Extension of the MME Data Format for nonlinear transducers

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Transfer function – Motivation

For the computing of the physical units from the transducer output transfer functions are necessary.

For a long time only linear regression has been used.

Some years ago the calibration of chest deflection potentiometers for the Hybrid III family has to be done with a 3rd order polynomial regression for special tests.

The MME format supports this situation since version 1.6 with a few new descriptors in the channel header. The exchanged values are linear calibrated but with these additional descriptors the polynomial calibrated values can be derived.

A new situation arises with the nonlinear transducers of the IR-TRACC, which needs a complete revision of the MME channel handling.

On the following pages we want to introduce a system of descriptors covering the needs of all known use cases and giving flexibility for future developments.

Description of coefficients

Since nonlinear transducers normally do not allow conventional scaling of the output values by the supply voltage – they have intrinsic supply regulators – the description of the transfer function coefficients does not contain any reference to supply voltage.

Furthermore, we consider digital sensors, too. Therefore we describe the transfer functions using **physical units** (short "unit" e.g. "g", …) and **electrical units** (short "EU" e.g. "mV", "LSB").

Example: linear inverse sensitivity b in "g/mV" or "g/LSB"

The following five use cases have to be considered:

Transfer function - Use cases

1) Linear transducer with relative measurement

Standard for most transducers

$$D = b \cdot S$$

where
D is the physical value in [Unit]
b is the inverse sensitivity in [Unit/EU]
S is the sensor output reading in [EU]

Channel File – Example:

```
Inverse sensitivity          : 5.070000E-003
.Transfer function used      : Linear Regression
.Direction polarity          : +
…
```

Transfer function - Use cases

2) Linear transducer with relative measurement and additional polynomial calibration

e.g. *Chest Deflection of H3 Dummy*

$$D = b \cdot S \quad \text{and} \quad D = M + C \cdot S + B \cdot S^2 + A \cdot S^3$$

where

D	is the physical value in [Unit]
b	is the inverse sensitivity in [Unit/EU)]
S	is the sensor output reading in [EU]
A,B,C,M	are the polynomial coefficients

Channel File – Example:

```
Inverse sensitivity           : 5.070000E-003
.Transfer function used       : Linear Regression
.Direction polarity           : +
Inverse polynom coeff A       : -1.0951781374E-12
Inverse polynom coeff B       : 4.6327907808E-8
Inverse polynom coeff C       : 4.7696179329E-3
Inverse polynom coeff M       : -1.1143570169E+0
…
```

Transfer function - Use cases

3) Linear transducer with absolute measurement

e.g. *Angular transducer in the 2D/3D IR-TRACC, absolute pressure*

$$D = b \cdot (S - SOff_{set}) = M + C \cdot S$$

where

D is the physical value in [Unit]

b is the inverse sensitivity in [Unit/EU]

S is the sensor output reading in [EU]

S_{Offset} is the electrical offset correction done directly before the test (offset pre test)]

C,M are the polynomial coefficients

Channel File – Example:

```
Inverse sensitivity            : 5.070000E-003
.Transfer function used        : Polynomial regression 3rd order
.Direction polarity            : +
Inverse polynom coeff A        : 0
Inverse polynom coeff B        : 0
Inverse polynom coeff C        : 4.7696179329E-3
Inverse polynom coeff M        : -1.1143570169E+0
…
Not necessary
```

Transfer function - Use cases

4) Nonlinear transducer with relative measurement and polynomial approximation
e.g. *Chest Deflection of H3 Dummy*

$$D = M + C \cdot S + B \cdot S^2 + A \cdot S^3$$

where

D	is the physical value in [Unit]
S	is the sensor output reading in [EU]
A,B,C,M	are the polynomial coefficients

Channel File – Example:

```
Inverse sensitivity          : 5.070000E-003
.Transfer function used      : Polynomial regression 3rd order
.Direction polarity          : +
Inverse polynom coeff A      : -1.0951781374E-12
Inverse polynom coeff B      : 4.6327907808E-8
Inverse polynom coeff C      : 4.7696179329E-3
Inverse polynom coeff M      : -1.1143570169E+0
…
Not necessary
```

Transfer function - Use cases

5) Nonlinear transducer with power function approximation

e.g. *Displacement transducer in the IR-TRACC*

$$D = \xi_1 \cdot (S + S_0)^\alpha + \xi_0 = \xi_1 \cdot \exp(\alpha \cdot \log(S + S_0)) + \xi_0$$

where

- D is the physical value in [Unit]
- S is the sensor output reading in [EU]
- S_0 is the power function electrical offset in [EU]
- α is the power function exponent
- ξ_0 is the power engineering offset in [Unit]
- ξ_1 is the power function sensitivity in [Unit/(EU)]

Channel File – Example:

```
Inverse sensitivity            : 1.0
.Transfer function used        : Power function
.Direction polarity            : +
.Power func eng offset         : 12.4
.Power func sensitivity        : .767
.Power func electr offset      : 0.9
.Power func exponent           : -0.5
…
Not necessary, but could be used for LSB output
```

Transfer function – Existing and new Parameters

Descriptor	Value	Status	Remark
.Transfer function used	Linear regression Polynomial regression 3rd order Power function	new	The transfer function used for the computing of the physical units *Linear regression* is the default
.Direction polarity	+ -	new	Polarity of the sensor mounting orientation
Inverse sensitivity	float	since 1.6	Inverse sensitivity (linear regression)
Inverse polynom coeff A	float	since 1.6	3^{rd} order polynomial - cubic part
Inverse polynom coeff B	float	since 1.6	3^{rd} order polynomial - quadratic part
Inverse polynom coeff C	float	since 1.6	3^{rd} order polynomial - linear part
Inverse polynom coeff M	float	since 1.6	3^{rd} order polynomial - constant part
.Power func eng offset	float	new	Power function - physical offset
.Power func sensitivity	float	new	Power function - sensitivity
.Power func electr offset	float	new	Power function – electrical offset
.Power func exponent	float	new	Power function – exponent α

Transfer function – Nonlinear transducers

- For some transducer channels the physical offset at the start of the test is important. This comes into conflict with the need of offset correction for the data exchange. Examples are the angle and the displacement transducers of the IR-TRACC.

  Possible solutions for this problem are:

1. These channels have to be exchanged without offset correction
2. The start values before offset correction have to be exchanged as separate one value channels
3. **The start values are stored in the descriptor *Offset post test* and the sample values are offset corrected**

Recommendation is the solution **3**

Transfer function - Usage

- Transfer functions and their parameters are only reasonable for transducer channels
- Computing of the output quantity has to be done in the test execution software
- Computing of calculated or derived channels has to be done in the test analysis software
- Storage of the transfer function, its parameters and the sensor polarity should be done in the channel file header
- The parameters of additional calibration methods may be stored in the channel file header (e.g. *Inverse sensitivity*)
- *Offset pre test* [EU] is only necessary, when it is required by the measurement chain
- *Offset post test* [Unit] is the value which is used for the physical offset correction within [*Start offset interval* , *End offset interval*]