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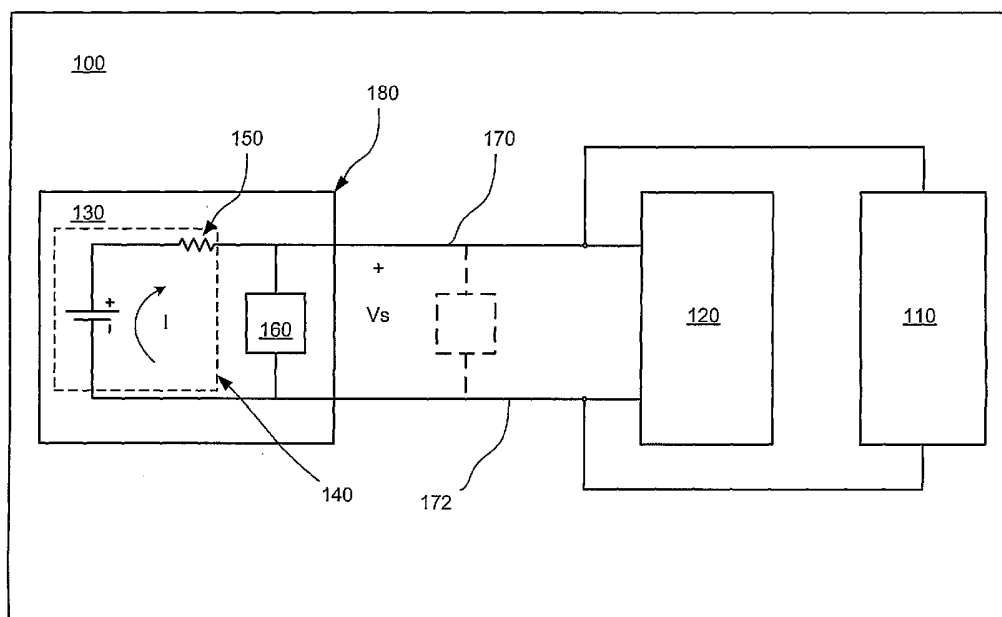
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(54) Title: POWER SUPPLY AND RELATED SYSTEMS AND METHODS



(57) Abstract: A power supply includes a power source having first and second terminals. A circuit is coupled to the source and is operable to maintain a first quantity between the terminals within a predetermined range of values until a second quantity between the terminals has a predetermined value. Such a power supply provides the ability to delay activating a load until the current that the supply can provide is at a level acceptable for proper load function.

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POWER SUPPLY AND RELATED SYSTEMS AND METHODS

STATEMENT OF GOVERNMENT INTEREST

The invention was made with United States Government support under Contract No. DAAH01-03-C-0010 awarded by the US Army. The United States Government has certain rights in this invention.

BACKGROUND

Thermal batteries are often used to power the circuitry in certain devices, such as missiles. Specifically, after activation, the battery powers, e.g., the electronic control circuitry and the motors that steer the missile.

A thermal battery is activated by igniting an internal portion of the battery. Upon ignition, the battery commences current and voltage production.

But unfortunately, upon activation, a thermal battery has a high equivalent series resistance (ESR) - typically on the order of tens of giga-ohms - which reduces the voltage level that the battery is able to generate across a load. Although the ESR reduces to a suitable value within a time typically on the order of $\frac{1}{4}$ to $\frac{3}{4}$ seconds, if the circuitry activates before the ESR is low enough - typically less than one ohm - and, thus, the output voltage high enough, the circuitry may initialize in an undesirable state or may otherwise malfunction. And if the circuitry malfunctions, it may cause a malfunction in the device, e.g., a missile, that incorporates the circuitry.

FIG. 1 is a schematic block diagram of a conventional device **10**, vehicle, such as a missile, having at least one load, such as a motor **20** and electronic circuitry **30**, and a power source **35**, including a thermal battery **40** with associated ESR **50**. The motor **20** and electronic circuitry **30** are coupled to and receive a supply voltage **V_s** from the battery **40** via conductors **60** and **62**. The assembly for igniting the battery is omitted for clarity.

Typically, the electronic circuitry **30** operates in a reset mode when the supply voltage **V_s** is between a minimum operational level and a reset level, e.g., 0.5 Volts (V), and is fully operational when **V_s** is greater than the reset

level. But if while the circuitry **30** is fully operational **Vs** falls below the reset level, then the circuitry re-enters the reset mode. Unfortunately, the circuitry **30** re-entering the reset mode may delay the start-up time for the missile **10**, or may cause the missile to malfunction.

More specifically, upon activation at missile-launch time, the battery **40** begins providing the supply voltage **Vs** to the motor **20** and electronic circuitry **30**, which typically requires minimal current (on the order of a few milliamps) to reset itself, exit the reset mode, and perform, for example, pre-launch system checks. Consequently, because the circuitry **30** presents a relatively small load to the battery **40**, **Vs** typically exceeds the circuitry's reset level relatively quickly, thus allowing the circuitry to become fully operational and perform the pre-launch routine within a few milliseconds after the battery **40** is activated. However, the motor **20**, when operating, draws a relatively large amount of current on the order of 10 Amps, and thus presents a relatively large load to the battery **40**. Therefore, if the circuitry **30** activates the motor **20** before the ESR **50** has fallen to a suitably small value, then the load presented by the motor **20** may cause **Vs** to fall below the reset level of the circuitry **30**, which, as discussed above, causes the circuitry **30** to re-enters its reset mode. Unfortunately, the circuitry **30** re-entering its reset mode may undesirably delay or abort the launch of the missile **10**.

SUMMARY

In an embodiment of the invention, a power supply includes a power source having first and second terminals. A circuit is coupled to the source and is operable to maintain a first quantity between the terminals within a predetermined range of values until a second quantity between the terminals has a predetermined value.

Such a power supply provides the ability to delay activating a load until the current that the supply can provide is at a level acceptable for proper load function.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic block diagram of a conventional device; and

FIG 2 is a schematic view of a device according to an embodiment of the invention.

DETAILED DESCRIPTION

FIG. 2 is a schematic block diagram of a device **100**, such as a missile, which, according to an embodiment of the invention, includes a motor **110**, electronic control circuitry **120**, and a power supply **130** that includes a power source **140**, such as a thermal battery with associated ESR **150**, and a supply-activation circuit **160** such as a fuse. The motor **110** and electronic control circuitry **120** are coupled to and receive a supply voltage **Vs** from the power supply **130** via conductors **170** and **172**.

The supply-activation circuit **160** prohibits **Vs** from increasing above the reset voltage level of the control circuitry **120** until the ESR **150** reduces to a value $ESR_{desired}$ that is low enough to allow the supply **130** to maintain **Vs** above the reset level while powering the control circuitry, the motor **110**, and any other load coupled to **Vs**.

According to Kirchoff's voltage and current laws:

$$(1) V_s = R_{160}/(ESR + R_{160})$$

$$(2) I = V_i/(ESR + R_{160})$$

where V_i is the internal voltage of the battery **140** and R_{160} is the equivalent resistance of the circuit **160** and is small enough, e.g., often less than an ohm, such that the impedances presented by the control circuitry **120** and the motor **110** can be ignored. As the value of ESR **150** falls toward $ESR_{desired}$ after the activation of the battery **140**, **Vs** and **I** both increase until:

$$(3) V_{s_{activate}} = R_{160}/(ESR_{desired} + R_{160})$$

$$(4) I_{activate} = V_i/(ESR_{desired} + R_{160})$$

Because V_i , $ESR_{desired}$, and R_{160} are known quantities, then $I_{activate}$ and $V_{sactivate}$ are also known.

Consequently, the circuit **160** is designed to transition from a relatively low impedance to a relatively high impedance, e.g., on the order of Megaohms or Gigaohms, in response to $I = I_{activate}$ and/or $V_s = V_{sactivate}$ per equations (3) and (4).

For example, the circuit **160** may be a fuse designed to blow when the current through it equals $I_{activate}$. Before the fuse blows, V_s has a level on the order of 0 V to a few hundred mV. Once the fuse blows, the value of ESR_{150} is low enough such that V_s becomes greater than the reset voltage level of the circuitry **120** and remains greater than the reset voltage level even after the motor **110** is activated. Consequently, the circuitry **120** is significantly less likely to re-enter its reset mode when the motor **110** is activated, thus reducing the chances that the circuitry will delay or abort the launch of the missile **10**.

Still referring to **FIG. 2**, the operation of the missile **10** during a launch sequence is discussed where the circuit **160** is a fuse.

First, an igniter (omitted from **FIG. 2** for clarity) activates the battery **140**. Because the fuse **160** is electrically closed, $V_s \sim 0$ V. If V_s is large enough to power the circuitry **120** in its reset mode, then the circuitry **120** resets itself. If V_s is not large enough, then the circuitry **120** is inactive.

Next, the value of the ESR_{150} begins decreasing while the fuse **160** remains electrically closed and V_s remains ~ 0 V.

Then, when the value of ESR_{150} equals or falls below $ESR_{desired}$, the fuse **160** blows (i.e., electrically opens), and V_s rises to a level above the reset level of the circuitry **120**. If the circuitry **120** has not previously reset itself, then it does so now before becoming fully operational.

Next, the circuitry **120** executes its pre-launch routine, activates the motor **110**, and launches the missile **10**.

The power supply **130** comprises a housing **180** in which the battery **140** is disposed, and the circuit **160** is disposed within the housing **180**.

Alternatively, the circuit **160** may be disposed outside of the housing **180** as indicated in **FIG. 2** by dashed lines.

Although described as being a fuse that is connected across the terminals **170** and **172** of the missile power supply **130**, other embodiments of the circuit **160** are contemplated. For example, the circuit **160** may include a one or more interconnected semiconductor components such as transistors, and may be reusable — a fuse, once blown, is typically not reusable. Furthermore, the circuit **160** may transition from a low to a high impedance in response to **Vs** in addition to or instead of in response to **I**. Moreover, the circuit **160** may be connected in a topology other than directly across the supply terminals **170** and **172**. In addition, the circuit **160** may be used in devices other than missiles.

The preceding discussion is presented to enable a person skilled in the art to make and use the invention. Various modifications to the disclosed embodiments will be readily apparent to those skilled in the art, and the generic principles herein may be applied to other embodiments and applications without departing from the spirit and scope of the present invention. For example, it should be recognized that all operations described herein could be applied to any device employing a load that, to function properly, requires a minimum sustained voltage applied to the load. Thus, the present invention is not intended to be limited to the embodiments shown, but is to be accorded the widest scope consistent with the principles and features disclosed herein.

WHAT IS CLAIMED IS:

1. A power supply, comprising:
a power source having first and second terminals; and
a circuit coupled to the source and operable to maintain a first quantity between the terminals within a predetermined range of values until a second quantity between the terminals has a predetermined value.
2. The power supply of claim 1 wherein the first quantity comprises a voltage across the terminals and the second quantity comprises a current flowing between the terminals.
3. The power supply of claim 1 wherein the first quantity comprises a voltage across the terminals and the second quantity comprises an equivalent series resistance of the power source.
4. The power supply of claim 1 wherein the first and second quantities comprise a voltage across the terminals.
5. The supply of claim 1 wherein the source comprises a battery.
6. The supply of claim 1 wherein the circuit comprises a fuse.
7. The supply of claim 1 wherein the source comprises a thermal battery.
8. A device, comprising:

first and second power-supply terminals; and

a circuit coupled to the terminals and operable to maintain a first quantity between the terminals within a predetermined range of values until a second quantity between the terminals has a predetermined value..

9. The device of claim 8, further comprising a load coupled across the terminals.

10. The device of claim 9 wherein the load comprises a motor.

11. The device of claim 9 wherein the load comprises control circuitry.

12. The device of claim 8, further comprising a power supply coupled across the terminals.

13. A method, comprising:
activating a power source having first and second terminals; and
maintaining a first quantity between the terminals within a predetermined range of values until a second quantity between the terminals has a predetermined value.

14. The power supply of claim 13 wherein the first quantity comprises a voltage across the terminals and the second quantity comprises a current flowing between the terminals.

15. The power supply of claim 13 wherein the first quantity comprises a voltage across the terminals and the second quality comprises an equivalent series resistance of the power source.

16. The power supply of claim 13 wherein the first and second quantities comprise a voltage across the terminals.
17. A method, comprising:
activating a power source having first and second terminals; and
preventing the activation of a load coupled to the first and second terminals until a quantity between the terminals has a predetermined value.
18. The method of claim 17 wherein the quantity comprises a current flowing between the terminals.
19. The method of claim 17 wherein the quantity comprises a voltage across the terminals.
20. The method of claim 17 wherein the quantity comprises an equivalent series resistance of the power source.

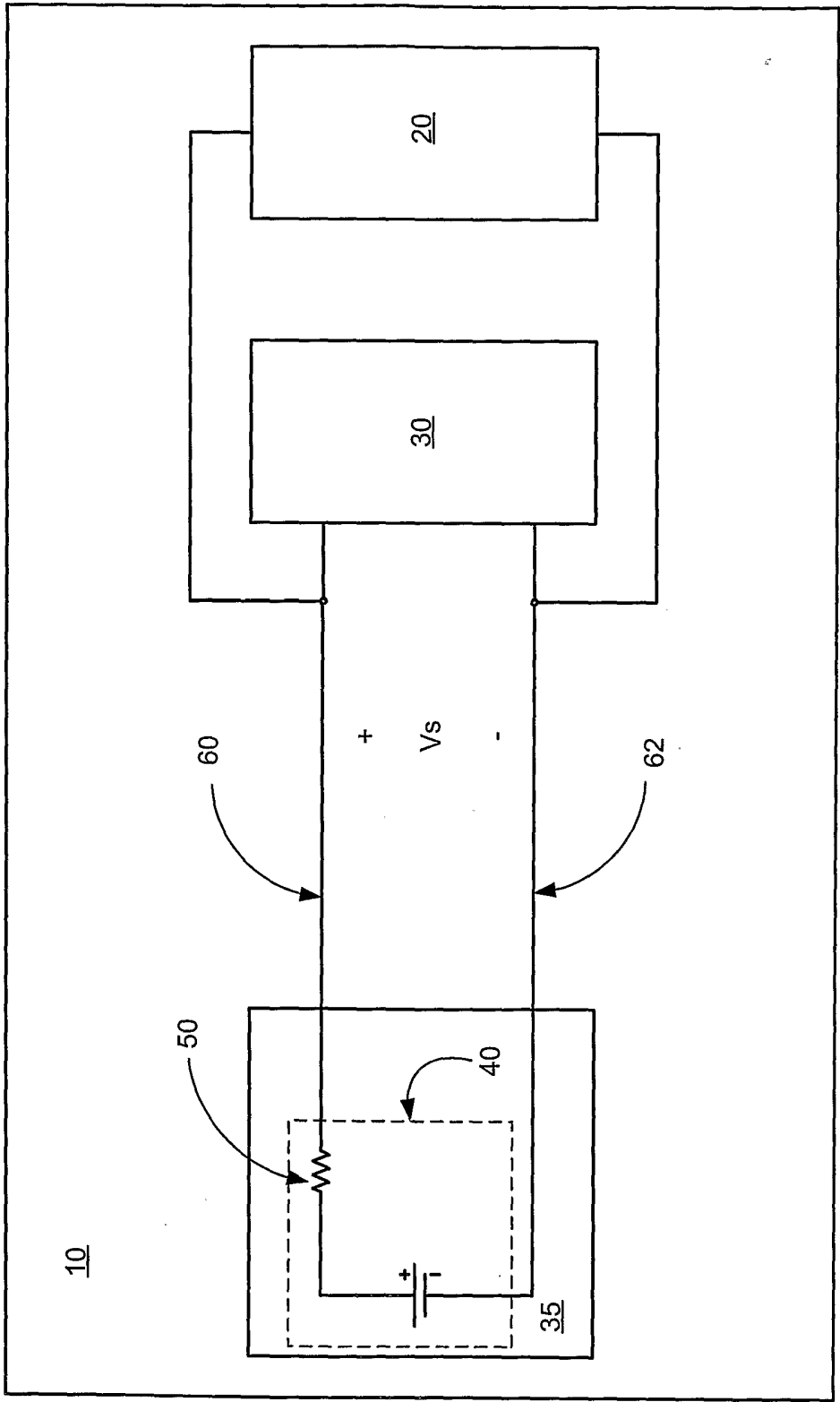


FIG. 1
(PRIOR ART)

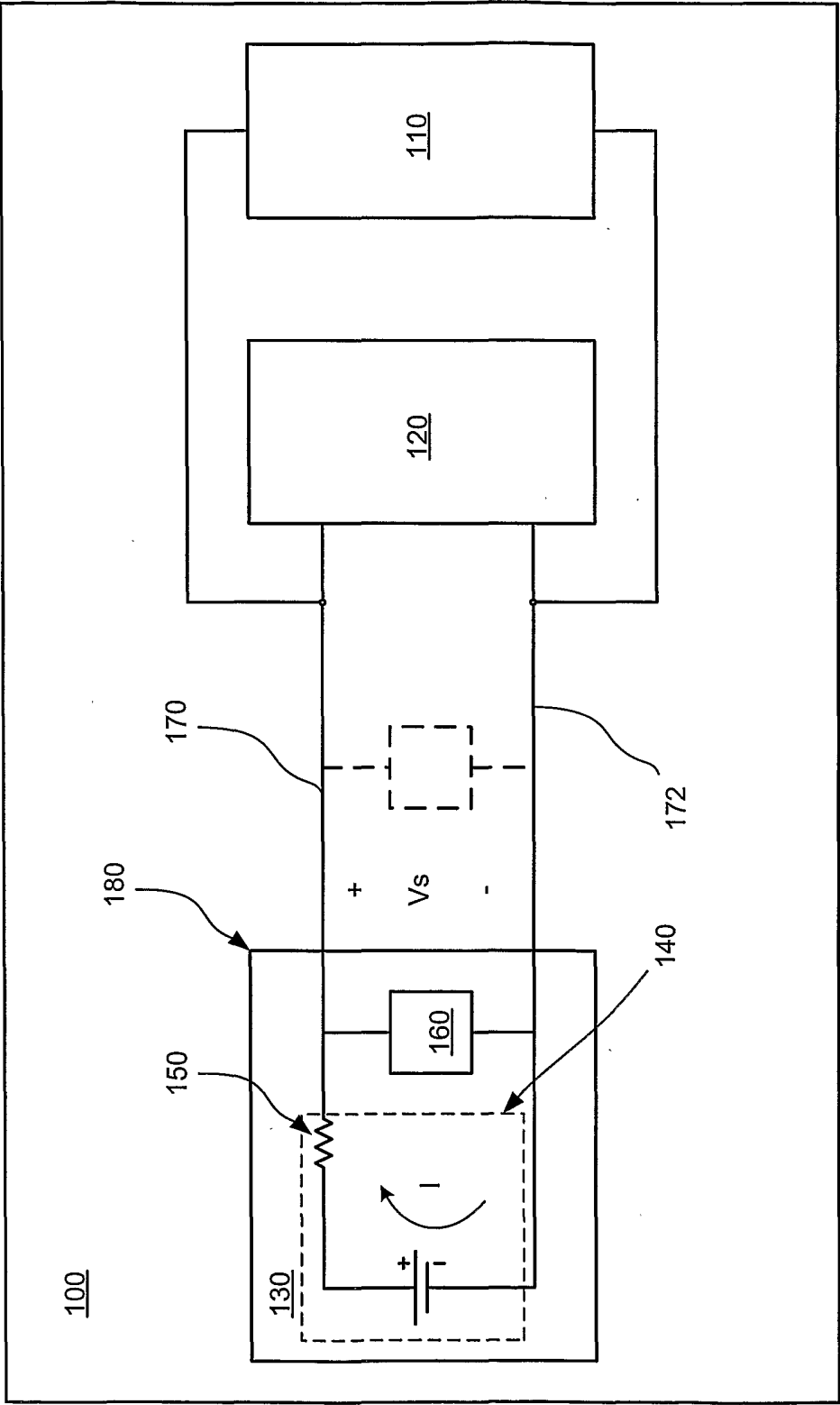


FIG. 2