Possible PRIUS+ Configurations; Advantages, Disadvantages, and Issues

Ron Gremban, 8/9/04 Updated, 8/17/04; added option 2b

Configuration	Advantages	Disadvantages	Issues
General issues	The PowerThat NiMH "D" cells are currently my first choice for powering the first PRIUS+ prototype. I have designed the 12-cell modules built from these such that 42 of them can be used with any of the configurations below as follows: 14 series x 3 parallel for #1 or #2 (185/202/252V min/nom/max @ 2.5 useable kWh) #2 may need 56 modules, 14 series x 4 parallel (same voltages) 21 series x 2 parallel for #3 (277/302/378V min/nom/max @ 4.0 useable kWh) 42 series for #4 or #5 (554/604/756V min/nom/max @ 4.0 u-kWh; 21x2 for charging)		Because the oil pump is driven by the ICE, we must ensure that the transaxle is properly oiled during EV-only operations. All configurations will require a grid charger, along with its controls, cooling air, and removable cord.
1. Traction battery in parallel with the hybrid battery (suggested by Dan and others)	**Major win:** Should reduce hybrid battery losses and thereby improve general hybrid performance as well as provide EV range.	**Major possible loss:** May disrupt battery ECU's hybrid battery SOC control, thereby reducing the hybrid battery's cycle life. This is especially likely to void the hybrid battery's warranty.	**Major issue:** Can the battery ECU be made to properly understand the added SOC after a grid-based charge? Note: grid-charging only the traction battery, connecting it on the far side of the current sensor, and connecting it only during ig-on may solve this issue.
	Win balanced by loss: Unless it has extra cells, the traction battery can only be discharged to around 56% unless a diode is used to prevent recharge from the THS, then to 40%; in either case increasing its cycle life.	Loss balanced by win: The traction battery can only be discharged to around 56% unless a diode is used to prevent recharge from the THS; then to 40%; thereby reducing its effective capacity to 44% or 60%. Such a diode, however, will prevent improvement in regenerative braking efficiency and capacity. It is possible, however, that the traction battery's SOC range can be skewed by adding extra cells relative to what the hybrid battery has. Three extra traction battery cells, for example, will cause 56% hybrid charge to correspond to around 35% traction charge and 40% hybrid charge to correspond to around 20% traction charge. This ruse, however, might cause the battery ECU to misread the hybrid battery's SOC, thereby operating the hybrid battery beyond its normal SOC limits and reducing its cycle life.	**Major issue:** Can the hybrid battery ECU and the THS system be made to continue working right, despite the interactions? For example, if SOC is partially determined by integrating current, the ECU's idea of battery size may limit the battery capacity that actually gets used. Expanded battery capacity may remain unused. This will not be a problem if the ECU dynamically determines battery capacity and learns the new capacity. However, in this case, the original hybrid battery will be overcharged and overdischarged for a while if the additional capacity is removed, until the ECU learns of the once again reduced capacity.
	The hybrid battery will run cooler because the traction battery will be reducing its power loads.	Already handled: Requires a 168 cell NiMH traction battery. It may be advisible to divide the traction battery into 12-cell units and parallel each with a hybrid battery tap.	**Major issue:** How to control the traction battery's SOC and charge balancing? Note: the above solution to grid-based charging may work here, too.
	If a diode is not used to prevent the THS from recharging the traction battery with the hybrid battery, then regenerative braking will be more efficient and can last longer during a long descent. Maybe this effect can be switchable, e.g. turned on when "B" is selected instead of "D".		The traction battery will need to be disconnected from the hybrid battery except during ig-on, to prevent overcharging the hybrid battery and reduction of its cycle life. Hey, there's a theme here! But will this be sufficient? And it might cause problems as the THS notices extraneous current flowing into the hybrid battery.
	The THS' propensity to move the hybrid battery's SOC toward 56%, combined with use of the already-available EV-only mode makes use of the traction battery's charge automatic.		On which side of the hybrid battery's current sensor should the traction battery be connected? Should its individual modules be connected to the hybrid battery's taps?
			The traction battery may need temperature control, due to high peak power requirements.

2. Traction battery replaces the hybrid battery (suggested by Andy Frank)	**Major win:** Cannot reduce the hybrid battery's cycle life, as it is no longer in use. If fact, the battery can be sold to help finance the modification! **Major win:** A traction battery with a low enough internal resistance should reduce hybrid battery losses and thereby improve hybrid (including regenerative braking) performance (though not as much as with config. #1) as well as provide EV range. The larger traction battery does double duty, thereby reducing overall weight, maybe as much as the increase required by its reduced capacity due to limited discharge depth.	Loss balanced by win: The value of the hybrid battery's low internal resistance is thrown away (vs. keeping it in parallel). Due to grid-charging to or near 100%, the traction battery will probably not last as long as the hybrid battery would have; however, it will probably last as long as can be expected for a traction battery. Already handled: Requires a 168 cell NiMH traction battery divisible into 12-cell units to match the hybrid battery taps.	The traction battery will need temperature control, due to high peak power requirements. It may, however, fit in the hybrid battery's box, with its existing cooling air and temperature sensors.
2a. Toyota's battery ECU remains untouched	**2a only:** Win balanced by loss: The traction battery can only be discharged to an average of 56%, thereby increasing its cycle life. **2a only:** The THS' propensity to move the hybrid battery's SOC toward 56%, combined with use of the already-available EV-only mode makes use of the traction battery's charge automatic. **2a only:** It may be easier to get the battery ECU to properly register and control a different but homogenious battery's SOC and charge balancing than to do so with a combination of the original and added battery. Also, multiple battery THS interactions are eliminated.	**2a only:** Loss balanced by win: The traction battery can only be discharged to around 56% (a diode cannot be used to prevent recharge from the THS); thereby reducing its effective capacity to 44%.	**2a only: Major issue:** Will the battery ECU properly control a different battery's SOC and charge balancing? For example, if SOC is partially determined by integrating current, the ECU's idea of battery size may limit the battery capacity that actually gets used. Expanded battery capacity may remain unused. This will not be a problem if the ECU dynamically determines battery capacity and learns the new capacity. However, in this case, the battery will be overcharged and overdischarged for a while if the additional capacity is removed and replaced by the original hybrid battery, until the ECU learns of the once again reduced capacity. **2a only: Major issue:** Can the battery ECU be made to properly understand the added SOC after a grid-based charge?
2b. Toyota's battery ECU is replaced with a custom controller (suggested by Greg Hanssen)	**2b only: Major win:** Custom designed and programmed controller can properly manage a traction/hybrid battery's SOC, and encourage the rest of the THS to make best use of the additional battery capacity and power handling capabilities, while optimizing battery life.		**2b only:** Need to design and program a replacement battery ECU to accurately gauge SOC, take good care of the battery, and interface with the other ECUs, telling them what they need to know to encourage higher power peaks, both discharge and charge.
3. Traction battery provides controlled current into the hybrid battery (suggested by Ron)	**Major win:** The traction battery's SOC and discharge rate can be separated from any hybrid battery and HSC control issues. Traction battery current can be doled out based on hybrid battery voltage, SOC, and/or other criteria as desired.	**Major cost:** A DC:DC downconverter is needed to control current injection from the traction battery. A DC motor controller should be able to do this duty.	**Major issue:** Injecting current on the hybrid battery's side of its current sensor may upset the battery ECU's tracking of the hybrid battery's SOC, thereby loosening its control and shortening its cycle life.
	Major win: Traction battery SOC can be separately monitored and controlled; a full 80% of capacity can be used, or any other amount to optimize EV range vs. battery cycle life cost.	**Development cost:** A control system, complete with data inputs (possibly from the CAN bus) and traction battery SOC monitoring, must be created to control the current injection.	**Major issue:** Injecting current on the far side of the hybrid battery's current sensor may upset the THS' tracking of system currents and voltages, making the system erratic or nonfunctional.
	Major win: A traction battery (e.g. Li-ion) with limited discharge rate and/or different chemistry can be used without harm or inefficiency.	To avoid requiring a DC:DC upconverter, the minimum traction battery voltage must be higher than 252V, the highest voltage required for hybrid battery charging.	
	Limited win: If a battery capable of high discharge rate is used, the current injection can be increased when necessary (until the traction battery is depleted), to improve general hybrid performance.	A charge controller and a DC:DC upconverter or dynamic battery reconfiguration is required to improve the efficiency and duration of regenerative braking by recharging the traction battery, too.	
	The major issue of current injection into the high voltage bus is replaced by one of this configuration's two major issues.		

4. Traction battery provides controlled current into the high voltage (500V) bus (suggested by Ron)	**Major win:** The traction battery's SOC and discharge rate can be separated from any hybrid battery and HSC control issues. Traction battery current can be doled out based on hybrid battery voltage, SOC, and/or other criteria as desired.	**Major cost:** A DC:DC downconverter is needed to control current injection from the traction battery. A high voltage DC motor controller should be able to do this duty.	**Major issue:** Depending on how the THS control loop is designed, current injection into the high voltage bus may cause the THS to do the right thing with the extra energy, or not. This must be discovered, and worked around if not what is needed.
	Major win: Traction battery SOC can be separately monitored and controlled; a full 80% of capacity can be used, or any other amount to optimize EV range vs. battery cycle life cost.	**Development cost:** A control system, complete with data inputs (possibly from the CAN bus) and traction battery SOC monitoring, must be created to control the current injection.	
	Major win: A traction battery (e.g. Li-ion) with limited discharge rate and/or different chemistry can be used without harm or inefficiency.	To avoid requiring a DC:DC upconverter, the minimum traction battery voltage must be higher than 500V.	
	Major possible win: If the THS control system is set up in such a way that this configuration works well, it may be possible to use this current injection fool the THS into greatly increasing maximum EV acceleration and maybe even speed, within the limitations of MG2 and MG1.	A charge controller and a DC:DC upconverter or dynamic battery reconfiguration is required to improve the efficiency and duration of regenerative braking by recharging the traction battery, too. Note: this reconfiguration may already be available for grid-charging.	
	Limited win: If a battery capable of high discharge rate is used, the current injection can be increased when necessary (until the traction battery is depleted), to improve general hybrid performance.		
	The two major issues of current injection into the hybrid battery are replaced by this configuration's one major issue.		
5. Traction battery drives MG2 & MG1 via added controller (suggested by Victor Tikhonov)	**Major win:** The traction battery's SOC and discharge rate can be separated from any hybrid battery and THS control issues.	**Major cost:** A high voltage (500V), 50kW three-phase AC motor/generator controller is required to drive MG2.	**Major issue:** Can the new controller's regenerative braking be integrated with the brake pedal and friction brakes in the sophisticated user-friendly way it is done by the THS?
	Major win: Traction battery SOC can be separately monitored and controlled; a full 80% of capacity can be used, or any other amount to optimize EV range vs. battery cycle life cost.	**Major development cost:** A control system, complete with data inputs (possibly from the CAN bus), traction battery SOC monitoring, and MG2 current and phase monitoring, must be created to control MG2, including regenerative braking functionality. Much of this may be built into the motor controller, however.	**Major issue:** Flux-weakening is needed to obtain MG2 torque at its higher RPM ranges. Can a third-party three-phase AC motor controller be found that can properly handle this flux-weakening chore?
	Major win: The replacement traction control system can be used to greatly increase EV acceleration and speed, within the limitations of MG2 and MG1.	**Major limitation:** The traction battery must be able to handle high discharge rates for acceleration and high charge rates for regenerative braking.	
		To avoid requiring a DC:DC upconverter, the minimum traction battery voltage must be 500V.	