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(54) **SUPPLEMENTAL HEATING FOR VARIABLE LOAD EVAPORATIVE COLD PLATES**

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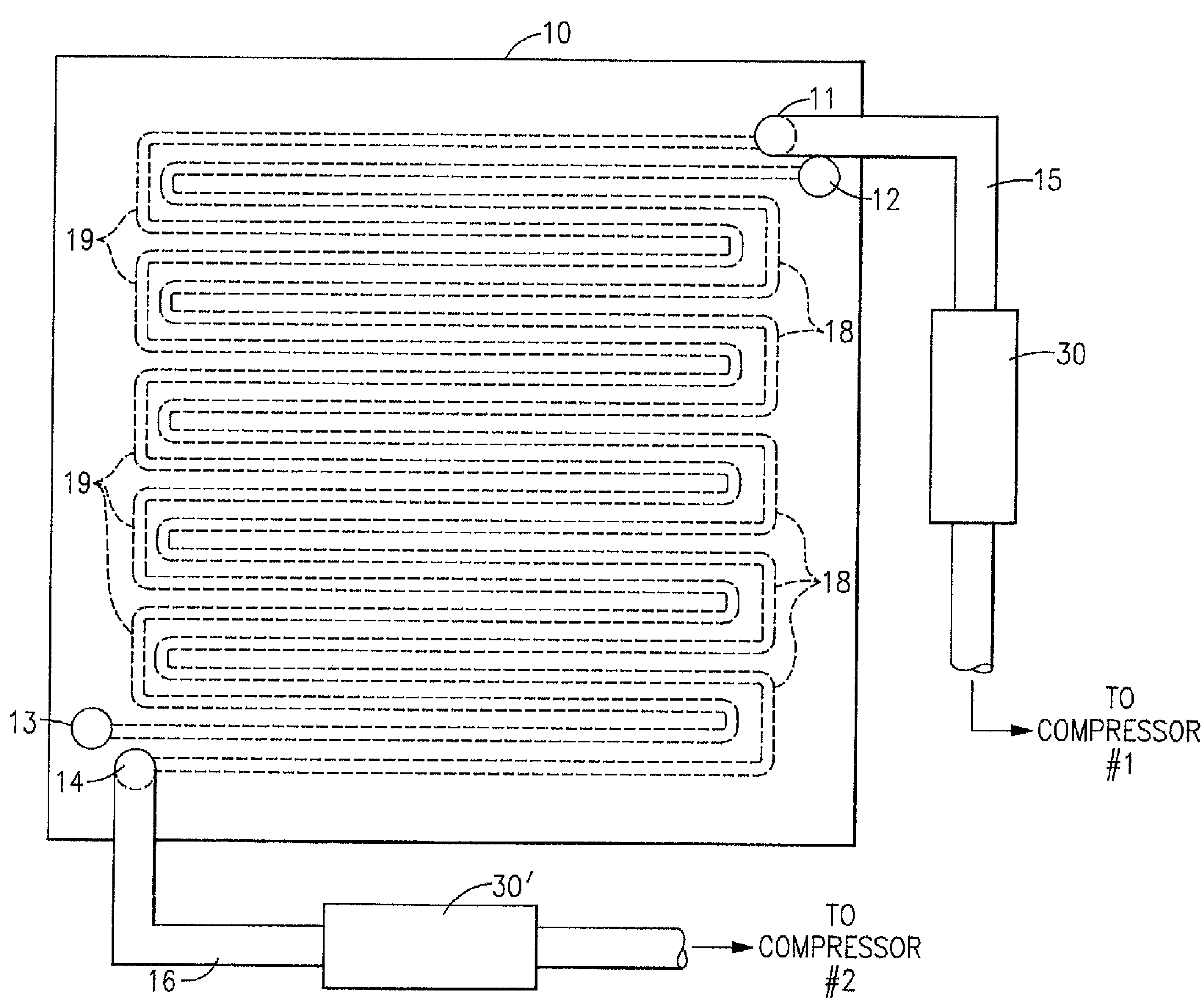
(57) **ABSTRACT**

Supplemental heat mechanisms are employed to ensure that refrigerant in evaporative cold plates for electronic modules not only returns to the compressor in a vapor phase but also further operates to maintain electronic circuit junction temperatures at relatively constant temperature levels. Furthermore, the supplemental heating system responds within a time frame which is faster than other methods which may be employed to achieve the same or similar objectives. In particular, in preferred embodiments of the present invention pressure and temperature measurements of refrigerant exiting the evaporative cold plate are employed to control the turning on of supplemental electrical resistive heating elements to make up for thermal dissipation fluctuations occurring in the electronic module. The supplemental heat may be provided either with a single flat element or through the use of in-line heating elements. The supplemental heating mechanism provides a method for insuring that refrigerant material is returned to the compressor in a vapor state so as to particularly not adversely affect compressor life and/or operating efficiency.



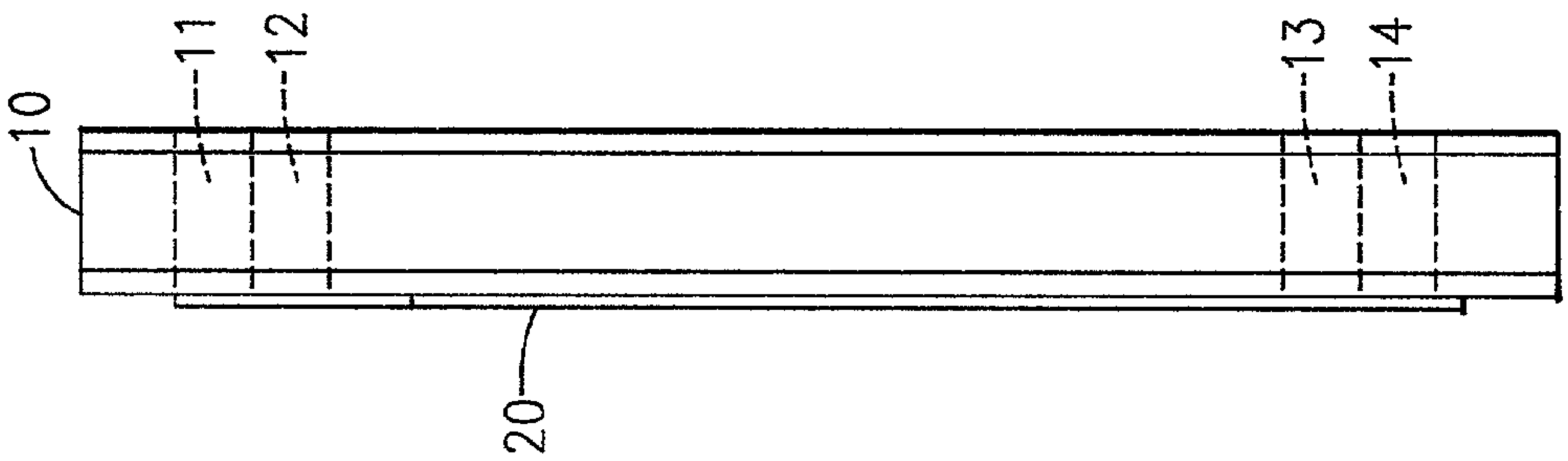


FIG.1B

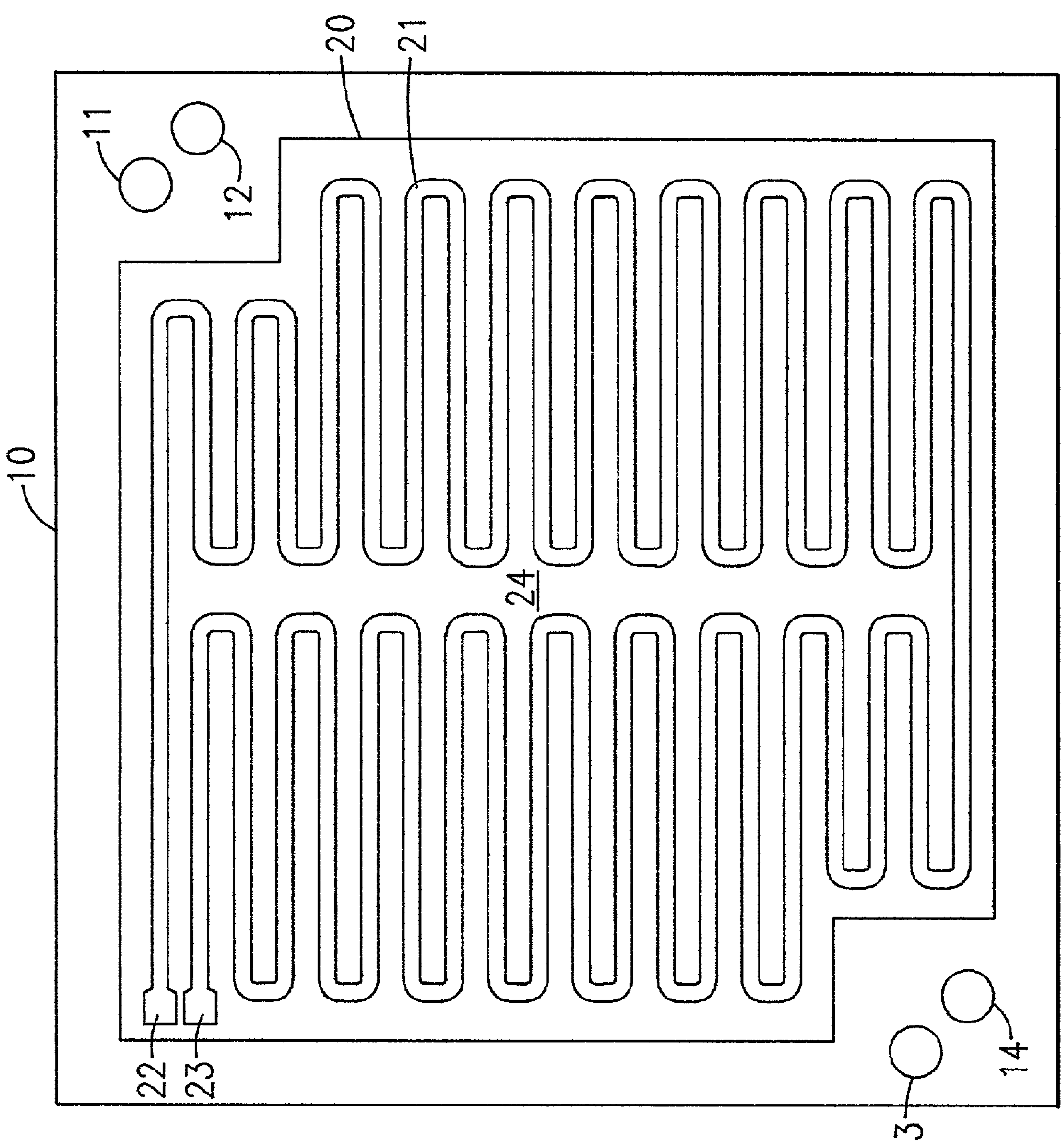


FIG.1A

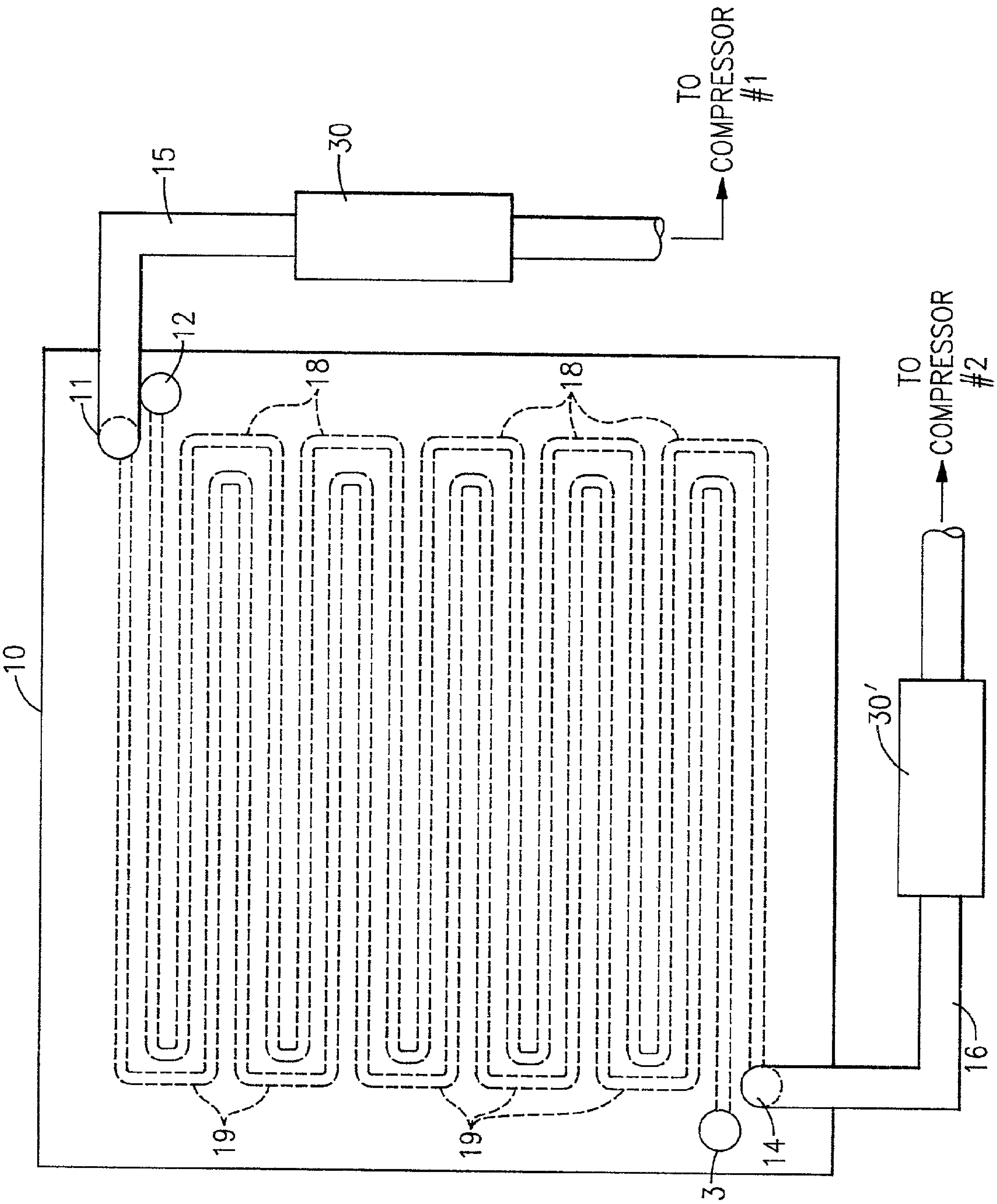


FIG.2

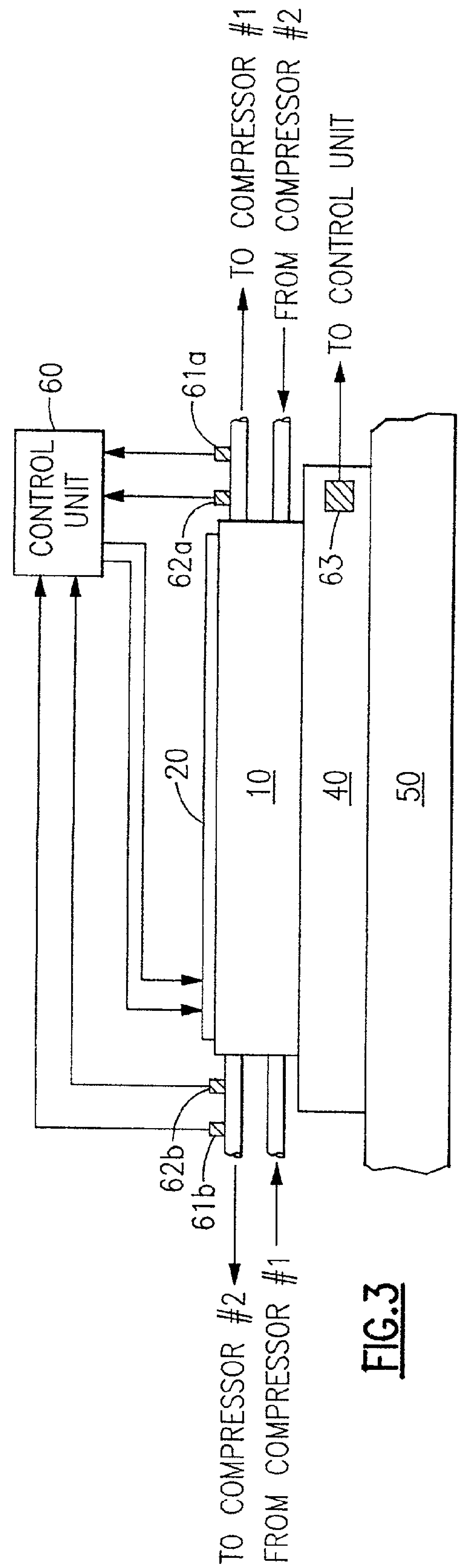

TO COMPRESSOR #1
FROM COMPRESSOR #2
TO CONTROL UNIT
CONTROL UNIT
60
61a
62a
63
20
10
40
50
62b
61b
TO COMPRESSOR #2
FROM COMPRESSOR #1

FIG.3

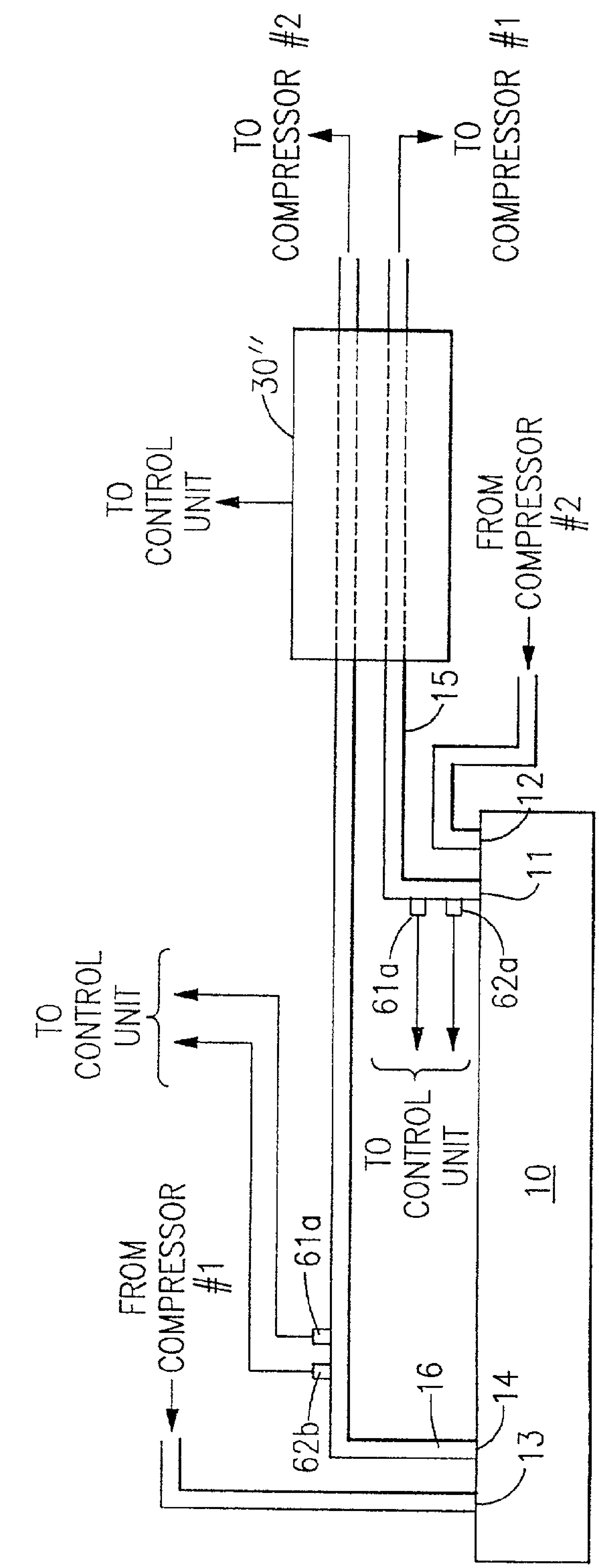

TO COMPRESSOR #2
TO COMPRESSOR #1
30''
TO CONTROL UNIT
FROM COMPRESSOR #2
15
12
11
61a
62a
TO CONTROL UNIT
TO CONTROL UNIT
10
FROM COMPRESSOR #1
61a
62b
16
14
13

FIG.4

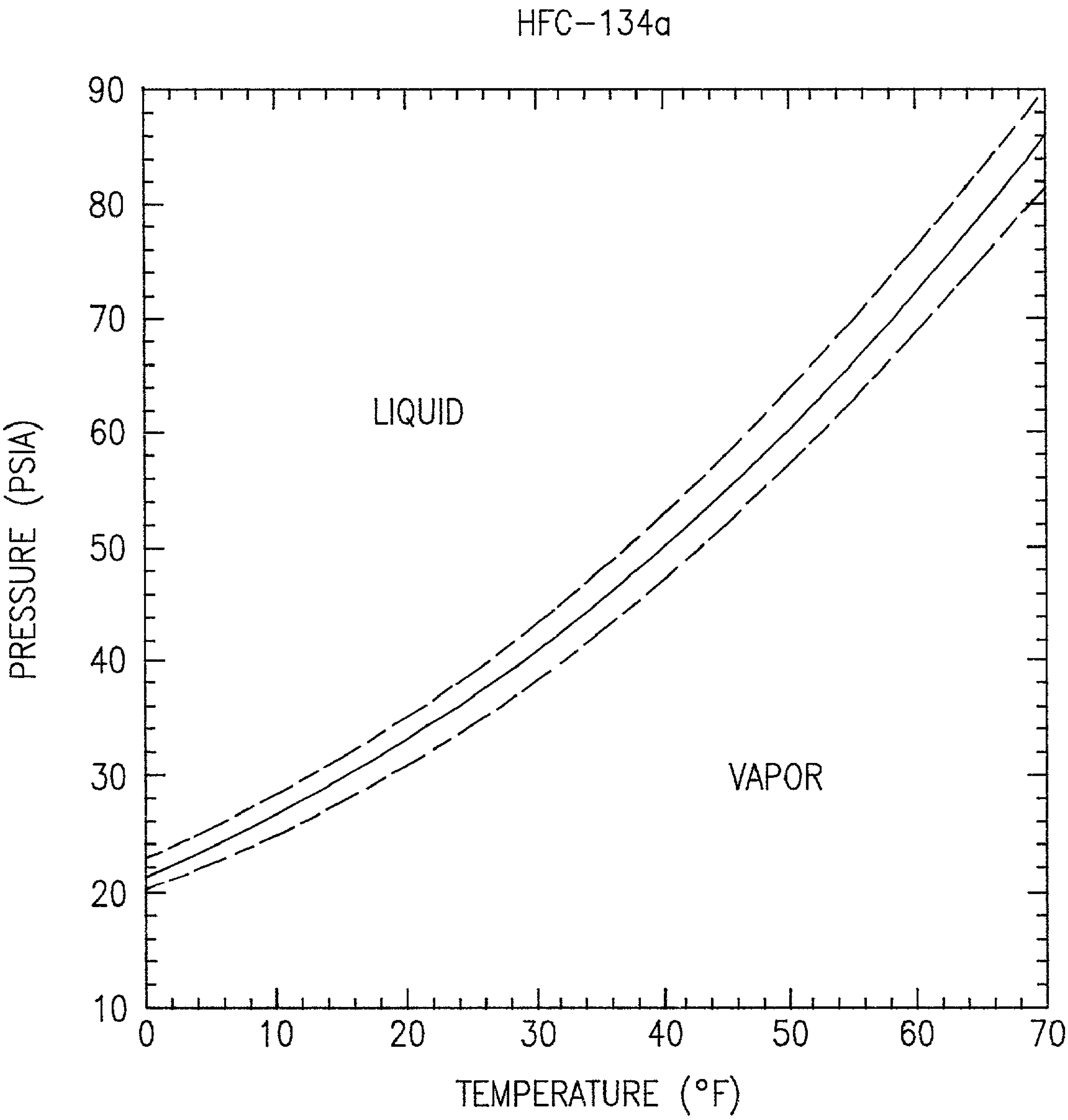

HFC-134a
PRESSURE (PSIA)
90
80
70
60
50
40
30
20
10
LIQUID
VAPOR
0
10
20
30
40
50
60
70
TEMPERATURE (°F)

FIG.5

SUPPLEMENTAL HEATING FOR VARIABLE LOAD EVAPORATIVE COLD PLATES

[0001] This application is a divisional of application Ser. No. 09/281,141 filed on Mar. 29, 1999 which is assigned to the same assignee as this application.

CROSS REFERENCE TO RELATED APPLICATION

[0002] This application is related to application Ser. No. 09/579,156 filed on May 25, 2000 which is assigned to the same assignee as this application.

BACKGROUND OF THE INVENTION

[0003] The present invention is generally directed to systems and methods for solving the problem of variable thermal load conditions that exist in refrigerant-cooled electronic modules, particularly those including computer processing elements. More particularly the present invention is directed to a system and method of supplying supplemental heat to a refrigerant either by directly heating an evaporative cold plate or by providing an in-line heater for the refrigerant. Even more particularly, the present invention is directed to a method for preventing liquid refrigerant from being returned to the compressor in a refrigeration based electronic chip module cooling system.

[0004] In recent models of high-end computer processing systems refrigeration units have been built-in to solve problems associated with thermal energy dissipation occurring within the chips and modules which make up the computer system. Such refrigeration systems have been described in U.S. Pat. No. 5,954,127, titled "A Cold Plate for Dual Refrigeration Systems" issued Sep. 21, 1999, and having a filing date of Nov. 21, 1997, and assigned to the same assignee as the present application. The contents of this application are hereby incorporated herein by reference thereto.

[0005] Typical refrigeration systems are designed to handle relatively fixed thermal loads. However, fluctuations in cooling requirement can be handled to some degree by various methods. In particular the speed of the motor driving the compressor may be varied. Additionally, a thermostatic expansion valve or a hot gas bypass valve may be employed to respond to variations in thermal load. However, the problem with all of these methods is that the time constant associated with their control function is too long for the purposes of the present invention which is designed to provide appropriate cooling for computer processor modules which can experience relatively rapid power fluctuations in the module being cooled. Additionally, the control systems for these various thermal load handling mechanisms is very complex. As a result of these conditions, the mismatch in time constants between thermal load balancing mechanisms and the thermal energy developed within the circuit modules can result in circuit temperatures rising above desirable temperature levels or falling below minimum temperature levels. Furthermore, there is a significant problem that exists that when power dissipation levels in a processor module falls to certain low levels; in such cases, the over capacity of the refrigeration system can result in the compressor ingesting liquid refrigerant, rather than vapor. This significantly reduces compressor life.

[0006] For example, if one is employing a computer processor module which is designed for and is dissipating one kilowatt of thermal power and if a power fluctuation reduces the level of power being dissipated to 800 watts, then there is a two-hundred watt excess capacity in a refrigeration system which was designed to cool this module. As a result of this over capacity, refrigerant in the cooling loop may not be completely vaporized in the evaporator/cold plate. As a result of this, liquid refrigerant may be returned to the compressor which will thus reduce its workable life, since such compressors are designed to work best with gaseous input.

[0007] This is a problem in the systems considered herein since the refrigeration units are designed to handle fixed thermal loads. Furthermore, the refrigeration systems of the present invention are particularly unique in that they are designed to run in a continuous fashion. This is a different mode of operation than is normally encountered in refrigeration systems. Furthermore, an additional complexity exists in that the preferred evaporative cold plate for various embodiments of the present invention includes multiple, distinct, isolated passages for the refrigerant. These multiple passages form parts of distinct refrigeration loops which are provided to assure continuous operation as a result of redundant passages and redundant refrigeration loops.

SUMMARY OF THE INVENTION

[0008] In accordance with one embodiment of the present invention, an electronic system with cooling capacity for variable thermal load levels comprises an electronic circuit module together with a cold plate, which is in thermal contact with the module. The cold plate has at least one passage through it for transport of refrigerant. There is provided a means for sensing power levels being supplied to the module. Additionally, and most importantly for the present invention, there are provided means for heating the refrigerant and means for controlling this heating so as to maintain a relatively constant cooling load as seen by the refrigerant and refrigerant system. In one embodiment of the present invention, the heating means comprises a flat electrical resistance heater affixed to the top of the cold plate. In accordance with another embodiment of the present invention heating of the refrigerant in the supplemental manner provided herein is accomplished by means of heaters exposed around one or both of the conduits which return refrigerant from the evaporator/cold plate to their respective compressors. Supplemental refrigerant heating may also be applied upstream of the evaporator/cold plate. However, the downstream location is preferred.

[0009] In another embodiment of the present invention, a method is provided for preventing liquid refrigerant from returning to the compressor. This is accomplished by determining the state of the refrigerant as it exits the cold plate and by then adding heat to the refrigerant upon the condition that the state is determined to be within or close to the liquid state. In accordance with preferred embodiments of the present invention, the state of the refrigerant is determined by measuring its pressure and temperature. In yet other embodiments of this invention the state of the refrigerant is monitored over a period of time and supplemental heat is added in response to anticipated thermal reduction conditions occurring within the electronic module which the system is cooling.

[0010] Accordingly, it is an object of the present invention to provide a refrigeration system for cooling electronic modules which experience fluctuations in dissipated power.

[0011] It is also an object of the present invention to prevent liquid refrigerant from returning to a compressor in a refrigeration loop.

[0012] It is also an object of the present invention to avoid complicated control systems for dealing with the problem of thermal load fluctuations in an electronic system which is being cooled.

[0013] It is still further object of the present invention to provide supplemental heat to a refrigerant cooled electronic system to compensate for variations in power being dissipated by this system.

[0014] It is also an object of the present invention to provide compensation for thermal load fluctuations in a rapid fashion and with time constants which are more effective than those provided by other thermal compensation methodologies.

[0015] It is a still further object of the present invention to provide thermal fluctuation balance in an evaporative cold plate system employing dual refrigerant loops for purposes of redundancy.

[0016] It is also an object of the present invention to prevent circuit chip junction temperatures from rising above maximum reliability temperature conditions or falling below desired minimum temperatures.

[0017] It is yet another object of the present invention to prolong compressor life in the specified refrigeration systems.

[0018] Lastly, but not limited hereto, it is an object of the present invention to control thermal fluctuations occurring in refrigerant cooled electronic systems.

DESCRIPTION OF THE FIGURES

[0019] The subject matter which is regarded as the invention is particularly pointed out and distinctly claimed in the concluding portion of the specification. The invention, however, both as to organization and method of practice, together with the further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawings in which:

[0020] **FIG. 1A** is a top view illustrating an evaporative cold plate together with an electrical resistive heating element in accordance with one embodiment of the present invention;

[0021] **FIG. 1B** is a side view of the cold plate shown in **FIG. 1A**;

[0022] **FIG. 2** is a top view illustrating an alternate embodiment of the present invention in which in-line heaters are employed in separate return paths to the compressors;

[0023] **FIG. 3** is a side view illustrating the control mechanism employed in the present invention;

[0024] **FIG. 4** is a side elevation view illustrating an alternate embodiment of the present invention in which a single in-line heater element is disposed around two of the conduit lines which are connected to compressor inputs; and

[0025] **FIG. 5** is a graph of pressure versus temperature illustrating regions of liquid and gaseous phases for a typical refrigerant together with a desired guard band for purposes of controlling supplemental heat levels.

DETAILED DESCRIPTION OF THE INVENTION

[0026] **FIG. 1A** illustrates one embodiment of the present invention. In this embodiment electrical heater **20** is disposed on top of cold plate **10**. The bottom of cold plate **10** is in thermal contact with the modules to be cooled (see **FIG. 3**). In particular, evaporative cold plate **10** includes inlet port **11** for refrigerant loop **1** together with outlet port **13**, also for refrigerant loop **1**. The refrigerant in loop **2** preferably flows in the opposite direction, from inlet port **14** through plate **10** to outlet port **12**. A hidden view of one embodiment of these loops is more particularly illustrated as dashed lines in **FIG. 2**. While the example provided herein is particularly addressed to the situation in which the cold plate includes two independent cooling fluid passages, the present invention is not linked by the number of such passages; the cold plate could include only a single passage or a plurality of passages.

[0027] In the embodiment of the present invention shown in **FIG. 1A** supplemental heater **20** includes resistive heating element **21** disposed on electrically insulative substrate material **24**. Electrical power for supplemental heating purposes is supplied by means of contact pads **22** and **23**. The relative height of heater **20** and cold plate **10** is illustrated in **FIG. 1B**. Heating element **21** may be disposed in any convenient pattern. The pattern shown has the particular advantage that contact ends **22** and **23** are located in adjacent positions for ease of connection.

[0028] An alternate embodiment of the present invention is illustrated in **FIG. 2** wherein return conduits **15** and **16**, to compressors #1 and #2 respectively, include in-line heaters **30** and **30'**, also respectively. These heaters are activated when power dissipation in the module being cooled (see reference numeral **40** in **FIG. 3**) drops off. **FIG. 2** also illustrates, in hidden view fashion, the presence of dual passage sets **18** and **19** in cold plate **10**. This includes passage **19** extending from inlet port **13** to outlet port **11** together with passage **18** extending from inlet port **12** to outlet port **14**.

[0029] **FIG. 3** illustrates the control variables used to monitor the state of the refrigerant in its return path to its respective compressor. **FIG. 3** also illustrates a side view of the environment in which the present invention is employed. In particular, it is noted that cold plate **10** is employed to maintain the junction temperature for transistors and other devices located on electronic (circuit chip) module **40** which in turn is disposed on an underlying substrate containing connecting wires (not visible) for the operation of the circuits in module **40**.

[0030] Additionally, it is seen that pressure sensors **62*a*** and **62*b*** are disposed to measure the pressure of the refrigerant in its return path to its respective compressor. Likewise, temperature sensors **61*a*** and **61*b*** are employed to measure the temperature of the refrigerant in the two loops shown. These measurements are supplied to control unit **60** which controls power to supplemental heater **20**. In the event that in-line heaters are employed, control unit **60** controls the electrical power supplied to these heater units so as to provide supplemental thermal heat input to compensate for reduced power levels within module **40** which are sensed, for example, by means of temperature sensor **63**.

[**0031**] In an alternate embodiment of the present invention rather than employing two separate in-line heaters as illustrated in **FIG. 3**, it is also possible to employ a single in-line heater **30**" as seen in **FIG. 4**. It is noted, however, that while return lines **15** and **16** to their respective compressors pass through a single supplemental in-line heater unit **30**", there is no fluid communication between the refrigerants in these two lines. For purposes of reliability, the two refrigerant loops are always maintained separately without any flow communication between them. It is also noted that while the embodiments shown herein illustrate the inclusion of only two independent refrigerant loops, any number of such loops may be employed. One is constrained only by the practical limitations of conduit size within the cold plate.

[**0032**] **FIG. 5** illustrates the basis for a control methodology which is applicable in the present invention. In particular, control unit **60**, by means of pressure, temperature, and measurements determines the phase of the refrigerant being returned to its respective compressor. If it is determined that liquid phase refrigerant is being returned or if it is determined that the refrigerant that is being returned to a compressor is in a guard band phase region such as that shown in **FIG. 5**, then supplemental heat is added by control unit **60** by supplying power to supplemental heaters **20**, **30**, **30**' or **30**". The guard band shown in **FIG. 5** corresponds to a temperature range of plus or minus **3** degrees Fahrenheit.

[**0033**] There are two options with respect to establishing the capacity of each supplemental heater employed. In one embodiment, the supplemental heater is sized so as to be sufficiently large to provide the total power that is developed in the electronic module being cooled. In this event, if the module is powered off, the refrigerator unit can remain on and the supplemental heater makes up essentially the entire thermal load. For example, if the electronic module is designed to develop one kilowatt, then the supplemental heater is also sized to produce one kilowatt. However, another more desirable option is that the supplemental heater is sized for typical power fluctuations encountered in the module. This option makes the heater smaller and easier to manage. For example, in this case if the module is again designed to develop one kilowatt and the fluctuations due to typical system usage is 200 watts, then the supplemental heater is sized only for this 200 watt fluctuation rather than for a full kilowatt. It is however noted that in the case that the supplemental heater is designed to make up the entire thermal load produced by the electronics module, the in-line heater option is significantly less desirable since such in-line heaters are typically not available in these power levels. However, it is also noted that with respect to the in-line supplemental heaters, it is possible that they are disposed upstream of the evaporator plate.

[**0034**] However, in preferred embodiments of the present invention the supplemental heater design is that shown in **FIGS. 1A and 1B**. In this form of supplemental heater, the device is a foil, film or mat heater attached to the top surface of the evaporative cold plate. This configuration is shown in **FIGS. 1A and 1B**. The heater is connected to a power supply and is controlled by sensors as illustrated in **FIG. 3**. One advantage of this supplemental heater design is that only one heater is required, even if there are dual loop refrigerant circuits present in the cold plate. In this regard, it is also noted that the use of the present invention is not confined to cold plates with dual refrigerant loops.

[**0035**] The control of the supplemental heaters is best understood via an examination of a phase diagram such as that illustrated in **FIG. 5**. The control of the supplemental heater is most easily and accurately accomplished by monitoring the temperature and pressure immediately downstream of the evaporative cold plate. However, other sensors and other sensing locations may be employed. Knowledge of both the temperature and pressure properties allows a substantially instantaneous real-time determination of whether or not there is a possibility of liquid existing in the refrigerant stream in its return path to a compressor. Furthermore, the actual control scheme preferably includes monitoring the rate of change of these state properties to determine if increased or reduced supplemental power is required. This produces a system which is anticipatory of upcoming thermal loads and refrigerant phase conditions.

[**0036**] The embodiment which employs in-line heaters is illustrated in **FIG. 2**. In this figure, the single supplemental heater of **FIG. 1** is replaced by an in-line heater in each refrigerant return line. For a dual circuit evaporative cold plate, two in-line heaters are therefore required. The actual heater may comprise any suitable design, including cartridge heaters or a foil heater wrapped around the return line or lines. It is unlikely that this second method is capable of supplying a supplemental thermal load equal to the module design load since there is typically not enough surface area. However, the method is useable to moderate the normal fluctuations in the module so that the total thermal load on the refrigeration system remains relatively constant and the compressor does not ingest liquid refrigerant. The embodiment of **FIG. 2** is also used to ensure that the refrigerant leaving the evaporative cold plate and entering the compressor is entirely vapor. However, its down stream location does not provide any compensating effect to modulate the actual circuit temperatures as the electronics module power level fluctuates. However, as indicated above, there is yet another option, namely, that of providing in-line supplemental heaters in a position upstream of the evaporative cold plate. In this location, they are usable to preheat refrigerant as the module power drops, thereby providing increased circuit temperature stability.

[**0037**] From the above it should be appreciated that the objects set forth herein have all been met by the method and system set forth above. In particular, it is seen that there is provided both a method and a system for supplying supplemental heat to a refrigerant cooled electronic module and evaporative cold plate to compensate for power fluctuations in the electronic module.

[**0038**] While the invention has been described in detail herein in accord with certain preferred embodiments thereof, many modifications and changes therein may be effected by those skilled in the art. Accordingly, it is intended by the appended claims to cover all such modifications and changes as fall within the true spirit and scope of the invention.

What is claimed is:

1. An electronic system with cooling for variable thermal load levels, said system comprising:

an electronic circuit module;

a cold plate in thermal contact with said module, said cold plate having at least one passage therein for transport of refrigerant;

means for sensing power being supplied to said module;

at least one in-line heater surrounding at least one conduit for carrying said refrigerant;

means for controlling said in-line heater to compensate for changes in said power being supplied to said module, so as to maintain a relatively constant cooling load for said refrigerant.

2. The system of claim 1 in which said cold plate has dual passages therein for distinct refrigerant loops.

3. The system of claim 1 in which said sensing means is a temperature sensor disposed in thermal contact with said module.

4. The system of claim 1 in which said sensing means comprises pressure and temperature sensors for said refrigerant.

5. The system of claim 4 in which said pressure and temperature sensing means is located substantially immediately downstream of said cold plate.

6. The system of claim 1 in which said cold plate includes a plurality of passages therein.

7. The system of claim 1 in which said in-line heater is located downstream of said cold plate.

8. The system of claim 1 in which said in-line heater is located upstream of said cold plate.

9. The system of claim 1 in which a single in-line heater surrounds a plurality of conduits for carrying said refrigerant.

10. The system of claim 1 in which a plurality of in-line heaters each surround one conduit for carrying said refrigerant.

* * * * *