



# Sub-mW Integrated Power Management Systems for Hearing aids Applications

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# Modern hearing aids

## Overview of features

### Invisible Size

- ❑ There must be room for a decent battery
- ❑ A minimum distance between microphones

### Advanced sound processing

- ❑ Algorithms running on custom DSP

### 2.4 GHz Bluetooth directly to the hearing aid

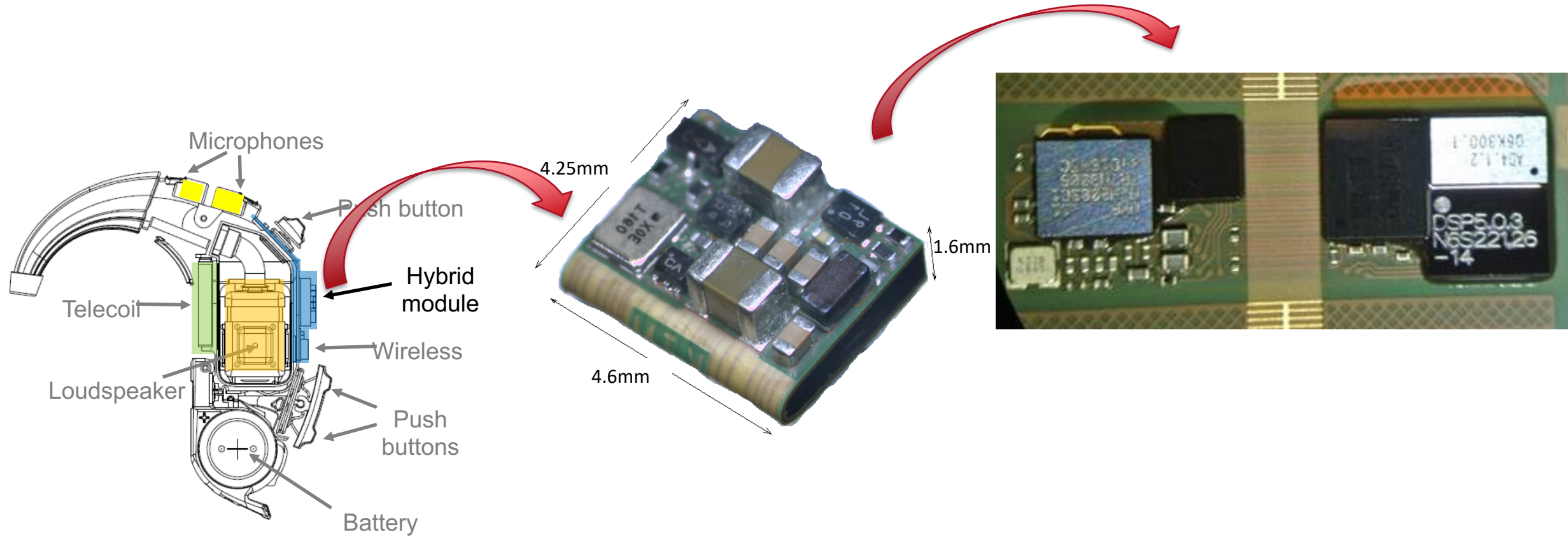
- ❑ Made for iPhone
- ❑ The hearing aids can be used as a wireless stereo headset.
- ❑ Stream audio from TV, smart phone, mini microphone directly to the HA.

### Extremely Low Power

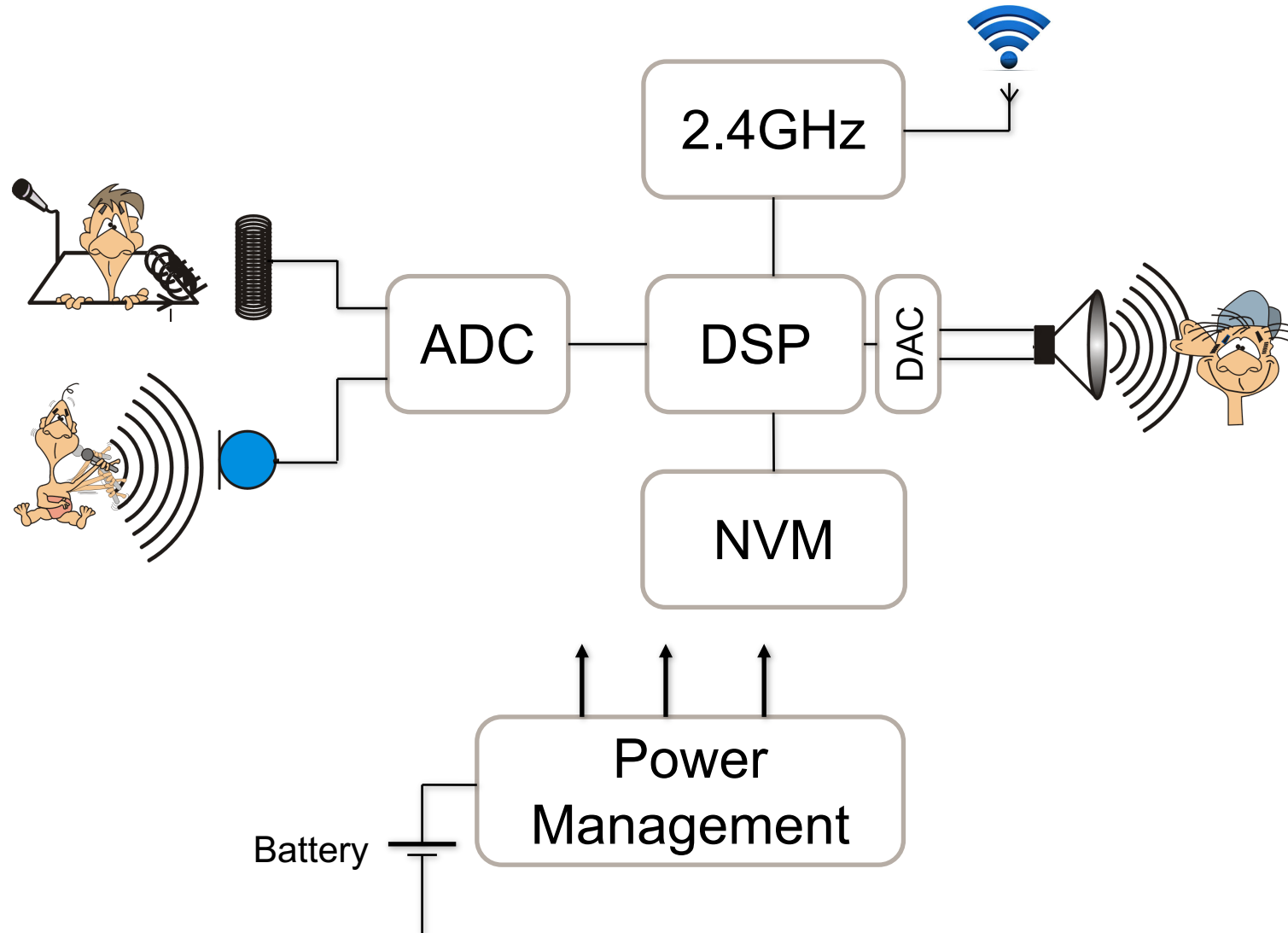
- ❑ Hearing aids running for the whole week on one battery



# A typical hearing aid platform



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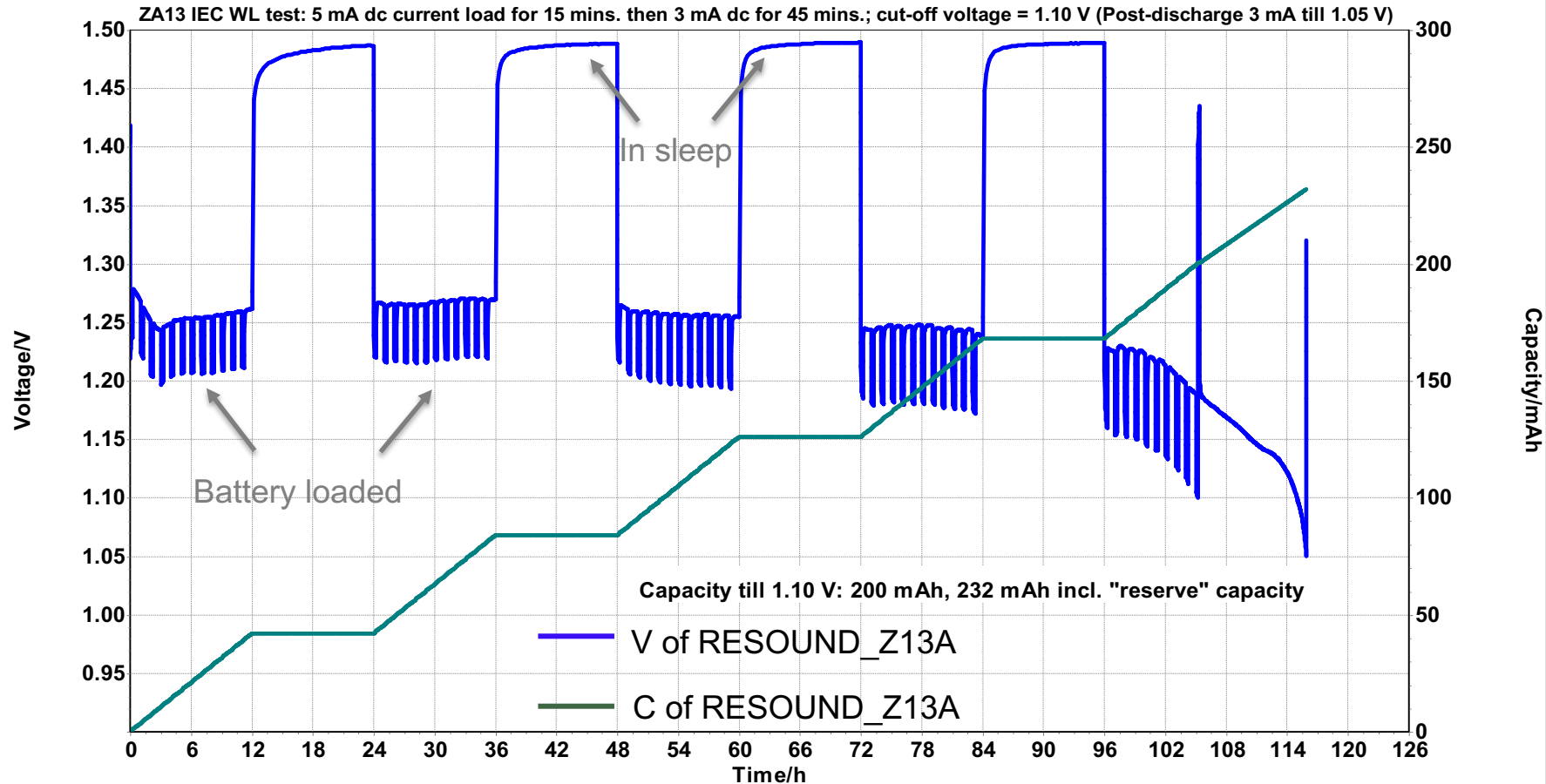




# The battery used in the hearing-aids

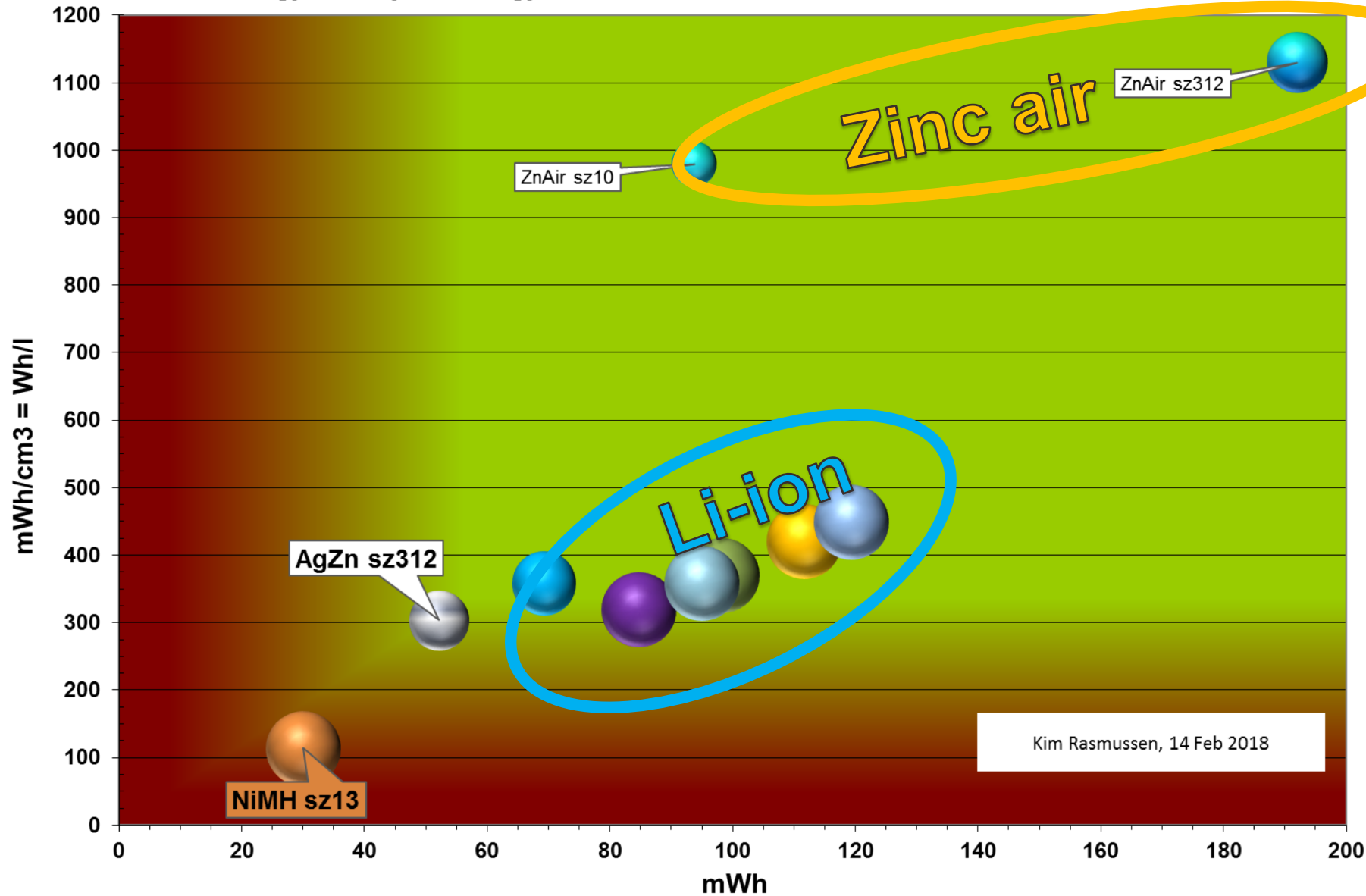
Traditionally, hearing aids have used **ZnAir batteries which are non-rechargeable**

Typical discharge voltage profile for a zinc air hearing aid battery, size 13



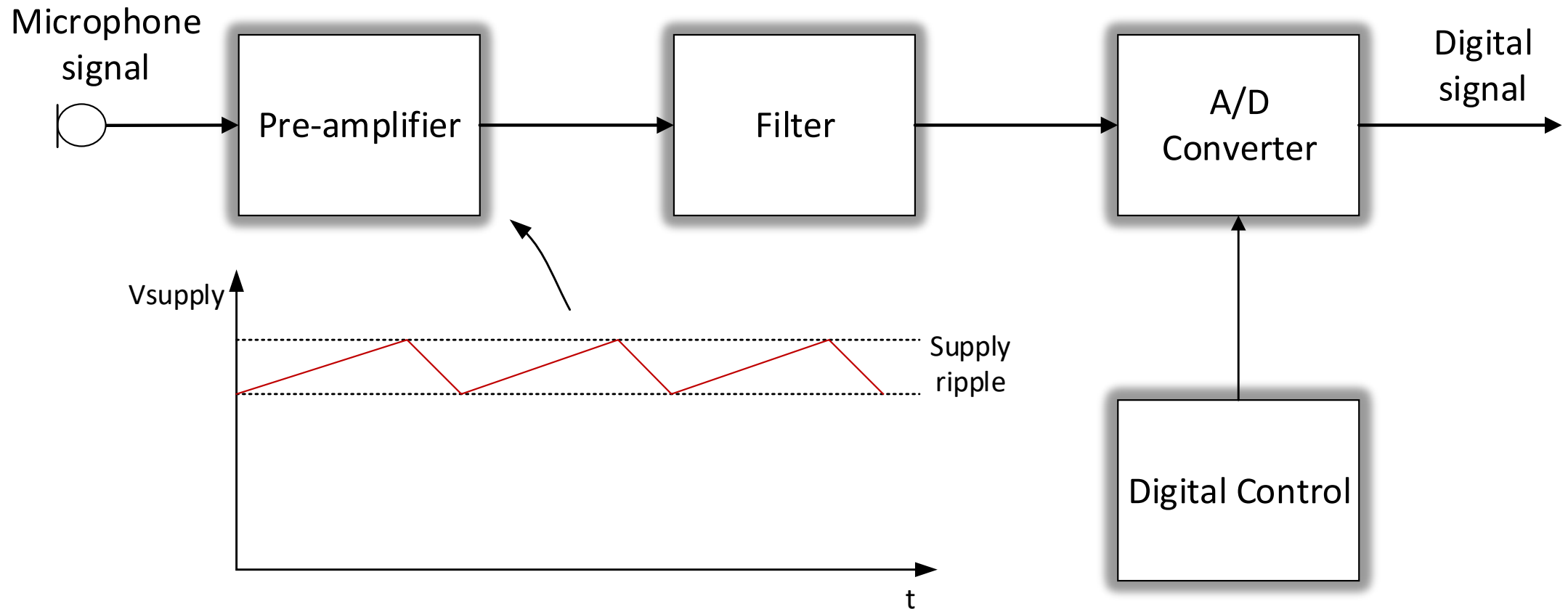
# Energy densities of available and future hearing aid batteries

Energy Density vs. Energy for various cell chemistries (bubble size indicates cell volume)



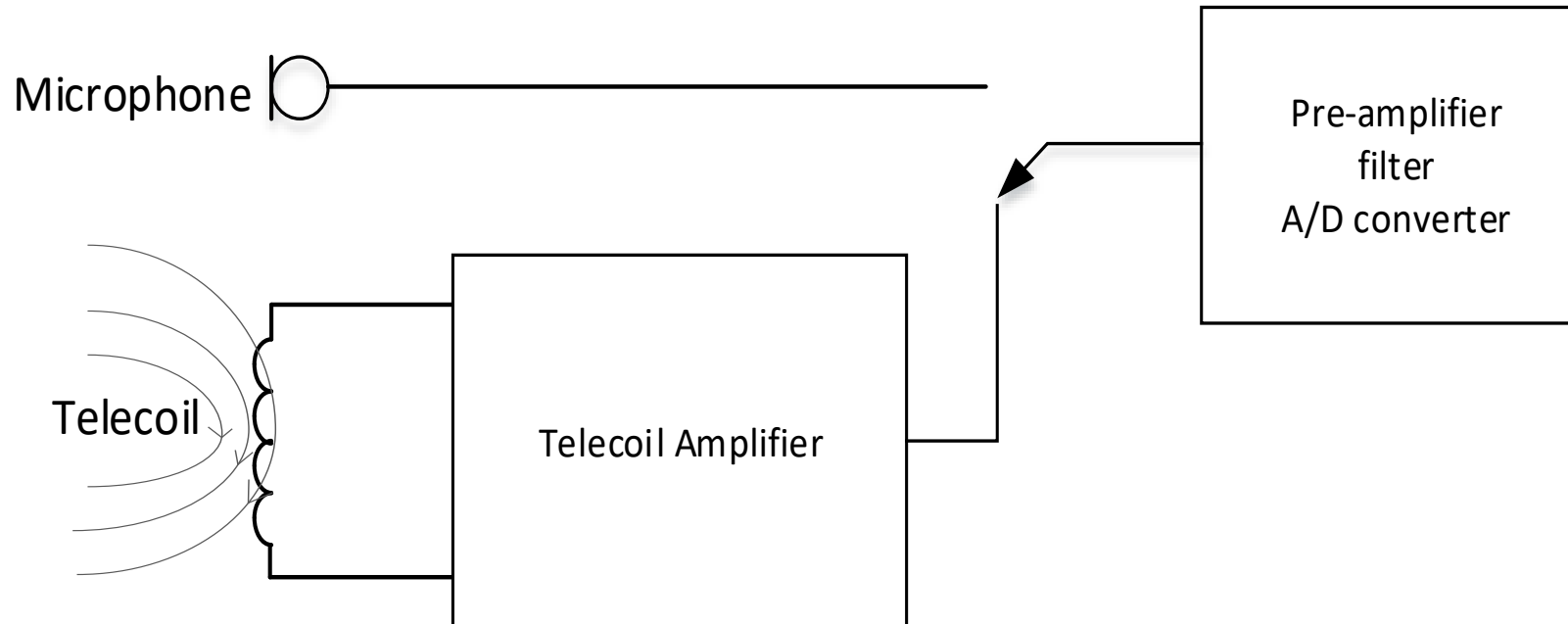
Kim Rasmussen, 14 Feb 2018

# Power supply disturbances in the audio input stage



- ❑ Supply ripple in the audio frequency range could couple into the signal path **LDOs with GOOD PSR!!**
- ❑ Supply ripple at multiples of the A/D oversampling rate (typically 500k-1MHz) could couple into the signal path. **Anti-aliasing filter to filter such noise**

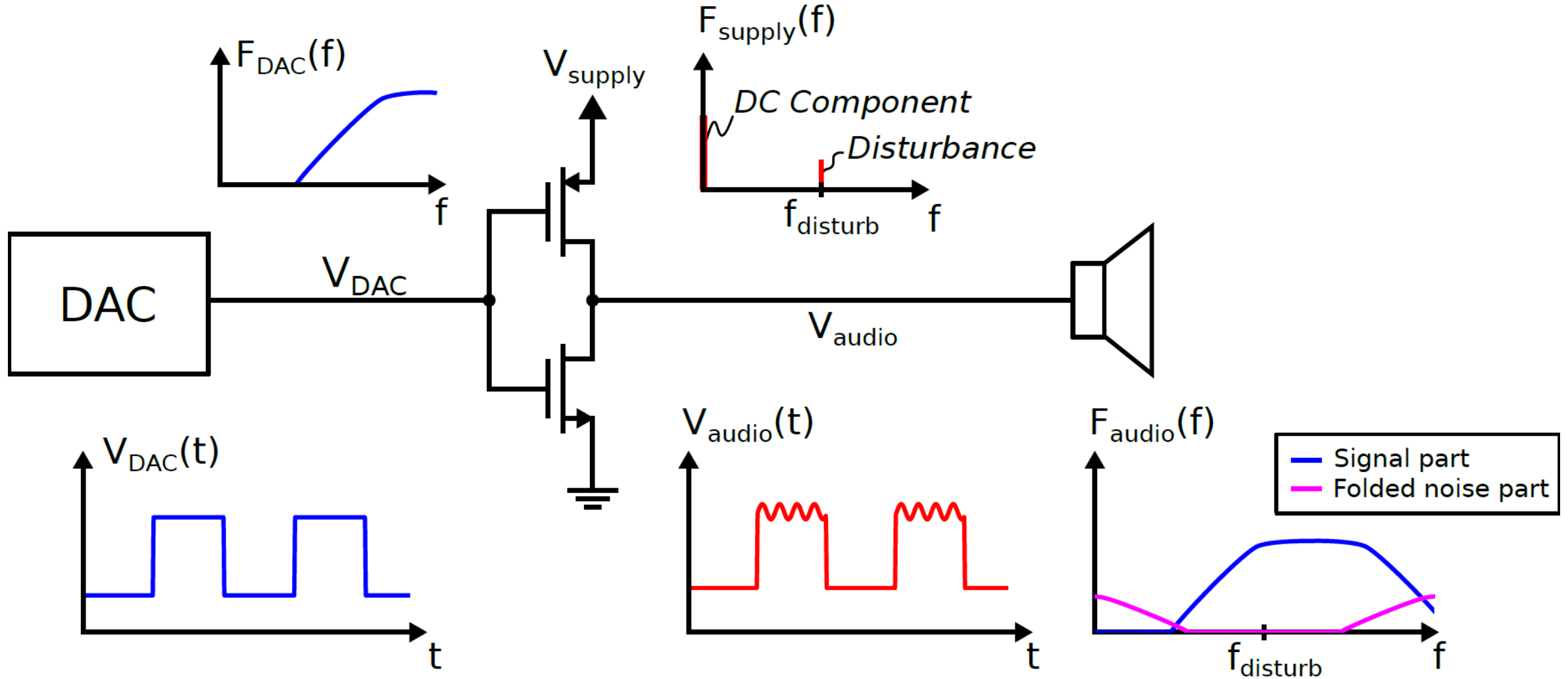
# Power supply disturbances in the audio input stage



- ❑ Any varying current draw at audio frequency going through long wiring or inductors (eg. in inductive switching power management units) will create H-field which couples into the very sensitive telecoil.

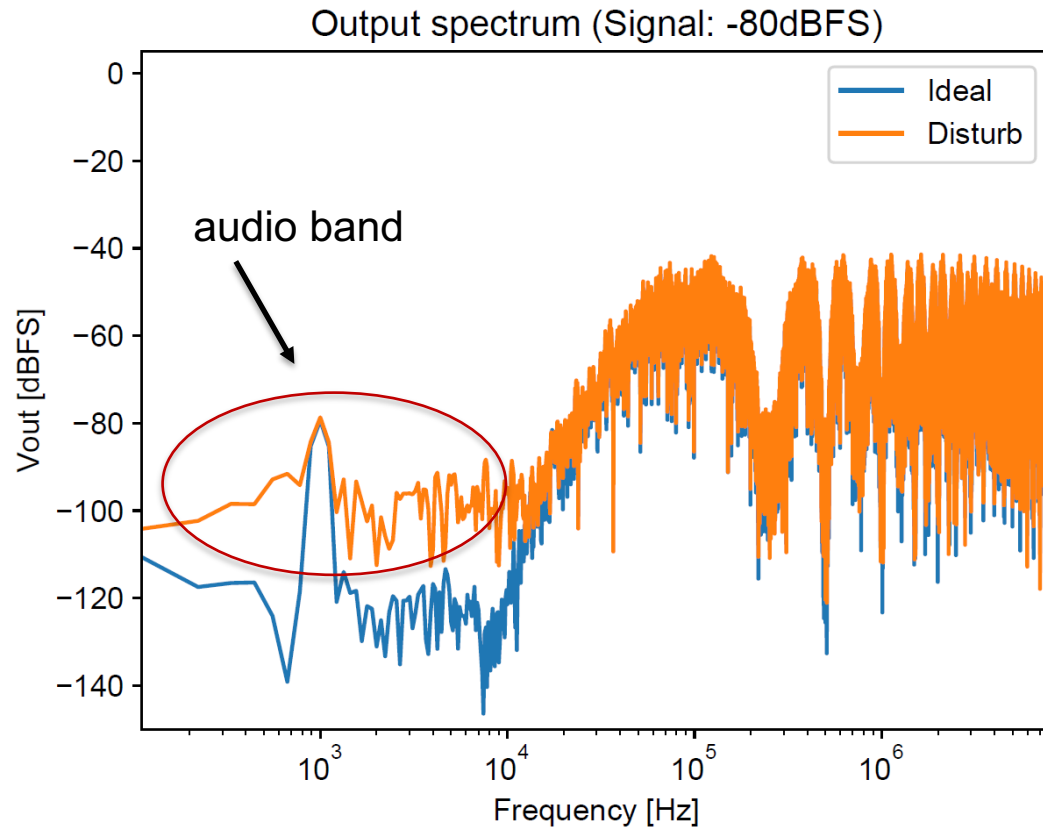


# Power supply disturbances in the audio output stage

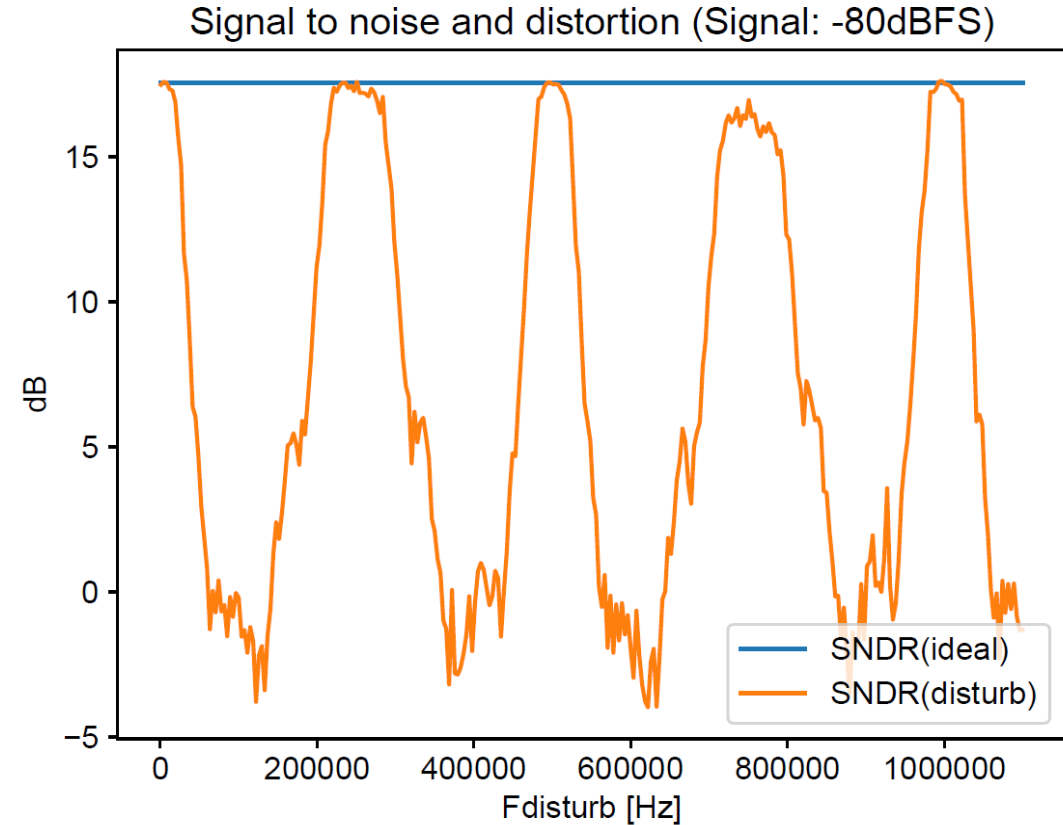


- ❑ One side of the output stage is depicted above
- ❑ The supply noise from  $V_{supply}$  is mixed with  $V_{DAC}$ . This can result in noise folding into the audio band

# The resulting output spectrum & Sweeping the disturbance frequency



Spectrum with a  
10mV@100KHz disturbance

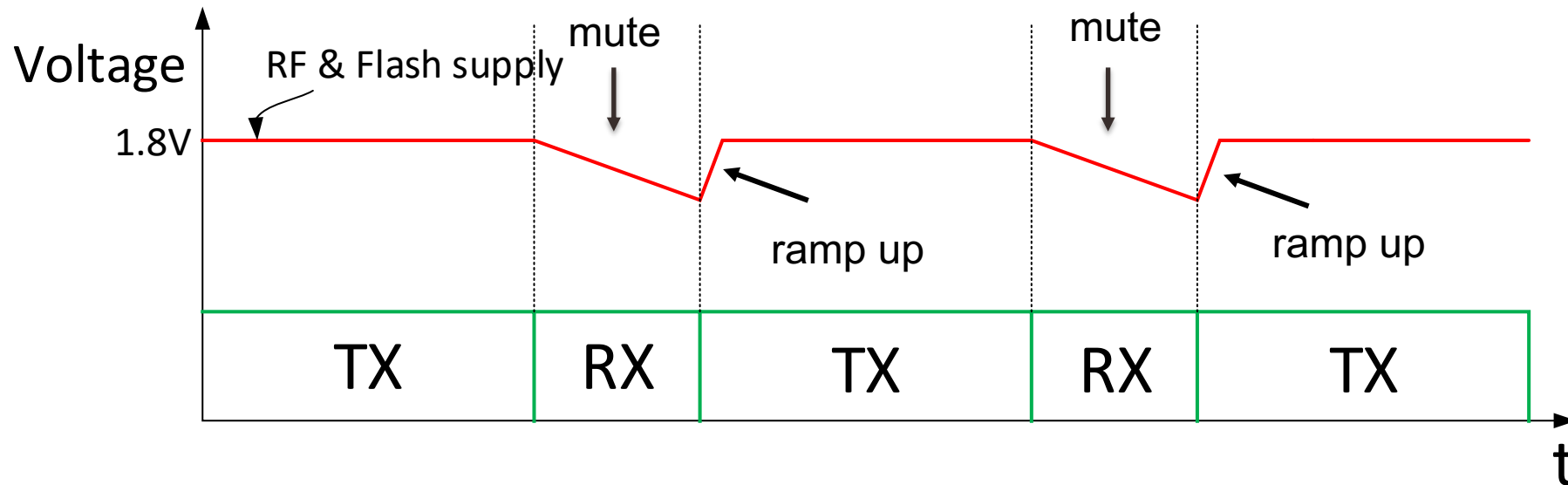
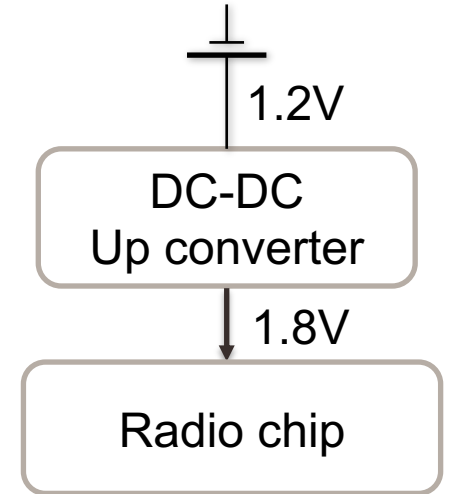


We observe that 250 kHz,  
500 kHz, 750 kHz and 1 MHz  
are “immune” to noise, and  
the regions in between are  
sensitive

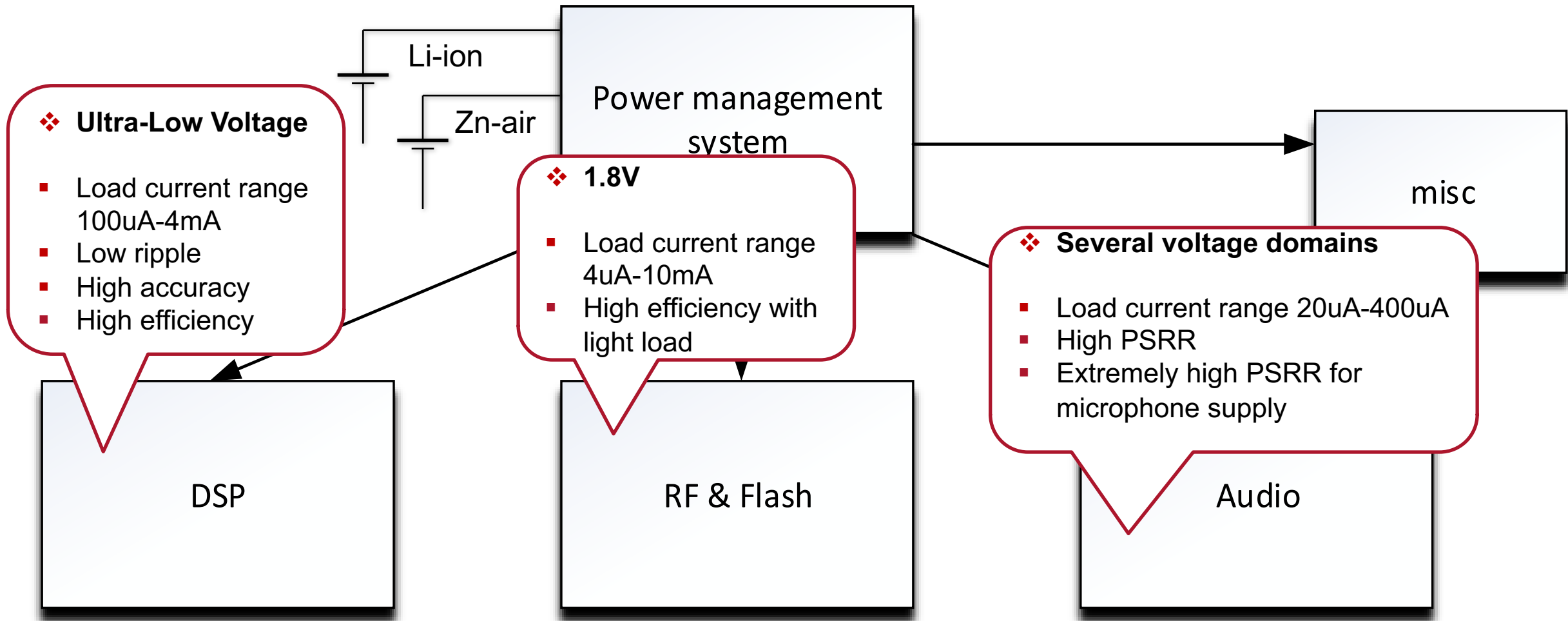
# Power supply disturbances in the radio

The radio chip is supplied by 1.8V

- ❑ Large capacitors required to lower the ripple from the DC-DC converter
- ❑ The disturbance can be minimized by using:
  - A fixed-frequency voltage doubler followed by a LDO
  - 1.2V supply for the radio chip
  - Completely stop the DC-DC converter when the radio is receiving



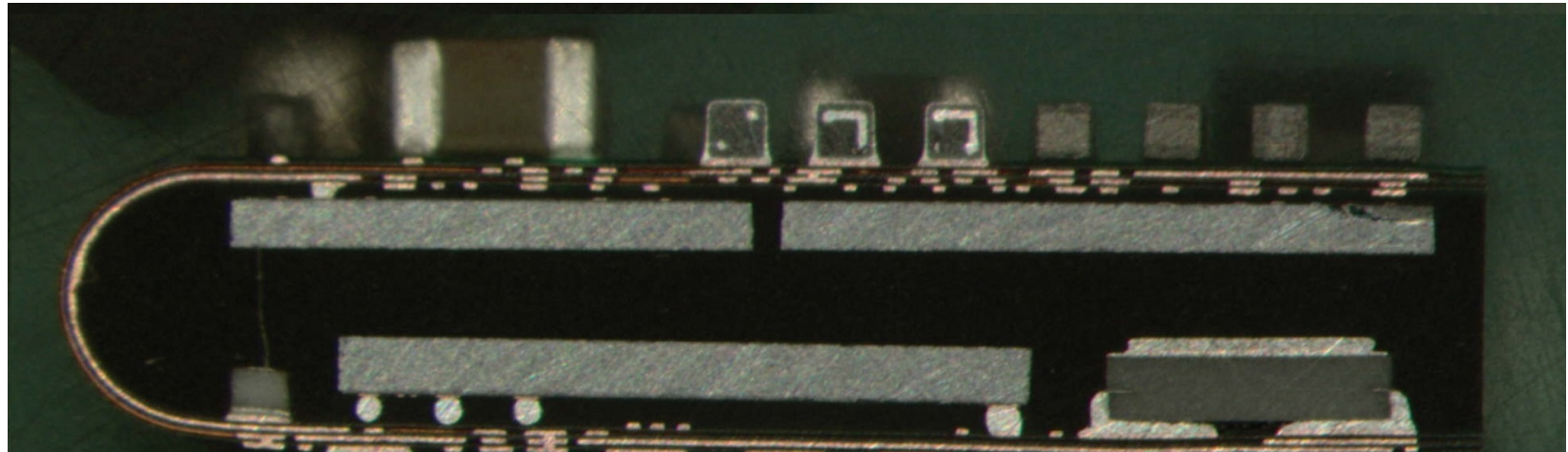
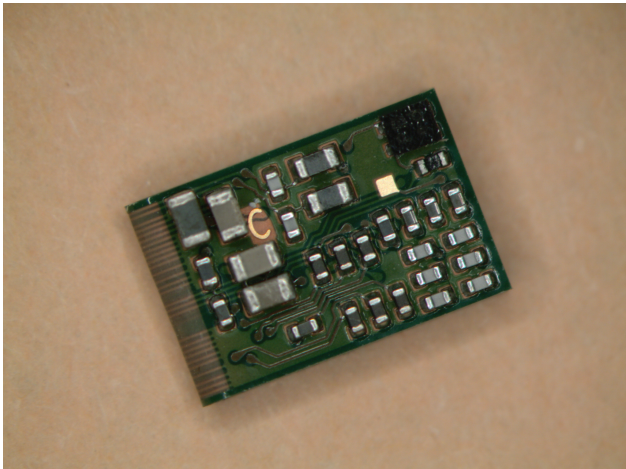
# Power distribution in hearing aids chipset





# Power management design due to the hearing aid size

- ❑ Trend had always been to make *invisible* devices
- ❑ Due to the number of passive components and the number of chips required for the hybrid module, power management design is becoming more challenging with the limited space
- ❑ Total volume of all chips: 14 mm<sup>3</sup>
- ❑ Total volume of all external components 3 mm<sup>3</sup>



# Challenges in the next generation Switched-capacitor DC-DC converter

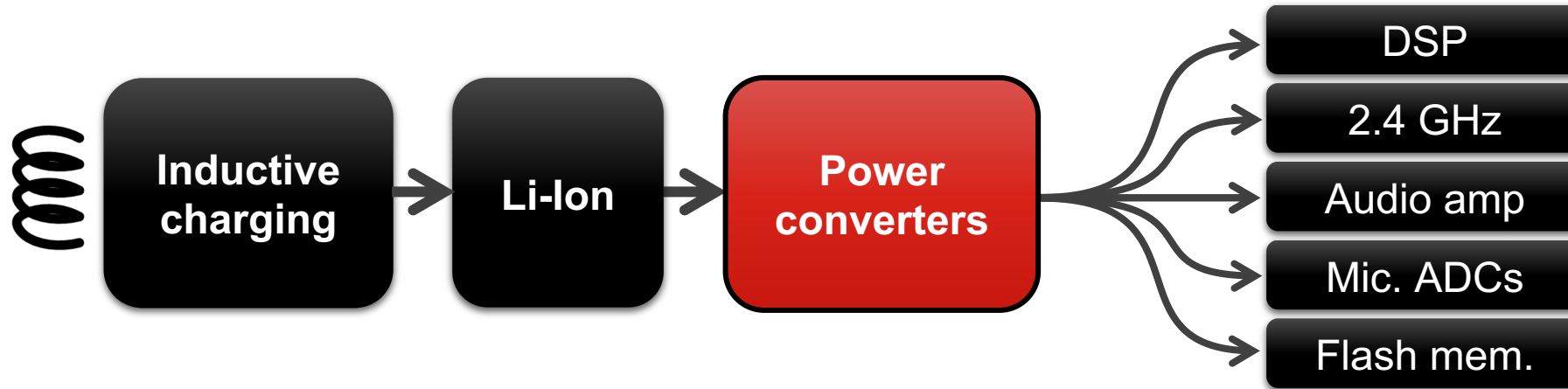
- ❑ Reduce ripples
  - Lower the ripple amplitude
  - More predictable spectrum
  
- ❑ Reduce the size of the external capacitors
  - Small PCB pitch gives the opportunity of splitting a big capacitor into several small capacitors
  
- ❑ Multiple outputs and reuse fly capacitors in different configurations

# The current status of the rechargeability solution

GN hearing introduced its first wireless rechargeable hearing aids in August, 2018



# Integrated DC-DC converter for Li-Ion rechargeable solution



## Power management challenges:

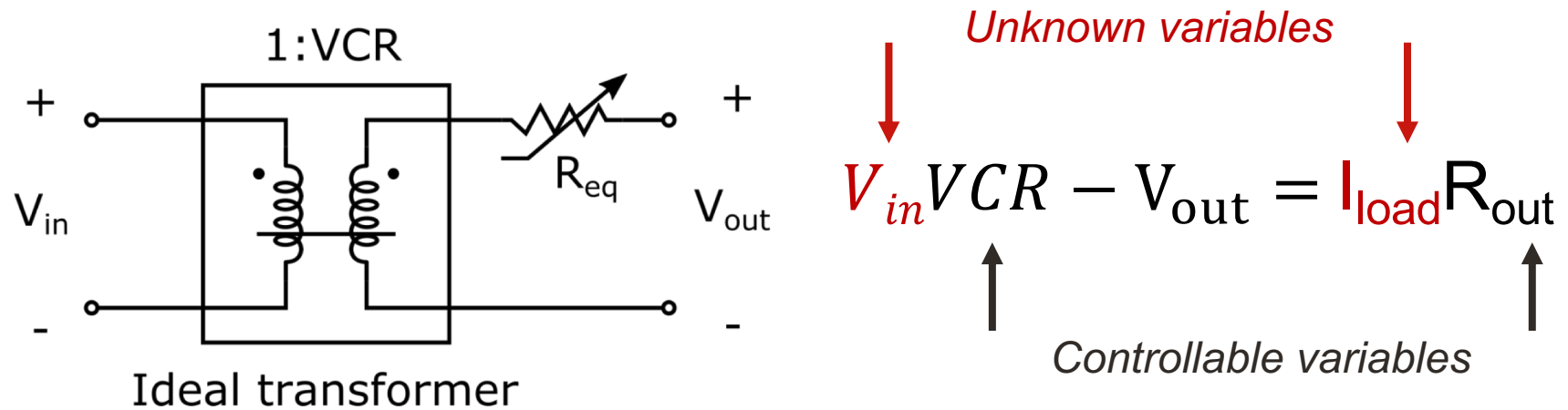
- ❑ Small battery → efficiency
- ❑ Small volume → power density
- ❑ Wireless connectivity → EMI

D. Ø. Larsen, M. Vinter and I. Jørgensen, "Switched capacitor DC-DC converter with switch conductance modulation and Pseudo-fixed frequency control, " ESSCIRC 2017 – 43rd IEEE European Solid State Circuits Conference, Leuven, 2017, pp. 283-286



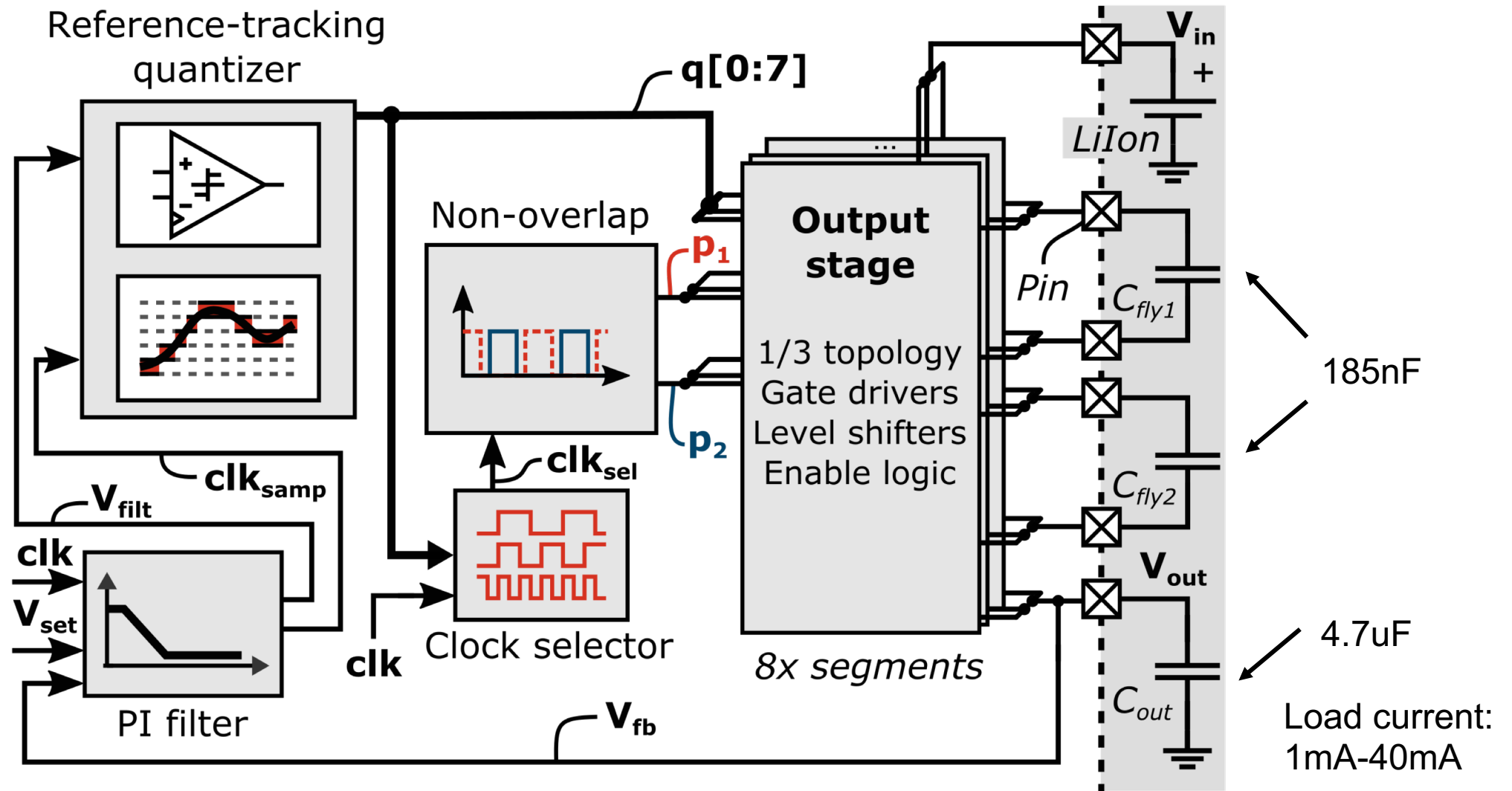


# Output stage

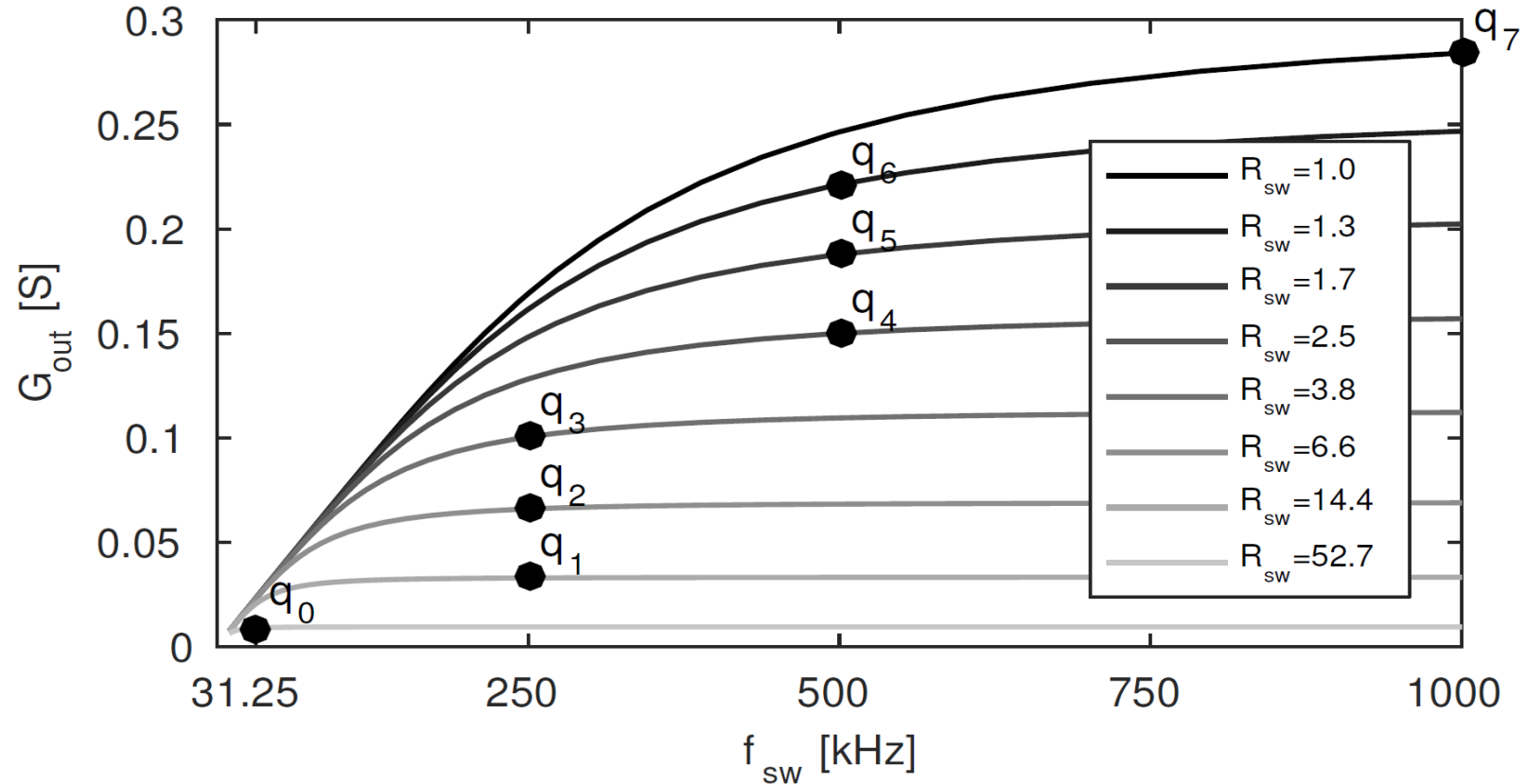


- ❑ The equivalent output resistance needs to be controlled
- Can be done with varying switch conductance and switching frequency
- ❑ Gears could be added to cover larger range

# The implemented regulator



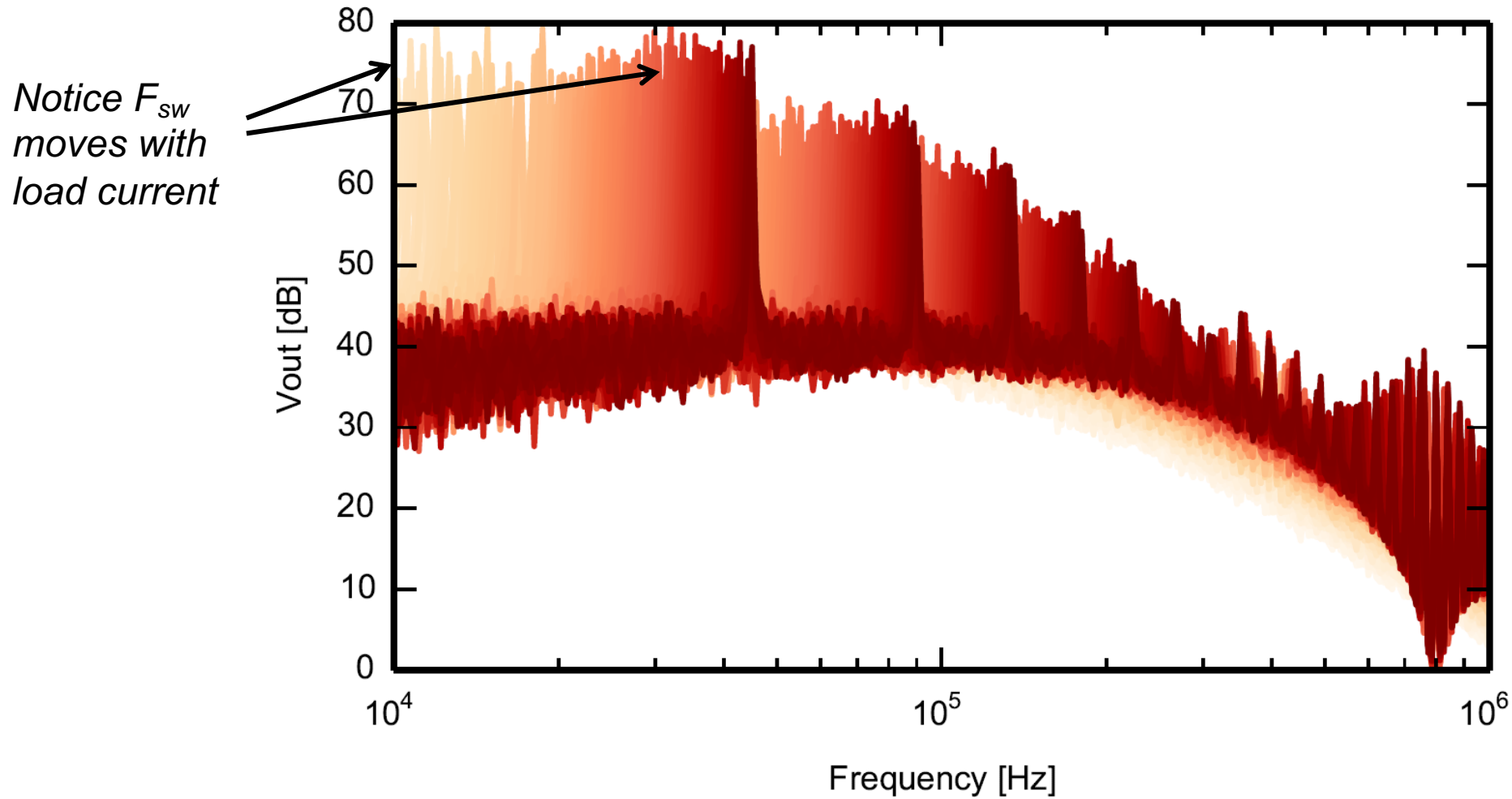
# Output impedance regulation



- ❑ Output conductance used to design controller
- ❑ Target: equidistant operating points in the  $G_{out}$  dimension

# Measurement

Pulse skipping | Iload sweep = 1-10 mA

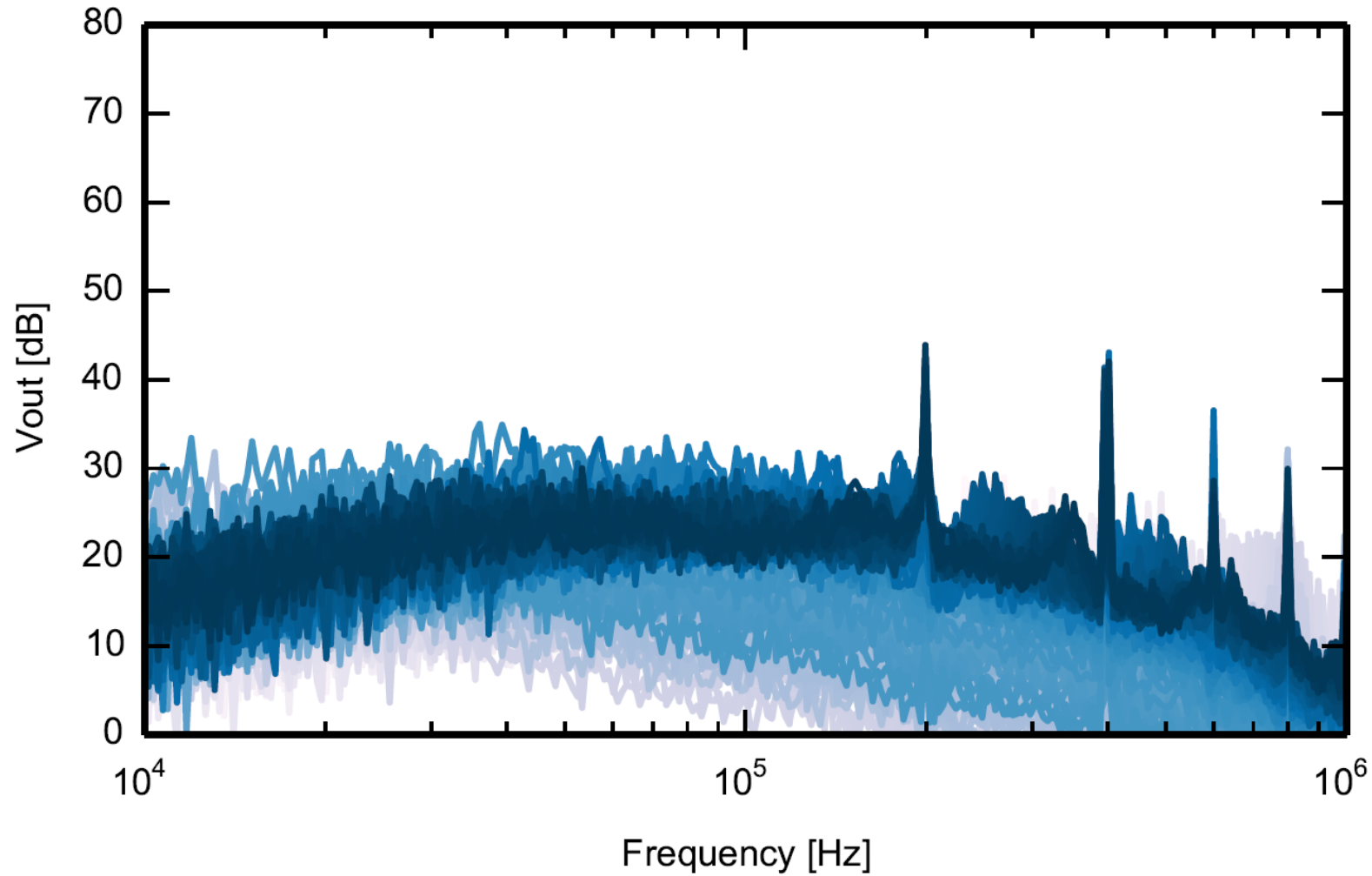


Output spectrum of pulse skipper

□ Load sweep of 1-10 mA

# Measurement

Proposed controller | Iload sweep = 1-10 mA



Output spectrum of proposed controller

Has predictable spectrum

# Summary

- ❑ Power management design for chipset used in hearing aids becomes more challenging due to more features and functionalities are desired
- ❑ Rechargeable hearing aids with Lithium-Ion batteries is the trend
- ❑ Supply disturbances in audio channel need to be thoroughly taken care
- ❑ The proposed DC-DC converter in the recent study shows how we can achieve more predictable spectrum



**Thank you!**