Scope

This application note provides information about Ripple Detection method, external part configuration and schematic examples in conjunction with the E910.40 IC.

General Description

The Ripple Counter IC E910.40 allows a µC to track the position of a DC-motor by counting its current ripples. The ripple signal is available on an output pin to connect to microcontrollers or dedicated logic. With the bidirectional interface the actual position can be read out and IC parameters are motor and PWM to control high side drivers. The IC can be adapted to different motor characteristics by changing a few external components.

Features

- Operating voltage range VDD 9V to 16V
- Full motor control and diagnosis
- Driving N-channel-power-MOSFET full bridge
- 8-bit PWM resolution for high-side drivers
- Nominal PWM frequency of 23kHz
- Smooth motor acceleration and deceleration
- Active motor braking
- -40°C to +125°C operating temperature
- SO20w package

Applications

- Seat adjustment
- Steering column adjustment
- Fuel pump
Package Pin Out

<table>
<thead>
<tr>
<th>Pin-No.</th>
<th>Name</th>
<th>Typ</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GND</td>
<td>S</td>
<td>Ground</td>
</tr>
<tr>
<td>2</td>
<td>VGH1</td>
<td>AO</td>
<td>Gate voltage for high side driver 1</td>
</tr>
<tr>
<td>3</td>
<td>VGH2</td>
<td>AO</td>
<td>Gate voltage for high side driver 2</td>
</tr>
<tr>
<td>4</td>
<td>VGL1</td>
<td>AO</td>
<td>Gate voltage for low side driver 1</td>
</tr>
<tr>
<td>5</td>
<td>VGL2</td>
<td>AO</td>
<td>Gate voltage for low side driver 2</td>
</tr>
<tr>
<td>6</td>
<td>VDD</td>
<td>S</td>
<td>Input supply voltage</td>
</tr>
<tr>
<td>7</td>
<td>BSI</td>
<td>AI</td>
<td>Input bootstrap voltage</td>
</tr>
<tr>
<td>8</td>
<td>SENSE1</td>
<td>AI</td>
<td>Voltage sense bridge 1</td>
</tr>
<tr>
<td>9</td>
<td>SENSE2</td>
<td>AI</td>
<td>Voltage sense bridge 2</td>
</tr>
<tr>
<td>10</td>
<td>RSR</td>
<td>AI</td>
<td>External resistor to adjust the slew rate</td>
</tr>
<tr>
<td>11</td>
<td>OLP</td>
<td>AO</td>
<td>Output low pass filter</td>
</tr>
<tr>
<td>12</td>
<td>IDIF</td>
<td>AI</td>
<td>Inverting input differentiating amplifier</td>
</tr>
<tr>
<td>13</td>
<td>ODIF</td>
<td>AO</td>
<td>Output differentiating amplifier</td>
</tr>
<tr>
<td>14</td>
<td>VSA</td>
<td>AI</td>
<td>Internal 9V analog supply</td>
</tr>
<tr>
<td>15</td>
<td>RB</td>
<td>AI</td>
<td>External bias resistor</td>
</tr>
<tr>
<td>16</td>
<td>VREF</td>
<td>AO</td>
<td>Internal 5V supply voltage</td>
</tr>
<tr>
<td>17</td>
<td>BRTH</td>
<td>AI</td>
<td>Input brake threshold</td>
</tr>
<tr>
<td>18</td>
<td>TEMP</td>
<td>AI</td>
<td>Input temperature monitor</td>
</tr>
<tr>
<td>19</td>
<td>IMP OUT</td>
<td>AO</td>
<td>Incremental output for counting pulses, open drain</td>
</tr>
<tr>
<td>20</td>
<td>DATA I/O</td>
<td>AO</td>
<td>Serial data I/O</td>
</tr>
</tbody>
</table>

\(D = \text{digital}, \ A = \text{Analog}, \ S = \text{Supply}, \ I = \text{Input}, \ O = \text{Output}, \ HV = \text{High Voltage (max. 40V)}\)
SO20w Package Outline

Index Area

Seating Plane

\[ h \times 45^\circ \]

\[ \text{phi} \]
1 Introduction to ripple detection

An applied voltage across the DC-motor terminals causes a current flow which establishes a rotation of the rotor. To keep the rotor turning the motor windings need to be activated at the right moment to create a torque which is the cause of the mechanical rotation. The commutation (activating the windings at the right moment) is done mechanically by the commutator.

Figure 1 shows a DC-motor with stator (2 permanent magnets), rotor with 3 windings, brushes and the commutator.

![Figure 1: Simple example of a DC motor](image)

Electrically a DC motor can be viewed as a series RL network with a voltage generator $V(\omega)$. The generator represents the back electromotive force (BEMF) generated by the motor’s rotation and which opposes the electromotive force of the supply. The value of the BEMF is a function of the motor’s angular velocity. If the motor has no external load and its velocity is not limited, it will accelerate up to the velocity which equals $V(w)$ at the supply voltage $V_s$. In our example the BEMF is a vector sum of the three winding voltages $P_1$, $P_2$ and $P_3$ which is shown below.

![Figure 2: Electrical schematics of motor windings](image)
During rotor’s movement the resistance measured at the motor terminals for a short period of time (during the commutation) changes its value; here from \( R_{\text{tot}} = R_1 \parallel R_2 = \frac{2}{3} R \) to \( R_{\text{tot}} = R_1 \parallel R = \frac{1}{2} R \) (excluding effects caused by switching of winding inductances).

This causes a change of the current value seen as short commutation spikes, also called commutation ripple which follows this equation:

\[
I_{\text{mot}} = \left( \frac{V_{\text{bat}} - \text{BEMF}}{R_{\text{tot}}} \right)
\]

- \( I_{\text{mot}} \): Motor current
- \( V_{\text{bat}} \): Battery voltage
- \( \text{BEMF} \): Back ElectroMotive Force
- \( R_{\text{tot}} \): Total winding resistance
Additional inductance in the windings reduces the peak amplitude and creates an quasi-sinusoidal signal shape of the current.

Figure 5: Motor resistance change with resulting current ripple (neglecting the armature inductance)
To improve the inductive coupling between the windings they can be wrapped around two armatures. In this case the DC-motor can have unsymmetrical windings, the ripple current gets additional dynamic component as a superpositioned sinusoidal wave with lower frequency which corresponds with the motor speed. This is caused by different copper wire lengths of the different windings. Consequently the different winding resistance causes fluctuating current flowing through the motor.

Figure 7: Unsymmetrical windings

Figure 6: Quasi-sinusoidal current shape
Further parasitic effect on the ripple current is the magnetic flux weakening across the rotor and motor housing caused by its geometry.

Another unwanted effect is the bending of the stator magnetic field caused by superposition of the rotor’s magnetic flux. This effect is strongly motor current and turning direction dependent and is intensified when the motor current rises.

The result are double pulses which can be out of the commutation phase and must be recognized by the ripple counter.
2 Motor ripple signal processing with E910.40

The E910.40 measures the motor current fluctuation indirectly via the SENSE1/2 pins. The voltage drop across the MOSFET’s $R_{DS_{on}}$ is measured and subsequently filtered. The filtered analog ripple signal is provided to a min/max detection circuit which further generates a TTL compatible signal provided to the µC.

The SENSE1/2 input is internally connected to a 2$^{nd}$ order low-pass filter with an edge frequency of 2.5kHz to suppress the PWM frequency. Following the low-pass filter a band pass filter using external components is implemented:

- Pin 11 – OLP output internal 2$^{nd}$ order low pass filter,
- Pin 12 – IDIF Inverting input differential amplifier,
- Pin 13 – ODIF Output differential amplifier

![Filter schematics](image-url)

---

*Figure 11: Undefined Phase Relation due to Field Bending*

*Figure 12: Filter schematics*
Mathematical description of the low pass filter followed by a band pass circuit:

2nd order Low Pass frequency response:

\[ A_1 = \left( 1 + j \frac{\omega}{\omega_0} \right)^2 \]

with \( \omega_0 = 2\pi f_0 \), \( f_0 = 2.5 \text{kHz} \)

Band pass frequency response:

\[ X_1 = R_1 + \frac{1}{j\omega C_1} \]

\[ X_2 = \frac{R_2}{j\omega C_2} = \frac{1}{1 + j\omega R_2 C_2} \]

\[ |A_2| = \frac{X_2}{X_1} = \frac{R_2}{R_1} \cdot \frac{1}{1 + j\omega R_2 C_2 + \frac{R_2 C_2}{C_1}} \]

\[ = \frac{R_2}{R_1} \cdot \frac{1}{1 + \frac{R_2 C_2}{R_1 C_1} + j \left( \omega R_2 C_2 - \frac{1}{\omega R_1 C_1} \right)} \]

The expressions \( \frac{R_2}{R_1}, \frac{1}{1 + \frac{R_2 C_2}{R_1 C_1}} \) the frequency independent amplification factor of the amplified voltage across the motor and MOSFET voltage. The equation \( \frac{1}{1 + \frac{R_2 C_2}{R_1 C_1}} \) can be simplified to \( \frac{R_2}{R_1} \)

which is more suitable for further empiric component adjustment.
With $\omega = 2\pi f$ the expression \[ f_1 = \frac{1}{2\pi R_1 C_1} \] indicates the lower edge frequency of the band pass filter. \[ f_2 = \frac{1}{2\pi R_2 C_2} \] on the other hand is the higher band pass frequency of the band pass.

3 Adjusting the parameters $C_1, C_2, R_1, R_2$ of the band pass filter

First the amplification factor $\frac{R_2}{R_1}$ must be adjusted to the expected voltage drop across the switching MOSFET.

The voltage range at the SENSE1/2 pin is -1.5V..2V. The internal OPA’s supply voltage is 9V and the working voltage was set to 4V.

Later on the edge frequencies $f_1$ and $f_2$ are adjusted to the expected frequency range of the motor current ripple. These steps are done by empirical measuring and analyzing of the signal quality at OLP/IDIF/ODIF pins.

Examining several automotive DC-motors allowed to extract following suitable start parameters for further “fine-tuning” approach:

- $R_1 = 10k\Omega$
- $R_2 = 330k\Omega$
- $C_1 = 1\mu F$
- $C_2 = 470pF$
- $f_1 = 16Hz$
- $f_2 = 1026Hz$
Frequency response of the band pass filter with listed parameters above (including the internal E910.40 2nd-order low pass filter):

![Frequency response graph](image)

*Figure 13: Proposed filter frequency response*

## 4 Dynamic ripple amplification gain adjustment

Because the analog ripple counting signal processing bases on a standard OPA circuit it can be modified to your application needs.

Depending on the ripple counter application, a possible modification of the described band pass filter is the dynamic amplification gain adjustment of the OPA to prevent the OPA from overdrive.

Circuit which decreases the amplification factor of the OPA during high motor current ripple.
Figure 14: Dynamic gain reduction (schematics)

Measured signal at IN_OP and digital ripple counter output:

Figure 15: Dynamic gain reduction (simulation)
Circuit which increases the amplification factor of the OPA during high motor current ripple.

Figure 16: Dynamic gain reduction (measured)

Figure 17: Dynamic gain amplification (schematics)
Measured signal at IN_OP and digital ripple counter output:

Figure 18: Dynamic gain amplification (simulation)

Figure 19: Dynamic gain amplification (measured)
Example of misconfigured filter parameters
The following oscilloscope screenshot shows a misconfigured bandpass filter. The ripple frequency signal is suppressed. Some of the ripple counter pulses are lost.

Example of well configured filter parameters
The following screenshot shows well configured filter parameters. No pulses are lost.
5 Temperature supervision

The E910.40 provides temperature supervision of any connected application device. Two possible temperature sensitive devices or a digital information circuit can be used:

- 1. NTC device
- 2. PTC device
- 3. external digital signal source

As soon as the voltage at the pin TEMP (pin 18) reaches the threshold of

\[(0.5 \pm 0.1) \cdot V_{\text{ref}}\]

the OVERLOAD bit will be set to '1'.

The following formula is used for estimation of \(V_{\text{TEMP}}\) at pin 18.

Using an NTC:

\[V_{\text{TEMP}} = V_{\text{ref}} \cdot \frac{R}{R + R_{\text{NTC}}} = V_{\text{ref}} \cdot \frac{1}{1 + \frac{R_{\text{NTC}}}{R}}\]

where \(R_{\text{NTC}} = f(T)\)

Using a PTC:

\[V_{\text{TEMP}} = V_{\text{ref}} \cdot \frac{R_{\text{PTC}}}{R + R_{\text{PTC}}} = V_{\text{ref}} \cdot \frac{1}{1 + \frac{R}{R_{\text{PTC}}}}\]

where \(R_{\text{PTC}} = f(T)\)

Using a digital signal source:

- \(V_{\text{TEMP \; high}}\) \rightarrow OVERLOAD bit '1'
- \(V_{\text{TEMP \; low}}\) \rightarrow OVERLOAD bit '0'

Figure 22: Temperate supervision circuits
6 Adjusting the slew rate of Power MOSFET gate signals

The E910.40 provides an EMI conform switching behavior of the Power MOSFETs by reducing the gate signal's slew rate. The resistor \( R_{SR} \) connected to pin 10 of the E910.40 is responsible for the slew rate adjustment which can reach values from 2 to 15 V/µs.

Note: The slew rate adjustment strongly depends on the gate capacitance of the Power MOSFET.
Note: \( R_{SR} = 47kΩ \) @ \( C_{GS} = 1.5nF \) provides a good EMI performance of the circuit.

7 Adjusting the motor braking ripple threshold

After a stop or direction change command during motor run it will be smoothly stopped by increasing/decreasing of the switching PWM duty cycle. In addition the ripple signal is evaluated again and the braking PWM change actively adjusted.

![Figure 23: Smooth PWM duty cycle change from 100% to 0%](image)

The threshold of the succeeding ripple signal can be adjusted by an external voltage (i.e. Voltage divider) at the pin BRTH. The equation for the braking threshold:

\[
\frac{V_{BRTH}}{5V} = \frac{\text{brake threshold}}{50mV}
\]

\[\text{brake threshold} = \frac{V_{BRTH} \cdot 50mV}{5V}\]

A use of a voltage divider of 2x10kΩ:

\[\text{brake threshold} = \frac{2.5V \cdot 50mV}{5V} = 25mV\]
8 E910.40 DATA I/O protocol

For detailed information and examples please refer to the E910.40 datasheet.

Dokument-No.: 03SP0275E.xx Specification E910.40

9 Typical E910.40 Application

Figure 24: E910.40 Typical application
10 E910.40 Evaluation Kit

For evaluation of the E910.40 ELMOS Semiconductor AG provides an E910.40 Evaluation Kit which can be ordered at sales@elmos.de.

Figure 25: E910.40 Evaluation Board

Figure 26: E910.40 Evaluation Board Control
Features:

- Designed for 12V automotive applications,
- Driving motor with a blocking current up to 30A,
- Based on an easy to use ATMEGA32L™ * µC,
- C-sources available,
- Basic functions like:
  - speed up motor,
  - slow down motor,
  - motor position counter reset,
- are accessed by integrated on-board switches,
- Processing of 2 end position switches,
- Feedback and diagnosis available via RS232,
- PC connection via parallel port,
- PC based LabVIEW GUI, allows operations like:
  - cyclic motor speed ramp generation,
  - cyclic direction change,
  - watchdog function,
  - graphical motor position tracking,
  - processing of end switches,
- Easy accessible test points to adjust the filter components,
- External ripple filter components designed to be in SMD and through hole technology

* ATMEGA32L is a Trade Mark of Atmel Corporation
11 Record of Revisions

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Rev.</th>
<th>Change and Reason for Change</th>
<th>Date</th>
<th>Released</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Initial Revision</td>
<td>18.01.2006</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>New Figure 7</td>
<td>18.05.2006</td>
<td>ZOE/EM</td>
</tr>
</tbody>
</table>
Contents

Package Pin Out .......................................................................................................................................................................................... 2
Pin Description .............................................................................................................................................................................................. 2
SO20w Package Outline ............................................................................................................................................................................. 3
1 Introduction to ripple detection.............................................................................................................................................................. 4
2 Motor ripple signal processing with E910.40 ........................................................................................................................................ 9
3 Adjusting the parameters C1, C2, R1, R2 of the band pass filter .................................................................................................. 10
4 Dynamic ripple amplification gain adjustment .................................................................................................................................. 12
5 Temperature supervision ........................................................................................................................................................................ 17
6 Adjusting the slew rate of Power MOSFET gate signals .............................................................................................................. 18
7 Adjusting the motor braking ripple threshold ..................................................................................................................................... 18
8 E910.40 DATA I/O protocol ............................................................................................................................................................... 19
9 Typical E910.40 Application ............................................................................................................................................................... 19
10 E910.40 Evaluation Kit ..................................................................................................................................................................... 20
11 Record of Revisions .......................................................................................................................................................................... 22

List of Figures

Figure 1: Simple example of a DC motor .................................................................................................................................................. 4
Figure 2: Electrical schematics of motor windings ......................................................................................................................... 4
Figure 3: Generation of Commutation Ripple ..................................................................................................................................... 5
Figure 4: Generation of Commutation Spikes ..................................................................................................................................... 5
Figure 5: Motor resistance change with resulting current ripple (neglecting the armature inductance) .................................................. 6
Figure 6: Quasi-sinusoidal current shape ............................................................................................................................................ 7
Figure 7: Unsymmetrical windings ....................................................................................................................................................... 7
Figure 8: Low frequency signal superposition ..................................................................................................................................... 8
Figure 9: Stator field weakening ............................................................................................................................................................ 8
Figure 10: Stator field distortion ............................................................................................................................................................ 8
Figure 11: Undefined Phase Relation due to Field Bending ................................................................................................................. 9
Figure 12: Filter schematics .................................................................................................................................................................... 9
Figure 13: Proposed filter frequency response ....................................................................................................................................... 12
Figure 14: Dynamic gain reduction (schematics) ................................................................................................................................. 13
Figure 15: Dynamic gain reduction (simulation) ..................................................................................................................................... 13
Figure 16: Dynamic gain reduction (measured) ..................................................................................................................................... 14
Figure 17: Dynamic gain amplification (schematics) ............................................................................................................................ 14
Figure 18: Dynamic gain amplification (simulation) ............................................................................................................................ 15
Figure 19: Dynamic gain amplification (measured) ............................................................................................................................... 15
Figure 20: Example of misconfigured bandpass filter ........................................................................................................................ 16
Figure 21: Example of well configured bandpass filter ....................................................................................................................... 16
Figure 22: Temperate supervision circuits ........................................................................................................................................... 17
Figure 23: Smooth PWM duty cycle change from 100% to 0% ......................................................................................................... 18
Figure 24: E910.40 Typical application ................................................................................................................................................ 19
Figure 25: E910.40 Evaluation Board .................................................................................................................................................... 20
Figure 26: E910.40 Evaluation Board Control ......................................................................................................................................... 20
WARNING – Life Support Applications Policy

ELMOS Semiconductor AG is continually working to improve the quality and reliability of its products. Nevertheless, semiconductor devices in general can malfunction or fail due to their inherent electrical sensitivity and vulnerability to physical stress. It is the responsibility of the buyer, when utilizing ELMOS Semiconductor AG products, to observe standards of safety, and to avoid situations in which malfunction or failure of an ELMOS Semiconductor AG Product could cause loss of human life, body injury or damage to property. In development your designs, please ensure that ELMOS Semiconductor AG products are used within specified operating ranges as set forth in the most recent product specifications.

General Disclaimer

Information furnished by ELMOS Semiconductor AG is believed to be accurate and reliable. However, no responsibility is assumed by ELMOS Semiconductor AG for its use, nor for any infringements of patents or other rights of third parties, which may result from its use. No license is granted by implication or otherwise under any patent or patent rights of ELMOS Semiconductor AG.

ELMOS Semiconductor AG reserves the right to make changes to this document or the products contained therein without prior notice, to improve performance, reliability, or manufacturability.

Application Disclaimer

Circuit diagrams may contain components not manufactured by ELMOS Semiconductor AG, which are included as means of illustrating typical applications. Consequently, complete information sufficient for construction purposes is not necessarily given. The information in the application examples has been carefully checked and is believed to be entirely reliable. However, no responsibility is assumed for inaccuracies. Furthermore, such information does not convey to the purchaser of the semiconductor devices described any license under the patent rights of ELMOS Semiconductor AG or others.

Copyright © 2006 ELMOS Semiconductor AG
Reproduction, in part or whole, without the prior written consent of ELMOS Semiconductor AG, is prohibited.