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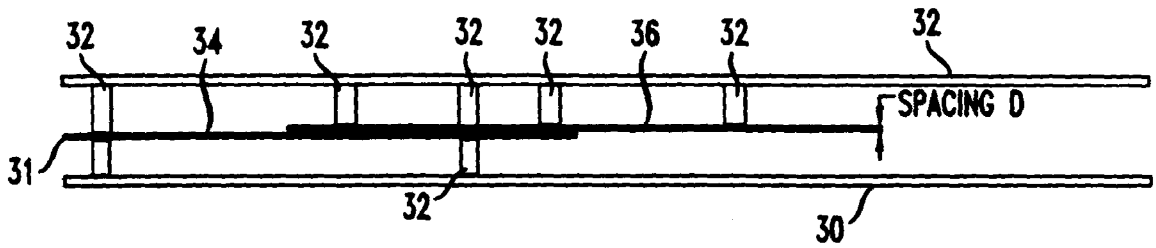
(54) **Ultrawide bandwidth electromechanical phase shifter**

(57) The invention is a phase shifter (26) that does not suffer from metallic contact and corrosion problems and that is linear (in high power circuitry/devices), light weight and inexpensive with minimal insertion and return losses. The phase shifter is a stripline structure comprising a first signal board (34) having an input signal line and an output signal line and a second signal board (36) having a U-shaped signal line. The U-shaped signal line is configured to complete a signal trace between the input signal line and the output signal line when the second signal board is positioned a distance D over the first signal board using a slidable mounting system (31, 32). The distance D is a distance sufficient to enable electrical coupling between the U-shaped signal line and the input and output signal lines. The slidable mounting system allows for variations in the signal trace.

FIG. 2

26



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Description

FIELD OF THE INVENTION

[0001] The present invention relates generally to antenna technology, and more particularly to electromechanical phase shifter antenna technology.

BACKGROUND OF THE RELATED ART

[0002] It is widely known in the wireless communication community that a base station antenna needs to be downtilted from the horizon to reduce intercell interference among antenna beams. Current practice to configure antenna beams involves adjusting downtilt angles of the antennas via their mechanical mountings. The configuration of the antennas is dependent upon a cell installer's experience. Such antenna adjustment is costly, time-consuming and inaccurate.

[0003] Typically, once the downtilt angles of the antennas are adjusted by the cell installer, the downtilt angles will not be re-adjusted. Thus, the downtilt angles and the antenna beams are typically fixed. Fixed antenna beams makes it near impossible to optimize system performance when thee are variations in environmental conditions, such as seasonal traffic changes and network growth. One manner for resolving this dilemma involves employing steerable phased-array antennas. Such antennas allows for remote manipulation of the antenna beams.

[0004] Steerable phased-array antennas are directive antenna comprising a group of individual, properly distributed and oriented radiators in a one or two-dimensional spatial configuration. The phase associated with each radiator can be individually excited using phase shifters to form a desired radiation pattern in space. This allows for the positioning of antenna beams by varying the relative phase associated with the excitations being applied to the individual radiators. Hence, beam steering in the azimuth or beam tilting in the elevation can be accomplished without re-adjusting the downtilt angle of the antennas via manipulating the mechanical mountings.

[0005] There exist several categories of phase shifters for generating differential phases among the radiators. The first category employs switchable delay lines having different lengths, wherein phases are linearly adjusted by varying the distance signals travel. This category of phase shifters are usually big and expensive. The second category utilizes wild state hybrid coupled diodes that initiate phase shifting based on different bias voltages. This category of phase shifters suffer from non-linearity (between current and voltage in high power circuitry/devices) and high insertion loss.

[0006] The third category of phase shifters uses ferromagnetic material, such as ferrite. These phase shifters shift phases by varying the permeability of the ferromagnetic material using an applied DC magnetic field. Due to the permeability change, the phase associated with an electromagnetic wave traveling through the ferromagnetic material is changed. Ferromagnetic material, however; are large, heavy and expensive. The fourth category of phase shifters involves the introduction of dielectric material in the signal path to cause phase delay. This category, however, has associated impedance mismatch causing high return loss, therefore degrading performance.

[0007] The fifth category of phase shifters are referred to in the art as "trombones." FIG. 1 depicts a trombone phase shifter 10 comprising an input coaxial cable 12, an output coaxial cable 14 and an trombone arm 16. Coaxial cables 12, 14 comprise cables 18, 20 and shielding 22, 24. Trombone arm 16 is preferable constructed using a solid metal piece and configured to slidably fit between cables 18, 20 and shielding 22, 24 in order to complete a signal trace between input and output coaxial cables 18, 20. The phase of a signal traveling though trombone phase shifter 10 is linearly adjusted by sliding trombone arm 16. Trombone phase shifter 10, however, suffers from some drawbacks. Specifically, since the trombone phase shifter is manufactured to make sure to have a good metallic contact to minimize the insertion and return loss, the trombone arm 16 must be precisely constructed to fit provide sufficient electrical coupling with cables 18, 20 while minimizing friction with cables 18, 20. However, such precise construction increase the cost significantly and make this approach become uneconomical for the commercial applications. Besides, because of this type of configuration is meant to be metallic contact, it suffers from corrosion and metallic contact problems over time.

[0008] Accordingly, there exists a need for a phase shifter that does not have the drawbacks associated with the above prior art phase shifters. Specifically, there is a need for a phase shifter that can provide extremely linear performance (in high power circuitry/devices) over a very broad bandwidth, while still maintaining lightweight and inexpensive with minimal insertion and return losses. There also exists a need for a phase shifter with little or no metal contact and not subject to corrosion.

SUMMARY OF THE INVENTION

[0009] The present invention is a phase shifter that does not suffer from metallic contact and corrosion problems and that is linear (in high power circuitry/devices), light weight and inexpensive with minimal insertion and return losses over a very broad bandwidth. The present invention phase shifter is constructed using a stripline structure. The present invention comprises a first signal board having an input signal line and an output signal line and a second signal board having a U-shaped signal line. The U-shaped signal line being configured to complete a signal trace between the input signal line and the output signal line when the second signal board is positioned a distance D over the first signal board with an overlap OD. The distance D and overlap OD being a distance sufficient to enable electrical coupling between the U-shaped signal line and the input and output signal lines. The first and/or second signal boards are mounted using a slidable mounting system such that the length of signal trace may be varied by moving the first and/or second signal board - that is, the phase of a signal is varied by varying the distance the signal travels from the input signal line to the U-shaped signal line to the output signal line. Advantageously, the present invention does not require a metallic contact. The two signal boards are separated by the distance D in order to make sure no friction exist during the moving process. Since there is no metallic contact between the signal boards, consequently, there is no fiction or corrosion problem.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The features, aspects, and advantages of the present invention will become better understood with regard to the following description, appended claims, and accompanying drawings where:

FIG. 1 depicts a trombone phase shifter used in the prior art;

FIG. 2 depicts a side view of a phase shifter in accordance with the present invention;

FIG. 2a depicts a cross sectional view of the phase shifter of FIG. 2 having a slidable mounting with a moving slide;

FIGS. 3 and 4 depict top views of input/output signal boards and U-shaped signal board;

FIG. 5 depicts input/output signal board overlapping with U-shaped signal board; and

FIGS. 6 and 7 depict and input/output signal board and a double U-shaped signal board.

DETAILED DESCRIPTION

[0011] FIG. 2 depicts a side view of a phase shifter 26 in accordance with the present invention. Phase shifter 26 is a stripline structure comprising top plate 28, bottom plate 30, a slidable mounting system 31, input/output signal board 34 and U-shaped signal board 36. Top and bottom plates 28, 30 are ground plates and are preferably constructed using metal. Signal boards 34 and 36 are mounted to bottom and top plates 28, 30, respectively, using slidable mounting system 31. In one embodiment, slidable mounting system 31 comprises a plurality of spacers 32 and a moving slide 29. Spacers 32 are used to mount input/output signal board 34 to bottom plate 30, and to mount U-shaped signal board 36 to moving slide 29, as shown in FIG. 2a which depicts a cross-sectional view of phase shifter 26 having this embodiment of slidable mounting system 31. Moving slide 29 is slidably mourned within a channel in top plate 28, thus allowing for U-shaped signal board 36 to slide over input/output signal board 34. Note that input/output signal board 34 is mounted in a fixed position. Alternately, input/output signal board 34 is mounted to moving slide 29 and U-shaped signal board 36 is mounted in a fixed position, or both signal boards 34, 36 are mounted to different moving slides. Spacers 32 are constructed using conductive or non-conductive material, such as metal and nylon.

[0012] FIGS. 3 and 4 depict top views of input/output signal boards 34 and U-shaped signal board 36, respectively. In one embodiment, input/output signal board 34 is a planar circuit board 44 having an input signal line 40 and an output signal line 42, and U-shaped signal board 36 is a planar circuit board 46 having a U-shaped signal line 48, wherein the U-shaped signal line has legs 50, 52 and an arc 54. The signal lines 40, 42, 48 are preferably etched onto circuit boards 44, 46 and configured into a transmission line structure. Possible transmission line structures include, but are not limited to, microstrip line, stripline and finline. If thin film technology is applied to signal boards 34, 36, circuit boards 44, 46 can be structured to comply with specified geometry or curved surfaces (and may not be planar).

[0013] Input and output signal lines 40, 42 are etched parallel to each other onto circuit board 44, wherein the space between input and output signal lines 40, 42 is equal to the space between legs 50, 52 of U-shaped signal line 48. Input, output and U-shaped signal lines 40, 42, 48 preferably having a same thickness. When U-shaped signal board 36 is positioned over input/output signal board 34 such that U-shape signal line 48 overlaps a minimum amount OD with input and output signal lines 40, 42, a complete signal trace is formed from input signal line 40 to U-shaped signal line 48 to output signal line 42, or vice versa, where OD is a minimum overlap/overlay amount between the input/output signal board and U-shaped signal board that allows for sufficient electrical coupling between the input/output signal lines and the U-shaped signal line. The value of OD being dependent upon the circuit board material, the stripline structure dimensions (i.e., distance between the top and bottom plates), and the signal line widths. See FIG. 5. Note that the term "U-shaped" is used to describe the shape of the signal line etched onto circuit board 46 (and not for describing the shape of circuit board 46). Further note that the present invention should not be construed as limited to a U-shaped signal line etched on circuit board 46. For purposes of this application, the term "U-shaped" should be construed to describe any shape for a signal line etched on circuit board 46 that will allow for a complete signal trace to be formed when circuit board 46 is positioned over circuit board 44.

[0014] As mentioned earlier, U-shaped signal board 36 is configured using spacers 32 such that U-shape signal board 36 can slide over input/output signal board 34. When U-shaped signal board 36 slides along its slidably mount (via spacers 32) over input/output signal board 34, the distance a signal traveling from input signal line 40 to output signal line 42 (via U-shaped signal board 46) varies, thus causing the phase of the signal to shift at the output signal line.

[0015] Signal boards 34, 36 are spaced a maximum distance D apart from each other, wherein D represents a maximum distance that enables sufficient electrical coupling between input and output signal lines 40, 42 with U-shaped signal line 48 while avoiding friction between signal boards 44, 46. The distance D being dependent upon the circuit board material, the stripline structure dimensions (i.e., distance between the top and bottom plates), and the signal line widths.

[0016] Provided here is an example of a phase shifter in accordance with the present invention. The phase shifter is a stripline structure with the two metallic plates (top and bottom plates) being spaced 332 mil apart. The circuit boards used for etching the input/output signal lines and the U-shape signal line are Rogers 4003 32 mil laminated with a dielectric constant of 3.38 and loss tangent of 0.002. Under such stripline dimension and material used, the signal line width would be 425 mil. A return loss of less than -20 dB and an insertion loss of less than 0.2 dB over a 50% frequency bandwidth can be obtained if the circuit board spacing and signal line overlap dimension are less than 10 mil and more than 2",respectively.

[0017] Phase shifters of the present invention may be incorporated into steerable phasedarray antennas. This will allow transmitting entities, such as base stations, to form desired radiation patterns without readjusting the downtilt of their antennas.

[0018] Although the present invention has been described in considerable detail with reference to certain embodiments, other versions are possible. For example, the phase shifter may have a double U-shaped signal line, as shown in FIGS. 6 and 7. Therefore, the spirit and scope of the present invention should not be limited to the description of the embodiments contained herein.

Claims

1. A phase shifter comprising:

   a slidable mounting system;
   a first signal board having an input signal line and an output signal line; and
   a second signal board positioned no more than a distance D and no less than an overlap amount OD over the first signal board using the slidable mounting system, the second signal board having a U-shaped signal line configured to complete a signal trace between the input signal line and the output signal line, the distance D being a maximum distance between the first and second signal boards and the overlay amount OD being a minimum amount of overlap between the first and second signal boards while enabling sufficient electrical coupling between the U-shaped signal line and the input and output signal lines.

2. The phase shifter of claim 1, wherein the distance D is no more than 10 mil.

3. The phase shifter of claim 1, wherein the overlap amount OD is at least 2 inches.

4. The phase shifter of claim 1, wherein the input and output signal lines are etched onto a first circuit board, and the U-shaped signal line is etched onto a second circuit board.

5. The phase shifter of claim 1 further comprising:

   a first plate to which the first signal board is mounted using the slidable mounting system, and
   a second plate to which the second signal board is mounted using the slidable mounting system.

6. The phase shifter of claim 5, wherein the first and second plates are constructed using a material for electrically grounding the phase shifter.

7. The phase shifter of claim 5, wherein the first and second plates are constructed using metal.

8. The phase shifter of claim 5, wherein the slidable mounting system comprises a plurality of spacers and a moving slide.

9. The phase shifter of claim 8, wherein the spacers are interposed between the first plate and the first signal board, and the spacers are interposed between the moving slide and the second signal board, the moving slide being slidably mounted within a channel in the second plate.

10. A phased array antenna comprising:

    a plurality of radiators for transmitting signals; and
    a phase shifter for generating differential phase among the plurality of radiators, the phase shifter including a slidable mounting system, a first signal board having an input signal line and an output signal line, and a second signal board positioned a distance D over the first signal board using the slidable mounting system, wherein the second signal board having a U-shaped signal line configured to complete a signal trace between the input signal line and

the output signal line, the distance D enabling sufficient electrical coupling between the U-shaped signal line and the input and output signal lines.

FIG. 1

PRIOR ART

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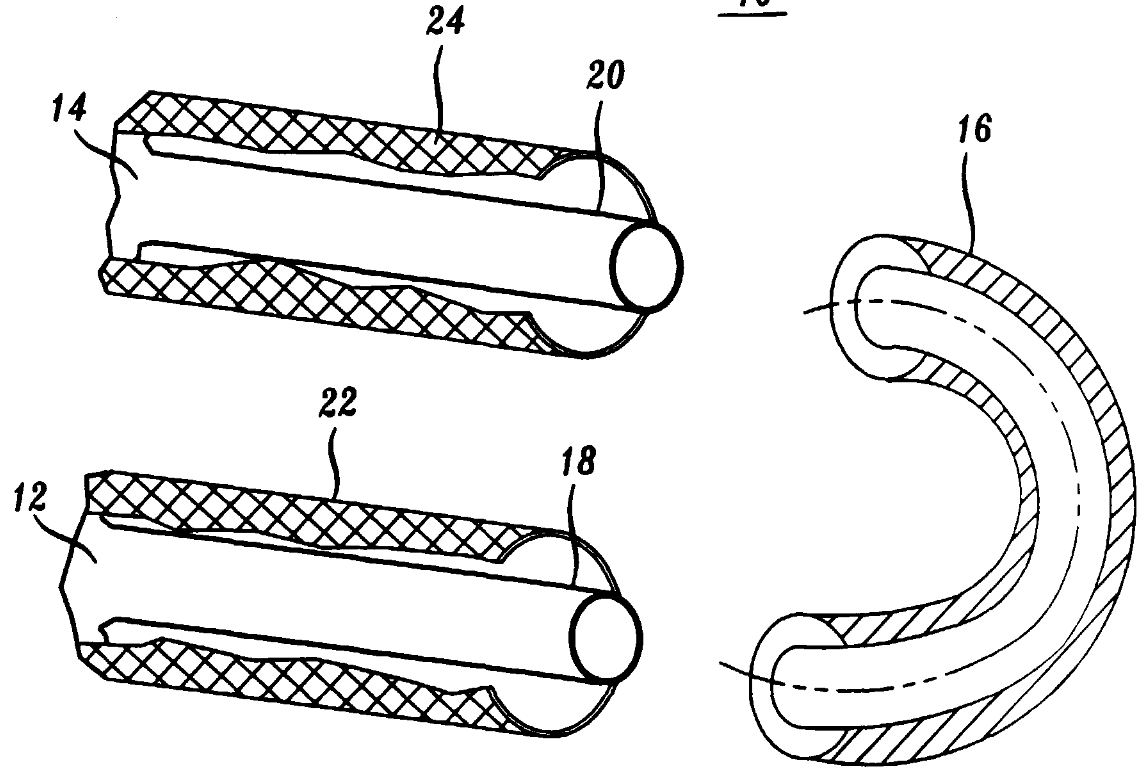


FIG. 2

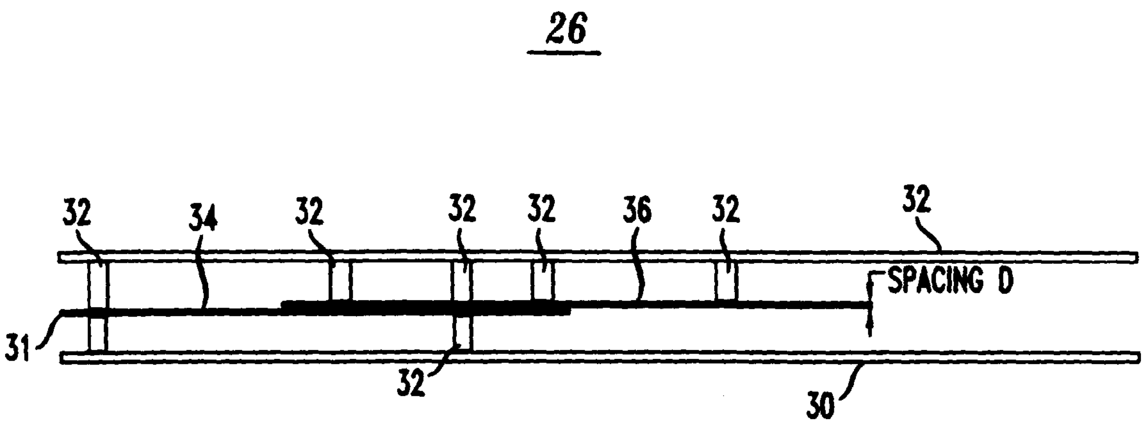


FIG. 2A

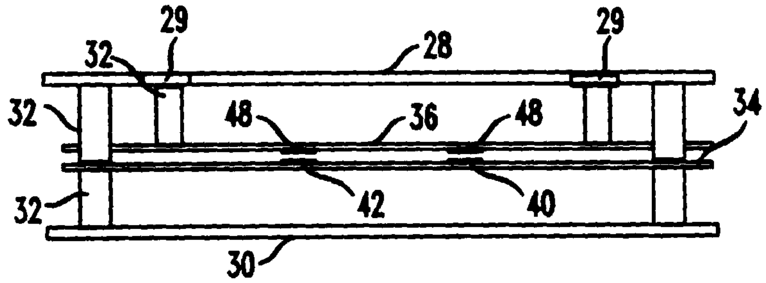


FIG. 3

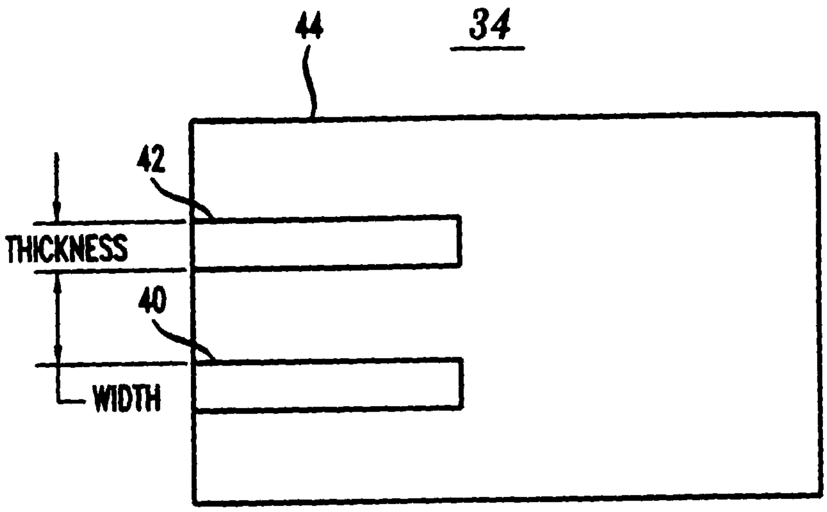


FIG. 4

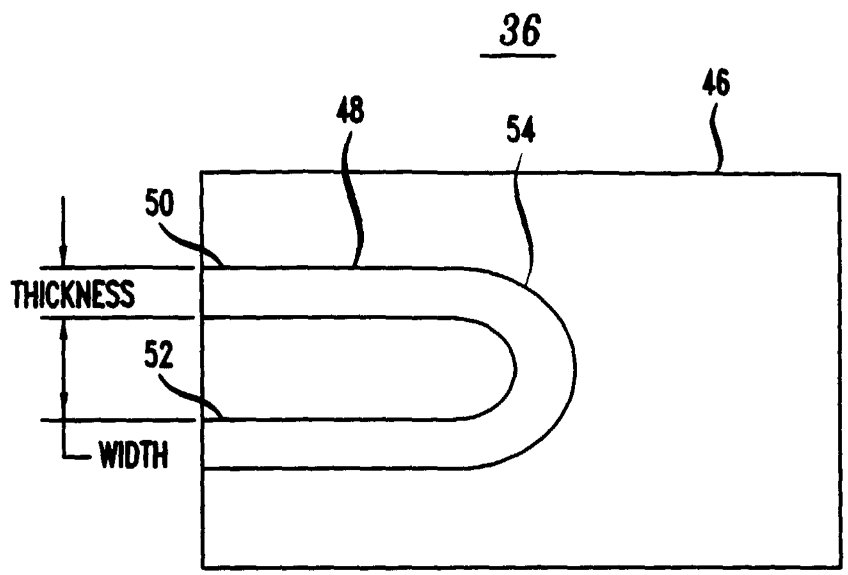

36
46
48
54
50
THICKNESS
52
WIDTH

FIG. 5

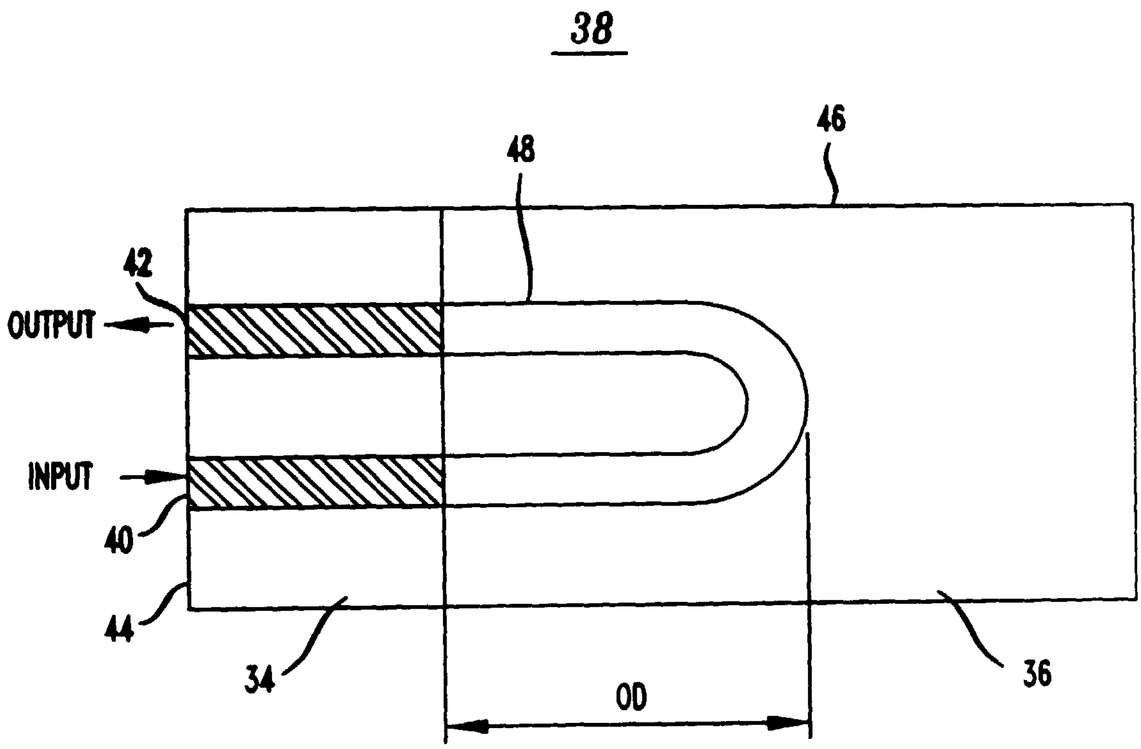

38
46
48
42
OUTPUT
INPUT
40
44
34
OD
36

FIG. 6

60

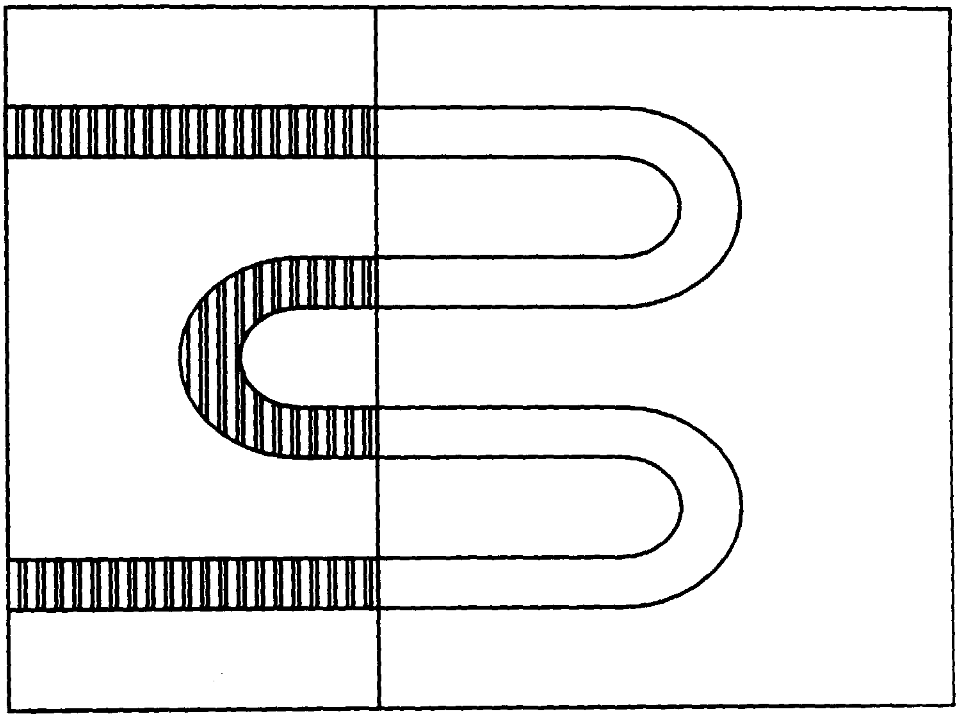
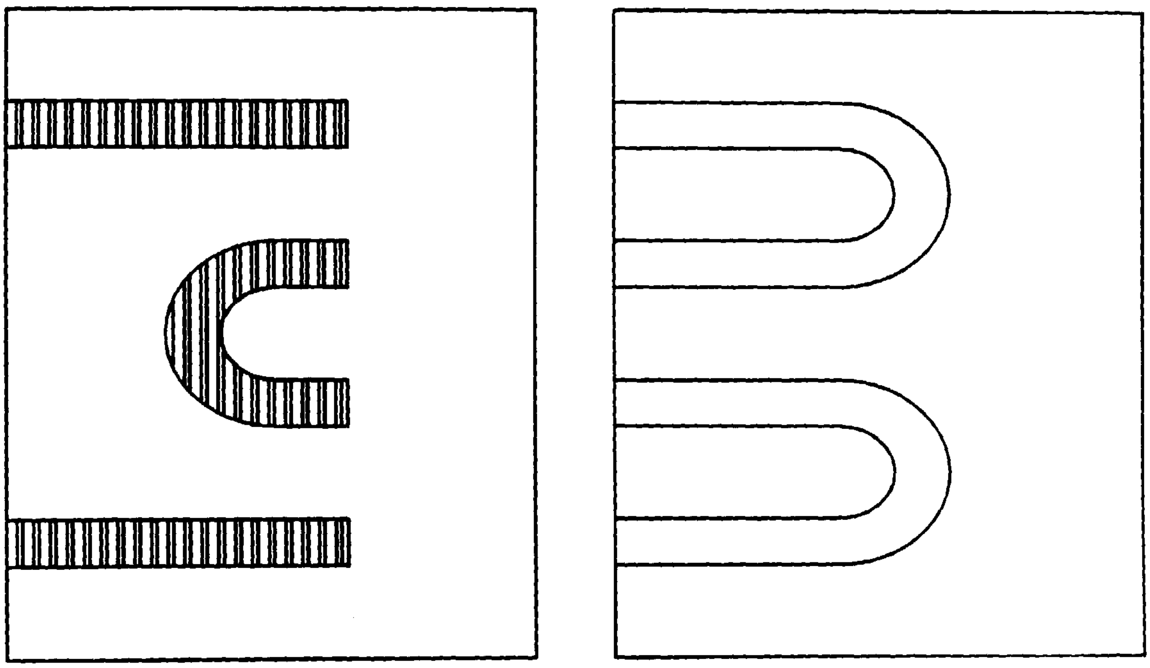


FIG. 7

<u>*70*</u>



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EUROPEAN SEARCH REPORT

Application Number
EP 00 30 1381

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X	PATENT ABSTRACTS OF JAPAN vol. 8, no. 235 (E-275), 27 October 1984 (1984-10-27) -& JP 59 117301 A (MITSUBISHI DENKI KK), 6 July 1984 (1984-07-06) * abstract *	1,4	H01P1/18
Y		5-8	
Y	US 2 961 620 A (SOMMERS) 22 November 1960 (1960-11-22) * column 2, line 62 - line 67 * * column 3, line 12 - line 40; figures 1-3,7-12 *	5-8	
X	PATENT ABSTRACTS OF JAPAN vol. 1998, no. 5, 30 April 1998 (1998-04-30) -& JP 10 004305 A (FURUKAWA ELECTRIC CO LTD), 6 January 1998 (1998-01-06) * abstract; figure 6 *	1,4,10	
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	28 March 2000	Den Otter, A

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 00 30 1381

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