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(54) **METHOD AND APPARATUS FOR A HARD DISK DRIVE PROVIDING DUAL HEAT TRANSFERS FOR AN INTERNAL THERMAL ZONE**

(76) Inventors: **Michael Sullivan**, Fremont, CA (US); **George Tyndall**, San Jose, CA (US)

Correspondence Address:
**GREGORY SMITH & ASSOCIATES**
**3900 NEWPARK MALL ROAD, 3RD FLOOR**
**NEWARK, CA 94560**

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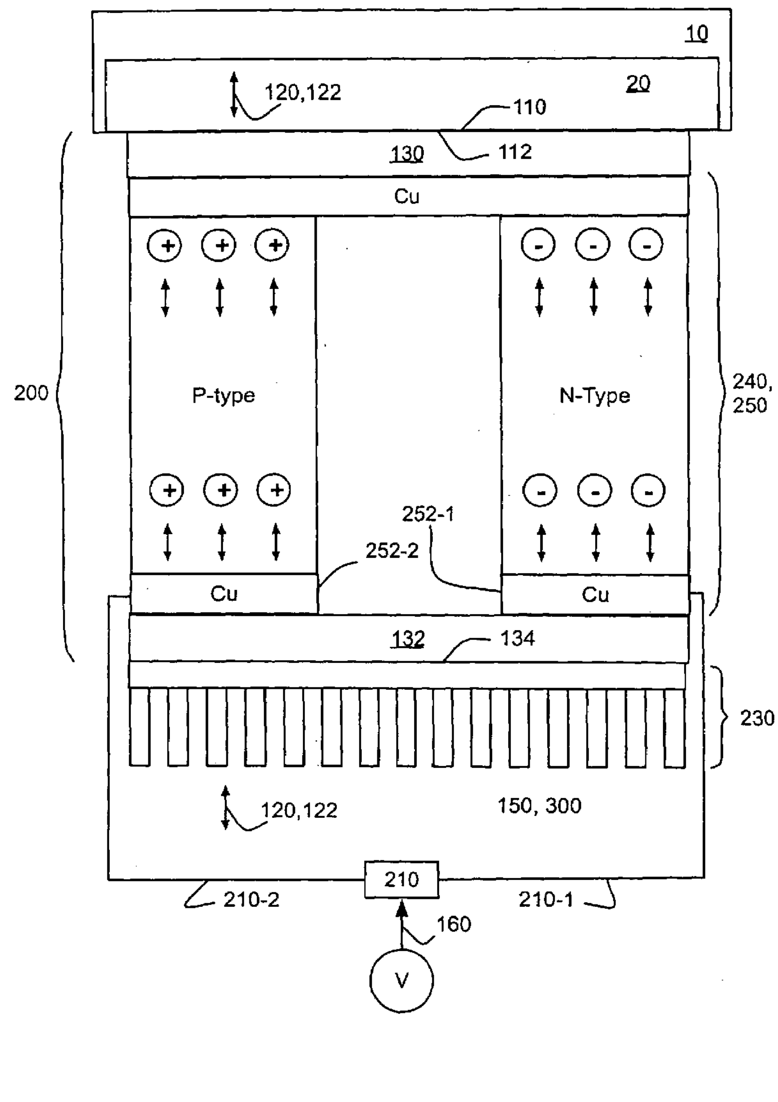
(52) **U.S. Cl.** .................................................... **219/494**

(57) **ABSTRACT**

A hard disk drive (HDD) controlling the temperature of an internal thermal zone. The HDD preferably includes a thermal controller directing a thermoelectric device based upon a temperature measure of internal thermal zone. The thermoelectric device thermal-couples via thermal interface to internal thermal zone and to air exterior to HDD, providing a first heat transfer to remove heat from the internal thermal zone and providing a second heat transfer to add heat to the internal thermal zone. The thermal controller directs the thermoelectric device to provide the first heat transfer, when the temperature measure is above a top operating temperature, and directs the thermoelectric device to provide the second heat transfer, when the temperature measure is below a bottom operating temperature. A system may include at least one HDD and may be a RAID, server computer, desktop computer, and notebook computer. Manufacturing HDD and HDD as manufacturing product.



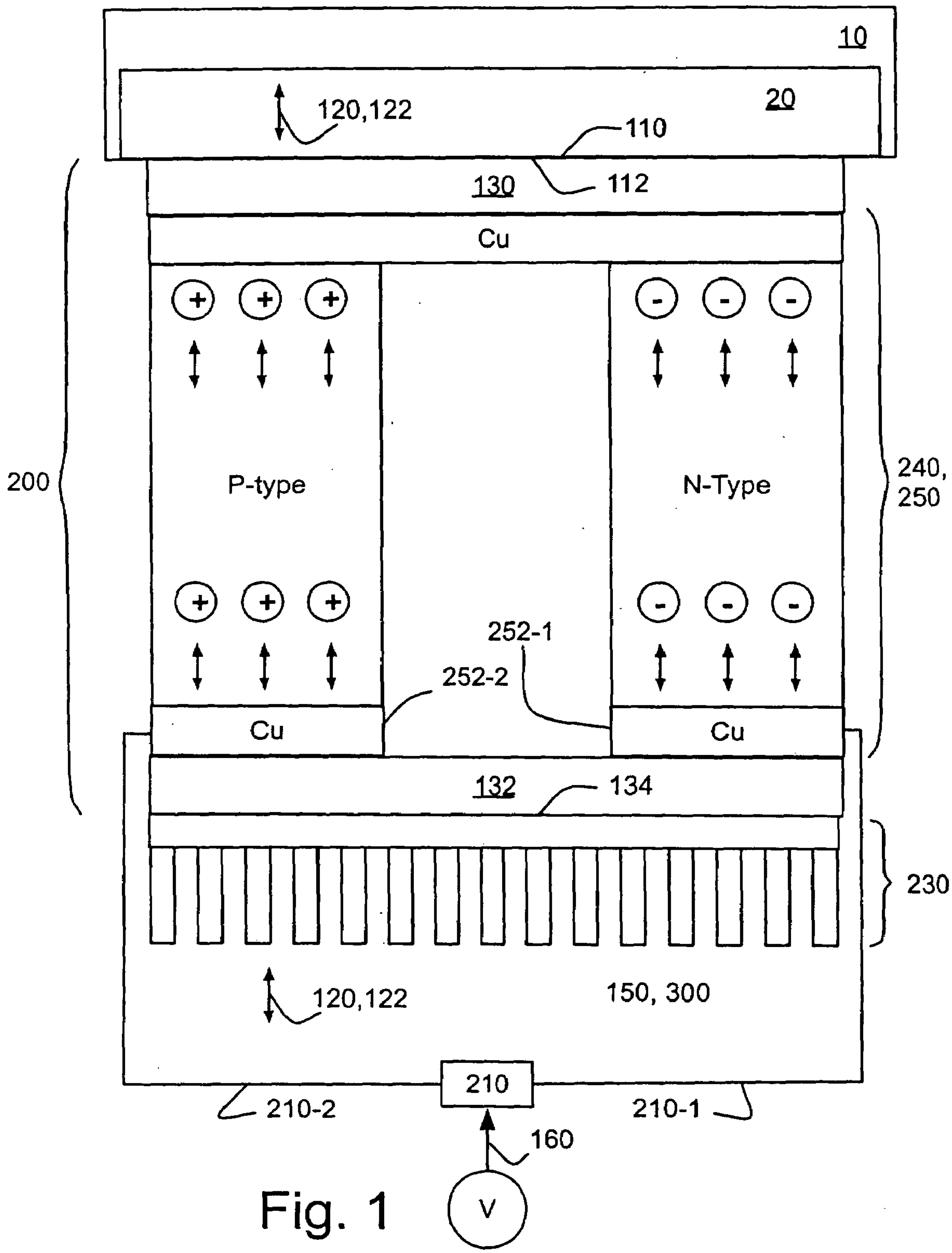

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Fig. 1

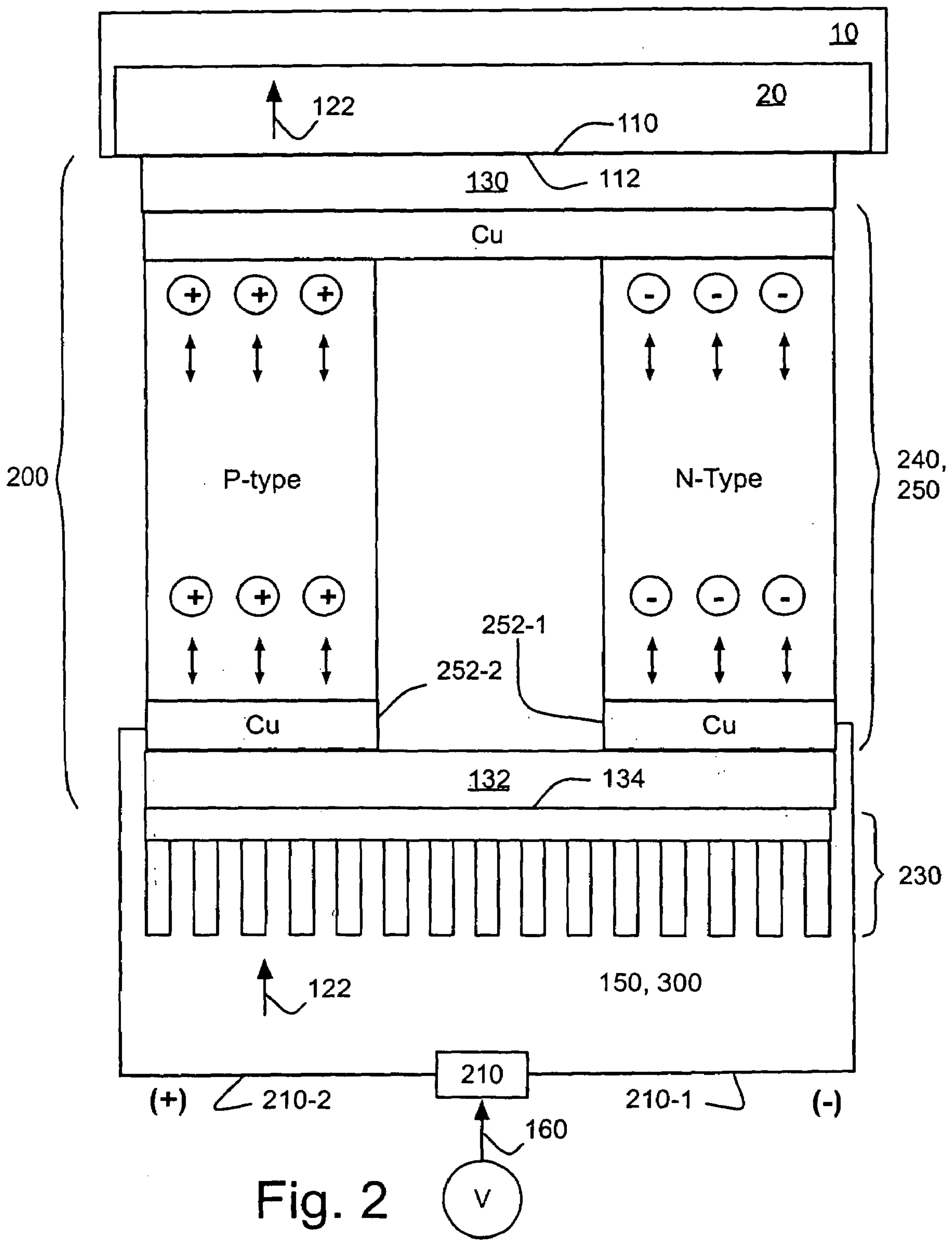
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Fig. 2

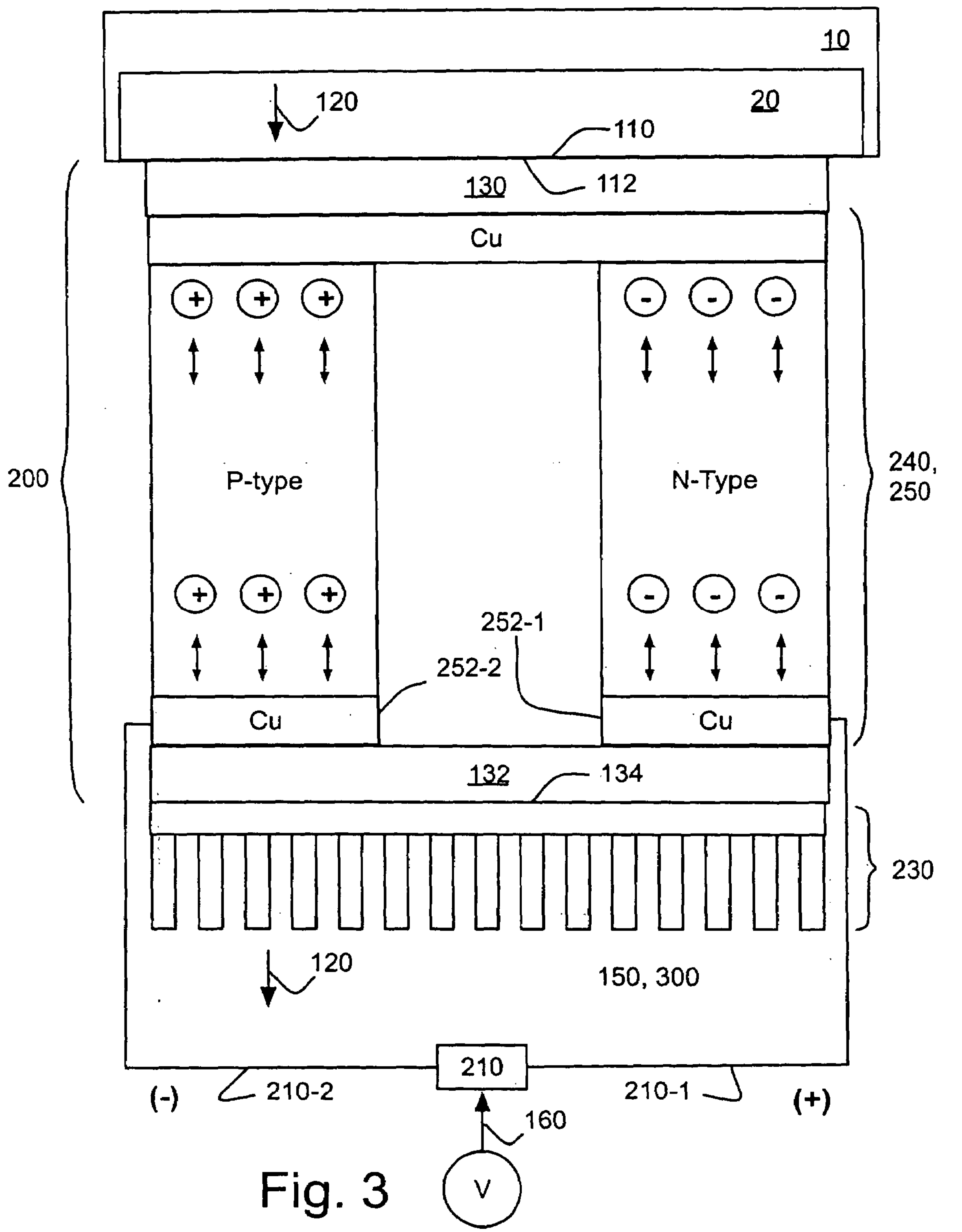

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Fig. 3

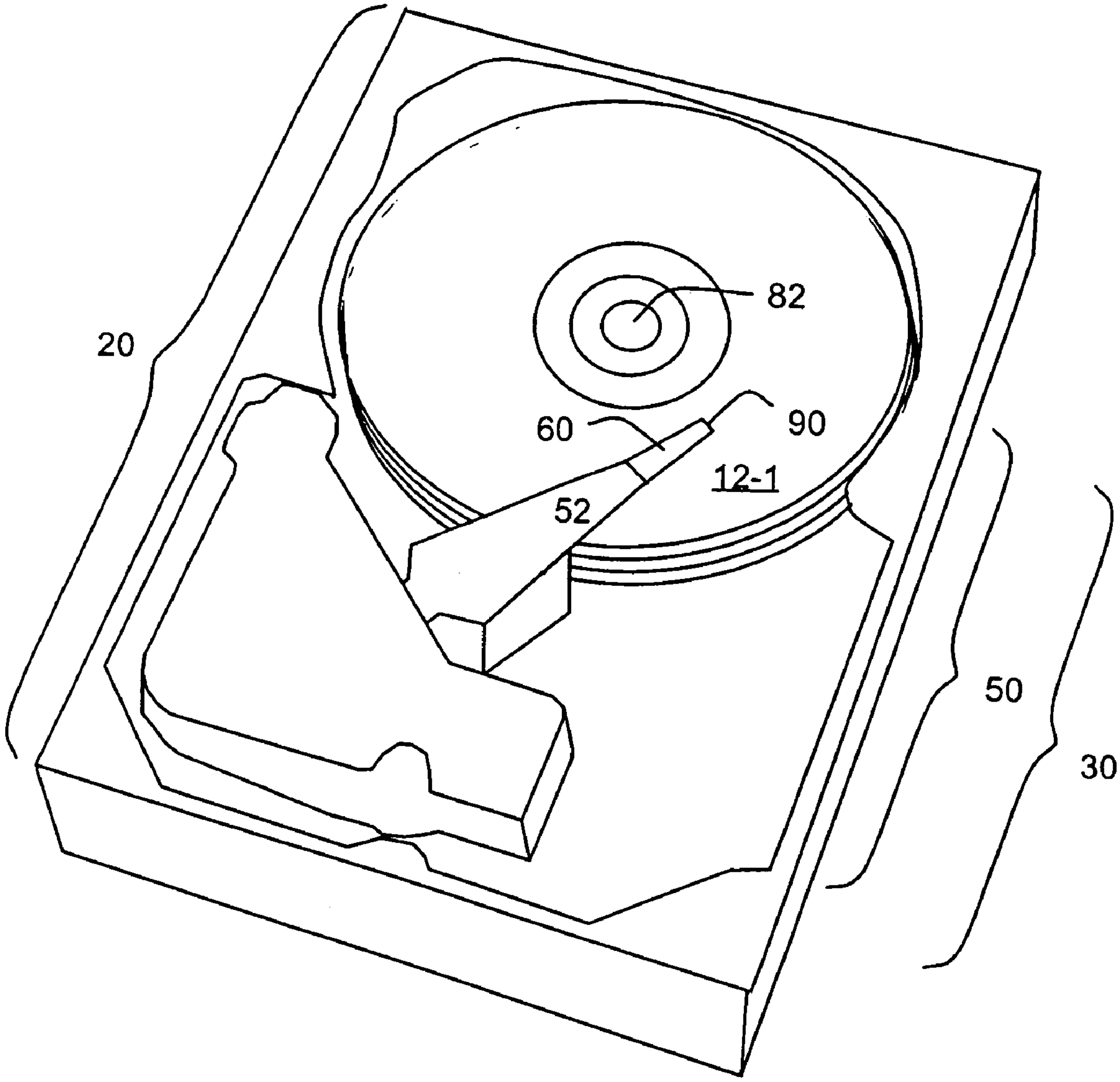



Fig. 4

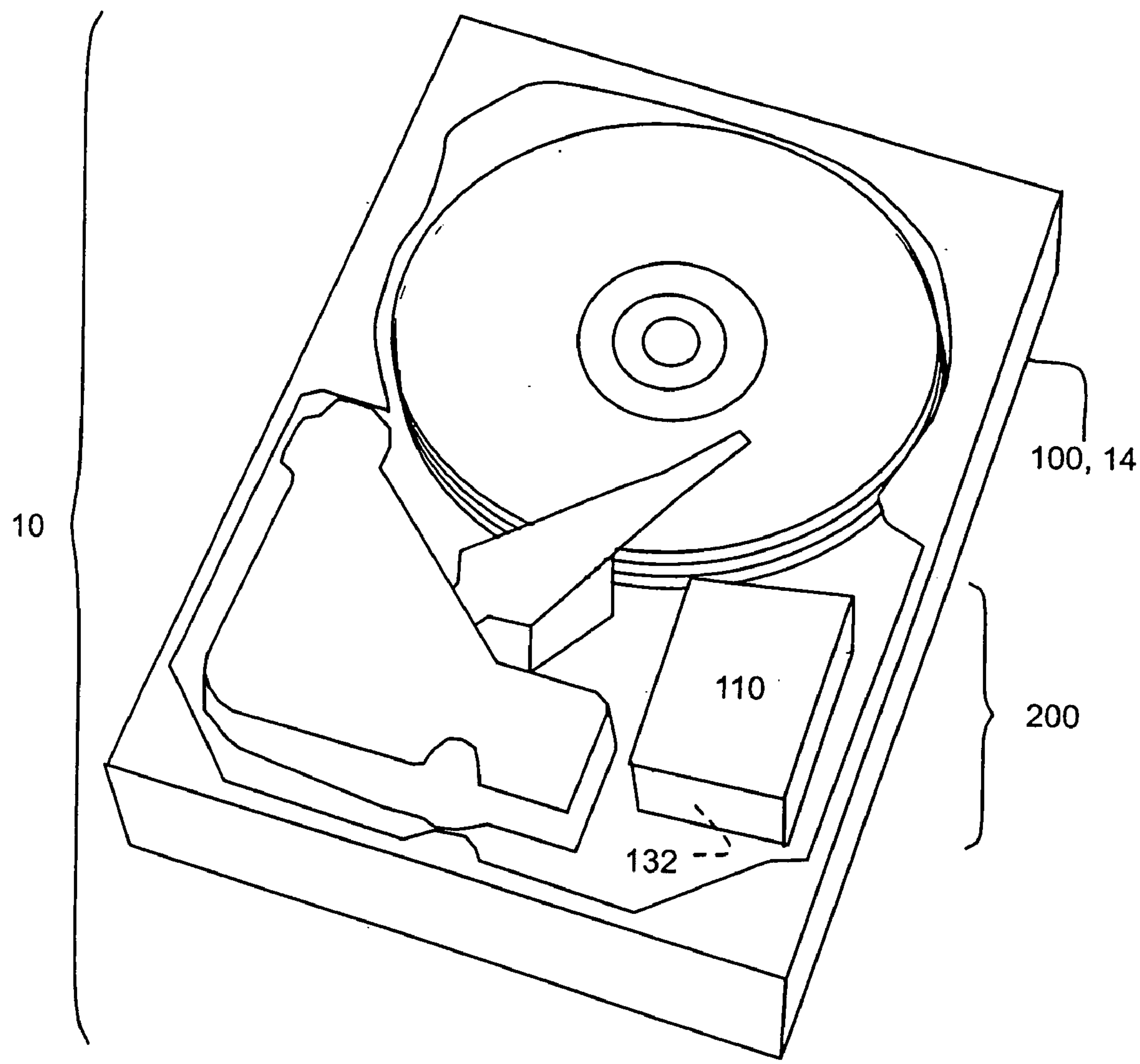



Fig. 5

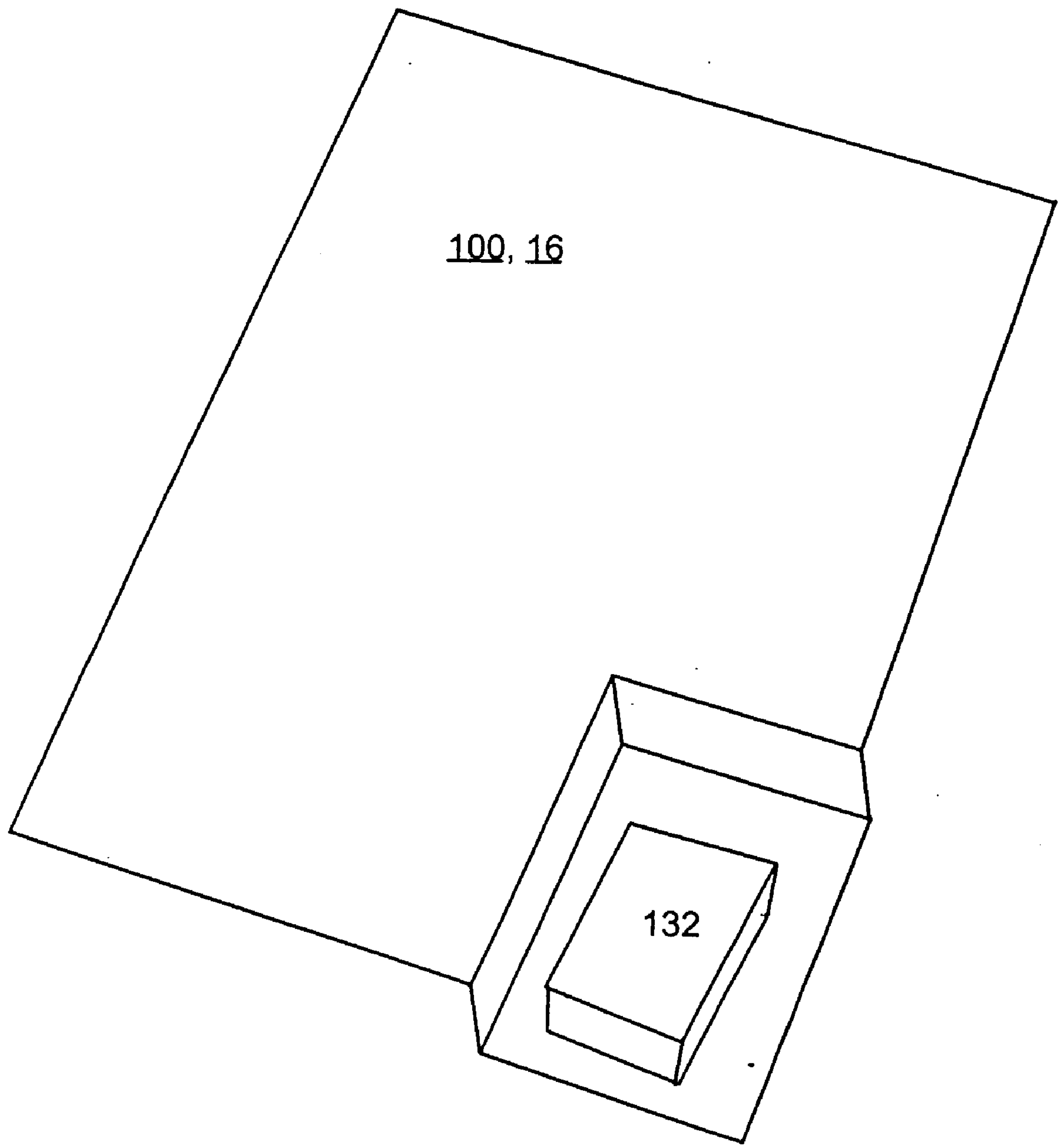



Fig. 6

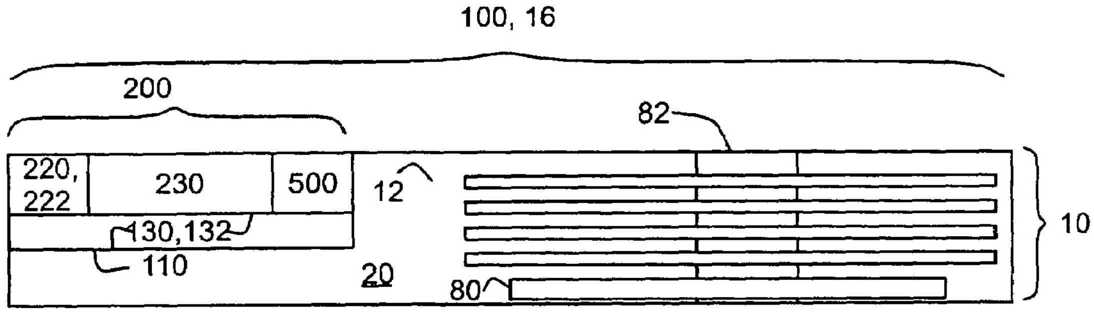



Fig. 7A

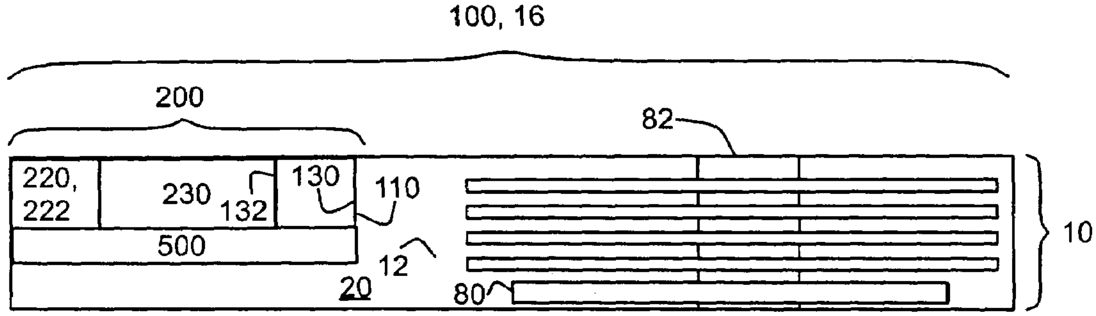



Fig. 7B

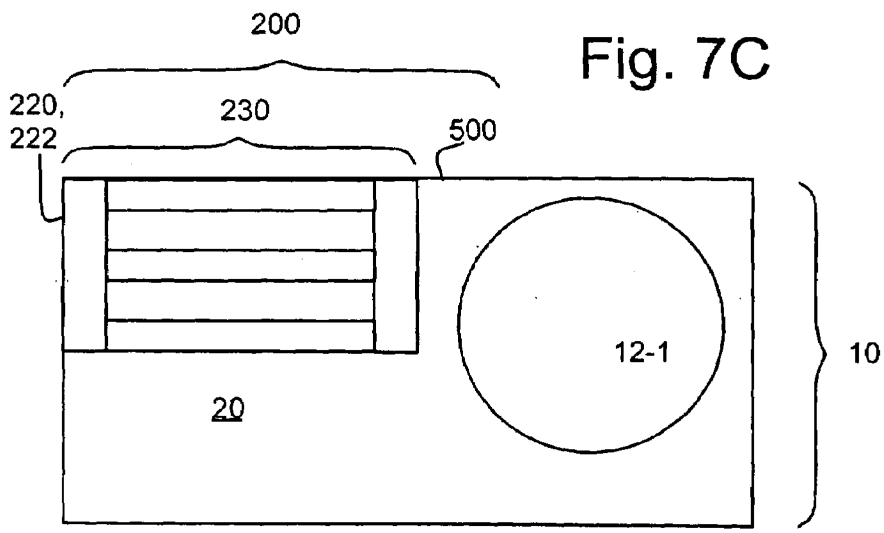



Fig. 7C

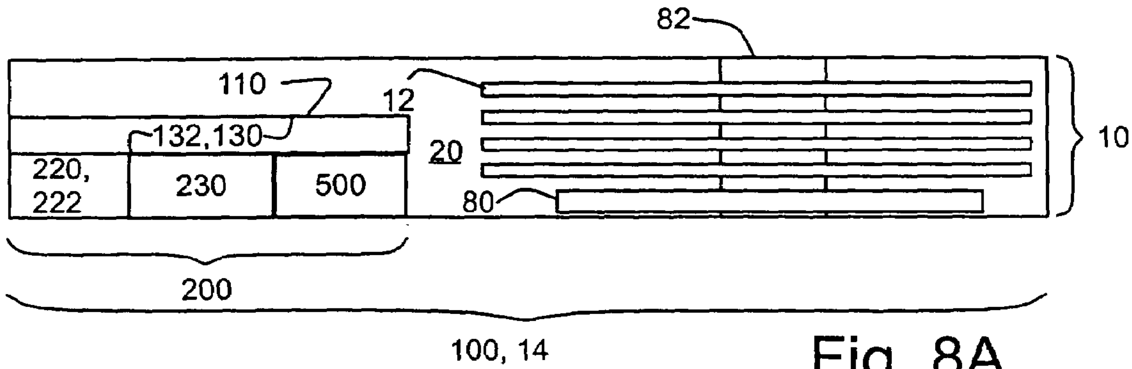



Fig. 8A

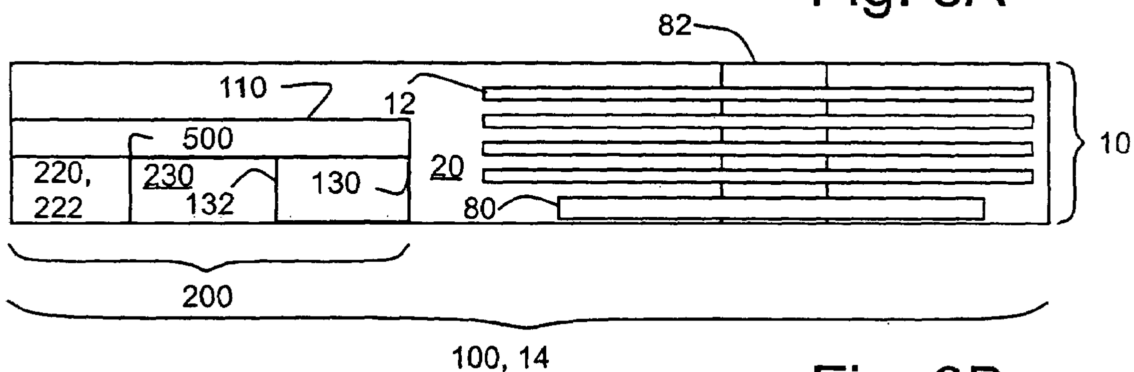



Fig. 8B

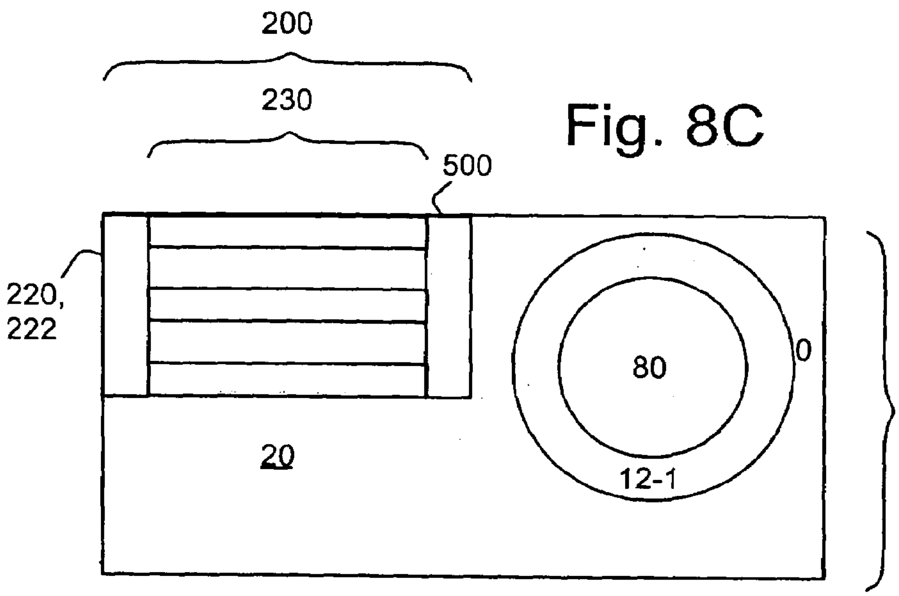



Fig. 8C

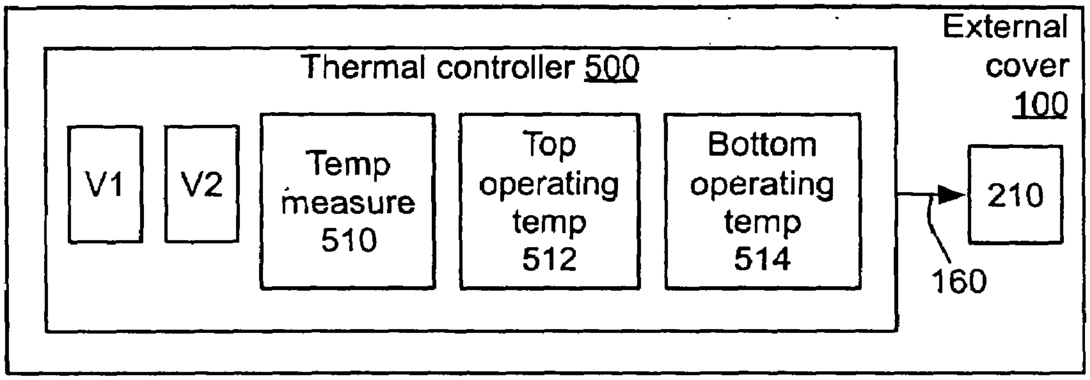



Fig. 9A

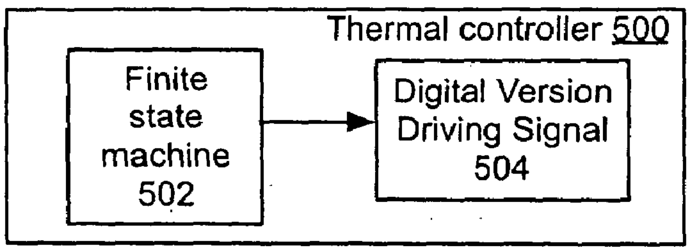
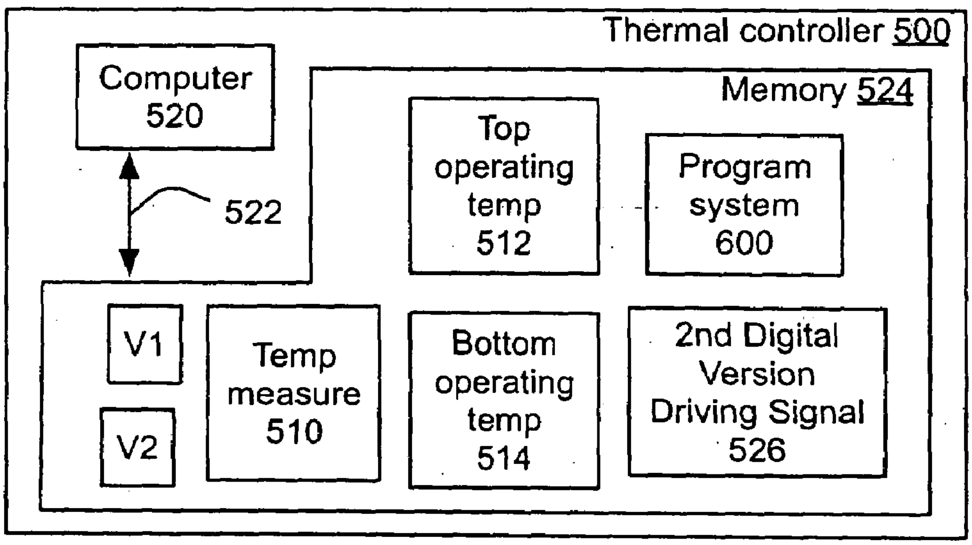



Fig. 9B

Fig. 9C



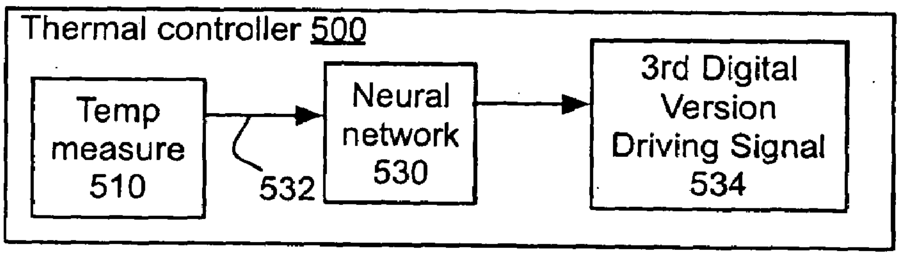




Fig. 9D

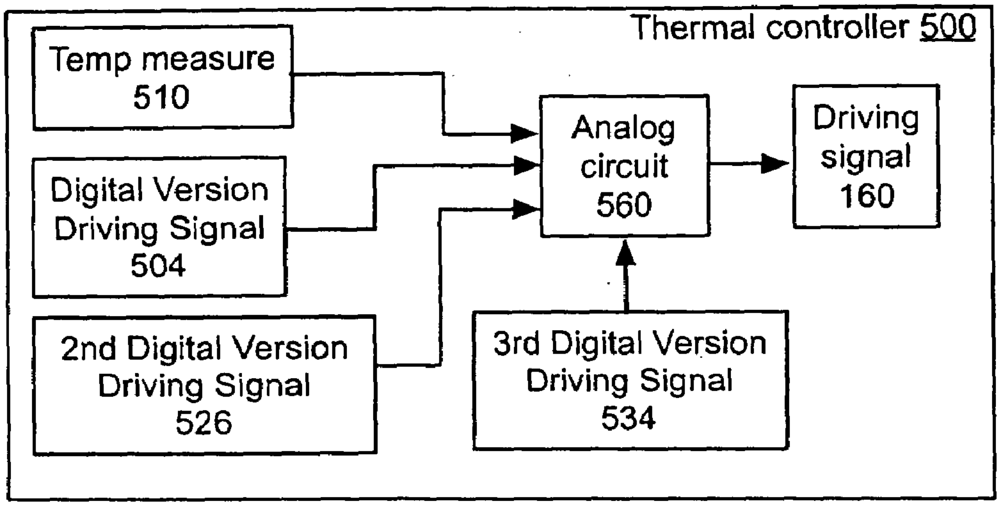



Fig. 10A

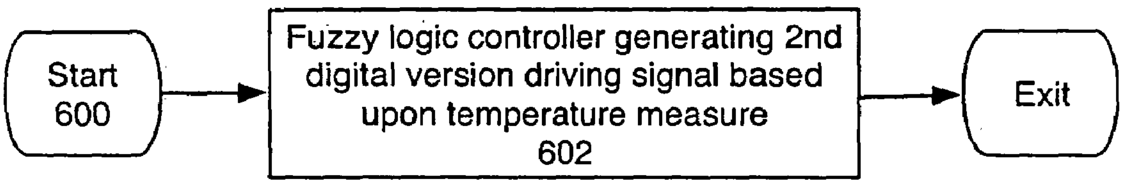



Fig. 10B

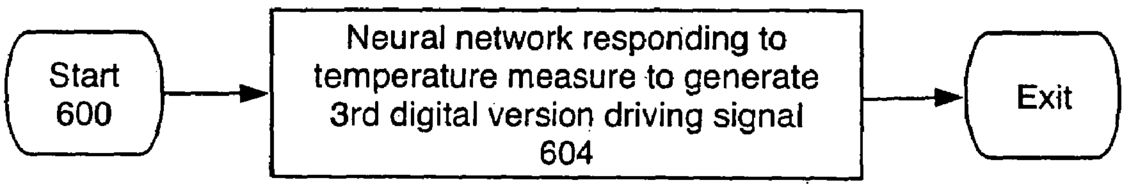



Fig. 10C

Fig. 10D

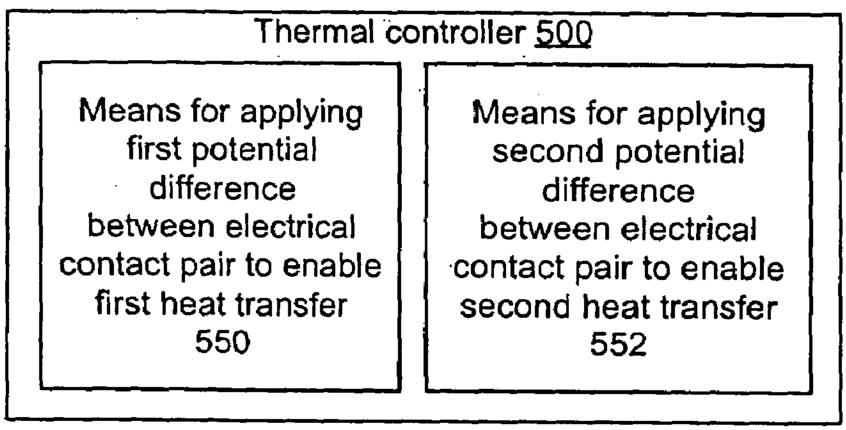
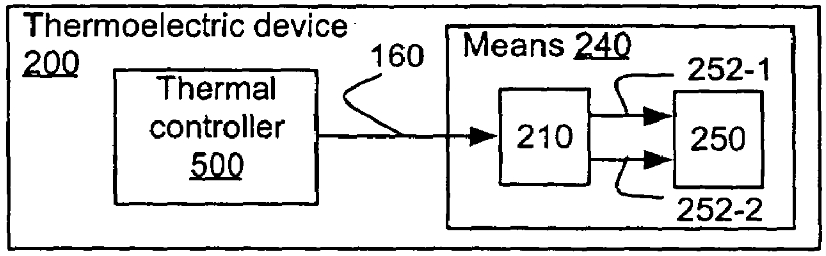


Fig. 11A

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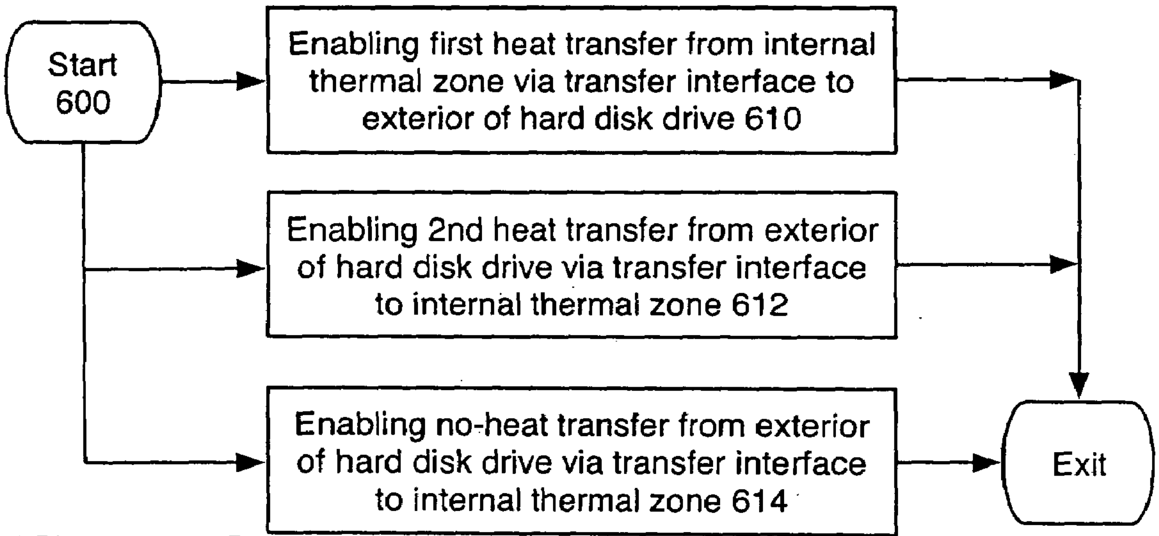


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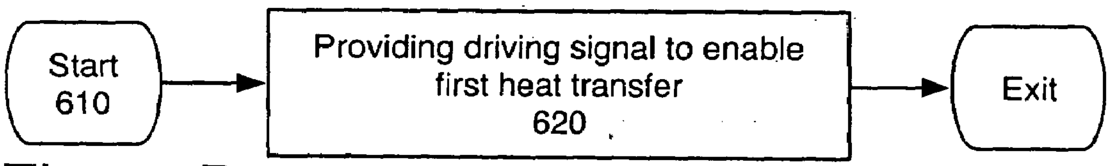


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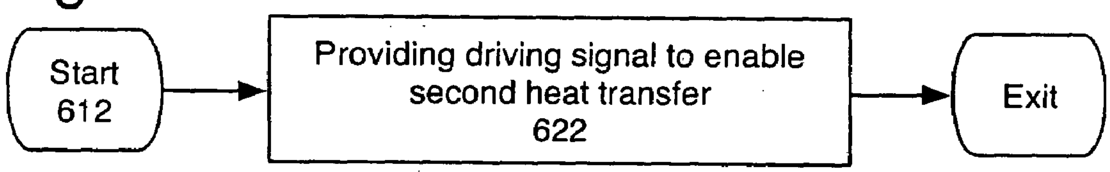


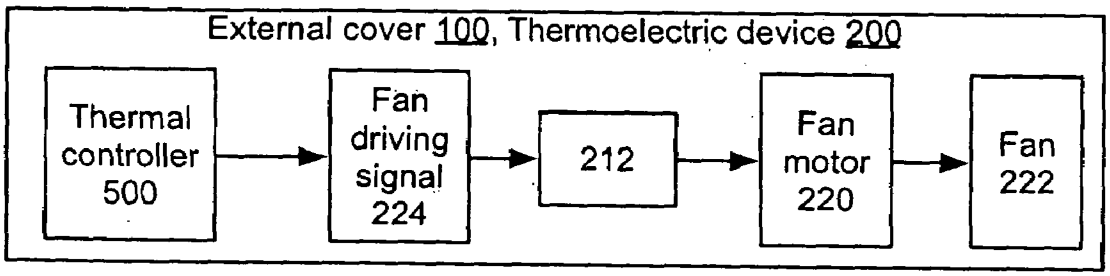




Fig. 11E

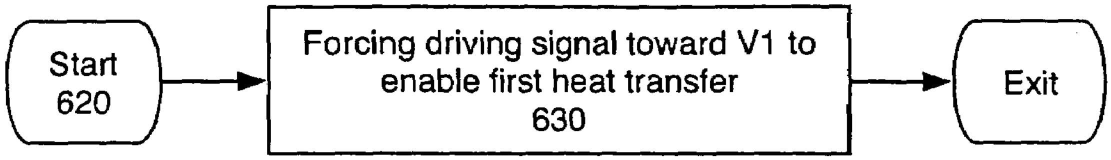



Fig. 12A

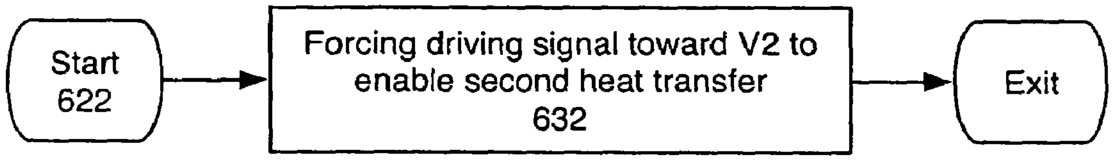
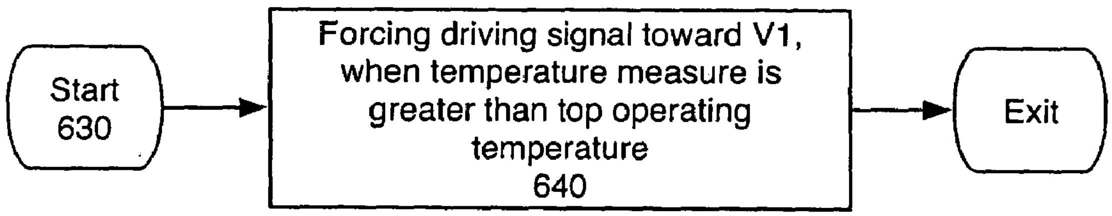



Fig. 12B

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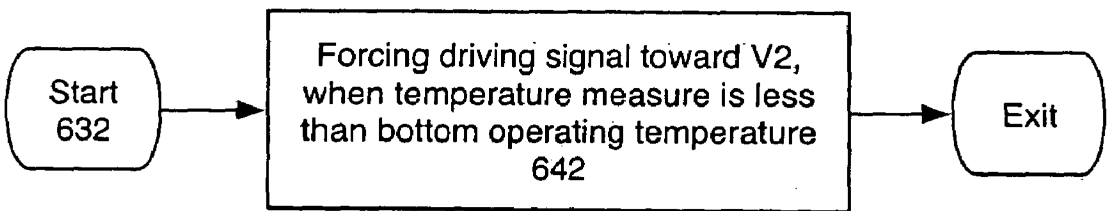


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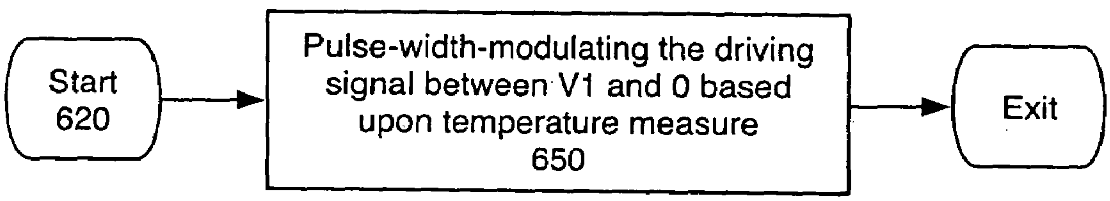
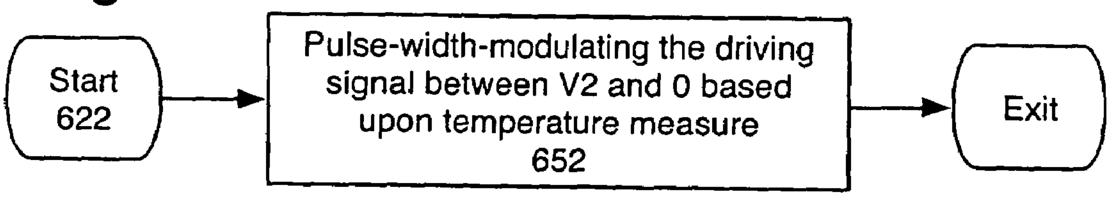



Fig. 12E

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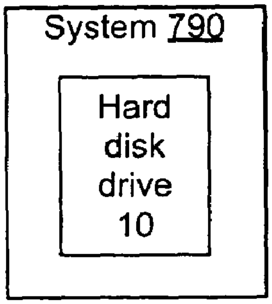



Fig. 13A

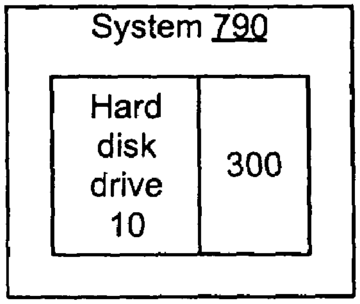



Fig. 13B

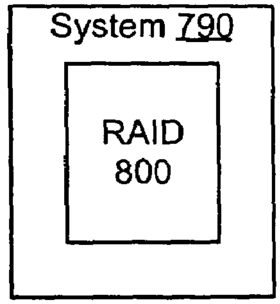



Fig. 13C

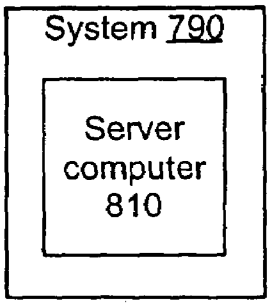



Fig. 13D

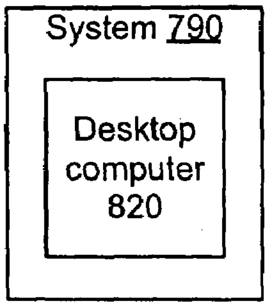



Fig. 13E

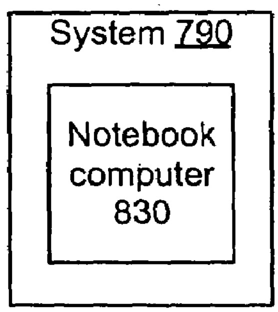



Fig. 13F

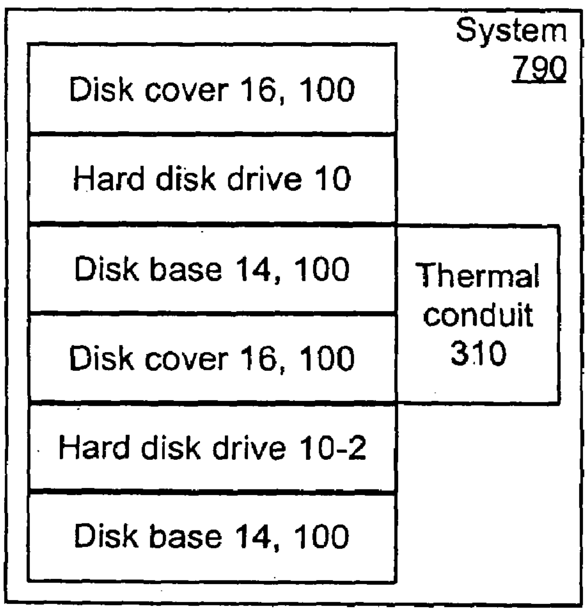



Fig. 13G

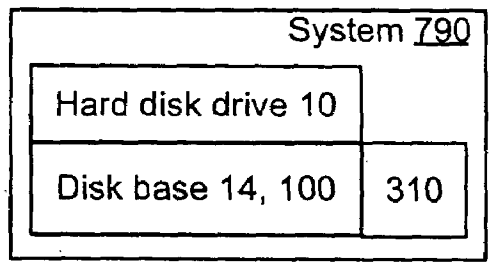



Fig. 13H

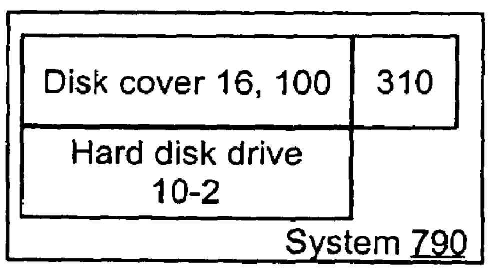



Fig. 13I

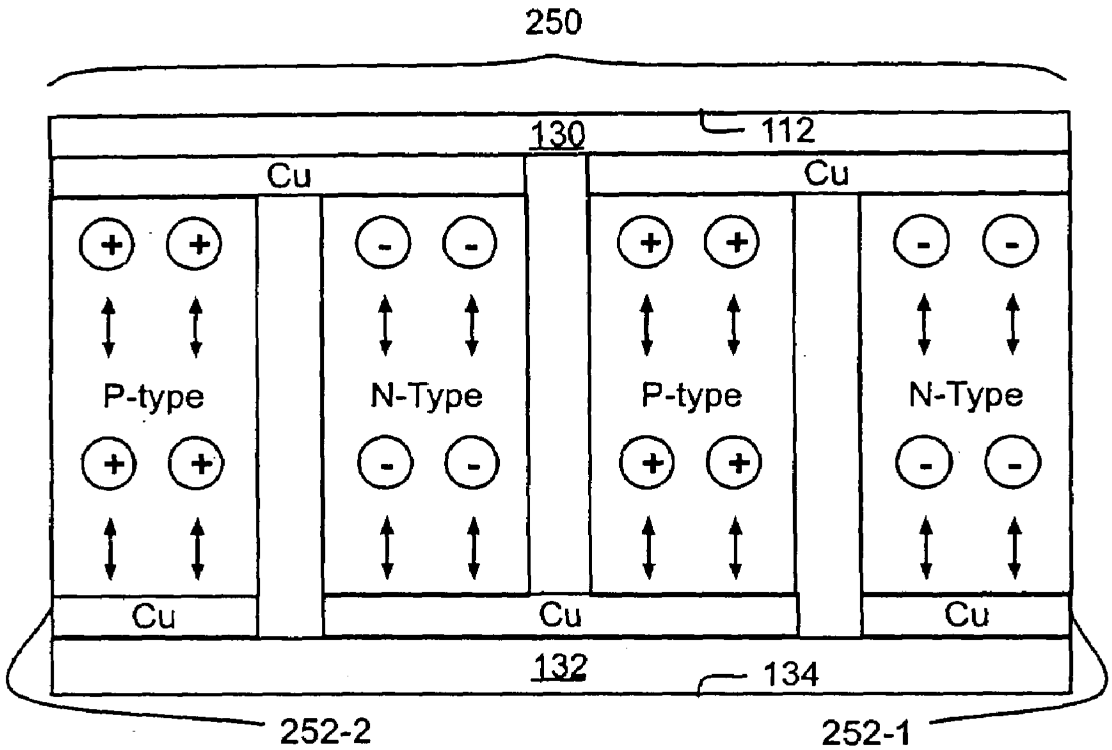



Fig. 14A

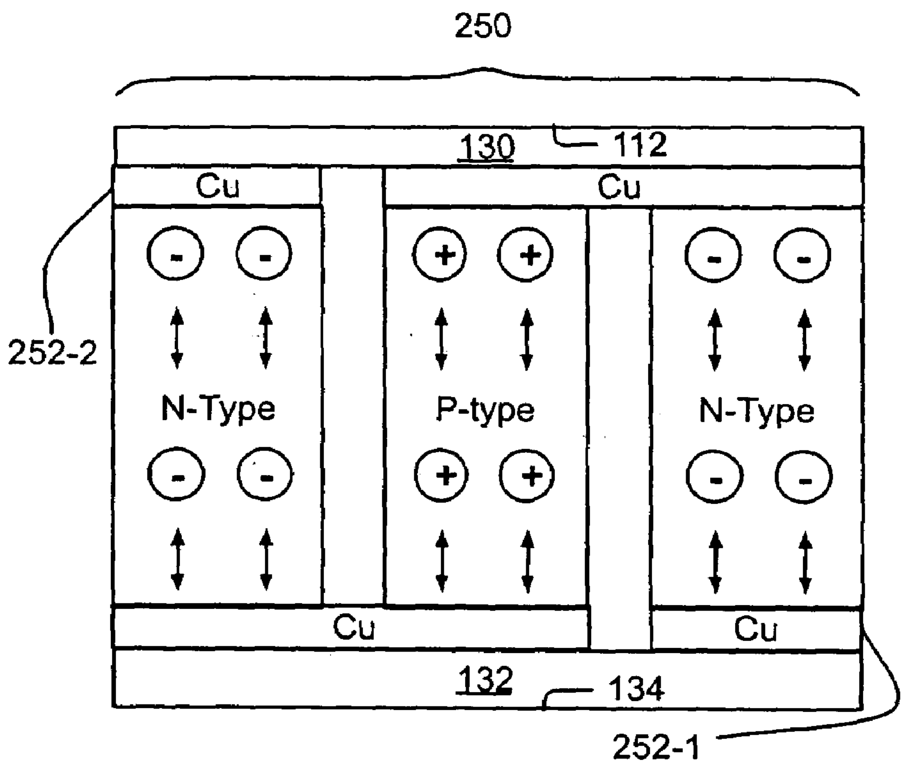



Fig. 14B

Fig. 15A

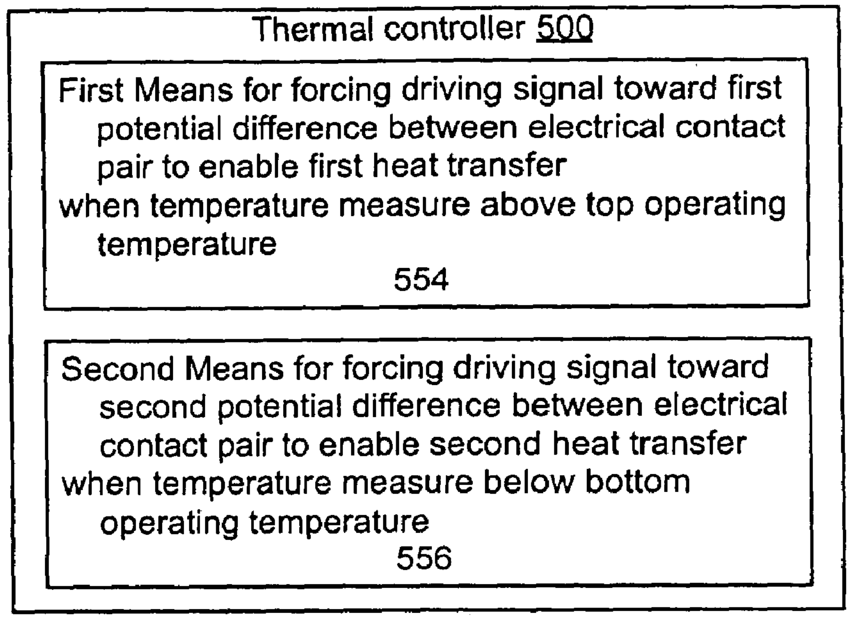



Fig. 15B

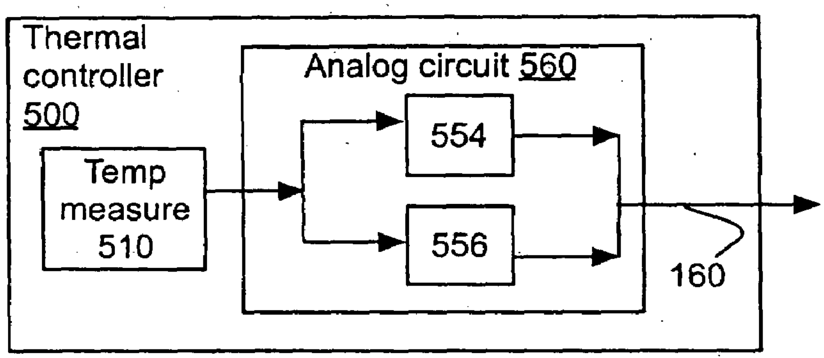



Fig. 15C

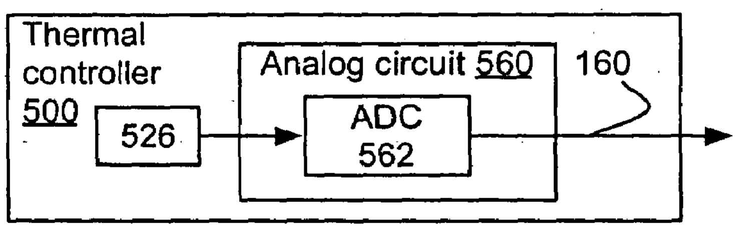
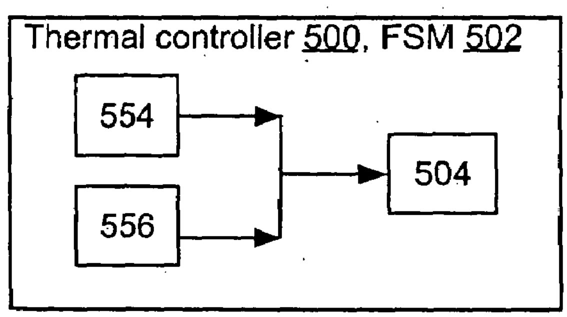



Fig. 15D



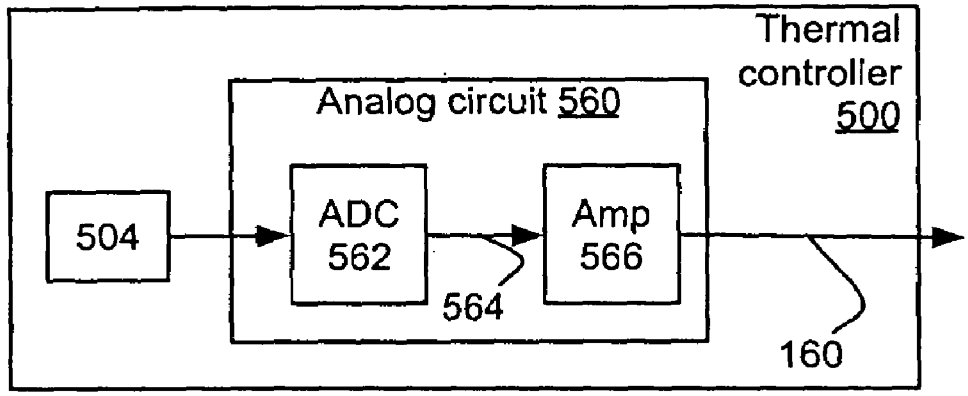



Fig. 16A

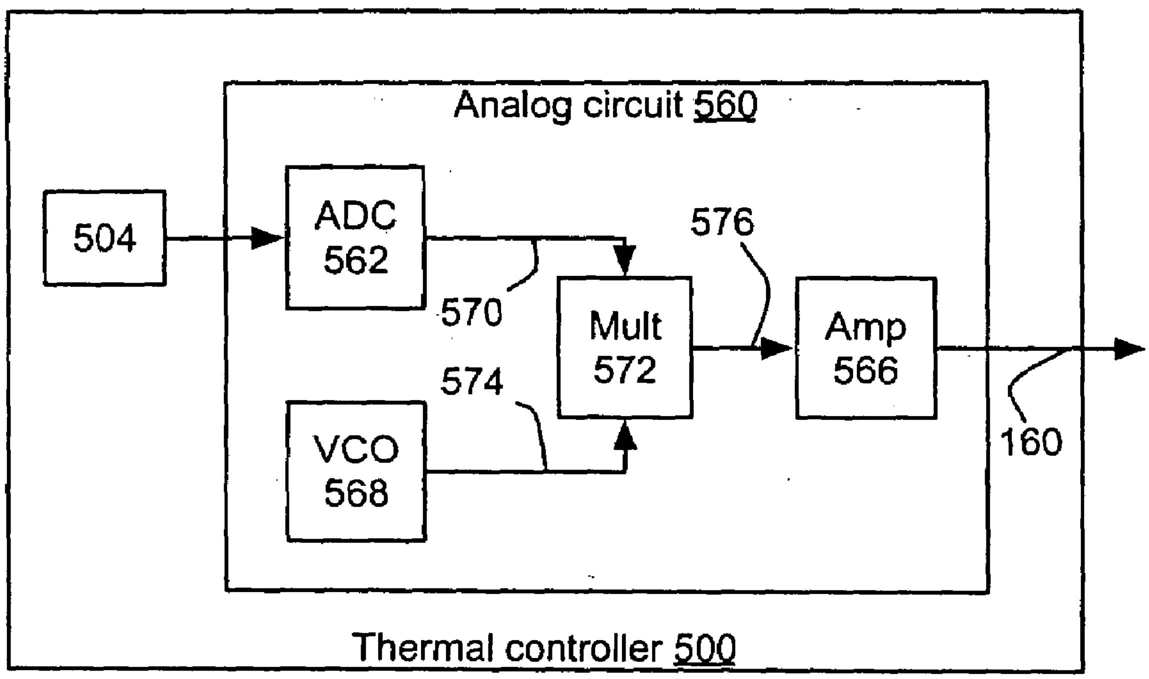



Fig. 16B

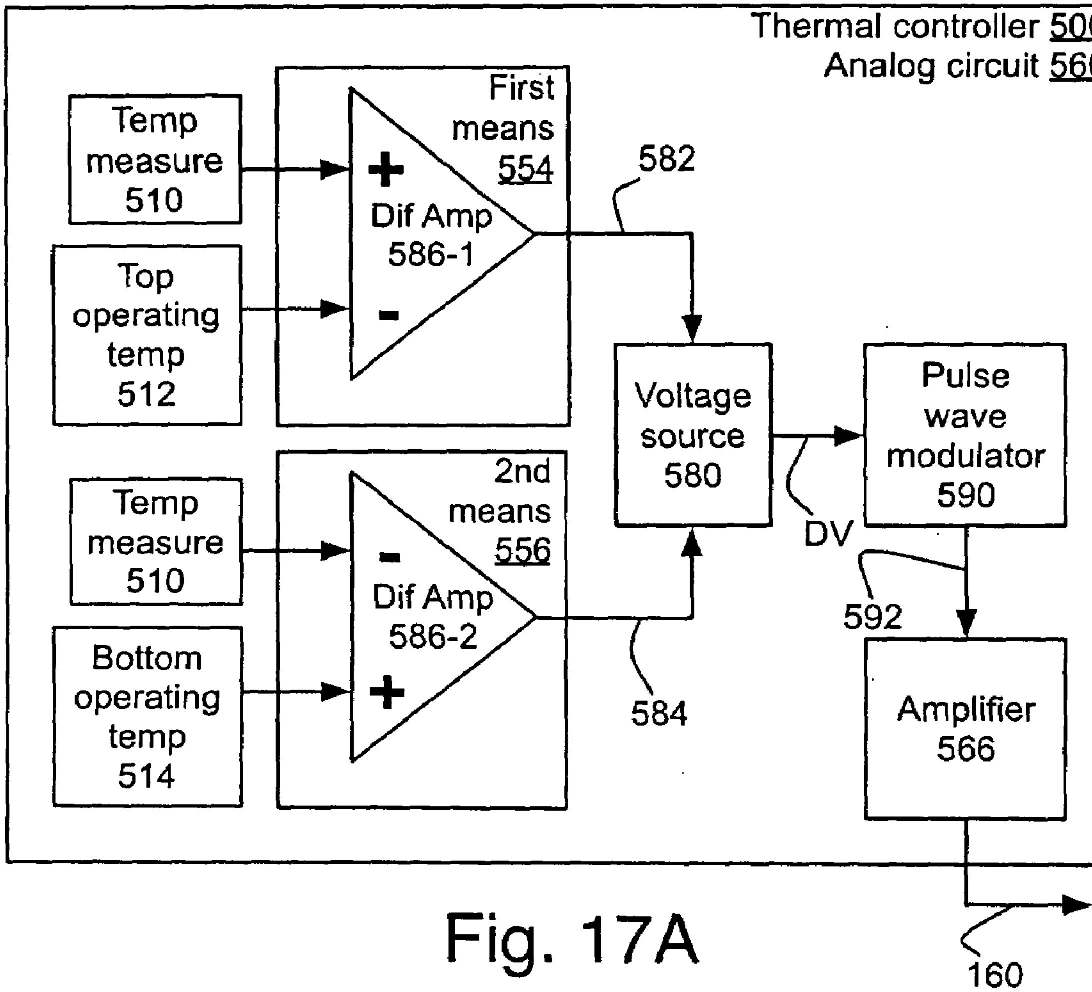



Fig. 17A

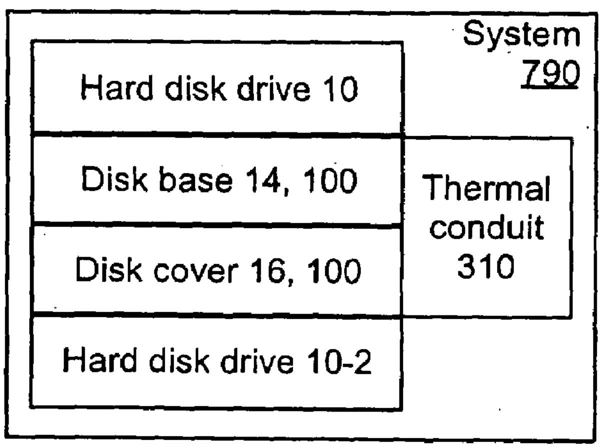



Fig. 17B

# METHOD AND APPARATUS FOR A HARD DISK DRIVE PROVIDING DUAL HEAT TRANSFERS FOR AN INTERNAL THERMAL ZONE

## CROSS REFERENCE TO RELATED APPLICATIONS

**[0001]** This patent application is a continuation-in-part application of pending patent application Ser. No. 11/323,624, filed Dec. 30, 2005, which pending application is incorporated herein by reference in its entirety.

## TECHNICAL FIELD

**[0002]** This invention relates to hard disk drives including mechanisms to regulate and control the temperature of an internal thermal zone within the hard disk drive.

## BACKGROUND OF THE INVENTION

**[0003]** Contemporary hard disk drives are faced with severe challenges. They must operate wherever their users decide to operate them, in environments where the hard disk drive must operate outside of room temperature.

**[0004]** When a hard disk drive is too hot, many operating problems develop. Heat tends to decay the material of the rotating disk surfaces on which the data is stored. The mechanical component tolerances degrade due to differences in their coefficients of thermal expansion. The pressure at the air bearing surface will change due to the high temperature. The breakdown of lubricants used in the hard disk drive is accelerated. The sensitivities due to thermal asperities during read operations is increased. The effects of thermal pole tip protrusion are maximized.

**[0005]** When the hard disk drive is too cold, other operating problems develop. The thermal coercivity of the disk media is lowered, degrading the ability to write data to tracks on the disk surfaces. The pressure at the air bearing surface will change due to the low temperature. It takes longer to start up the hard disk drive when it is cold, due to the viscosity of the lubricant in the spindle motor. The effects of thermal pole tip protrusion are minimized.

**[0006]** Today, many hard disk drives include some device measuring the internal temperature, and in some situations, the operating parameters of the hard disk drive are altered based upon the measured internal temperature. In many hard disk drives, at least part of the exterior face of the disk base is configured as a primitive thermal transfer element. However, no hard disk drives are known to be able to adjust their internal temperature. What is needed is a hard disk drive able adjust its internal temperature toward its optimal operating temperature range.

## SUMMARY OF THE INVENTION

**[0007]** Definitions: Heat transfer interface as used herein means any passageway for heat transfer. Thermal-couple as used herein refers to a layer of material between adjacent transfer interfaces which assists the transfer of heat between the transfer interfaces; typically but not necessarily an adhesive material. Thermal-coupling as used herein describes the action of providing a passageway for heat transfer.

**[0008]** The invention includes a hard disk drive controlling the temperature of an internal thermal zone within said hard disk drive.

**[0009]** The hard disk drive includes a thermoelectric device and a thermal controller directing the thermoelectric device based upon a temperature measure.

**[0010]** The thermoelectric device thermal-couples via a thermal interface to the internal thermal zone and to air in the exterior of the hard disk drive.

**[0011]** The thermoelectric device provides a first heat transfer to remove heat from the internal thermal zone to cool the hard disk drive and provides a second heat transfer to add heat to the internal thermal zone to warm the hard disk drive.

**[0012]** The thermal controller directs the thermoelectric device to provide the first heat transfer, removing heat from the internal thermal zone, when the temperature measure is above a top operating temperature.

**[0013]** The thermal controller directs the thermoelectric device to provide the second heat transfer, adding heat to the internal thermal zone, when the temperature measure is below a bottom operating temperature.

**[0014]** The thermal controller directs the thermoelectric device to affect the temperature of an internal thermal zone in a hard disk drive. This preferably includes the following:

**[0015]** Applying a first potential difference between an electrical contact pair to enable a first heat transfer from an internal heat transfer interface included in a thermal interface to an exterior heat transfer interface thermally coupling to the exterior of said hard disk drive.

**[0016]** The thermal interface is thermally coupled to the internal thermal zone of the hard disk drive.

**[0017]** And applying a second potential difference between the electrical contact pair to enable a second heat transfer from the exterior heat transfer interface to the internal heat transfer interface.

**[0018]** The sign of the first potential difference is the opposite of the sign of the second potential difference.

**[0019]** The controller may also receive a signal from the drive firmware to enable or disable applying one or both of the potential differences.

**[0020]** The internal thermal zone may preferably include at least one disk surface, and may preferably further include all the disk surfaces and sliders moving near the disk surfaces.

**[0021]** The intermediate thermal transfer interface may provide a nearly planar surface to the thermoelectric device. The planar surface may have a surface area of at least one square inch, and may further be at most four square inches.

**[0022]** The thermal controller may include the following.

**[0023]** A first means for forcing the driving signal toward the first potential difference between the electrical contact pair, when the temperature measure is above the top operating temperature.

**[0024]** And a second means for forcing the driving signal toward the second potential difference between the electrical contact pair, when the temperature measure is below the lower operating temperature.

**[0025]** The thermal controller may include at least one of the following.

**[0026]** A finite state machine generating a digital version of the driving signal based upon the temperature measure.

**[0027]** A computer accessibly coupled to a memory containing a program system including at least one program step generating a second digital version of the driving signal based upon the temperature measure.

[0028] A neural network responding to the temperature measure to generate a third digital version of the driving signal.

[0029] The thermal controller may further include exactly one of the finite state machine, the computer and the neural network.

[0030] The program system may include at least one of the following program steps

[0031] Forcing the second digital version of the driving signal toward the first potential difference.

[0032] And forcing the second digital version of the driving signal toward the second potential difference.

[0033] The program system may include a program step implementing the neural network responding to the temperature measure to generate the third digital version of the driving signal.

[0034] The thermal controller may include an analog circuit generating the driving signal based upon at least one of the temperature measure, the digital version of the driving signal, the second digital version of the driving signal, and the third digital version of the driving signal. The analog circuit may further generate the driving signal based upon exactly one of these.

[0035] The analog circuit may include one or both of the following or their refinements as discussed elsewhere in this document.

[0036] Means for applying the first potential difference between the electrical contact pair to enable the first heat transfer from the internal heat transfer interface to the exterior heat transfer interface.

[0037] And means for applying the second potential difference between the electrical contact pair to enable the second heat transfer from the exterior heat transfer interface to the internal heat transfer interface.

[0038] Pulse-width-modulation may be employed.

[0039] Forcing the driving signal toward the first potential difference may preferably include pulse-width-modulating the driving signal between the first potential difference and zero volts, preferably based upon the temperature measure.

[0040] Forcing the driving signal toward the second potential difference may preferably include pulse-width-modulating the driving signal between the second potential difference and zero volts, preferably based upon the temperature measure.

[0041] An external cover of the hard disk drive may include the thermal controller receiving a temperature measure of the internal thermal zone and providing a driving signal to the first electrical contact pair of the thermoelectric device.

[0042] The external cover may further include the thermoelectric device.

[0043] A disk cover and/or a disk base may serve as the external cover for the hard disk drive.

[0044] The external cover may further include a second electrical contact pair driving a fan motor powering a fan to move air across a thermal transfer element exterior to the hard disk drive.

[0045] The thermal controller may further provide a fan driving signal to the second electrical contact pair.

[0046] The thermal controller may preferably provide the fan driving signal with at least one fan potential difference distinct from zero volts, when the temperature measure is either above the top operating temperature or below the bottom operating temperature.

[0047] The fan driving signal may be at least temporarily a Direct Current (DC) signal and/or an Alternating Current (AC) signal.

[0048] Manufacturing the hard disk drive may preferably include at least one of the following:

[0049] Providing the thermal controller electrically coupled to direct the thermoelectric device based upon the temperature measure to at least partly create the hard disk drive.

[0050] The hard disk drive is a product of the manufacturing process.

[0051] Manufacturing the hard disk drive, may further include at least one of the following.

[0052] Using a disk cover as the external cover to create the hard disk drive.

[0053] Using a disk base as the external cover to create the hard disk drive.

[0054] The manufacturing may include using both the disk cover and the disk base as external covers for the hard disk drive.

[0055] The invention includes a system comprising at least one of a hard disk drive controlling the temperature of an internal thermal zone in the hard disk drive.

[0056] The system may further include a thermal conduit to the hard disk drive.

[0057] These systems include, but are not limited to, a Redundant Arrays of Inexpensive Disks (RAID), a server computer, a desktop computer, and a notebook computer.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0058] FIGS. **1** to **3** shows the hard disk drive moving heat into and out of its internal thermal zone;

[0059] FIG. **4** shows some of the various aspects of the internal thermal zone of FIGS. **1** to **3**;

[0060] FIGS. **5** to **8**C show various aspects of the external cover with the intermediate thermal transfer interface of FIGS. **1** to **3** with regards to the hard disk drive;

[0061] FIGS. **9**A, **11**A and **11**E show details of the external cover and/or the thermoelectric device of the previous Figures including a thermal controller;

[0062] FIGS. **9**B to **10**A show various aspects of the thermal controller;

[0063] FIGS. **10**B, **10**C, **11**B, **11**C, **11**D, and **12**A to **12**F show flowcharts discussing some of the operational aspects of the external cover;

[0064] FIGS. **13**A to **131** show various aspects of systems using the hard disk drives of the invention; and

[0065] FIGS. **14**A and **14**B show some alternative embodiments of the semiconductor device of the previous Figures;

[0066] FIGS. **15**A to **17**A show further aspects of the thermal controller; and

[0067] FIG. **17**B show a further aspect of systems using the hard disk drives of the invention.

## DETAILED DESCRIPTION

[0068] This invention relates to hard disk drives including mechanisms to regulate and control the temperature of an internal thermal zone within the hard disk drive.

**[0069]** The invention preferably includes a hard disk drive **10** controlling the temperature of an internal thermal zone **20** within said hard disk drive.

**[0070]** The hard disk drive includes

**[0071]** a thermoelectric device **200** as shown in FIGS. **1** to **3**, **14**A and **14**B and

**[0072]** a thermal controller **500** directing the thermoelectric device based upon a temperature measure **510**, as shown in FIGS. **7**A to **12**F and **15**A to **17**A.

**[0073]** The thermoelectric device thermal-couples via a thermal interface **110** to the internal thermal zone and to air **150** in the exterior **300** of the hard disk drive.

**[0074]** The thermoelectric device provides a first heat transfer **120** to remove heat from the internal thermal zone and provides a second heat transfer **122** to add heat to the internal thermal zone.

**[0075]** The thermal controller directs the thermoelectric device to provide the first heat transfer, removing heat from the internal thermal zone, when the temperature measure is above a top operating temperature **512**.

**[0076]** The temperature measure may be above the top operating temperature when the temperature measure is greater than the top operating temperature.

**[0077]** Alternatively, the temperature measure may be above the top operating temperature when the temperature measure is greater than or equal to the top operating temperature.

**[0078]** The thermal controller directs the thermoelectric device to provide the second heat transfer, adding heat to the internal thermal zone, when the temperature measure is below a bottom operating temperature **514**.

**[0079]** The temperature measure may be below the bottom operating temperature, when the temperature measure is less than the bottom operating temperature.

**[0080]** Alternatively, the temperature measure may be below the bottom operating temperature, when the temperature measure is less than or equal to the bottom operating temperature.

**[0081]** The thermal controller **500** directs the thermoelectric device **200** to affect the temperature of an internal thermal zone **20** in the hard disk drive **10**. This preferably includes the following:

**[0082]** Applying a first potential difference V**1** between an electrical contact pair **210** to enable a first heat transfer **120** from an internal heat transfer interface **130** included in a thermal interface **110** to a second heat transfer **132** interface thermally coupling to the exterior **300** of said hard disk drive.

**[0083]** The thermal interface is thermally coupled to the internal thermal zone of the hard disk drive.

**[0084]** And applying a second potential difference V**2** between the electrical contact pair to enable a second heat transfer **122** from the exterior heat transfer interface to the internal heat transfer interface.

**[0085]** The sign of the first potential difference is the opposite of the sign of the second potential difference.

**[0086]** The invention includes an external cover **100** for a hard disk drive **10** including the intermediate thermal transfer interface **110** thermal-coupling to the internal thermal zone and to a thermoelectric device **200** as shown in FIGS. **1** to **3** through the thermal-couple **112**. A disk cover **16** and/or a disk base **14** may serve as the external cover for the hard disk drive as shown in FIGS. **5** to **7**C.

**[0087]** The thermoelectric device **200** may preferably provide two heat transfers across the intermediate thermal transfer interface **110** to the exterior **300** of the hard disk drive **10**, into the internal thermal zone **20** to warm it, and out of the internal thermal zone to cool it, as shown in FIG. **1**.

**[0088]** The thermoelectric device **200** may preferably provide a first heat transfer **120** across the intermediate thermal transfer interface from the internal thermal zone to the exterior of the hard disk drive to cool it as shown in FIG. **3**.

**[0089]** The thermoelectric device also provides a second heat transfer **122** from the exterior to the internal thermal zone to warm the internal thermal zone as shown in FIG. **2**.

**[0090]** The thermoelectric device preferably includes the means for enabling power **240** from the electrical contact pair for the first thermal transfer and for the second thermal transfer.

**[0091]** The means for enabling power may preferably include at least one semiconductor device **250**.

**[0092]** The internal thermal zone **20** may preferably include at least one disk surface **12-1**, and may preferably further include each disk **12**, each disk surface **12-1** and each slider **90** moving near the disk surfaces as shown in FIG. **4**.

**[0093]** The internal thermal zone may further include the head gimbal assembly **60** including the slider.

**[0094]** The internal thermal zone may further include the actuator arm **52** including the head gimbal assembly, likewise the actuator assembly **50** and the voice coil motor **30**.

**[0095]** The internal thermal zone may also include the spindle **82** and/or the spindle motor **80** as shown in FIGS. **7**A, **7**B, **8**A, and **8**B.

**[0096]** The intermediate thermal transfer interface **110** may provide a nearly planar surface to the thermoelectric device **200**, as shown in FIGS. **1** to **3**, and **5** to **7**B. The planar surface may have a surface area of at least one square inch, and may further be at most four square inches.

**[0097]** The external cover **100** may further include the thermoelectric device **200** providing an exterior heat transfer interface **132** thermal-coupling to the exterior **300** of the hard disk drive **10** through a second thermal-couple **134**. The thermoelectric device may include an internal heat transfer interface **130** thermal-coupling to the intermediate thermal transfer interface **110** through the thermal-couple **112**. The second thermal-coupling may further preferably be to air **150** exterior **300** to the hard disk drive **10**.

**[0098]** The thermoelectric device **200** may preferably include an electrical contact pair **210** providing enabling power for a first heat transfer **120** from the intermediate thermal transfer interface **110** including the internal heat transfer interface **130** to the exterior heat transfer interface **132**, and a second heat transfer **132** from the exterior heat transfer interface to the transfer interface. Preferably, applying a first potential difference V**1** between the electrical contact pair **210** enables the first heat transfer as shown in FIG. **2**, and applying a second potential difference V**2** between the electrical contact pair enables the second heat transfer as in FIG. **3**. Preferably, the sign of the first potential difference is opposite the sign of the second potential difference.

**[0099]** The thermoelectric device **200** includes at least one semiconductor device **250** acting as a heat pump and using the intermediate thermal transfer interface **110** to thermally-affect the internal thermal zone **20**, as shown in FIGS. **1** to **3**. The thermoelectric device may use the intermediate thermal transfer interface to move heat out of the internal thermal zone, which will tend to thermally-affect the internal thermal zone by lowering its temperature, as shown in FIG. **2**. Also, the thermoelectric device may use the intermediate thermal transfer interface to move heat into the internal thermal zone, tending to thermally-affect the internal thermal zone by raising its temperature, as shown in FIG. **3**.

**[0100]** The semiconductor device **250** preferably includes a first semiconductor terminal **252-1** electrically coupled to a first electrical contact **210-1**, and a second semiconductor terminal **252-2** electrically coupled to a second electrical contact **210-2**. The electrical contact pair **210** preferably consists essentially of the first electrical contact and the second electrical contact. The electrical contact pair may also be considered to include electrical insulation and conductive paths, which do not change the essential electrical circuitry of the first electrical contact and the second electrical contact.

**[0101]** A thermoelectric device **200** refers herein to a solid-state heat pump that may preferably operate on the Peltier effect. The semiconductor device **250** preferably contains an array of p- and n-type semiconductor elements heavily doped with electrical carriers. This array is often electrically connected in series and thermally connected in parallel and then affixed to two ceramic substrates, the internal heat transfer interface **130** and the exterior heat transfer interface **132**, one on each side of the elements, as in FIGS. **1** to **3** and **14**A and **14**B. In FIGS. **1** to **3** and **14**A, the semiconductor device is shown with the number of N-type semiconductor elements is the same as the number of P-type semiconductor elements. In FIG. **14**B, the number of N-type semiconductor elements is distinct from the number of P-type semiconductor elements. While FIG. **14**B shows more N-type semiconductor elements than P-type semiconductor elements, the invention also includes semiconductor devices with more P-type semiconductor elements than N-type semiconductor elements.

**[0102]** Consider how the heat transfer occurs as electrons flow through one pair of n- and p-type elements, which is referred to herein as a couple within the thermoelectric device. Electrons can travel freely in the conductors, which are often made of copper, but not so freely in the semiconductor. These conductors are labeled Cu in FIGS. **1** to **3**. This discussion will now focus on FIG. **3**, however, the discussion of FIG. **2** basically reverses the sign of the voltage of the driving signal **160**, reversing the flowing of holes and electrons, as well as the direction of heat transfer,

**[0103]** As the electrons leave the conductor Cu, they enter the hot side of the P-Type and must fill a hole in order to move through the P-Type. When an electron fills a hole, it drops to a lower energy level, releasing heat. The holes in the P-Type move from the cold side to the hot side. As an electron moves from the P-Type into the conductor Cu on the cold side, the electron moves to a higher energy level through absorbing heat. The electron moves freely through the conductor CU until reaching the cold side of the N-Type semiconductor. When the electron moves into the N-Type, it bumps up an energy level in order to move through the semiconductor, absorbing heat. As the electron leaves the hot-side of the N-Type, it moves freely in the conductor Cu. It drops to a lower energy level releasing heat.

**[0104]** Heat is always absorbed at the cold side of the n- and p-type elements. The electrical charge carriers (holes in the P-Type; electrons in the N-Type) always travel from the cold side to the hot side, and heat is always released at the hot side of a thermoelectric element. The heat pumping capacity of a thermoelectric device is proportional to the current and dependent on the element geometry, number of couples, and material properties.

**[0105]** As used herein, the Peltier effect is the phenomenon whereby the passage of an electrical current through a junction consisting of two dissimilar metals results in a cooling effect. When the direction of current flow is reversed heating will occur.

**[0106]** A thermal transfer element **230** refers herein a device that is typically thermally coupled to a heat transfer interface of a thermoelectric device **200**, usually the exterior heat transfer interface **132**, for heat transfers with the exterior **300** of the hard disk drive **10**. It is used to facilitate the transfer of heat between the thermoelectric device and the exterior of the hard disk drive. The most common thermal transfer element is an aluminum plate that has fins attached to it, as shown in FIGS. **1** to **3**, **7**C and **8**C. A fan **222** is used to move ambient air **150** through the thermal transfer element to transfer heat. Another style of thermal transfer element uses a plate with tubing embedded in it. A liquid is sent through the tubing to pick up heat from the thermoelectric device.

**[0107]** The external cover **100** may further include a thermal controller **500** receiving a temperature measure **510** of the internal thermal zone **20** and providing a driving signal **160** to the electrical contact pair **210**, as shown in FIG. **9**A. Alternatively, the thermoelectric device **200** may preferably include the thermal controller, as shown in FIG. **11**A. The thermal controller may include a means for applying the first potential difference **550** between the contact pair to enable the first heat transfer **120**, and the means for applying the second potential difference **552** between the contact pair to enable the second heat transfer **122**, as shown in FIG. **10**D. Preferably, the thermal controller forces the driving signal **160** toward the first potential difference V**1** when the temperature measure **510** is greater than a top operating temperature **512**. Preferably, the thermal controller forces the driving signal toward the second potential difference V**2**, when the temperature measure is less than a lower operating temperature **514**.

**[0108]** The thermal controller **500** may include at least one of the following. A finite state machine **502** generating a digital version **504** of the driving signal based upon the temperature measure **510** as in FIG. **9**B. A computer **520** accessibly coupled **522** to a memory **524** containing a program system **600** including at least one program step generating a second digital version **526** of the driving signal based upon the temperature measure as in FIG. **9**C. A neural network **530** responding **532** to the temperature measure to generate a third digital version **534** of the driving signal, as in FIG. **9**D. The thermal controller may further include exactly one of the finite state machine, the computer and the neural network, or a combination of these elements, such as a finite state machine and a computer, two finite state machines, and so on.

**[0109]** As used herein, the computer **520** will include at least one instruction processor and at least one data processor. Each data processor will be directed by at least one instruction processor. The computer may be implemented in, or as, a Field Programmable Gate Array, gate array, an application specific integrated circuit, a digital signal processor, and/or a general-purpose microprocessor.

**[0110]** The memory **524** may include memory components that are non-volatile memories and/or volatile memories. Non-volatile memories tend to retain their memory contents without the application of external power, whereas volatile memories tend to lose their memory contents without the application of external power. The memory may and often does contain both non-volatile memory components and volatile memory components.

**[0111]** The finite state machine **502** may be implemented by any combination of: a logic circuit, a programmable logic device, and/or a Field Programmable Gate Array. The logic circuit may be implemented in a gate array and/or an application specific integrated circuit.

**[0112]** The neural network **530** may be implemented similarly to the finite state machine **502**, and include neurons, each with a neural state and coupling through weighted paths to other neurons. Upon the stimulus of the temperature measure **510**, the neural network responds by calculating the path couplings, possibly changing the state of at least some of the neurons, and taking the weighted path response to generate the third digital version **534** of the driving signal.

**[0113]** The following figures include flowcharts of at least one method of the invention possessing arrows with reference numbers. These arrows will signify of flow of control and sometimes data, supporting implementations including at least one program step or program thread executing upon a computer, inferential links in an inferential engine, state transitions in a finite state machine, and learned responses within a neural network.

**[0114]** The step of starting a flowchart refers to at least one of the following and is denoted by an oval with the text "Start" in it. Entering a subroutine in a macro instruction sequence in a computer. Entering into a deeper node of an inferential graph. Directing a state transition in a finite state machine, possibly while pushing a return state. And triggering at least one neuron in a neural network.

**[0115]** The step of termination in a flowchart refers to at least one of the following and is denoted by an oval with the text "Exit" in it. The completion of those steps, which may result in a subroutine return, traversal of a higher node in an inferential graph, popping of a previously stored state in a finite state machine, return to dormancy of the firing neurons of the neural network.

**[0116]** A step in a flowchart refers to at least one of the following. The instruction processor responds to the step as a program step to control the data execution unit in at least partly implementing the step. The inferential engine responds to the step as nodes and transitions within an inferential graph based upon and modifying a inference database in at least partly implementing the step. The neural network responds to the step as stimulus in at least partly implementing the step. The finite state machine responds to the step as at least one member of a finite state collection comprising a state and a state transition, implementing at least part of the step.

**[0117]** Several flowcharts include multiple steps. In certain aspects, any one of the steps may be found in an embodiment of the invention. In other aspects, multiple steps are needed in an embodiment of the invention. When multiple steps are needed, these steps may be performed concurrently, sequentially and/or in a combination of concurrent and sequential operations. The shapes of the arrows in multiple step flowcharts may differ from one flowchart to another, and are not to be construed as having intrinsic meaning in interpreting the concurrency of the steps.

**[0118]** The program system **600** of FIG. **9**C may implement a fuzzy logic controller generating the second digital version **526** of the driving signal based upon the temperature measure **510**, as shown in operation **602** of FIG. **10**B. Typically, a fuzzy logic controller includes a list of at least two fuzzy inferences.

**[0119]** The program system **600** may include a program step implementing the neural network **530** responding **532** to the temperature measure **510** to generate the third digital version **534** of the driving signal, as shown by operation **604** of FIG. **10**C.

**[0120]** The thermal controller **500** may include an analog circuit **560** generating the driving signal **160** based upon at least one of the temperature measure **510**, the digital version **504** of the driving signal, the second digital version **526** of the driving signal, and the third digital version **534** of the driving signal as shown in FIG. **10**A. The analog circuit may further generate the driving signal based upon exactly one of these.

**[0121]** The thermal controller **500** may further include the following:

**[0122]** A first means for forcing **554** the driving signal **160** toward the first potential difference V1 between the electrical contact pair **210** to enable the first heat transfer **120** when said temperature measure **510** is above a top operating temperature **512**.

**[0123]** And a second means for forcing **556** said driving signal toward said second potential difference between said electrical contact pair, when said temperature measure is below a lower operating temperature **514**.

**[0124]** FIG. **15**A shows the first means and the second means included in the thermal controller.

**[0125]** FIGS. **15**B and **17**A show the first means and the second means included in the analog circuit **560**. This represents a predominantly analog circuit approach.

**[0126]** Alternatively, FIG. **15**C shows the first means and the second means included in the Finite State Machine **502**, collectively generating the digital version of the driving signal **504**, within the thermal controller. This is a predominantly digital logic approach.

**[0127]** FIG. **15**C shows the second digital version **526** of the driving signal being presented to an Analog to Digital Converter **562** to at least partly create the driving signal **160**. The second digital version of the driving signal is preferably generated by the computer **520** shown in FIG. **9**C. This is a predominantly computer based approach.

**[0128]** FIG. **16**A shows an alternative and a refinement to FIG. **15**C, where the digital version of the driving signal is presented to the Analog to Digital Converter to create a first analog signal version **564** of the driving signal, which is presented to the first amplifier **566** to at least partly create the driving signal.

**[0129]** FIG. **16**B shows a further refinement of FIG. **16**A. The analog to digital converter provides a second analog signal version **570** to an analog multiplier **572**. A Voltage Controlled Oscillator **568** also provides an oscillating carrier signal **574** to the analog multiplier. The analog multiplier provides a third analog signal version **576** to the first amplifier to at least partly create the driving signal.

**[0130]** Looking in greater detail at FIG. **17**A, the temperature measure **510** is provided to the first means **554** and to the second means **556** as in FIG. **15**B.

**[0131]** The first means includes a first differential amplifier **586-1**, to which the temperature measure is provided to the "+" terminal, and the top operating temperature **512** is provided to the "−" terminal to create the too hot signal **582**.

**[0132]** The second means includes a second differential amplifier **586-2**, to which the temperature measure is provided to the "−" terminal, and the bottom operating temperature **514** is provided to the "+" terminal to create the too cold signal **584**.

**[0133]** The voltage source **580** receives the too hot signal and the too cold signal and uses them to create the driving voltage DV provided to the pulse wave modulator **590**.

**[0134]** When the temperature measure is above the top operating temperature, the too hot signal is active.

**[0135]** When the too hot signal is active, the too cold signal is preferably inactive.

**[0136]** The voltage source preferably provides the driving voltage sufficient that the resulting driving signal forces the contact pair **210** toward the first potential difference V**1**.

**[0137]** When the temperature measure is below the bottom operating temperature, the too cold signal is active.

**[0138]** When the too cold signal is active, the too hot signal is preferably inactive.

**[0139]** The voltage source preferably provides the driving voltage sufficient that the resulting driving signal forces the contact pair toward the second potential difference V**2**.

**[0140]** When the temperature measure is within normal operating temperatures

**[0141]** The temperature means is not below the bottom operating temperature, and the too cold signal is preferably inactive.

**[0142]** The temperature means is not above the top operating temperature, and the too top signal is preferably inactive.

**[0143]** Both the too cold signal and the too hot signal are preferably inactive.

**[0144]** The voltage source preferably provides the driving voltage sufficient that the resulting driving signal forces the contact pair toward a low or zero potential difference.

**[0145]** The external cover **100** and alternatively, the thermoelectric device **200**, may further include a second electrical contact pair **212** driving a fan motor **220** powering a fan **222**, as shown in FIG. **11**E.

**[0146]** When powered, the fan moves air **150** across a thermal transfer element **230** exterior **300** to the hard disk drive **10**, as in FIGS. **7**A to **8**C.

**[0147]** The thermal controller **500** may further provide a fan driving signal **224** to the second electrical contact pair.

**[0148]** The thermal controller may preferably provide the fan driving signal with at least one fan potential difference distinct from zero volts, when the temperature measure is either greater than the top operating temperature **512** or less than the bottom operating temperature **514**.

**[0149]** The fan driving signal may be at least temporarily a Direct Current (DC) signal and/or an Alternating Current (AC) signal.

**[0150]** Manufacturing the thermoelectric device **200** may include providing the means for enabling power **240** with a thermal coupling to the internal heat transfer interface **130** and with a thermal coupling to the exterior heat transfer interface **132**, and coupling the electrical contact pair **210** to the means for enabling power **240**.

**[0151]** The thermoelectric device is a product of this manufacturing process.

**[0152]** Manufacturing the thermoelectric device may further include electrically coupling the thermal controller **500** to the electrical contact pair, and/or thermally coupling the thermal transfer element **230** to the exterior heat transfer interface.

**[0153]** Manufacturing the thermal controller **500** may include at least one of the following steps.

**[0154]** Providing said means for applying the first potential difference **550** and said means for applying said second potential difference **552** to at least partly create said thermal controller.

**[0155]** Providing

**[0156]** a first means **554** for forcing the driving signal **160** toward said first potential difference V**1** between said electrical contact pair **210**, when a temperature measure **510** is above a top operating temperature **512** and

**[0157]** a second means **556** for forcing said driving signal toward said second potential difference V**2** between said electrical contact pair, when said temperature measure is below a lower operating temperature **514**

**[0158]** to at least partly create said thermal controller.

**[0159]** Providing at least one finite state machine **502** generating a digital version **504** of said driving signal to at least partly create said thermal controller.

**[0160]** Providing at least one computer **520** generating a second digital version **526** of said driving signal to at least partly create said thermal controller.

**[0161]** Providing a neural network generating **530** a third digital version **534** of said driving signal to at least partly create said thermal controller.

**[0162]** Providing said program system **600** in said memory **524** to at least partly create said thermal controller.

**[0163]** And/or providing an analog circuit **560** to at least partly create the thermal controller.

**[0164]** Manufacture of the external cover **100** may include at least one of the following.

**[0165]** Die-stamping **700** a sheet of metal **702** to at least partly create the external cover including the intermediate thermal transfer interface **110**.

**[0166]** Molding **710** molten metal **712** to at least partly create the external cover including the intermediate thermal transfer interface.

**[0167]** The sheet of metal may preferably include a form of sheet stainless steel.

**[0168]** The molten metal may include a form of molten aluminum.

[0169] The invention includes the external cover as a product of this process.

[0170] The manufacture of the external cover **100** may further include thermal-coupling a thermoelectric device **200** via the intermediate thermal transfer interface **110** to its internal heat transfer interface **130**.

[0171] Such external covers are shown in FIGS. **1** to **3**, and may be preferred for use in a system employing shared fans and fan motors.

[0172] Further, a thermal transfer element **230** may be thermally-coupled to the exterior heat transfer interface **132**.

[0173] A fan motor **220** and fan **222** may further be positioned near the thermal transfer element **230**, as shown in FIGS. **7**A to **8**C.

[0174] Manufacture of the hard disk drive **10** may include at least one of the following:

[0175] Providing the thermal controller **500** and the thermoelectric device **200**.

[0176] And electrically coupling the thermal controller via the electrical contact pair **210** to the thermoelectric device to create the hard disk drive.

[0177] The hard disk drive is a product of this manufacturing process.

[0178] These steps may be implemented by providing the thermoelectric device including the thermal controller.

[0179] Alternatively, the external cover **100** may include the thermoelectric device and possibly further include the thermal controller electrically coupled via the electrical contact pair, so that providing the external cover implements one or both of the above steps.

[0180] The manufacturing process for the hard disk drive **10** may further include at least one of the following.

[0181] Using a disk cover **16** as the external cover **100** as shown in FIGS. **6** to **7**C to create the hard disk drive.

[0182] Using a disk base **14** as the external cover, as shown in FIGS. **5** and **8**A to **8**C, to create the hard disk drive.

[0183] The manufacturing may include using both the disk cover and the disk base as external covers for the hard disk drive.

[0184] The external cover **100** and the hard disk drive **10** operate as follows.

[0185] While these operations may be implemented in a variety of fashions, to simplify their discussion, they will be discussed as implemented through operations performed by the program system **600**.

[0186] The thermoelectric device **200** enables a first heat transfer **120** from the internal thermal zone **20** via the intermediate thermal transfer interface **110** to the exterior **300** of the hard disk drive **10** as shown in FIG. **2**.

[0187] The thermoelectric devices also enables a second heat transfer **122** from the exterior of the hard disk drive via the intermediate thermal transfer interface to the internal thermal zone, as shown in FIG. **3**.

[0188] Operation **610** of FIG. **11**B supports enabling the first heat transfer and operation **612** supports enabling the second heat transfer.

[0189] The thermoelectric device **200** may preferably include the thermal controller **500** electrically coupling with the electrical contact pair **210** to the means for enabling power **240** as shown in FIG. **11**A. The means for enabling power may further preferably include the electrical contact pair coupling with the semiconductor device **250** through the first semiconductor terminal **252-1** and the second semiconductor terminal **252-2**.

[0190] A driving signal **160** may preferably be provided to the electrical contact pair **210** to enable the first heat transfer **130** as in operation **620** of FIG. **11**C, the second hear transfer **132** as in operation **620** of FIG. **11**C, or essentially no-heat transfer as shown in operation **614** of FIG. **11**B. Essentially no-heat transfer refers herein to the thermal transfer condition when no power is being expended through the electrical contact pair.

[0191] Providing the driving signal **160** may preferably include forcing the driving signal toward the first potential difference **V1** to enable the first heat transfer **120** as in operation **630** of FIG. **12**A, and forcing the driving signal toward the second potential difference **V2** to enable the second heat transfer **122** as in operation **632** in operation **12**B.

[0192] A temperature measure **510** may preferably be determined for the internal thermal zone **20**. Forcing the driving signal **160** toward the first potential difference **V1** may preferably occur when the temperature measure is greater than a top operating temperature **512** as in operation **640** of FIG. **12**C. Forcing the driving signal toward the second potential difference **V2** may preferably occur when the temperature measure is less than the bottom operating temperature **514** as in operation **642** of FIG. **12**D. In certain embodiments, the test for when may include equality, so that forcing the driving signal toward the first potential difference may occur when the temperature measure is greater than or equal to the top operating temperature.

[0193] Pulse-width-modulation may be employed.

[0194] Forcing the driving signal **160** toward the first potential difference **V1** may preferably include pulse-width-modulating the driving signal between the first potential difference and zero volts, preferably based upon the temperature measure **510**, as in operation **650** of FIG. **12**E.

[0195] Forcing the driving signal toward the second potential difference **V2** may preferably include pulse-width-modulating the driving signal between the second potential difference and zero volts, preferably based upon the temperature measure, as in operation **652** of FIG. **12**F.

[0196] The invention includes the hard disk drive **10**, including the thermoelectric device **200** providing the internal heat transfer interface **130** thermal-coupling to the internal thermal zone **20** and the exterior heat transfer interface **132** thermal-coupling with an exterior **300** of the hard disk drive.

[0197] The invention may preferably include the hard disk drive **10**, containing the external cover **100** providing the intermediate thermal transfer interface **110** thermal-coupling to the internal thermal zone **20**. The hard disk drive may further include the thermoelectric device **200** thermal-coupling to the intermediate thermal transfer interface and to an exterior heat transfer interface **132** for heat transfers with an exterior **300** of the hard disk drive.

[0198] The invention includes a system **790** using at least one of the hard disk drive **10** as shown in FIG. **13**A.

[0199] The system may include a thermal conduit **310** thermal-coupling to the exterior **300** of the hard disk drive as shown in FIG. **13**B.

[0200] These systems include, but are not limited to, a Redundant Arrays of Inexpensive Disks **800** (RAID) as in FIG. **13**C, a server computer **810** as in FIG. **13**D, a desktop computer **820** as in FIG. **13**E, and a notebook computer **830** as in FIG. **13**F.

[0201] The invention includes manufacturing the system **790**, including providing the hard disk drive **10** of the invention.

[0202] The manufacturing process may further include thermal coupling the thermal conduit **310** to the hard disk drive.

[0203] The system is the product of the manufacturing process.

[0204] The hard disk drive with both its disk base **14** and disk cover **16**, each acting as an external cover **100**, each possessing a intermediate thermal transfer interface **110**, may be preferred in a system **790** supporting multiple hard disk drives, such as a RAID 800, because adjacent pairs of hard disk drives may share a thermal conduit **310**, as shown in FIG. **13**G. The manufacturing process may further include

[0205] Using a second hard disk drive **10-2**.

[0206] Thermal coupling the thermal conduit to the disk base of the hard disk drive.

[0207] And thermal coupling the disk cover of the second hard disk drive.

[0208] Alternatively, the system **790** may include one hard disk drive **10** with the disk base **14** as the external cover **100**, and a second hard disk drive **10-2** with the disk cover **16** as its external cover, as shown in FIG. **17**B. Such embodiments of the system are also useful when supporting multiple hard disk drives, such as a RAID 800, also allowing adjacent pairs of hard disk drives to share the thermal conduit **310**. The manufacturing process is similar:

[0209] Using the hard disk drive.

[0210] Using the second hard disk drive.

[0211] Thermal coupling the thermal conduit to the disk base of the hard disk drive.

[0212] And thermal coupling the thermal conduit to the disk cover of the second hard disk drive.

[0213] Alternatively, the system **790** may include only the hard disk drive **10** using the disk base **14** as the external cover **100**, as shown in FIG. **13**H. Manufacturing this systems using this hard disk drive may preferably include:

[0214] Using the hard disk drive.

[0215] And thermal coupling the thermal conduit to the disk base of the hard disk drive.

[0216] Another alternative, the system **790** may include only the hard disk drive **10** using the disk cover **16** as the external cover **100**, as shown in FIG. **131**. Manufacturing this systems using this hard disk drive may preferably include:

[0217] Using the second hard disk drive.

[0218] And thermal coupling the thermal conduit to the disk cover of the second hard disk drive.

[0219] The preceding embodiments provide examples of the invention and are not meant to constrain the scope of the following claims.

What is claimed is:

**1**. A hard disk drive controlling the temperature of an internal thermal zone within said hard disk drive, comprising:

a thermoelectric device thermal coupling via a thermal interface to said internal thermal zone and to air in the exterior of said hard disk drive, providing a first heat transfer to remove heat from said internal thermal zone and providing a second heat transfer to add heat to said internal thermal zone; and

a thermal controller directing said thermoelectric device based upon a temperature measure of said internal thermal zone;

wherein said thermal controller directs said thermoelectric device to provide said first heat transfer removing heat from said internal thermal zone, when said temperature measure is above a top operating temperature; and

wherein said thermal controller directs said thermoelectric device to provide said second heat transfer adding heat to said internal thermal zone, when said temperature measure is below a bottom operating temperature.

**2**. The hard disk drive of claim **1**, wherein said thermoelectric device includes an electrical contact pair; and

wherein said thermal controller, comprises:

means for applying a first potential difference between said electrical contact pair to enable said first heat transfer from said internal heat transfer interface included in said thermal interface to an exterior heat transfer interface thermally coupling to the exterior of said hard disk drive; wherein said thermal interface is thermally coupled to said internal thermal zone; and

means for applying a second potential difference between said electrical contact pair to enable a second heat transfer from said exterior heat transfer interface to said internal heat transfer interface;

wherein the sign of said first potential difference is the opposite of the sign of said second potential difference.

**3**. The hard disk drive of claim **2**,

wherein the means for applying said first potential difference, comprises:

means for forcing a driving signal toward said first potential difference between said electrical contact pair; and

wherein the means for applying said second potential difference, comprises:

means for forcing said driving signal toward said second potential difference between said electrical contact pair.

**4**. The hard disk drive of claim **3**,

wherein the means for applying said first potential difference, further comprises:

means for pulse-width-modulating said driving signal toward said first potential difference between said electrical contact pair; and

wherein the means for applying said second potential difference, further comprises:

means for pulse-width-modulating said driving signal toward said second potential difference between said electrical contact pair.

**5**. The hard disk drive of claim **2**, wherein the means for applying said first potential difference, comprises:

first means for forcing said driving signal toward said first potential difference between said electrical contact pair, when said temperature measure is above a top operating temperature; and

wherein the means for applying said second potential difference, comprises:

second means for forcing said driving signal toward said second potential difference between said electrical contact pair, when said temperature measure is below a lower operating temperature.

**6**. The hard disk drive of claim **2**, wherein said thermal controller comprises at least one member of the group consisting of:

at least one finite state machine generating a digital version of said driving signal;

at least one computer generating a second digital version of said driving signal;

a neural network generating a third digital version of said driving signal;

wherein said computer is accessibly coupled to a memory and directed by a program system including at least one program step residing in said memory;

wherein said computer includes at least one instruction processor and at least one data processor; wherein for each of said data processors, said data processor is directed by at least one of said instruction processors.

**7**. The hard disk drive of claim **6**,

wherein said finite state machine, further comprises: said finite state machine generating said digital version of said driving signal based upon a temperature measure of said internal thermal zone;

wherein said computer, further comprises: said computer generating said second of said digital versions of said driving signal based upon said temperature measure; and

wherein said neural network, further comprises: said neural network generating said third of said digital versions of said driving signal based upon said temperature measure.

**8**. The hard disk drive of claim **6**, wherein said program system includes at least one of the program steps:

forcing said second digital version of said driving signal toward said first potential difference; and

forcing said second digital version of said driving signal toward said second potential difference.

**9**. The hard disk drive of claim **8**,

wherein the program step forcing said second digital version of said driving signal toward said first potential difference, further comprises the program step:

pulse-width-modulating said second digital version of said driving signal toward said first potential difference; and

wherein the program step forcing said second digital version of said driving signal toward said second potential difference, further comprises the program step:

pulse-width-modulating said second digital version of said driving signal toward said second potential difference.

**10**. The hard disk drive of claim **7**, wherein said thermal controller further comprises:

an analog circuit receiving at least one member of the analog input group to create said driving signal;

wherein said analog input group, consists of: said temperature measure, said digital version of said driving signal, said second digital version of said driving signal, and said third digital version of said driving signal.

**11**. The hard disk drive of claim **3**, wherein said thermal controller further comprises:

an analog circuit receiving a temperature measure to create said driving signal, comprising:

means for forcing said driving signal toward said first potential difference between said electrical contact pair, when said temperature measure is above said top operating temperature; and

means for forcing said driving signal toward said second potential difference between said electrical contact pair, when said temperature measure is below said lower operating temperature.

**12**. The hard disk drive of claim **11**, wherein said analog circuit, further comprises at least one instance of the group consisting of:

a Digital to Analog Converter (DAC);

an amplifier; and

a voltage switcher.

**13**. A method of manufacturing said hard disk drive of claim **2**, comprising the steps:

providing said thermal controller electrically coupled via the electrical contact pair to direct said thermoelectric device based upon said temperature measure to create said hard disk drive.

**14**. The hard disk drive as a product of the process of claim **13**.

**15**. The hard disk drive of claim **2**, wherein said thermoelectric device, comprises:

said internal heat transfer interface;

said exterior heat transfer interface; and

means for enabling power from said electrical contact pair for said first thermal transfer and for said second thermal transfer.

**16**. The hard disk drive of claim **2**, comprising:

said thermal controller providing a driving signal to said electrical contact pair to direct said thermoelectric device in said first heat transfer and in said second heat transfer.

**17**. The hard disk drive of claim **1**, further comprising:

an embedded circuit board including said thermal controller.

**18**. An external cover for said hard disk drive of claim **1**, comprising:

said thermal controller directing said thermoelectric device in said first heat transfer and in said second heat transfer.

**19**. The external cover of claim **18**, wherein said external cover is a member of the group consisting of a disk cover and a disk base.

**20**. A system, comprising: at least one of said hard disk drives of claim **1**.

**21**. The system of claim **20**, further comprising: a thermal conduit thermal-coupling to said exterior of said hard disk drive.

**22**. The system of claim **20**, wherein said system acts as at least one of a Redundant Array of Inexpensive Disks (RAID), a server computer, a desktop computer, and a notebook computer.

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