Force Sensor Design with NCV7192

AND90385/D

In modern mechanical systems, the ability to accurately sense and report force or torque has become increasingly critical due to the growing complexity of machinery—characterized by a higher number of degrees of freedom—and the heightened emphasis on workplace safety. As systems become more dynamic and interactive, precise force measurement ensures both operational efficiency and protection for human operators. A widely adopted method for force sensing involves the use of strain-gauge resistors, which detect minute deformations in mechanical components. These resistors are typically configured in a Wheatstone bridge circuit, which enhances sensitivity and accuracy. When the bridge is electrically biased, it produces a differential output signal that reflects the mechanical strain experienced by the bridge. This signal can then be transmitted to a electronic control unit (ECU), enabling real-time monitoring and responsive control actions. Such integration of sensing technology is foundational to the development of intelligent, safe, and adaptive mechanical systems.

While the fundamental principle behind strain-gauge-based force sensing is relatively straightforward, its practical implementation presents several challenges that must be carefully addressed to ensure reliable performance. One key concern is the proper biasing and connection of the Wheatstone bridge circuit, which is essential for generating a usable differential output signal. Due to the nature of the strain-gauge deformation, this output is typically very small compared to the bias voltage, making it highly susceptible to electrical noise. Such noise can be introduced through capacitive or inductive coupling from nearby electronic systems, especially in environments with high integration density. As mechanical and electronic systems continue to evolve, the number of integrated sensors will increase—not only to enhance functionality but also to provide redundancy in safety-critical applications. These sensors are often co-located with actuators and share common buses for signal transmission and power supply, further complicating noise management and signal integrity.

To maintain accurate and consistent performance across all operating conditions and system states, a state-of-the-art interface device is required. This device must exhibit high levels of amplification of the weak sensor signals while ensuring robust communication with the central control unit, thereby preserving the fidelity of the measurement data in increasingly complex and noisy environments.

Figure 1. Illustration Photo of Robotic Arm

NCV7192 has been purposefully engineered to meet the demands of today’s increasingly complex and electrically noisy environments. Its robust design features low-noise amplification and a high-quality, versatile output driver, making it ideal for precision force sensing applications. The device supports two different output modes: it can deliver measurement data either as a continuous analog voltage or as a digital SENT (Single Edge Nibble Transmission) signal, offering flexibility for integration into a wide range of control systems. This standard protocol is particularly valuable in modern systems where sensors and actuators are densely packed and often share a central harness for communication and power lines. Maintaining signal integrity and accuracy becomes paramount.

The SENT (Single Edge Nibble Transmission) protocol, standardized under SAE J2716, is a unidirectional, low-cost, high-resolution digital communication protocol designed primarily for automotive sensor-to-ECU data transmission. Here’s a breakdown of its signal shape, cost advantages, and electromagnetic compatibility (EMC) features:

- Signal Shape and Encoding
  SENT uses pulse-width modulation (PWM) to encode data in nibbles (groups of 4 bits). Each nibble is transmitted as:
  - A fixed-width low pulse (typically expressed in number of ‘ticks’, with duration in the range from 3 to 90 μs)
  - Followed by a variable-width high pulse, where the total duration between falling edges ranges from 12 to 27 ticks, representing values from 0 to 15

Each message frame begins with a synchronization/calibration pulse of 56 ticks, allowing the receiver to determine the tick time and adapt to clock variations of up to ±25%. A typical SENT message includes a status nibble, up to 6 data nibbles (24 bits in total), a CRC nibble and an optional pause pulse to standardize message intervals.

- Cost Efficiency

  SENT is designed to be hardware-efficient:
  - Requires only three wires: signal, power (5 V), and ground.
  - Operates with low-cost RC oscillators due to its tolerance for clock variation.
  - Avoids the need for complex transceivers or bidirectional communication, reducing system complexity
  - No need for ADCs since it transmits digital data directly from smart sensors to a digital input of a general-purpose microcontroller
- Electromagnetic Compatibility (EMC)

  SENT is robust against electromagnetic interference due to:
  - Over-damped signal transitions (longer rise/fall times than PWM), which reduce high-frequency emissions
  - Pulse-width encoding rather than edge-based encoding, making it less sensitive to noise
  - Unidirectional transmission, which avoids the complexity and potential EMC issues of bidirectional protocols

These features make SENT particularly suitable for harsh automotive environments, such as engine compartments with high EMI levels.

The purpose of this document is to guide the reader through a complete design cycle, from concept to implementation, with the goal of achieving a best-in-class force sensor solution using the NCV7192 as a core component.

Step by Step Design Phases

Step 1: Bridge Component Selection

Select an appropriate strain-gauge bridge based on mechanical and electrical requirements.

Examples of usable force sensors or load cells:

- FC23 – TE Connectivity
- FX29 – TE Connectivity
- FSG Series Force Sensor (e.g. FSG020WNPB) – Honeywell
- A series Strain Gages – Hottinger Brüel & Kjaer
- LCL Series Full-Bridge Thin-Beam Load Cells (e.g. LCL-816G) – Omega
- SGT-4/1000-FB11 – Omega
- SEN-21669 – SparkFun Electronics

Step 2: Electrical Connectivity

Connect the four terminals of the sensor bridge to the NCV7192 interface as follows:

- SN (Sensor North, bridge positive supply terminal)
- SS (Sensor South, bridge negative supply terminal)
- SE (Sensor East, negative input terminal)
- SW (Sensor West, positive input terminal)

Ensure that the total impedance between SN and SS is 1 kΩ or higher to guarantee proper operation and signal integrity. A connection to SS instead of the ground net is required to benefit from the full suite of diagnostic flags.

Step 3: Power Supply Decoupling

Install decoupling capacitors on the following pins:

- VCC (Supply Voltage) to GND
- OUT (Output Signal) to GND

Use high-quality ceramic capacitors with low parasitic characteristics to minimize noise, enhance stability and improve ESD robustness.

Step 4: Signal Estimation and Gain Configuration

Estimate the maximum expected output signal from the bridge, including a margin for over-strain conditions. Based on this estimation, determine the appropriate gain setting and configure it in the NCV7192's non-volatile memory (NVM).

Step 5: Signal Acquisition and Digital Processing

After analog amplification, the signal is sampled by the internal ADC. The DSP section compensates for non-linearity and temperature variations. If necessary, additional digital amplification can be applied to optimize signal resolution and amplify the output signal to the maximum dynamic.

Step 6: Output Signal Configuration

Define the desired output mode—either analog voltage or SENT (Single Edge Nibble Transmission)—based on system architecture and communication needs:

- Analog Output: Provides the fastest response, limited only by the ADC sampling rate
- SENT Output: Offers digital communication with a slower update rate, dependent on the selected transmission rate

If reduced responsiveness is acceptable or needed, a configurable digital low-pass filter within the DSP can be enabled to smooth the output signal. DSP low-pass filter can also help to reduce noise when using strain gauges with very low sensitivity. The analog output can be loaded with additional filters depending on the needs.

Step 7: Sensor Calibration and System Integration

Calibrate the sensor according to the specific requirements of the target application. Programming of the module can happen via its output, whatever output mode is configured. Once calibrated, integrate the sensor into the final system assembly.

Step 8: Final Connectivity and Noise Immunity Considerations

As far as the supply and output connections are concerned, a connection of several meters from sensor to a controller unit is possible. For multiple sensors that provide signals to a unique controller unit, maintain a three-signal connection between the sensor and the receiving control unit to preserve noise immunity and to benefit from the full EMC performance of the sensor. This is represented in Figure 2.

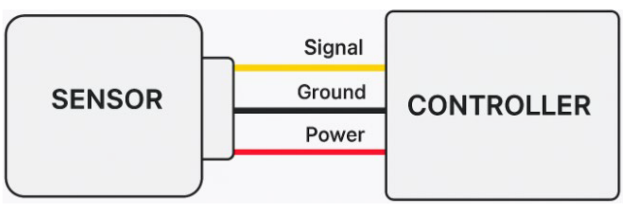

Figure 2. Block Diagram of Sensor Connected to the Controller Unit (Receiver Module)

Example Design: 10 kg Weight Scale Using NCV7192 and a Load Cell

The goal of this example is to demonstrate:

- A simple yet precise force-sensing system
- Achievable accuracy across a 0–10 kg range
- Noise performance with a low-sensitivity Wheatstone bridge
- NCV7192 behavior when driven by a bridge sensitivity below the datasheet recommendations

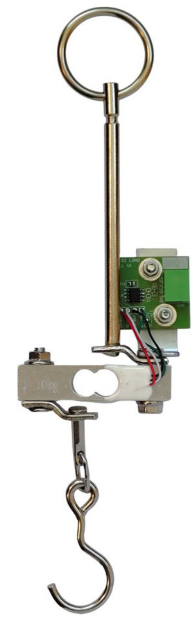

Figure 3. Photo Of Assembled Weight Scale

The load cell (SEN-21669 – SparkFun Electronics) in this design uses four strain gauges arranged in a full Wheatstone bridge. Its total resistance is 1 kΩ, and the datasheet specifies a sensitivity of 1 ±0.1 mV/Vbdr. In our experiments, the actual sensitivity measured 1.071 mV/Vbdr, which uses only 22 % of the ADC's input range. Full-scale resolution is recovered in the digital domain via DSP calibration coefficients.

The schematic diagram of the system with SENT is shown in Figure 4, and the one with analog output is shown in Figure 5. The analog output path features a simple RC low-pass filter, a 510 Ω resistor with a 100 nF capacitor yielding a cutoff frequency of 3.12 kHz. This filter suppresses high-frequency noise while preserving a faster step response. If sub-millisecond response isn't required, lowering the cutoff still further improves noise performance and EMI immunity.

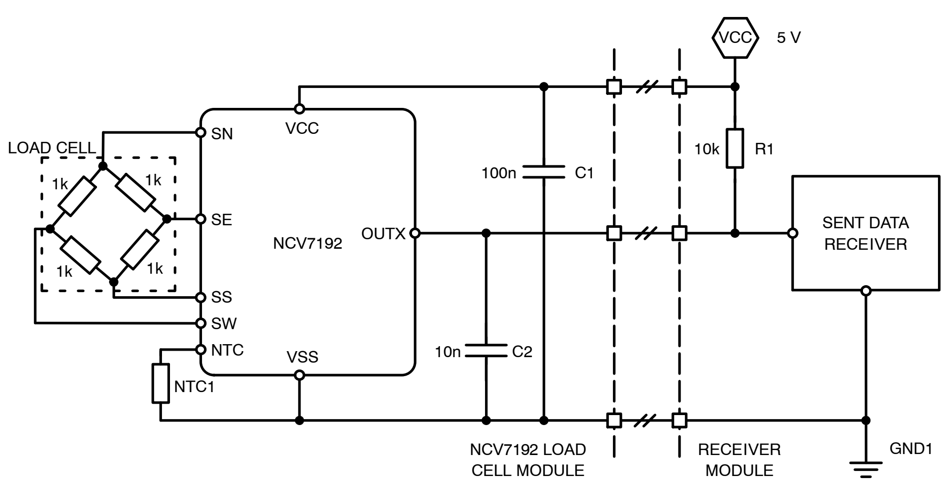

Figure 4. Schematic Diagram of Weight Scale Sensor Using SENT Output

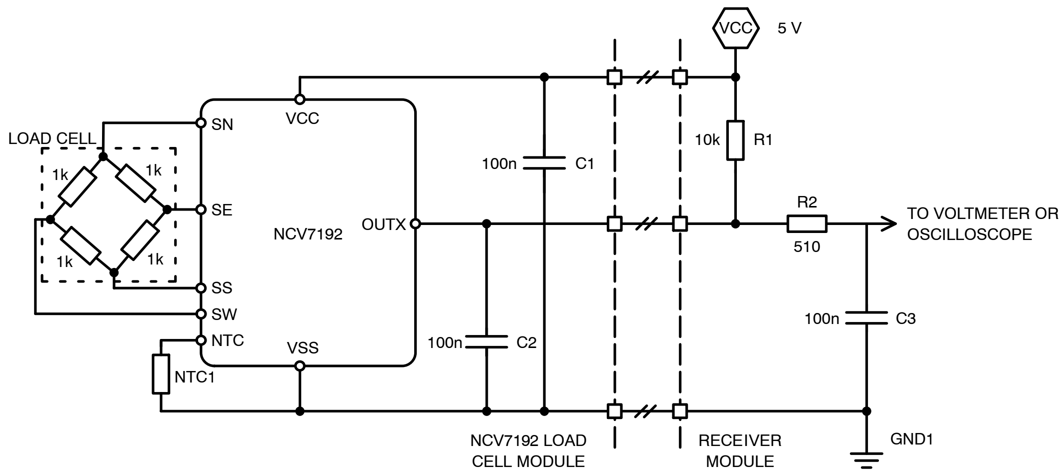

Figure 5. Schematic Diagram of Weight Scale Sensor Using Analog Output

For digital output, the SENT interface delivers a calibrated weight code directly to a host microcontroller. When temperature measurement is needed alongside weight, we recommend an external NTC sensor. This approach achieves superior temperature accuracy, especially with low-resistance bridges.

SENT Output Accuracy

To measure performance via the SENT output, the device was calibrated so that 0 kg corresponds to a code of 50 and 10 kg to a code of 4050. A real physical load was attached to the hook. Results are shown in Table 1:

Table 1. MEASUREMENT OF WEIGHT ACCURACY USING SENT OUTPUT

Applied Load (kg)	Calculated Ideal Transducer Signal (mV)	Average SENT Code	Measured Weight by Loadcell Module (kg)	Error (%)
0	0.000	50.8	0.002	0.02
1.226	0.367	539.6	1.224	−0.02
2.438	0.730	1024.4	2.436	−0.02
3.713	1.112	1533.6	3.709	−0.04
4.977	1.490	2039.2	4.973	−0.04
6.199	1.856	2527.6	6.194	−0.05
7.467	2.236	3035.2	7.463	−0.04
8.668	2.595	3515.2	8.663	−0.05
9.979	2.988	4039.6	9.974	−0.05

Analog Output Accuracy

For the measurement of performance using analog output, the device ratio-metric output was calibrated to source: 10% at 0 kg and 90 % at 10 kg. The Device was supplied a precise 5.000 V voltage source. Table 2 details the results:

Table 2. MEASUREMENT OF WEIGHT ACCURACY USING ANALOG OUTPUT

Applied Load (kg)	OUTX Voltage (V)	Measured Weight by Loadcell Module (kg)	Error (%)
0	0.5012	0.003	0.03
1.226	0.9911	1.228	0.02
2.438	1.476	2.440	0.02
3.713	1.986	3.715	0.02
4.977	2.491	4.978	0.01
6.199	2.981	6.203	0.04
7.467	3.489	7.473	0.06
8.668	3.97	8.675	0.07
9.979	4.495	9.988	0.09

SENT Noise Performance

SENT noise was evaluated over 700 frames using a 3 μs tick time. Noise performance was measured without any load or by unbalancing the bridge by external high value resistor, avoiding mechanical noise from a hanging weight which influences the result. Electrical noise is the main point of interest. Table 3 and Figure 7 present the results.

Table 3. NOISE PERFORMANCE USING SENT OUTPUT VS. DSP FILTER SETTINGS

DSP Filter Settings (step_filt)	Peak-to-Peak SENT Code Variation	Peak-to-Peak Code Variation (% of Full Scale)	RMS Value of Code Variation	RMS Value of Code Variation (% of Full Scale)
0	39	0.975	5.946	0.149
1	21	0.525	3.596	0.090
2	14	0.350	2.373	0.059
3	11	0.275	1.843	0.046
4	8	0.200	1.325	0.033
5	6	0.150	0.977	0.024
6	4	0.100	0.812	0.020
7	4	0.100	0.715	0.018
8	3	0.075	0.496	0.012
9	3	0.075	0.536	0.013

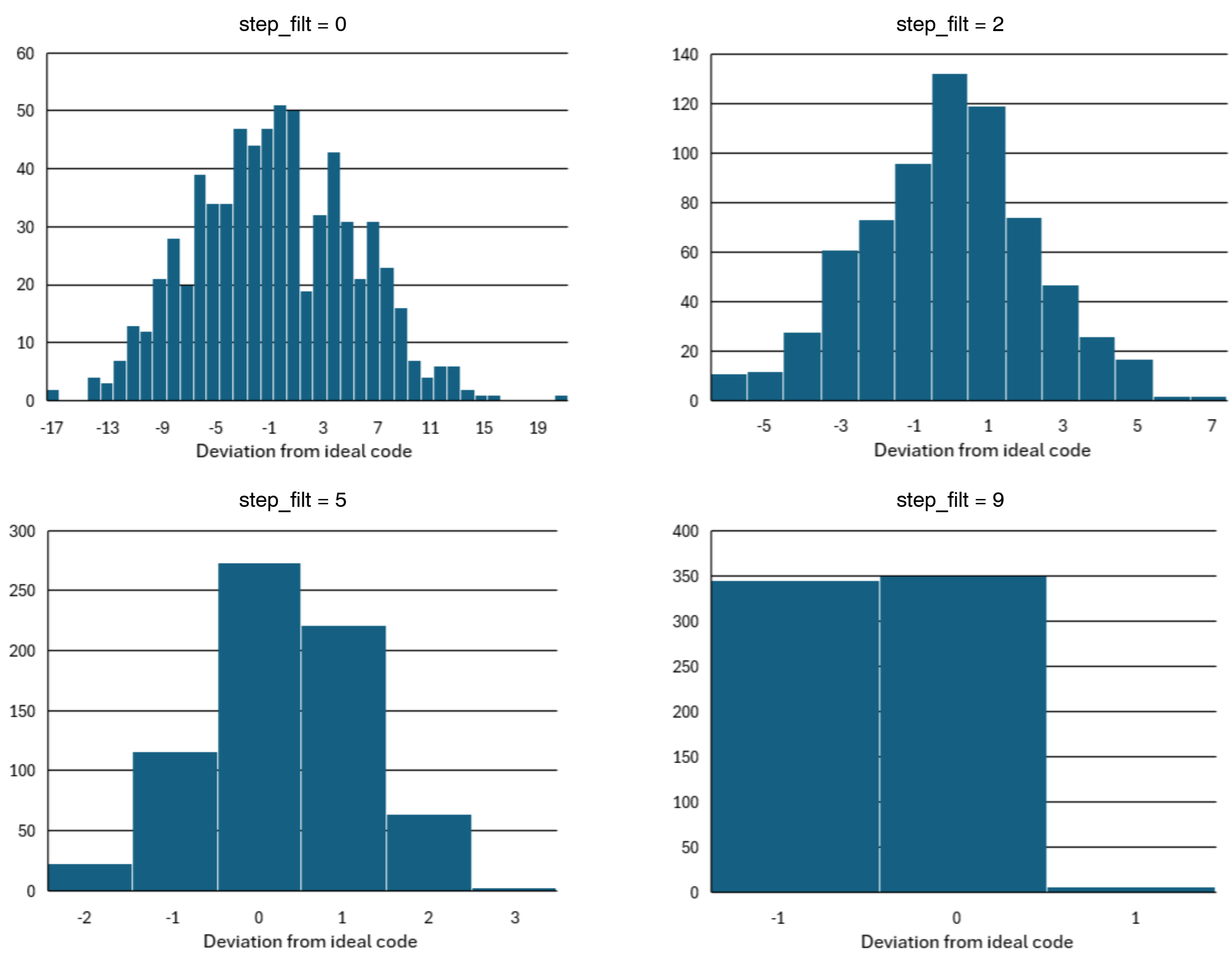

Figure 6. Histograms of Noise Using SENT Output for DSP Filter (step_filt) Settings 0, 2, 5 and 9

Analog Output Noise Performance

Under the same bridge conditions (unbalanced bridge in Figure 8), analog noise was measured via the receiver in Figure 4. It was measured by Rohde & Schwarz RTM3004 oscilloscope at 5mV/div with enabled BW limitation to 20 MHz. If very low analog noise is required, it is recommended to set slow step response in DSP settings (step_filt) and to lower cutoff frequency in the receiver filter. Table 4 and Figure 7 summarize the results.

Table 4. NOISE PERFORMANCE USING ANALOG OUTPUT VS. DSP FILTER SETTINGS

DSP Filter Settings (step_filt)	Peak-to-Peak Output Noise Voltage (mV)	Peak-to-Peak Output Noise (% of Full Scale)	RMS Output Noise Voltage (mV)	RMS Output Noise (% of Full Scale)
0	16.76	0.419	2.415	0.060
1	12.59	0.315	1.878	0.047
2	9.85	0.246	1.366	0.034

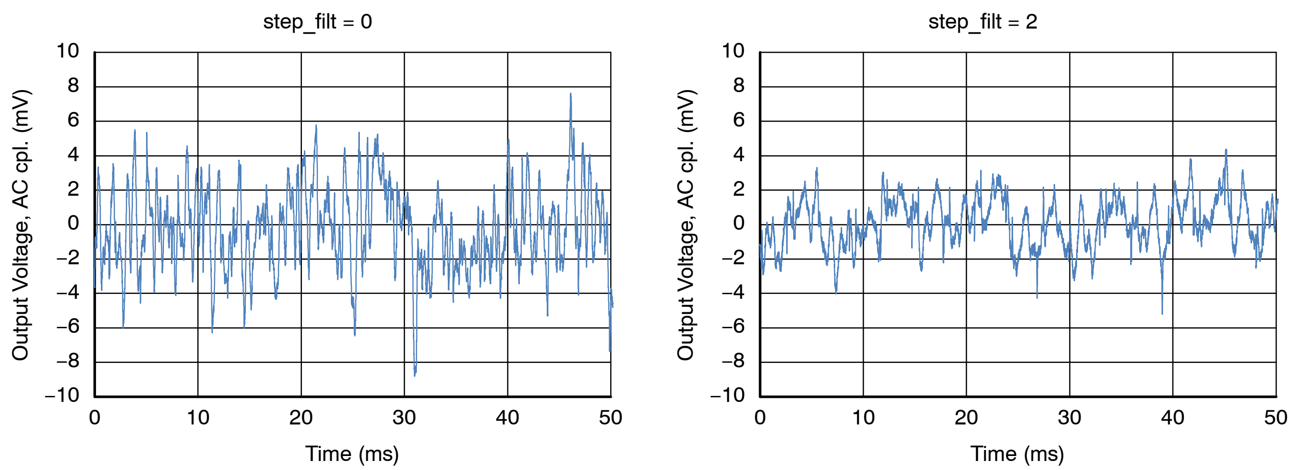

Figure 7. Captured Output Noise for DSP Filter (step_filt) Settings 0 and 2, AC Coupling

Noise results show that, with a low-sensitivity bridge, noise significantly affects unfiltered signals. We recommend some DSP filtering for low-level inputs. If a higher-sensitivity (lower analog front gain needed) Wheatstone bridge is used, noise becomes negligible.

Step Response (Analog)

Step response was captured for analog output only, because analog outputs provide near-instantaneous signal changes, whereas SENT frames involve slow digital encoding, resulting in higher latency (a 3 μs-tick SENT frame including temperature is ~800 μs long, versus a 95 μs analog sample period). Measurements used the input circuit in Figure 9; the 3.12 kHz output filter from Figure 5 had minimal impact. This test illustrates available response time when high bandwidth is required, even though the load cell itself does not need high bandwidth.

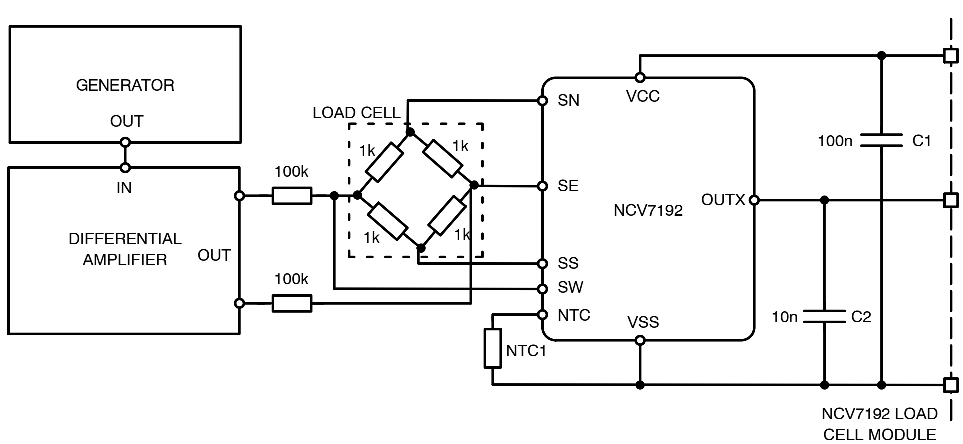

Figure 8. Schematic Diagram of the NCV7192 Input Stage for Measurement of Step Response

Two parameters were measured:

* Rise time from 10 % to 90 % of the output step
* Latency from the input step edge to 90 % of the output

Table 5. STEP RESPONSES USING ANALOG OUTPUT VS. DSP FILTER SETTINGS

DSP Filter Settings (step_filt)	Typical Datasheet Value (ms)	10%−90% Step Response (ms)	Response from Input Edge to 90% of Output (ms)
0	0.2085	0.248	0.422
1	0.417	0.427	0.616
2	0.834	0.758	1.047
3	1.668	1.543	1.94
4	3.336	3.121	3.686
5	6.672	6.42	7.169
6	13.34	12.8	14.448
7	26.69	25.85	28.296
8	53.38	50.83	56.664
9	106.8	100.14	105.66

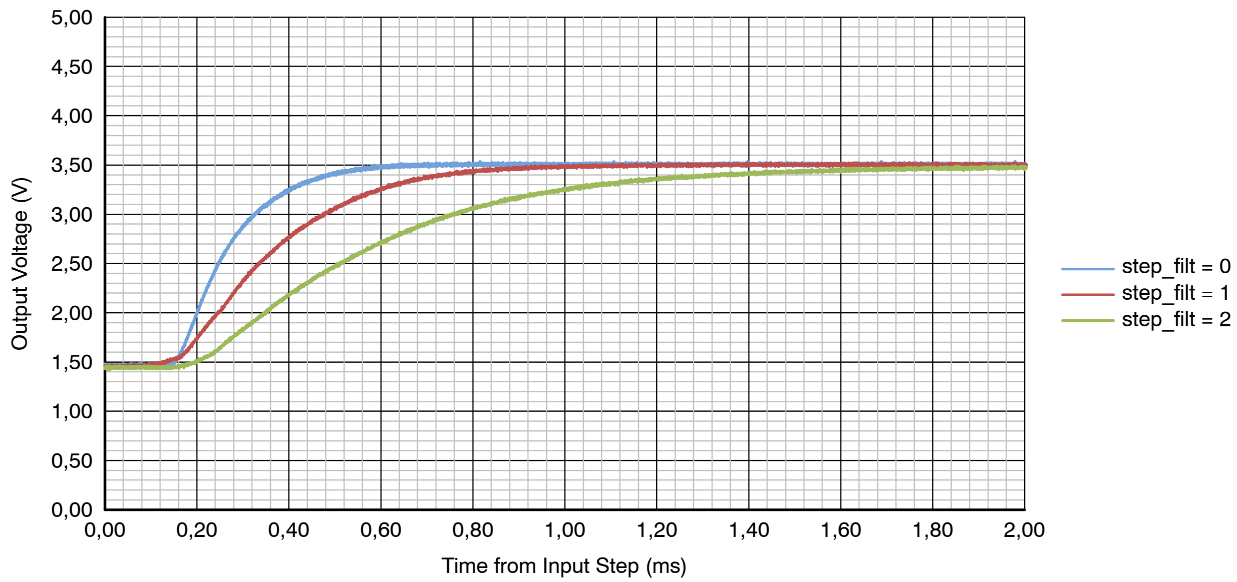

Figure 9. Step Responses for DSP Filter Settings (step_filt) 0, 1 and 2

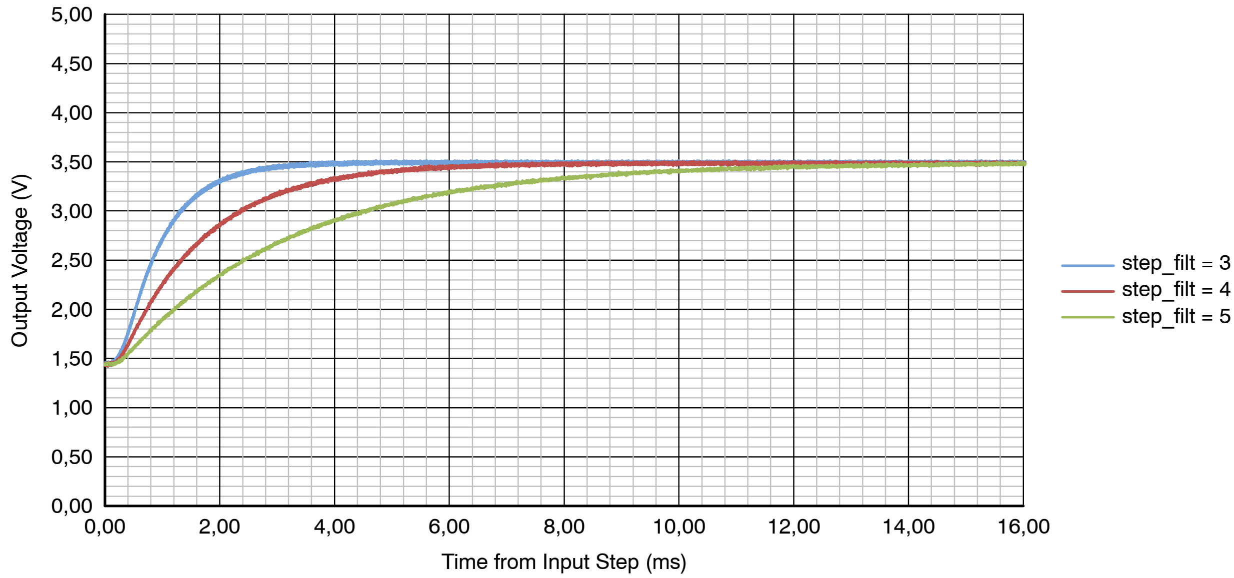

Figure 10. Step Responses for DSP Filter Settings (step_filt) 3, 4 and 5

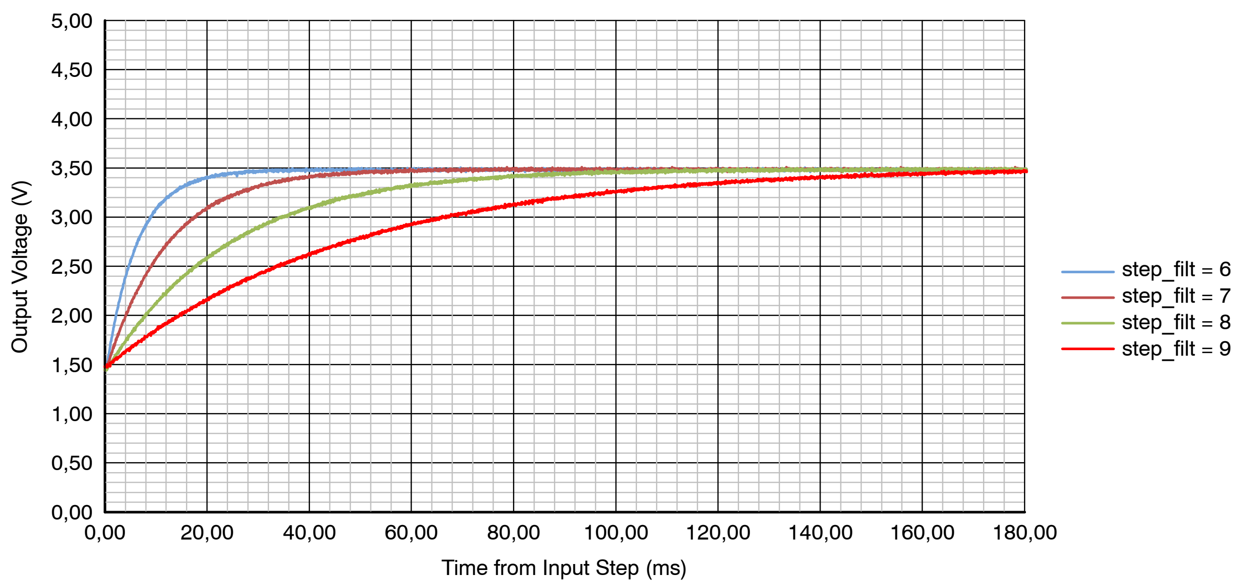

Figure 11. Step Responses for DSP Filter Settings (step_filt) 6, 7, 8 and 9

Conclusion

The integration of the NCV7192 into the force sensor (weight scale) architecture has demonstrated excellent performance, validating its suitability for precision sensing applications. By carefully selecting optimal components and configuring the system for minimal noise and maximum signal integrity, the resulting force sensor can achieve outstanding accuracy.

In this reference design we paired lower sensitivity bridge below the datasheet recommendation and still achieved precision of 0.09% or better. This high level of accuracy, combined with the NCV7192's robust signal handling and compact footprint, enables seamless integration into a diverse ecosystem of sensors and actuators. Whether deployed in automotive, industrial, or robotic environments, the solution offers scalability, reliability, and cost-efficiency, making it a compelling choice for next-generation sensing platforms.

To learn more about the NCV7192 and request samples, please visit the **onsemi** website.

REVISION HISTORY

Revision	Description of Changes	Date
0	Initial document version release.	10/3/2025
1	Figure 1 update.	10/29/2025