Innovation, Sciences et Développement économique Canada
Office de la Propriété Intellectuelle du Canada

Innovation, Science and Economic Development Canada
Canadian Intellectual Property Office

CA 3073547 C 2024/06/18

(11)(21) **3 073 547**

(12) **BREVET CANADIEN**
CANADIAN PATENT

(13) **C**

(22) Date de dépôt/Filing Date: 2020/02/21
(41) Mise à la disp. pub./Open to Public Insp.: 2020/10/25
(45) Date de délivrance/Issue Date: 2024/06/18
(30) Priorité/Priority: 2019/04/25 (US16/394,609)

(51) Cl.Int./Int.Cl. *H05K 7/20* (2006.01), *H03H 7/01* (2006.01)
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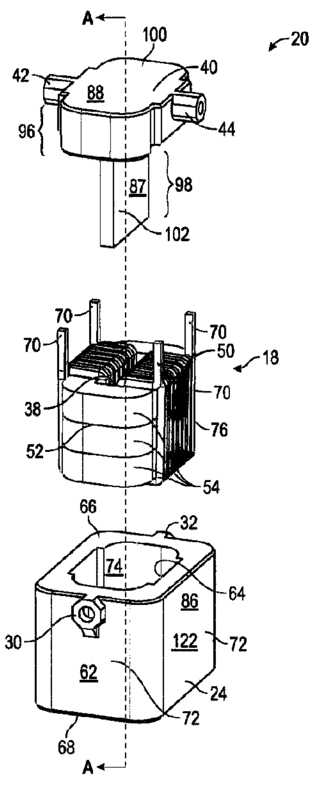
(54) Titre : DISPOSITIF DE REFROIDISSEMENT AUTONOME POUR UN FILTRE D`INTERFERENCE ELECTROMAGNETIQUE
(54) Title: SELF-CONTAINED COOLING DEVICE FOR AN ELECTROMAGNETIC INTERFERENCE FILTER



(57) Abrégé/Abstract:
A cooling device for an electromagnetic interference filter is disclosed. The cooling device includes a housing. The housing includes a main body having a cavity shaped to receive the electromagnetic interference filter and one or more cooling channels surrounding at least a portion of the cavity in the main body of the housing. The one or more cooling channels define one or more flow paths that are contained completely within the housing. The housing also includes an inlet port and an outlet port. The one or more cooling channels fluidly connect the inlet port to the outlet port, and a cooling medium is configured to flow into the inlet port, through the one or more cooling channels, and exit the housing through the outlet port.

ABSTRACT

A cooling device for an electromagnetic interference filter is disclosed. The cooling device includes a housing. The housing includes a main body having a cavity shaped to receive the electromagnetic interference filter and one or more cooling channels surrounding at least a portion of the cavity in the main body of the housing. The one or more cooling channels define one or more flow paths that are contained completely within the housing. The housing also includes an inlet port and an outlet port. The one or more cooling channels fluidly connect the inlet port to the outlet port, and a cooling medium is configured to flow into the inlet port, through the one or more cooling channels, and exit the housing through the outlet port.

SELF-CONTAINED COOLING DEVICE FOR AN ELECTROMAGNETIC INTERFERENCE FILTER

INTRODUCTION

The present disclosure relates to a cooling device for an electromagnetic interference filter. More specifically, the present disclosure is directed towards a self-contained cooling device having a housing for receiving an electromagnetic interference filter, where the housing includes one or more cooling channels that are contained completely within the housing.

BACKGROUND

Electromagnetic interference represents an electric or magnetic field acting on an electronic device to disrupt operation. Electromagnetic interference is a broad term that encompasses all frequencies in the electromagnetic spectrum such as direct current (DC) and alternating current (AC). When the interference falls within the radio frequency range of the electromagnetic spectrum, then the interference may be referred to as radio frequency interference. It is to be appreciated that any device having electronic circuitry may be susceptible to electromagnetic interference. While electromagnetic interference may be generated from any electronic device, some devices such as, for example, AC motors, microprocessors, and power switching supplies are more likely to create disturbances.

An electromagnetic interference filter is a passive electronic device for suppressing electromagnetic interference. Electromagnetic interference filters include passive components such as capacitors and inductors that are connected together to form a resonant circuit. The inductors allow for lower frequency current to pass through to the load but block higher frequency current. However, the inductors dissipate the higher frequency current as heat. Therefore, in some instances, a cooling system may be required to reduce the operating temperatures of the electromagnetic interference filter. For example, in one approach to reduce the operating temperatures, cooled air is blown over the filter. However, it may be challenging to provide sufficient cooling using this approach, especially when packaging space is limited. Although other approaches for cooling the electromagnetic interference filter exist, these approaches may also have drawbacks. For example, some types of cooling devices may be complex or costly to manufacture. Furthermore, some of cooling devices may be prone to leakage.

SUMMARY

According to several aspects, a cooling device for an electromagnetic interference filter is disclosed. The cooling device includes a housing. The housing includes a main body having a cavity shaped to receive the electromagnetic interference filter and one or more cooling channels surrounding at least a portion of the cavity in the main body of the housing. The one or more cooling channels define one or more flow paths that are contained completely within the housing. The housing also includes an inlet port and an outlet port. The one or more cooling channels fluidly connect the inlet port to the outlet port. The cooling medium is configured to flow into the inlet port, through the one or more cooling channels, and exit the housing through the outlet port.

In another aspect, a cooling system is disclosed. The cooling system includes a source of cooling medium, a pump fluidly connected to the source of cooling medium, an electromagnetic interference filter, and a cooling device. The cooling device is configured to provide cooling to the electromagnetic interference filter. The cooling device includes a housing. The housing includes a main body having a cavity shaped to receive the electromagnetic interference filter and one or more cooling channels that surround at least a portion of the cavity in the main body of the housing. The one or more cooling channels define one or more flow paths that are contained completely within the housing. The housing also includes an inlet port fluidly connected to the source of cooling medium and an outlet port. The one or more cooling channels fluidly connect the inlet port to the outlet port. The pump moves the cooling medium into the inlet port, through the one or more cooling channels, and out of the cooling device through the outlet port.

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In one embodiment, there is provided a cooling device for an electromagnetic interference filter. The cooling device comprises a housing. The housing comprises: a main body having a cavity defined by an inner wall, wherein the inner wall of the main body is shaped to receive the electromagnetic interference filter; one or more cooling channels surrounding at least a portion of the cavity in the main body, wherein the one or more cooling channels define one or more flow paths that are contained completely within the housing; an inlet port; and an outlet port. The one or more cooling channels fluidly connect the inlet port to the outlet port and a cooling medium is configured to flow into the inlet port, through the one or more cooling channels, and exit the housing through the outlet port. Contact between the inner wall of the main body and the electromagnetic interference filter draws heat away from the electromagnetic interference filter as the cooling medium passes through the one or more cooling channels.

In another embodiment, there is provided a cooling system, comprising: a source of cooling medium; a pump fluidly connected to the source of cooling medium; an electromagnetic interference filter; and a cooling device configured to provide cooling to the electromagnetic interference filter. The cooling device includes a housing. The housing comprises: a main body having a cavity defined by an inner wall, wherein the inner wall is shaped to receive the electromagnetic interference filter; one or more cooling channels that surround at least a portion of the cavity in the main body, wherein the one or more cooling channels define one or more flow paths that are contained completely within the housing; an inlet port fluidly connected to the source of cooling medium; and an outlet port. The one or more cooling channels fluidly connect the inlet port to the outlet port. The pump moves the cooling medium into the inlet port, through the one or more cooling channels, and out of the cooling device through the outlet port. Contact between the inner wall of the main body and the electromagnetic interference filter draws heat away from the electromagnetic interference filter as the cooling medium passes through the one or more cooling channels.

In another embodiment, there is provided a method of cooling an electromagnetic interference filter. The method comprises moving, by a pump, a cooling medium into an inlet port of a housing that is part of a cooling device. The pump

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is fluidly connected to a source of cooling medium, the housing of the cooling device includes a cavity that receives the electromagnetic interference filter, and the cooling medium exits the housing of the cooling device through an outlet port. The method further comprises cooling the electromagnetic interference filter by drawing heat generated by the electromagnetic interference filter as the cooling medium flows through one or more cooling channels located completely within the housing of the cooling device. Contact between an inner wall of a main body of the housing and the electromagnetic interference filter draws the heat away from the electromagnetic interference filter, and the one or more cooling channels at least partially surround the cavity of the housing.

In another embodiment, there is provided a cooling device for an electromagnetic interference filter. The cooling device comprises a housing. The housing comprises: a main body having a cavity shaped to receive the electromagnetic interference filter, wherein the main body includes an upper face and a lower face, and wherein the cavity in the main body is disposed along the upper face; one or more cooling channels surrounding at least a portion of the cavity in the main body, wherein the one or more cooling channels define one or more flow paths that are contained completely within the housing extend along an entire length of the main body, and wherein the entire length of the main body is measured between the upper face and the lower face; an inlet port; and an outlet port. The one or more cooling channels fluidly connect the inlet port to the outlet port. A cooling medium is configured to flow into the inlet port, through the one or more cooling channels, and exit the housing through the outlet port.

In another embodiment, there is provided a cooling device for an electromagnetic interference filter. The cooling device comprises a housing. The housing comprises: a main body having a cavity shaped to receive the electromagnetic interference filter; one or more cooling channels surrounding at least a portion of the cavity in the main body, wherein the one or more cooling channels define one or more flow paths that are contained completely within the housing; an inlet port; and an outlet port. The one or more cooling channels fluidly connect the inlet port to the outlet port. A cooling medium is configured to flow into the inlet port, through the one or more

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cooling channels, and exit the housing through the outlet port. The cooling device further comprises a cap. A portion of the cap is shaped to extend into the cavity of the main body. The cap comprises: a cap inlet port; a cap outlet port; one or more internal cooling channels, wherein the one or more internal cooling channels define one or more internal flow paths of the cap that are separate from the one or more flow paths of the housing; and a head and a stem. A portion of the head of the cap extends out of the cavity of the main body and the stem extends into the cavity of the main body along a central axis of the housing.

In another embodiment, there is provided a cooling device for an electromagnetic interference filter. The cooling device comprises a housing. The housing comprises: a main body having a cavity shaped to receive the electromagnetic interference filter; one or more cooling channels surrounding at least a portion of the cavity in the main body, wherein the one or more cooling channels define one or more flow paths that are contained completely within the housing; an inlet port; an outlet port, wherein the one or more cooling channels fluidly connect the inlet port to the outlet port, and wherein a cooling medium is configured to flow into the inlet port, through the one or more cooling channels, and exit the housing through the outlet port; one or more peripheral cooling channels that are defined in part by an outermost wall of the housing; and one or more cooling fins are disposed within the one or more peripheral cooling channels.

In another embodiment, there is provided a cooling device for an electromagnetic interference filter. The cooling device comprises a housing. The housing comprises: a main body having a cavity shaped to receive the electromagnetic interference filter; one or more cooling channels surrounding at least a portion of the cavity in the main body, wherein the one or more cooling channels define one or more flow paths that are contained completely within the housing; an inlet port; an outlet port, wherein the one or more cooling channels fluidly connect the inlet port to the outlet port, and wherein a cooling medium is configured to flow into the inlet port, through the one or more cooling channels, and exit the housing through the outlet port; one or more bottom cooling channels defined in part by a lower face of the housing; and a plurality of support structures disposed within the one or more bottom cooling

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channels. Each support structure includes a tapered profile that diverges in an opposite direction from the lower face.

In another embodiment, there is provided a cooling device for an electromagnetic interference filter. The cooling device comprises a housing. The housing comprises: a main body having a cavity shaped to receive the electromagnetic interference filter; one or more cooling channels surrounding at least a portion of the cavity in the main body, wherein the one or more cooling channels define one or more flow paths that are contained completely within the housing, and wherein the one or more cooling channels include a spiral configuration; an inlet port; and an outlet port. The one or more cooling channels fluidly connect the inlet port to the outlet port. A cooling medium is configured to flow into the inlet port, through the one or more cooling channels, and exit the housing through the outlet port.

The features, functions, and advantages that have been discussed may be achieved independently in various embodiments or may be combined in other embodiments further details of which can be seen with reference to the following description and drawings.

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BRIEF DESCRIPTION OF THE DRAWINGS

The drawings described herein are for illustration purposes only and are not intended to limit the scope of the present disclosure in any way.

FIG. **1** is a schematic diagram of a cooling system including a cooling device for drawing heat from an electromagnetic interference filter according to an exemplary embodiment;

FIG. **2** is an elevated perspective view of the cooling device shown in FIG. **1**, where the cooling device further includes a cap according to an exemplary embodiment;

FIG. **3** is an exploded view of the cooling device, the electromagnetic interference filter, and the cap shown in FIG. **2** according to an exemplary embodiment;

FIG. **4** is a perspective view of the magnetic core shown in FIG. **3** according to an exemplary embodiment;

FIG. **5** is a cross-sectioned view of the cooling device, the electromagnetic interference filter, and the cap shown in FIG. **2** according to an exemplary embodiment;

FIG. **6** is a perspective view of another embodiment of the electromagnetic interference filter having a toroidal magnetic core according to an exemplary embodiment;

FIG. **7** is a perspective view of another embodiment of the cooling device and the cap, where the cooling device and the cap are both for drawing heat from the toroidal magnetic core as shown in FIG. **6** according to an exemplary embodiment;

FIG. **8** is a perspective view of the cooling device shown in FIG. **7** according to an exemplary embodiment;

FIG. **9** is a perspective view of the cap shown in FIG. **7** according to an exemplary embodiment;

FIG. **10**A is a cross-sectioned view of the cap shown in FIG. **9** according to an exemplary embodiment;

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FIG. **10**B is a cross-sectioned view of the housing shown in FIG.**8** according to an exemplary embodiment;

FIG. **11** is a process flow diagram illustrating a method for providing cooling to the electromagnetic interference filter by the disclosed cooling device according to an exemplary embodiment; and

FIG. **12** is a process flow diagram illustrating a method for providing cooling to the electromagnetic interference filter by the disclosed cap according to an exemplary embodiment.

DETAILED DESCRIPTION

The present disclosure is directed towards a self-contained cooling device for an electromagnetic interference filter. The cooling device includes a housing having a cavity shaped to receive the electromagnetic interference filter, an inlet, an outlet, and one or more cooling channels. The cooling channels define one or more flow paths that are contained completely within the housing of the cooling device, where a cryogenic fluid flows through the cooling channels to draw heat generated by the electromagnetic interference filter. In some embodiments, the cooling device includes a cap, however, it is to be appreciated that the cap is optional. The cap further enhances cooling of the electromagnetic interference filter and clamps the busbars of the electromagnetic interference filter, which improves electrical conductivity and isolation.

The cooling device is a self-contained monolithic unit that does not require multiple components. Because the cooling device is self-contained, this eliminates any potential leaks that may form between mating surfaces when multiple components are employed. Additionally, the self-contained cooling device also provides improved dispersion of cryogenic fluid, which in turn results in a more uniform cooling of the electromagnetic interference filter.

The following description is merely exemplary in nature and is not intended to limit the present disclosure, application, or uses.

Referring to FIG. **1**, a schematic diagram of an exemplary cooling system **10** for an electromagnetic interference filter **18** is shown. The cooling system **10** includes a cooling device **20**, a source **22** of cooling medium, and a pump **25**. The pump **25** is fluidly connected to the source **22**. The cooling device **20** includes a housing **24** that contains the electromagnetic interference filter **18**. The housing **24** also includes an inlet port **30** and an outlet port **32**. The inlet port **30** of the housing **24** is fluidly connected to the source **22** by a fluid conduit **34**. The fluid conduit **34** also fluidly connects the outlet port **32** of the housing **24** to the pump **25**. As explained below, the cooling device **20** is configured to draw heat generated by the electromagnetic interference filter **18**.

In the non-limiting embodiment as illustrated in FIG. **1**, the cooling device **20** also includes a cap **40**. The cap **40** includes a cap inlet port **42** and a cap outlet port **44**. The cap inlet port **42** is fluidly connected to the source **22** by the fluid conduit **34**. The fluid conduit **34** also fluidly connects the cap outlet port **44** to the pump **25**. It is to be appreciated that the cap **40** is an optional component and may be omitted in some embodiments. However, the cap **40** may further enhance or improve cooling of the electromagnetic interference filter **18**.

The source **22** is a vessel configured to store the cooling medium. In one embodiment, the cooling medium is a cryogenic fluid. For example, the source **22** may be a cryogenic Dewar flask and the cryogenic fluid is liquid nitrogen. Although liquid nitrogen is described, it is to be appreciated that the cryogenic fluid is not limited to liquid nitrogen. Instead, the particular cryogenic fluid is selected based on the heat loads experienced by a specific application. Alternatively, in another embodiment, the cooling medium may be a non-cryogenic fluid instead. For example, a refrigerant such as Dichlorodifluoromethane (R-**12**) may be used. Some other examples of a non-cryogenic fluid include, but are not limited to, water (cooled or heated), cooled air, ethylene glycol, fuel, cold gaseous dinitrogen, and cold carbon dioxide. It is to be appreciated that the fluid may refer to liquid or gas. If the cooling medium is a cryogenic fluid, then the pump **25** may also be referred to as a cryopump. The pump **25** is fluidly connected to the cooling device **20** and the source **22** by the fluid conduit **34**. The pump **25** includes a cryostat or condenser pump configured to compress and cool gaseous cryogenic fluid received from the cooling device **20** into a liquid state.

FIG. **2** is an elevated perspective view of the cooling device **20** including the cap **40**. FIG. **3** is an exploded view of the cooling device **20** shown in FIG. **2**, where the electromagnetic interference filter **18** is visible. Referring specifically to FIG. **3**, the electromagnetic interference filter **18** includes one or more inductors **50**, which are also referred to as chokes, that are conductive wires. The electromagnetic interference filter **18** also includes a magnetic core **52**. The inductors **50** are wrapped around the magnetic core **52**. Current passes through the inductors **50** from a power source (not shown) and to a load (not shown). The inductors **50** allow for lower frequency current to pass through to the load but block higher frequency current. However, the inductors **50** dissipate the higher frequency current as heat. Accordingly, the cooling system **10** and the cooling device **20** are provided to draw the heat generated by the electromagnetic interference filter **18**, thereby reducing the temperature of the electromagnetic interference filter **18**. As explained below, a cooling medium that is provided by the source **22** flows through the cooling device **20** to draw the heat generated by the inductors **50** of the electromagnetic interference filter **18**.

In some embodiments, the magnetic core **52** is constructed of multiple magnetic cores **54**. Specifically, in the example as shown in FIG. **4**, the magnetic cores **54** are horseshoe style magnetic cores (i.e., U-shaped magnetic cores) that include two side bars **56** and an arcuate end portion **58** that joins the side bars together. The magnetic cores **54** are joined together at their respective end faces **60** to create the magnetic core **52**. The magnetic core **52** also defines a centrally located aperture **38**. It is to be appreciated that the embodiment shown in FIGS. **3** and **4** is merely exemplary in nature, and the magnetic core **52** may include any number of shapes or profiles. For example, in the alternative embodiment as shown in FIG. **6**, the magnetic core **52** includes a toroidal shape instead.

Referring to FIGS. **2** and **3**, the housing **24** of the cooling device **20** includes a main body **62** having a cavity **64** shaped to receive the electromagnetic interference filter. Specifically, the entire magnetic core **52** of the electromagnetic interference filter **18** fits within the cavity **64** of the housing **24**. The inductors **50** wrapped around the magnetic core **52** are also received completely within the cavity **64** of the housing **24**. However, as seen in FIG. **2**, a portion **70** of the inductors **50** that are not wrapped around the magnetic core **52** project in an upward direction and protrude from the cavity **64** of the housing **24**. The portion **70** of the inductors **50** exposed to the environment act as busbars and electrically connect the electromagnetic interference filter **18** to an electrical circuit (not shown).

The main body **62** of the housing **24** includes the upper face **66** and a lower face **68**. The cavity **64** in the main body **62** of the housing **24** is disposed along the upper face **66** of the main body **62**. In the non-limiting embodiment as illustrated, both the inlet port **30** and the outlet port **32** of the housing **24** are disposed along the upper face **66**. However, it is to be appreciated that the inlet port **30** and the outlet port **32** may be oriented along the housing **24** in a variety of different arrangements. For example, in another embodiment the inlet port **30**, the outlet port **32**, or both the inlet port **30** and the outlet port **32** may be located along the lower face **68** of the housing **24**. In yet another embodiment, the inlet port **30**, the outlet port **32**, or both the inlet port **30** and the outlet port **32** are located along a side **72** of the housing **24** between the upper face **66** and the lower face **68**.

Referring specifically to FIG. **3**, the cavity **64** in the main body **62** of the housing **24** is defined by an inner wall **74**. The inner wall **74** is shaped to substantially correspond with an outermost surface **76** defined by both the magnetic core **52** and the inductors **50** of the electromagnetic interference filter **18**. Therefore, when the electromagnetic interference filter **18** is placed within the cavity **64** of the main body **62** of the housing **24**, the inner wall **74** that defines the cavity **64** substantially contacts the outermost surface **76** of the electromagnetic interference filter **18**. As cryogenic fluid passes through one or more cooling channels **80** that are located completely within the housing **24** (shown in FIG. **5**), the contact between the inner wall **74** of the housing **24** and the outermost surface **76** of the electromagnetic interference filter **18** draws heat away from the electromagnetic interference filter **18**.

In an embodiment, the housing **24** as well as the cap **40** are both constructed by additive manufacturing techniques, which is also referred to as 3D printing. The housing **24** and the cap **40** are both constructed of a material that is compatible with the specific type of cryogenic fluid that is employed by the cooling device **20**. For example, if the cryogenic fluid is liquid nitrogen, then the material employed by the housing **24** and the cap **40** is compatible with liquid nitrogen. Some examples of materials that may be used by the housing **24** and the cap **40** include, but are not limited to, polyetherimide, polyether ether ketone (PEEK), and polyetherketoneketone (PEKK).

In one non-limiting embodiment, an outermost surface **86** of the housing **24** is coated or painted with a structural primer paint. An outermost surface **88** of the cap **40** may also be painted with the structural primer as well. For example, the structural primer paint may be a two-component epoxy polyamide primer that is also utilized for protecting an aircraft. The structural primer paint creates a barrier or seal that substantially eliminates any fluid leaks within the cooling device **20**.

FIG. **5** is a cross-sectioned view of the cooling device **20** shown in FIGS. **2** and **3**, which reveals one or more cooling channels **80** that surround at least a portion of the cavity **64** in the main body **62** of the housing **24**. The cooling channels **80** fluidly connect the inlet port **30** to the outlet port **32**, where the cooling medium (i.e., the cryogenic fluid) flows into the inlet port **30**, through the cooling channels **80**, and exits the housing **24** through the outlet port **32** of the housing **24**. The cooling medium draws heat generated by the electromagnetic interference filter **18** as the cooling medium flows through the cooling channels **80**. The cooling channels **80** define one or more flow paths **82** that are contained completely within the housing **24**. In other words, a complete cooling circuit may be defined between the housing **24**, the source **22** of cooling medium, and the pump **25** (FIG. **1**). Thus, it is to be appreciated that the cooling device **20** is a self-contained monolithic cooling unit, which in turn reduces or substantially eliminates occurrences of leaks that sometimes occur when cooling medium flows between multiple components that are joined together.

The cooling channels **80** are arranged in either a series configuration or a parallel configuration, where the specific configuration is determined based on the specific cooling requirements of the electromagnetic interference filter **18**. It is to be appreciated that characteristics of the cooling medium such as, for example, flow rate and Reynolds number (i.e., to determine if the flow is laminar or turbulent) depend upon whether the cooling channels **80** are arranged in the series or the parallel configuration.

In the embodiment as shown, the one or more cooling channels **80** extend along an entire length L of the main body **62** of the housing **24**. Referring to FIG. **2**, the entire length L of the main body **62** is measured between the upper face **66** and the lower face **68** of the housing **24**. It is to be appreciated that in another embodiment the cooling channels **80** may not extend along the entire length L of the main body **62** of the housing **24**. However, having the cooling channels **80** extend along the entire length L of the main body **62** of the housing **24** may increase or provide more uniform cooling to the electromagnetic interference filter **18**.

Referring to FIG. **5**, in one embodiment the housing **24** also includes one or more peripheral cooling channels **120** that are defined in part by an outermost wall **122** of the housing **24**. In the embodiment as shown in FIG. **5**, the cooling channels **80** are also labeled as the peripheral cooling channels **120**, however it is to be appreciated that in another embodiment there may be separate peripheral cooling channels **120** instead. Furthermore, FIG. **5** also illustrates the cooling channels **80** including a spiral configuration. Specifically, the cooling channels **80** are arranged in a winding pattern around the central axis A-A of the housing **24**. Although a spiral configuration is described, it is to be appreciated that the disclosure is not limited to this particular configuration.

Continuing to refer to FIG. **5**, in an embodiment one or more cooling fins **130** are disposed within the cooling channels **80**. Specifically, FIG. **5** illustrates the one or more cooling fins **130** disposed within the peripheral cooling channels **120**. The cooling fins **130** are projections located along an inner surface **140** of the peripheral cooling channels **120** and are used to increase a surface area of the housing **24** used to draw heat from the electromagnetic interference filter **18**. Therefore, the cooling fins **130** may further improve or enhance cooling of the electromagnetic interference filter **18**.

In an embodiment, the housing **24** includes one or more bottom cooling channels **160** defined in part by the lower face **68** of the housing **24**. The bottom cooling channels **160** may further enhance cooling of the electromagnetic interference filter **18** by drawing heat from a bottom portion **162** of the electromagnetic interference filter **18**. Specifically, the bottom cooling channels **160** are defined by a plurality of support structures **170** that are disposed within the one or more bottom cooling channels **160**. Each support structure **170** includes a tapered profile that diverges in an opposite direction from the lower face **68** of the housing **24**. It is to be appreciated that the tapered profile of the support structures **170** in the event the cooling device **20** is manufactured using additive manufacturing techniques (i.e., 3D printing). This is because the housing **24** of the cooling device **20** is generally constructed bottom to top, and the tapered profile of the support structures **170** results in reduced or almost no sacrificial material required to build the bottom cooling channels **160**. In other words, the housing **24** is constructed by first creating the lower face **68** and then adding material in an upwards direction.

The cap **40** of the cooling device **20** is now described. Referring to FIGS. **3** and **5**, in one embodiment a portion **98** of the cap **40** is shaped to extend into the cavity **64** of the main body **62** of the housing **24**. The cap **40** includes a head **100** and a stem **102**, where the head **100** is shaped to cover the cavity **64** of the housing **24** and the stem **102** includes an elongated profile that serves as the portion **98** of the cap **40** that extends into the cavity **64** of the housing **24**. A portion **96** of the head **100** of the cap **40** extends out of the cavity **64** of the main body **62** of the housing **24**, while the stem **102** extends into the cavity **64** of the main body **62** of the housing **24** along the central axis A-A of the housing **24**.

Referring specifically to FIG. **5**, the cap **40** includes one or more internal cooling channels **90** that are disposed within the stem **102** of the cap **40**. The one or more internal cooling channels **90** define internal flow paths **92**. It is to be appreciated that the internal flow paths **92** of the internal cooling channels **90** are separate from the flow paths **82** of the housing **24**. In other words, the cooling medium flowing through the housing **24** does not intermingle with the cooling medium flowing through the cap **40**. The internal flow paths **92** of the one or more internal cooling channels **90** extends into the stem of the cap **40**. Referring to FIGS. **3**, and **5**, the stem **102** of the cap **40** extends into the centrally located aperture **38** defined by the magnetic core **52** of the electromagnetic interference filter **18**, where an outermost surface **87** of the stem **102** is shaped to correspond with the outermost surface **76** of the electromagnetic interference filter **18** around the centrally located aperture **38**.

As mentioned above, the magnetic core **52** may include any number of different configurations and shapes and is not limited to the embodiments shown in the figures. Referring now to FIG. **6**, an alternative embodiment of the electromagnetic interference filter **18** having a toroidal magnetic core **152** is illustrated. In the embodiment as shown, the toroidal magnetic core **152** is constructed of multiple magnetic cores **154**. Specifically, in the example as shown in FIG. **6**, the magnetic cores **154** are ring shaped magnetic cores that are stacked on top of one another to create the toroidal shape.

FIG. **7** is a perspective view of the cooling device **20** that provides cooling for the toroidal magnetic core **152** shown in FIG. **6**. In the embedment as shown in FIG. **7**, the housing **24** of the cooling device **20** includes a substantially cylindrical profile. Furthermore, the embodiment shown in FIG. **7** also illustrates the inlet port **30** and the outlet port **32** located along the lower face **68** of the housing **24** instead of the upper face **66** as seen in the embodiment of FIG. **2**. FIG. **8** illustrates the housing **24** where the cap **40** is removed. Since the cap **40** is removed, the inner wall **74** of the cavity **64** in the main body **62** of the housing **24** is visible in FIG. **7**.

Referring now to FIGS. **6** and **8**, the inner wall **74** of the housing **24** is shaped to substantially correspond with the outermost surface **76** of the electromagnetic interference filter **18**. Specifically, in the embodiment as shown, the inner wall **74** of the housing **24** includes a plurality of depressions **206** that are each shaped to accommodate one of the inductors **50** wrapped around the toroidal magnetic core **152**. Furthermore, as seen in FIG. **9**, an inner surface **202** of the cap **40** also includes a plurality of depressions **204** that are also shaped to accommodate one of the inductors **50** of the toroidal magnetic core **152**.

In the embodiment as shown in FIG. **9**, the cap **40** does not include the stem **102** (i.e., the stem **102** shown in FIG. **2**). Instead, the cap **40** includes a centrally located aperture **208**. The centrally located aperture **208** is centered around the central axis A-A of the cooling device **20**. Referring to FIGS. **7**, **8**, and **9**, the centrally located aperture **208** of the cap **40** is shaped to receive a stem **210** that is part of the housing **24**. The stem **210** of the housing **24** defines a surface **212** that is shaped to correspond with the outermost surface **76** of the centrally located aperture **38** of the electromagnetic interference filter **18**.

FIGS. **10**A and **10**B illustrate cross-sectioned views of the cap **40** seen in FIG. **9** and the housing **24** seen in FIG. **7**, respectively. Referring to FIGS. **9** and **10**A, the cap **40** includes one or more internal cooling channels **90** that fluidly connect the cap inlet port **42** to the cap outlet port **44**. Similar to the embodiment as shown in FIG. **5**, the one or more internal cooling channels **90** shown in FIG. **10**A define internal flow paths **92** that are separate from the flow paths **82** of the housing **24** (seen in FIG. **10**B). The internal cooling channels **90** illustrated in FIG. **10**A extend within the head **100** of the cap **40**, since the cap **40** shown in FIG. **10**A does not include a stem portion.

In the embodiment as shown in FIG. **10**B, the stem **210** of the housing **24** includes one or more central cooling channels **150**. The central cooling channels **150** extend around the central axis A-A of the housing **24**. As seen in FIG. **10**B, the flow path **82** of the cooling channels **80** now include the central cooling channels **150**. In the embodiment as shown, the central cooling channels **150** include a spiral configuration, however it is to be appreciated that other shapes and configurations may be used as well. Therefore, when the electromagnetic interference filter **18** (FIG. **6**) is placed within the cavity **64** of the main body **62** of the housing **24**, the surface **212** of the stem **210** of the housing **24** substantially contacts the outermost surface **76** of the electromagnetic interference filter **18** around the centrally located aperture **38**. Thus, cooling medium flows through the central cooling channels **150** to draw away heat generated around the centrally located aperture **38** of the electromagnetic interference filter **18**.

In the embodiment as shown in FIG. **10**A, the central cooling channels **150** are fluidly connected to the cooling channels **80** as well as the bottom cooling channels **160** of the housing **24**. Thus, the central cooling channels **150** are fluidly connected to both the inlet port **30** and the outlet port **32** of the housing **24**. It is to be appreciated that similar to the embodiment as shown in FIG. **5**, the cooling channels **80** of the housing **24** shown in FIG. **10**A also serve as the peripheral cooling channels **120** of the housing **24**. Moreover, the peripheral cooling channels **120** in FIG. **10**B also include one or more cooling fins **130** disposed within the peripheral cooling channels **120**.

Referring now to FIGS. **11** and **12**, process flow diagrams illustrating exemplary methods **300** and **400** are shown. Specifically, FIG. **11** illustrates the method **300** of cooling the electromagnetic interference filter **18** by the housing **24**, while FIG. **12** illustrates the method **400** of cooling the electromagnetic interference filter **18** by the cap **40**. It is to be appreciated that the method **300** may be performed along, or in conjunction with method **400**.

The method **300** is first described. Referring to generally to FIGS. **1-3**, **4-5**, and **7-11**, the method **300** begins at block **302**. In block **302**, the method **300** includes moving, by the pump **25**, a cooling medium into the inlet port **30** of the housing **24** that is part of the cooling device **20**. Referring specifically to FIG. **1**, the pump **25** is fluidly connected to the source **22** of cooling medium. As seen in FIGS. **3** and **10**A, the housing **24** of the cooling device **20** includes the cavity **64** that receives the electromagnetic interference filter **18**. The method **300** may then proceed to block **304**.

In block **304**, the method **300** includes cooling the electromagnetic interference filter **18** by drawing heat generated by the electromagnetic interference filter **18**. The heat is drawn as the cooling medium flows through one or more cooling channels **80** located completely within the housing **24** of the cooling device **20**. The one or more cooling channels **80** at least partially surround the cavity **64** of the housing **24**. The method **300** may then proceed to block **306**.

In block **306**, the method **300** includes having the cooling medium exit the housing **24** of the cooling device **20** through an outlet port **32**. The method **300** may then terminate.

The method **400** in FIG. **12** is now described. Referring to generally to FIGS. **1-3**, **4-5**, **7**, and **12**, the method **400** begins at block **402**. In block **402**, the method **400** includes moving, by the pump **25** (FIG. **1**), the cooling medium into the cap inlet port **42** of the cap **40**. The method **400** may then proceed to block **404**.

In block **404**, the method includes cooling the electromagnetic interference filter **18** by drawing the heat generated by the electromagnetic interference filter **18**. The heat is drawn as the cooling medium flows through one or more internal cooling channels **90** of the cap **40** (FIGS. **5** and **9**). The method **400** may then proceed to block **406**.

In block **406**, the method **400** includes having the cooling medium exit the cap **40** through a cap outlet port **44**. The method **400** may then terminate.

Referring generally to the figures, the disclosures relates to a self-contained monolithic cooling device for an electromagnetic interference filter that does not require

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multiple components. The self-contained design eliminates any potential leaks that may form between mating surfaces when multiple components are employed. Additionally, the self-contained cooling device improves dispersion of cryogenic fluid which in turn provides a more uniform cooling of the electromagnetic interference filter. The disclosed cooling device is made based on additive manufacturing techniques that result in a reduced amount of sacrificial material when compared to conventional techniques presently used to fabricate electromagnetic interference filters. In one embodiment, the cooling device may include a cap that further enhances or improves cooling of the electromagnetic interference filter as well.

Further, the disclosure comprises embodiments according to the following clauses:

Clause 1. A cooling device for an electromagnetic interference filter, the cooling device comprising:

a housing, comprising:

a main body having a cavity shaped to receive the electromagnetic interference filter;

one or more cooling channels surrounding at least a portion of the cavity in the main body of the housing, wherein the one or more cooling channels define one or more flow paths that are contained completely within the housing;

an inlet port; and

an outlet port, wherein the one or more cooling channels fluidly connect the inlet port to the outlet port, and wherein a cooling medium is configured to flow into the inlet port, through the one or more cooling channels, and exit the housing through the outlet port.

Clause 2. The cooling device of Clause 1, wherein the main body of the housing includes an upper face and a lower face, and wherein the cavity in the main body of the housing is disposed along the upper face.

Clause 3. The cooling device of Clause 2, wherein the one or more cooling channels extend along an entire length of the main body, and wherein the entire length of the main body is measured between the upper face and the lower face.

Clause 4. The cooling device of Clause 1, further comprising a cap, wherein a portion of the cap is shaped to extend into the cavity of the main body of the housing.

Clause **5**. The cooling device of Clause **4**, wherein the cap includes:

a cap inlet port;

a cap outlet port; and

one or more internal cooling channels , wherein the one or more internal cooling channels define internal flow paths that are separate from the flow paths of the housing.

Clause **6**. The cooling device of Clause **5**, wherein the cap includes a head and a stem, wherein a portion of the head of the cap extends out of the cavity of the main body of the housing and the stem extends into the cavity of the main body of the housing along a central axis of the housing.

Clause **7**. The cooling device of Clause **6**, wherein internal flow paths of the one or more internal cooling channels extends into the stem of the cap.

Clause **8**. The cooling device of Clause **1**, wherein the housing includes one or more peripheral cooling channels that are defined in part by an outermost wall of the housing.

Clause **9**. The cooling device of Clause **8**, wherein one or more cooling fins are disposed within the one or more peripheral cooling channels.

Clause **10**. The cooling device of Clause **8**, wherein the housing includes one or more central cooling channels that extend along a central axis of the housing, and wherein the one or more central cooling channels are fluidly connected to the one or more peripheral cooling channels.

Clause **11**. The cooling device of Clause **1**, wherein the housing includes one or more bottom cooling channels defined in part by a lower face of the housing.

Clause **12**. The cooling device of Clause **11**, wherein a plurality of support structures are disposed within the one or more bottom cooling channels, and wherein each support structure includes a tapered profile that diverges in an opposite direction from the lower face of the housing.

Clause **13**. The cooling device of Clause **1**, wherein the one or more cooling channels are arranged in either a series configuration or a parallel configuration.

Clause **14**. The cooling device of Clause **1**, wherein the one or more cooling channels include a spiral configuration.

Clause **15**. A cooling system, comprising:

a source of cooling medium;

a pump fluidly connected to the source of cooling medium;

an electromagnetic interference filter; and

a cooling device configured to provide cooling to the electromagnetic interference filter, wherein the cooling device includes a housing, and wherein the housing comprises:

a main body having a cavity shaped to receive the electromagnetic interference filter;

one or more cooling channels that surround at least a portion of the cavity in the main body of the housing, wherein the one or more cooling channels define one or more flow paths that are contained completely within the housing;

an inlet port fluidly connected to the source of cooling medium; and

an outlet port, wherein the one or more cooling channels fluidly connect the inlet port to the outlet port, and wherein the pump moves the cooling medium into the inlet port, through the one or more cooling channels, and out of the cooling device through the outlet port.

Clause **16**. The cooling system of Clause **15**, wherein the cooling medium is a cryogenic fluid.

Clause **17**. The cooling system of Clause **15**, further comprising a cap fluidly connected to the source of cooling medium, wherein a portion of the cap is shaped to extend into the cavity of the main body of the housing.

Clause **18**. The cooling system of Clause **17**, wherein the cap includes:

a cap inlet port fluidly connected to the source of cooling medium;

a cap outlet port fluidly connected to the source of cooling medium; and

one or more internal cooling channels, wherein the one or more internal cooling channels define internal flow paths that are separate from the flow paths of the housing.

Clause **19**. A method of cooling an electromagnetic interference filter, the method comprising:

moving, by a pump, a cooling medium into an inlet port of a housing that is part of a cooling device, wherein the pump is fluidly connected to a source of cooling medium and the housing of the cooling device includes a cavity that receives the electromagnetic interference filter;

cooling the electromagnetic interference filter by drawing heat generated by the electromagnetic interference filter, wherein the heat is drawn as the cooling medium flows through one or more cooling channels located completely within the housing of the cooling device, and wherein the one or more cooling channels at least partially surround the cavity of the housing; and

having the cooling medium exit the housing of the cooling device through an outlet port.

Clause **20**. The method of Clause **19**, further comprising:

moving, by the pump, the cooling medium into a cap inlet port of a cap;

cooling the electromagnetic interference filter by drawing the heat generated by the electromagnetic interference filter, wherein the heat is drawn as the cooling medium flows through one or more internal cooling channels of the cap; and

having the cooling medium exit the cap through a cap outlet port.

The description of the present disclosure is merely exemplary in nature and variations that do not depart from the gist of the present disclosure are intended to be within the scope of the present disclosure. Such variations are not to be regarded as a departure from the spirit and scope of the present disclosure.

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EMBODIMENTS IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A cooling device for an electromagnetic interference filter, the cooling device comprising:

a housing, comprising:

a main body having a cavity defined by an inner wall, wherein the inner wall of the main body is shaped to receive the electromagnetic interference filter;

one or more cooling channels surrounding at least a portion of the cavity in the main body, wherein the one or more cooling channels define one or more flow paths that are contained completely within the housing;

an inlet port; and

an outlet port, wherein the one or more cooling channels fluidly connect the inlet port to the outlet port and a cooling medium is configured to flow into the inlet port, through the one or more cooling channels, and exit the housing through the outlet port, and wherein contact between the inner wall of the main body and the electromagnetic interference filter draws heat away from the electromagnetic interference filter as the cooling medium passes through the one or more cooling channels.

2. The cooling device of claim **1**, wherein the main body includes an upper face and a lower face, and wherein the cavity in the main body is disposed along the upper face.

3. The cooling device of claim **2**, wherein the one or more cooling channels extend along an entire length of the main body, and wherein the entire length of the main body is measured between the upper face and the lower face.

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4. The cooling device of claim **1**, wherein the housing includes one or more bottom cooling channels defined in part by a lower face of the housing.

5. The cooling device of claim **4**, wherein a plurality of support structures are disposed within the one or more bottom cooling channels, and wherein each support structure includes a tapered profile that diverges in an opposite direction from the lower face.

6. The cooling device of any one of claims **1**-**5**, further comprising a cap, wherein a portion of the cap is shaped to extend into the cavity of the main body.

7. The cooling device of claim **6**, wherein the cap includes:

a cap inlet port;

a cap outlet port; and

one or more internal cooling channels, wherein the one or more internal cooling channels define one or more internal flow paths of the cap that are separate from the one or more flow paths of the housing.

8. The cooling device of claim **7**, wherein the cap includes a head and a stem, wherein a portion of the head of the cap extends out of the cavity of the main body and the stem extends into the cavity of the main body along a central axis of the housing.

9. The cooling device of claim **8**, wherein the one or more internal flow paths of the cap extends into the stem of the cap.

10. The cooling device of any one of claims **1**-**5**, wherein the housing includes one or more peripheral cooling channels that are defined in part by an outermost wall of the housing.

11. The cooling device of claim **10**, wherein one or more cooling fins are disposed within the one or more peripheral cooling channels.

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12. The cooling device of claim **10** or **11**, wherein the housing includes one or more central cooling channels that extend along a central axis of the housing, and wherein the one or more central cooling channels are fluidly connected to the one or more peripheral cooling channels.

13. The cooling device of any one of claims **1**-**12**, wherein the one or more cooling channels are arranged in either a series configuration or a parallel configuration.

14. The cooling device of any one of claims **1**-**13**, wherein the one or more cooling channels include a spiral configuration.

15. The cooling device of any one of claims **1**-**14**, where in the inlet port is fluidly connected to a source of cooling medium.

16. The cooling device of any one of claims **1**-**15**, wherein the cooling medium is a cryogenic fluid.

17. A cooling system, comprising:

a source of cooling medium;

a pump fluidly connected to the source of cooling medium;

an electromagnetic interference filter; and

a cooling device configured to provide cooling to the electromagnetic interference filter, wherein the cooling device includes a housing, and wherein the housing comprises:

a main body having a cavity defined by an inner wall, wherein the inner wall is shaped to receive the electromagnetic interference filter;

one or more cooling channels that surround at least a portion of the cavity in the main body, wherein the one or more cooling channels define one or more flow paths that are contained completely within the housing;

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an inlet port fluidly connected to the source of cooling medium; and

an outlet port, wherein the one or more cooling channels fluidly connect the inlet port to the outlet port, and wherein the pump moves the cooling medium into the inlet port, through the one or more cooling channels, and out of the cooling device through the outlet port, wherein contact between the inner wall of the main body and the electromagnetic interference filter draws heat away from the electromagnetic interference filter as the cooling medium passes through the one or more cooling channels.

18. The cooling system of claim **17**, wherein the cooling medium is a cryogenic fluid.

19. The cooling system of claim **17**, further comprising a cap fluidly connected to the source of cooling medium, wherein a portion of the cap is shaped to extend into the cavity of the main body.

20. The cooling system of claim **19**, wherein the cap includes:

a cap inlet port fluidly connected to the source of cooling medium;

a cap outlet port fluidly connected to the source of cooling medium; and

one or more internal cooling channels, wherein the one or more internal cooling channels define one or more internal flow paths that are separate from the one or more flow paths of the housing.

21. A method of cooling an electromagnetic interference filter, the method comprising:

moving, by a pump, a cooling medium into an inlet port of a housing that is part of a cooling device, wherein the pump is fluidly connected to a source of cooling medium, the housing of the cooling device includes a cavity that receives the electromagnetic interference filter, and the cooling medium exits the housing of the cooling device through an outlet port; and

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cooling the electromagnetic interference filter by drawing heat generated by the electromagnetic interference filter as the cooling medium flows through one or more cooling channels located completely within the housing of the cooling device, wherein contact between an inner wall of a main body of the housing and the electromagnetic interference filter draws the heat away from the electromagnetic interference filter, and the one or more cooling channels at least partially surround the cavity of the housing.

22. The method of claim **21**, further comprising:

moving, by the pump, the cooling medium into a cap inlet port of a cap, wherein the cooling medium exits the cap through a cap outlet port; and

cooling the electromagnetic interference filter by drawing the heat generated by the electromagnetic interference filter as the cooling medium flows through one or more internal cooling channels of the cap.

23. A cooling device for an electromagnetic interference filter, the cooling device comprising:

a housing, comprising:

a main body having a cavity shaped to receive the electromagnetic interference filter, wherein the main body includes an upper face and a lower face, and wherein the cavity in the main body is disposed along the upper face;

one or more cooling channels surrounding at least a portion of the cavity in the main body, wherein the one or more cooling channels define one or more flow paths that are contained completely within the housing extend along an entire length of the main body, and wherein the entire length of the main body is measured between the upper face and the lower face;

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an inlet port; and

an outlet port, wherein the one or more cooling channels fluidly connect the inlet port to the outlet port, and wherein a cooling medium is configured to flow into the inlet port, through the one or more cooling channels, and exit the housing through the outlet port.

24. A cooling device for an electromagnetic interference filter, the cooling device comprising:

a housing, comprising:

a main body having a cavity shaped to receive the electromagnetic interference filter;

one or more cooling channels surrounding at least a portion of the cavity in the main body, wherein the one or more cooling channels define one or more flow paths that are contained completely within the housing;

an inlet port; and

an outlet port, wherein the one or more cooling channels fluidly connect the inlet port to the outlet port, and wherein a cooling medium is configured to flow into the inlet port, through the one or more cooling channels, and exit the housing through the outlet port; and

a cap, wherein a portion of the cap is shaped to extend into the cavity of the main body, wherein the cap comprises:

a cap inlet port;

a cap outlet port;

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one or more internal cooling channels, wherein the one or more internal cooling channels define one or more internal flow paths of the cap that are separate from the one or more flow paths of the housing; and

a head and a stem, wherein a portion of the head of the cap extends out of the cavity of the main body and the stem extends into the cavity of the main body along a central axis of the housing.

25. A cooling device for an electromagnetic interference filter, the cooling device comprising:

a housing, comprising:

a main body having a cavity shaped to receive the electromagnetic interference filter;

one or more cooling channels surrounding at least a portion of the cavity in the main body, wherein the one or more cooling channels define one or more flow paths that are contained completely within the housing;

an inlet port;

an outlet port, wherein the one or more cooling channels fluidly connect the inlet port to the outlet port, and wherein a cooling medium is configured to flow into the inlet port, through the one or more cooling channels, and exit the housing through the outlet port;

one or more peripheral cooling channels that are defined in part by an outermost wall of the housing; and

one or more cooling fins are disposed within the one or more peripheral cooling channels.

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26. A cooling device for an electromagnetic interference filter, the cooling device comprising:

a housing, comprising:

a main body having a cavity shaped to receive the electromagnetic interference filter;

one or more cooling channels surrounding at least a portion of the cavity in the main body, wherein the one or more cooling channels define one or more flow paths that are contained completely within the housing;

an inlet port;

an outlet port, wherein the one or more cooling channels fluidly connect the inlet port to the outlet port, and wherein a cooling medium is configured to flow into the inlet port, through the one or more cooling channels, and exit the housing through the outlet port;

one or more bottom cooling channels defined in part by a lower face of the housing; and

a plurality of support structures disposed within the one or more bottom cooling channels, and wherein each support structure includes a tapered profile that diverges in an opposite direction from the lower face.

27. A cooling device for an electromagnetic interference filter, the cooling device comprising:

a housing, comprising:

a main body having a cavity shaped to receive the electromagnetic interference filter;

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one or more cooling channels surrounding at least a portion of the cavity in the main body, wherein the one or more cooling channels define one or more flow paths that are contained completely within the housing, and wherein the one or more cooling channels include a spiral configuration;

an inlet port; and

an outlet port, wherein the one or more cooling channels fluidly connect the inlet port to the outlet port, and wherein a cooling medium is configured to flow into the inlet port, through the one or more cooling channels, and exit the housing through the outlet port.

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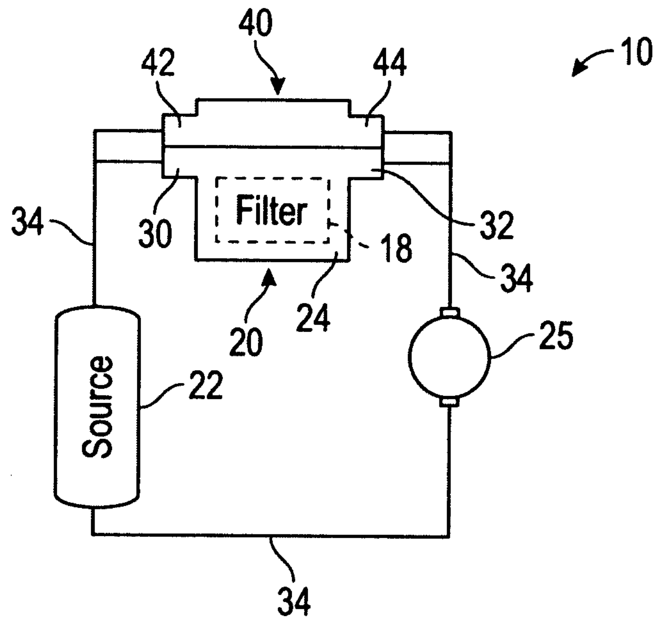
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44
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Filter
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30
32
18
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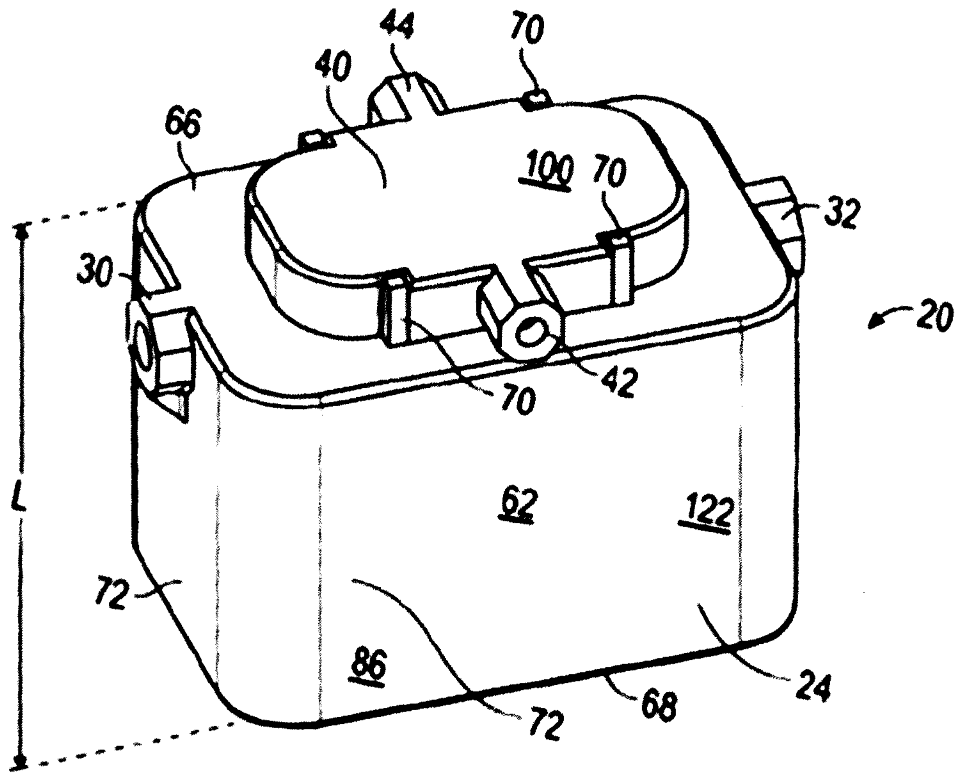
24
20
25
Source
22
34

FIG.1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100
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32
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42
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62
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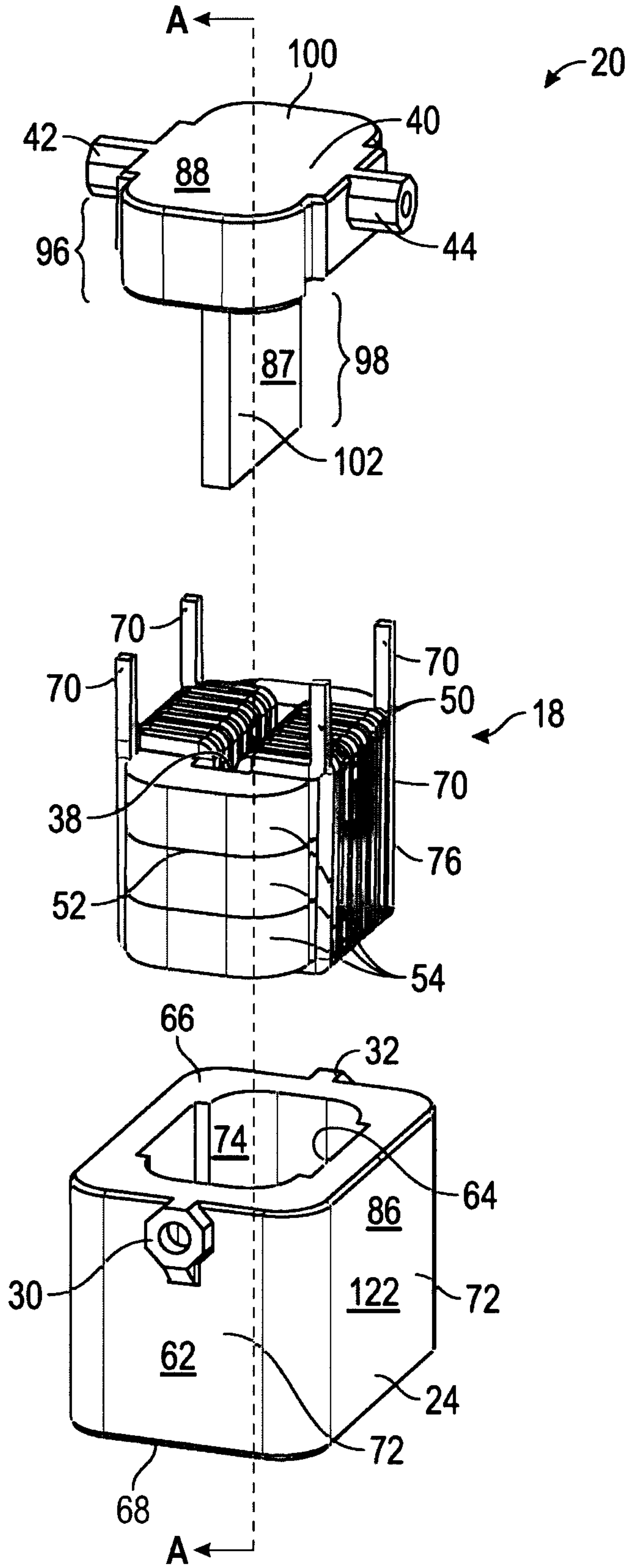
72
68
24

FIG.2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42
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70
70
50
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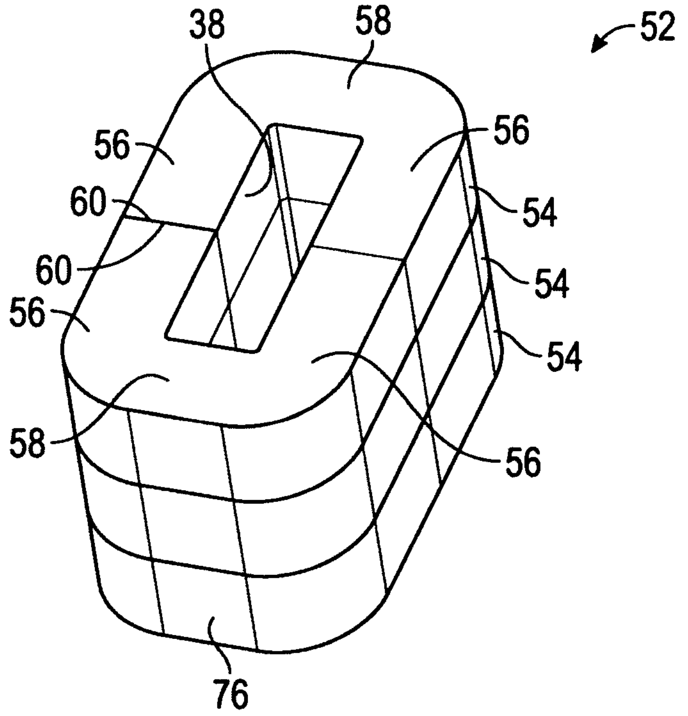
66
32
74
64
86
30
122
72
62
24
72
68
A

FIG. 3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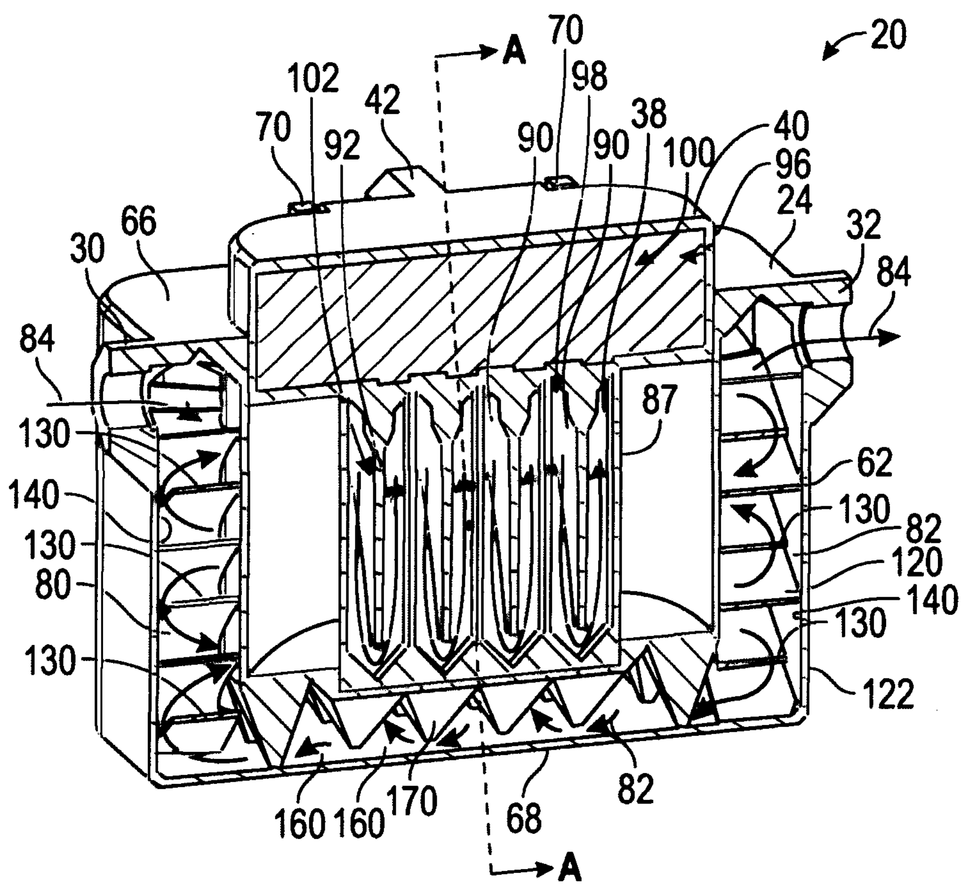
56
76

FIG. 4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A
70
102
42
98
70
92
90
90
38
40
100
96
24
30
66
32
84
84
87
130
62
140
130
130
82
80
120
140
130
130
122
82
160
160
170
68
A

FIG. 5

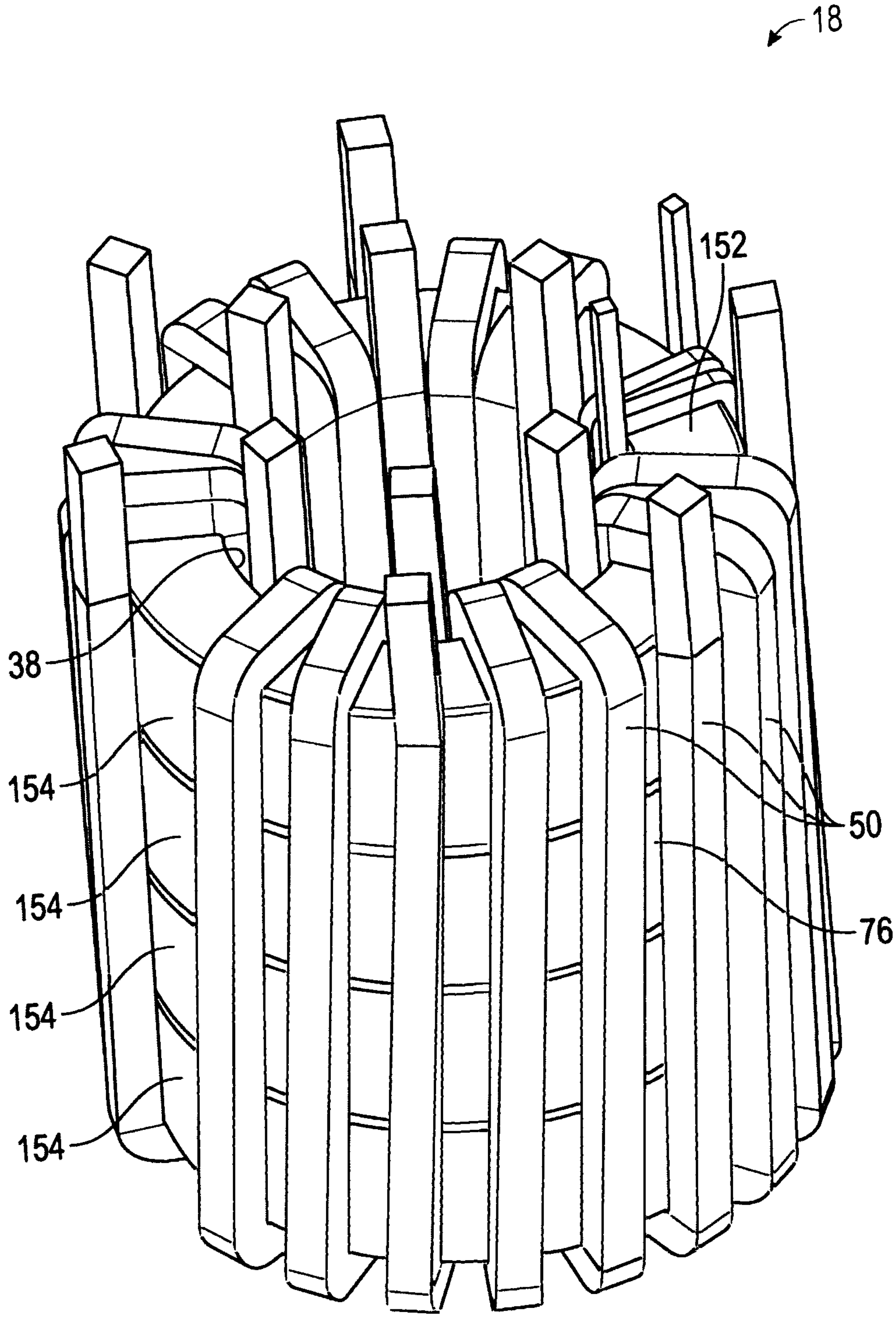


FIG. 6

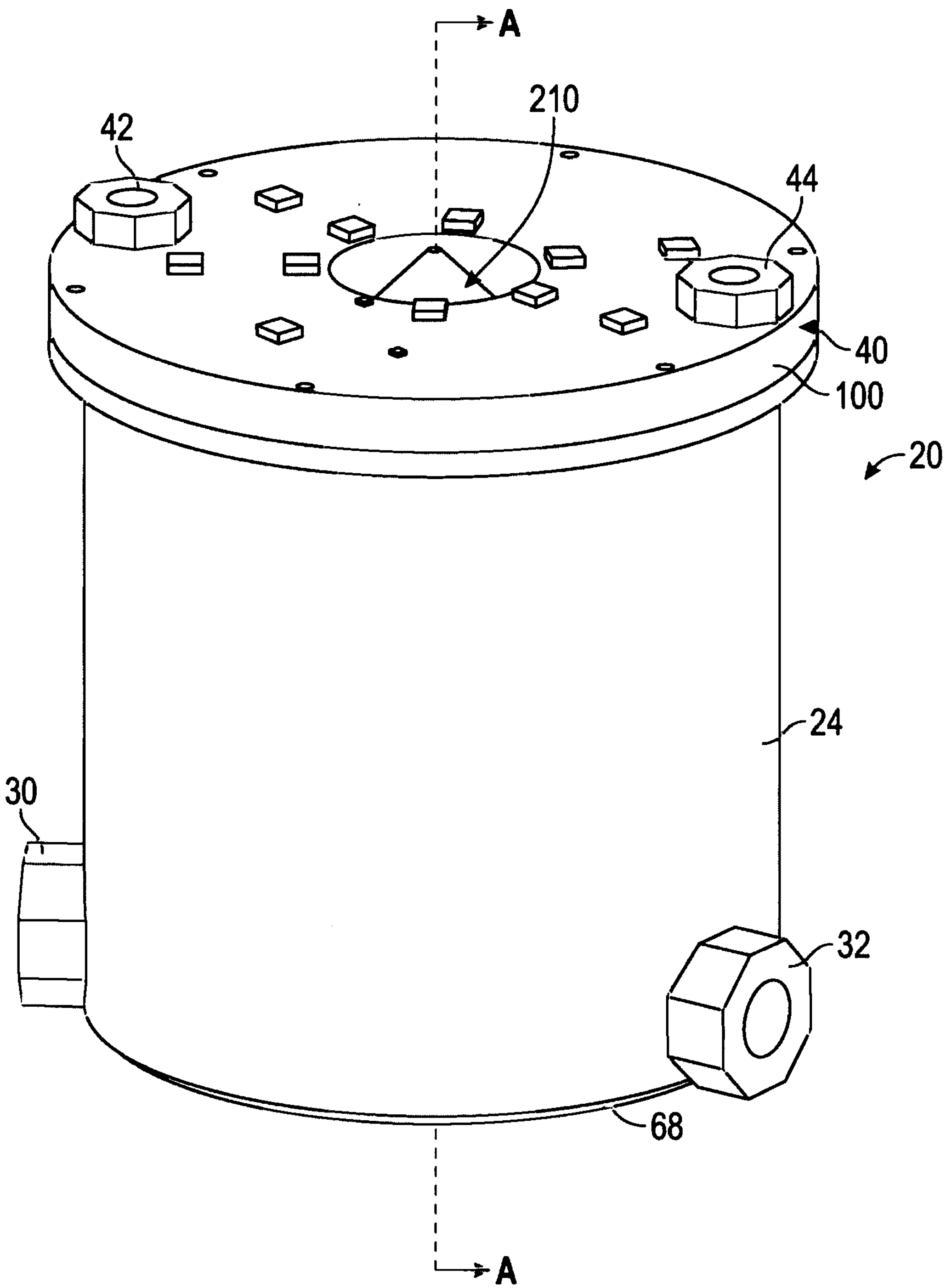


FIG. 7

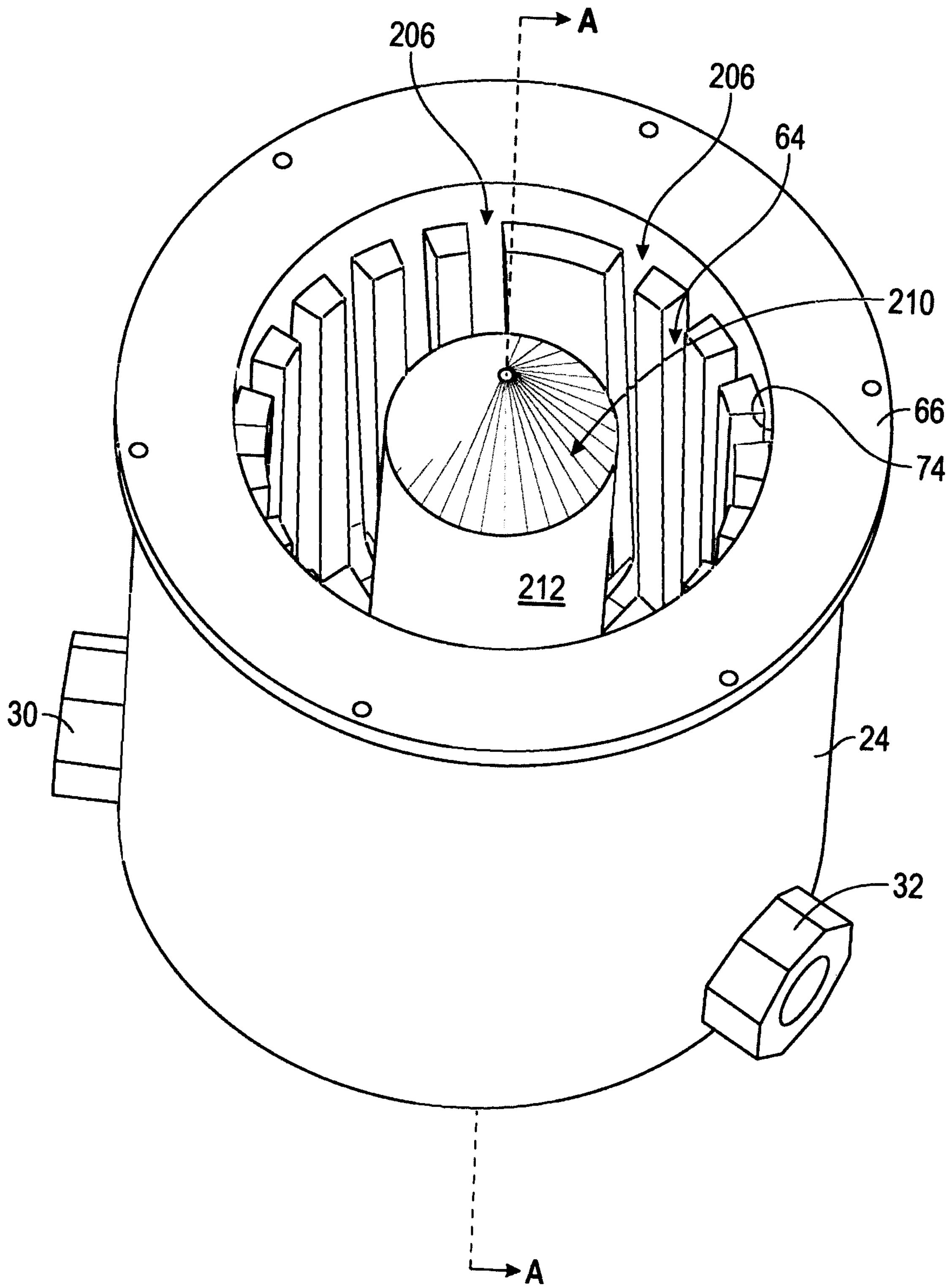


FIG. 8

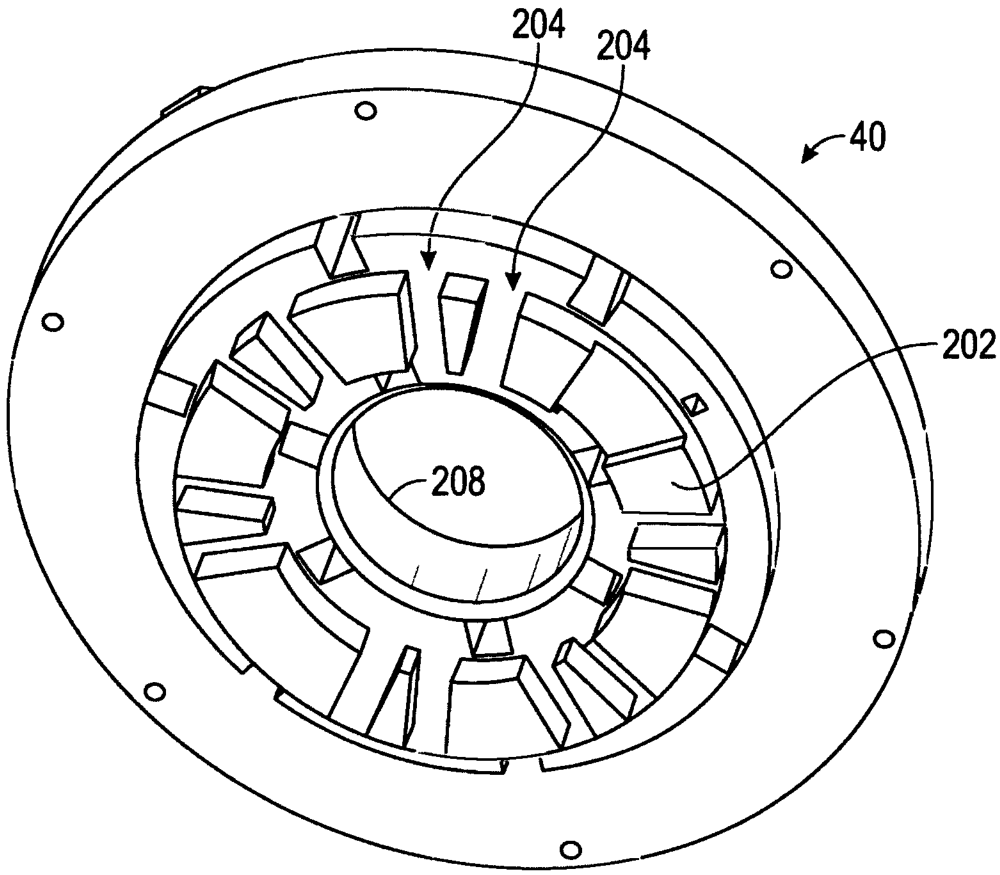


FIG. 9

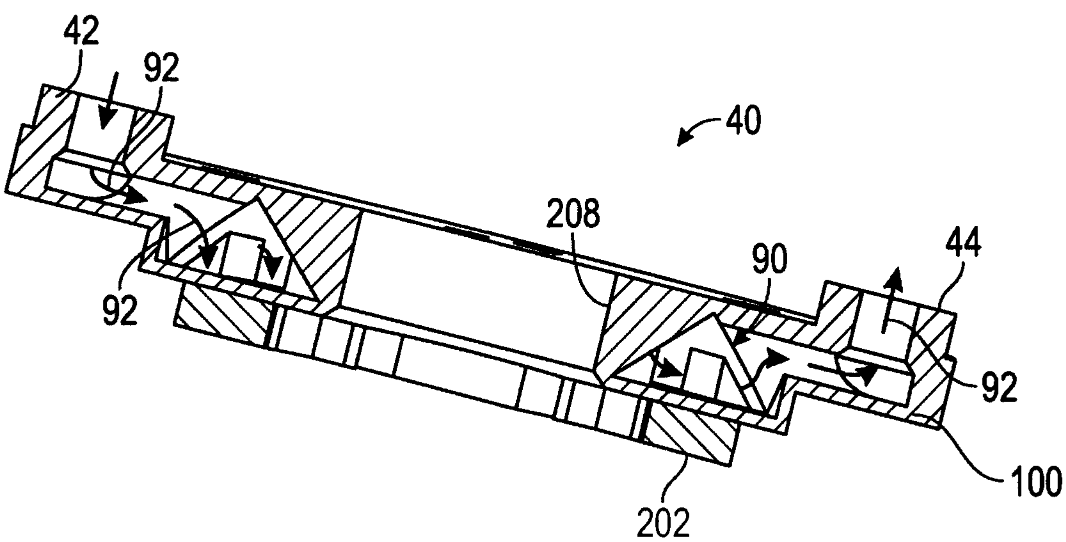


FIG. 10A

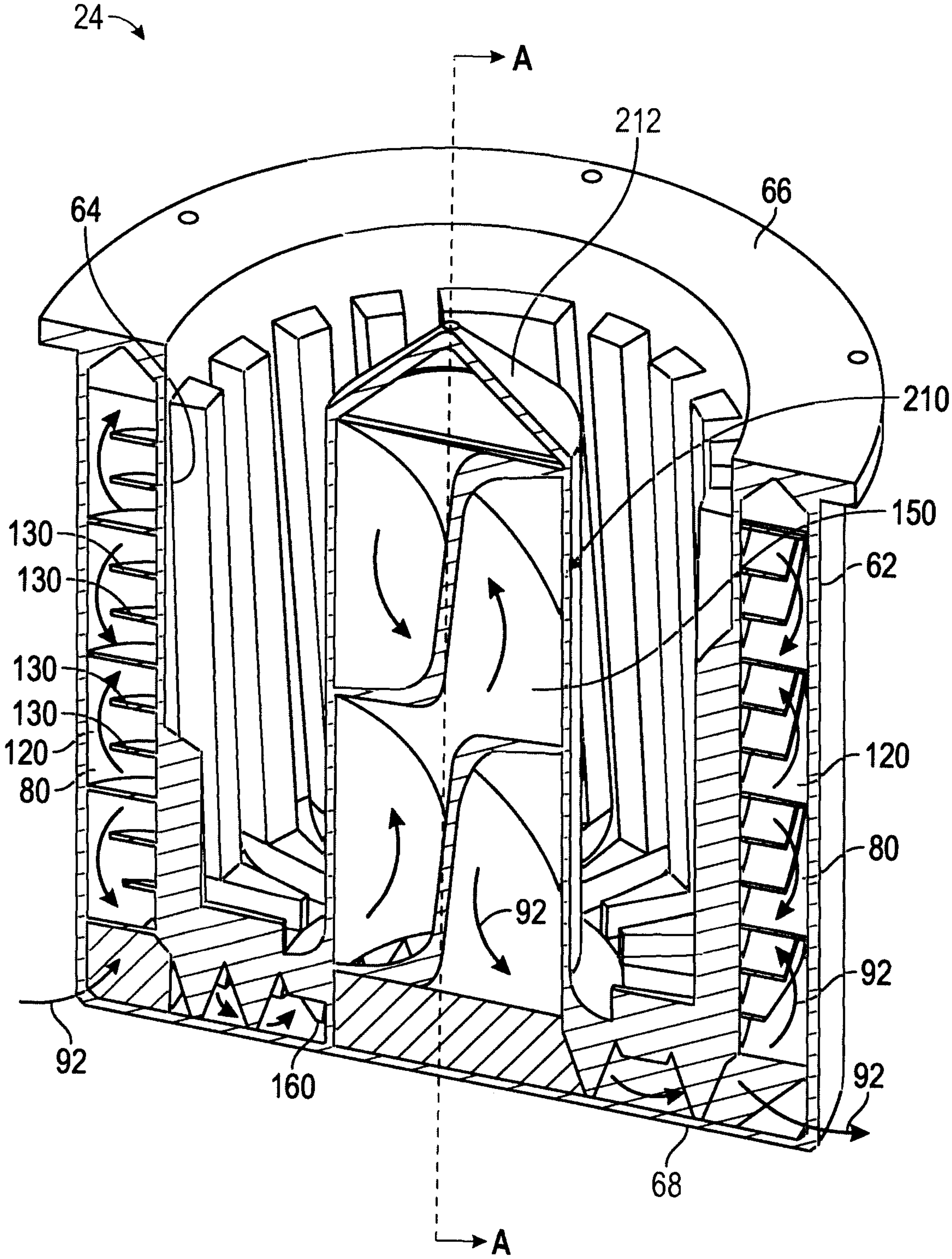

24
A
212
66
64
210
150
130
130
130
130
120
80
62
120
80
92
92
92
160
92
68
A

FIG. 10B

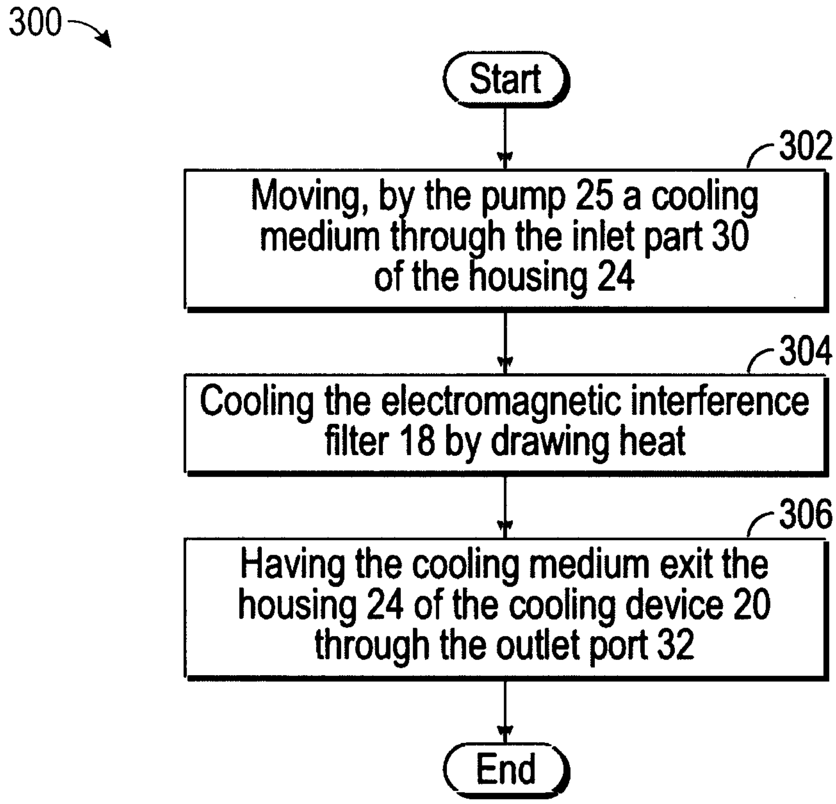

300
Start
302
Moving, by the pump 25 a cooling medium through the inlet part 30 of the housing 24
304
Cooling the electromagnetic interference filter 18 by drawing heat
306
Having the cooling medium exit the housing 24 of the cooling device 20 through the outlet port 32
End

FIG. 11

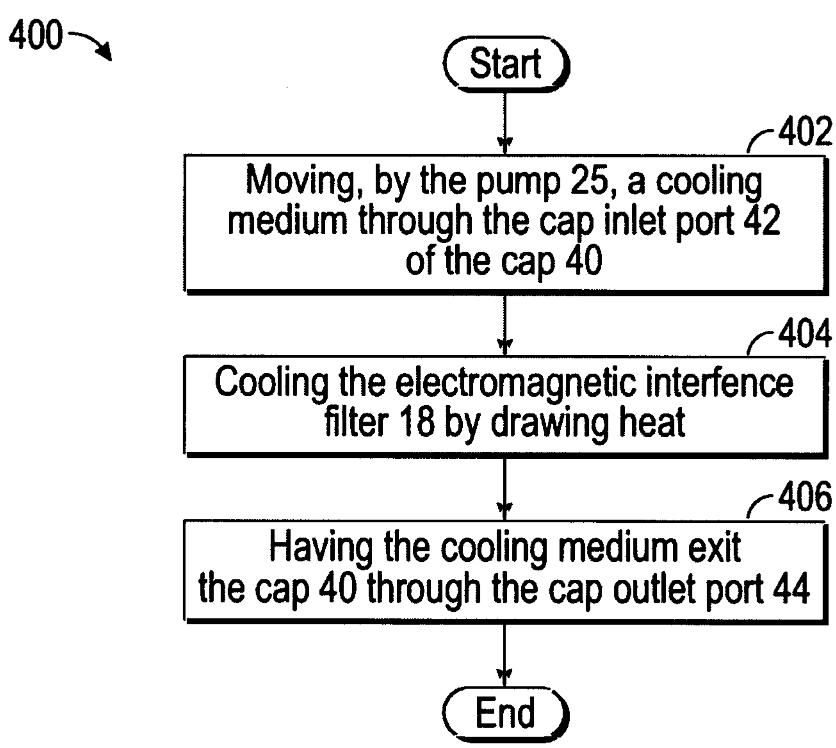
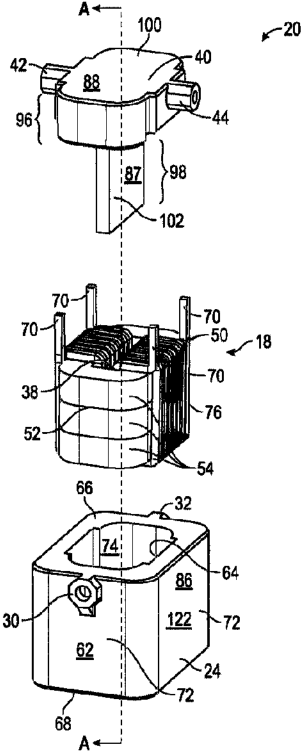

400
Start
402
Moving, by the pump 25, a cooling medium through the cap inlet port 42 of the cap 40
404
Cooling the electromagnetic interfence filter 18 by drawing heat
406
Having the cooling medium exit the cap 40 through the cap outlet port 44
End

FIG. 12


A
100
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42
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88
44
96
87
98
102
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70
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50
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76
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54
66
32
74
64
86
30
122
72
62
24
72
68
A