July 2020

Cell Age Balancing For Wireless Earbuds

Jonathan D. Hurwitz

Cell Age Balancing For Wireless Earbuds

ABSTRACT

True wireless earbuds that include on-board batteries are popular. This disclosure describes techniques to balance cell aging of wireless earbuds and enable utilization of the full capacity of the battery cells of wireless earbuds. A fuel gauge value (available cell capacity) for each earbud is recorded. When the earbuds are charging, e.g., in a charging case, the fuel gauge value for each earbud is read. A cell age equalization mode is invoked if the difference between the available cell capacities meets a predetermined threshold. When the earbuds are placed in cell equalization mode, a code path may be configured to enable more frequent master-slave role switches between the earbuds, configure the earbud with the healthier cell automatically as the master earbud, and/or deactivate some compute functionality on the earbud with the weaker cell.

KEYWORDS

- Wireless earbuds
- Wireless headphones
- Cell aging
- Battery aging
- Cell capacity
- Cell age equalization
- Coulomb counter
- Fuel gauge
- Master-slave design

BACKGROUND

True wireless earbuds are wearable devices that are becoming increasingly popular with consumers. On-board rechargeable batteries (e.g., lithium-ion batteries) are utilized to power such earbuds. Charging is commonly performed via a case that stores the earbuds when not in use. As with all batteries, the usable capacity of earbud batteries decreases over time due to successive charge/discharge cycles.

Batteries can be characterized by a battery charge state (or battery level) that represents a state of charge of the battery relative to its available capacity, and by an available cell capacity, which is an estimate of the health of the battery in terms of how much of the cell capacity is actually usable. The available cell capacity can be determined by a Coulomb counter, which measures the cumulative current (by integrating the instantaneous current in/out of the cell) flowing through the cell.

True wireless earbuds typically employ a master-slave design such that only one earbud is utilized to wirelessly receive audio from a host source (such as a mobile phone) and to transmit audio to the other earbud. For example, if a right earbud is configured as the master, it receives stereo audio from a mobile phone, plays the right audio channel of the stereo, and transmits the left audio channel to the left earbud. In such a scenario, the left earbud is only utilized to receive audio packets from the right earbud, and play the left audio channel.

In this example, the left earbud has a relatively low transmit (Tx) burden when compared to the right earbud, since the left earbud may at most be utilized to transmit acknowledgement (ACK) packets or for stereo synchronization. The right earbud consumes relatively greater energy since it is utilized to transmit audio packets to the left earbud, thereby having a greater Tx burden. A master-slave design typically leads to one earbud discharging faster than the other, e.g. in this case, the right earbud is likely to discharge faster than the left earbud.

Some true wireless earbuds include a role-switch feature to balance battery discharge between the earbuds. The role-switch feature enables the master and slave earbuds to switch roles, based on configurable settings and/or RF conditions. Such a switch helps balance the battery discharge. If a user actively utilizes the earbuds for a sufficiently long duration, the master and slave earbuds typically switch roles during the listening session to balance battery discharge.

If the earbud batteries undergo balanced discharge during most listening sessions, their respective cells would age at the same rate. However, cell aging can be non-uniform if the duration of user listening sessions is such that a role switch is not triggered during a substantial proportion of listening sessions. In some cases, where the user is in a challenging RF environment, the RF conditions may not permit a seamless role switch, leading the primary earbud to discharge faster, and consequently, the battery of the primary earbud to age faster.

Additionally, a user may always put the same earbud in the ear first, e.g., always the right earbud first, thereby having the right earbud configured as the master earbud. In such a situation, the battery cells of the right earbud can age faster than the left earbud due to the repeated deeper depths of discharge.

Over long-term use of the earbuds, if the battery cells of one earbud ages more than that of the other, it discharges faster. The faster discharge rate triggers a change in the role of earbud (to a slave mode) such that it can lead to a higher role switch frequency. The role-switch feature can mitigate cell-aging to a limited extent.

DESCRIPTION

This disclosure describes techniques to automatically balance cell aging of wireless earbuds and enable utilization of the full capacity of the battery cells of wireless earbuds. Balanced cell ageing can also provide a balanced cell discharge rate during wireless earbud use.

Per techniques of this disclosure, a fuel gauge value (available cell capacity) for each earbud is recorded at each earbud. When the earbuds are placed in a case for charging, the fuel gauge value for each earbud is read. Based on a difference between the available cell capacities of the batteries in the earbuds, a cell age equalization mode is automatically invoked if the difference between the available cell capacities meets a predetermined threshold. When earbuds are placed in cell equalization mode, a code path is configured to enable more frequent master-slave role switches between the earbuds, to configure the earbud with the healthier cell automatically as the master earbud, and/or to deactivate some compute functionality on the earbud with the weaker cell, etc.

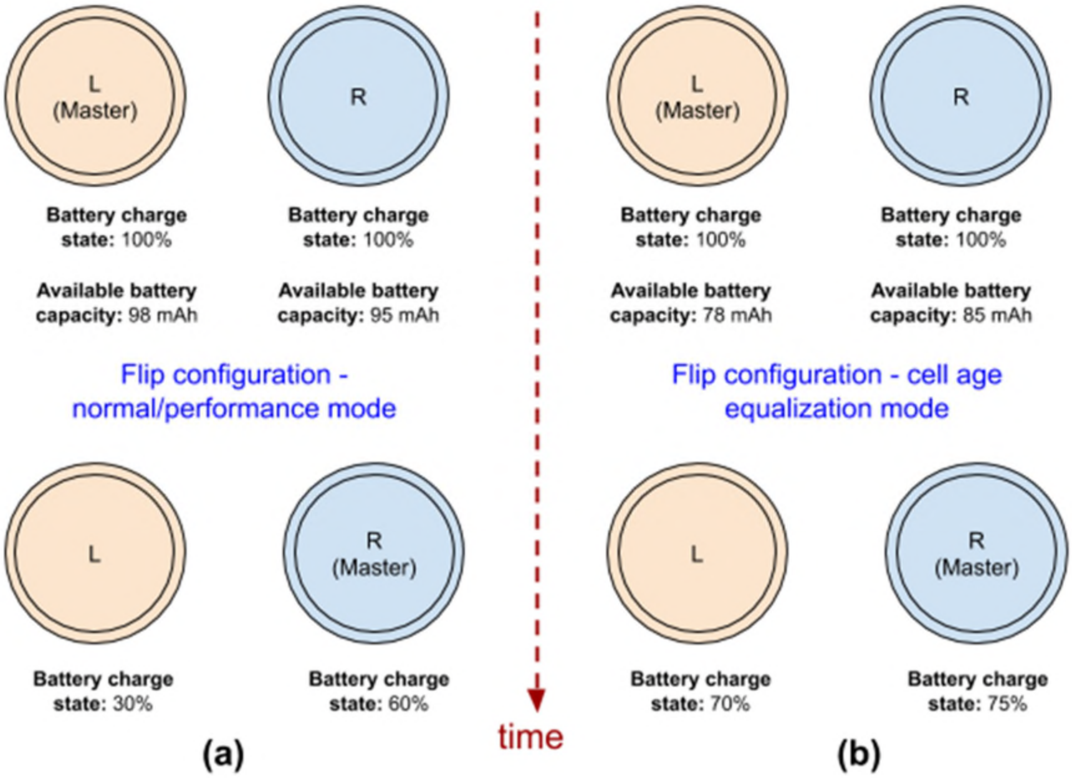

Fig. 1: Master-slave role switches expedited in cell age equalization mode

Fig. 1 illustrates examples of wireless earbuds in cell age equalization mode. Fig. 1(a) depicts an example role-switch in a scenario where the cell aging of both earbud batteries is balanced. In this illustrative example, the batteries of the left (L) and right (R) earbuds start from a fully charged state (100% battery charge state) as shown in the top portion of Fig. 1(a) and have similar available cell capacities of 98 mAh and 95 mAh, respectively. During use of the earbuds, the battery of the master earbud, in this case, the L earbud discharges at a faster rate than the R earbud. At a predetermined discharge state, a role-switch is performed to balance the discharge rates of the two earbuds. In this illustrative example, the role switch, shown in the bottom portion of Fig. 1(a), is set to occur when a difference in battery charge state between the two earbuds is 30%, RF and other conditions permitting.

Fig. 1(b) depicts an example role-switch in a scenario where the cell aging is not balanced, and the L earbud is determined to have a lower available cell capacity of 78 mAh, when compared with the R earbud, which is determined to have a lower available cell capacity of 85 mAh, as shown in the top portion of Fig. 1(b). The cell capacities may be determined, for example, when the earbuds are placed in their case during a previous charging cycle.

Per techniques of this disclosure, a cell equalization mode is enabled (configured) for the earbuds, that enables a code path that causes a role-switch at an earlier battery charge state of the L earbud, which is the master earbud in this case. In this illustrative example, the role-switch occurs earlier in the discharge cycle, as shown in the bottom portion of Fig. 1(b), at a 5% difference in battery charge state between the two earbuds, RF and other conditions permitting. The earlier role switch, compared to normal/performance mode of Fig. 1(a), causes the R earbud to become the master earbud, and with a higher battery discharge rate. Across this and additional listening sessions, this can achieve the effect of balancing cell aging between the two earbuds.

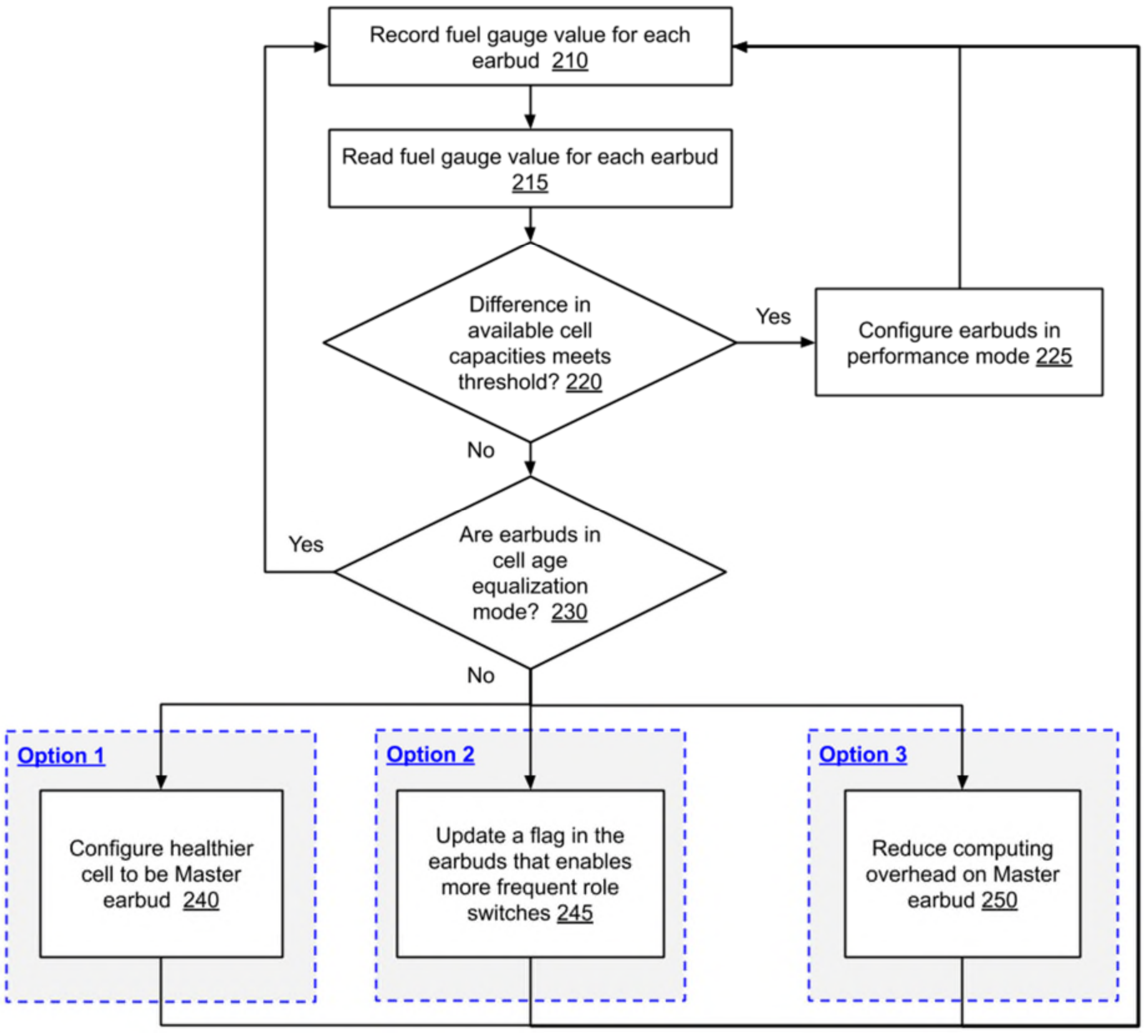

Fig. 2: Fuel gauge value based configuration of earbuds for cell age equalization

Fig. 2 depicts an example method to balance cell aging in wireless earbuds, per techniques of this disclosure. Cell aging is measured and expressed in terms of the maximum storage capacity of the cell that is still available for use. This can be measured by using a coulomb counter, also referred to as a fuel gauge. The fuel gauge is integrated into a chip and measures the charge flowing into and out of a cell (cumulative current flow through the cell) and provides an indication of available cell capacity of a battery.

During use of the earbuds, each earbud records (210) the fuel gauge value (available battery cell capacity) for its battery cells. When the earbuds are placed in an earbud case for charging, the recorded fuel gauge values are read (215) via a charging interface, e.g., a pogo pin interface, by a logic circuit included in the case. The reading of fuel gauge values from each earbud is performed within a threshold interval so that the values may be suitably compared. In some implementations, the fuel gauge measurements can be stored on the buds themselves and an atomic updating process can be utilized between the earbuds for an earbud to provide the fuel gauge measurements to the other earbud.

The available cell capacities of the batteries of the two earbuds are compared by determining a difference between the available cell capacities and comparing to a threshold (220). The threshold is configurable and can be adjusted based on the specific earbud design, use case scenarios, etc. The threshold can be determined based on field data obtained regarding listening session length(s), cell charge depth(s), cell aging, and observed differences in maximum charge capacities of batteries.

If the difference meets the threshold, e.g. difference between available less capacities is less than a specified threshold, the earbuds are configured in normal performance mode (225).

If it is determined that the difference between the available cell capacities does not meet the threshold, it is determined whether the earbuds are in a cell age equalization mode (230). If it is determined that the earbuds are already in a cell age equalization mode, no configuration changes are made. If the earbuds are not already in a cell age equalization mode, they are configured to be in cell age equalization mode, in any of the options described below.

According to a first option for cell age equalization, the cell with the greater available cell capacity (the healthier cell) is prioritized to be configured as the master earbud (240), subject to suitable RF conditions. Prioritization of the healthier cell as the master can expedite its wear and thereby provide cell age equalization between the two buds during subsequent use. This option for cell age equalization can pose audio performance challenges in situations where the master bud is sufficiently far away, or shielded from the slave bud, e.g. still in its charging case, etc.

According to a second option for cell age equalization, a flag is updated that enables more frequent master-slave role switches (245). The battery capacity charge state difference between the earbuds that is utilized to trigger a role-switch can be lowered, with an optional relaxation in the role-switch RF conditions requirements. To optimize user experience, role switch requirements can include requirements to mitigate audio quality glitches, e.g. ensure good RF conditions, pause in user listening activity, etc.

According to a third option for cell age equalization, some features are turned off on the master earbud (250), if it is determined that the master earbud has low available cell capacity. Turning off features can reduce the computing overhead and can mitigate additional imbalances in cell capacity between the earbuds. The example shown in Fig. 2 assumes that the master bud has worse cell health, but turning off features is also applicable to the slave bud.

For example, the compute requirements on the master earbud can be reduced by turning off beamforming and instead relying on only the slave mic(s), using fewer microphones on the master earbud, turning off gesture recognition, turning off motion detection features on the master earbud that utilize the Inertial measurement Unit (IMU), turning off health features on the master earbud, etc. Additionally, always-on listening features on the master earbud, e.g. hotword detection (if permitted and enabled by the user), sound pressure estimation, volume adjustment based on ambient environment, etc. can also be turned off or performed at a lower frequency than in normal/performance mode.

Techniques of this disclosure can also be extended to perform cell age balancing in other devices, e.g. multiple audio speaker systems, etc.

CONCLUSION

This disclosure describes techniques to balance cell aging of wireless earbuds and enable users to utilize the full capacity of the battery cells of their wireless earbuds. Per techniques of this disclosure, a fuel gauge value (available cell capacity) for each earbud is recorded at each earbud. When the earbuds are placed in a case for charging, the fuel gauge value for each earbud is read. Based on a difference between the available cell capacities of the batteries in the earbuds, a cell age equalization mode is invoked if the difference between the available cell capacities meets a predetermined threshold. When earbuds are placed in cell equalization mode, a code path may be configured to enable more frequent master-slave role switches between the earbuds, configure the earbud with the healthier cell automatically as the master earbud, and/or deactivate some compute functionality on the earbud with the weaker cell.

REFERENCES

1. BU-808: How to Prolong Lithium-based Batteries, accessed 17 June 2020.
2. Battery Fuel Gauges: Accurately Measuring Charge Level, accessed 17 June 2020.
3. Battery Fuel (Gas) Gauge | Products | Battery Management | Power Management, accessed 17 June 2020.
4. LTC4150 Coulomb Counter Hookup Guide, accessed 17 June 2020.
5. The Best Battery Fuel Gauge Solution for TWS Headphone-RT9426, accessed 17 June 2020.
6. Bluetooth 1.1: Connect Without Cables, 2/E, accessed 17 June 2020.