Powertrain NVH- and Sound Design-Development of the new Ford Fiesta ST 1.5L GTDI I3 Performance Vehicle

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Abstract
Performance vehicle products need to explicitly satisfy customer expectations and market demands by delivering an excellent brand sound design and by creating an exceptional customer experience. In contrast, more and more stringent CO2-emissions and fleet goals create cross-attribute target conflicts in vehicle development and make it more and more difficult to meet Powertrain NVH- and brand sound quality targets. Here, intelligent system designs and NVH-features are required to resolve such target conflicts. This is even more critical as soon as downsized engine designs are used for performance vehicle segments. Within this article, selected aspects of the development of the new Ford Fiesta ST MY2018 Performance Vehicle will be discussed. Sound quality key enabling technologies such as an exhaust valve actuator system and the engine sound enhancement-feature (ESE) will be reviewed. Furthermore, the newly introduced I3-cylinder deactivation feature and the corresponding NVH-countermeasures will be discussed.
Vehicle Mass Production - Plant Cologne-Niehl:
- Fiesta = 7000 units per week
- Fiesta ST = 385 units per week
**VEHICLE DATA & KEY FEATURES**

- **Mechanical limited-slip differential** to enhance cornering traction of all-new Ford Fiesta ST for the first time.
- **Patented force vectoring springs** deliver sharper turn-in and responsiveness for engaging, fun-to-drive experience. Launch Control delivers consistently fast standing starts on track.
- **200 PS 1.5-litre EcoBoost engine** delivers uniquely exhilarating three-cylinder soundtrack; features cylinder deactivation contributing to 11 per cent fuel efficiency improvement (Ford's industry-first cylinder deactivation system for a three-cylinder).
- **Selectable Drive Modes** shift all-new Fiesta ST character from flexible everyday hatchback to track-focused sports car, flattering novice drivers and rewarding experts.
- **Active exhaust valve technology** to amplify the uniquely exhilarating and naturally sporty three-cylinder engine sound.
- **Available equipment including SYNC 3 connectivity, B&O PLAY high-end audio, and sophisticated driver assistance technologies** such as Lane Keeping Aid and Traffic Sign Recognition.
- ...and many more...

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**VEHICLE PERFORMANCE & ENGINE DESIGN**

**FIESTA ST (B479 NEW MODEL)**

**1.5 L NEXT GENERATION ECOBOOST**

- 200HP / 290Nm with 210HP / 300Nm transient overboost
- Upgraded 6-Speed Manual transmission
- 3-Cylinder, TiVCT, Integrated Exhaust Manifold
- Radial-Axial flow (RAAX) Turbocharging
- Features intelligent cylinder de-activation technology (VDE), dual fuel injection and low inertia turbocharging
- EU Stage 6.2 compliant; GPF fitted as standard

vs.

**Fiesta ST B299**

**1.6 L ECOBOOST**

- ST200 200HP
- 6-Speed manual transmission
- 4-Cylinder, TiVCT

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1.5 l ECOBOOST – 3 CYLINDER

- Power: 200 PS
- Torque: 290 Nm
- Max. Speed: 232 kph
- 0-100 kph: 6.5 sec
- 80-120 kph 5th gear: 6.6 sec
- ¼ mile: 14.7 sec
- Min curb weight (3dr): 1.187 kg

FORD PT NHV INTERIOR SOUND QUALITY DNA & PRODUCT STRATEGY

OBJECTIVES:
- deliver a specific ST-image sound character with superior sound quality among competitive OEMs
- satisfy Ford's Global Brand Sound Quality DNA-Requirements & Interior Sound Targets
  - 'refined' and 'smooth' in low/part load situations
  - 'powerful' and 'rough' in high load situations
  - sporty roughness resp. envelope modulations (half engine order-spacing – engine order roughness)
  - responsive load feedback with noticeable change in loudness/level and in change in sound character (Sound Window)
- provide a plausible & natural sound character in all driving situations
- match acoustic modality with overall vehicle behavior (e.g. selectable drive modes, performance feel, vehicle dynamics)
TARGET SOUND DEVELOPMENT – ESE-TUNING APPROACH & STATUS

3rd gear WOT-run-up – Interior Sound Spectrograms: Changing sound character vs. engine speed:
1. Low-rpm: powerful \(0.5\text{th}\) order
2. Medium-rpm: sporty \(2\text{nd}\) and \(1.5\text{th}\) order
3. High-rpm: aggressive and sporty \(0.5\text{th}\) order

...fine-tuned balance of sound elements across all drive modes
...enhanced low-frequency ESO’s for increased powerfulness...
...significant increase of \(0.5\text{th}\) order modulation due to \(2\text{nd}\) order ESE-contribution

1.5\text{th}\) order spacing due to main combustion orders and exhaust contribution (exhaust valve open)
...wide-band half order pattern for sporty roughness and complex time structure
...increased ESE-feedback + engine misfirings/pops and burbles for liveliness...
...increased ESE feedback + engine misfirings/pops and burbles for liveliness...

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TARGET SOUND DEVELOPMENT – ESE-TUNING APPROACH & STATUS

Base / ESE off Normal Mode Sport Mode Track Mode


...fine-tuned balance of sound elements across all drive modes
...enhanced low-frequency ESO’s for increased powerfulness...
...increased ESE feedback + engine misfirings/pops and burbles for liveliness...
1. Superposition Principle

\[ \sum_{n} S_{\text{prim}}(n) = S_{\text{FL,prim}} \]

2. Target Reference (e.g., WOT, full load condition)

\[ S_{\text{FL,target}}(t) = S_{\text{FL,prim}} \]
\[ S_{\text{FL,target}}(f) = S_{\text{FL,prim}} \]

3. Vehicle Complexity: Prerequisite: The PT-sound character of the vehicle needs to be (nearly) identical across all variants

\[ S_{\text{FL,target}}(f, t) = S_{\text{FL,prim}} \]
\[ S_{\text{FL,target}}(f, rpm) = S_{\text{FL,prim}} \]

\[ S_{\text{FL,prim}}(f, t) = S_{\text{FL,prim}}(f, rpm) = \]
SUMMARY & OUTLOOK

- The product strategy and important design features of the new Fiesta ST model were discussed in particular with regard to the NVH-attribute.
- NVH-countermeasures and interior brand sound DNA-target enablers were discussed with focus on active sound design features (ESE).
- The ESE-tuning-approach and deployment-process was discussed and analyzed in detail.
- Trade-offs and target conflicts due to engine downsizing were successfully compensated and resolved by a well-balanced combination of traditional/passive and active NVH-countermeasures.
- A performance vehicle with a three-cylinder engine can sound sporty and appealing!

Press Feedback & Contents

For me, the top of the cake of the day, came with the Fiesta ST. Agile, precise and fun to drive. Hard to think in any other car with those components so well mixed. Cylinder deactivation works so smoothly that you can hardly tell… Alex Aguilar (AutoBild Spain).

'That ST is a truly great car. Brilliant fun. Car rotates brilliantly. Loads of character, sounds great, and the engine is very clever in terms of activation and deactivation. OEM's really need to find a better way to do hot hatches and I am so glad that it is Ford that has done it. Charlie Turner, Top Gear

The engine is still very 'catchy' with a lot of torque, I almost did not notice the cylinder deactivation, this technology is very smooth and responsive.' Christophe Congregat,