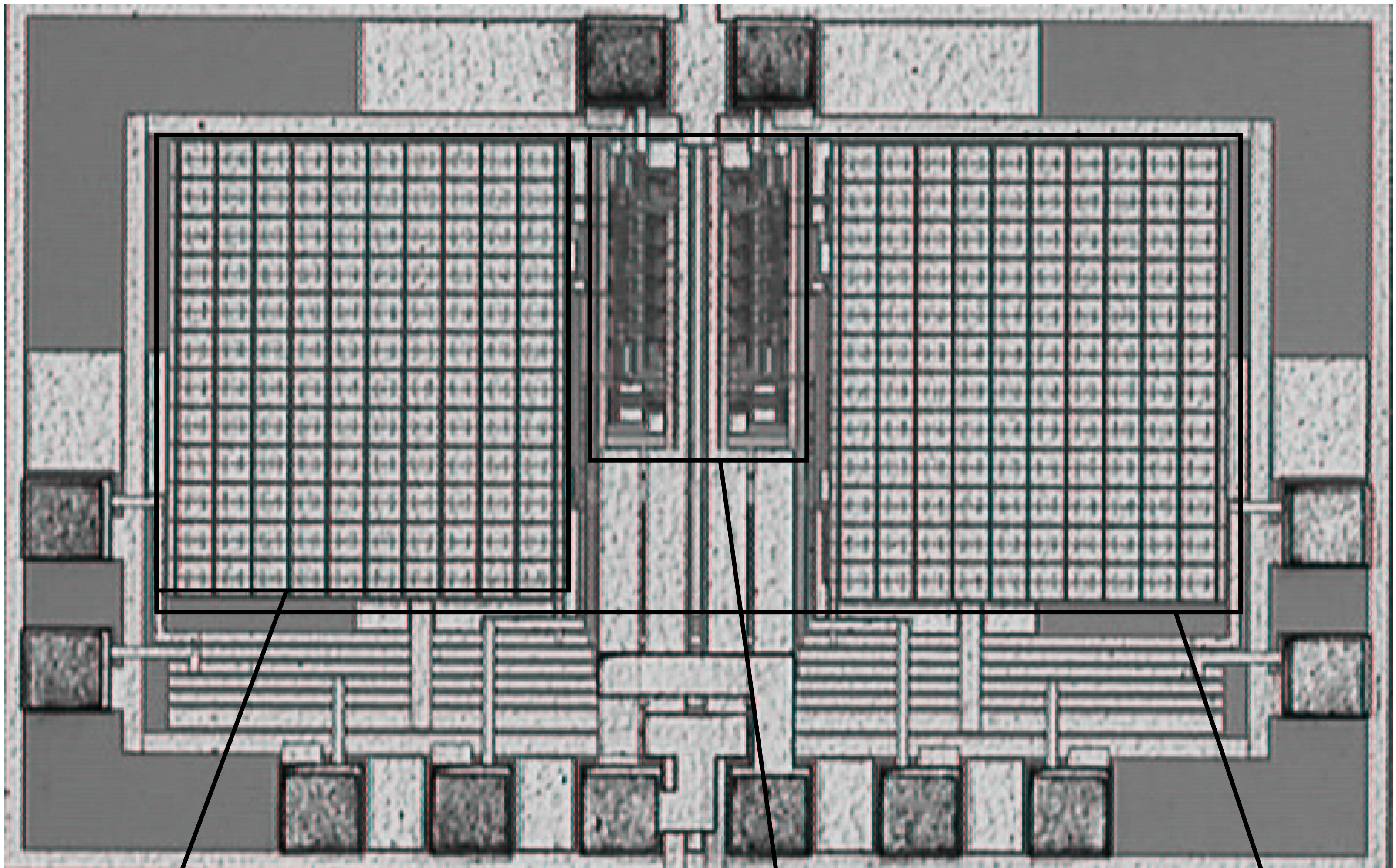
Feedback paths in the filter





- Separate emitter follower for the feedback path ensures frequency response integrity.

Chip photograph

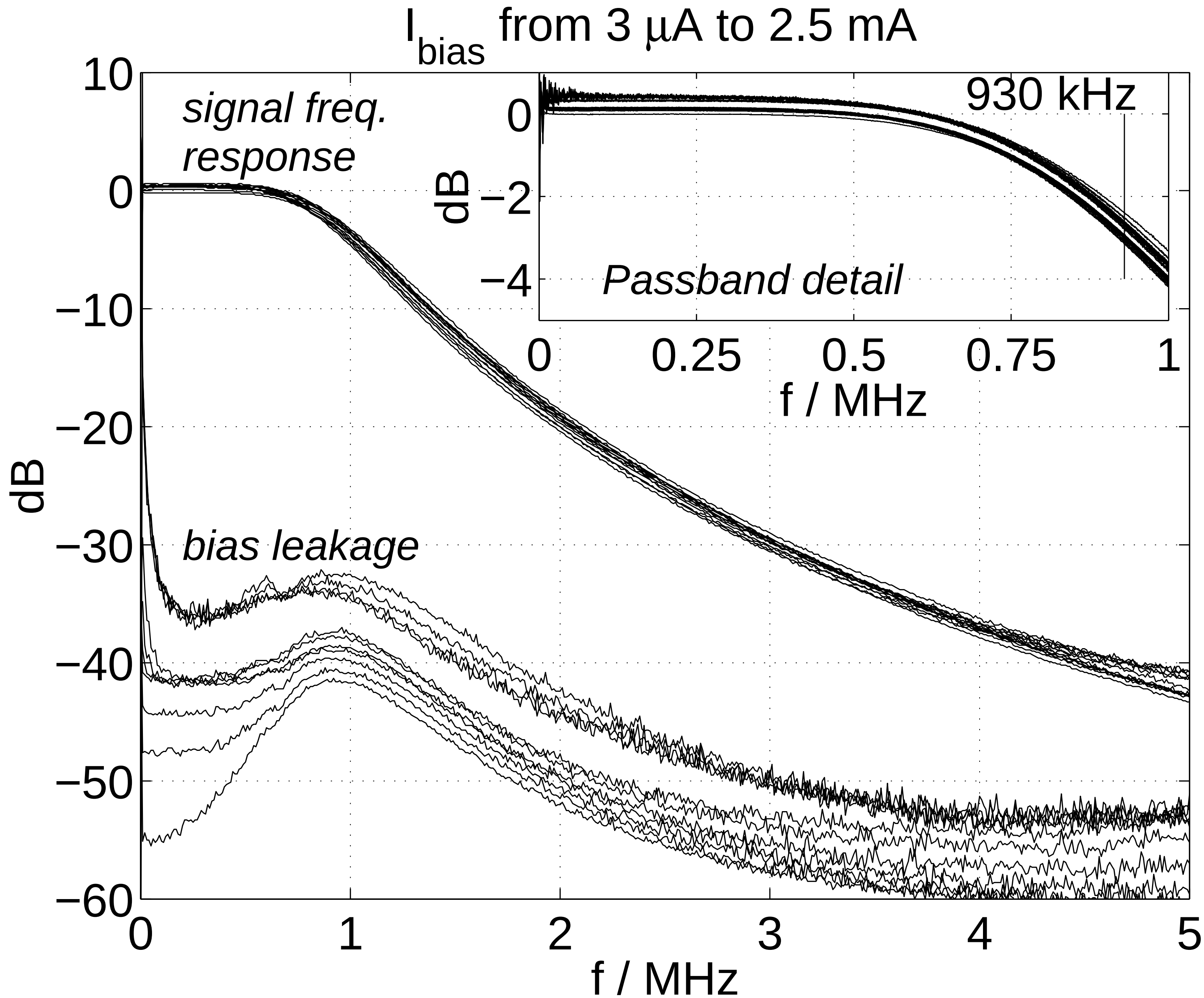


capacitor (0.19 mm^2) active circuit 0.52 mm^2

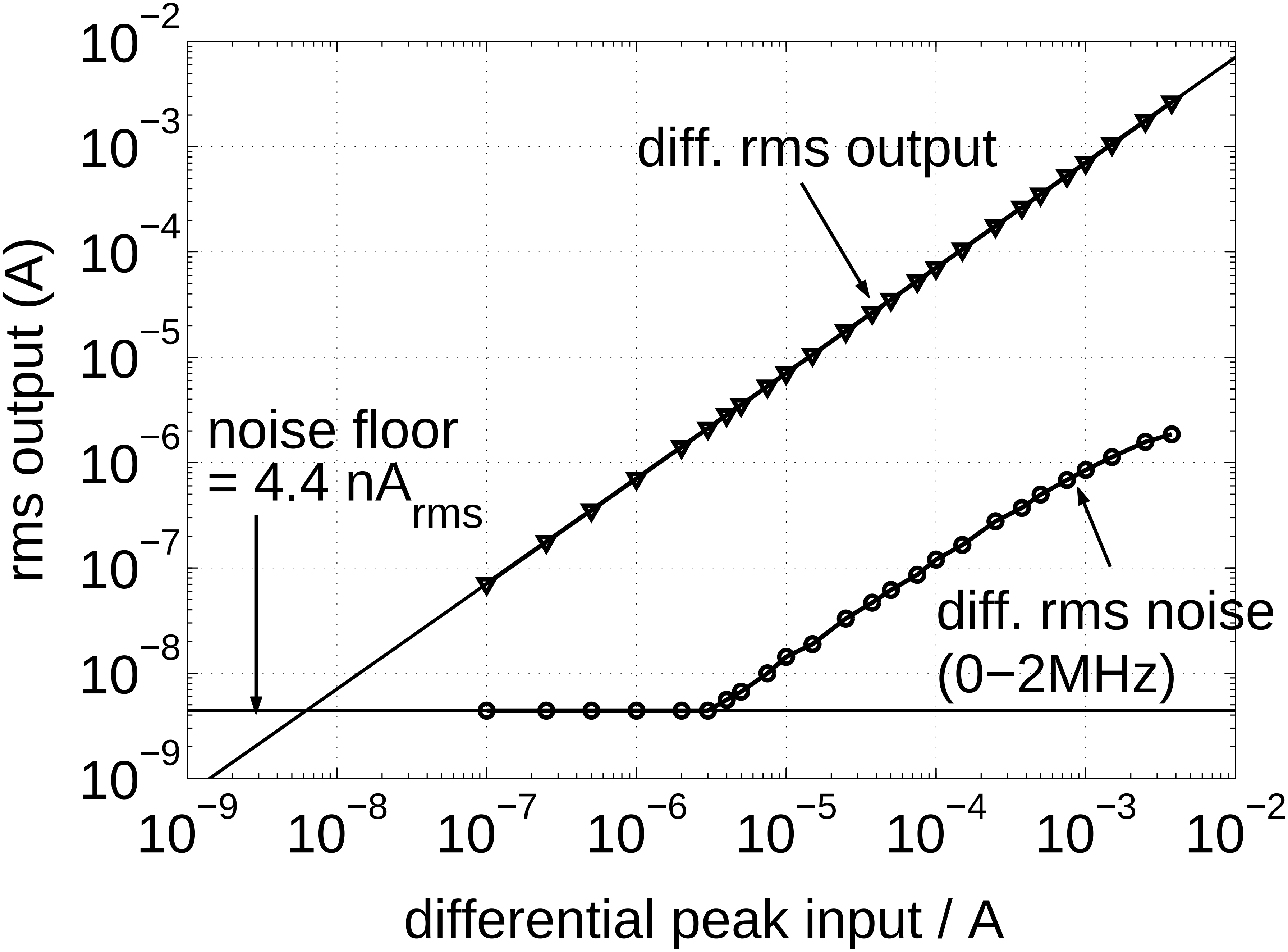
Measurement conditions

- V_{dd} = 2.5 V.
- I_{tune} = 5 μA.
- I_{bias}: 3 μA to 2.5 mA.
- "Dynamic" bias: I_{bias} = $2\times$ the single-ended input peak, subject to a minimum of 3 μA.
- 400 kHz input for THD measurements.
- 1 MHz $\pm$ 20 kHz inputs for IM_3 measurements.

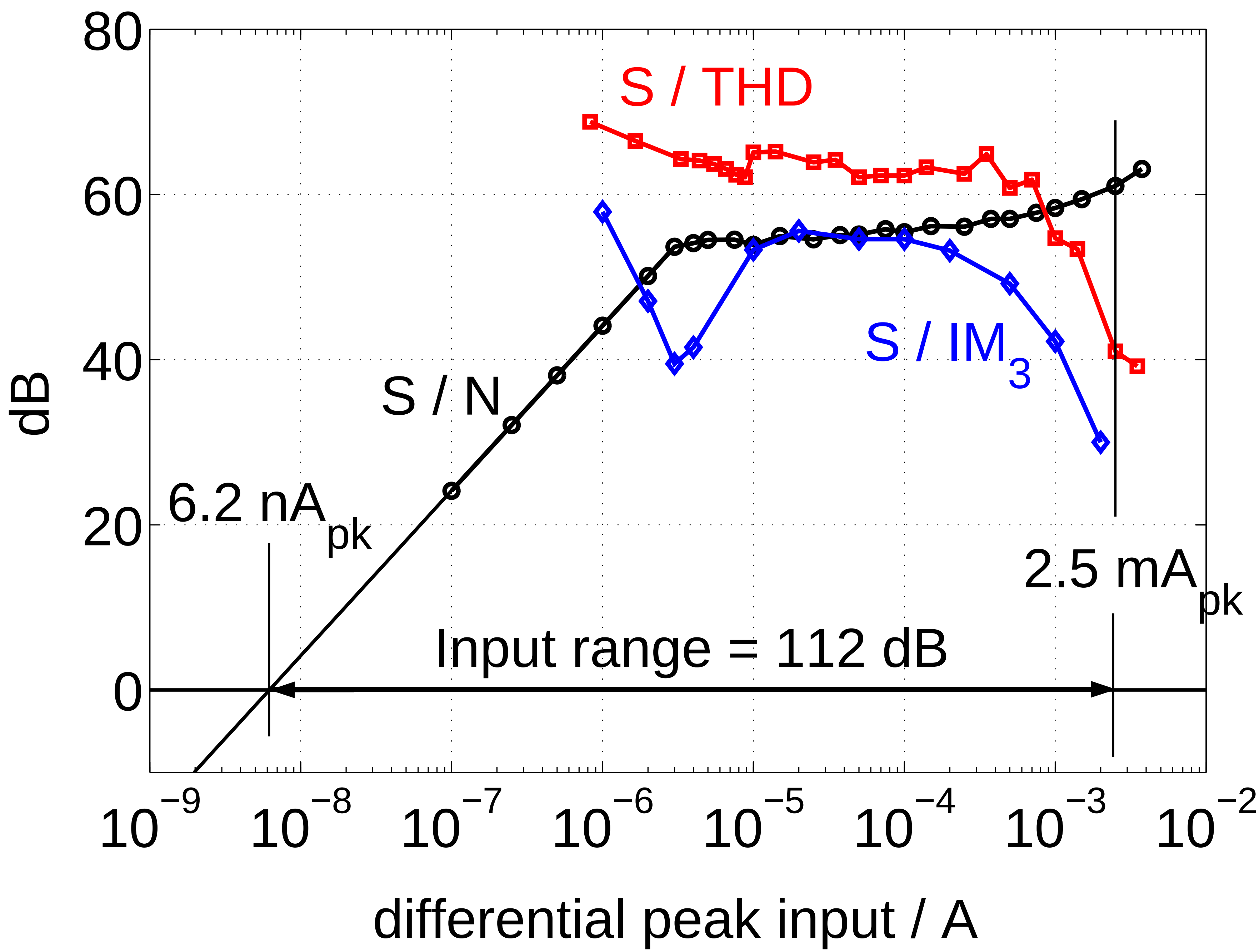
Measured results: Frequency response



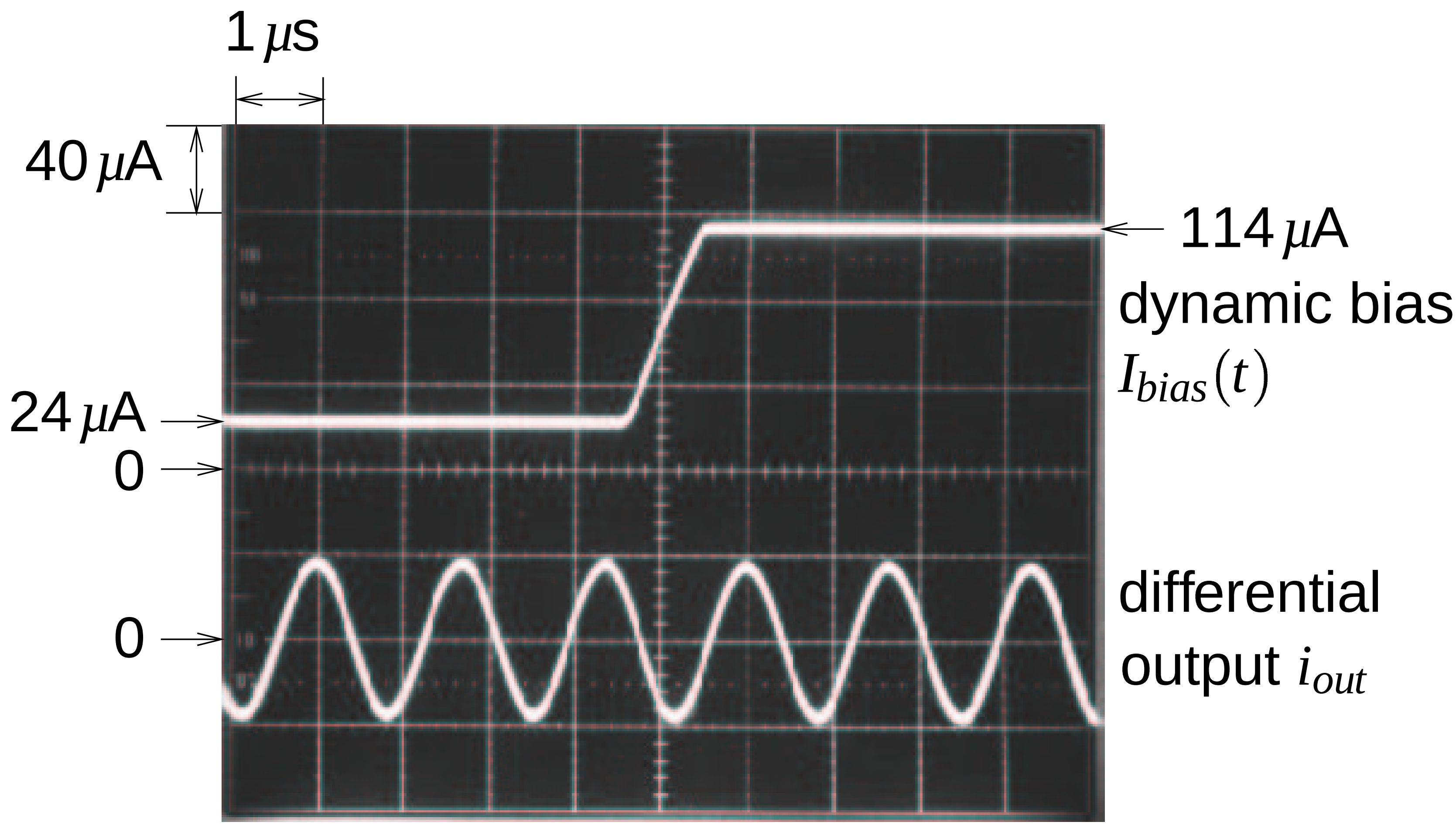
Measured results: Noise



Measured results: Distortion

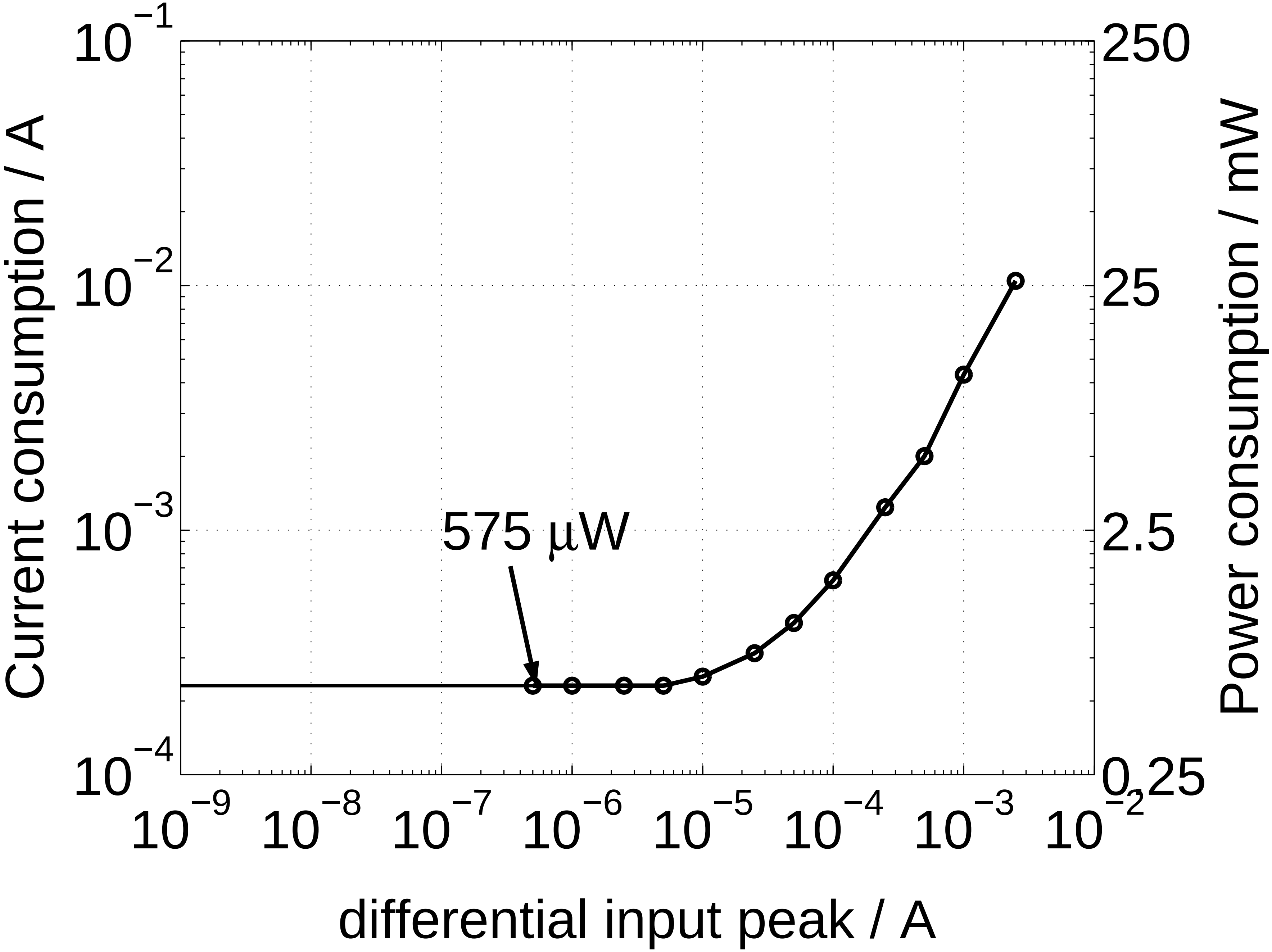


Output with dynamically changing bias



- 20 μA single-ended peak input @ 600 kHz.
- I_{bias} switched from 24 μA to 114 μA.
- Barely perceptible change in the output.

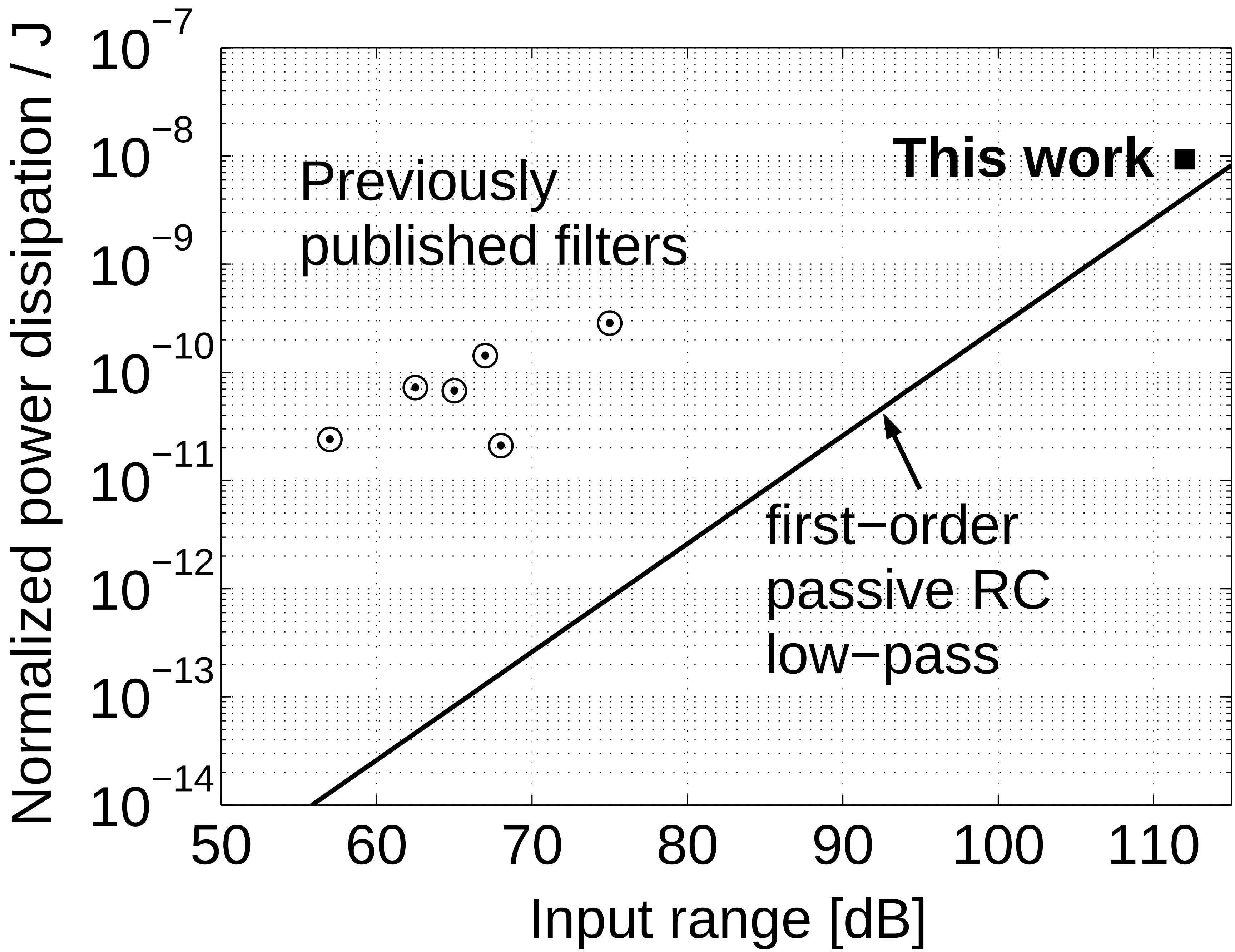
Measured results: Power consumption



Summary

Technology	0.25 μm BiCMOS	
Area (excl. pads)	0.52 mm^2	
Supply voltage	2.5 V	
-3 dB BW	930 kHz	
I_{bias}	3 μA	2.5 mA
Power diss. (P_d)	575 μW	26.1 mW
Output noise	4.4 nA	1.5 μA
THD (input peak = $0.5I_{bias}$)	-64.3 dB	-41 dB
IM_3 (input peak = $0.5I_{bias}$)	-39.5 dB	-30 dB
Input range (THD $\leq$ 40 dB)	112 dB	
Maximum P_d / Order $\cdot$ BW	9.35 nJ	

Comparison



Normalized power dissipation / J
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
Previously
published filters
This work
first−order
passive RC
low−pass
50
60
70
80
90
100
110
Input range [dB]

Conclusions

- A technique for dynamic biasing without disturbing the output.
- Noise and power reduction for small input signals.
- A log-domain filter with 112 dB input range in a 0.25 μm BiCMOS technology.
- Quiescent power: $40\times$ smaller than maximum.
- Over an order of magnitude improvement in power efficiency of analog filters.