Part IA Paper 3 : Electrical and Information Engineering

For supervisors only

LINEAR CIRCUITS AND DEVICES
EXAMPLES PAPER 1
DISCUSSION QUESTION B

12. A particular Walkman cassette tape player is powered by a single AA battery. The current consumed by the player in normal operation is 150 mA, and it may be assumed to be independent of the type of battery or its state of charge. The manufacturer's specification indicates that the Walkman may be used with a zinc-carbon, alkaline, or (rechargeable) nickel-cadmium battery. Specific information about each battery type is given in the Table. The charging circuit used for the Ni-Cad battery is shown in simplified form in Fig 8, and resembles the Design Example considered in Lecture 4. It consists of a 25 V supply which may be assumed ideal, powered from the AC mains. You may assume that the cost of electricity from the supply is 10p per kWh, and that the value chosen for R is 400Ω.

Estimate the following:

(i) how many hours each battery will last in operation
(ii) the energy supplied in joules and watt-hours for each battery
(iii) the comparative costs of operating the Walkman for 1000 hours with the various power options;

Comment on the environmental impact of each option, and discuss the approximations and simplifications you have had to make in reaching these estimates.

[In carrying out this comparison, you will need to make sensible estimates of the energy consumed by the Walkman from its battery in 1000 hours, and, for the case of the rechargeable battery, the energy consumed in recharging it, as well as plausible estimates of the costs involved (economic and environmental)].

Data / AA Battery type	Zinc-carbon	Alkaline	Ni-Cad
Capacity (Ah)	0.9	2.1	0.6
Terminal voltage (V)	1.5	1.5	1.2
No of discharge cycles till end of life	1	1	1000
Unit cost (£)	0.30	0.50	4

See also information and links on the web at: http://www2.eng.cam.ac.uk/~dmh/ptialcd/battery

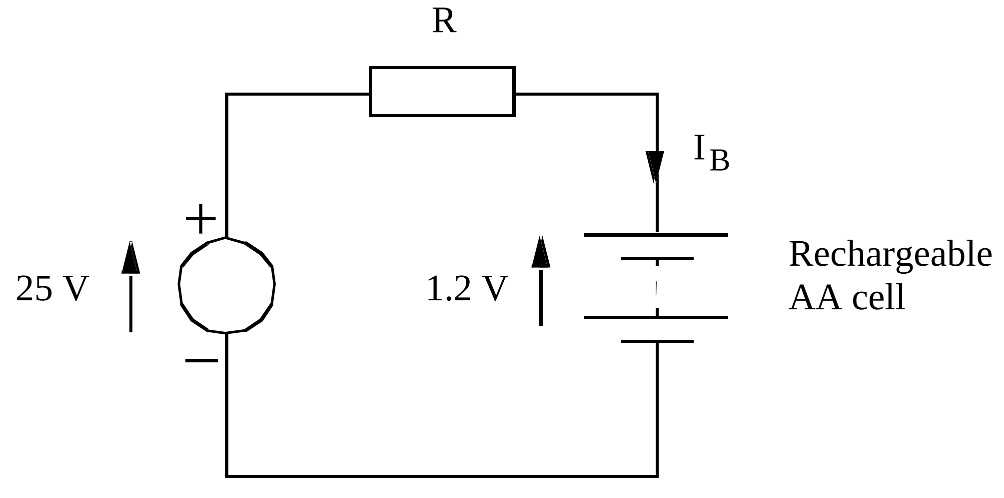

Fig. 8 Ni-Cad battery charger circuit

Suggested answers are given in the Supervisor's sheet.

12. The battery lifetime τ (in hours) is given by:

$$\tau = \text{capacity in Ah / current drawn}$$

The energy supplied is given by

$$J = V \times I \times \tau \times 3600$$

where V is the terminal voltage, assumed to be at the nominal value throughout the battery's life (a fairly poor approximation for both primary batteries); I is the current drawn, assumed fixed at 150mA (unlikely to be so for the entire battery life and for different operating conditions (volume setting, use of rewind, etc); and τ is the lifetime in hours. With V and I in basic units, the consumption is in Joules or Watt-seconds. To convert to Watt-hours, divide by 3600.

To determine the cost H using primary cells (one use only) which each cost £G

$$H = G \times 1000 / \tau$$

In the case of the rechargeable battery, we shall assume the battery is chemically efficient, i.e. every Ah of charge received when charging is available for discharge. In practice real batteries may be about 60-70% efficient and need to be charged about 35% longer than this elementary treatment predicts.

In charging, then, the current being delivered to the battery is:

$$I_c = (25 - 1.2)/400 = 59.5 \text{ mA}$$

Time to charge Tc is:

$$T_c = \text{capacity / current} = 0.6/0.0595 = 10.08 \text{ hours}$$

The battery is being charged at the 'ten hour rate', with a charging current about equal to one tenth of its numerical capacity in Ah. In practice it might take 12-14 hours to charge fully.

During this time the supply delivers energy, of:

$$25 \times 0.0595 \times 10.08 \text{ Wh} = 14.99 \text{ Wh} = 53978 \text{ J}$$

Most of this goes to heating the resistor required to limit the current. Only a small percentage of this is converted into chemical energy by the battery. A better charger design would further reduce the losses.

One charge is enough to power the Walkman for 4 hours (see Table); hence for 1000 hours of operation we must recharge 250 times. This is well within the expected life of the Ni-Cad. The total number of Wh expended in charging is 14.99 × 250 = 3740 Wh, or 3.74 kWh. At 10p per kWh, the energy cost is 37.4 pence. To this should be added 25% of the £4 battery cost (since 25% of its expected life has been consumed). In addition, an element needs to be added for cost of ownership of the charger, a few pounds perhaps.

Data / Battery type	Zinc-carbon	Alkaline	Ni-Cad
Hours of operation/discharge	6	14	4
Energy (J) / discharge	4860	11340	2592
Energy (Wh) / discharge	1.35	3.15	0.72
Number of discharges/1000 hrs	167	73	250
Cost for 1000 hrs	£50.00	£35.70	£1.37 *

* plus cost of ownership of charger, say £5, which can theoretically be amortised over a period of years.

It is very clear that use of zinc-carbon or alkaline is very costly, both in economic terms, and in an environmental sense, since far more batteries have to be disposed of.

Some discussion points

Every year over 15 billion batteries are produced and sold worldwide. About half of these are primary (zinc-carbon or alkaline) batteries which are discarded after a single use. It is estimated that in 2000, almost 19,000 tonnes of waste general purpose batteries required disposal in the UK. Currently, only a very small percentage of consumer disposable batteries are recycled (less than 2%) and most waste batteries are disposed of in landfill sites. The average household uses 21 batteries a year.

Whilst the exact chemical make-up varies from type to type, most batteries contain heavy metals, which are the main cause for environmental concern. When disposed of incorrectly, these heavy metals may leak into the ground when the battery casing corrodes. This can contribute to soil and water pollution and endanger wildlife. Some batteries, such as button cell batteries, also contain mercury, which has similarly hazardous properties. Mercury is no longer being used in the manufacture of non-rechargeable batteries, except button cells where it is a functional component, and the major European battery suppliers have been offering mercury-free disposable batteries since 1994.

Fortunately, thanks to ongoing advances in both rechargeable batteries and battery chargers, single-use batteries can largely be replaced with higher capacity, environmentally friendly, rechargeable Nickel-Metal Hydride (NiMH) or Lithium-ion (Li-ion) batteries that last far longer in high drain devices - each time they are charged - and can be used many hundreds of times...saving a great deal of money. Note that use of rechargeable batteries does not entirely eliminate the disposal problem at end-of-life – automotive batteries contain lead, and Ni-Cad rechargeables contain Cadmium. Cadmium, for example, can be toxic to aquatic invertebrates and can bio-accumulate in fish, which damages ecosystems and makes them unfit for human consumption. The rate for recycling of consumer rechargeable batteries is estimated to be 5%.

What we can do

- Use the mains when possible.
- Use rechargeable batteries and a battery charger. This saves energy because the energy needed to manufacture a battery is on average 50 times greater than the energy it gives out. (But note that rechargeable batteries are not suitable for all applications, e.g. smoke alarms)
- Opt for appliances that can use power derived from the sun via solar panels or from a winding mechanism, e.g. radios, mobile phone wind-up chargers.
- Participate in local authority battery collection schemes where they are available. Seek guidance on how to dispose or recycle batteries from either the distributor who originally supplied the battery, the battery manufacturer or the appliance manufacturer.
- Send batteries back to manufacturers for recycling or reprocessing where such a scheme is available.

Web sites:

http://www.wasteonline.org.uk/resources/InformationSheets/Batteries.htm
http://www.batteryuniversity.com/index.htm