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Ji

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(54) **MINIATURE 180 DEGREE POWER SPLITTER**

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This patent is subject to a terminal disclaimer.

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(51) **Int. Cl.**[7] **H04B 1/52**

(52) **U.S. Cl.** **333/119**; 333/25; 333/118; 333/124; 333/131

(58) **Field of Search** 333/25, 118–119, 333/124, 131

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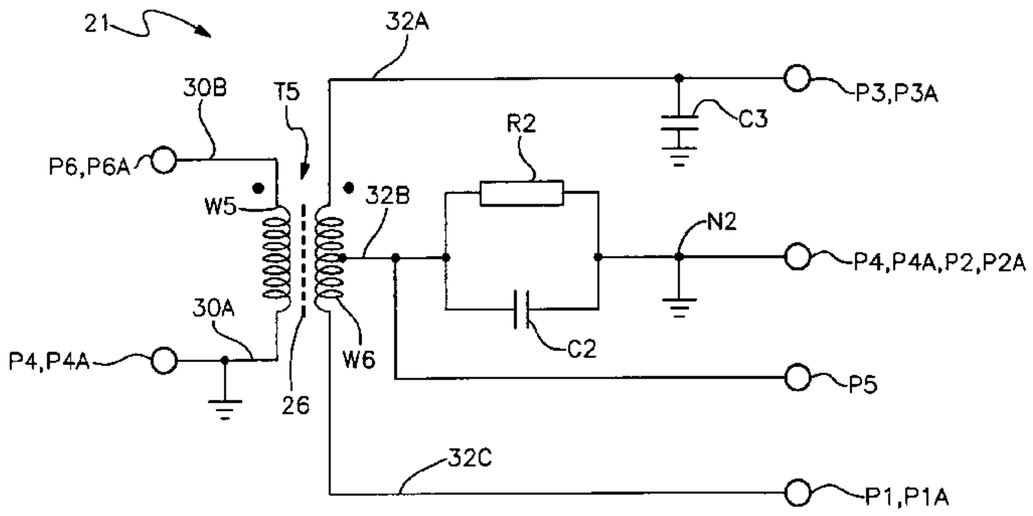
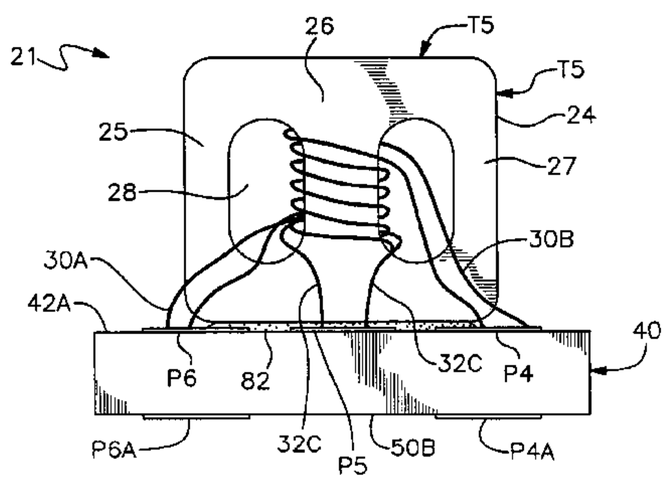
(57) **ABSTRACT**

A power splitter that has a small package size and repeatable electrical characteristics. The power splitter includes a low temperature co-fired ceramic (LTTC) substrate with several layers. Electrical components such as resistors, capacitors and ground planes are integrated within the LTTC substrate. A binocular core transformer is attached to the upper surface of the LTTC substrate and is electrically connected to the resistors, capacitors and ground plane. The transformer provides impedance matching and dividing functions. The LTTC substrate has electrically conductive vias extending through the layers. The vias are used to connect the power splitter to terminals on outer surfaces of the substrate and to make electrical connections between the layers of the LTTC substrate. The power splitter circuit requires only one transformer.

11 Claims, 8 Drawing Sheets





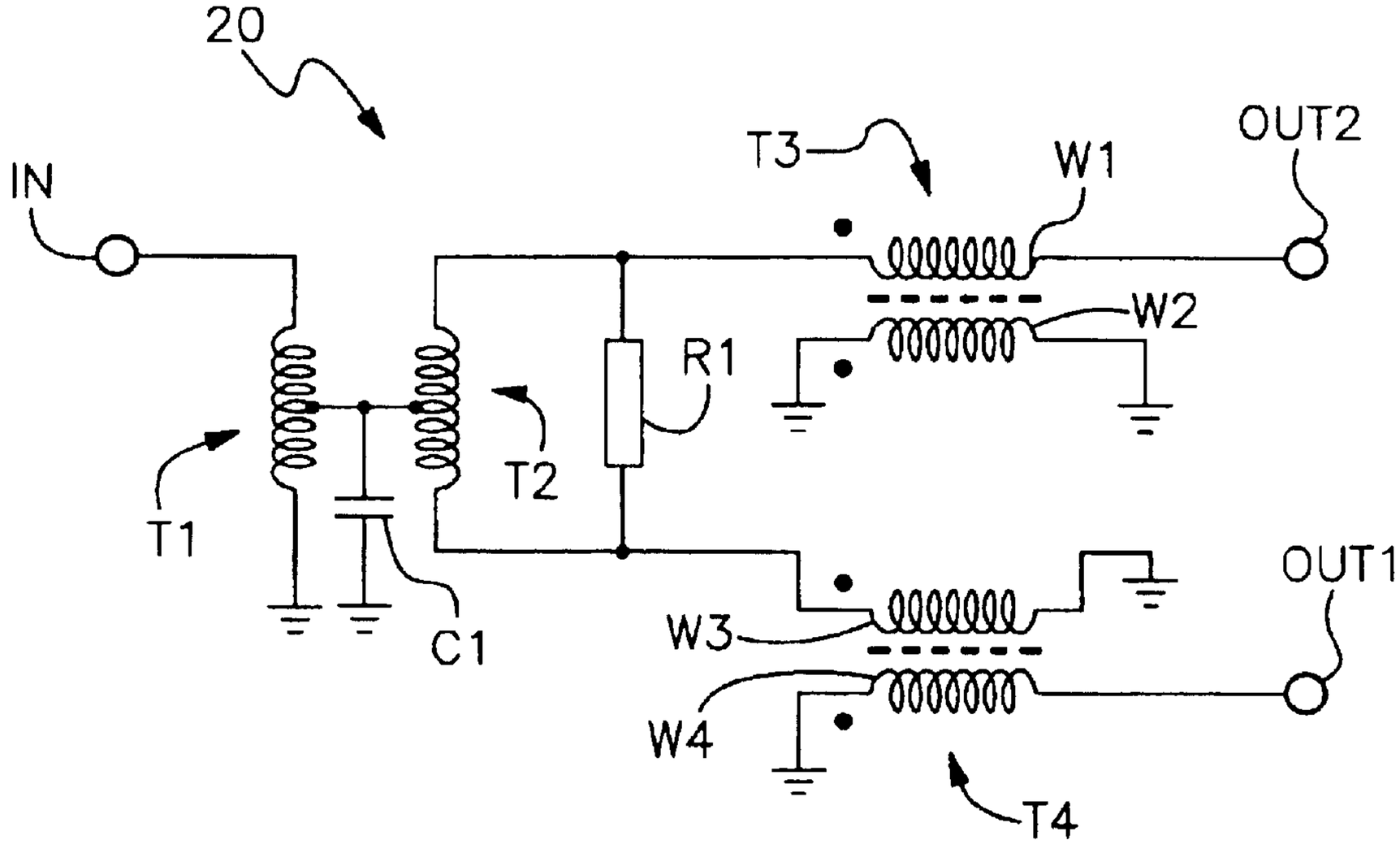


Fig. 1
Prior Art

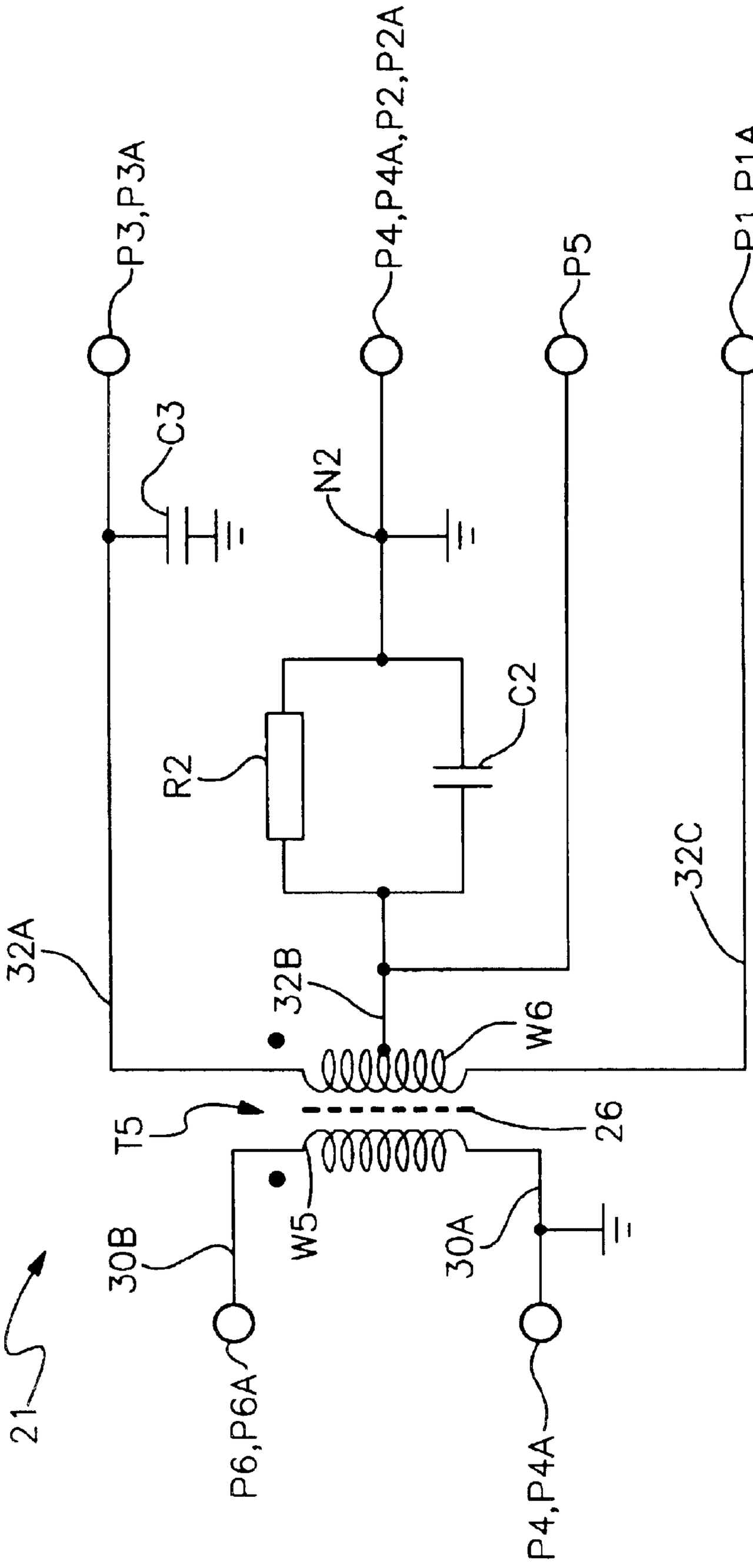

P3,P3A
C3
P4,P4A,P2,P2A
N2
P5
P1,P1A
R2
C2
32A
32B
W6
32C
T5
26
W5
30B
30A
21
P6,P6A
P4,P4A

Fig. 2

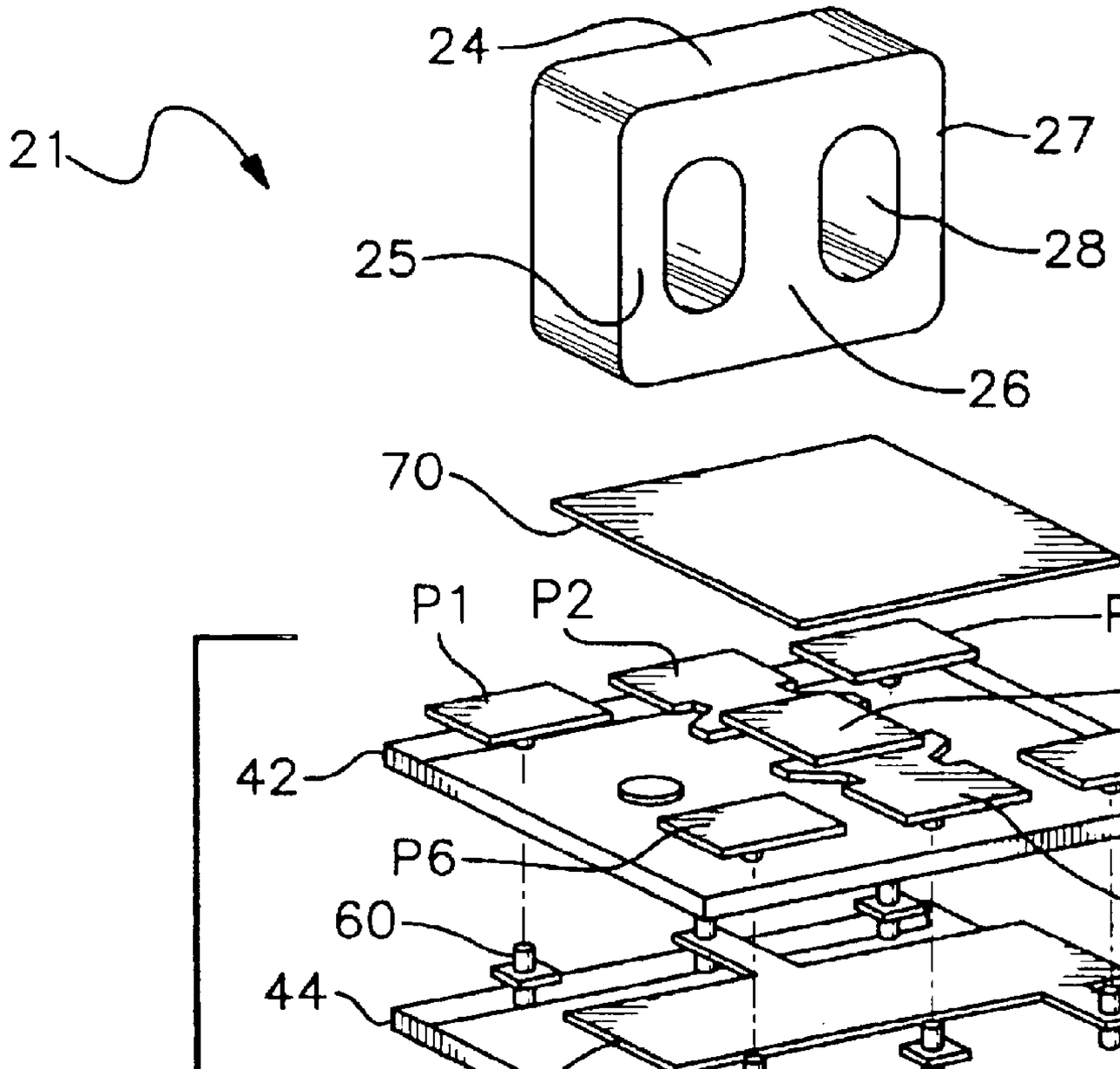

21
24
25
26
27
28
70
P1
P2
P3
R2
P4
42
42A
42B
P6
P5
60
44
44A
44B
63
40
65
46
46A
46B
64
48
48A
48B
66
P3A
60
50
50A
50B
P1A
P2A
60
P4A

Fig. 3

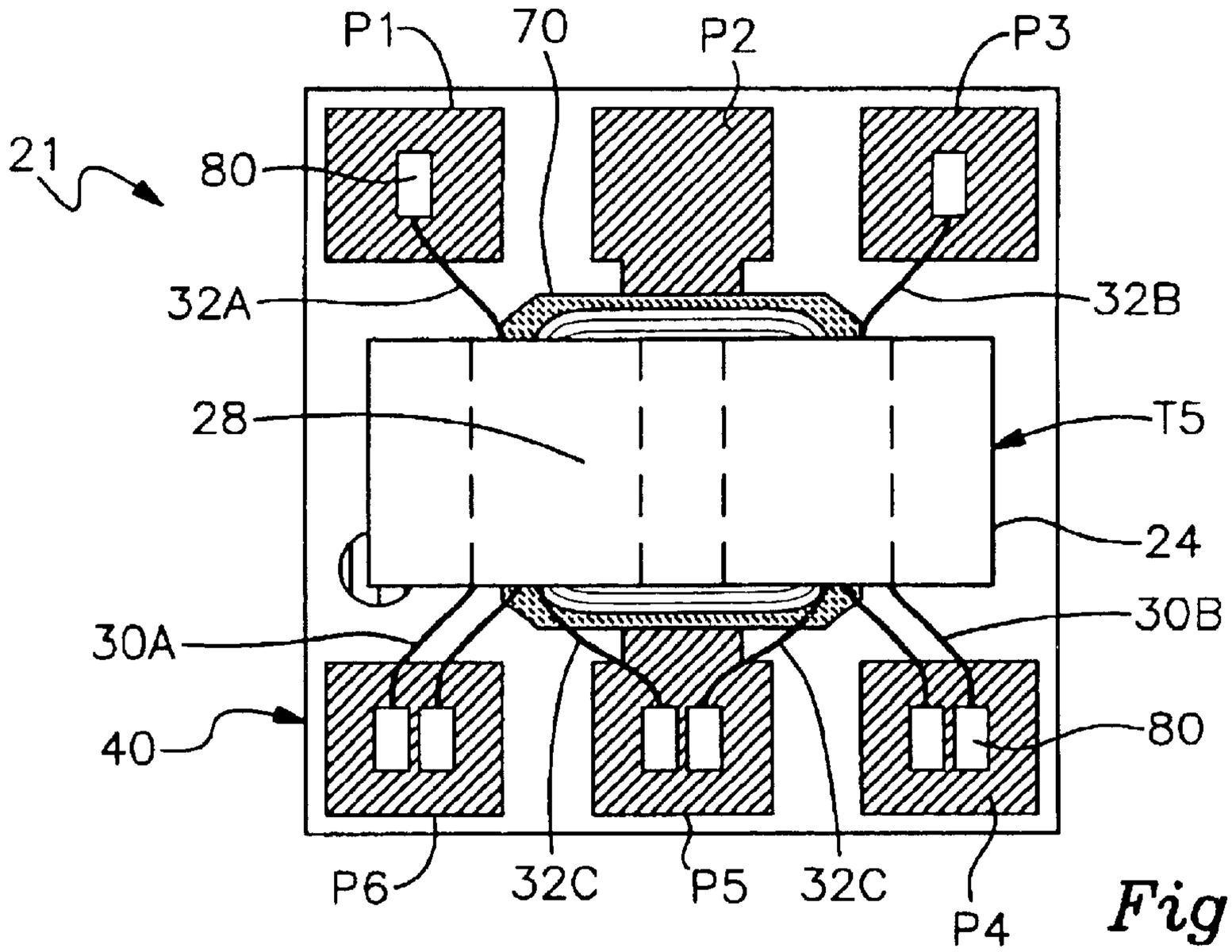

P1
70
P2
P3
21
80
32A
32B
28
T5
24
30B
30A
40
80
P6
32C
P5
32C
P4

Fig. 4

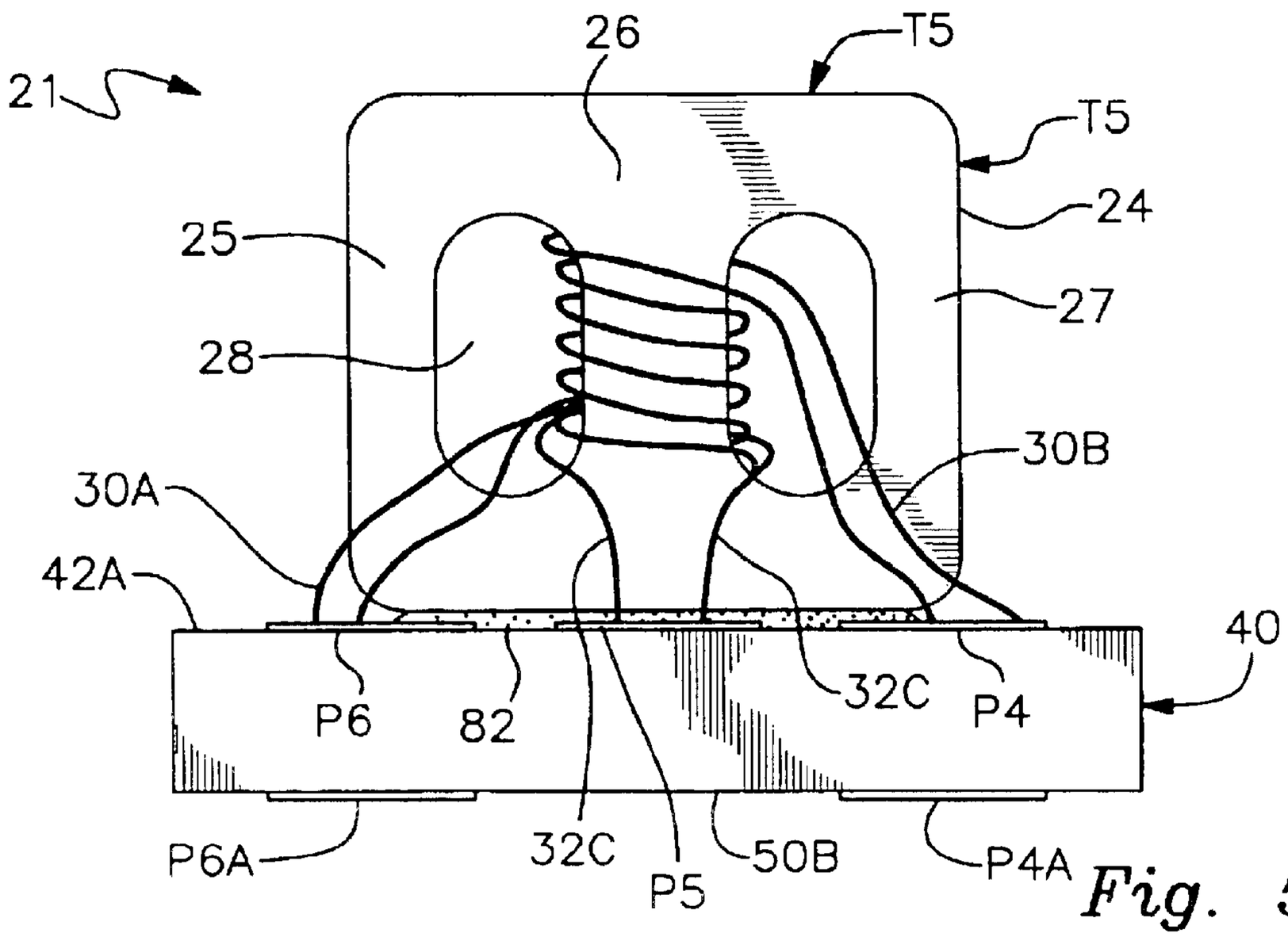

26
T5
21
T5
24
25
27
28
30B
30A
42A
40
P6
82
32C
P4
P6A
32C
P5
50B
P4A

Fig. 5

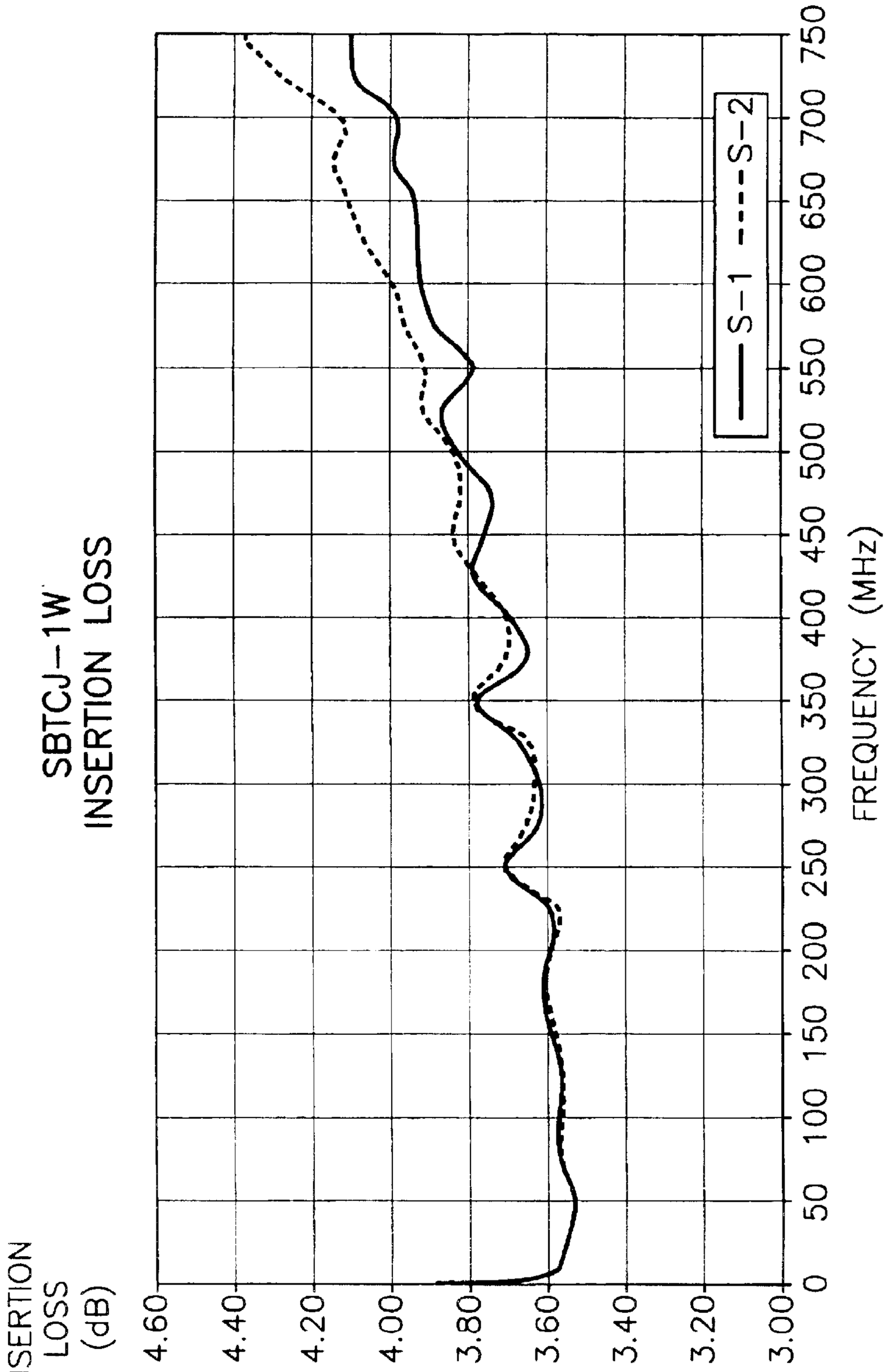

SBTCJ-1W
INSERTION LOSS
INSERTION LOSS (dB)
4.60
4.40
4.20
4.00
3.80
3.60
3.40
3.20
3.00
0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750
FREQUENCY (MHz)
S-1
S-2

Fig. 6

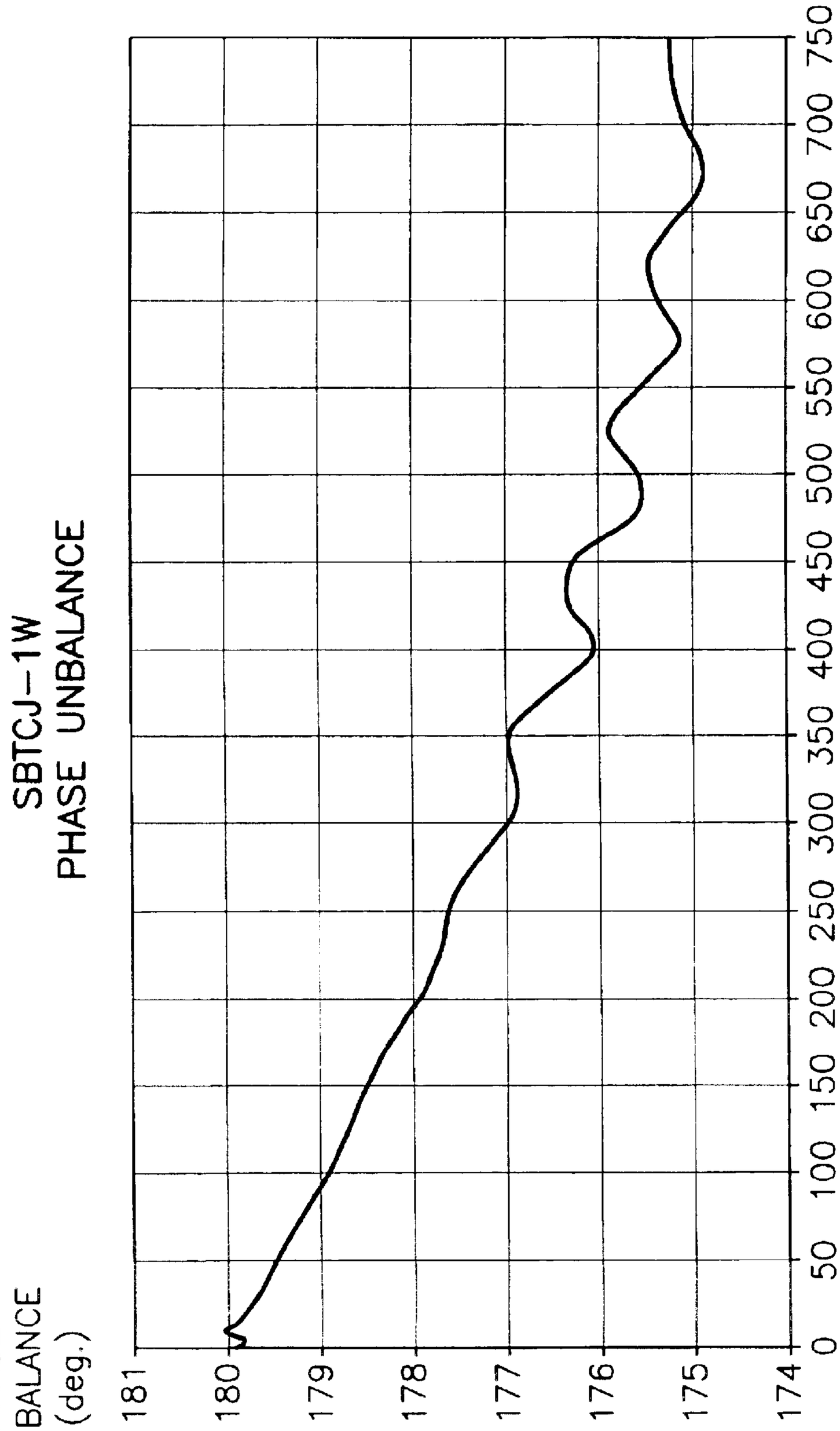

SBTCJ-1W
PHASE UNBALANCE
PHASE UNBALANCE (deg.)
181
180
179
178
177
176
175
174
0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750
FREQUENCY (MHz)

Fig. 7

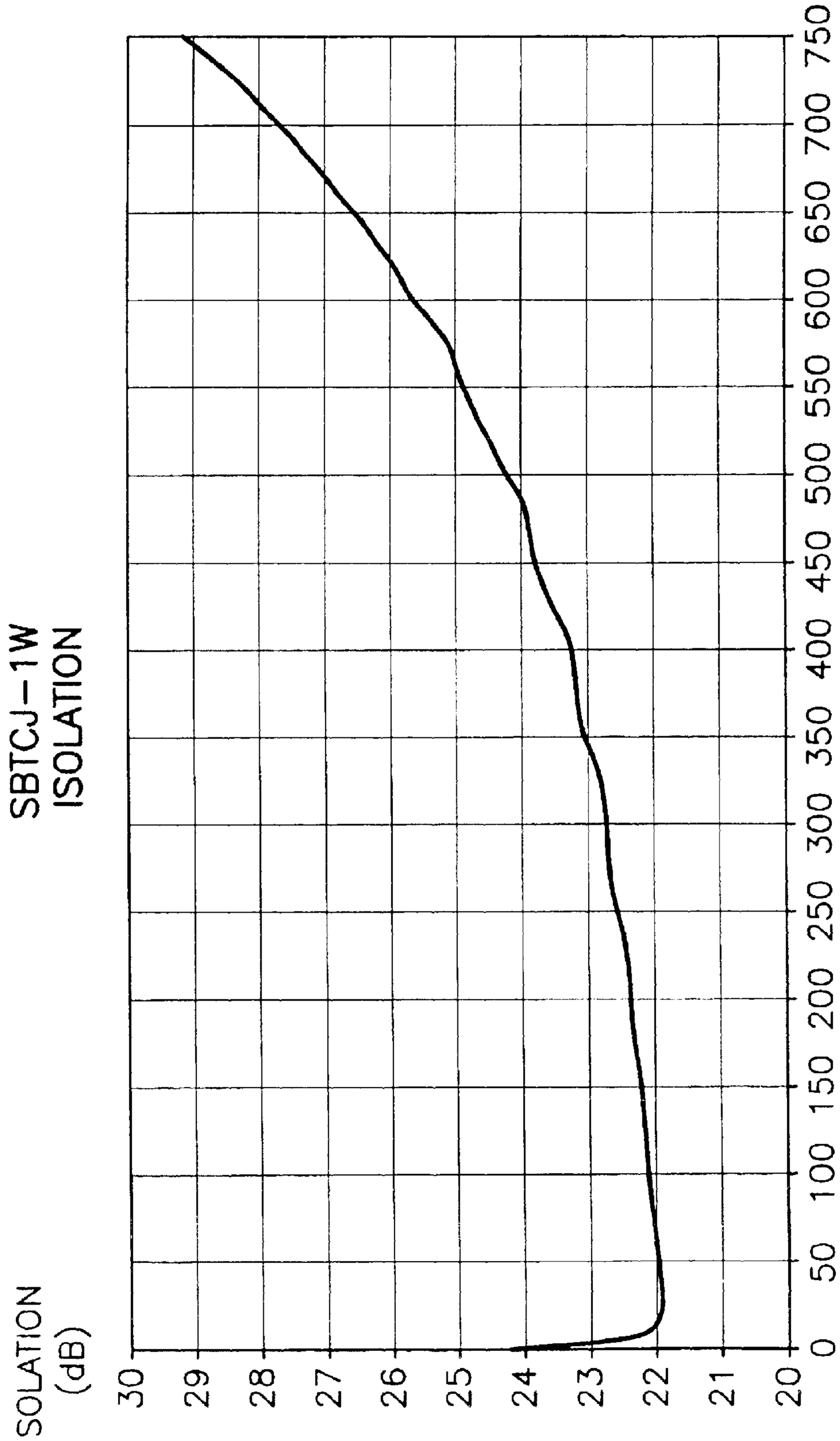

SBTCJ-1W
ISOLATION
ISOLATION
(dB)
30
29
28
27
26
25
24
23
22
21
20
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
FREQUENCY (MHz)

Fig. 8

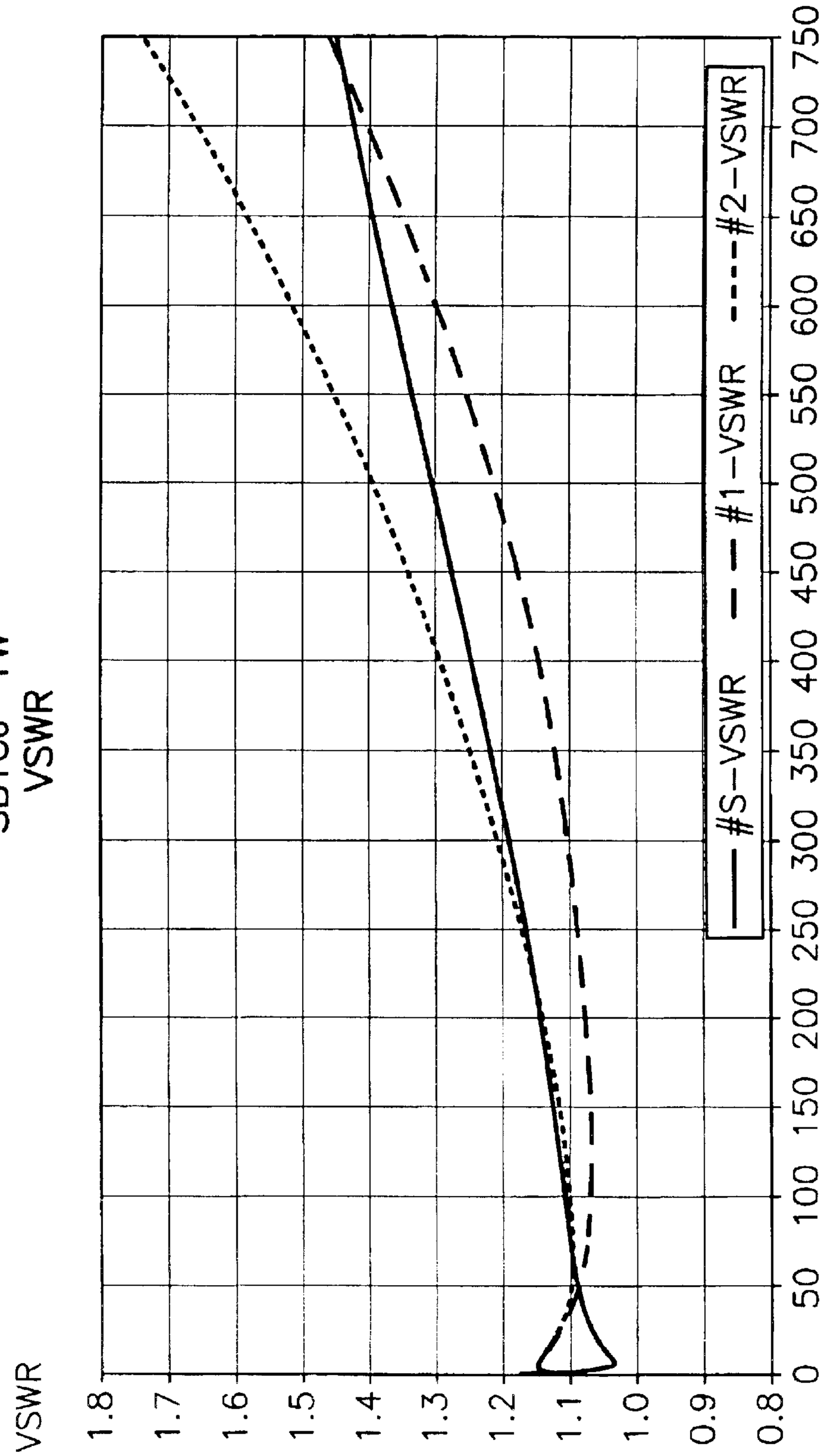

SBTCJ-1W
VSWR
VSWR
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
FREQUENCY (MHz)
#S-VSWR
#1-VSWR
#2-VSWR

Fig. 9

MINIATURE 180 DEGREE POWER SPLITTER

This application claims priority to U.S. provisional patent application Ser. No. 60/357,322 filed on Feb. 19, 2002, which is herein incorporated by reference in entirety.

BACKGROUND

1. Field of the Invention

This invention relates to power splitters in general and more particularly to a two way 180 degree power splitter having a small package size.

2. Description of the Prior Art

Power splitters operating at frequencies below 1GHz have been made with ferrite transformers along with appropriate resistors and capacitors arranged around the ferrite transformer. These splitters provide multi-decade bandwidth. The power splitter components are packaged on a printed circuit board. In some applications, printed circuit board space can be extremely limited with additional space just not available. In some applications, it is desirable to build multiple output-port splitters such as 4-way and 8-way by cascading the splitters. Unfortunately, placing resistors and capacitors beside each transformer complicates the assembly program followed by the automated pick and place surface mount assembly equipment. This leads to lower production by the assembly machinery.

FIG. **1** shows a schematic of a prior art 2 way 180 degree power splitter circuit for frequencies of 1–750 MHz. Circuit **20** has transformers T**1**, T**2**, T**3** and T**4**. Transformer T**1** is connected between ground and an input terminal IN. Transformer T**2** has one end connected to winding W**1** of transformer T**3** and the other end connected to winding W**3** of transformer T**4**. The mid-points of transformers T**1** and T**2** are connected to ground through a capacitor C**1**. A resistor R**1** is connected across transformer T**2**. Transformer T**3** has a windings W**1** and W**2**. Winding W**1** is connected between transformer T**2** and output terminal OUT**2**. Winding W**2** has both ends connected to ground. Transformer T**4** has windings W**3** and W**4**. Winding W**3** is connected between transformer T**2** and ground. Winding W**4** has one end connected to ground and the other end connected to output terminal OUT**1**. The circuit of FIG. **1** is a 2 way power splitter that provides an output signal that has 0 degrees of phase shift at terminal OUT**2** and 180 degrees of phase shift at terminal OUT**1**. The circuit of FIG. **1** requires four transformers to perform the power splitting function.

While power splitters have been used, they have suffered from taking up excessive printed circuit board space and in having multiple transformers that add expense and complexity to manufacturing. A current unmet need exists for a power splitter that takes up less printed circuit board space with fewer components that can be easily assembled.

SUMMARY

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

Another feature of the invention is to provide a power splitter that includes a substrate having several layers. The substrate has a first and a second outer surface. A resistor is formed on the first outer surface. A ground plane is formed on one of the layers. One or more capacitor electrodes are located on one of the layers. The capacitor electrodes form a capacitor. Several terminals are located on the first and second outer surfaces. A transformer is attached to the first outer surface and is electrically connected to the terminals, the resistor, the capacitor and the ground plane. The transformer provides impedance matching and dividing. Several vias extend between the layers to provide an electrical connection between the resistor, the capacitor, the terminals, the ground plane and the transformer.

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 object of the invention is to provide a method of manufacturing a 180 degree power splitter.

BRIEF DESCRIPTION OF THE DRAWINGS

In order that the invention may be more fully understood, it will now be described, by way of example, with reference to the accompanying drawings in which:

FIG. **1** is a schematic of a prior art power splitter.

FIG. **2** a schematic of the power splitter of the present invention.

FIG. **3** is an exploded perspective view of the present invention.

FIG. **4** is an assembled top view of FIG. **3**.

FIG. **5** is an assembled side view of FIG. **3**.

FIG. **6** is a graph showing insertion loss of the power splitter of FIG. **3**.

FIG. **7** is a graph showing phase unbalance of the power splitter of FIG. **3**.

FIG. **8** is a graph showing isolation of the power splitter of FIG. **3**.

FIG. **9** is a graph showing VSWR of the power splitter of FIG. **3**.

It is noted that the drawings of the invention are not to scale. In the drawings, like numbering represents like elements between the drawings.

DETAILED DESCRIPTION

Referring to FIG. **2**, a schematic of a 2-way 180 degree power splitter **21** in accordance with the present invention is shown. Power splitter **21** has a transformer T**5**. Transformer T**5** has windings W**5** and W**6** wound on the center leg **26** of a binocular ferrite core. One end of winding W**5** is connected to terminals P**4**, P**4**A and the other end is connected to input terminals P**6**, P**6**A. One end of winding W**6** is connected to terminals P**3**, P**3**A and to ground through a capacitor C**3**. The other end is connected to output terminals P**1**, P**1**A. The mid-point of winding W**6** at node N**1** is connected to a parallel combination of resistor R**2** and capacitor C**2**. Node N**1** is also connected to terminal P**5**. A node N**2** joins the other end of resistor R**2** and capacitor C**2**. Node N**2** is connected to terminals P**4**, P**4**A, P**2**, P**2**A and to ground.

Power splitter **21** provides an output signal that has 0 degrees of phase shift at terminal P**3**, P**3**A and 180 degrees of phase shift at terminal P**1**, P**1**A. Transformer T**5** is a 1:2 transformer and matches the impedance at the input of the splitter to two outputs. In a 50 ohm system, resistor R**2** has a value of 25 ohms. Resistor R**2** provides isolation and impedance matching between output terminals P**1**, P**1**A and P**3**, P**3**A. The coupling of primary winding W**5** to secondary winding W**6** in transformer T**5** is important for isolation and return loss. Capacitor C**2** improves isolation and return losses at high frequencies. Capacitor C**3** improves phase unbalance at high frequencies. Power splitter **21** is a 2-way power splitter since the input signal is split into two output

signals. Power splitter **21** uses fewer transformers than the prior art circuits.

Referring to FIGS. **3**, **4** and **5**, the physical implementation of power splitter **21** is shown. Power splitter **21** has a transformer T**5**. Transformer T**5** has a ferrite binocular core **24** with three legs **25**, **26** and **27** and a pair of holes **28**. Windings W**5** and W**6** are wound around center leg **26**. Winding W**5** has wires **30**A and **30**B. Winding W**6** has wires **32**A, **32**B and **32**C. Transformer T**5** performs the power splitting and matching functions.

Transformer T**5** is mounted to a low temperature co-fired ceramic (LTCC) structure or substrate **40** using an epoxy **82**. LTTC substrate **40** is comprised of multiple layers of LTCC 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 terminals P**1**, P**2**, P**3**, P**4**, P**5** and P**6** and a resistor R**2**. Terminals P**4**, P**4**A, P**2** and P**2**A are connected to ground. The terminals are electrically connected to vias **60**. The resistor R**2** has a protective overglaze **70** to protect the resistor from abrasion and shorting. Layer **44** has a ground plane **63** formed on surface **44**A. Ground plane **63** is connected on two sides to a via **60**. Layer **48** has a ground plane **66** formed on surface **48**A. The ground plane **66** is connected on two sides to a via **60**. Layer **46** has a pair of capacitor electrodes **64** and **65** formed on surface **46**A The capacitor electrodes **64** and **65** are each connected to separate vias. The capacitor electrodes **64** and **65**, ground planes **63** and **66** and the insulative LTCC layers **44** and **46** in between form capacitors C**2** and C**3**. Layer **50** has terminals P**1**A, P**2**A, P**3**A, P**4**A, and P**6**A located on bottom surface **50**B.

The circuit features such as resistors, capacitor electrodes, vias and ground planes are formed by screening a thick film paste material and firing in an oven as is known in the art. First, the LTCC layers have via holes punched, the vias are then filled with a conductive material. Next, the circuit features are screened onto the layers. The terminals, ground planes and capacitor electrodes are formed with a conductive material. The layers are then aligned and stacked on top of each other to form LTCC substrate **40**. The LTCC structure **40** is then fired in an oven at approximately 900 degrees centigrade to form a unitary piece. The resistor is formed with a resistor material, fired, and trimmed to a desired value. An insulative overglaze is screened over the resistor and fired. Next, the transformer T**5** is glued above overglaze **70** using an epoxy **82**. Wires **30**A, **30**B, **32**A, **32**B and **32**C are welded to their respective terminals using welds **80**.

The power splitter **21** would be mounted to a printed circuit board (not shown). Terminals P**1**A, P**2**A, P**3**A, P**4**A, and P**6**A on the bottom of surface **50**B would be attached to the printed circuit board using a reflowed solder paste. The paste could be screened onto the terminals and then the splitter is set on the printed circuit board and reflowed in an oven.

The present invention has several advantages. Since, the resistor R**2** and capacitors C**2** and C**3** are integrated into the LTCC structure, they do not have to be mounted separately on the printed circuit board. Further, the mounting of transformer T**5** above the resistor and capacitor provides a compact, small package, that saves space on the printed circuit board and allows for a faster assembly process at lower cost.

Repeatability of electrical performance is a prime concern for electrical design engineers. Fabricating the power splitter using an LTCC process with the circuit of FIG. **2** results in a more uniform electrical performance in the resulting power splitter. Referring to FIG. **6**, a graph showing S**1** and S**2** insertion loss for power splitter **21** is shown for frequencies from 0 to 750 MHz.

FIG. **7** is a graph showing the phase unbalance of the power splitter. FIG. **8** shows a graph of isolation of the power splitter between the output terminals P**3** and P**1** for 0 to 750 MHz. FIG. **9** is a graph showing VSWR at the input terminal P**6** and output terminals P**1** and P**3** of the power splitter. The VSWR match is very good with a typical value of 1.25:1. The power splitter **21** is designed to operate over the frequency range of 1–750 MHz.

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 plurality of layers, the substrate having a first and second surface;

b) a resistor formed on the first surface;

c) a ground plane formed on one of the layers;

d) a first and second capacitor electrode located on one of the layers, the capacitor electrodes forming a first and second capacitor;

e) a plurality of terminals located on the first and second surfaces;

f) a binocular core transformer attached to the first surface, the binocular core transformer having a center leg, the transformer providing impedance matching and dividing;

g) a first and second wire wound on the center leg, the first wire having a first end, a second end and a midpoint, the second wire having a third and fourth end, the first end connected to an input terminal, the third end connected to the first capacitor and a first output terminal, the fourth end connected to a second output terminal, the midpoint connected to a parallel combination of the resistor and the second capacitor, the parallel combination of the resistor and second capacitor further connected to ground; and

h) a plurality of vias extending between the layers for providing electrical connections between the resistor, the capacitors, the terminals and the ground plane.

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 transformer is attached to the substrate using an epoxy.

4. The power splitter according to claim **1** wherein a first ground plane is located on a first layer and a second ground plane is located on a second layer.

5. The power splitter according to claim **4** wherein the first and second capacitor electrodes are located between the first and second ground planes.

6. A power splitter comprising:

a) a multi-layered low temperature co-fired ceramic substrate, the substrate having a top surface, a bottom surface and a plurality of inner layers;

b) a first set of terminals located on the top surface and a second set of terminals located on the bottom surface;

c) a resistor formed on the top surface and connected between two of the terminals an overglaze covering the resistor;

d) a first ground plane formed on one of the inner layers;

e) a second ground plane formed on another inner layer;

f) a first and second capacitor electrode located on another inner layer, the capacitor electrodes forming a first and second capacitor;

g) a plurality of vias extending through the layers between the first and second set of terminals, the vias providing an electrical connection between the terminals, the resistor, the capacitors and the ground planes; and

h) a transformer attached to the top surface over the overglaze, the transformer having a center leg, a first and second wire wound on the center leg, the first wire having a first end, a second end and a midpoint, the second wire having a third and fourth end, the first end connected to an input terminal, the third end connected to the first capacitor and a first output terminal, the fourth end connected to a second output terminal, the midpoint connected to a parallel combination of the resistor and the second capacitor, the parallel combination of the resistor and second capacitor further connected to ground.

7. The power splitter according to claim **6** wherein the transformer is attached to the overglaze with an epoxy.

8. The power splitter according to claim **6** wherein the first and second windings are electrically connected to the first set of terminals by a plurality of welds.

9. The power splitter according to claim **6** wherein the substrate is connected to a printed circuit board by a reflowed solder paste attached to the second set of terminals on the bottom surface.

10. A power splitter for splitting an input signal into two output signals comprising:

a) a transformer having a binocular core with a center leg, a first and second wire wound on the center leg forming a first and second winding;

b) the first wire having a first end and a second end, the first end connected to a ground terminal and the second end connected to an input terminal;

c) the second wire having a third and fourth end and a mid-point, the third end connected to a first output terminal and the fourth end connected to a second output terminal;

d) a resistor; and

e) a first capacitor connected in parallel with the resistor, the parallel combination of the capacitor and resistor having one end connected to the mid-point and the other end connected to the ground terminal.

11. The power splitter according to claim **10** wherein, a second capacitor is connected between the third end and the ground terminal.

* * * * *