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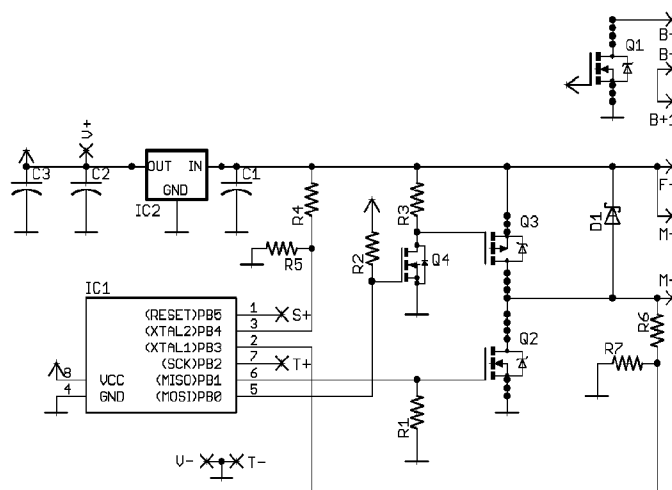


FIG. 1

(57) Abstract: A motor controller and method for providing motor control having a microcontroller debounced switch that may operate as a user interface permitting selection between varied modes of operation. The motor controller has a means for detecting motor stall and providing constant motor performance independent of supply voltage. Embodiments include a polarity protecting means utilizing a low-side MOSFET switch, an overcurrent protecting means, a high- and low- voltage protecting means, a high- and low-temperature protecting means, and a MOSFET half H-bridge to provide control and braking. Other embodiments utilize a relay. Embodiments of the motor controller include a load-sensing means measuring back-EMF including a timeout means to cut motor power to prevent motor runaway. A method for providing Automatic Electric Guns with a motor controller.

ELECTRONIC MOTOR CONTROLLER AND METHOD FOR CONTROLLING A MOTOR

CROSS-REFERENCE TO RELATED APPLICATIONS

5 [0001] This application claims the benefit of priority under 35 U.S.C. §119(e), of U.S. Provisional Application 60/937,806, filed on June 28, 2007, entitled “ELECTRONIC MOTOR CONTROLLER FOR TOY GUN” and U.S. Provisional Application 61/001,355, filed on November 2007, entitled “ELECTRONIC MOTOR
10 CONTROLLER FOR TOY GUN” the entirety of which is incorporated herein by reference and made a part of the present disclosure.

FIELD OF THE INVENTION

[0002] The present invention relates to motor controllers generally, and more
15 particularly to motor controllers incorporating logic-based switching and control.

BACKGROUND

[0003] As motor controllers are well described generally in the prior art, one application for the present inventive motor controller permits improved use with electric,
20 motor-driven toy guns known as an Airsoft Automatic Electric Gun (AEG). A typical AEG is described in U.S. Pat. No. 5,261,384 to Hu, incorporated herein by reference and U.S. Pat. No. 6,564,788 to Hu, incorporated herein by reference. Such devices attempt to replicate their real firearm counterparts in appearance and function. These guns typically fire in single-shot semi-automatic mode, as well as fully-automatic mode. Some fire in a
25 "burst" mode for a predetermined number of shots or period of time. Many AEGs use a motor that is driven by a battery, switched on and off using one or more trigger switches, and may generally feature an electromechanical or timed cutoff to stop the motor after one or multiple shots. The present invention may be applied to a variety of applications including AEGs, AEPs, AEG Boys, Electric Blowback (EBB) Pistols, Hybrids,
30 Low/Medium Powered Electric Guns, mini electrics, and Radio Controlled Battle Tanks.

[0004] However, due to its simple electromechanical design, an AEG's projectile-firing behavior does not mimic that of an automatic firearm. An automatic firearm fires at a consistent rate from the first to last round, and can jam and stop firing from overheating if fired continuously. When the battery is fully-charged, the typical AEG rate of fire is relatively rapid. As the charge decreases, the rate of fire also drops proportionally with respect to the battery voltage. More specifically, the drop in the rate of fire is initially relatively sharp followed by a period of modest drop, and then finally by a period of sharp drop when the battery is near depletion.

[0005] While relatively simple electronic controllers have been described in the prior art, AEGs fitted with these controllers behave much the same as their non-electronic counterparts. Without proper excess current, reverse battery, static discharge, and temperature protection in place, these relatively simple and fragile electronic controllers are more prone to damage and failure during typical gun use. The present invention differs from prior art in that it, *inter alia*, reduces initial motor speed to maximize battery life and realism and analyzes the battery type and sets the controller operating parameters according to a list of known battery types. Further, to measure motor speed, known prior art solutions use more complex algorithms such as back-EMF measurements that require repeatedly cutting off the motor's power for brief periods of time in order to measure generated EMF across the motor terminals. Other prior art uses current sensing resistors to determine motor current. My invention does not require removal of power or the addition of resistance to the motor power circuit, and so the motor is able to deliver efficient, uninterrupted speed and power. Because of the high motor speed, measuring back-EMF noticeably slows motor rotation. My method for regulating speed and power usage adapts to a variety of motors and batteries without the added complexity of rotation sensors and associated circuitry, and the added time spent calculating motor rotation and load. Additionally, in known prior art solutions, where motor voltage and regulation is not implemented, the motor speed over time curve is proportional to the battery voltage over time curve. That is, the motor rotates at a higher speed when the battery is at higher charge levels, then tapers to a more gradual decreasing curve, and then drops steeply near the end of the charge. Known prior art solutions allows AEGs to run at a speed

proportional to battery voltage which imparts the same function as the gun's original design. With the present invention, the motor spins at a regulated, pulse-width-modulated voltage as if the battery is always near its resting voltage or user-specified level. Near the end of the charge, the controller increases the duty cycle to bolster the falling voltage and attempts to maintain the speed of the motor as long as possible. By conserving initial charge capacity, the controller increases battery life over that of an AEG without the controller. Further, unlike known prior art which detects whether the motor has already stopped moving through the timing of motor rotation, the present invention can detect and stop the motor while it is still running (but slowing and nearing stall) to protect it from excess current, overheating, and damage to the controller and motor. Moreover, it is believed that prior art AEGs do not employ means to protect against excess temperature. Regarding configuration of sensors, it is believed that prior art is either not configurable, or uses jumpers, potentiometers, and other controls to configure and adjust sensors. Further, the prior art is believed to be relatively limited with regard customization.

SUMMARY

[0006] One aspect of the present invention permits motor control using a microcontroller, a MOSFET half H-bridge, and a low-side MOSFET switch. The low-side MOSFET switch may advantageously provide reversed battery polarity protection, as it is not uncommon for RC battery packs (having opposite polarity) to be erroneously inserted in place of Airsoft battery packs. Another aspect of the present invention permits the motor to be started and stopped with a low-voltage, low-current, microcontroller-debounced trigger switch to reduce power loss and contact wear caused by mechanically switching higher motor voltages and currents. Another aspect of the invention permits an operation switch, which in one embodiment is a gun trigger, to function as a user interface, allowing the user to select between different modes of operation. Another aspect of the present invention provides for a regulated, low-voltage power supply permitting use of optional sensors and optional external components requiring an external power supply. Another aspect of the invention provides regulation of motor speed and performance using pulse-width modulation (PWM) to provide

consistent motor performance, which maximizes battery life, and/or permits use of smaller, lighter, and/or lower-capacity batteries. Still another aspect of the invention regulates motor speed by sensing power supply voltage through use of microcontroller analog-to-digital converter channels instead of costly and technically complex position and rotation sensors on the motor. Another aspect of the present invention provides a means to detect motor stall or impending motor stall and a means to interrupt the power supply in such circumstances to advantageously minimize motor heating and excess current generation. Another aspect of the present invention reduces excess motor spin through braking, which permits a motor to stop in a predictable manner. Excess motor spin supplies current back to a rechargeable power source, both with and without the microcontroller in a deep sleep mode.

[0007] In one particular embodiment, the present invention is applied to providing a more realistic and efficient operation of an AEG to permit the gun's trigger to function as a user interface allowing user selection between firing modes including timed, indexed, or continuous motor run modes with adjustable run times and index positions by using an optional sensor or back-EMF sensing. The present invention also discloses two methods for fitting AEGs with the present inventive motor controller. Additionally, the present invention may permit a more refined motor starting to minimize AEG gear tooth breakage from sudden, full-voltage, high-torque motor starts by gradually increasing the voltage used to start the motor until it reaches a target voltage. Prior art applies the full voltage or target duty cycle immediately at startup, or applies a duty cycle and repeatedly measures the motor feedback to adjust the duty cycle. Motor speed and performance may be controlled using pulse-width modulation (PWM) to provide consistent firing rates, maximize battery life, and/or allow the use of smaller, lighter, and/or lower-capacity batteries to save size and weight. Further, the present invention provides a regulated, low-voltage power supply for an optional sensor or other optional external components that require such a power supply. Additionally, the present invention may reduce excess motor spin when higher-voltage batteries are used so that the air piston and projectile loader consistently start and stop in the same position during single and timed motor run modes, and optionally under indexed and continuous modes, and recharge the battery

when the controller is slowing the motor by directing generated current and voltage back to the battery.

[0008] Because the trigger switch may be used to configure the parameters of the present invention, the controller can be easily adapted and fitted to existing gun designs. This characteristic is different from some prior art devices which require additional switches or compound switches to actuate or configure operating modes and parameters. The present invention offers greater motor and battery regulation and protection without the need for redesign, added space, and added circuitry to accommodate additional switches and controls. However, the controller permits incorporation of an additional, optional switch or sensor where desired.

[0009] Further, in one embodiment, battery readings are averaged over a plurality of ADC samples to filter noise, and the averaged result is stored in an multi-value circular buffer, with a running average of the buffer values is calculated by the microcontroller. In a further specific embodiment, battery readings are averaged over 8 ADC samples to filter noise. Furthermore, the averaged result is stored in a 8-value circular buffer, and a running average of the buffer values is calculated. This provides for a smoother, more predictable battery discharge curve for use in analysis by the controller. This differs from known prior art that utilize single, instantaneous samples.

[0010] Another aspect of the invention provides a safety timer cutoff. If no back-EMF is detected, a timer cuts power to the motor as a safety feature to prevent runaway firing when the trigger is released and no activity is detected causing the motor to continue running.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1 is a schematic drawing of one embodiment of the motor controller.

[0012] FIG. 2 demonstrates top layer copper and placement of one embodiment of the controller.

[0013] FIG. 3 demonstrates bottom layer copper and placement of one
5 embodiment of the controller.

[0014] FIG. 4 is a schematic demonstrating an embodiment bus-powered USB programming cable and module.

10 [0015] FIG. 5 demonstrates programming cable top layer copper and placement of one embodiment of the controller.

[0016] FIG. 6 demonstrates programming cable bottom layer copper and placement of one embodiment of the controller.

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[0017] FIG. 7 is a block diagram depicting an embodiment plug-in location of the motor controller relative to the battery and trigger.

[0018] FIG. 8 is a block diagram depicting an embodiment hard-wired location of
20 the motor controller relative to the battery and trigger.

[0019] FIG. 9 illustrates an alternative embodiment electronically controlled motor relay with brake.

25 [0020] FIG. 10 demonstrates top and bottom copper and placement for a motor relay embodiment.

[0021] FIG. 11 is a flow diagram demonstrating an embodiment controller initialization, configuration, and entering and exiting a sleep state.

[0022] FIG. 12 is a flow diagram demonstrating an embodiment main motor loop.

[0023] FIG. 13 is a flow diagram demonstrating an embodiment timer overflow interrupt: shot timing/counting, and trigger/sensor filtering.

[0024] FIG. 14 is an example embodiment sample output from the controller during configuration mode.

DETAILED DESCRIPTION OF CERTAIN PREFERRED AND ALTERNATIVE EMBODIMENTS

[0025] Regarding example components contained in one embodiment of the invention, FIG. 1 illustrates one exemplar schematic diagram. It is important to note that the present invention should not be construed to be limited to the disclosed example embodiment. B+ and B- are the battery positive and negative wire leads. M+ and M- are the motor positive and negative leads. Not shown in illustration 1 is a mini blade fuse and holder installed across pads B+1 and F+. The holder is a pair of universal fuse clips, one soldered to each pad, and positioned horizontally to minimize thickness of the completed assembly. T- and V- are digital signal ground pads for both trigger switch input T+ and switch/sensor input S+. T+ and S+ are also used as a two-wire, serial interface with T+ as the receive pin and S+ as the transmit pin. FIGS. 2 and 3 illustrate the copper layers, stop masks, and component placement on the circuit board.

[0026] IC2 is an STMicroelectronics LD2981 5V, low-dropout, linear voltage regulator that provides power to a microcontroller (IC1) as well as any optional external sensors and components. The LD2981 accepts up to 16V DC input which allows the use

of standard 7.2V to 12V nickel-cadmium and nickel-metal-hydride rechargeable battery packs as well as 2- to 3-cell lithium-based battery packs. The low-dropout feature helps the regulator provide clean 5V power through the periods of low, depleted battery voltage levels as well as the voltage dip that occurs when the motor starts. Other regulators with similar or greater features and capabilities can be substituted. C1 and C2 provide the recommended, manufacturer-specified noise filtering and dropout protection. C3 provides filtering of the programming interface power supply or auxiliary 5V supply provided by the controller to external components and sensors. When the programming connector is connected, power from the connector is applied to the low-voltage regulated output side. An optional protection diode may be required between the input and output pins of the regulator if it cannot tolerate higher voltage on the output side versus the input side.

[0027] Q1 and Q2 are NXP/Philips PH4840S LFPAK N-channel, logic-level MOSFETs that are used as a low-side, reverse battery switch and motor power switch, respectively. They are capable of handling large motor currents. Because of the compact size requirement, no additional heat sinking can be provided and therefore a greatly overrated part is used. The use of LFPAK and SOIC-8 form factors with the circuit board design shown above allow the board, battery leads, and motor leads to conduct heat away from the MOSFETs. Other models and form factors of MOSFETs with similar or greater features and capabilities can be substituted. In another embodiment, a heavy-duty version of the controller can be constructed with International Rectifier IRL3713 TO-220 or TO-262 MOSFETs, for example, for Q1 and Q2. These larger MOSFETs can handle more current and dissipate more heat. In either version, multiple parallel MOSFETs can also be used for higher current-handling capability.

[0028] The gate pin of Q1 is connected to the regulated, low-voltage output of IC2. When the battery is properly connected, IC2 supplies a low voltage to the gate and the low-side MOSFET Q1 is turned on causing the controller's ground to be connected to the battery negative terminal. When the battery terminals are reversed, the regulator is off and Q1 stays off.

[0029] In this embodiment, the gate pin of Q2 is connected to one of the PWM output pins of microcontroller IC1. The PWM timer for switching the motor has multiple drive frequencies available allowing the user to select the best frequency for maximizing motor torque and efficiency.

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[0030] Q3 is a Fairchild Semiconductor FDS6681Z SOIC-8 P-channel MOSFET that is used as a regenerative brake connecting the motor terminals. It is also greatly overrated to withstand the current surge during fast braking without the need for additional heat sinking. Other models and form factors of MOSFETs having similar or greater features and capabilities may be substituted. Both Q2 and Q3 MOSFETs feature avalanche diodes and form a half H-bridge. D1 is a fly-back diode and provides additional brake current-handling capability. Use of the diode is recommended to absorb high transient voltages that can damage the MOSFETs. Other transient voltage suppression (TVS) devices and snubber circuits of similar or greater capabilities can be substituted. An additional TVS device can also be installed between M- and ground to protect against ground spikes. In a heavy-duty embodiment version of the controller, Q3 is an STMicroelectronics P80PF55 TO-220 or TO-262 MOSFET, for example. In either version, multiple parallel MOSFETs can be used for higher current-handling capability.

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[0031] Q4 is an NXP/Philips BSS123 N-channel MOSFET that is used to switch the gate of Q3 at battery voltage. Other logic-level MOSFETs with similar or greater features and capabilities can be substituted. External pull-up resistors R2 and R3 are used because the internal pull-up resistors in the Atmel ATtiny85 microcontroller (IC1) are disabled while it is asleep and the microcontroller enters its deep sleep state before the motor can come to a full stop, and continued brake application is needed. R1 ensures that the low-side motor switch is off whenever the controller is in a brownout condition and helps prevent both MOSFETs of the half bridge from conducting simultaneously, thereby causing a short circuit. A diode in series with R3 and a capacitor across Q4 can be added to further prevent short circuits during low battery conditions. Further, although the brake is not driven by PWM in normal use, it could be PWM-driven if necessary. An optional

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dead time generator on the controller prevents Q2 and Q3 from activating simultaneously and allows conventional back-EMF sensing to be implemented.

[0032] R4 and R5 form a resistor divider to measure battery voltage and voltage
5 at the positive terminal of the motor. R6 and R7 form another resistor divider to measure voltage at the negative terminal of the motor. Each resistor divider is connected to an analog-to-digital converter input pin on the microcontroller. The resistors are sized so that the converters can measure the full range of battery voltages supported by the controller and MOSFETs. Capacitors can be installed and stacked on top of R5 and R7 to
10 reduce measurement noise from the running motor.

[0033] The Atmel ATtiny85 microcontroller features an internal temperature sensor connected to an analog-to-digital converter channel. Other microcontrollers with similar or greater features and capabilities can be substituted. The MOSFETs Q1, Q2, and
15 Q3 are mounted so that their heat spreaders face the circuit board and transfer their heat to the case of the microcontroller allowing a more accurate temperature measurement.

[0034] The trigger switch positive input T+ is connected to an external interrupt
20 input pin (INT0) on the microcontroller. When the trigger switch is closed, an interrupt is generated and the microcontroller wakes from its deep sleep.

[0035] The external reset pin of the microcontroller is disabled so that it can be used as an input pin for the external sensor/switch (S+). The internal pull-up resistor is
25 enabled when the controller is configured for use with an active low sensor, and disabled when used with an active high sensor. An external pull-up resistor is not needed since the sensor can be disabled while the gun is not firing.

[0036] Optional resistors in series with the MOSFET gate pins provide
30 microcontroller and regulator protection in case the MOSFETs fail. Optional color LEDs can also be added to each gate circuit to indicate MOSFET switching, or as

condition/status indicators during operation and configuration. Optional resistor/capacitor filters provide noise suppression on the trigger and sensor inputs. The optional components can be omitted to satisfy space and other functional requirements of the controller depending on the application.

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[0037] In one alternative embodiment heavy-duty version of the controller, high-voltage, high-current pads connect wires directly to the MOSFET leads. This configuration eliminates the need for wide traces such as those used in the standard version yet still allows for a compact circuit board. Instead of the thicker, silicone-
10 insulated wires found in many AEGs, PTFE/*Teflon*-insulated wires may be used to further minimize space requirements.

[0038] On a heavy-duty embodiment of the controller, surface-mount and through-hole components are mounted to both sides of the circuit board to take advantage
15 of available space. The standard controller uses surface-mount components to save space.

[0039] Pads may be labeled to ease attachment of color coded wire segments or connectors. The standard version has pads located on both ends to minimize the controller's space usage. The completed assembly can be encased in epoxy or silicone
20 with a moisture- and abrasion-resistant coating or sleeve around it.

[0040] A low-voltage, low-current, logic-level trigger switch is used to reduce power loss, contact wear, and pitting from arcing caused by a traditional switch that directly controls higher motor voltages and currents. With filtering, switch bounce from
25 unintentional and intermittent switch contact, poor switch quality, and worn and pitted switch contacts is noticeably reduced. Switch operation is precise and reliable, and the AEG behaves more closely to the firearm that it attempts to replicate.

[0041] The trigger switch is also used to configure the controller to run the motor
30 in timed, indexed, and continuous modes. The controller prevents the motor from starting when the trigger switch is closed and the battery is connected. This safety feature allows

the initial closure of the switch to toggle the controller between timed, indexed, and continuous motor run modes. It also reduces the chances of an accidental discharge if the trigger is pulled while the battery is installed.

5 **[0042]** The trigger switch is also used to adjust the timeout period for timed and indexed motor run modes. The timeout is selected from a range of fixed time periods, but can also be a starting value that the controller uses as it measures the motor's behavior and adjusts itself accordingly. For example, the controller can measure the time elapsed for a single shot, and then extrapolate the time required for a burst of shots. Thus, the
10 controller can adapt to a variety of AEG motors, springs, and gear box designs.

[0043] It should be noted that lower voltage microcontrollers (ie. 3.3V, 2.5V, 1.8V) may be used in order to save power, and especially in the case of battery-powered devices. It will be recognized by those skilled in the art, that although there are
15 MOSFETs that respond to lower gate voltages, there are fewer higher-powered models that do. Therefore, a second smaller MOSFET may be required to drive the gate, not unlike the braking MOSFET used in the present invention. The same principle of adding a smaller MOSFET may be used on the motor MOSFET for lower-powered microcontrollers.

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[0044] FIGS. 7 and 8 illustrate two methods for wiring AEGs with the subject electronic motor controller. The first embodiment plug-in installation 700a provides installation places motor controller 225a within the 3AG fuse holder typically used in an
25 AEGs, and connects controller 225a between the AEG and battery 702a using the existing electrical connectors. Thus, the controller can be installed without disassembling the gun housing and without permanent changes to the wiring. In this embodiment configuration, the controller provides limited braking function and the higher motor voltage passes through trigger switch 706a. Since there is a short delay from the time
30 trigger switch 706a closes to the starting of motor 704a, switch arcing is reduced when controller 225a is installed. Controller 225a automatically detects the installation

configuration. When controller 225a is connected between the gun and the battery 702a, the battery voltage does not appear on the negative motor terminal because the trigger switch 706a is in series with motor 704a and is open. In addition, this method will only work if the original trigger switch was installed on the negative, low-side wire. If the trigger switch is installed on the high side, the AEG will not fire when the trigger is pulled.

[0045] In the second embodiment, illustrated by FIG. 8, the motor controller 225b is hard-wired, the battery voltage appears on both motor terminals. The analog-to-digital sensors are described further below.

[0046] Regarding fuse protection, the present invention replaces the existing 3AG fuse with a commonly-available, automotive-type mini-blade fuse, such as the Littlefuse 897 (not shown). In alternative embodiments, circuit breakers, self-healing fuses, and other types of reusable, excess-current protection devices designed to replace mini-blade fuses can also be used in place of the supplied fuse.

[0047] The battery negative terminal is switched with a low-side, N-channel MOSFET for reverse battery protection. The gate of this MOSFET is connected to the output of the controller's voltage regulator such that when the battery is connected in reverse, the regulator is off and the MOSFET switch is open. Because the gate voltage is regulated, the MOSFET will not be damaged if a high voltage power source is connected that exceeds the maximum allowable gate threshold. In most cases, the same model MOSFET that is used as the low-side motor switch can be used because of the equivalent amount of current that it must handle.

[0048] The present invention regulates motor speed, including in one embodiment, the speed of an AEG motor using pulse-width modulation (PWM) in order to increase battery life and maintain realistic and consistent firing behavior. Motor speed is regulated through analog-to-digital converter channels (ADC) of a microcontroller and

a resistor divider to measure the battery voltage when the battery is first connected to the controller and just before each time that the motor is started.

[0049] The microcontroller uses the ADC voltage value to determine the size of the battery installed and calculate the initial PWM duty cycle needed to run the motor at the appropriate speed for maximizing the life of the battery. Since the voltage applied to the motor is proportional to its speed, a voltage value close to the resting voltage of the battery is applied to the motor via PWM. It should be noted that various hardware PWM frequencies (and even multiple frequencies within the firing cycle) can be used to minimize MOSFET switching power loss and heat generation. The PWM frequency is scaled off of the microcontroller's system clock. The microcontroller is programmed to contain tables of battery parameters for different standard battery types. If the user wants a faster or slower rate of fire, a higher or lower-voltage battery can be used, respectively. The controller can also be configured by the user (described below) with the performance and battery parameters desired. My invention differs from prior art in that it reduces initial motor speed to maximize battery life and realism, and analyzes the battery type and sets the controller operating parameters according to a list of known types.

[0050] For battery-powered motors, the battery charge decreases at a higher rate as the load is increased, therefore monitoring the battery voltage before and during motor operation is a good way to determine the work that a motor has done. Since the load driven by an example AEG motor is identical for each rotation and a typical motor runs at 20,000 rpm or higher, the inventive method of monitoring the battery voltage to regulate the motor's speed is adequate for most AEGs.

[0051] The present invention starts the motor with the PWM duty cycle at 0% (or some other user-preset value) and increases it to the target level over a relatively short period of time. In one embodiment, it increases the duty cycle at a rate of roughly 0.39% per PWM cycle and this rate can be changed by the user. For example, as the duty cycle may range from 0 to 255, incrementing the cycle by 1 will yield a 0.39% or 1/256 increase. However, the firmware may be changed to optimize the start and ramp values

to most efficiently drive a particular motor and gearbox found in a specific AEG. By ramping the duty cycle, the moving parts engage more slowly and gradually. Since motor 704 startup period is brief and involves little initial motor movement, the added time, effort, and cost of removing power from motor 704 and monitoring rotation feedback is not worthwhile and detracts from applying continuously increasing power to start the initial rotation.

[0052] When controller 225 reaches target duty cycle, controller 225 continues to monitor battery 702 voltage and adjust the duty cycle to compensate for decreasing voltage as battery 702 charge depletes. If the voltage drops below a preset threshold for a particular size of battery, then controller 225 stops motor 704 to prevent further charge depletion of battery 702. If motor 704 has not yet started but the user closes the trigger switch 706, then controller 225 prevents motor 704 from starting and draining the already depleted battery 702.

[0053] Nickel-metal hydride (NiMH), nickel-cadmium (NiCd), and lithium-based rechargeable batteries can be irreversibly damaged if they are allowed to discharge below a certain voltage. Over time, the battery capacity diminishes. The low voltage threshold differs between battery types, and for NiMH and NiCd batteries is approximately equal to the number of cells in the battery. The present invention uses the initial voltage of a fully-charged battery to determine motor's 704 optimal target duty cycle for maximizing battery life and the low voltage threshold of a depleted battery. The microcontroller contains tables of depleted voltage thresholds and other battery parameters pertaining to each type of commonly-used AEG battery. The user can also specify these thresholds and parameters. The controller 225 continues to monitor battery levels while the motor is running to maintain a consistent speed and shut off the motor if the battery is depleted.

[0054] The positive terminal of battery 702 is connected to the positive terminal of 704 motor, so the analog-to-digital converter described earlier also measures the voltage applied to the positive terminal of motor 704. My invention uses a second analog-to-digital converter channel on the microcontroller to measure the voltage of the negative

terminal of motor 704 after it has reached its target duty cycle. The negative terminal is also connected to the drain of an N-channel, logic-level MOSFET which my invention uses as a low-side, high-current, low on-resistance power switch. The source of the N-channel MOSFET is connected to the negative terminal of battery 702 (ground). The following formula is used to calculate voltage drop across a DC motor:

$$V(\text{neg terminal}) = \text{EMF}(\text{forward}) - \text{EMF}(\text{backward}) - (I(\text{motor}) * R(\text{motor}))$$

Since we know that back-EMF is zero for a halted or stalled motor, and motor resistance is very small, we can assume that those terms drop out of the equation. So, at stall:

$$V(\text{neg terminal}) = \text{EMF}(\text{forward})$$

Forward EMF is simply the voltage applied to a motor from a battery. Thus, the voltage at the negative terminal is the same as the voltage at the positive terminal if a motor has stalled. After motor 704 has started, the present invention monitors the voltages at each motor terminal and when they are nearly equal, the controller 225 immediately cuts power to motor 704 to prevent high current from flowing through motor 704. A threshold value defines when the voltages are nearly equal, and can be changed by the user.

[0055] Under heavily-loaded conditions, back-EMF monitoring can be used for counting shots. Since the motor is compressing a heavy spring behind the piston and suddenly releasing it, the voltage at the negative terminal will approach the voltage applied at the positive motor terminal. Higher microcontroller system clock speed, faster analog-to-digital converters, and finer tuning specific to motor, gear, and spring configurations may be utilized to analyze voltage trends during the firing cycle.

[0056] The present invention may also utilize a temperature sensor to monitor the temperature of controller 225. The temperature sensor is integrated into the microcontroller, but it may be a separate component. If the controller is mounted on or near the motor, then it can also monitor the motor temperature. If the temperature rises

above a preset threshold, then the controller will stop the motor and enter a low power mode until the temperature drops below a lower threshold and a specified cool-down time period has elapsed. If the temperature is above the threshold and the user closes the trigger switch, then the controller will prevent the motor from starting so that both the motor and controller have the opportunity to cool and recover. Because many AEG housings are constructed of thermoplastics, limiting the temperature to a threshold below the melting point of these thermoplastics protects the integrity of the structural and decorative components. The temperature threshold can also be changed.

[0057] In one embodiment, the present permits use of an optional sensor or switch to determine motor, gear, or actuator position. The sensor may be necessary if the piston or projectile loader must start and stop in a position other than the default, forward resting position. The installer can specify whether a sensor or switch is active high or active low, so a variety of switches and optical, magneto-resistive, and Hall-effect sensors can be used with the controller. The controller provides a regulated, low-voltage supply for sensors and other optional components that require an external supply. When a sensor is configured, the controller detects a level change on the sensor input to the microcontroller. Like the trigger switch input, the sensor input is filtered by the microcontroller to reduce bounce and noise. If a level change is detected, the controller will continue to detect changes and stop the motor when the shot index has reached the maximum index, or if the trigger was released during indexed or continuous fire, when the shot index is incremented. If the index is not reached in the expected amount of time while in indexed mode, the controller stops the motor to prevent runaway. The maximum index and time limit can be changed using the trigger switch as described earlier.

[0058] When the controller is in the timed/index mode and the trigger switch is held closed for a specified time period after the motor has stopped, the controller will advance to the next higher timeout and index value. Repeat the procedure to advance to the next timeout and index value. When the highest timeout and index value is reached, the controller reverts to the lowest timeout and index value.

[0059] When the trigger is released and the gun is not firing, the microcontroller enters a deep sleep state to conserve battery power. During sleep, battery consumption is far below that of the self-discharge rate of conventional rechargeable batteries.

5 **[0060]** The present invention may also be connected to a personal or handheld computer or serial terminal to configure its parameters at startup and to update the firmware. Examples of possible interfaces include: RS-232, SPI, TWI, OWI, or USB. If needed, the motor and battery characteristics can be configured before the controller is installed into a gun, or the controller can be removed in the field, configured, and
10 replaced. Timed, indexed, or continuous run modes; PWM on/off; timed/index cutoff; low voltage cutoff; baseline duty cycle; high temperature threshold; motor braking on/off; stall cutoff point; sensor active high/low; and all other aspects of the controller can be configured through the interface. The trigger and sensor input pins are used as a bidirectional interface. The controller detects whether it is connected to a host if the
15 battery is disconnected and no voltage is detected at both motor terminals. Power is supplied through the programming module/cable, for example, 5V through a bus-powered USB interface or from another external, regulated 5V supply. If a microcontroller having more I/O pins is substituted, those additional pins can be used as a dedicated interface (for example, for an external port on the gun housing) or to specify
20 entry into configuration mode. Once in configuration mode, the user can send commands via the connected host to configure the various aspects of controller behavior, to view controller status, and to diagnose controller operation.

[0061] FIGS. 7 and 8 illustrate the typical AEG wiring diagram on top. For the
25 simple, plug-in installation of an EMC, crimp a battery plug connector to the motor wires of the EMC and a battery receptacle connector to the battery wires of the EMC. Disconnect the battery from the Airsoft AEG, plug the EMC into the gun, and plug the battery into the EMC.

30 **[0062]** FIG. 8 represents a wiring diagram of electronic motor controller (EMC) installed in the hard-wired configuration. Again, the illustration shows the typical AEG

wiring diagram on top. For a retrofit, hard-wired installation of an EMC into an AEG, the following steps are recommended:

1. With the AEG pointing in a safe direction, remove the magazine and clear any chambered projectiles from the AEG. Disconnect and remove the battery pack.
- 5 2. Disassemble the AEG so that you can access the gear box and wiring harness. During this process, note possible locations for the EMC. Because the EMC has a fuse, you can remove the factory fuse holder and install the EMC in its place.
3. Note any motor polarity markings on the motor case and terminals. Note the battery connector polarities and wire colors (red=positive, black=negative). Use a
10 voltmeter to verify all polarities at all ends of the AEG wiring harness. Be sure to connect the EMC at a location in the trigger circuit that is closed when the trigger is pulled and the semi- and full-automatic selector switch is in either position.
4. Decide whether to splice into the existing harness, to lengthen or replace wires with longer wires, or if the AEG has connectors at the motor and gear box, to
15 create an entirely new harness with connectors. Consider the latter option if you plan to restore the AEG to the factory configuration at a later time. Plan how to route the wires in such a way that they will not be pinched during reassembly.
5. Connect the motor wires to the motor terminals, trigger wires to the trigger circuit, and battery wires to the battery connector. Note that the trigger wires from
20 the EMC have polarity. If one of the terminals of the AEG trigger is connected to or sits near the metal body of the gear box, or if it is a common wire between the trigger and selector switches, then choose that wire to be negative (black). Solder and insulate all connections.
6. If you are not using a sensor or full/semi selector switch, wrap the end of the
25 EMC sensor wire (if present) in electrical tape or other insulation. Otherwise, read the section following these steps for switch/sensor installation and configuration.
7. Verify all connections and polarities. Verify that the trigger circuit is closed and grounded (negative) when the trigger is pulled and the selector switch is in either position.

8. Reassemble the AEG making sure that there is adequate clearance for wires and the EMC. Do not install the magazine and battery pack just yet.

[0063] The EMC switch/sensor input is 5V active low by default. That is, the switch or sensor must pull the input low to ground to signal full auto fire or the end of the firing cycle has been reached, respectively. The actual voltage depends on the regulator used.

[0064] Installation of the EMC changes the operation the AEG in several ways. By default, the EMC operates in burst mode with a minimum timed burst or a minimum fixed number of shots if the sensor or back-EMF counting is enabled. With the selector switch in the semi-auto position, the AEG fires a single shot with each pull of the trigger, as before the installation. With the selector switch in the full auto position, the AEG will fire a burst of shots up to the minimum burst period, or up to the minimum burst count if a sensor is installed, with each pull of the trigger.

To deactivate burst mode and use full auto mode:

1. Make sure that the AEG is unloaded, clear, and pointing in a safe direction.
2. Pull the trigger and while holding the trigger down, connect the battery pack. The AEG will not fire during this step.
3. Release the trigger. Disconnect and reconnect the battery pack.

[0065] It should be noted that for the plug-in installation of an EMC, the user will need to short the T+ pin to ground to enter configuration mode. When changing burst timeout and maximum burst count, the gun's trigger is used just as it is for a hard-wired installation. With the selector switch in the semi-auto position, the AEG fires a single shot with each pull of the trigger, as before the installation. With the selector in the full auto position, the AEG will fire continuously until the trigger is released, again as before the installation.

[0066] The selected fire mode is retained in EEPROM memory even if you remove and replace the battery pack. To deactivate full auto mode and use burst mode, repeat the steps described above for switching to full auto mode.

5 **[0067]** If an external selector switch is installed and both selector and trigger switches are closed, then the gun will either fire in full auto mode or in the opposite mode depending on the controller configuration.

[0068] The user can change the maximum burst time within the full range of
10 available times or within the full range of shot counts if a sensor is used. In burst mode, continue to hold the trigger for 3 seconds (or another user-specified timeout period) after a burst is fired. The EMC will increase the burst time by 0.1 seconds (or another user-specified timeout period), or if a sensor is installed, by 1 shot. To increment the burst
15 time by another 0.1 seconds or another 1 round, fire another burst and hold the trigger for 3 seconds. When the EMC exceeds the maximum burst time or the maximum burst count, it will revert back to time minimum time and count. Repeat until the desired burst time or shot count is reached. The selected burst time and shot count are retained in EEPROM
memory even if you remove and replace the battery.

20 **[0069]** To configure the controller from a host, make sure that the battery and motor are disconnected from the controller. Attach the programming cable/module to the controller and then to the host serial or USB port. Start the communications or configuration application on the host and initiate connection to the controller. Parameters are configured using alphanumeric keystrokes and commands.

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[0070] The microcontroller is programmed with firmware before the controller is assembled. The firmware resides in non-volatile flash memory within the microcontroller and is protected from viewing and modification using development tools from the microcontroller manufacturer. The firmware may contain a method for the user to update
30 the microcontroller with new firmware through the programming module/cable.

[0071] The ATtiny85 microcontroller can run at a maximum system clock speed of 16MHz using the PLL clock. From the system clock, the firmware instructs the microcontroller to generate a PWM clock frequency and a timer clock frequency. Various clock frequencies can be used depending on the type of motor and MOSFET used to maximize torque and efficiency. Likewise, alternative brands and types of microcontrollers can also be substituted so long as they have similar size, power requirements, and hardware capabilities.

[0072] Regarding FIGS. 11-13, there are two loops in the example embodiment firmware: the main loop and the firing loop. The firing loop is nested within the main loop. Point A is the entry into the main loop. In this loop, the controller waits for the trigger, releases the brake, starts the motor, goes into the nested loop to monitor the trigger and firing. Upon exiting the nested loop, the controller shuts off the motor, applies the brake, looks at the trigger to see if the trigger is held, and repeats the loop at point A. Point B marks the exit from the firing loop. The steps following the exit lie within the main loop.

[0073] Controller initialization and configuration is addressed by FIG. 11. At block 1105, PWM pin OC0B is configured as the motor low-side switch output control and PWM pin OC0A is configured as the brake output control. Unused features are shut off for power savings and input pin pull-up resistors are enabled. At block 1110, all configurable parameters of the controller such as fire mode, index mode, sensor active state, burst count limit, PWM enable, soft start enable, stall detection enable, and low voltage threshold are loaded from non-volatile EEPROM. At block 1115, 1125, and 1130, a delay of up to several seconds can be employed to test for trigger pull and interface connected. In one particular embodiment, no delay is specified to minimize controller start-up delay. At block 1120, the operator must disconnect the battery and restart the controller for the new settings to take effect. This is a safety feature to prevent accidental AEG firing. At block 1135, the computer interface is enabled. In one particular embodiment, an interrupt-driven software RS-232 interface is implemented that allows communications at 4800 baud, 8 bits, no parity, 1 stop bit through the RS-232 or

USB port of a PC. The PCINT0 interrupt is used to detect a low status on the RX pin which indicates that data is ready to be sent from the host to the controller. TIMER1 is configured to transmit and received bits at the specified rate and stop bits.

5 **[0074]** At block 1145 and 1175, the battery is tested for being above a high and below a low voltage threshold. High voltages can damage electronic components and the motor. If the voltage is out of range, the controller becomes inactive until the battery is replaced with one having suitable voltage. Likewise, the temperature is also tested for being above or below certain thresholds. At lower temperatures, lubricant can become
10 much more viscous and hinder mechanical operation. In one particular embodiment, the battery range is 6-15V and the temperature is 0-80C.

[0075] In one particular embodiment, the battery readings at blocks 1145, 1175, and 1242 are averaged over 8 ADC samples to filter noise. Furthermore, the averaged
15 result is stored in a 8-value circular buffer and a running average of the buffer values is calculated. This provides for a smoother, more predictable battery discharge curve for use in analysis by the controller. Smaller or larger buffers or sample sizes can be used.

[0076] Comparing blocks 1160 and 1165, the controller does not sleep if it is
20 installed using the plug-in method at the expense of higher power consumption. This is necessary since the presence of voltage at the motor terminal is used to signal firing rather than the trigger input pin.

[0077] FIG. 12 represents the main firing loop. At block 1209, if the trigger is
25 released and a single complete motor cycle has not been detected, stop firing immediately. This behavior is required in a situation where the piston is fully retracted and on the brink of release. Once the motor is started, the factory switch cut-off lever actuates before the controller can analyze enough back-EMF data points to determine whether a shot was fired. At block 1218, a timer cuts power to the motor if no back-EMF
30 activity is detected. This is a safety feature to prevent runaway firing if the trigger is released and no activity is detected causing the motor to continue running. At block

1221, full auto fire is interrupted only immediately after piston release is detected or if the shot timer runs out in block 1218. If piston release was not detected and there is still time available on the timer, the motor is allowed to continue to run. At block 1227, the TOIE1 flag is checked to see if the interrupt is still enabled. The interrupt handler
5 compares OCR1A (current duty cycle 0-255) against the target duty cycle and if OCR1A is smaller, increments OCR1A. Once the duty cycle is equal to the target, the interrupt is disabled. If PWM is configured as disabled, PWM is stopped and then the motor is turned on fully. If PWM is configured as enabled and an alternate PWM rate is configured, then once the target duty cycle is reached, the PWM rate is switched to the alternate rate. In
10 one particular embodiment, a higher PWM rate of 3906.25Hz is used to start the motor turning, then once it is spinning, a PWM rate of 976.56Hz is selected.

[0078] In one particular embodiment, blocks 1230 through 1248 are placed in an ADC interrupt handler for sampling at more regular intervals during the firing cycle. Just
15 before the motor firing loop, the ADC is put in a timer-driven or free-running mode and the interrupt handler is executed whenever ADC sampling is complete. Immediately after execution of the handler, the ADC automatically samples at the next interval. The intervals can be timed with PWM frequency to sample whenever there is either an on or off pulse sent to the motor switch.

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[0079] At block 1242, target duty cycle is analyzed and compared to battery voltage. Thus, motor performance is only evaluated after each firing cycle. Motor performance cannot be evaluated within the cycle because changes to the PWM duty cycle affect back-EMF analysis and detection of cusps in the voltage curve corresponding
25 to piston release.

[0080] FIG. 13 represents the timer, sensor shot counter, and filter interrupt handler. At block 1365, the value used to test the sensor input buffer can be one of three values depending on the input configuration chosen. The value is 0b10000000 if an
30 active-high sensor is installed and configured, 0b01111111 if an active-low sensor is installed and configured, and 0b00000000 if the sensor input is used as a burst/full

selector switch input. If configured as a selector switch, a step is executed before block 1203 to determine the state of the switch and the set the corresponding burst or full-auto mode.

5 **[0081]** FIG. 14 represents sample output from the controller during configuration mode. The output can be viewed using a host terminal program such as HyperTerminal in Microsoft Windows XP configured at 4800 baud, 8 bits, no parity, and 1 stop bit. The USB module/cable is connected to the controller and the entire assembly plugged into a USB port. After starting the host terminal program on the PC, the operator presses the ?
10 key to display the menu from the controller. To change the configuration, the operator presses the key corresponding to the character in square brackets in the corresponding menu item. After changing the configuration, the controller redisplay the menu showing the newly-changed parameter. To exit from configuration mode, exit the host terminal program, unplug the assembly from the USB port, and disconnect the USB module/cable.

15

[0082] When trigger 706 is pulled, the microcontroller executes the external interrupt handler (for INT0). The handler disables sleep mode and disables the external interrupt from triggering again so that the handler is not repeatedly executed as the user continues to hold the trigger switch closed. Firmware execution continues from after the
20 point of entering sleep mode.

[0083] If soft start is enabled, an overflow interrupt handler for the PWM timer increments the PWM duty cycle from the initial value until it has reached the target duty cycle. When it reaches the target, the firmware disables the overflow interrupt to stop
25 further incrementing the duty cycle.

[0084] During the firing cycle, the motor terminal voltages are analyzed for sudden speed increases and load decreases that indicate piston release. The changes in ADC voltage differential readings from both motor terminals are sampled and averaged
30 in order to filter motor brush noise. The samples are stored in a circular buffer and

averaged. As the motor compresses the spring, back-EMF voltage decreases. When the piston is released, back-EMF will suddenly increase.

[0085] The state of back-EMF changes (increasing or decreasing) is stored in another 8-bit circular buffer. When all 8 bits are decreasing and the average back-EMF value is below the stall differential voltage level, the motor is approaching stall and the controller stops the motor immediately. If the left 4 bits are decreasing and the right 4 bits are increasing, a sudden directional change in back-EMF has occurred and indicates that the piston was released. These changes in back-EMF rate can be counted in order to implement indexed burst and continuous fire modes. This method of shot counting is optional and must be carefully tuned to motor, gear, and spring characteristics. The buffer length and the number of bits sampled can be increased or decreased to adapt to a variety of motors and microcontrollers.

[0086] Before and during the firing cycle, the battery voltage and temperature are checked to see if they are within the operating threshold. If not, or if the motor has stalled, the controller enters a sleep state for a specified time period in order to let the controller and motor cool. If the battery voltage is out of range, the controller enters a sleep state until the battery is replaced. A lower temperature threshold can be specified so that the controller must reach this temperature before it wakes and enables firing again. The hysteresis range is adjustable and allows for longer firing periods between over-temperature and stall conditions. It also helps the user distinguish between controller failure and when it is actively protecting itself, the motor, and the battery.

[0087] The 62.5Khz timer is configured to interrupt 244 times per second, so after the shot time counter is incremented 244 times, the firmware increments the seconds counter and resets the shot time counter. Other timer frequencies can also be used but the shot time counter limit must be adjusted accordingly for accurate timing.

[0088] Most automatic firearms fire the full string of timed or indexed mode shots within one second in order to provide the user with better control of recoil and minimize waste of ammunition when recoil has shifted the weapon out of alignment with the intended target.

5

[0089] The overflow handler also left shifts the current trigger and sensor pin states into two 8-bit circular buffers. Since the pull-up resistor on the trigger input pin is enabled and closing the trigger switch shorts the pin to ground, the firmware specifies that the trigger switch is closed only when all eight bits in the trigger state buffer are zero. Any switch bounce that occurs during the initial switch closure is ignored. Likewise, the firmware specifies that the trigger switch is open only when all eight bits in the buffer are one. The buffer length and the number of bits sampled can be increased or decreased to adapt to a variety of switches and switch quality.

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[0090] To filter the sensor input, the firmware checks the sensor state buffer for a leftmost one bit followed by seven zeros for an active high switch or sensor, and a leftmost zero bit followed by seven ones for an active low switch or sensor. Thus, the firmware checks for the trailing level change after the switch or sensor is triggered. When it detects a change, the shot index is incremented and a longer timeout threshold is set that is appropriate for indexed mode. If the shot index exceeds the threshold for indexed mode, then the firmware signals for motor rotation to stop. Again, the buffer length and number of bits sampled can be increased or decreased.

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[0091] When the trigger switch is released, the controller checks the shot index count to see if it has been incremented by the sensor filter or through back-EMF sensing. An index greater than one indicates that a sensor is installed or back-EMF changes are detectable, and that a single shot was fired but not in semi-automatic mode. If a sensor is installed or back-EMF is active and the controller is in indexed mode, then the motor will continue to rotate until the next index or the timeout period is reached. The controller then turns off the motor. If a sensor is not installed or back-EMF changes are not detected, then the controller stops the motor as soon as the trigger switch is opened.

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[0092] Once the motor has stopped and the controller turns off the N-channel MOSFET output, the controller turns on the P-channel MOSFET to brake the motor and send generated voltage and current back to the positive terminal of the battery. The P-channel MOSFET is driven by a small N-channel MOSFET which provides adequate gate voltage to the larger MOSFET. The gates have pull-up resistors to ensure that the brake is still applied when the microcontroller enters its sleep state. The two large MOSFETs form a half H-bridge.

[0093] A variety of alternative embodiments may be implemented without departing from the spirit and scope of the present invention. In an alternative embodiment, the low-voltage, low-current trigger switch can operate at other low voltages as long as they are higher than the gate threshold voltage of the low-side MOSFET used in the H-bridge. Logic-level MOSFETs with sufficient high-voltage and high-current capabilities to drive a motor but with equivalent or lower gate threshold voltages can be substituted. In an alternative embodiment, a different voltage regulator can be substituted that provides higher current capability for driving external components and accessories. In an alternative embodiment, the reverse battery protection MOSFET can be disabled or omitted if protection is not needed and/or space for the controller is limited. If space permits, a FET bridge can be added in place of the reverse battery protection MOSFET to allow Airsoft batteries of any polarity configuration to be used. Thus, the AEG motor will always be driven in the correct direction and there is no risk of damaging the controller, motor, or gears.

[0094] Other embodiments include higher current and power handling MOSFETs with similar or different packages can be substituted for motor, brake, and reverse battery protection MOSFETs to create a heavy-duty controller. A corresponding change to the circuit board layout may be required to accommodate packages other than SOIC-8 and LPAK. Further, in another alternative embodiment, the motor speed regulation can be disabled or omitted if the MOSFETs cannot dissipate the heat generated by PWM switching and/or space for the controller is limited. The motor switch PWM frequency

can also be changed to reduce MOSFET heating and adjust efficiency. Further, in another alternative embodiment, during a PWM-driven firing cycle, ADC sampling of motor voltages could be performed when a timer compare match interrupt has occurred. The ADC sampling occurs whenever the PWM output pin for the low-side motor switch
5 has been high for some time, that is, when the voltage pulse applied to the motor has stabilized at a high level. By measuring voltage at the same point relative to the end of each pulse, a more accurate back-EMF sampling can be obtained without having to stop PWM and short the motor terminals for each sampling.

10 **[0095]** With other alternative embodiments, the motor brake can be disabled or omitted to make the controller smaller if the braking and regeneration functions are not needed, or if the MOSFET and/or fly-back diode cannot dissipate the heat generated by braking. In an alternative embodiment, a different microcontroller with equivalent or greater features, speed, and capabilities can be substituted. For example, a
15 microcontroller with more I/O pins can be used to provide a dedicated serial interface allowing the controller to be permanently installed in an AEG while still allowing the user to configure its parameters. The controller's status can then be viewed and parameters changed in real time as the gun operates. Or, the pins can be used to select configuration mode or set some application-specific parameter.

20 **[0096]** MOSFET gate and half H-bridge driver ICs can be used to further prevent both MOSFETs from conducting simultaneously. These ICs may be more costly and require more circuit board space. Some ICs feature dead time generators and additional overload and over-temperature protection. Some may even allow a lower-cost. N-channel
25 MOSFET to be used for braking.

[0097] The overload and thermal protection devices and their firmware routines can be removed, resulting in less or no protection and less space requirement for the controller. Protection may be unnecessary in cases where a light load is driven such as if
30 the motor and gearing capabilities far exceed the load that it drives or if the piston is driven by a lighter spring.

[0098] An optional external switch can be added allowing more convenient selection between timed/indexed and continuous run modes. The switch shorts the S+ input to ground and can be enabled using the serial interface.

5

[0099] A switch can also be added to the positive battery lead to simulate battery disconnection and reconnection in order to ease mode changes using the mode change procedure described earlier. The switch can also be used as a master power switch to prevent excessive battery drain.

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[0100] The serial interface, firmware upgrade, and their associated firmware routines can be omitted if configurability and updating are not needed.

[0101] All maximum and minimum timing periods, maximum and minimum shot counts, and timer and PWM frequencies can be adjustable or fixed for a specific application.

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[0102] It should be noted that firmware monitoring of the ADC channels during the firing cycle can be interrupt-driven and removed from the main firing loop. The microcontroller's ADC unit can be placed into a timer driven interrupt mode or into a free-running mode so that voltage readings are taken at preset times or continuously. For example, it could be synchronized with the motor PWM cycle. This method provides greater accuracy from more frequent and regular samplings. Where this monitoring is utilized, it may be advantageous to utilize a microcontroller with storage capabilities exceeding that of the ATtiny 85.

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[0103] Braking intensity can be reduced or modulated using PWM. In addition, if the controller has a dead-time generator, the H-bridge can be configured for PWM so that both MOSFETs are switched in an alternating fashion allowing conventional back-EMF measurements to be made during the firing cycle.

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[0104] The present invention could also be installed in other motor-driven, projectile-firing, recreational guns, including but not limited to paintball, pellet, and metallic BB guns. The controller can also be used in hybrid guns, such as gas-electric guns that use one or more electric motors to actuate loading and gas valves, and a
5 pressurized gas to propel the projectile. The controller can also trigger ignition components if the gun uses a combustible liquid or gas fuel to propel the projectile.

[0105] In an alternative embodiment, as illustrated by schematic FIG. 9, and by the copper and placement illustration of FIG. 10, instead of diodes, other transient voltage
10 suppressors (TVS) and snubber circuits can be used to absorb motor voltage spikes. Additional transient protection may be required on the battery terminals of the invention to prevent MOSFET damage and microcontroller glitches due to spikes.

[0106] In an alternative embodiment, instead of using separate MOSFETs to
15 switch and brake the motor, a single SPDT relay can be used. The Panasonic/NAIS CP1-12V "1 Form C" relay (component R1 in the diagram) is an example of a compact 12V automotive relay that can be used to replace the two TO-220 sized MOSFETs while still providing high-current-switching capabilities. Either the CP1-12V or the CP1A-12V surface mount relay can be mounted to the circuit board. Although PWM can no longer
20 be used to modulate motor speed and braking, PWM can still be employed to reduce coil power consumption after the relay is initially switched on. A common, low-cost transistor is used to switch the coil. A TVS is installed on the relay coil to protect the transistor. The contact resistance of the relay is often less than the on resistance of the MOSFETs, and when combined with the coil power dissipation, the overall power dissipation of the
25 relay is still less than that of the MOSFETs. Relays can be more rugged, less static sensitive, and more cost effective than MOSFETs. Unlike MOSFETs that have built-in diodes, relays are not prone to damage when the battery polarity is reversed or when the terminals are handled. The polarity protection MOSFET can thus be omitted. The motor negative terminal voltage sensing circuit was also omitted to save board space. The parts
30 reduction offers additional cost savings during production.

[0107] By using an SPDT relay, the braking function is automatically applied whenever the relay coil is deenergized. No additional control is required from the microcontroller and the extra pin can remain disconnected or can be used for other functions.

5

[0108] The electronic control circuitry can optionally be separated and operated remotely from the relay switching circuitry. The circuit board layouts below show where the invention can be separated into two smaller modules. Separation allows this invention to be fitted to AEGs that have limited internal space and cannot accommodate the larger module. It also provides the option of no microprocessor control in applications where burst fire is not needed but trigger reliability and longevity are.

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[0109] The TVS devices on the relay coil and motor terminals reduce contact sparking and prolong switch and relay life. In one embodiment, an STMicroelectronics SMA6J18CA Transil SMA device rated at 600W and 18V is installed across the relay coil, and a Diodes Incorporated 1.5KE24CA DO-201 device rated at 1500W and 24V is installed across the motor terminals. They are bidirectional devices to prevent damage due to accidental battery polarity reversal. Since less power is consumed by the relay than the MOSFETs, the temperature sensing function of the microcontroller is less critical to reliable operation of the switching. The microcontroller can still be located in proximity to the motor for motor temperature sensing.

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[0110] A Littlefuse 897 Low Profile MINI fuse and Keystone 3557 fuse clips are used to further reduce space requirements. These components can be installed on all versions of this invention. In one relay-based embodiment, the fuse and clips are installed vertically next to the relay so that the top of the fuse is at the same height as the top of the relay and the overall length of the controller is reduced when compared to a horizontally-positioned fuse.

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[0111] Although the microcontroller is placed in a low-power sleep state, idle power consumption by the relay-based invention can be eliminated entirely by placing

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the regulator and the battery voltage sensing circuit behind the trigger switch. The software algorithm must be changed so that the accidental discharge safety feature and power-on configuration are disabled, and the trigger input is ignored and the motor started immediately. Other unused features can be disabled in the firmware configuration.

5 The simpler mode of operation is more appropriate for a cost-cut product.

[0112] In one embodiment, the present invention includes a method of providing consistent motor drive. This method comprises: providing a microcontroller having a first analog-to-digital converter channel and a second analog-to-digital converter channel, said microcontroller having an integrated temperature sensor. The method next provides a resistor divider capable of producing an output voltage, and measuring an initial output voltage value of a power source derived through said resistor divider connected to said analog-to digital channel. Next, the method calculates a target pulsed-width-modulation duty cycle based upon said voltage value of said power source, and starts a pulsed-width-modulation duty cycle at a predetermined starting value, and actuating a motor where said output voltage value is greater than a predetermined depletion value. The method measures for a voltage stall detection value of the negative terminal of said motor, derived through said second analog-to-digital channel after said target duty cycle is reached. The method measures a temperature value. The pulsed-width-modulation duty cycle is increased at a preset ramp value. The method re-measures a subsequent battery voltage value derived through said first analog-to-digital channel just prior to each motor actuation. The duty cycle is adjusted based upon the subsequent battery voltage value derived through said first analog-to-digital channel. The motor is stopped where said re-measured subsequent battery voltage value derived through said first analog-to-digital channel is less than a predetermined depletion value. Power to said motor is interrupted where the difference between said measured negative terminal voltage stall detection value and said power source voltage value is less than a predetermined imminent stall threshold value. The motor is stopped where measured temperature value exceeds a temperature threshold value.

[0113] It should be noted that several aspects of the present invention, described in various embodiments herein, may be practiced independently. The incorporation of various aspects of the invention into example embodiments should not be construed to limit the inventive aspect to that embodiment. It is specifically recognized that the aspects of the present invention described herein, which may be independently applied to similar or varied fields of use, are intended to be independently utilized as inventive proprietary engineering solutions.

[0114] Although the present invention has been described with reference to the preferred embodiments, it should be understood that various modifications and variations can be easily made by those skilled in the art without departing from the scope and spirit of the invention. Accordingly, the foregoing disclosure should be interpreted as illustrative only and is not to be interpreted in a limiting sense. It is further intended that any other embodiments of the present invention that result from any changes in application or method of use or operation, method of manufacture, shape, size, or material which are not specified within the detailed written description or illustrations contained herein yet are considered apparent or obvious to one skilled in the art are within the scope of the present invention.

WHAT IS CLAIMED IS:

1. A motor controller for an automatic electric gun comprising:

a microcontroller;

means, connected to said microcontroller, for detecting motor stall;

a multi-function trigger switch connected to said microcontroller, wherein said microcontroller provides low-voltage low-current noise filtering from said trigger switch input, wherein said trigger switch is debounced by said microcontroller, wherein said trigger switch may function as a user interface to select between varied microcontroller modes of operation;

means, connected to said microcontroller, for providing consistent motor performance independent of power supply voltage;

means for receiving a power supply;

a low-dropout voltage regulator connected to said power supply receiving means and microcontroller, wherein said microcontroller is supplied with regulated power and filtered by a capacitor on the input and output of said regulator and ground.

2. The motor controller of claim 1, further comprising a polarity protecting means, wherein said means includes a positive and a negative power supply terminal, and a low-side MOSFET, having a source, a drain, and a gate, connected to said voltage regulator output at its gate, wherein the source of said low-side MOSFET is connected to ground, wherein the drain of said low-side MOSFET is connected to the negative supply terminal, wherein when power is supplied to the corresponding polarity power supply terminals, said regulator is powered and said low-side MOSFET is turned on, and wherein power is

supplied to the opposite power supply terminals, said regulator is not powered and said MOSFET is off.

3. The motor controller of claim 1, further comprising a load sensing means,
5 wherein voltage is measured at both motor terminals of a motor, wherein said microcontroller senses for a decrease in back-EMF indicating that a motor load has been engaged, wherein said microcontroller senses for a sudden directional increase in back-EMF indicating that a motor load has been overcome.

10 4. The motor controller of claim 3, further comprising a timeout means, wherein a timer cuts power to the motor if no back-EMF activity is detected within a predetermined time period.

5. The motor controller of claim 1, further comprising a voltage determination
15 means wherein battery readings are averaged over a plurality of ADC samples to filter noise, wherein the averaged result is stored in an multi-value circular buffer, and wherein a running average of the buffer values is calculated by said microcontroller.

6. The motor controller of claim 5, wherein said plurality of ADC samples is 8 ADC
20 samples to filter noise, wherein the averaged result is stored in an 8-value circular buffer.

7. The motor controller of claim 1, wherein said means for detecting motor stall
includes sensing for a voltage stall value, wherein positive motor terminal voltage is measured by a first resistor divider, said positive terminal voltage determined through a
25 first analog-to-digital converter channel of said microcontroller, wherein negative motor terminal voltage is measured by a second resistor divider, said negative terminal voltage determined through a second analog-to-digital converter channel of said microcontroller, wherein said microcontroller calculates the voltage stall value as the difference between said positive terminal voltage and said negative terminal voltage, wherein where voltage
30 stall value is less than a predetermined voltage stall threshold, said microcontroller interrupts power supply to said motor.

8. The motor controller of claim 1, wherein said means for providing consistent motor performance includes regulating said motor speed using pulse-width-modulation.

5

9. The motor controller of claim 8, wherein said pulse-width-modulation duty cycle is started at a predetermined start value and increased, each duty cycle, by predetermined ramp value.

10. The motor controller of claim 8, wherein voltage of a power supply is determined through a resistor divider, wherein a target duty cycle is calculated based upon a predetermined power supply values stored in said microcontroller.

11. The motor controller of claim 1, wherein said microcontroller is an ATtiny 85 microcontroller.

15

12. The motor controller of claim 1, wherein said low-dropout voltage regulator is a LD2981 linear regulator.

13. The motor controller of claim 1, wherein said varied modes of operation are timed, indexed, and continuous motor run.

20

14. The motor controller of claim 1, wherein said means for producing continuous motor performance comprise a low-side MOSFET switch and a MOSFET half H-bridge in electrical contact with said microcontroller.

25

15. The motor controller of claim 1, further comprising a pull-down resistor, wherein said resistor ensures that the gate and low-side motor switch is off whenever said microcontroller is in a brownout condition, whereby both MOSFETs of said half bridge are prevented from conducting simultaneously.

30

16. The motor controller of claim 1, wherein said means for providing consistent motor performance comprises a single SPDT relay, wherein motor braking is automatically applied whenever said relay coil is deenergized.

5 17. The motor controller of claim 16, wherein said relay is a Panasonic/NAIS CP CP1-12V relay version.

18. An electronic motor controller comprising: a first logic-level N-channel power MOSFET, wherein said first logic-level N-channel power MOSFET is used as a low-side
10 reverse battery switch, wherein the gate pin is connected to the regulated, low-voltage output of said low-dropout voltage regulator; a second logic-level N-channel power MOSFET, wherein said second logic-level N-channel power MOSFET is used as a motor power switch, wherein said MOSFET has an avalanche diode, wherein said MOSFET forms a half H-bridge; a microcontroller, wherein said microcontroller is ATtiny85,
15 wherein a pulse width modulation output pin is connected to the gate pin of said second logic-level N-channel power MOSFET; a P-channel power MOSFET, wherein said P-channel power MOSFET is a FDS6681Z SOIC-8, wherein said P-channel MOSFET is used as a regenerative brake connecting motor terminals, wherein said MOSFET features an avalanche diode and forms a half H-bridge, wherein the gate pin of said P-channel
20 MOSFET is connected to a pulse width modulation output pin of said microcontroller; a N-channel MOSFET, wherein said N-channel MOSFET is a BSS123 N-channel MOSFET used to switch the gate of said P-channel power MOSFET at battery voltage; pull up resistors on the gates of said BSS123 MOSFET and the P-channel MOSFET to battery voltage.

25

19. The electronic motor controller of claim 18, wherein both said N-channel MOSFETs are NXP/Philips PH4840S LFPK.

20. The electronic motor controller of claim 18, wherein said P-channel power
30 MOSFET is a FDS6681Z SOIC-8.

21. The electronic motor controller of claim 18, wherein both said N-channel MOSFETs are International Rectifier IRL3713 TO-220.

22. The electronic motor controller of claim 18, wherein said P-channel power MOSFET is a STMicroelectronics P80PF55 TO-220.

23. The electronic motor controller of claim 18, wherein both said N-channel MOSFETS are International Rectifier IRL3713 TO-262.

24. The electronic motor controller of claim 18, wherein said P-channel power MOSFET is a STMicroelectronics P80PF55 TO-262.

25. A method of providing consistent motor drive comprising:

providing a microcontroller having a first analog-to-digital converter channel and a second analog-to-digital converter channel, said microcontroller having an integrated temperature sensor;

providing a resistor divider capable of producing an output voltage;

measuring an initial output voltage value of a power source derived through said resistor divider connected to said analog-to digital channel;

calculating a target pulsed-width-modulation duty cycle based upon said voltage value of said power source;

starting a pulsed-width-modulation duty cycle at a predetermined starting value;

actuating a motor where said output voltage value is greater than a predetermined depletion value;

measuring a voltage stall detection value of the negative terminal of said motor derived through said second analog-to-digital channel after said target duty cycle is reached;

measuring a temperature value;

5

increasing said pulsed-width-modulation duty cycle at a preset ramp value;

re-measuring a subsequent battery voltage value derived through said first analog-to-digital channel just prior to each motor actuation;

10

adjusting said duty cycle based upon said subsequent battery voltage value derived through said first analog-to-digital channel;

stopping said motor where said re-measured subsequent battery voltage value derived through said first analog-to-digital channel is less than a depletion value;

15

interrupting power to said motor where the difference between said measured negative terminal voltage stall detection value and said power source voltage value is less than a predetermined imminent stall threshold value;

20

stopping said motor where measured temperature value exceeds a temperature threshold value.

26. A method of installing an electronic motor controller in an automatic electric gun comprising:

25

providing an automatic electric gun, said gun having at least: a gear box, a wiring harness, a trigger, a trigger circuit, a fuse in a fuse holder space, a motor having motor terminals, and a battery connector;

30

disassembling said gun to expose said gun's gear box and wiring harness;

removing said gun's factory fuse holder from fuse holder space within said gun;

5 providing an electronic motor controller having at least: motor controller wires, trigger wires, and battery wires;

placing said electronic motor controller in said fuse holder space;

10 connecting said electronic motor controller's motor wires to said gun's motor terminals;

connecting said trigger wires connected to said gun's trigger circuit;

connecting said battery wires to said gun's battery connector;

15 reassembling said gun.

27. The method according to claim 26, further comprising:

20 verifying polarities of all ends of the automatic electric gun's wiring harness prior to connecting said gun to said controller;

verifying connections and polarities after connections between said gun and said controller;

25 verifying trigger circuit is closed and grounded when said trigger is pulled;

insulating any unused controller wires before reassembling said gun.

28. The method according to claim 26, further comprising: fixing said motor
30 controller in fuse holder space prior to reassembling said gun.

29. The method according to claim 26, wherein said gun has a multipositional selector switch, and wherein trigger wires are connected to said gun's trigger circuit at a location in said circuit that is closed when the trigger is pulled and said gun's multipositional switch is in any position of operation.

5

30. The method according to claim 29, further comprising: verifying trigger circuit is closed and grounded when said trigger is pulled and the selector switch is in any position of operation before said gun is reassembled.

10

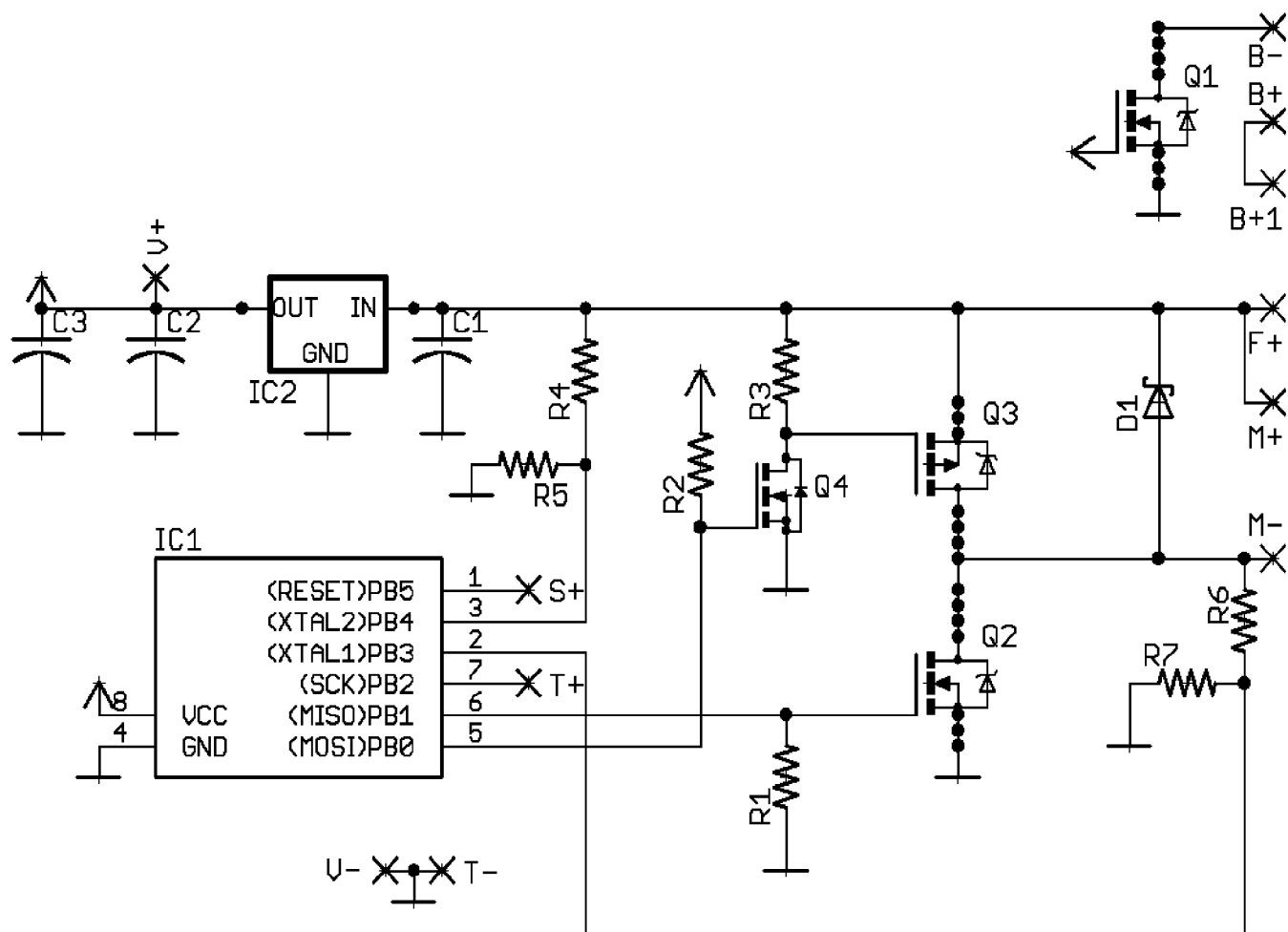


FIG. 1

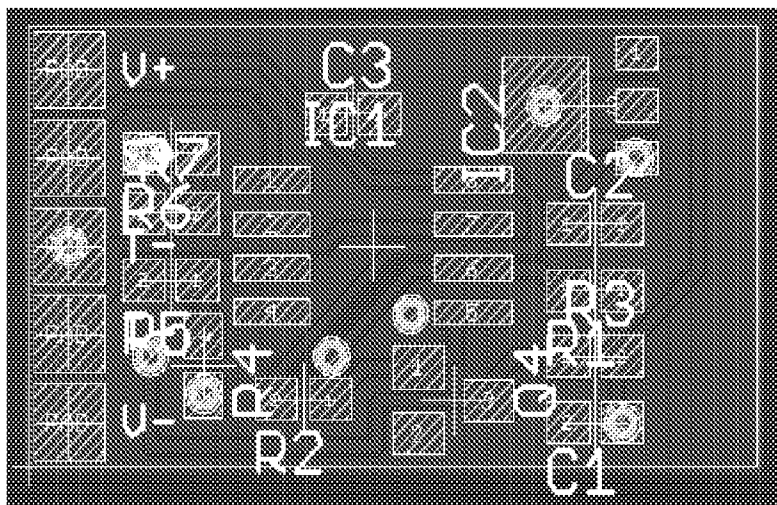


FIG. 2

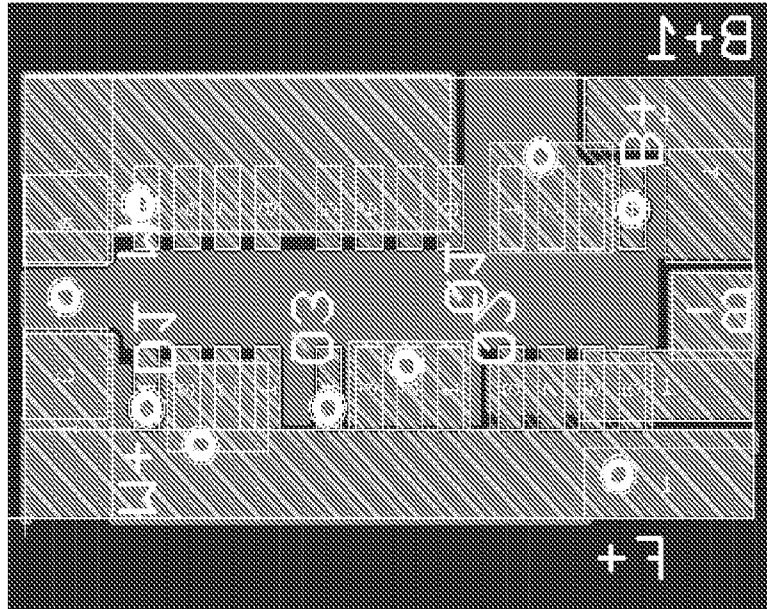


FIG. 3

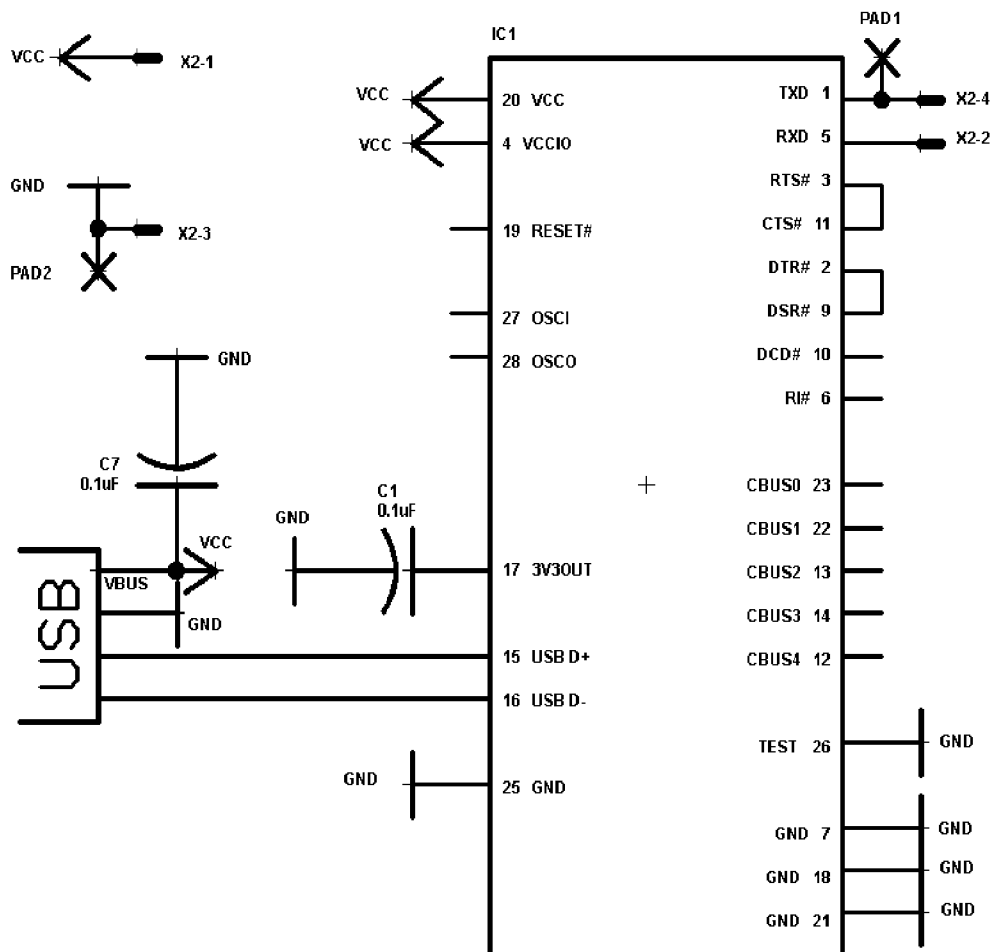


FIG. 4

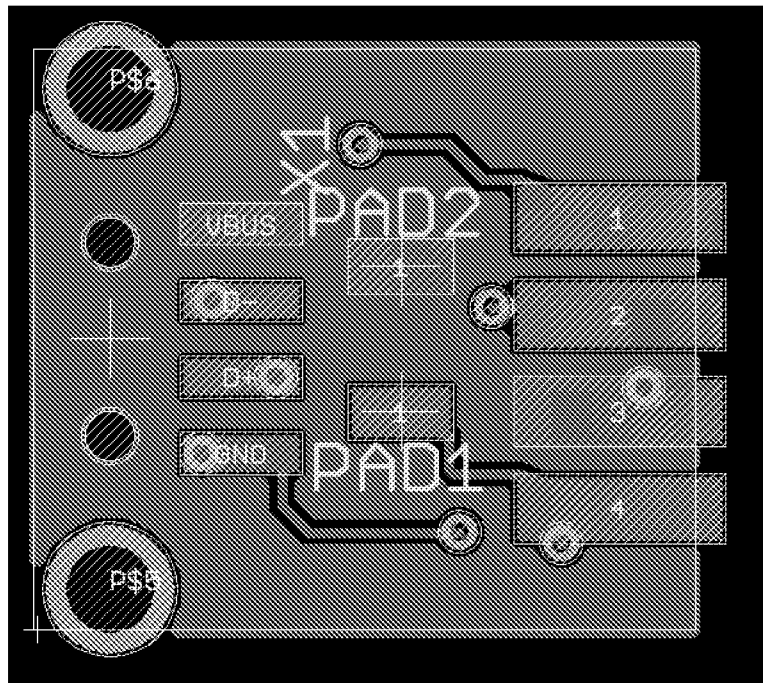


FIG. 5

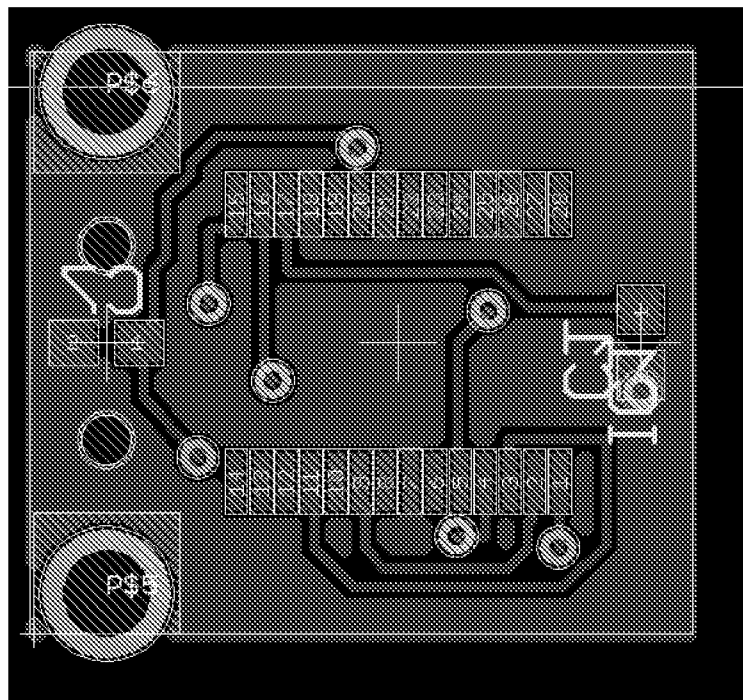


FIG. 6

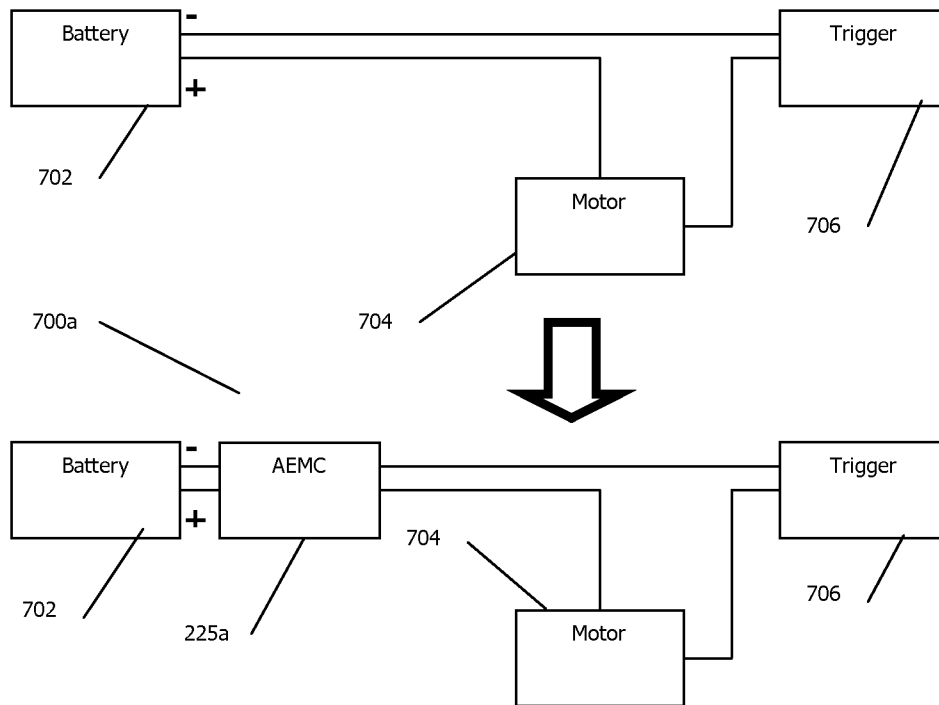


FIG.7

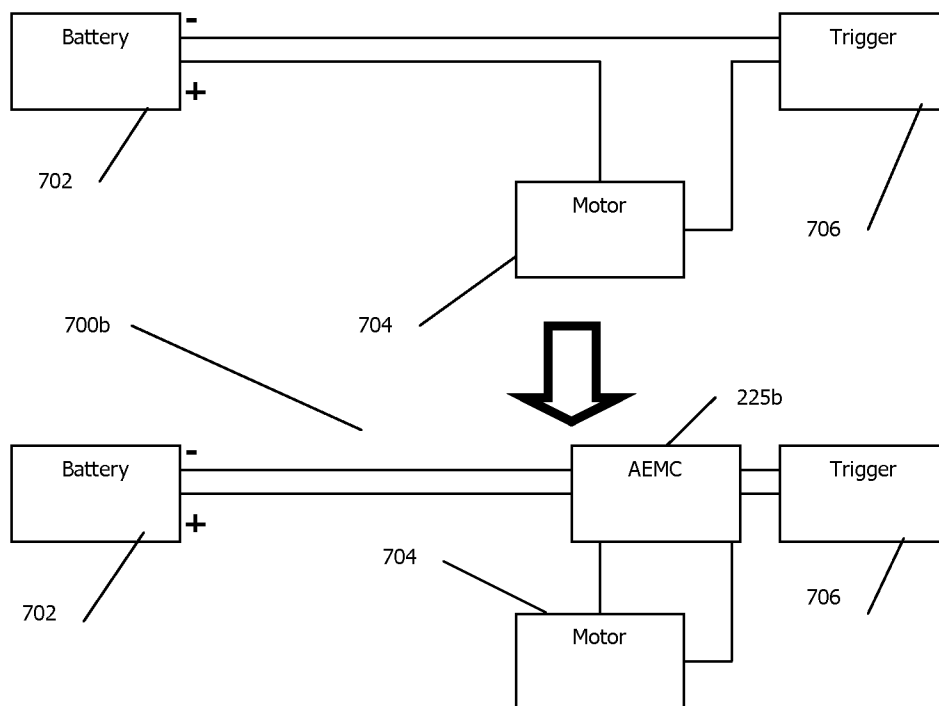


FIG.8

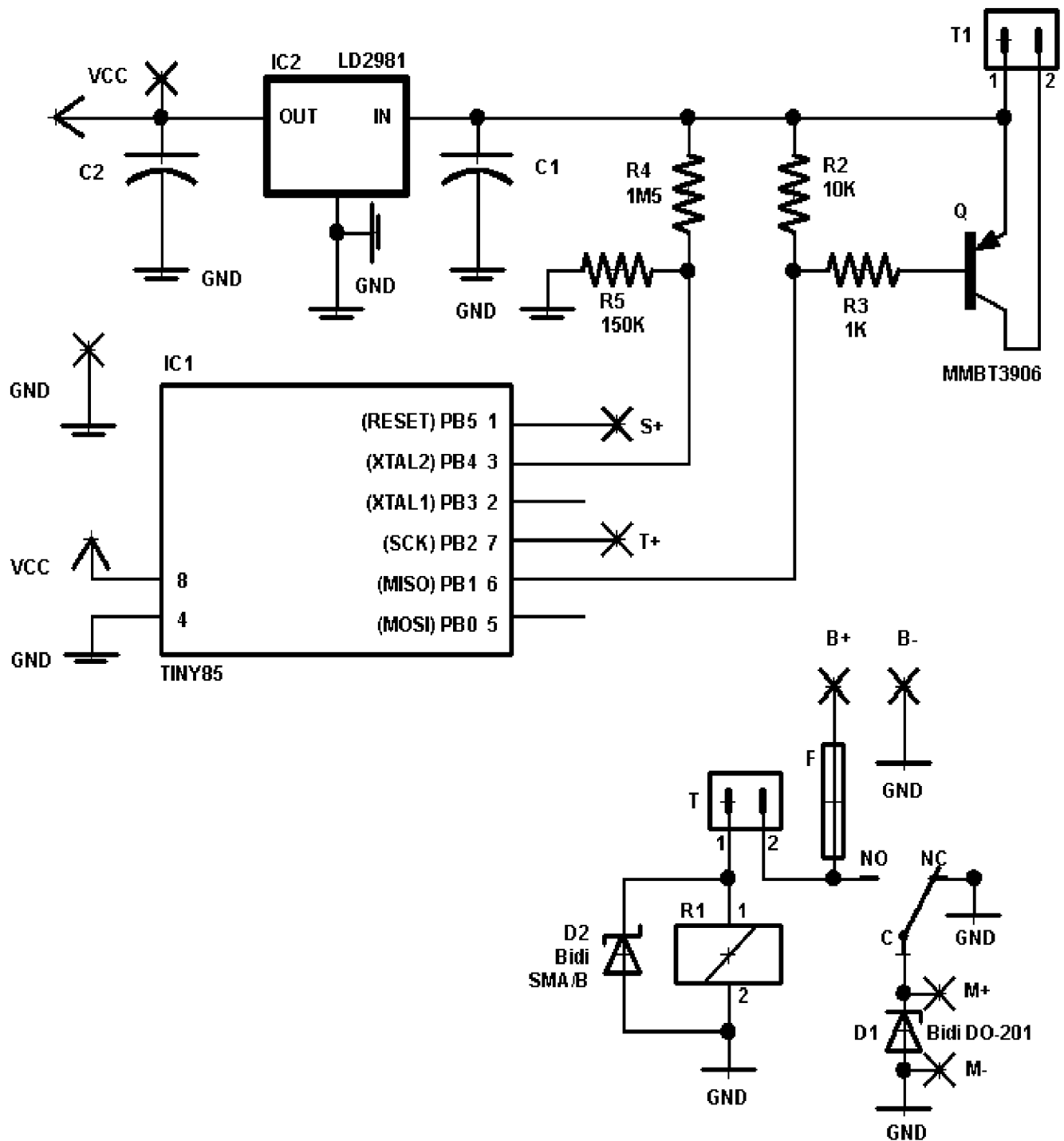


FIG. 9

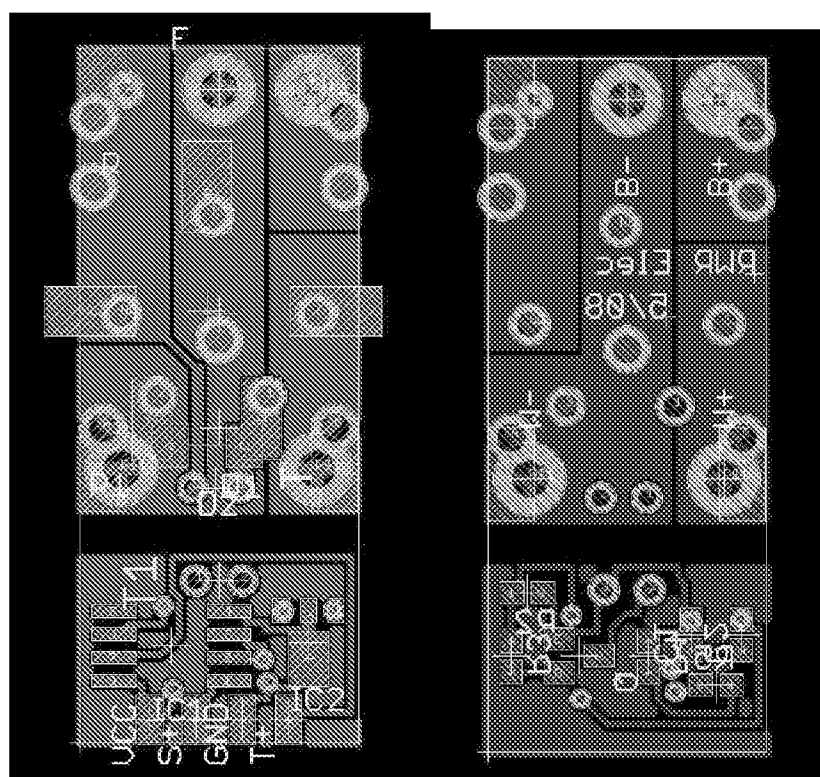


FIG. 10

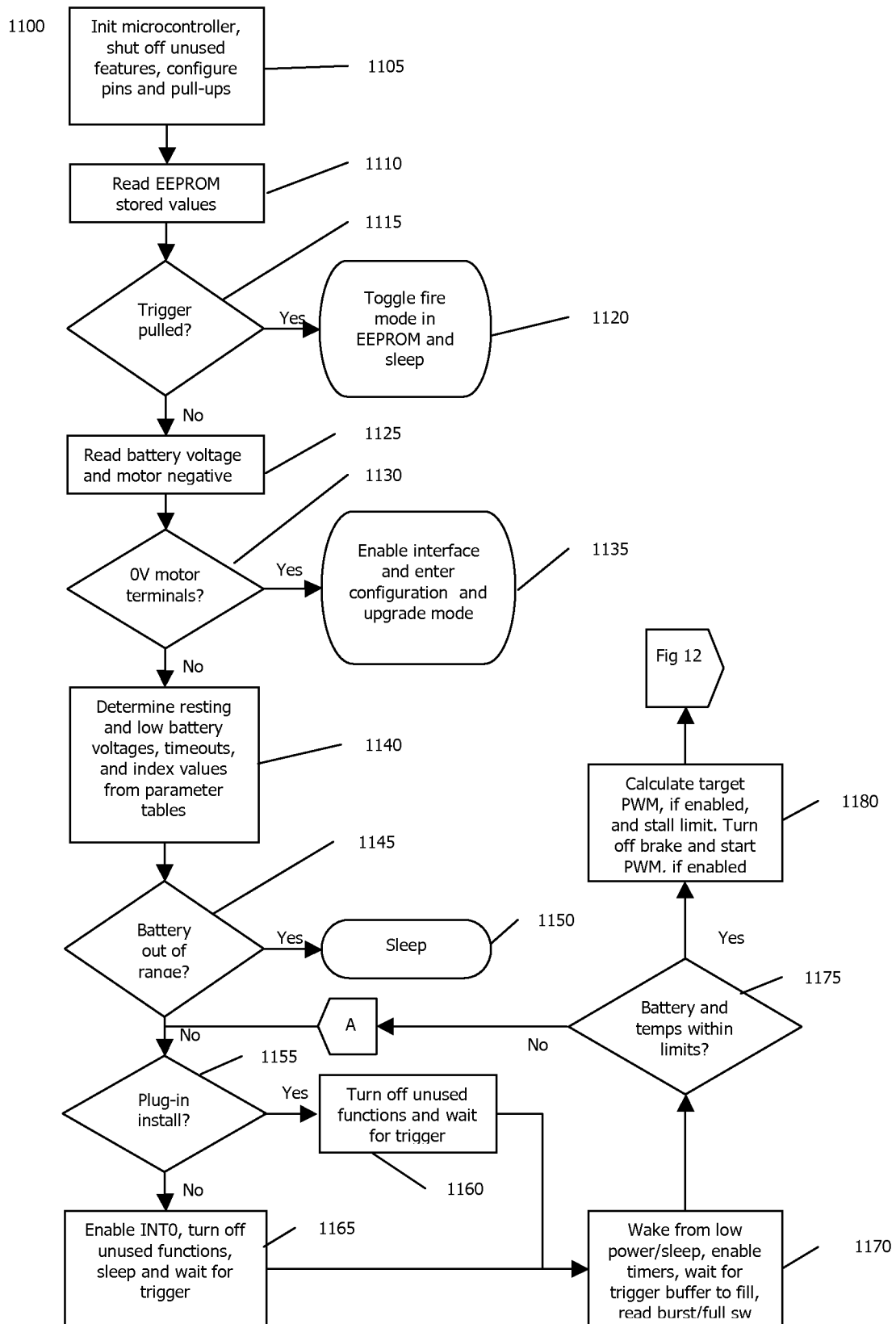


FIG. 11

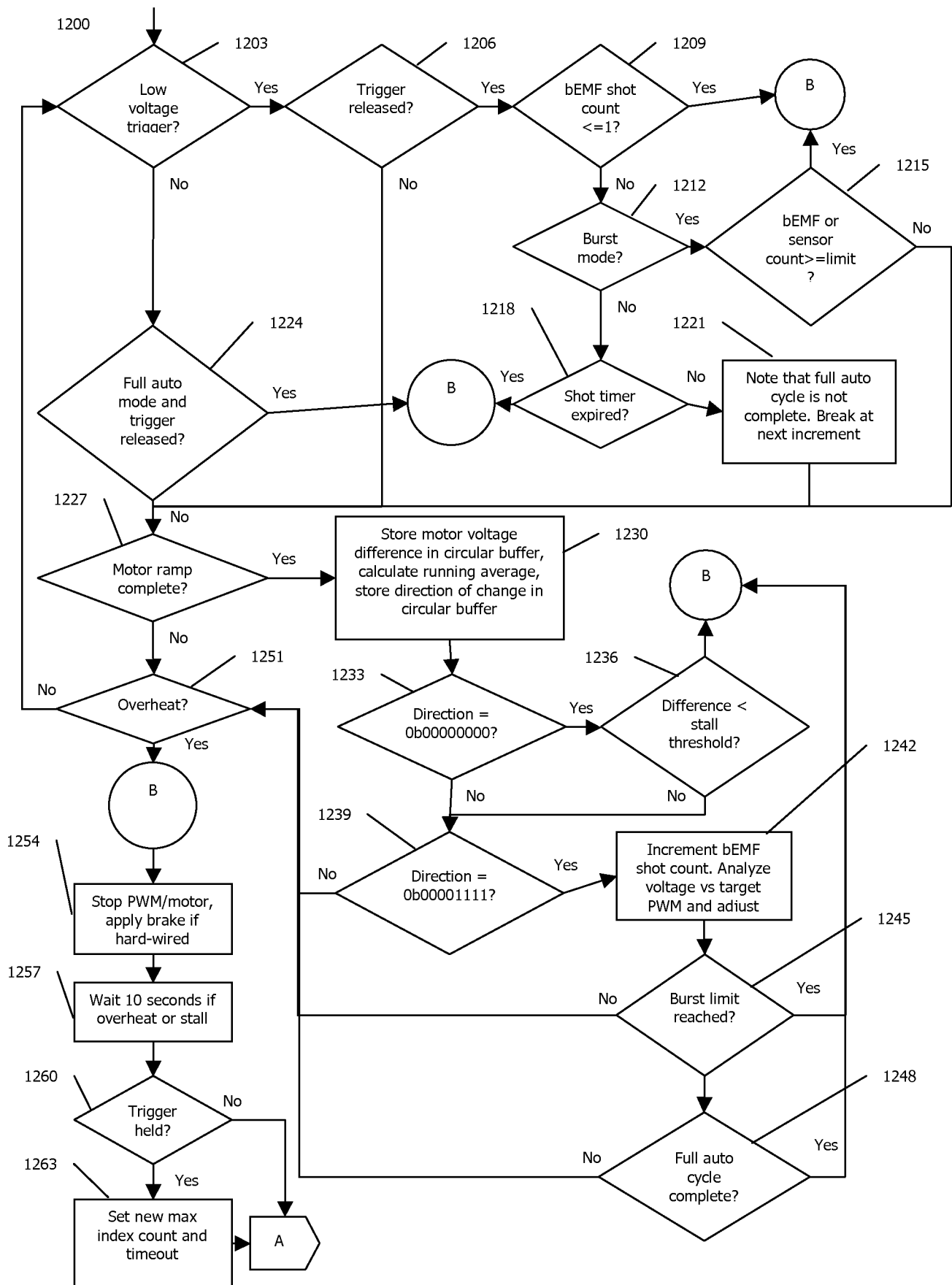


FIG. 12

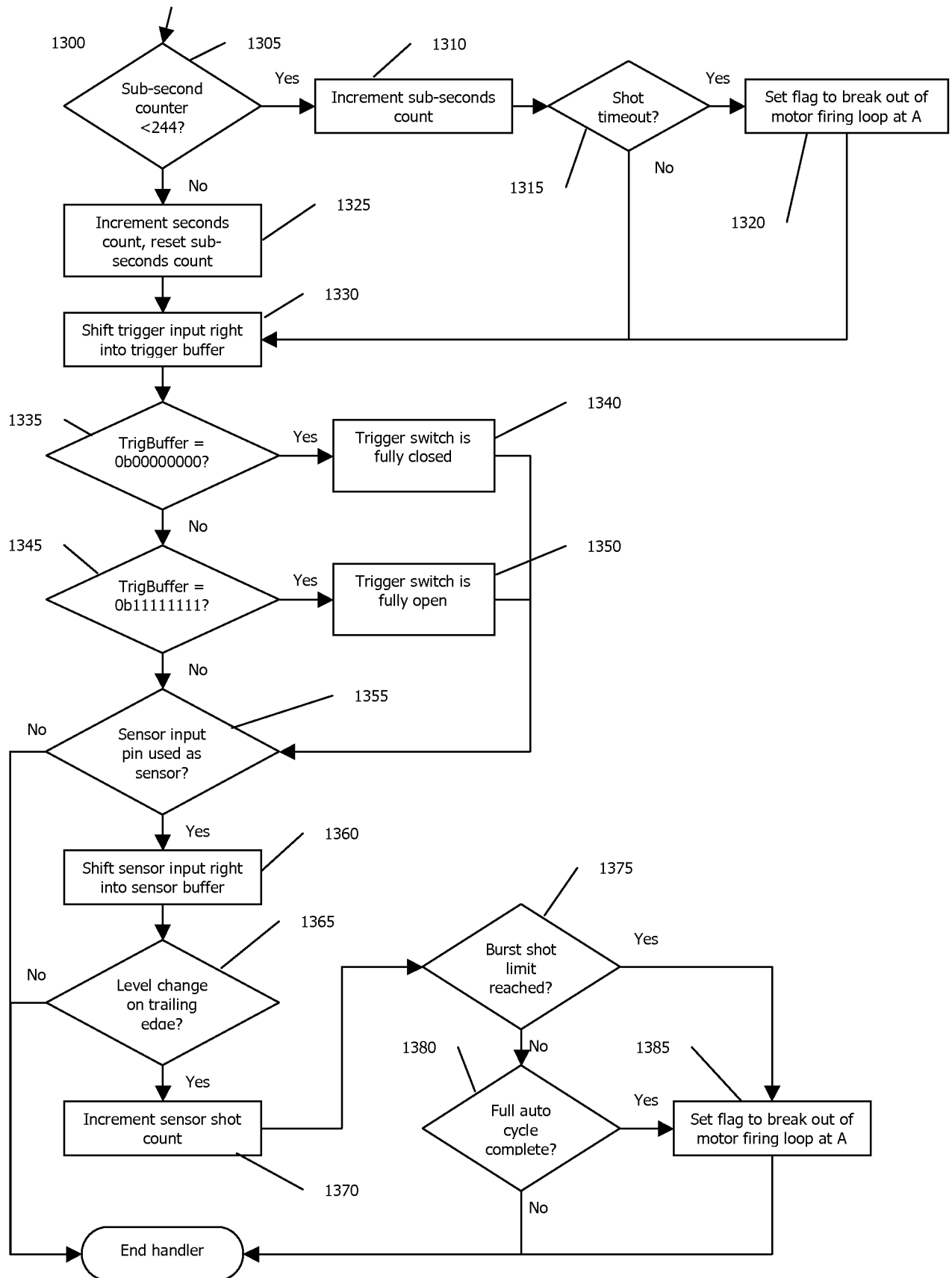


FIG. 13

RWR Electronics fw#07C05

EMC Status:

[F]ire Mode = 2-rnd [B]urst
[V]olt Limit = Auto
[S]ensor Lvl = Sw
S[p]eed Ctrl = N
S[o]ft Start = N
[I]ndex Chk = Y
S[t]all Chk = Y
Max B[r]ake = Y

B

RWR Electronics fw#07C05

EMC Status:

[F]ire Mode = 3-rnd [B]urst
[V]olt Limit = Auto
[S]ensor Lvl = Sw
S[p]eed Ctrl = N
S[o]ft Start = N
[I]ndex Chk = Y
S[t]all Chk = Y
Max B[r]ake = Y

F

RWR Electronics fw#07C05

EMC Status:

[F]ire Mode = Auto
[V]olt Limit = Auto
[S]ensor Lvl = Sw
S[p]eed Ctrl = N
S[o]ft Start = N
[I]ndex Chk = Y
S[t]all Chk = Y
Max B[r]ake = Y

P

RWR Electronics fw#07C05

EMC Status:

[F]ire Mode = Auto
[V]olt Limit = Auto
[S]ensor Lvl = Sw
S[p]eed Ctrl = Y
V[a]ry Spd = N
[D]ead Time = N
S[o]ft Start = N
[I]ndex Chk = Y
S[t]all Chk = Y
Max B[r]ake = Y

FIG. 14