June, 2010

Reducing System Cost with Integrated MCU Solutions for Engine and Transmission Applications

FTF-AUT-F0354

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Introduction

- Lower system cost and increasing system complexity of new technology drives feature integration within the MCU

- This session explores integrated features on the Freescale MPC56xx family used to reduce system cost and improve flexibility

- Examples of two Applications can be used to demonstrate new integrated features on the Freescale MPC56xx family
  - Knock Detection
  - Closed Loop Current Control

- **Presenter**: Robert Moran
- **Expertise**: Applications Engineer at Freescale for the last 6 years
  - Worked on the MPC5500 and MPC5600 Powertrain MCU families
  - Enabling and supporting customers with new IP

- This presentation should take about one hour.

Session Objectives

- ►**This session will demonstrate:**

- ►How to reduce overall system cost by integrating functionality into the MCU

- ►The functionality of these integrated features to illustrate the flexibility they offer

- ►How integrated functionality is implemented with minimal impact on run-time CPU loading

Agenda

- ► **Knock Detection**
    - Existing solutions
    - The Freescale solution
    - Specific MCU features for Knock Detection
    - A zero CPU loading Knock Detection solution
- ► **Closed Loop Current Control**
    - Existing Solutions
    - The Freescale solution
    - Reaction module
    - Zero CPU Boosted Injector Control Example
    - Zero CPU Solenoid Control Example

Knock Detection

- Knock is essentially an abnormal ignition causing potential damage to the engine
  - Economy and Performance suffer
- Knock Detection is common place on modern automobiles
  - Knock Sensor “listens” for a resonant knock frequency
- Knock Control is set to detect Knock and alter spark timing appropriately:
  - Conversely, a good angle for spark ignition (for economy/performance) is typically prone to knock
  - Thus, there is a trade-off between ideal spark timing and reducing knock occurrence.

An Existing Knock Detection Solution

▶ Knock Control Characteristics

- Capture the voltage of knock sensor
- Evaluate voltage in freq domain and identify presence of knock (resonant freq~7KHz)
- Alter the spark ignition control appropriately

▶ Custom ASIC (Application Specific IC) for Knock Detection

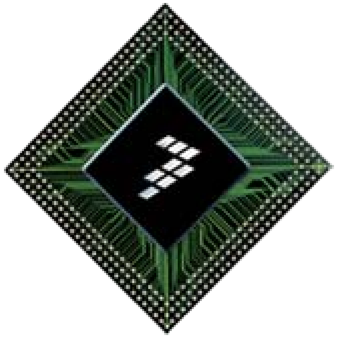
- Expensive
- Reduced design flexibility

▶ MCU (Micro Control Unit) and a dedicated DSP (Digital Signal Processor)

- Expensive and DSP Filter response times are not as good as analog solutions

Existing Knock Detection Solutions

Challenges of Migrating to MCU Knock Solution



►Signal Quality

- ADC has to measure small voltage variations
- Conversion speed and bandwidth of ADC
- Self resonance of sensor

►Filter Response

- DSP filters require settling time, which affects the filter’s response

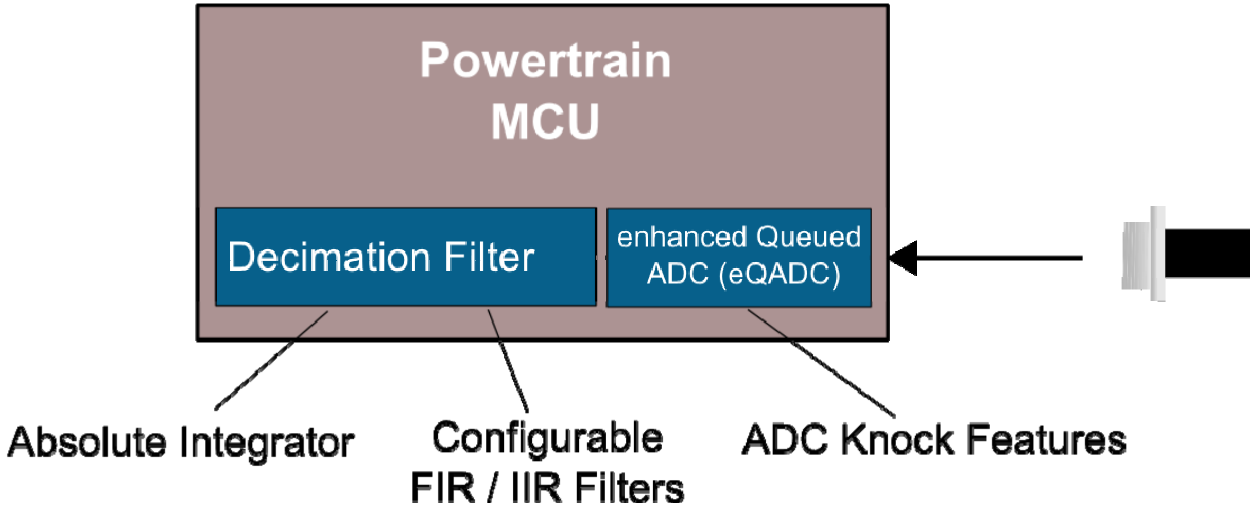
►CPU Loading

- Desire is to minimize overall CPU bandwidth

►Diagnostics

- Solution is required to determine faults in the knock sensor

The Freescale MCU Knock Detection Solution



►Immediate cost savings

- No external semiconductors - Discrete components only
- Zero CPU loading

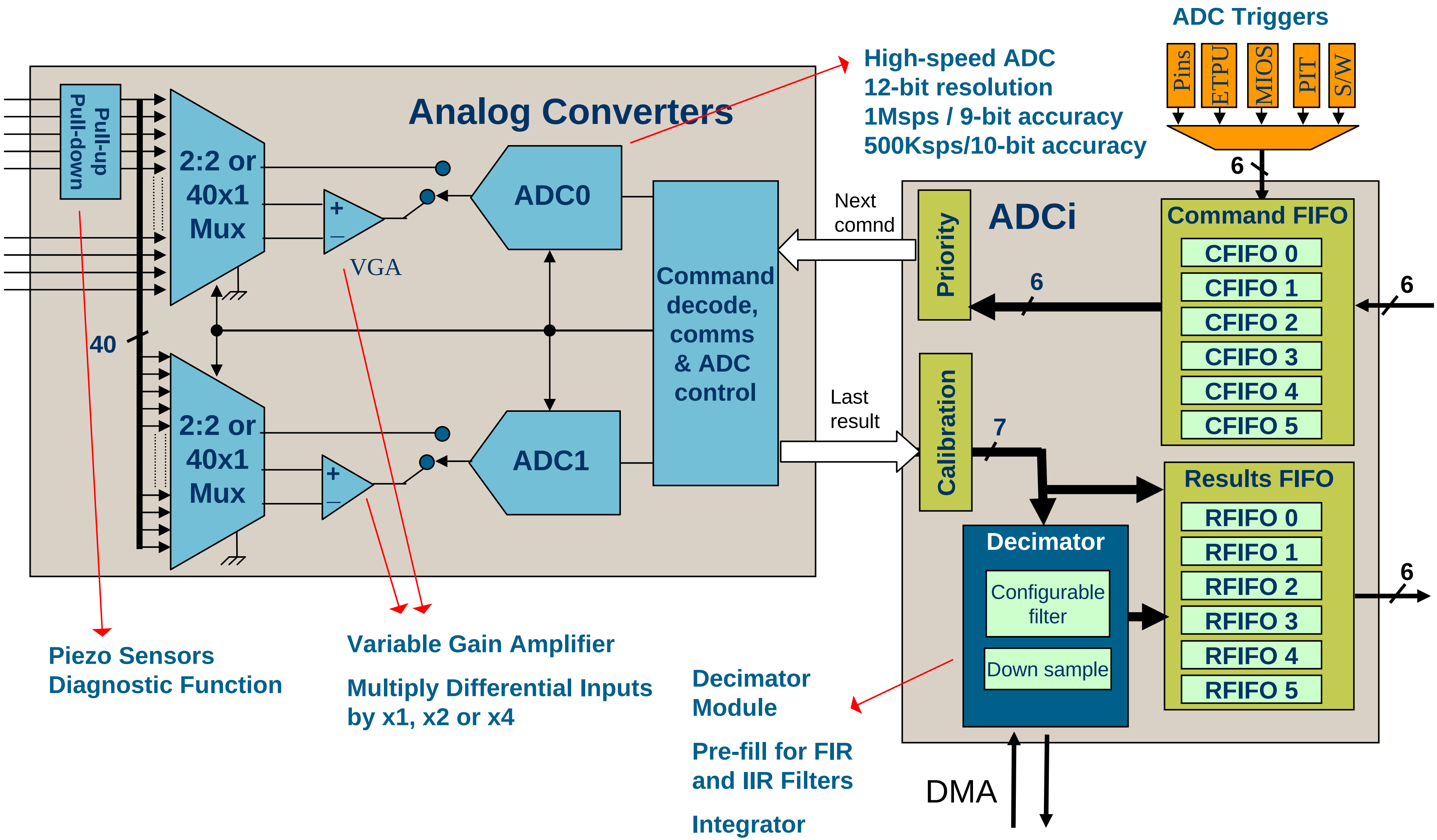
►Improvements in Flexibility

- On-chip features are highly configurable

Knock Detection Requirements

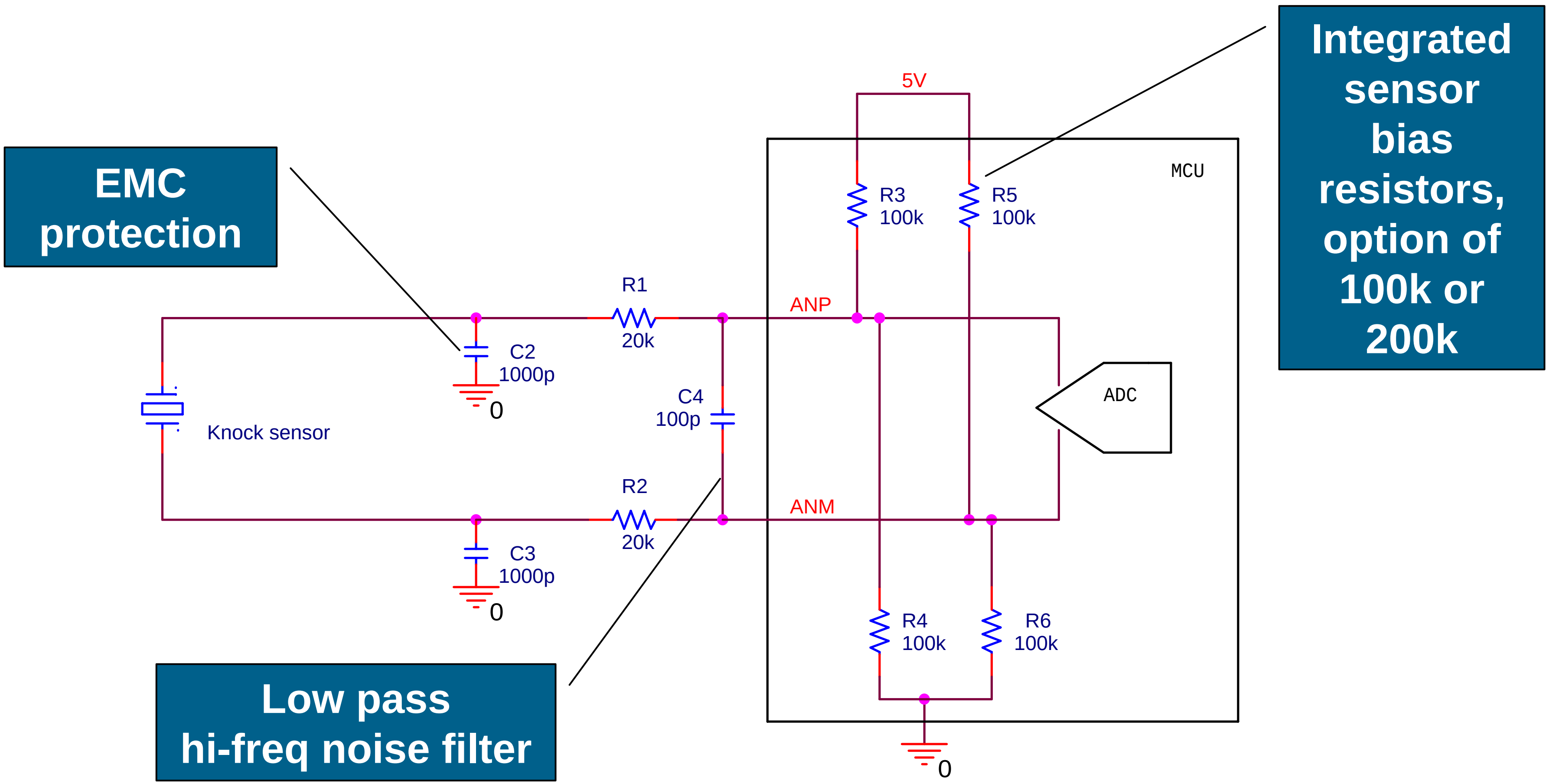
- The process of Knock Detection involves:
  - Amplifying the knock signal to increase resolution
  - Sampling the knock signal, capturing key frequencies (~<50KHz)
  - Filter the knock signal to leave only key knock frequencies
  - Integrate the filtered signal to detect if a knock freq element is present
- Diagnostics of the knock sensor are required to detect faults
- The enhanced Queued Analogue to Digital Converter (eQADC) on the MPC5600 family incorporates new features for knock detection

…PC56xx Enhanced Queued Analogue to Digital Converter (eQADC)



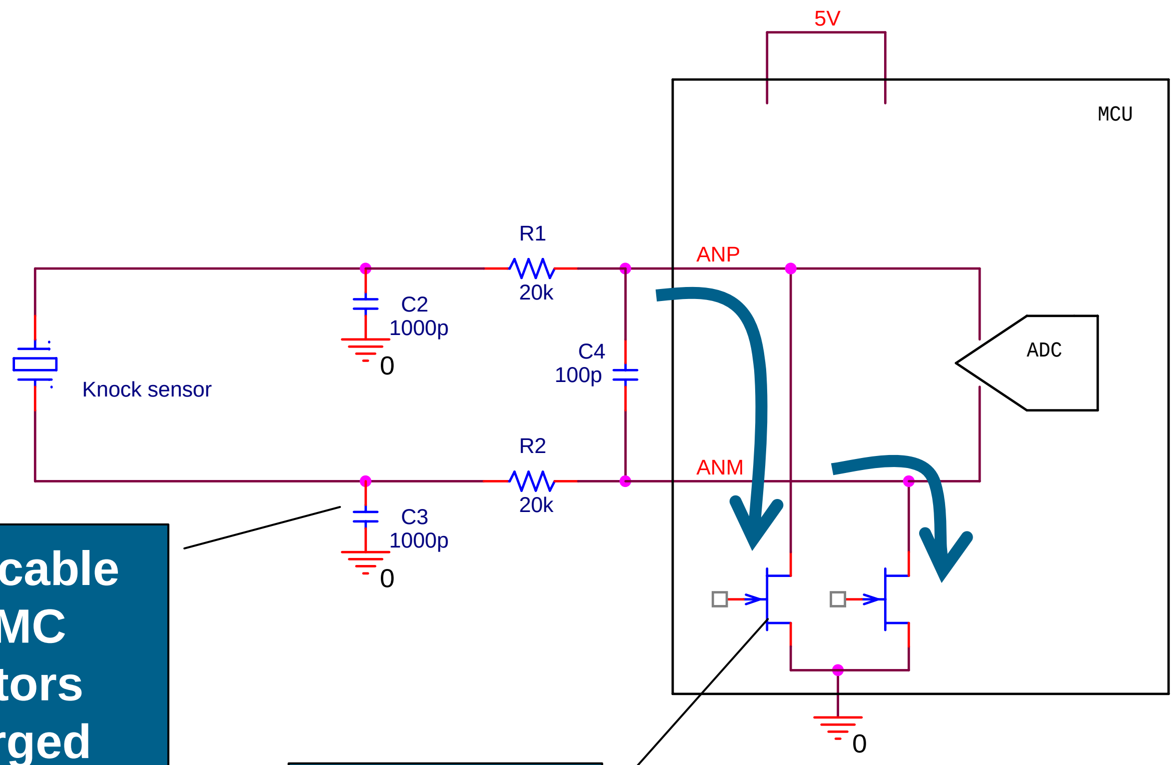
Sensor Bias and Diagnostics

- Circuit is in bias state.



Knock Sensor Diagnostics

- Circuit is in discharge state.



Sensor, cable and EMC capacitors discharged through filter resistors

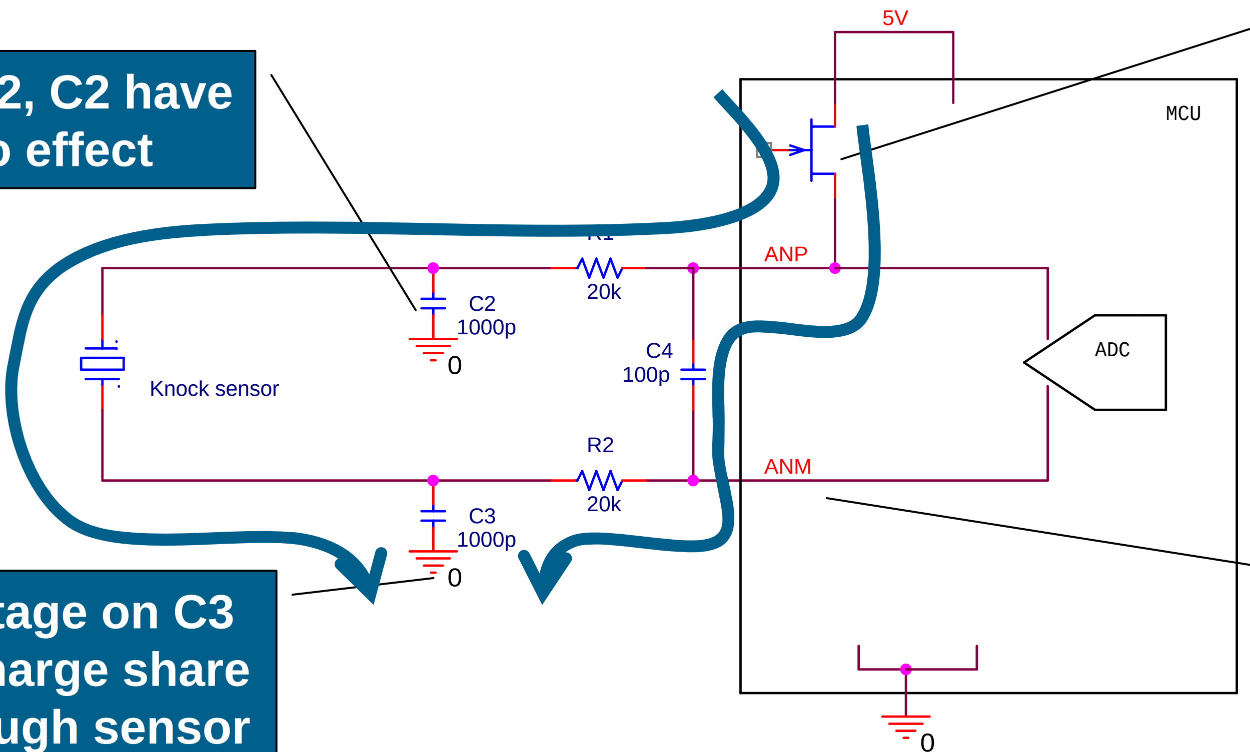
Both pins grounded

Knock Sensor Diagnostics

- Circuit in charge share state
- Symmetrical – can test either or both inputs
- Short Circuit, short to battery included

R1, R2, C2 have no effect

One side connected to 5V



Voltage on C3 is charge share through sensor and cable

Read pin in single ended mode

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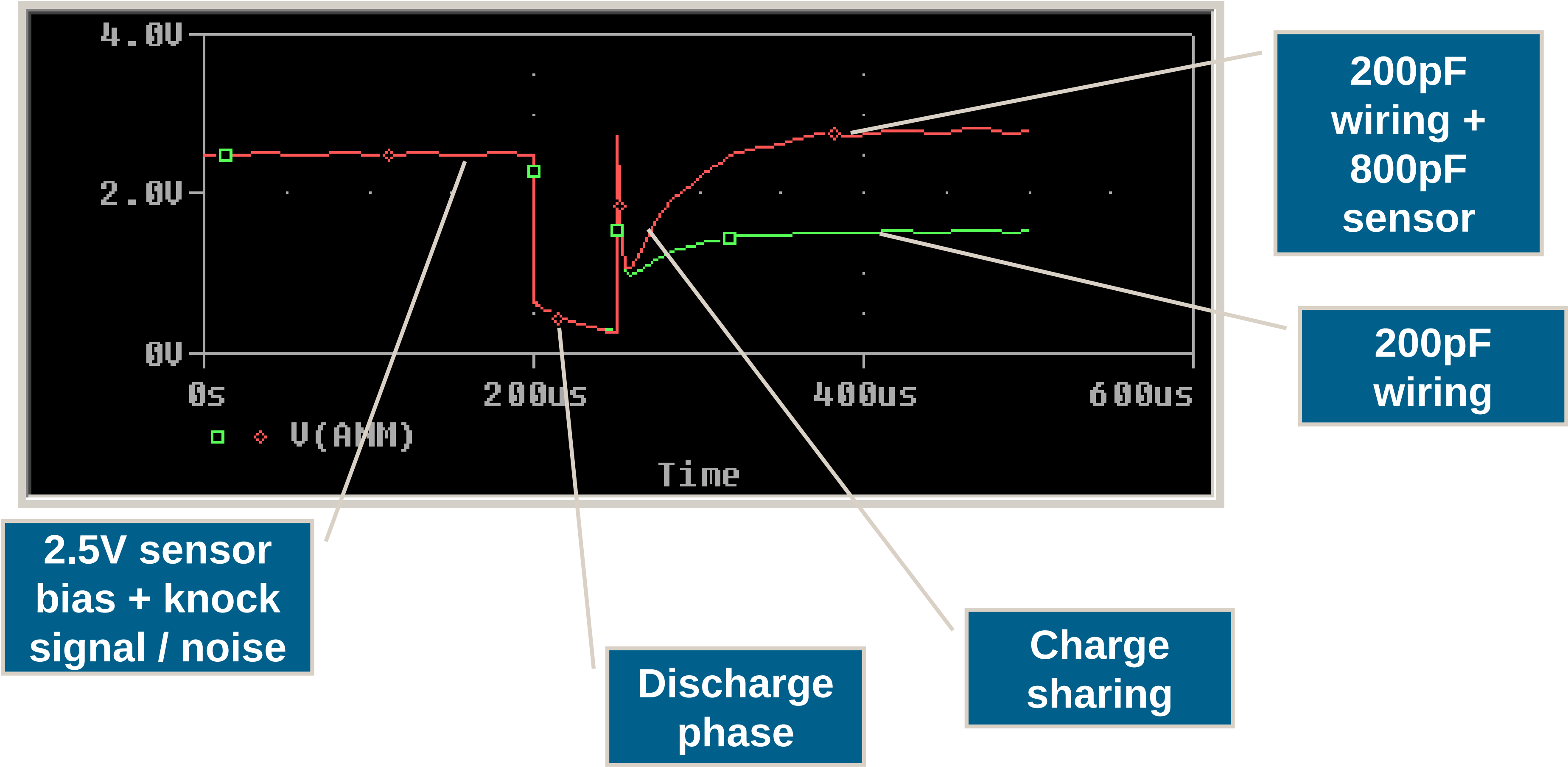
- Diagnostic process: Discharge → Charge share → Read input



Enhanced Queued Analogue to Digital Converter (eQADC) Knock Features

▸12-bit resolution ADC

- 9-bit accuracy at 1M samples/sec
- 10-bit accuracy at 500K samples/sec

▸Abort

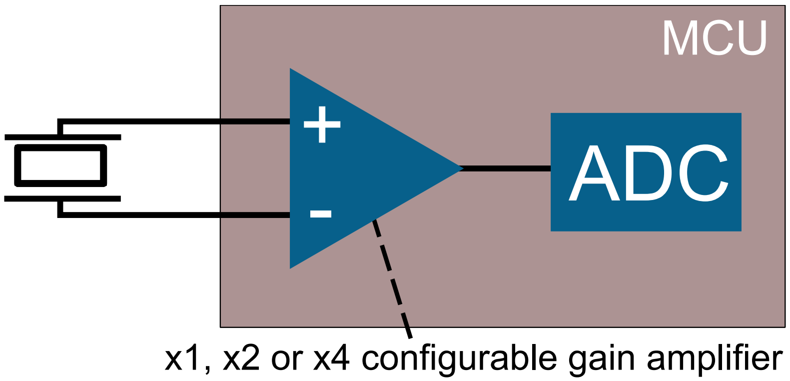
- Stops any existing conversions
- High priority conversion can proceed

▸Streaming

- Stores common conversion requests in Command FIFO
- E.g.: a Knock conversion command
- Reduces latency of fetching commands

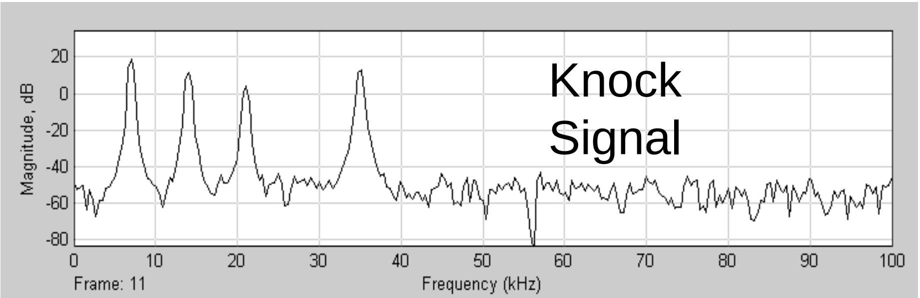
▸Variable Gain Amplifier

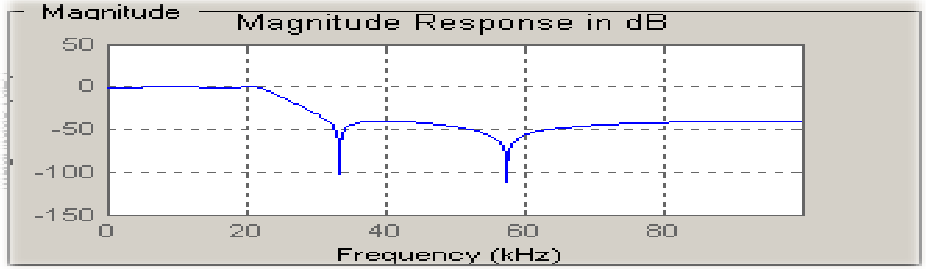
- Amplifies the knock signal by:
  - x1, x2 or x4
- Improves the resolution of ADC results

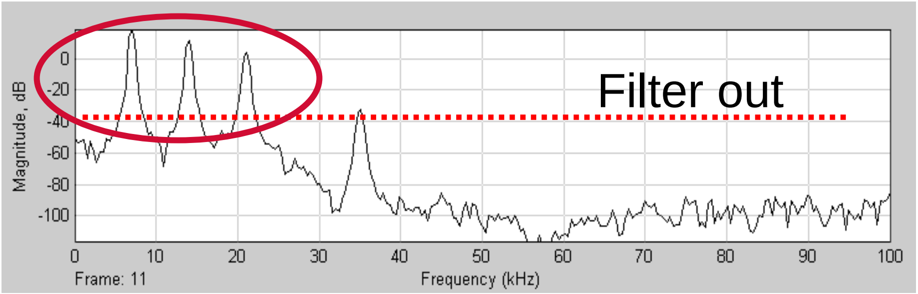


Decimation Filter and Integrator – Knock Function

- The decimator down-samples the Analog-to-Digital Converter’s (ADC) results to reduce noise
- The knock signal is then passed through the Finite Impulse Response (FIR) or Infinite Impulse Response (IIR) filter (in the decimator)
- The integrator sums the energy in the filtered knock signal
- Integrator output is transferred to the knock strategy routine by the DMA (Direct Memory Access)
- eTPU spark angle can be updated based on the result of the knock detection







Decimation Filter and Integrator – Features

► Decimation Filter

- Selectable 4^{th} order IIR or 8^{th} order FIR
- Cascading of 2 or more filters to create complex filters
- ADC results are routed directly to the decimation filter
- “Pre-fill” feature to remove latency of settling time
    - Explained on next slide

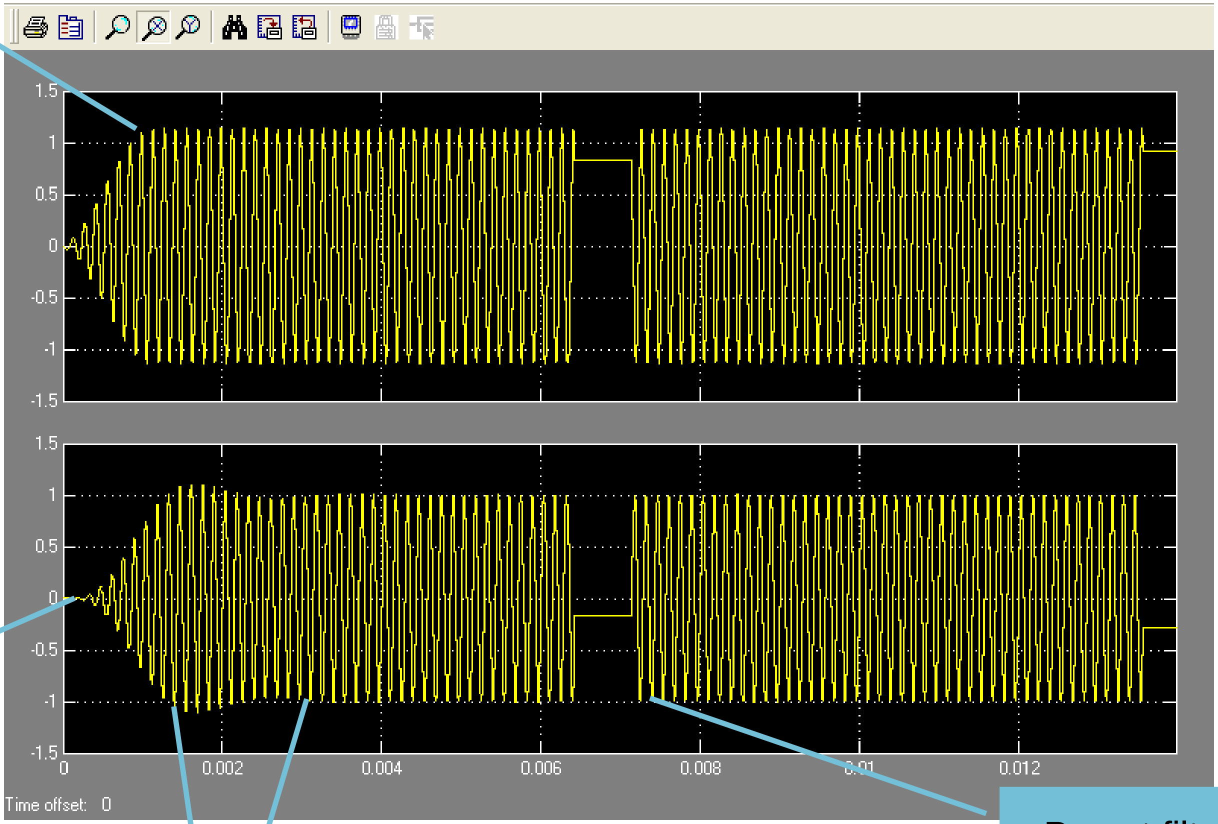
► Integrator

- Absolute integrator is on the output of the decimation filter
- Halting and Reset of integrator using HW triggers
- DMA triggers to transfer the output of the integrator

Filter with Pre-set Data vs Zeroed Data

FIR settles in one data fill, 1ms

- 7kHz sine wave
- 150K samples/s

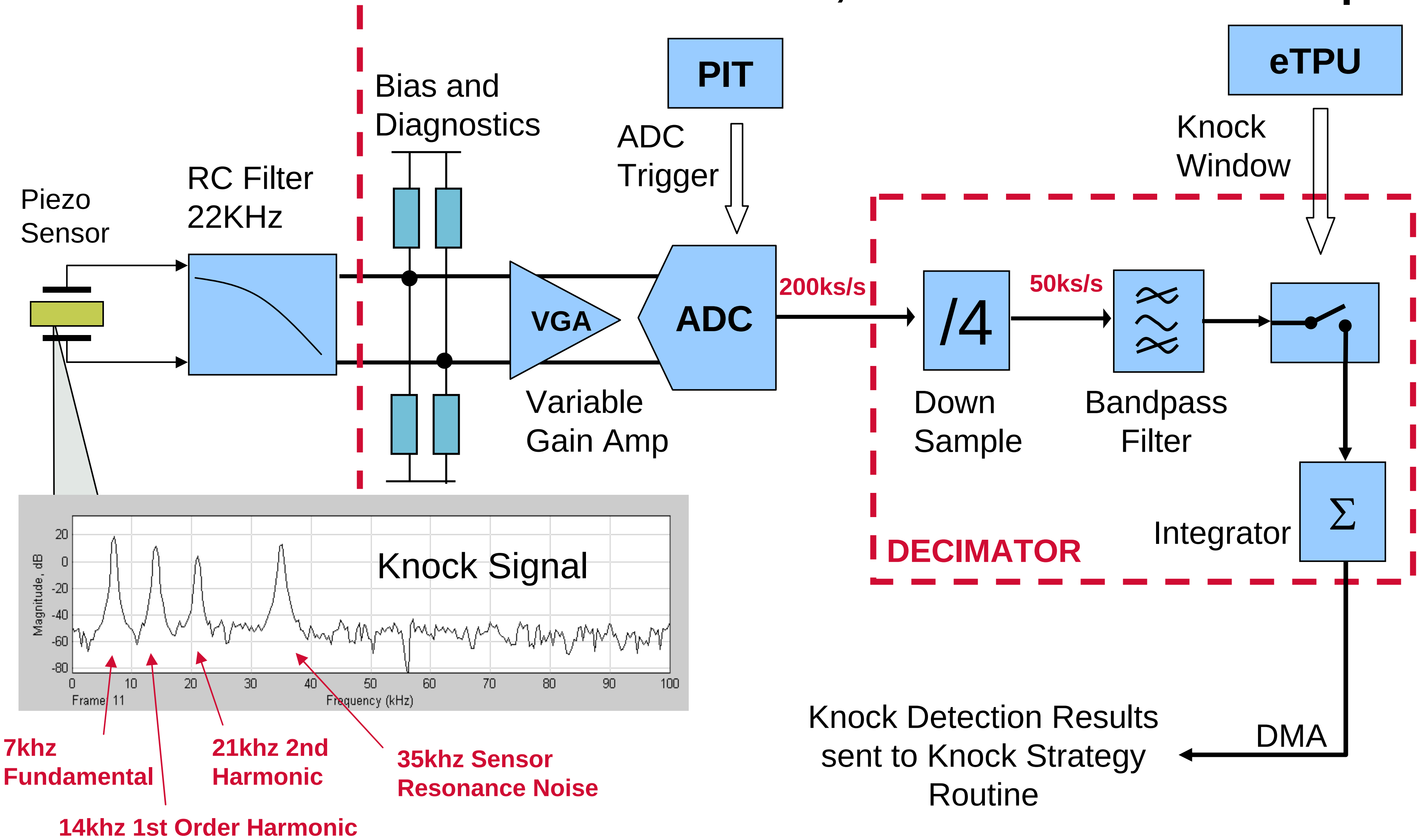


Zeroed filter takes time to settle

IIR takes 1.3ms to reach amplitude, and 3ms to settle fully

Preset filter settles immediately

Zero CPU Load, Knock Detection Example



Closed Loop Current Control

▶ What is Closed Loop Current Control?

- Modulation and controlling current to create complex current waveforms
- Required by a wide range of applications

▶ Engine Control Applications

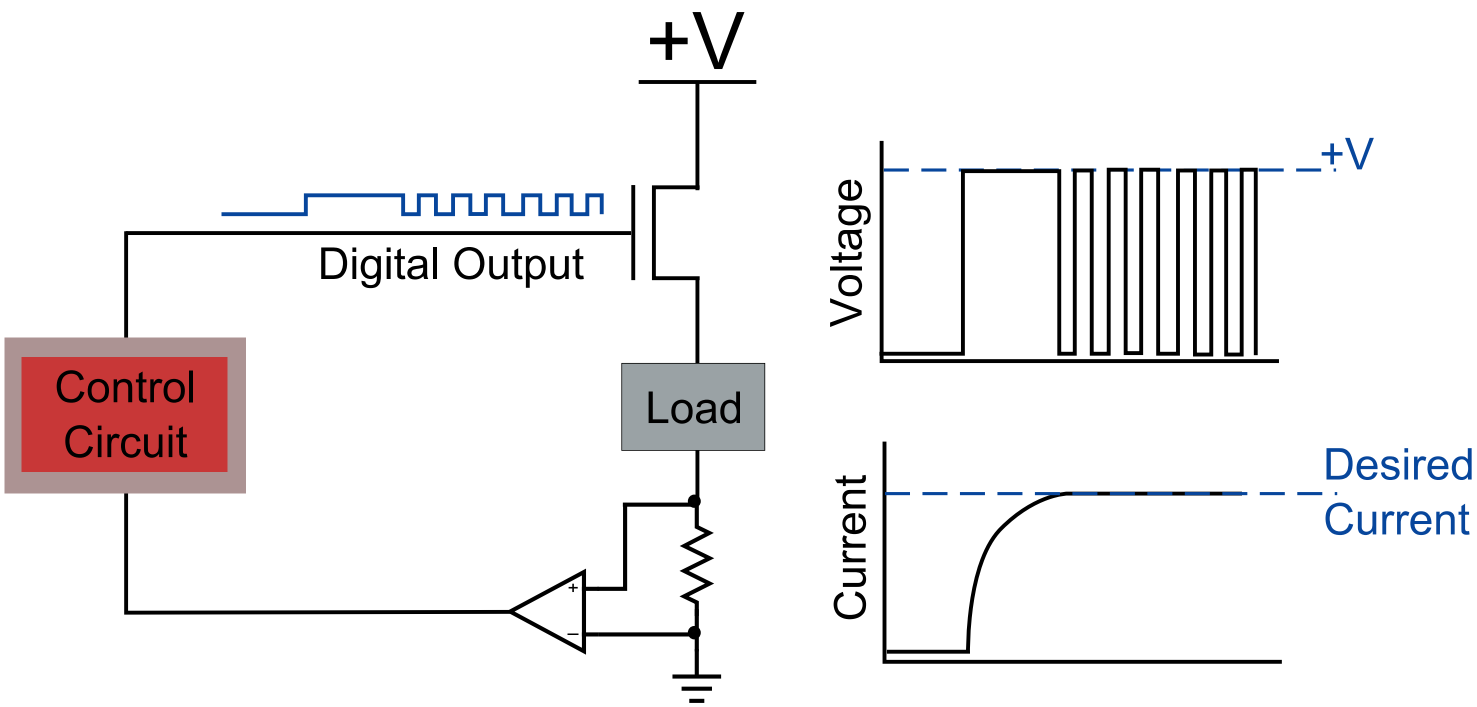
- Injector control
- Complex waveforms are required to comply with emission standards

▶ Transmission Applications

- Variable Force Solenoids
- Torque Converters
- Control of current levels with dithering

▶ What is Current Control?

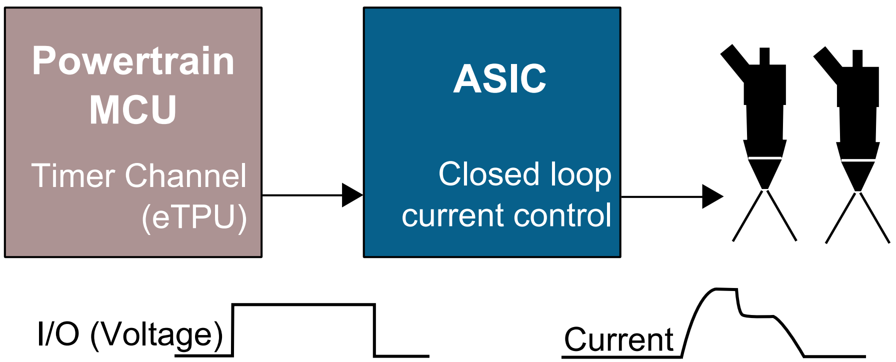
- Allows DC current levels to be varied by a control circuit
- Controlling current by pulsing digital outputs of varying widths
- The control circuit monitors current, and adjusts the ON/OFF timing of the output to ensure that the desired current level is maintained



Existing Solution : Injection Control

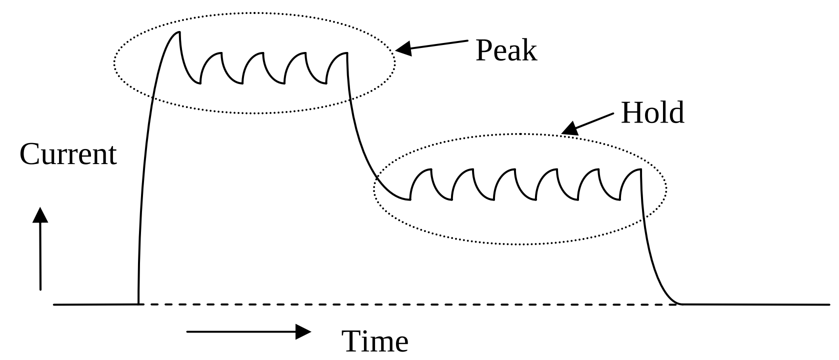
▶ Direct Injection Control

- MCU controls timing
- ASIC controls complex current waveforms



▶ Injection Waveforms

- Complex waveforms required to meet tougher emissions regulations
- Peak and Hold
- Multiple Pulses



▶ Reducing System Cost

- Move control to the MCU
- Replace an ASIC with cheaper FET drivers
- Minimal changes to Engine Control Unit (ECU) hardware

Existing Solution : Transmission Solenoid Control

▶ Variable Force Solenoid

- Controls the hydraulics
- Controls Clutch / Gears / Shift

▶ Control Current of Solenoid

- Adjustable current level required
- Dithering of current is used for control, to reduce static friction in hydraulic valves
  - Dither : ~70-350Hz

▶ Reducing System Cost

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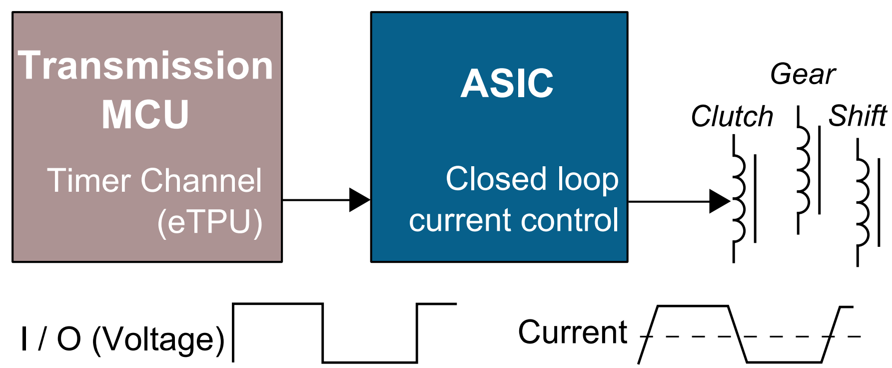
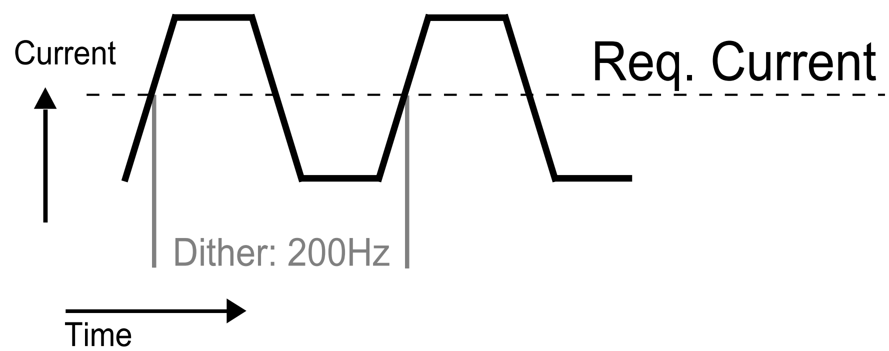
- Replace an ASIC with cheaper FET drivers
- Minimal changes to TCU hardware





Key Challenges for Integrating Control in MCU

► Timing of feedback loop

- ADC Sample Speed
- ADC Data Path to Control Logic

► Updating of Control Parameters

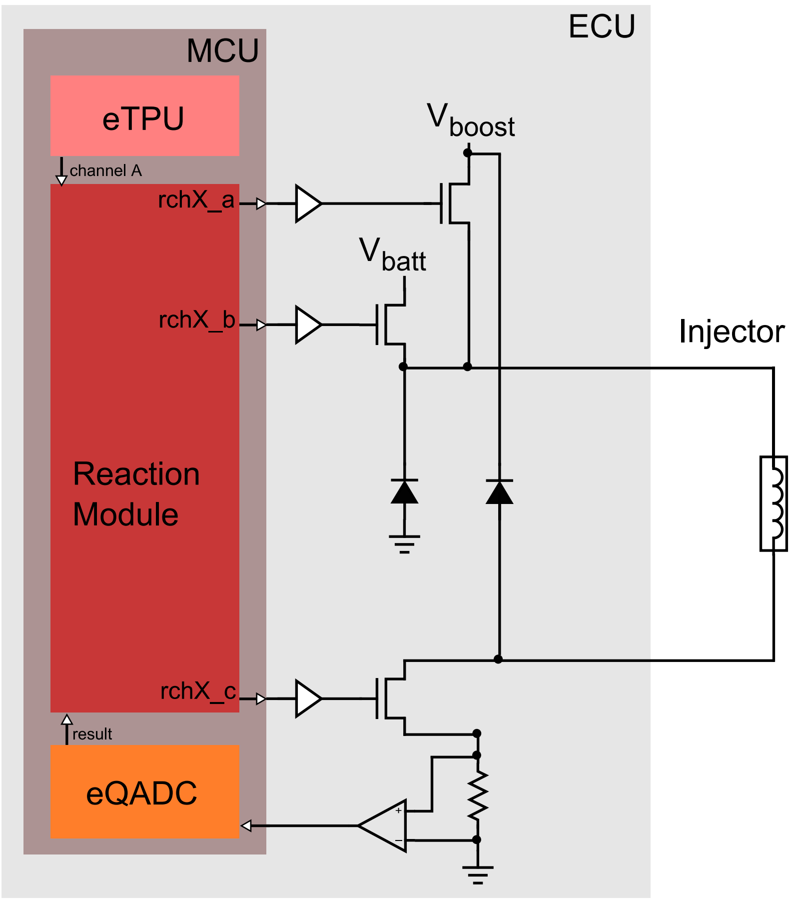
- Continuous control and modulation of current
- Fast switching of modulation parameters required to reduce latencies

► CPU bandwidth

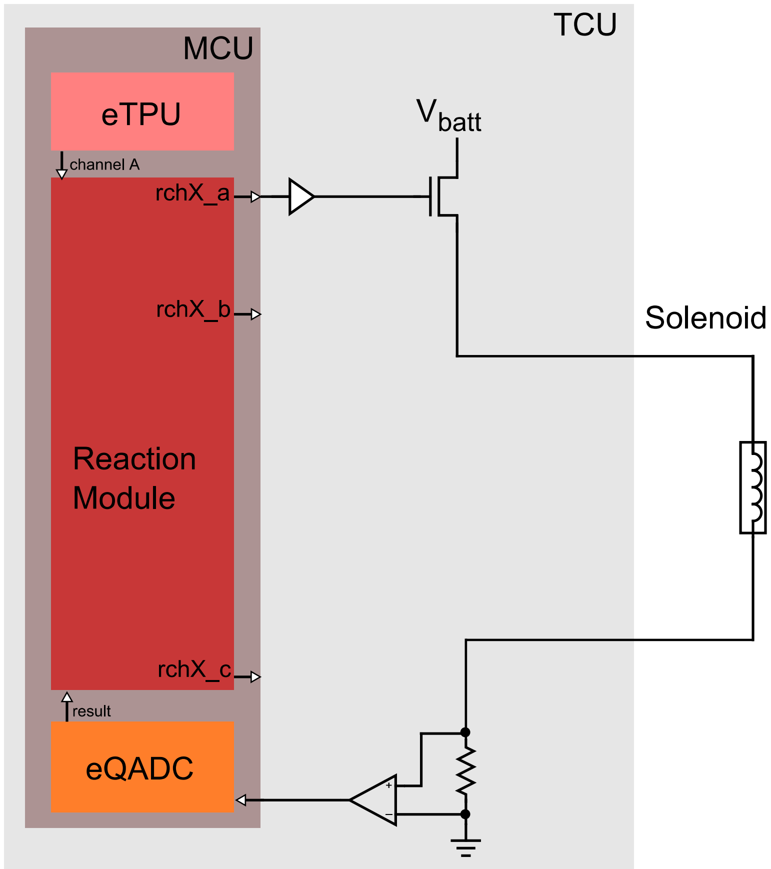
- Desire to minimize CPU usage for load reduction & optimal performance
- Minimize the routing of the feedback loop to reduce response time

The Freescale Solution: Introducing the Reaction Module

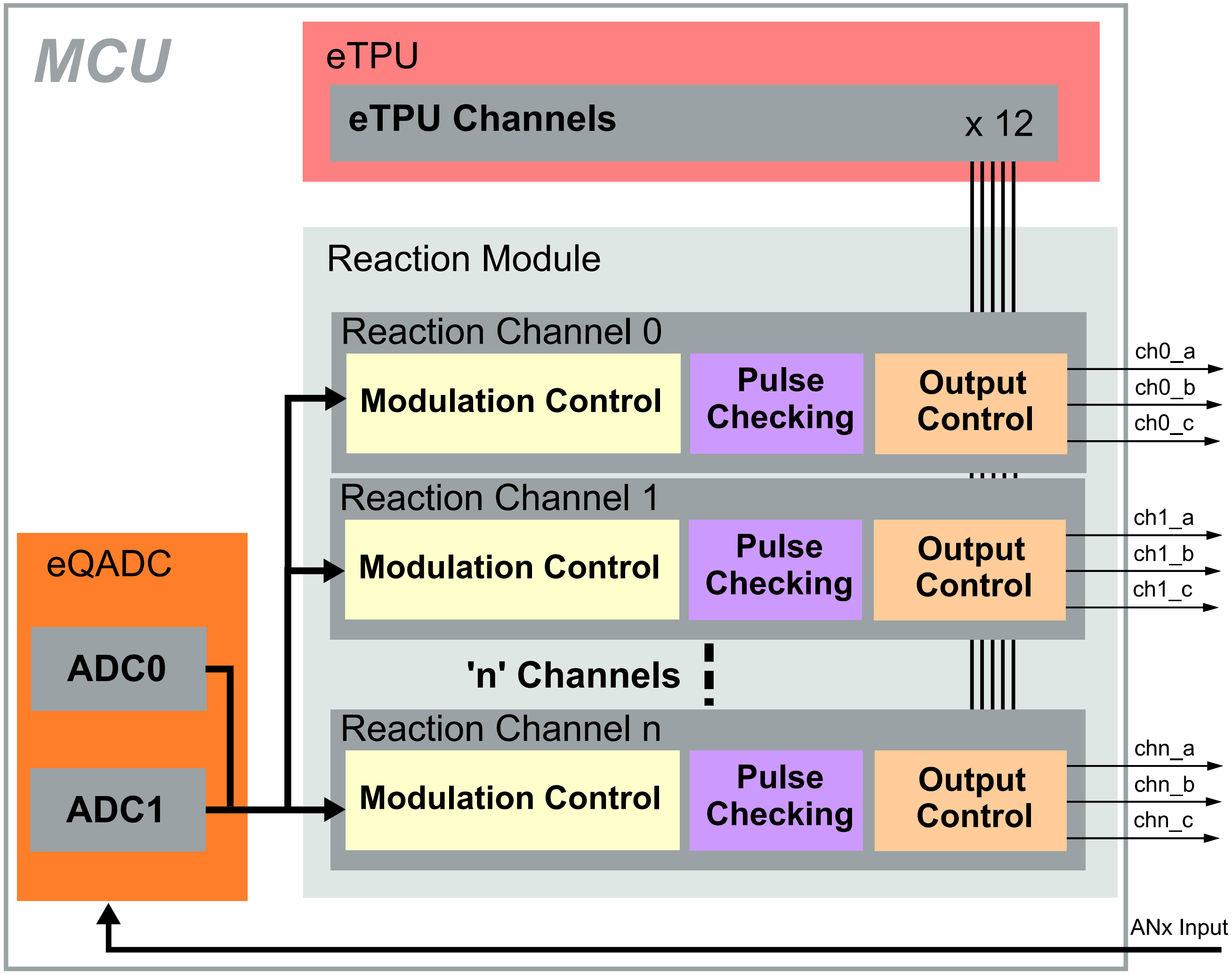
Boosted Direct Injector Control



Variable Force Solenoid Control

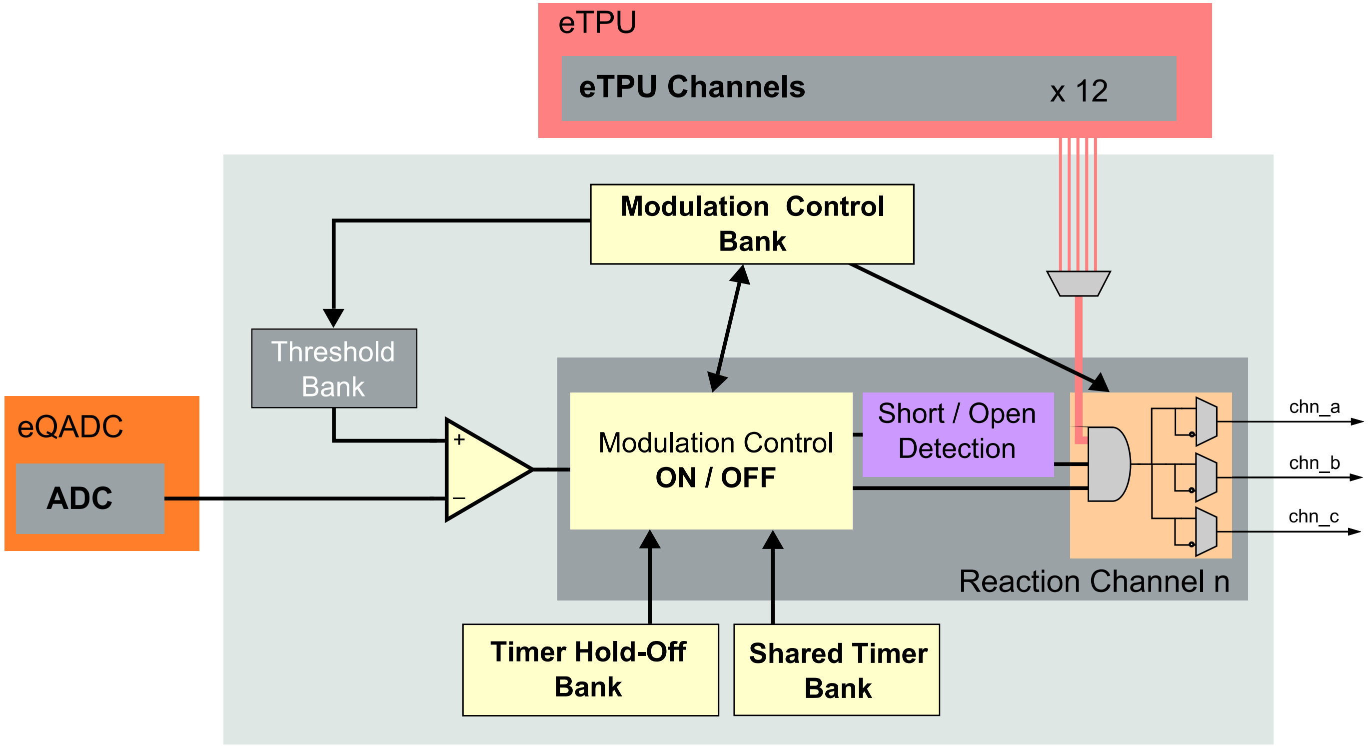


Reaction Module Overview



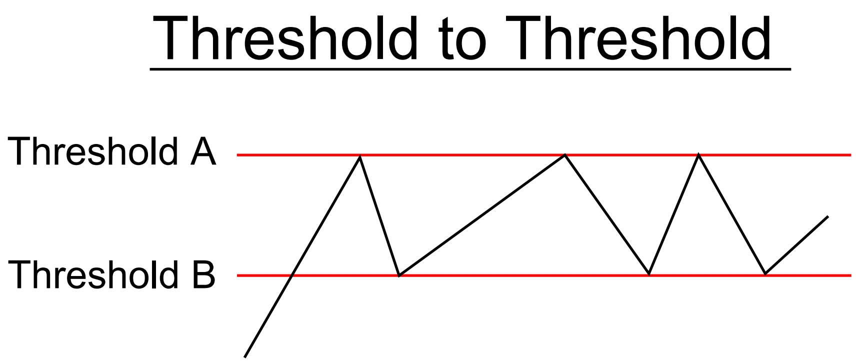
Reaction Module Channel

- **Modulation Control** – Determines ON / OFF status
- **Pulse Checking** – Short or long pulse detection
- **Output Control** – 3 configurable outputs per channel

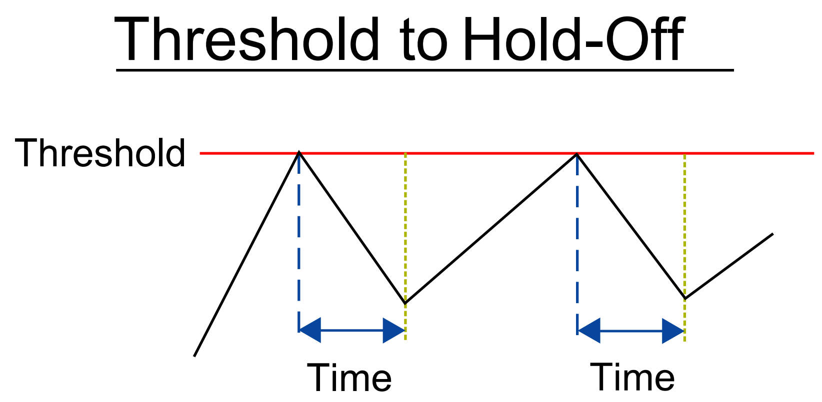


► Two types of modulation:

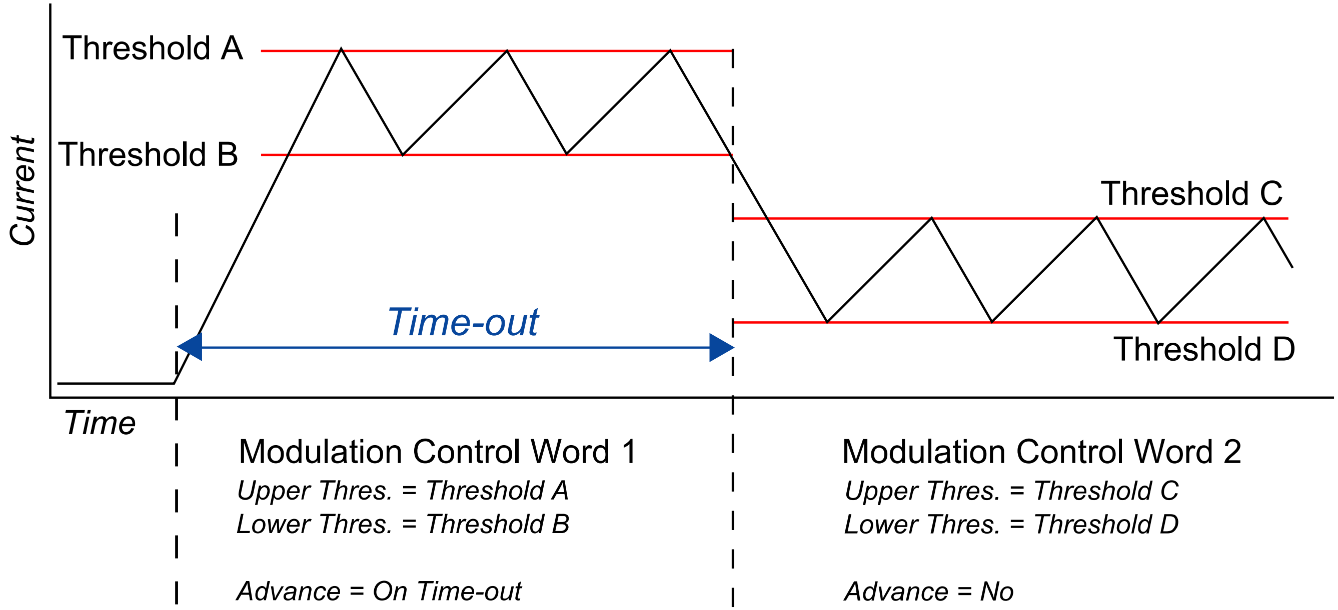
- **Threshold to Threshold**
  - >= Threshold A triggers OFF state
  - <= Threshold B triggers ON state



- **Threshold to Hold-off**
  - >= Threshold triggers OFF state
  - Hold-off Timeout triggers ON state
  - Maximum Switching Freq can be defined



- **Modulation control words are used to configure modulation**
- **This configures:**
  - Threshold modes and levels
  - Timer Configuration
  - Output states for all 3 outputs
  - **“Advance”**: Allows multiple modulation words to be used per channel



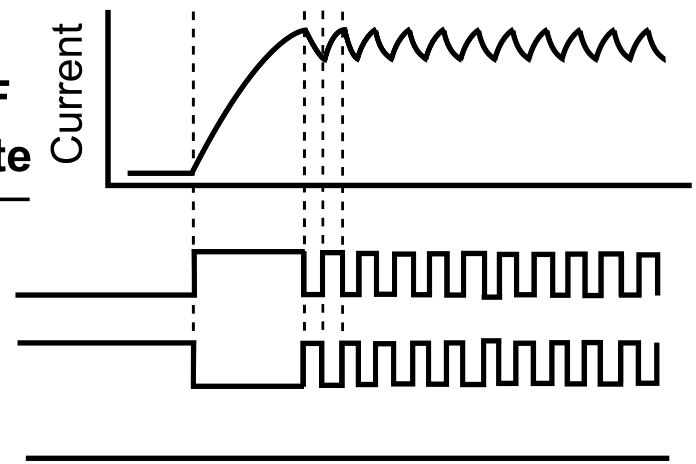
Reaction Channel Outputs

- **3 Outputs per Reaction Channel** – a, b, c
  - Modulating Outputs based on ON / OFF state from modulation control

- Each output can be configured with different ON state and OFF state per modulation control word

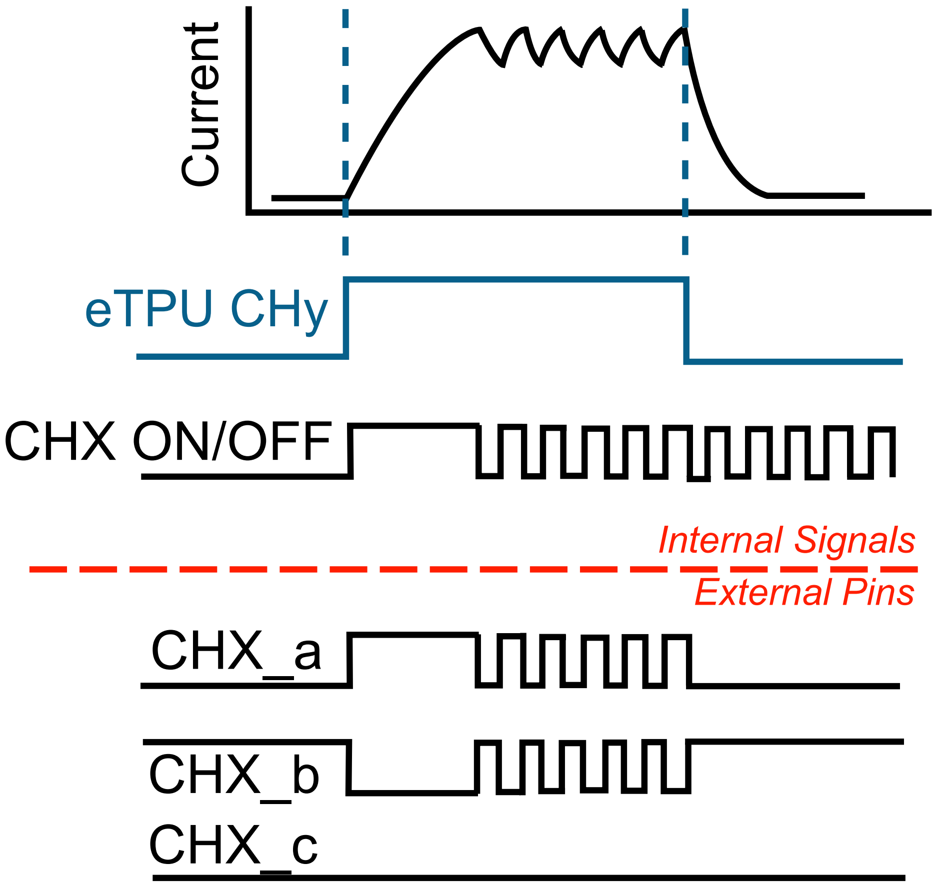
- There exists a configurable “Drive Off” state for each pin, when modulation is disabled or an error event occurs

Channel X Output	Drive Off State	ON State	OFF State
ChX_**a**	0	1	0
ChX_**b**	1	0	1
ChX_**c**	0	0	0

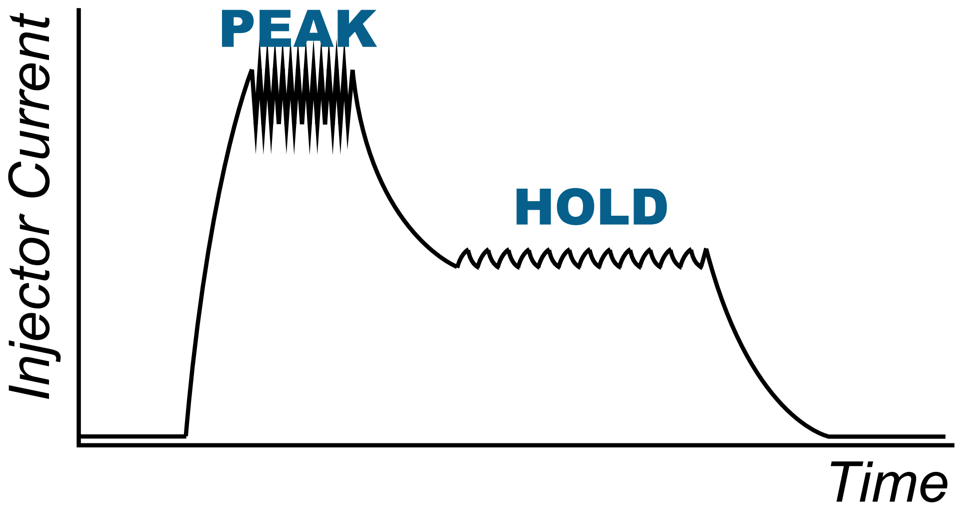


Reaction Channel Output Gating

- **Reaction Channel Outputs can be gated**
  - eTPU (12 eTPU channels)
  - Software
- **Allows modulation to begin relative to engine timing from eTPU**
  - Important for Injector control
  - eTPU controls engine timing

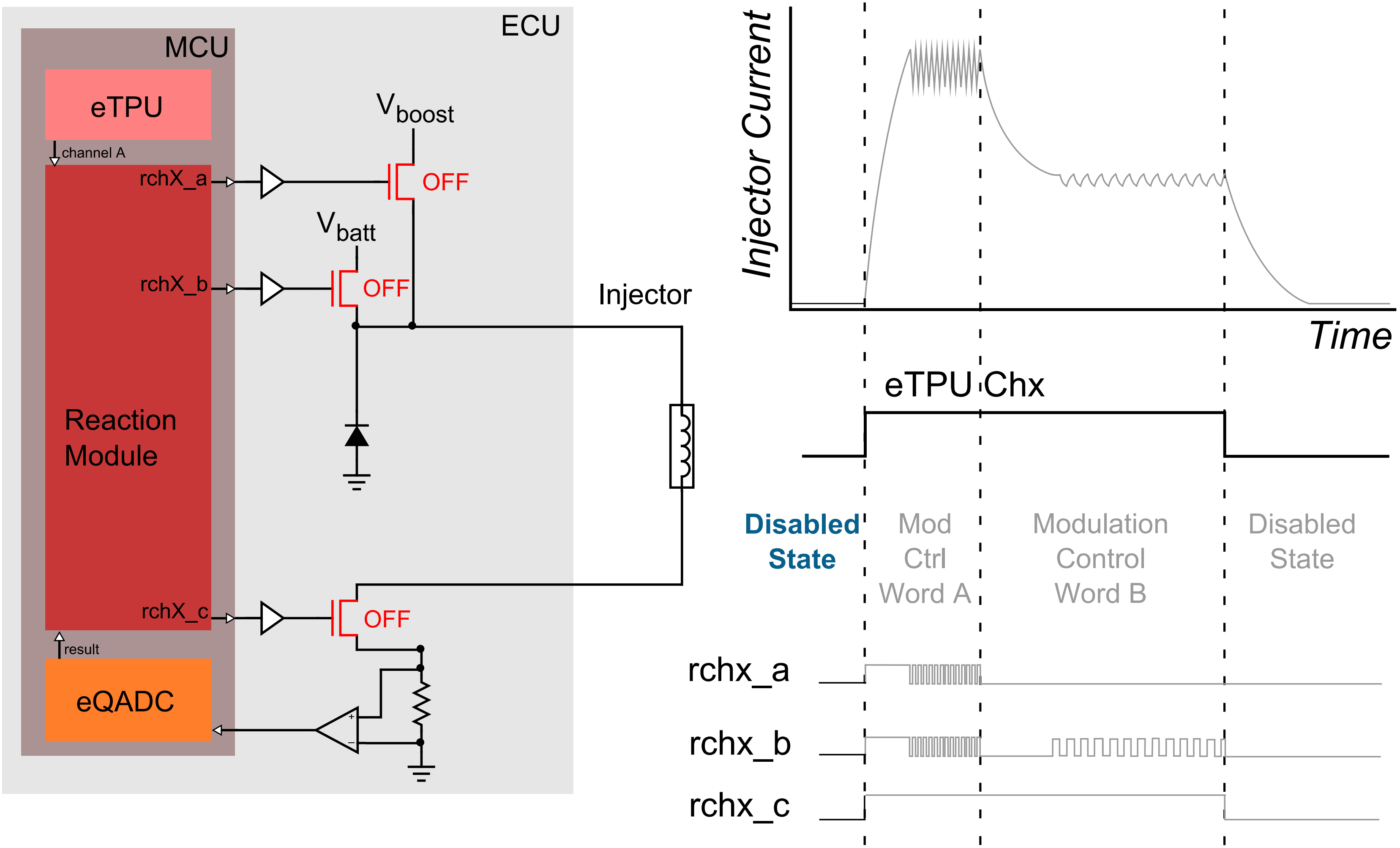


►Example: Boosted Injection Control

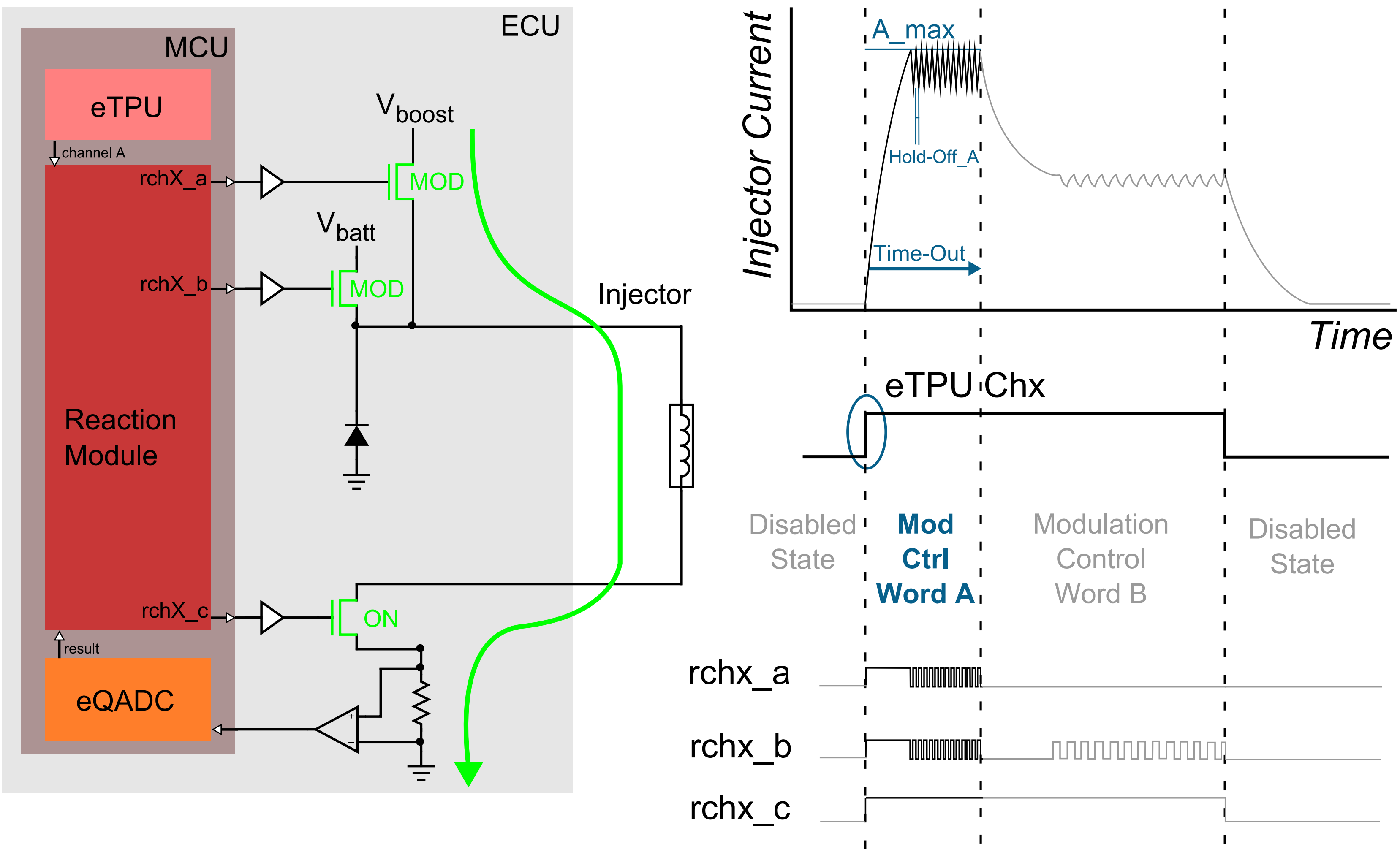


e.g. Diesel Direct Injection

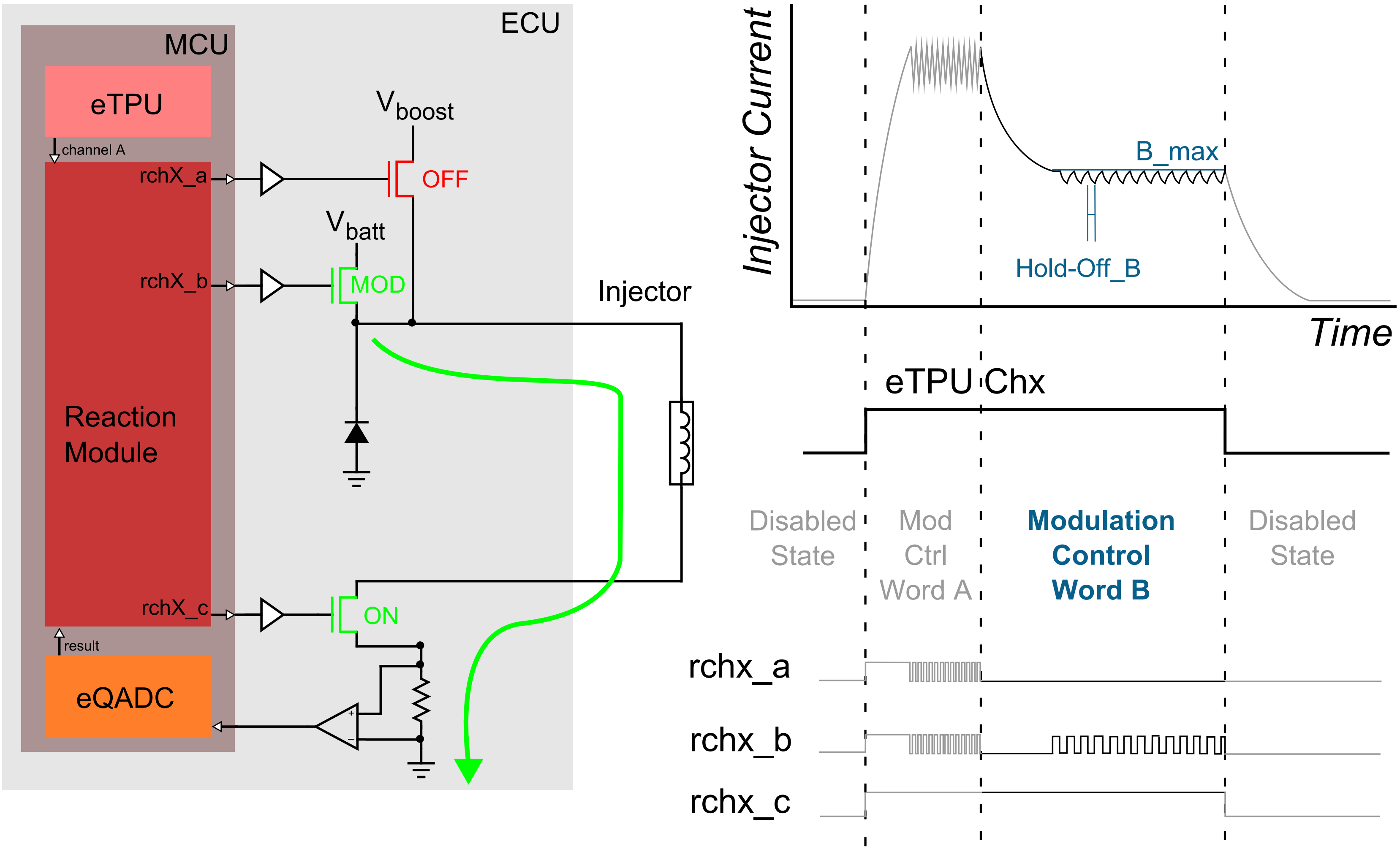
Boosted Injector Control – START



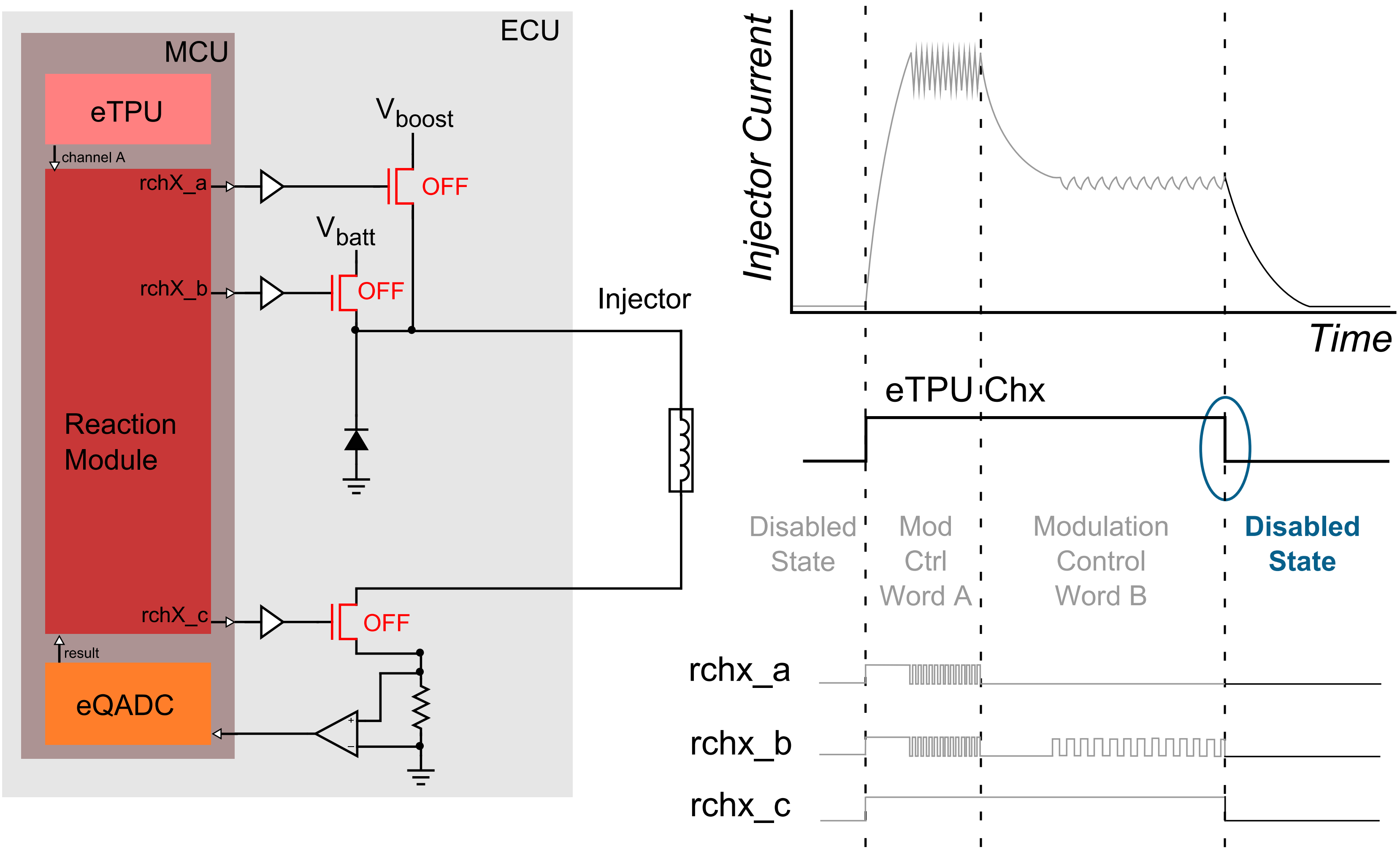
Boosted Injector Control – PEAK



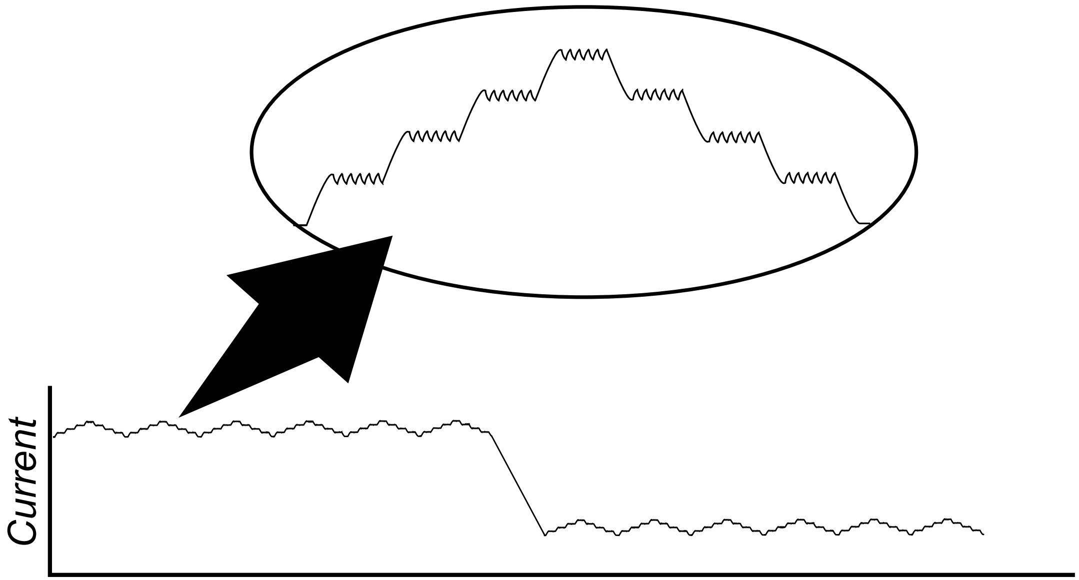
Boosted Injector Control – HOLD



Boosted Injector Control – END

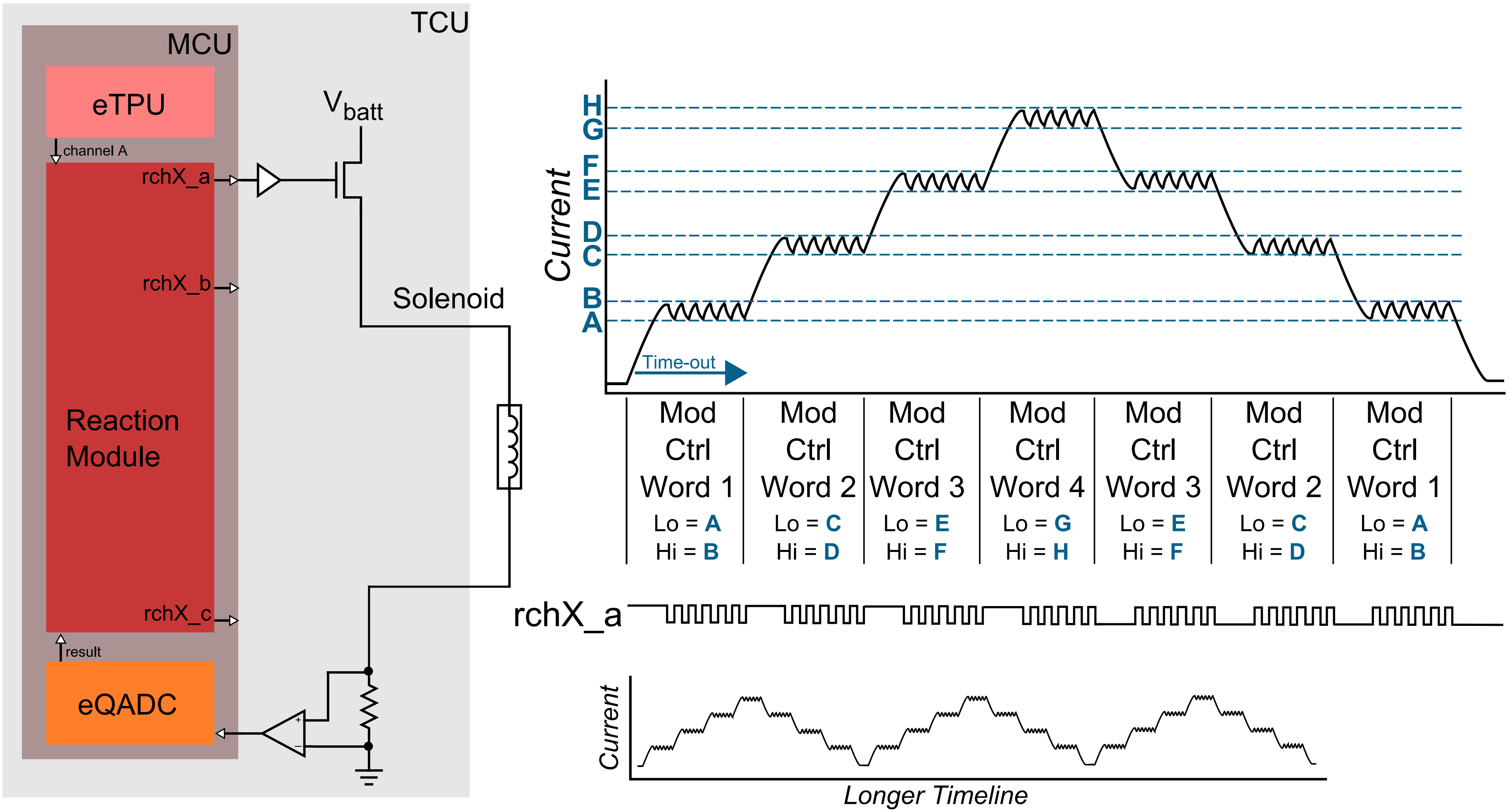


►Example: Solenoid Control



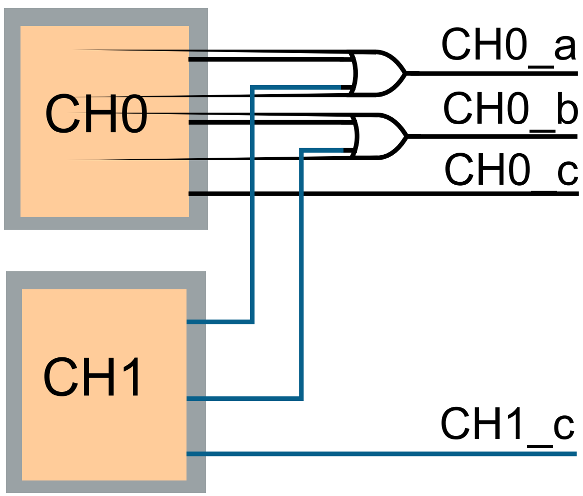
e.g. Variable Force Solenoid with Dither

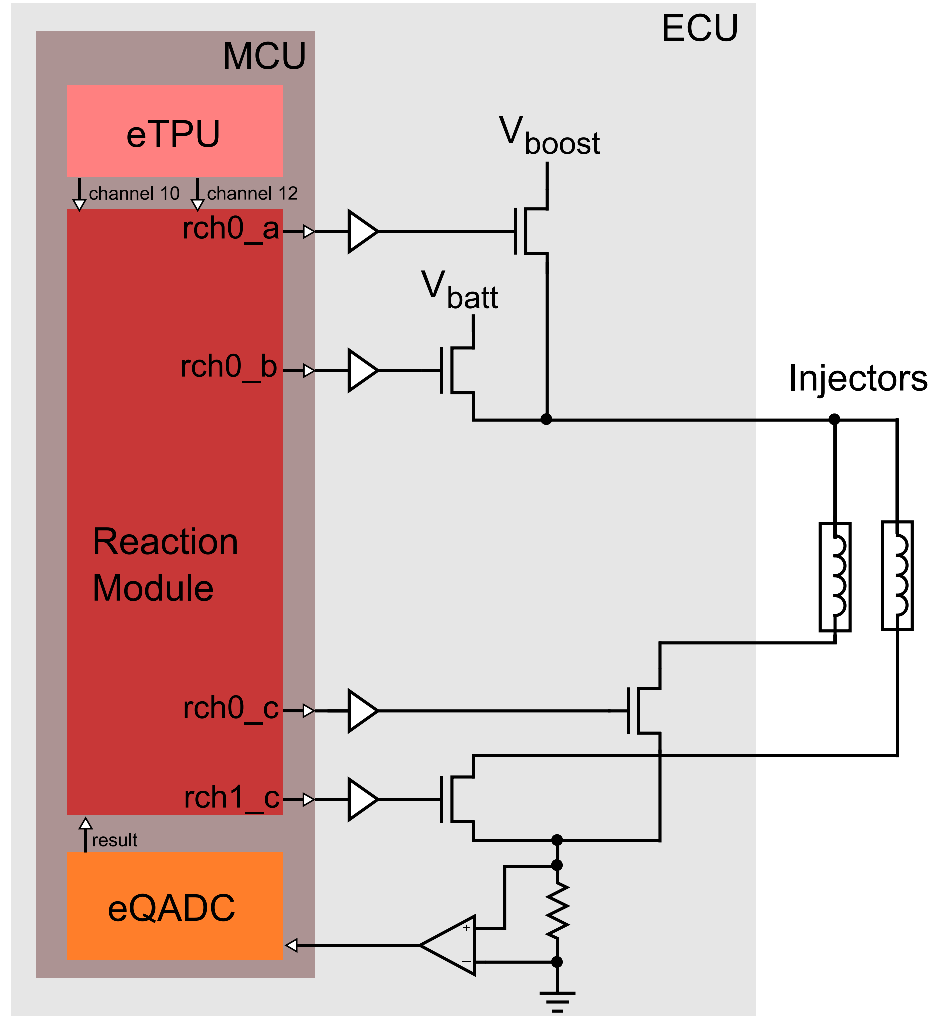
Triangle Current Wave



Banked Mode Outputs

- ▶ Banked Mode allows reaction channels to share outputs
  - Reduces number of FET's required
- ▶ Common Boost / Battery Control for a set of injectors





- **This session has demonstrated:**

- Methods to reduce overall system cost by using integrated MCU functionality

- The functionality and flexibility offered with the use of integrated MCU features

- How integrated functionality has been implemented without impacting run-time CPU loading

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