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High-Level Power Management of Audio Power Amplifiers for Portable Multimedia Applications

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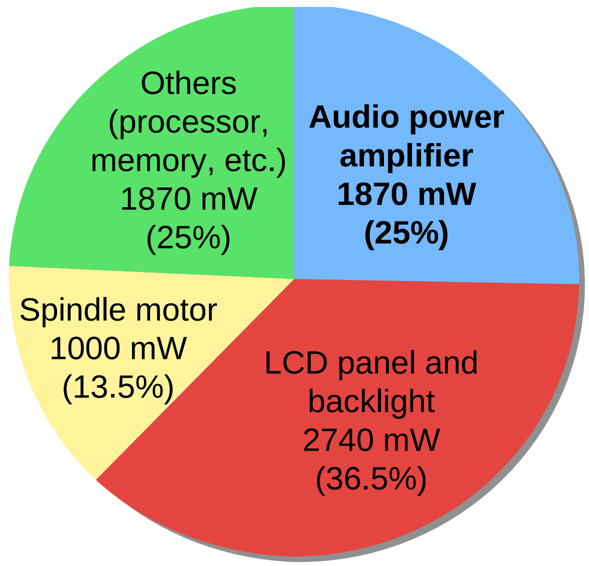
Outline

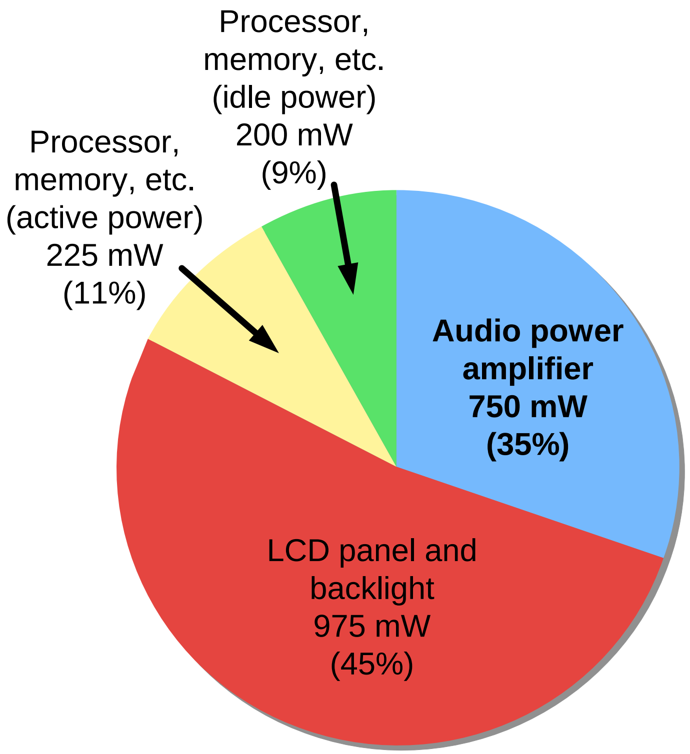
- Introduction
- Background
  - Measurement setup
  - Loudspeaker characteristics
  - Audio power amplifiers characteristics
- Loudspeaker-aware low-power filtering
- Experimental results
- Conclusions

Introduction

- Modern portable multimedia devices have high-quality displays and provide high-fidelity audio output



Portable DVD player with 7” LCD



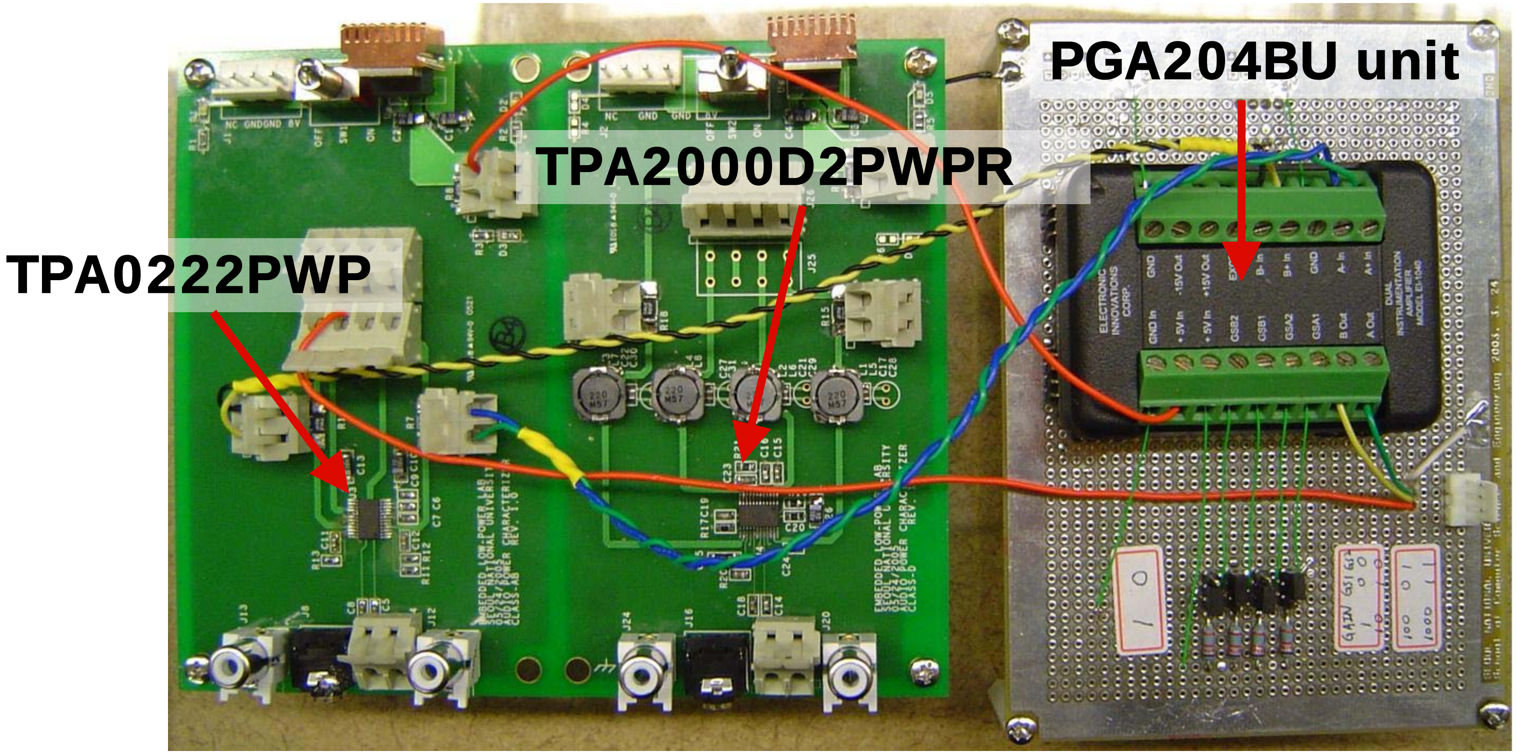
IPAQ360 PDA (MP3 player application)

Related work

- M. Mesarina and Y. Turner, *Multimedia systems*, 2003.
  - Power-quality trade-off
  - A low-power MPEG decoder
- S. Chakraborty and et al., *ESTIMedia*, 2005.
  - Power-quality trade-off
  - Reducing the bandwidth of the audio signal
- Previous high-level power reduction technique for audio subsystems
  - Focus on reducing the audio processing
  - Did not consider the audio power amplifier, which is the most part of the audio power consumption

Measurement Setup

- In-house platform for the audio power amplifier power management
  - Class-AB: TPA0222PWP
  - Class-D: TPA2000D2PWPR
  - Differential amplifier: Burr-Brown PGA204BU



Measurement Setup

- Logging the current and the voltage
  - Intelligent Instrument UDAS1001E USB data acquisition system
  - Fluke 87V trueRMS digital multimeter
  - TDS3052B Tektronix digital storage oscilloscope (500MHz and 5GS/s)

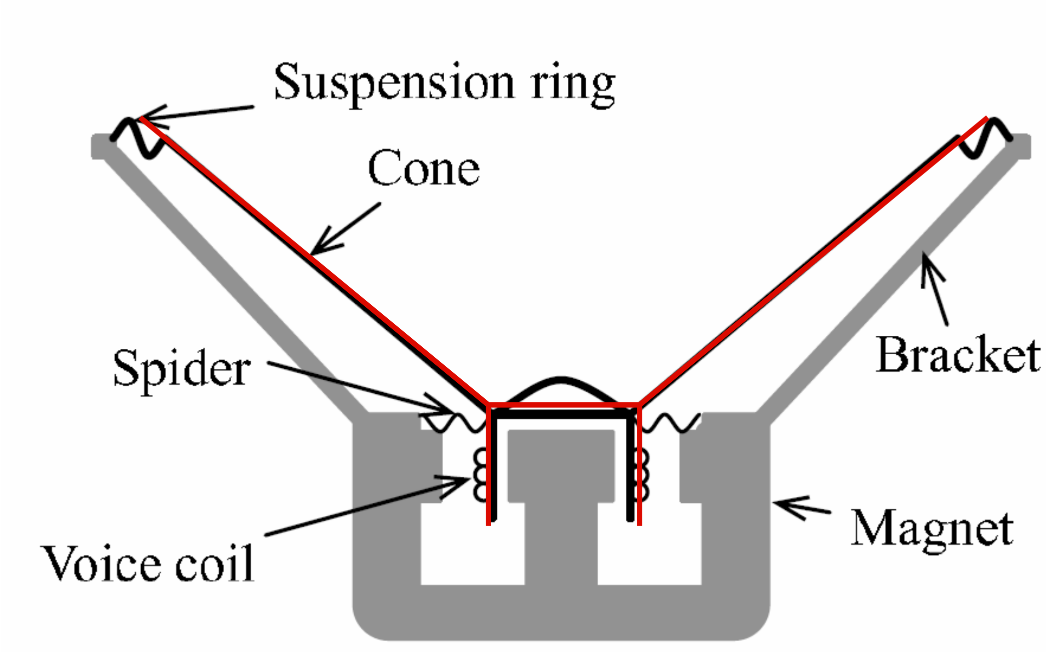
- SPL (Sound Pressure Level) measurement
  - To be free from ambient interference
    - Measured at night in remote desert area
    - Extremely quiet and superior to standard closed acoustic chamber
  - Audio-Technica AT4040 high-performance condenser microphone
    - Sound ranging from 20Hz to 20KHz with a fairly flat frequency response
  - Extech407730 sound pressure lever meter

Characteristics

- Loudspeaker
- Audio power amplifier

Characteristics: Loudspeakers

- Structure of a magnetic loudspeaker
  - The other types are rarely found in portable applications



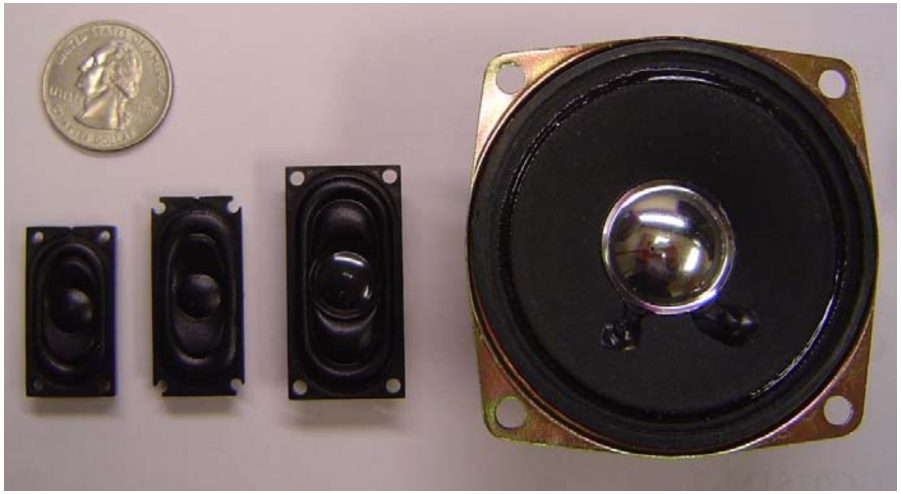
- The voice coil is the only electric component

Characteristics: Loudspeakers

- Voice coil
  - Inductor with a non-zero resistance
- Resonant behavior of the loudspeaker
  - If the frequency of the voltage across the voice coil matches the resonant frequency of the cone and voice coil, the loudspeaker exhibits its resonant impedance

Characteristics: Loudspeakers

- Loudspeaker units



	GC0301K	GC0351P-1	GC0401S	GF0668
Size	16mm X 30mm	16mm X 35mm	20mm X 40mm	66mm X 66mm
SPL	77dB	82dB	89dB	90dB
Bandwidth	500 Hz~4 KHz	630 Hz~13 KHz	550 Hz~12 KHz	300 Hz~20 KHz

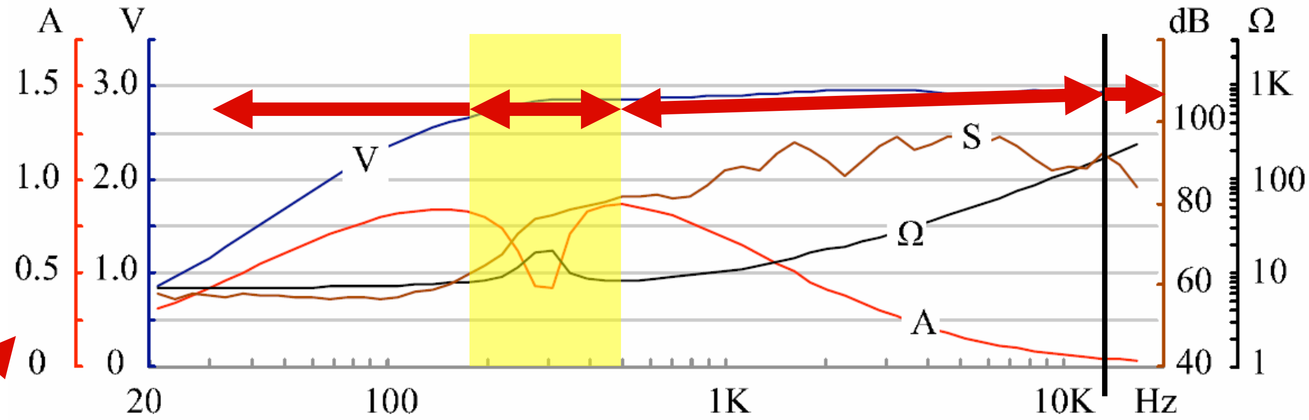
- SPL: 0.5 meter distance measurement (from data sheets)

Characteristics: Loudspeakers

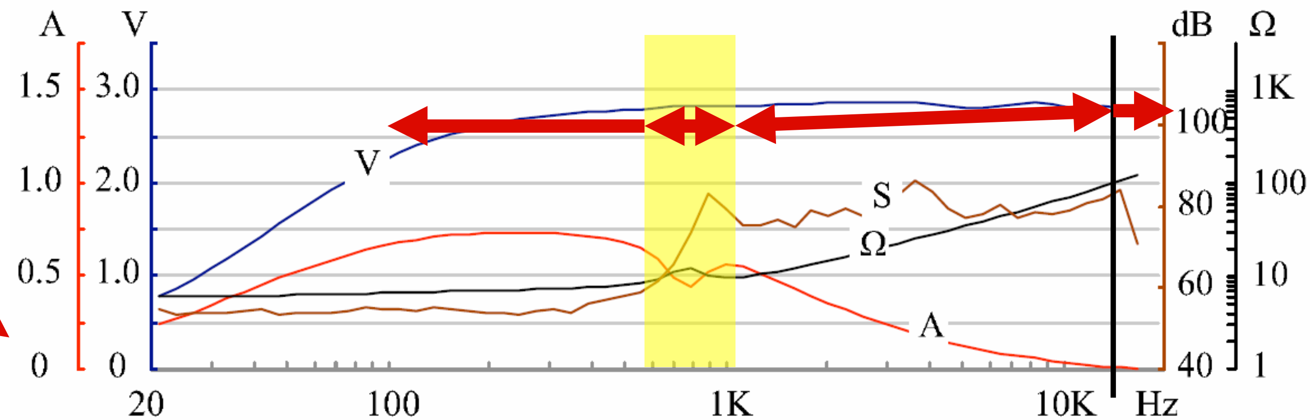
- The resonant region
  - Power amplifier consumes the least power
  - The SPL is the highest
- Below the resonant region
  - No audible sound output (for the same input amplitude)
  - The region with the lowest impedance, because of the inductive negligible reactance
- Linear region
  - The resonant effect decreases
- Beyond the linear region
  - No audible sound output
  - The power consumption in this upper region is much smaller than that in the region below the resonant region

Characteristics: Loudspeakers

- Resonant region
- Below the resonant region
- Linear region
- Beyond the linear region



(a) GF0668



(b) GC0401S

- V: Speaker RMS voltage
- S: Sound pressure level (SPL) @ C weighting
- Ω: Speaker impedance
- A: Speaker RMS current

Characteristics: Amplifiers

- Audio power amplifiers
  - Class-A
    - The least distortion and the most linear
    - Bias current flowing to the output at all times
    - The most wasteful power consumption (about 20% efficiency)
  - Class-C, class-E and class-F
    - Non-linear amplifiers
    - The most power efficient design (over 90% efficiency)
    - Designed for high frequency radio signals (not for audio applications)
  - Class-AB
    - Combines advantages of the class-A and class-B amplifiers
    - In place of the class-B amplifier
    - Most common type of power amplifiers
  - Class-D
    - Converts audio signals into pulse width modulated signals
    - Significantly reduces the power loss

Characteristics: Amplifiers

- Power efficiency of an audio power amplifier

$$\eta_A = \frac{P_L}{P_A}$$

where,

P_L: the power consumed by the loudspeaker

P_A: the power consumed by the power amplifier

η_A: the efficiency of the power amplifier

- Measured power amplifier efficiency
  - Class-AB: TPA0222PWP
    - Significantly varies with the output power
    - 100mW @1KHz output: 20%
    - 1W @1KHz output: 40%
  - Class-D: TPA2000D2PWPR
    - Near uniform efficiency over the wide range of the output power
    - 100mW @1KHz output: 64.5%
    - 1W @1KHz output: 67.8%

Loudspeaker-Aware Low-power Filtering

- Power waste
  - Modern portable systems play high-fidelity digital audio source (20Hz~22KHz)
  - Miniature loudspeakers have quite a narrow bandwidth
  - Thus, the power amplifier wastes a significant amount of power in driving loudspeaker, but produces no sound
  - Especially in the range from 20Hz to near the resonant frequency, the waste amount of the total amplifier power consumption is around 20%~40%

Loudspeaker-Aware Low-power Filtering

- Power efficiency of the SPL

$$\eta_S(f) = \frac{S(f)}{P_A(f)} = \eta_A \frac{S(f)}{P_L(f)}$$

where,

$S(f)$: the SPL at the input signal frequency f

$P_L(f)$: the power consumed by the loudspeaker

$P_A(f)$: the power consumed by the power amplifier

η_A : the efficiency of the power amplifier

- η_S is independent of the input signal amplitude
- Filtering with cut-off frequency determined by η_S

Loudspeaker-Aware Low-power Filtering

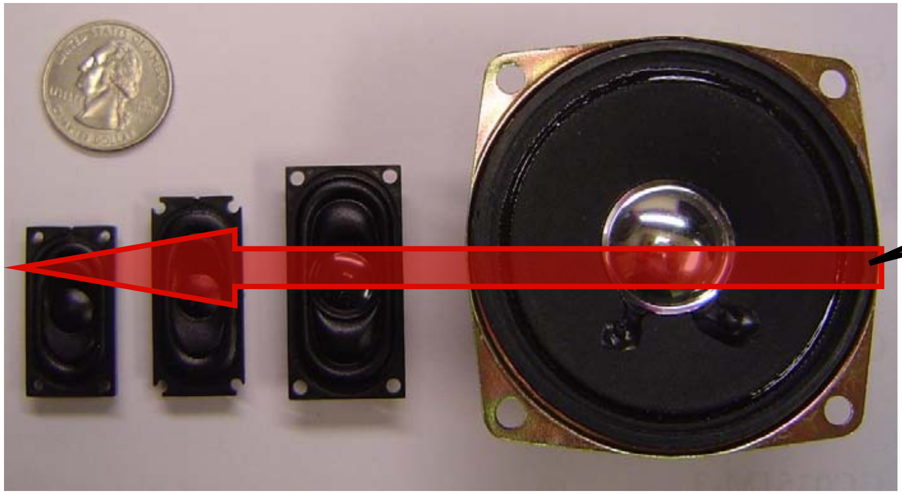
- The built-in miniature loudspeakers
  - Loudspeaker-aware low-power filtering is activated
- The headphone
  - Headphones offer far better bandwidth performance
  - Higher impedance (an order of magnitude higher impedance than the loudspeakers) allows lower power consumption in the power amplifier
  - No filtering
- The external speakers
  - External power sources are often available as well
  - No filtering in this case

Experimental Results

- Three different types of sound sources
  - Movie sound track
    - A beautiful mind
  - Pop music
    - Abba, Lay all your love on me
  - Classic music
    - Beethoven Symphony No.5 in c minor
- Using an iPod shuffle as a player
- Cut-off frequencies for the low-power filtering
  - Determined by η_S : select the threshold value
    - GF0668: 200Hz
    - GC0401S: 500Hz
    - GC0351P-1: 600Hz
    - GC0301K: 600Hz

Experimental Results

Amplifier	Loudspeaker	Cut-off frequency		SNR (dB)			Power saving: mW (%)		
		Low	High	Movie	Pop	Classic	Movie	Pop	Classic
Class-AB	GF0668	200 Hz	N/A	33.0	42.6	33.6	19.5 (6.4%)	63.0 (15.9%)	17.5 (5.5%)
	GC0401S	500 Hz	N/A	35.4	33.1	26.3	60.5 (20.5%)	87.5 (22.6%)	55.0 (17.9%)
	GC0351P-1	600 Hz	N/A	33.5	33.6	24.4	65.0 (22.4%)	86.5 (22.9%)	66.0 (21.9%)
	GC0301K	600 Hz	N/A	31.2	31.0	20.2	63.0 (21.8%)	85.0 (22.7%)	63.0 (21.2%)
Class-D	GF0668	200 Hz	N/A	31.8	43.4	36.1	9.5 (6.7%)	54.4 (26.6%)	8.5 (5.9%)
	GC0401S	500 Hz	N/A	34.7	35.2	26.0	24.0 (18.0%)	66.5 (33.7%)	26.0 (19.4%)
	GC0351P-1	600 Hz	N/A	36.2	34.9	24.2	25.5 (19.4%)	67.0 (34.7%)	31.5 (23.9%)
	GC0301K	600 Hz	N/A	33.9	32.1	20.5	24.0 (18.3%)	65.0 (33.9%)	30.0 (22.9%)



Loudspeakers are sorted by this order

Experimental Results

Amplifier	Loudspeaker	Cut-off frequency		SNR (dB)			Power saving: mW (%)		
		Low	High	Movie	Pop	Classic	Movie	Pop	Classic
Class-AB	GF0668	200 Hz	N/A	33.0	42.6	33.6	19.5 (6.4%)	63.0 (15.9%)	17.5 (5.5%)
	GC0401S	500 Hz	N/A	35.4	33.1	26.3	60.5 ([illegible].5%)	87.5 (22.6%)	55.0 (17.9%)
	GC0351P-1	600 Hz	N/A	33.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]9%)
	GC0301K	600 Hz	N/A	31.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]2%)
Class-D	GF0668	200 Hz	N/A	31.8	43.4	36.1	9.5 (6.7%)	54.4 (26.6%)	8.5 (5.9%)
	GC0401S	500 Hz	N/A	34.7	35.2	26.0	24.0 ([illegible]8.0%)	66.5 (33.7%)	26.0 (19.4%)
	GC0351P-1	600 Hz	N/A	36.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	GC0301K	600 Hz	N/A	33.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]9%)

average power consumption = 305 mW

average power consumption = 142 mW

- Audio power output for the experimental setup
  - Maximum peak output around 1W
  - Wide dynamic ranges of the sound sources limit the average audio output at a few hundred mW
  - The class-AB consumes more power than class-D

Experimental Results: SNR

Amplifier	Loudspeaker	Cut-off frequency		SNR (dB)			Power saving: mW (%)		
		Low	High	Movie	Pop	Classic	Movie	Pop	Classic
Class-AB	GF0668	200 Hz	N/A	33.0	42.6	33.6	19.5 (6.4%)	63.0 (15.9%)	17.5 (5.5%)
	GC0401S	500 Hz	N/A	35.4	33.1	26.3	60.5 (20.5%)	87.5 (22.6%)	55.0 (17.9%)
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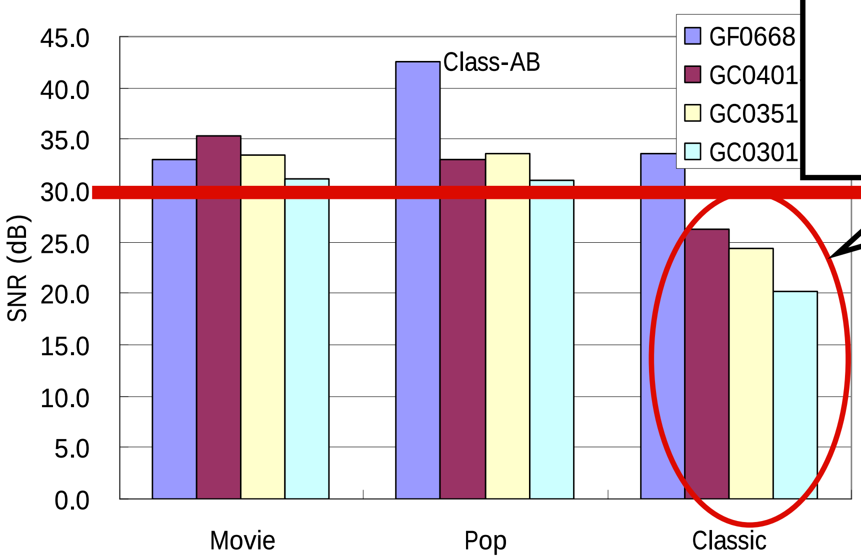
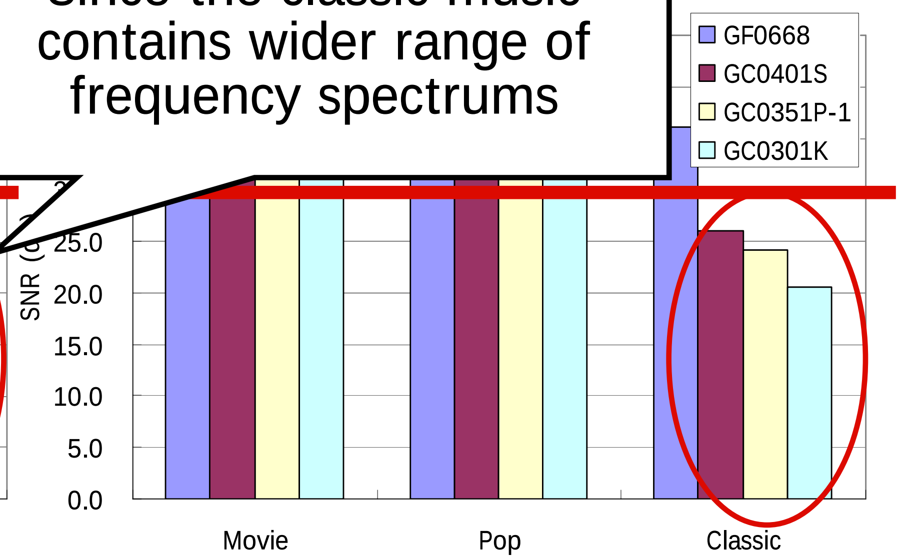


Since the classic music contains wider range of frequency spectrums



Experimental Results: Power Saving

Amplifier	Loudspeaker	Cut-off frequency		SNR (dB)			Power saving: mW (%)		
		Low	High	Movie	Pop	Classic	Movie	Pop	Classic
Class-AB	GF0668	200 Hz	N/A	33.0	42.6	33.6	19.5 (6.4%)	63.0 (15.9%)	17.5 (5.5%)
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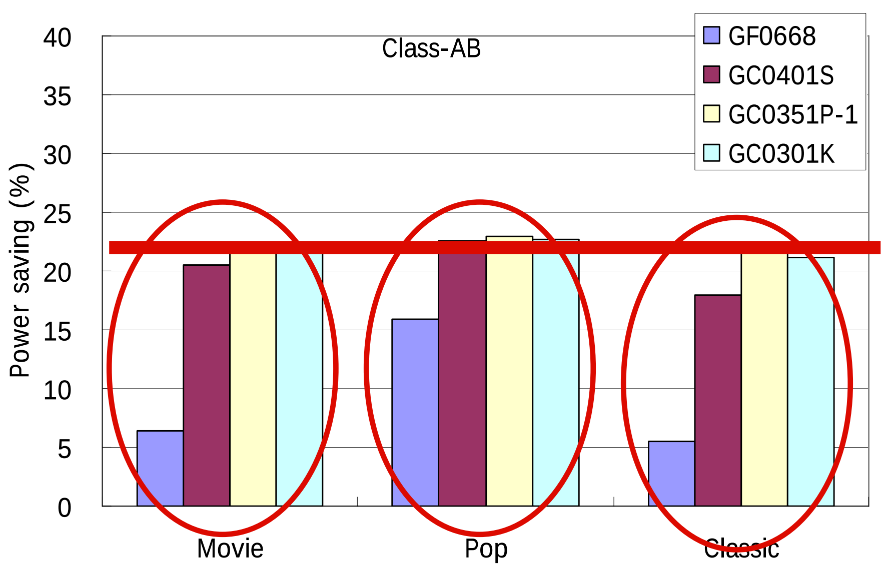

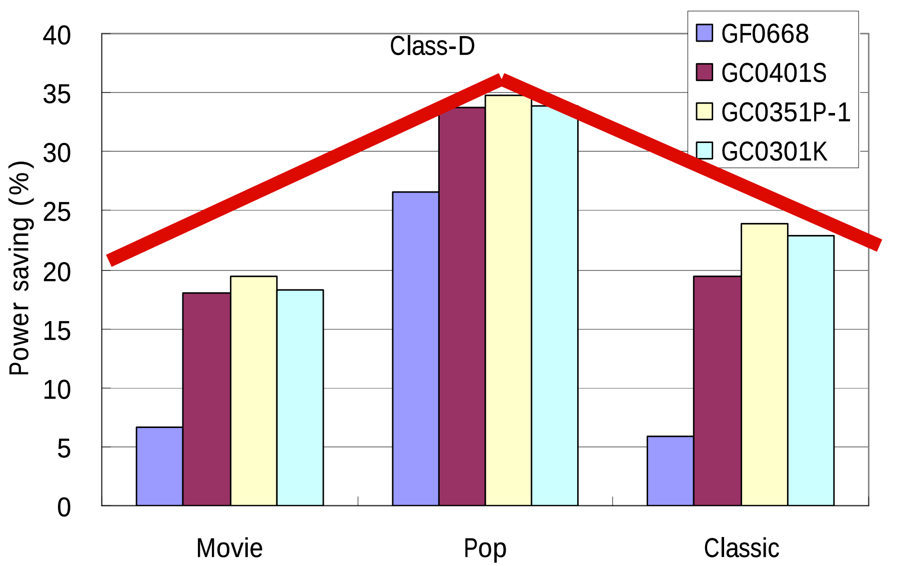

Conclusions

- Audio power amplifiers are primary power consumers of portable multimedia systems
  - So far, previous work focused on the audio signal processing power
- The proposed technique can save 20% to 35% of audio amplifier power consumption without any appreciable degradation of sound fidelity
  - Cutting off input signals below the resonant region
- Future work
  - Context-based filtering
    - Use different cut-off frequencies by the type of sound sources automatically

Q&A

- Demo will be shown in next poster session