

Behind the Portable Power Sources

Part I



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Even before the first electronic device rolled off the production line more than forty years ago, engineers were already searching for ways and means to reduce the weight and volume in every second device designed. Indeed, LSI and VLSI state-of-the-art resulted in an apparent breakthrough in the assembly of consumer electronic gadgets. However, greater the miniaturisation, greater the complexity and chances of failure. A large percentage of supplementary features are discarded in order to squeeze the dream device into your pocket. Ponderous constraints like power output, memory capacity and number of displays—to name a few—arise from the limitations of size, weight and hence the strength of the power sources.

The early portable devices were commodious but inconvenient, and often required a line-feed to balance the cost-benefit ratio. Today, the scene of affairs is changing rapidly. One can find digital clocks placed in anything from necklaces to head bands or at the end of ballpoint pens. The modern day grandfather's clock can select one of any twelve melodies played at every quarter of an hour. However, these devices can be disappointing if, without distorting their external dimensions, adequate driving energy is not provided.

Primary cells

The earliest form of portable electrochemical source of

power was the primary battery. This cell provides current at a certain voltage and gradually exhausts itself with use or on extended storage. The voltage slowly falls with time until the cell becomes unproductive and must be discarded. Energy density (watt hours or milliwatt hours per unit volume), shelf life (percentage of energy density left in the cell after a specified period) and the rate of salting (build up of salt crystals on the external cell surface) vary with the chemical system adopted for the fabrication of the cell. Normally, primary batteries cannot be recharged from an external source, since it may lead to spillage of chemicals and sometimes even cause explosions.

In the near future, thermal or photon power sources, apparently, will not be able to replace the ubiquitous chemical sources presently used in electronic circuits. The only viable competition may come from solar cells, which have yet to become popular. As an entirely separate venture, there is a growing split in the application areas of the principal energy sources. Electronic devices like wrist watches, hand-held games, hearing aids, cameras, flash lights, toys and pacemakers have fared rather well with chemical sources.

In the recent years, manufacturers have tried to accommodate solar cells by lowering the voltage and power consumption of the electronic devices, but this has resulted in a large-scale production of miniature cells and batteries. There is a spectacular boom in the production of throw-away primary cells. The focus of development is directed

mini-power sources along with new packaging and case designs.

The energy stored in a battery is fed into the consuming device, but several factors such as the load current, type of chemicals used, and the size of the device can cause disruptions. The voltage and current fall rapidly at a certain load current. This erratic behaviour results from a tug-of-war between two mechanisms: one generating electricity and the other draining it away. The former is a power house of remarkable capabilities if it is continuously replenished. The latter, often called the 'internal resistance' of the battery, however, puts restrictions on the current, voltage etc and acts like an internal load. Though the internal resistance of battery cannot be eliminated totally, its effects can be reduced by combining a number of sources parallel to each other. For higher voltages and effective power release in a battery, a low internal resistance is imperative.

The most widely used and readily available portable power source is the dry cell (a misnomer, since it is wet inside) belonging to the class of primary cells. A primary cell once charged is used until it is discharged completely and then discarded. The dry cell is a special form of the Leclanche cell. The three popular versions of the primary cell are carbon-zinc, zinc chloride, and alkaline manganese dioxide all packaged in standard cylindrical cases designated as D, C, AA, AAA, and N. Rectangular 9V packages with both the terminals on one end are also available (Table I).

The much talked-about polapulse wafer batteries are nothing but the traditional Leclanche carbon-zinc cells designed by Ray-

nium foil coated with manganese dioxide, while the other side of the battery has another aluminium foil coated with zinc acting as the negative terminal. The cell combination is mounted on a card of proper dimensions, with adhesive bonds around its perimeter providing a sturdy structure. A comparative data is presented in Table II. Polapulse is meant only for very short interval applications. In this respect, its utility is uncomparable to any other size capacity

TABLE II
Comparison of Properties

Load Current Amperes (150 msec)	Potentials Across the Battery of 6-volt Pack		Terminals-Volts
	Zinc-Carbon	Alkaline	Polapulse
0.5	5.5	5.5	6.2
1.0	4.0	5.0	6.1
1.5	3.0	4.5	6.0
2.0	1.5	4.0	6.0
2.5	0.5	3.5	5.9
3.0		3.0	5.8
3.5		2.5	5.6

Mercury batteries have a high energy density and comparatively long shelf life. In comparison with the primary cells, the decline of their voltage level is minimal and they can be discharged either continuously or intermittently without any recovery period. The major shortcoming often cited is their inability to supply short-term high current.

The alkaline cell is highly suitable for continuous heavy duty high-drain conditions. For the same cell size, an alkaline cell can provide twelve times the capacity provided by the carbon-zinc cell. Alkaline cells do not suffer from electrolytic leakage and can also function excellently within a temperature range of -20°C to $+70^{\circ}\text{C}$. If the power consumption is at extremely low temperatures, the appropriate choice is the silver oxide cell which can operate at temperatures as low as -30°C . Its other characteristics are otherwise similar to that of the mercury cells.

Though in the past, lithium cells played second fiddle to most notable energy sources, it is now fulfilling several present day energy requirements. For the convenience of a highly reliable standby power for CMOS RAM retention, lithium cells may prove to be an undisputable compromise.

All lithium cells are non-aqueous units using reactive alkaline lithium with compounds like iron sulphide, copper oxide or manganese dioxide as the cathode. These cells have characteristics similar to those of the alkaline manganese cells fortified with outstanding shelf life. Manganese dioxide-lithium cells are very popular among consumer and industrial applications ranging from wrist watches to calculators to cameras. Manganese dioxide-lithium cells in wrist watches guarantee five years of continuous operation as opposed to the six-month life of the carbon-zinc version of the same dimensions. Another superior version of solid lithium is the carbon fluoride-lithium cell manufactured by:

TABLE I
Standard Cell Housings

Size	Diameter mm	Height mm	Capacity NiCds, mAh
RR	22.6	42.1	1200
SF	41.7	91.3	10,000
AAA	44	11	180
AA	50.2	14.3	500
½ AA	28.1	14.3	250
½ A	28.1	17.3	450
C	49.7	25.9	2200
D	60.5	32.9	4000
F	91.3	32.9	7000
PP3	49(h)	26.5(l)	17.5(b) 110
PP9	81	66	17.52 1200

O-Vac mainly to power SX-70 Polaroid Land cameras. The physical dimensions being the only difference (77.2 mm × 87.6 mm × 4.6 mm), each cell appears like ten playing cards stuck together. Further, it weighs only 28 gm. This cell contains a thin conductive card (the duplex sheet) which is coated on one side with manganese dioxide and the other with zinc. This duplex sheet forms one half of each of the two adjacent 1.5-volt cells separated by a gelled electrolyte deposited on synthetic fibers. This conductive layer precludes the need of soldering or welding as in the case of ordinary

1.5 volts of the iron sulphide-lithium version.

Liquid cathode lithium cells use electrolytes like thionyl chloride, sulphuryl chloride or sulphur dioxide. Of these two, thionyl chloride has the maximum energy density and gives 3.5 volts output. In terms of capacity, these cells are

TABLE III
Energy Density of Cells

Type	Terminal PD volts	Capacity Range mA.H		Energy density W hr/Kg
		min.	max.	
Zinc-Carbon Alkaline	1.5	40	20,000	66
Manganese	1.5	40	20,000	97
Mercury-Zinc	1.35	35	28,000	98
Silver Oxide	1.5	50	750	130
Mercury-Cadmium	0.9	40	800	22
Zinc-Air	1.4	100	1000	220
Sea Water Lithium	1.9	200	2500	200
MnO ₂	2.8	190	1000	180
Nickel-Cd	1.34	750	7000	26
Lead-Acid	2.0	750	8000	24

similar to manganese dioxide or carbon fluoride cells. Conventional C and D sizes of thionyl chloride liquid lithium cells are manufactured by Saft and Taridan, Israel. The sulphur dioxide version of the 2.9V lithium cell is available from Duracell. The main area of consumption for liquid lithium cells is as semiconductor memory back-ups, aircraft rescue beacons, telemetric instruments, transceivers and in a variety of consumer, industrial, medical, scientific and military applications.

Some of the sulphur dioxide-lithium batteries have shown catastrophic failure within two or three years of operation. Researchers at the Sandia National Labs, USA found the cause to be the corrosion of the high quality silicon glass used to isolate the anode of the cell from the cathode. This problem was overcome by the introduction of a new, highly corrosion-resistant insulator called TA-23 glass which has significantly more alumina in its composition and contains about 20 per cent less silica than the conventional glass electrical insulators. According to the Sandia engineers, TA-23 glass helps reduce corrosion by at least a factor of 1000 as compared to the ordinary glass insulators. Further modifications may even increase this corrosion resistance factor to 10,000, guaranteeing the life of sulphur dioxide-lithium cells beyond five years. The Ferro Corporation, USA has undertaken the task of large-scale production of TA-23 glass, a progress towards the era of reliable high-stability batteries.

The zinc-air cells have received enormous stimulus today from acute requirements of highly inactive power sources while they are dormant or in no-load state. Zinc-air cells use oxygen as the positive electrode, while zinc acts as the negative electrode, the electrolyte being potassium hydroxide. The cell is activated by removing the tape seal stuck over an extremely narrow air hole which admits oxygen into the cell.

Vac are the pioneers in this field. Due to its simplicity in use and excellent shelf life, zinc-air button cells are preferred in hearing aids, made to customers' order and requirements.

Sea-water activated cells are an alternative to zinc-air, but are meant only for emergency use at sea with survival kits, location beacons, rescue buoys and May-Day callers. Based on either magnesium-silver chloride or magnesium-cuprous chloride, these cells activate within a few seconds of the electrodes coming in contact with the sea water. The cell has a shelf life well above six years and, under favourable conditions, its output voltage approximates to 1.9 volts. This is a special-purpose battery supplied according to the customers' orders. The major drawback is this cell's unreliability at temperatures close to zero and it may not get excited at sub-zero levels at all.

Secondary cells

The discharge-charge reactions for secondary cells are chemically reversible, i.e. after discharge they can be recharged by applying an external DC source and the discharge-charge cycle repeated. Also they can be recharged any number of times, restoring them to full operational voltage. They are commonly used in high current applications.

Lead-acid cells are available in a wide range of shapes and considered to be the best among the general-purpose batteries. Nickel-cadmium, or nickel-iron is the second among the secondary cells. A good many of these cells are interchangeable with the standard sizes of primary cells and are believed to be advantageous if the recharging facilities are readily available. Another alternative is the expensive silver-zinc batteries with outstanding high energy storage per unit volume and weight. These are used in instruments where low weight and high output are of supreme importance.

The positive electrode of the NiCds is formed by nickel hydroxide which bridges the negative electrode of metallic cadmium through the electrolyte potassium hydroxide. These cells are hermetically sealed. The voltage output is only 1.2 volts per cell as against 1.5 volts from carbon-zinc dry cell. A number of manufacturers produce cells of different capacities for a given size, ranging from 150 mA.h to 7 Ah at a 5-hr rate. Though nickel-cadmium cells may cost four to five times the price of dry batteries, their rechargeability offers a potential saving in the long run. Application areas are calculators, portable tools, toys, computer memories, transceivers, aircraft ignition systems and other transistorised systems.

Lead-acid and NiCd cells both have their advantages and disadvantages. Lead-acid cells are bulkier but their charging conditions are not as stringent as that of NiCds since the latter must be discharged completely before charging in order to achieve maximum capacity. Besides, NiCds' charging characteristics are dependent on the case ambient temperature and the internal pressure. If the process of recharging is

not carefully controlled, there is also a strong possibility of an explosion. Table IV shows that for quick charging, the initial rise in temperature is very rapid with a nominal

TABLE IV
Typical NiCd Fast Charging Pattern

Cell Charge per cent	Terminal PD volts	Rise in Temperature °C	Rise in Pressure per cent
25	1.43	30	10
40	1.44	32	12
50	1.44	34	15
60	1.45	36	17
70	1.45	38	18
80	1.46	40	20
90	1.47	42	35
100	1.48	45	40
110	1.49	47	60
120	1.48	47	100

Note: Ambient/initial cell temperature 28°C; initial pressure 76cm of mercury.

change in internal pressure. A further increase in the internal temperature with respect to the percentage charge is sluggish but offers a drastic change in its internal pressure. In an overcharged state, the internal pressure shoots up along with the drop in the cell voltage. Any further attempt to overcharge may culminate in an explosion. However, all cells may not explode due to variations in the tensile strength of the case or container.

Cell sizes and potential

The size of the cell is more decisive in its ability to deliver the current into the load, but this cannot be completely expressed in terms of the capacity of the cell. Though its voltage may be equal to that of a cell of the same family, the current capacity of a cell depends on its size. The selection of a battery size for an instrument depends on its current requirement, frequency and duration of usage. For AAA cells, a 30mA current may prove to be quite heavy, while it is apparently light for D cells. This general statement is valid only if the time for which the load receives the current from the cell is convincingly long, say, a few minutes. If the duration is only a few milliseconds and the passivity after the 'on' state is of the order of a few-hours, the same AAA cells can withstand 30mA of current without an abrupt change in voltage. The majority of cells, especially the carbon-zinc have the ability to rejuvenate, showing an appreciable increase in its terminal voltage level. Intermittent operations at low current levels show a remarkable extension of the usable life span.

Measuring the cell potential is another erroneous area. The cell potential differs substantially under load conditions due to the presence of its own internal resistance. If the internal resistance of the voltmeter is extremely high, the current through it is negligible and the measured voltage under these conditions closes on to the emf of the cell. The reduction in the cell voltage is due to the source resistance or

the internal resistance of the cell. For an ideal cell, this internal resistance is zero. However, in practical cases, low internal resistance of the source improves its capacity. The voltage drop across the internal source resistance increases with the increase in load current. Hence, the cell potential is best indicated only at the given load. To avoid false level indications, the terminal voltage of the cell is measured with a dummy load across it. The dummy load can be determined by the simple rule V/I , where V is the no-load voltage and I the load current. This method is reliable only up to a meter rating of 100k per volt, below which the meter resistance at the given range has to be considered as a parallel combination of dummy resistance.

In general, larger cells have better shelf life. For example, the 9-volt PP3 battery has a better shelf life than that of AAA cells. The use of leak-resistant double jackets and storage at low temperatures, preferably at sub-zero levels considerably extends the shelf life of the batteries. High body-ambient temperature and humidity are inversely related to the shelf life. To ensure the maximum benefit, miniature button cells are often sealed in partially evacuated plastic capsules. Once it is removed from this capsule, a gradual and continuous decay sets in. In this regard, both mercury and lithium cells show excellent storage characteristics.

The accumulation of hydrogen on the electrode during discharge is called polarisation. The purpose of special cathode materials is to overcome this effect and are thus often known as depolarisers. Polarisation results as a change in the electrode potential, electrolyte composition and blocking of electrodes by resultant products. These effects are separately identified as polarisation by concentration and mass transport action. The lack of instantaneous depolarisation tends to decline the theoretical properties of the cell. Since the effect of polarisation is unavoidable, no cell can provide a theoretical output voltage and current while it is in use.

Packages of button cells are invariably cylindrical but their dimensions vary immensely. The most common specification is 8mm diameter and 3mm height (often coded by the number.392 and 192). Other versions are 7.5mm(d)×5mm(h) (often coded as 193), 11.6mm(d)×2mm(h), 11.6mm(d)×3mm(h) and 16mm(d)×11.6mm(h). Button cell blocks of 9V, 90 mAh are also available.

A common size standard and nomenclature has not yet been adopted in the area of primary or secondary cells as in the case of electronic components. However, PX and MN numbers have become common codes for mercury and alkaline batteries. Solar cells often adopt the semiconductor terms like BPX. Sizes also vary drastically but a common directive is bound to emerge soon.

Unlike electronic devices and components, brand image of cell manufacturers has not yet reached its full potential. However, cells and batteries made in India are rarely found in the market even though they are manufactured in collabo-

ration with prominent and experienced foreign companies. Japanese manufacturers like Hitachi, Toshiba, Sakura, Yuasa, Sanyo and Matsushita are popular probably due to the overflow of their electronic goods which carry these batteries. Other manufacturers are Duracell, Philips, Ray-O-Vac, Union Carbide, Varta (Germany), General Electric, Gould, Elpower, Globe Union, Honeywell, Saft & Tadiran (Telaviv, Israel), Stottron (UK) etc. The only prominent Indian manufacturer is the Tamil Nadu Alkaline Batteries Ltd (IABC) which manufactures batteries in collaboration with Yardney Electric Corporation, USA.

Recharging power sources

A good rechargeable power source is marked by its outstanding float and cyclical characteristics in addition to the superior storage life. Much more has been said about NiCd's than about any other rechargeable version of batteries. A chain of electronic circuitry has been developed to support the ailing NiCd's, yet under normal use their life is limited to around 500 to 1000 recharge cycles which can spread over two to three years. For this, the cells have to be discharged fully at least twice a month and then recharged accordingly. Repeated instances of excessive battery discharging and delayed passive state before the next recharge may permanently damage the battery pack. And even so, a chargeless dead time of three months after the battery is fully discharged (which is very common in normal use), will spell the end of its life. Even the best variety of NiCd's can rarely withstand a few repetitions of chargeless dead time of 24 hours.

Four basic approaches to all recharging processes are widely used today: (i) trickle charging, (ii) normal charging, (iii) fast charging, and (iv) ultrafast charging. The first two are time consuming processes but relatively simple and safe. However, the uncertainty always remains as to how well the cell has been charged and how many usable hours will result from it. In the case of fast and ultrafast charging, it is wise to check the procedure and its reliability against the manufacturers' directives.

The ampere-hour capacity of a cell determines the charging rate of the cell packs. A charging rate of 0.1 for AA pack will be around 50 mA which is the product of its ampere-hour capacity and the charging rate. Similarly, a charging rate of 0.5 for a PP9 packs falls around 600 mA from a constant current source. Charging rates are usually denoted by 0.1C or 0.5C etc.

Trickle charging techniques are employed where the self discharge of the pack is to be compensated. This is almost inevitable in standby packs as in the case of memory circuits, where they come into action for only a very short duration when the leading supply fails. Primary as well as secondary sources are subjected to the trickle charging process. Trickle charging is relatively more effective in dry cells and alkaline sources. On an average, the charging rate is around 0.01C and may increase momentarily to 0.02C-0.05C when the pack returns to its standby mode. No appreciable change in

temperature of the cell is expected during this process.

The safe normal charging rate is considered to be around 0.1C. In the case of NiCd's, the duration of charging extends from 10 to 14 hours. A considerable change in cell temperature is expected but it will usually be only lukewarm. These power sources are meant to discharge soon after the charging process. In contrast to this, the devices which profit from the quick charging process are the heavy duty versions, which warrant the back-up services of the cell sources very frequently. The sole purpose of this sort of hasty charging is to increase the redundancy and reliability of the leading unit. For NiCd's, the charging hours can be reduced to 1-3 hours by a fast rate of 0.3C to 1C, but the cells might become hot. After the fast charging, the cells can be reused within hours. This cooling period is the major drawback of the fast charging technique.

There are several reasons to avoid the ultra-fast charging method. A majority of the presently available cells do not permit this process in regard to their shelf life and discharge characteristics. The ultra-fast charge rate is around 20C within a repetitive pace of few minutes until the system accepts full charge. The individual cell life in the battery pack is difficult to predict, but on an average it is much less than the life span offered by the cells charged by other methods. If all the cells in a battery pack do not have approximately identical characteristics, fast charging becomes increasingly difficult, eventually becoming highly resistant to any further charging attempts. Ultra-fast chargers are normally equipped with the facility for discharging the cells fully before the onset of charging cycles.



Nickel-cadmium cells are recharged periodically or trickle charged continuously, thus being more cost effective than primary batteries which cannot be recharged. On the other hand, rechargeable batteries can only be justified if their portability is fully exploited. If the device is only used indoors or at a place where the power supply is more economical, it is better to use the mains supply leaving the cells as a standby mode. Hearing aids and some of the bio-medical remote controls have a peculiar pattern for power

consumption filled with intermittent lay-offs. Rechargeable cells are extremely beneficial in these cases where the charging pattern of the cells can be very well maintained.

A good charger should be equipped with charge indicators and, if possible, a monitor for the polarity of the cell.

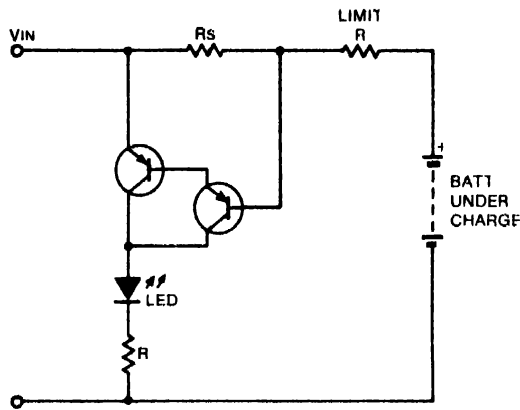


Fig. 1: Battery charge indicator.

The circuit in Fig. 1 gives a good charging indication which can be connected with any charging device, provided the current determining elements are precise and calculated. The base-emitter drop of the transistor is provided by the sensing resistor R_s which can be calculated by the simple relationship

$$R_s = 1200 / I$$

where I is the charge current in milliamperes. When the cells are subjected to a charge, current flows through the sensing resistor causing a voltage drop across it and turning on the darlington combination. Thus, the LED indication will appear only when the cells on charge draw some current.

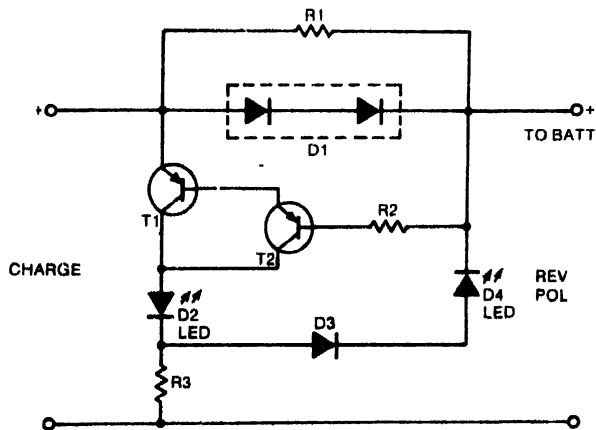


Fig. 2: Battery charge and polarity indicator.

A minor modification for charge indicator will help detect wrong polarities of the cells under charge (Fig. 2). Here, diode D_1 provides the base-emitter drive to the transistor. The resistor across D_1 bypasses sufficient current into the cells under charge. As long as the cells are charging, the darlington pair will get sufficient drive, turning on LED D_2 . The presence of D_2 indirectly provides a means for the

charge regulation. Diode D_2 lights as soon as the current flows through diode D_1 or resistor R_1 . Diode D_3 and LED D_4 take care of the polarity reversal problems. Under the reversed polarity conditions, diode D_3 will be forward biased, turning on LED D_4 .

Variable three-terminal regulators like LM317 peg the output voltage within very close limits over a wide range of input voltage variations and output load variations. This also eliminates the need to stock several voltages. Basically, these can be considered as a combination of a high-gain error amplifier and a pass transistor. The error amplifier monitors the output of the emitter-follower and adjusts the drive to the power transistor keeping the output voltage within tight limits. The whole system is so adjusted that it maintains a constant current through R_2 with an output voltage specified by the equation

$$1.25 \left(1 + \frac{R_2}{R_1} \right)$$

This current source can be made use of as a charger, especially for NiCds, which unlike lead-acid batteries have to be charged at a constant current. The charging rate can be fully controlled by inserting a series resistor R_s as given in Fig. 3. Then, the source impedance is set by the equation

$$R_s \left(1 + \frac{R_2}{R_1} \right)$$

An interesting modification is possible by introducing a

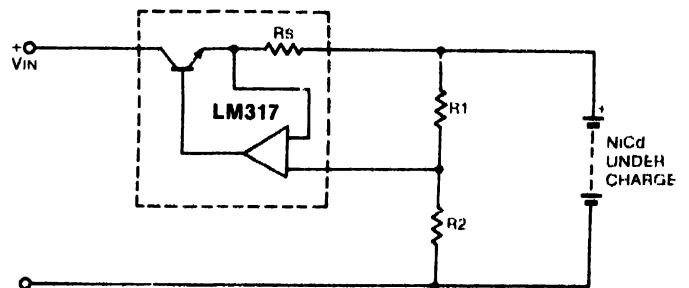


Fig. 3: Variable power source for battery charging.

limiting circuit at the adjust terminal of the regulator. The maximum current that can pass through the cells to be charged is dictated by the sense resistor R_s (Fig. 4). Under these conditions, the adjust transistor remains active due to

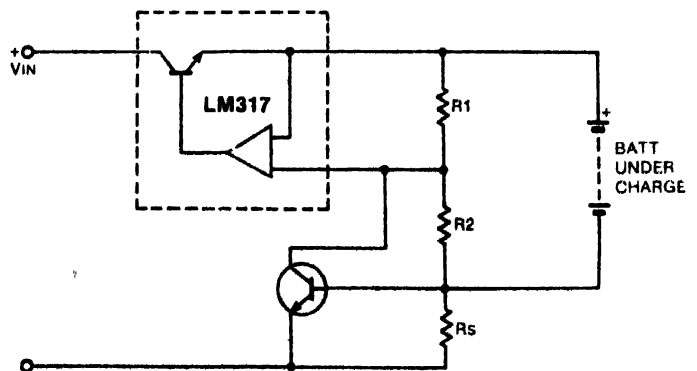


Fig. 4: Battery charger with limiter.

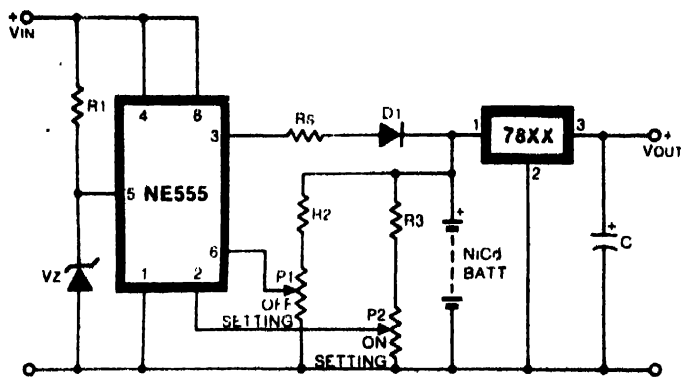


Fig. 5: NiCd standby: mode I.

the base-emitter drive and the charge rate is gradually decreased according to the voltage level developed by the cells.

555 timers are equally popular in battery charging and monitoring circuits. The circuit in Fig. 5 keeps up the full charge in a standby battery supply for any instrument that requires an uninterrupted power supply, but normally draws power from a step-down mains supply. The timer uses a reference voltage by means of a zener diode. The threshold and trigger terminals are used to monitor the maximum and the minimum voltage of the cells under standby mode. In the case of NiCds, the maximum voltage can be 1.4 volts per cell and minimum 1.2 volts per cell. The timer turns on as soon as the trigger terminal senses the preset minimum voltage.

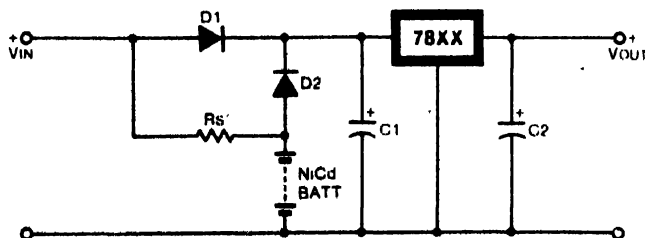


Fig. 6: NiCd standby: mode II.

While it is on, the timer supplies a constant current into the standby battery, the magnitude of which is governed by the series resistor R_s . The output is then regulated by a three-terminal fixed voltage regulator. This supply is almost uninterrupted if there is a short-time power failure.

A majority of the recent versions of the VCRs and video cameras are made to run on rechargeable 12-volt NiCds or alkaline cells. The current consumption is kept to a minimum and a trade-off is adopted between battery size, weight and the video recording time. For example, the VCR of type JVC HR2200 employs a NiCd battery mainly to reduce the weight, sacrificing a number of possible extra functions and features. The set up in this VCR can be approximated as in Fig. 7. To charge the battery, switch S1 is pressed to energise the relay. The two sets of relay contact switches SR1 and SR2 become active, connecting the charge supply through D2 in series with the resistor-thermistor combination and the relay drive is achieved through D3. The resistor-

thermistor combination tends to behave like a constant current supply to the charging cells.

The charging rate is fairly faster than normal, hence the cell temperature rises rapidly. At a specified temperature, the thermal switch which is at close proximity to the body of the charging cells opens up, thus stopping the relay from continuing in its active state. Apart from this auto-stopping facility, the normally-closed switch S2 can be opened to return to its main supply mode. Here, the cells are in touch with the charging unit but very little charging takes place due to the voltage drop across diodes D1 and D2. This trickle charging technique keeps the minor losses of the charged cells at a minimum.

A completely self-contained portable oscilloscope is a dream device for electronic enthusiasts. 'Tektronix-221' portable oscilloscope weighs only 2.9 kg and measures 7.5cm x 23cm x 13cm with a display that measures 6.4cm diagonally.

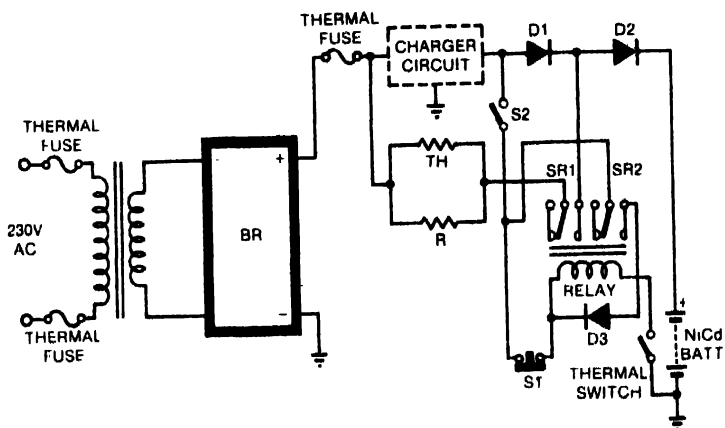


Fig. 7: Typical VCR charger supply.

This is powered from ten A-size NiCd batteries and with full charge it can run for two to three hours. If the mains supply is available, it can run on mains simultaneously charging the NiCds.

A battery indicator on the oscilloscope shows full, low and recharge conditions. When showing recharge, it indicates that the battery charge has dropped to less than 10 volts and a battery discharge protection circuit has interrupted the operation of the oscilloscope to prevent excessive discharge. When the indicator reads low, there are less than ten minutes of operating time left in the system. Obviously, the discharge rate of the battery is a direct function of the trace intensity. In spite of all these restrictions, the controls on the oscilloscope do not differ too much from a standard oscilloscope. The maximum safe input voltage is 600 volts peak-to-peak AC or 600 volts positive DC. The timing of the internal sweep generator spreads from 200ms to 1 μ s per division. 'Tektronix-221' oscilloscope can operate over a large line voltage range with an AC range from 90 to 250 volts at a frequency of 48 to 62Hz and a DC operating range from 80 to 250 volts.

(To be continued)