Power estimation, measurement, and budgeting

Two types of estimates are used

- End result:
  - MIPS/mW
  - hours of battery life

  This is very subjective, as it depends on workload assumptions

  Also, people have lied about this, and everyone cheats on the simplest standard benchmarks, e.g. ZD's Rundown tests, because firmware is smart enough to detect lack of real user activity.

- Subsystem budget – a guide for designers
  - Separate total power consumption by subsystem
  - Use "typical" or worst case workloads with respect to each subsystem, and then treat those (or reductions of them) as design targets separately

How to produce a "typical" workload for PCs?

- Worst case workload used to be a problem, now solved – it's DVD play in software – 2x the power consumption of any office application
- For typical workloads, a human operator executes a script, loads files, does simple editing tasks, closes files, pauses for specified times. This is then recorded and reproduced by some software emulator, perhaps enhanced by hardware to press keys or create communications events.
- Reliable reproduction is not easy, especially when one simulated workload is to be used on many different machines

Measurement Tools

Which power consumption to measure and what activities relate to it?

- External power (at the DC power input connector or laptop) is easiest to implement, can be applied to multiple machines.
    - Remove battery, measure current and voltage applied
    - Current measurement must not decrease voltage supplied by more than 5%.
    - This is slightly inflated by loading from charging circuits
    - Measurement of idle and standby current activities requires more sensitive tools.
- Data is captured on a PC card, either
    - Totally generic data capture card (gpib, Labview)
    - More PC-specific bus monitoring card, to link in information about interrupts occurring
- Capture of system activity and tying it to power consumption is not at all straightforward
    - "Hooking BIOS interrupts" – worked for DOS, WIN3.1
        - still works for Win9x, NT and 2000, but only external I/O (disk, communications)
    - Software monitors of activity – not easily linked to recording apparatus, most display graphically.
- Internal power measurements require cutting leads on dense printed circuit boards, inserting carefully sized resistors, data capture on one or several data capture cards in an external PC.
    - Requires 3-6 months work, specific to one model PC
    - Only a few manufacturers do this, and not too often.
    - Problem of monitoring activity during idle is more severe

Extrapolating from Measurements

Simplest examples: cellphones

- Battery capacities have stabilized:
  - 3.0 WHr (Li-ion) to 1.8 WHr (Li-polymer) slim units
- Talk times for digital units are about 3 hours => 1 W average talk power. (note – transmit power is still rated 0.6W)
  - Expect this to continue to decrease by 2x every 3-4 years.
  - Why? Continued circuit improvements; smaller cells as coverage improves require less transmit power.
- Listen times quoted from 3 days to 200 hrs -> 50mW to 15mW
  - Why? Lighter duty cycle; framing protocols tell systems when it is worth listening. Digital systems start and stop much more tidily than analog did.
- Best case for duty cycle is the simple pager
  - AAA battery (1.6 WHr) can support 6 months use (4320 hr)
  - That's .37 mW average power! More likely, a duty cycle of less than 10^-3. Pagers have a clock (after all, watches run for a year or two on even less battery power), and listen at short, prearranged times to see if they have a message, if not, sleep.
  - 10-100 msec listening / 30-120 sec between wakeups.

More complicated calculation – example is determining power strategy for disk drives in laptops. (Harris et al. paper, Appendix A)

	Old 2.5" files	Newer files
P(idle)	1 W	still true
P(sleep)	0.2 W	0.1 W or less
t(wake)	7 sec (!)	1 or 2 sec
P(wake)	4 W	2 or 1 W
Pt(wake)	28 Wsec	1-4 Wsec

Two analyses possible – ideal (lower bound) strategy is to always idle the disk is there is enough time before next access to permit saving energy. Realistic strategy is timeouts when inactive. Threshold can be accurately set with measurements of access intervals. Short thresholds with newer files save 3x in power. (See figs. 14, 15, 16.)

Digital Video Cameras

Very power-sensitive, because they are battery-powered, and carried in the hand. Tasks done on board: capture and compress image from 1-3 CCD's – 3 colors x up to 400,000 pixels captured 30 times per second. Auto-focus, auto-exposure, auto-white balance, auto-levelling of audio, image stabilization, motor zoom are expensive tasks. Use DSP, not microprocessor for data compression (mini-DV is 5:1, less lossy than MPEG2). Digital VCR for the miniature 6 mm DV tape cassette, which contains more data than a VHS cassette 10x its volume). I/O facilities support NTSC/PAL and 1394 export data protocols, plus small viewfinder and larger (2.5-3.5") LCD panel with backlight.

Pace of improvement reflects Moore's Law.

Top "pro-sumer" cameras (Sony, Panasonic, Canon GL-1) weigh about 1 kg , equal quality of 5-10 kg broadcast equipment from 1995.

Canon Elura (1998) – 600 gm, 5.9 watts (viewfinder only)

Canon Elura-2 (2001) – 400 gm, 4.4 watts (viewfinder only)

We can guess a power budget from looking at three present cameras' specifications, with and without the LCD panel extended:

Elura-2 (very small unit):	
CCD and data encoder	1 W
VCR subunit	2 W
Servos for autofocus, zoom	1 W
Viewfinder	.4 W (a heads-up display)
2.5" LCD	1.4 W
GL—1 (larger model)	
CCD and encoder	2 W
VCR subunit	2 W
Autotfocus, stabilizer, etc.	2 W
Viewfinder	.5 W

PC Power budgeting

I'll compare mid 1990's Thinkpad with today's, using low level measurements. Battery technology has improved 2X in this time period, but this is mostly used to decrease size of battery:

1995	30 WHr	NiMH, Li-Ion
2000-1	40 WHr	Li-Ion (3.6 A Hr, 10.8 V, 6 cells)

Useful lifetime in a mixed workload with pauses is still 2.5 – 3.5 hours. The relative fraction of power consumed by different parts of the PC is not likely to have changed since the last measurements and projections I have access to:

Thinkpad 755-760 used a total of 9-10 W on average

LCD and backlight	4.1W
HDD/CD Rom	1.1W
Video and Graphics	1.1W
CPU and core logic	1-2W
Memory	0.1W
Other I/O	1.1W
DC-DC losses	0.8-.9W

The LCD situation was still changing then.

First TFT-LCD's (1990) used 20 W.

Today's average about 2W (narrow angle of view reduces backlight requirements, improved cell design blocks less light). No one has yet exploited opportunity to build very low power controller that exploits time redundancy.

Integrating all the I/O is the big savings in onboard logic power (e.g. TransMeta's chips integrate North Bridge, save almost a watt).

Note power lost in DC-DC conversion and regulation. Most PDAs, by contrast, run straight from the batteries and tolerate large voltage variations over life of the battery.

These numbers don't capture the always-on communications workload, which will benefit as protocols begin to incorporate power awareness

CPU power reduction (on average, over real workload) is critical, since users have insisted on having the latest cpu speeds in top of line laptops. Usually it is done by simply inserting idle cycles and running the cpu in short bursts, so that net performance is ½ or less of the specification. Latest designs reduce clock frequency when there seems to be no user-generated workload. Transmeta does it best, by reducing voltage at the same time. 10% reduction in freq for TM gives 30% reduction in power. (CV^2*f). PIII and above need heatsink, fan, … and use over 10W. TransMeta's Crusoe (700 MHz) runs at 2W in worst case (DVD decode and play).

Extreme optimization for low power takes us to DSPs, which offer lowest mW/MIPS but make software development much more difficult:

Pentium	15-50 mW/MIPS
TransMeta	3-4 mW/MIPS
TI 320-67xx floating point DSP	.25 mW/MIPS

This is how cell phones can do as much computation as they now do…