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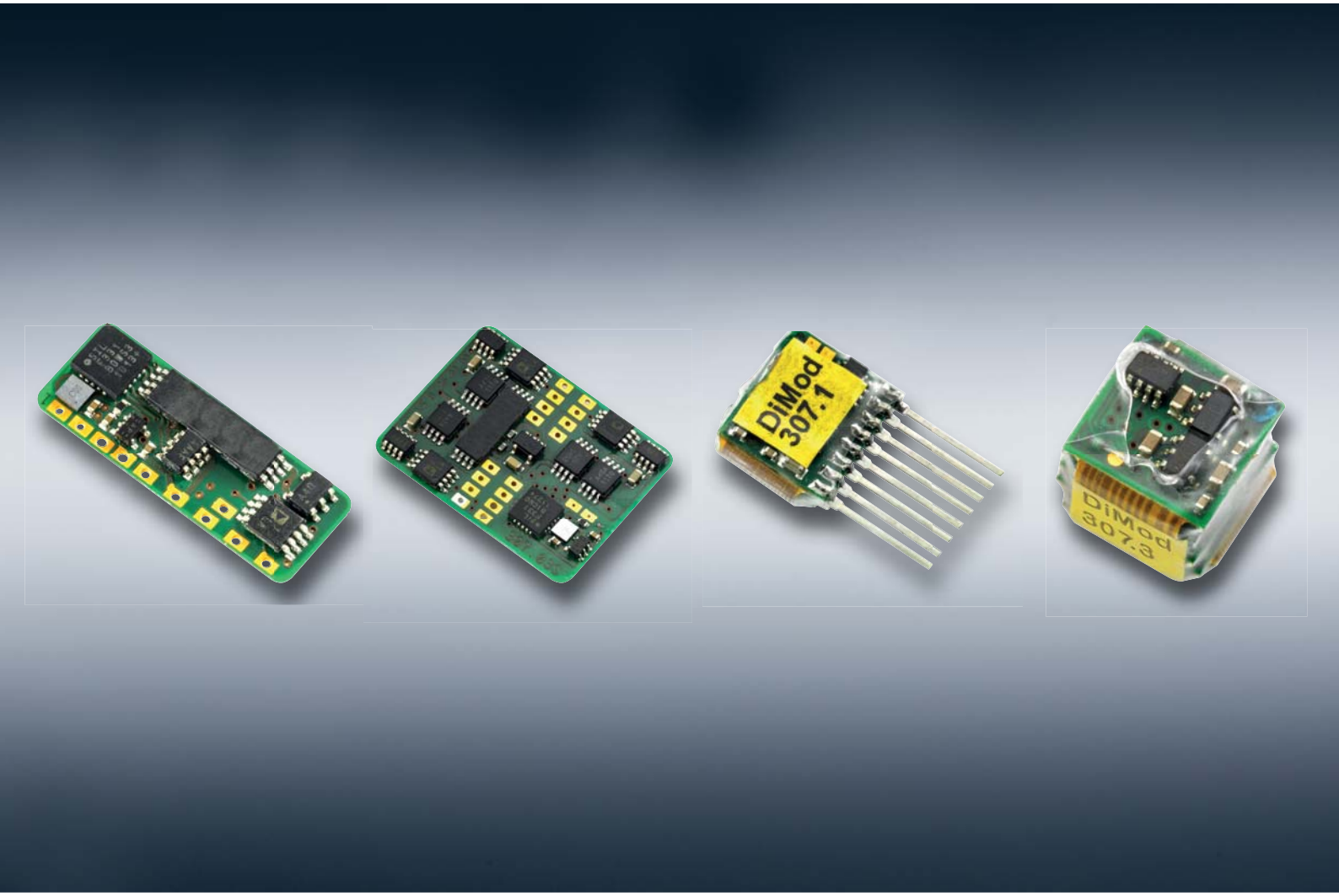

DiMod 307 and SAE J211-1 Compliance

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This document compares the technical measurement characteristics of the DTI measuring system with the requirements arising from SAE J211-1, Rev. MAR 2014, subsequently referred to as SAE J211-1.

1 Performance Requirements for a Data Channel

SAE J211-1 describes a data channel in the form of a measuring chain comprising the transducer, data acquisition system, internal and external wiring and all the analytical processes that can influence the frequency and time behavior of the measuring chain.

The DTI measuring system is designed for use with an extensive range of active as well as passive sensor technology. Therefore, the following study can only examine the behavior of a DiMod with the use of a DTI data recorder. To arrive at a complete assessment of the SAE compliance of the measuring chain, consideration must be given to the manufacturer's specific information on the transducer and the software used.

On commissioning, any DiMod undergoes a complex and extensive series of tests that aim to ensure the correct functioning of individual electronic components and compliance with various specification limits. Where available, the aforementioned specification limits are defined in accordance with the requirements of SAE J211-1.

2 Linearity Error

According to SAE J211-1, the linearity error must not exceed a maximum value of 2,5 % (in relation to the measuring range). The DTI measuring system provides multiple and simultaneous verifications of this parameter's compliance:

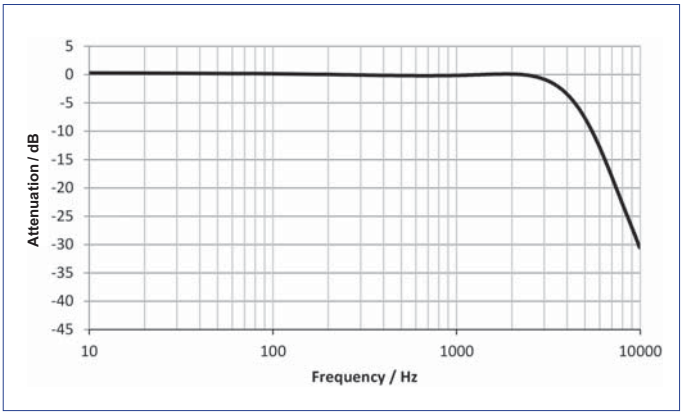
Test	Requirement in SAE J211-1	Specification of the DTI measuring system
Commissioning/specification test	≤2,5 % in relation to the measuring range, measured between F_L und F_H	For target gains of 10, 100 und 1 000 <0,2 % (3 different test cycles)
Final test on the DiMod after final processing	≤2,5 % in relation to the measuring range, measured between F_L und F_H	For fixed/defined gain <0,2 %
Final test on the DiMod after final processing	≤2,5 % in relation to the measuring range, measured between F_L und F_H	Dependent on the transducer type; typ. <1 %

Table 1: Comparison between the requirement for the linearity error as per SAE J211-1 and the specification limits of the DTI measuring system

3 Frequency Response of the Filter

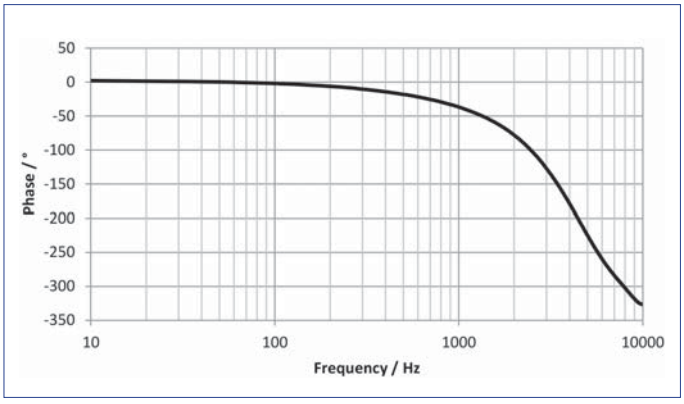
At the input of every DTI measuring channel, there is a 5-pole filter with a 3-dB cut-off frequency of 4 kHz. This filter is implemented with hardware, and its primary purpose is to provide analog protection against foldover (anti-aliasing filter).

Graph 1 shows the amplitude response of a filter of this sort, in relation to the signal frequency:



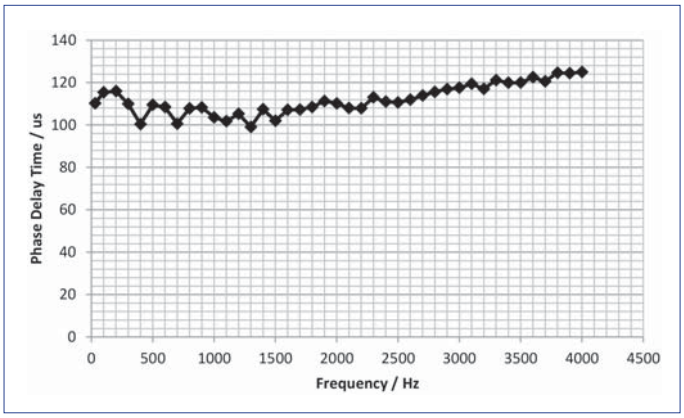
Graph 1: Amplitude response: anti-aliasing filter

SAE J211-1 also describes another important parameter, namely the phase delay. The following graph (Graph 2) shows the phase response in degrees over the signal frequency (sampling rate 20 kHz; 3 dB cut-off frequency 4 kHz):



Graph 2: Phase response over signal frequency

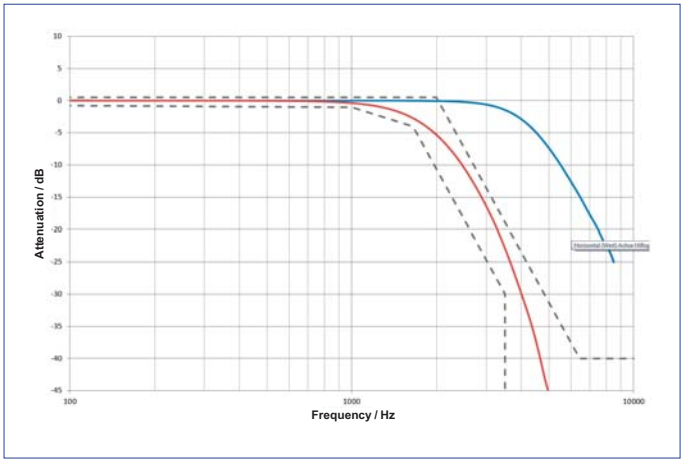
The measured phase response can now be used to define the corresponding time delays. SAE J211-1 requires a time variance <100 µs in the 30 Hz to 1 000 Hz frequency range (CFC1 000). As can be seen in the following graph (Graph 3), the DTI measurement technology can meet these requirements.



Graph 3: Time variance over signal frequency

4 Frequency Response of the Digital Measuring Chain

To achieve filtering compliant with the requirement in SAE J211-1, digital post-filtering of the measurement signal is required, depending on the Channel Frequency Class (CFC) in each case. The following graph shows the prefiltered amplitude response of the digital output of a DiMod (blue). The red curve profile shows the associated digitally post-filtered signal (CFC1 000), which remains within the specification limits as per SAE (dashed lines).



Graph 4: Amplitude response of the digital output (blue) against the post-filtered signal (red)

5 Time Base

SAE J211-1 requires a resolution for the time base of 1/100 seconds with a maximum error of <0,1ms.

A 1-kHz central clock pulse is used to synchronize various DTI data recorders or other types of measuring and/or video equipment. This means that all devices used in the test receive a uniform time stamp in relation to the t_0 trigger signal. This pulse is generated by a very narrow-band phase-locked loop (abbreviated as PLL) with a capture range of ±200 ppm. The frequency accuracy of the PLL used for this purpose is stated as ±100 ppm, giving a value of 0,2 µs for the maximum time error.

6 Relative Time Delay Error

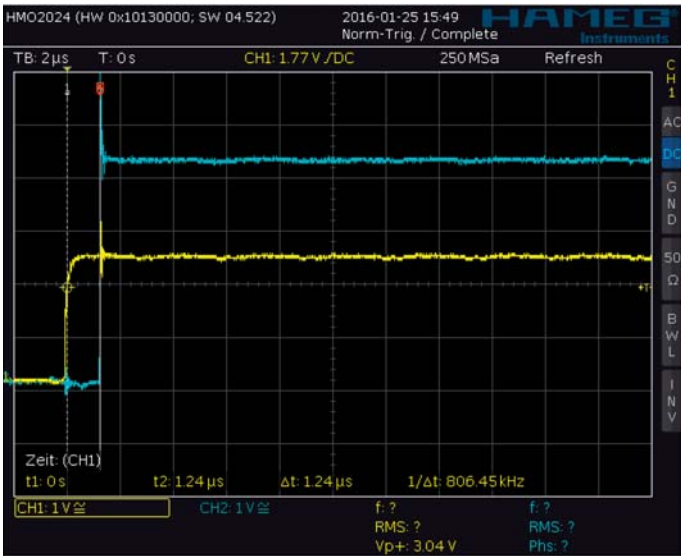
According to SAE J211-1, the maximum relative time delay error of the respective measuring channels in relation to one another must not exceed a value of 1 ms. If the channels are mathematically correlated, moreover, a maximum relative time delay error of 0,1 ms is required.

The relative time delay error is verified with the help of the DiMod's own oscillator pulse and a counter; this verification is completed for each measuring channel after final processing. The deviation between the ascertained counter value and the specified setpoint must be in the ±0,5 % range. This corresponds to a maximum inaccuracy of ±0,75 µs.

7 Time of Contact

Forwarding of the t_0 trigger signal to all components used in the test is an essential task which is accomplished by the 'ComBox' when DTI measurement technology is used. According to SAE J211-1, the contact time, i.e. the precise time that elapses between detection of the trigger contact and actuation of the trigger event (forwarding of the trigger) must not exceed a value of 0,4 ms.

The following chart shows the determination of the ComBox contact time. A t_0 (yellow) is simulated with the help of a contact switch. Actuation of the trigger event is recorded at a t_0 output of the ComBox (turquoise):
the time of contact for the DTI measuring system is less than 5 µs and is therefore significantly below the requirements of SAE J211-1.

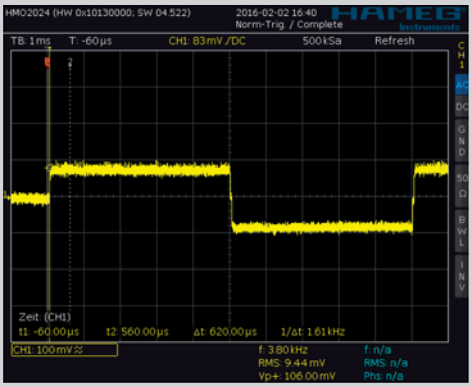
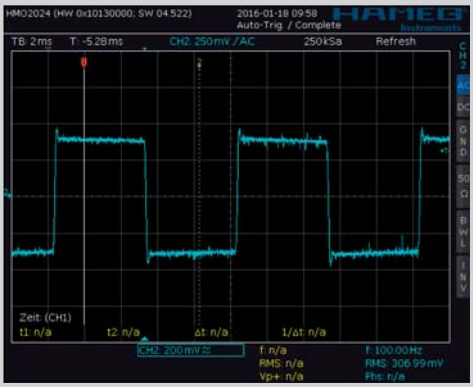
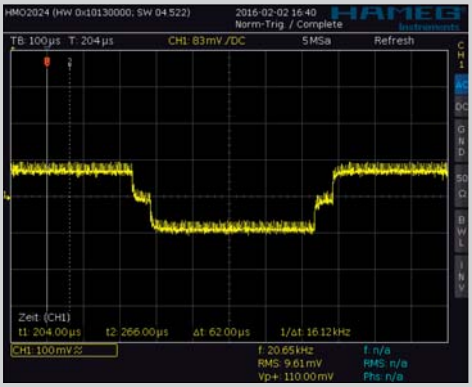
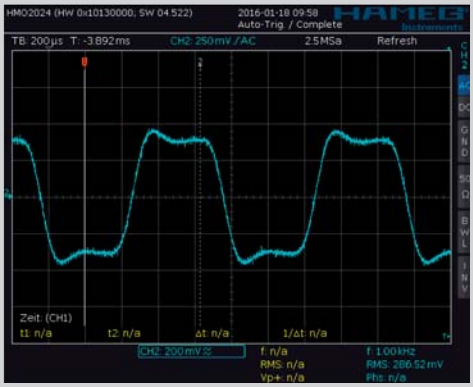


Graph 5: Time of contact for the ComBox

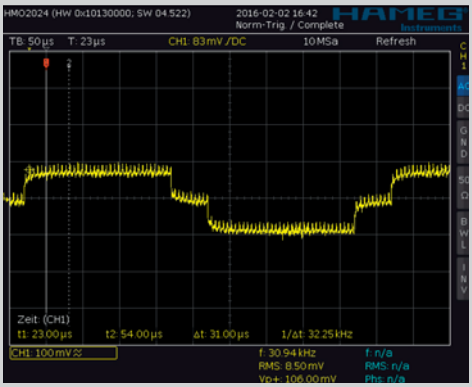
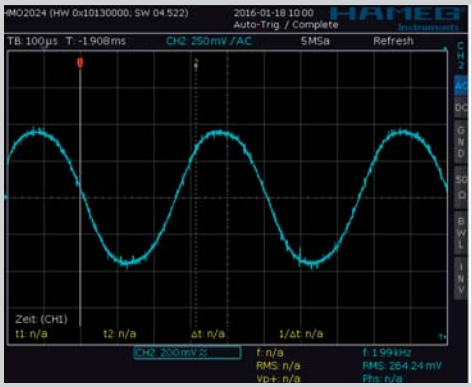
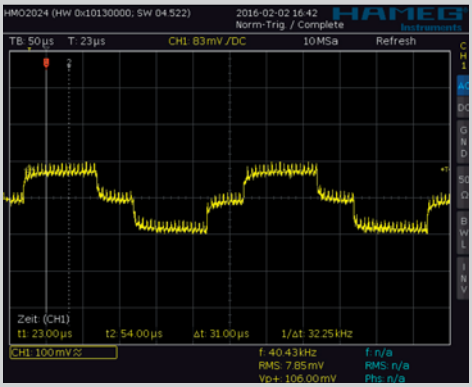
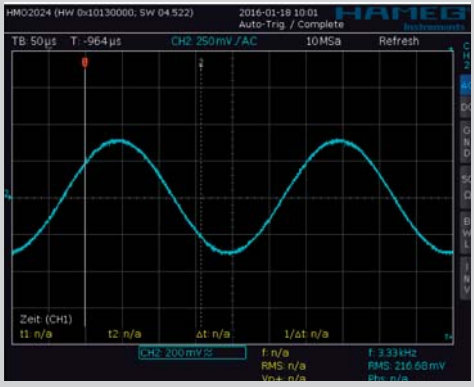
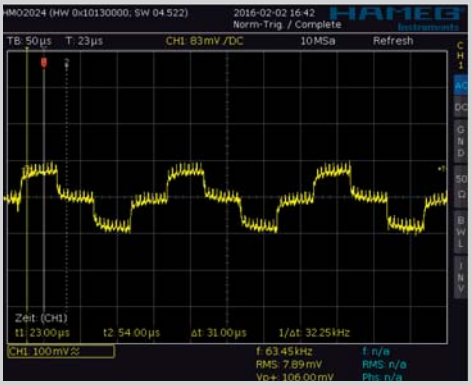
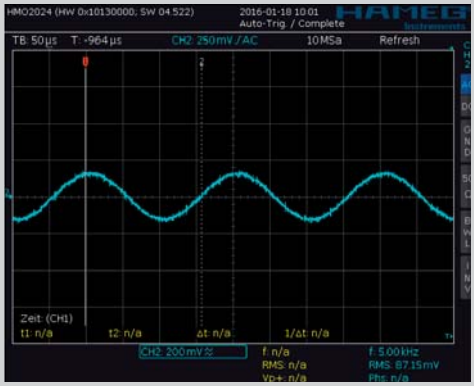
8 Dynamic Shunt Stimulation

The purpose of the dynamic shunt stimulation is to verify the filter coefficients after final processing and fixed wiring of the DiMod with the relevant analog transducer. For this purpose, use is made of the shunt switches located at the input which are now switched with corresponding frequencies. A square wave signal is generated due to the positive or negative transducer bridge imbalance; this signal is digitally captured and evaluated.

The following analog signal forms can be recorded during the dynamic shunt stimulation (Stim R = 22 100 Ω; Gain R = 18 200 Ω):

Frequency	Unfiltered	Filtered
100 Hz		
1 kHz		

Graph 6: Dynamic Shunt Stimulation

Frequency	Unfiltered	Filtered
2 kHz		
3,33 kHz		
5 kHz		

Graph 7: Dynamic shunt stimulation

In this series of tests, the different amplitude attenuations of the signals listed here are determined in relation to the 100 Hz signal. The values determined are stored in the memory of the relevant measuring channel, so they can be reviewed at any time by repeating this test.

Typically, the following amplitude attenuations are determined for an unswitched (open) DiMod:

- 1 000 Hz – typ. -0,6 dB
- 2 000 Hz – typ. -1,3 dB
- 3 330 Hz – typ. -3 dB
- 5 000 Hz – typ. -10 dB

9 Overview

Section in SAE J211-1	Description	Requirements from SAE J211-1	Specifications of the DTI measuring system
4.1	Linearity error	≤2,5 % in relation to the measuring range between F_L und F_H	• <0,2 % in the specification test • Typ. <1 % for the calibration
4.2	Amplitude response	See the graphs in SAE: • Figure 1: CFC600 and CFC1000 • Figure 2 : CFC60 and CFC180	• Filter test with sinusoidal excitation for specification test • Dynamic shunt stimulation for specification test and calibration
4.3	Phase response	Max. variation in the time delay of <100 µs in the range from 30 Hz to 1 000 Hz	<30 µs in the 30 to 4 000 Hz range
4.4.1	Time base	Min. resolution of 1/100 seconds for an error <0,1 ms	Central synchronization pulse of 1 kHz For a maximum error <1 µs
4.4.2	Relative time delay error	<1 ms between all channels <0,1 ms between mathematically correlated channel	<1 µs between all channels
4.6.4	Calibration of the frequency response	Measurement of a known input signal from DC to 3 kHz	• Filter test with sinusoidal excitation for specification test from DC to 4 kHz • Dynamic shunt stimulation for specification test and calibration from 100 Hz to 5 kHz
8.1	Presample filtering	In or above the range of CFC1000	• 4 kHz hardware filtering compliant with CFC1000 corridor ranges
8.2	Sampling rate	Min. 10 kHz sampling rate per channel	• 20 kHz sampling rate per channel • Simultaneous capture of all channels
8.3	Resolution	Min. 12 Bit and LSB <0,2 % of measuring range	16 Bit
8.4.1	Digital filtering	CFC filters must comply with the limits in point 4.2	• Attained with Butterworth 4-pole phaseless filter algorithms
8.4.2	Scaling	Software is utilized to ensure use of the correct scaling	• Definition of the gain factor during final processing of the DiMod • Determination of the digital transmission factor by calibration • Digital transmission factor in the memory of the DiMod
8.4.3	Zeroing	Software is used for zeroing of the signal	Several options for signal zeroing (depending on the evaluation software used)
10	Time of contact	0,4 ms	5 µs

Table 2: Comparison between the requirements as per SAE J211-1 and the specification limits of the DTI measuring system

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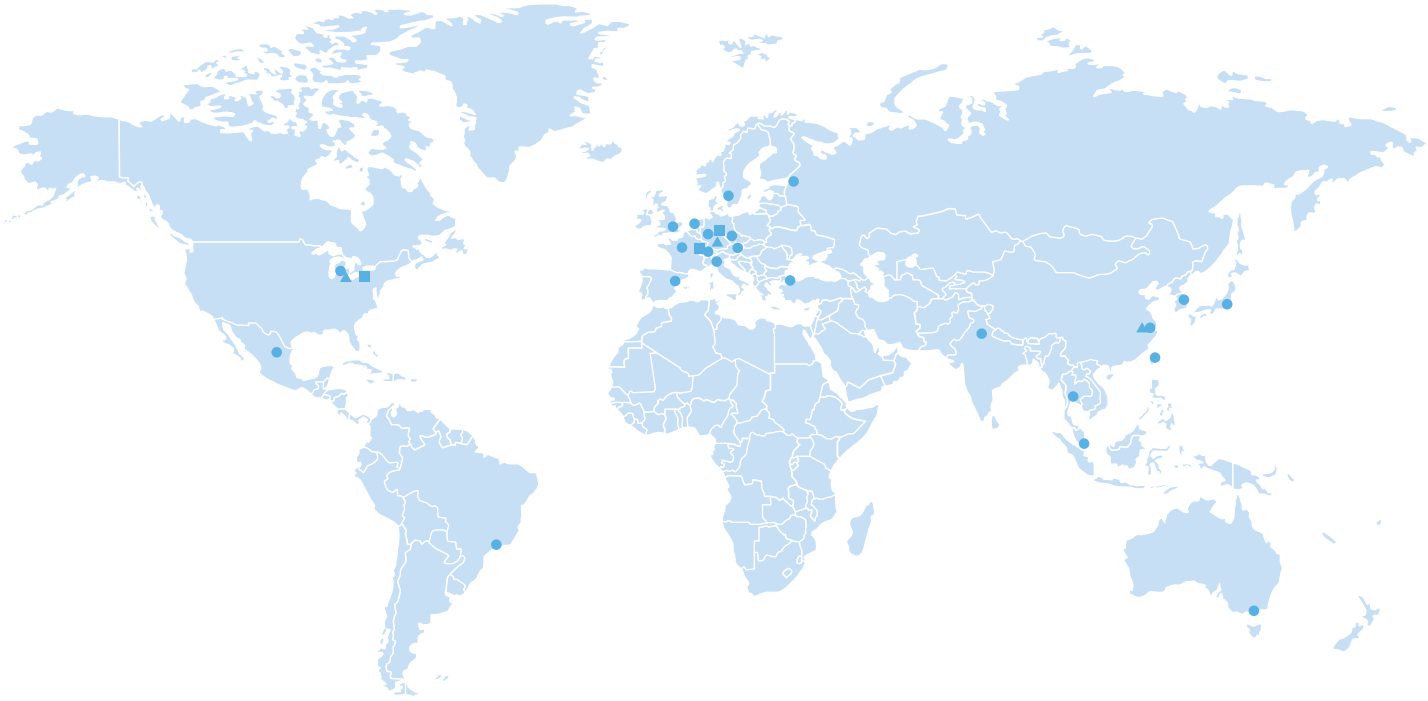

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