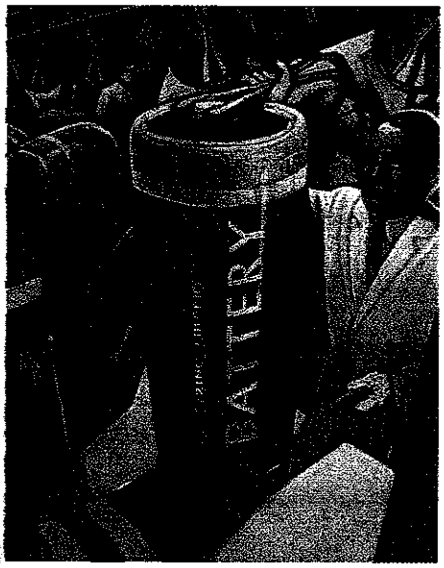


Recharging the unchargeable

Our fears about charging zinc-carbon and alkaline cells are based on fifties battery technology and are no longer justifiable, argue Michael Slifkin and Yaakov Levy. They also present a simple and cheap charger that works much faster than the traditional 'dirty-dc' solution.

Although most people believe that recharging zinc-carbon and alkaline primary cells is both difficult and dangerous, our experiments have indicated that this is not the case. Older readers among you may remember wireless sets available in the UK in the fifties. While using ordinary throw away batteries, these sets also had a recharge switch for extending battety life.

In recent years, a number of devices for 'recharging' primary cells and batteries has appeared on the market. But literature on this topic is hard to come by. Most present-day solutions appear to be based on a charger described by Alan Tong in *Everyday Electronics*.

However Alan stated in his article that to prevent batteries from leaking or exploding, it is necessary to charge using pulsed positive charges with the occasional negative going pulse – a technique known as pcr, or pulse charge reversal.

The rationale behind this, is that it is known from the electroplating industry that metals plated by pcr have a much denser plating layer. Plating using pure dc can produce spongy layers that occupy a much larger volume. If this should happen inside a battery, then the spongy layer's additional volume would cause a marked increase in internal pressure, leading to leaks or explosions.

Folk lore

Although there is little literature on the subject, there is a certain amount of folk lore. In earlier times, when the cost of batteries was relatively more expensive than nowadays, various methods were tried to increase their life.

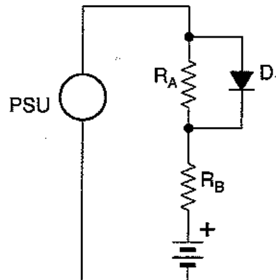
A favoured method, which works to some extent, was to put the failing battery in a warm oven overnight. Other people would apply a dc voltage to their batteries hoping to revive them. But this only worked if the battery had not been completely exhausted, leading people to consider this method a failure.

It is possible to extend the life of a button battery used in watches and calculators by applying a 2.5V direct current until the battery gets warm. But again, this only works when the battery is not completely flat.

A very old article, in the October 1955 issue of *Wireless World*, refers to the use of "dirty dc" in recharging these batteries. The dirty dc charger consisted of a half wave rectified supply with a small amount of alternating current superimposed by using a 200Ω bypass resistor around the rectifying diode This is probably the simplest charger you can build.

After we completed our research work into chraging cells, a very detailed article by Rod Cooper appeared in the March 1997 of *Electronics World*. In this article, he described a fairly elaborate series of experiments and a charger based on this pcr principle. In addition Rod said that it is necessary to adjust the charging current to the voltage so that as the

Fig. 1. 'Dirty dc' charger has a diode, which passes all of the positive half cycle, with a series resistor to let through a small portion of the negative half cycle.



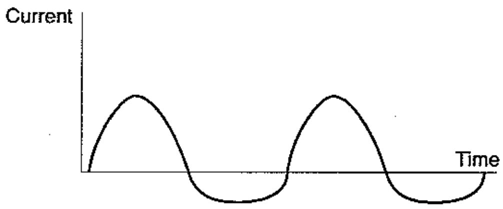
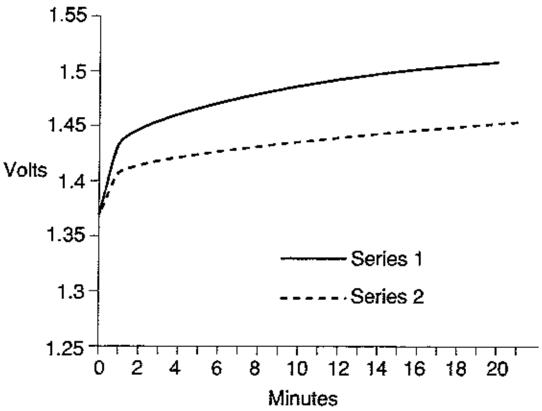


Fig. 2. Charging characteristics of AA zinc-chloride batteries at different frequencies. Series 1 at 50Hz, series 2 at 1kHz.



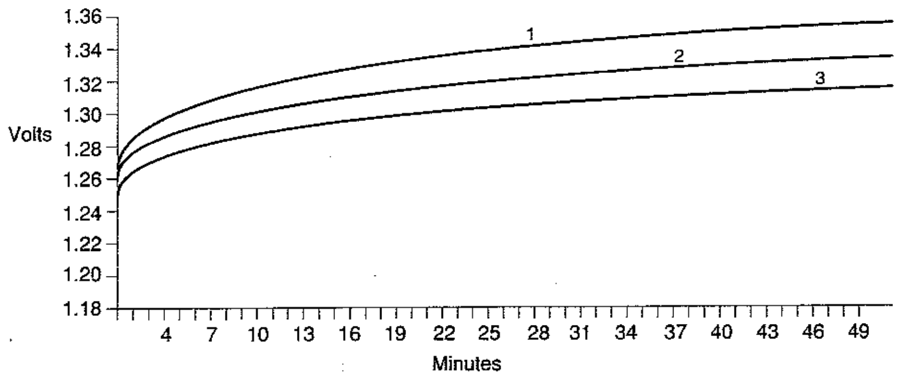


Fig. 3. Successive charging characteristics of AA manganese-alkaline batteries. Curve 1 at 50Hz, curve at 2 at 1kHz, curve 3 at 50Hz.

Table 1. Resistors suitable for charging other battery sizes using the 'dirty dc' charger.

Battery type	D	C	AA	AAA
R_A (Ω)	68	220	560	1500
R_B (Ω)	6.8	18	47	120
Power supply (W)	5	2	1	1

battery's voltage rises, the current must be decreased.

Dirty dc chargers suffer from having low duty cycles of not more than 30 %. The intention of our work was to find the optimum conditions for recharging so that we could build an efficient fast charger – hopefully with a very high duty cycle and for a cheap price.

In this article we describe a number of experiments we carried out on extending the life of primary batteries. At the end, we present a description of a simple apparatus incorporating our results.

Our experiments were carried out over a period of about a year using in all about 100 batteries – mainly of the AA type. All our experiments involved 4.5V peak pulses. Negative pulses were fixed at 1.5V.

The important factor is the charging current. We used about 50mA for AA type batteries at a duty cycle of 50%. Higher duty cycles have proportionately higher currents.

It is interesting that Rod suggested that the maximum charging current for batteries should be about the total capacity divided by 30 or 40 – which would be about 50mA for the AA battery.

In our experiments, batteries were discharged in a controlled manner to about 1V before recharging. We considered a battery to be recharged when the final voltage showed no change for about five minutes.

For new batteries this steady charged state usually occured at between 1.5 and 1.6V. Older batteries never reached this voltage. In common with earlier authors, we found that very old batteries, or batteries that had been completely discharged, were impossible to revive.

Is frequency important?

Our first series of experiments involved a pulsed supply of variable frequency to see whether or not frequency was important. In the electro-plating industry, it is accepted that very low frequency pcr of about 10Hz gives much more compact layers than higher frequencies.

First we used a simple dirty dc charger, as in **Fig. 1**. Results obtained for zinc-chloride batteries are shown in **Fig. 2**. Clearly, much faster charging occurs at 50Hz than at 1kHz.

An interesting set of results are shown for a manganese alkaline battery that has been discharged and recharged three times. The first and third cycle is at 50Hz and the middle cycle is at 1kHz. The superiority of 50Hz charging is amply demonstrated.

A similar experiment is shown for another manganese cell, but in this case, the cell has been subjected to a deeper discharge. Again the superiority of the 50Hz charging regime is demonstrated.

And duty cycle?

The next experiment compares the charging effect of square – i.e. 50% duty cycle – pulses as opposed to the sinusoidal pulses. **Figure 3** shows that cells charged with square pulses reache a slightly higher voltage – even though they start from a much lower discharged voltage. In general, we found that higher duty cycle pulses are more efficient in charging batteries than lower duty cycle sinusoids.

Next we looked at increasing the duty cycle. A typical plot is shown in **Fig. 4**. It shows that the 95% duty cycle is superior to that of the 75% duty cycle, reaching a higher terminal voltage.

Is the discharge cycle needed?

Next we looked at the effect of charging using only positive pulses. We compared the results of positive-pulse-only charging directly against a charging regime using alternate 1.5V negative pulses and 4.5V positive pulses, while maintaining the same duty cycle.

We found that the absence of a negative pulse had no effect on charging efficiency. Even more surprisingly, we also got a slightly higher end point voltage using only positive pulses and the same duty cycle.

After this finding we carried out many charge/discharge cycles on zinc-carbon and alkaline batteries, but found no signs of distress. It became clear to us that pcr is not a requirement for the revitalisation of these batteries.

So is 'dirty dc' really necessary? While our only case of a leaking battery was one that we charged using pure dc, the leak only occurred after many hours. We found that, provided the state of the battery being charged is monitored, and that the battery is taken off charge when its voltage does not change after a few minutes, other precautions were unnecessary.

Later, we present a charger with 85% duty cycle that is easily varied. We added this variable duty cycle feature because most other people in this field believe that pure dc should not be used – a fact we feel needs to be proven. Having a circuit with a variable duty cycle allows you to experiment for yourelves.

Useful – but not immortal

We should stress that during our experiments, we never managed to restore a battery to its original capacity. And each recharge cycle

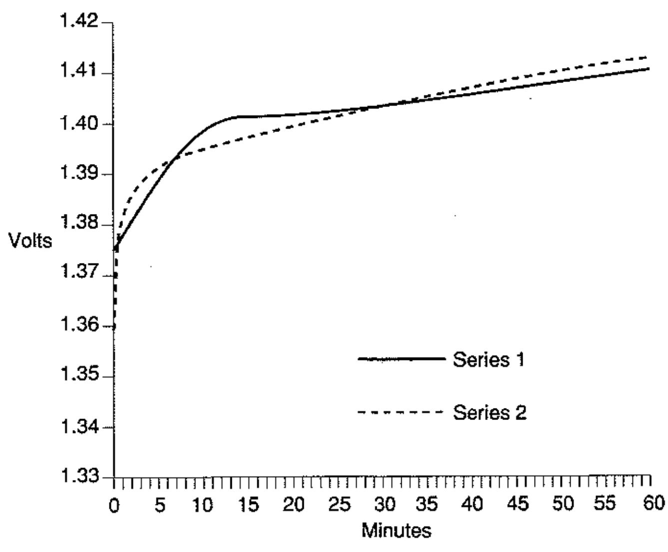


Fig. 4. Charging AA manganese-alkaline battery with sinusoidal versus square pulses. Curve 1 is sinusoidal pulses, curve square.

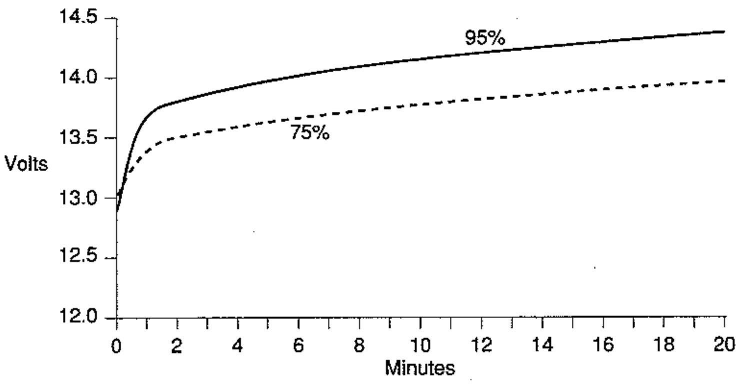


Fig. 5. Effect of charging AA manganese-alkaline battery with high duty cycles.

gave us less capacity.

We found that the internal resistance of the battery increases after each charging. After about ten cycles or so the internal resitance reaches a value that is too high to allow recharging. There was also considerable diffenence in recharging capacity between batteries of the same type.

The word recharge is a misnomer. The situation with these primary batteries is quite different from that with secondary batteries, such as nickel-cadmium types. With secondary cells, you get a complete recharge of the battery for perhaps hundreds of cycles, which suggests a complete reversal of the discharge process. This obviously does not happen with the zinc or alkaline batteries. Revitalise is a better description than recharging.

One point worth noting is that much of the folklore relating to the revitalising of primary cells originated very many years ago. Nowadays modern batteries from reputable firms are manufactured with much better quality control and have far better seals. Leakage from old batteries is far less likely now than it was 50 years ago.

Earlier batteries had a different structure from their modern counterparts. Warnings about attempting to recharge earlier batteries were no doubt valid at that time, although as we have already noted, in the fifties, wireless sets were available with a recharger for extending the life of zinc-carbon batteries.

A commercial charger

We mentioned earlier that commercial chargers are now available on the market. We were able to obtain and examine one called the '*Smart Charger*'. This product allows four batteries ranging in size from AAA to D to be charged simultaneously.

The charger has a three-colour led for each cell. Red indicates that the battery is either in the holder the wrong way or is too depleted to be revitalised. Amber indicates that the battery is being charged and green indicates that the battery is fully charged and no current is being applied to the battery.

With old batteries, it never proved possible to arrive at the green colour – even though the battery still had useful energy. It is clear from our experiments that older batteries do not reach the final voltage of a new battery after multiple recharging even though they still deliver a useful capacity.

The charging pattern of the charger is shown in **Fig. 6.** It is interesting that the designer of this charger uses only one half of a mains cycle and splits it into four equal rectangular pulses.

Fig. 6. Output waveform of the Kenwill Smart Charger switches between 4.8V and 1.5V at a 50Hz repetition frequency. Its peak current is about 60mA.

This gives an overall duty cycle of only 35%.

Each pulse is 4.8V and the base line is 1.5V. This charging process should be much slower than ours with its 85% duty cycle. The designer has also realised that pcr is not a necessary requirement for this charger.

Is it worth it?

The main question is, is this process worth doing? Although it is possible to recharge up to about 40 times under controlled conditions, each cycle gives successively less capacity.

Overall, we estimate that you can only increases the life of the best of batteries by five times under optimal conditions. In general – even under optimal condition – three times the life is more common.

As mains electricity is very cheap indeed compared to the price of electicity from a battery – by a factor of about 1:500 – and the cost of such a recharger is no more that about £25 then clearly a charger is worthwhile for any company using batteries regularly.

Even for domestic users, who are not going to measure the end voltage of their batteries, there are worth-while savings to be made. One of us used the charger on batteries at home, mainly from clocks, torches and radios, for around 18 months. The batteries were only recharged when the equipment concerned ceased to function properly, but they were replaced without delay.

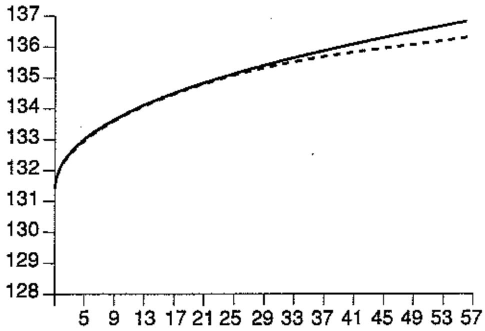


Fig. 7. Comparison between charging with and without pulse charge reversal using the same duty cycle. Upper curve without pcr illsutrates that the negative discharge pulse is not necessary as far as efficient charging is concerned.

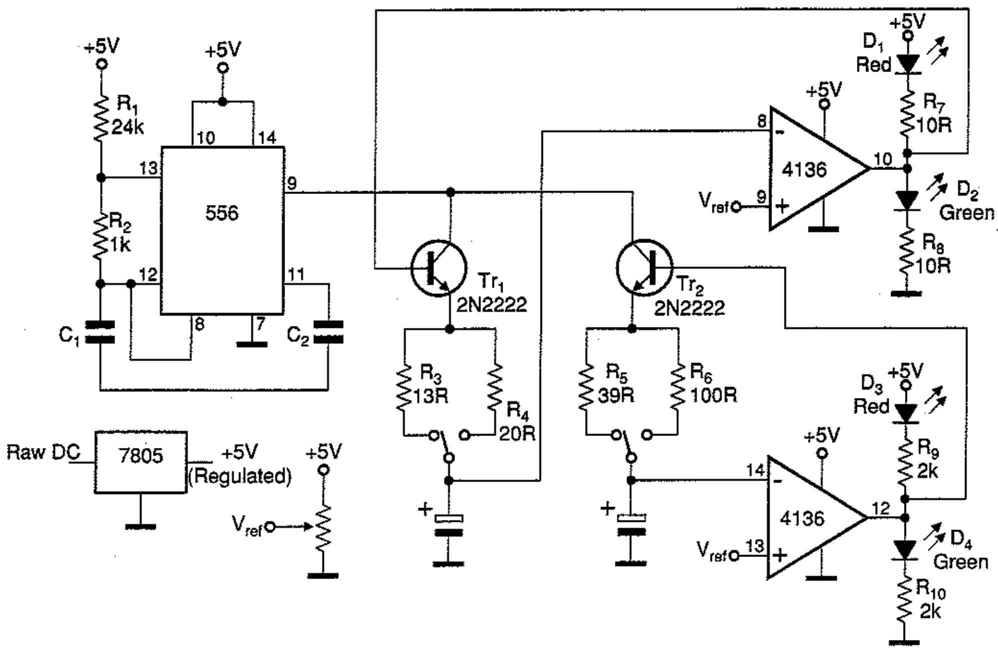


Fig. 8. Primary-cell charger is kept simple since it involves no negative cycle. Our prototype had two of these charging circuits, handling up to four cells.

The charger

The circuit of the charger giving a duty cycle of about 85% is shown here. Resistors R_5 and R_9 set the current for D type batteries, R_6 and R_{10} for C type, R_7 and R_{11} for AA type and R_8 and R_{12} for A-AA type. These can be varied if you want to experiment with the values of the charging current. Power for the charger is provided by an easily available regulated ac/dc adapter rated for 500mA dc and using the 9V output.

To the right hand side of the diagram is a circuit for operating two leds per cell, red and green, which switch on according to the voltage on the battery. This is not very useful though because, as we pointed out in the main text, the end voltages of the batteries vary considerably.

With component values prescribed, the red led comes on when power is applied to the circuit. When a battery is inserted in the holder with the correct polarity, the green led lights. This green light goes out when the preset level, of around 1.6V is reached with the components shown.

If an exhausted battery is inserted, the green light does not come on because the preset voltage is never reached. Such a depleted battery can be left in place for about eight hours. However we have frequently left depleted batteries for more than 24 hours without any problems.

Batteries showing signs of corrosion should not be used under any circumstances.

During the period of this study, not a single battery needed to be replaced. This equates to a saving certainly equal to the cost of such a charger, and a more effective use of environmentally-unfriendly materials.

The alternative to charging alkaline batteries is to use rechargeable nickel-cadmium batteries. These are much more expensive than alkaline batteries and suffer from having a lower voltage, of 1.2V as opposed to 1.5V. Because of this, they are not always a replacement for alkaline or zinc batteries.

Further, the capacity of NiCd batteries is very much lower than that of alkaline batteries – at about an eighth – so you have to recharge at much smaller intervals, which can be annoying.

In summary

It appears that the recharging of zinc carbon and alkaine batteries is perfectly feasible using quite simple charging methods, without resorting to pulse-charge reversal. We consider that the dangers of these techniques have been greatly exaggerated.

While the extension of the battery life is less than that claimed in the advertisements we have seen for commercial chargers of this kind, it is nevertheless useful. ■

Watch out

Do not let what the authors say here make you complacent. Primary cells will explode or leak under adverse conditions, so please take care. Use at least eye and skin protection while experimenting and don't risk building a primary cell charger into expensive equipment – Ed.