AXIOM IC TWENTE

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HOW THE "DIGITAL" AMPLIFIER BECOMES MORE DIGITAL

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Outline

- Introduction
- Class D: the “Digital” Amplifier
- “Digital” vs. More Digital
- Challenges in design of feedback AD converter
- Conclusions

Introduction

Axiom IC: who are we?

- Mixed-signal IC design house
- Specialized in low-power data converters and audio
- Located in Enschede
- Close contacts with University of Twente
- Founded in October 2007
- 20 Employees

Trends in audio

- All audio sources become digital
  - even broadcast radio
- Digital sound processing for “better” sound quality
- Improved fidelity at lower cost
- Car audio: tailored towards specific car acoustics
- Portable audio:
  - higher sound levels for less juice
  - longer battery life
- More channels
  - Home: 5.1, 7.1, 9.1
  - Car: currently 12 channels, going up 20+

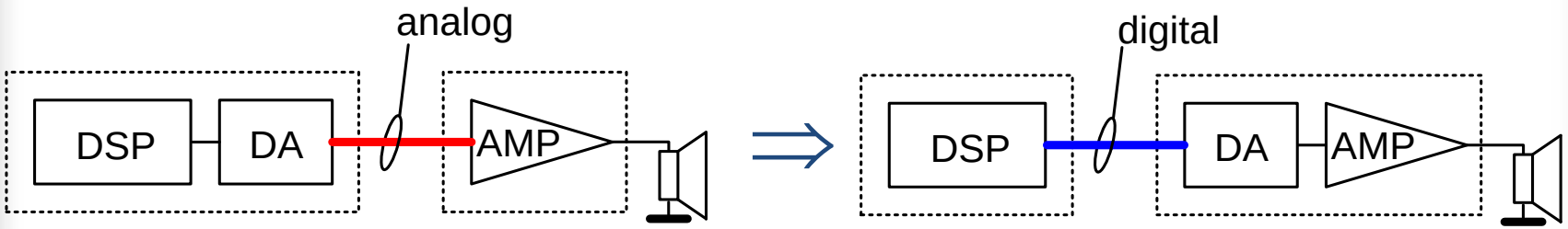
$\Rightarrow$ Need for efficient HiFi power amplifiers

Reasons for going digital

- More flexibility
- Easier to add features
- Scales with technology
- Cost reduction
- Less sensitive to cross talk
- Automatic layout place and route
- No specialized analog design skills required
- Testability
- Sexy

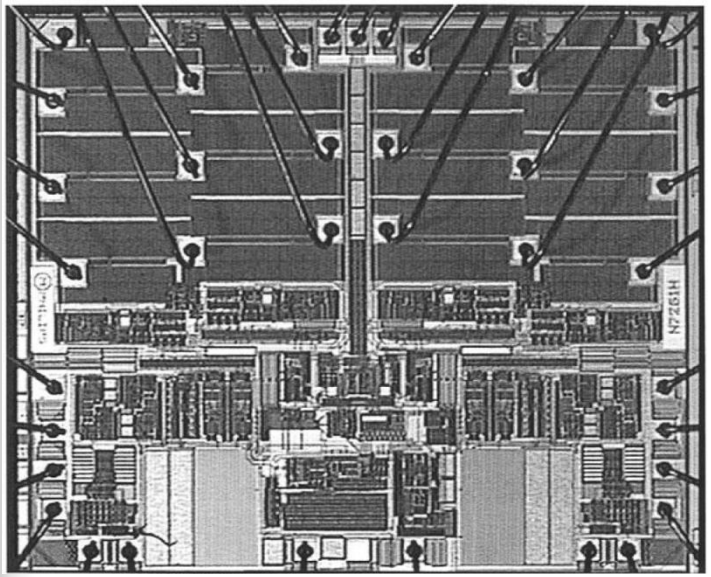
Current status “digital” amplifier

DA converter moves to the power die

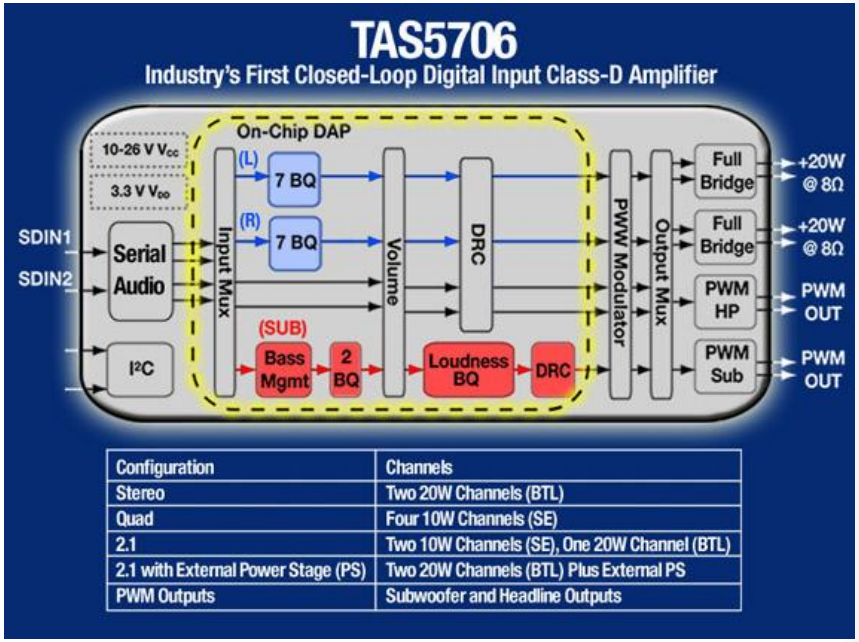


- DSP and amplifier remain on separate die, to allow for aggressive scaling of DSP
- DA converter moves to the power amplifier die
  - made possible by faster CMOS in power technology
  - interface becomes digital:
    - less cross talk problems
    - allows for connecting amps to a bus (in car)

Examples: high power class D



2x100W Class D; 22mm^2
M. Berkhout, NXP, JSSC 2003
- closed loop, PWM
- analog loop filter
- analog inputs



2x20W Class D
Texas Instruments 2008
- closed loop
- analog loop filter
- digital inputs

Where are we headed?

We are headed for a more digital amplifier:

Closed loop amplifier with internal digital gain and digital feedback

Some have claimed the term in the past for:

- Any *analog* amplifier with digital inputs (DA converter at input)
- Open or closed-loop *analog* class D amplifier ("switching is digital")

⇒"digital" is often misleading: internally the gain is implemented analog

⇒ Class D does not mean digital

Keep in mind:

the pure digital amplifier does not exist:

the power stage is always analog

Axiom IC

In the past, Axiom IC has developed:

- integrated class AB audio power amplifiers for car audio
- high performance DA converters for amplifiers with digital input

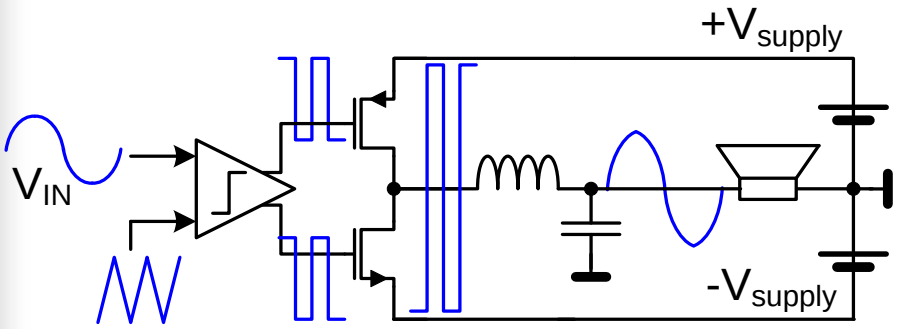
Axiom IC currently develops a closed-loop class D power amplifier featuring:

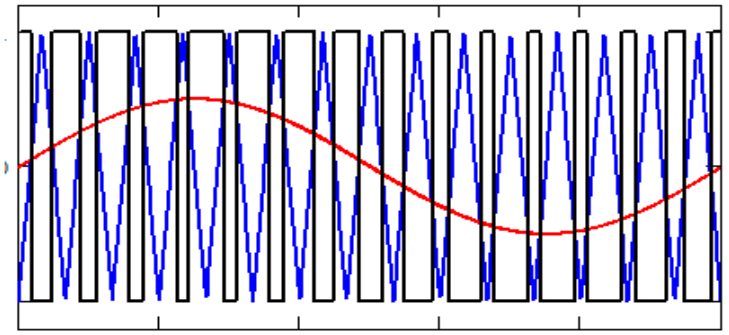
- Digital inputs
- Digital internal loop filter (internal gain is digital)
- ADC in the feedback path

..such that the internal audio processing is digital (including gain and feedback)

Class D: the “digital” amplifier

Class D: principle



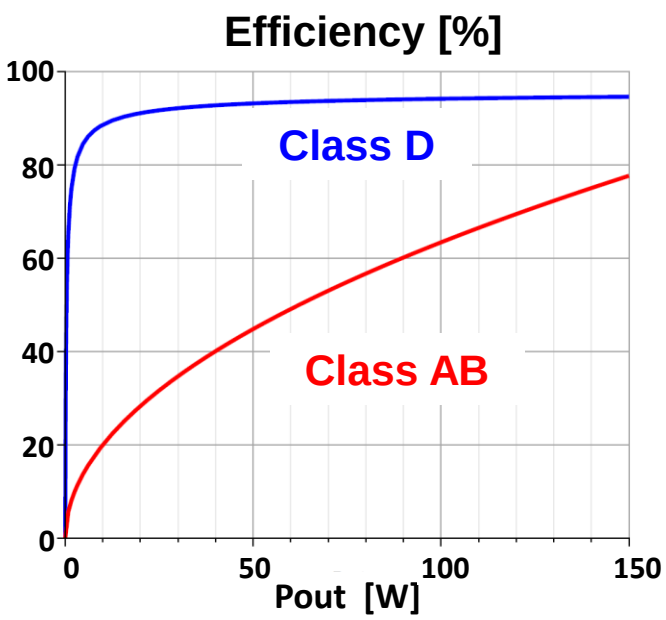


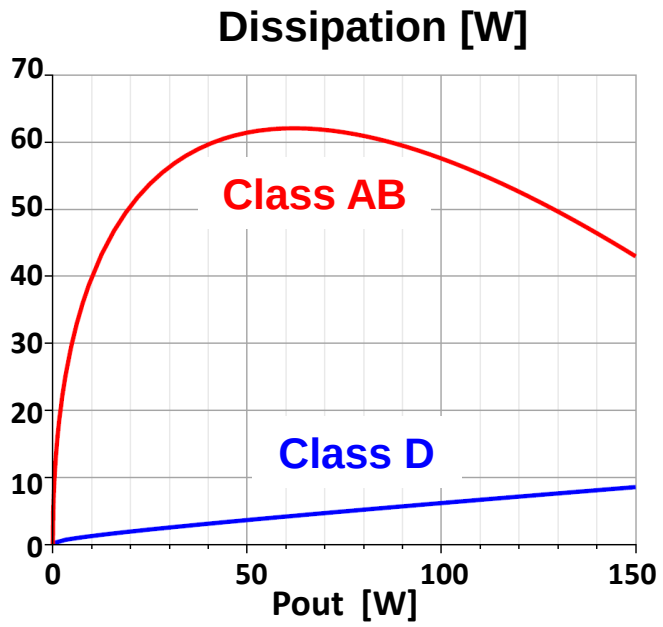
Principle of class D:

- Output stage switches between supply rails
  $\Rightarrow$ Low dissipation in power transistors ($P_{diss} = V_{DS} \cdot I_{load}$)
- Audio modulates the pulse width ("PWM")
- Requires external reconstruction LC filter

The design and operation of a class D power stage + drivers is analog by nature!

Efficiency comparison

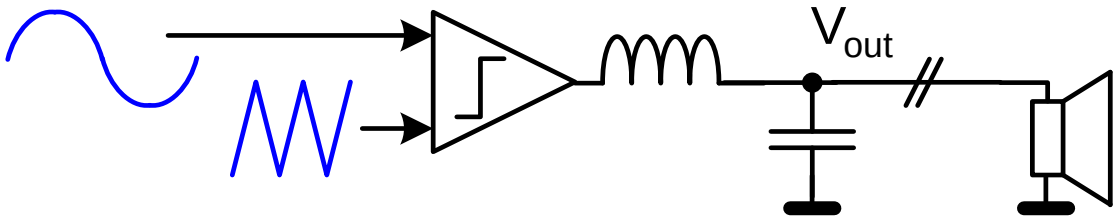


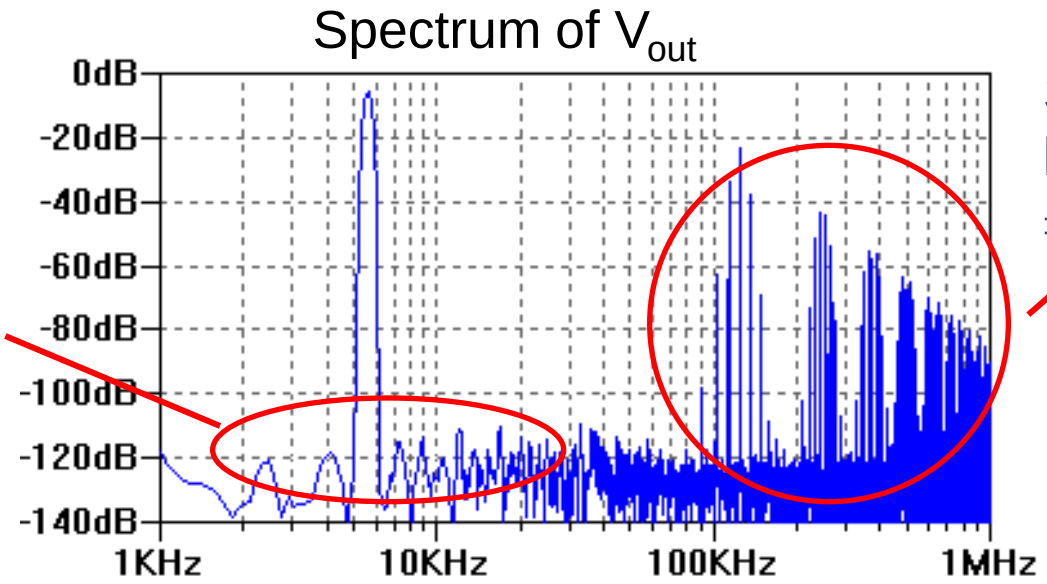


Class AB: linear Class D: switching

Class D $\Rightarrow$ smaller heat sink, cheaper IC package, smaller power supply, extended battery life

Class D: spectral content





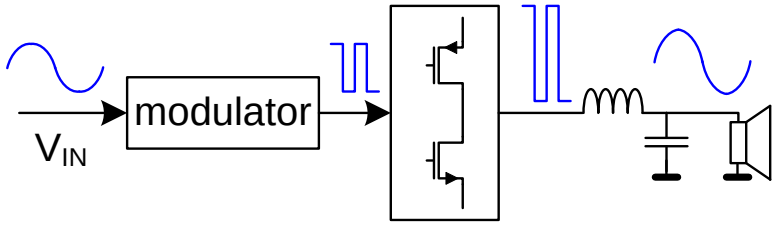
PWM is linear (no THD)

Switching harmonics ⇒ EMI

Switching harmonics interfere with AM band (0.5 – 1.5MHz)

Class D: topologies

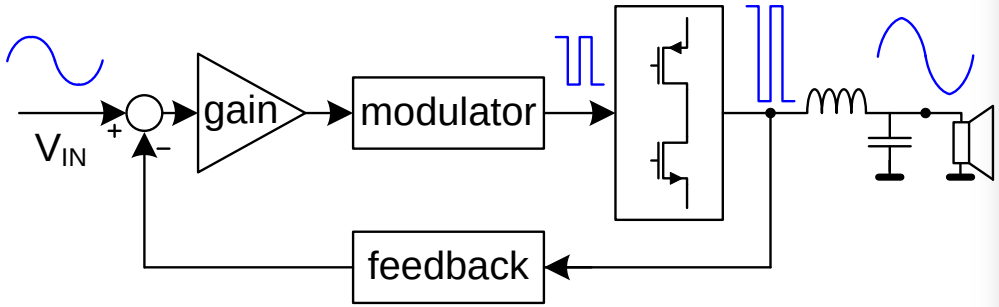
Open Loop



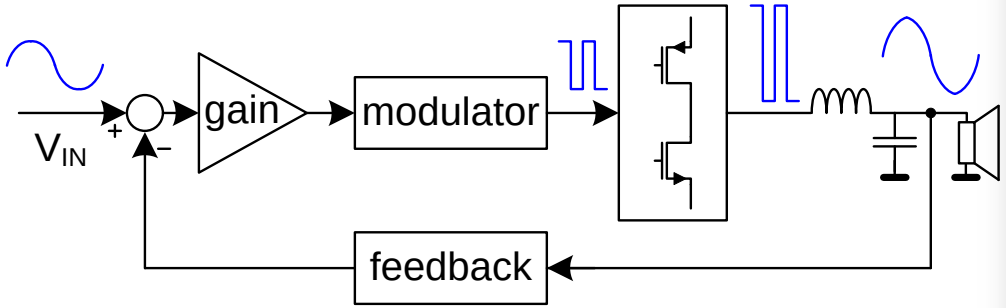
Closed Loop:

- Feedback Before Filter

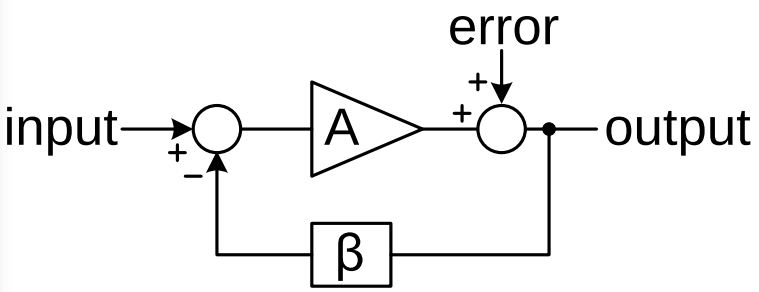
  Most commonly used analog solution nowadays



- Feedback After Filter (FBAF)



Why closed loop?



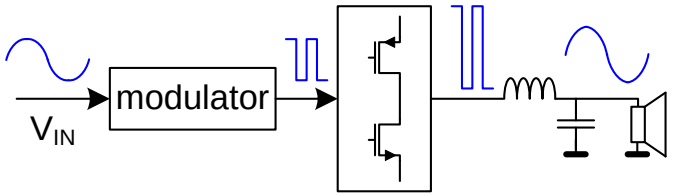
$$\text{output} = \frac{A}{1+A\cdot\beta}\cdot\text{input} + \frac{1}{1+A\cdot\beta}\cdot\text{error}$$

$$\approx \frac{1}{\beta}\cdot\text{input} + \frac{1}{A\cdot\beta}\cdot\text{error}$$

Assumptions:
- Gain A is large, but inaccurate
- $A\cdot\beta >> 1$

Conclusion:
- $\Rightarrow$ Make β accurate for well-defined transfer
- $\Rightarrow$ Make A large for good error suppression

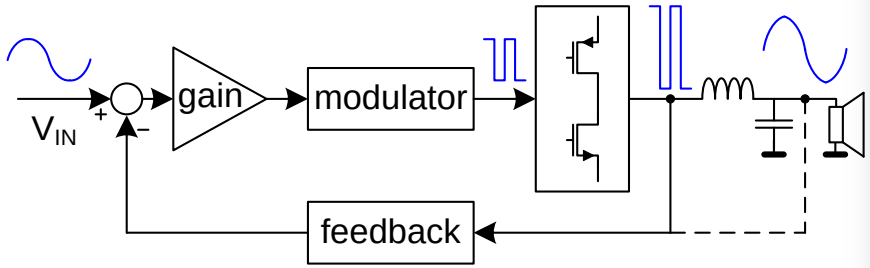
Open Loop



- ☺ Simple
- ☹ No suppression of non-linearity
- ☹ No power supply rejection
- ☹ Requires excellent supply (bulky, cost)

Popular in combination with a digital modulator

Closed Loop

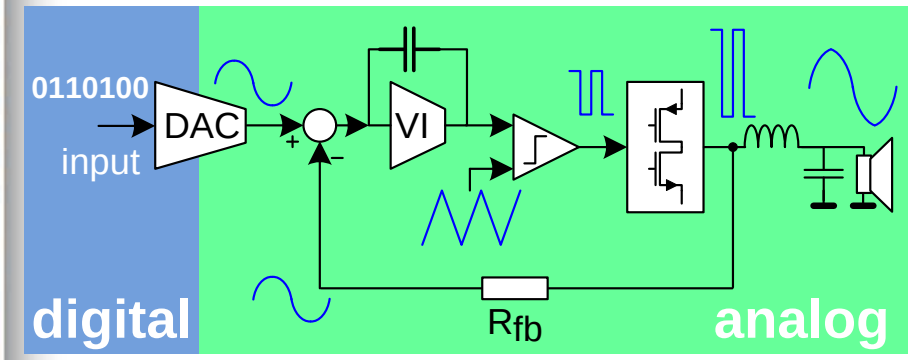


- ☺ Suppression of non-linearity
- ☺ Good power supply rejection
- ☺ With feedback after filter: frequency response independent of speaker impedance

Challenge:
Stability

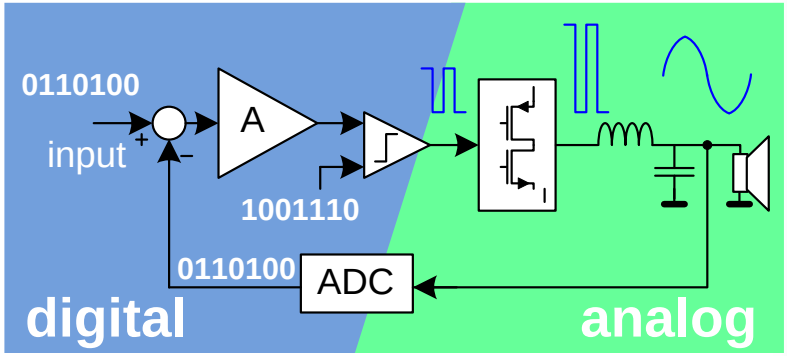
“Digital” vs. More Digital

"Digital"



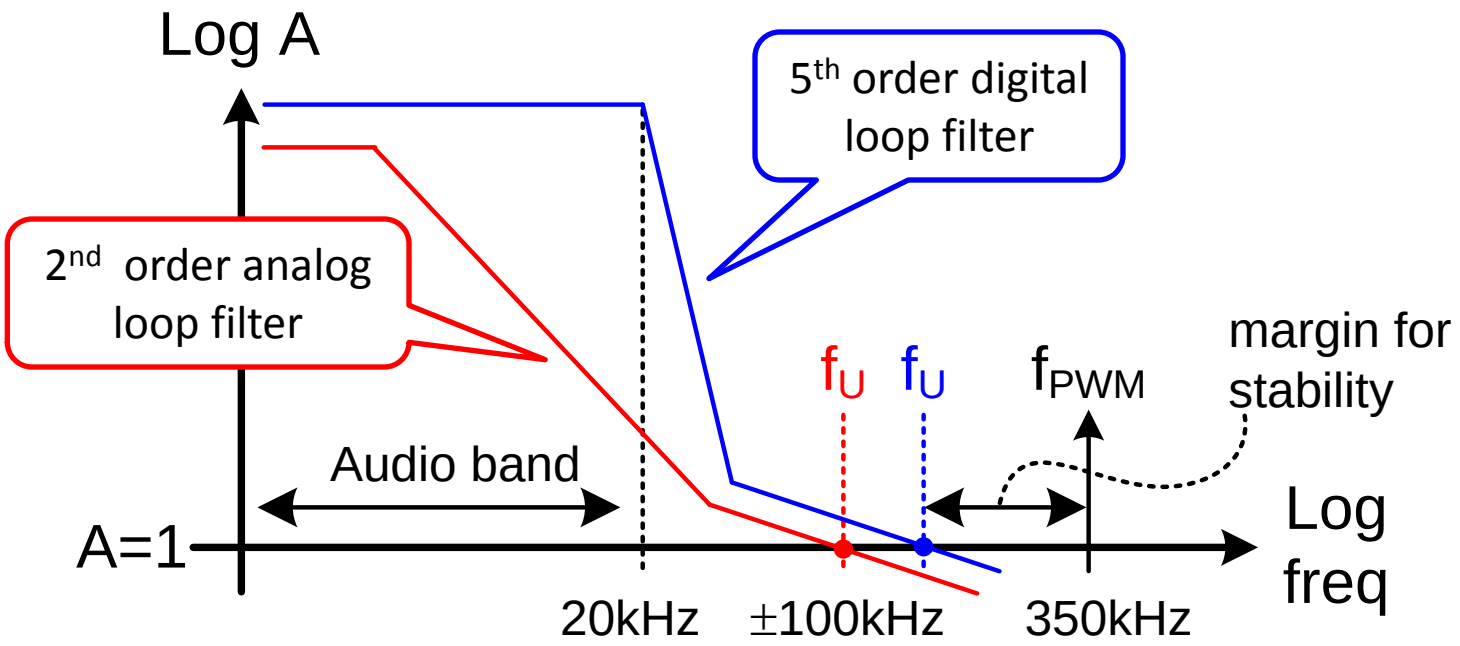
- ☺ Feedback is a simple resistor
- ☺ Proven performance
- ☹ Loop filter requires capacitors (area)
- ☹ Component spread ⇒ low order loop filter ⇒ average THD
- ☹ Internal analog nodes ⇒ sensitive to cross talk

More Digital



- ☹ Feedback is ADC: not simple
- ☹ Not proven yet: research topic
- ☺ Area efficient
- ☺ No component tolerance ⇒ high order loop filter ⇒ good THD
- ☺ Internal digital nodes
- ☺ Rapid prototyping (FPGA)
- ☺ Flexible

Analog vs. digital loop gain

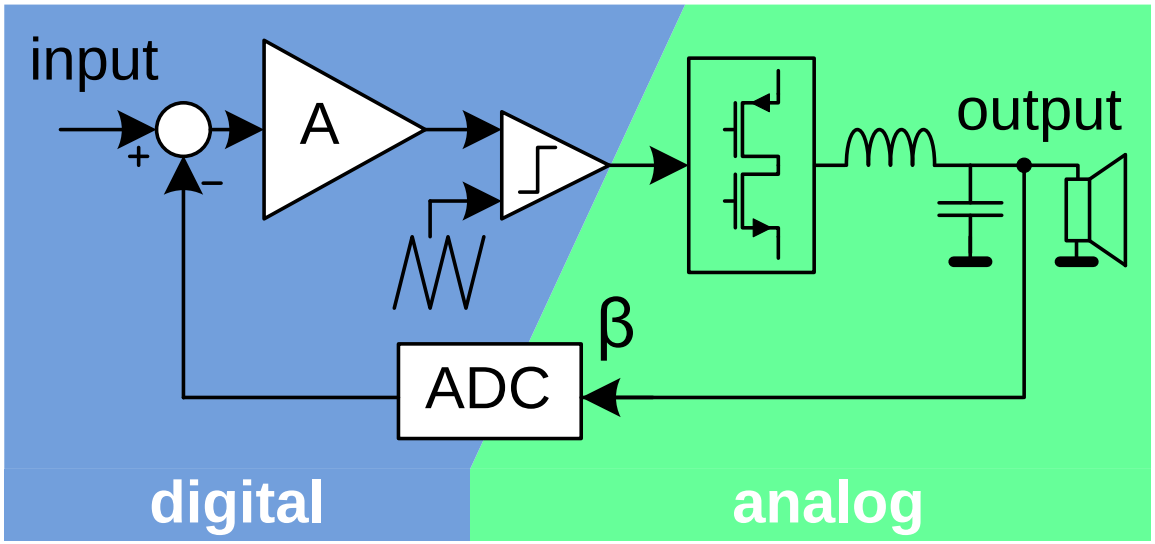


Analog loop filter must be of relative low order, due to margins for component spread

Digital allows a more aggressive loop filter
⇒ better THD at high audio frequencies

Feedback ADC

Feedback ADC



$$\text{output} = \frac{A}{1+A\cdot\beta}\cdot\text{input} \approx \frac{1}{\beta}\cdot\text{input}$$

ADC is in feedback path and determines performance of overall system!

Feedback ADC

Requirements:

- High signal-to-noise and low distortion: 120dB audio dynamic range
  ⇒ sigma delta
- Low out-of-band noise: to avoid down mixing in PWM modulator
  ⇒ additional internal filtering
- Low latency (for loop stability): delay << 1 PWM cycle
  ⇒ conflicts with filtering

Risks:

- Supply & substrate bounce: ADC on same die as power stage!
  ⇒ Design must be fully differential with good CMRR

Conclusions

- The term “digital” amplifier is quite misleading:
  at best, it refers to an analog amplifier with DA converter @ input
- Axiom IC currently develops a more digital amplifier featuring
  a digital loop filter and feedback ADC:
  - More aggressive loop filter possible ⇒ lower THD
  - More flexible than analog
  - Fewer interference-sensitive analog nodes
- The feedback ADC is the most critical part:
  - Will determine overall performance
  - Challenge: low latency, low HF quantization noise

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