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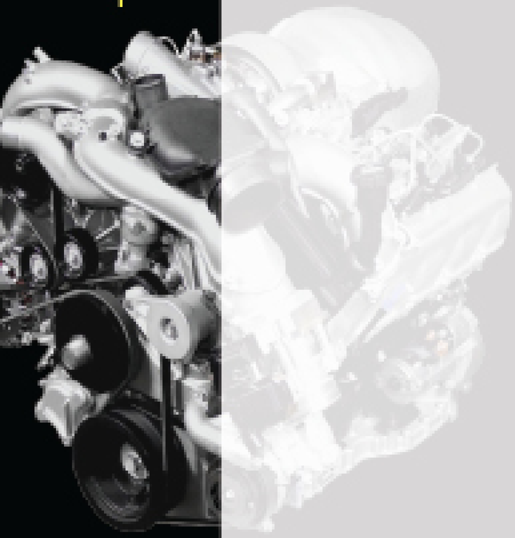

# *Design of Systems for On Board Diagnostics*


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# Introduction

On Board Diagnosis costs money

- If OBD is not considered early in the design process, it may cost a lot more money
- OBD must be considered in all design stages to allow for an optimal cost-function trade-off:
    - Hardware selection
    - Sensor architecture
    - SW design
    - Calibration of functions

The best design for OBD is often not the best design for function

# Case studies

1. Optimal accuracy range of a pressure sensor
2. Diesel particulate filter geometry
3. SCR catalyst configuration

# 1. Optimal accuracy range of a pressure sensor

(based on an example presented in the 2009 CLEER conference)

- Most single die sensors fail by a drift in offset, not in gain
- We can monitor this by an offset check at known pressure , or comparison with another pressure sensor
- Eg, correlation between boost pressure and ambient pressure at key-on
- A well defined failure mode allows for monitoring in specific failure conditions

Pressure sensors typically calibrated at end of line in 2 points:

- •Wide range: minimum and maximum voltage
- •Narrow range: 2 voltages in the middle of the range

Narrow range sensor cannot be corrected for offset, since there is no reference pressure that can be generated during normal drive cycles

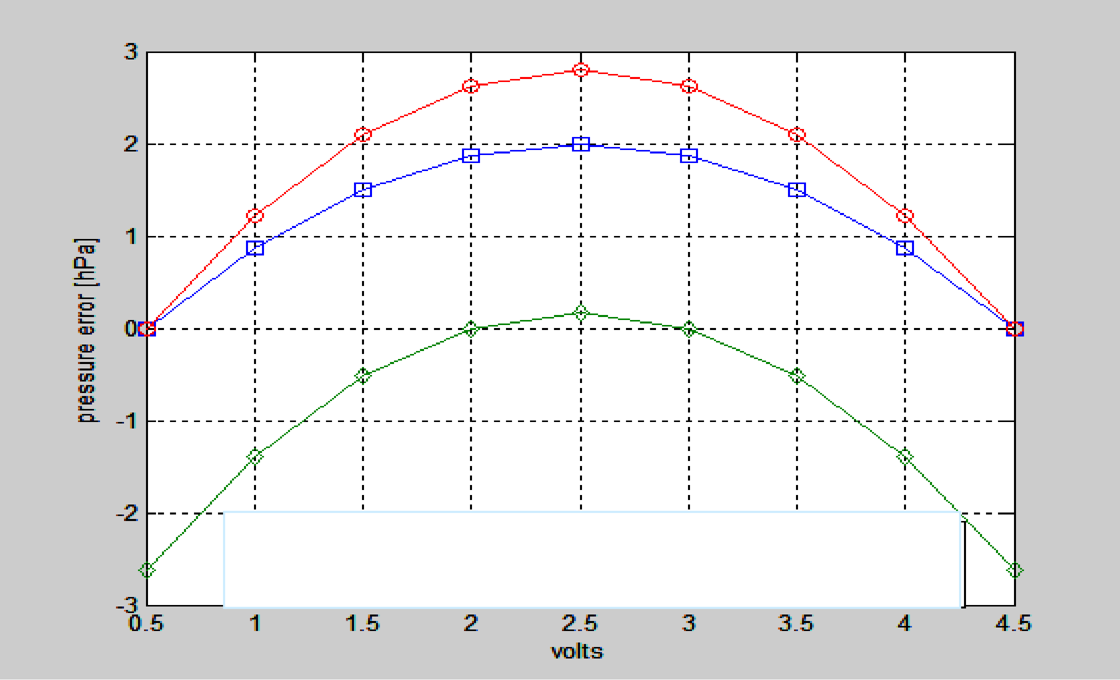
Here the sensor that is most accurate in the range of interest, is much harder to diagnose than the sensor that is less accurate

**Components need to be designed for OBD!!!**

Pressure error wide range [hPa]

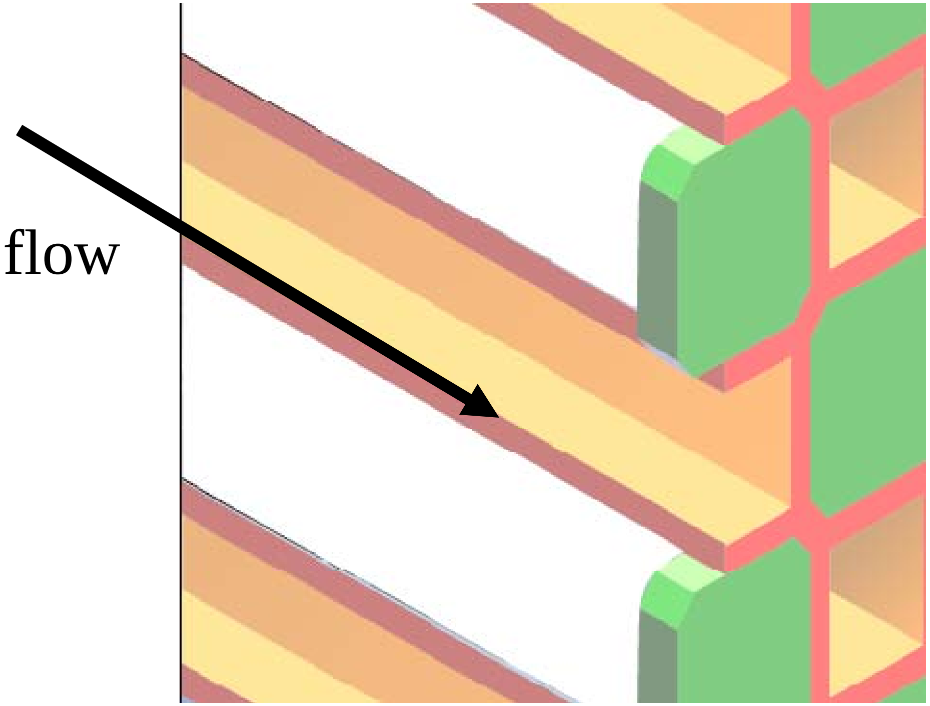
Pressure error narrow range [hPa]

Pressure error narrow range with offset correction[hPa]



# 2. Diesel particulate filter geometry

- Inspired by SAE paper 2008-01-2648 , Van Nieuwstadt and Brahma
- Several manufacturers of DPF substrates have proposed an asymmetric geometry with wider inlet channels than outlet channels
- This allows for ash and soot to be stored in the inlet channels, while maintaining a lower pressure drop over the regeneration cycle of the DPF
- Increase in pressure for a given soot load is less than with a symmetric geometry



One solution proposed for DPF OBD is to compare the pressure drop over the DPF with the expected pressure drop based on a soot model (SAE 2008-01-2648)

Soot balance: $$S_{bal} = \int S_{in} - S_{rgn} dt$$

Soot into DPF: $$S_{in} = S_{fg} - S_{doc}$$

Soot estimate from pressure drop: $$S_{dp}$$

Monitor:

Compare $S_{bal}$ to $S_{dp}$

If $S_{bal}-S_{dp} >> 0$: DPF leaks

If $S_{bal}-S_{dp} << 0$: more soot generation than expected (combination of EGR bias, fuel pressure bias, … that individually will not trigger their respective monitors)

# Pressure drop vs. Soot load

At low flow conditions, and at fixed flow, the pressure drop is approximately linear in soot load.

Assume:

Dp[kPa] = 3.5*soot [grams]

# Uncertainty in pressure drop

Assuming:

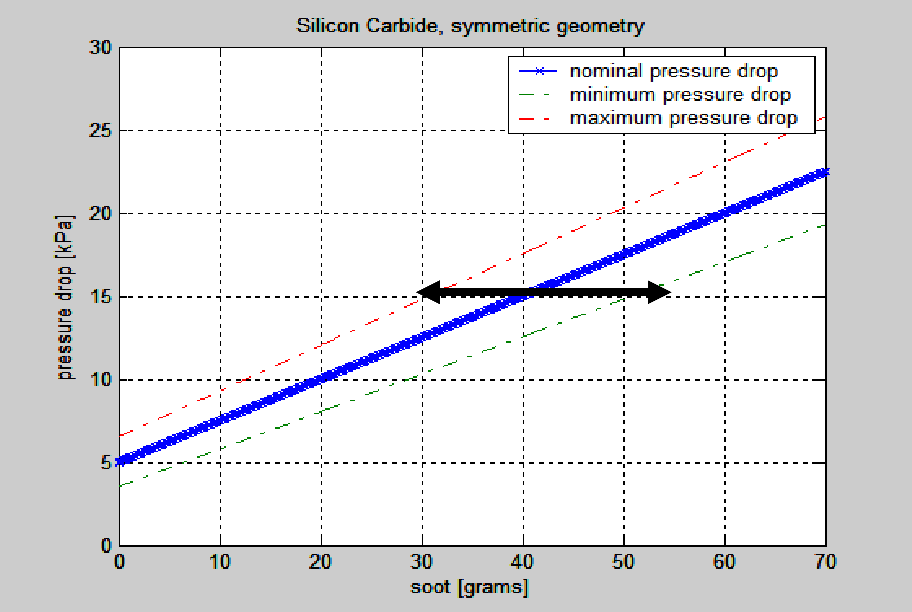
- 5% mass flow uncertainty
- 5% temperature uncertainty
- 1kPa pressure uncertainty

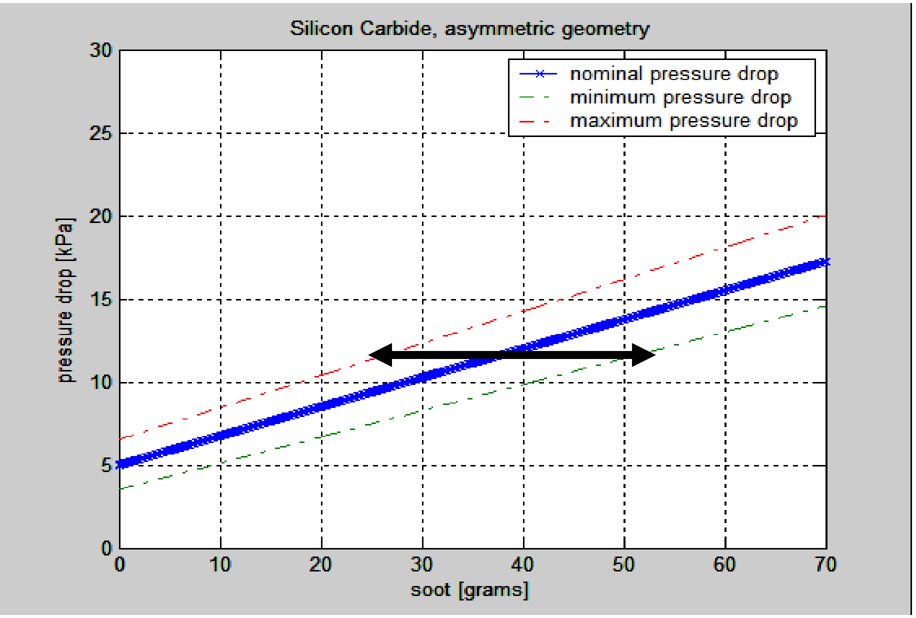
The resulting uncertainty in soot estimation at 40 grams is:

20.2 grams for the symmetric DPF

25.3 grams for the asymmetric DPF

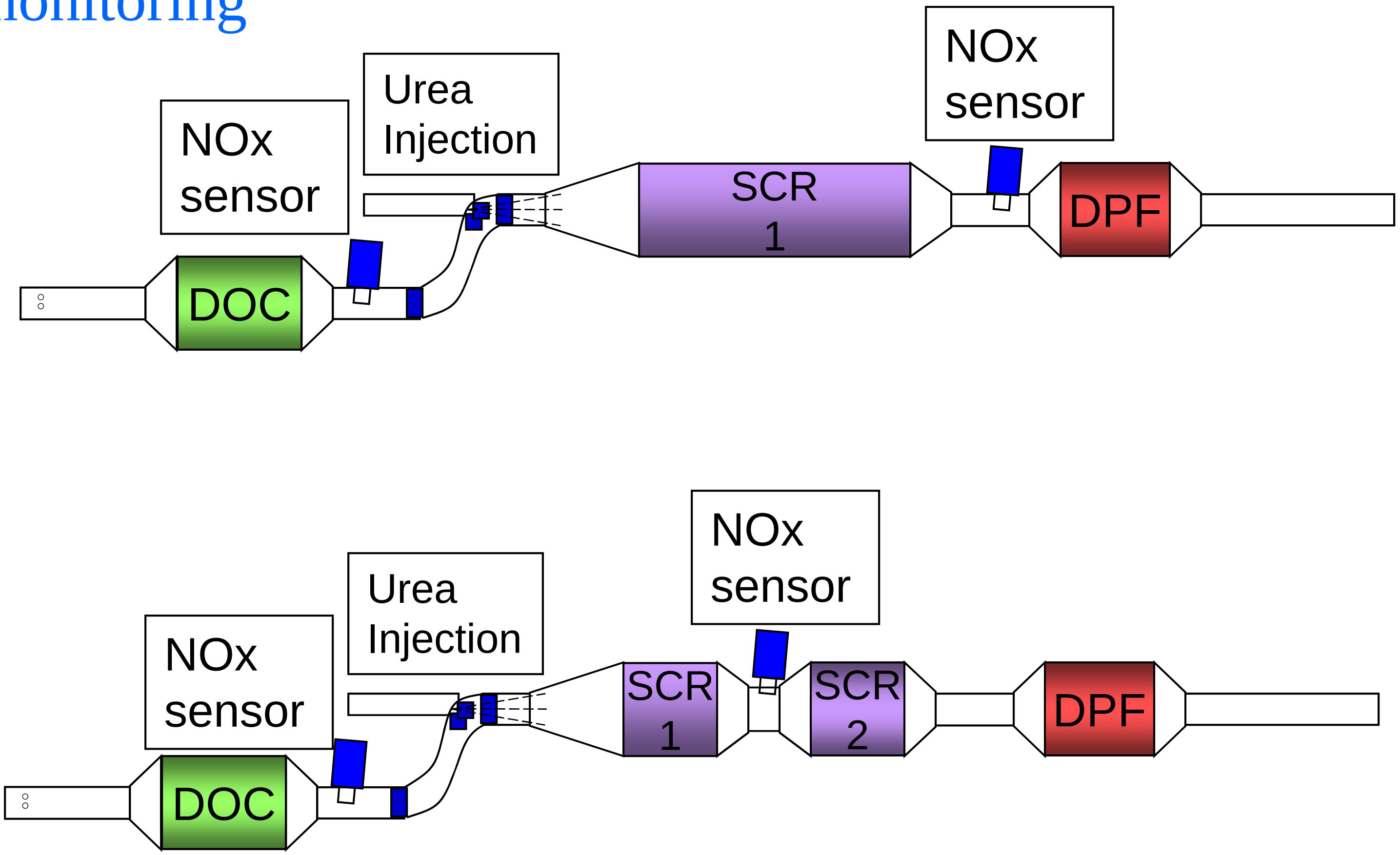
This translates to a 25% bigger leak size to allow detectability with the asymmetric DPF



# 3. SCR catalyst configuration

- Based on SAE paper 2006-01-3548 (Y.W. Kim and M. van Nieuwstadt)
- Compare a single brick SCR against a split brick SCR for purposes of monitoring



# Deterioration profiles

Typically diesel exhaust aftertreatment fails by exposure to high temperature

Heat typically travels through the brick from the front to the rear

Typically, NOx catalysts fail from the front to the rear

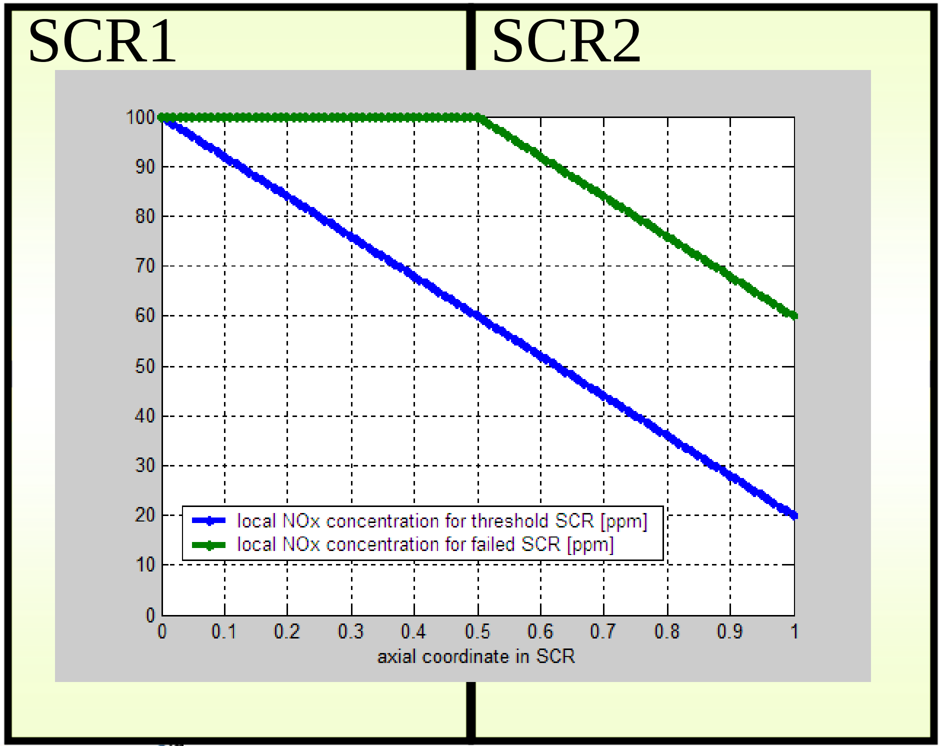
Investigate the benefit of a split brick system by looking at the front portion of the SCR

# Deterioration profiles

Example:

- FG NOx = 100 ppm
- Efficiency of a threshold SCR: >80%
- Efficiency of a failed SCR: < 40%
- Assume extreme case: front brick fails completely, rear brick undamaged

Resulting local NOx concentration as a fcn of SCR position:



# NOx sensor uncertainty model

Post SCR NOx: $NOx_{fg}*(1-\eta)$

Feedgas NOx uncertainty: $c* NOx_{fg}$

Tailpipe NOx sensor uncertainty: $(1+a) *NOx_{tp} + b$

Measured post SCR NOx: $(1\pm a)(1\pm c)* NOx_{fg} *(1-\eta)\pm b$

Typical values:

- a = 0.1-0.2
- b = 5-10ppm
- c= 0.2

For robust OBD we need separation between the maximum NOx measured out of a threshold catalyst, and the minimum NOx measured out of an OBD catalyst:

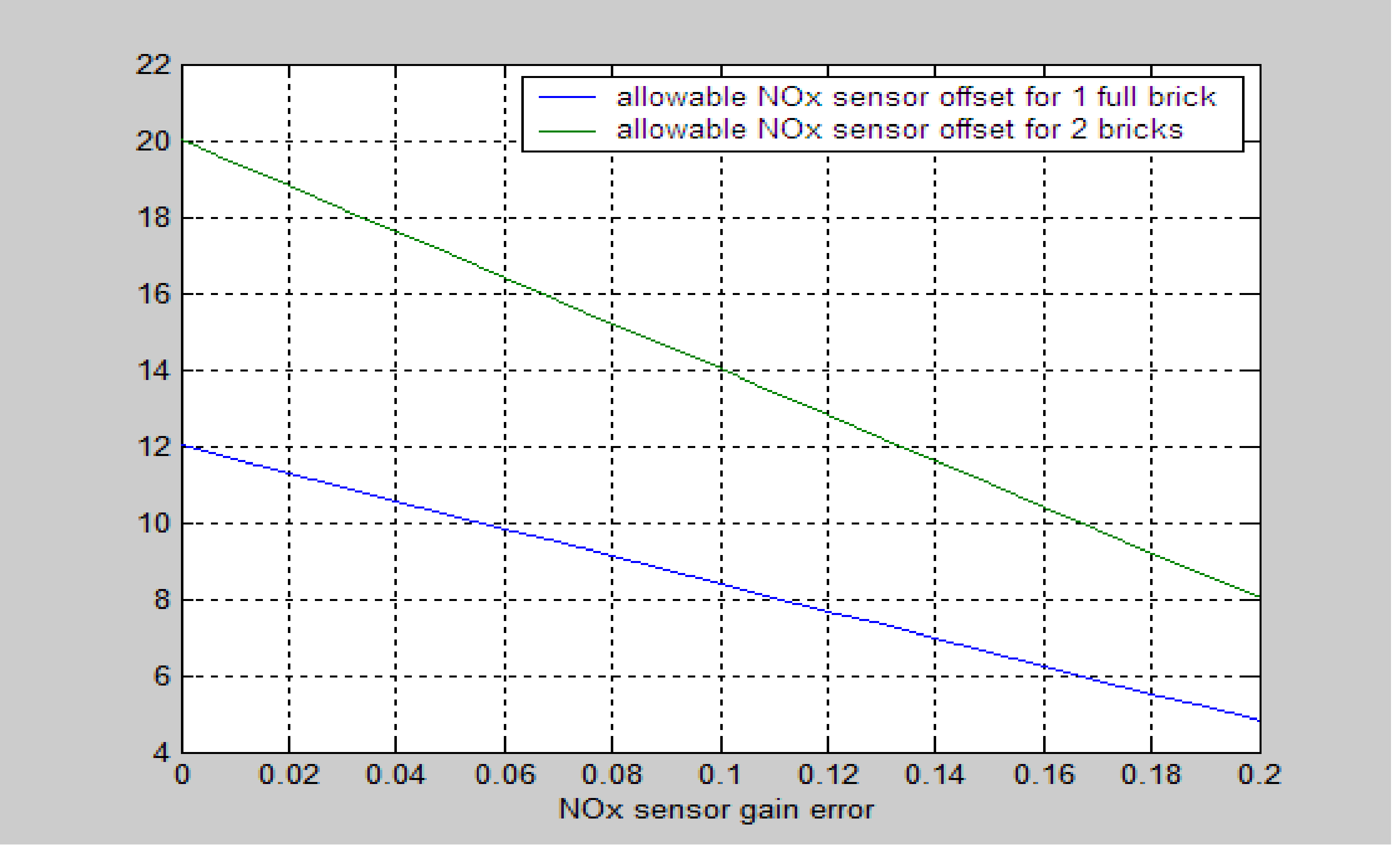
$$[(1-a)(1-c)* NOx_{fg} *(1-\eta_{obd})-b] - [(1+a)(1+c)* NOx_{fg} *(1-\eta_{thr})+b] > 0$$

# Sweep over gain error

Allowable offset error is a function of gain error

The higher the gain error, the lower the allowed offset error

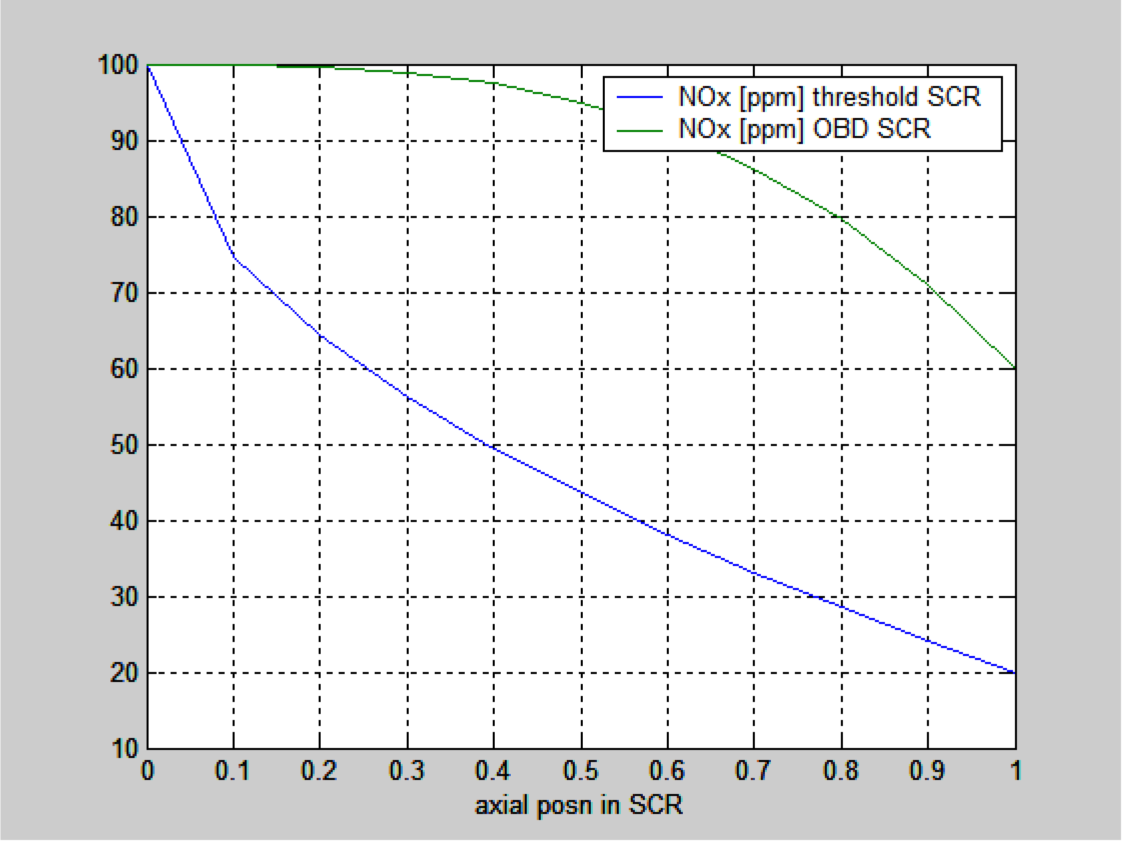
Split brick allows 80% higher offset error while still maintaining separation



# Example – general NOx profile

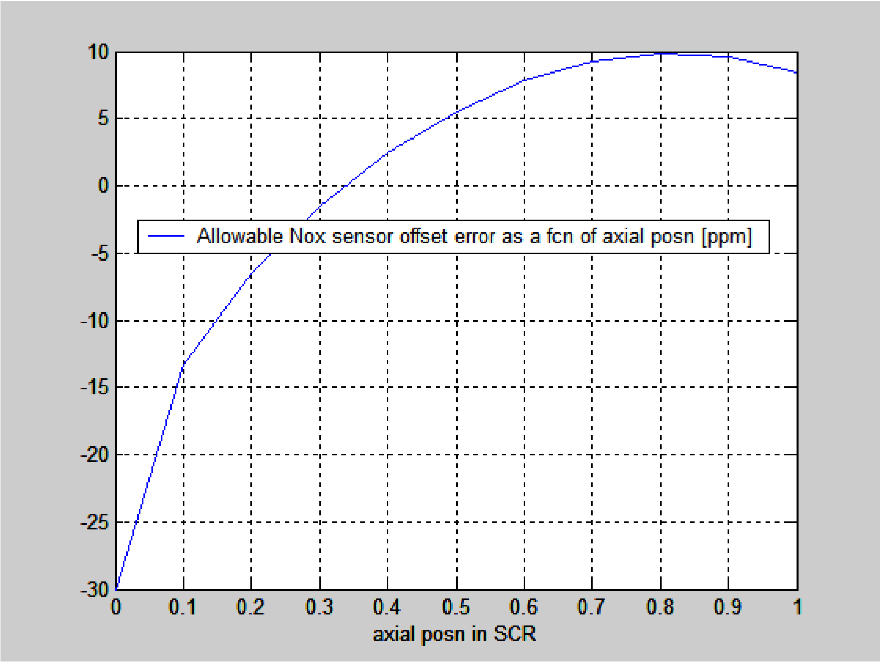
Consider the following local NOx profile for threshold and failed SCR catalyst:

(note that the threshold SCR has more NOx conversion in the front of the brick, compared to the failed SCR)



# Separation as a fcn of axial position

- Compute the maximum NOx concentration of the threshold part and the minimum NOx concentration of the OBD part, the difference is 2x the allowable NOx sensor offset
- Best separation towards the rear of the SCR: about 80% into the brick
- Translates to an allowable offset error of 10ppm



# Generalization

As long as the failed brick shifts NOx conversion to the rear, compared to the threshold (good) brick) there is an optimal NOx sensor location for OBD somewhere in the middle of the brick

# Conclusion

- OBD costs money and/or functionality
- OBD must be designed into the system early to mitigate cost
- OBD capability can be improved by focusing on particular (most likely) failure modes

# contact

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