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Setty et al.

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(54) **LOW COST SPLITTER**

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(52) **U.S. Cl.** **333/131**; 333/118
(58) **Field of Search** 333/131, 118, 119

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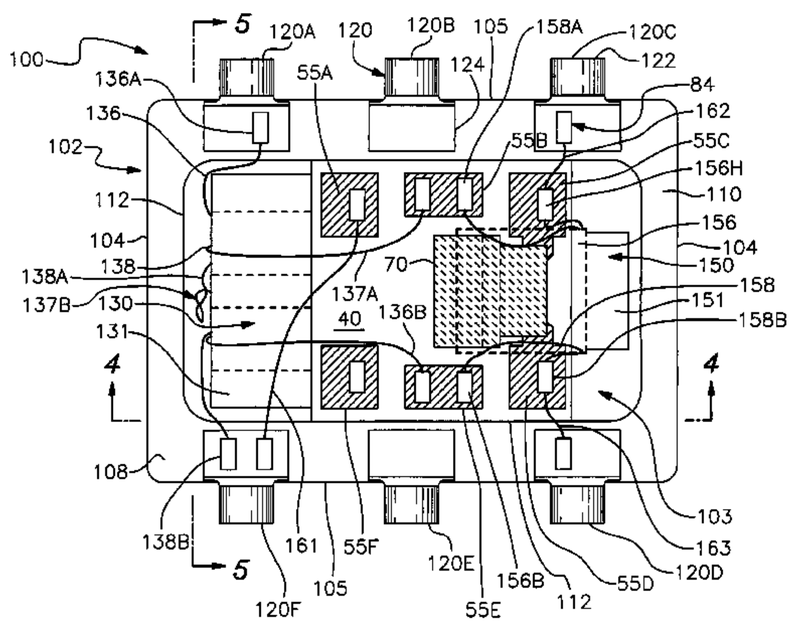
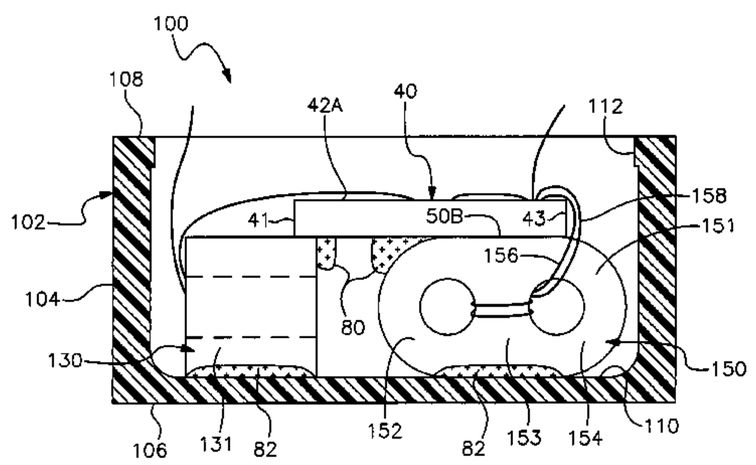
(57) **ABSTRACT**

A low cost power splitter that has a small size and can be used with automated surface mount manufacturing equipment. The power splitter includes a case having a cavity and a lead mounting surface. Leads are secured to the lead mounting surface. A substrate is mounted in the cavity. The substrate has top surface, a bottom surface and inner layers. A resistor is formed on the top surface. A capacitor is formed on the inner layers. Terminals are located on the top surface and vias extend through the substrate. A pair of transformers are attached to the bottom surface and to the case by an adhesive. The transformers have windings that are connected to the terminals. Connector wires are connected between the terminals and the leads.

20 Claims, 10 Drawing Sheets





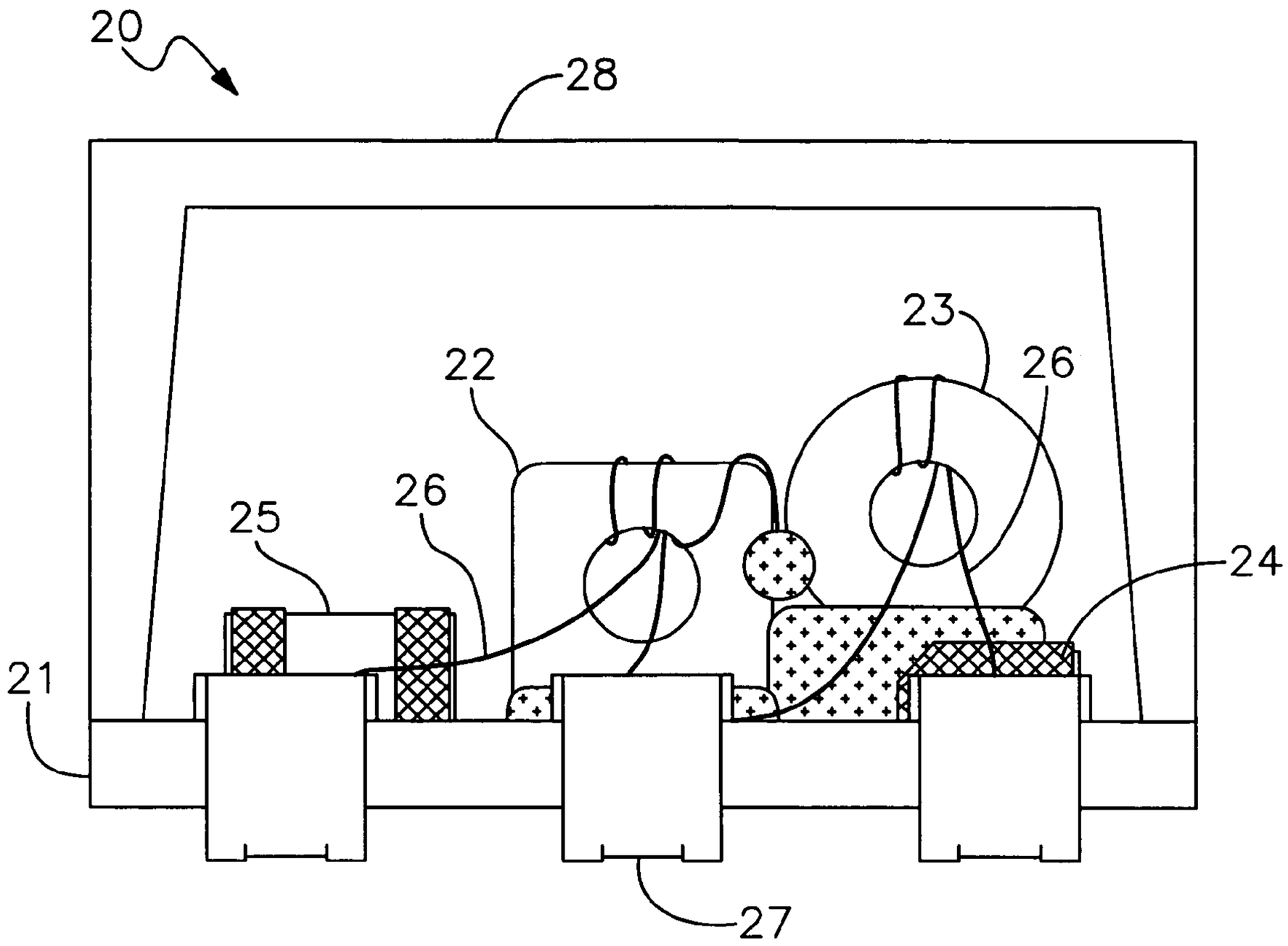


Fig. 1 (Prior Art)

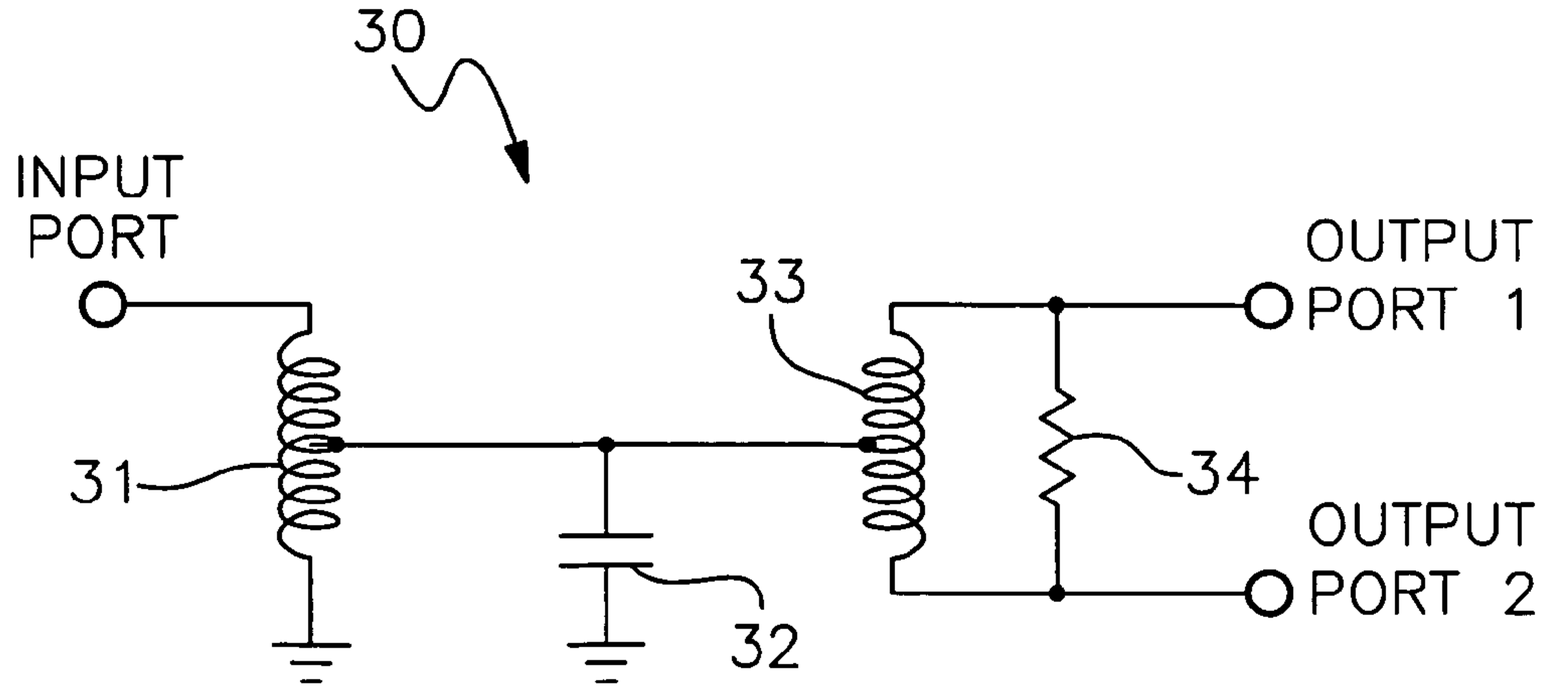


Fig. 2

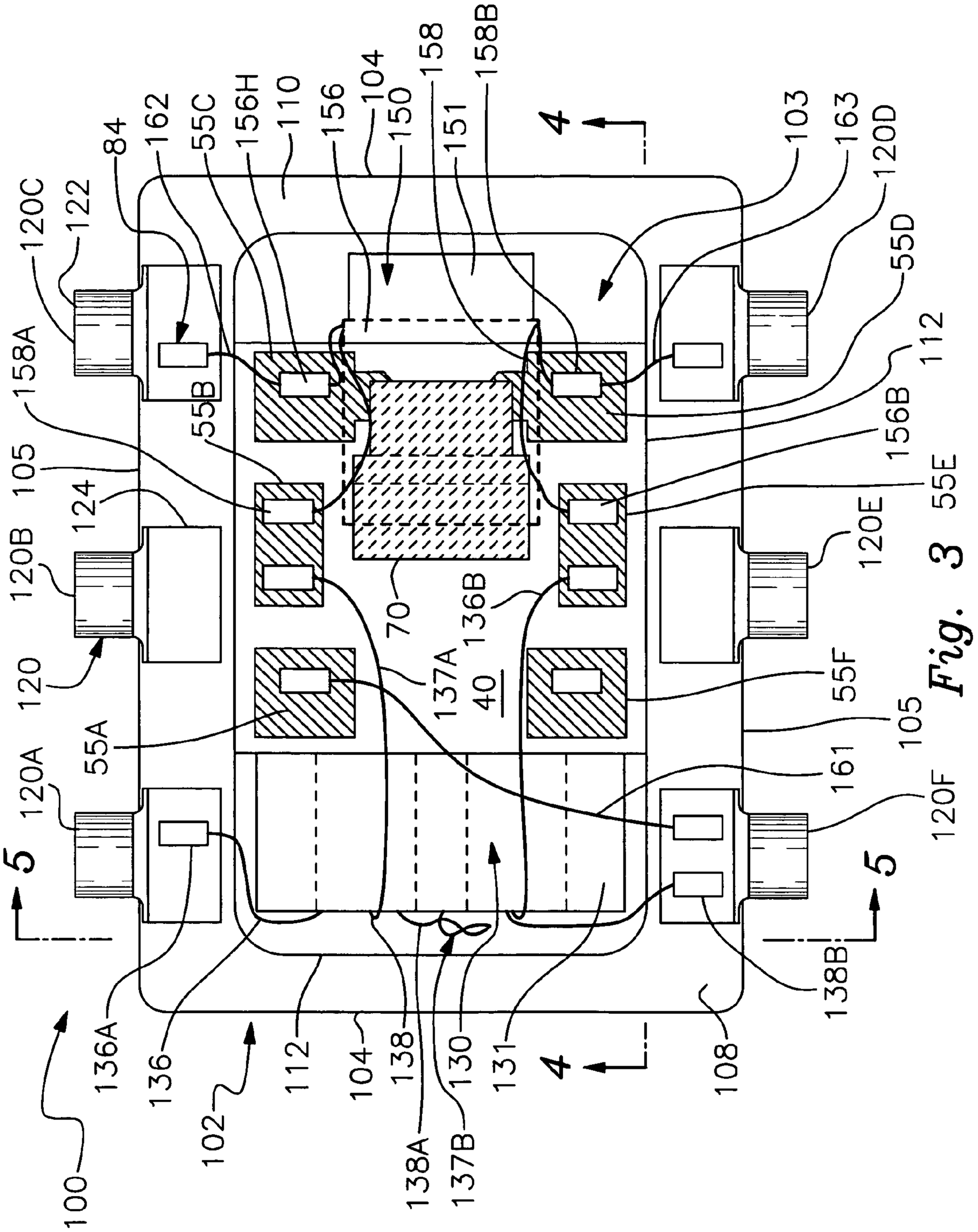

84
162
55C
156H
110
156
104
150
158
151
158B
4
103
163
120D
55D
112
156B
55E
120E
55F
105
161
120F
138B
158A
55B
105
124
120B
120
55A
120A
5
70
136B
137A
40
136A
136
102
112
104
138
130
131
138A
137B
100
108

Fig. 3

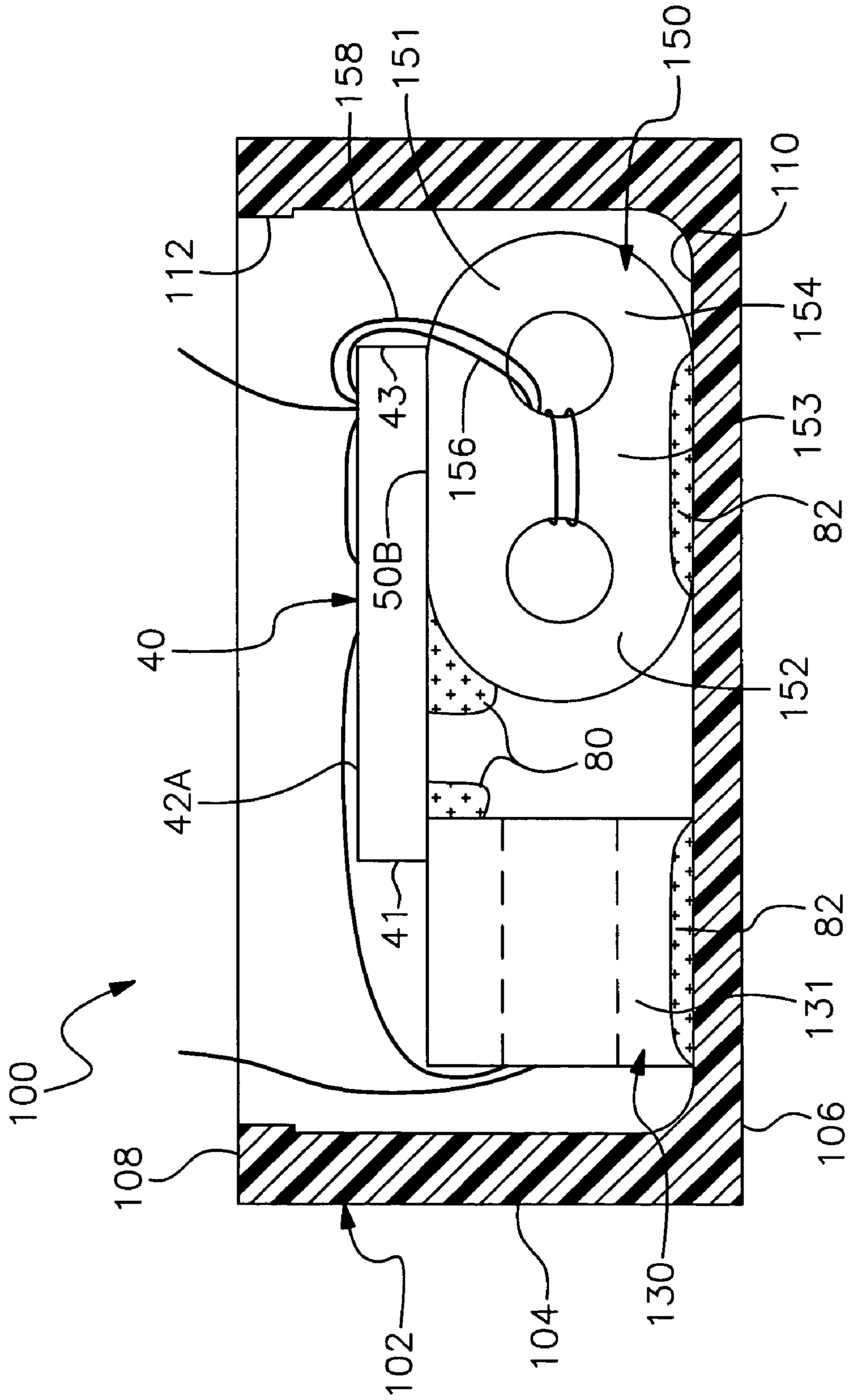

158
151
150
110
112
154
43
153
156
82
50B
40
152
80
42A
41
82
131
100
106
108
102
104
130

Fig. 4

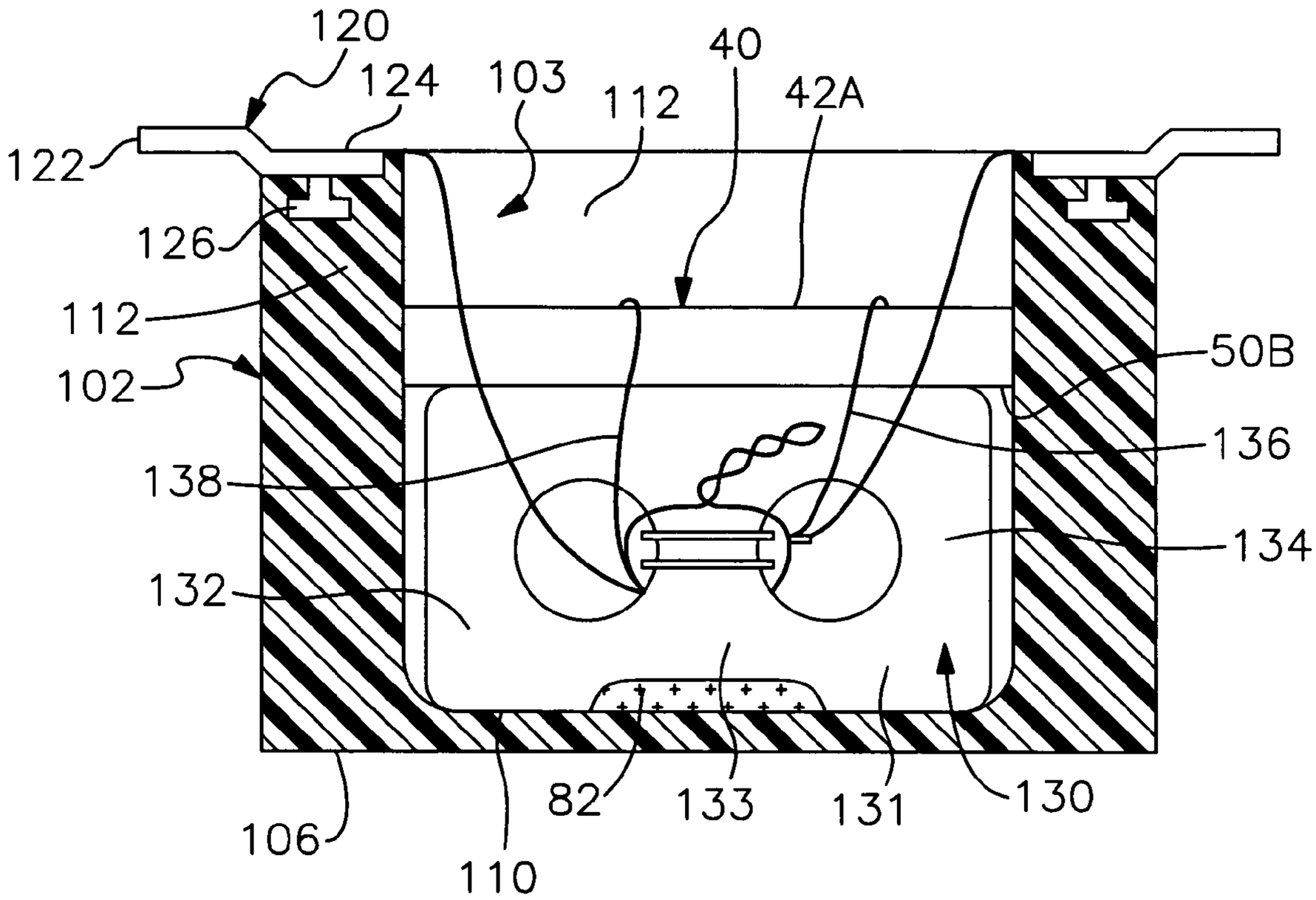

120
124
103
112
40
42A
122
126
112
102
50B
136
138
134
132
82
133
131
130
106
110

Fig. 5

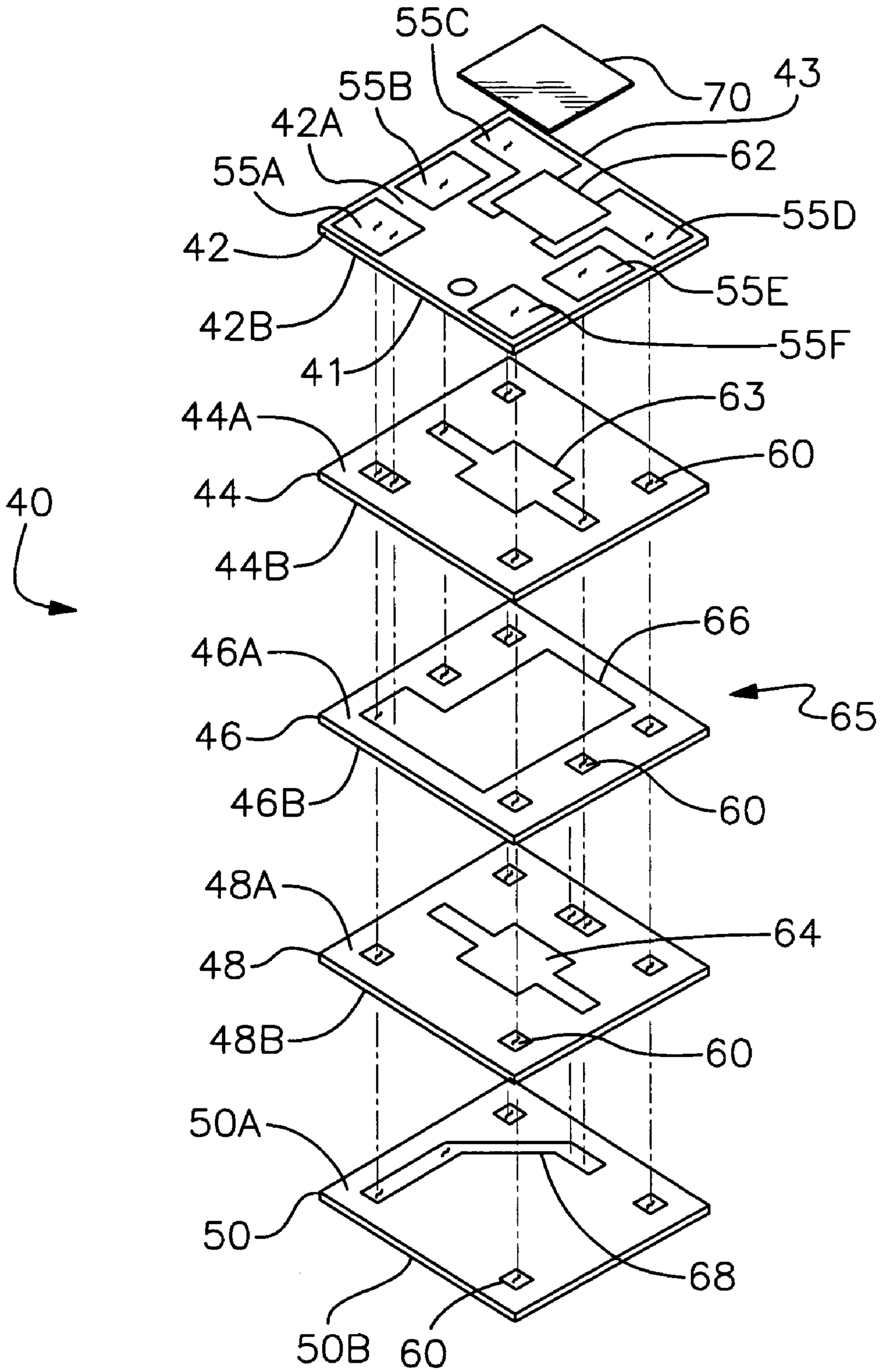

55C
55B
42A
55A
42
42B
41
44A
44
44B
40
70
43
62
55D
55E
55F
63
60
66
46A
46
46B
65
60
48A
48
48B
64
60
50A
50
50B
60
68

Fig. 6

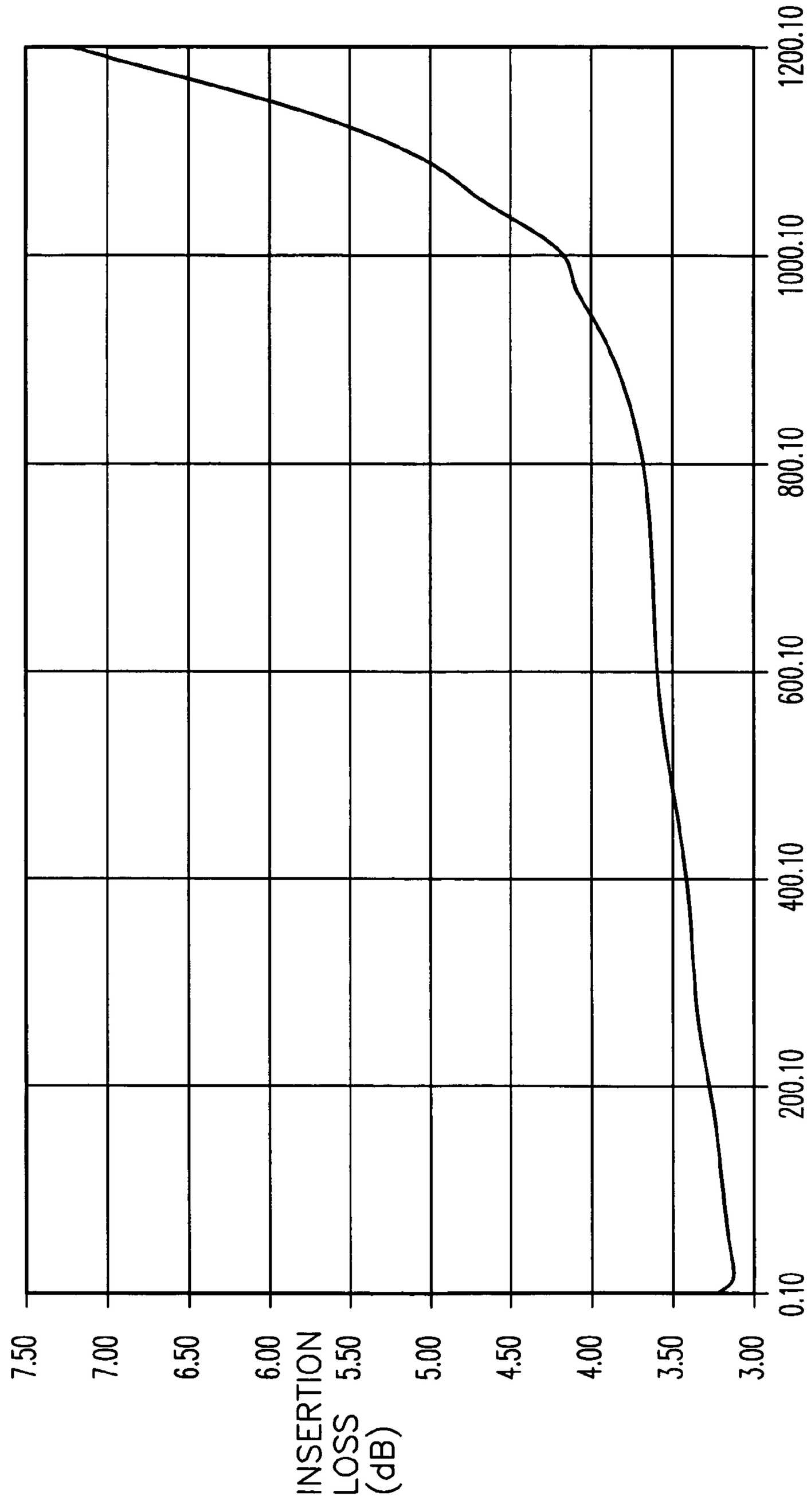

INSERTION LOSS
INSERTION LOSS (dB)
7.50
7.00
6.50
6.00
5.50
5.00
4.50
4.00
3.50
3.00
0.10
200.10
400.10
600.10
800.10
1000.10
1200.10
FREQUENCY (MHz)

Fig. 7

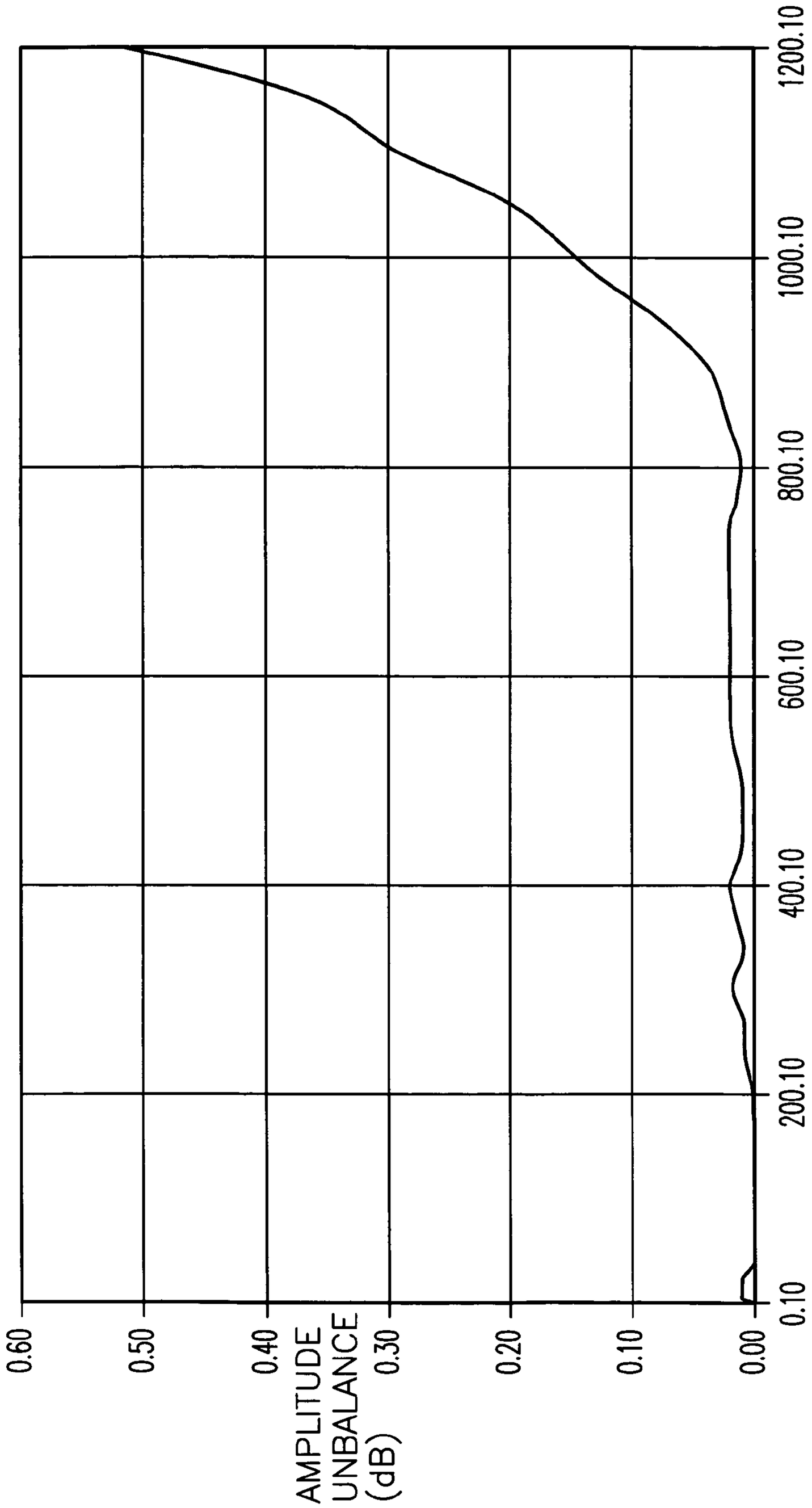

AMPLITUDE UNBALANCE (dB)
0.60
0.50
0.40
0.30
0.20
0.10
0.00
FREQUENCY (MHz)
0.10
200.10
400.10
600.10
800.10
1000.10
1200.10

Fig. 8

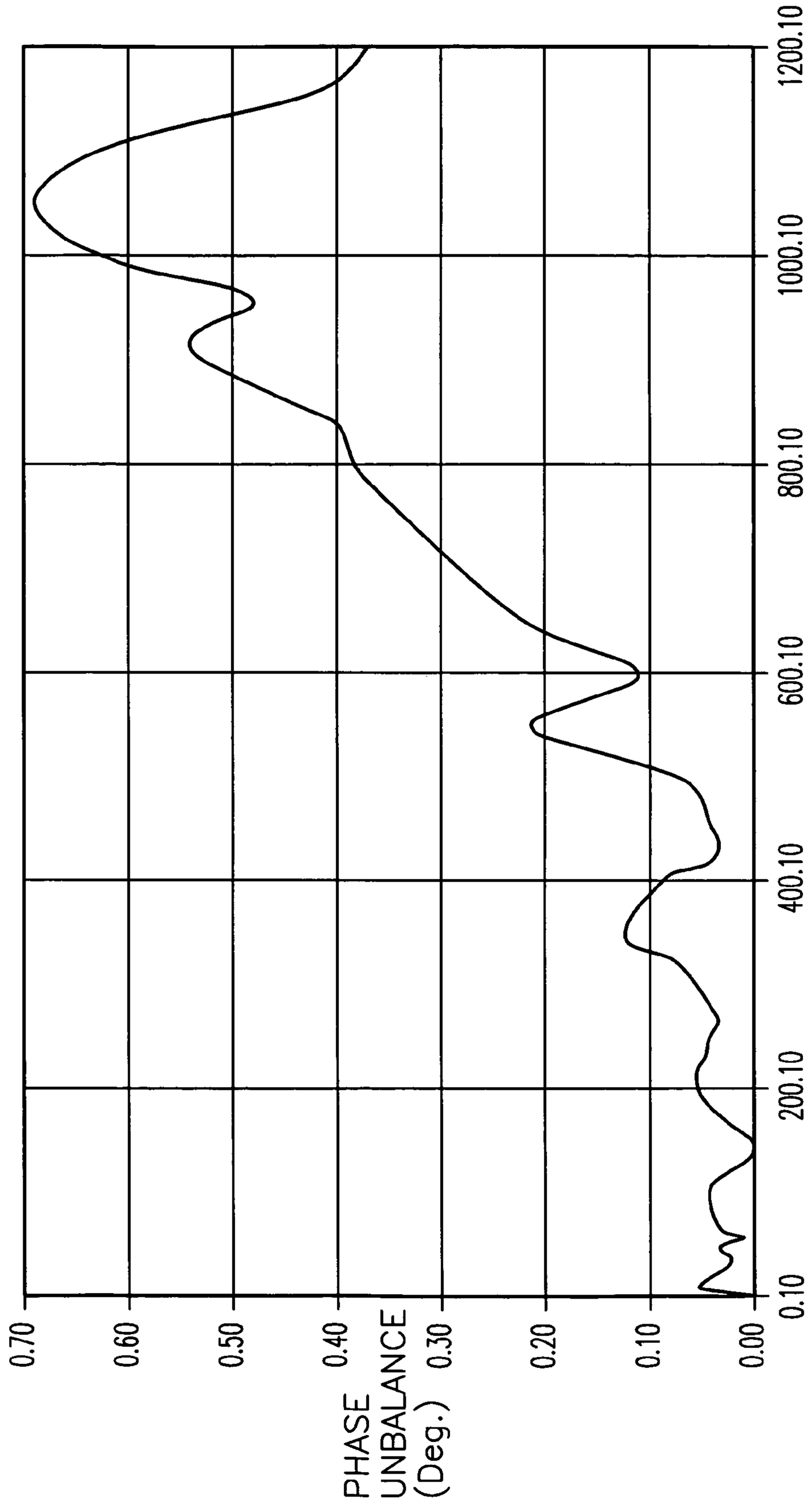

PHASE UNBALANCE
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
PHASE UNBALANCE (Deg.)
0.10
200.10
400.10
600.10
800.10
1000.10
1200.10
FREQUENCY (MHz)

Fig. 9

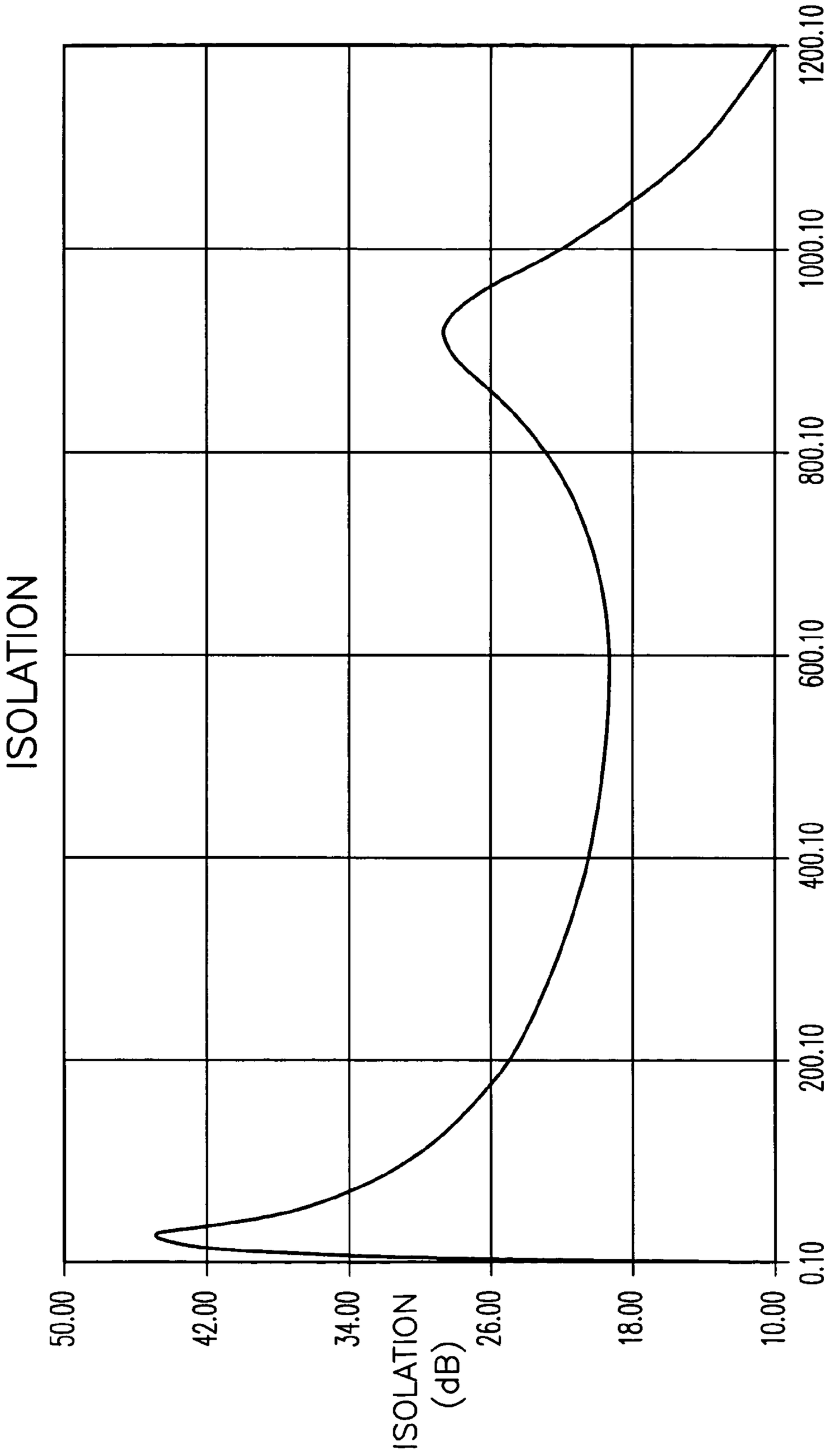

ISOLATION
FREQUENCY (MHz)
1200.10
1000.10
800.10
600.10
400.10
200.10
0.10
ISOLATION (dB)
50.00
42.00
34.00
26.00
18.00
10.00

Fig. 10

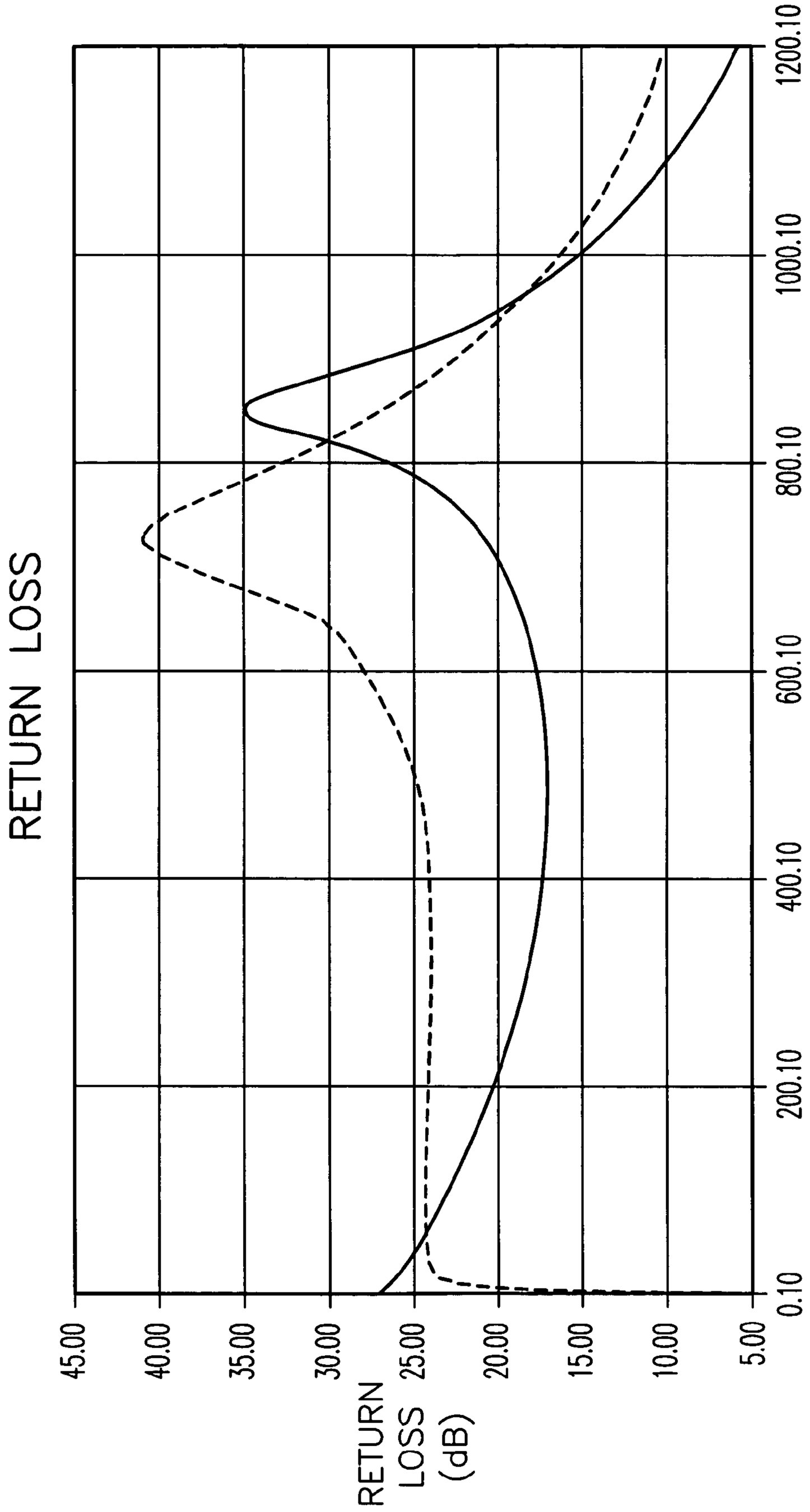

RETURN LOSS
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
RETURN LOSS (dB)
0.10
200.10
400.10
600.10
800.10
1000.10
1200.10
FREQUENCY (MHz)

Fig. 11

LOW COST SPLITTER

BACKGROUND

1. Field of the Invention

This invention relates to power splitters used with RF and microwave frequency signals in general and more particularly to a power splitter having a small package size that can be manufactured at low cost.

2. Description of the Related Art

Power splitters operating at frequencies up to 3 GHz have been made with ferrite transformers along with resistors and capacitors arranged around the ferrite transformers. When the frequency range starts below 10 MHz, two ferrite cores are necessary to achieve the desired electrical performance. The power splitter components typically use chip resistors and chip capacitors packaged on a circuit board.

Referring to FIG. **1**, a prior art power splitter package is shown. Power splitter package **20** has a circuit board **21** upon which are mounted a pair of single core transformers **22** and **23**. A chip resistor **24** and chip capacitor **25** are soldered onto circuit board **21** to one side of the transformers **22** and **23**. Transformer wires **26** are attached to leads **27**. A cover **28** is required to be placed over circuit board **21**. The cover is required in order to protect the splitter components and to provide a surface for an automated surface mount machine to grasp and pickup the power splitter.

Unfortunately, placing the resistors and capacitors beside each transformer increases the size or footprint of the power splitter package and also complicates the assembly process. The mounting of the cover adds additional process steps and the expense of the cover. The use of the cover also reduces the ability to cool the power splitter. The cover causes the power splitter package to have a large height, which is undesirable in many applications. The cover can also trap liquids used during the manufacturing process possibly leading to increased corrosion or failure.

While power splitters have been used, they have suffered from being too large, difficult to assemble and are not easily used with automated surface mount equipment. A current unmet need exists for a power splitter that has a smaller size, can be assembled at a low cost and that can be used with automated surface mount equipment.

SUMMARY

It is a feature of the invention to provide a power splitter having a small package size that has improved electrical characteristics.

Another feature of the invention is to provide an electronic package for a power splitter that can be used with automated surface mount manufacturing equipment.

Another feature of the invention is to provide a power splitter that takes up less printed circuit board space and has improved electrical repeatability.

A further feature of the invention is to provide a method of manufacturing a low cost power splitter.

A further feature of the invention is to provide an electronic package for a power splitter that includes a case having a cavity, a top surface and a lead mounting surface. The cavity defines four walls and a bottom surface. The cavity is exposed in order to provide access to the cavity.

Leads are secured to the lead mounting surface on two of the walls. The leads have a proxil end attached to the lead mounting surface and a distal end that extends outwardly from the case and downwardly away from the lead mounting surface. Each lead has a lead extension which is embedded in one of the walls in order to secure the lead to the case.

A substrate is mounted within the cavity and is surrounded by the walls. The substrate includes a first end, a second end, a top surface, a bottom surface and a plurality of inner layers. A film resistor is formed on the top surface. A capacitor is formed on the inner layers. Terminals are located on the top surface and vias extend through the substrate between the top surface and the bottom surface. The vias electrically connect the resistor, the capacitor and the terminals.

A first transformer is attached to the bottom surface of the substrate at the first end. The first transformer has a first winding. The first winding extends from the first transformer on the bottom surface to the terminals on the top surface. The first winding is electrically connected to the terminals. A second transformer is attached to the bottom surface of the substrate at the second end. The second transformer has a second winding. The second winding extends from the second transformer on the bottom surface to the terminals on the top surface. The second winding is electrically connected to the terminals. The first and second transformers are attached to the bottom surface of the case by an adhesive. Several connector wires are connected between the terminals and the leads.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a side cross-sectional view of a prior art power splitter package.

FIG. **2** is an electrical schematic of a power splitter.

FIG. **3** is a top assembled view of a low cost power splitter in accordance with the present invention.

FIG. **4** is a side cross-sectional view of FIG. **3** along section line **4**—**4**.

FIG. **5** is another side cross-sectional view of FIG. **3** along section line **5**—**5**.

FIG. **6** is an exploded view of the substrate of the present invention.

FIG. **7** is a graph showing insertion loss versus frequency for the power splitter of FIG. **3**.

FIG. **8** is a graph showing amplitude imbalance versus frequency for the power splitter of FIG. **3**.

FIG. **9** is a graph showing phase unbalance versus frequency for the power splitter of FIG. **3**.

FIG. **10** is a graph showing isolation versus frequency for the power splitter of FIG. **3**.

FIG. **11** is a graph showing return loss versus frequency at the input and output ports for the power splitter of FIG. **3**.

It is noted that the drawings of the invention are not to scale.

DETAILED DESCRIPTION

Referring to FIG. **2**, a schematic diagram of a power splitter circuit **30** is shown. Power splitter **30** has an input port connected to a transformer **31**. One end of the transformer **31** is connected to ground. A capacitor **32** is connected between a midpoint of transformer **31** and to ground. Another transformer **33** has a midpoint connected to capacitor **32**. Transformer **33** has one end connected to output port **1** and another end connected to output port **2**. A resistor **34** is connected between output ports **1** and **2**. A signal applied to the input port is equally split into two signals at the output ports **1** and **2**. Transformer **33** splits the input signal. Transformer **31** and capacitor **32** provide impedance match-

ing to the input port. Capacitor **32** is required to match the reactive part of the impedance. The resistor **34** plays an important role in providing isolation between the two output ports **1** and **2**. Power splitter **30** is a 2 way power splitter since the input signal is split into two output signals.

Referring to FIGS. **3–6**, the electrical schematic of the power splitter of FIG. **2** is realized in a physical package. Power splitter **100** has a case **102** having a cavity **103**. Case **102** has outer surfaces **104, 105**, a top surface **106**, and a lead mounting surface **108**. Case **102** has a length, a height and a width. Cavity **103** defines four walls **112** and a bottom surface **110**. Cavity **103** is exposed in order to provide access to the cavity. The case can be formed from an insulative material such as plastic. Six metal leads **120** are secured to the lead mounting surface **108** adjacent to outer surface **105**. The leads include leads **120**A, **120**B, **120**C, **120**D, **120**E and **120**F. The leads have a proxil end **124** that is attached to the lead mounting surface **108** and a distal end **122** that extends outwardly from the case outer surface **105**. Distal end **122** also extends downwardly away from the lead mounting surface **108**. Leads **120** have a lead extension **126** which is embedded into wall **112** in order to secure the lead to the case. Further details on the construction of case **102** can be found in U.S. Pat. No. 6,133,525, the contents of which are herein incorporated by reference in entirety.

FIG. **6** shows a low temperature co-fired ceramic (LTCC) substrate **40**. Substrate **40** has ends **41** and **43**. LTCC substrate **40** is comprised of multiple layers of low temperature co-fired ceramic material. Planar layers **42, 44, 46, 48** and **50** are all stacked on top of each other and form a unitary structure **40** after firing in an oven. LTCC layers **42–50** are commercially available in the form of a green unfired tape from Dupont Corporation. Each of the layers has a top surface, **42**A, **44**A, **46**A, **48**A and **50**A. Similarly, each of the layers has a bottom surface, **42**B, **44**B, **46**B, **48**B and **50**B.

The layers have several circuit features that are patterned on the top surfaces. Multiple vias **60** extend through each of the layers. Vias **60** are formed from an electrically conductive material and electrically connect one layer to another layer. Layer **42** has several circuit features that are patterned on surface **42**A. Surface **42**A has six terminals **55** and a film resistor **62**. Terminals **55** include terminal **55**A, **55**B, **55**C, **55**D, **55**E and **55**F. One of the terminals **55** forms an input port. Two of the terminals **55** form output ports **1** and **2**. The terminals are electrically connected to vias **60**. The resistor **62** has a protective insulative overglaze **70** to protect the resistor from abrasion and shorting. Layer **44** has an upper capacitor electrode **63** formed on surface **44**A. The upper electrode **63** is connected on two sides to a via **60**. Layer **46** has a ground plane **66** formed on surface **46**A. The ground plane **66** is connected on two sides to a via **60**. Layer **48** has a lower capacitor electrode **64** formed on surface **48**A. The lower electrode **64** is connected on two sides to a via **60**. The upper and lower electrodes and the insulative LTCC layers in between form a capacitor **65**. Layer **50** has a circuit line **68** formed on surface **50**A. The circuit line **68** is connected at the ends and the middle to vias **60**. Further details on the construction of substrate **40** can be found in U.S. patent publication No. 2002/0186,096 the contents of which are herein incorporated by reference in entirety.

Turning now to FIGS. **3, 4** and **5**, transformers **130** and **150** are mounted to substrate **40**. The transformers perform the power splitting and matching functions. Transformer **130** is mounted to surface **50**B at end **41** by an adhesive **80**. Transformer **150** is mounted to surface **50**B at end **43** by an adhesive **80**. Adhesive **80** can be an epoxy or other suitable glue. Transformer **130** has a ferrite binocular core **131** with three legs **132, 133** and **134**. Transformer **150** has a ferrite binocular core **151** with three legs **152, 153** and **154**.

Transformer **130** has three wire windings **136, 137** and **138**. Transformer **130** has a core **131** with outer legs **132, 134** and a middle leg **133**. Wire winding **136** has ends **136**A and **136**B. Wire winding **137** has ends **137**A and **137**B. Wire winding **138** has ends **138**A and **138**B. Windings **136, 137** and **138** are wound around middle leg **133**. The wire ends are attached to leads **120** and terminals **55** by welds **84**. End **136**A is connected to lead **120**A. End **136**B is connected to terminal **55**E. End **137**A is connected to terminal **55**B. End **137**B is connected to end **138**A by soldering. End **138**B is connected to lead **120**F.

Transformer **150** has a pair of wire windings **156** and **158**. Transformer **150** has a core **151** with outer legs **152, 154** and a middle leg **153**. Wire winding **156** has ends **156**A and **156**B. Wire winding **158** has ends **158**A and **158**B. Windings **156** and **158** are wound around middle leg **153**. The wire ends are attached to terminals **55** by welding. End **156**A is connected to terminal **55**C. End **156**B is connected to terminal **55**E. End **158**B is connected to terminal **55**D. End **158**A is connected to terminal **55**B.

Substrate **40** is located within cavity **103**. Surface **42**A faces upwardly and is exposed. Surface **50**B faces toward bottom surface **110**. Transformers **130** and **150** are further mounted to bottom surface **110** of case **102** by adhesive **82**. Adhesive **82** can be an epoxy or other suitable glue. Adhesive **82** holds the transformers, which hold substrate **40**. Several connector wires are connected between the terminals and the leads. Connector wire **161** is connected between terminal **55**A and lead **120**F. Connector wire **162** is connected between terminal **55**C and lead **120**C. Connector wire **163** is connected between terminal **55**D and lead **120**D.

The power splitter **100** would be mounted to a printed circuit board (not shown). The leads **120** would be attached to the printed circuit board using a reflowed solder paste. The leads are bent such that distal end **122** would extend down to and contact the printed circuit board. Solder paste would be screen printed onto the printed circuit board. Ends **122** would be placed onto the solder paste and melted in a re-flow oven to attach the power splitter package to the printed circuit board.

Power splitter **100** can be assembled in the following manner:

1. Dispensing an adhesive **82** onto the bottom surface **110** of the case.
2. Transformers **130** and **150** with windings are placed onto adhesive **82** and cured.
3. Adhesive **80** is dispensed onto the top of transformers **130** and **150**.
4. Substrate **40** is placed on adhesive **80** and cured.
5. Wire welding the appropriate windings to terminals **55** and leads **120**.
6. Attaching connecting wires **161, 162** and **163** between the leads and the terminals.
7. Electrically testing the completed assembly.

Power splitter **100** can be used to make 4-way and 8-way splitters as well as higher order splitters. Since power splitter **100** is a 2-way power splitter, the 2-way splitter is cascaded to form 4-way and 8-way power splitters. Multiple power splitters **100** would be mounted side by side on a printed circuit board. Although this technique is well known there are several advantages of cascading power splitter **100**. First, the small size of power splitter **100** makes cascading practical because the higher order splitter is still very small. It is still possible to fit multiple splitters **100** used in 4 & 8-way splitters in a small space. Second, using the same 2-way

splitter repeatedly in high volume reduces cost because the same splitter parts can be bought in large volume and at reduced cost.

The present invention has several advantages. Since, the resistor **62** and capacitor **65** are integrated into the low temperature co-fired ceramic substrate, they do not have to be mounted separately adjacent to a transformer. This allows for a smaller package that can be assembled faster at lower cost. Fabricating the power splitter using a low temperature co-fired ceramic substrate results in more uniform electrical characteristics in the power splitter.

Another advantage of the present invention is that it eliminates the need for a separate cover. Since the case **102** is mounted with cavity **103** facing downward onto a printed circuit board, a separate cover is not needed. The mounting of the cover adds additional process steps and the expense of the cover itself.

A further advantage of the present invention is improved electrical performance.

Another advantage of the present invention is that the case allows an automated surface mount machine to grasp the outer surface of the case during assembly processing. Automated assembly reduces the cost of manufacturing the end product.

Omitting a cover improves cooling by exposing the power splitter to ambient air. Eliminating the cover prevents the trapping of liquids used during the manufacturing process that may be corrosive.

A further advantage of the present invention is that the combination of mounting substrate **40** within case **102** results in a power splitter package that has a very low overall height, which is very desirable in many applications.

Referring to FIG. **7**, a graph showing the insertion loss for power splitter **100** is shown for frequencies from 0 to 1200 MHz. FIG. **8** shows a graph of amplitude unbalance versus frequency for power splitter **100**. Amplitude unbalance is the difference of output power between output ports **1** and **2**.

FIG. **9** is a graph showing phase unbalance versus frequency for the power splitter. FIG. **10** shows a graph of isolation versus frequency for the power splitter between the output ports **1** and **2**. FIG. **11** shows a graph of return loss versus frequency for the power splitter. The return loss at the input port and output ports are shown.

While the invention has been taught with specific reference to these embodiments, someone skilled in the art will recognize that changes can be made in form and detail without departing from the spirit and the scope of the invention. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather than by the description. All changes that come within the meaning and range of equivalency of the claims are to be embraced within their scope.

What is claimed is:

1. A power splitter comprising:

a) a substrate having a top layer, a bottom layer, and a plurality of inner layers;

b) a resistor formed on the top layer;

c) a capacitor formed between one of the inner layers;

d) a plurality of terminals located on the top layer;

e) a plurality of vias extending through the substrate, the vias electrically connecting the resistor, the capacitor and the terminals;

f) a first transformer attached to the bottom layer, the first transformer having a first winding, the first winding extending from the first transformer on the bottom layer to the terminals on the top surface, the first winding electrically connected to the terminals;

g) a second transformer attached to the bottom layer, the second transformer having a second winding, the second winding extending from the second transformer on the bottom layer to the terminals on the top surface, the second winding electrically connected to the terminals;

h) a case having a cavity, a top surface and a lead mounting surface, the cavity defining four walls and a bottom surface, the cavity being exposed in order to provide access to the cavity;

i) a plurality of leads secured to the lead mounting surface, the leads having a proxil end attached to the lead mounting surface and a distal end that extends outwardly from the case and downwardly away from the lead mounting surface, each lead including a lead extension which is embedded in one of the walls in order to secure the lead to the case;

j) the substrate mounted within the cavity such that the first and second transformers are attached to the bottom surface; and

k) a plurality of connector wires connected between the terminals and the leads.

2. The power splitter according to claim **1** wherein the substrate is formed from layers of low temperature co-fired ceramic.

3. The power splitter according to claim **1** wherein the first transformer has a first binocular core and the second transformer has a second binocular core.

4. The power splitter according to claim **1** wherein the transformers are attached to the bottom layer of the substrate using an adhesive.

5. The power splitter according to claim **1** wherein the transformers are attached to the bottom surface of the case using an adhesive.

6. The power splitter according to claim **1** wherein the windings are electrically connected to the terminals by a plurality of welds.

7. The power splitter according to claim **1** wherein the connector wires are electrically connected to the leads by a plurality of welds.

8. The power splitter according to claim **1** wherein the case is adapted to be grasped by an automated machine.

9. The power splitter according to claim **1** wherein the capacitor has a first electrode formed on one of the inner layers and a second electrode formed on another of the inner layers.

10. An electronic package for a power splitter comprising:

a) a case having a cavity, a top surface and a lead mounting surface, the cavity defining four walls and a bottom surface, the cavity being exposed in order to provide access to the cavity;

b) a plurality of leads secured to the lead mounting surface on two of the walls, the leads having a proxil end attached to the lead mounting surface and a distal end that extends outwardly from the case and downwardly away from the lead mounting surface, each lead including a lead extension which is embedded in one of the walls in order to secure the lead to the case;

c) a multi layered substrate mounted within the cavity and surrounded by the walls, the substrate including a first end, a second end, a top surface, a bottom surface and a plurality of inner layers, a film resistor being formed on the top surface, a capacitor formed on the inner layers, a plurality of terminals located on the top surface and a plurality of vias extending through the substrate between the top surface and the bottom sur-

face, the vias electrically connecting the resistor, the capacitor and the terminals;

d) a first transformer attached to the bottom surface of the substrate at the first end, the first transformer having a first winding, the first winding extending from the first transformer on the bottom surface to the terminals on the top surface, the first winding electrically connected to the terminals;

e) a second transformer attached to the bottom surface of the substrate at the second end, the second transformer having a second winding, the second winding extending from the second transformer on the bottom surface to the terminals on the top surface, the second winding electrically connected to the terminals;

f) the first and second transformers attached to the bottom surface of the case by an adhesive; and

g) a plurality of connector wires connected between the terminals and the leads.

11. The power splitter according to claim **10** wherein the first transformer has a first binocular core having a first leg, a middle leg and a third leg and the second transformer has a second binocular core having a first leg, a second leg and a third leg.

12. The power splitter according to claim **11** wherein the first winding is wound on the middle leg.

13. The power splitter according to claim **11** wherein the second winding is wound on the middle leg.

14. The power splitter according to claim **11** wherein the second winding has four ends, two of the ends connected to the terminals and the other two ends connected to the leads.

15. The power splitter according to claim **10** wherein a portion of the transformers extend over the ends of the substrate.

16. The power splitter according to claim **10** wherein the transformers are attached to the bottom surface of the substrate using an adhesive.

17. The power splitter according to claim **10** wherein the cavity being openly exposed allows the power splitter to be cooled.

18. The power splitter according to claim **10** wherein the case is adapted to be grasped by an automated machine.

19. A method of manufacturing a power splitter package comprising the steps of:

a) providing a low temperature co-fired ceramic substrate having a resistor, a capacitor and a plurality of terminals;

b) providing a case having a cavity, a bottom surface and a plurality of leads extending from the case;

c) dispensing a first adhesive on the bottom surface of the case;

d) inserting a first and second transformer onto the first adhesive, the transformers having a plurality of windings;

e) curing the first adhesive;

f) dispensing a second adhesive onto the first and second transformers;

g) placing the substrate onto the second adhesive;

h) curing the second adhesive;

i) wire welding the windings to the terminals; and

j) attaching a plurality of connecting wires between the leads and the terminals.

20. The method according to claim **19** wherein the power splitter package is attached to a printed circuit board, further comprising the steps of:

a) screening a solder paste onto the printed circuit board;

b) placing the power splitter package such that a distal end of the leads contacts the printed circuit board; and

c) reflowing the solder paste such that the power splitter package is attached to the printed circuit board.

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