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Designing High-Performance On-Board Weighing (OBW) Systems in Commercial Vehicles

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1 Introduction

Overloaded heavy-goods vehicles pose a threat to road safety, road degradation, and the environment. Both on-board weighing (OBW) and weigh-in-motion (WIM) systems monitor overloaded trucks and allow inspectors to preselect vehicles suspected of infringement without stopping them. Better weight enforcement is one of the European commission's top priorities.

WIM systems are built into the road infrastructure. Depending on accuracy requirements, these systems are costly and require periodic maintenance. A large number of WIM systems need to be installed to support high compliance-check density.

On the other hand, OBW systems are integrated into vehicles instead of the road infrastructure and allow the weight data to be communicated at any given time from a moving vehicle to the concerned inspection authority. Current OBW systems typically achieve 5% to 10% typical accuracy and are well-suited for pre-selection. However, for direct enforcement of legal weight limits, which is generally dictated by respective legislation, much higher accuracy levels (typically <3%) are required. In many locations, especially in Europe, about 1% to 2% accuracy is desirable for direct enforcement of overloaded vehicles.

2 Overview of an On-Board Weighing (OBW) System

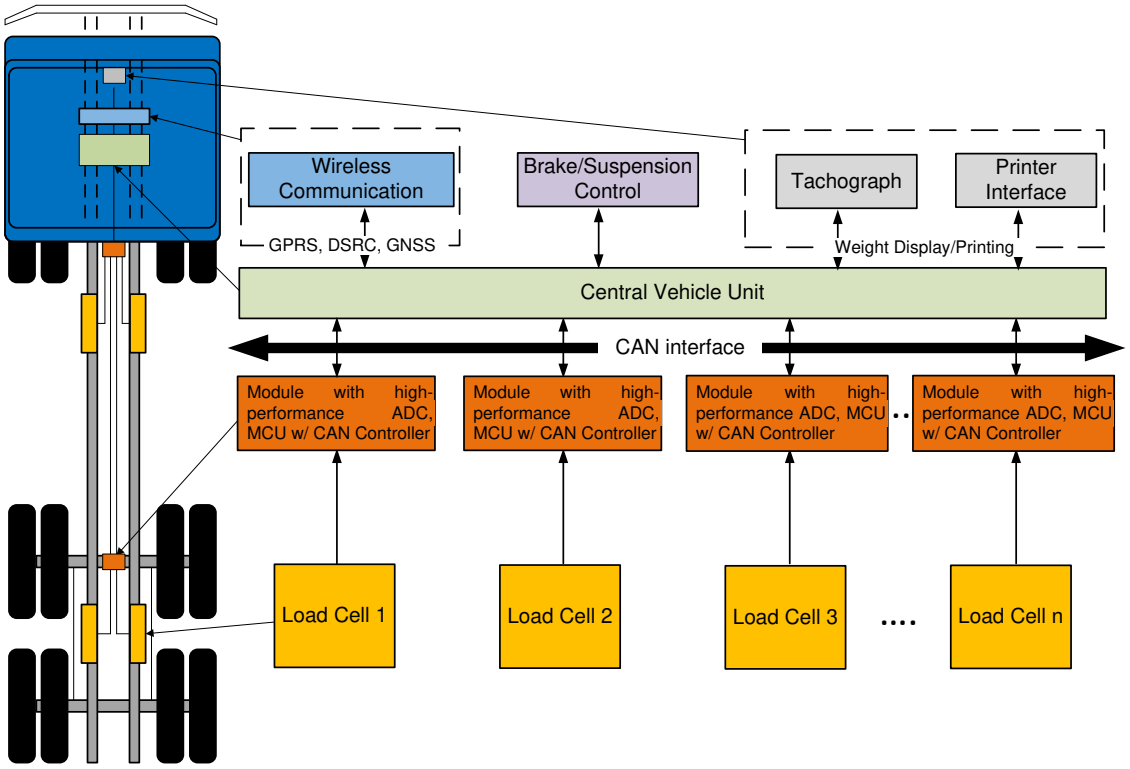

Figure 1. Typical Implementation of an On-Board Weighing (OBW) System

As shown in Figure 1, there are four major implementation blocks in a typical OBW system.

- **Weight Sensors** such as load-cells, strain gauges, or air pressure transducers
- **Load Cell Modules** that typically integrate a high-performance analog-to-digital converter (ADC), and a micro-controller (MCU) with CAN interface
- **Central Vehicle Unit** that interfaces to a tachograph or a printer or a wireless communication module
- **Display and Communication Modules** that display the results and transmit the data wirelessly to concerned authorities

2.1 Common Sources of Inaccuracy in OBW Systems

The accuracy and robustness of an OBW system primarily depends on:

- The type of sensor
- The number of sensors used in the system
- The ADC used to digitize the weight sensor signal
- The calibration procedures employed to calibrate weight sensor and ADC errors

A load-cell, in general, is more accurate (<1%), reliable, and durable, compared to other weight sensors. The OBW system accuracy and reliability dictates how often an accuracy check or re-calibration is required.

2.2 Understanding ADC Requirements in Load-cell based OBW Systems

To meet the accuracy requirements for direct weight enforcement, an ADC with high DC accuracy, high dynamic range, and low drift is needed to resolve small load-cell signals, typically less than ±20 mV. Depending on the number of axles, a certain system tolerance is required to maintain a certain level of certification. An example being a 40-t (40000 kg) vehicle with 5 axle groups that needs to maintain a worst-case accuracy of ±1150 kg that is ±1150 kg/40000 kg ≈ ±2.88% to maintain certification, avoid frequent accuracy checks and re-calibration. This level of accuracy is needed under harsh automotive conditions like temperature, humidity, vibrations, and so forth. The requirement for an ADC to digitize the load-cell signals is even more stringent since this worst-case accuracy includes the load-cell and ADC inaccuracies. Moreover, for manufacturers to build and re-use the same system solution across a wide variety of heavy-goods vehicles, the ADC needs to support high dynamic range, accuracy, and low drift. A 24-bit ADC with greater than 18 bits of Noise-Free Resolution with achievable calibrated accuracy over temperature of less than 0.5% is ideally suited.

As shown in Figure 2, weight is translated into a differential analog voltage using a resistive Wheatstone bridge configuration.

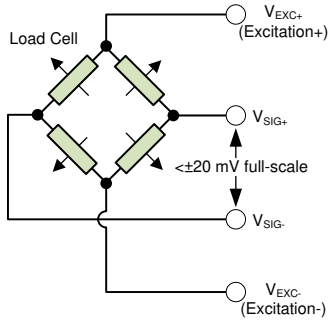

Figure 2. Typical Load-cell Implementation

Load-cells are often specified by the output voltage they produce for a 1-V excitation voltage with the load-cell maximum rated weight applied. The specification is given in units of mV/V. For example, a 2-mV/V load-cell excited with 5 V has a full-scale differential output voltage of only 10 mV. Remember, this is the maximum output voltage. To determine the resolution required by the ADC, the full-scale voltage of the bridge is divided by the desired scale resolution. The resolution is typically specified in noise-free counts. Assuming a 2-mV/V load-cell excited with 5 V and a scale requirement of 20,000 counts of noise-free resolution, the ADC should be able to repeatedly measure signals of (2 mV/V) x (5 V) / 20000 = 500 nV.

To make the design even more challenging, for a good scale design, the readings must be perfectly stable that is the readings should not flicker or toggle between codes because of noise. This requirement in turn places additional demands on the ADC, resulting in the need for noise resolution much better than what the scale reports to you. It is not uncommon for the noise performance to be ten times better than the displayed resolution. Hence, an internal resolution of 50 nV is what is desired.

To amplify the small load-cell signal with high accuracy and dynamic range, a low-noise gain stage is required before the ADC stage. Bandwidth of the gain stage is usually not a significant concern, given that the load weight changes relatively slow over time. What is critical, however, is that the gain stage be extremely stable over temperature and time. Any change in gain or input-referred offset over time or temperature adversely affects accuracy. In fact, in some high-end designs, the gain-stage stability over temperature is what sets the overall scale specifications. Since the signals being measured change slowly over time, and high resolution is required, delta-sigma ($\Delta\Sigma$) ADC architectures are preferred over other architectures. Similar to the gain stage, the performance of the ADC over temperature and time is also important so as to not limit the overall performance.

Additionally, the ADC should be able to make ratiometric measurements by supporting use of the bridge excitation voltage as the reference voltage (see Figure 2). The differential output signal of the bridge is proportional to the weight and the excitation voltage applied to the load-cell. By measuring the load-cell signal with the ADC ratiometrically that is with the excitation voltage serving as the ADC reference voltage, variations in the absolute value of the excitation voltage are cancelled out. This ratiometric approach reduces sensitivity to reference voltage errors, allowing to build a more robust system.

3 Introduction to ADS1260-Q1 and ADS1261-Q1

The ADS1260-Q1 and ADS1261-Q1 are AEC-Q100 Grade 1 qualified ADCs that provide designers with high-performance, low-drift, single-chip solutions for digitizing the output of load-cell bridge sensors. Figure 3 show the block diagram of the ADS1260-Q1 and ADS1261-Q1. The ADS1260-Q1 and ADS1261-Q1 incorporate the entire signal chain for load-cell measurements, and differ in number of input channels and AC bridge excitation option only.

A low-noise programmable gain amplifier (PGA) allows you to select gains from 1 to 128. The gains of 64 and 128 are typically used when the bridge is directly connected to the ADC since the load-cell signals are usually in few millivolts. The high-impedance PGA inputs (1 GΩ) reduce measurement error caused by sensor loading. The PGA and delta-sigma modulator are chopper-stabilized at high frequency in order to reduce offset voltage, offset voltage drift, and 1/f noise. The offset and noise artifacts are modulated to high frequency and removed by the integrated digital filter. Although chopper stabilization is designed to remove all offset, a small offset voltage may remain. The global-chop mode removes the remaining offset errors to the levels of noise, and thereby improves the offset drift performance. Precision and trimmed onboard resistors used in the integrated PGA provide outstanding gain stability over temperature and time.

In addition, the ADS1261-Q1 offers a special AC bridge-excitation feature that can switch the bridge polarity between measurements to calibrate the system level offset errors and offset drift over time and temperature. The ADC reference is either 2.5-V internal, external, or the 5-V analog power supply. A low-drift 2.5 V internal reference is buffered and routed to the REFOUT pin and can be used to provide excitation voltage to the load-cell. Alternatively, an external reference, as high as the analog supply voltage can be used to provide excitation voltage to the load-cell. Both these methods allow ratiometric measurements.

The onboard digital filter of these ADCs provides a selectable data rate from 2.5 SPS to 40 kSPS.

The precision onboard oscillator eliminates the need for an external oscillator or crystal, although an external clock source can be used if desired.

Signal and reference monitors, a temperature sensor, and cyclic redundancy check (CRC) data verification enhance data reliability.

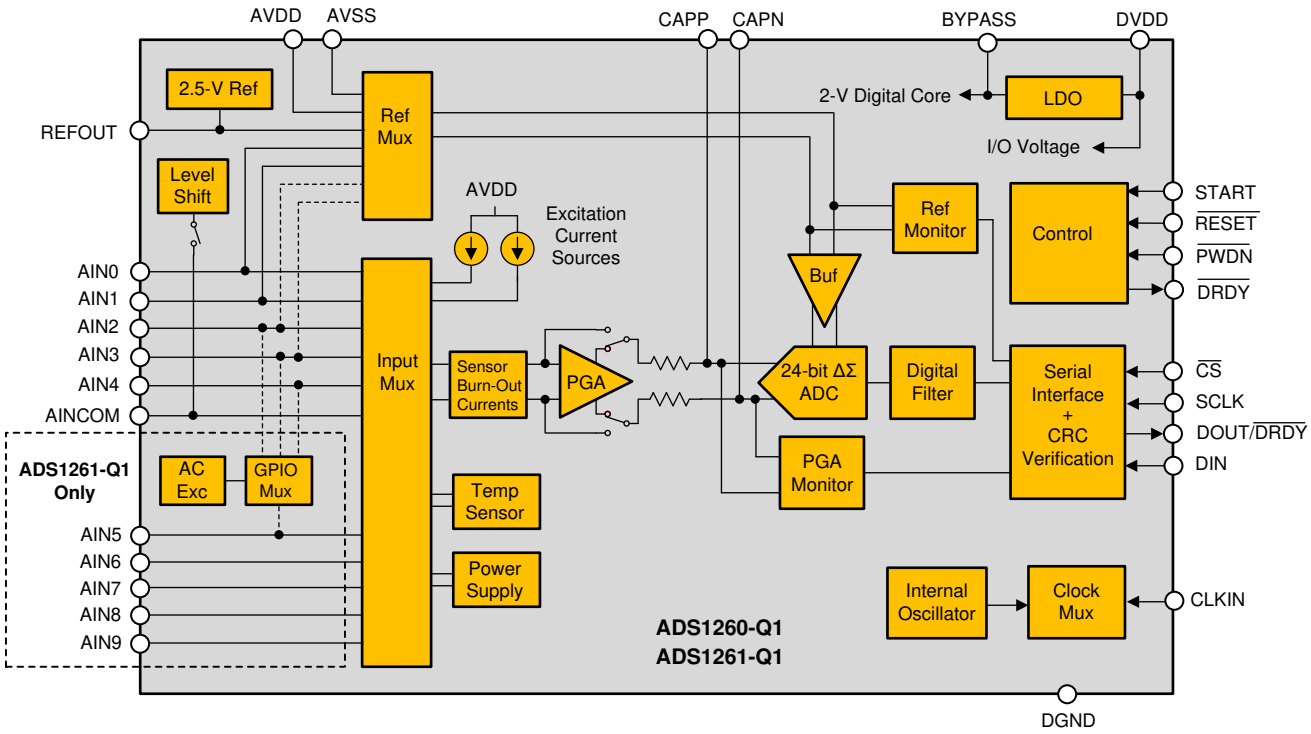

Figure 3. ADS1260-Q1 and ADS1261-Q1 Block Diagram

4 Implementing an OBW System Using ADS1260-Q1

4.1 Block Diagram

Figure 3 shows an implementation of a load-cell based OBW system using the ADS1260-Q1.

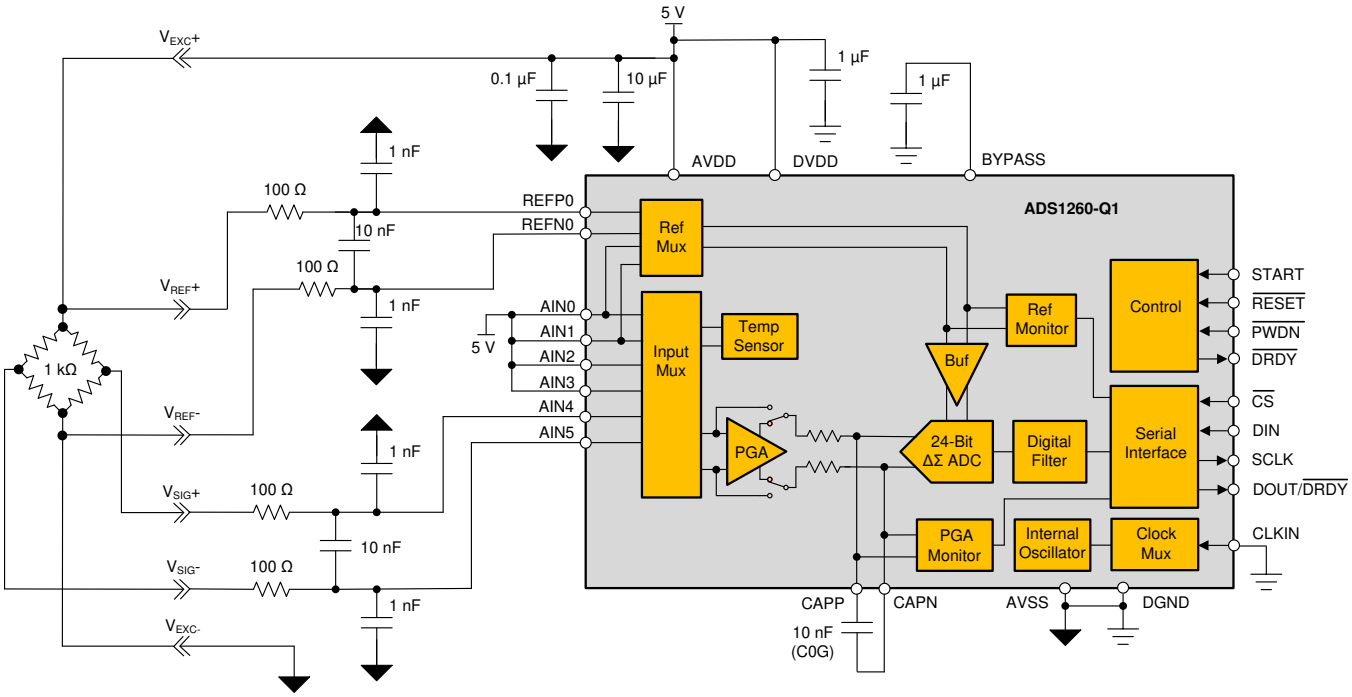

Figure 4. Implementation of an OBW System Using ADS1260-Q1

4.2 Design Requirements

The ADS1260-Q1 can be configured to provide tradeoffs between conversion noise, sample rate, and conversion settling time. Key design parameters and performance goals are summarized in Table 1 and Table 2 respectively.

Table 1. Design Parameters

DESIGN PARAMETERS	VALUE
Bridge resistance	1 kΩ
Bridge excitation voltage	5 V
Bridge sensitivity	2 mV/V
Bridge full-scale signal	10 mV

Table 2. Design Goals

DESIGN GOAL	VALUE
Noise-free counts	>20000
Data rate	100 SPS
Settling time	<25 ms

4.3 Actual Design Procedure

The excitation voltage (V_{EXC}+, V_{EXC}-) provided to the bridge is the ADC analog power supply voltage (5 V). Because of the very low input-referred noise of the ADS1260-Q1 at higher internal gain, there is no need for any additional gain in the front-end. The excitation voltage sense lines (V_{REF}+, V_{REF}-) are connected to the reference inputs of the ADC. This configuration provides ratiometric operation that cancels noise and drift of the excitation voltage.

The input-signal and reference-voltage paths are filtered with equal-value components to remove high-frequency noise from affecting the measurement.

External filter components filter the signal and reference inputs of the ADC, removing both differential and common-mode high-frequency noise. Component value mismatch in the common-mode filters converts common-mode noise into differential noise. To minimize the effect of the mismatch, the differential filter-capacitor values (10 nF) should be at least 10x the common-mode filter-capacitor values (1 nF). Increase the capacitor values to provide additional noise filtering. Maintain the resistors at low values to minimize thermal noise. For consistent noise performance, match the corner frequencies of the input and reference filters. More information is found in the *Ratiometric Measurements and Filtering Using the ADS1148 and ADS1248 Family of Devices Application Note*.

The ADC configuration that yields >20000 noise-free counts (refer to Section 2.2 for details on how to derive the required input-referred noise of the ADC) while achieving the data rate and settling time requirements is PGA Gain = 128, Data Rate = 100 SPS, Filter = Sinc 1, and Chop Mode = ON. Refer to the *Noise Performance* and *Chop Mode* sections of the ADS1260-Q1 datasheet to understand the input-referred noise performance under this ADC configuration. Use of the chop mode has the additional advantage of eliminating offset drift from the ADC.

The ADS1261-Q1 additionally offers an AC bridge-excitation feature to reduce system-level offset errors from a resistive bridge. AC excitation operates by using external switches to alternate the bridge polarity between measurements. More information is found in the *Using the ADS1261's Integrated AC Excitation Mode to Remove System Offset and Offset Drift Application Note*.

5 Conclusion

The ADS1261-Q1 meets the high-accuracy and robustness requirements of on-board weighing (OBW) systems by providing a low-noise, high-dynamic range, high accuracy, low-drift analog front-end with integrated bridge excitation and global chopping features.

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