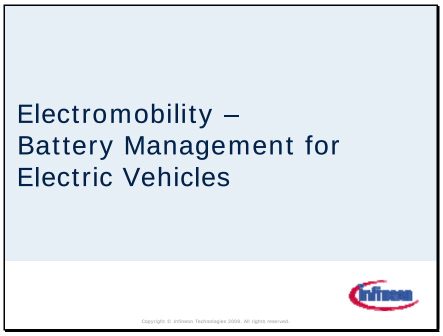
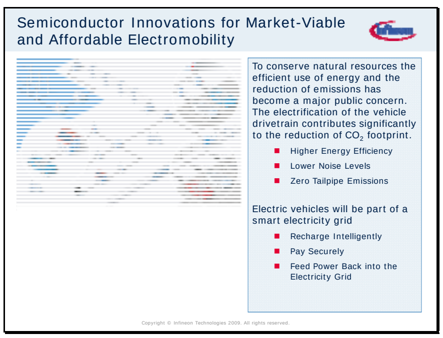
SCRIPT FOR PRESENTATION



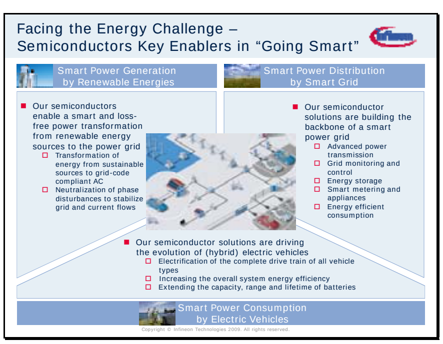
Infineon Technologies welcomes you to this presentation:
Electromobility – Battery Management for Electric Vehicles



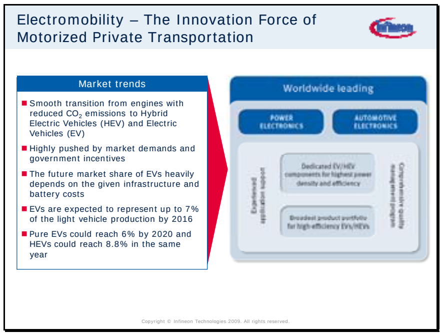
To conserve natural resources the efficient use of energy and the reduction of emissions has become a major public concern. The electrification of the vehicle drivetrain contributes significantly to the reduction of the CO2 footprint.

The advantages of electric cars include higher energy efficiency of the drivetrain, lower noise levels and zero tailpipe emissions when driving solely electrically.
Electric vehicles will be part of a smart electricity grid, allowing drivers to recharge intelligently, pay securely and feed power back into the electricity grid.
Semiconductors play a key role in building such intelligent power networks.

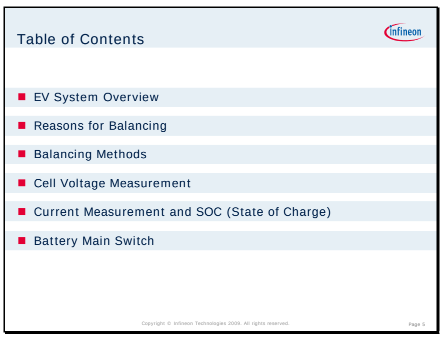
As an innovation driver and supplier of key components for electromobility, Infineon will actively help to shape the paradigm shift toward electromobility on the road.



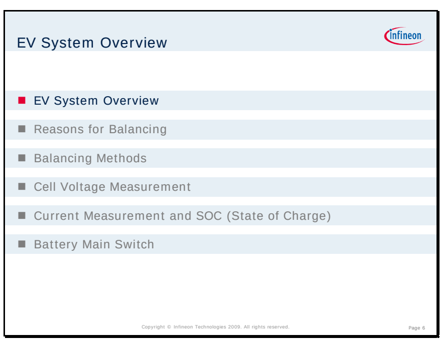
When facing the energy challenge, semiconductors are key enablers in "Going Smart".
Our semiconductors enable a smart and loss-free power transformation from renewable energy sources to the power grid
Our semiconductor solutions are building the backbone of a smart power grid
Our semiconductor solutions are driving the evolution of (hybrid) electric vehicles



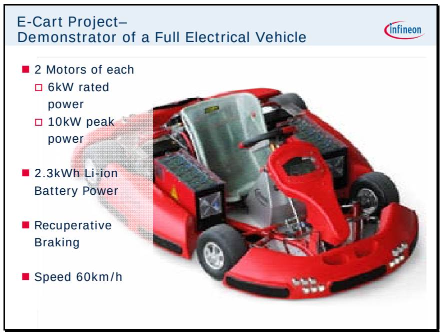
There are a number of market trends driving the electromobility market.
There is a smooth transition from engines with reduced CO2 emissions to Hybrid Electric Vehicles (HEV) and Electric Vehicles (EV). Innovation is being pushed by market demands and government incentives. The future market share of EVs heavily depends on fuel prices and battery costs. EVs are expected to represent up to 7% of the light vehicle production by 2016. Pure EVs could reach 6% by 2020 and HEVs could reach 8.8% in the same year.
Infineon Technologies is the only worldwide supplier who combines both - forty years experience in automotive with the number one position in power electronics. Coupled with years of experience in industrial drives, as well as power generation and supply, we can actively help you shape the paradigm shift toward electromobility.



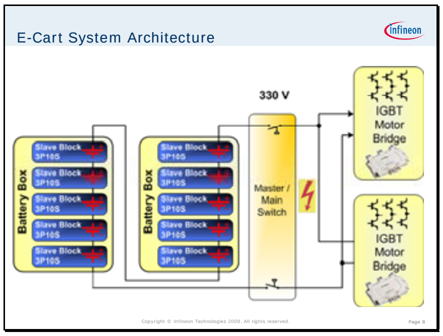
Let us start with an overview of the whole presentation and the different topics we will be discussing.
We will start with an electrical vehicle systems overview. We will then discuss the reasons for balancing and some balancing methods. Cell Voltage measurements will be discussed followed by a section on current measurement and state of charge. The final section will cover the battery main switch.



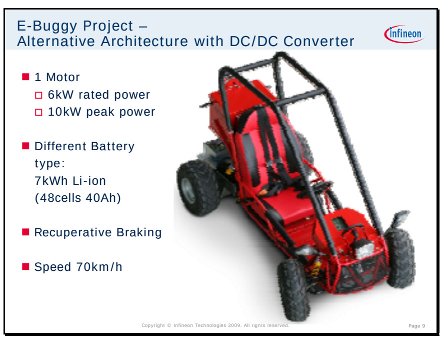
Electric Vehicle System Overview



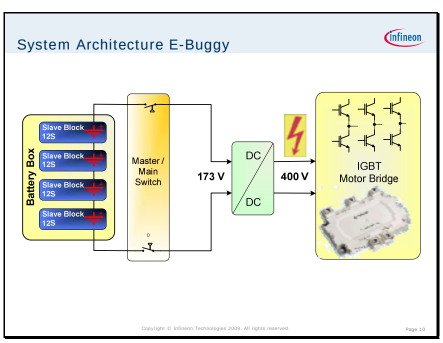
Infineon has developed this E-cart, which is a demonstrator model of a fully operational electrical vehicle. This drivable vehicle contains two motors on each rear wheel with 6 kilowatts rated power and 10 kilowatts peak power.
The lithium ion battery has a capacity of 2.3 killowatt hours and are located in the boxes beside the seat. The E-Cart has recuperative braking that allows for battery charging during braking.
The vehicle can operate at speeds up to about 60 kilometers/hour, making it a fun experience to drive.



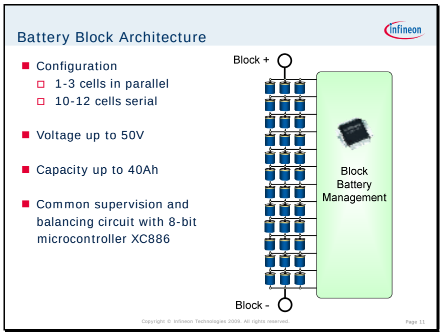
The E-Cart system architecture is illustrated on this slide. Each battery box contains five blocks with 3P10S batteries, indicating 3 Parallel and 10 cells in Series. The series connection of the two battery boxes provides a total of 10 blocks and 100 cells in series which provides a nominal value of 330 Volts. After the main switch the power is supplied to the two IGBT motor bridges, located near each motor of the cart.



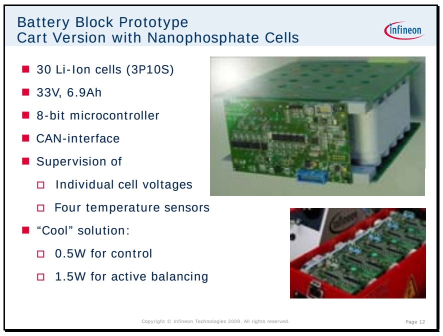
Another demonstrator project is the E-Buggy that uses an alternative architecture with a DC/DC Converter. This vehicle contains only one motor due to the limited space. Different lithium ion batteries were also used consisting of 7 kilowatt hours, resulting in only 48 cells with 40 amp hours. The recuperative braking was also used in this vehicle and the speed was slightly higher at 70 kilometers per hour.



The system architecture for the E-Buggy is illustrated here. There are only four blocks in the battery box that yield 173 volts nominal current. The DC/DC converter raises the current to 400 Volts to provide a stable current to the IGBT motor drive.

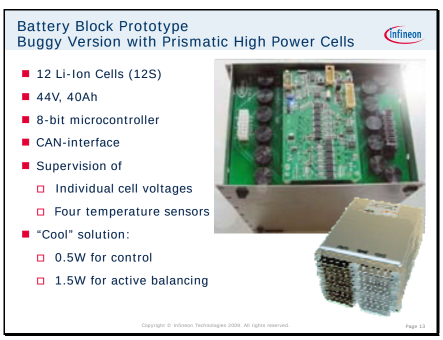


The battery block architecture is shown on this slide. The application configuration has 1-3 cells in parallel although there is not a limit to the cells in parallel. The application also has 10-12 cell in series connected to the battery management block. The relatively low voltage of 50 volts can be managed without special high voltage precautions. The capacity is up to 40 amp hours and the common supervision and balancing circuit is managed with an 8-bit microcontroller.



This is a photo of the E-Cart battery block. There are 30 round Lithium-Ion cells that are located between the two PCB boards. The PCB board contains the 8-bit microcontroller and a CAN interface, providing supervision of individual cell voltages and communication of the four temperature sensors (1 sensor on the board and 3 distributed in the cells).

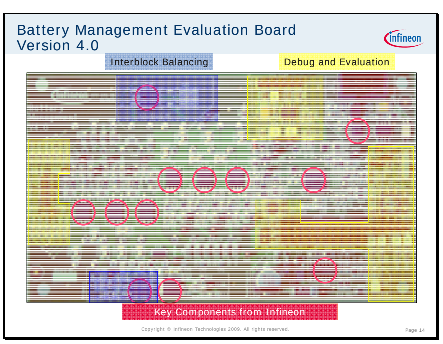
This "cool" solution only needs half a watt for the microcontroller and there are 1.5 watt losses for the active balancing. Five of the blocks are placed vertically in the battery box of the E-Cart as shown in the lower photo.



This is a photo of the Buggy battery block that contains prismatic high power cells. In this application there are 12 Lithium-Ion cells providing 44 volts and 40 amp hours.

The cells are placed in an aluminum box to form the series connection. The cables are for the temperature sensors that are placed between the battery cells.

The adapter board is located on top of the battery cells that contains the microcontroller, CAN interface and the temperature and voltage supervision. The black knobs are covering the screws and have no special functions.

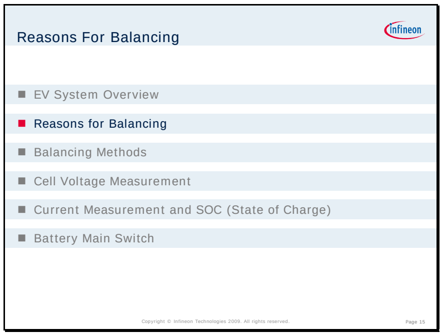


This is an image of the battery management evaluation board. This version has 12 MOSFETs. There is also the 8-bit microcontroller, an onboard voltage regulator and the CAN transceiver.

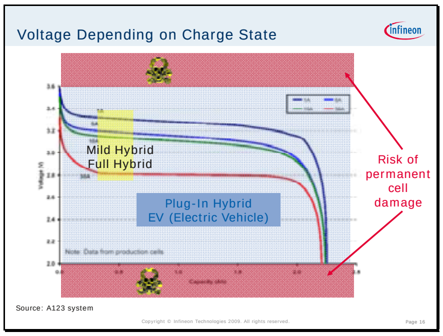
The areas in yellow are for debug and evaluation functions. On the left are special connections to measure the voltages, there is a special RS232 interface. In the center is the large JTAG connector and a reset button. On the right side are switches and LEDs for different test modes.

The areas in blue are for the interblock balancing.

The areas marked in red are key components supplied by Infineon that are automotive qualified.

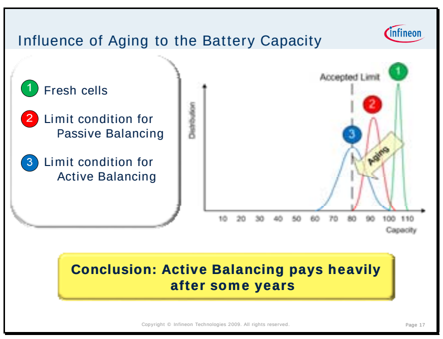


The next topics we will cover are the Reasons for Balancing.



Here you see the voltage curve of the battery cells depending on the charge state. The red areas have the risk of permanent cell damage and care should be taken not to drive the cells into this range.

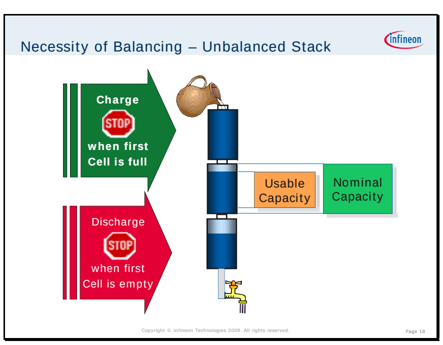
In a mild or full hybrid application the batteries are generally used in the 70% state of charge area. However, Plug-in Hybrid or Electric Vehicle applications should use the entire capacity range.



This graph shows the influence of aging on the battery capacity. The fresh cells indicated with number 1 shows that no cell is less than 100% capacity. The cells indicated with number 2 begin to show the effects of aging and have limited condition for passive balancing. The cells indicated with the number 3 shows the distribution decreasing and the capacity widening, since each cell will age at an individual rate.

The accepted limit for replacing a battery pack is at 80% state of charge. Since the weakest point will determine the ability to charge the cells in series, even the cells indicated with number 2 will meet this 80% criteria level.

Active Balancing has the ability to move a charge from one cell to the other and as a result can improve the battery lifetime dramatically through cell averaging. Initially there is a small cost increase to include Active Balancing into the application, but during the life of the battery this feature could return the investment by 10% or more.



In the unbalanced stack on the right when the first cell is full the charging will stop and when the first cell is empty the driving must stop. In this case the usable capacity compared to the nominal capacity is lower. Balancing can help equalize the charge content of the battery cells to help maximize the total capacity.

Balancing Methods

Next we will review some of the Balancing Methods.

Balancing Methods for Battery Stacks

Feature \ Method	Passive (Resistive)	Active: Capacitive	Active: Inductive
TOP Balancing (Charge)	✓		
Bottom Balancing (Discharge)	✗		
Measurement Internal Resistance	✗		
Balancing Power (typically used)	100 mA		
Balancing between Blocks	✗		
Power Dissipation	High		

We go for the Inductive Method

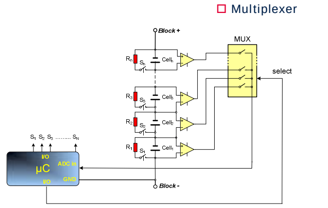
In the passive balancing method TOP Balancing is achieved only during charging and no bottom balancing during discharge is possible. Only 100 milliamps are used in this process but no balancing between the blocks is possible.

Active balancing requires a medium to transport energy between cells. In the Capacitive method a capacitor could be used to transport energy from a strong cell to a weaker cell, but this efficiency is below 50% and the current is limited to 1.5 amp maximum.

For the Inductive balancing method, energy is stored in a magnetic field and allows for top balancing, bottom balancing, internal resistance measurements and balancing between blocks. The typical balancing power can be up to 10 amps with very low power dissipation. All of these benefits have led us to choose the Inductive Method.

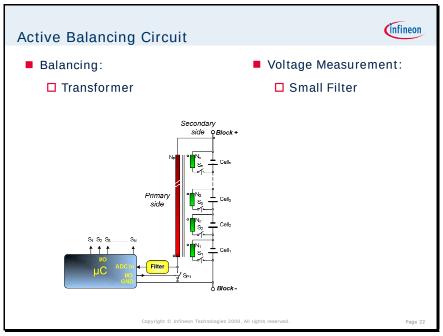
Passive Balancing Circuit

- Balancing:
  - Power Resistors R_1 to R_n
- Voltage Measurement:
  - Differential Amplifiers
  - Multiplexer

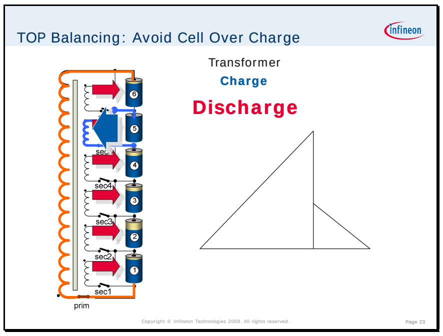


The diagram on this slide illustrates the passive balancing circuit. On the left side are resistors with a switch beside every cell. When the switch is closed the charge can be converted into heat to avoid over charging. On the right side is a differential amplifier and multiplexer since all the cells have different potentials.

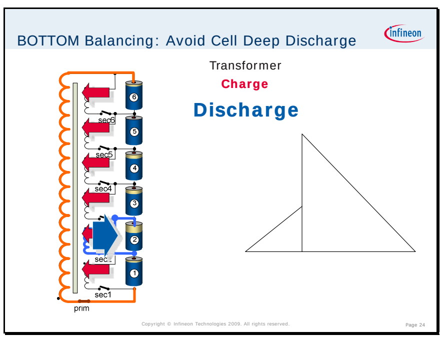
If we remove the resistors and the voltage measurement elements . . .



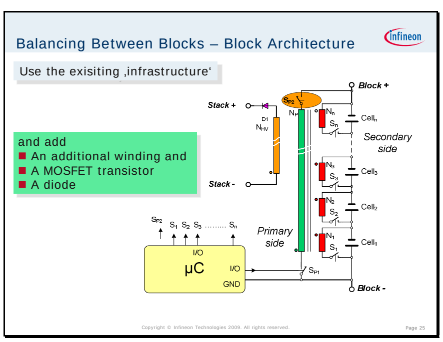
reinforce the switches and add a transformer we have the Active Balancing Circuit shown on this slide.
This is a typical flyback transformer principle with a primary winding over all the cells. In this drawing there are only four cells, but in a typical application there would be 10 to 12 cells. Beside every cell is a small winding with a switch and all the components are controlled with a microcontroller.
A small filter can be used for voltage measurement.



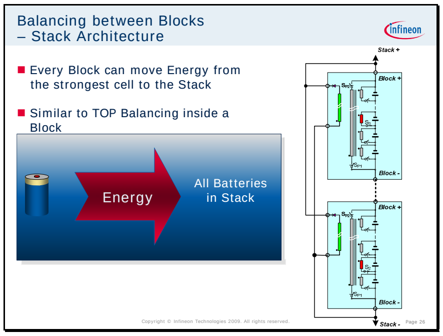
Top Balancing is illustrated on this slide. Since cell 5 is strong, the switch is closed. Energy is removed from the transformer core of cell 5 and the energy is discharged to all the cells, distributing the charge throughout the system.



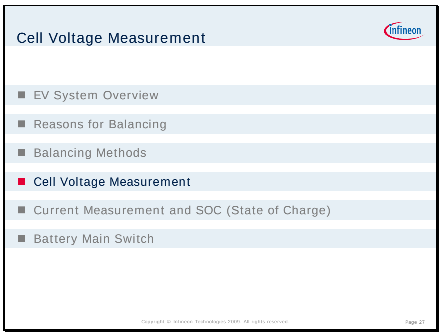
Bottom Balancing uses the opposite method. Energy is removed from all the cells and distributed to the weakest cell.



Balancing between blocks uses the existing infrastructure and adds an additional winding, a MOSFET transistor and a diode.



In this case energy removed from the individual cell (shown in red) can be distributed to all the blocks, since the green windings are all in parallel and cover the complete battery stack voltage. This allows equalization of the charge during the battery charging phase.



The next topic we will discuss is the cell voltage measurement.