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.

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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:

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Transfer function - Use cases

1) Linear transducer with relative measurement
Standard for most transducers

$$D = b \cdot S$$

	Description	Unit	Descriptor	Example Value
S	sensor output reading	[EU]	-	-
D	physical value	[Unit]	-	*Values of Sample*
b	inverse sensitivity	[Unit/EU]	`Inverse sensitivity`	`5.070000E-003`
			`.Transfer function used`	`Linear regression`
			`.Direction polarity`	`+`
		[EU]	`Offset pre test`	`0.01`
		[Unit]	`Offset post test`	`NOVALUE`
	Sensitivity	[EU/Unit]	`.Sensitivity`[1]	`197.2`

[1] must not be used if *Inverse sensitivity* is missing or NOVALUE

Transfer function - Use cases

2) Linear transducer with relative measurement and additional polynomial calibration
e.g. *Chest Deflection of H3 Dummy*

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

	Description	Unit	Descriptor	Example Value
S	sensor output reading	[EU]	-	-
D	physical value	[Unit]	-	*Values of Sample*
b	inverse sensitivity	[Unit/EU]	Inverse sensitivity	5.070000E-003
A	polynomial coefficient (cubic)	[Unit/(EU)^3]	Inverse polynom coeff A	-1.0951781374E-12
B	polynomial coefficient (quadratic)	[Unit/(EU)^2]	Inverse polynom coeff B	4.6327907808E-8
C	polynomial coefficient (linear)	[Unit/(EU)^1]	Inverse polynom coeff C	4.7696179329E-3
M	polynomial coefficient (constant)	[Unit]	Inverse polynom coeff M	-1.1143570169E+0
			.Transfer function used	Linear regression
			.Direction polarity	+
		[EU]	Offset pre test	0.01
		[Unit]	Offset post test	NOVALUE
	Sensitivity	[EU/Unit]	.Sensitivity[1]	197.2

[1] must not be used if *Inverse sensitivity* is missing or NOVALUE

Transfer function - Use cases

3) Linear transducer with absolute measurement

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

$$D = b \cdot (S - S_{Cal}) = M + C \cdot S$$

	Description	Unit	Descriptor	Example Value
S	sensor output reading	[EU]	-	-
D	physical value	[Unit]	-	*Values of Sample*
A	polynomial coefficient (cubic)	[Unit/(EU)^3]	Inverse polynom coeff A	0
B	polynomial coefficient (quadratic)	[Unit/(EU)^2]	Inverse polynom coeff B	0
C	polynomial coefficient (linear)	[Unit/(EU)^1]	Inverse polynom coeff C	4.7696179329E-3
M	polynomial coefficient (constant)	[Unit]	Inverse polynom coeff M	-1.1143570169E+0
			.Transfer function used	Linear regression with offset
			.Direction polarity	+
	Must not be used!	[EU]	Offset pre test	NOVALUE
		[Unit]	Offset post test	NOVALUE

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Transfer function - Use cases

4) Nonlinear transducer with relative measurement and polynomial approximation
e.g. *polynomial calibrated belt force*

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

	Description	Unit	Descriptor	Example Value
S	sensor output reading	[EU]	-	-
D	physical value	[Unit]	-	*Values of Sample*
A	polynomial coefficient (cubic)	[Unit/(EU)^3]	Inverse polynom coeff A	-1.0951781374E-12
B	polynomial coefficient (quadratic)	[Unit/(EU)^2]	Inverse polynom coeff B	4.6327907808E-8
C	polynomial coefficient (linear)	[Unit/(EU)^1]	Inverse polynom coeff C	4.7696179329E-3
M	polynomial coefficient (constant)	[Unit]	Inverse polynom coeff M	-1.1143570169E+0
			.Transfer function used	Polynomial regression 3rd order
			.Direction polarity	+
	Must not be used!	[EU]	Offset pre test	NOVALUE
		[Unit]	Offset post test	NOVALUE

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Transfer function - Use cases

5) Nonlinear transducer with power function approximation
e.g. *Displacement transducer in the IR-TRACC*

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

	Description	Unit	Descriptor	Example Value
S	sensor output reading	[EU]	-	-
D	physical value	[Unit]	-	*Values of Sample*
ξ_0	power function engineering offset	[Unit]	.Power func eng offset	12.4
ξ_1	power function sensitivity	[Unit/(EU)]	.Power func sensitivity	.767
α	power function exponent	[1]	.Power func exponent	-0.5
S_0	power function electrical offset	[EU]	.Power func electr offset	0.9
			.Transfer function used	Power function
			.Direction polarity	+
	Must not be used!	[EU]	Offset pre test	NOVALUE
		[Unit]	Offset post test	NOVALUE

Transfer function – Existing and new Parameters

Descriptor	Values	Status	Remark
`.Transfer function used`	Linear regression Linear regression with offset 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	3rd order polynomial - cubic part
`Inverse polynom coeff B`	float	since 1.6	3rd order polynomial - quadratic part
`Inverse polynom coeff C`	float	since 1.6	3rd order polynomial - linear part
`Inverse polynom coeff M`	float	since 1.6	3rd order polynomial - constant part
`Offset pre test`	float	since 1.6	Electrical offset short before the test
`Offset post test`	float	since 1.6	Physical offset after the test
`.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
`.Sensitivity` [1]	float	new	Sensitivity (for Linear regression only)

[1] must not be used if *Inverse sensitivity* is missing or NOVALUE

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

- *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*]

- For transducer channels with transfer functions other than *Linear regression* 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. **All these channels have to be exchanged without offset correction**