

METHOD AND CIRCUITRY TO DETECT AND PREVENT SHORTING IN FUEL INJECTOR DRIVE CIRCUITRY

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TECHNICAL FIELD

10 This invention relates to circuitry and methods used to operate fuel injectors i.e. the actuators thereof. It has specific but not exclusive application to operation of solenoid actuators of fuel injectors. It specifically relates to circuitry and methodology to detect shorting conditions in fuel injector systems such as in fuel injector drive circuitry.

BACKGROUND OF THE INVENTION

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Circuitry (such as IC's) has been designed which is adapted to drive (e.g. Diesel) fuel injectors; to be precise fuel injector actuators such as solenoid actuators. This usually comprises associated circuitry which is controlled by an ECU, and is located between the ECU and the fuel injectors; typically this circuitry comprises of injector High and Low Side drives for drive functionality. So in other words, circuitry is typically provided to actuate fuel injectors controlled by an ECU and such drive circuitry typically provides Low and High Side drive functionality to injector actuators such as solenoids. The circuitry is typically embodied on an ASIC (application-specific integrated circuit) chip.

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The High Side Drive function of such circuitry provides the requisite voltage to the injector according to the current operational injection activation profile as dictated by the ECU. This involves ramping up to a current or voltage level and thereafter may include current chopping based on requisite current level.

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The Low Side Drive functionality is provided to turn on the connection to the low side terminal of an injector. Effectively Low Side driver arrangements circuitry allow e.g. selection of which injector in an injector bank of multiple injectors is driven to be driven.

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The High Side Drive has the capability of a minimum "on time" of 1 μ sec and minimum "off time" of 3.7 μ sec. So its fastest drive frequency is 212KHz although in actual Diesel injector drive applications, it only needs drive frequency below 50KHz.

So this high frequency drive capability of the injector high side drive (enable signal) referred to as (BNK[x]_HS_EN signal) can under circumstances be also a glitch, hazard and weakness in its architecture. In certain circumstances of operation, the High Side Drive output FET will eventually be damaged by the high frequency switching under short conditions e.g. at very high shorted load current.

It is an object of the invention to overcome these problems.

SUMMARY OF THE INVENTION

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In one aspect is provided drive circuitry for a fuel injector actuator, said drive circuitry including a High Side Drive portion and a Low Side Drive Portion, and including determination means to determine a short condition, said determination means adapted to perform a frequency analysis of a voltage(s) or a voltage signal at, or from, one or more points in the High Side Drive, and to determine if a faulty short conditions exists based on said analysis.

Said voltage may be the voltage at the high side connection terminal for the fuel injector actuator.

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Said voltage may be the voltage of the High Side Drive Enable Signal.

Said determination means may be adapted to perform the frequency analysis of a voltage(s) by being adapted to compare the frequency of the voltage with a stored value, and output a signal indicative of a faulty short condition dependent on said comparison.

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Said determination means may be adapted to determine that a short condition exists if said voltage frequency is higher than said stored value, or higher than the stored value plus a tolerance threshold..

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Said stored value and/or tolerance threshold may be variable and/or programmable.

Said stored value and/or tolerance threshold may be variable and/or programmable and set according to operating conditions of the injector or type of fuel injector and/or fuel injector actuator.

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The stored frequency value may be the operational switching frequency measured at an earlier time-point..

- 5 The drive circuitry may be adapted to stop the high side drive switching if a fault condition is determined.

In a further aspect is provided a method of determining a short condition in drive circuitry for a fuel injector actuator, said drive circuitry including a High Side Drive portion and a Low Side Drive Portion, comprising performing a frequency analysis of a
10 voltage(s) or a voltage signal at, or from, one or more points in the High Side Drive; and, determining if a faulty short conditions exists based on said analysis.

Said voltage may be the voltage at the high side connection terminal for the fuel injector
15 actuator.

Said voltage may be the voltage of the High Side Drive Enable Signal.

The method may comprise a) comparing the frequency of the voltage with a stored
20 value, and determining a short condition dependent on said comparison.

Step a) may comprise determining if said frequency is higher than said stored value, or higher than the stored value plus a tolerance threshold..

25 said stored value and/or tolerance threshold may be variable and/or programmable.

Said stored value and/or tolerance threshold may be variable and/or programmable and set according to operating conditions of the injector or type of fuel injector and/or fuel injector actuator.

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The stored frequency value may be the operational switching frequency measured at an earlier time-point.

The method may include stopping the high side drive switching if a fault condition is
35 determined

BRIEF DESCRIPTION OF THE DRAWINGS

- 5 The present invention is now described by way of example with reference to the accompanying drawings in which:
- Figure 1 shows circuitry of a high side and low side drive circuitry use to operate a fuel injector solenoid or other actuator;
 - Figure 2 shows a schematic figure the high side circuitry of figure 1 with a
 - 10 protection/analytical circuit;
 - Figure 3 shows normal operation plots of the circuitry of figure 1;
 - Figure 4 shows a plot of various parameters in a shorted load conditions;
 - Figure 5 shows one example of the invention.

15 DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 shows circuitry of a high side and low side drive circuitry use to operate a fuel injector solenoid or other actuator. The circuitry generally consists of a high side drive circuitry 2 and low side drive circuitry 1. A connection (voltage O_PH_HC1) from the

20 high side circuitry is to one terminal of a load such as a fuel injector solenoid represented by coil and resistor 4 and the connection to the low side (voltage O_PL_HC1) is to the other terminal of the load.

The low side circuitry predominantly operates to select which fuel injector in a bank is

25 operational and the low side is predominantly controlled by the input voltage GD_PL_HC1 controlling FET 5. The low side includes means to detect and e.g. provide feedback of the current by measuring the voltages BANKA_CURR_HI and BANKA_CURR_LO across resistor R1.

30 The high side provides the voltage levels and waveform according to the requisite activation profile. The voltage to the high side terminal is predominantly controlled via MOSFET 6 connected to supply voltage V1. Power to the gate drive for MOSFET 6 is supplied via PROTECTED_T30 terminal. The gate of this MOSFET 6 is connected to a portion of circuitry and is controlled by the high side drive enable signal BNKA_HS_EN.

35 So in other words the high side circuitry includes a portion connected to the high side output Drive signal (BNK[x]_HS_EN).

On the right hand side of the figure is a portion of the High Side circuitry 7 connected to the high side terminal of the actuator (solenoid) 4. This include two transistors as shown and includes a connection which outputs an external signal (BNK[x]_HS_DS) from the circuitry external to ASIC, where [x] denotes the bank/injector A, so BNKA_HS_DS. So the High Side drive also includes circuitry portion 7 which is used e.g. for monitoring and which provides a voltage (signal) BNKA_HS_DS. There is also an output connection to the solenoid high side as shown which gives an output BNKA_INJ_HI.

Figure 2 shows block diagrams representing the high side circuitry of Figure 1. It shows a protection/analytical circuit C2MIO 10 (not shown in Figure 1). The circuit 10 has inputs representative of voltages BNKA_INJ_HI and BNKA_HS_DS, described above with reference to Figure 1, from appropriate points in the HS drive circuit of Figure 1 along lines 101 and 102 respectively. Each of this is connected to a comparators 103 and 104 respectively where the input voltage is compared with reference values V_{Fth} and V_{stg} respectively. The outputs are then fed into logic circuitry along with inputs from BNKA_HS_EN and BNK[x] RECIRC_EN) which include AND gates 105 and 106 for BNKA_INJ_HI and BNKA_HS_DS derived inputs respectively. The output of 105 and 106 indicate possible short conditions. These outputs are fed into fault timers and 107 and 108 respectively and the outputs 109 and 110 therefrom indicate positively shorting conditions.

Figure 1 also shows a shorted load fault condition represented by arrow A i.e. it shows a Shorted Load is a fault event where the terminal of HS output is shorted to the terminal of LS output e.g. O_PH_HC1 (High Side Drive output) is shorted to O_PL_HC1 (Low Side Drive output) as shown. In Figure 1 (the High Side Drive output and Low Side Drive output shorted), the output load is bypassed with e.g. a shorted wire harness (lower impedance) and the wire harness has now become the output load.

During a shorted load, current will flow from V1 voltage through MOSFET 6 and through shorted wire harness (between O_PH_HC1 and O_PL_HC1) and to MOSFET 5 and lastly to R1 current sense resistor that is connected to Ground and this current will rise very fast (as BNKA_HS_EN goes High) and surpasses the maximum current threshold (3.2A set in the circuitry) and then decays very fast (as BNKA_HS_EN goes Low) and surpasses the minimum current threshold (1.8A set in the circuitry).

The output current, (e.g. during normal operation) will flow from V1 voltage through MOSFET 6 and through output load (coil and resistance between O_PH_HC1 and O_PL_HC1) and to MOSFET 5 and lastly to R1 current sense resistor that is connected to Ground. *This* will be measured by the circuitry in C2MIO (through current feedback (BANKA_CURR_HI) in this case) i.e., Voltages measured at BANKA_CURR_HI will represent the output current magnitude.

During Shorted Load, O_PH_HC1 will repeatedly switch (on and off) by High Side Drive BNKA_HS_EN based on the output current feedback through voltage at BANKA_CURR_HI when BNKA_HS_DS could not detect this Shorted Load fault; when it could not detect this fault as it thinks that it is operating in normal condition (current chopping and the outputs 109 and 110 do not register faults. So the circuitry will not be able to guarantee 100% detection of Shorted Load fault as its shortest available overcurrent fault filter time is only 5.3µsec. If the High Side Drive On time is less than 5.3µsec during shorted load, this means the voltage above the fault threshold will also be shorter than 5.3µsec and causes the overcurrent mechanism in C2MIO (not being able to detect this fault and turn off the outputs.

The High Side Drive output FET 6 will eventually be damaged by the high frequency switching at very high shorted load current. An example of real application in a powertrain project is shown in Figure 2.

Output current (see 21 in figure 3) will flow from V1 voltage through MOSFET 6 and through output load (coil and resistance between O_PH_HC1 and O_PL_HC1) and to MOSFET 5 and lastly to R1 current sense resistor that is connected to Ground. Gate O_PH_HC1 = Gate of MOSFET 6. O_PH_HC1 = High Side Drive Output terminal. Figure 3 shows normal operation plot with switching frequency at about 500Hz with showing the plot of output (SV) current 21 Gate O_PH_HC1 voltage 22 (gate of MOSFET 6) and O_PH_HC1 voltage 23

Figure 4 shows a plot of various parameters in a shorted load conditions and shows plot 31 which is the shorted output (SV) current, plot 32 shows the BNKA HS EN voltage, plot 33 shows the short current and 34 shows the voltage at gate O_PL_HC1. Plot 31 is Shorted Output Voltage. Plot 33 is Shorted Output Current. During Shorted Load, electrical current will flow from V1 voltage through MOSFET 6 and through shorted wire

harness (between O_PH_HC1 and O_PL_HC1) and to MOSFET 5 and lastly to R1 current sense resistor that is connected to Ground.

- 5 BNKA_HS_EN “On time” is very short at 4usec (<5.3usec fault time) and very high frequency 143KHz. So the prior art system of figure 2 cannot detect this fault and will continue to switch.

Invention

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The problem of hardware damaged during Shorted Load conditions is solved by having a High Frequency Switching Detection Module 120 (e.g. in the ASIC) as shown in Figure 5. The module is able to monitor the High Side Drive voltages/signals e.g. internally in ASIC for example (BNK[x]_HS_EN) in this case (so for injector A, BNKA_HS_EN),
 15 also known as the high side drive enable signal). It can also monitor the external signal (BNK[x]_HS_DS) from the circuitry external to ASIC, so BNKA_HS_DS for injector A.

In the figure these two signals are ORed by OR gate 121 and the signal(s) fed into the High Frequency Switching Detection Module 120 (either one of the signals high
 20 frequency switching can be detected). In an alternative schematic, the system can be regarded as either BNK_HS_EN and /or the BNK[x]_HS_DS signals going into the module 120. Module 120 determines the frequency of the input signal (either BNK_HS_EN and /or the BNK[x]_HS_DS signals) and compares with pre-stored frequency threshold(s). If the frequency is higher than the threshold then a shorted load
 25 condition is flagged.

So e.g. when abnormal high frequency switching happens on High Side Drive signal BNK[x]_HS_EN or High Side Drive output Drain Feedback (BNK[x]_HS_DS), this module 120 will measure the switching frequency and shall compare it with the normal
 30 operation switching frequency measured earlier.

The frequency module essentially compare the frequency component of the BNK[x] HS_DB and/or INJ_HI signal and compares these with set or programmable threshold(s) of frequency; this gives flexibility to design engineer to select the frequency threshold to
 35 be set in the ASIC depending on the product application needs and requirements.

When the ASIC detected that the high side drive switching frequency higher than the frequency threshold set in ASIC, it shall stop the high side drive switching immediately and latch a high frequency switching fault until a command to clear this fault and re-enable the high side drive is received by the ASIC.

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This solution is robust as it can turn off the ASIC drive hardware almost immediately when Shorted Load/high frequency switching happened and latch the high frequency switching fault till the MicroP (software) started to retry (re-enable) the output.

- 10 The advantage of this solution is that the ASIC is able to turn off its own injector output based on internal switching signal or external output signal. This High Frequency Switching Detection Module shall be independent from other diagnostics module. Therefore, any output oscillation or Shorted Load fault event is 100% detectable and ensure 100% hardware protection as compared to existing Overcurrent mechanism in
- 15 C2MIO which does not guarantee 100% detectable fault and 100% hardware protection. The High Frequency Switching Detection module could be integrated in ASIC as shown below to detect and confirm the validity of the high frequency switching fault.

- The table below is an example of high frequency threshold setting choices that could be
- 20 made available for design/application engineers (ASIC users).

High Frequency fault register settings [1:0]	Frequency Threshold (KHz)	Comments
00	50	Note: output switching at frequency higher than this selected frequency threshold will result in a high frequency fault detected by ASIC.
01	75	
10	100	
11	150	

CLAIMS

1. Drive circuitry for a fuel injector actuator, said drive circuitry including a High Side Drive portion and a Low Side Drive portion, and including determination means to
5 determine a short condition, said determination means adapted to perform a frequency analysis of a voltage(s) or a voltage signal at, or from, one or more points in the High Side Drive, and to determine if a faulty short conditions exists based on said analysis.
2. Drive circuitry as claimed in claim 1 where said voltage is the voltage at the high
10 side connection terminal for the fuel injector actuator.
3. Drive circuitry as claimed in claim 1 or 2 where said voltage is the voltage of the High Side Drive Enable Signal.
- 15 4. Drive circuitry as claimed in claims 1 to 3 where said determination means is adapted to perform the frequency analysis of a voltage(s) by being adapted to compare the frequency of the voltage with a stored value, and output a signal indicative of a faulty short condition dependent on said comparison.
- 20 5. Drive circuitry as claimed in claim 4 said determination means is adapted to determine that a short condition exists if said voltage frequency is higher than said stored value, or higher than the stored value plus a tolerance threshold..
6. Drive circuitry as claimed in claim 5 wherein said stored value and/or tolerance
25 threshold is variable and/or programmable.
- 7 Drive circuitry as claimed in claim 6 wherein said stored value and/or tolerance threshold is variable and/or programmable and set according to operating conditions of the injector or type of fuel injector and/or fuel injector actuator.
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8. Drive circuitry as claimed in claims 5 to 7 where the stored frequency value is the operational switching frequency measured at an earlier time-point..
9. Drive circuitry as claimed adapted to stop the high side drive switching if a fault
35 condition is determined.

10 A method of determining a short condition in drive circuitry for a fuel injector
actuator, said drive circuitry including a High Side Drive portion and a Low Side Drive
Portion, comprising performing a frequency analysis of a voltage(s) or a voltage signal
at, or from, one or more points in the High Side Drive; and, determining if a faulty short
5 conditions exists based on said analysis.

11. A method as claimed in claim 10 where said voltage is the voltage at the high
side connection terminal for the fuel injector actuator.

10 12. A method as claimed in claims 10 or 11 where said voltage is the voltage of the
High Side Drive Enable Signal.

13. A method as claimed in claims 10 to 12 comprising;
a) comparing the frequency of the voltage with a stored value, and determining a short
15 condition dependent on said comparison.

14. A method as claimed in claim 13 where step a) comprises determining if said
frequency is higher than said stored value, or higher than the stored value plus a
tolerance threshold..

20 15. A method as claimed in claim 14 wherein said stored value and/or tolerance
threshold is variable and/or programmable.

16. A method as claimed in claim 15 wherein said stored value and/or tolerance
25 threshold is variable and/or programmable and set according to operating conditions of
the injector or type of fuel injector and/or fuel injector actuator.

17. A method as claimed in claim 14 to 16 where the stored frequency value is the
operational switching frequency measured at an earlier time-point.

30 18. A method as claimed in claim 17 including stopping the high side drive switching
if a fault condition is determined.