Current and Emerging Motor System Technologies for Hybrid Electric Vehicles
Agenda

- HEV Market
- Traction Motor Efficiency
- Traction Motor System
- Electronics for HEV Traction Motor System
- IRIS Platform
- Summary
Traction Motor Efficiency

- HEV/EV overall efficiency is a key metric. (35kWh / 100mi)
- HEV/EV “all electric” range is a key metric. (38 miles using pure electric)
- Traction motors are ~70-90% efficient
- Traction motor efficiency is a primary factor in HEV/EV performance
- Electrical energy storage/retrieval are ~70-80% efficient
Next Gen HEV Traction Motor

- The need for efficiency cannot be overstated
  - KWh per mile is a critical characteristic
  - “All electric” range is a critical characteristic
  - These directly correlate to gasoline MPG, and OEMs pay $2-$20 per vehicle for just 0.1 MPG improvement

- The need for cost reductions cannot be overstated
  - Plug-in HEVs (Volt, Leaf, Prius, new Focus) are initially priced much higher than comparable gas vehicles ($40K vs. $20K)
  - Even this premium does not cover actual OEM expenses
  - After 15 years of volume and cost reductions, Prius apparently makes money
  - HEVs will not sell in appreciable volumes with such high customer costs (unless gas prices rise significantly)

- The need for battery improvements cannot be overstated
  - Gasoline has ~63 times more energy per kg than Li-ion batteries
Traction Motor

- PMSM – Permanent Magnet Synchronous Motor
  - Permanent (rare earth) magnets in the rotor provide more torque, making PMSM motors smaller and lighter than equivalent options.
  - All of the power loss is in the stator windings, which makes cooling easier.
  - Smoother operation, particularly in low speed/high torque situations, which makes the motors quieter and reduces mechanical stress.
  - The current/torque relationship is more predictable, allowing accurate control.
  - However, permanent magnets are relatively expensive, can experience demagnetization at higher temperatures and greater loss of torque at high RPM compare to other options.

- Motor design is and will continue to be unique and proprietary.
Today’s Traction Motor System

Software Algorithms

Microcontroller

Opto-isolator

Gate Driver

6 PWMs

6 x

6 x

Resolver to Digital Converter (RDC)

Traction Motor with Resolver

IGBT with FRD

With significant heatsink and cooling

motor position

current feedback
Software Algorithms

**Today**
- System Level
- Determine User Request
- Determine System Status
- Calculate New Motor Values
  - System Level
  - Determine User Request
  - Read angle from RDC
  - Read motor currents
  - Clarke & Park Transforms
  - Iq & Id Control Loop
  - Inverse Transforms
  - Duty Cycle Calculations

**Next Gen**
- System Level
- Every 50 - 250 usec
- Read angle from RDC
- Read motor currents
- Clarke & Park Transforms
- Iq & Id Control Loop
- Custom Wave Shaping
- Inverse Transforms
- Duty Cycle Calculations
Microcontroller

Today

- 128 - 160 MHz, 32 bit, 90nm
- 768K – 2M Flash, 96K -128K RAM
- Fast FPU
- Peripherals to generate complementary PWMs
- 1 – 2 Traction motors controlled per micro

Next Gen

- 160 - 300 MHz, 32 bit Lock Step Dual Core (LSDC), 40-55nm
- 80 - 240 MHz, 32 bit core (3rd core)
- 4M – 6M Flash, 192 - 240K RAM
- Fast FPU for LSDC, or Fast FPU for each core
- More capable PWM peripherals
  - Some peripherals integrate motor control software functions
- Integrated RDC, or software RDC
- 2 Traction motors controlled per micro
Opto Isolator & Gate Driver

- **Isolation Required**
  - Motor coils switched at 600V, so need to isolate micro

- **IGBT Gate Driver Required**
  - Large IGBTs require significant charge to turn on/off
  - Need to switch quickly to reduce losses

- **Today**
  - True, *discrete* opto isolators
  - *Discrete* gate drivers
  - Limited gate driver feedback & protection

- **Next Gen**
  - *Integrated* isolator and gate driver in a single device
  - High gate drive capability: *3.5A output*
  - Rail-to-rail gate drive
  - On-chip *Protections*
    - Open circuit/short circuit detection
    - IGBT chip temp feedback
    - Internal thermal shutdown
    - Undervoltage lockout
    - Fault feedback
IGBT and FRD

- **Today**
  - 300V 100A to 600V 300A, depending on size of motor
  - **Bare die** available as separate IGBT & FRD devices
  - **Packaged** parts available often as single package

- **Next Gen**
  - 900V and 1200V IGBT/FRDs @ 400A
    - 400A allows more motor torque
    - 900V and 1200V allows higher transients and higher motor voltages
Resolver & RDC

- Resolver
  - Absolute angle sensor
  - Essentially a rotating transformer with specifically positioned secondaries
  - Resolves (modulates) rotor angle into orthogonal pieces: sine & cosine signals
  - Provides resolution better than 0.1°

- Resolver to Digital Converter (RDC)
  - Generates 10KHz to 20KHz excitation signal
  - Converts sine & cosine signals to 8-12 bit digital value

- Today
  - External RDC
  - Minimal number of excitation frequency selections

- Next Gen
  - Fully integrated RDC hardware into micro
  - Software RDC in micro (optimized ADC, and hardware filtering, with software support)
  - Many excitation frequency selections to reduce disturbances from motor magnetics and 2nd motor resolver
Next Generation Traction Motor System

High-Level Software Algorithms

Microcontroller with Motor SW functions & RDC

Gate Driver with Isolator

Traction Motor with Resolver

IGBT with FRD

6 x

current feedback

With significant heatsink and cooling

6 PWMs

6 x
IRIS Platform

Control Board (ECU)
• Micro Daughterboard
• Current, voltage, temp inputs
• Multiple RDCs & resolver circuits
• FPGA motor simulator
• CAN x 2
• Power supplies
• LEDs, switches

Power Supply

ATI A7 Data Acq. & Calibration Tool
• Control software
• Software drivers

Micro D’board

Inverter Board
• IGBTs
• Gate drivers
• Volt, current sensors
• Temp sensors

Motor & resolver 1
sin, cos, exc

Motor & resolver 2

harness

USB

CAN x 2
IRIS Controller & Daughterboard
IRIS SH72AY Daughterboard

- Mode Select
- Debug Connector
- Sin/Cos Buffers
- SH72AY (with caps, xtal, pullups, etc.)
- Exc. Select
- Exc. Buffer
IRIS PCE (RH850/E1x) Daughterboard

- Exc. Buffer
- RH850/E1x-FCC (with caps, xtal, pullups, etc.)
- AU6805 RDC
- Debug Connector
- AU6805 RDC
Summary

- HEV market is continuing to gain sales
- HEV efficiency is dominated by the traction motor and batteries
- The energy density of Li-ion batteries is 1.5% that of gasoline (by weight)
- Traction motor efficiency continues to improve due to advanced software and high performance electronics
- Traction motor capability continues to advance with higher voltage, higher current IGBTs
- Traction motor cost continues to improve due to electronic hardware integration
- Renesas is on the leading edge of these electronics, and working with customers to develop compelling development platforms