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(54) **SYSTEMS AND METHODS FOR FERRITE REDUNDANCY SWITCH NETWORKS**

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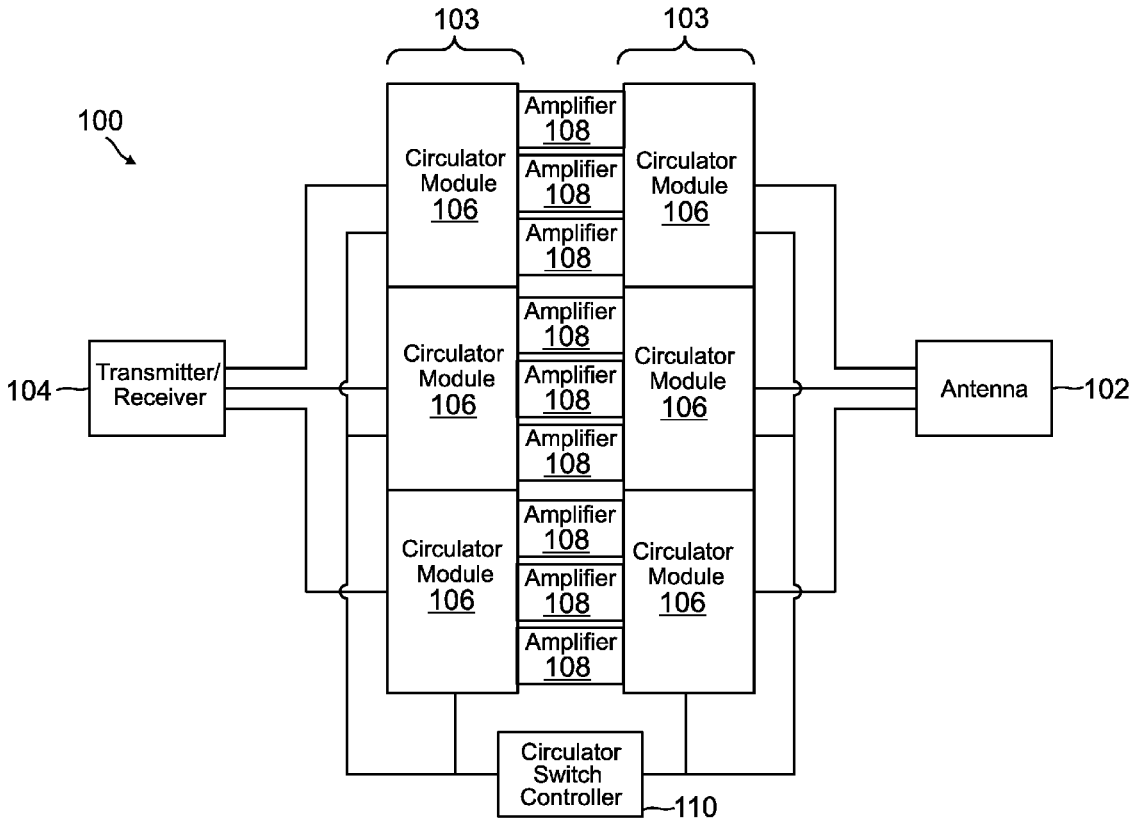
(57) **ABSTRACT**

Systems and methods for ferrite redundancy switch networks are disclosed. In one embodiment, a redundant ferrite switch system comprises: a first plurality of circulator modules, a second plurality of circulator modules, and a plurality of components coupled to the first plurality of circulator modules and coupled to the second plurality of circulator modules, wherein the first plurality of circulator modules and the second plurality of circulator modules is able to route a path through the redundant ferrite switch system when more than two components in the plurality of components have failed. The first plurality of circulator modules and the second plurality of circulator modules each comprise, respectively: a plurality of inputs; a plurality of outputs; and a plurality of circulators connecting the plurality of inputs to the plurality of outputs.



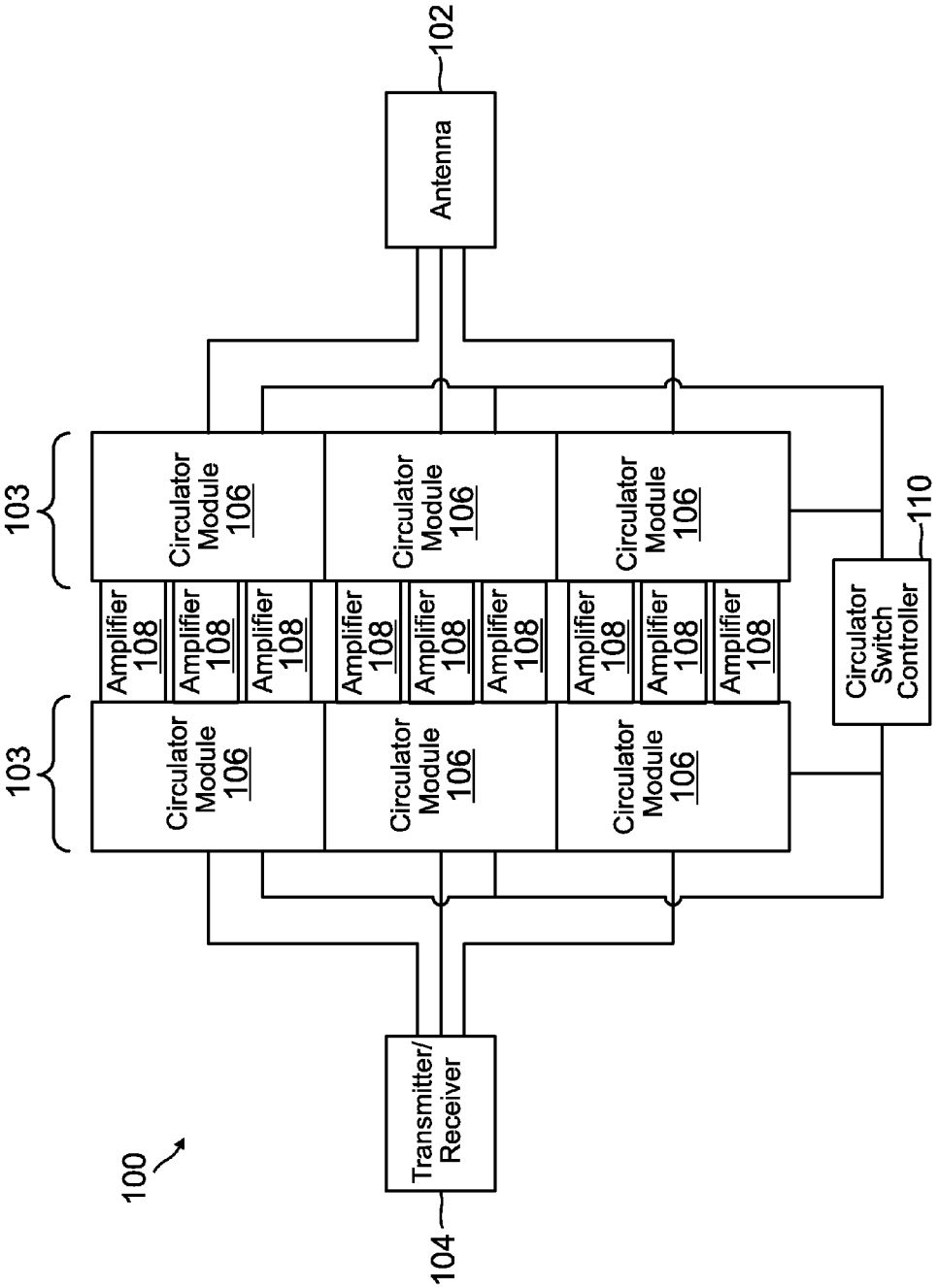

100
Transmitter/ Receiver
104
Antenna
102
103
Circulator Module 106
Amplifier 108
Circulator Switch Controller
110

FIG. 1

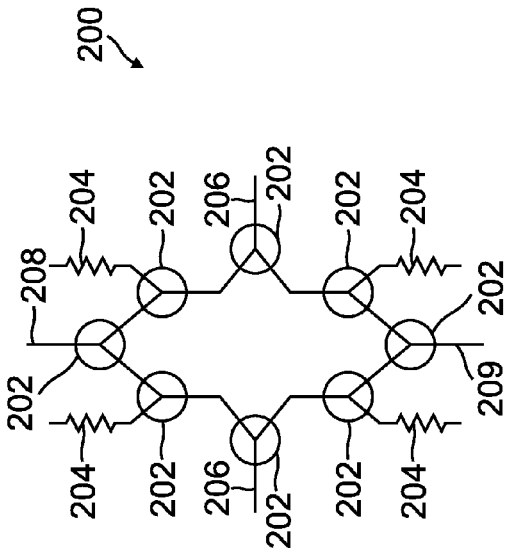

200
208
204
202
206
202
202
204
202
202
209
202
204
202
206
202
202
204

FIG. 2A

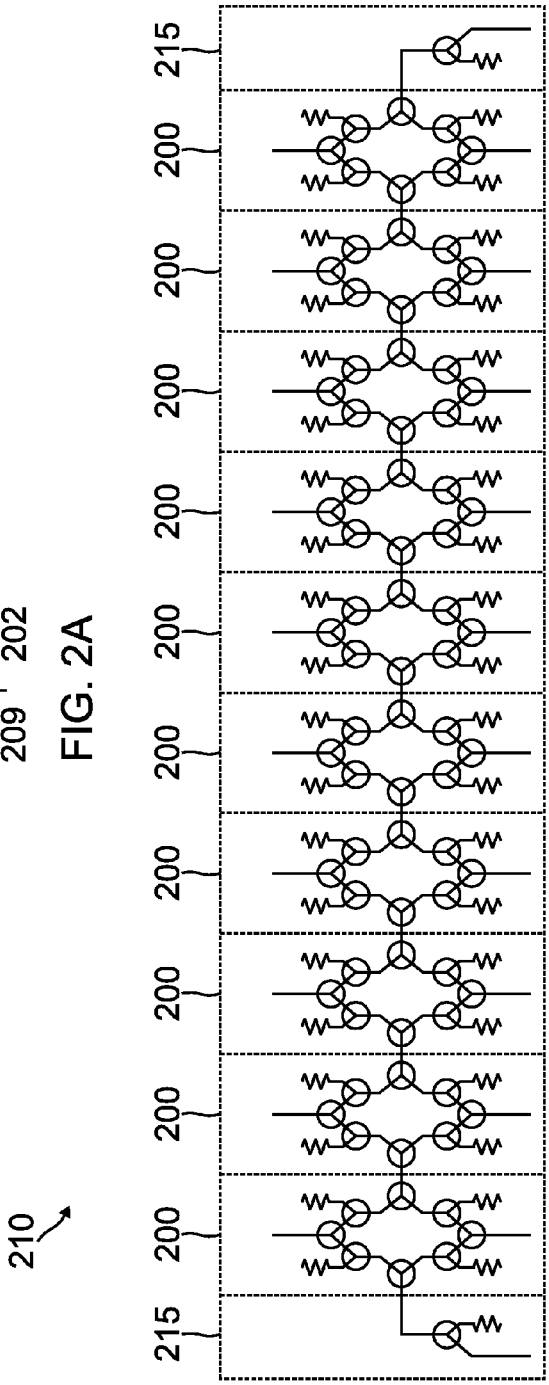

210
215
200
200
200
200
200
200
200
200
200
215

FIG. 2B

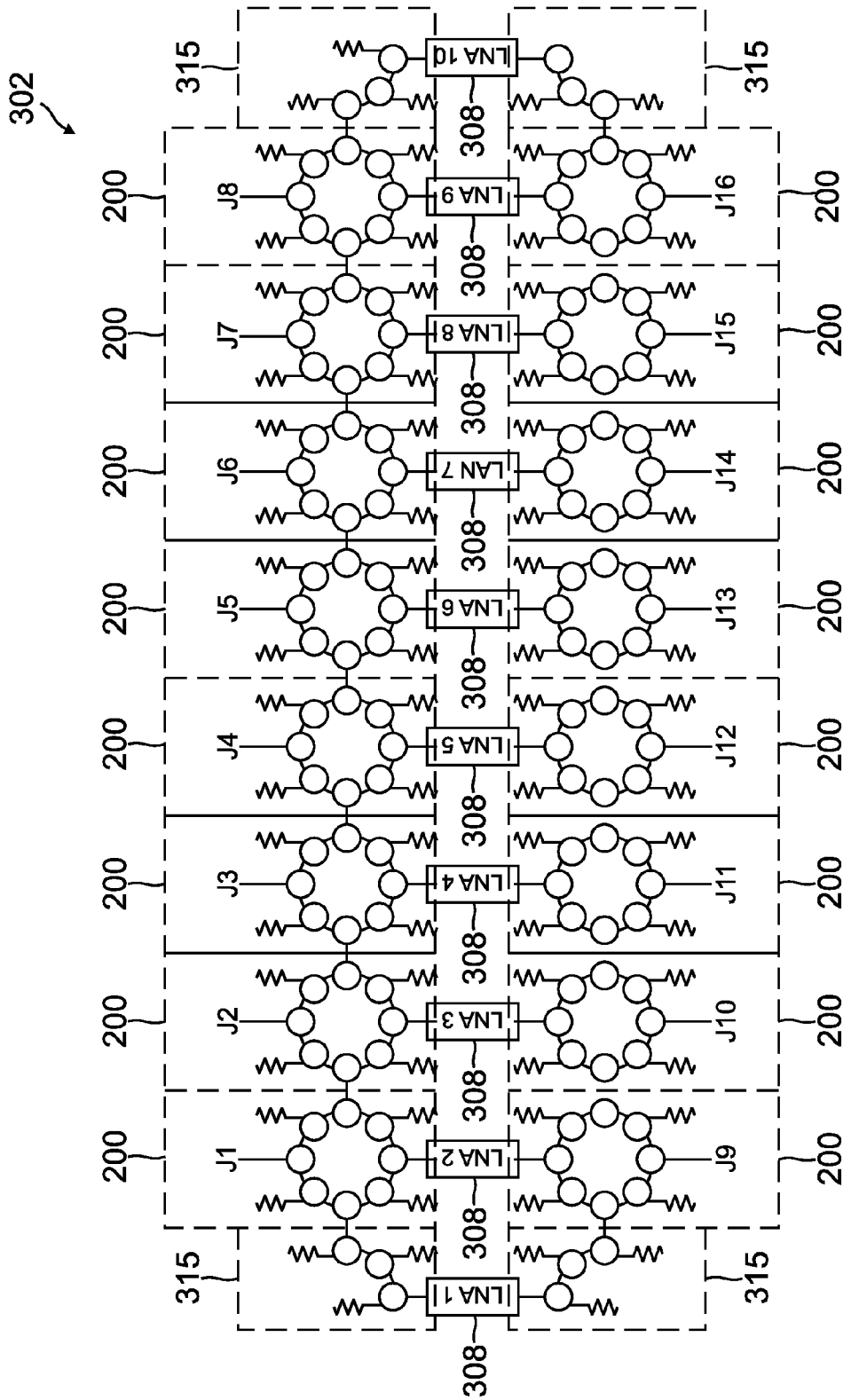

302
315
315
LNA 10
308
J8
LNA 9
J16
200
J7
LNA 8
J15
J6
LAN 7
J14
J5
LNA 6
J13
J4
LNA 5
J12
J3
LNA 4
J11
J2
LNA 3
J10
J1
LNA 2
J9
LNA 1
315
315
308

FIG. 3

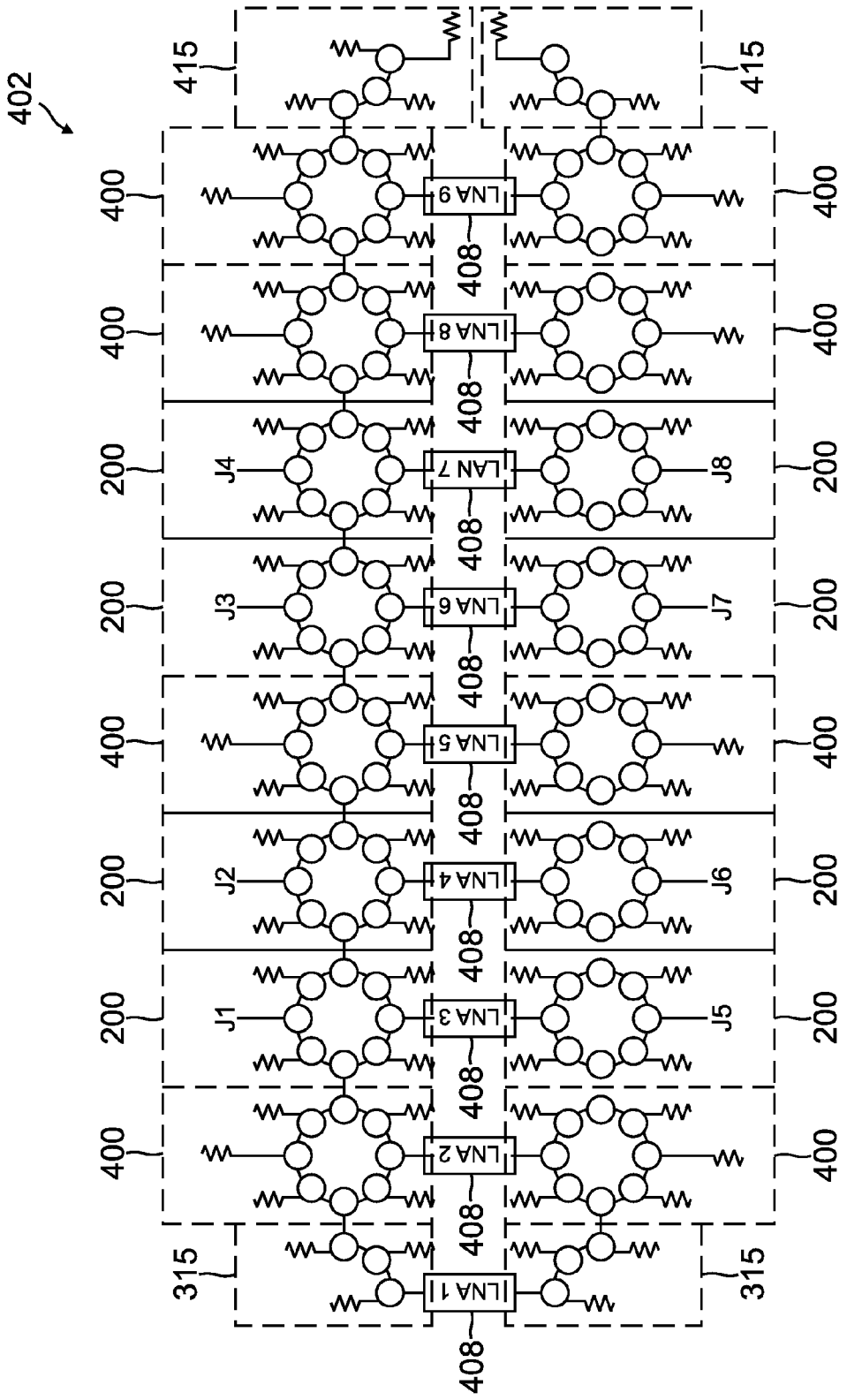

402
415
415
400
400
LNA 9
408
400
400
LNA 8
408
200
J4
LAN 7
J8
200
408
200
J3
LNA 6
J7
200
408
400
400
LNA 5
408
400
200
J2
LNA 4
J6
200
408
200
J1
LNA 3
J5
200
408
400
400
LNA 2
408
400
315
LNA 1
315
408

FIG. 4

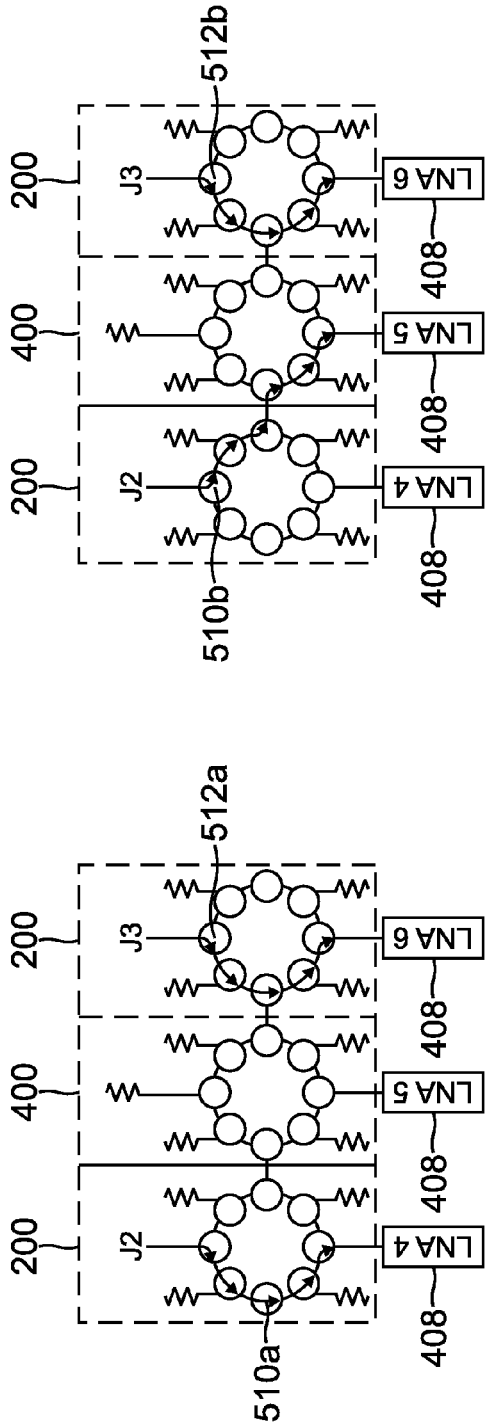


FIG. 5A

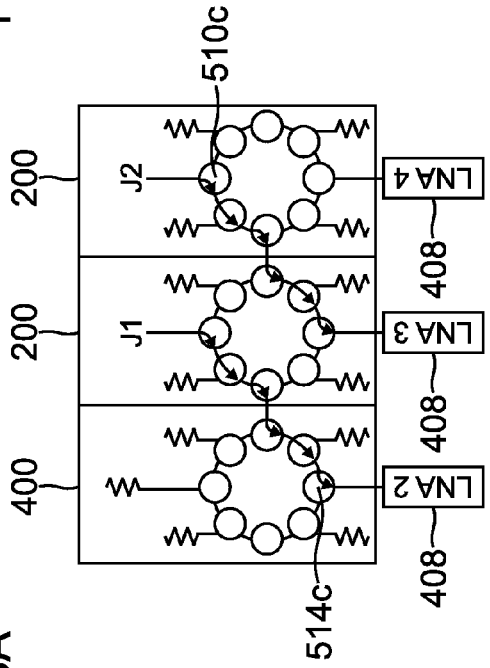


FIG. 5C

FIG. 5B

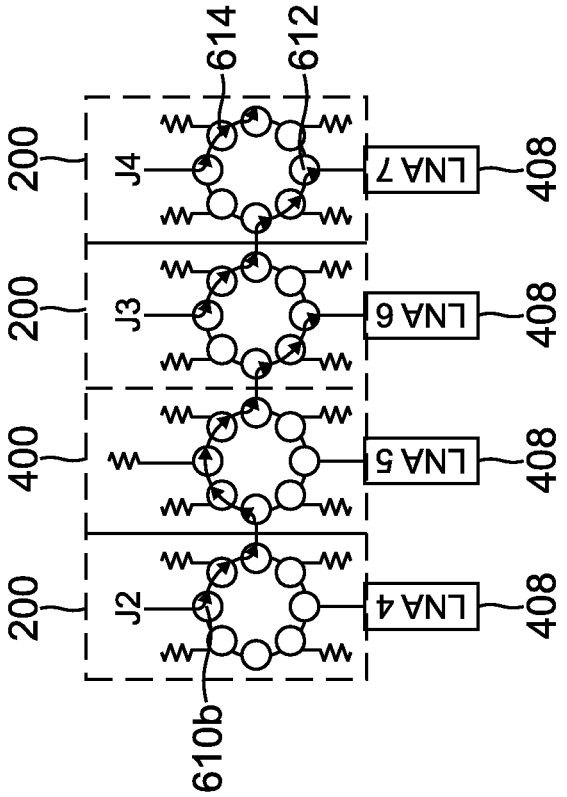

614
612
200
J4
LNA 7
408
200
J3
LNA 6
408
400
LNA 5
408
200
J2
LNA 4
408
610b

FIG. 6B

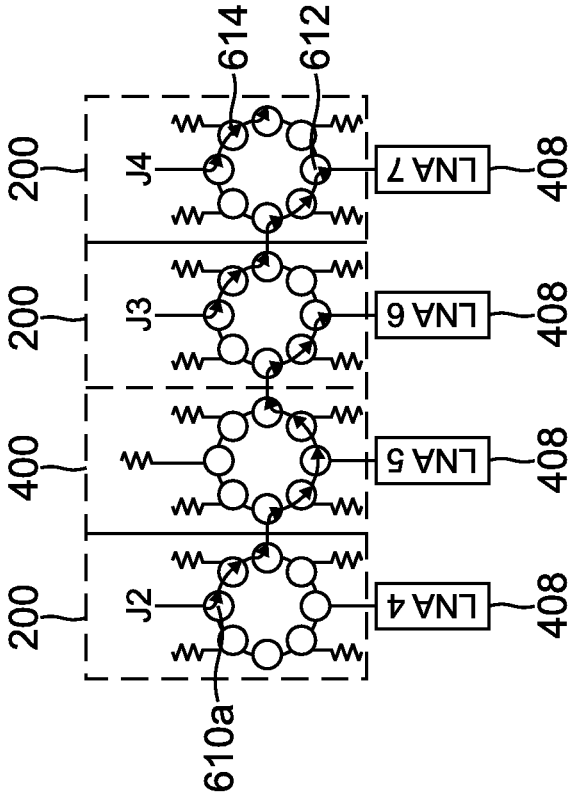

614
612
200
J4
LNA 7
408
200
J3
LNA 6
408
400
LNA 5
408
200
J2
LNA 4
408
610a

FIG. 6A

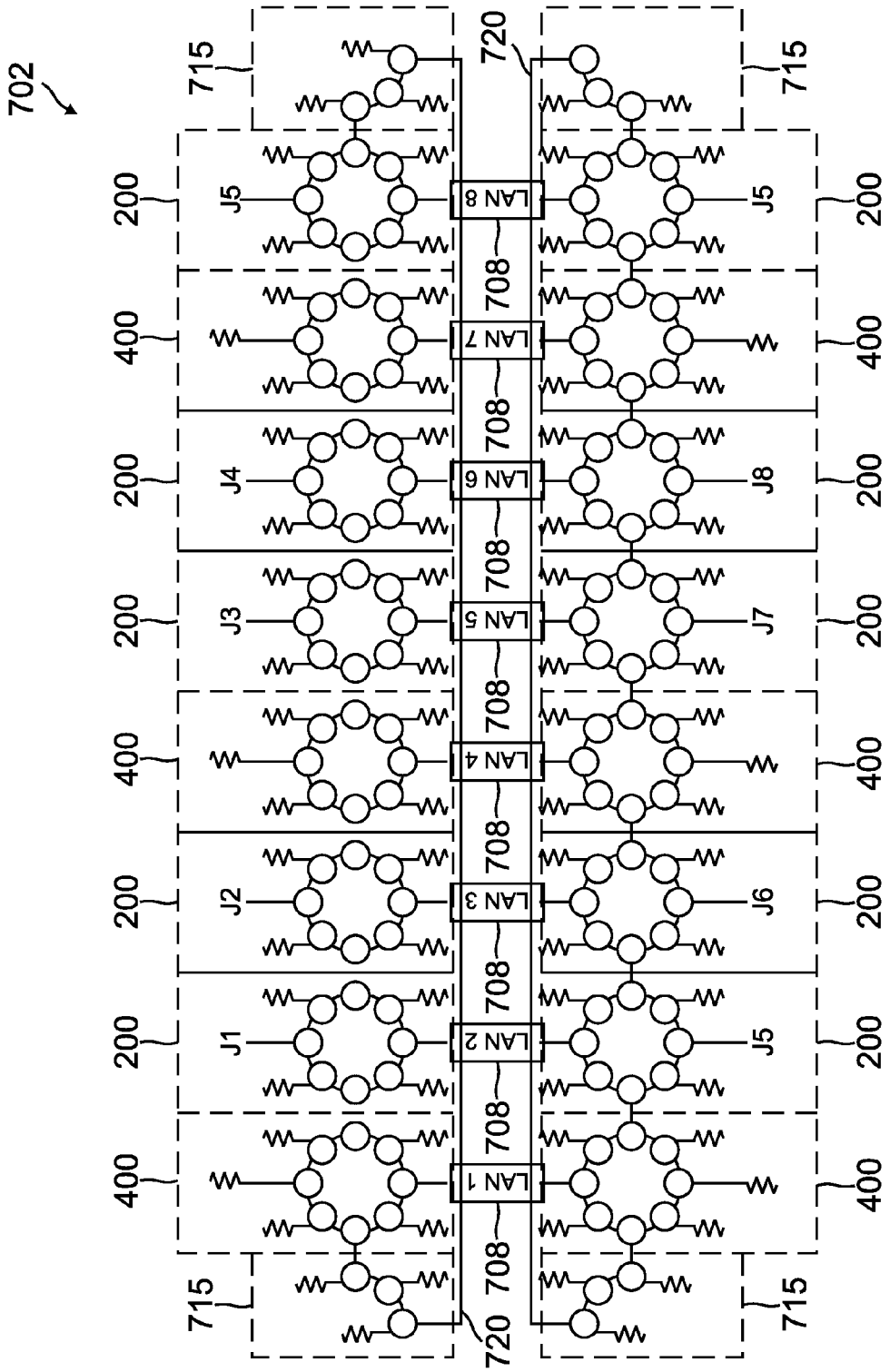

702
715
720
200
400
J5
J4
J3
J2
J1
J8
J7
J6
LAN 8
LAN 7
LAN 6
LAN 5
LAN 4
LAN 3
LAN 2
LAN 1
708

FIG. 7

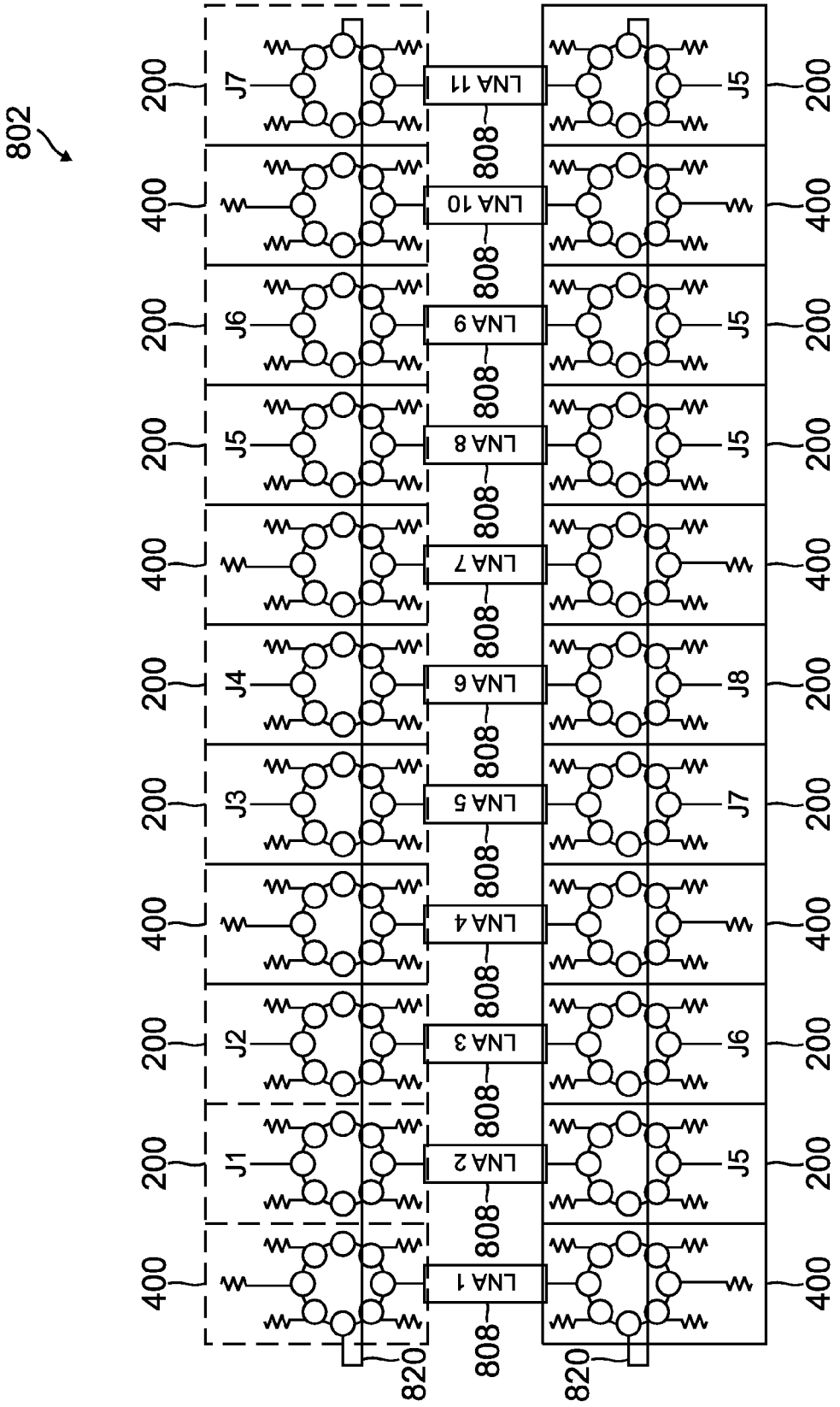

802
200
400
J7
J6
J5
J4
J3
J2
J1
J8
LNA 11
LNA 10
LNA 9
LNA 8
LNA 7
LNA 6
LNA 5
LNA 4
LNA 3
LNA 2
LNA 1
808
820

FIG. 8

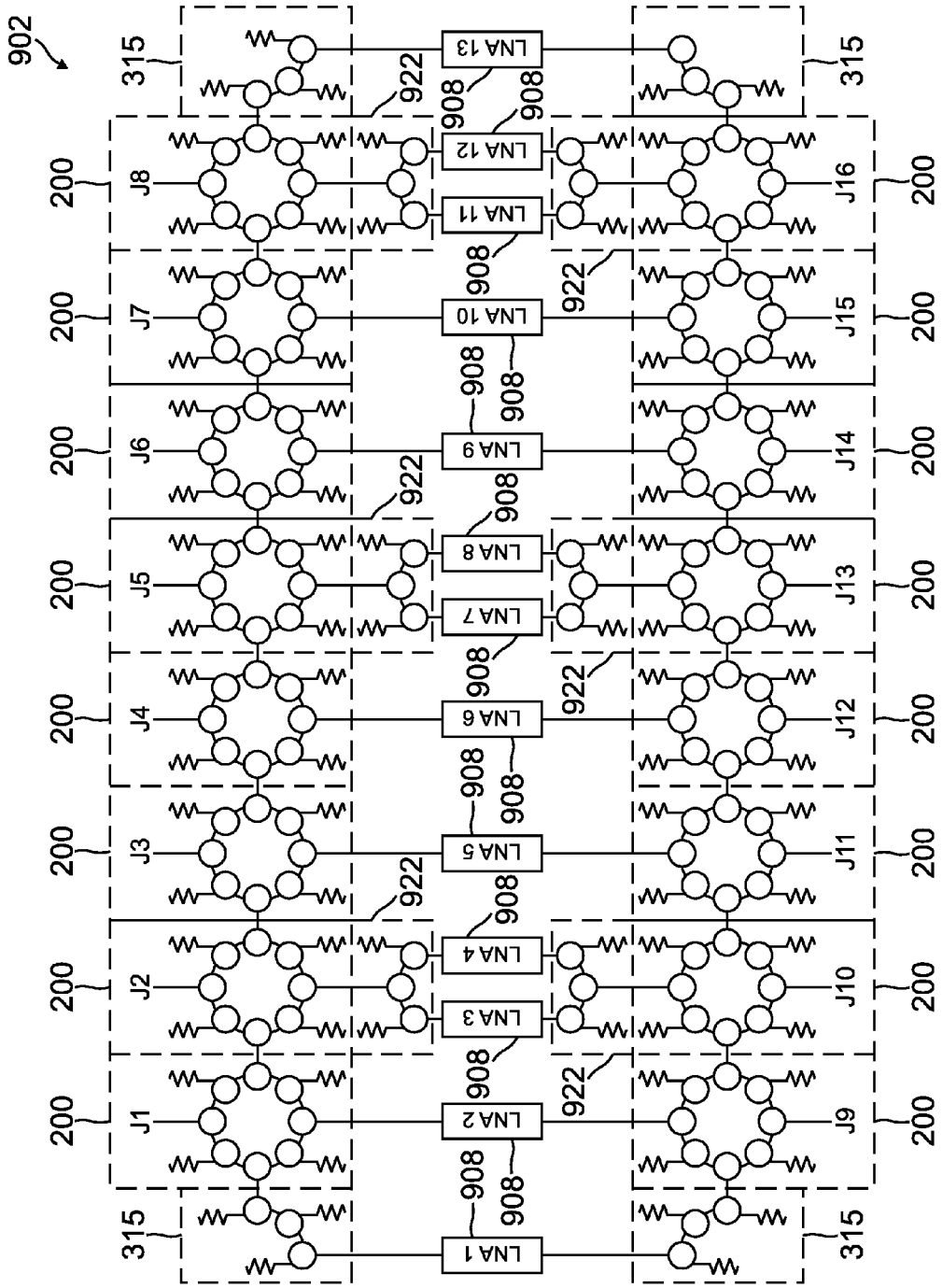
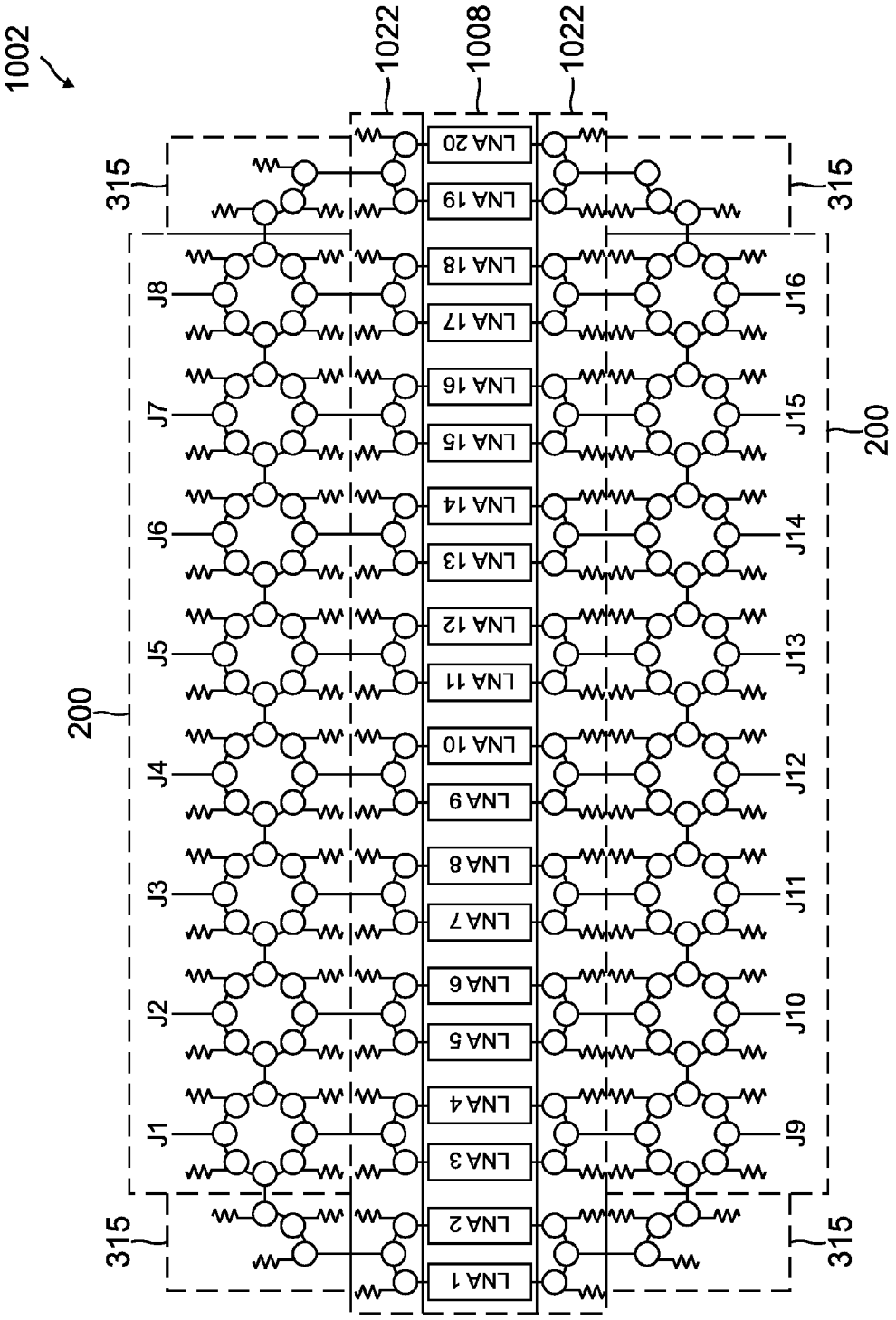

902
315
922
908
LNA 13
LNA 12
LNA 11
LNA 10
LNA 9
LNA 8
LNA 7
LNA 6
LNA 5
LNA 4
LNA 3
LNA 2
LNA 1
200
J8
J16
J7
J15
J6
J14
J5
J13
J4
J12
J3
J11
J2
J10
J1
J9

FIG. 9


1002
1022
1008
1022
315
315
200
200
315
315
J1
J2
J3
J4
J5
J6
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J8
J9
J10
J11
J12
J13
J14
J15
J16
LNA 1
LNA 2
LNA 3
LNA 4
LNA 5
LNA 6
LNA 7
LNA 8
LNA 9
LNA 10
LNA 11
LNA 12
LNA 13
LNA 14
LNA 15
LNA 16
LNA 17
LNA 18
LNA 19
LNA 20

FIG. 10

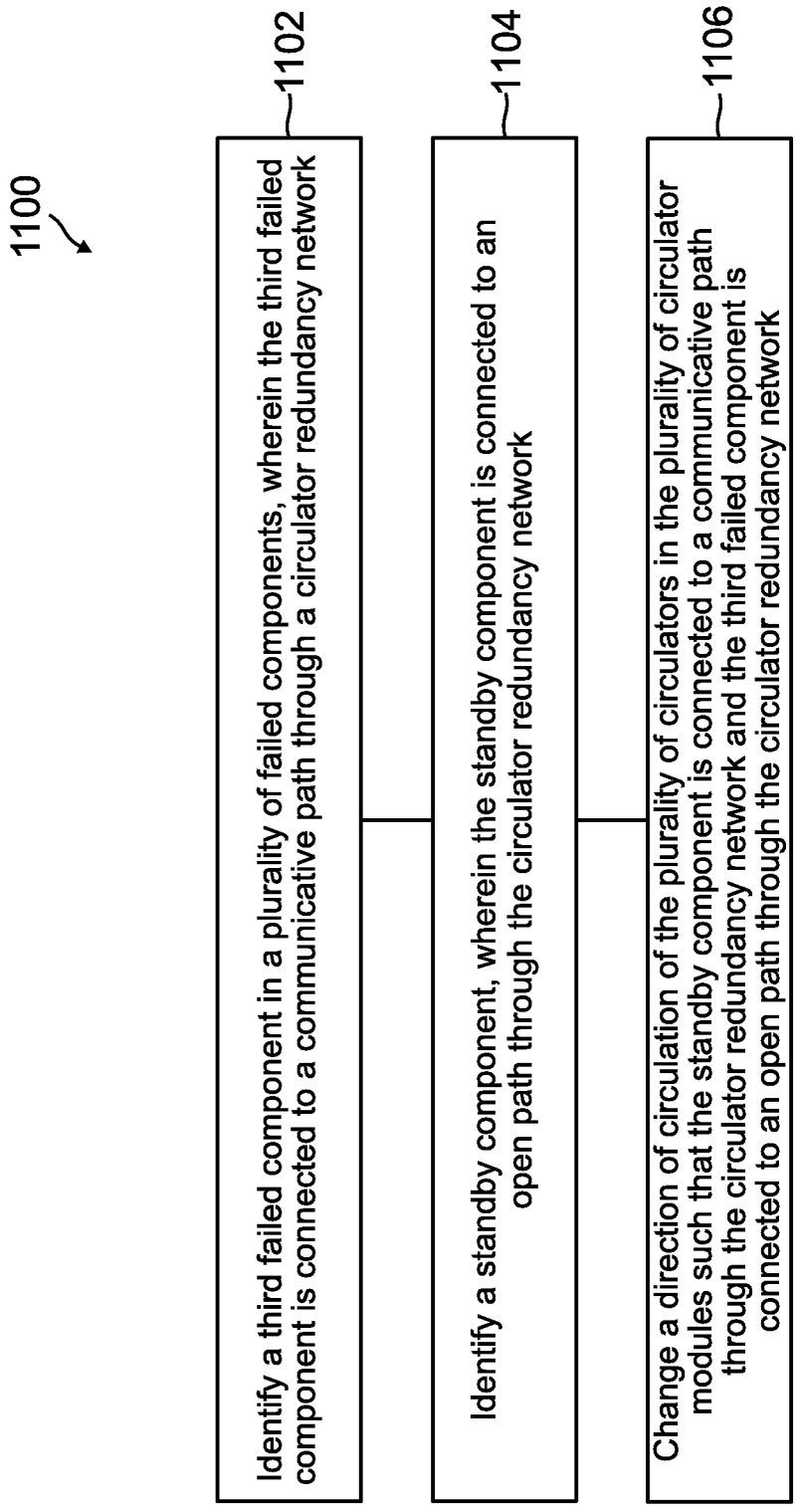
1100
1102
Identify a third failed component in a plurality of failed components, wherein the third failed component is connected to a communicative path through a circulator redundancy network
1104
Identify a standby component, wherein the standby component is connected to an open path through the circulator redundancy network
1106
Change a direction of circulation of the plurality of circulators in the plurality of circulator modules such that the standby component is connected to a communicative path through the circulator redundancy network and the third failed component is connected to an open path through the circulator redundancy network

FIG. 11

SYSTEMS AND METHODS FOR FERRITE REDUNDANCY SWITCH NETWORKS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application Ser. No. 62/022,275, filed on Jul. 9, 2014, which is hereby incorporated herein by reference.

BACKGROUND

[0002] In certain communication networks, certain communication nodes in the network are not easily accessible for repairs in the event that equipment on the communication node experiences a failure. For example, communication nodes located in space are practically inaccessible and, as such, that failed equipment cannot be repaired. To prevent the failures from affecting the operation of the communication node, the communication equipment on the communication node includes standby equipment that increases the redundancy of any communication paths through the communication equipment. To control which communication paths are used through the communication equipment, a switch network is used to switch a communication path from failed equipment to standby equipment.

[0003] In at least one example, low noise amplifiers are prone to failures. Thus, a communication node will include a number of spare amplifiers. For example, at any given time, the communication node may use at most M amplifiers. The communication equipment may include N amplifiers such that when any of the M amplifiers experiences a failure, the switch network switches the communication path through one of the N amplifiers that is not currently active and switches the communication path away from the amplifier that failed. This redundant configuration of amplifiers and switch networks may be referred to as N for M redundancy.

[0004] In certain implementations, a switch network can be implemented using a network of switching ferrite circulators. One configuration of ferrite circulators that offers N for M redundancy for connecting N input ports to M output ports is known as order constrained networks. An order constrained network of circulators allows that any M of the N input ports can be connected to the M output ports. However, order constrained networks can be complex, such that switching networks have a different design for different combinations of N and M. Thus, the order constrained network generally fails to provide the opportunity to reuse previously designed switch networks that implement ferrite circulators.

[0005] Further, certain implementations of switch networks are subject to further constraints. For example, a system that includes low noise amplifiers and switch networks may provide sufficient redundancy to handle the failure of at least three low noise amplifiers. Also, a system may be constrained such that upon experiencing the first failure of a low noise amplifier, the system is able to switch a communication path from an input through the switch network without affecting other communication paths through the switch network.

SUMMARY

[0006] The embodiments of the present disclosure provide systems and methods for ferrite redundancy switch networks are disclosed.

[0007] In one embodiment, a redundant ferrite switch system comprises: a first plurality of circulator modules, wherein the first plurality of circulator modules comprises: a first plurality of first inputs; a first plurality of first outputs; and a first plurality of circulators configured to connect the first plurality of first inputs to the first plurality of first outputs. Furthermore, the redundant ferrite switch system comprises: a second plurality of circulator modules, wherein the second plurality of circulator modules comprises: a second plurality of second inputs; a second plurality of second outputs; and a second plurality of circulators configured to connect the second plurality of second inputs to the second plurality of second outputs; and a plurality of components coupled to the first plurality of circulator modules and coupled to the second plurality of circulator modules, wherein the first plurality of circulator modules and the second plurality of circulator modules is able to route a path through the redundant ferrite switch system when more than two components in the plurality of components have failed.

DRAWINGS

[0008] Understanding that the drawings depict only exemplary embodiments and are not therefore to be considered limiting in scope, the exemplary embodiments will be described with additional specificity and detail through the use of the accompanying drawings, in which:

[0009] FIG. **1** is a block diagram of a switch network in one embodiment described in the present disclosure

[0010] FIGS. **2**A and **2**B are schematic illustrations of switch network configuration in one embodiment described in the present disclosure;

[0011] FIG. **3** is a schematic illustration of a switch network configuration in one embodiment described in the present disclosure;

[0012] FIG. **4** is a schematic illustration of a switch network configuration in one embodiment described in the present disclosure;

[0013] FIGS. **5**A-**5**C are schematic illustrations of the routing of signals through a switch network configuration in one embodiment described in the present disclosure;

[0014] FIGS. **6**A-**6**B are schematic illustrations of the routing of signals through a switch network configuration when more than two low noise amplifiers experience failures in one embodiment described in the present disclosure;

[0015] FIG. **7** is a schematic illustration of a switch network configuration including a waveguide run in one embodiment described in the present disclosure;

[0016] FIG. **8** is a schematic illustration of a switch network configuration including a waveguide run in one embodiment described in the present disclosure;

[0017] FIG. **9** is a schematic illustration of a switch network configuration that includes two for one redundant triads in one embodiment described in the present disclosure;

[0018] FIG. **10** is a schematic illustration of a switch network configuration that includes two for one redundant triads in one embodiment described in the present disclosure; and

[0019] FIG. **11** is a flow diagram of a method for routing signals through a circulator redundancy network in one embodiment described in the present disclosure.

[0020] In accordance with common practice, the various described features are not drawn to scale but are drawn to emphasize specific features relevant to the exemplary embodiments.

DETAILED DESCRIPTION

[0021] In the following detailed description, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration specific illustrative embodiments. However, it is to be understood that other embodiments may be utilized and that logical, mechanical, and electrical changes may be made. Furthermore, the method presented in the drawing figures and the specification is not to be construed as limiting the order in which the individual steps may be performed. The following detailed description is, therefore, not to be taken in a limiting sense.

[0022] In the present disclosure, various implementations are described for providing switching networks comprised of circulators that provide sufficient redundancy to allow for the failure of at least three communication paths through the switching networks. Further, the implementations described herein further provide switching networks where the communication path of a channel can change without affecting the communication paths of other channels when the switching network first experiences a failure. In subsequent failures, the communication paths of the different channels may change to accommodate the rerouting of communication paths through the switching network. To meet the criteria, a base circulator module, that is able to provide redundancy that can withstand failures on up to two communication paths, is combined with other similar circulator modules. Then a combination of terminating loads and/or 2-for-1 redundant triad switches are coupled to the base circulator modules such that the arrangement of components in the switching network is able to operate such that the above described criteria is satisfied.

[0023] FIG. **1** is a block diagram of a portion of a system **100** that implements redundancy networks that are fabricated from circulator modules. In one implementation as shown, system **100** is part of a communication node that transmits and receives signals. For example, the system **100** receives a signal through an antenna **102**. The signal is amplified by at least one amplifier **108** and then processed by a transmitter/receiver **104**. In at least one implementation the amplifier **108** may be a low noise amplifier, a power amplifier, a travelling wave tube amplifier, or the like. Also, in certain implementations, the transmitter/receiver **104** provides a signal that is amplified by the amplifiers **108** and then provided to the antenna **102** for radiation to another communication node in the communication network. In certain embodiments, the system **100** is implemented on a platform that is inaccessible for repairs when a component on the system experiences a fault. For example, the system **100** may be implemented on a satellite located in space or other inaccessible location. In at least one embodiment, an amplifier **108** in the system **100** may experience a failure during the life of the system **100**. To prevent the failure from negatively affecting the operation of the system **100**, when the system **100** begins operation, the system **100** may include multiple amplifiers **108**, where a portion of the amplifiers **108** function as standby amplifiers in the event that an operating amplifier fails. When an operating amplifier fails, a switching network **103** changes a communication path that diverts away from the failed LNA to pass through a standby LNA. As shown in FIG. **1**, the amplifiers **108** are used as examples of electronic components, where the input/output ports of the components may connect to other components through transmission media that includes waveguides, microstrip, coaxial, and the like. In at least one implementation, the components may connect to other components via adapters that allow the component to interface with other components fabricated in a different transmission media. It is intended that the switching network **103**, as described herein, can be used to change electrical paths through an operating component to a standby component.

[0024] In certain implementations, the switching network **103** is comprised of circulator modules **106**. A circulator module **106** is a modular network of circulators that can be interconnected with one another to create the larger switching network **103**. In at least one embodiment, a circulator module **106** contains multiple ferrite circulators that are connected to one another to provide switching capabilities between a number of module inputs and module outputs. In certain implementations, the ferrite circulators in a circulator module **106** may be waveguide circulators, where each circulator has three arms arranged at 120° that meet in a common junction. The common junction may be loaded with a non-reciprocal material such as ferrite. When a magnetizing field is created in the ferrite element that is located at the common junction, a gyromagnetic effect can be used to switch the microwave signal from one waveguide arm to another. By reversing the direction of the magnetizing field, the direction of switching between the waveguide arms is reversed. Thus, a switching circulator is functionally equivalent to a fixed-bias circulator but has a selectable direction of circulation. RF energy can be routed with low insertion loss from one waveguide arm to either of the two outputs arms. If one of the waveguide arms is terminated in a matched load, then the circulator acts as an isolator, with high loss in one direction of propagation and low loss in the other direction. Reversing the direction of the magnetizing field will reverse the direction of high and low isolation.

[0025] In certain embodiments, to control the direction of magnetization for the ferrite circulators in the different circulator modules **106**, the system **100** includes a circulator switch controller **110**. The circulator switch controller **110** sends electrical signals to the individual circulators that control the direction of circulation for each circulator. For example, the circulator switch controller **110** sends a high current pulse to a particular circulator that changes the direction of circulation in that circulator. In certain implementations, the circulator switch controller **110** includes a separate driver that is associated with each circulator in the system **100**, where the driver provides a switching signal to an individual circulator. In at least one other implementation, where switching time is not critical, the circulator switch controller **110** may include a single driver that is multiplexed to the separate circulators in the circulator module **106**. In a further embodiment, the circulator switch controller includes an interface that allows a user to control the switching directly through another device.

[0026] The circulator modules **106** include multiple ferrite elements that typically have impedance-matching transitions between each ferrite element. For example, a conventional waveguide circulator may transition from one ferrite element to a dielectric-filled waveguide such as a quarter-wave dielectric transformer structure, to an air-filled waveguide, and then back to another dielectric-filled waveguide section and the next ferrite element. The dielectric transformers are typically used to match the lower impedance of the ferrite element to that of an air-filled waveguide.

[0027] As stated above, a circulator module **106** may contain multiple waveguide circulators. Further, the circulator module **106** may also include multiple load elements for isolation of certain ports in some of the ferrite circulators,

where the multiple load elements are designed to match the impedance of an air-filled waveguide interface. The circulators and load elements can be connected in various configurations according to the modular design of the circulator module **106**. In certain implementations, the system **100** is comprised of modular components that allow the system **100** to include at least three standby components. For example, a system **100**, having N amplifiers **108** where M amplifiers **108** are operational at any given time, provides switching so that N−M standby amplifiers **108** can be switched into the communication paths in system **100** such that there are always M communication paths available between the transmitter/receiver **104** and the antenna **102**. As described herein, N−M≥3 as provided by the circulator modules described hereafter.

[0028] FIG. **2**A illustrates one embodiment of a circulator module **200** and FIG. **2**B illustrates another embodiment of a redundancy network **210**, where the redundancy network **210** is formed by combining the circulator module **200** to other circulator modules **200**. The circulator module **200** is configured for N−M=2 redundancy and the waveguides in the circulator module **200** do not cross over. Also, circulator module **200** includes multiple circulators **202** and multiple matched loads **204** that terminate sections of waveguides to isolate signals that may propagate in an undesired direction. FIG. **2**B illustrates an N−M=2 redundancy network **210** that includes circulator modules **200** and modified circulator modules **215**. A modified circulator module **215** is formed by removing module output **208** from a circulator module **200** and removing circuitry that becomes superfluous with the removal of module output **208**. As shown in FIG. **2**B, modified circulator module **215** is an exemplary implementation of a modified circulator module. Other configurations may be used, where some of the configurations include superfluous circulators and other components. Any open waveguide sections that are formed by the removal of circuitry may be terminated with a matched load **204**. As shown, in the redundancy network **210**, a signal that is received through a module input of the modified circulator module **215** is circulated into the neighboring circulator module **200**. Conversely, any signal that is circulated into the modified circulator module **215** from a neighboring circulator module **200** is circulated into a matched load **204**. As illustrated, circulator module **200** is only an example of a circulator module that can be formed that lacks crossing waveguides. Other circulator modules that lack crossing waveguides may be designed that can be formed into N−M=2 redundancy networks. Also, multiple other circulator modules may be formed that can be formed into different redundancy networks. For example, multiple circulator modules are described in the U.S. patent application Ser. No. 13/923,497 (the '497 application) titled "MODULAR FERRITE SWITCH FOR CONSTRUCTING SWITCH NETWORKS," filed on Jun. 21, 2013, and which is herein incorporated by reference.

[0029] FIG. **3** is a schematic illustration of a switching network **302** that provides N−M=2 redundancy and comprises the circulator modules **200** described in FIGS. **2**A and **2**B. In particular, FIG. **3** illustrates a switching network **302** having 10 for 8 implementation. As used here in the phrase "10 for 8" can be represented generally as "N for M". As described above, the N indicates how many amplifiers **308** are provided in the system and the M indicates how many communication paths are available through the switching network **302**. Also, the M indicates how many amplifiers **308** are operational at a time. Thus, the switching network **302** having 10 for 8 redundancy indicates that the switching network **302** includes ten amplifiers **308** where only eight amplifiers **308** are operational at a given time. In a similar manner as illustrated in FIG. **2**B, switching network **302** also includes modified circulator modules **315**, which function similarly to modified circulator module **215** described above. The switching network **302** is substantially described in the '497 application. While the switching network **302** is able to provide N−M=2 redundancy, the switching network **302** fails to provide any greater levels of redundancy. Also, upon experiencing a failure of a single amplifier **308**, the switching network **302** potentially alters up to three different communication paths through the switching network **302**. For example if either of LNA **5** or LNA **6** fails, then three other communication paths through the switching network **302** will also change.

[0030] FIG. **4** is a schematic illustration of a switching network **402** that provides N−M=3 redundancy where only the communication path interrupted by a failed amplifier **408** is altered upon the first failure experienced in switching network **402**. As shown switching network **402** has 9 for 4 redundancy and contains three different circulator modules. Two of the circulator modules (circulator modules **200** and **315**) are described above in relation to FIGS. **2**A, **2**B, and **3**. However, switching network **402** also includes circulator module **400**, which is similar to circuit module **200** with the exception of having a terminating load attached to the input port. As such, switching network **402** is an altered version of switching network **302**. In particular, every third circulator module **200** of FIG. **3** has been replaced by a circulator module **400** having the terminated input port. Also, the first and last input ports may be terminated with loads, which is why an 8 input switching network, such as switching network **302**, is able to be reconfigured for 4 inputs as compared to 5. As shown, the same pattern of circulator modules may be repeated on the output side of the switching network **402**. In an alternative implementation, as compared to terminating the circulator modules **400** with a load, the circulator modules **400** may also be terminated with a short circuit. Further, to enable the N−M=3 redundancy, two amplifiers **408** may be located in the paths adjacent to the first input (denoted by a J**1**) and a last input (denoted by J**4**). For example, LNA **1** and LNA **2** may be located adjacent to the first input J**1**. Also, LNA **8** and LNA **9** may be located adjacent to the last input J**4**. As two amplifiers **408** may be located in the paths adjacent to the first input J**1** and the last input J**4**, a 10th LNA (as used in switching network **302**) becomes unnecessary and may be removed from the reconfigured switching network **402**. In certain implementations, the LNA **10** of switching network **302** may be replaced with terminations such as loads on the 2 connecting ports of one of the modified circulator modules **415**.

[0031] FIGS. **5**A-**5**C illustrate different communication paths through the switching network **402** of FIG. **4**, when the switching network **402** has experienced up to 2 failures. For example, FIG. **5**A illustrates the communication paths from the inputs J**2** and J**3** when the switching network **402** has yet to experience a failure along one of the communication paths and can also be said to be a starting configuration. In a starting configuration, all LNAs **408** located directly in the path of the inputs would be turned on, the signal through input J**2** would go through LNA **4** along communication path **510***a* and the signal through input J**3** would go through LNA **6** along communication path **512***b*.

[0032] FIG. **5**B illustrates one example of the rerouting of communication paths when the switching network **402** experiences a failure. As illustrated, LNA **4** along communication path **510***a* experiences a failure. In the case of a first LNA **408** failure, the input with the failed LNA may be switched to the adjacent path having a standby LNA. As shown, the adjacent path having a standby LNA would be the path to the left for J**1** and J**3** or the path to the right for J**2** and J**4** as shown in switching network **402** in FIG. **4**. Because each input port has an adjacent path to one side that does not have an input port connection, any first failed LNA can be switched out of the path to a standby (redundant) LNA without disrupting other active paths, which disruptions would force the other active paths to also switch to an adjacent LNA. As shown, FIG. **5**B shows this change of communication paths from inputs J**2** and J**3** following a failure on LNA **4**, where the communication path **510***b* is changed such that J**2** is connected to LNA **5**. Communication path **512***b* remains substantially the same as communication path **512***a*. Thus, in regards to the switching network **402** of FIG. **4**, the inputs are connected to the LNAs as follows: J**1**-LNA **3**, J**2**-LNA **5**, J**3**-LNA **6**, and J**4**-LNA **7**.

[0033] FIG. **5**C illustrates one exemplary implementation for the rerouting of a communication path if a second LNA were to fail following the failure of LNA **4** described above with respect to FIG. **5**B. When two LNAs **408** fail, there are multiple reconfiguration variations. For example, If LNA **3** or LNA **7**, in switching network **402**, fails, then the associated signals could be respectively rerouted through LNA **2** or LNA **8** without disrupting other active channels. If LNA **6** were to fail, then the failed path from input J**3** would change to pass through LNA **7**, and this would force the path from input J**4** path to also change and pass through LNA **8**. When other paths are forced to change, it may be considered a disruption to the active paths from other inputs. As illustrated in FIG. **5**C, LNA **5** is the second LNA **408** to fail after LNA **4**. The failure of LNA **5** is the second failure along a path from input J**2** as path **510***a* was reconfigured to create path **510***b* through LNA **5**. To reroute the communication path **510***b*, the input from J**2** is rerouted to form communication path **510***c*, which passes through LNA**3**. Accordingly, the input from J**1** is rerouted along communication path **514***c*, which connects to LNA **2**. As such, after the failures of LNA **4** and LNA **5**, the connectivity in switching network **402** may be J**1**-LNA **2**, J**2**-LNA **3**, J**3**-LNA **6**, and J**4**-LNA **7**.

[0034] FIGS. **6**A and **6**B illustrate different alternatives if a third LNA **408** were to fail following the failure of LNA **4** and LNA **5**. If a third LNA were to fail following the LNA **4** and LNA **5** failures, then there may be multiple reconfiguration variations, some of which may be similar to the reconfigurations described above. In one scenario, the LNA **408** fails that receives a signal from the input J**2**. For example, LNA **3** fails after the failure of LNA **4** and LNA **5**. As the failure of LNA **3** would be the third failure on the communication path from input J**2**, the LNA to the left (LNA **3**), right (LNA **5**), and directly in line with input J**2** (LNA **4**) have failed. To reconfigure the path **510***c* from input J**2**, a reconfigured path **610***a* in FIG. **6**A or path **610***b* in FIG. **6**B routs a signal from input J**2** past 2 failed LNAs to connect to LNA **6**. As with the first failure of LNA **4**, the direction of paths **610***a* and **610***b* may be in the direction of the loaded input port, or to the right, towards LNA **6** for the example involving input J**2**. To reconfigure according to path **610***a*, the signal is routed through the bottom **5** ferrite switches in the circulator module **400** to the right of the circulator module **200** that contains input J**2**, as shown in FIG. **6**A. Alternatively, to reconfigure according to path **610***b*, the signal is routed through the top 5 ferrite switches in the circulator module **400** to the right of the circulator module **200** that contains input J**2**, as shown in FIG. **6**B. Paths **612** and **614** that are respectively connected to input J**3** and input J**4** are also shifted to the right to allow the path from input J**2** to connect to LNA **6**. After the reconfiguration, the connectivity in switching network **402** may be J**1**-LNA **2**, J**2**-LNA **6**, J**3**-LNA **7**, J**4**-LNA **8**. Further, if LNA **6** were to fail, for a 4th failure in the J**2** path connection, then J**2** would be unable to switch to a 5th LNA. However, if LNA **2** or LNA **8** were to fail for a 4th or 5th LNA **608** failure, then LNA **1** or LNA **9** could be switched in, respectively. Thus, the switching network **402** of FIG. **4** is able to accommodate up to 3 LNA failures and 4 or 5 LNA failures in specific cases. As has been shown through, FIGS. **5**A-**6**B illustrate the changing of paths through input circulator modules having inputs J**1**-J**4**. As illustrated in FIG. **3**, there are corresponding output circulator modules having outputs J**5**-J**8**. As the LNAs **408** in the switching network **402** fail, the paths through the output circulator modules are altered in a similar manner to the input circulator modules. In one implementation, the paths through the output circulator modules are altered to mirror the paths through the input circulator modules.

[0035] In further implementations, other modifications to the switching network **302** of FIG. **3** may also be made. Other modifications may have an increased efficiency, however, other modifications also are accompanied by other tradeoffs. FIG. **7** provides an illustration of a switching network **702** that permits an additional input, when compared to the switching network **402**. Further, the switching network **702** uses one less LNA **708** and is an 8-for-5 redundancy scheme. However, the switching network **702** includes a waveguide **720** that connects opposite sides of the switching network **702**. For example, in the locations where the switching network **302** would contain LNA **1** and LNA **10**, switching network **702** includes a waveguide **720** that connects the modified circulator modules **715** to one another. The inclusion of a waveguide adds complexity as well as insertion loss, which degrades the noise figure of the path in the case where RF must be switched from one side to the other through the long waveguide run.

[0036] Certain implementations may use up to 7 channels through a switching network. In one implementation, to provide 7 channels through a switching network, two of switching network **402** or two of switching network **702** may be combined. FIG. **8** illustrates a switching network **802** that comprises a modified version of switching network **702**, where additional modules have been added to increase the number of operating channels from 5 to 7. As shown, the switching network **802** is an 11 for 7 switching network. Similar to switching network **702**, the switching network **802** includes a waveguide **820** that extends from the circulator modules on the ends of the switching network **802**, which switching network **802** includes a circulator module **400** on one end and a circulator module **200** on the other end, where the two circulator modules are connected by a waveguide **820**.

[0037] As described above, in the case where three failures occur to the same path, the affected path then passes through 11 different ferrite switches as shown in FIGS. **6**A and **6**B. Each additional ferrite switch that a signal passes through negatively affects the noise figure of the signal. To decrease the noise figure, a 2 for 1 redundant triad switch may be added

to every third path. A 2 for 1 redundant triad switch is described in greater detail in U.S. Pat. No. 6,885,257, titled "Multi junction waveguide circulator without internal transitions", which is incorporated herein by reference. The addition of a 2 for 1 redundant triad serves a similar function to skipping every third input as described in the implementation of FIG. **4**, however, in contrast to switching network **402**, all the inputs may be used. As shown in FIG. **9**, each path through a circulator module **200** can be switched straight through or to one switch ring **200** to the left or right, and one of these 3 positions includes an extra standby LNA **908** as a result of the 2 for 1 redundant triad switches **922**. This allows each input of the switching network **902** to connect to four LNAs **908**, which allows full connectivity after three LNA failures. However, unless the first LNA failure is one of the LNA's connected to a 2-for-1 triad switch **922**, a failure would result in disruption not only to the failed path but also to a neighboring path. If the connection between input J**2** and LNA **3** fails, then LNA **4** can be switched in without disrupting other paths. This is not the case if LNA **5** is the first failure, which would require a number of the paths to move over 1 LNA position to the left or right. Further, as illustrated by FIG. **10**, a switching network **1002** places the 2-for-1 redundant triad switches **1022** in all 10 locations of the original 10-for-8 switching network **302** to assure that the first failed LNA **1008** does not require the other 7 paths through the circulator modules **200** to be disrupted. If LNA **3** were to fail, then LNA **4** could be switched in. The switching network **1002** also may be able to accommodate up to 4 LNA failures, whereas the other examples of FIGS. **4-9** are able to accommodate up to 3 LNA failures. However, switching network **1002** requires the most standby LNAs **1008**, as switching network **1002** is a 20 for 8 switching network.

[0038] FIG. **11** is a flow diagram of a method **1100** for routing signals through a circulator redundancy network when a third component fails. For example, method **1100** proceeds at **1102**, where a third failed component in a plurality of failed components is identified, wherein the third failed component is connected to a communicative path through a circulator redundancy network. Method **1100** then proceeds at **1104**, where a standby component is identified, wherein the standby component is connected to an open path through the circulator redundancy network. Further, method **1100** proceeds at **1106**, where a direction of circulation of the plurality of circulators in the plurality of circulator modules is changed such that the standby component is connected to a communicative path through the circulator redundancy network and the third failed component is connected to an open path through the circulator redundancy network.

Example Embodiments

[0039] Example 1 includes a redundant ferrite switch system, the system comprising: a first plurality of circulator modules, wherein the first plurality of circulator modules comprises: a first plurality of first inputs; a first plurality of first outputs; and a first plurality of circulators configured to connect the first plurality of first inputs to the first plurality of first outputs; a second plurality of circulator modules, wherein the second plurality of circulator modules comprises: a second plurality of second inputs; a second plurality of second outputs; and a second plurality of circulators configured to connect the second plurality of second inputs to the second plurality of second outputs; and a plurality of components coupled to the first plurality of circulator modules and coupled to the second plurality of circulator modules, wherein the first plurality of circulator modules and the second plurality of circulator modules is able to route a path through the redundant ferrite switch system when more than two components in the plurality of components have failed.

[0040] Example 2 includes the system of Example 1, wherein each third input of the first plurality of first inputs is terminated with a load and wherein each third output of the second plurality of second outputs is terminated with a load.

[0041] Example 3 includes the system of any of Examples 1-2, wherein the first plurality of circulator modules comprises at least six circulator modules.

[0042] Example 4 includes the system of any of Examples 1-3, wherein the second plurality of circulator modules comprises at least six circulator modules.

[0043] Example 5 includes the system of any of Examples 1-4, wherein each module of the first plurality of circulator modules comprises at least three circulators; and wherein each module of the second plurality of circulator modules comprises at least three circulators.

[0044] Example 6 includes the system of any of Examples 1-5, wherein each third circulator module in the first plurality of circulator modules is coupled to a 2-for-1 redundant triad switch, wherein each third circulator module in the second plurality of circulator modules is coupled to a 2-for-1 redundant triad switch, and wherein each of the 2-for-1 redundant triad switches is coupled to two components of the plurality of components.

[0045] Example 7 includes the system of any of Examples 1-6, wherein each circulator module in the first plurality of circulator modules is coupled to a 2-for-1 redundant triad switch, wherein each circulator module in the second plurality of circulator modules is coupled to a 2-for-1 redundant triad switch and wherein each of the 2-for-1 redundant triad switches is coupled to two components of the plurality of components.

[0046] Example 8 includes the system of any of Examples 1-7, further comprising: a first waveguide connecting a first end of the first plurality of circulator modules to a second end of the first plurality of circulator modules, wherein the first end is located opposite the second end in the first plurality of circulator modules; and a second waveguide connecting a first end of the second plurality of circulator modules to a second end of the second plurality of circulator modules, wherein the first end is located opposite the second end in the second plurality of circulator modules.

[0047] Example 9 includes the system of any of Examples 1-8, wherein if a first component in the plurality of components fails, the first plurality of circulator modules and the second plurality of circulator modules is able to route a path through a redundant component in the plurality of components without disrupting an active communication path in the redundant ferrite switch system other than the path that was active prior to when the first component failed.

[0048] Example 10 includes a plurality of circulator modules for use in a redundant ferrite switch system comprising: a plurality of inputs; a plurality of outputs; a plurality of circulators coupling the plurality of inputs to the plurality of outputs; wherein either the plurality of inputs or the plurality of outputs is coupled to a plurality of components; and wherein the plurality of circulator modules is able to route a path through the redundant ferrite switch system when more than two components in the plurality of components have failed.

[0049] Example 11 includes the plurality of circulator modules of Example 10, wherein either at least three of the plurality of inputs are terminated with loads or at least three of the plurality of outputs are terminated with loads or both.

[0050] Example 12 includes the plurality of circulator modules of any of Examples 10-11, wherein each third input of the plurality of inputs is terminated with a load and wherein each third output of the plurality of outputs is terminated with a load.

[0051] Example 13 includes the plurality of circulator modules of any of Examples 10-12, wherein the plurality of circulator modules comprises at least six circulator modules.

[0052] Example 14 includes the plurality of circulator modules of any of Examples 10-13, wherein each module of the plurality of circulator modules comprises at least three circulators.

[0053] Example 15 includes the plurality of circulator modules of any of Examples 10-14, wherein each third circulator module in the plurality of circulator modules includes a 2-for-1 redundant triad switch and wherein each of the 2-for-1 redundant triad switches is coupled to two components in the plurality of components.

[0054] Example 16 includes the plurality of circulator modules of any of Examples 10-15, wherein every circulator module in the plurality of circulator modules includes a 2-for-1 redundant triad switch and wherein each of the 2-for-1 redundant triad switches is coupled to two components in the plurality of components.

[0055] Example 17 includes the plurality of circulator modules of any of Examples 10-16, further comprising a waveguide connecting a first end of the plurality of circulator modules to a second end of the plurality of circulator modules, wherein the first end is located opposite the second end in the plurality of circulator modules.

[0056] Example 18 includes the plurality of circulator modules of any of Examples 10-17, wherein if a first component in the plurality of components fails, the plurality of circulator modules is able to route a path through a redundant component in the plurality of components without disrupting an active communication path in the plurality of circulator modules other than the path that was active prior to when the first component failed.

[0057] Example 19 includes a method for switching communication paths in a circulator redundancy network, the method comprising: identifying a failed component in a plurality of failed components, wherein the failed component is connected to a communicative path through the circulator redundancy network and the plurality of failed components comprises at least two previously failed components, the circulator redundancy network comprising a plurality of circulator modules, wherein a circulator module comprises: a plurality of circulators that are configurable to route received signals through the circulator redundancy network along a plurality of communication paths by connecting with other circulator modules in the plurality of circulator modules and by connecting with a plurality of components; identifying a standby component in the plurality of components, wherein the standby component is connected to an open path through the circulator redundancy network and the at least two previously failed components are connected to open paths through the circulator redundancy network; and changing a direction of circulation of one or more of the plurality of circulators in the plurality of circulator modules such that the standby component is connected to a communicative path through the circulator redundancy network, and the failed component is connected to an open path through the circulator redundancy network.

[0058] Example 20 includes the method of Example 19, further comprising changing a direction of circulation of one or more of the plurality of circulators in the plurality of circulator modules such that an active communication path is not disrupted in the circulator redundancy network when a first failed component in the plurality of failed components fails.

[0059] Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement, which is calculated to achieve the same purpose, may be substituted for the specific embodiments shown. Therefore, it is manifestly intended that this invention be limited only by the claims and the equivalents thereof.

What is claimed is:

1. A redundant ferrite switch system, the system comprising:

a first plurality of circulator modules, wherein the first plurality of circulator modules comprises:
- a first plurality of first inputs;
- a first plurality of first outputs; and
- a first plurality of circulators configured to connect the first plurality of first inputs to the first plurality of first outputs;

a second plurality of circulator modules, wherein the second plurality of circulator modules comprises:
- a second plurality of second inputs;
- a second plurality of second outputs; and
- a second plurality of circulators configured to connect the second plurality of second inputs to the second plurality of second outputs; and

a plurality of components coupled to the first plurality of circulator modules and coupled to the second plurality of circulator modules, wherein the first plurality of circulator modules and the second plurality of circulator modules is able to route a path through the redundant ferrite switch system when more than two components in the plurality of components have failed.

2. The system of claim **1**, wherein each third input of the first plurality of first inputs is terminated with a load and wherein each third output of the second plurality of second outputs is terminated with a load.

3. The system of claim **1**, wherein the first plurality of circulator modules comprises at least six circulator modules.

4. The system of claim **1**, wherein the second plurality of circulator modules comprises at least six circulator modules.

5. The system of claim **1**, wherein each module of the first plurality of circulator modules comprises at least three circulators; and wherein each module of the second plurality of circulator modules comprises at least three circulators.

6. The system of claim **1**, wherein each third circulator module in the first plurality of circulator modules is coupled to a 2-for-1 redundant triad switch, wherein each third circulator module in the second plurality of circulator modules is coupled to a 2-for-1 redundant triad switch, and wherein each of the 2-for-1 redundant triad switches is coupled to two components of the plurality of components.

7. The system of claim **1**, wherein each circulator module in the first plurality of circulator modules is coupled to a 2-for-1 redundant triad switch, wherein each circulator module in the second plurality of circulator modules is coupled to

a 2-for-1 redundant triad switch and wherein each of the 2-for-1 redundant triad switches is coupled to two components of the plurality of components.

8. The system of claim **1**, further comprising:

a first waveguide connecting a first end of the first plurality of circulator modules to a second end of the first plurality of circulator modules, wherein the first end is located opposite the second end in the first plurality of circulator modules; and

a second waveguide connecting a first end of the second plurality of circulator modules to a second end of the second plurality of circulator modules, wherein the first end is located opposite the second end in the second plurality of circulator modules.

9. The system of claim **1**, wherein if a first component in the plurality of components fails, the first plurality of circulator modules and the second plurality of circulator modules is able to route a path through a redundant component in the plurality of components without disrupting an active communication path in the redundant ferrite switch system other than the path that was active prior to when the first component failed.

10. A plurality of circulator modules for use in a redundant ferrite switch system comprising:

a plurality of inputs;

a plurality of outputs;

a plurality of circulators coupling the plurality of inputs to the plurality of outputs;

wherein either the plurality of inputs or the plurality of outputs is coupled to a plurality of components; and

wherein the plurality of circulator modules is able to route a path through the redundant ferrite switch system when more than two components in the plurality of components have failed.

11. The plurality of circulator modules of claim **10**, wherein either at least three of the plurality of inputs are terminated with loads or at least three of the plurality of outputs are terminated with loads or both.

12. The plurality of circulator modules of claim **10**, wherein each third input of the plurality of inputs is terminated with a load and wherein each third output of the plurality of outputs is terminated with a load.

13. The plurality of circulator modules of claim **10**, wherein the plurality of circulator modules comprises at least six circulator modules.

14. The plurality of circulator modules of claim **10**, wherein each module of the plurality of circulator modules comprises at least three circulators.

15. The plurality of circulator modules of claim **10**, wherein each third circulator module in the plurality of circulator modules includes a 2-for-1 redundant triad switch and wherein each of the 2-for-1 redundant triad switches is coupled to two components in the plurality of components.

16. The plurality of circulator modules of claim **10**, wherein every circulator module in the plurality of circulator modules includes a 2-for-1 redundant triad switch and wherein each of the 2-for-1 redundant triad switches is coupled to two components in the plurality of components.

17. The plurality of circulator modules of claim **10**, further comprising a waveguide connecting a first end of the plurality of circulator modules to a second end of the plurality of circulator modules, wherein the first end is located opposite the second end in the plurality of circulator modules.

18. The plurality of circulator modules of claim **10**, wherein if a first component in the plurality of components fails, the plurality of circulator modules is able to route a path through a redundant component in the plurality of components without disrupting an active communication path in the plurality of circulator modules other than the path that was active prior to when the first component failed.

19. A method for switching communication paths in a circulator redundancy network, the method comprising:

identifying a failed component in a plurality of failed components, wherein the failed component is connected to a communicative path through the circulator redundancy network and the plurality of failed components comprises at least two previously failed components, the circulator redundancy network comprising a plurality of circulator modules, wherein a circulator module comprises:

a plurality of circulators that are configurable to route received signals through the circulator redundancy network along a plurality of communication paths by connecting with other circulator modules in the plurality of circulator modules and by connecting with a plurality of components;

identifying a standby component in the plurality of components, wherein the standby component is connected to an open path through the circulator redundancy network and the at least two previously failed components are connected to open paths through the circulator redundancy network; and

changing a direction of circulation of one or more of the plurality of circulators in the plurality of circulator modules such that the standby component is connected to a communicative path through the circulator redundancy network, and the failed component is connected to an open path through the circulator redundancy network.

20. The method of claim **19**, further comprising changing a direction of circulation of one or more of the plurality of circulators in the plurality of circulator modules such that an active communication path is not disrupted in the circulator redundancy network when a first failed component in the plurality of failed components fails.

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