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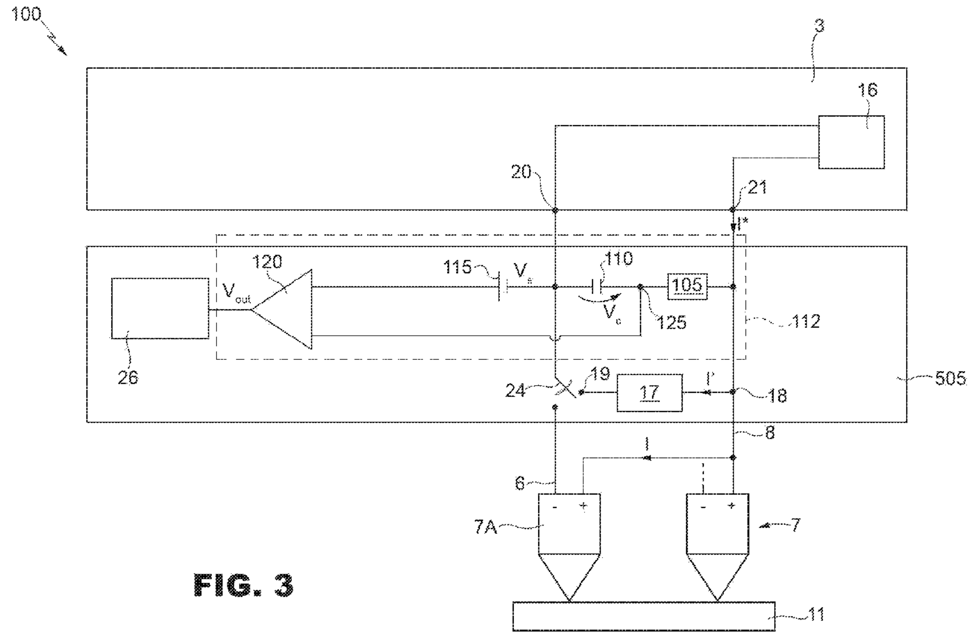

FIG. 3

(57) **Abstract:** Estimation circuit (112) couplable to an injection system (3, 6, 7, 8, 9, 12, 14) including: a control unit (3), which generates a driving signal (V_+, V_-); and a first injector (7; 7A) couplable to the control unit so as to receive the driving signal and inject, in response, a first fuel into a combustion chamber (11) during a time interval having a duration equal to an injection time (t_1). The estimation circuit (112) includes: a capacitor (110), which, when the estimation circuit is coupled to the injection system, is subjected to a voltage (VC) that depends on the driving signal; and a comparator circuit (120), which generates an output signal (V_{out}) based on the comparison between the voltage (V_c) and at least one threshold (Vs), the output signal being indicative of the injection time.

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"ESTIMATION CIRCUIT OF THE INJECTION TIME IN A COMBUSTION CHAMBER OF A DIRECT INJECTION ENGINE AND CONTROL DEVICE INCLUDING THE SAME"

CROSS REFERENCE TO RELATED PATENT APPLICATIONS

This application claims priority from Italian Patent Application No. 102018000008651 filed on 17/09/2018, the entire disclosure of which is incorporated herein by reference.

TECHNICAL FIELD

The present invention relates to an estimation circuit of the injection time in a combustion chamber of a direct injection engine and to a control device including the same.

PRIOR ART

As already known, direct injection engines include electromechanical systems that allow fuel to be injected into one or more combustion chambers of a car. In particular, the fuel injected into these engines is, for example, petrol (primary fuel) or a mixture of petrol and an additional fuel (alternative fuel), such as, for example, methane or LPG (in liquid or gaseous form). In the following, reference is made to an alternative fuel in gaseous form (defined hereinafter as gas) without losing its general character.

Figure 1 schematically shows a direct injection system (hereinafter defined briefly as system) 1 of known type, which uses a mixture of petrol and gas as fuel to be injected into a combustion chamber 11.

In detail, the system 1 comprises: a first and a second engine control unit (ECU) 3, 5; and a first and a second plurality of injectors (in particular, electro-injectors) 7, 9, electrically coupled, respectively, to the first and to the second ECUs 3, 5. Moreover, the first and the second plurality of injectors 7, 9 are designed to inject petrol and gas respectively into the combustion chamber 11 and into an intake manifold 13, which in turn is connected to the combustion chamber 11 by means of one or more intake valves (not shown).

Each injector of the first and of the second plurality of injectors 7, 9 has a positive terminal and a negative terminal.

In particular, each injector of the first plurality of injectors 7 is electrically coupled to the first ECU 3 by means of a first and of a second driving line 6, 8, respectively connected to the negative terminal and to the positive terminal of said injector of the first plurality of injectors 7.

Analogously, each injector of the second plurality of injectors 9 is electrically coupled to the second ECU 5 by means of a third and of a fourth driving line 12, 14, respectively connected to the negative terminal and to the positive terminal of said injector of the second plurality of injectors 9.

In the system 1, the positive terminals of sub-assemblies (for example, pairs) of injectors of the first plurality of injectors 7 may share the same second driving line 8. In this way, the positive terminals of sub-assemblies of injectors of the first plurality of injectors 7 are simultaneously driven by the corresponding first ECU 3. On the other hand, by way of example, the positive terminals of the injectors of the second plurality of injectors 9 are respectively connected to a corresponding fourth driving line 14.

The first ECU 3 regulates, in use, the petrol injection into the combustion chamber 11 by controlling the first plurality of injectors 7 by means of the first and of the second driving lines 6, 8. Analogously, the second ECU 5 regulates the gas injection into the intake manifold 13 by controlling the second plurality of injectors 9 by means of the third and of the fourth driving lines 12, 14.

In detail, each injector of the first plurality of injectors 7 is controlled by a first integrated logic 16, incorporated in the first ECU 3. Analogously, each injector of the second plurality of injectors 9 is controlled by a second integrated logic 26 incorporated in the second ECU 5. Moreover, the injectors of the first plurality of injectors 7 operate independently of each other. Analogously, the injectors of the second plurality of injectors 9 operate independently of each other.

The second ECU 5 further comprises, for each injector of the first plurality of injectors 7: a corresponding emulation load 17 (for example, a coil) having a first and a second terminal 18, 19; and a corresponding switch 24, arranged between a corresponding first central unit output terminal 20 of the first integrated logic 16 and the first driving line 6 of the corresponding injector of the first plurality of injectors 7.

In particular, the switch 24 is able to electrically connect the corresponding first central unit output terminal 20 with the negative terminal of the corresponding injector of the first plurality of injectors 7 (closing step) or with the second terminal 19 of the emulation load 17 (opening step). In detail, the closing and opening steps of the switch 24 are controlled by the second integrated logic 26 (the connection between the switch 24 and the second integrated logic 26 is not shown). The first terminal 18 of the emulation load 17 is connected to a corresponding second central unit output terminal 21 of the first integrated logic 16 and to the second driving line 8 connected to the corresponding injector 7.

The switch 24 is a solid-state device, for example a pair of MOSFET transistors with attached driving circuitry.

Each injector of the first and of the second plurality of injectors 7, 9 is electrically equivalent to a series of an inductor with inductance $L_{i,1}$ and, respectively, $L_{i,2}$ and a resistor with resistance $R_{i,1}$ and, respectively, $R_{i,2}$ (not shown). For example, the inductance $L_{i,1}$, $L_{i,2}$ is between 1 mH and 2 mH and the resistance $R_{i,1}$, $R_{i,2}$ is between 1Ω and 2Ω. Moreover, each injector of the first or of the second plurality of injectors 7, 9 has a respective time constant $\tau_{i,1}$ and $\tau_{i,2}$, defined, in a known way, as the ratio between the inductance $L_{i,1}$, $L_{i,2}$ and the resistance $R_{i,1}$, $R_{i,2}$ of said injectors; for example, the time constants $\tau_{i,1}$, $\tau_{i,2}$ have values between 0.3 ms and 2 ms, for example 1 ms.

Furthermore, the emulation load 17 is modelled at the circuit level as a series of an inductor and a resistor (not shown), having respectively the inductance L_{em} and the resistance R_{em}. In particular, the inductance L_{em} is of the same order of magnitude as the inductance $L_{i,1}$ of the first plurality of injectors 7. Moreover, the inductance L_{em} is characterized by a time constant τ_{em}, defined as the ratio between the inductance L_{em} and the resistance R_{em}. In some cases, the inductance L_{em} can vary, for example, up to -50% or + 100% with respect to the inductance $L_{i,1}$, such variations not significantly modifying the operation and/or performance of the system 1. In practice, the time constant τ_{em} of the emulation load 17 is typically comprised in an interval $\tau_{i,1}$ + ΔT, with ΔT comprised between $-0.5*\tau_{i,1}$ and $\tau_{i,1}$.

In use, the system 1 can operate according to different operating steps, as described below. In particular, for reasons of clarity and ease of understanding, reference will be made to the operation of a single injector, indicated in Figure 1 with the reference number 7A, belonging to the first plurality of injectors 7, without however losing general character. In fact, the same considerations apply to the other injectors of the same first plurality of injectors 7, which can operate simultaneously or sequentially with respect to the injector 7A. Hereinafter it is further assumed that the gas injection follows the petrol injection (namely that there is no overlap between the command of the petrol injection and the gas injection). However, in some cases, the gas injection can be carried out during the petrol injection command, namely the second ECU 5 can control the second plurality of injectors 9 so that the gas injection is at least partly temporally superimposed to the petrol injection command by the first plurality of injectors 7.

In a first step, the second integrated logic 26 controls the switch 24 so as to close it and make the second terminal 19 of the emulation load 17 floating. In this way, from an operational point of view, the emulation load 17 is disconnected from the first ECU 3, while the negative terminal of the injector 7A is connected to the first central unit output terminal 20 of the first ECU 3 by means of the first driving line 6.

In this first step, the injector 7A receives a voltage driving signal, for example a pulsed signal (e.g., to a first approximation, a square wave). The driving signal generates, in turn, a current I, which flows into the injector 7A. By means of this driving signal, the injector 7A is controlled so as to inject petrol into the combustion chamber 11 during a time interval having a duration equal to a first injection time t_1, set by the first ECU 3.

Operationally, a precise estimation of the first injection time t_1 is given by the time elapsing between the instant (indicated as the first threshold instant t_{S1}) in which the current I in the injector 7A exceeds a first threshold current I_{S1} (equal, for example, to the minimum value of the current I sufficient to open the injector 7A) and the time instant (indicated as the second threshold instant t_{S2}) in which the current I falls below a second threshold current I_{S2} (namely, when the current I is no longer able to keep the injector 7A open). The second threshold current

I_{S2} is, for example, equal to or lower than the first threshold current I_{S1}.

Moreover, when the injector 7A is controlled to introduce the petrol into the combustion chamber 11, the remaining injectors 7 of the first plurality can be inactive, i.e. the first ECU 3 does not supply the driving signal to said injectors. Therefore, the remaining injectors 7 of the first plurality are subjected to zero voltage. For this purpose, the corresponding first and second central unit output terminals 20, 21 have the same voltage. Alternatively, the remaining injectors of the first plurality of injectors 7 can be activated simultaneously with the injector 7A so as to inject petrol into the combustion chamber 11 for the same first injection time t_1. To a first approximation, and in particular in stationary conditions, the first injection time t_1 is the same for any injector of the first plurality of injectors 7.

Moreover, in this first step, the second ECU 5 controls the second plurality of injectors 9 so that they are inactive during the petrol injection.

In a second step, the second integrated logic 26 controls the switch 24 of the injector 7A to open it. In this way, the second terminal 19 of the emulation load 17 is connected to the first central unit output terminal 20, while the negative terminal of the injector 7A keeps floating. In this second step, the driving signal of the first ECU 3 generates, to a first approximation, the same driving signal used in the first step. However, the driving signal does not reach the injector 7A, which, therefore, is not ordered to inject further petrol into the combustion chamber 11. Furthermore, to a first approximation, the emulation load 17 is crossed by a current (indicated in Figure 1 with I') approximately equal to the current I.

The aforementioned switching of the switch 24 of the injector 7A takes place when the second ECU 5 detects the presence of conditions (for example, temperature and pressure) required by the system 1 for the gas injection; these conditions are detected by an integrated sensor system (not shown) in the system 1, in a per se known manner.

During the second step, each injector of the second plurality of injectors 9 is controlled by a corresponding driving signal, for example a voltage driving signal, by the second integrated logic 26, so as to inject gas into the intake manifold 13. In this regard, the negative terminal of each injector of the second plurality of injectors 9 is connected to a corresponding first central unit output terminal 27 of the second integrated logic 26 through the corresponding third driving line 12. Furthermore, the positive terminal of each injector of the second plurality of injectors 9 is connected to a corresponding second central unit output terminal 28 of the second integrated logic 26, through the respective fourth driving line 14. In this way, the second integrated logic 26 is able to send to each injector of the second plurality of injectors 9 the corresponding driving signal, so that it injects gas into the intake manifold 13 and therefore into the combustion chamber 11, during a time interval having a duration equal to a second injection time t_2, which is calculated in a per se known manner based on parameters such as for example, in addition to the first injection time t_1, the type of gas, the temperature and the pressure of the gas in the injectors of the second plurality of injectors 9, as well as based on engine parameters, such as, for example, engine revolutions and load. Therefore, the second injection time t_2 is the time in which the second ECU 5 controls each injector of the second plurality of injectors 9 so as to inject an amount of gas which depends, in a per se known manner, on the amount of petrol injected by each injector of the first plurality of injectors 7. In particular, by changing the type of fuel, the engine parameters of the engine remain unchanged, so that the engine maintains a regular operation even during the transition from petrol to gas supply.

Operationally, the second ECU 5 estimates the first injection time t_1; subsequently, the second ECU 5 calculates the second injection time t_2.

Figure 2 shows time trends of electrical quantities characteristic of the system 1. In particular, reference will be made to a system operating solely on petrol, as previously described with reference to the first step.

In particular, Figure 2 shows the following electrical quantities: the voltages on the positive and negative terminal of the injector 7A, indicated respectively with V_+ (graph 30) and V_- (graph 38), and whose difference defines the driving signal of the injector 7A; and the current I in the injector 7A (graph 42). In particular, the voltages V_- and V_+ are generated by the first integrated logic 16, respectively on their first and second central unit output terminals 20, 21; moreover, the first integrated logic 16 implements a voltage driving.

In greater detail, depending on the voltages V_- and V_+, and therefore on the driving signal imposed by the first integrated logic 16, it is possible to generally identify four steps: a peak step, a hold step, a demagnetization step and an off step.

In detail, the system 1 is initially in the off step (namely when the first ECU 3 does not supply the driving signal to the injector 7A), in which the voltages V_+, V_- are both equal, for example 7.5 V, so that the potential difference (indicated hereinafter with ΔV) between the positive terminal and the negative terminal of the injector 7A is zero. Therefore, the corresponding current I is zero. A subsequent time instant t_3 corresponds to the beginning of the peak step, in which the positive terminal of the injector 7A is brought, e.g. to about 67 V; on the other hand, the negative terminal of the 7A injector is grounded (i.e. zero voltage). In this way, the 7A injector is opened. In the peak step, the current I in the injector 7A rises quickly (portion 44 of the third graph 42) until reaching, for example, 10A at a time instant t_4. In this case, the injector 7A, having an electrical behaviour equivalent to that of an inductor, is gradually charged by the current I.

After the time instant t_4 there is the hold step, in which the voltage V_+ of the injector 7A is first zero, so as to partially discharge the injector 7A, and then varies according to a pulsed waveform, not necessarily periodic, such as e.g. a square wave form, with values ranging between 0 V and 13 V (the latter value being provided for example by a battery not shown). In this way, the current I varies according to a saw-tooth pattern with values comprised between, for example, 3A and 4A. In the hold step, the voltage V_- is still zero.

With regard to the off step, it involves that the voltage drop ΔV is about zero, so that the solenoid valve corresponding to the injector 7A remains closed. Moreover, before the beginning of the off step, the inductor representing the injector 7A is discharged thanks to the use of demagnetization pulses (described below). In Figure 2, the current I is zeroed in a time instant t_5.

With regard to the demagnetization step, it consists in the inversion of the sign of the driving signal of the injector 7A. In particular, one or more demagnetization pulses are applied to the negative terminal of the injector 7A, thus keeping the positive terminal grounded, so that the injector 7A tends to close and, therefore, the current I quickly drops to reach a desired value, not necessarily zero. For example, these demagnetization pulses have maximum values of about 70 V and durations equal to or less than 100 µs. In this way, the inductor representing the injector 7A is temporarily forced to discharge, causing a sharp decrease in the current I.

Given the above, Figure 2 shows a first demagnetization pulse 40A, which is generated during the hold step, starting from a time instant t_6 (portion 46 of graph 42). A second demagnetization pulse 40B is generated just before the start of the off step, starting from a time point t_7, so as to cause a sharp decrease in the current I, which, as mentioned above, is extinguished at the time instant t_5. In general, the following refers to an injection cycle to indicate the operations carried out in the time interval between the time instants t_3 and t_5.

Again with reference to Figures 1 and 2, referring, as previously mentioned, to the current I' to indicate the current flowing in the emulation load 17 (for example, with a positive direction towards the switch 24), to a first approximation it would have the same trend described with reference to the current I, if the switch 24 were open during the injection cycle. In this case, the petrol injection would not actually take place, but the current I' could still be used to determine an estimation of an injection emulation time t_{em}, equal to the first injection time t_1.

As anticipated above, the second ECU 5 estimates the first injection time t_1 (or the injection emulation time t_{em}), i.e. the duration of the time interval in which the injector 7A is open and injects (would inject) petrol into the combustion chamber 11. The electric quantity indicative of the state of closure/opening of the injector 7A, and therefore more significant for determining the first injection time t_1, is the current I. Different solutions are available to measure the current I and then estimate the first injection time t_1.

According to a first known solution, a shunt element (not shown) is arranged along the first driving line 6, between the first central unit output terminal 20 and the switch 24. In particular, the shunt element is a resistor with resistance R_{sh}, for example, between 20mΩ and 200mΩ.

In use, when the first ECU 3 drives the injector 7A (or the emulation load 17, in the case of gas injection), the shunt element is crossed by a current that generates a voltage drop ΔV_{sh} proportional to the current I (or current I'). This voltage drop ΔV_{sh} is typically amplified by a differential amplifier or by instrumentation and then compared with one or more threshold voltages by a threshold comparator. At the end of the comparison, the comparator supplies an output voltage to the second ECU 5, which estimates the first injection time t_1.

Unfortunately, this solution has some disadvantages. In fact, the shunt element is designed to have a low resistance value R_{sh}, so as not to significantly affect the driving of the first plurality of injectors 7 (or of the emulation load 17). Consequently, the shunt element is crossed by currents of high value (even in the order of tens of amps, as previously shown with reference to Figure 2), making it difficult to correctly dissipate heat. Furthermore, the voltage drop ΔV_{sh} is of a few mV and, therefore, must be amplified by the differential amplifier or by instrumentation. In particular, the instrumentation amplifier must be insensitive to the common mode, which has a value, for example, of the order of 60-100V. However, it is difficult to find on the market instrumentation amplifiers or threshold comparators capable of meeting this requirement. Therefore, it is complex to design a shunt element and an amplifier or comparator suitable for the purpose with discrete components and reduced production costs.

Another solution uses a Hall sensor, rather than a shunt element, to detect the current I. In particular, according to this other solution, the Hall sensor is arranged between the first central unit output terminal 20 and the switch 24.

In use, the detection of the current I with the Hall sensor occurs in a similar way to the detection obtained by means of the shunt element. In particular, the Hall sensor generates a voltage output, referred to ground and proportional to the current I (or to the current I′ in the case of driving the emulation load 17). Subsequently, the voltage output is directly compared with one or more threshold voltages from a threshold comparator. The output of the comparator is then supplied to the second ECU 5, which estimates the first injection time t_1. The Hall sensor does not introduce significant additional voltage drops on the system 1 and is almost insensitive to the common mode.

However, this other solution also has disadvantages. In particular, it is difficult to find a Hall sensor capable of detecting relatively small currents (for example, of a few amperes) without introducing noise into the measurement. Furthermore, the Hall sensor has a slow response at the output, especially if it is necessary to filter the measurement to reduce the noise. Moreover, Hall sensors are typically quite expensive.

GB 2521820 describes a method for determining the derivative of a signal to detect the movement of a solenoid armature. GB 2521820 provides, among other things, the possibility of detecting the current flowing in a solenoid by using a resistor and a differential amplifier.

EP 1533503 describes a device for controlling electro-actuators with detection of the instant of completion of the actuation.

It follows that methods and systems that are simple and inexpensive to manufacture and that can accurately estimate the first injection time t_1 and consequently allow the second injection time t_2 to be determined are not known.

OBJECT OF THE INVENTION

The object of the present invention is to provide an estimation circuit for the injection time that at least partially overcomes the drawbacks of the prior art.

The present invention provides an estimation circuit, a control device including the same and an estimation method, as defined in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the present invention, preferred embodiments thereof will be now described purely by way of non-limiting example with reference to the attached drawings, in which:

- Figure 1 shows a block diagram of a direct petrol and gas injection system;
- Figure 2 shows trends over time of electrical quantities characteristic of the system of Figure 1;
- Figure 3 shows a block diagram of an injection system including the present control device;
- Figure 4 shows trends over time of characteristic quantities of the system of Figure 3;
- Figures 5-8 and 11 show equivalent circuits of injection systems including further embodiments of the present control device;
- Figure 9 shows a block diagram of a variant of the system of Figure 3; and
- Figure 10 shows trends over time of characteristic quantities of the system of Figure 9.

PREFERRED EMBODIMENT OF THE INVENTION

Figure 3 schematically shows a direct injection system (hereinafter briefly defined as system) 100, which uses a mixture of petrol and gas as fuel. Elements shown in Figure 3 corresponding to elements already shown in Figure 1 are indicated with the same reference numbers and will not be further described. Moreover, to facilitate the understanding of the present invention, the second plurality of injectors 9 is not shown. In addition, the following refers, by way of example, to a system operating in one of the combustion chambers of an endothermic controlled ignition engine with direct injection.

In detail, the system 100 comprises a measuring circuit 112, incorporated in the second ECU (here indicated with 505) and described in the following only with regard to the portion coupled to the injector 7A, without thereby losing its general character. The second ECU 505 represents a control device. In particular, the second ECU 505 and the second plurality of injectors 9 connected to it can be electrically interposed between the first ECU 3 and the injectors of the first plurality 7, in a transparent manner with regard to the operation of the first ECU 3 and in a releasable manner. Furthermore, considering each injector of the first plurality 7, the second ECU 505 is electrically interposed between the terminals of this injector and the first and second central unit output terminal 20, 21.

In the following description, reference is made, for simplicity's sake, to the case in which the second ECU 505 is always coupled to the first ECU 3.

In greater detail, the measuring circuit 112 includes: a measurement resistor 105 having a first terminal connected to the second driving line 8 and then to the second control unit terminal 21 of the first integrated logic 16; and a measurement capacitor 110 having a first terminal, connected to a second terminal of the measurement resistor 105, with which it forms a common node 125, and a second terminal, connected to the first central unit output terminal 20 of the first integrated logic 16.

In greater detail, the measurement resistor 105 has a resistance R_m, for example, between 50Ω and 1MΩ, for example 10kΩ. This value of R_m means that the presence of the measurement resistor 105 does not substantially modify the operation of the injectors 7, of the emulation loads 17 and of the relative currents described above.

The measurement capacitor 110 has a capacity C_m, for example between 100pF and 10μF, for example 47nF. In addition, the measurement capacitor 110 has a time constant τ_m approximately equal to the product between the capacitance C_m and the resistance R_m of the measurement resistor 105.

The measurement circuit 112 further comprises a threshold generator 115, which generates a threshold voltage V_S and has a first terminal connected to the first central unit output terminal 20 of the first integrated logic 16. Furthermore, the measuring circuit 112 comprises a threshold comparator 120, which has a first and a second input, respectively connected to a second terminal of the threshold generator 115 and to the common node 125.

In the present embodiment, the measurement capacitor 110 has a capacity such that its own time constant τ_m is such that the voltage trend at the ends of the measurement capacitor 110 (hereinafter indicated with V_C) reproduces to a first approximation the trend of the current I in the injector 7A. For this purpose, the time constant τ_m approximates the time constant $\tau_{i,1}$ of the inductor $L_{i,1}$ of the injector 7A. For example, the time constant τ_m may be included in the interval [$0.5*\tau_{i,1}$ - $2*\tau_{i,1}$]. Furthermore, the time constant τ_m of the measurement capacitor 110 may be included in the interval [$0.5*\tau_{em}$ - $2*\tau_{em}$], where, as explained above, τ_{em} indicates the time constant of the emulation load 17.

In use, the system 100 operates according to the steps described with reference to Figure 1. Moreover, for a simpler exposition, reference is made only to the operation of the injector 7A, without however losing general character.

In particular, in the aforementioned first step (i.e. when the switch 24 is closed), the first integrated logic 16 applies the aforementioned voltages V_- and V_+ respectively on its first and second central unit output terminal 20, 21. Consequently, a current I* (supplied by the first ECU 3) enters the second central unit output terminal 21, while on the first central unit output terminal 20 there is a current of approximately -I*.

A first part of the current I* flows in the measurement resistor 105 and loads the measurement capacitor 110, which is subject to the time-varying voltage V_C. To a first approximation, the first part of the current I* is negligible. A second part of the current I* flows in the injector 7A, thus constituting the aforementioned current I. Furthermore, since the time constant τ_m of the measurement capacitor 110 is approximately equal to the time constant $\tau_{i,1}$ of the injector 7A (or of the emulation load 17), the voltage V_C has a trend over time, to a first approximation, equal to the trend over time of the current I in the injector 7A. Consequently, based on the voltage V_C, it is possible to estimate the first injection time t_1.

In the same way, in the second step (i.e. when the switch 24 is open and the emulation load 17 is connected to the first central unit output terminal 20), the first integrated logic 16 applies again the aforementioned voltages V_- and V_+. Therefore, the emulation load 17 is traversed by the current I', which is approximately equal to the current I. Furthermore, the measurement capacitor 110 and the measurement resistor 105 are subjected to the same electrical stimuli (i.e., they are flown through by the same current) to which they were subjected during the first step. Consequently, the voltage V_C on the measurement capacitor 110 follows the same trend followed during the first step. Therefore, based on the voltage V_C, it is still possible to estimate the aforementioned injection time t_{em}.

In general, the following refers to a possible injection time t_1' to indicate the duration of the time interval in which petrol injection can occur for each injection cycle. Therefore, the possible injection time t_1' is independent of the closing state of the switch 24. In practice, if the switch 24 remains closed for the entire duration of the possible injection time t_1', this latter coincides with the aforementioned first injection time t_1; vice versa, if the switch 24 remains open for the entire duration of the possible injection time t_1', this latter coincides with the aforementioned injection emulation time t_{em}. The possible injection time t_1' is therefore indicative of the voltages V- and V_+, but does not depend on the state of the switch 24. Furthermore, the possible injection time t_1' can be determined based on the voltage V_C.

The voltage V_C of the measurement capacitor 110 is compared with the threshold voltage V_S of the threshold generator 115 by the threshold comparator 120. After the comparison, the threshold comparator 120 sends to the second integrated logic 26 an output voltage V_{out}, starting from which the second integrated logic 26 estimates the possible injection time t_1' and calculates the second injection time t_2. Subsequently, in a per se known manner, the second integrated logic 26 controls the injectors 9 so as to inject the desired amount of gas.

In greater detail, the output voltage V_{out} is a logic signal indicative of time instants $t_{s1}*$, $t_{s2}*$ in which the voltage V_C respectively exceeds the threshold voltage V_S and becomes lower than the threshold voltage V_S. To a first approximation, the time instants $t_{s1}*$, $t_{s2}*$ are respectively equal to the time instants t_{s1}, t_{s2}, as qualitatively shown in Figure 4. Therefore, the possible injection time t_1' can be estimated as equal to the difference between the time instants $t_{s1}*$ and $t_{s2}*$.

In detail, Figure 4 shows trends of electrical quantities characteristic of the system of Figure 3. In particular, electrical quantities of Figure 4 corresponding to electrical quantities of Figure 2 are indicated in Figure 4 with the same reference numbers and not further described.

Unlike what is shown in Figure 2, in which the feeding cycle took place with the switch 24 permanently closed, Figure 4 refers to the case in which, during the feeding cycle, and in particular during the hold step, the switch 24 switches from closed to open. In detail, the switch 24 switches in a time instant t_{sw}.

Given the above, Figure 4 shows the trend of the current I* present on the second central unit output terminal 21 (fourth graph 142). This trend has a first portion 144, comprised between the time instants t_3 and t_{sw}, and a second portion 146, comprised between the time instants t_{sw} and t_5. The trend of the current I and of the current I in the emulation load 17 are respectively equal, to a first approximation, to the aforementioned first and second portions 144, 146 of the current I*.

Figure 4 further shows a fifth graph 150, representing the trend of the voltage V_C of the measurement capacitor 110 in the different operating steps described with reference to Figure 2. In detail, the fourth graph 150 has a trend that, to a first approximation, is the same as the one of the fourth graph 142, in particular as regards the portions close to the time instants t_3 and t_5. On the other hand, greater deviations occur close to the current peak and in a portion subsequent to the time instant t_{sw}, due to the switching of the switch 24, this latter deviation being therefore absent when the switch 24 does not switch during the injection cycle.

Finally, Figure 4 further shows a sixth graph 152, relating to an example of the output voltage V_{out}.

Thanks to the fact that the voltage V_C on the measurement capacitor 110 has, to a first approximation, a trend proportional to the one of the current I*, the output voltage V_{out} generated by the threshold comparator 120 is still indicative of the possible injection time t_1', regardless of the fact that, during the supply cycle, a changeover of the switch 24 has occurred.

Figure 5 shows an embodiment of the threshold generator 115 in greater detail.

In particular, the threshold generator 115 comprises: a current generator 160 connected to a threshold node 161 and to a supply node 163, which is placed at a supply voltage V_{DD}; and a threshold resistor 162, interposed between the threshold node 161 and the first central unit output terminal 20 of the first integrated logic 16. The threshold resistor 162 has a resistance R_S equal, for example, to 47kΩ.

The current generator 160 generates a threshold current I_{th}, which, assuming that the comparator 120 has a high impedance, flows in the threshold resistor 162, generating a voltage drop on this latter. In this way, the threshold resistor 162 has the threshold voltage V_S.

In this embodiment, the current generator 160 is, for example, a current mirror.

Figure 6 shows another embodiment of the threshold generator 115; in particular, elements shown in Figure 6 corresponding to elements shown in Figure 5 are indicated in Figure 6 with the same reference numbers and not further described.

The threshold generator 115 comprises: a threshold diode 170, arranged in series with the current generator 160; and a threshold capacitor 172, arranged in parallel with the threshold resistor 162. In particular, the threshold diode 170 has the cathode and the anode respectively connected to the threshold node 161 and to the threshold current generator 160. The threshold capacitor 172 has terminals respectively connected to the threshold node 161 and to the first central unit output terminal 20. Moreover, the threshold capacitor 172 has a capacity C_S equal, for example, to 10nF.

The present configuration is advantageously usable to maintain the constant threshold voltage V_S in the presence of demagnetization pulses 40A, 40B. In fact, the demagnetization pulses 40A, 40B may cause the threshold voltage V_S to vary significantly in the event of malfunctions of the threshold current generator 160.

In particular, the threshold diode 170 allows a momentary interruption of the connection between the threshold current generator 160 and the threshold resistor 162, so as to prevent the threshold current I_{th} from flowing towards the supply node 163. Furthermore, the threshold capacitor 172 has a time constant τ_S defined as the product between the capacity C_S and the resistance R_S of the threshold resistor 162. In order to maintain the constant threshold voltage V_S during a demagnetization pulse, the time constant τ_S may be, for example, greater than five times the duration of said demagnetization pulse. Moreover, this configuration allows tolerating short periods of time in which the supply voltage V_{DD} is lower than the voltage V_-.

Figure 7 shows a further embodiment of the threshold generator 115. In particular, elements shown in Figure 7 corresponding to elements shown in Figure 6 are indicated in Figure 7 with the same reference numbers and not further described.

The threshold generator 115 comprises a compensation generator 180, which is a current generator with terminals respectively connected to the first central unit output terminal 20 and to the ground. Operationally, the compensation generator 180 is designed to discharge at least part of the threshold current I_{th} to the ground, starting from the first central unit output terminal 20.

This configuration can be advantageously used to reduce the interference of the measuring circuit 112 on the operation of the first plurality of injectors 7. In fact, by subtracting the threshold current I_{th} from the first central unit output terminal 20, it is possible to avoid that part of the threshold current I_{th} flows towards the negative terminal of the injector 7A.

Figure 8 shows a further embodiment of the threshold generator 115. In particular, elements shown in Figure 8 corresponding to elements shown in Figure 7 are indicated in Figure 8 with the same reference numbers and not further described.

In detail, the system 100 comprises a first limitation diode 201, such as for example a Zener diode. In particular, the first limitation diode 201 has an anode and a cathode respectively connected to the first central unit output terminal 20 and to the common node 125.

For practical purposes, the first limitation diode 201 allows limiting the voltage V_C at the ends of the measurement capacitor 110, with the following advantages.

In detail, during the rapid increase of the current I in the peak step, the injector 7A presents non-linear phenomena due to magnetic saturation. Such phenomena, mainly in the presence of high current values I (for example, 10A in the peak step), may cause sudden variations of the aforementioned current I with respect to an ideal case. Moreover, these current variations I are faster also with respect to the trend of the voltage V_C at the ends of the measurement capacitor 110, since the voltage V_C has a behaviour closer to an ideal case. Consequently, the limitation of the voltage V_C introduced by the first limitation diode 201 allows avoiding a possible overestimation of the possible injection time t_1'.

Moreover, the system 100 of Figure 8 comprises a second and a third limitation diode 203, 205 and a limitation resistor 207, arranged in series.

The cathode and the anode of the second limiting diode 203 are respectively connected to the cathode of the third limiting diode 205 and to the common node 125. Furthermore, the third limitation diode 205 is a Zener diode, whose anode is connected to a first terminal of the limitation resistor 207, whose second terminal is connected to the second central unit output terminal 21.

Operationally, the configuration shown in Figure 8 allows improving the behaviour of the system 100 for the reasons described below.

In detail, the Applicant has observed how, in the off step, the current I decreases faster than the voltage V_C at the ends of the measurement capacitor 110. This discrepancy can represent a further cause of overestimation of the possible injection time t_1'. This configuration represents a solution to the problem, since the second and third limitation diodes 203, 205 and the limitation resistor 207 allow speeding up the discharge of the measurement capacitor 110. In practice, the second limitation diode 203 disconnects the third limitation diode 205 in the charging step, enabling it, together with the limitation resistor 207, only to discharge. On the other hand, the first limitation diode 201 limits the voltage only during the charging step.

Figure 9 shows a further embodiment of the system 100, which is now described with reference only to the differences with respect to the embodiment shown in Figure 3.

In detail, the system 100 comprises a correction circuit 130, which has two inputs connected to the negative and positive terminals of the injector 7A. In particular, the correction circuit 130 is a demagnetization pulse detector, namely it generates and supplies to the second integrated logic 26 of the second ECU 505 a detection signal indicative of the starting instants of the demagnetization pulses 40A, 40B. The second integrated logic 26 of the second ECU 505 then calculates an improved estimation of the possible injection time t_1', which is estimated as the time elapsing between the time instant t_{s1}* and the time instant t_{df} when the last demagnetization pulse 40B begins before the time instant t_{s2}*. This solves the problem described below with reference to Figure 10.

In detail, in addition to examples of trends of the voltage V_C, of the current I* and of the output voltage V_{out}, Figure 10 shows an example of the trend of the voltage V_-, indicated with 132 and including a pair of respective demagnetization pulses 40A', 40B'. In this regard, the Applicant has observed that, during the off step, the voltage V_C on the measurement capacitor 110 decreases more slowly than the current I. Therefore, an overestimation (indicated with t_1'*) of the possible injection time may occur.

Figure 11 shows another embodiment of the present system. In detail, Figure 11 shows a system 300 having a general structure similar to the one of the system 100 shown in Figure 7, so that parts identical to those shown and described with reference to Figure 7 are indicated in Figure 11 with the same reference numbers.

In particular, the system 300 has an additional measurement circuit 112', which is the same as the measuring circuit 112, except for the differences described below. Consequently, the elements of the additional measurement circuit 112' are indicated with the same reference numbers as the corresponding elements of the measuring circuit 112 with the addition of an apex. Furthermore, the additional measurement circuit 112′ connects to the first and second central unit output terminal 20, 21 of the first ECU 3 in the same way as the measurement circuit 112.

In detail, the additional measurement circuit 112' is such that an additional threshold voltage V_S' greater than the threshold voltage V_S is set on the threshold resistor 162'. To a first approximation, the voltages V_C and V_C' have the same trend, proportional to the current I* generated on the second central unit output terminal 21 of the first ECU 3. The output voltage V_{out}' is indicative of time instants t_{s1}**, t_{s2}** in which the voltage V_C′ respectively exceeds the threshold voltage V_S' and becomes lower than the threshold voltage V_S′. Moreover, the second integrated logic 26 estimates the possible injection time t_1′ as equal to the time interval between the time instants t_{s1}** and t_{s2}*.

The present embodiment is advantageously usable in the case in which, before the peak step, the voltage V_+ is non-zero (for example has a pulsed trend), in which case the beginning of the possible injection time t_1′ could be incorrectly anticipated with respect to the actual occurrence of the peak step, if only the threshold voltage V_S were available.

The present control device, represented by the second ECU 505, has several advantages.

In particular, the present control device includes a circuit for estimating the injection time that allows obtaining an efficient and precise estimation of the petrol injection time, comparing a voltage signal with one or more thresholds without having to resort to direct current measurements. Moreover, the estimation circuit uses discrete components and therefore is inexpensive, with low power consumption and a reduced need to dissipate heat. In addition, the estimation circuit is composed of small sized components that are easy to find.

Moreover, as already previously mentioned, the control device does not interfere with the normal operation of the direct injection system, since it is inserted between the first ECU and the first plurality of injectors in a transparent manner with respect to the first ECU, namely without causing any modification in the operation of this latter.

Finally, it is clear that modifications and variations can be made to the estimation circuit described and illustrated herein without thereby departing from the protective scope of the present invention, as defined in the attached claims.

CLAIMS

1. An estimation circuit (112) couplable to an injection system (3, 6, 7, 8, 9, 12, 14) that comprises:

– a control unit (3) configured to generate a driving signal (V_+, V_-);

- a first injector (7; 7A) couplable to the control unit so as to receive the driving signal and to inject, in response, a first fuel into a combustion chamber (11) during a time interval having the same duration as an injection time (t_1);

said estimation circuit (112) comprising:

– a first capacitor (110), which, when the estimation circuit is coupled to the injection system, is subjected to a first voltage (V_c) that depends on the driving signal; and

– a comparator circuit (120) configured to generate a first output signal (V_{out}) based on the comparison between said first voltage (V_c) and at least a first threshold (V_s), said first output signal being indicative of said injection time.

2. The estimation circuit according to claim 1, wherein the control unit (3) comprises a first and a second node (20, 21) and is configured to generate a first and a second electric signal (V_+, V_-), respectively on the first and on the second node, said driving signal being based on

the first and the second electric signal; and wherein the first injector (7; 7A) has a first and a second terminal; and wherein, when it is coupled to the injection system (3, 6, 7, 8, 9, 12, 14), the estimation circuit (112) is electrically interposed between the first and the second terminal of the first injector and the first and the second node of the control unit; said estimation circuit further comprising a first resistor (105); and wherein, when the estimation circuit is coupled to the injection system, the first capacitor (110) and the first resistor are connected between said first and second nodes.

3. The estimation circuit according to claim 2, wherein the first capacitor (110) has a first terminal, coupled to the first resistor (105), and a second terminal, configured to be coupled to said first node (20); said estimation circuit (112) further comprising a threshold generator (160, 162; 160, 162, 170, 172; 160, 162, 170, 172, 180, 201, 203, 205, 207) including:

– a second resistor (162), having a first terminal coupled to the second terminal of the first capacitor; and

– a first current generator (160) configured to inject a threshold current (I_{th}) into a second terminal of the second resistor, so that a first reference voltage (V_S; V_S') is set on the second resistor;

and wherein the comparator circuit (120) is configured so that said first threshold (V_S; V_S') is based on said first reference voltage.

4. The estimation circuit according to claim 3, wherein the threshold generator (160, 162; 160, 162, 170, 172; 160, 162, 170, 172, 180, 201, 203, 205, 207) further comprises a second capacitor (172), coupled in parallel to the second resistor (162).

5. The estimation circuit according to claim 3 or 4, wherein the threshold generator (170, 172; 160, 162, 170, 172, 180, 201, 203, 205, 207) further comprises a first diode (170), interposed between the current generator (160) and the second resistor (162).

6. The estimation circuit according to any one of the claims 3 to 5, wherein the threshold generator (160, 162, 170, 172, 180, 201, 203, 205, 207) further comprises a second current generator (180), coupled to the first terminal of the second resistor (162) and configured to drain at least part of the threshold current (I_{th}) that flows in the second resistor.

7. The estimation circuit according to any one of the claims 2 to 6, further comprising a first Zener diode (201), coupled in parallel to the first capacitor (110).

8. The estimation circuit according to any one of the claims 2 to 7, wherein the first terminal of the first capacitor (110) is coupled to a first terminal of the first

resistor (105), said estimation circuit (112) further comprising a series circuit (203, 205, 207) coupled in parallel to the first resistor (105) and including:

- a third resistor (207);

- a second Zener diode (205); and

- a second diode (203);

and wherein the anode of the second diode and the cathode of the second Zener diode are turned towards the first terminal of the first resistor.

9. A control device couplable to the injection system (3, 6, 7, 8, 9, 12, 14) and comprising:

- the estimation circuit (112) according to any one of the claims from 2 to 8, further comprising a switch (24);

- an inductive load (17); and

- a logic unit (26), couplable to a second injector (9) that can be controlled so as to inject a second fuel, different from the first fuel, towards the combustion chamber, said logic unit being configured to control the second injector (9) based on said first output signal (V_{out});

- and wherein the switch (24) is controllable by the logic unit so that, when the estimation circuit is coupled to the injection system, the driving signal is applied alternatively to the first injector (7) or to the inductive load.

10. The control device according to claim 9, wherein the first capacitor (110) is configured to be charged, when the control device (505) is coupled to the injection system (3, 6, 7, 8, 9, 12, 14), with a timing that depends on a first time constant (τ_{em}); and wherein the inductive load (17) is configured so that, when the switch (24) applies the driving signal to the inductive load, a corresponding current (I') passes through the inductive load, said current varying according to a respective timing that depends on a second time constant (τ_{em}); and wherein the first time constant falls in the range [$0.5*\tau_{em}$ - $2*\tau_{em}$] where τ_{em} indicates said second time constant.

11. The control device according to claim 10, wherein the logic unit (26) is configured to determine, based on the first output signal (V_{out}), an initial instant ($t_{s1}*$), wherein the first voltage (V_c) exceeds the first threshold (V_s), and a final instant ($t_{s2}*$), wherein the first voltage drops below the first threshold; and wherein the logic unit (26) is configured to control the second injector (9) based on said initial instant ($t_{s1}*$) and final instant ($t_{s2}*$).

12. The control device according to claim 11, wherein the first injector (7) is configured so that a current (I) passes through the first injector when the first injector receives the driving signal; and wherein the second electric signal comprises a number of pulses configured to

cause a reduction of the current that passes through the first injector; said control device (505) further comprising a detection circuit (130) configured to be electrically coupled to the first injector (7) and to detect an intermediate instant (t_{df}), wherein the last pulse of the second electric signal occurs before the final instant (t_{s2}*); and wherein the logic unit (26) is further configured to:

- calculate an improved estimation of said injection time (t_1) based on the initial instant (t_{s1}*) and the intermediate instant (t_{df}); and

- control the second injector (9) based on the improved estimation.

13. The control device according to any one of the claims 9 to 12, further comprising:

- a third capacitor (110'), which, when the control device (505) is coupled to the injection system (3, 6, 7, 8, 9, 12, 14), is subjected to a second voltage (V_C') substantially equal to the first voltage (V_C); and

- an additional comparator (120') configured to generate a second output signal (V_{out}') based on the comparison between said second voltage and a second threshold (V_S') different from the first threshold;

and wherein the logic unit (26) is configured to control the second injector (9) based on the first and on the second output signals.

14. A system comprising:

- the control device (505) according to claim 10; and

- the injection system (3, 6, 7, 8, 9, 12, 14);

and wherein the first injector (7) is configured so that, when it receives the driving signal, a current (I) that varies according to a timing depending on a third time constant ($\tau_{i,1}$) passes through the first injector; and wherein the first time constant τ_m falls within the range [$0.5*\tau_{i,1}$ - $2*\tau_{i,1}$], where $\tau_{i,1}$ indicates said third time constant.

15. Method for determining an estimation of an injection time in an injection system (100) couplable to a combustion chamber (11) and comprising a first injector (7; 7A) and a control unit (3), the first injector being couplable to the control unit (3) so as to receive a driving signal (V_+, V_-) generated by the control unit and inject, in response, a first fuel into the combustion chamber during a time interval having a duration equal to said injection time (t_1);

said method comprising the steps of:

- coupling to the injection system a first capacitor (110), so that said first capacitor is subjected to a first voltage (V_C) that depends on the driving signal; and

- coupling to the injection system a comparator circuit

(120), so that it generates a first output signal (V_{out}) based on the comparison between said first voltage (V_C) and at least a first threshold (V_S), said first output signal being indicative of said injection time.

16. Method according to claim 15, wherein the control unit (3) comprises a first and a second node (20, 21) and is configured to generate a first and a second electrical signal (V_+, V_-), respectively on the first and on the second node, said driving signal being based on the first and second electrical signals; and wherein the first injector (7; 7A) has a first and a second terminal;

said method further comprising the steps of:

- connecting the first capacitor (110) and a first resistor (105) between said first and second node, so that they are interposed between the first and second terminal of the first injector and the first and second node of the control unit.

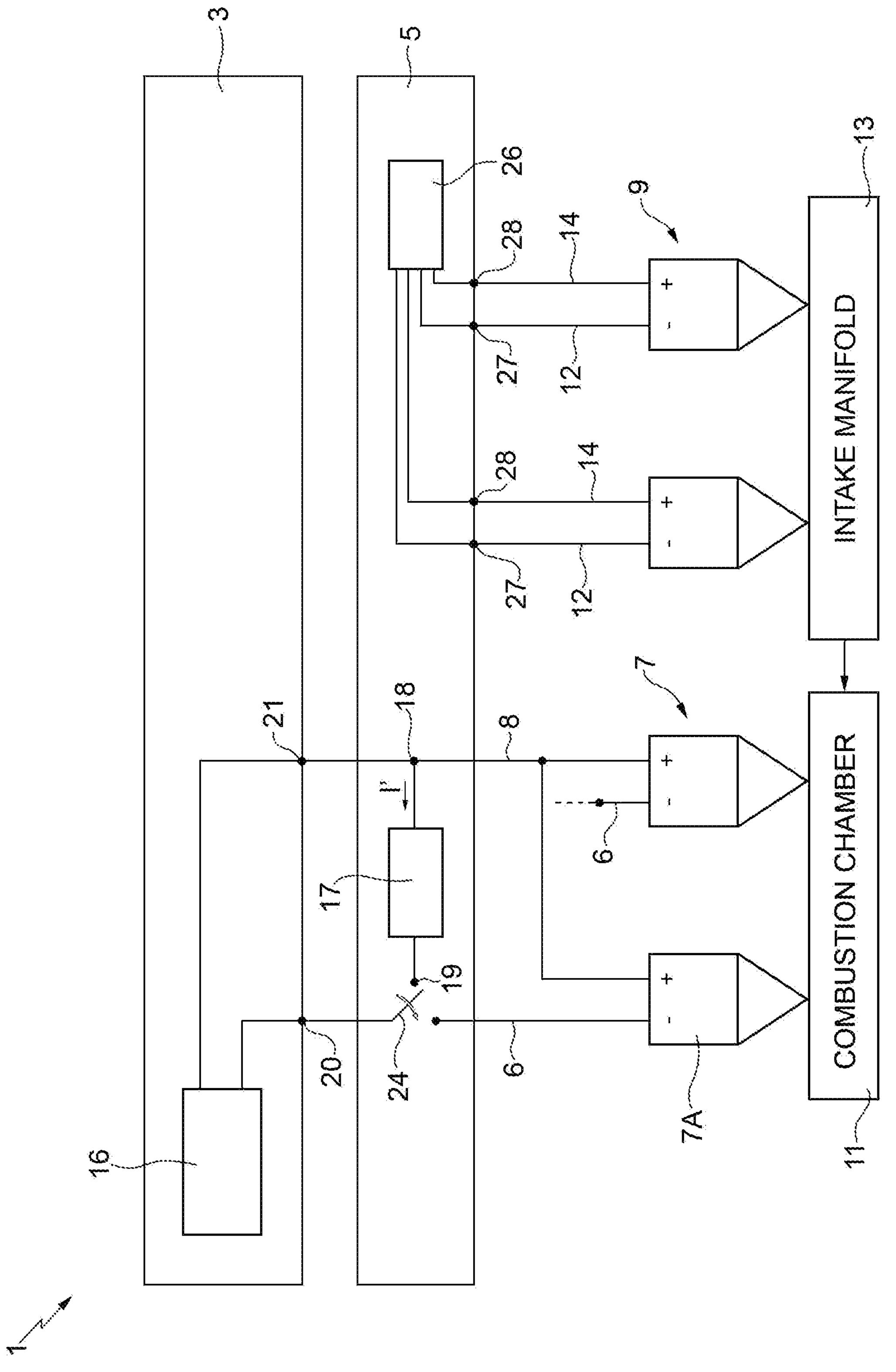

INTAKE MANIFOLD
COMBUSTION CHAMBER
1
3
5
6
7
7A
8
9
11
12
13
14
16
17
18
19
20
21
24
26
27
28

FIG. 1

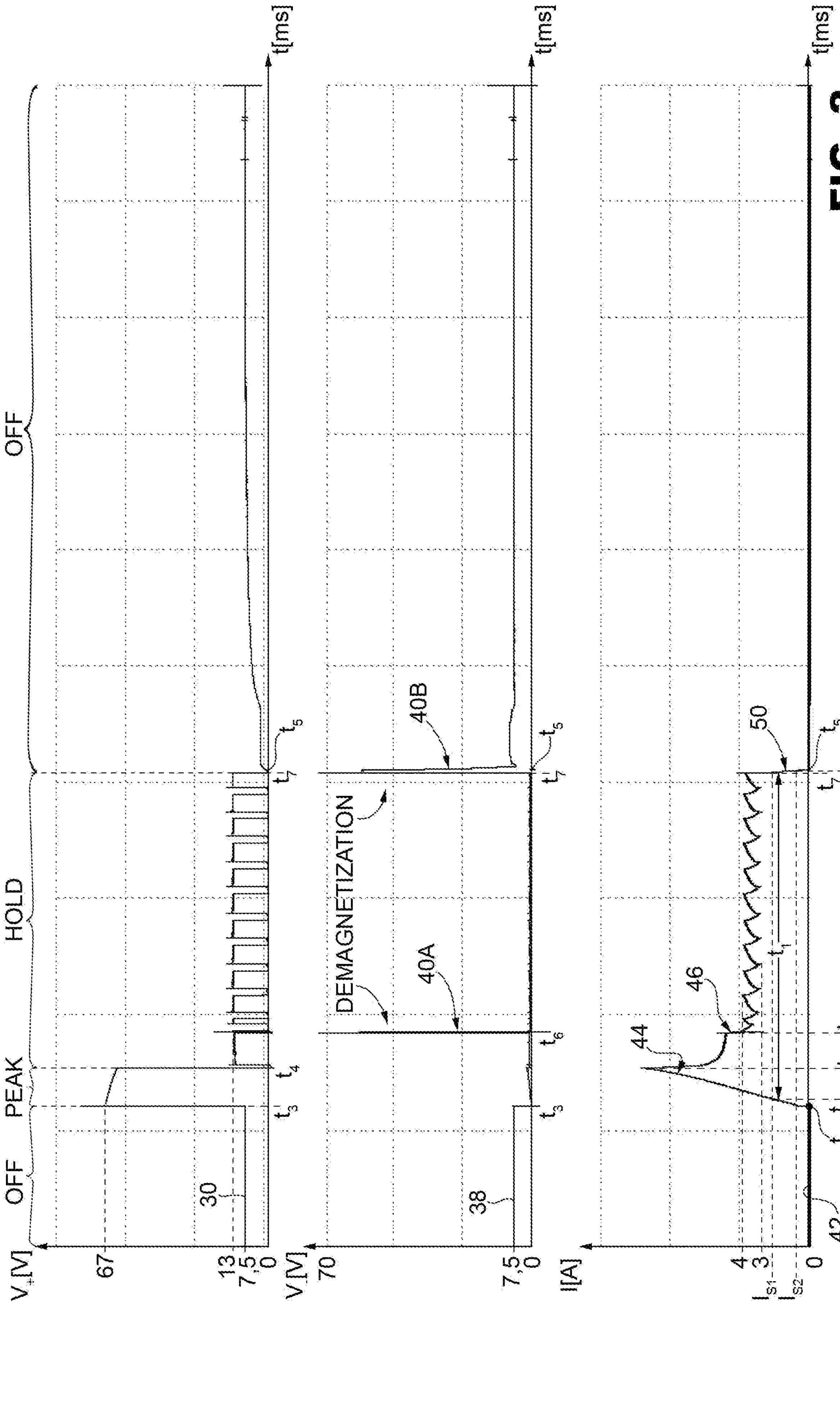
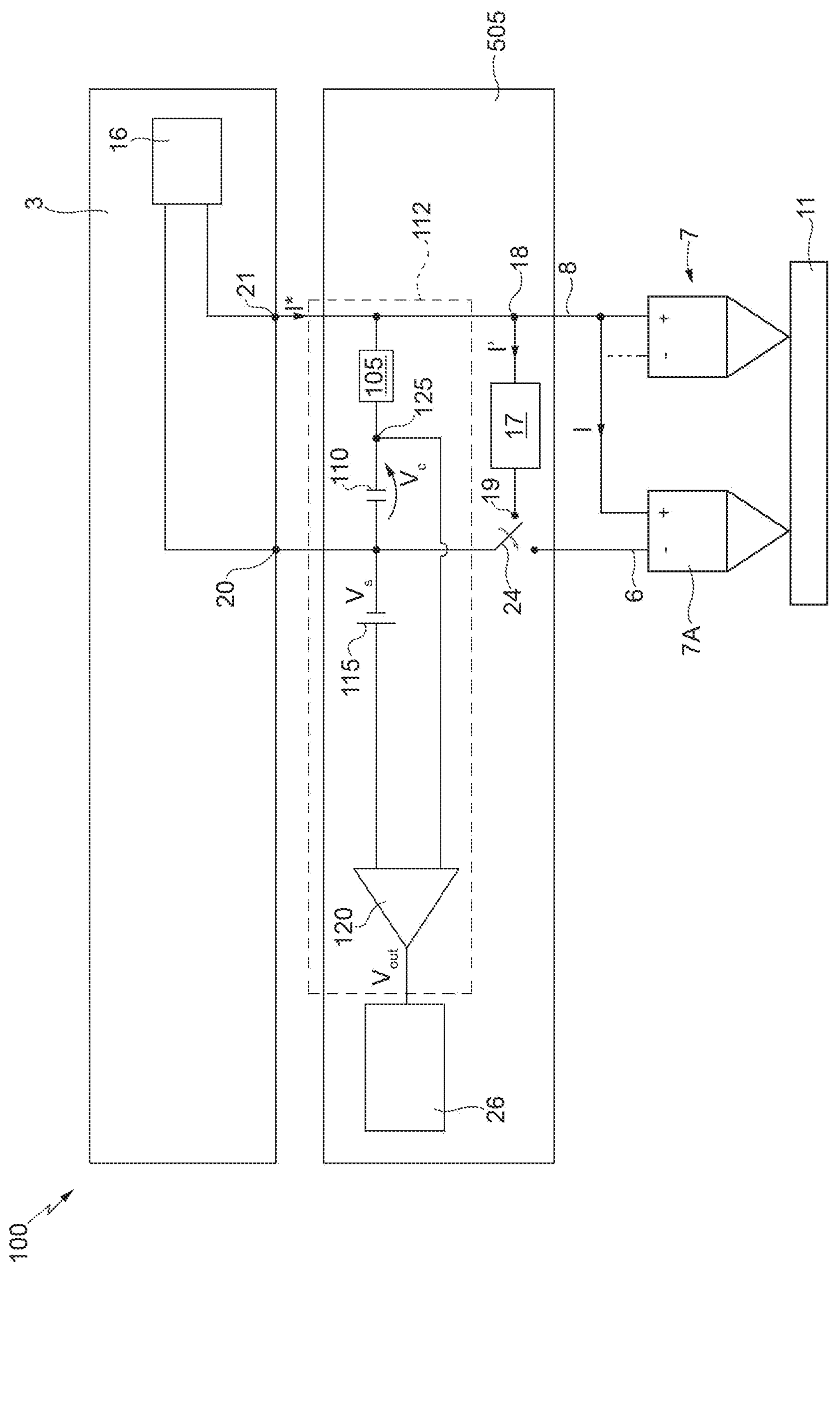

V+[V]
t[ms]
OFF
PEAK
HOLD
OFF
67
13
7,5
0
30
t3
t4
t7
t5
V[V]
70
7,5
0
38
DEMAGNETIZATION
40A
40B
t6
I[A]
4
3
0
IS1
IS2
42
44
46
50
t1
tS1
tS2

FIG. 2



3
16
505
112
21
I*
18
8
7
11
105
125
17
I'
I
110
V_c
19
20
24
6
7A
V_s
115
120
V_{out}
26
100

FIG. 3

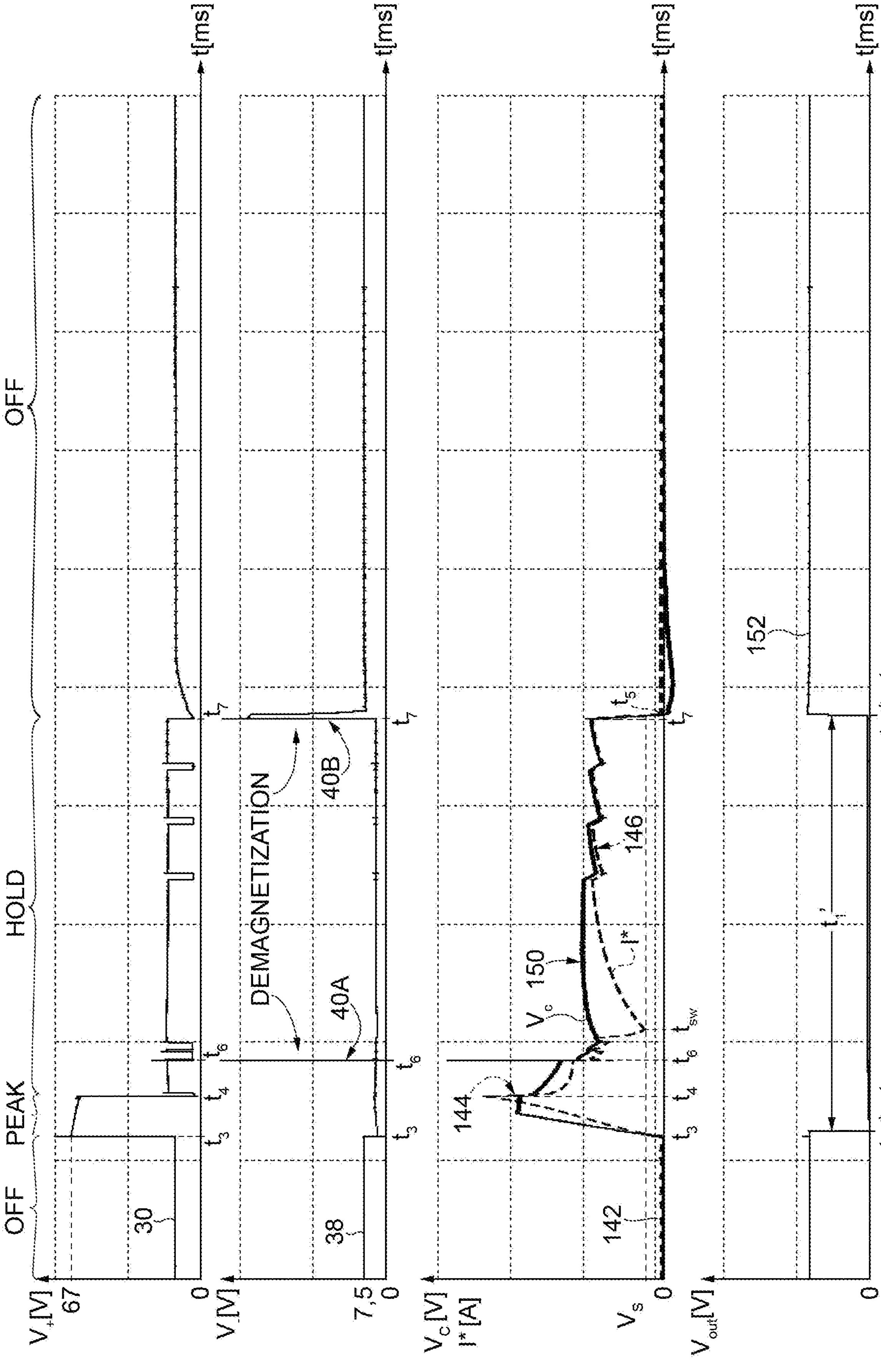

OFF
PEAK
HOLD
OFF
V+[V]
67
0
30
V-[V]
7,5
0
38
DEMAGNETIZATION
40A
40B
VC[V]
I*[A]
VS
0
142
144
146
150
Vc
I*
t3
t4
t5
t6
t7
tsw
Vout[V]
0
152
t'i
tS1* ≈ tS1
tS2* ≈ tS2
t[ms]

FIG. 4

FIG. 5

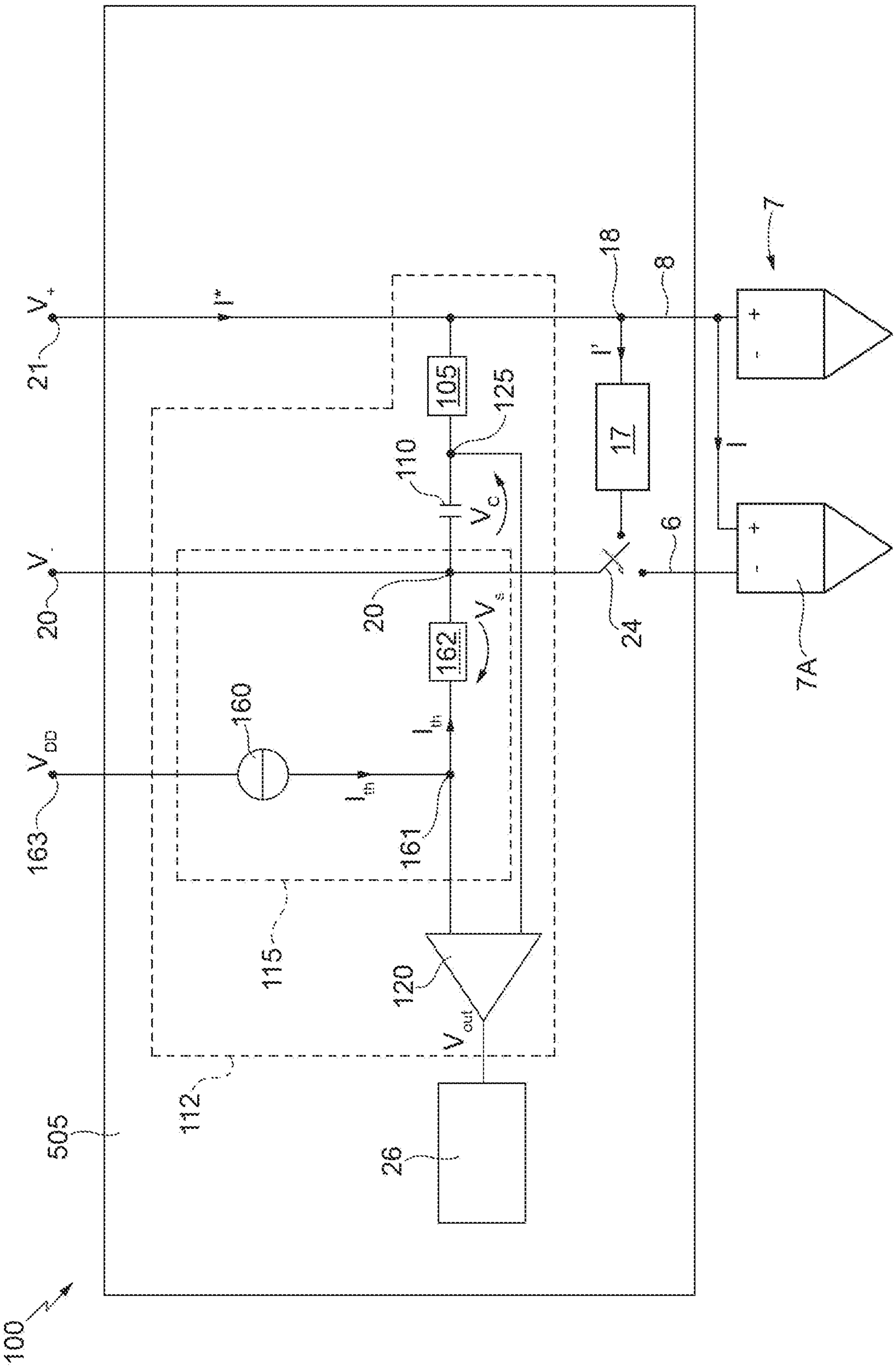
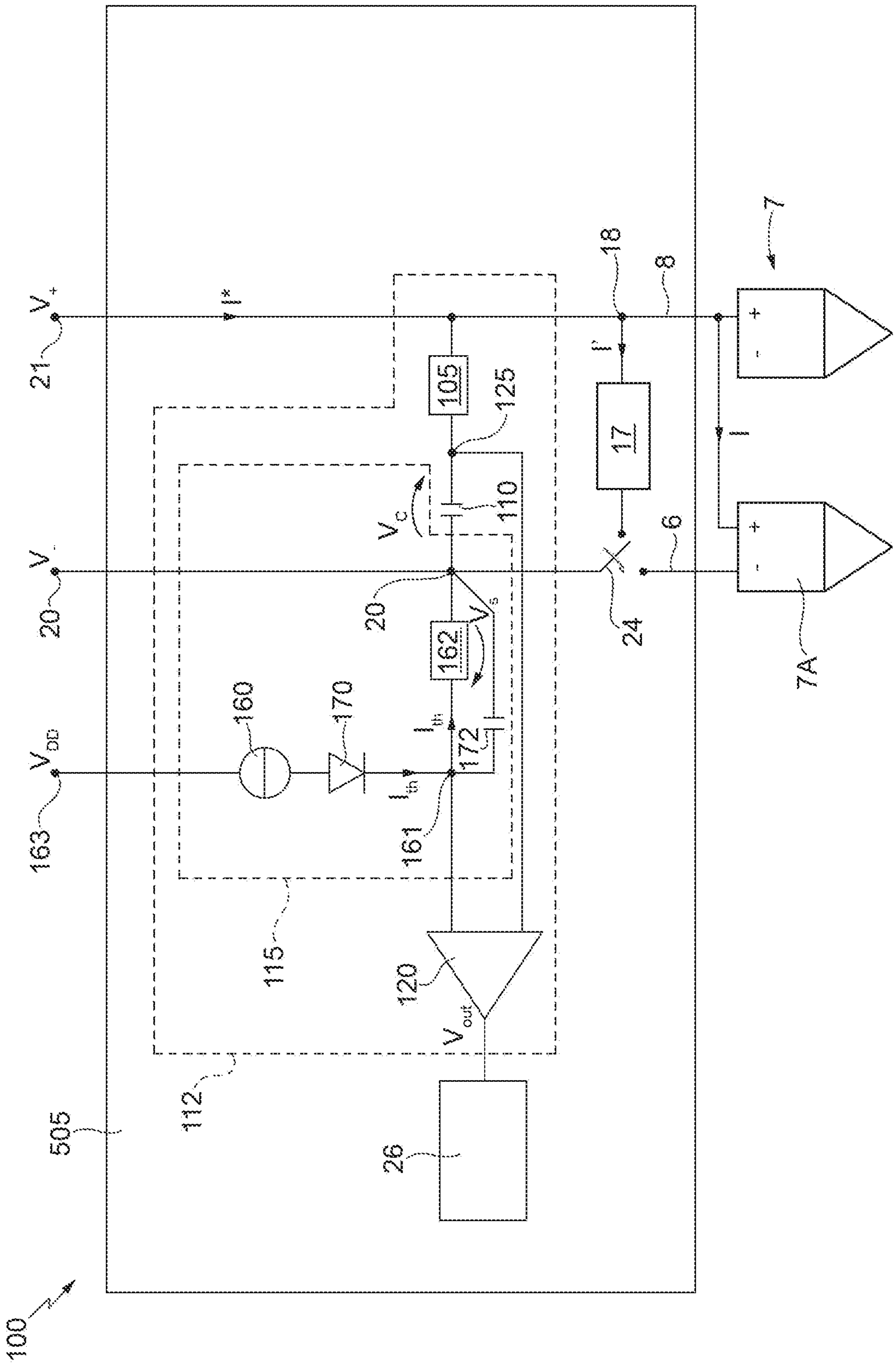

21
V+
I*
105
125
110
Vc
20
V-
162
Vs
163
VDD
160
Ith
161
115
120
Vout
112
505
26
100
18
8
7
I'
17
I
6
24
7A

FIG. 6


21
V_+
I*
20
V_-
163
V_{DD}
160
170
105
125
110
V_C
20
162
V_S
I_{th}
172
I_{th}
161
115
120
V_{out}
112
505
26
17
I'
18
8
7
I
6
24
7A
100

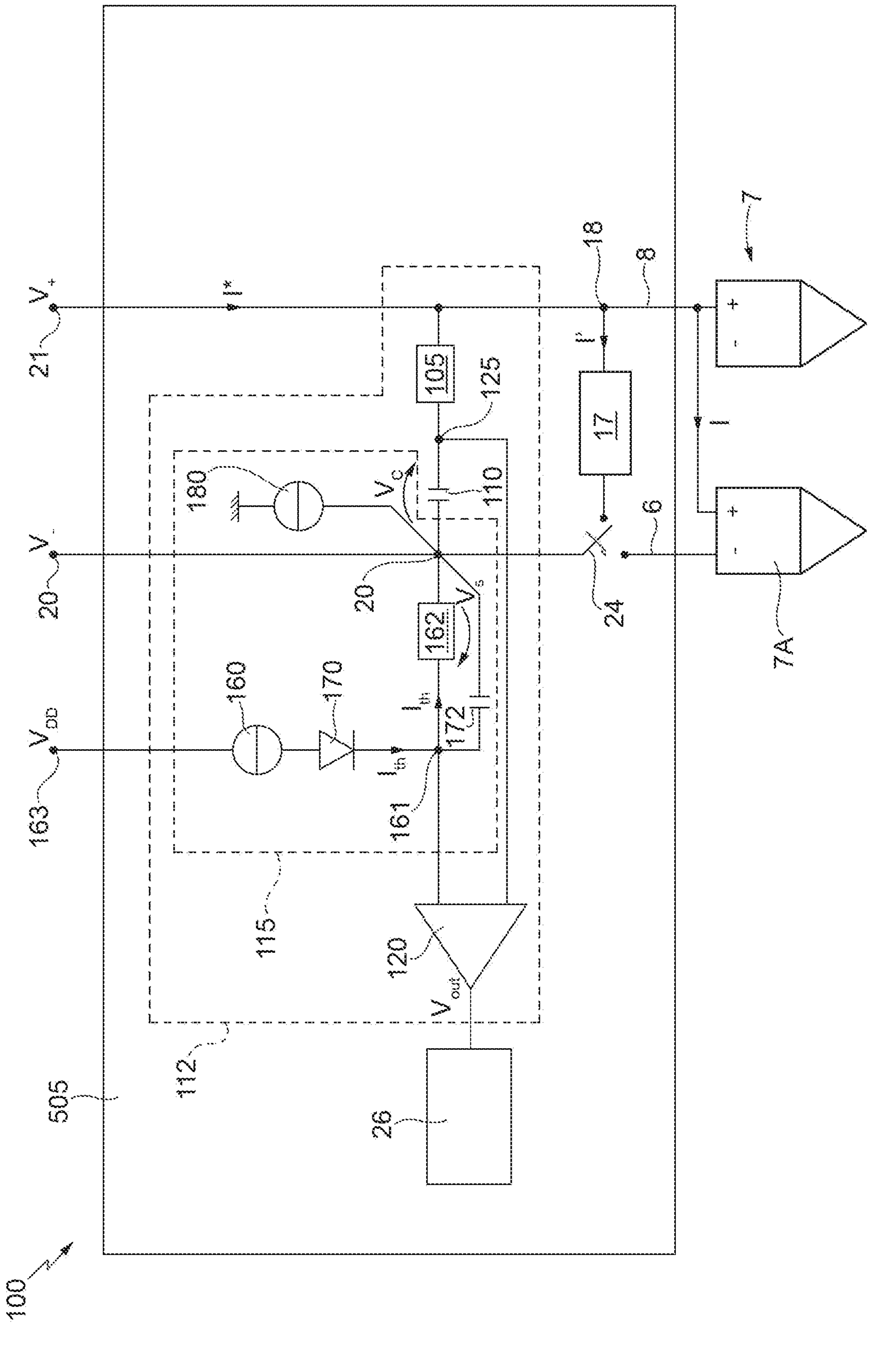
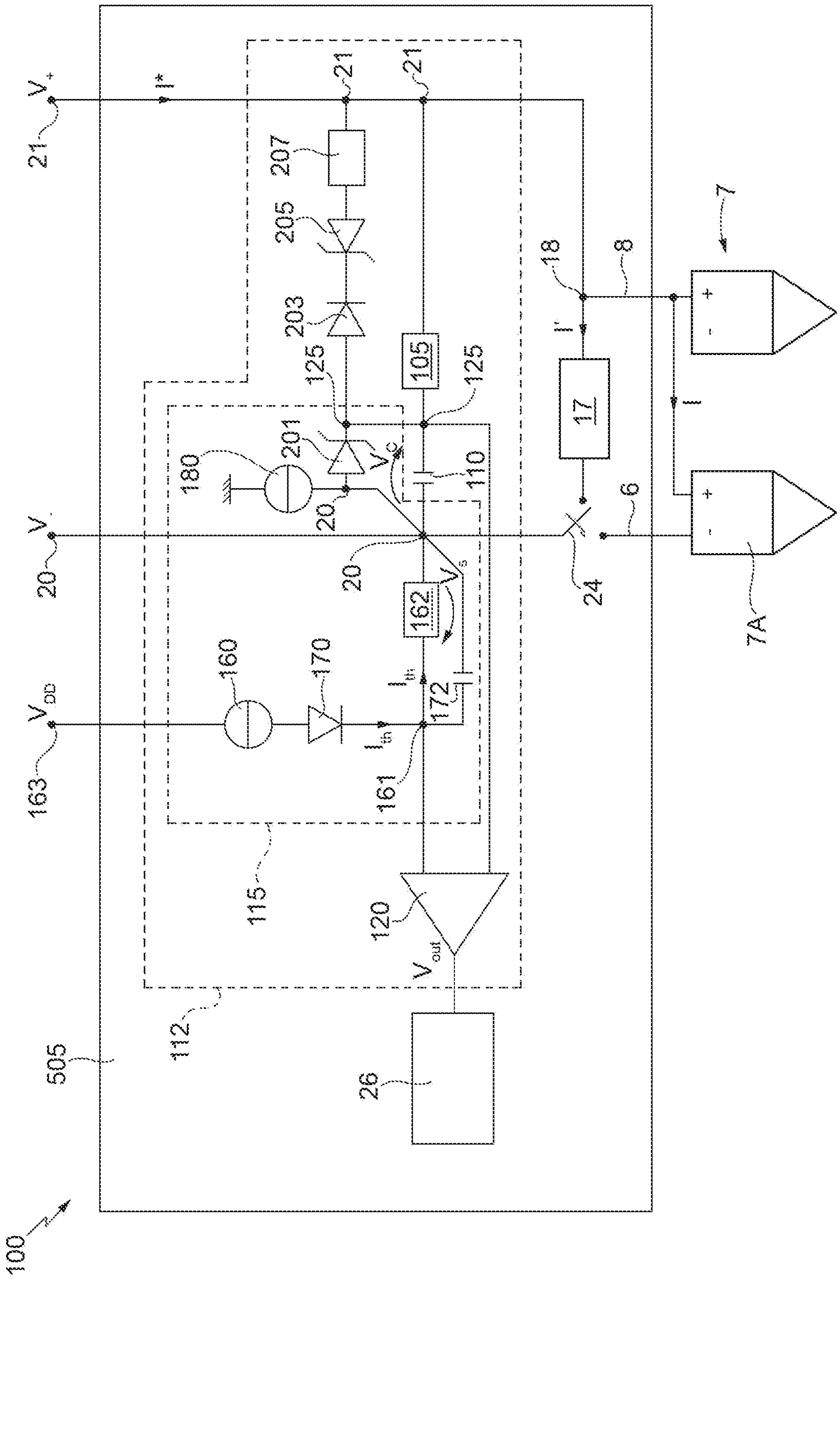

21
V+
I*
20
V-
163
VDD
105
125
180
VC
110
17
18
8
7
I'
I
6
24
20
Vs
162
160
170
Ith
172
161
115
120
Vout
112
505
26
100
7A

FIG. 7

FIG. 8


V+
I*
21
207
205
203
125
105
201
180
110
VC
V-
20
24
6
18
8
I'
17
I
7
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Ith
172
160
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VDD
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115
120
Vout
112
26
505
100

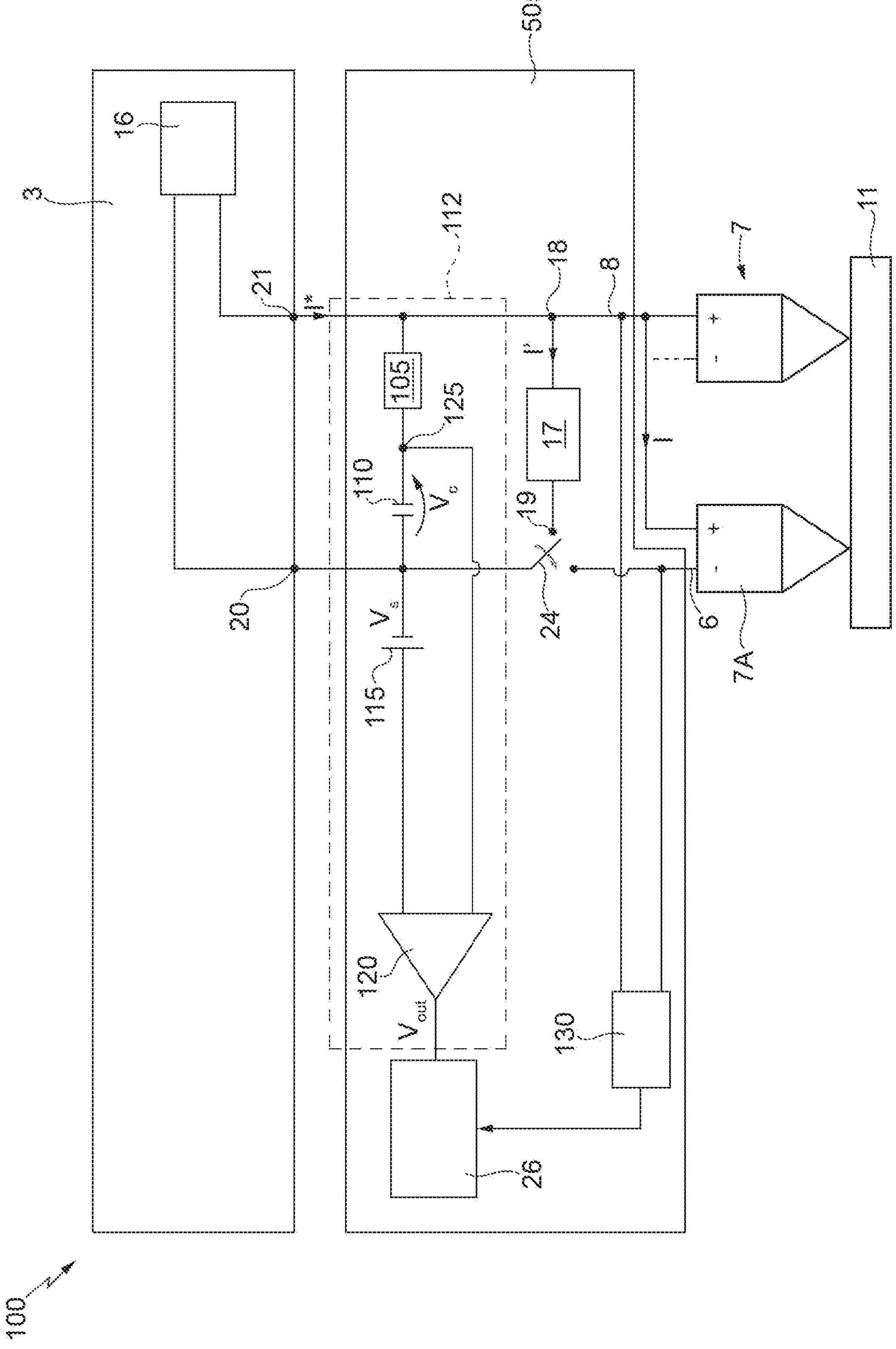
100
3
16
21
20
505
112
105
125
110
115
120
130
26
17
18
19
24
8
6
7
7A
11

FIG. 9

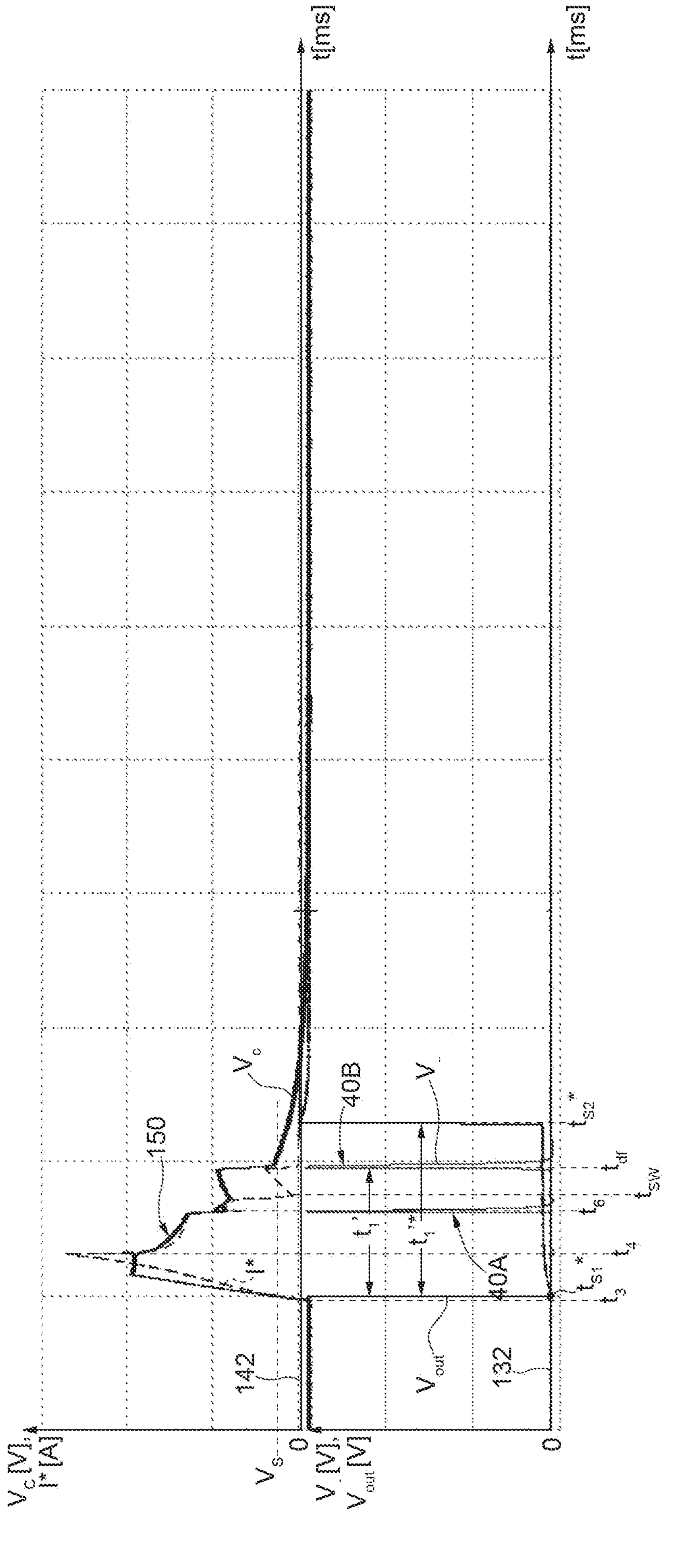

FIG. 10

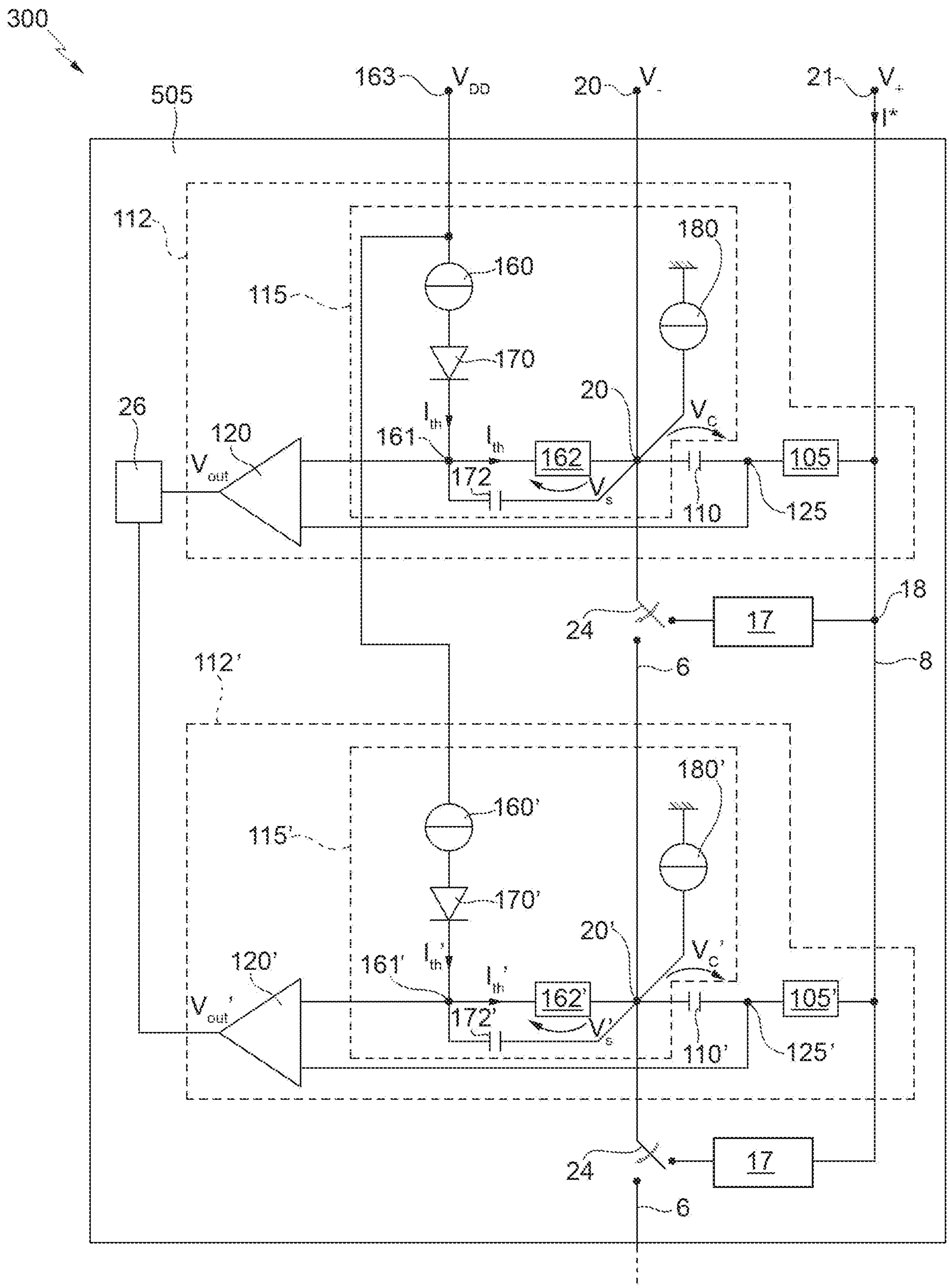
300
505
163
V_{DD}
20
V_-
21
V_+
I*
112
115
160
180
170
I_{th}
20
V_C
26
120
161
I_{th}
162
105
V_{out}
172
V_s
110
125
18
24
17
6
8
112'
115'
160'
180'
170'
I_{th}'
20'
V_C'
120'
161'
I_{th}'
162'
105'
V_{out}'
172'
V'_s
110'
125'
24
17
6

FIG. 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2019/057818

A. CLASSIFICATION OF SUBJECT MATTER
INV. F02D41/20 F02D19/06 F02D41/00
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

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 practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	GB 2 521 820 A (CONTINENTAL AUTOMOTIVE SYSTEMS [US]) 8 July 2015 (2015-07-08) abstract; claims 1-4; figures 3,6 paragraph [0033] - paragraph [0050] paragraph [0055] -----	1,2,15, 16 3-14
X A	EP 1 533 503 A1 (FIAT RICERCHE [IT]) 25 May 2005 (2005-05-25) abstract; claims 1-3; figure 1 paragraph [0047] - paragraph [0053] -----	1,2,15, 16 3-14
A	DE 10 2016 108027 A1 (GEN ELECTRIC [US]) 3 November 2016 (2016-11-03) abstract; figure 3 paragraph [0055] - paragraph [0060] -----	1,15
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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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

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Date of the actual completion of the international search	Date of mailing of the international search report
14 November 2019	27/11/2019

Name and mailing address of the ISA/	Authorized officer
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 1 533 504 A1 (FIAT RICERCHE [IT]) 25 May 2005 (2005-05-25) abstract; claims 1-5; figure 1 paragraph [0023] - paragraph [0037] -----	1,15

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Information on patent family members

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