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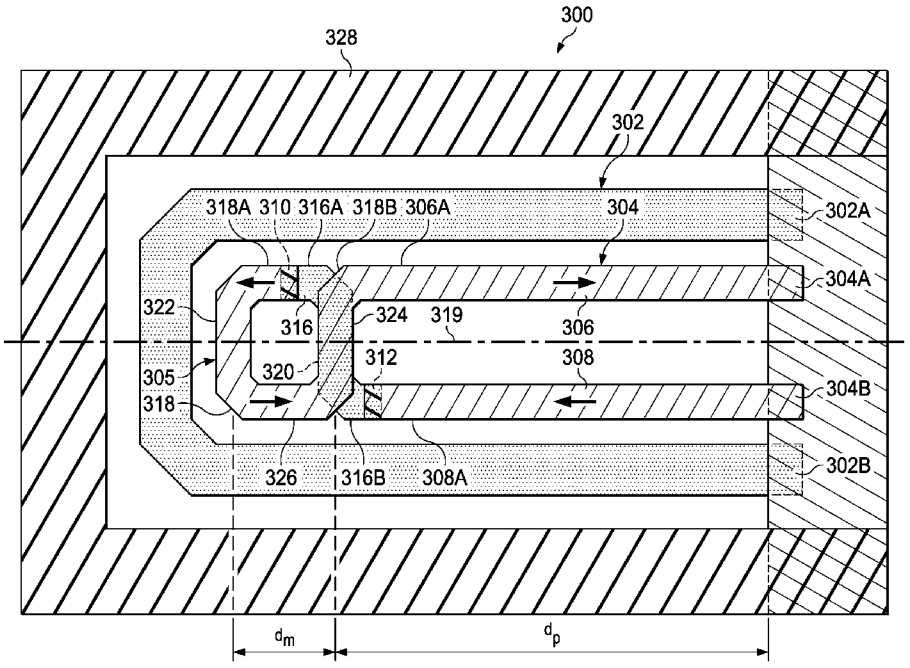


FIG. 3

(57) Abstract: An on-chip directional coupler (300) includes a first linear conductive trace (306), a second linear conductive trace (308), and a conductive loop (305). The first linear conductive trace (306) includes an end (306A) and a coupled port (304A). The second linear conductive trace (308) is spaced apart from and parallel to the first linear conductive trace (306). The second linear conductive trace (308) includes an end (308A) and an isolated port (304B). The conductive loop (305) includes a first end (318B) conductively coupled to the end (306A) of the first linear conductive trace (306), and a second end (316B) conductively coupled to the end (308 A) of the second linear conductive trace (308).

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[Continued on next page]

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— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

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ON-CHIP DIRECTIONAL COUPLER

BACKGROUND

[0001] Directional couplers are devices that detect signal power being transmitted in a particular direction. Directional couplers are used to detect signal in a wide variety of radio frequency circuits. A directional coupler includes four ports. The first port is an input port that receives a transmitted signal from a source. The second port is an output port that provides the transmitted signal to a destination. As signal propagates from the first port to the second port, a portion of the signal is coupled to the third port. The third port is a coupled port that outputs signal coupled from the transmitted signal. The fourth port is an isolated port. Preferably, no signal is coupled to the fourth port. Output of the third port may be applied to measure or control the power of the transmitted signal, or to determine parameters of the transmission signal path.

SUMMARY

[0002] Directional couplers that provide independent control of magnetic and capacitive coupling are described herein. In one example, an on-chip directional coupler includes a first linear conductive trace, a second linear conductive trace, a first curved conductive trace, and a second curved conductive trace. The first linear conductive trace is formed in a first metal layer, and includes an end and a coupled port. The second linear conductive trace is formed in the first metal layer, and is spaced apart from and parallel to the first linear conductive trace. The second linear conductive trace includes an end and an isolated port. The first curved conductive trace is formed in a second metal layer, and includes a first end and a second end. The first end is conductively coupled to the end of the of the first linear conductive trace. The second curved conductive trace is formed in the first metal layer, and includes a first end and a second end. The first end of the second curved conductive trace is conductively coupled to the second end of the first curved conductive trace. The second end of the second curved conductive trace is conductively coupled to the end of the second linear conductive trace.

[0003] In another example, an on-chip directional coupler includes a first linear conductive trace, a second linear conductive trace, and a conductive loop. The first linear conductive trace including an end and a coupled port. The second linear conductive trace is spaced apart from and parallel to

the first linear conductive trace. The second linear conductive trace includes an end and an isolated port. The conductive loop includes a first end conductively coupled to the end of the first linear conductive trace, and a second end conductively coupled to the end of the second linear conductive trace.

[0004] In a further example, an integrated circuit includes a transmit power amplifier, a transmission conductor, a transmit terminal, and a directional coupler. The transmit power amplifier including an output. The transmission conductor includes a first end and a second end. The first end of the transmission conductor is conductively coupled to the output of the transmit power amplifier. The transmit terminal is conductively coupled to the second end of the transmission conductor. The directional coupler is configured to detect signal in the transmission conductor, and includes a first linear conductive trace, a second linear conductive trace, and a conductive loop. The first linear conductive trace is formed in a first metal layer and includes an end and a coupled port. The second linear conductive trace is formed in the first metal layer, and is spaced apart from and parallel to the first conductive trace. The second linear conductive trace includes an end and an isolated port. The conductive loop is formed in the first metal layer and a second metal layer, and includes a first end and a second end. The first end of the conductive loop is conductively coupled to the end of the first linear conductive trace. The second end of the conductive loop is conductively coupled to the end of the second linear conductive trace.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] FIG. 1 is a diagram of a conventional directional coupler.

[0006] FIG. 2 is schematic of an equivalent circuit for portion of the directional coupler of FIG. 1.

[0007] FIG. 3 is a diagram of a first directional coupler that provides independent control of magnetic and capacitive coupling.

[0008] FIG. 4 is a graph showing performance of the directional coupler of FIG. 3.

[0009] FIG. 5 is a diagram of a second directional coupler that provides independent control of magnetic and capacitive coupling.

[0010] FIG. 6 is a graph showing performance of the directional coupler of FIG. 5.

[0011] FIG. 7 is a diagram of a third directional coupler that provides independent control of magnetic and capacitive coupling.

[0012] FIG. 8 is a block diagram for a circuit that includes a directional coupler that provides independent control of magnetic and capacitive coupling.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

[0013] Radio frequency (RF) integrated circuits, such as automotive radar integrated circuits, include built-in self-test systems the employ on-chip directional couplers to verify signal path components and connections. Conventional on-chip directional couplers suffer from interdependency of parameters that result in performance compromises, such as large circuit area or low directivity. FIG. 1 is a diagram of a conventional directional coupler 100. The conventional directional coupler 100 includes a conductive signal trace 102, a conductive coupling trace 108, ground planes 114 and 116, and loading trace segments 118. The conductive signal trace 102 and the conductive coupling trace 108 are disposed on a same metal layer of an integrated circuit. The conductive signal trace 102 includes an input port 104 and an output port 106. The conductive coupling trace 108 includes a coupled port 110 and an isolated port 112. Signal enters the conductive signal trace 102 at the input port 104, and exits the conductive signal trace 102 at the output port 106. As signal propagates through the conductive signal trace 102, a portion of the signal is coupled, magnetically and/or capacitively, to the conductive coupling trace 108. Coupled signal is provided at the coupled port 110.

[0014] The ground plane 114 and the ground plane 116 isolate the conductive signal trace 102 and the conductive coupling trace 108 from noise sources in the integrated circuit. The ground plane 114 and the ground plane 116 may be formed on the same metal layer as the conductive signal trace 102 and the conductive coupling trace 108, and/or on a metal layer other than that of the conductive signal trace 102 and the conductive coupling trace 108.

[0015] The loading trace segments 118 are provided on a metal layer of the integrated circuit other than that of the conductive signal trace 102 and the conductive coupling trace 108. The loading trace segments 118 load the conductive signal trace 102 and the conductive coupling trace 108 to help control parasitic capacitance.

[0016] FIG. 2 is schematic of an equivalent circuit 200 for a segment 120 (shown in FIG. 1) of the conventional directional coupler 100. The segment 120 is modeled as inductors 202 and 204 (L is inductance and k is magnetic coupling between the inductors), coupling capacitors 206 and 208 (coupling capacitance C_c), and parasitic capacitors 212 (parasitic capacitance C_p), 214, 216, and 218. In the equivalent circuit 200, the values of k, C_p, and C_c are interdependent. That is, changing a physical parameter of the segment 120 (e.g., width or spacing of the conductive signal trace 102 and the conductive coupling trace 108) does not change k, C_p, or C_c. in isolation, but changes more than

one of k, C_p, or C_c.. This interdependence limits the performance of the conventional directional coupler 100. In the equivalent circuit 200, characteristic impedance (Z_0) is:

$$Z_0 = \sqrt{Z_e Z_o} \quad (1)$$

where:

Z_e is even mode impedance; and

Z_o is odd mode impedance.

[0017] Even mode impedance is:

$$Z_e = \sqrt{\frac{(1+k)L}{2C_p}} \quad (2)$$

[0018] Odd mode impedance is:

$$Z_o = \sqrt{\frac{(1-k)L}{2(C_p + C_c)}} \quad (3)$$

[0019] The ratio of even mode impedance to odd mode impedance is:

$$\frac{Z_e}{Z_o} = \sqrt{\frac{(1+k)}{(1-k)}\left(1+\frac{C_c}{C_p}\right)} \quad (4)$$

[0020] The ratio of odd mode propagation constant (β_o) to even mode propagation constant (β_e) is:

$$\frac{\beta_e}{\beta_o} = \sqrt{\frac{(1-k)}{(1+k)}\left(1+\frac{C_c}{C_p}\right)} \quad (5)$$

[0021] In equations (2)-(5), because k, C_p, and C_c. are not independent, even and odd mode impedance and propagation constant cannot be set independently to achieve low coupling and high directivity. FIG. 3 is a diagram of a directional coupler 300 that provides independent control of magnetic and capacitive coupling. The directional coupler 300 may be formed on an integrated circuit, a packaging substrate, a printed circuit board, etc. With independent control of magnetic and capacitive coupling, the directional coupler 300 allows even and odd mode impedance and propagation constant to be set independently, which allow for improved directivity.

[0022] The directional coupler 300 includes a signal conductor 302 and a coupling conductor 304. The signal conductor 302 includes an input port 302A and an output port 302B. The coupling

conductor 304 includes a coupled port 304A and an isolated port 304B. Signal introduced to the signal conductor 302 via the input port 302A exits the signal conductor 302 at the output port 302B. As signal traverses the signal conductor 302, a portion of the signal is magnetically and/or capacitively coupled into the coupling conductor 304, and exits the coupling conductor 304 via the coupled port 304A.

[0023] The coupling conductor 304 includes a linear conductive trace 306, a linear conductive trace 308, and a conductive loop 305. A first end of the linear conductive trace 306 is conductively coupled to the coupled port 304A, and a second end 306A of the linear conductive trace 306 is conductively coupled to the conductive loop 305. A first end of the linear conductive trace 308 is conductively coupled to the isolated port 304B, and a second end 308A of the linear conductive trace 306 is conductively coupled to the conductive loop 305. The linear conductive trace 306, the linear conductive trace 308, and the conductive loop 305 form a transformer-like structure that allows for control of magnetic coupling in the directional coupler 300 (magnetic coupling between the signal conductor 302 and the coupling conductor 304) as a function of (a ratio of) diameter (d_m) of the conductive loop 305 to length (d_p) of the linear conductive trace 306 and linear conductive trace 308. As shown in FIG. 3, the diameter of the conductive loop 305 is measured along the centerline 319. The conductive loop 305 reverses the direction of current flow, so the current flow in the conductive loop 305 is in a direction opposite the direction of current flow in the linear conductive trace 306 and the linear conductive trace 308, and the polarity of magnetic flux within the conductive loop 305 is opposite the polarity of magnetic flux between the linear conductive trace 306 and the linear conductive trace 308.

[0024] The linear conductive trace 306 and the linear conductive trace 308 are formed in a same metal layer of the integrated circuit. A first portion of the conductive loop 305 is formed in the same (a first) metal layer as the linear conductive trace 306 and the linear conductive trace 308, and second portion of the conductive loop 305 is formed in a different (a second) metal layer of the integrated circuit. The conductive loop 305 includes a first curved conductive trace 316, and a second curved conductive trace 318. The second curved conductive trace 318 is formed in the same metal layer as the linear conductive trace 306 and the linear conductive trace 308 (first metal layer). The first curved conductive trace 316 is formed in a different metal layer (second metal layer) than the second curved conductive trace 318. The first curved conductive trace 316 includes a first end 316A and a second end 316B. The second curved conductive trace 318 includes a first end 318A and a second

end 318B. The first end 316A of the first curved conductive trace 316 is coupled to the first end 318A of the second curved conductive trace 318 by a via 310 that connects the metal layers of the first curved conductive trace 316 and the second curved conductive trace 318. Similarly, the second end 316B of the first curved conductive trace 316 is coupled to the second end 308A of the linear conductive trace 308 by a via 312 that connects the metal layers of the first curved conductive trace 316 and the linear conductive trace 308. The second end 318B of the second curved conductive trace 318 is coupled to the second end 306A of the linear conductive trace 306.

[0025] The first curved conductive trace 316 includes a conductive trace segment 320 that is coupled to the linear conductive trace 308, and may be perpendicular to the linear conductive trace 306 and the linear conductive trace 308. The second curved conductive trace 318 includes a conductive trace segment 322, a conductive trace segment 324, and a conductive trace segment 326. The conductive trace segment 322 may be perpendicular to the linear conductive trace 306 and the linear conductive trace 308. The conductive trace segment 326 is coupled to, and may be perpendicular to, the conductive trace segment 322. The conductive trace segment 324 is coupled to, and may be perpendicular to, the conductive trace segment 326.

[0026] The signal conductor 302 may be formed in the same metal layer as the first curved conductive trace 316, the same metal layer as the second curved conductive trace 318, or a different metal layer. The coupling capacitance between the signal conductor 302 and the coupling conductor 304 may be reduced by placing the signal conductor 302 on a different metal layer from the linear conductive trace 306 and the linear conductive trace 308. A ground plane 328 isolates the signal conductor 302 and the coupling conductor 304 from other circuitry of the integrated circuit.

[0027] By providing independent control of magnetic coupling, the directional coupler 300 provides improved directivity (e.g., 3 decibels (dB) improvement) in a significantly smaller (e.g., 60% smaller) area than conventional directional couplers. FIG. 4 is a graph showing s-parameters of an implementation of the directional coupler 300. FIG. 4 shows that an implementation of the directional coupler 300 provides: -16dB of coupling (S31), isolation of about 34dB (S41), 17-18dB of directivity (D1, D2) with an 80 gigahertz (GHz) input signal, and less than 0.48dB (S21) of loss from the input port to the output port.

[0028] FIG. 5 is a diagram of another directional coupler 500 that provides independent control of magnetic and capacitive coupling. The directional coupler 500 is an implementation of the directional coupler 300, and includes additional linear conductive trace segments 502 disposed

orthogonal to the signal conductor 302. The linear conductive trace segments 502 may be coupled to the ground plane 328. The linear conductive trace segments 502 periodically load the signal conductor 302 to increase parasitic capacitance (C_p) and improve isolation and directivity. FIG. 5 shows that the ports 302A, 302B, 304A, and 304B of the directional coupler 500 may be routed in different directions as needed to facilitate connection of the directional coupler 500 to other circuitry of the integrated circuit.

[0029] FIG. 6 is a graph showing performance of the directional coupler 500. Loading the signal conductor 302 by the linear conductive trace segments 502 produces about a 5dB improvement in directivity relative to conventional directional couplers. In FIG. 6 an implementation of the directional coupler 500 produces directivity (D1, D2) of better the 20dB, loss (S21) of less than 0.35dB, coupling (S31) of better than 16dB, and isolation (S41) of better than 37dB.

[0030] FIG. 7 is a diagram of another directional coupler 700 that provides independent control of magnetic and capacitive coupling. The directional coupler 700 is an implementation of the directional coupler 300 or the directional coupler 500, and includes a signal conductor 702 and a coupling conductor 704. The coupling conductor 704 includes a conductive loop 705 that corresponds the conductive loop 305 of the directional coupler 300. In the directional coupler 700, the width of the conductive loop 705 has been increased (relative to the spacing of the linear conductive trace 306 and the linear conductive trace 308), with a corresponding increase in the width of the signal conductor 702 about the conductive loop 705.

[0031] The conductive loop 705 may be provided in various shapes. For example, the conductive loop 705 may be rectangular, octagonal, circular, etc. Similarly, the shape of the signal conductor 702 surrounding the conductive loop 705 may be provided in various shapes (e.g., rectangular, octagonal, circular, etc.). The shape of the signal conductor 702 surrounding the conductive loop 705 may be the same as or different from the shape of the conductive loop 705.

[0032] FIG. 8 is a block diagram for an integrated circuit 800 that includes a directional coupler 804 that provides independent control of magnetic and capacitive coupling. The integrated circuit 800 may be a communication system integrated circuit, a Radar sensor integrated circuit, or other integrated circuit. The directional coupler 804 may be an implementation of the directional coupler 300 or the directional coupler 500. The integrated circuit 800 includes a transmit power amplifier 802, a transmission conductor 806, and a transmit terminal 808. The transmit power amplifier 802 receives and amplifies a signal to be transmitted. The transmit power amplifier 802 includes an

output 802A that is coupled to an end 806A of the transmission conductor 806. The transmission conductor 806 may effectively serve as the signal conductor of the directional coupler 804. An end 806B of the transmission conductor 806 is coupled to the transmit terminal 808. The transmit terminal 808 may be an output of the integrated circuit 800 for connecting the integrated circuit 800 to a package. The directional coupler 804 detects signal in the transmission conductor 806, and provides coupled signal to circuitry of the integrated circuit 800 for analysis and control.

[0033] In some implementations of the integrated circuit 800, the directional coupler 804 is designed to in conjunction with packaging of the integrated circuit 800 so that package capacitance is included in the design of the directional coupler. By including package capacitance in the parasitic capacitance of the directional coupler 804, transmitted signal loss may be reduced relative to designs employing a shunt stub to resonate out package capacitance.

[0034] The term "couple" is used throughout the specification. The term may cover connections, communications, or signal paths that enable a functional relationship consistent with the description of the present disclosure. For example, if device A generates a signal to control device B to perform an action, in a first example device A is coupled to device B, or in a second example device A is coupled to device B through intervening component C if intervening component C does not substantially alter the functional relationship between device A and device B such that device B is controlled by device A via the control signal generated by device A.

[0035] Modifications are possible in the described embodiments, and other embodiments are possible, within the scope of the claims.

CLAIMS

What is claimed is:

1. An on-chip directional coupler, comprising:

a first linear conductive trace formed in a first metal layer, and including an end and a coupled port;

a second linear conductive trace, spaced apart from and parallel to the first linear conductive trace, formed in the first metal layer, and including an end and an isolated port;

a first curved conductive trace formed in a second metal layer, and including:

a first end conductively coupled to the end of the of the first linear conductive trace; and

a second end; and

a second curved conductive trace formed in the first metal layer, and including:

a first end conductively coupled to the second end of the first curved conductive trace; and

a second end conductively coupled to the end of the second linear conductive trace.

2. The on-chip directional coupler of claim 1, further comprising:

a first via connecting the end of the first linear conductive trace and the first end of the first curved conductive trace; and

a second via connecting the second end of the first curved conductive trace and the first end of the second curved conductive trace.

3. The on-chip directional coupler of claim 1, further comprising:

a signal trace disposed around the first linear conductive trace, the second linear conductive trace, the first curved conductive trace, and the second curved conductive trace, the signal trace including an input port and an output port.

4. The on-chip directional coupler of claim 3, wherein the signal trace is formed in the second metal layer.

5. The on-chip directional coupler of claim 3, further comprising:

a plurality of linear conductive trace segments; wherein each of the conductive trace segments is:

orthogonal to the signal trace; and

on a different metal layer than the signal trace.

6. The on-chip directional coupler of claim 1, wherein:

the first curved conductive trace includes a first conductive trace segment perpendicular to the first linear conductive trace and the second linear conductive trace; and

the second curved conductive trace includes a second conductive trace segment perpendicular to the first linear conductive trace and the second linear conductive trace.

7. The on-chip directional coupler of claim 6, wherein:

the second curved conductive trace includes a third conductive trace segment conductively coupled to and perpendicular to the second conductive trace segment.

8. The on-chip directional coupler of claim 7, wherein the second curved conductive trace includes a fourth conductive trace segment conductively coupled to and perpendicular to the third conductive trace segment.

9. An on-chip directional coupler, comprising:

a first linear conductive trace including an end and a coupled port;

a second linear conductive trace, spaced apart from and parallel to the first linear conductive trace, and including an end and an isolated port; and

a conductive loop including:

a first end conductively coupled to the end of the first linear conductive trace; and

a second end conductively coupled to the end of the second linear conductive trace.

10. The on-chip directional coupler of claim 9, wherein the first linear conductive trace and the second linear conductive trace are formed in a first metal layer.

11. The on-chip directional coupler of claim 10, wherein the conductive loop includes:

a first curved conductive trace formed in a second metal layer, and including:

a first end conductively coupled to the end of the first linear conductive trace; and

a second end;

a second curved conductive trace formed in the first metal layer, and including:

a first end conductively coupled to the second end of the first curved conductive trace; and

a second end conductively coupled the end of the second linear conductive trace.

12. The on-chip directional coupler of claim 11, further comprising:

a first via connecting the first end of the first curved conductive trace and the end of the first

linear conductive trace; and

a second via connecting the second end of the first curved conductive trace and the first end of the second curved conductive trace.

13. The on-chip directional coupler of claim 9, further comprising:

a signal trace disposed around the first linear conductive trace, the second linear conductive trace, and the conductive loop; the signal trace including an input port and an output port.

14. The on-chip directional coupler of claim 13, further comprising:

a plurality of linear conductive trace segments configured to periodically load the signal trace.

15. The on-chip directional coupler of claim 9, wherein:

magnetic coupling in the on-chip directional coupler is a function of a ratio of diameter of the conductive loop to length of the first linear conductive trace and the second linear conductive trace; and

diameter of the conductive loop is measured along a centerline of the conductive loop that is parallel to the first linear conductive trace and the second linear conductive trace.

16. An integrated circuit, comprising:

a transmit power amplifier including an output;

a transmission conductor including:

a first end conductively coupled to the output of the transmit power amplifier; and

a second end;

a transmit terminal conductively coupled to the second end of the transmission conductor;

a directional coupler configured to detect signal in the transmission conductor, the directional coupler including:

a first linear conductive trace formed in a first metal layer, the first linear conductive trace including an end and a coupled port;

a second linear conductive trace, spaced apart from and parallel to the first linear conductive trace, formed in the first metal layer, the second linear conductive trace including an end and an isolated port; and

a conductive loop formed in the first metal layer and a second metal layer, the conductive loop including:

a first end conductively coupled to the end of the first linear conductive trace; and

a second end conductively coupled to the end of the second linear conductive trace.

17. The integrated circuit of claim 16, wherein the directional coupler further includes a signal trace formed as a portion of the transmission conductor disposed around the first linear conductive trace, the second linear conductive trace, and the conductive loop.

18. The integrated circuit of claim 17, further comprising:

a plurality of linear conductive trace segments; wherein each of the linear conductive trace segments is:

orthogonal to the signal trace; and

on a different metal layer than the signal trace.

19. The integrated circuit of claim 16, wherein:

the first linear conductive trace is configured to provide current flow to the conductive loop; and

the second linear conductive trace is configured to provide current flow from the conductive loop.

20. The integrated circuit of claim 16, wherein:

magnetic coupling in the directional coupler is a function of a ratio of diameter of the conductive loop to length of the first linear conductive trace and the second linear conductive trace; and

diameter of the conductive loop is measured along a centerline of the conductive loop that is parallel to the first linear conductive trace and the second linear conductive trace.

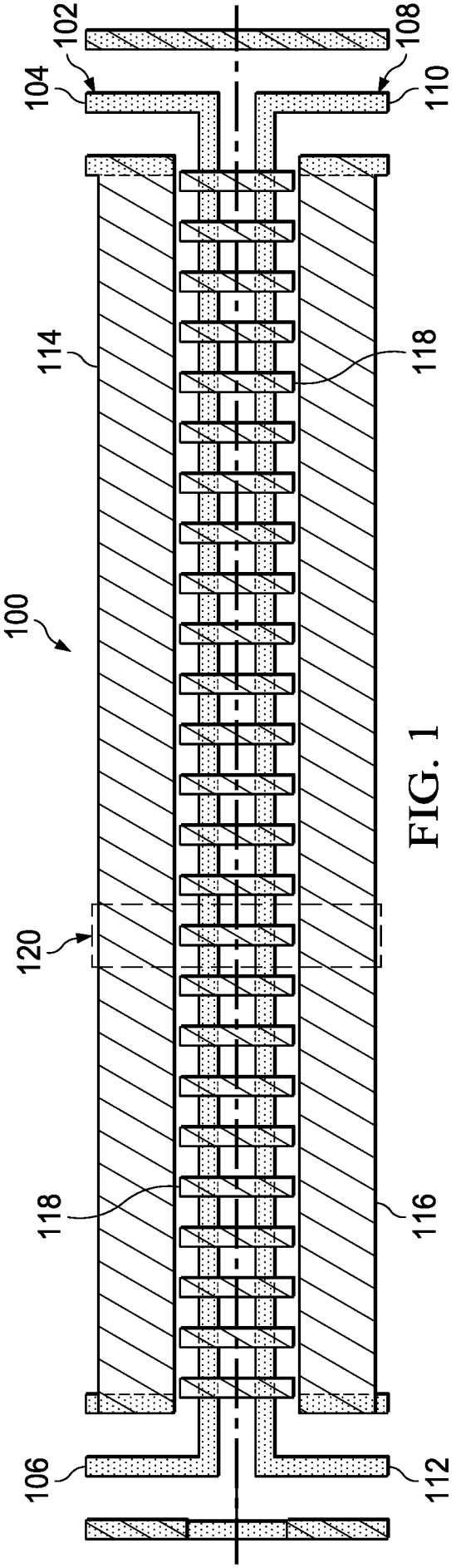


FIG. 1

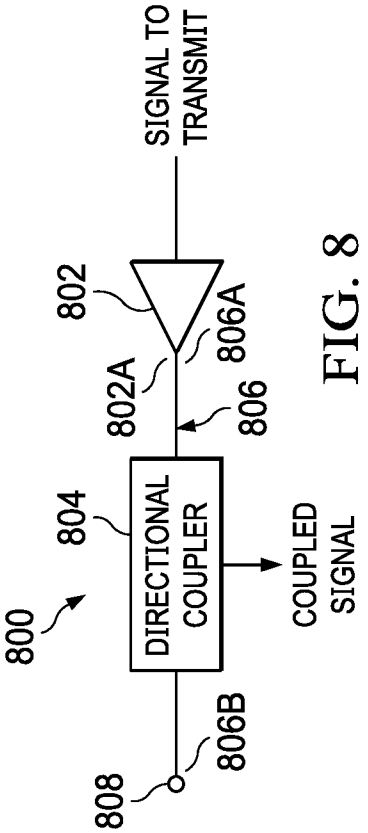


FIG. 8

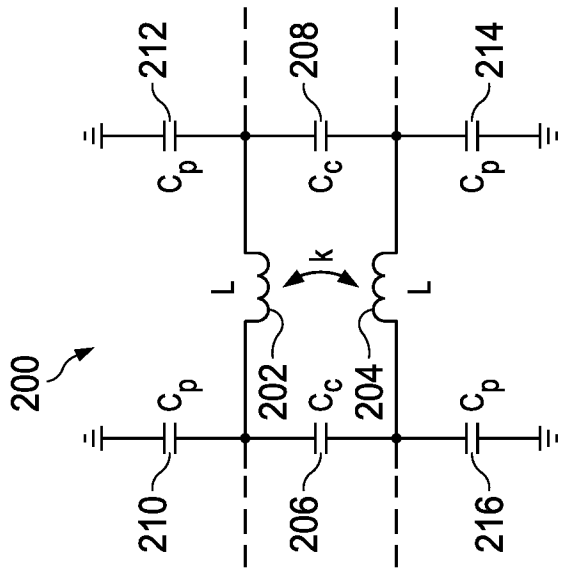


FIG. 2

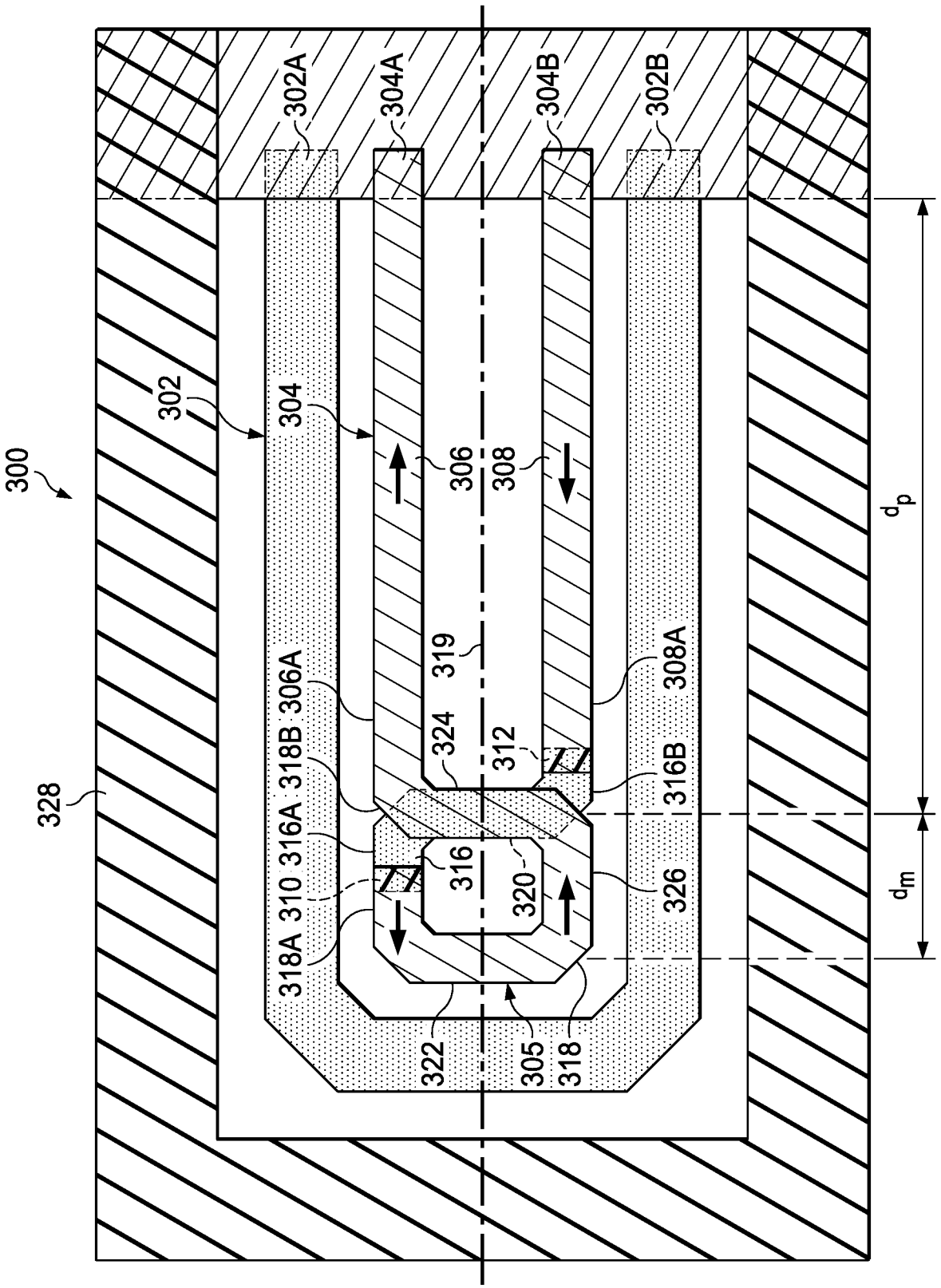

300
302
304
302A
304A
304B
302B
306
308
319
306A
318B
316A
318A
310
316
320
324
312
316B
308A
326
328
322
305
318
d_p
d_m

FIG. 3

FIG. 4

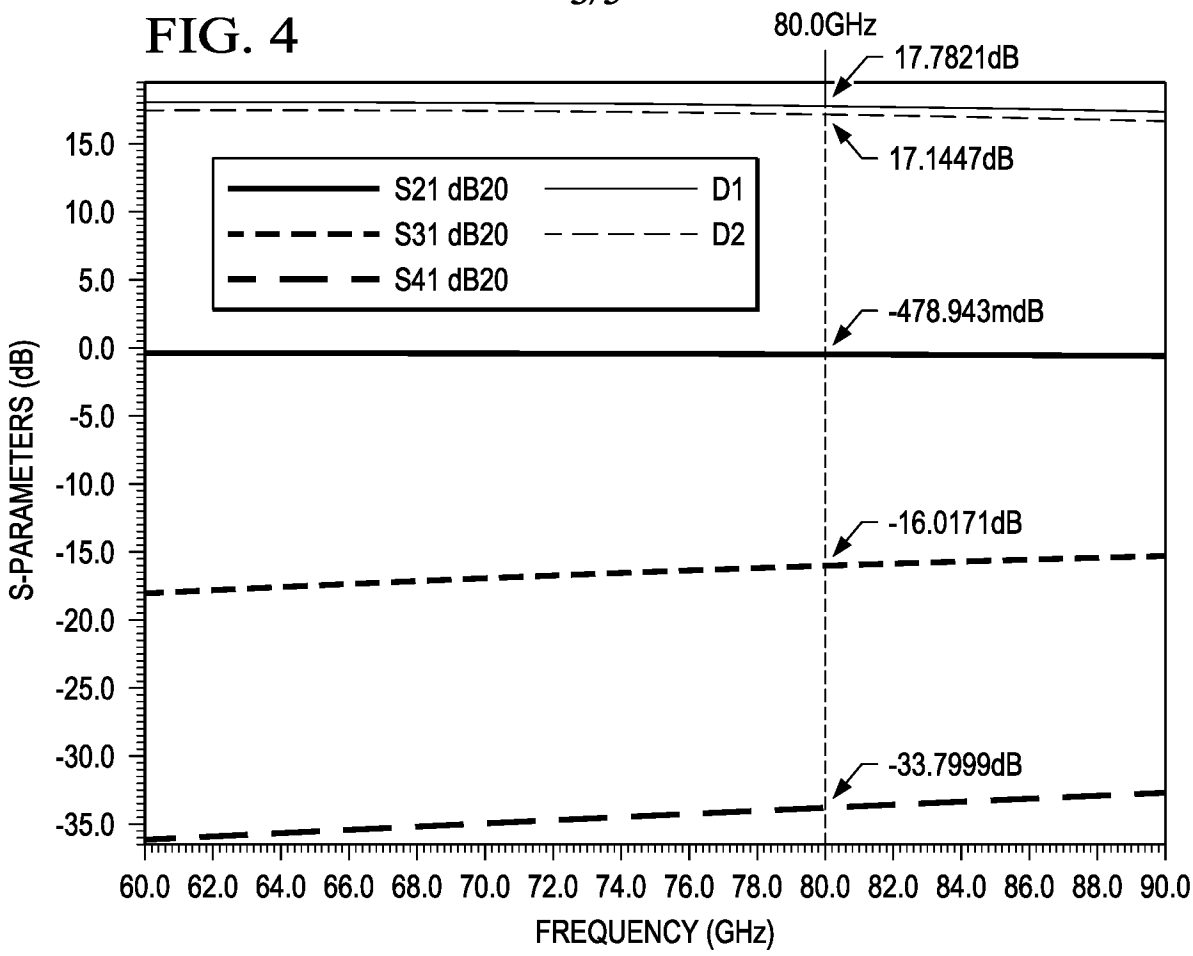
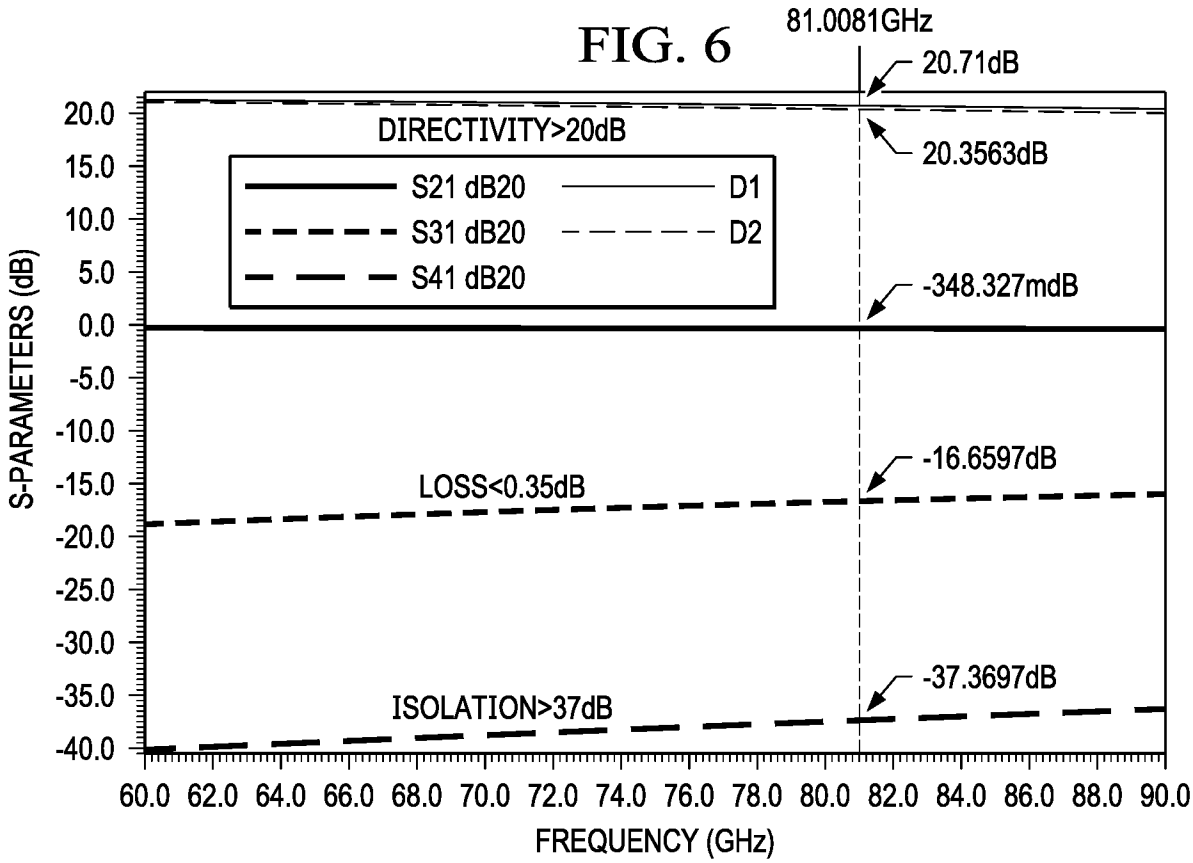

80.0GHz
17.7821dB
17.1447dB
-478.943mdB
-16.0171dB
-33.7999dB
S21 dB20
S31 dB20
S41 dB20
D1
D2
S-PARAMETERS (dB)
15.0
10.0
5.0
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
60.0 62.0 64.0 66.0 68.0 70.0 72.0 74.0 76.0 78.0 80.0 82.0 84.0 86.0 88.0 90.0
FREQUENCY (GHz)

FIG. 6


81.0081GHz
20.71dB
20.3563dB
-348.327mdB
-16.6597dB
-37.3697dB
DIRECTIVITY>20dB
LOSS<0.35dB
ISOLATION>37dB
S21 dB20
S31 dB20
S41 dB20
D1
D2
S-PARAMETERS (dB)
20.0
15.0
10.0
5.0
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
60.0 62.0 64.0 66.0 68.0 70.0 72.0 74.0 76.0 78.0 80.0 82.0 84.0 86.0 88.0 90.0
FREQUENCY (GHz)

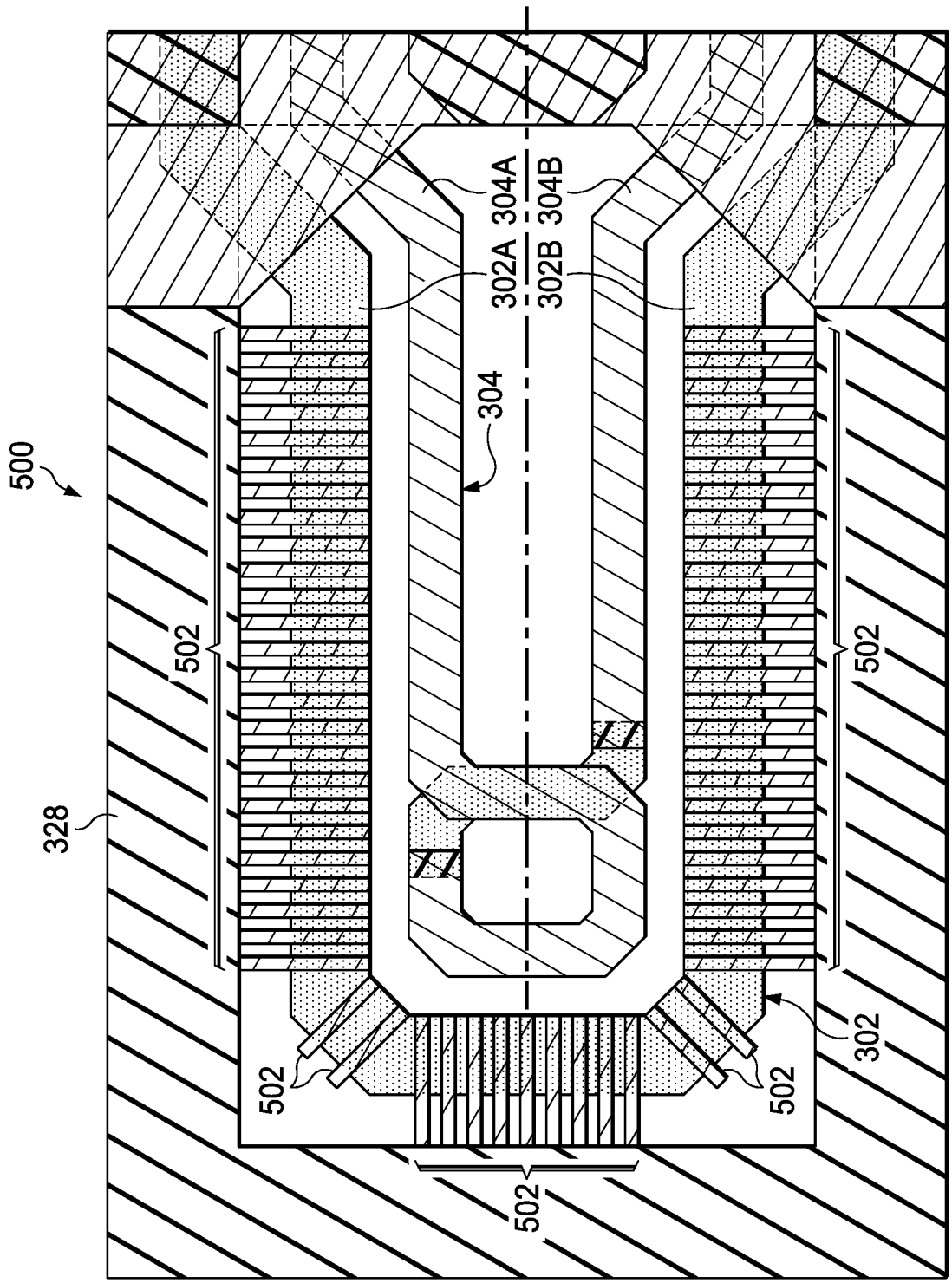


FIG. 5

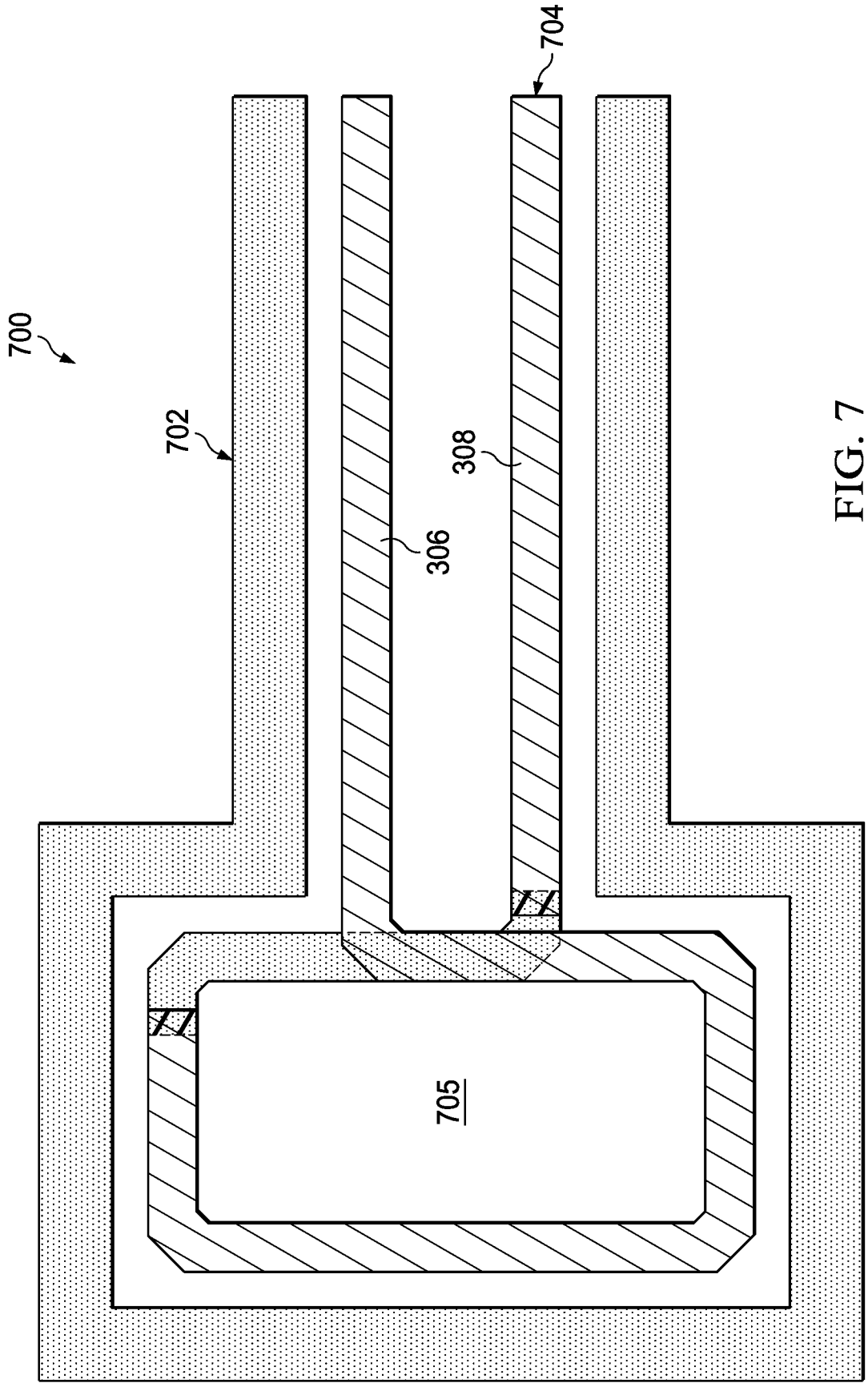


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2022/033194

A. CLASSIFICATION OF SUBJECT MATTER

H01P 5/18(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H01P 5/18(2006.01); H01P 1/212(2006.01); H01P 5/04(2006.01); H01Q 1/50(2006.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: directional coupler, linear conductive trace, coupled port, isolation port, conductive loop, different metal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2017-0317395 A1 (SKYWORKS SOLUTIONS, INC.) 02 November 2017 (2017-11-02) paragraphs [0003]-[0053]; and figure 3E	9,10,13
A		1-8,11,12,14-20
A	JP 2013-021437 A (NIPPON DENGYO KOSAKU CO., LTD.) 31 January 2013 (2013-01-31) paragraphs [0009]-[0012]; and figure 2	1-20
A	US 2014-0152396 A1 (ANDREAS FACKELMEIER et al.) 05 June 2014 (2014-06-05) paragraphs [0074]-[0133]; and figures 1-2	1-20
A	US 2021-0159580 A1 (AKCIONERNOE OBSHESTVO "MICROVOLNOVYE SISTEMY") 27 May 2021 (2021-05-27) paragraphs [0003]-[0014]; and figures 3-4	1-20
A	US 2018-0233796 A1 (YIFEI ZHANG et al.) 16 August 2018 (2018-08-16) paragraphs [0065]-[0109]; and figures 4(b)-6(b)	1-20

☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"D" document cited by the applicant in the international application
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 September 2022	**27 September 2022**

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/US2022/033194

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