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Electrified Dynamic Skip Fire (eDSF) Design and Benefits

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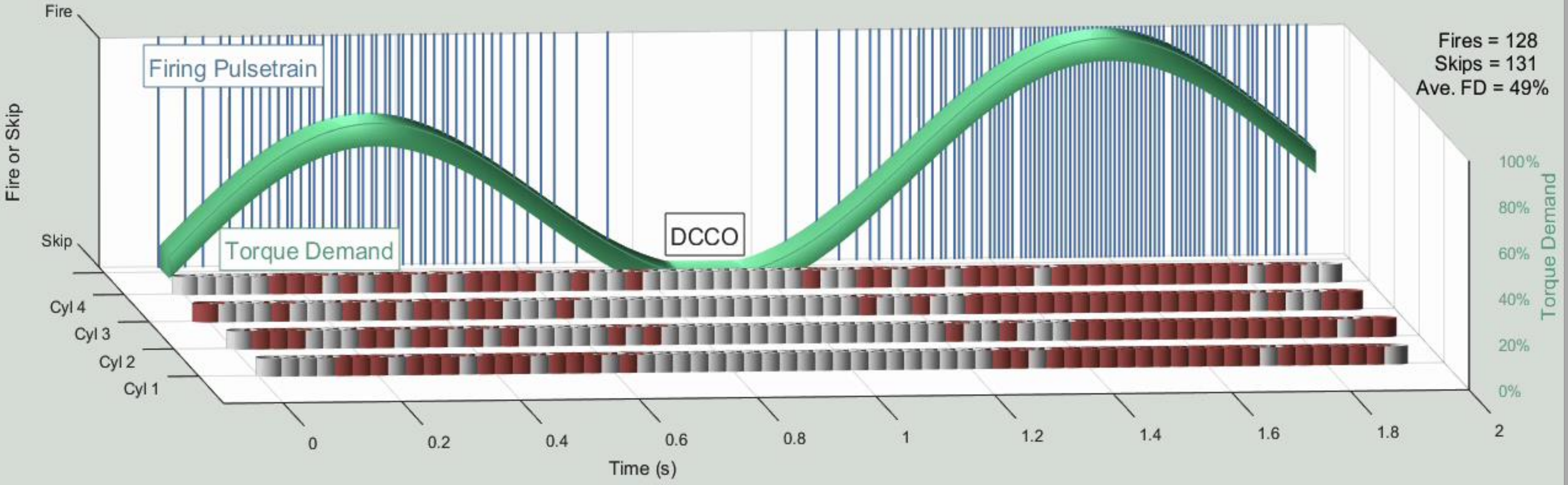
Agenda

- Background: Dynamic Skip Fire
- eDSF motivation
- eDSF torque smoothing concept and requirements
- Fuel economy projections
- Value proposition and summary

Background: Tula DSF Technology

DSF
DYNAMIC SKIP FIRE

- Determination of whether a cylinder's torque is required is made immediately prior to firing
- Firing Decisions are made on an event-by-event basis: *"Dynamic Downsizing"*
- Firing Density (FD) is chosen to optimize fuel consumption, subject to certain constraints

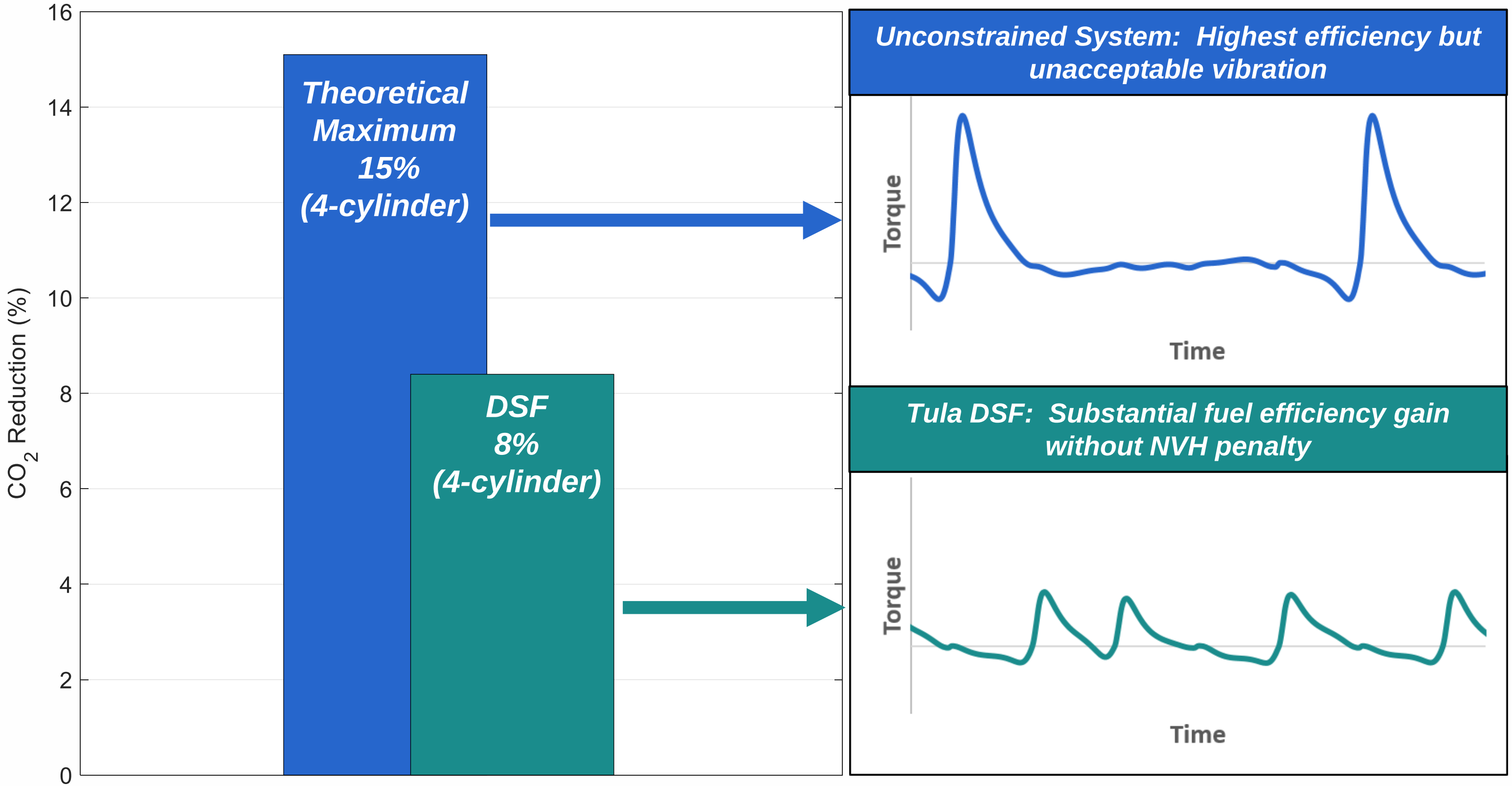


SAE Presentations and Publications

- 2013-01-0359 Design and Benefits of Dynamic Skip Fire Strategies
- 2014-01-1675 Methods of Evaluating and Mitigating NVH when Operating an Engine in DSF
- 2015-01-0210 Misfire Detection in a Dynamic Skip Fire Engine
- 2015-01-1717 Modeling and Simulation of Airflow Dynamics in a Dynamic Skip Fire Engine
- 2016-01-0672 Fuel Economy Gains through Dynamic-Skip-Fire in Spark Ignition Engines

- 2018-01-0891 λDSF: Dynamic Skip Fire with Homogeneous Lean Burn for Improved Fuel Consumption, Emissions and Drivability
- PFL170 (oral) mDSF: Uncompromised Engine Fuel Efficiency and Performance Via DSF and Miller Cycle Synergies
- 2018-01-1158 Machine Learning for Misfire Detection in a Dynamic Skip Fire Engine
- 2018-01-1162 Method to Compensate Fueling for Individual Firing Events in a 4-Cylinder Engine Operated with Dynamic Skip Fire

Motivation: CO_2 Reduction Potential for DSF



- Powertrain modes
- human perception

2018-01-0891

PFL170 (oral)

DSF DYNAMIC SKIP FIRE

eDSF DYNAMIC SKIP FIRE

mDSF DYNAMIC SKIP FIRE

λDSF DYNAMIC SKIP FIRE

aDSF DYNAMIC SKIP FIRE

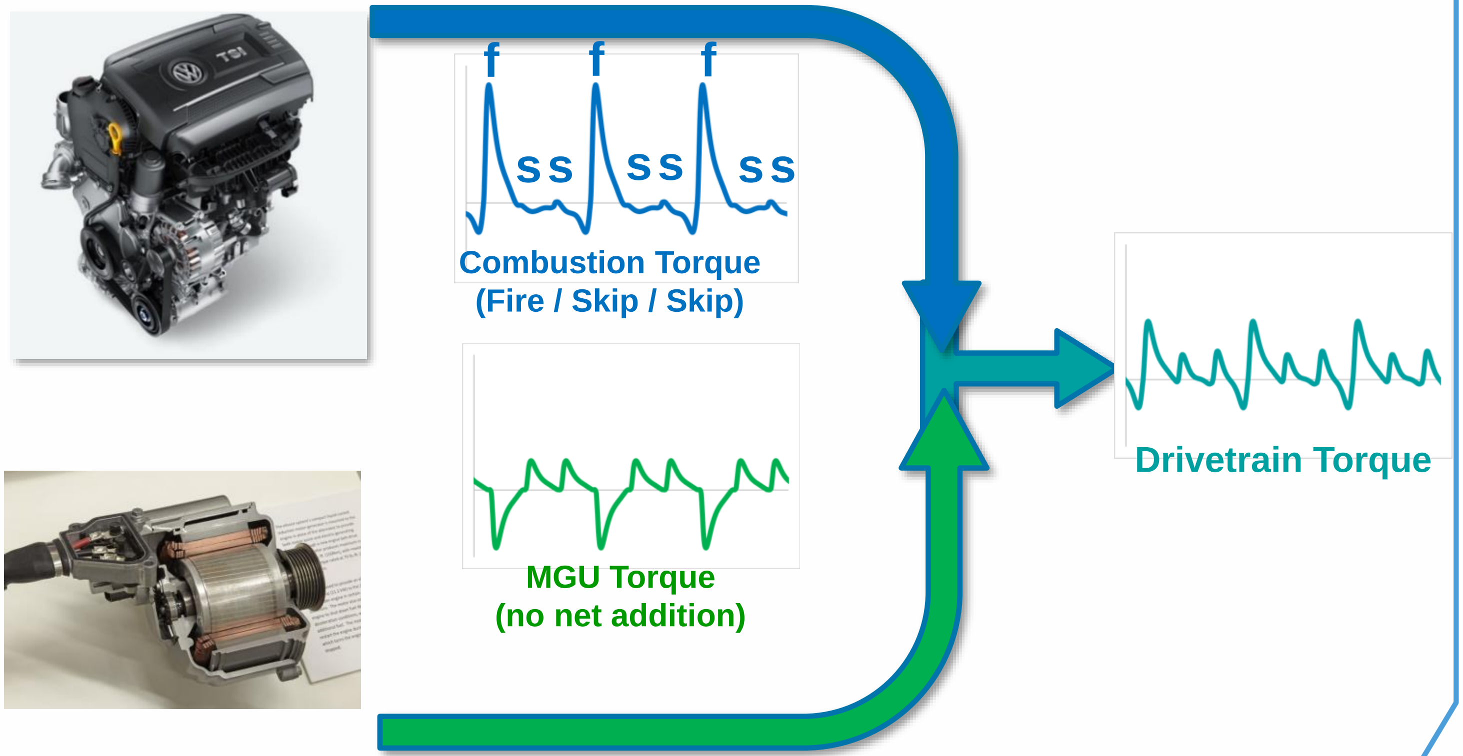
eDSF Synergies

- Being a part load technology, operation of DSF is mostly separate from mild-hybrid operation (launch assist, regen braking)
  - ➢ FE gains largely additive

- Synergies that make them more than additive

1. Enhanced kinetic energy recapture in coast regen via DCCO
2. Increased skip-fire operation due to application of torque assist
3. Increased allowable cylinder loading via use of torque smoothing

eDSF Torque Smoothing Concept



Torque Smoothing Requirements

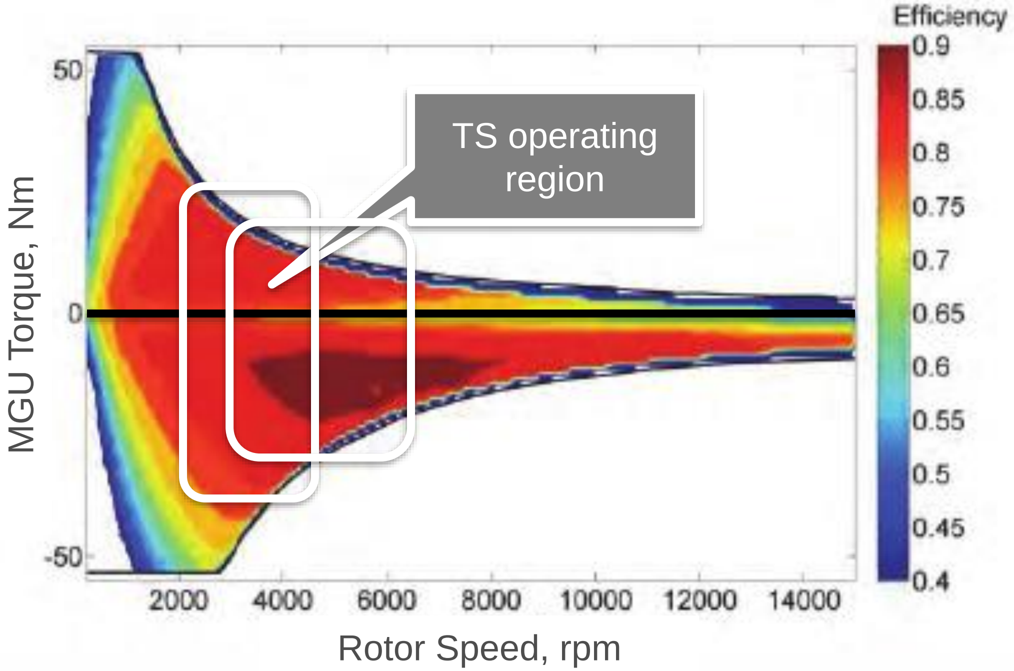
Motor-Generator
High efficiency in TS operating range via winding and magnetics matching

Energy Storage System
High efficiency achieved with modern battery chemistries or combinations with capacitors

Inverter
High efficiency via field-oriented control (FOC) correctly configured for moderate bandwidth, and low-loss power electronics

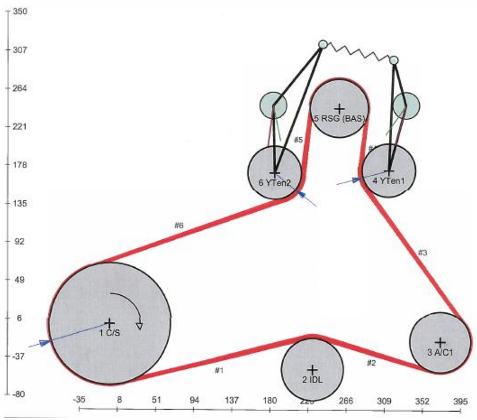
Front-End Accessory Drive
Optimized design configuration to keep belt in contact with torque carrying pulleys under oscillating load

MGU Efficiency Map Example



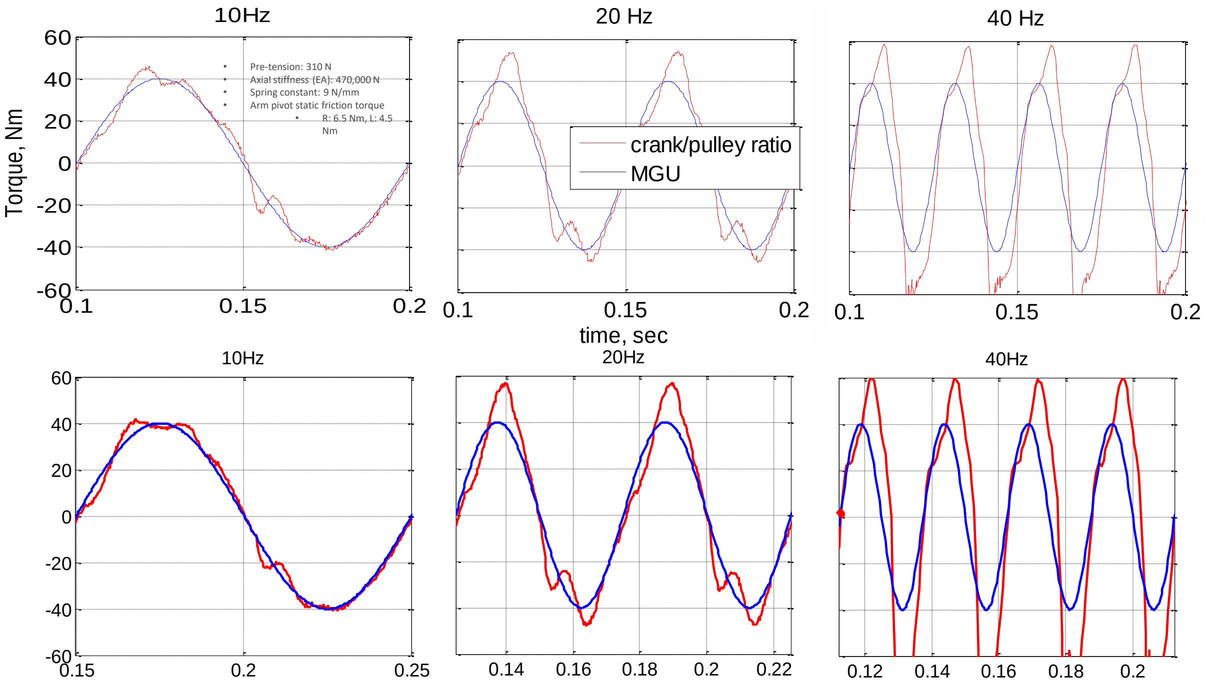
- **Select MGU winding and magnetics for best efficiency in the DSF operating region**
- **Select advantageous pulley ratio**

Accessory Drive Tensioner Design

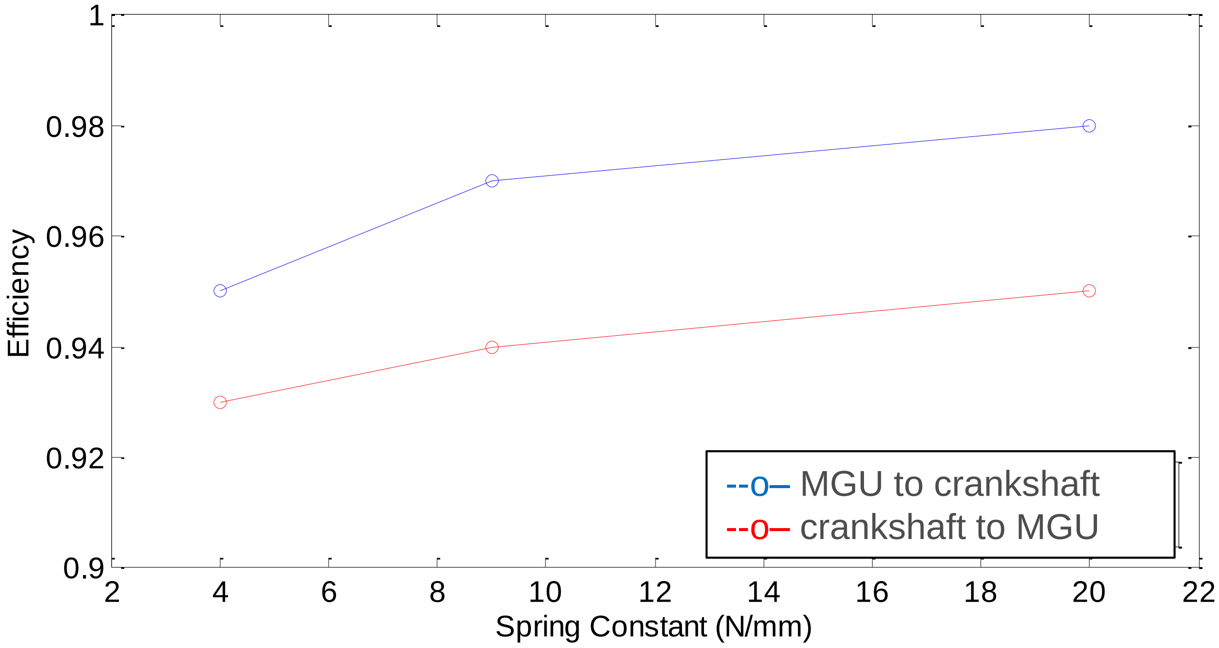


Parametric study to determine optimal drive and tensioner system design factors

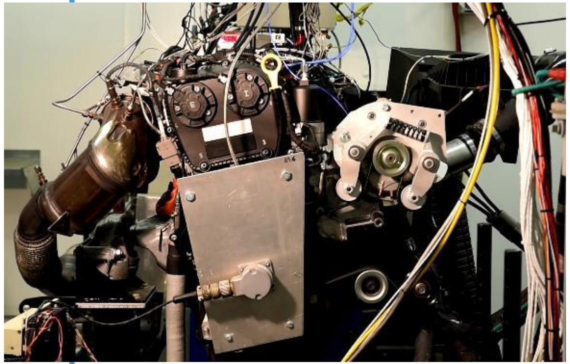
FEAD Simulations with Sinusoidal MGU Torque



FEAD Parameter Optimization Example – tensioner spring

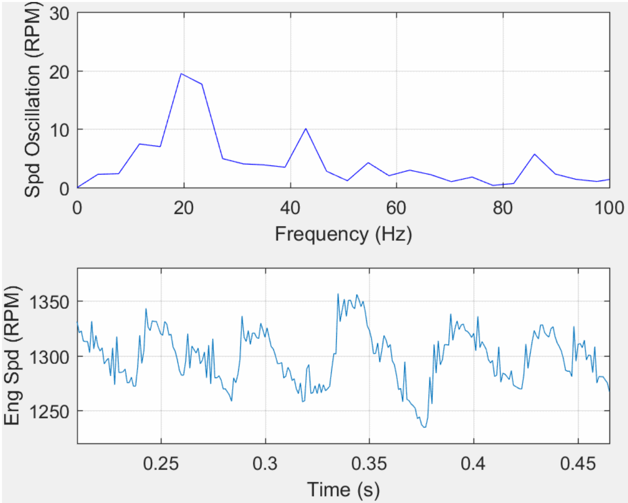


Impact of eDSF Torque Smoothing: Dynamometer Test

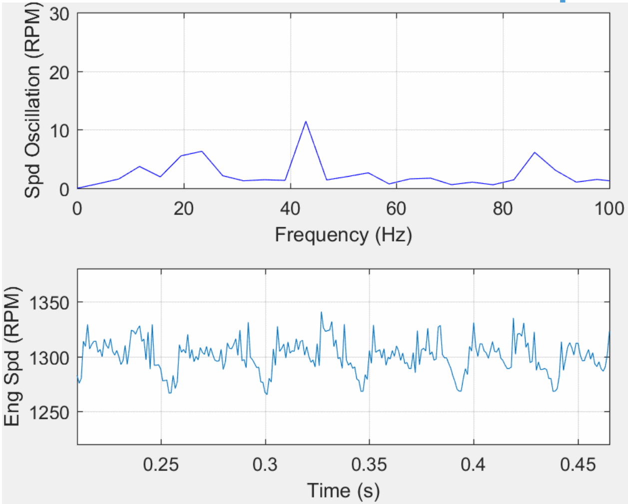


4-Cylinder Engine with MGU on Dyno

Baseline: no MGU torque



eDSF:
700W amplitude torque waveform
(200W power consumption)



Dynamometer test shows torque smoothing effective, can extend DSF operating zone

4-Cylinder Vehicle Platform

Specifications	
Engine Displacement	1.8L TSI®
US Test Weight Class	3500 lb. (1588 kg)
Transmission	6 speed AT
Emissions	SULEV / Zero Evap
TCM	Delphi TCM8
ECM	RPC with Tula SW
Deactivation Hardware	Sliding cam element
MGU	12kW P0 (BAS) PMSM
Battery	8Ah 48V LFP
Inverter	Tula (high torque bandwidth)
FEAD Tensioner System	Bidirectional

GOAL: Prove eDSF gains on 4-cyl GTDI vehicle

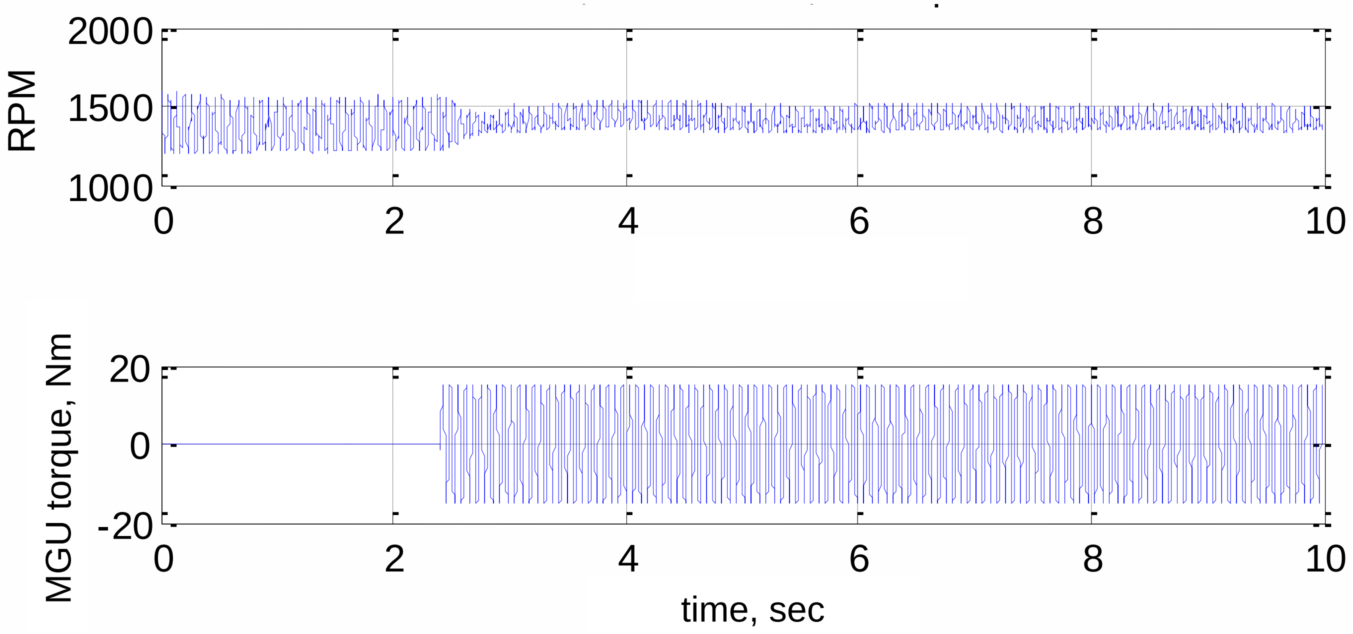
4-Cyl CO_2 Emissions Projections by Drive Cycle

- Stop-start assumed for all modes (except base I4)
- Very basic mild-hybrid strategy included

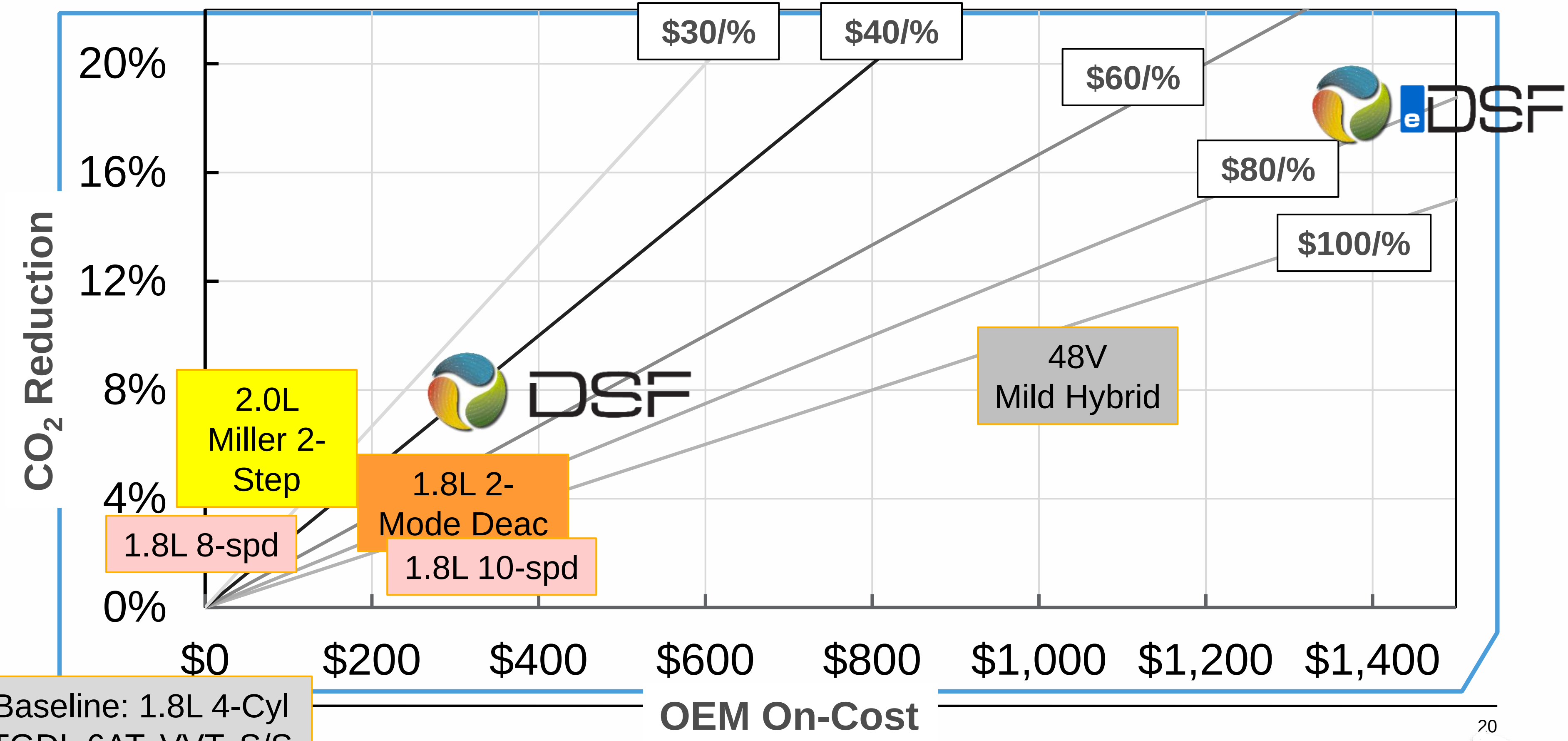
- **8-11% eDSF projected FE gain over mild-hybrid I4**
- **Torque smoothing provides roughly 2% of this reduction**

eDSF Torque Smoothing in Action

eDSF Crank Torsional Variation Reduction



DSF Enhances Hybrid Powertrains



Baseline: 1.8L 4-Cyl TGDI, 6AT, VVT, S/S

Summary – eDSF

- **Pairing DSF with mild electrification expands high efficiency operation**
  - eDSF provides ~11% Metro-Highway CO_2 reduction over I4 mild-hybrid operation
  - Torque smoothing provides roughly 2% of this benefit
- **Best gains obtainable through high-efficiency design of electrification components and belt tensioner**
- **eDSF improves the value proposition of mild-electrified powertrains in a more than additive manner**

Thank you!