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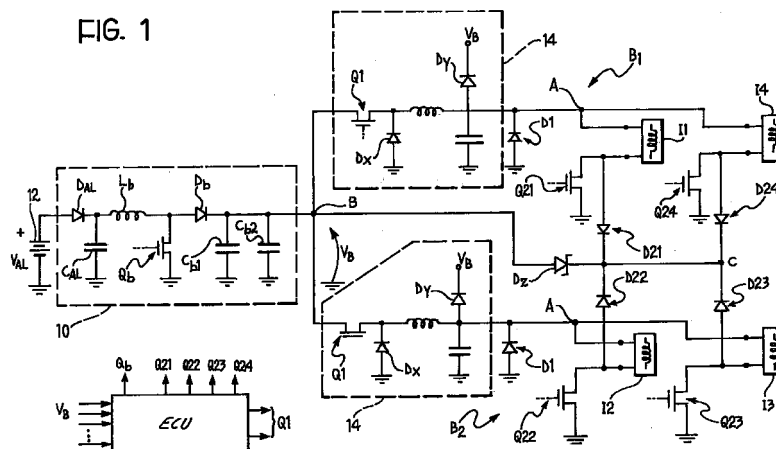
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(54) **A circuit device for driving inductive loads**

(57) A circuit device for driving inductive loads is described, the device being connectable to a direct-current voltage supply (12) and comprising at least one circuit branch (B₁, B₂) for connection to at least one respective inductive load (I₁, I₄; I₂, I₃). Each circuit branch (B₁, B₂) comprises, in combination: a current-regulator module (14) comprising a first electronic switch (Q₁) which is arranged to be turned on by pulse-width-modulated enabling signals so as to regulate the current to be supplied to each load (I₁, I₄; I₂, I₃); sec-

ond electronic switches (Q₂₁, Q₂₄; Q₂₂, Q₂₃) each of which is associated with a respective load (I₁, I₄; I₂, I₃) and which can be turned on selectively in predetermined ways such as to permit a flow of current from the supply (12) through the respective load (I₁, I₄; I₂, I₃); and a current-recirculation network (D₁, D₂₁, D₂₄; D₁, D₂₂, D₂₃) for taking away the transient discharge current generated every time a load is disconnected from the supply (12).



Description

[0001] The present invention relates in general to a circuit device for driving inductive loads, of the type defined in the preamble to Claim 1.

[0002] More specifically, the invention relates to a circuit device for driving fuel injectors for an internal combustion engine or even for the electromagnetic driving of the valves of such an engine.

[0003] The essential requirement in the driving of fuel injectors or electromagnetic valves is precision in the definition of the actuation times. In particular, in the case of a direct-injection system in which the fuel injectors are disposed directly in the combustion chambers, it is necessary to inject precise quantities of fuel at the appropriate moments, overcoming the high pressure present in the chambers.

[0004] This precision can be achieved by rapid actuation of the injector or of the valve, for which it is necessary for the voltages available to be sufficiently higher than the battery voltage available at present in most vehicles (12 volts). It is also necessary to use a circuit which ensures rapid recirculation and possibly recovery of the discharge current typical of an inductive load, thus limiting dissipation towards an earth conductor.

[0005] According to the prior art, current is supplied to the coil of an injector by means of a resonant discharge of a capacitor (the conventional technique used, for example, in the injection of fuel in Diesel engines), or by the partial discharge of electrolytic capacitors which are recharged by means of the discharge current of the coil.

[0006] The greatest disadvantage of these solutions is that they do not permit a rapid succession of repeated actuations of the same injector, for example, in order to perform a multiple injection, which is preferred in direct-injection systems in order to optimize the combustion process. The use of a capacitor in a resonant configuration does not enable a voltage adequate for rapid actuation of the injector to be available at all times since, after the resonant discharge, the capacitor has to be recharged from the battery (or from another supply) before it can again have the necessary energy to operate the injector. Problems of efficiency also arise in a system in which electrolytic capacitors recharged by the injector coils are used if rapidity of operation is required.

[0007] To prevent these problems and in order to drive fuel injectors and/or electromagnetic valves more rapidly and precisely, the subject of the invention is a device for driving inductive loads having the characteristics recited in the appended claims.

[0008] In particular, this device may advantageously comprise a voltage-boosting circuit for increasing the battery voltage, when it is not adequate (12 volt motor-vehicle battery), to a driving voltage of predetermined value which is independent of the number of loads to be driven and which is always available to per-

mit repeated actuations of the same load in rapid succession.

[0009] In the device according to the invention, filtering means are also advantageously provided for eliminating electrical and electromagnetic interference which is produced in operation and which is conducted towards the supply or radiated outwardly, respectively.

[0010] Further characteristics and advantages of the invention will be explained in greater detail in the following specific description, given by way of non-limiting example with reference to the appended drawings, in which:

Figure 1 is a circuit diagram of a first embodiment of the device according to the invention, and

Figure 2 is a circuit diagram of a second embodiment of the device according to the invention.

[0011] In particular, the appended drawings show a device for driving fuel injectors in an internal combustion engine with four cylinders, but the following description may be extended to the more general case of the driving of any number of inductive loads.

[0012] In a first embodiment, the circuit described has, at its input, a voltage booster 10 connected directly to a battery 12. The voltage V_{AL} at the terminals of the battery 12 is raised to a predetermined value V_B at an output node B of the booster circuit 10.

[0013] Two circuit branches, each for driving two injectors, are connected to the node B: a first circuit branch B_1 drives injectors I1 and I4; a second circuit branch B_2 drives injectors I2 and I3.

[0014] In order to keep the notation in the following description to a minimum, corresponding and equivalent circuit elements in each branch are identified by the same reference symbols.

[0015] Each circuit branch comprises a current-regulator module and a filtering circuit, generally indicated as a modulation block 14. The input of this block is connected directly to the node B and its output is connected to a node A of the branch; a first terminal of each corresponding injector coil is connected directly to the node A.

[0016] A second terminal of each injector coil is connected to an earth conductor via a corresponding selection switch $Q2n$ ($n = 1$ to 4) formed as a MOSFET transistor.

[0017] The current-regulator module comprises a switch $Q1$, also formed as a MOSFET transistor, connected to the node B by means of its drain electrode, and to the filtering circuit by means of its source electrode.

[0018] The filtering circuit is represented by a conventional LC circuit arranged in series between the source electrode of the transistor $Q1$ and the node A.

[0019] A first diode D_x connects the earth conductor to the inductor of the LC filter at the source electrode of

the transistor Q1, for the recirculation of the current in the filter during the periods of time in which Q1 is cut off. A second diode D_y is connected between the node A and a node at the potential V_B in order to limit to this value the voltage which can be reached by the node A in operation.

[0020] The device also comprises a recirculation network associated with the injector coils for taking away the transient discharge current which is generated in each coil every time the supply thereto is interrupted by the cutting-off of the transistor Q1 or the corresponding selection transistor Q2n.

[0021] This recirculation network comprises, for each circuit branch, a first recirculation diode D1 of which the anode is kept at the earth potential and the cathode is connected to the node A, and hence to the first terminal of each inductive load of the branch.

[0022] It also comprises a plurality of second recirculation diodes D2n ($n = 1$ to 4) each associated with a respective injector coil and having its anode connected to a second terminal of the corresponding coil and its cathode connected to a node C common to the recirculation paths of all of the coils. The common node C is connected to the node B by means of a Zener diode D_z .

[0023] The input booster circuit 10 is formed in accordance with a known configuration. It has at its input a supply capacitor C_{AL} which is charged by the battery via a supply diode D_{AL} . An inductor L_b is arranged in series downstream of the supply capacitor and is connected to earth via a switch Q_b . A diode D_b arranged in series with the inductor L_b connects the latter to two storage capacitors C_b (C_{b1} and C_{b2}) the positive electrodes of which are connected directly to the output node B and have the predetermined voltage value V_B , relative to the earth conductor.

[0024] In operation, the voltage booster 10 keeps the voltage V_B substantially constant, recharging the storage capacitors when the voltage at their terminals falls below the predetermined value V_B .

[0025] A control unit (ECU) associated with the device detects the voltage present at the node B and drives the switch Q_b accordingly. If the voltage V_B is greater than the predetermined value, the transistor Q_b is cut off and the storage capacitors are discharged progressively, supplying current to the injector coils. When the voltage V_B detected falls below the predetermined value, the control unit turns the transistor Q_b on, drawing current from the battery through the diode D_{AL} and the inductor L_b towards the earth, charging the inductor. The control unit also monitors the current flowing in the transistor Q_b and, when this reaches a predetermined intensity, causes Q_b to be cut off again, so that the inductor L_b is discharged towards the storage capacitors which are consequently recharged. The control unit then repeats the cycle when it again detects that the voltage V_B is below the predetermined value.

[0026] Each injector is actuated by the driving of the transistor Q1 belonging to the circuit branch to which

the coil of the injector in question is connected, and of the transistor Q2n corresponding to that coil, by means of the same control unit.

[0027] The operation of the device during the actuation of the injector I1 will be described below by way of example.

[0028] The coil of the injector I1 is selected by turning the corresponding selection transistor Q21 on. The intensity of the current conveyed through I1 is regulated by the driving of the transistor Q1 of the branch B_1 , by means of pulse-width modulated enabling signals (PWM). The voltage which is established at the node A during the periods of time in which the transistor Q1 is conductive is substantially the voltage V_B minus the potential drop in the transistor Q1. This voltage is limited to a maximum value V_B by the connection of the node A to this reference voltage by means of the diode D_y .

[0029] Since the voltage downstream of Q1 varies rapidly (PWM modulation), the LC filter disposed upstream of the wiring for connection to the injectors limits the slope of the voltage fronts between the node A and earth and eliminates the undesired high-frequency components of the corresponding electric field radiated.

[0030] The particular circuit configuration of the voltage booster 10 (and, in particular, the presence of the inductor L_b) also acts as a filter towards the battery for filtering the current oscillations which are produced as a result of the switching of each of the transistors Q1 and Q_b .

[0031] If there is no voltage-booster circuit owing to the availability of an adequate voltage (for example 42 volts) directly from the battery, an inductance is advantageously provided in series between the battery and each circuit branch as a filter for the current oscillations towards the battery.

[0032] During the periods of time in which the transistor Q1 is cut off, the current from the injector is recirculated through a path constituted by D1, I1 and Q21.

[0033] At the end of the period of actuation of the injector, the selection transistor Q21 is also cut off and recirculation takes place through a path constituted by D1, I1, D21 and D_z , towards the storage capacitors C_b . By virtue of this configuration, with the use of a suitable Zener diode, it is possible to bring the voltage at the node C, which is given by the sum of the reference voltage V_B and of the voltage drop in D_z , to a preferred voltage as large as desired, to permit rapid discharge of the injector coil.

[0034] The choice of connecting the Zener diode to the node B rather than to the earth conductor permits the use of a Zener diode which has a smaller voltage drop at its terminals and hence lesser dissipation problems, and enables some of the energy coming from the injector coils to be recovered by conveying their recirculation current towards the storage capacitors C_b .

[0035] In an alternative embodiment shown in Figure 2, each circuit branch is connected to the battery 12 by means of a voltage-regulator circuit 20 which oper-

ates as a current regulator with bi-directional switching to enable the battery also to be recharged.

[0036] The circuit 20 comprises an inductor L_b arranged in series with the battery, a storage capacitor C_b the positive electrode of which is connected to the output node B and has the predetermined voltage value V_B relative to the earth conductor, and transistors Q_{b1} and Q_{b2} disposed downstream of the inductor L_b and connected, respectively to the positive electrode of the capacitor C_b and to earth. For completeness, the parasitic diodes D_{b1} and D_{b2} between the drain and source electrodes of the transistors are indicated in the drawing.

[0037] During operation as a voltage booster, the circuit 20 behaves in the same manner as the voltage-booster circuit 10 of Figure 1, the transistor Q_{b1} , which is turned on, corresponding to the diode D_b .

[0038] If the storage capacitor C_b is over-charged by the recirculation current coming from the injector coils, the control unit recognizes this condition by detecting the voltage present at the node B and drives both of the transistors appropriately so as to allow the storage capacitor to release current towards the battery, which is recharged.

[0039] Naturally, the principle of the invention remaining the same, the forms of embodiment and details of construction may be varied widely with respect to those described and illustrated purely by way of non-limiting example, without thereby departing from the scope of protection of the present invention as defined in the appended claims.

Claims

1. A circuit device for driving inductive loads, which can be connected to a direct-current voltage supply (12) and comprises at least one circuit branch (B_1 , B_2) for connection to at least one respective inductive load (I1, I4; I2, I3), the circuit device being characterized in that the at least one circuit branch (B_1 ; B_2) comprises, in combination:
 - a current-regulator module (14) having an input for connection to the voltage supply (12), its output being intended to be connected to a first terminal of the at least one respective inductive load (I1, I4; I2, I3), the module (14) comprising first electronic switching means (Q1) arranged to be turned on so as to regulate the current to be supplied to the at least one load,
 - second electronic switching means (Q21, Q24; Q22, Q23) each of which is associated with a respective load (I1, I4; I2, I3) and which are intended to be connected between a second terminal of the load and a conductor which is kept at a first reference potential, the second switching means (Q21, Q24; Q22, Q23) being

capable of being turned on selectively in predetermined ways such as to permit a flow of current from the supply (12) through the respective load (I1, I4; I2, I3) when the first switching means (Q1) are turned on, and

- a current-recirculation network (D1, D21, D24; D1, D22, D23) associated with the at least one inductive load (I1, I4; I2, I3) in order to take away the transient discharge current which flows therein every time such a load is disconnected from the voltage supply (12), the recirculation network comprising:

a first recirculation diode (D1) of which the anode is kept at the first reference potential and the cathode is connected to the first terminal of the at least one inductive load, and at least one second recirculation diode (D21, D24; D22, D23) which is associated with a respective load (I1, I4; I2, I3) and of which the anode is connected to a second terminal of the respective load and the cathode is connected to a node (C) which can be controlled at a second reference potential, the second reference potential being controlled by corresponding voltage-regulation means.

2. A circuit device according to Claim 1, characterized in that the at least one circuit branch (B_1 ; B_2) comprises a filtering circuit arranged between the first switching means (Q1) and the first terminal of the at least one load (I1, I4; I2, I3) for filtering the harmonic voltage components which are generated downstream of the first switching means (Q1) when the circuit is in operation.
3. A circuit device according to Claim 2, characterized in that the filtering circuit is an LC filter.
4. A circuit device according to any one of the preceding claims, characterized in that the voltage-regulator means comprise a Zener diode (D_z) of which the cathode is connected to the cathode of the at least one second recirculation diode (D21, D24; D22, D23) and the anode is kept at the first reference potential.
5. A circuit device according to any one of Claims 1 to 3, characterized in that the voltage-regulator means comprise a Zener diode (D_z) of which the cathode is connected to the cathode of the at least one second recirculation diode (D21, D24; D22, D23) and the anode is connected to the voltage supply (12).
6. A circuit device according to any one of the preceding claims, characterized in that the at least one cir-

cuit branch (B_1 ; B_2) can be connected to the voltage supply (12) via a voltage booster (10) adapted to generate a voltage of predetermined value (V_B) from the supply voltage (V_{AL}), the predetermined value then being supplied to the input of the current-regulator module (14).

7. A circuit device according to any one of Claims 1 to 3, characterized in that the at least one circuit branch (B_1 ; B_2) can be connected to the voltage supply (12) via the voltage-regulator means, and in that the regulator means comprise a switching current-regulator circuit (20) arranged to operate as a booster of the voltage from the supply (12) towards the circuit branch (B_1 ; B_2) and as a reducer of the voltage from the circuit branch (B_1 ; B_2) towards the supply (12).
8. A circuit device according to Claim 7, characterized in that the switching current-regulator circuit (20) comprises, in combination:
 - an inductive element (L_b) having a first terminal which can be connected to the direct-current supply (12),
 - a capacitive element (C_b) having a first terminal connected to a second terminal of the inductive element (L_b) by means of a first switch (Q_{b1}), and a second terminal connected to an earth conductor, and
 - a second switch (Q_{b2}) connected between the second terminal of the inductive element (L_b) and the earth conductor, the capacitive element (C_b) being able:
 - to receive a current from the inductive element (L_b) in order to increase the voltage (V_B) at its own terminals so as to reach a voltage which is greater than the voltage (V_{AL}) provided by the supply (12) and corresponds to the second reference potential;
 - to receive a discharge current from the recirculation network ($D1$, $D21$, $D24$; $D1$, $D22$, $D23$), and
 - to release a current towards the supply (12) when the voltage (V_B) at its own terminals has exceeded a predetermined value corresponding to the second reference potential.
9. A circuit device according to any one of the preceding claims, characterized in that it comprises a control unit (ECU) for turning the first and second switching means ($Q1$; $Q21$, $Q24$, $Q22$, $Q23$) on in predetermined ways such as to regulate the inten-

sity of current to be supplied to the at least one load ($I1$, $I4$, $I2$, $I3$), and such as selectively to supply the current to the at least one load ($I1$, $I4$, $I2$, $I3$), respectively.

10. A circuit device according to Claim 9, characterized in that the control unit (ECU) is adapted to turn the first switching means ($Q1$) on by means of pulse-width modulated enabling signals.
11. A circuit device according to any one of the preceding claims, characterized in that the first and second switching means ($Q1$; $Q21$, $Q24$, $Q22$, $Q23$) are formed as MOSFET transistors.
12. A circuit device according to Claim 8, characterized in that the first and second switches (Q_{b1} , Q_{b2}) are formed as MOSFET transistors.

FIG. 1

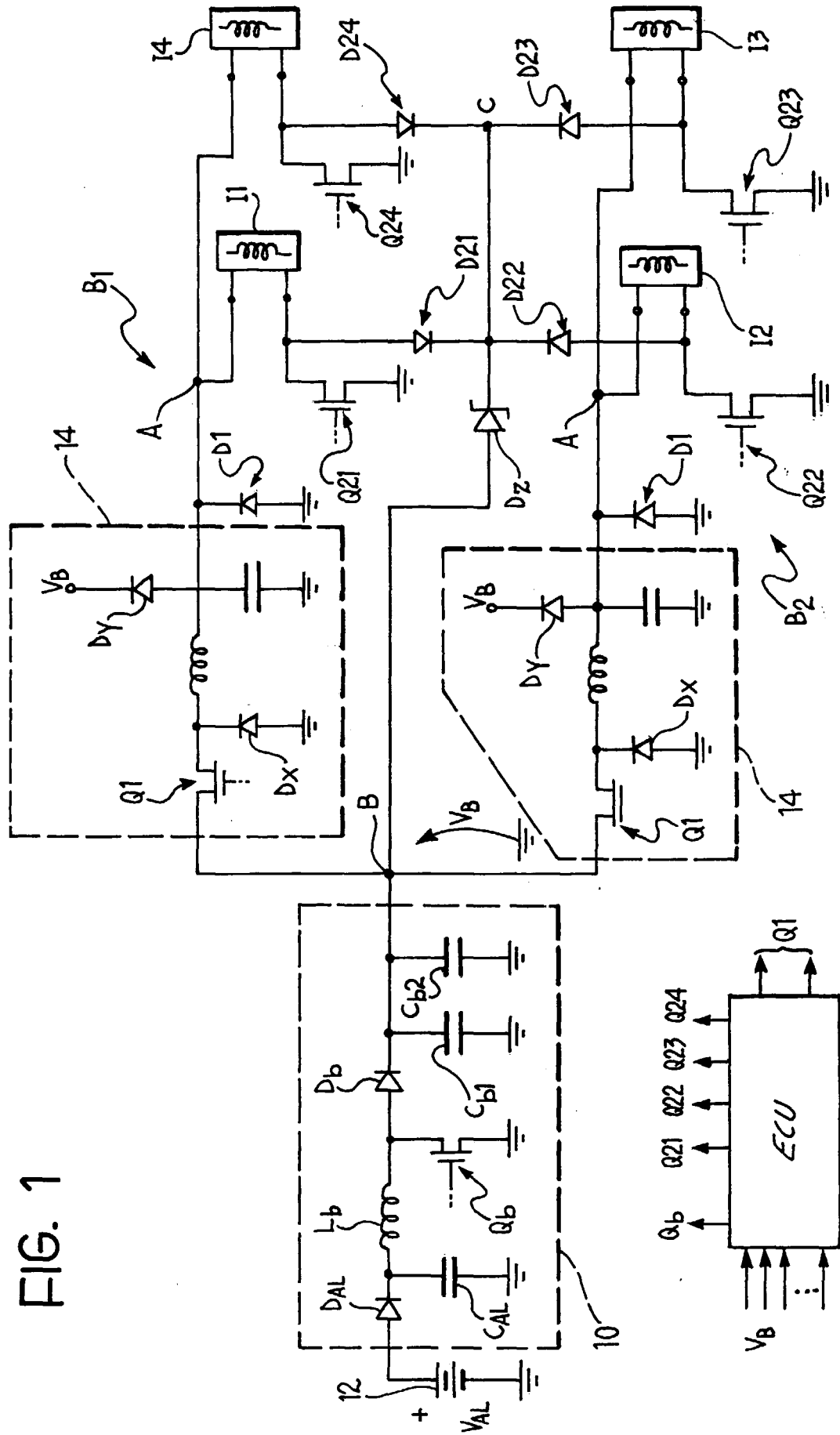
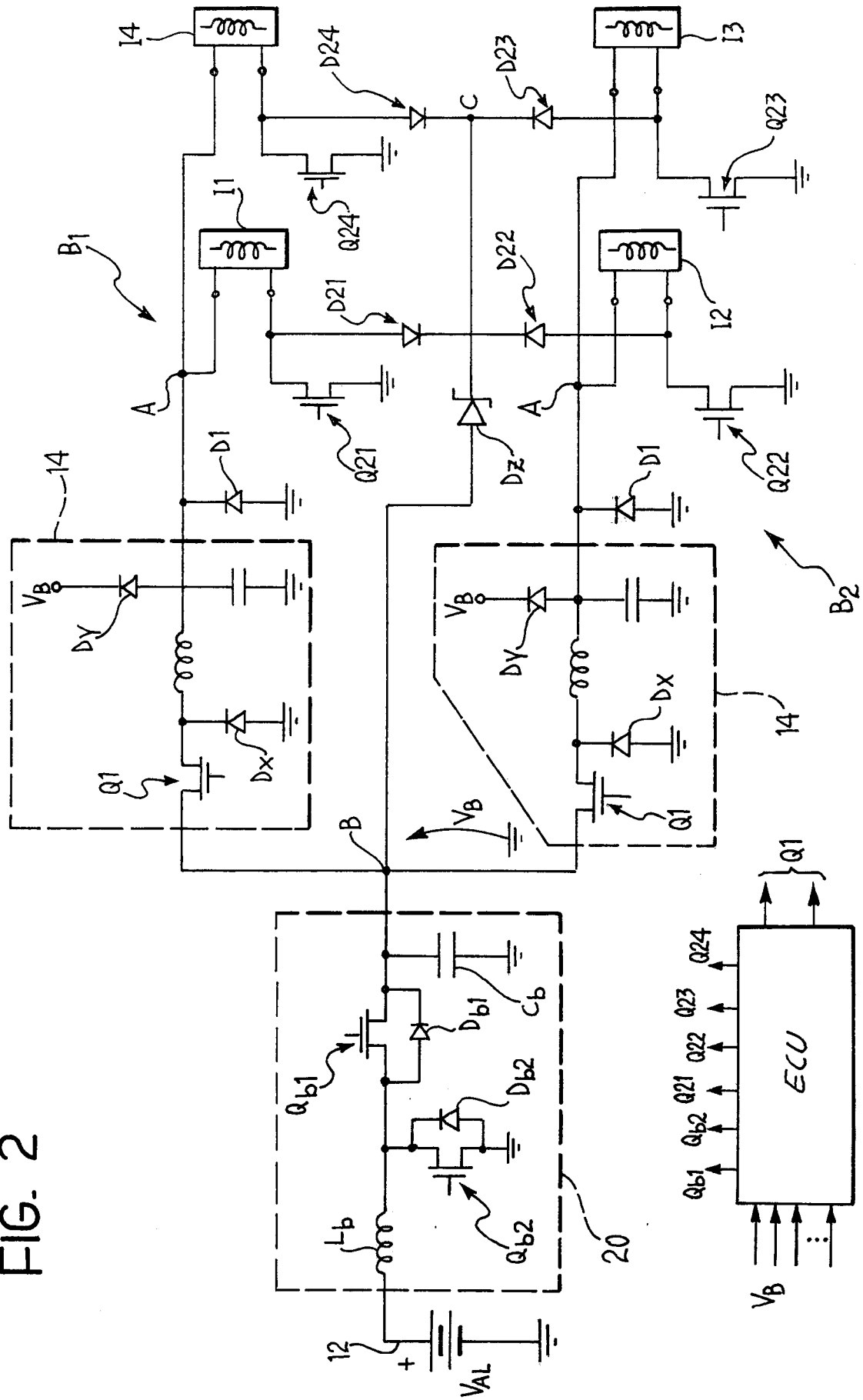


FIG. 2





European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 99 12 4311

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
A	EP 0 478 436 A (RENAULT) 1 April 1992 (1992-04-01) * abstract *	1	F02D41/20
A	US 4 862 866 A (CALFUS MARCO) 5 September 1989 (1989-09-05) * abstract *	1	
			TECHNICAL FIELDS SEARCHED (Int.Cl.7)
			F02D H01F H01H
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 14 March 2000	Examiner Salm, R
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 99 12 4311

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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14-03-2000

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