# DESIGN AND STUDY OF AUDIO- AMPLIFIER AND RADIO-RECEIVER USING TRANSISTORS

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TRANSISTORS are nowadays being used more and more in hearing aids, radio and television receivers and other tele-communication equipment. Being of recent origin the transistors are constantly being improved by the manufacturers. Alongside of this, there is ample scope for improving the performance of existing units through better circuit designs.

Many circuit designs of transistor amplifiers and receivers are available in the current literature, in most of which interstage transformer coupling has been used. However, in hearing-aid circuits, resistance-capacity coupling has found favour due to compactness and light weight. Power handling capacity of hearing aid transistors is small and so even for hearing aid amplifiers a number of transistors have to be used. The successful use of transistors in hearing aid encouraged us to build low cost and light weight audio-amplifiers of different designs and to study their performance characteristics. Three different types of amplifiers using three hearing-aid type transistors (number OC70/OC71) in each were built. For each of the three amplifiers, the relative voltage gain at different frequencies and also at different input levels was measured. Moreover, the harmonic distortion in all the three amplifiers was studied.

Finally a semi-conductor diode was incorporated in one of the amplifiers to convert it into a radio receiver.

## Design

In using a transistor in place of a radio valve either the base or the collector or the emitter may be earthed. Each method has its advantages and disadvantages. For example, when an amplifier is built in the earthed emitter to earth-emitter arrangement, it has a high gain, but its distortion figure is also correspondingly high. For low distortion, an earthed base arrangement is suitable.

Our aim was to use hearing aid transistors giving the high voltage gain needed for a radio receiver. So in our design, the earthed emitter arrangement was preferred. Our next step was to find out a suitable cascading arrangement which would give low distortion.

Now the input and output impedances are given by the following equations :

$$R_{in} = r_{11} - \frac{r_{12}r_{21}}{r_{22}+R_L} \quad \ldots\ldots\ldots\ldots(1)$$

$$\text{and, } R_{out} = r_{22} - \frac{r_{12}r_{21}}{r_{11}+R_S} \quad \ldots\ldots\ldots\ldots(2)$$

where $r_{11}$ = incremental emitter resistance for an incrementally open-circuited collector.

$r_{12}$ = incremental backward transfer resistance for an incrementally open-circuited emitter.

$r_{21}$ = incremental forward transfer resistance for an incrementally open-circuited collector.

$r_{22}$ = incremental collector resistance for an incrementally open-circuited emitter.

$R_L$ = load resistance.

$R_S$ = resistance of the signal source.

The presence of the load impedance term $R_L$ in (1) and the source impedance term $R_S$ in (2) indicates that there is much more interaction between the input and the output than there is in a valve. Thus cascading transistors need rather a careful arrangement.

In our design the values of resistors $R_1$, $R_2$, $R_3$ and $R_4$ (fig. 1) for stability of the circuits were determined empirically. The potential divider controls the base bias, $R_4$ is used for stabilising negative feed back, and $R_3$ is the load resistance. All the components were of standard sizes used in valve circuits.

## Gain and Distortion

Schematic diagram of the experimental set up for the measurement of gain is shown in figure (2). For the distortion measurement, the output meter was replaced by the distortion analyser.

The output of the signal generator was connected to a potentiometer which in turn

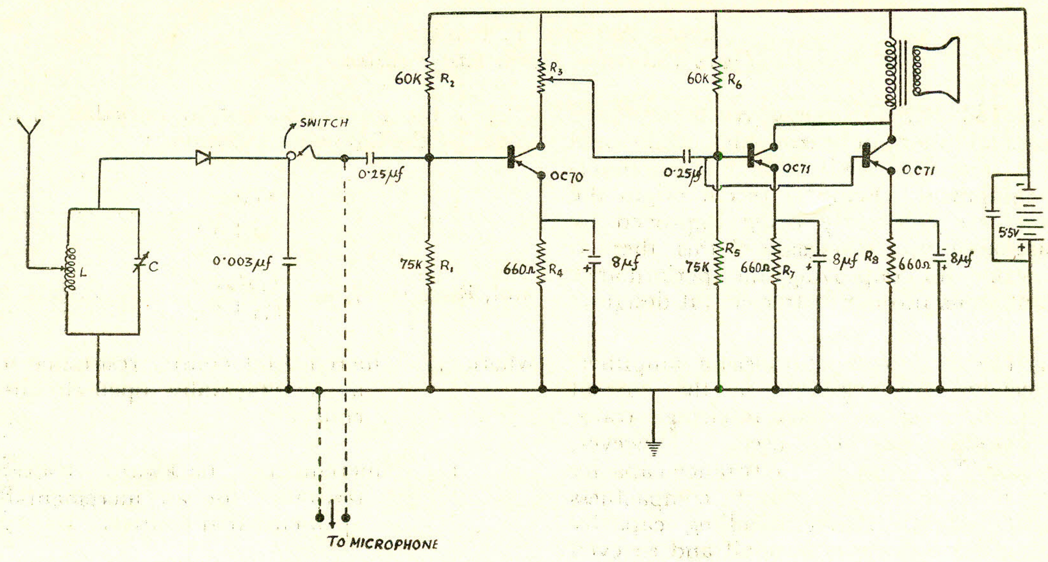


Fig. 1.—Circuit diagram of a transistor receiver.

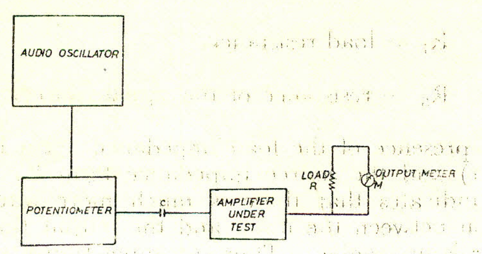


Fig. 2.—Schematic diagram of apparatus for measuring circuit gain.

was coupled to the amplifier input by means of a coupling condenser C. The amplified output voltage was developed across the load R. An output meter (M) was connected across the load. Two series of measurements were made. In the first case the frequency of the signal was kept constant while the amplitude was varied and in the second case the amplitude of the signal was kept constant while the frequency was varied. The gain of the amplifier is given by the formula :

$$N_{db} = 20 \log V_2/V_1 + 10 \log Z_1/Z_2 + 10 \log K_2/K_1$$

where subscript 1 refers to input and 2 refers to the output. V, Z, K denote voltage, impedance and power factors respectively. It should be noted that for a resistive load the last term vanishes. When the input and output resistances are equal, the second term also vanishes. If, however, they are not equal, $20 \log V_2/V_1$ shows the nature of the gain curve but does not give its value.

In measuring distortion both type TF455D/1 Wave Analyser of Marconi and Model 330B distortion analyser of Hewlett-Packard were used. The signal source was Model 206A Audio Oscillator of Hewlett and Packard. The experimental arrangement was similar to that in the previous case except that in place of the output meter the distortion analyser or Marconi Wave analyser was used. The distortion analyser measured the percentage of total distortion while the wave analyser measured the percentage of distortion due to any of the harmonics. As in the case of gain measurements, the distortion was measured for different amplitudes of the signal at a constant frequency and for different frequencies at a constant input signal level.

Some of the experimental results are shown graphically, (figs. 3-6).

The present investigation has shown that hearing aid transistors can deliver enough

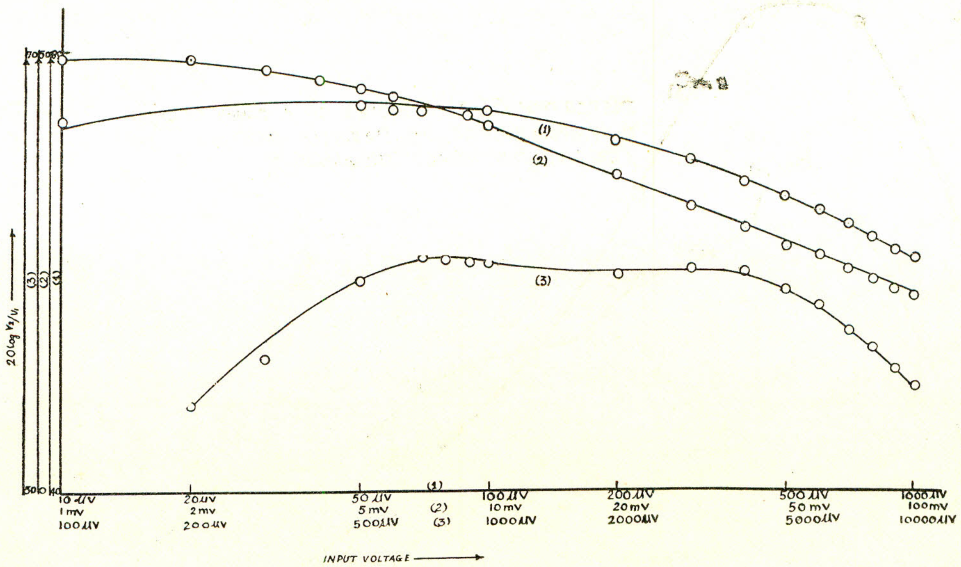


Fig. 3.

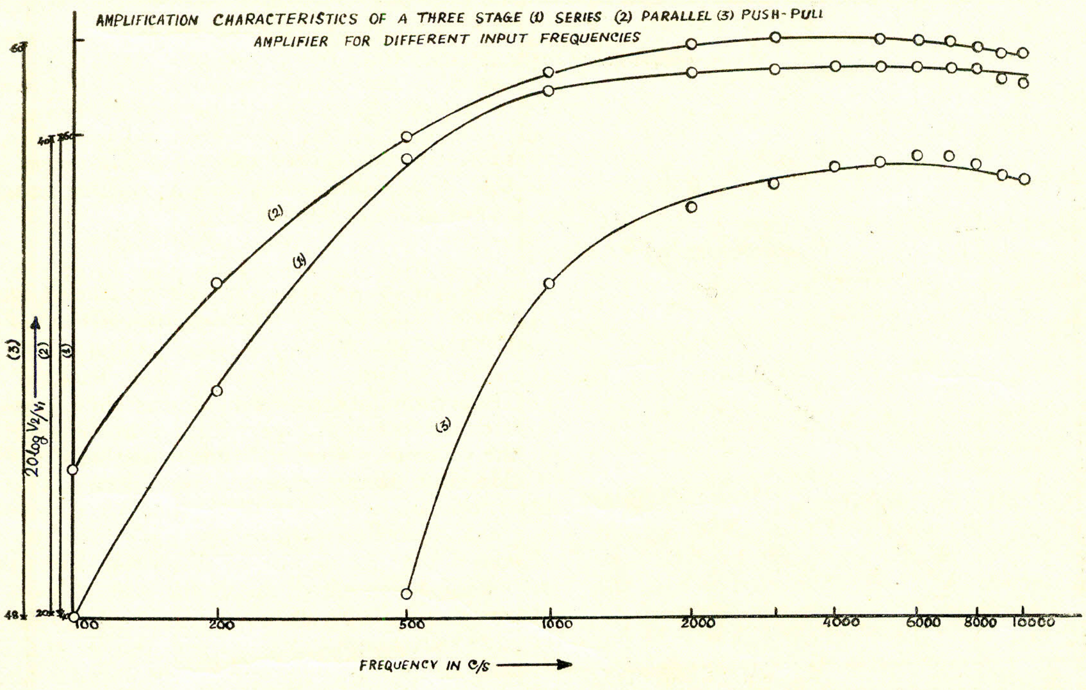


Fig. 4.

power even when R-C coupling is used. These transistors were found to be most suitable for low level amplifications. Cascading of more than two of them in series lowered the overall voltage gain and increased distortion when the input signal was as high as 10 mV. At 1 mV input the overall amplification for three stage series, parallel or push-pull amplifiers were

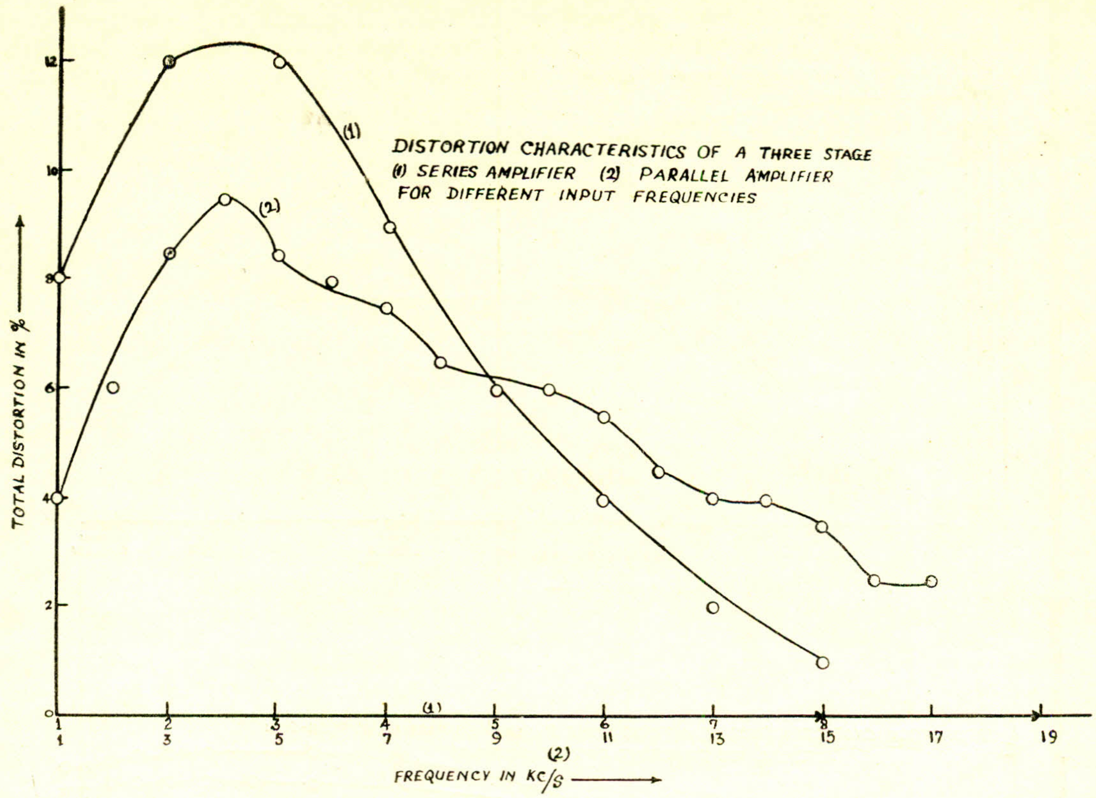


Fig. 5.

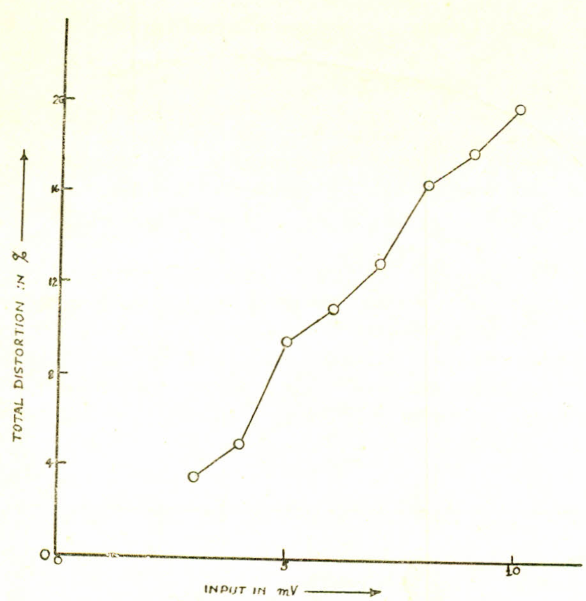


Fig. 6.

found to be higher than two stage ones. However, the overall amplification for parallel amplifier at this low input level was less compared to that of other two types, but at the same time the percentage of distortion in this case was lower compared to other arrangements.

At 0.03 mV input the voltage amplification was as high as 5,000 in the case of three-stage series arrangement.

The amplification was found to increase with increasing supply voltage till it reached the value of 5.5 volts. beyond which the amplification remained more or less constant.

### The Receiver

By adding a detector stage to any audio amplifier, it is possible to convert it into a radio receiver provided the rectified signal is strong enough for the amplifier. Since our transistors were of the low level type, the amplifier was suitable for such conversion. Because of low distortion and fewer component requirement the parallel amplifier was selected. A germanium crystal diode with a tuning circuit was added to the amplifier and it was converted into a good local receiver.

At a distance of about 20 miles from the local radio station the programme was very clearly heard with good loudspeaker strength using an improvised antenna. At night the programme from Calcutta and even Ceylon could be heard in loudspeaker strength, but the fading was severe.

The power consumption was only 5 ma at 6 volts. Thus four flash-light cells would supply enough power to operate the receiver for several hundred hours.

Since resistance-capacity coupling was used throughout, the initial cost of the receiver was also comparatively low.

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# DESIGN OF AN IMPROVED TYPE OF DRY CELL

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THE dry Leclanche cell, which has proved itself to be a most convenient and fully proved source of portable power, is today one of the major callers on the world zinc supplies, because of its variety of uses, which include portable telecommunication equipment, hearing aid appliances, portable wireless receivers, and transisterized electronic equipment. In the usual type of dry-cell, only a small fraction of the zinc forming the outer vessel is utilized chemically. It is, therefore, of considerable importance to investigate methods for a more economic utilization of the zinc in such cells.

The present investigation aims at (a) improving the quality of the dry-cell by giving it longer life and (b) incorporating the minimum possible quantity of zinc compatible with proper working of the cell. The essential feature of our new design is that the zinc is in the form of a fin-shaped rod and constitutes the inner electrode instead of the outer one as in the usual type of dry-cell. Two cells using the same quantities of the chemicals in identical proportions were prepared, one according to the usual pattern and the other according to our improved design. These two cells were discharged under identical conditions of test so that a comparative study of their performances was made.

The investigation was restricted to a measurement of the relative power output of the two cells. Due to the non-availability of the proper quality of the chemical ingredients, an exhaustive study of the improved cells could not be made, neither was a direct comparison of these cells possible with the commercially manufactured cells. Nevertheless, the superiority of the improved type of cells over the conventional design appears to be proved by our comparative methods of test. It is hoped that the present communication will induce manufacturers in our country to make a break with tradition and try out the new type of cell.

## Theoretical Considerations

The Leclanche cell produces a current of electricity by the chemical consumption of zinc, the flow of electricity through the external load circuit being maintained by the chemical energy liberated in the following reaction :

$$2NH_4Cl + Zn = Zn\,Cl_2 + 2NH_3 + 2H$$

To counteract the polarization caused by the liberated hydrogen, manganese dioxide is used as the de-polariser. Its action, which occurs in the immediate vicinity of the carbon electrode, can be represented approximately by the following equation :

$$2MnO_2 + 2H = Mn_2O_3 + H_2O$$

The de-polarization, however, soon becomes less effective, perhaps because of the actual chemical reaction being more complex than indicated by the above equation. Therefore, the effectiveness and the voltage of the cell drops sharply if it is used continuously for extended periods.

Assuming that the zinc is used with 100% efficiency, it is easy to calculate how many ampere hours will be produced by an average cell, whose zinc container weighs approximately 19 g. Since one g. equivalent (*i.e.*, 32.7 g.) of zinc if consumed will produce one faraday of electricity *i.e.*, 96,450 coulombs, it follows that 19 g. of zinc would produce $96{,}450 \times \frac{19}{32.7} = 56{,}000$ coulombs, *i.e.*, $\frac{56{,}000}{60 \times 60} = 15.6$ ampere hours. Thus, if the zinc is completely consumed, our cell should give 15.6 ampere hours as against the normal rating of about three ampere hours. It follows that only about 20% of the zinc is usefully consumed, the major part going waste.

### Constructional Details

Figure 1 shows the constructional details of a conventional type of dry-cell. The carbon rod together with the de-polarizing paste are to be considered as a composite electrode, the de-polarizing action taking place at the outer surface of the paste and proceeding inwards as the cell is progressively discharged. Between the de-polarizing paste and the zinc container is the electrolytic paste. The electrolyte is made up of ammonium chloride, zinc chloride, starch, and plaster of Paris, with enough water to make a paste. The de-polarizing mixture is usually made up of $MnO_2$ and graphite together with a small proportion of the electrolyte. The exact compositions are, of course, a trade secret.

Some suitable methods must be adopted to prevent the carbon rod and the de-polarizing paste from touching the bottom of the zinc container, otherwise a short-circuit results ; this separation is usually accomplished by putting an insulating material such as cardboard, soaked in paraffin wax (seen at E in figure 1) in the bottom of the zinc can. The dimensions of a medium (torch) dry cell are as below :

| | |
|---|---|
| Length of the prepared zinc can . . | $2\frac{1}{4}$ in. |
| Diameter of the can . . . . | $1\frac{1}{4}$ in. |
| Weight of the zinc used in the can | 19 g. |
| Weight of depolarizing mixture . . | 46 g. |
| Weight of electrolytic paste . . | 10.25 g. |

The modified dry-cell proposed by the authors is essentially a sort of inverted cell (fig. 2) with the zinc electrode in the middle and the carbon electrode on the outside of the cell. The zinc electrode is fin-shaped as shown in figure 3. The outer carbon electrode is prepared by taking a hollow glass-tube, with a small hole at the bottom, into which fits a binding terminal of copper, and depositing graphite powder on the inner surface of the tube. The deposition was done by making the graphite powder in the form of a suitable paste by adding a little sticky substance to it. The paste was then spread uniformly over the inner surface of the tube and then allowed to dry up. This method is defective because it increases the internal resistance of the cell due to non-compactness of the graphite particles. The internal resistance of the cell could be reduced considerably if the outer carbon (graphite) electrode could be made by hydraulic pressure, so that the carbon granules would be much more compact. But unfortunately no such press was available in our laboratory.

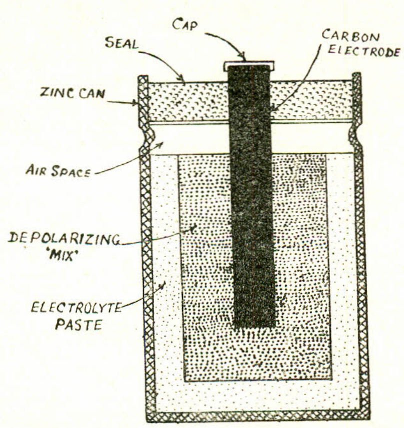


Fig. 1.—Conventional dry cell.

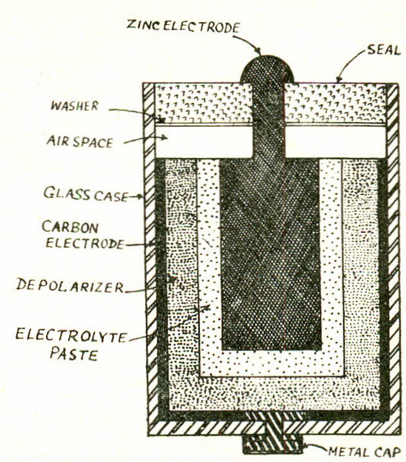


Fig. 2.—Proposed inverted dry cell.

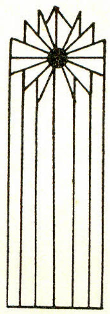

Fig. 3.—Zinc electrode in proposed cell.

Having prepared the carbon electrode, the depolarizing mix was placed inside it and pressed sufficiently, keeping a gap for introducing the electrolytic paste which surrounded the fin-shaped zinc electrode. The electrolytic paste with the zinc electrode was then placed in the gap. Any residual space left was filled in by pouring the electrolytic paste in it and then allowing the paste to set. The rest was done as in the previous case. The preparation of the depolarising mix and the electrolytic paste was also similar to the previous case. The exact arrangement is shown in figure 2.

Dimensional and other data are given below :—

| | |
|---|---|
| Weight of the fin-shaped zinc electrode .. .. | 19 g. |
| Diameter of the fin-shaped zinc electrode .. .. | ¾ in. |
| Length of the fin-shaped zinc electrode .. .. | 2 in. |
| Weight of the depolarising mix .. | 46 g. |
| Weight of the electrolytic paste .. | 10.25 g. |
| Length of the glass tube .. | 2½ in. |
| Inner diameter of the glass tube .. | 1¼ in. |

The two cells thus prepared were then put under experimental test.

## Testing Procedure

The two cells were connected to two separate but similar circuits and were allowed to discharge through a resistance (fig. 4). The two cells were subjected to continuous discharge. In the discharge process the current was kept constant by varying the ohmite rheostat R and the fall of voltage with time was noted. The cells were discharged till they attained a closed-circuit voltage of value 0.10 volt. The total ampere hour obtained for each individual case was then calculated.

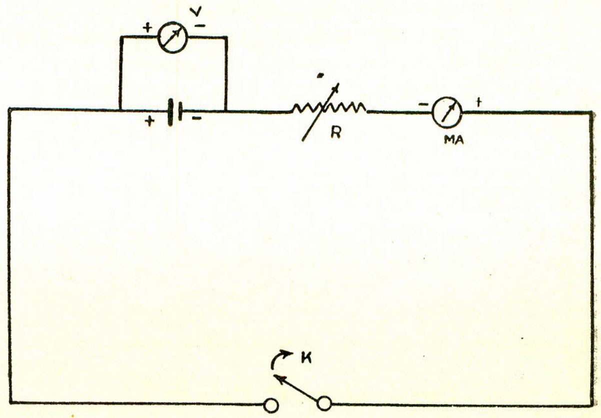


Fig. 4.—Discharge circuit.

The usual way of discharging a cell is by an intermittent process *i.e.*, to discharge the cell for a convenient period, then to stop discharging and again to start the process. But we discharged the cell continuously *i.e.*, under the most unfavourable condition with a view to establishing the fact that performance will definitely be better under the intermittent process than under the continuous process of discharging.

It is to be noted that in the case of both the conventional cell and the improved type of cell the internal resistance was high because they were hand-made. If suitable high-pressure machines were used the internal resistance could be made very small. Due to the large internal resistance the discharge rate was kept very low. The results of the discharge are shown graphically (fig. 5).

## Discussion of Results

The conventional cell was continuously discharged for 163 hours at 15 ma constant current during which period the open circuit voltage dropped from 1.7V to 0.7V. Thus 2.445 ampere hour was taken out.

The modified cell was continuously discharged for 288 hours at 15 ma constant current

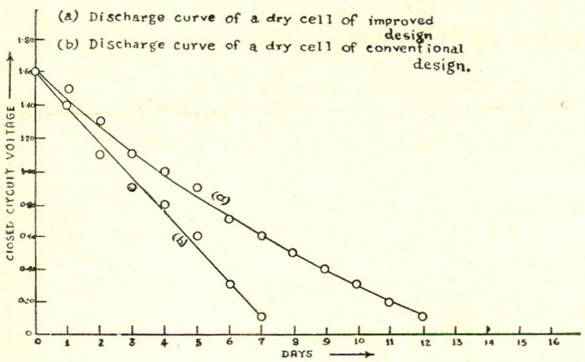


Fig. 5.

during which period the voltage dropped from 1.7V to 0.7V. In this case 4.32 amp. hours of energy were taken out. Thus the modified cell was found to be 43.4% more efficient than the conventional one.

The improvement in the capacity of the cell was due entirely to the design and arrangement of the electrodes. However, both the cells constructed in the laboratory suffered from the defect of high internal resistance. Resistance of the carbon electrode depends primarily on the compactness of the carbon granules forming it. For want of any press it was not possible for us to prepare a compact cylindrical carbon container required for the construction of the cell of improved design.

Moreover, $MnO_2$ used by us contained iron as an impurity. This caused local action and as such the efficiency was reduced.

Inspite of these defects the cell designed non-conventionally exhibited higher efficiency due primarily to two factors :

(1) The area of the carbon electrode surface exposed for the depolarisation was higher ; and

(2) the zinc was more completely used up. In the case of a conventional cell, when the zinc container is perforated, it becomes useless, whereas, in the case of our improved design, the question of perforation does not arise. This ensures longer life and hence higher capacity.

Thus it may be concluded that for the same amount of material much higher efficiency is obtainable if the cells are designed along the lines suggested above.