BATTERY RECYCLING: AN OTHER WAY

Dr. Rolf Zinniker, ETH Zürich, Institut für Elektronik, Switzerland

Abstract

A representative lot of discarded Alkaline Batteries of Size AA (LR6) out of randomly selected recycling-boxes have been collected and their remaining capacity has been determined. The adopted procedure is explained in detail, the at least astonishing results are presented and discussed: About one third (33%) of the initial capacity has not been used, about 10% of all batteries can be considered new. In Switzerland alone, users throw away an LR6-battery capacity – value of about 20 Million sFr per year. Reasons for this attitude and possible counter-measures are discussed.

Introduction

Since several years, we had the presumption, that not all batteries disposed in recycling boxes are as empty as they should be. Thus, a more or less significant percentage of their initial (as new) capacity is thrown away. In 2002, an investigation was made for the Swiss television consumer magazine "Kassensturz" wherein the most popular battery-type alkaline size AA (LR6) has been covered. Until the end of this paper, the term "battery" will mean this type (LR6). Results have been diffused in a very popular form only in Kassensturz of 8.Oct.2002 [1] and in the Swiss consumer magazine Saldo [2]. Here results are presented for the first time in detail, they largely surpass our initial presumption.

Battery recycling an other way (or even two other ways), as outlined in Fig.1, is very attractive. The ordinary way we all know and have heard much about during this conference. A first other way ((1) in Fig.1) can be implemented by selecting still usable batteries out of the recycling box and directly reinsert them into the sales chain. This way, some work is needed which could be done by non-profit organisations and every body who likes to do some light work. The second other way ((2) in Fig. 1) is finally preferable: all recycling is done by the user himself. He must get the information, how to manage this batteries properly and avoid throwing away unused battery capacity into the recycling box .

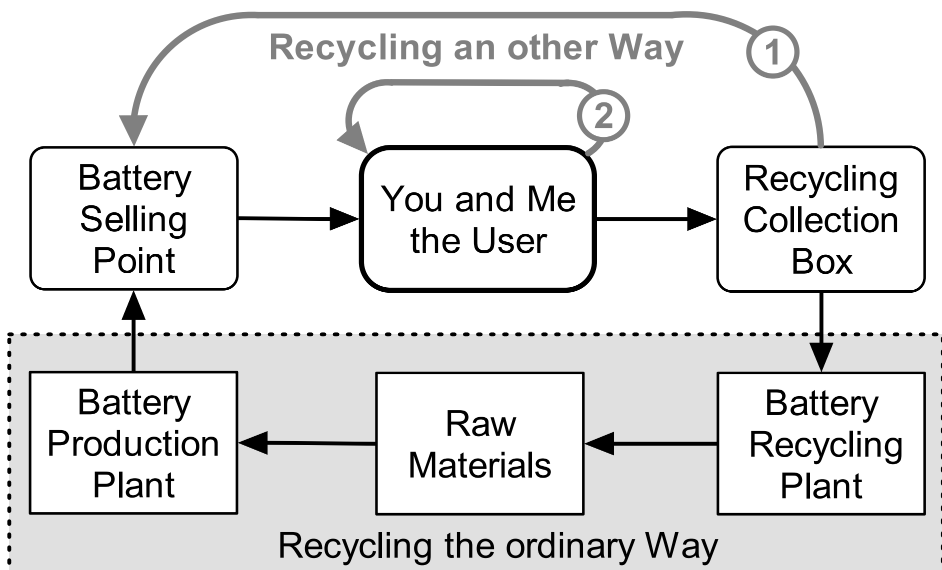
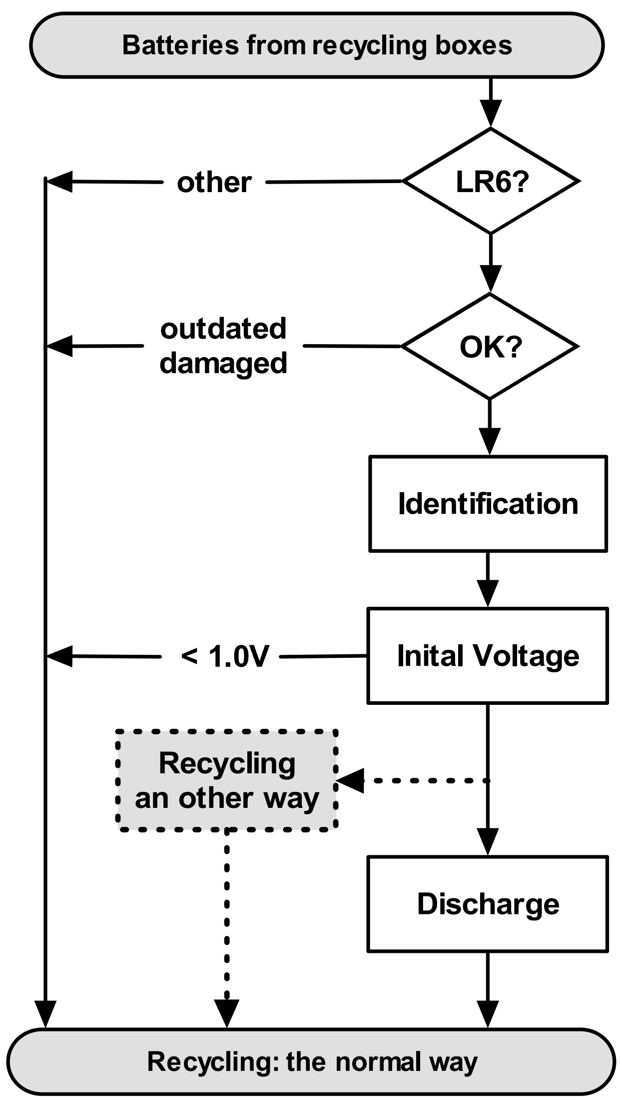


Fig. 1: Battery recycling, the ordinary and other way.

Test Procedure

The flow-chart of the test procedure is shown in Fig. 2. The sample batteries have been collected by Kassensturz during spring 2002 from 19 recycling boxes in supermarkets, consumer electronic shops and offices in the Zurich and Basle area. From every box, always all batteries have been collected.

In a first step, batteries other than LR6, outdated or visibly damaged batteries (very few) have been discarded. Next, the accepted batteries (636) have been labeled and registered in a database (Number, Source, Brand, Date). Then the initial voltage was measured using the following procedure: apply a constant current load of 120mA (rathly corresponding to a resistive load of 10 Ohms), wait 30 seconds, read the initial voltage Vi from the digital voltmeter (DVM), classify the battery into one of 6 classes of width 0.1V from 1.0V to 1.5V in order to build sets of 8 with similar capacity for the following discharge test.



Batteries from 19 boxes are collected.

LR6 (Alkaline size AA) only are retained.

Outdated and damaged batteries are rejected.

Batteries are numbered and entered in database with Brand, Date and Source.

Initial voltage Vi is measured under 120mA load after 30s. Less than 1V assumed empty, Vi entered in database.

All not discharged batteries are stocked for reuse.

262 batteries are discharged with 120mA to 0.9V. Cd entered in database.

Normal recycling at end of fully discharged batteries.

Fig. 2: Test procedure flowchart.

Almost discharged batteries (Vi < 1.0V) show a rapid declining voltage, measurement is not significant, their remaining capacity is very low. Thus, all batteries with an initial voltage of less than 1.0V are registered as 0V and assumed fully discharged. Of course this is for most of them not true, they still contain a small remaining capacity which could be used to power low power devices (e.g. clock, or small radio). This was not considered important in our work. Last, the batteries are classified into 6 classes 0.1V wide from 1.0V to >1.5V in order to build sets of 8 with similar capacity for following the discharge test.

Discharge Test

In the discharge test, groups of 8 batteries from the same class are discharged in a battery-tester built at our institute in order to exactly measure their remaining capacity. From each of the 5 classes, batteries have been randomly selected for discharge. All batteries are discharged with a constant current load of 120mA down to 0.9V. A constant current load (I-load) is typical for electronic devices with linear voltage regulators and a good compromise between the primitive and seldom realistic constant resistance load (R-load, e.g. 10 Ohms as specified in the IEC-Recorder Test) and the constant power load (P-load) typical for most hightech electronic devices with switchmode voltage regulators. R-load leads to a declining current drawn from the battery during discharge (at an end-of discharge voltage of 0.9V almost half the initial value at 1.6V). With P-load, the current is rising the same way during discharge. Current (I), voltage (V) and an approximative internal Resistance (Ri) for each of the 8 cells under test are measured in intervals of 60, 120 or 180 seconds depending on the class. All measured data is saved on disk for further reference. The discharged capacity is exactly calculated online, the values downto 1.0V, 0.9V and 0.8V are stored for each battery (only the value for 0.9V is further used). An example of discharge data is shown in Fig. 3 a,b,c. (The artefacts in the Ri curves are not significant artefacts).

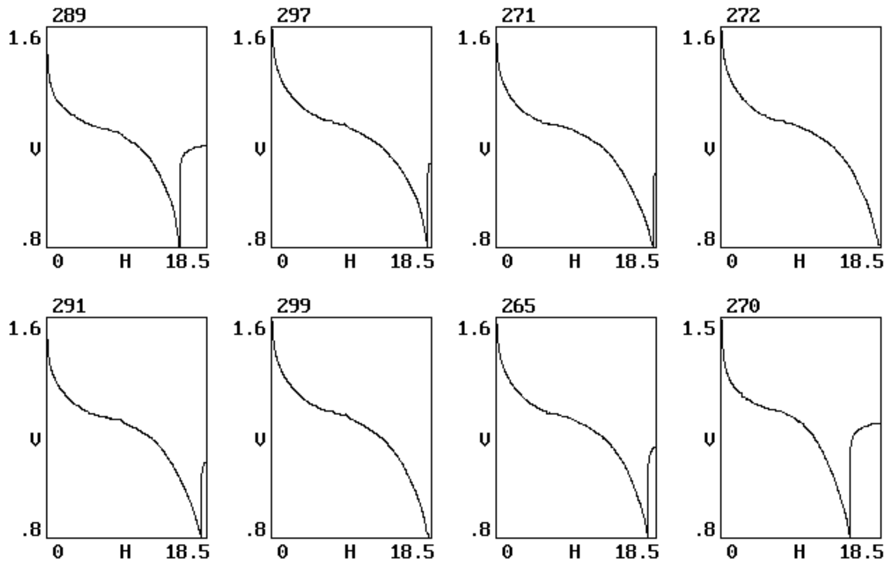


Fig. 3a: Sample discharge data of an 8 battery group from class 5, Voltage.

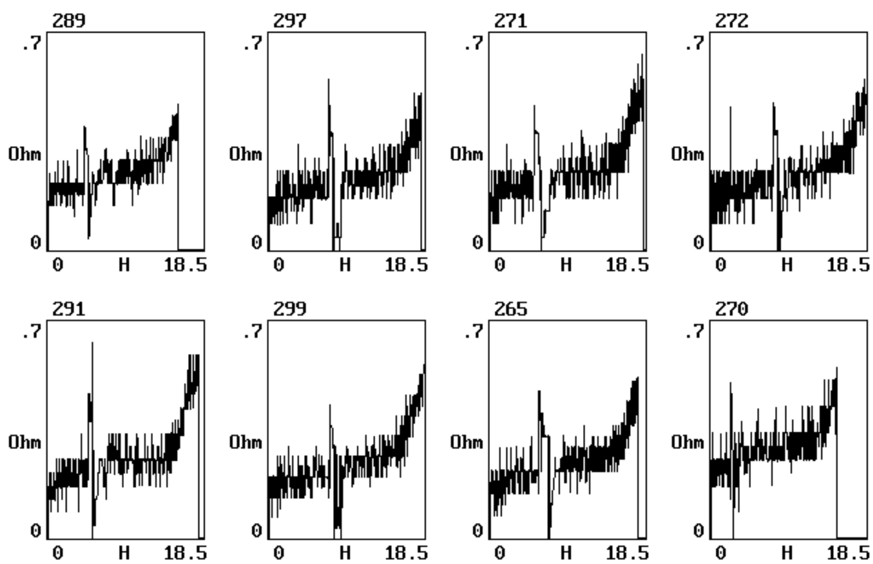


Fig. 3b: Sample discharge data, internal Resistance.

Battery #	I [A]	1V	**0.9V**	0.8V
289	0.12	1657	**1780**	1831
291	0.12	1856	**2010**	2120
297	0.12	1971	**2099**	2166
299	0.12	1973	**2122**	2227
271	0.12	1870	**2035**	2149
265	0.12	1921	**2055**	2136
272	0.12	1942	**2084**	2182
270	0.12	1520	**1661**	1751

Fig. 3c: Sample discharge data, Capacity.

Fitting capacity to initial voltage

After dischargeing almost half of the batteries (265), the correlation between initial voltage (Vi) and discharged capacity (Cd) has been checked in a scatter plot. As Fig. 4 shows, the correlation is quite good.

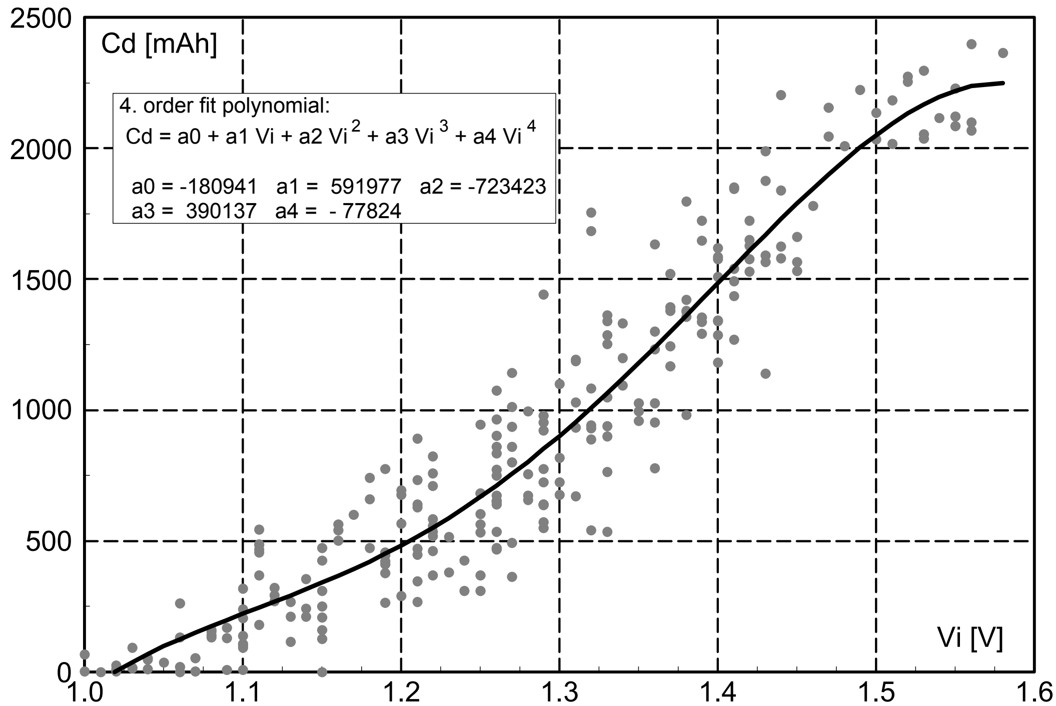


Fig. 4: Scatter Plot of discharged Capacity Cd versus initial Voltage Vi with fourth order Polynomial fit.

A fourth order polynomial was fitted to the data and further used to calculate all capacities from initial voltage. (Negative values, for initial voltages slightly above and below 1.0V, are set to 0). No more batteries have been discharged. The rest is recycled an other way and used instead of new ones.

Test Results

The capacity (Cc) of all 636 batteries has been calculated from their initial voltage using a 4. order fit polynomial (negative values for Vi below and slightly above 1.0V are set to zero):

$$C_c = -180941 + 591977\,V_i - 723423\,V_i^{2} + 390137\,V_i^{3} - 77824\,V_i^{4}$$

The calculated capacities (Cc) are sorted in descending order and plotted over a relative (0 to 100%) and absolute (0 to 636 batteries) scaled X-axis as shown in Fig. 5. We can see, that about 10% of all batteries can be considered as new, 30% are less than half discharged, only 40% are appearently fully discharged! If we apply a manufacturer proposed test procedure [6] (good for V > 1.1V under 10 Ohm load), more than 50% of all batteries would pass as good.

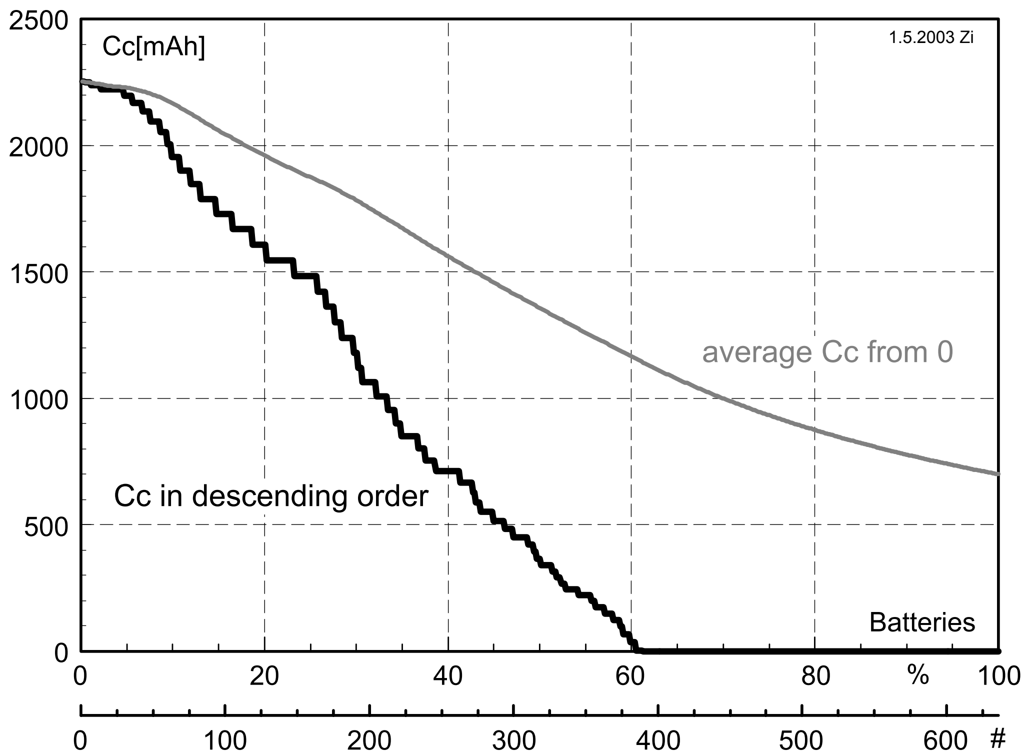


Fig. 5: Remaining calculated capacity Cc in the collected batteries.

As a second characteristic, the accumulated average from 0 was calculated and plotted in Fig. 5, some values are extracted in Fig. 6. The percentage of initial (as new) capacity is added in the last column. For this calculation, the average capacity (2111mAh) of 16 battery brands tested for K-Tipp in 1997 [5] is used as reference. The average capacity of all batteries (100%) is one third (33%) of the as new reference, 50% have almost two thirds of the as new capacity and again, 10% can be considered as new (the value of 103% is an indication for the slow but steady progress in battery technology over the past 5 years).

% of Batteries	Cav[mAh]	C % of new
10	2165	**103**
20	1962	**93**
30	1783	**84**
40	1559	**74**
50	1358	**64**
60	1165	**55**
70	998	**47**
80	875	**41**
90	777	**37**
100	700	**33**

Fig. 6: Average capacity in the collected Batteries.

Fig. 7 shows the Cc-graphs for all 19 collection points separately and again the total (from Fig. 5). No fundamental differences exist. It can be assumed with reasonably, that other collection points, also in other industrialised countries would show a similar result.

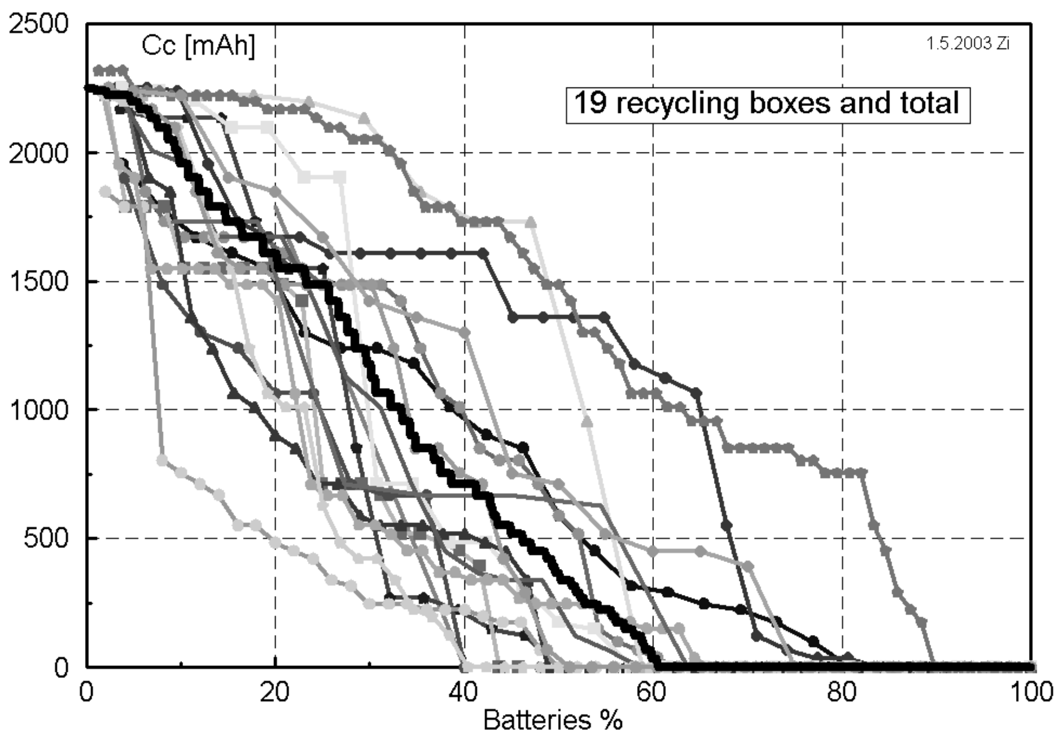


Fig. 7: Remaining capacity Cc for all 19 collection points and the total.

Discussion

Our investigation has clearly shown, that the batteries in the recycling boxes are not fully discharged. A significant part (33%) of capacity is thrown away and could be recycled an other way.

We will now first discuss reasons why people buy batteries and then throw away one third of the power they payed for and how this wasted battery-capacity could be recycled an other way.

Second we will discuss what can be done to initiate people to manage their batteries and effectively recycle the other way directly at home.

Why do users throw away one third of battery capacity

Hightech devices

In hightech electronic devices with great power consumption, best example the digital camera, the batteries can not be fully discharged. Due to the batteries internal series resistance, the voltage will sooner (with general purpose batteries) or later (with high-power batteries) fall below the low-battery trip point of the device and shut it off until the batteries are replaced, despite they are only partially discharged. To verify this behaviour, a foto test has been made for Kassensturz in February 2001 [3], [4].

The test setup is shown in Fig. 8. The Olympus C3040 Camera (courtesy of Olympus Europe) is equiped with 4 AA-Batteries under test. Every 20 seconds, a foto with full flash power in VGA-Resolution (in order to have enough capacity on the SM storage card) and display on is made (the RM-1 IR-remote control is connected to a pulse generator).

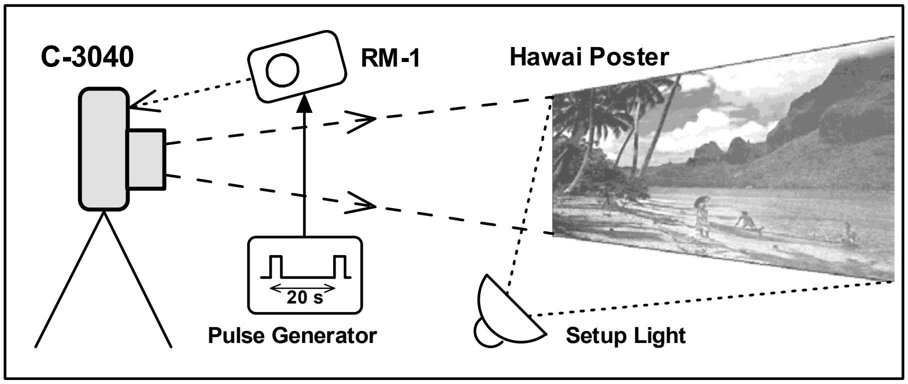


Fig. 8: Setup Foto Test.

As soon as the battery voltage drops under 4V, the camera shuts off and the number of fotos taken can be determined. After a pause of 12 to 24 hours, the batteries are discharged with 120mA constant current to 0.9V in order to find their remaining capacity. From this rest capacity, an equivalent number of Fotos is estimated (measurements during the test showed, that for one foto an average current of 690mA can be estimated). Results are shown in Fig. 9.

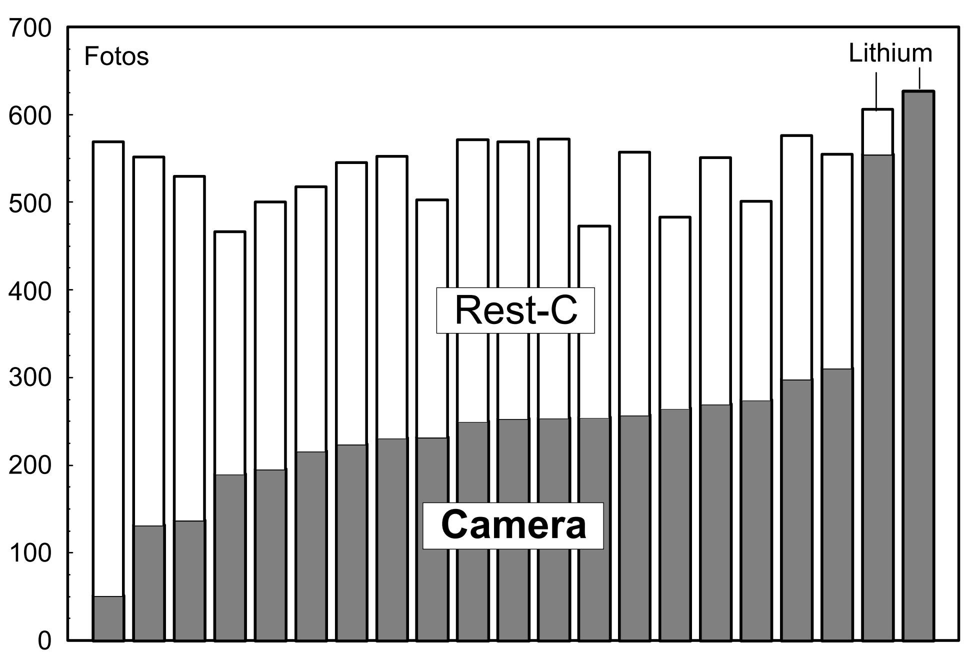


Fig. 9: Results from Foto Test, Camera- and Rest-C- Fotos.

High power batteries allow to take a great number of fotos and still keep a remarkable amount of capacity. Cheap general purpose batteries allow less fotos but keep a higher amount of capacity. The sum of real (Camera) fotos and equivalent (Rest-C) fotos is varying quite randomly. The two rightmost bars in the diagram are for two types of lithium primary batteries (Energizer e2 1.5V and rightmost Olympus CR-V3, 3V) and illustrate the superiority of this technology.

Be sure to have good batteries

Before a weekend-trip or other activities, people want to be sure, to have good batteries in their equipment. So they put in new ones and dispose the "old" ones.

Mix up old and new batteries

While changeing batteries, the new set is ready for insertion, the old one retracted and the phone is ringing. After some nice conversation, the batteries have rolled around on the table. Now which are the new, which are the old ones? Dispose all and take an other new set.

Can not test the state of batteries

State of battery indicators in electronic devices just give an indication on how good (or bad) the batteries are for use in this device. As was shown in the foto-test, this gives now indication on the general state of the batteries.

Universal battery testers can be bought quite everywhere. Most of them are not useful.

Two manufacturers produce batteries with integrated tester. These should help to find out the state of the battery. Thus, one would expect, that the tester-batteries in the recycling box should be fully discharged, or at least more than those without tester. The number of tester-batteries collected (46) is to small to make a significant statement. But there is, at least for one of the two brands, no evidence, that tester-batteries are really emptier than others.

Batteries are to cheap

For the price of a good cup of coffee, we can get 4 batteries. Dont worry, put new ones in the caddy, you will not remark it at the cash box.

What can be done to avoid throwing away battery capacity

Place a useful battery tester near every recycling box

A useful battery tester must give more information than just "good" or "bad". As we have shown, the remaining capacity can reliably be identified by measuring the initial voltage, - this is the voltage of the battery under some reasonable load, e.g. 120mA or 10 Ohms. In [6], this procedure is recommended, but only a good (Vi > 1.1V) and bad (Vi <=1.1V) classification is proposed. We think, that a tester with 5 indications would be a good solution as shown in Fig. 10

Vi	Indication
> 1.4V	new
1.3 – 1.4 V	slightly discharged
1.2 – 1.3 V	used
1.1 – 1.2 V	almost discharged
< 1.1 V	discharged

Fig. 10: Proposition for a useful battery tester.

This tester could be built with a 4-LED bar display and powered from the battery under test, (DC-DC up-converter necessary). Fig. 11 shows a possible circuit diagram.

Make useful battery testers available for every body

The above proposed battery tester would be very cheap once produced in large quantity and be affordable for every battery user.

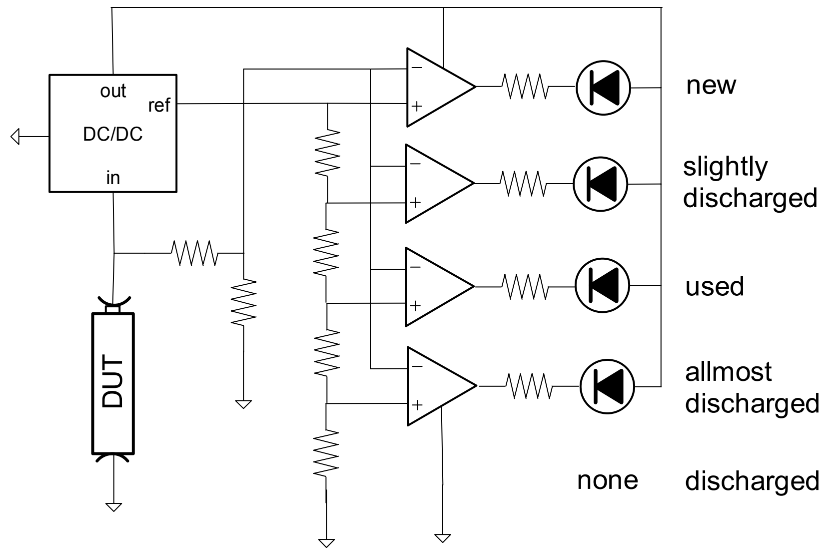


Fig. 11: Circuit diagram of a useful battery tester.

Enable Hightech equipment to fully discharge batteries

With a more elaborated power management in hightech equipment by using e.g. super capacitors to deliver the high peak-currents, batteries could be much deeper discharged in the devices [7]. Fig. 12 shows as an illustration a current profile of the Olympus C3040 digital camera. The high current peak of 1.4A will prematurely trigger the low battery shut off.

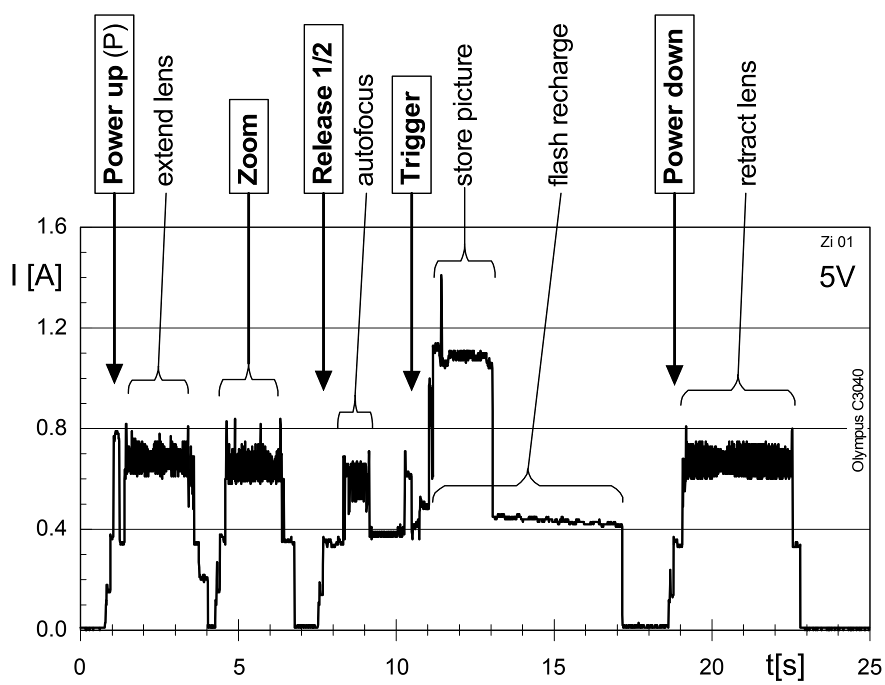


Fig. 12: Current profile from a hightech digital camera.

Inform users how to manage their batteries

Last but not least, there is a tremendous lack of suitable information for battery users. Some manufacturers have started to put information on the enclosure, but most prefer to use this precious space for publicity. Much is done by recycling organisations and state agencies to initiate users to dispose their used batteries in a recycling box instead of in the waste basket [8], almost nothing is done to learn users how to make full use of their batteries capacity, to recycle them an other way.

Obviously, no body is really interested to promote measures which could hurt battery sales. Each other way recycled battery as well as each refreshed battery is a battery not sold.... Business is business, - any way.

References

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Author

Rolf Zinniker, Dr. sc. techn. dipl. el. Ing. ETH.

ETH Zürich, Institut für Elektronik, Gloriastrasse 35, CH8092 Zürich, Switzerland.

Email: zinniker@ife.ee.ethz.ch

Homepage: www.ife.ee.ethz.ch/showcase/members/zinniker

Telephone: 0041 1 632 2739 Fax: 0041 1 632 1210.