A Quadrature Bandpass ΔΣ ADC for a Multi-Standard TV Tuner

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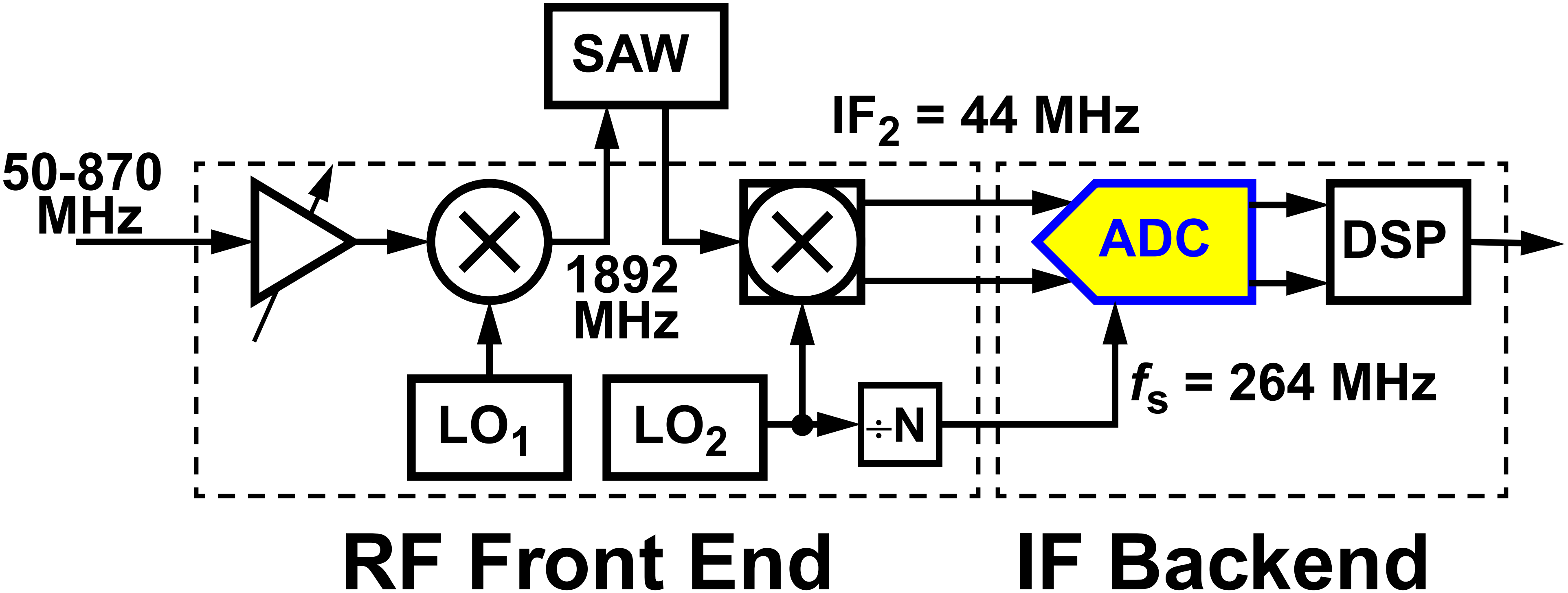
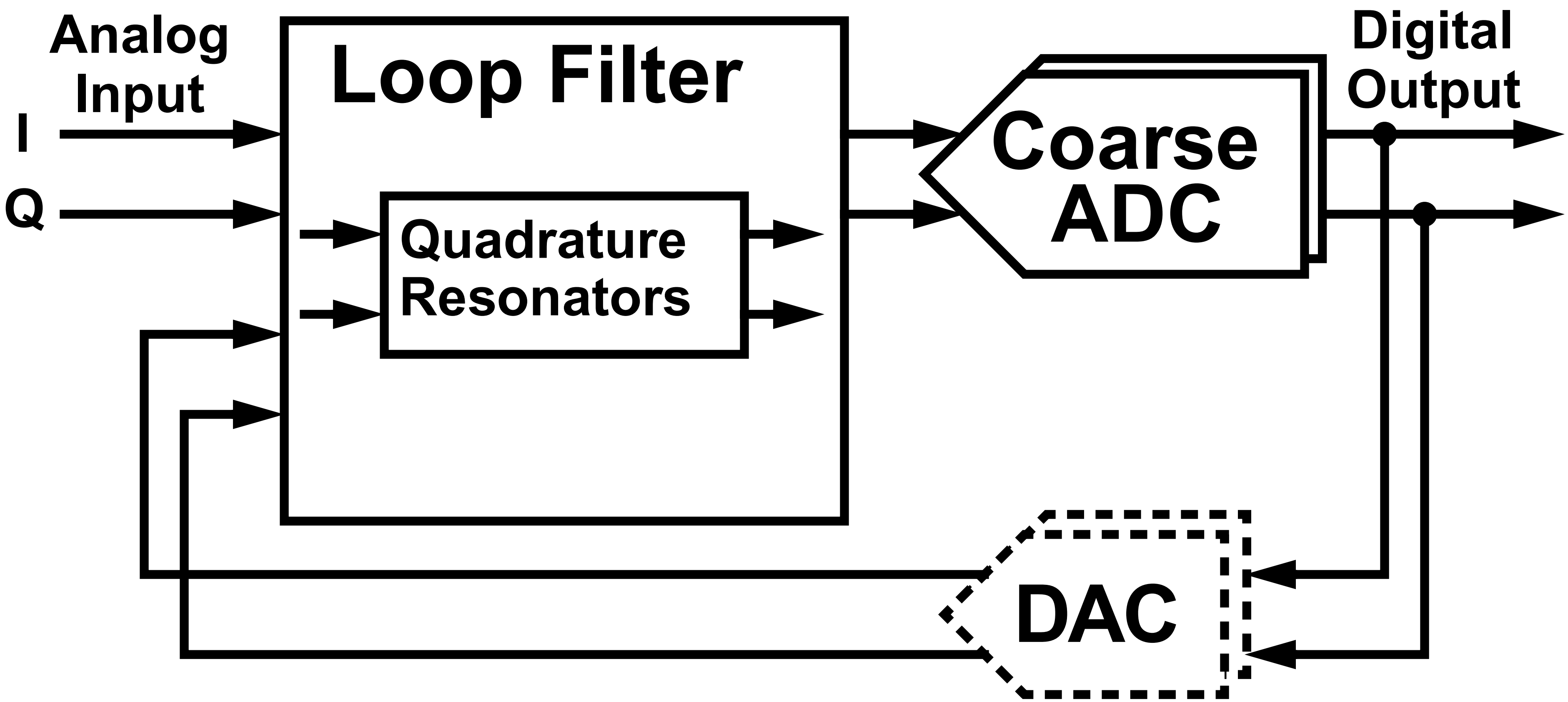
TV Tuner System



- Dual-conversion super-heterodyne receiver with an ADC at second IF
- ADC input is current-mode I&Q at 44 MHz
  BW = 8.5 MHz

A Quadrature ΔΣ ADC Is:

[Jantzi 1997]



- A ΔΣ ADC with quadrature everything
  NTF and STF are complex

Worry List

1 DAC linearity and noise at high f_s

⇒ Current-mode DAC, mismatch-shaping

2 Resonator Accuracy: f_0 and Q

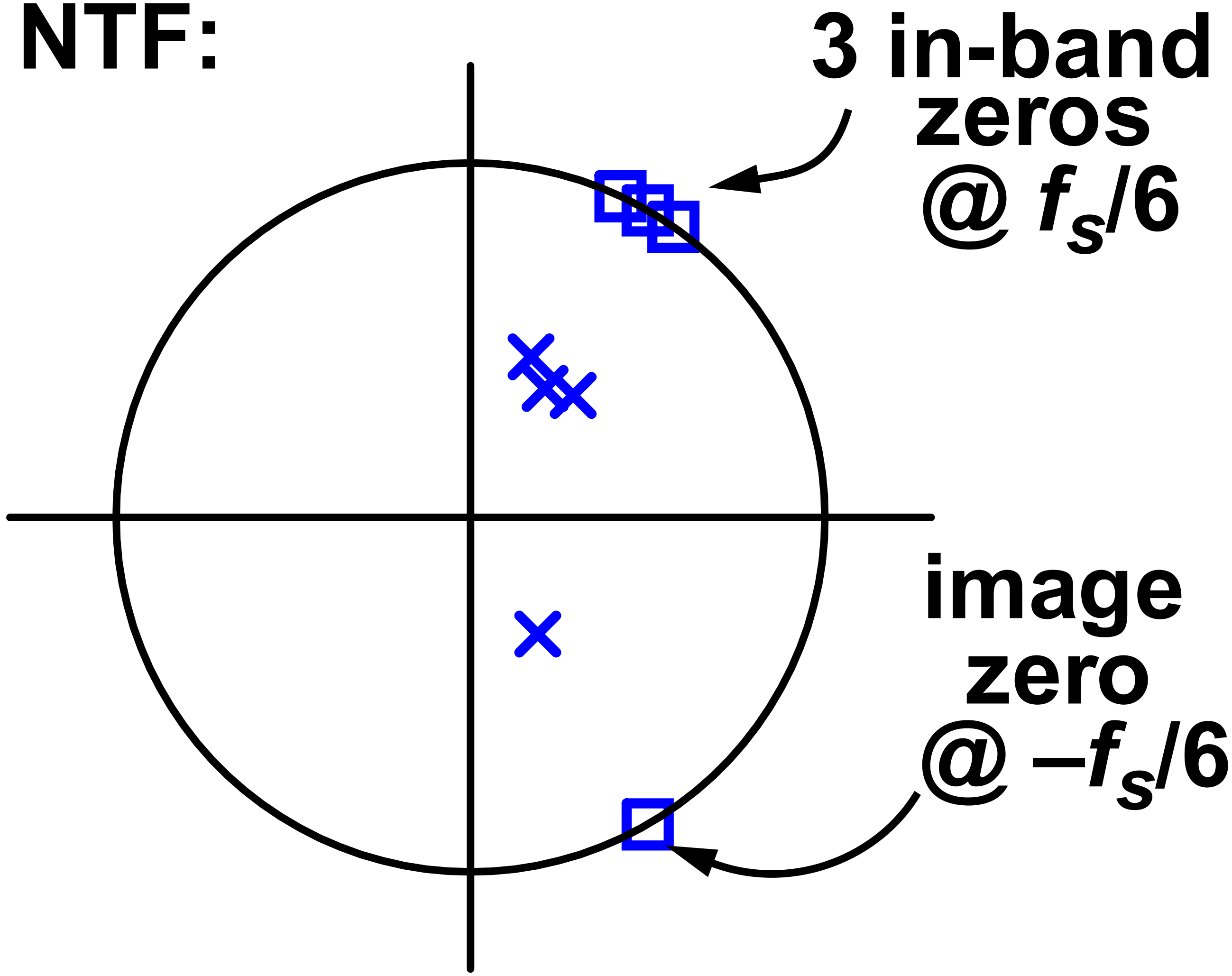
⇒ Coming soon!

3 Path Matching

⇒ Large devices, symmetric/merged layout

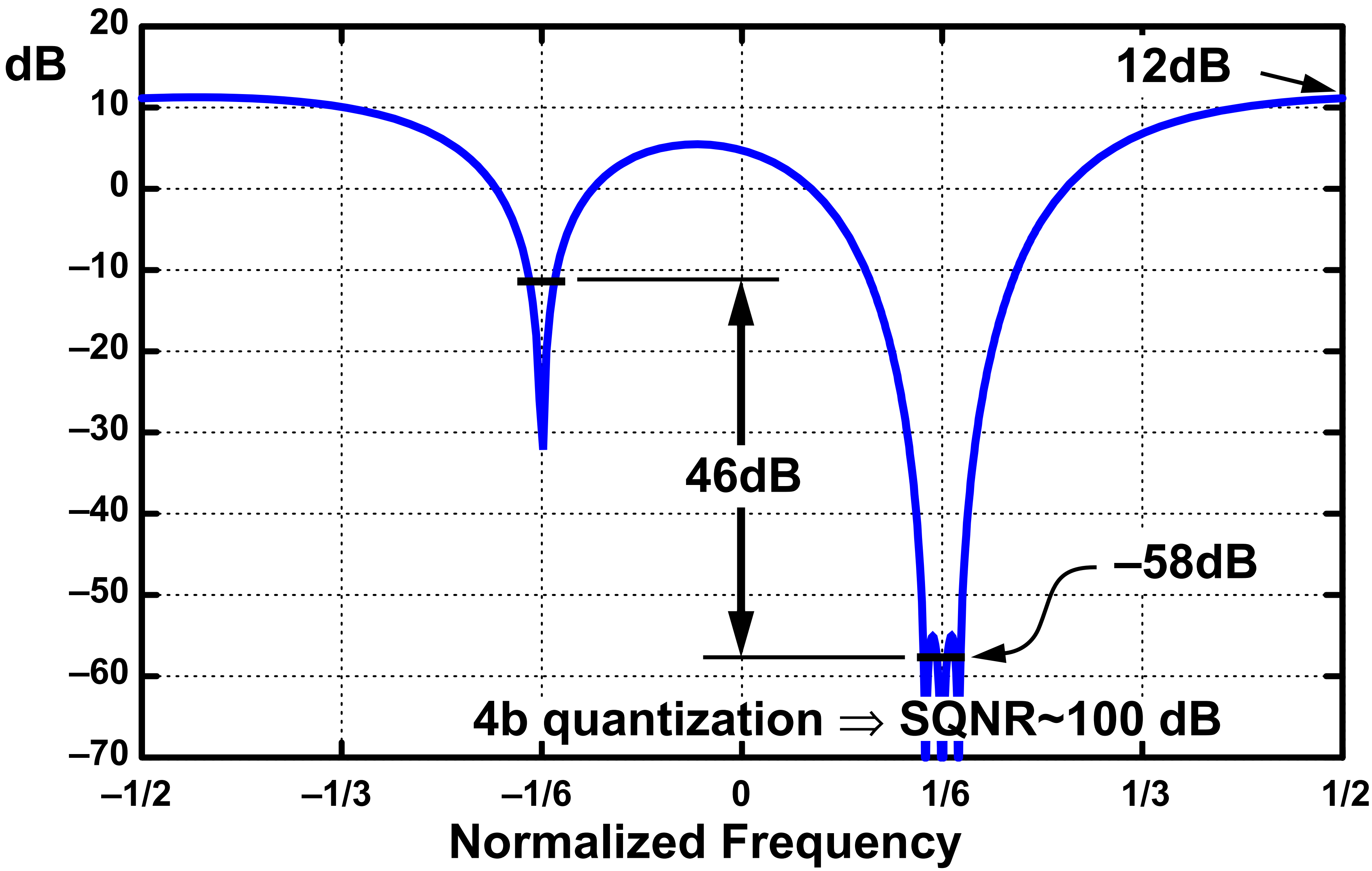
Ideal NTF– Poles and Zeros

4^{th}-order NTF:

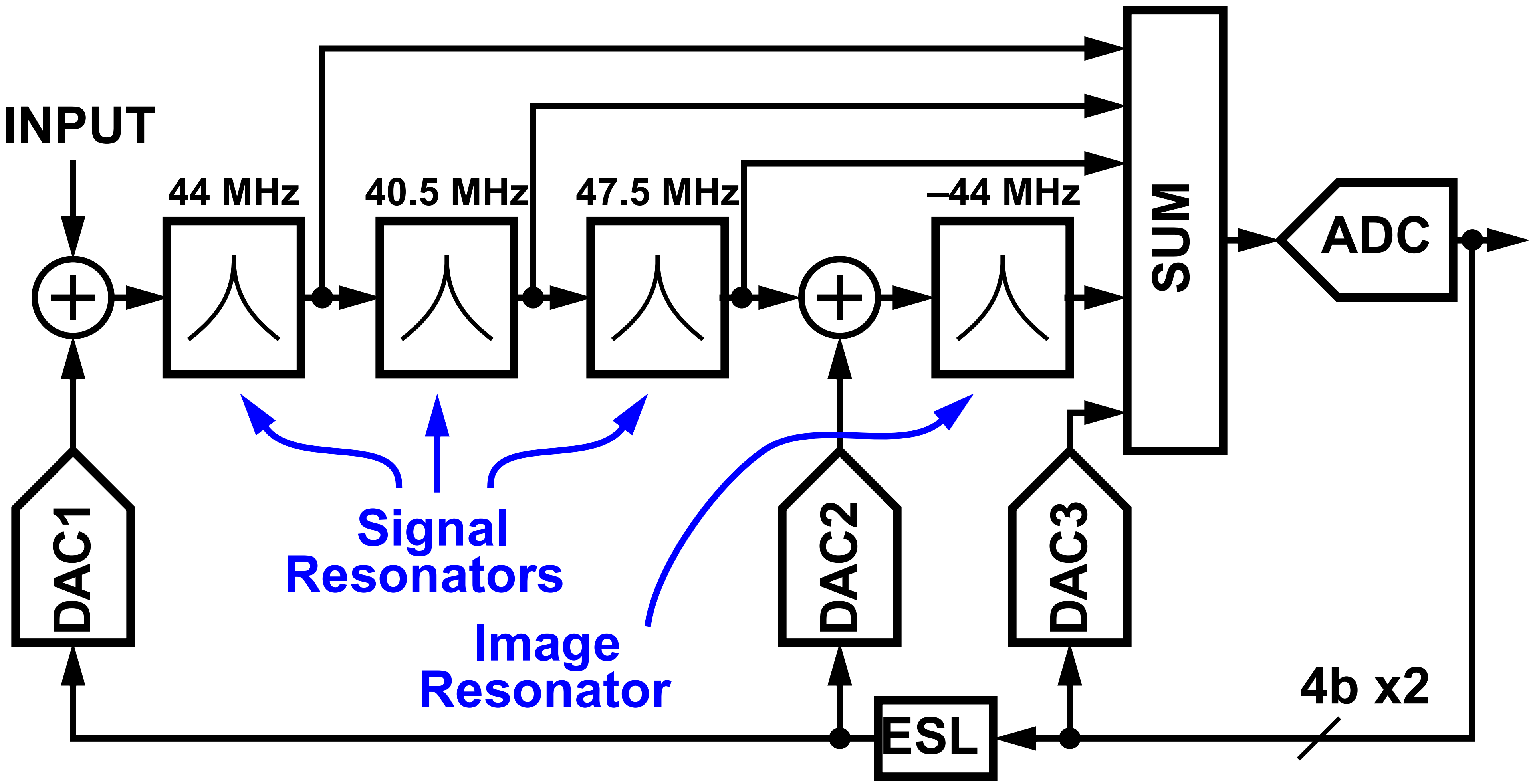


OSR = f_s/f_B = 31

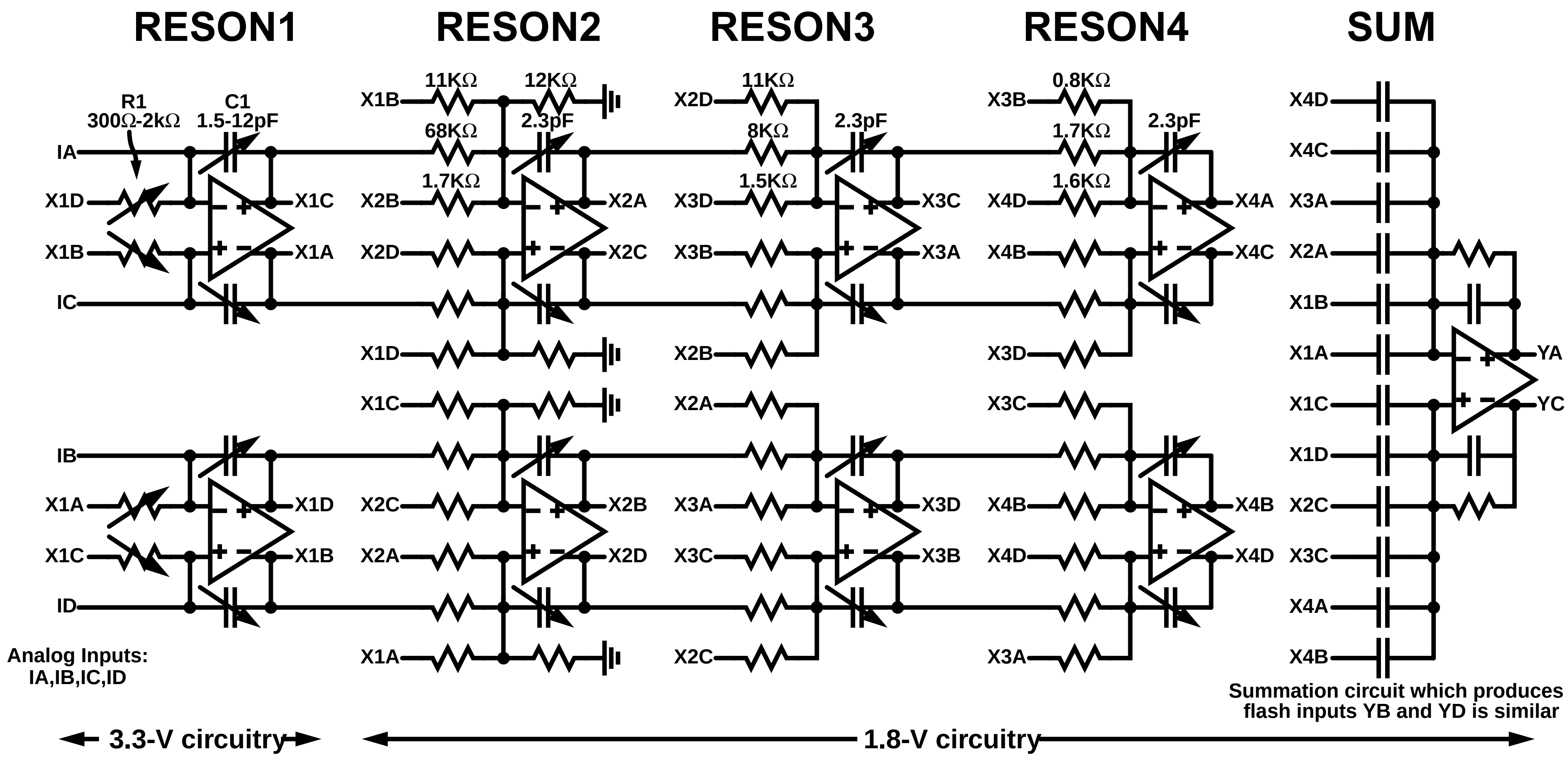
NTF Magnitude



ADC Architecture

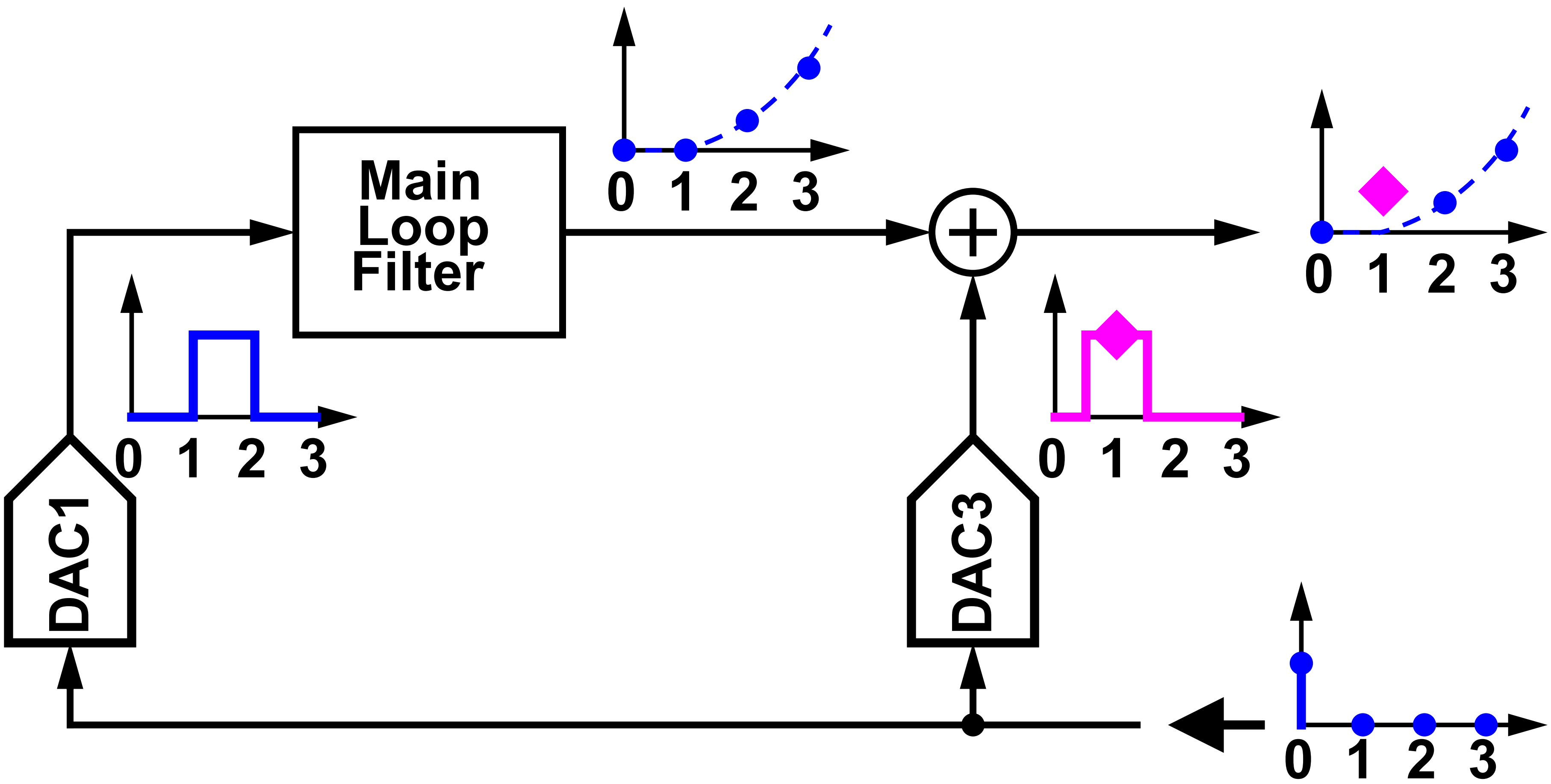


Loop Filter Schematic

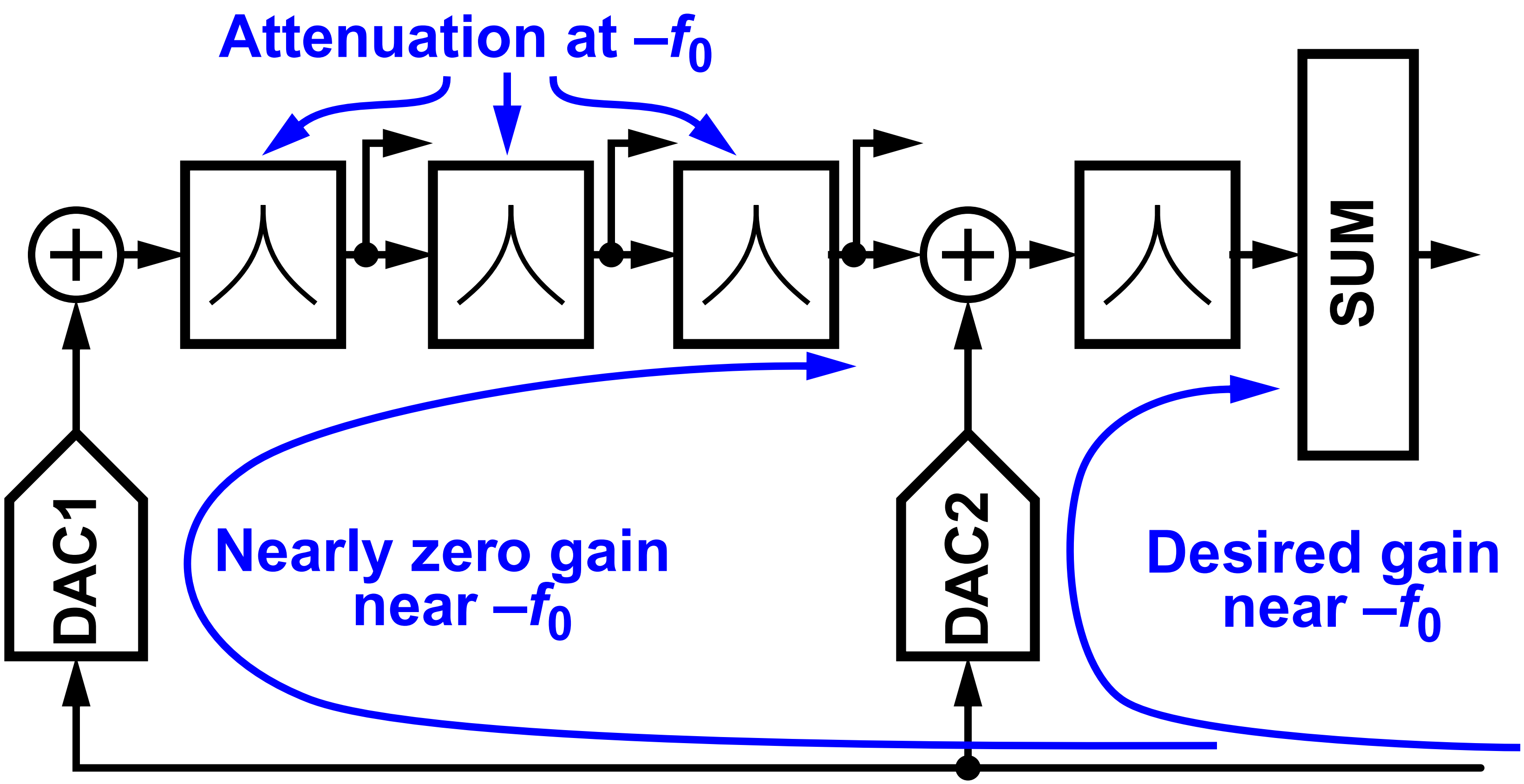


Why DAC3?

- **DAC3 allows any LF/NTF to be realized**
  Even though DAC1 has 1 clock cycle of delay
  DAC3 supplies the missing point

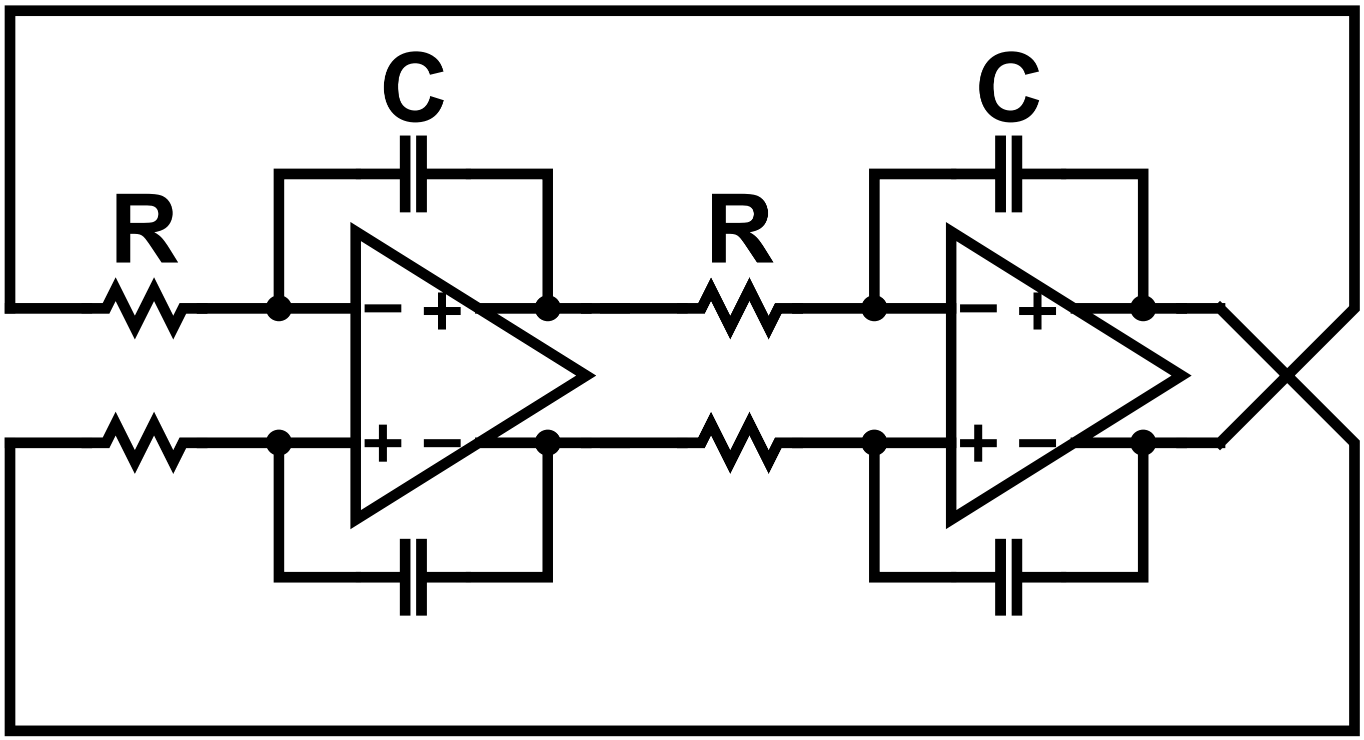


Why DAC2?



- **DAC2 provides a low-attenuation feedback path for signals in the vicinity of –f_0**
  - **Thereby resolving a near singularity in the coefficient calculation procedure**

Resonator Structure



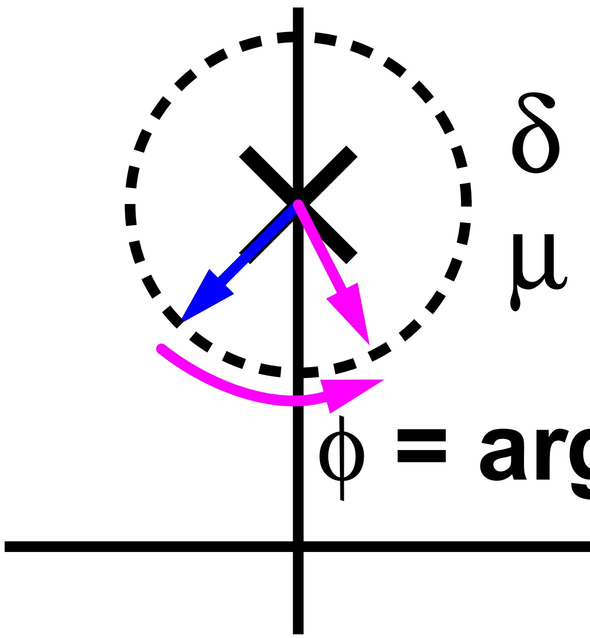
$$f_0 = \frac{1}{2\pi RC}$$

- **Tuned by adding positive feedback to make an oscillator and adjusting C until the desired resonance is achieved**

– **Amplifier drives both R and C $\Rightarrow$ trouble?**

Amplifier Gain and Phase

- **Finite gain degrades Q**
- **Phase lag enhances Q**
- **Analysis shows $\phi = 45^{\circ}$ yields high Q, regardless of amplifier gain**

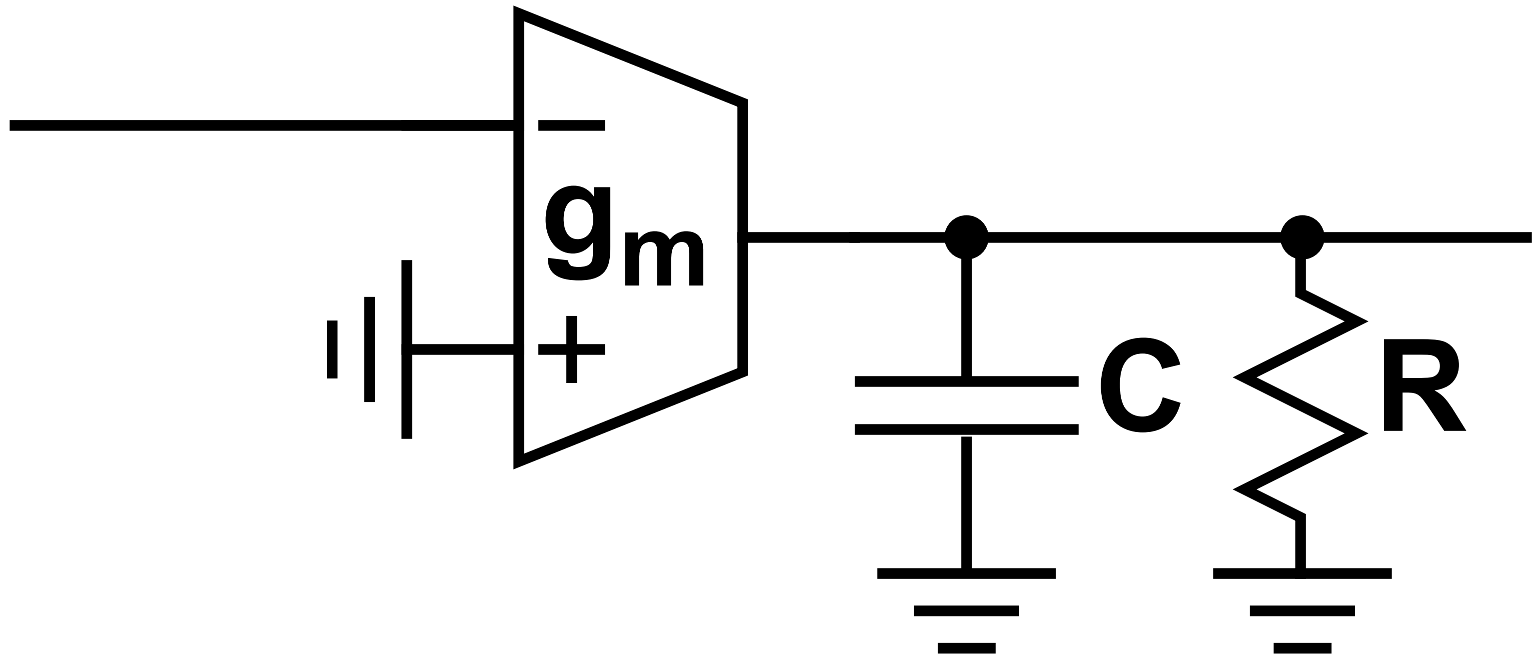


$$\delta = -\mu(1 + j)\omega_0$$

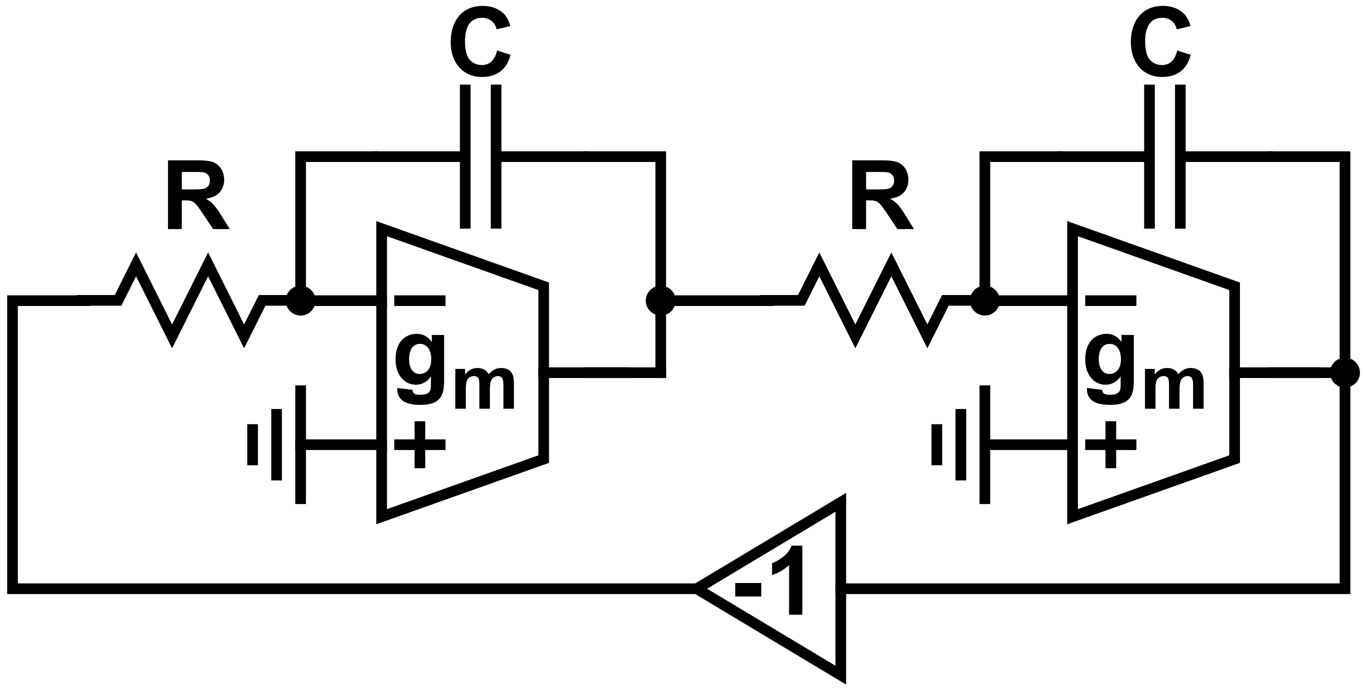
$$\mu = 1/A$$

$$\phi = \arg(\mu)$$

An Amplifier with ϕ = 45º @ f_0:



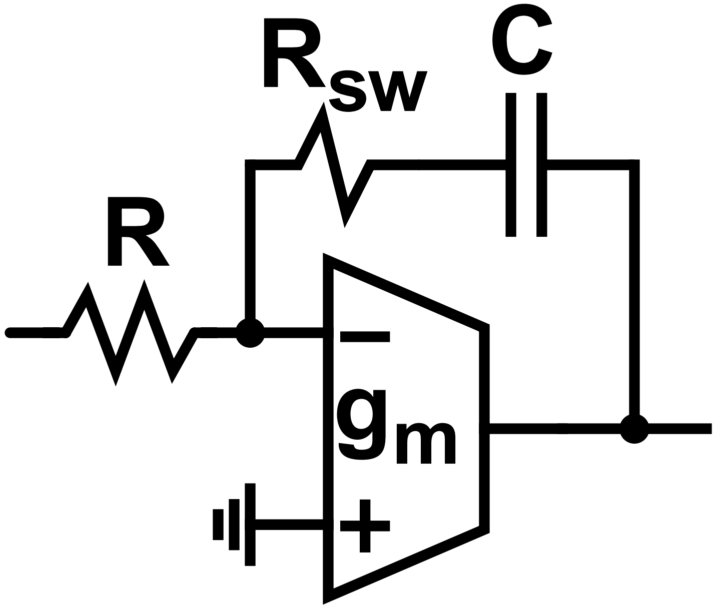
Resulting High-Q Resonator



- Amplifier load yields ϕ = 45º @ f_0
- Finite g_m shifts the pole frequency, but does not degrade Q!

Finite g_m Bandwidth & Non-Zero Switch Resistance

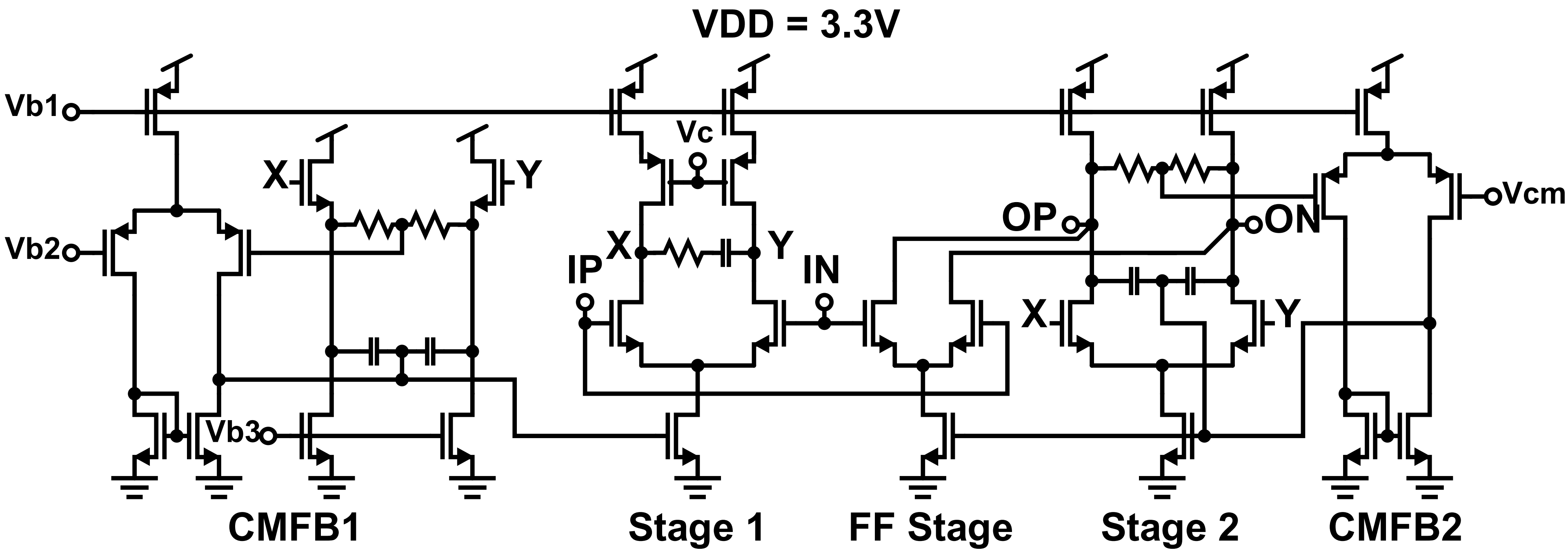
- **Switch resistance degrades Q**
- **Finite gm bandwidth enhances Q**



$$g_m = \frac{g_{m0}}{1 + s/\omega_p}$$

- **Cancellation occurs if** $R_{sw} = \frac{2\omega_0}{g_{m0}\omega_p}$

1st Resonator's Amplifier

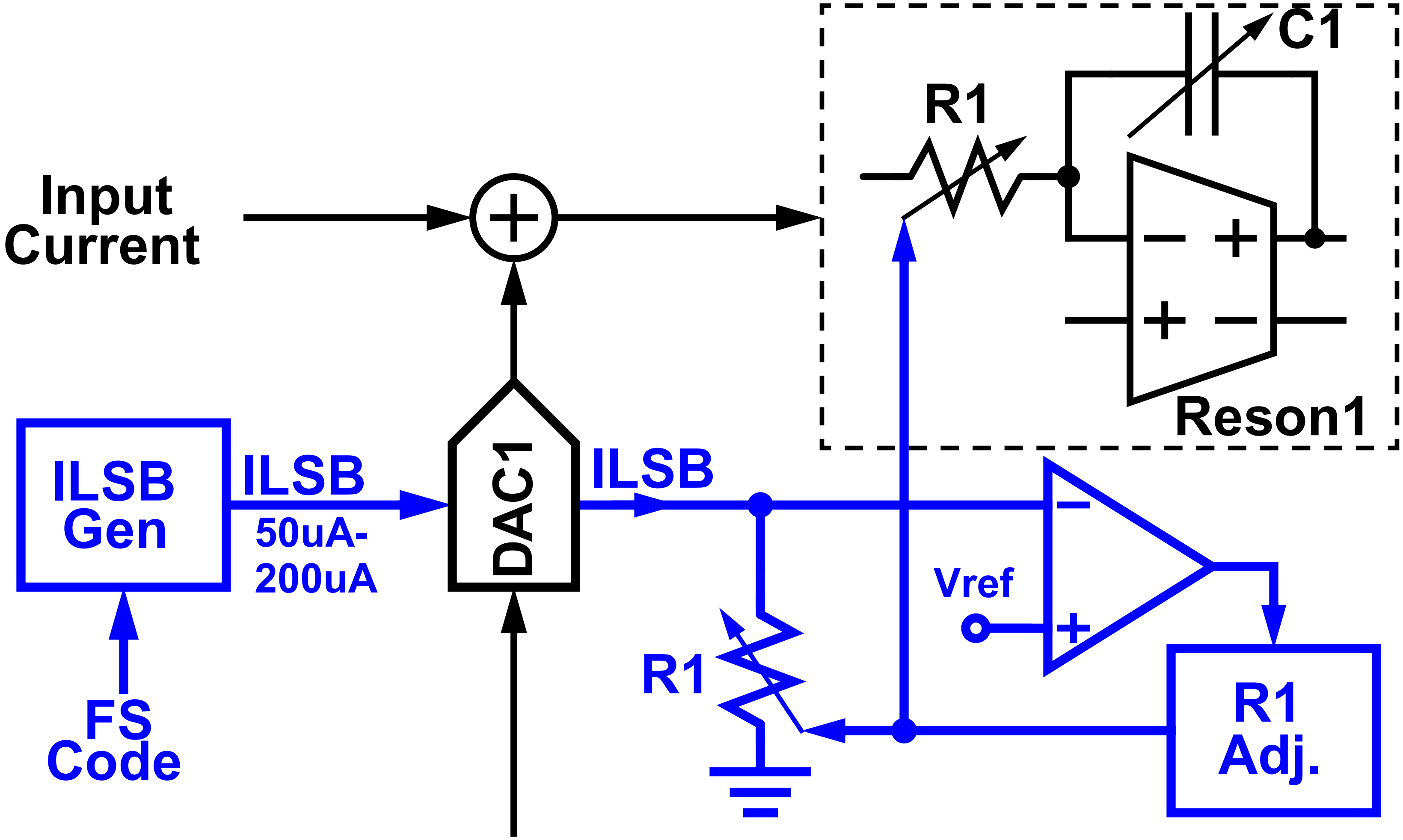


- 2-stage amplifier with feedforward stage and all-NMOS signal path

Gain-Scaling

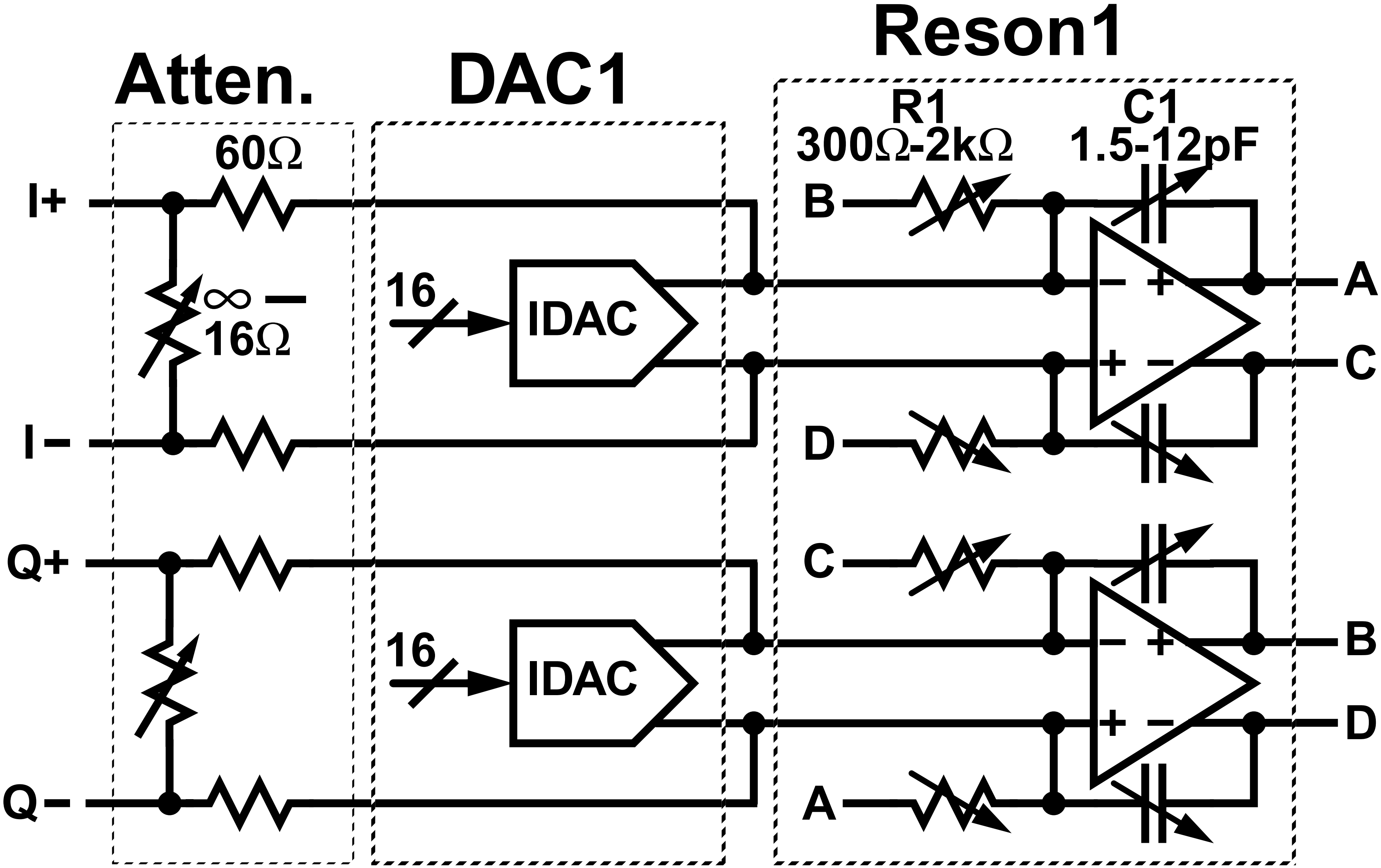
- **12-dB gain range implemented by scaling DAC1's LSB over a 4:1 range**
- **At the minimum LSB setting, DAC1's noise is 6 dB lower than at the maximum LSB setting**
- **Changes in DAC gain are counteracted by inverse change in Reson1 gain**
  - **Keeps gain of DAC1-Reson1 independent of LSB setting**
- **The gain-scaling burden is on the front end**
  - **No other circuits need to be adjusted**

Gain-Scaling Arrangement

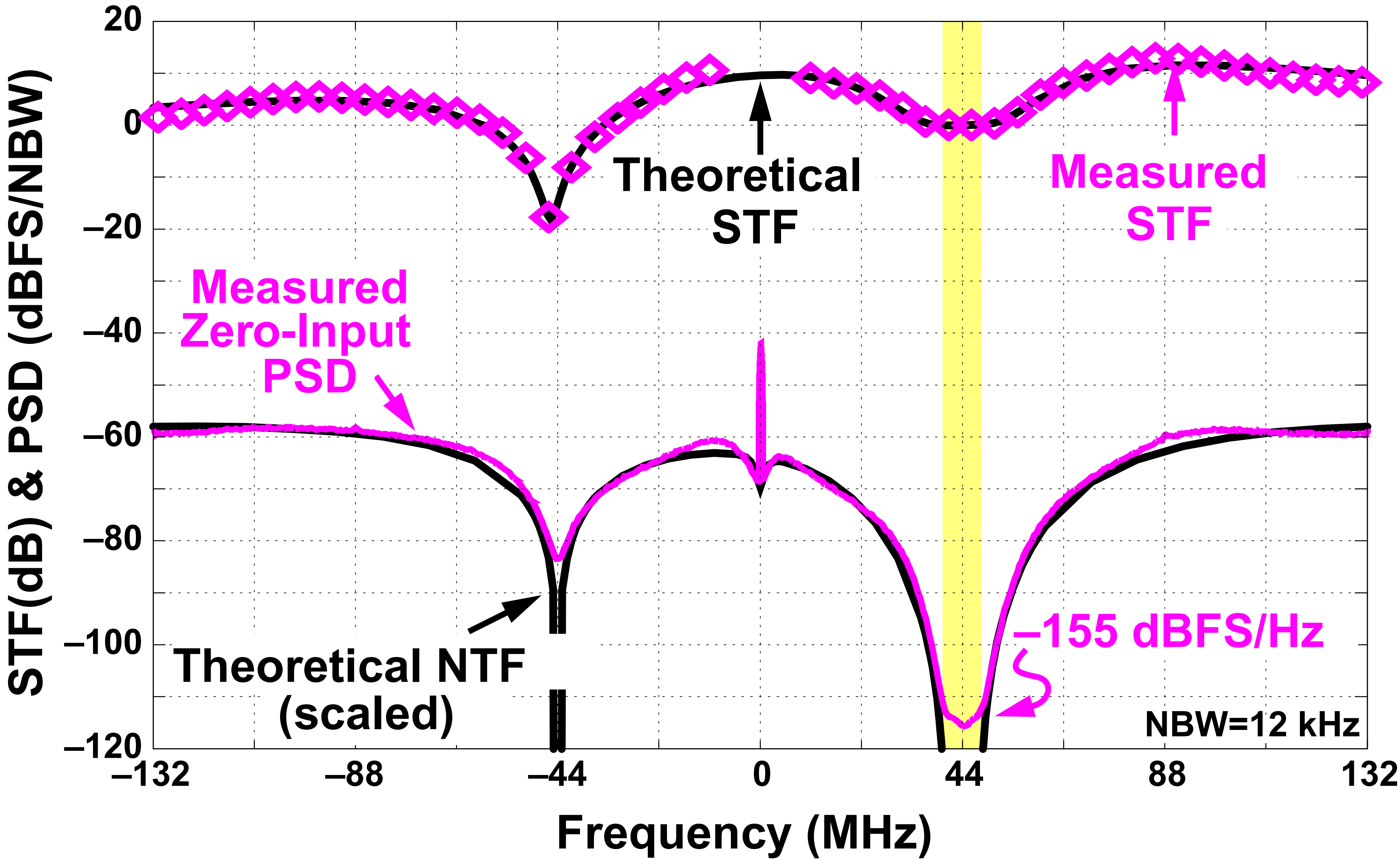


- Gain of DAC1+Reson1 kept constant

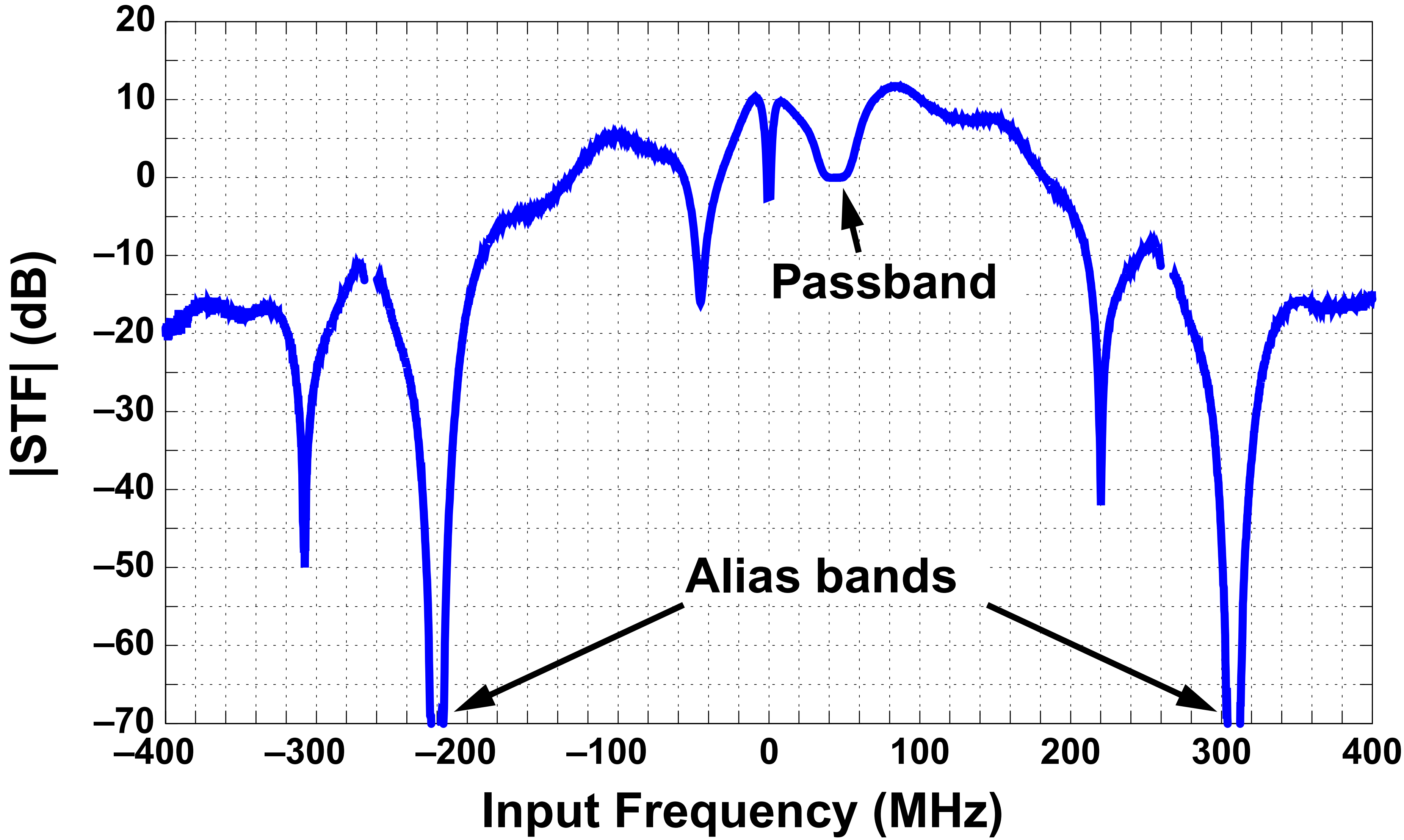
ADC Front-End



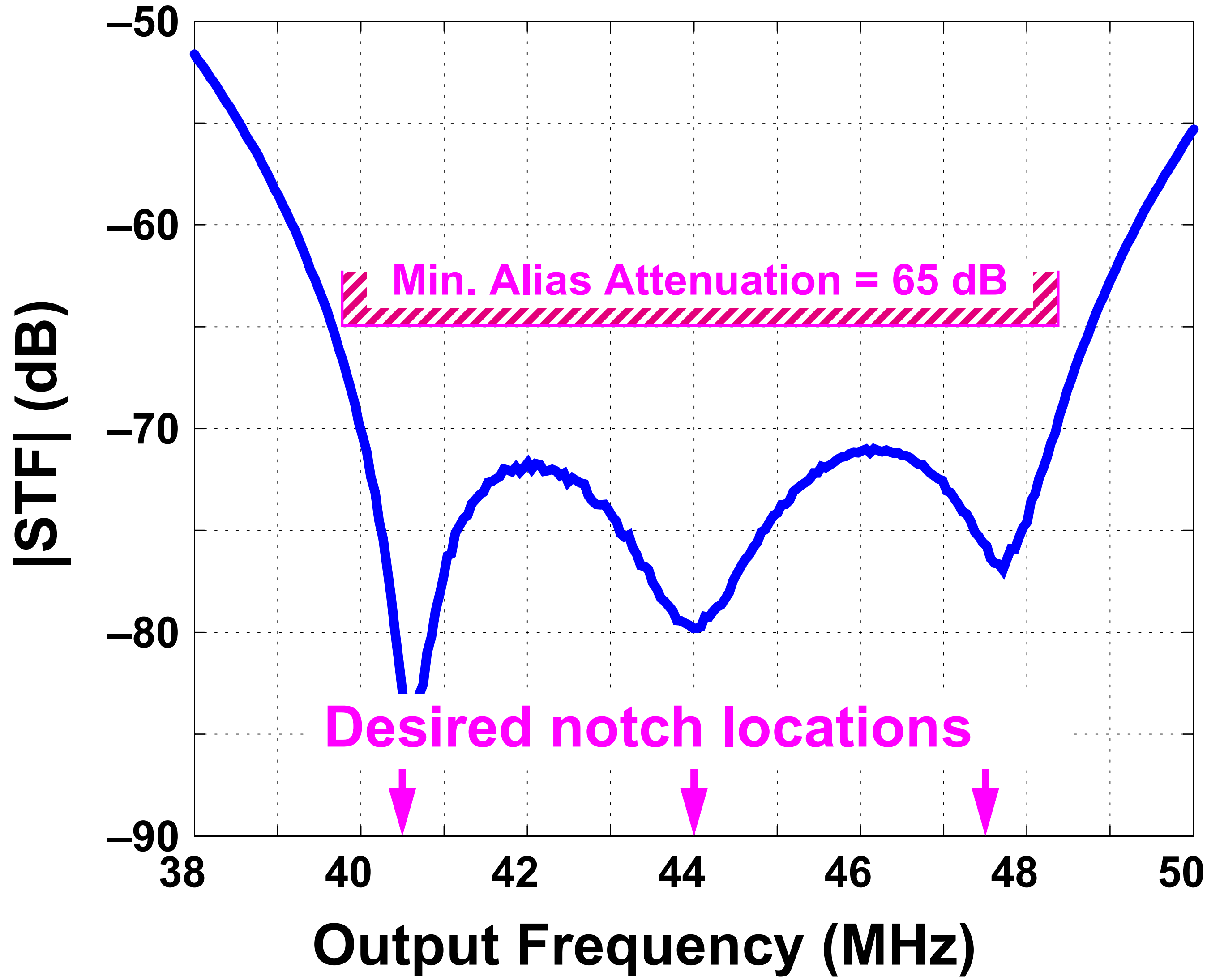
Results: STF & NTF



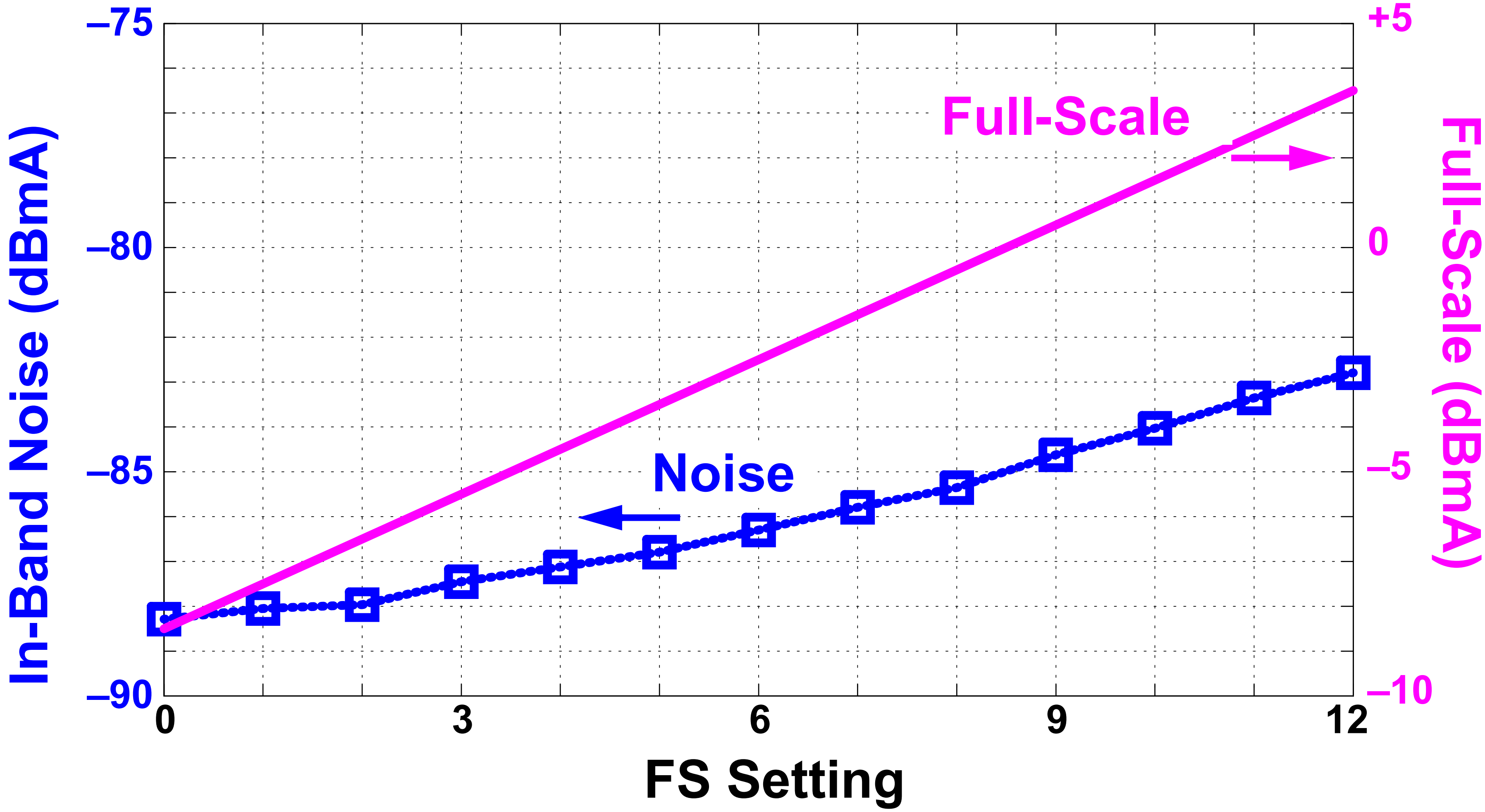
Wideband STF



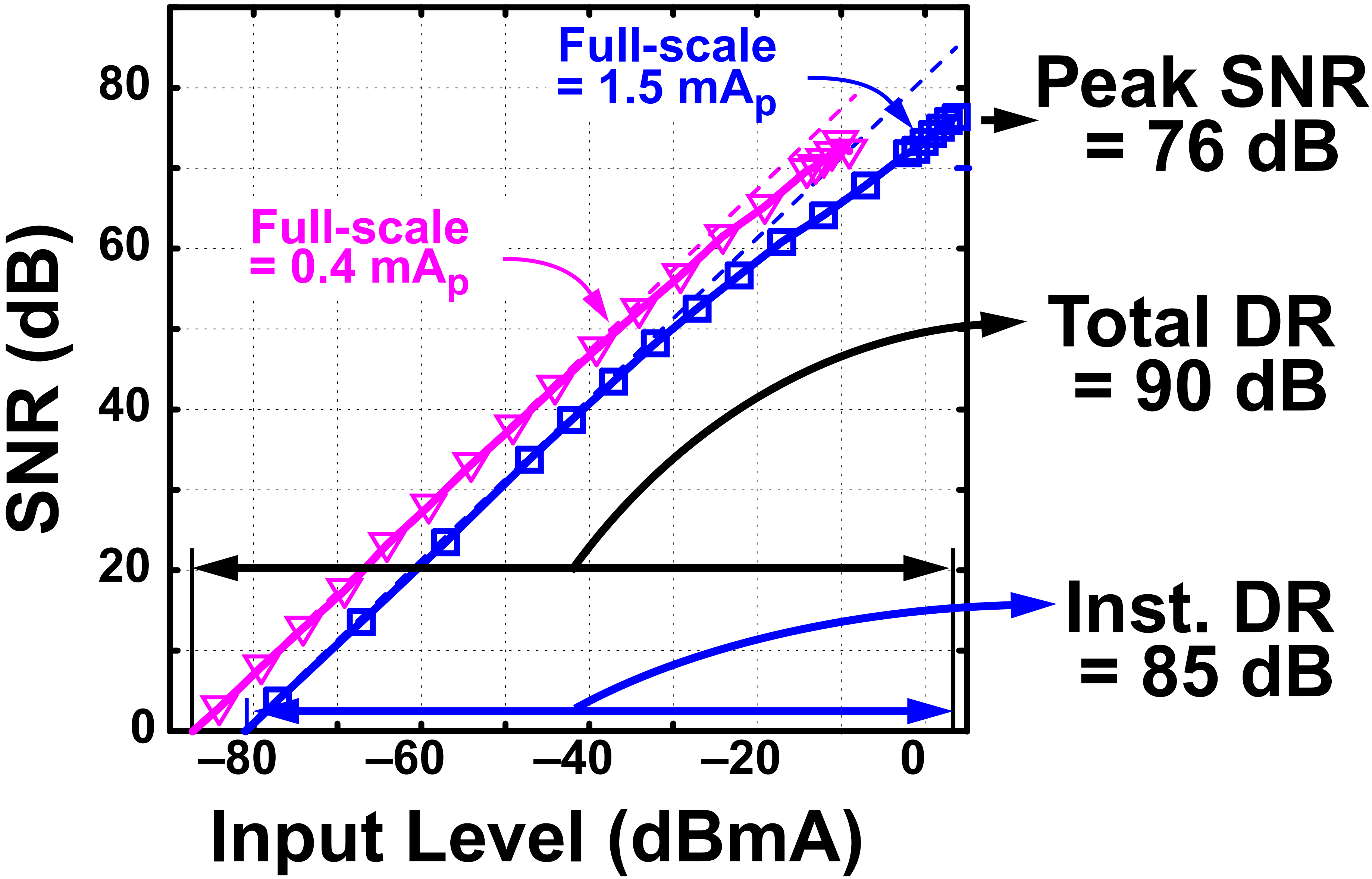
STF in +1 Alias Band



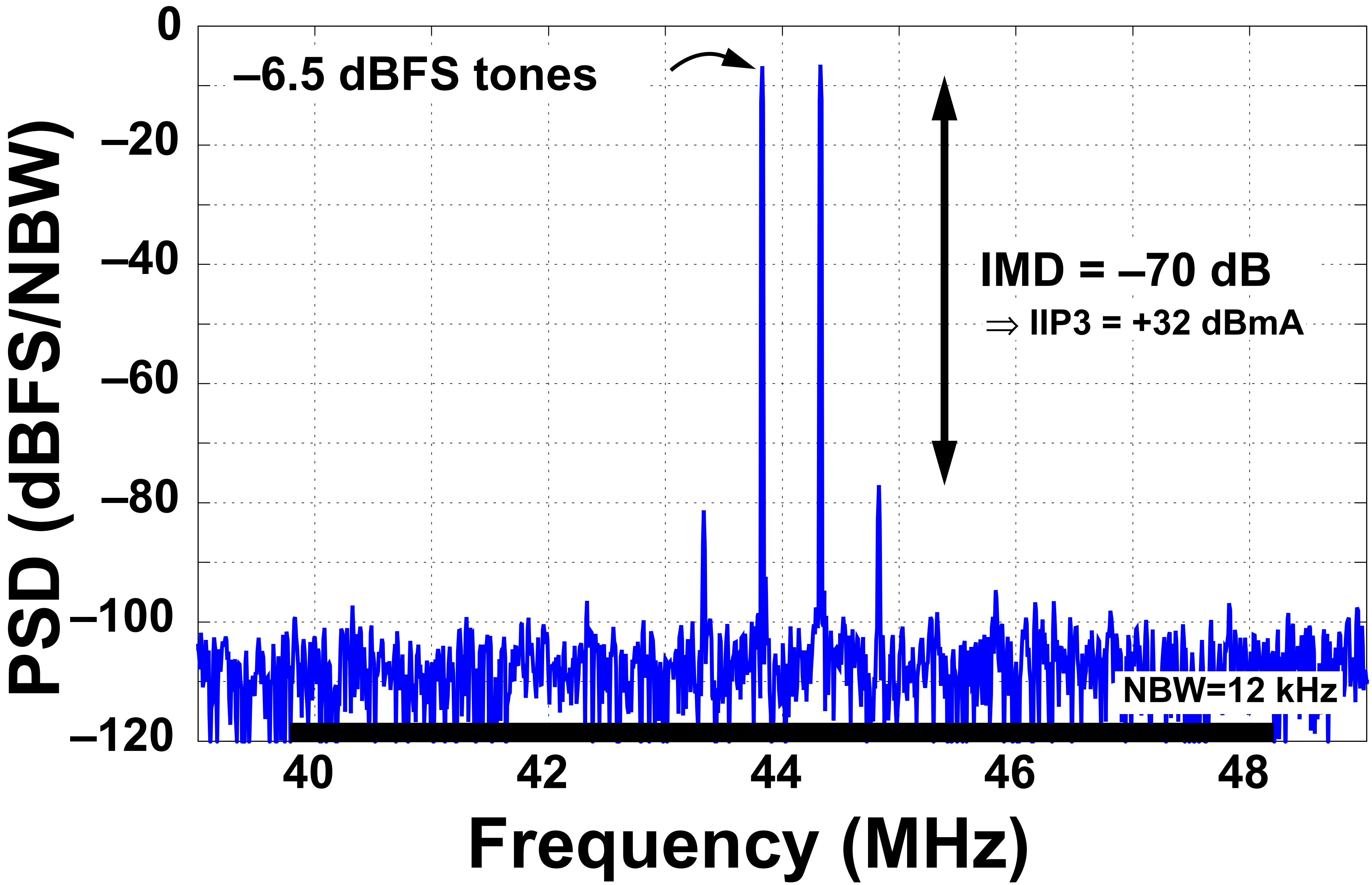
Noise vs. Full-Scale Setting



SNR vs. Input Level



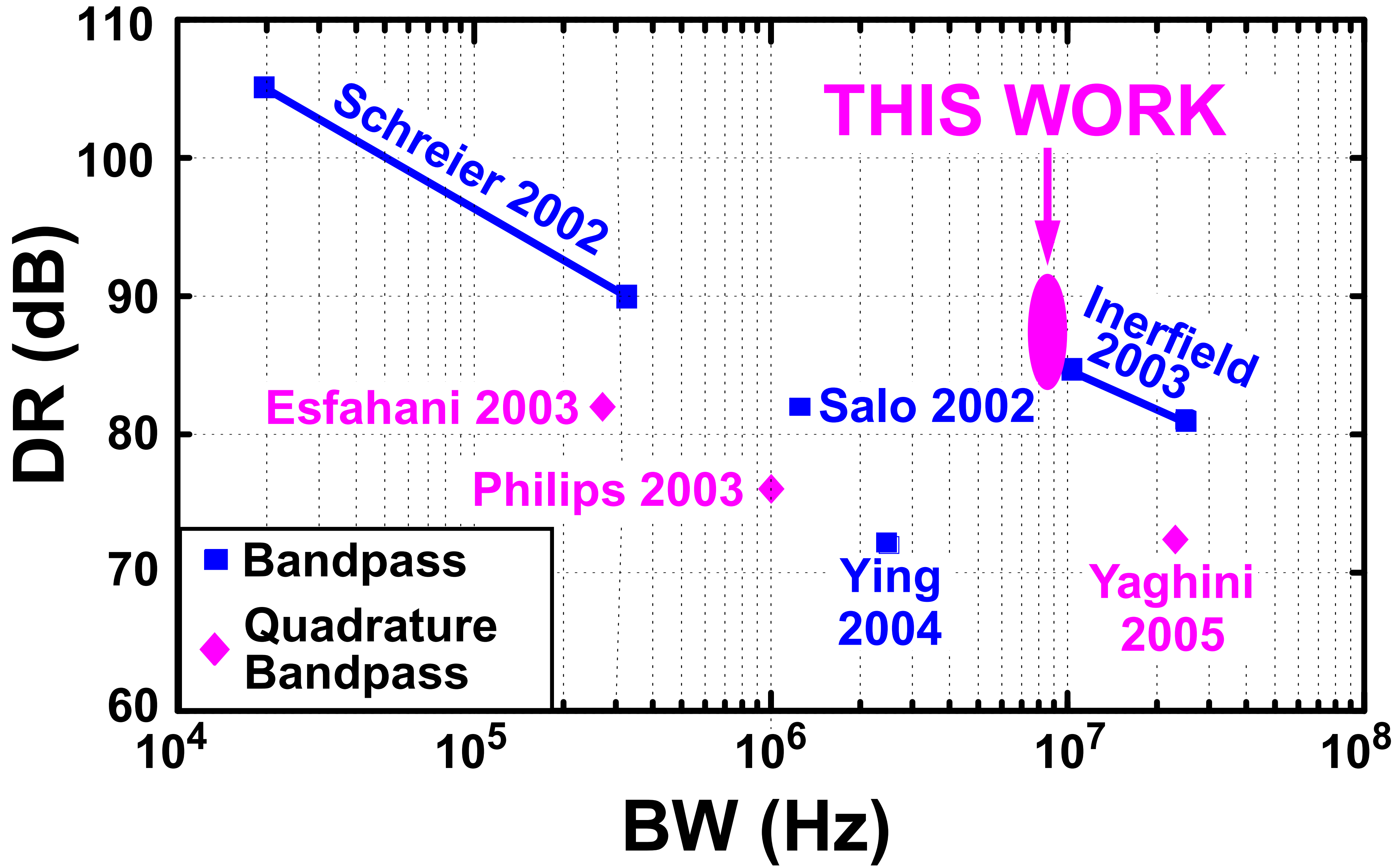
Two-Tone Spectrum



Performance Summary

Bandwidth	8.5	MHz
Center Frequency	44	MHz
Clock Frequency	264	MHz
Inst. Dynamic Range	85	dB
Full-Scale Range	12	dB
Total Dynamic Range	90	dB
Area in 0.18um CMOS	2.5	mm^2
Power Consumption	375	mW

Performance Comparison



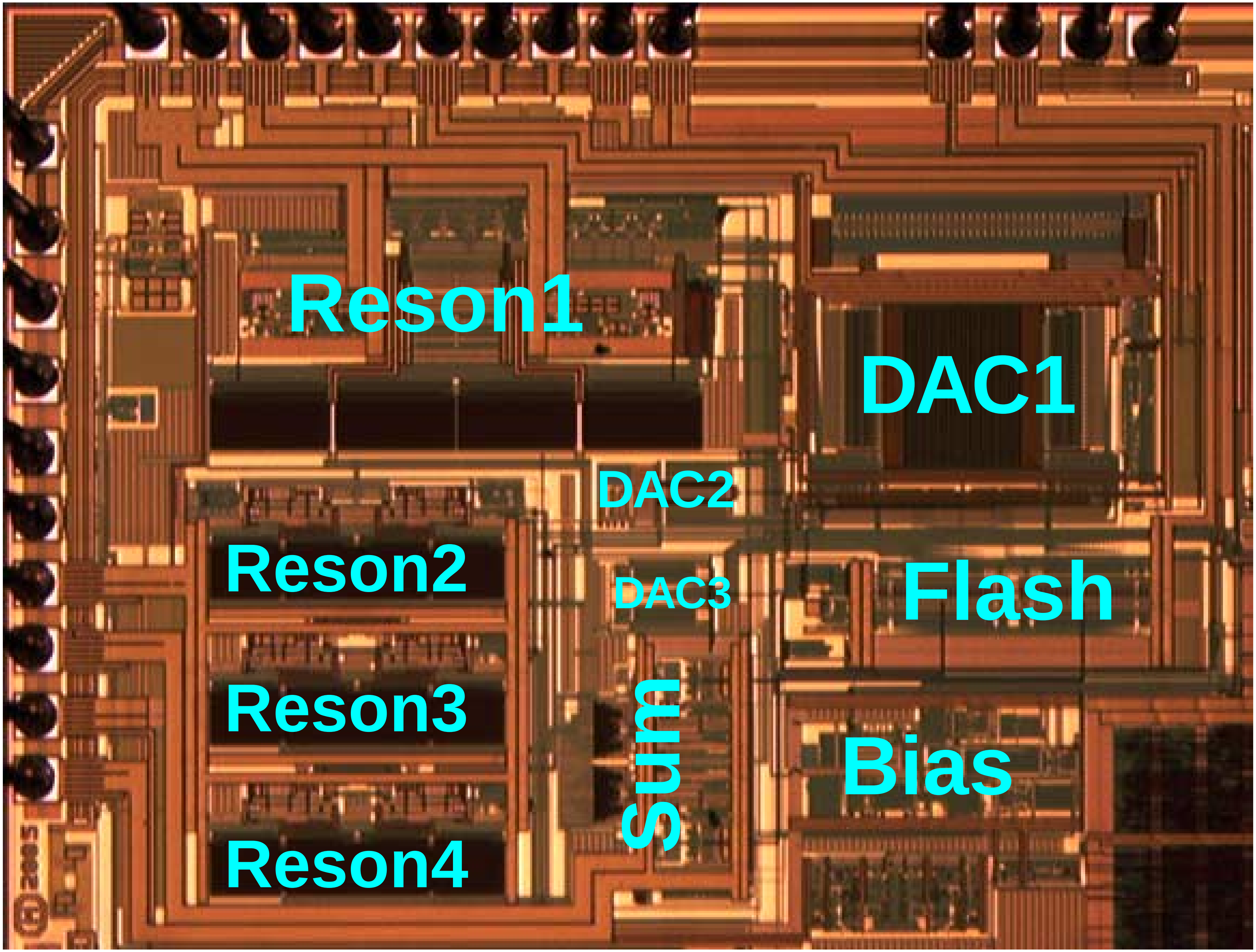
Conclusions

- **A feedforward implementation of a Quadrature Bandpass ΔΣ ADC needs an extra DAC**
  An input attenuator is a good idea too.

- **High Q resonance can be achieved by**
  1. Using a simple g_m instead of a true op amp
  2. Balancing finite g_m bandwidth and non-zero switch resistance

  Measured Q > 40

- **Gain-scaling extends DR**


Reson1
DAC1
DAC2
Reson2
DAC3
Flash
Sum
Reson3
Bias
Reson4