

(51) International Patent Classification:
F02D 41/20 (2006.01) *H01F 7/18* (2006.01)(21) International Application Number:
PCT/EP2010/001956(22) International Filing Date:
27 March 2010 (27.03.2010)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— of inventorship (Rule 4.17(iv))

Published:

— with international search report (Art. 21(3))

(54) Title: HYSTERESIS-TYPE ELECTRONIC CONTROLLING DEVICE FOR FUEL INJECTORS AND ASSOCIATED METHOD

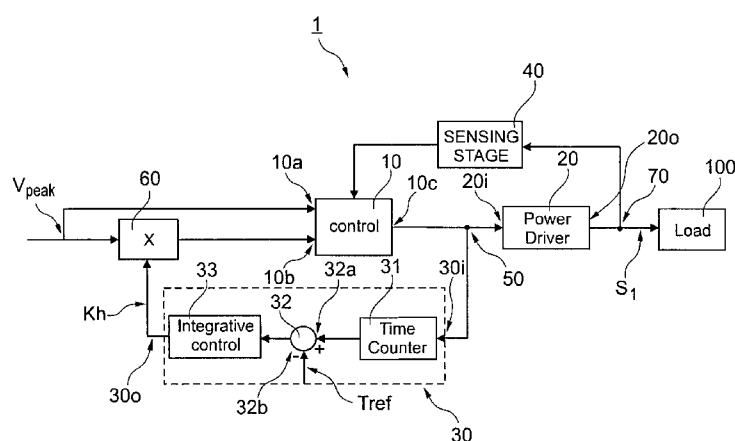


Fig. 1

(57) Abstract: Hysteresis-type electronic controlling device (1) for fuel injectors comprising a power driving unit (20) for driving the fuel injectors with an electric signal (Si), a control stage (10) connected to the power driving unit (20) and a sensing stage (40) fed by the power driving unit (20) and feeding the control stage (10); the device (1) has a feedback frequency control stage (30) for measuring a waveform period of the signal feeding the fuel injectors; the feedback frequency control stage (30) is fed by said control stage (10) with an electric signal (si). A fuel injector control method, comprising the steps of driving fuel injectors with an electric signal (si) coming from a power driving unit (20) fed by a control stage (10) and the step of sensing the signal (si) with a sensing stage (40); the method comprises a step of measuring a waveform period of the signal (si) through the feedback frequency control stage (30).

5 **Hysteresis-type electronic controlling device for fuel**
 injectors and associated method.

 The present invention relates to the field of the
controlling devices for fuel injectors and in
10 particular deals with a hysteresis-type electronic
controlling device for automotive injectors and
associated method.

 It is known that fuel injectors, used to inject a
fuel-air mixture in the combustion chamber of an engine
15 can be injectors, principally piezoelectric or
solenoidal.

 In particular, injectors are driven by electronic
controlling devices that comprise a power stage
designed to drive them with a proper current or voltage
20 signal.

 It is also known that the standard control
techniques for current generation in the power stage of
the aforementioned devices are principally PWM or
average current mode stages. Even if they do not
25 present sub-harmonic instability, they actually
introduce delays with respect to the switching
frequency; thus, those delays force the designers to
construct control loop stages operating with a
frequency that is at least three or four times lower

than the switching frequency of the power stage.

To solve this problem have been designed control loop stages with a reduced time delay; that type control loop stages operate typically with two
5 different circuit configurations, known in the art as a "peak current mode circuit" and "valley current mode circuit". Driving fuel injectors with "peak current mode circuits" or "valley current mode circuits", even if produces a reduced time delay, present instability.

10 In fact the power stage typically operates over MOS or FET transistors having a common switching node connected to the load (the injector) that presents a lot of ringing due to the reactive parasitic components. Since the control loop stages operate
15 sensing the current on that node, there is the need of a blanking time before the sensing (typically around 300 ns).

In particular when the load presents a very high duty cycle (bigger than 50%), subharmonic instability
20 occurs.

The peak or valley current mode circuits instability can be solved by using circuits with hysteretic current mode circuits, with a quasi-constant period that provide adequate stability of the current
25 control loop.

Nevertheless, the known circuits still present some disadvantages; on one hand they do need particularly complex circuits that make the measurement of the frequency (or the period) very convoluted. On

the other and, they do not give sufficient performances when used with injectors that operate with high frequencies. In particular, if the injector operates with frequencies higher than a hundredth of kilohertz, the switching frequency becomes too high for those circuits, thus making a stable and simple control loop stage technically not feasible.

A scope of the present invention is to provide a hysteresis-type electronic controlling device for fuel injectors that is free of the aforementioned disadvantages.

A further scope of the present invention is to provide a fuel injector control method.

According to the present invention a hysteresis-type electronic controlling device for fuel injectors is realized according to claim one.

According to the present invention, a method for controlling a fuel injector control method is provided as defined in claim ten.

For a better understanding of the invention, an embodiment thereof is now described, purely by way of non-limiting example and with reference to the attached drawings, wherein:

- figure 1 shows a block scheme for a first preferred embodiment of an hysteresis-type electronic controlling device for fuel injectors;
- figure 2 shows a timing diagram of signals present in the device of figure 1; and

- figure 3 shows a block scheme for a second preferred embodiment of an hysteresis-type electronic controlling device for fuel injectors.

5 With reference to figure 1, with the reference number 1 is indicated, in its integrity, a hysteresis-type electronic controlling device for fuel injectors.

The device 1 comprises:

- a driving unit control stage 10, having a first, 10 a second and a third input port 10a, 10b, 10d and one output port 10c;
- a power driving unit 20, having a respective input port 20i and an output port 20o for feeding with an electric power signal s_1 at least one fuel injector 15 electrically represented by the load 100;
- a feedback frequency control stage 30, having an input 30i and an output 30o; and
- a signal sensing stage 40, for detecting the magnitude of the electric signal s_1 fed to the load 20 100.

In detail, the control stage 10, has the first output port 10c connected through a wire line to a node 50 from which depart a first line directed to the input 20i of the power driving unit 20 and a second line 25 feeding the input 30i of the frequency feedback control stage 30.

The output 30i of the frequency feedback control stage 30 feeds a multiplier 60 on a first input, while its second input is fed with a reference signal V_{peak}

that defines the maximum magnitude of the electric signal fed to the load 100. The reference signal is also fed to the first input port 10a of the control stage 10.

5 In detail, as shown in figure 2, the electric signal s_1 fed to the load 100 assumes a triangular waveform having a proper ripple defined by the peak value, that is equal to the reference signal V_{peak} , and a valley value that defines the minimum magnitude of
10 the signal.

 The change of slope sign of the signal s_1 depends on the signal s_2 that control stage 10 feeds to the node 50 - and thus to the input 20i of the power driving unit 20 - from its output port 10c. In detail
15 s_2 assumes a squared waveform in which every period is defined by a first time T_{off} in which it assumes a first lower value and a second time T_{on} in which it assumes a second value higher than the first.

 The power driving unit 20, a D class type
20 amplifier, must be able to drive the load 100, thus producing on its output 20o the electric signal S_1 , to drive the load 100 in current or equivalently in voltage. Clearly, on the basis of the type of driving, the sensing stage 40 can be respectively a current
25 sensing stage or a voltage sensing stage of known type.

 The power driving unit 20, in particular, can be a buck converter, a boost converter or a buck-boost converter

 In detail, the fuel injector represented by the

load 100 varies the way it opens on the basis of the magnitude of the electric signal S_1 ; in detail, the higher it is, the faster the injector opens.

The present-day fuel injectors operate very fast,
5 with multiple fuel shots for each cycle of the engine on which they operate; in particular applications they can produce fuel shots requesting electric signals S_{pzt} that can reach frequencies 1MHz. For this reason also the power driving unit 20 shall be designed in order to
10 be able to produce this type of current or voltage signal.

The output 20o of the power driving unit 20 is connected to a respective node 70 from which two different lines depart. A first line reaches the input
15 of the load 100, while the second line reaches the input of the sensing stage 40, whose output is connected to and feeds through a line 41 the third input port 10d of the current control stage 10.

The control stage 10 operates with an hysteretic
20 electric signal variation. In detail, it receives the on the first and second input ports 10a, 10b respectively the peak value V_{peak} and the valley value that is produced by the multiplication of the peak value V_{peak} with the electric signal fed to the
25 multiplier 60 by a corrective signal coming of the feedback frequency control stage 30, whose details will be described in detail in the following part of the description; with a known circuit configuration, the control stage 10 generates on its output 10c the

reference signal s_2 , that assumes the first lower value during the period of time in which the electric signal s_1 , sensed by the sensing stage 40, is higher than the reference signal V_{peak} and that assumes the second
5 higher value during the period of time in which the electric signal s_1 is lower than the reference signal V_{peak} .

The control stage 10 is designed in order to keep the valley value of the signal s_1 as a gain (always
10 below the 100%) of the reference signal V_{ref} .

Finally, frequency feedback control stage 30 comprises a time counter 31, having the input directly connected to the input 30i of the frequency feedback control stage 30 and an output connected to a first
15 input 32a of an adder 32, in turn having a second input 32b that receives a reference timing signal T_{ref} , whose magnitude is decided a-priori by a value that can be constant in time or modulated with a very low frequency (typically up to 10Hz but, anyway, several magnitude
20 orders lower than the switching frequency of the driving stage 20).

The adder 32 has an own output 32c that is directly connected to the input of an integration stage 32.

25 The time counter 31, measures the period between two positive edges of the signal s_2 and produces on its output a respective signal T_{mis} that is the result of the aforementioned measure. The signal T_{mis} assumes a waveform whose magnitude directly depends on the

measured value itself. Thus, through the time counter 31 is measured also the period of the signal s_1 even if in

Then the adder 32 executes the difference of the
5 reference timing signal T_{ref} present on its second input 32b with respect to the signal T_{mis} present on its first input 30a and coming from the output of the time counter 30, producing on its output 30c a difference signal $e_T(t)$ that reaches the input of the integrator
10 33.

The integrator 33 generates a hysteretic corrective signal k_h that feeds one of the inputs of the multiplier 60. In detail, the integrator 33 is included in order to achieve a smoothed response of the
15 variation of the corrective signal k_h to the variation of the difference signal $e_T(t)$. In fact, if the device 1 as disclosed would be deprived of the integrator 33, at a step change of the difference signal $e_T(t)$, would result a variation of the corrective signal k_h having a
20 step waveform too. In contrast, due to the presence of the integrator 33, there is a smoothed response in the variation of the corrective signal k_h , even in case of abrupt changes of the difference signal $e_T(t)$.

In detail, the feedback frequency control stage 30
25 can be designed so as to work in discrete or continuous time domain. In the first case, that is the one presented in the following part of the description, the sampling frequency shall be kept sufficiently high so as to avoid aliasing problems and so as to provide

sufficient oversampling. Since the feedback frequency control stage 30 operates in the discrete time domain, thus sampling the difference signal $e_T(t)$ at constant intervals.

5 Clearly, the difference signal $e_T(t)$ cannot be maintained completely constant at each sampling instant, since the control operates with an error correction on the basis of the previous values. For this reason, even after a proper settling time, the
10 device 1 will present, at an idle operating condition, the difference signal $e_T(t)$ affected by a small amplitude ripple.

Due to the discrete time domain operation of the integrator 33, and given an instant of sampling time
15 (i) and a previous instant of sampling time $(i-1)$, then the corrective signal k_h at the instant (i) , is given by:

$$k_h(i) = k_h(i-1) + K_i \cdot (e_T(i))$$

wherein $e_T(i)$ represents the difference signal
20 $e_T(t)$ sampled at the time instant (i) , and k_i is a tuning parameter (integration gain) of the integrator. As it is known, increasing the *integration gain* of the integrator 33 results in a reduced rise time of its response, as well as an increase of the overshoot time
25 and the settling time. Thus the correct level of integration gain should be chosen considering the response of the rest of the components of the device 1, and also keeping into account the fuel injector operative frequency. The corrective signal $k_h(i)$ is

always saturated to a magnitude comprised within the range $(0 \div 1)$.

Multiplying the corrective signal $k_h(i)$ with the reference signal V_{peak} results in obtaining the valley value of the signal s_2 . Due to the fact that the corrective signal cannot exceed the unity, the valley value is forcedly kept lower than the reference signal's magnitude. Thus, the reference signal V_{ref} is kept constant, that means that the maximum magnitude of the signal s_1 fed to the load 100 is fixed too, while the valley value of the signal s_1 changes according to the variation of k_h .

A second preferred embodiment of the device 1 is shown in figure 3.

In said second embodiment, the reference values that are set by the designer are, as in the previous embodiment, the reference signal V_{ref} and the reference timing signal T_{ref} . The frequency feedback control 30 keeps the same structure and the same inputs if compared to the one disclosed for the previous embodiment. This applies also to the configuration and functioning of the power driving stage 20, of the sensing stage 40 and the load 100.

In the second embodiment, the control stage 10 receives on the first and the second input port 10a, 10b respectively the reference signal V_{ref} and the first time T_{off} in which the signal s_2 assumes the first lower value. The first time T_{off} is obtained from the output of the multiplier 60, that numerically multiplies the

corrective signal k_h and the reference timing signal T_{ref} , both fed to its inputs. In this second embodiment, the reference timing signal T_{ref} is thus fed to the input of the multiplier 60 and, as happens in the first
5 embodiment of the invention, to the adder's 32 input.

Thus the first and second embodiments still permit to obtain the same result with the same user defined inputs (the reference signal V_{ref} and reference timing signal T_{ref}) and with the same circuit configuration.
10 The internal operation of the control stage 10 and one of its inputs (the one that do not receive the reference signal V_{ref}) change from the first to the second embodiment.

Also in the second embodiment the reference signal
15 V_{ref} is kept constant, that means that the maximum magnitude of the signal s_1 fed to the load 100 is fixed too, while the valley value of the signal s_1 changes according to the variation of k_h ; in this case, in contrast, the variation of the valley value is
20 indirect, and is produced to a direct variation of the first time T_{off} through the action of the variation of k_h .

Of course, the two circuits whose block schemes are represented in figures 1 and 3 can be designed on a
25 hardware (for example an ASIC) or implemented via software with one or more procedures run on a computer, leaving only the amplifier as an hardware block.

The advantages and benefits of the device previously disclosed are clear: it allows the avoidance

of sub-harmonic instability that are present in classic peak current mode circuits and allows a simpler design and tuning with respect to frequency feedback circuits. In fact, the period measurement is executed using a
5 simple counter, while a frequency measurement necessitates complex division stages in order to be effectively implemented.

In addition, the presence of a integral control guarantees a smoothed variation of the hysteresis and
10 the a smoothed variation of the power driving stage 20. This produce a better functioning of the fuel injectors 100 and, consecutively, a enhanced performance of the engine on which they are mounted on.

Moreover, with the device herein disclosed it is
15 possible to achieve a better frequency tuning of all the components of the circuit; the maintenance of a quasi constant frequency, allows for a better filtering of the RF noise that is induced on the injectors.

In both the embodiments previously described, the
20 reference timing signal T_{ref} can be changed so as to adapt the device 1 functioning to a wide range of loads and system configurations without involving any modification in the interconnections of the circuit.

Finally it is evident that modification and
25 variations may be made to the device herein described, without departing from the scope of the present invention, as defined in the annexed claims.

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CLAIMS

1) Hysteresis-type electronic controlling device
(1) for fuel injectors, the device (1) comprising a
5 power driving unit (20) for driving said fuel injectors
with an electric signal (s_1) and a control stage (10)
connected to said power driving unit (20); the device
(1) further comprising a sensing stage (40) fed by said
power driving unit (20) and feeding said control stage
10 (10); the device (1) is characterized in that it
comprises a feedback frequency control stage (30) for
measuring a waveform period of said signal feeding the
fuel injectors; said feedback frequency control stage
(30) being fed by said control stage (10) with an
15 electric signal (s_1).

2) Hysteresis-type electronic controlling device
according to claim 1, wherein said feedback frequency
control stage (30) comprises a time counter (31), and
an integrator (33) electrically connected to said time
20 counter (31).

3) Hysteresis-type electronic controlling device
according to claim 2, wherein said feedback frequency
control stage (30) further comprises adding means (32)
interposed between said time counter (31) and said
25 integrator (33).

4) Hysteresis-type electronic controlling device
according to claims 1 and 3, characterized in that a
reference signal (V_{peak}) and a reference timing signal
(T_{ref}) are respectively applied to a first input of the

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control stage (10) and to said adding means (32).

5 5) Hysteresis-type electronic controlling device according to claim 2, wherein said integrator (33) generates a corrective signal (k_h), said signal depending on an error signal produced by said adding means (32).

10 6) Hysteresis-type electronic controlling device according to claim 4, further comprising multiplying means (60) for feeding a second input of said control stage (10).

15 7) Hysteresis-type electronic controlling device according to claims 5 and 6, wherein said multiplying means (60) have two inputs fed by said corrective signal (k_h) and said reference timing signal (T_{ref}).

8) Hysteresis-type electronic controlling device according to claims 5 and 6, wherein said multiplying means (60) have two inputs fed by said corrective signal (k_h) and said reference signal (V_{peak}).

20 9) A fuel injector control method, said method comprising the steps of driving said fuel injectors with an electric signal (s_1) coming from a power driving unit (20) fed by a control stage (10) and the step of sensing said signal (s_1) with a sensing stage
25 (40) for feeding said control stage (10); the method (1) being characterized by a step of measuring a waveform period of said signal (s_1) feeding the fuel injectors through a feedback frequency control stage (30) being fed by said control stage (10).

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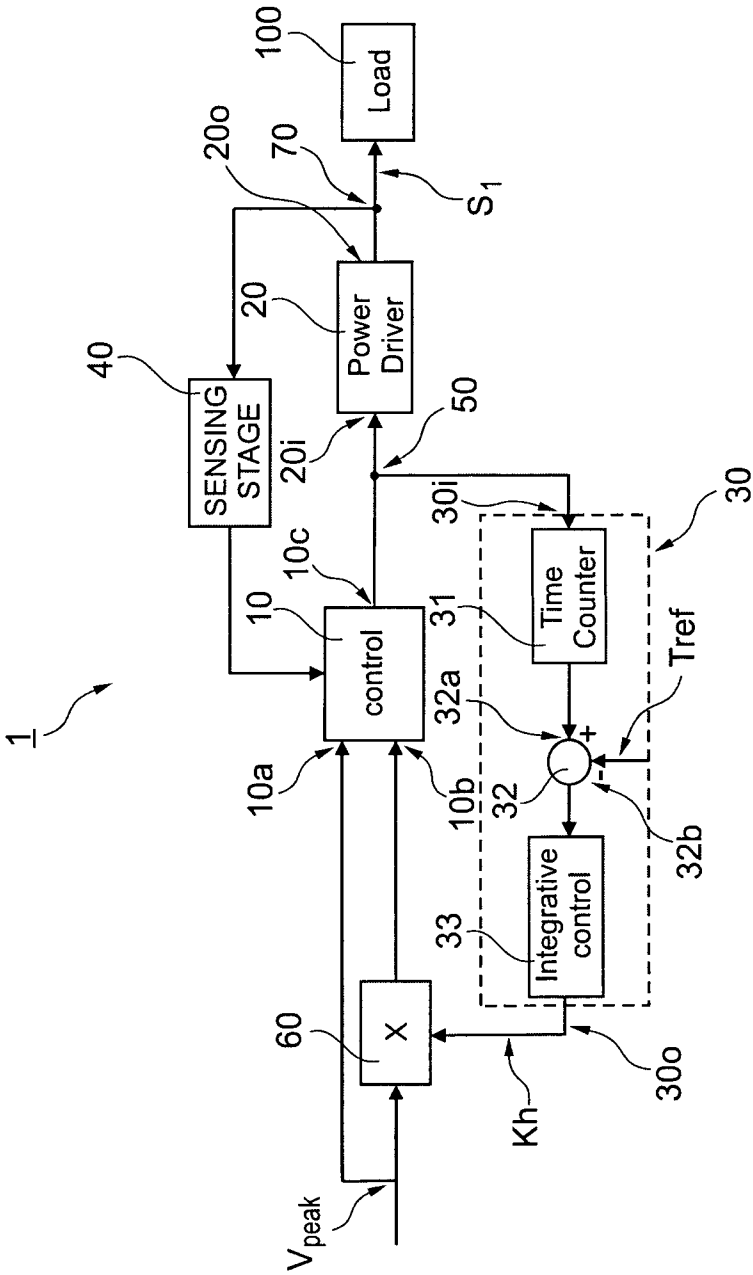
- 15 -

10) A fuel injector control method according to claim 9, further comprising a step of integration of an error signal ($e_T(t)$) produced from the difference between the measurement of the period of a driving
5 signal (s_2) produced by said control stage (10) and a reference timing signal (T_{ref}).

11) A fuel injector control method according to claim 10, wherein said step of integration results in a generation of a correcting signal (k_h), that is
10 multiplied with a reference signal (V_{peak}); the method further comprising the feeding:

- a first input port (10a) of said control stage (10) with a first electric signal result of said multiplication and
- 15 - a second input port (10b) of said control stage (10) with said reference signal (V_{peak}).

12) A fuel injector control method according to claim 11, wherein said driving signal (s_2) at the output of said control stage (10) assumes a first and a
20 second value; said first value being assumed when the electric signal (s_1) is higher than the reference signal (V_{peak}); said second value being assumed wherein the electric signal (s_1) is lower than the reference signal (V_{peak}).



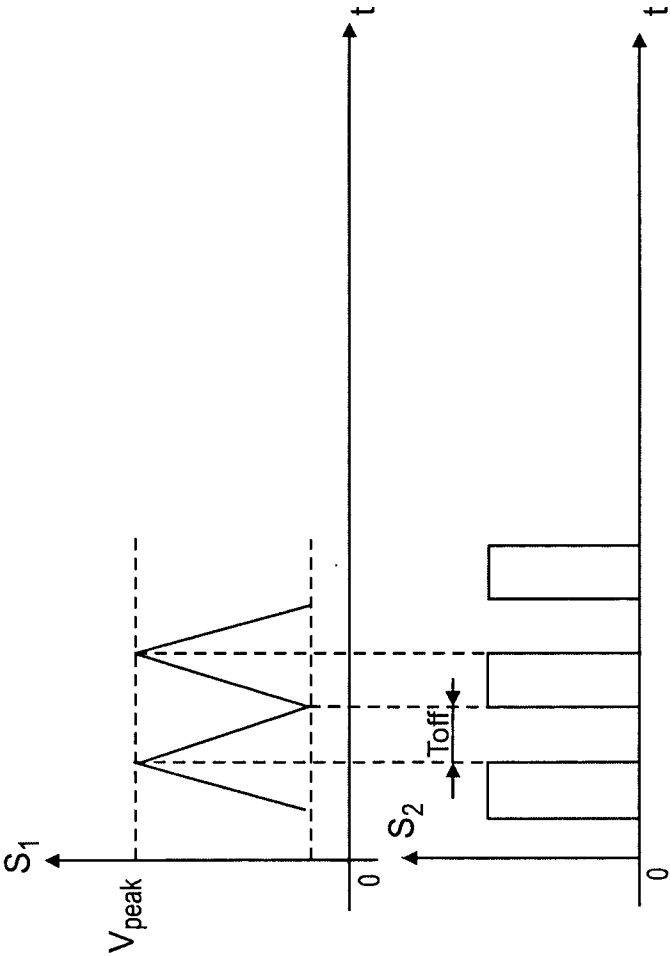


Fig. 2

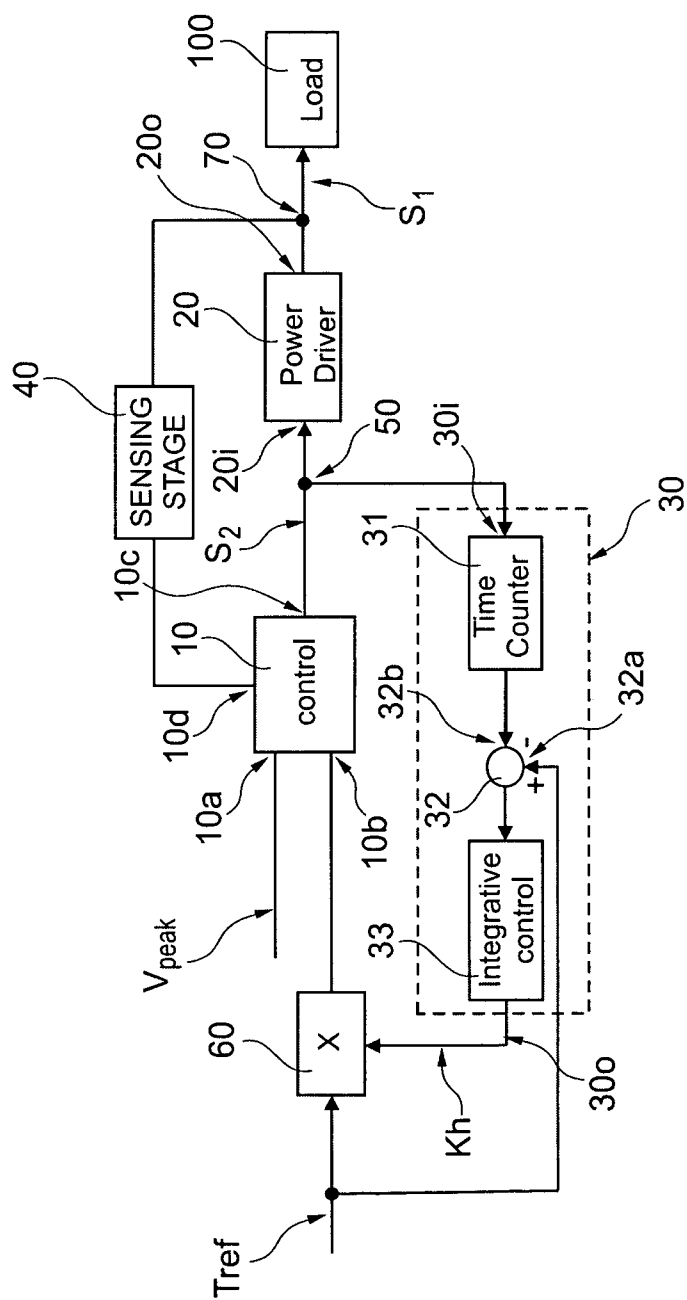


Fig. 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2010/001956

A. CLASSIFICATION OF SUBJECT MATTER
INV. F02D41/20 H01F7/18
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F02D H01F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 43 41 797 A1 (BOSCH GMBH ROBERT [DE]) 14 June 1995 (1995-06-14)	1, 10
Y	column 4, lines 27-66 column 5, lines 26-35 claims 1, 2	2-4, 6, 7, 11-13
X	EP 0 400 389 A2 (MOTOROLA INC [US]) 5 December 1990 (1990-12-05) column 9, line 35 - column 11, line 11	1, 10
Y	WO 99/19615 A1 (SIEMENS AG [DE]; KOCH ACHIM [DE]; ZINK HANSPETER [DE]) 22 April 1999 (1999-04-22) column 6, line 34 - column 7, line 8 figure 3	2-4, 6, 7, 11-13

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search

22 June 2010

Date of mailing of the international search report

02/07/2010

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2010/001956

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