Multibattery management in medical ultrasound systems

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Introduction

Patients in a hospital intensive-care unit require constant monitoring with equipment that must have continuous power. Any loss of patient data is completely unacceptable in critical medical applications; plus, a power failure is likely to damage expensive electrical components in scanning equipment.

Medical ultrasound imaging is a diagnostic technique that enables the visualization of a person's internal organs, including their size, structure and an estimate of their blood flow. Ultrasound scanners are available in premium, cart-based, portable and smart-probe versions, depending on the number of transmit and receive channels. Premium and cart-based ultrasound scanners are typically line-powered; however, they have multiple battery-packs to support backup power.

Understanding Battery Packs

A single cell is a electrochemical source of electrical potential, or voltage. Its size and chemical type determine the cell's nominal capacity and voltage rating, respectively. Battery packs achieve the desired operating voltage by connecting several cells in series; each cell adds its voltage potential to derive the total terminal voltage. A parallel connection of cells attains higher capacity by adding up the total ampere-hour ratings of the cells. Some packs comprise both series and parallel connections. For example, a battery pack with four cells in series and two cells in a parallel configuration is called 4S2P (4 series, 2 parallel); similarly, a 5S4P configuration has five cells in series and four cells in parallel.

Figure 1a shows a battery pack with two 4.2-V lithiumion (Li-ion) cells in series (2S), to produce a nominal voltage of 8.4 V. Adding cells in a string only increases the voltage; the capacity remains the same. For higher currents, one or more cells can be connected in parallel, as shown in Figure 1b. The combined series and parallel configuration shown in Figure 1c enables design flexibility and achieves the required voltage and current ratings for an ultrasound scanner application with a standard cell size.

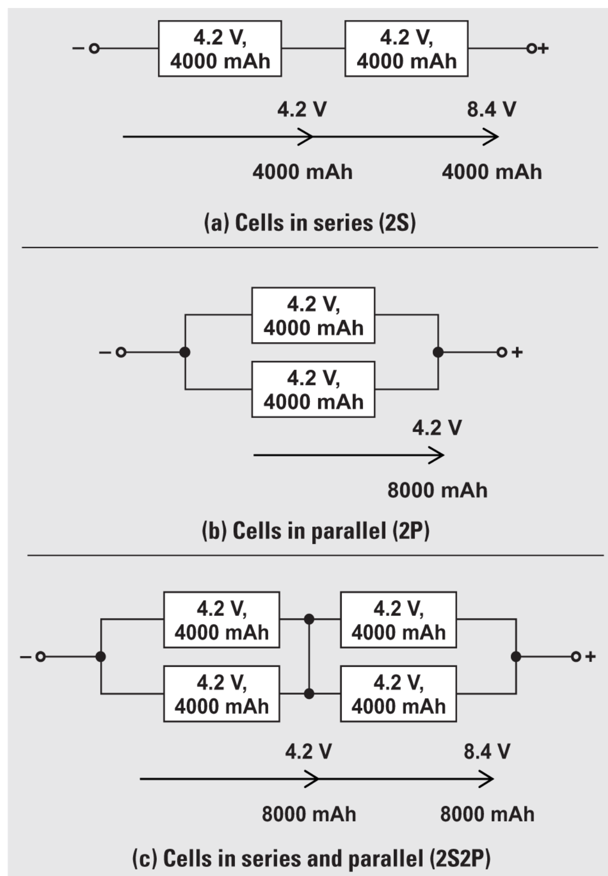

Figure 1. *Voltage and Capacity Scaling for a Li-ion Battery*

Stackability Requirements for Battery Packs

Lithium batteries are dangerous. Depending on the battery capacity and number of cells, there are restrictions on their transportation by air—it is only permitted with a U.N. 38.3 certification according to the U.N. Manual of Tests and Criteria. International Air Transport Association Dangerous Goods Regulations specify the classification, marking, packing, labeling and documenting of dangerous shipments.

Designing a multibattery management system so that it is stackable helps meet shipping restrictions by enabling ultrasound scanner manufacturers to ship smaller-capacity batteries. By stacking these smaller batteries, designers can achieve a higher battery capacity which can provide longer back-up run times for equipment.

A Multibattery Management System Design

A multibattery management system that can share the load accurately makes it easier to stack batteries. For example, a 4S4P Li-ion battery pack has four parallel paths, and each of those paths has four series cells.

Table 1 lists the specifications for a multibattery management system.

Specification	Value
Battery chemistry	Li-ion
Cell voltage	3.6 V to 4.2 V (when fully charged)
Battery configuration	4S4P
Maximum pack voltage	14.4 V to 16.8 V (when fully charged)
Input voltage of the system	12 V or 24 V (sometimes with a 19-V laptop charger used as the input)
Output voltage of the system	12 V or 24 V

Table 1. *Basic Specifications for 4S4P Battery-management System*

Figure 2 shows a multibattery system with five stages: battery charging, battery gauging and protection, DC-to-DC converter or controller stage, ORing control, and load sharing.

Battery Charging

A 4S battery voltage ranges from 14.4 V to 16.8 V. Most battery chargers come with power-path management, which means that the output of the battery charger can come from either the input voltage or the battery voltage. This power-path management happens dynamically. Depending on whether the input voltage is 12 V or 24 V, the battery charger needs to be either a boost or a buck charger, respectively.

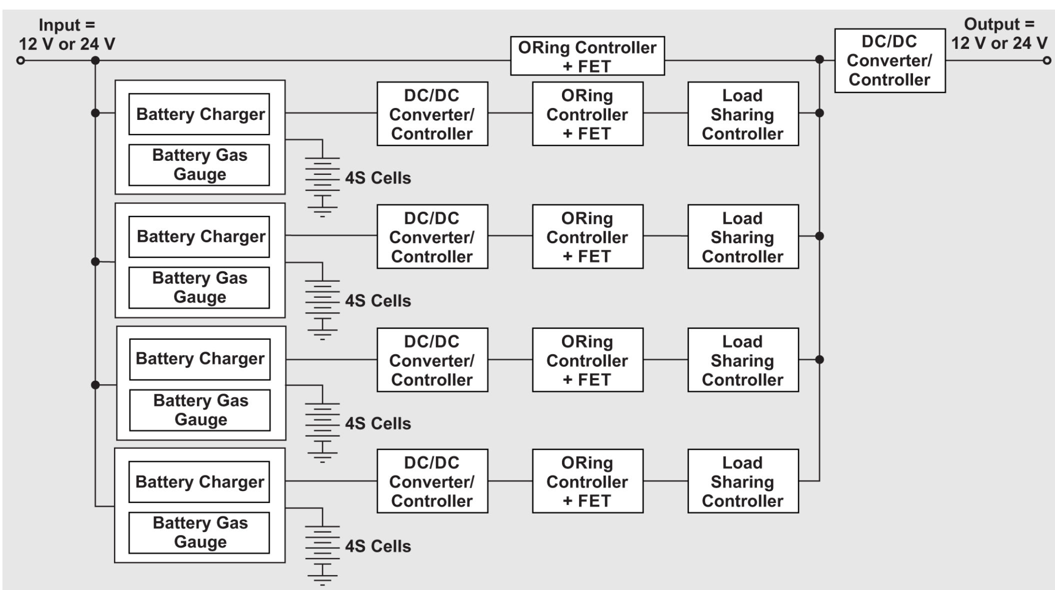

Figure 2. *Multibattery Management System for a 4S4P Battery Pack*

Based on the charging and discharging currents, a battery charger can have external or integrated field-effect transistors (FETs). For example, as shown in **Figure 3**, the BQ25713 from Texas Instruments (TI) is a one- to four-cell buck-boost battery charger controller that can work with a 12-V input. The BQ24610 is a stand-alone one- to six-cell synchronous buck battery charger controller that can work with a 24-V input. Both of these devices are charger controllers and use external FETs to support higher currents. If the load current is 5 A or less, a third device, the BQ25790, is a more suitable charger with integrated FETs.

Faster battery charging requires higher current; over time, this can accelerate cell aging. Lithium plating (a deposition of metallic lithium) can form during charging, resulting in reduced performance for rechargeable batteries. Plating can also occur when charging at low temperatures. With TI Impedance Track™ and smart charging technology, batteries can have increased longevity by predicting the remaining battery capacity with greater than 99% accuracy, as well as supporting the fastest possible charging without additional degradation.

A large battery in an ultrasound scanner does not necessarily mean that the battery will last longer. Battery capacity is affected by many parameters, such as current, voltage and temperature. Two important factors to consider are battery life (or the number of obtainable cycles from the battery) and run time (or being able to confidently use all of the available battery capacity with no surprises, such as early shutdown).

Battery Gauging and Protection

It is critical to have a robust battery system with a gauge and protector that can not only enhance the safety of an ultrasound system, but also extend the run time and life-time of the battery pack. An authentication feature ensures a battery's safe and authorized use, while a battery gauge with Impedance Track™ technology can directly measure the effect of the discharge rate, temperature, age and other factors by learning the cell impedance.

A battery gauge can provide an early warning of when a battery is nearing the end of its life; in a hospital setting, receiving such an early warning can help avoid patient casualties. Li-ion batteries are highly efficient, but battery failures do still occur. To operate safely and reliably, devices should offer accurate battery monitoring and provide thresholds for overcurrent protection during high discharge and charge current operation, as well as protection during battery overcharging and depleted conditions. The BQ40Z50-R2, one- to four-cell Li-ion battery-pack manager is an integrated, single-chip, pack-based solution that includes features for gas gauging, protection and authentication.

It is important to acknowledge the different components of a smart battery pack. A smart battery is a battery pack that comes with both an integrated gas gauge and an interface to enable the battery to communicate with a host device for the purposes of reading information on the battery's state of charge, state of health, reason of protection, preferred method of charge and many other items. With a smart battery, there is no algorithm or calculation required by the host processor.

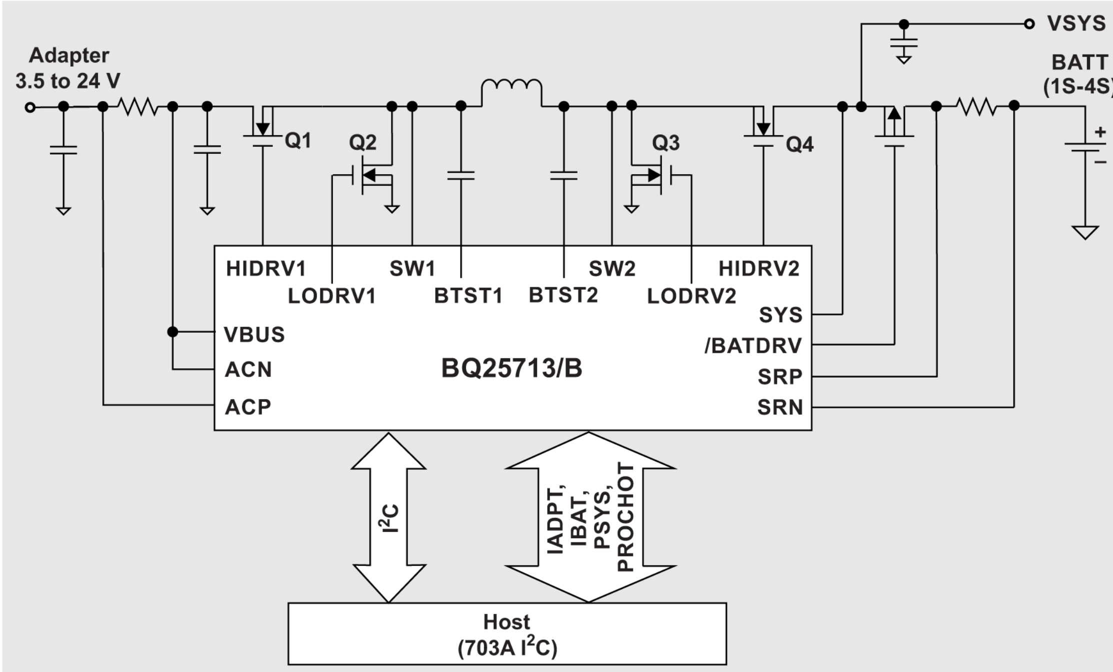

Figure 3. *Charging Stage and Dynamic Power-path Management for a 4S Battery Pack*

DC-to-DC Converter or Controller Stage (Boost or Buck-boost Stage)

Because each parallel path of a 4S4P pack is a combination of four series cells (14.4 V to 16.8 V), the output voltage going to an ultrasound system (front- and back- end units) can be 12 V, 19 V or 24 V. To achieve one of these system voltages, each parallel path in the pack should have a DC-to-DC converter or controller stage (the latter for higher output currents). The converter or controller can be boost or buck-boost, depending on the requirements. In the 4S4P Li-ion battery pack example, a buck-boost controller will work well.

ORing Control

An ORing function is required when multiple power paths must be connected together to form a single power source to a device. Traditionally, it is possible to perform ORing control using discrete diodes, but a major drawback of diodes is their high forward voltage drop, which causes high power dissipation and reduces the operating time of the battery. Replacing discrete diodes with an integrated ideal diode (like the LM73100 shown in **Figure 4**a) can help reduce the forward voltage drop.

With the voltage of the battery decreasing throughout its lifetime, because the discrete diode will reach its minimum voltage threshold first, the forward voltage drop of the discrete diode disables the system faster than the integrated ideal diode.

Another benefit of using an integrated ideal diode is that it has a lower reverse leakage current than a discrete diode. When the main power supply is active, reverse leakage current flowing into the backup battery can reduce its lifetime by deteriorating its capacity. On the other hand, when the backup battery is powering the system, reverse leakage current flowing into the main power-supply path can result in wasteful current consumption. Minimizing the reverse leakage current helps extend the life of the battery.

Replacing the ORing diode with low $R_{DS(on)}$ FETs, driven by an ORing FET controller like the LM74700 in **Figure 4**b, can help further improve overall battery life and system performance.

Load Sharing

When employing ORing control without load sharing, it is possible to have all of the FETs on at once if the path voltages are well matched. But the different capacities, voltage levels and accuracy of the cells can make it very difficult to balance current among the path. Each parallel path can charge and discharge at slightly different rates depending on the output load condition. Properly balancing and sharing the load across multiple paths is important.

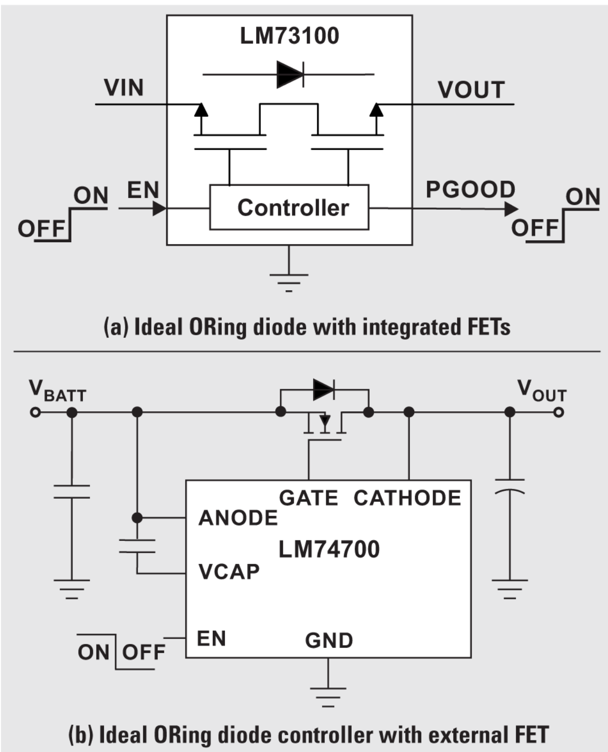

Figure 4. *Two ORing Configurations*

Accurate load sharing between the battery paths and active ORing with the main input voltage enables the use of standardized circuits across several platforms, reducing time to market. The resulting modularity provides great flexibility, making it easy to reconfigure systems to accommodate a broad variety of output-voltage and load-current combinations. The expandability of such a system provides a simple way to keep up with increasing load-current requirements. Load sharing also facilitates redundancy and eases thermal management because of smaller battery units.

Overall, load sharing improves system performance. It also helps in air shipments of smaller units that can be combined at the receiving end.

Finally, depending upon the input and output specifications, one more DC-to-DC converter (or controller) can power the front- and back-end units of ultrasound scanners.

Conclusion

Multibattery management is an essential part of any medical equipment, including cart-based and premium ultrasound scanners. For a highly efficient, low quiescent current and stackable battery-management system, the key elements are a battery charger, a battery gauge and protection, ORing control and load sharing.

References

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6. "Transportation of Lithium Batteries," Ultralife white paper, April 2018, UBM-5120 Rev. AJ, May 2018.

Related Web Sites

Product information:

BQ24610

BQ25713

BQ25790

BQ40Z50-R2

LM73100

LM74700-Q1