Power Analysis for Embedded Audio Processing

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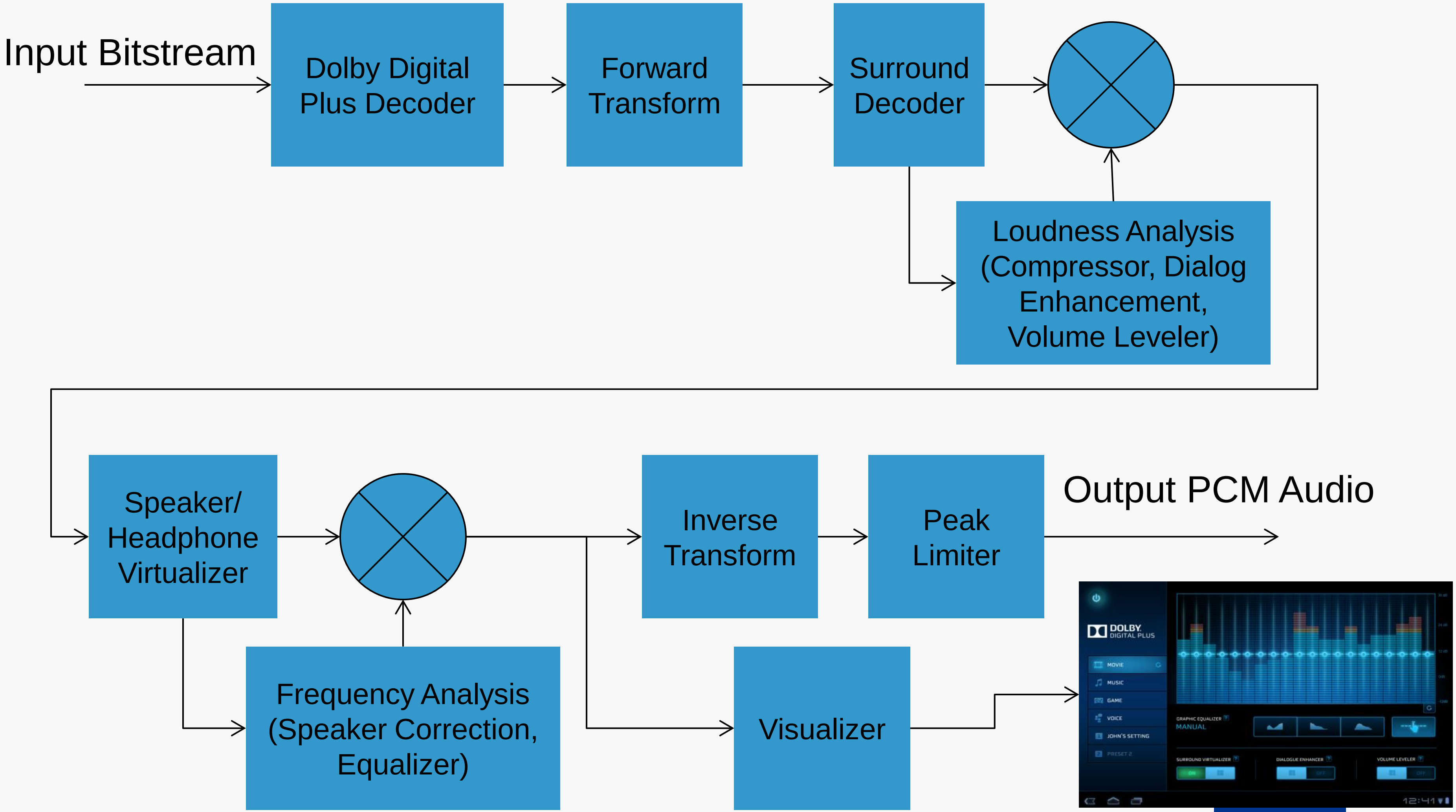
Important Note

- The experiment described in this presentation was performed in 2012 using an application processor that began shipping in 2010
- Therefore, the power consumption results obtained are not representative of the power consumption of current Dolby Audio Processing technology
- BDTI and Dolby have published this presentation for the engineering community in order to share the details of a sound approach to benchmarking energy consumption on complex devices

The Challenge

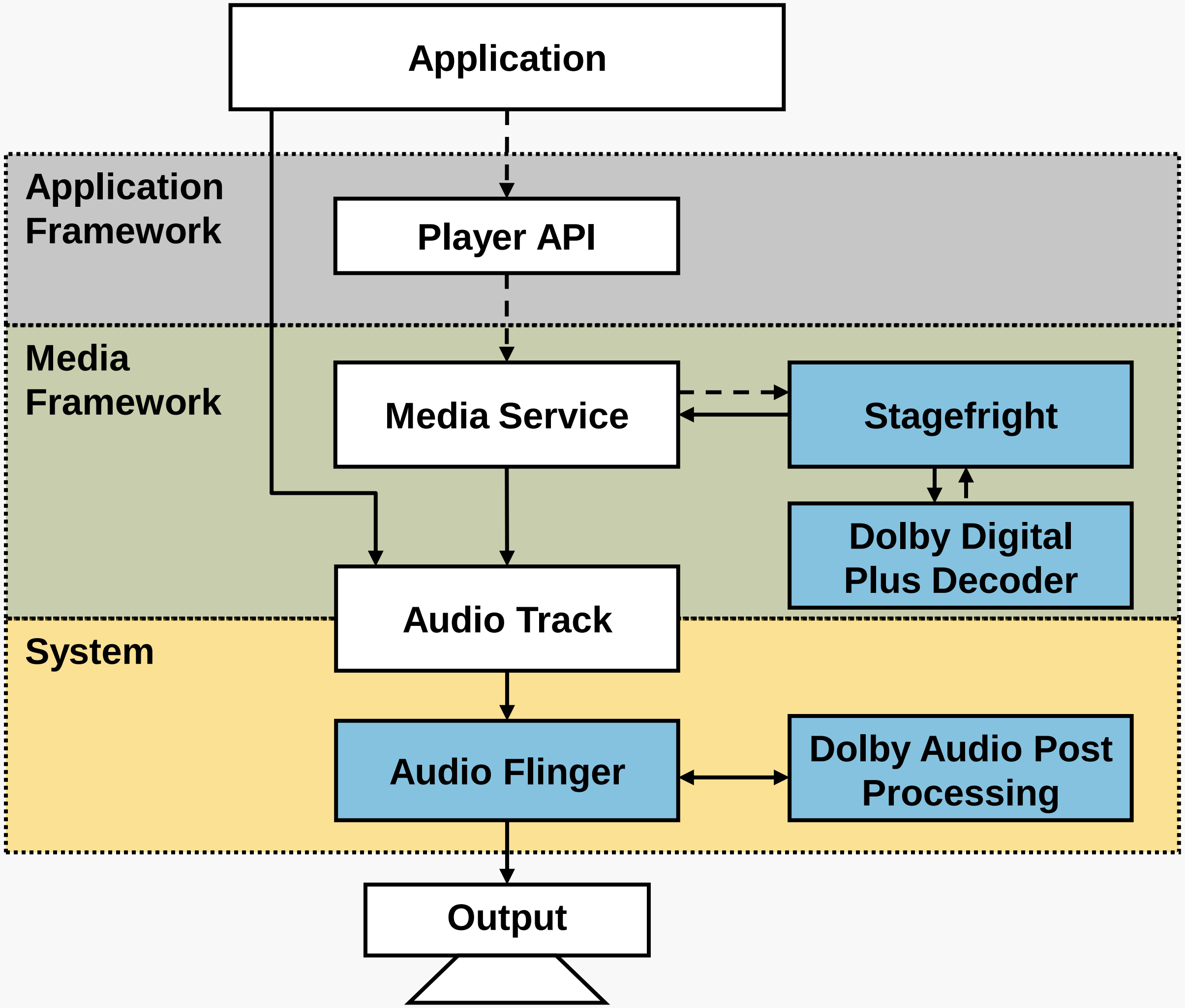
- Entertainment experiences are moving from the living room into portable battery power devices
- Thin and light form factors mean compromises in audio design and small batteries
- We want to make portable entertainment sound better while staying within the power budget for this class of device

Dolby DS1


Input Bitstream
Dolby Digital Plus Decoder
Forward Transform
Surround Decoder
Loudness Analysis (Compressor, Dialog Enhancement, Volume Leveler)
Speaker/ Headphone Virtualizer
Frequency Analysis (Speaker Correction, Equalizer)
Inverse Transform
Peak Limiter
Output PCM Audio
Visualizer

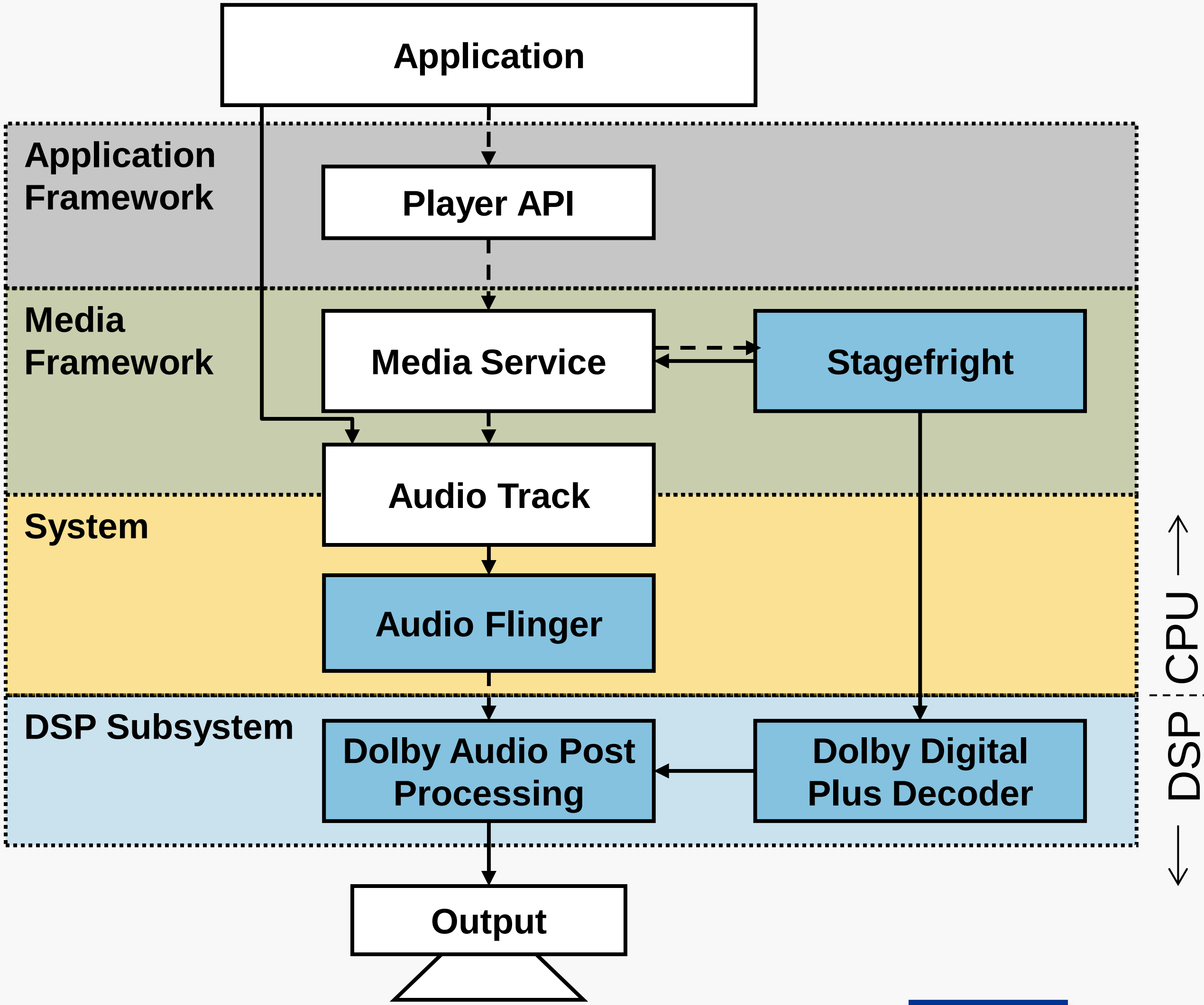
Implementation Topologies

- Typically implemented on host CPU
- Many integration points into the Android OS



Implementation Topologies

- May also be implemented on a DSP
- Can result in substantial power savings if the CPU can be moved to a lower power state



Hypothesis

- Primary hypothesis—Running DS1 processing on the CPU of a tablet device leads to a negligible decrease in battery life
- Additional hypothesis—Decoding multi-channel Dolby Digital Plus content does not substantively increase power use compared to stereo AAC
- Additional area of interest—What is the relative difference in power consumption between speaker and headphone output use cases?

Why This Partnership?

- Dolby had done some power measurements and shared initial results with customers and partners
- But we really needed an expert who would be respected as an independent and impartial third party to validate our results
- BDTI had a well established reputation for this type of analysis, had worked with Dolby in the past and is located close to Dolby HQ

Defining Requirements

- Commercially available device with a commonly used SoC
- Use cases—variables we wanted to analyze
  - Device specific conditions:
    - 100% screen brightness vs. 50% screen brightness
    - Speaker playback vs. headphone playback
  - Dolby technology differences
    - 5.1-ch Dolby Digital Plus vs. stereo AAC
    - Dolby post-processing on vs. off

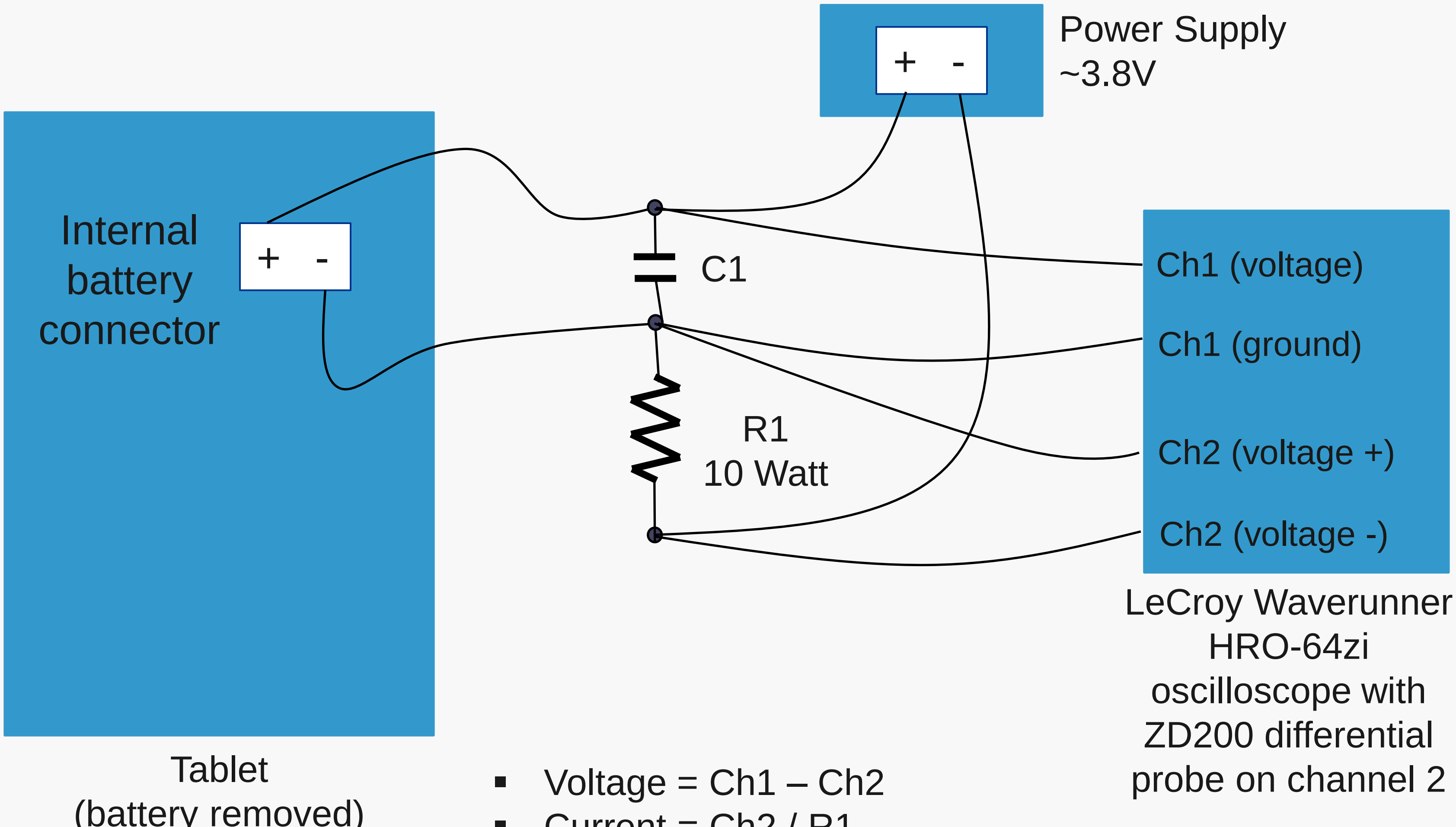
Power Measurement Challenges

- Power measurement on sophisticated devices such as a tablet or smartphone is an experiment with a very large number of variables
- High dynamic range of power consumption can push the limits of equipment and methodologies
- Measurement techniques need to be efficient and repeatable
- How to validate the results?

BDTI Power Measurement Methodology

- Remove battery from device and provide power with an external power supply
- Measure current and voltage at the battery lead wires
- Record current and voltage waveforms over time as the device is executing desired use cases
  - Power = Voltage × Current
  - Instantaneous power computed per voltage and current sample-pair
  - **Average power** can be computed by averaging the instantaneous power over the duration of the use case
  - **Total energy** required to perform the use case can be computed by integrating the instantaneous power over the duration of the use case

Power Measurement Hardware Setup

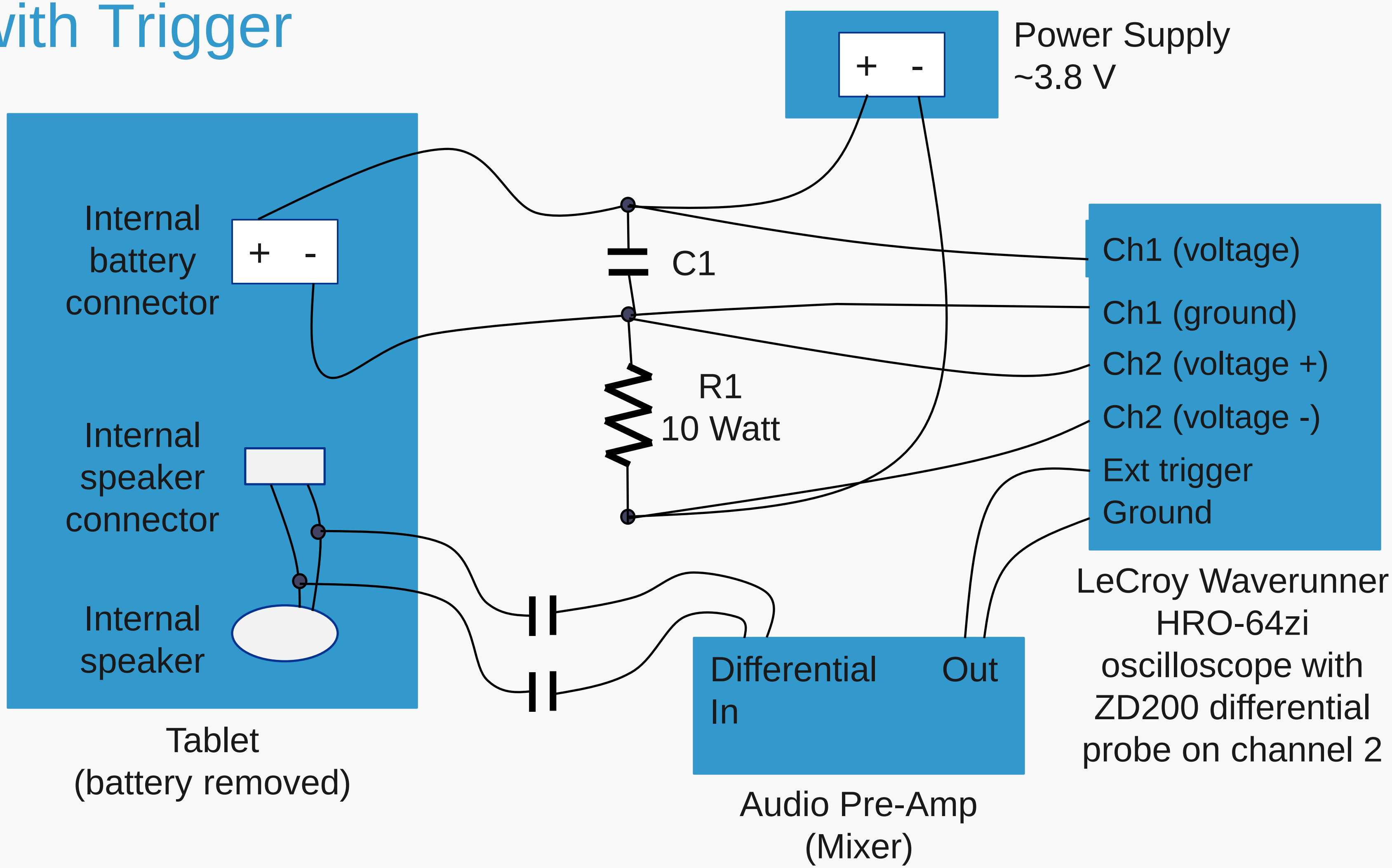


- Voltage = Ch1 – Ch2
- Current = Ch2 / R1
- Instantaneous Power = (Ch1 – Ch2) × (Ch2 / R1)

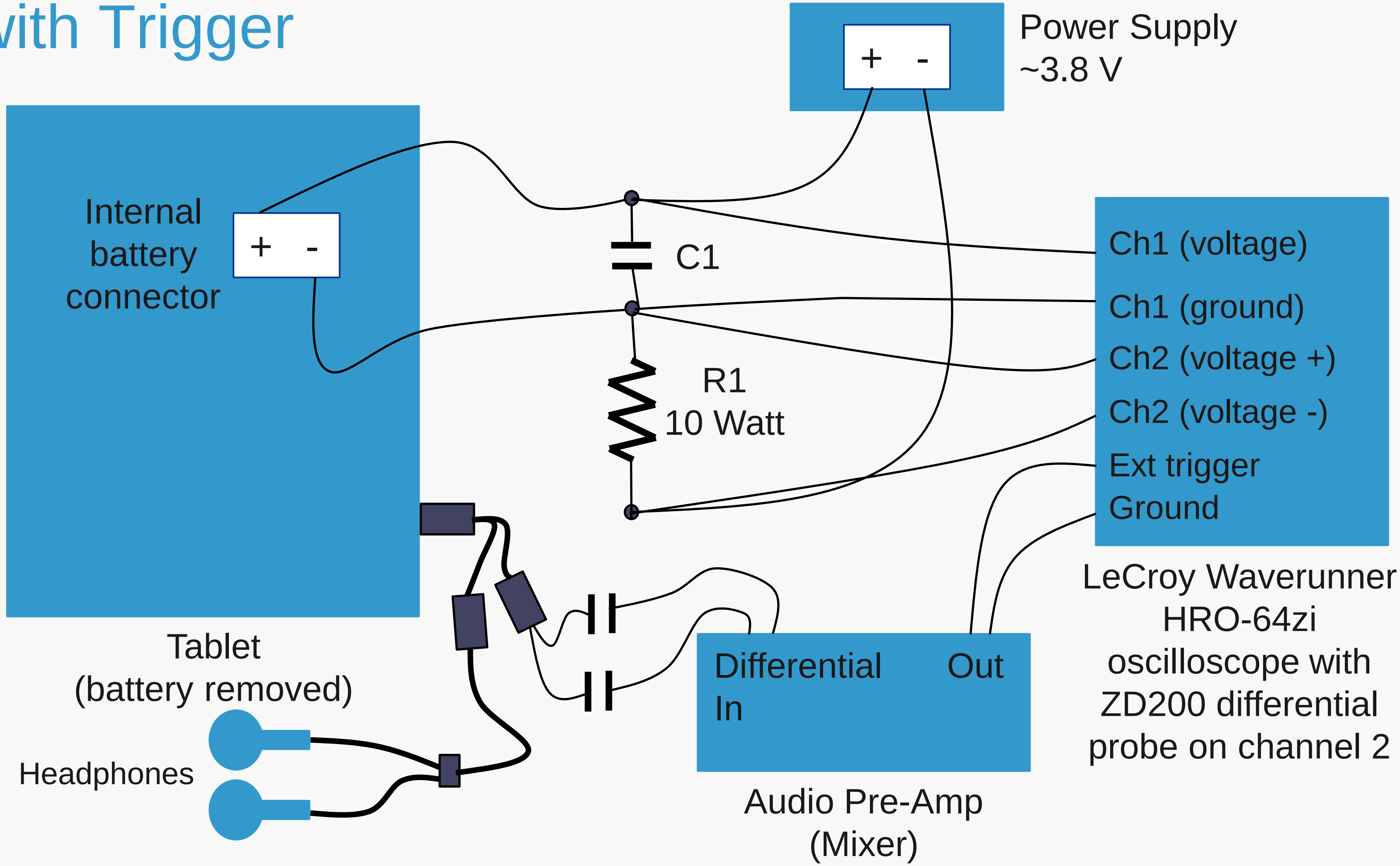
Power Measurement Methodology Challenges

- Background tasks run on tablet during the first 10 to 45 seconds of video playback
  - Therefore, start of measurement must be delayed in order to capture “steady state” behavior
- Even in steady state, power consumption might vary depending on the start time of the measurement, so we need to control for the start time
- Use audio signal to synchronize the measurement start
  - 1kHz trigger tone added to the beginning of each media clip
  - Measurement stated with a delay of 50 seconds after the trigger
- Allow media to play past the end of the measurement period

BDTI Power Measurement Hardware Setup with Trigger



BDTI Power Measurement Hardware Setup with Trigger



Test Equipment

- LeCroy HRO-64Zi was selected as the measurement device:
  - DAC resolution and accuracy
  - Data capture capacity

Results

Use Case			Amazon Kindle Fire HD (OMAP4460)		
Screen brightness	**Audio format**	**Audio output**	**Total power (W)**	**Dolby DS1 power (mW)**	**Dolby DS1 power (%)**
100%	5.1-chan DD+	speakers	**2.03**	**52**	**2.6%**
100%	5.1-chan DD+	headphones	**2.01**	**55**	**2.8%**
100%	stereo AAC	speakers	**2.01**	**51**	**2.6%**
100%	stereo AAC	headphones	**2.00**	**51**	**2.6%**
50%	5.1-chan DD+	speakers	**1.09**	**45**	**4.3%**
50%	5.1-chan DD+	headphones	**1.08**	**56**	**5.5%**
50%	stereo AAC	speakers	**1.07**	**49**	**4.8%**
50%	stereo AAC	headphones	**1.07**	**51**	**5.0%**

Other settings:
- Wireless networking: off
- Content source: on device
- Video Format: 720p, H.264

Results were obtained in 2012 using an application processor that began shipping in 2010, and are therefore not representative of the power consumption of current Dolby Audio Processing technology.

Key Findings

Results of power measurements obtained by BDTI show the following:

- During video playback, Dolby DS1 post-processing consumes roughly 50 mW of power
  - About 5% of total power consumed by the device at 50% screen brightness
  - About 2.6% of total power consumed by the device at 100% screen brightness
- When using the default media player in the Amazon Kindle Fire HD, a Dolby 5.1-channel DD+ decoder consumes roughly 10-15 mW more than a stereo AAC decoder

Validating the Results: Hollywood Content Test

- Movie trailer: “A Dark Truth” (in .mp4 container)
  - Similar to Dolby AAC clip, but different audio sample rate and bit rate
  - Short clip length required short measurement period (50 sec.)
- **Results for trailer at 50% brightness, using headphones:**
  - With DS1 on, measured average power of 1.04 W
  - Dolby DS1 contribution of 54 mW (5.4% of total)
- **Results for Dolby AAC clip under identical conditions and scope settings:**
  - With DS1 on, measured average power of 1.07 W
  - Dolby DS1 contribution of 51 mW (5.0% of total)

Validating the Results: Battery Drain Tests

- Starting with a fully-charged battery, play video continuously until the battery is drained and the device stops functioning. For each test, we recorded the total video playback time
  - Using aVia media player in loop mode
  - Dolby DD+ video clip, 50% volume, using headphones
  - Wireless networking turned off
- **50% brightness, 50% volume, DD+ video clip**
  - DS1 ON: 733 minutes, 26 seconds
  - DS1 OFF: 766 minutes, 53 seconds
  - Difference: 33 minutes, 37 seconds (~4.6%)
- **100% brightness, 50% volume, DD+ video clip**
  - DS1 ON: 411 minutes, 26 seconds
  - DS1 OFF: 419 minutes, 29 seconds
  - Difference: 8 minutes, 3 seconds (~2.0%)

Conclusions

- Findings have helped us to refine our messages to customers and partners on power use of our technology
- Results were based on floating point code, we have since deployed fixed point code which can take advantage of the ARM CPU’s SIMD (NEON) engine

Future Studies

- Other SoC platforms with:
  - Different implementations of ARM CPUs
  - Different CPU architectures (x86, MIPS, etc.)
  - DSPs for audio offload
- Alternate test equipment
- Deeper look at low power audio-only use cases
- For cross device comparisons, need additional controls
  - Screen brightness meter

Accuracy of Results (Detail)

- Errors in the measurements are due to two factors:
  - Uncontrollable variables in the experiment
    - E.g. precise timing of threads running on the application processor, RF interference, room temperature changes, etc.
    - Uncontrollable variables are dealt with by taking measurements over a long span of time, and by averaging multiple measurements for each data point
    - Standard deviation computations show that errors due to uncontrollable variables are small:
      - Less than 1% of the total power measured in audio tests
      - Less than 0.34% of the total power measured in video tests
  - Calibration errors in the equipment and methodology
    - E.g. DC and gain offsets of the scope probes and ADCs
    - For the most part, calibration errors apply equally to all measurements
    - Therefore, relative differences between two measurements are still valid
    - To minimize the effect of calibration drift, measurements with DS1 ON were always immediately followed by measurements with DS1 OFF for each use case
    - Gain calibration errors may be up to +/- 5% of the total power measured
    - DC offset errors may contribute up to +/- 40 mW to a total power measurement