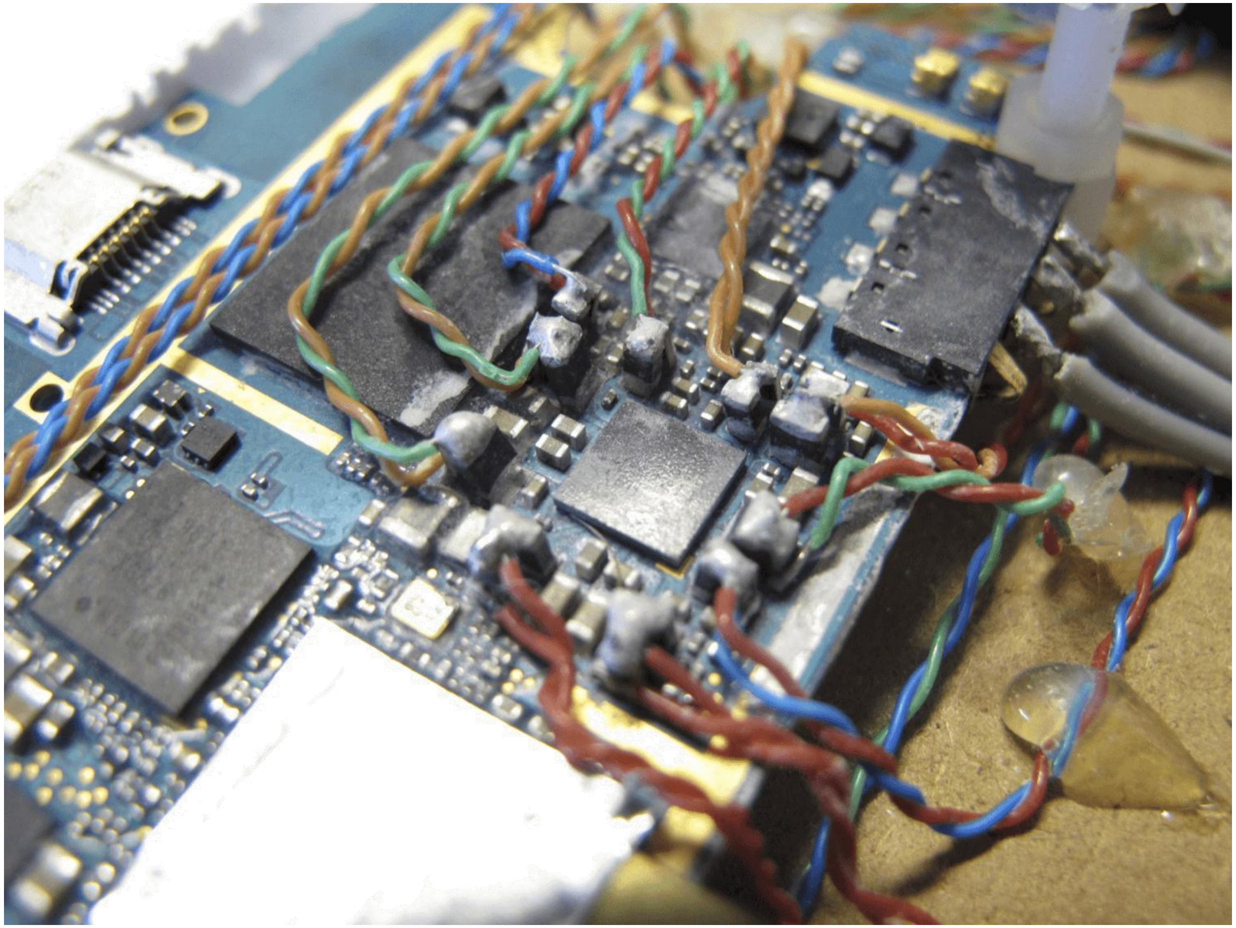
An Analysis of Power Consumption in Smart Phones



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Objective

- To determine where and how the power is used in the smart phones, ie exact break down of power consumption by the device’s main hardware component
- By a power model, analyze the energy usage and battery lifetime under usage pattern
- Analyze the energy impact of DVFS on device’s application processor

What they did to reach their goal

- They performed an experiment on directly measuring power consumption by the device’s main hardware components by executing various work loads using micro benchmarks (SPEC CPU2000) and macro benchmarks in a smart phone
- From the analysis of the result they discussed about the promissing area for better power management
- They implemented DVFS and they executed SPEC CPU2000 benchmark and observed the power consumption (total system power consumption) in three different smart phones

Previous research works referenced

- Analysis of power consumption on a laptop system, they also determined component wise power consumption.
- They measured direct power and then deduction using modelling and offline piece wise analysis
- Conclusion :CPU and display consumes more power , RAM power consumption is insignificant in real works

Previous research works referenced

- Component power estimation using modelling technique, the measurements are having errors less than 9%
- CPU, disk consumes more power, RAM and video systems consume very little power
- RAM power could exceed CPU power for highly memory bound work load

Previous research works referenced

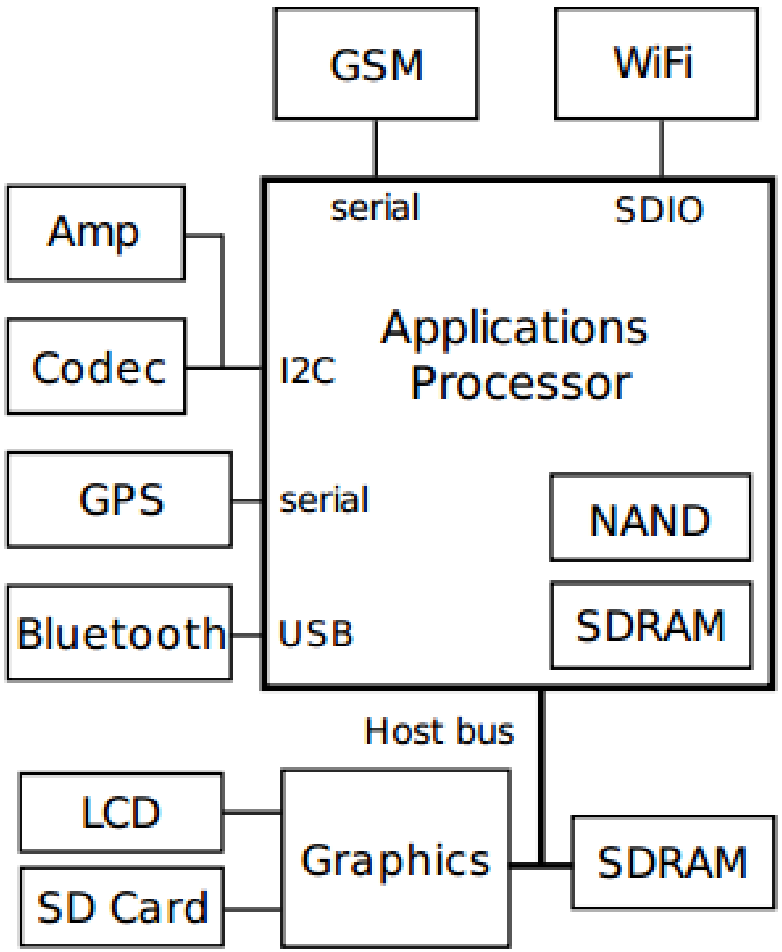
- They show significant power consumption in display subsystem, particularly in backlight brightness, dynamic power consumption in graphics subsystem.
- CPU and its operating frequency is important to overall power consumption

The Experiment

Openmoko Neo Freerunner

- It is a 2.5G smartphone
- This device was selected because the design files, particularly the circuit schematics
- Since they want to measure power at the component level on a piece of real hardware

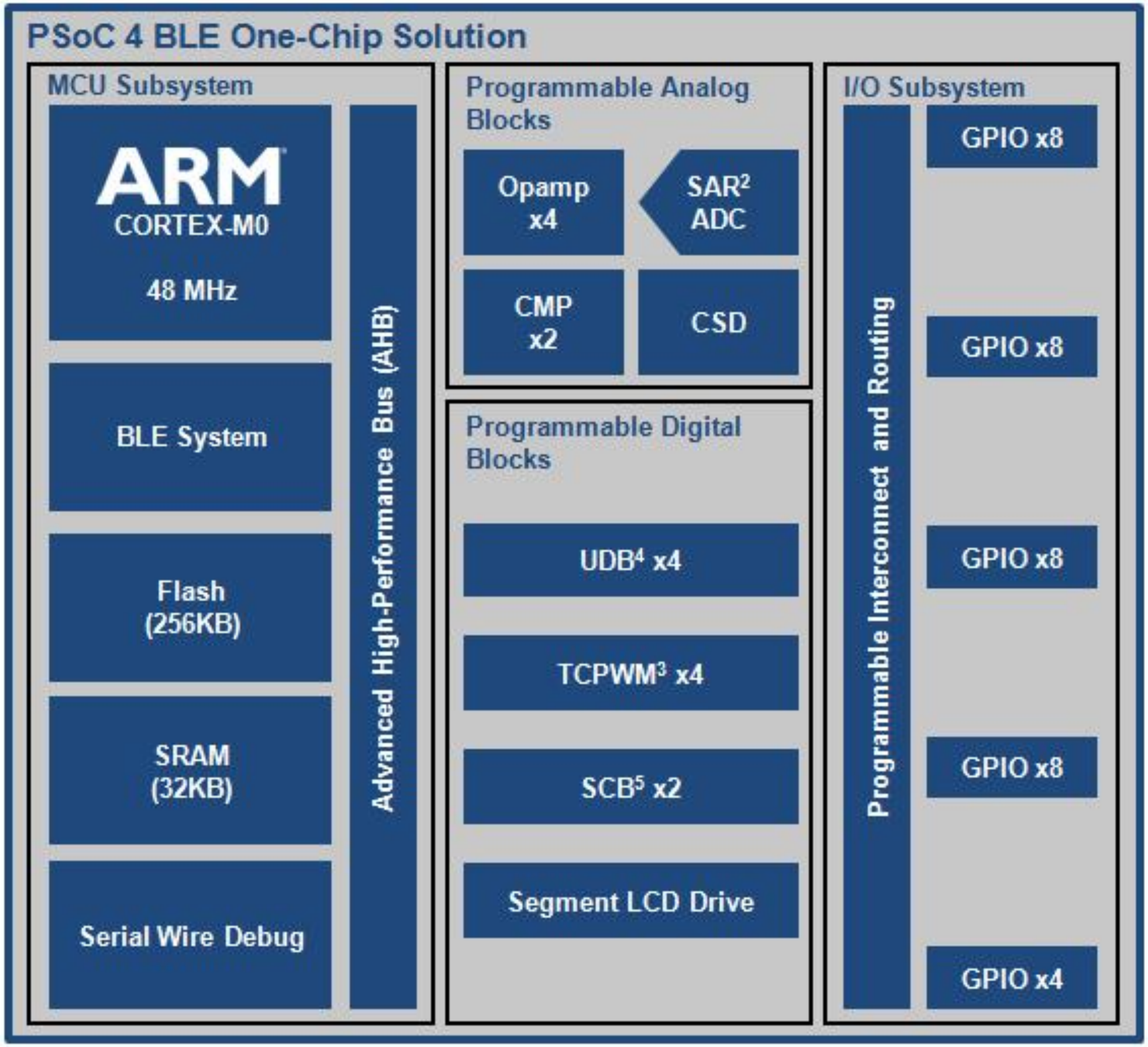
Architecture of Freerunner device



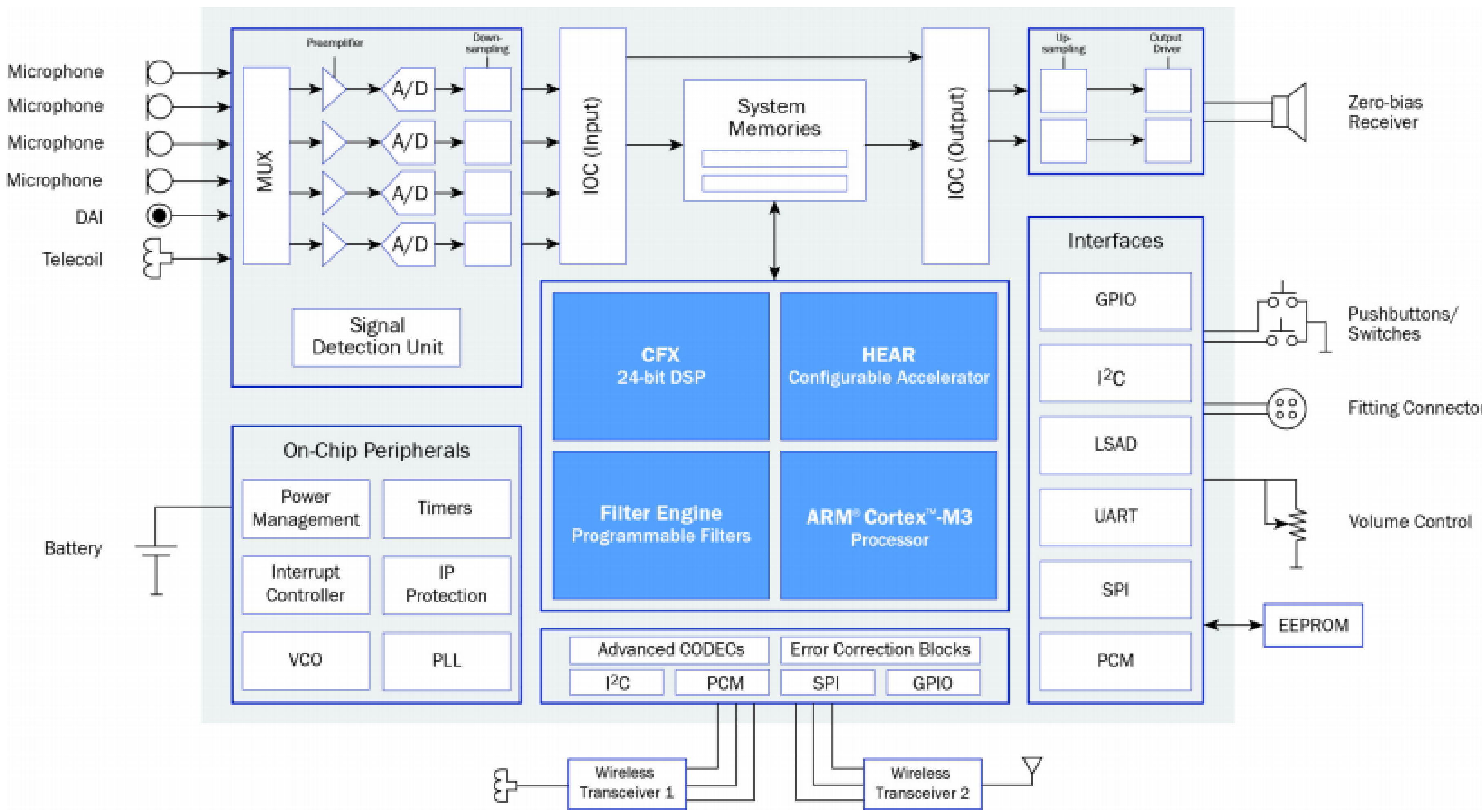
Freerunner hardware specification

Component	Specification
SoC	Samsung S3C2442
CPU	ARM 920T @ 400 MHz
RAM	128 MiB SDRAM
Flash	256 MiB NAND
Cellular radio	TI Calypso GSM+GPRS
GPS	u-blox ANTARIS 4
Graphics	Smedia Glamo 3362
LCD	Topploy 480 × 640
SD Card	SanDisk 2 GB
Bluetooth	Delta DFBM-CS320
WiFi	Accton 3236AQ
Audio codec	Wolfson WM8753
Audio amplifier	National Semiconductor LM4853
Power controller	NXP PCF50633
Battery	1200 mAh, 3.7 V Li-Ion

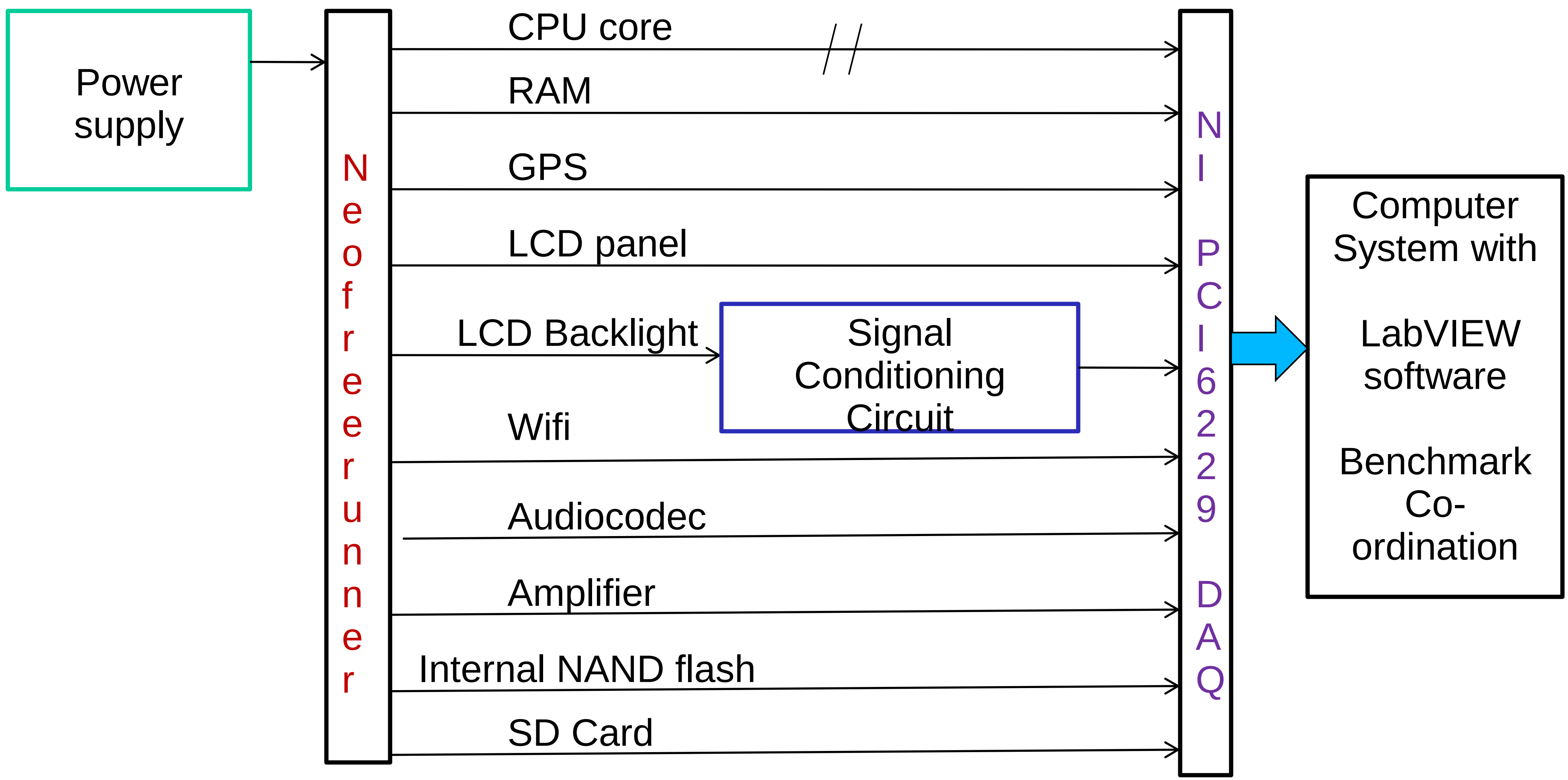
Some ASIC solutions for smart watches



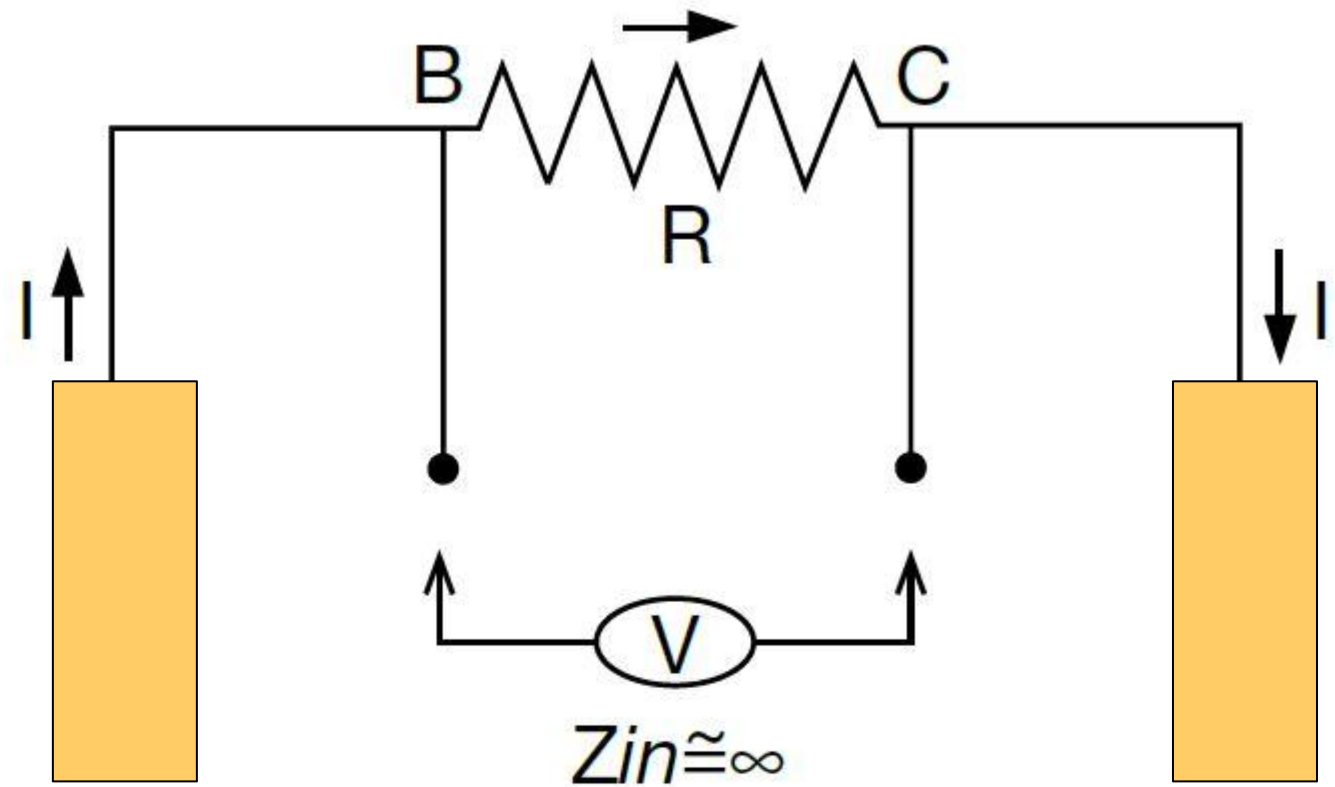
Hearing Aid Solution
Ezario 7100 , ON Semiconductors



Functional Block diagram of Experimental setup (Hardware)



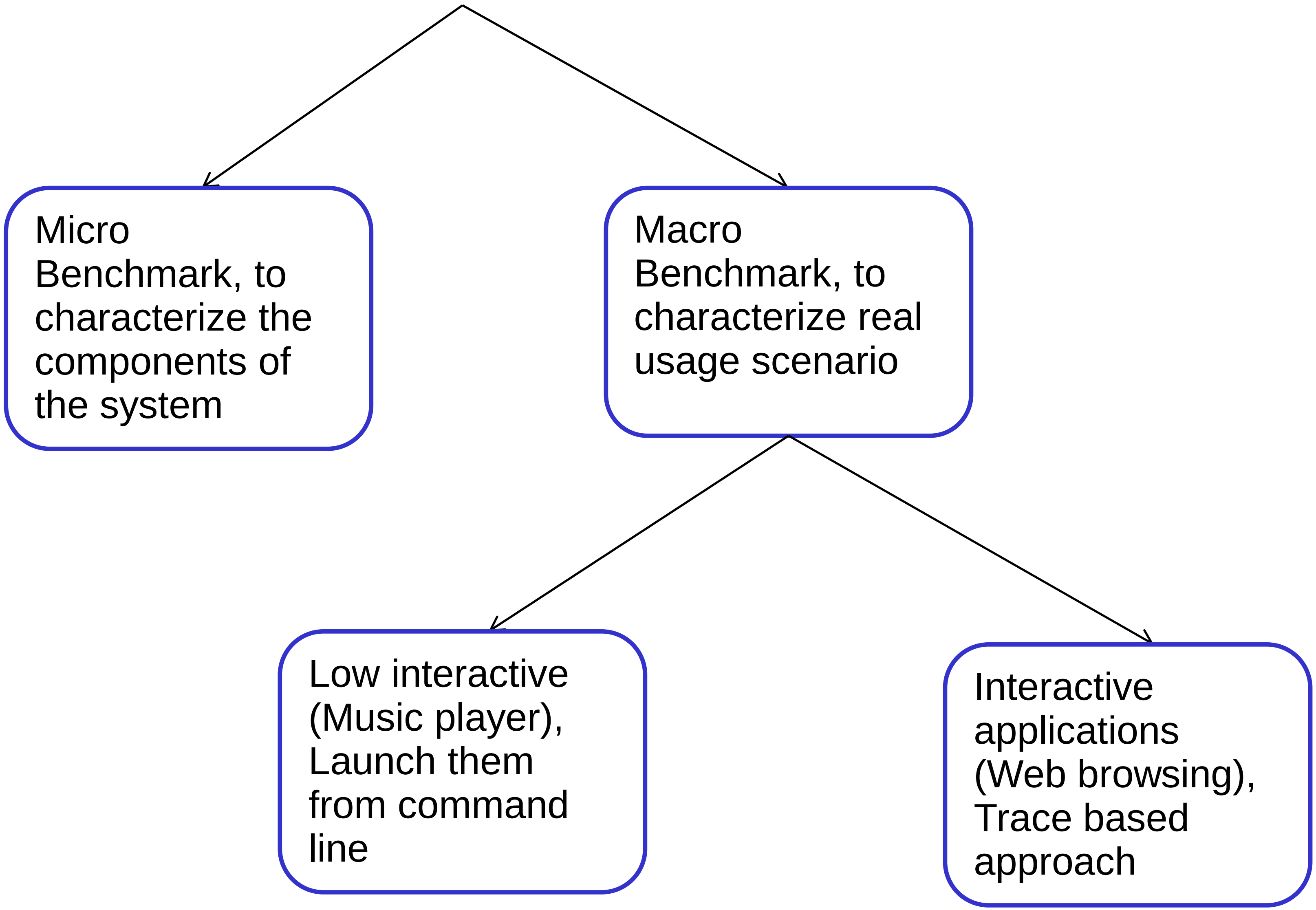
Sense resistor



Decoding how they synchronized the data collection and benchmark execution

- **Triggering Data Acquisition feature in NI PCI 6229 DAQ,** With digital triggering, you can begin acquiring at the precise moment that the digital pulse is received.
- Open the Android’s phone terminal in the computer system and run shell script such that it will trigger to start data acquisition, execute the Micro/ Macro benchmark and then after execution trigger to stop the data acquisition

Benchmarks



What is a trace? A trace consists of a sequence of input events including a time stamp , the name of the device providing the input , for the touch screen events the co-ordinates of the touch

Measuring the Baseline cases

- Suspended device
- Idle device
- Display

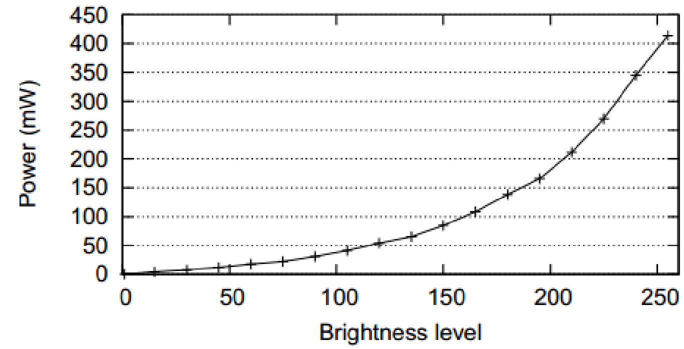


Figure 4: Display backlight power for varying brightness levels.

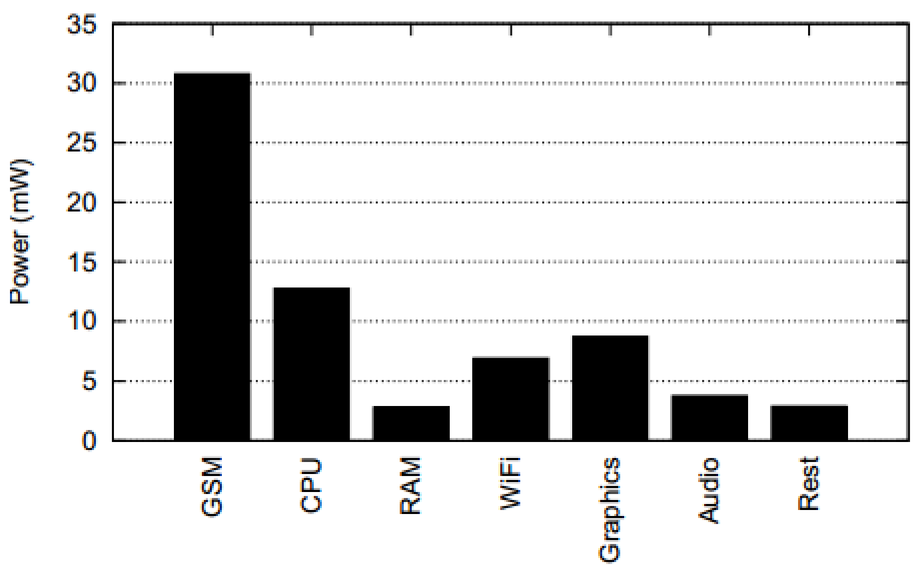


Figure 2: Power breakdown in the suspended state. The aggregate power consumed is 68.6 mW.

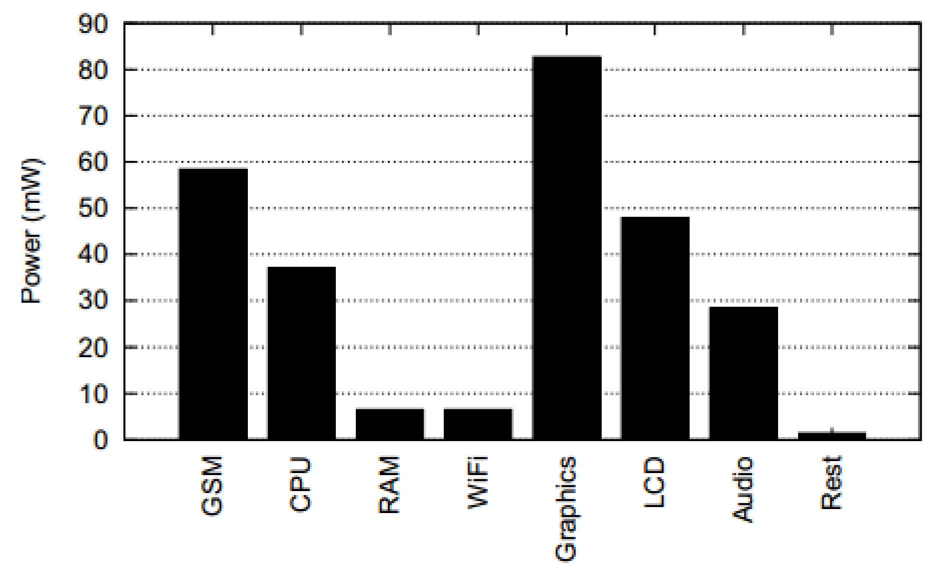


Figure 3: Average power consumption while in the idle state with backlight off. Aggregate power is 268.8 mW.

Micro-benchmarks

CPU and RAM

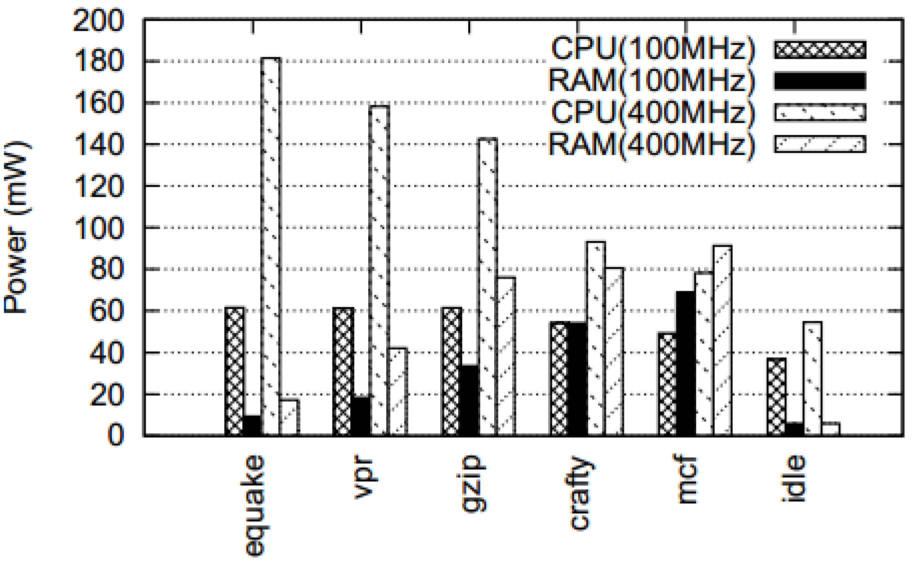


Figure 5: CPU and RAM power when running SPEC CPU2000 micro-benchmarks, sorted by CPU power.

Benchmark	Performance	Power	Energy
equake	26 %	36 %	135 %
vpr	31 %	40 %	125 %
gzip	38 %	43 %	112 %
crafty	63 %	62 %	100 %
mcf	74 %	69 %	93 %
idle	-	71 %	-

Flash Storage

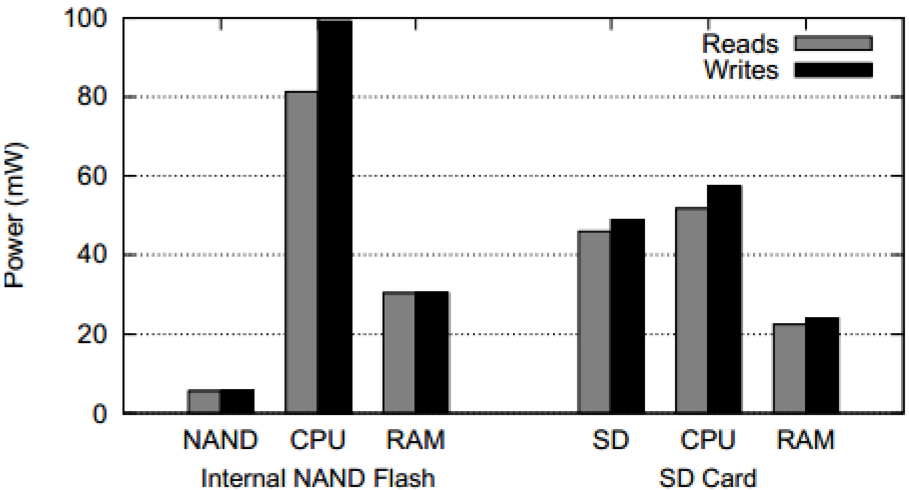


Figure 6: SD, NAND, CPU and RAM power for flash storage read and write benchmarks.

Networks

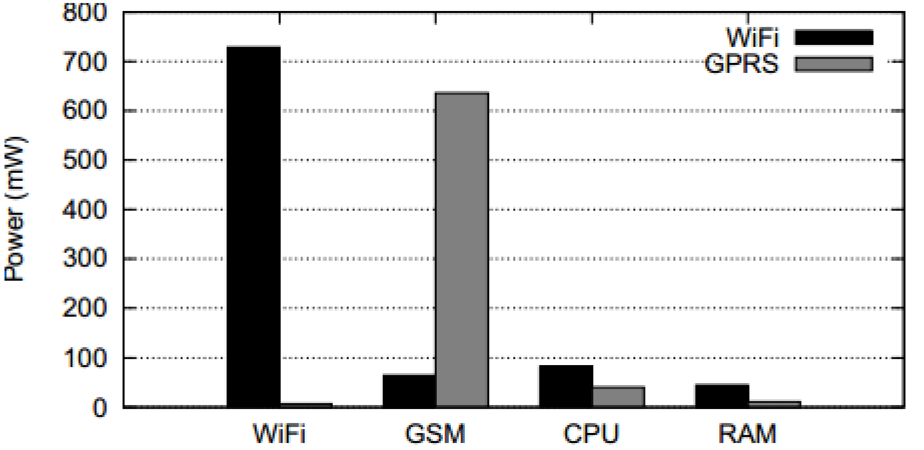


Figure 7: Power consumption of WiFi and GSM modems, CPU, and RAM for the network micro-benchmark.

GPS

State	Power (mW)
Enabled (internal antenna)	$143.1 \pm 0.05\,\%$
Enabled (external antenna)	$166.1 \pm 0.04\,\%$
Disabled	0.0

Table 5: GPS energy consumption.

Macro-Benchmarks

- Power usage examine under typical scenarios like audio and video playback, text messaging, voice calls, emailing and web browsing

Audio Playback

- The sample music is a 12.3 MiB, 537-second stereo 44.1 kHz MP3, with the output to a pair of stereo headphones
- Measurements are taken with backlight off but GSM power is included as phone being ready to receive calls or text messages

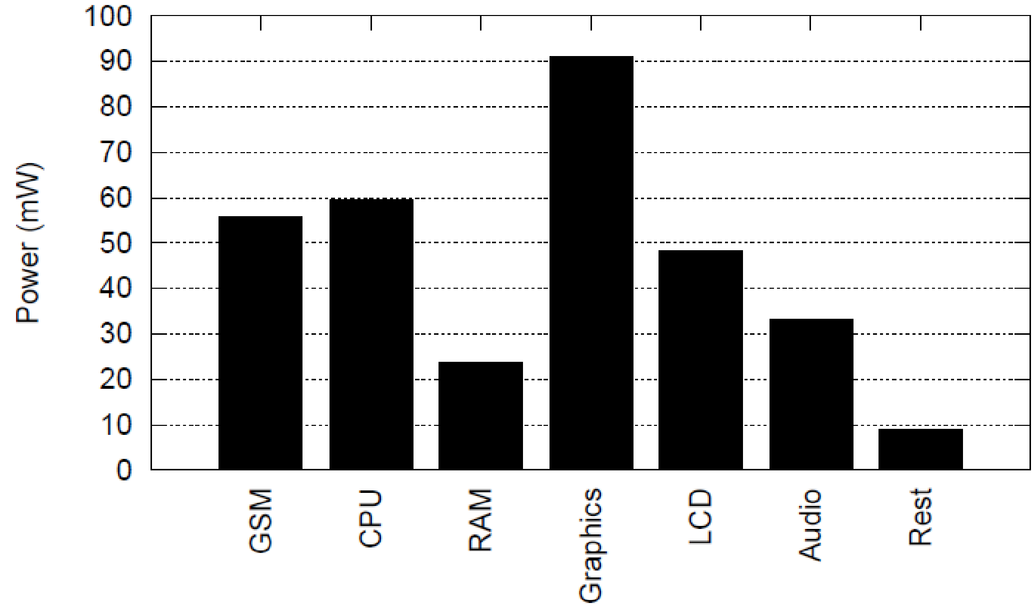
Audio playback power breakdown. Aggregate power consumed is 320.0mW.

Power measured at maximum volume, averaged over 10 iterations

Between successive iterations we forced a flush of the buffer cache to ensure that the audio file was re-read each time

Audio subsystem (amplifier 42% and codec 58%) consuming 33.1mW

Compared to the idle state amplifier power increased by 80%



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- Audio subsytem power decreased by 4.3mW (approx. 14%) mostly in the amplifier, at 13% volume
- For unknown reasons, the power consumed by the graphics chip increased by 4.6 mW
- As a result, the additional power consumed in the high-volume benchmark is less than 1mW compared with the low-volume case
- GSM network requires 55.6 ±19:7mW
- The MP3 file is loaded from the SD card, the cost of doing so is negligible at < 2% of total power

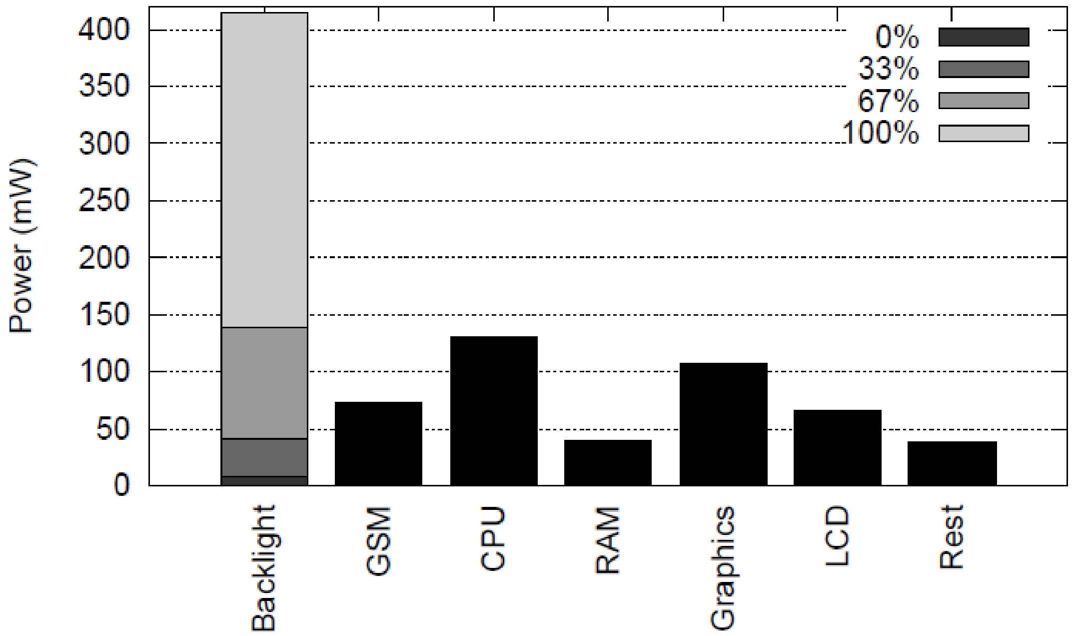
Video Playback

- Measured the power requirements for playing a video file
- Sample: 5 minute, 12.3 MiB H.263-encoded video clip (no sound), and played it with Android’s camera application
- Backlight power and GSM power included in the results
- Brightness levels of 30, 105, 180 and 255

Video playback power breakdown. Aggregate power excluding backlight is 453.5mW

CPU is the biggest single consumer of Power but display subsystem accounts for at least 38% of aggregate power; upto 68% with maximum backlight brightness

Energy cost of loading the video from the SD card is negligible, with an average power of 2.6mW over the length of the benchmark



Text messaging

- Benchmarked the cost of sending an SMS by using a trace of real phone usage

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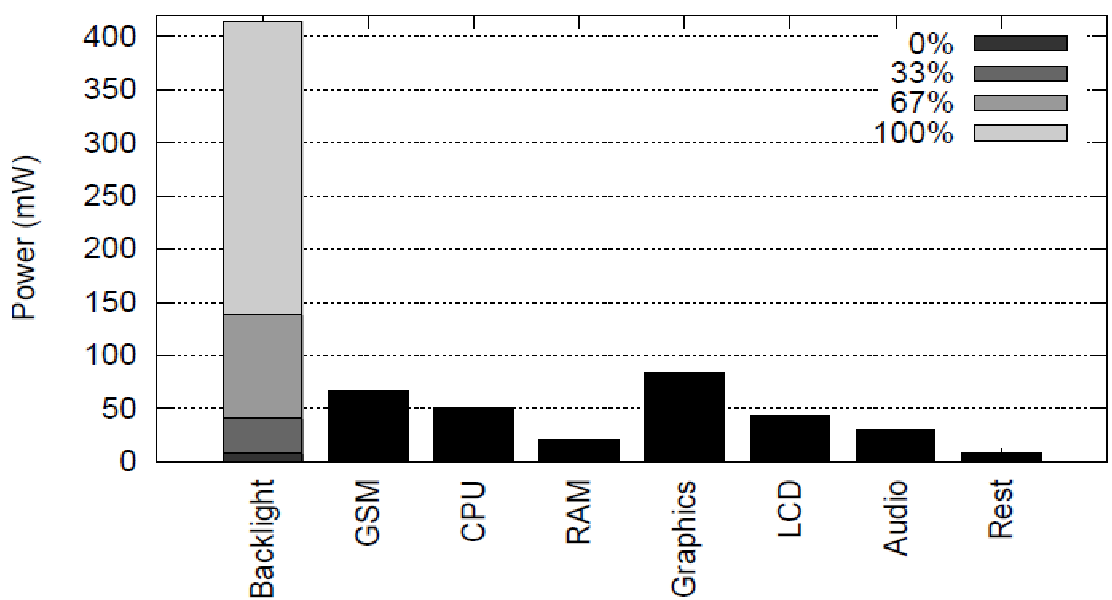
- To ensure the full cost of the GSM transaction; power is measured for an additional 20 seconds; total = 62s+20s



The GSM radio shows an average power of 66.3 ± 20.9mW, only 7.9mW greater than idle over the full length of the benchmark

22% of the aggregate power (excluding backlight)

All other components showed an RSD of below 3 %

Phone Call

The GSM phone call includes: loading the dialer application, dialing a number, and making a 57-second call

The total benchmark runs for 77 seconds

GSM power clearly dominates in this benchmark at 832.4±99.0 mW

The backlight is active for approximately 45% of the total benchmark

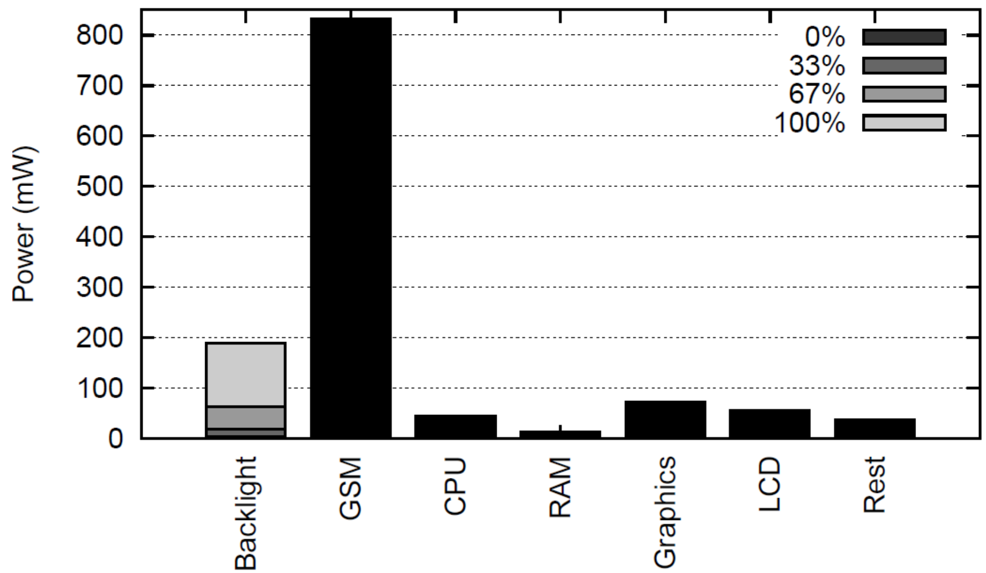


Figure 11: GSM phone call average power. Excluding backlight, the aggregate power is 1054.3 mW.

Emailing

Used Android's email application to measure the cost of sending and receiving emails

Workload consisted of opening the email application, downloading and reading 5 emails (one of which included a 60 KiB image) and replying to 2 of them

GSM consumes more than three times the power of WiFi

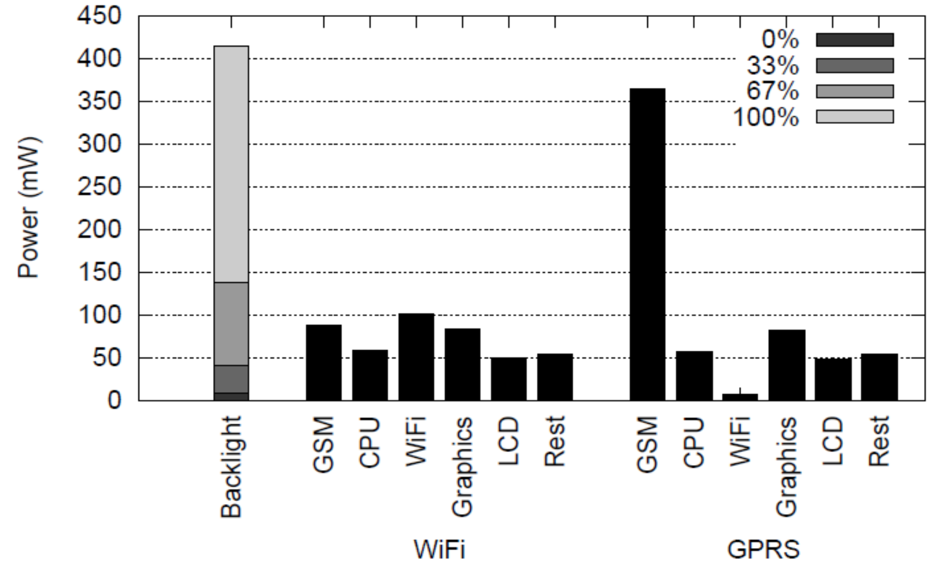


Figure 12: Power consumption for the email macro-benchmark. Aggregate power consumption (excluding backlight) is 610.0 mW over GPRS, and 432.4 mW for WiFi.

Web Browsing

Web-browsing workload using both GPRS and WiFi connections consisted of consisted of loading the browser application, selecting a bookmarked web site and browsing several pages for 490 seconds

GPRS consumes more power than WiFi by a factor of 2.5

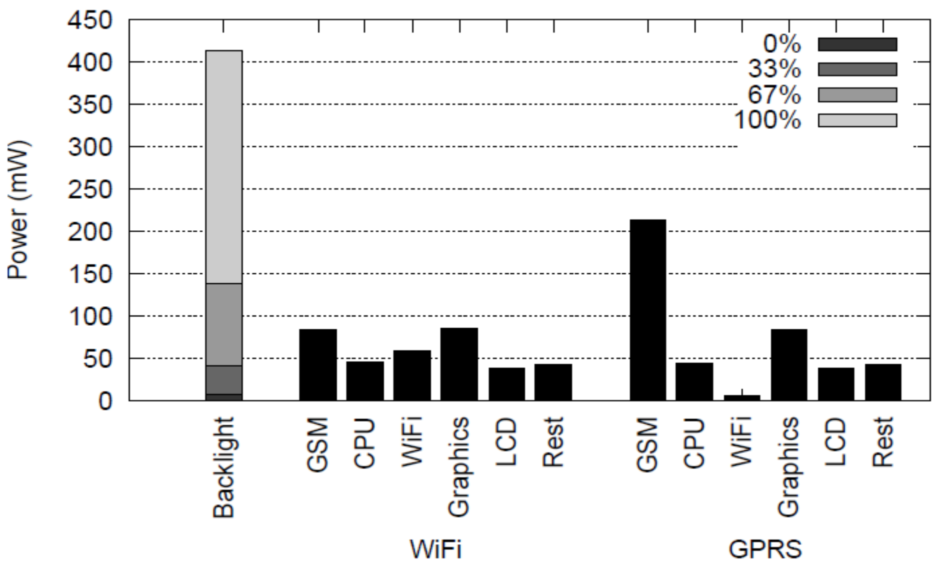


Figure 13: Web browsing average power over WiFi and GPRS. Aggregate power consumption is 352.8 mW for WiFi, and 429.0 mW for GPRS, excluding backlight.

Validation

- Measured the power consumption of two additional smartphones; the HTC Dream (G1), and the Google Nexus One (N1)

	G1	N1
SoC	Qualcomm MSM7201	Qualcomm QSD 8250
CPU	ARM 11 @ 528 MHz	ARMv7 @ 1 GHz
RAM	192 MiB	512 MiB
Display	3.2" TFT, 320x480	3.7" OLED, 480x800
Radio	UMTS+HSPA	UMTS+HSPA
OS	Android 1.6	Android 2.1
Kernel	Linux 2.6.29	Linux 2.6.29

Table 6: G1 and Nexus One specifications.

Display and Backlight

The content of the LCD display can affect power consumption by up to 17mW

Nexus One features an OLED display, and as such does not require a separate backlight like the Freerunner and G1

The OLED power consumption for a black screen is fixed, regardless of the brightness setting

For a completely white screen at minimum brightness, an additional 194mW is consumed, and at maximum brightness, 1313mW

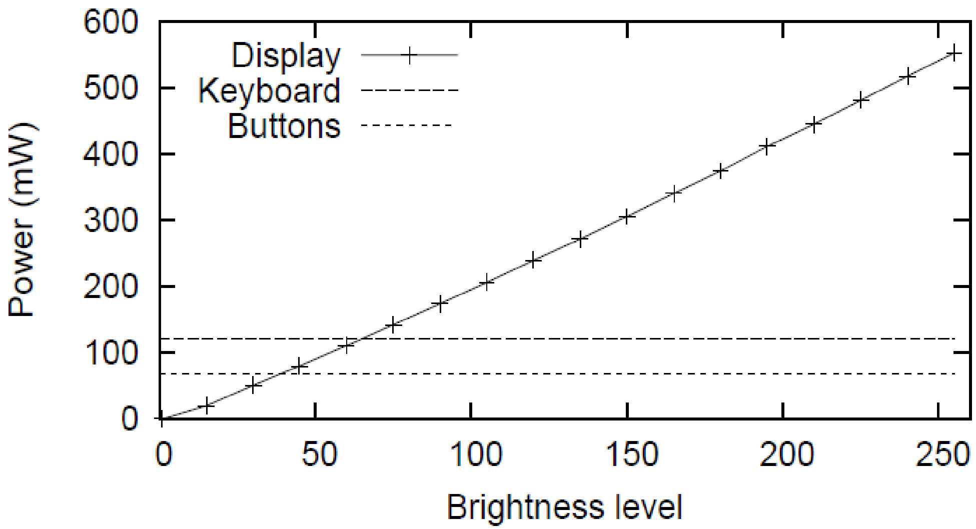


Figure 14: Display, button and keyboard backlight power on the G1.

CPU

Minimum and Maximum frequencies supported by the devices: 246MHz and 384MHz on the G1, and 245MHz and 998MHz on the N1

This benchmark was run with the display system powered down and all radios disabled

	Performance (%)		Power (%)	
Benchmark	G1	N1	G1	N1
`equake`	67	25	87	26
`vpr`	68	25	87	26
`gzip`	71	25	86	27
`crafty`	76	25	89	28
`mcf`	84	54	91	41

Table 7: SPEC CPU2000 performance and average system power of 246 MHz relative to 384 MHz on the G1, and 245 MHz relative to 998 MHz on the N1.

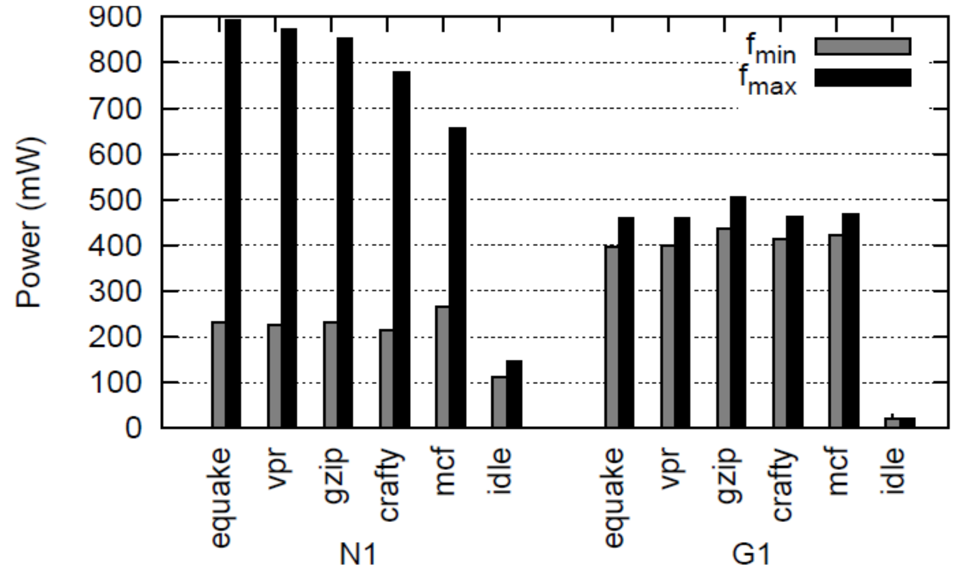


Figure 15: N1 and G1 system power for SPEC CPU2000 benchmarks.

Bluetooth

- Unable to get Bluetooth working reliably on the Freerunner phone
- Instead ran the audio benchmark on the G1 with the audio output to a Bluetooth stereo headset
- The power difference between this and the baseline audio benchmark should yield the consumption of the Bluetooth module
- total and estimated Bluetooth power

Benchmark	Power (mW) Total	Power (mW) Bluetooth
Audio baseline	459.7	-
Bluetooth (near)	495.7	36.0
Bluetooth (far)	504.7	44.9

Table 8: G1 Bluetooth power under the audio benchmark.

NEAR: Headset placed appx. 30cm from the phone

FAR: Headset placed appx. 10m from the phone

Summary

Lower power consumption of the G1 in the idle, web and email benchmarks can be attributed to the excellent low-power state of its SoC and effective use of it by software

Benchmark	Average System Power (mW)		
	Freerunner	G1	N1
Suspend	103.2	26.6	24.9
Idle	333.7	161.2	333.9
Phone call	1135.4	822.4	746.8
Email (cell)	690.7	599.4	-
Email (WiFi)	505.6	349.2	-
Web (cell)	500.0	430.4	538.0
Web (WiFi)	430.4	270.6	412.2
Network (cell)	929.7	1016.4	825.9
Network (WiFi)	1053.7	1355.8	884.1
Video	558.8	568.3	526.3
Audio	419.0	459.7	322.4

Table 9: Freerunner, G1 and N1 system power (excluding backlight) for a number of micro- and macro-benchmarks.

Benchmark	OLED Power (mW)	
	Min.	Max.
Idle	38.0	257.3
Phone call	16.7	112.9
Web	164.2	1111.7
Video	15.1	102.0

Table 10: Additional power consumed by the N1 OLED display at maximum and minimum brightness.

ANALYSIS

Where does the energy go?

- Majority of power consumption can be attributed to the GSM module and the display, including the LCD panel and touchscreen, the graphics accelerator/driver, and the backlight
- Brightness of the backlight is the most critical factor in determining power consumption
- The N1 OLED results show that merely selecting a light-on-dark colour scheme can significantly reduce energy consumption
- In all of our usage scenarios, except GSM phone call, static power accounts for at least 50% of the total

DVFS

- CPU micro-benchmarks show that DVFS can significantly reduce the power consumption of the CPU
- Previous results; *mcf* exhibit a reduction in CPU/RAM energy
- Pad idle power for more realistic scenario

$$E = Pt + P_{idle}(t_{max} - t)$$

Contd…

On G1 DVFS completely ineffective

Freerunner shows appx. 5% energy reduction

N1 shows considerable savings upto 35% with avg. power reduction of 135mW

Benchmark	% Energy		
	Freerunner	G1	N1
equake	95.5	126.0	75.6
vpr	95.8	124.5	75.9
gzip	95.8	120.1	77.7
crafty	95.5	115.6	77.3
mcf	94.9	105.3	65.9

Table 11: SPEC CPU2000 percentage total system energy consumption of the minimum frequency compared with the maximum frequency, padded with idle power.

Energy Model

$$
\begin{aligned}
E_{\text{audio}}(t) &= 0.32W \times t \\
E_{\text{video}}(t) &= (0.45W + P_{\text{BL}}) \times t \\
E_{\text{sms}}(t) &= (0.3W + P_{\text{BL}}) \times t \\
E_{\text{call}}(t) &= 1.05W \times t \\
E_{\text{web}}(t) &= (0.43W + P_{\text{BL}}) \times t \\
E_{\text{email}}(t) &= (0.61W + P_{\text{BL}}) \times t
\end{aligned}
$$

Modelling Usage Patterns

- *Suspend* : The baseline case, standy, no calls and mesages
- *Causal :* A user with small number of voice calls and text messages
- *Regular* : A commuter with extended time of listening to music or podcasts, combined with more lengthy or frequent phone calls, messaging and a bit of emailing
- *Buisness:* Extensive talking and email usage

Workload	SMS	Video	Audio	Phone call	Web browsing	Email
Suspend	-	-	-	-	-	-
Casual	15	-	-	15	-	-
Regular	30	-	60	30	15	15
Business	30	-	-	60	30	60
PMD	-	60	180	-	-	-

Table 12: Usage patterns, showing total time for each activity in minutes.

	Power (% of total)							Battery life
Workload	GSM	CPU	RAM	Graphics	LCD	Backlight	Rest	[hours]
Suspend	45	19	4	13	1	0	19	49
Casual	47	16	4	12	2	3	16	40
Regular	44	14	4	14	4	7	13	27
Business	51	11	3	11	4	11	10	21
PMD	31	19	5	17	6	6	14	29

Table 13: Daily energy use and battery life under a number of usage patterns.

Limitations

- Freerunner is not a latest generation mobile phone
- Main feature it is lacking is a 3G cellular interface, which supports much higher data rates than the 2.5G GPRS interface
- Difference in power consumption compared with more modern processors

Conclusions and Future Work

- Developed a model of the energy consumption for different usage scenarios, and showed how these translate into overall energy consumption and battery life under a number of usage patterns
- Compared the detailed measurements with a coarse-grained analysis of more modern phones, and shown the results to be comparable

New Paper

- The Systems Hacker’s Guide to the Galaxy Energy Usage in a Modern Smartphone by Aaron Carroll and Gernot Heiser. Published in: Proceeding APSys '13 Proceedings of the 4th Asia-Pacific Workshop on Systems Article No. 5 in 2013.