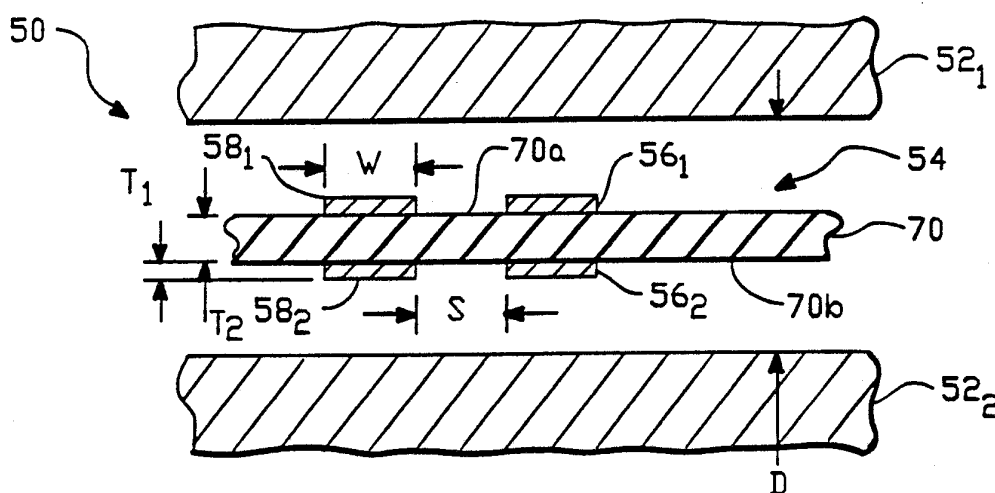




INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁵ : H01P 5/18	A1	(11) International Publication Number: WO 91/01574 (43) International Publication Date: 7 February 1991 (07.02.91)
<p>(21) International Application Number: PCT/US90/03846</p> <p>(22) International Filing Date: 9 July 1990 (09.07.90)</p> <p>(30) Priority data: 378,012 11 July 1989 (11.07.89) US</p> <p>(71) Applicant: WILTRON COMPANY [US/US]; 490 Jarvis Drive, Morgan Hill, CA 95037 (US).</p> <p>(72) Inventor: OLDFIELD, William, W. ; 413 Lakeview Way, Redwood City, CA 94062 (US).</p> <p>(74) Agents: FLIESLER, Martin, C. et al.; Fliesler, Dubb, Meyer and Lovejoy, 4 Embarcadero Center, Suite 400, San Francisco, CA 94111-4156 (US).</p>		<p>(81) Designated States: DE*, GB, JP.</p> <p>Published <i>With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i></p>

(54) Title: MICROWAVE COUPLER AND METHOD OF OPERATING SAME UTILIZING FORWARD COUPLING



(57) Abstract

A suspended substrate coupler (50) for operation at frequencies of 26 GHz or higher operated in a forward coupling mode. Coupling tends to improve with increased frequency and coupling as tight as 2dB is provided for frequencies of 40 to 60 GHz. The first (56₁, 56₂) and second (58₁, 58₂) coupled lines are suspended striplines provided on both surfaces (70A, 70B) of a dielectric (70) supported between two parallel ground planes (52₁, 52₂). The spacing (S) between the coupled striplines is approximately an order of magnitude greater than the spacing between the coupled lines of a conventional contra-directional coupler, and the length (L) of the coupled sections of the striplines is not required to be a multiple of a quarter wavelength.

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MICROWAVE COUPLER AND METHOD OF OPERATING
SAME UTILIZING FORWARD COUPLING

5

BACKGROUND OF THE INVENTION

Field of the Invention

10 The present invention relates to directional couplers, and more particularly to couplers for microwave applications.

Description of the Related Art

15 Arrays of parallel, coupled lines have two general areas of application in microwave circuits: (a) directional couplers; and (b) filters, delay lines, and matching networks. Directional couplers couple a prescribed amount of power input on a first transmission line to an second (or coupled) transmission line. For example, a 3dB coupler couples
20 one-half of the power transmitted by a first transmission line to a second transmission line -- the ratio of the power input to the first transmission line to the power coupled to the second transmission line is usually expressed in dB with increased
25 coupling being represented by a smaller coupling value in dB. Power input on the second transmission line is also coupled to the first transmission line. Directional couplers are useful measurement tools which provide a simple, convenient, and accurate means
30 for sampling microwave energy.

Fig. 1 illustrates the basic construction of a conventional coupled-line directional coupler 10 useful in, for example, microwave applications. Directional coupler 10 includes first and second
35 parallel striplines 12, 14 coupled over multiples of approximately one-quarter wavelength ($k/4$). Ports A and B are provided at first and second ends 16, 18 of first stripline 12 and ports C and D are provided at first and second ends 20, 22 of second stripline 14.

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The designation stripline, as used herein, refers to any conductor which has infinite ground planes on both sides of the conductor, including, for example, striplines, suspended striplines, and triplate striplines. The conductor itself may have different shapes, e.g., round or rectangular.

Ports A-D, which designate the first 16, 18 and second 18, 22 ends of first and second striplines 12, 14 will alternatively be referred to using the alphabetic port identifier or the following designations. An "input port" is any port to which a signal is applied. A stripline which has an input port is the "through stripline" and the other stripline is the "coupled stripline." With reference to an input port, a "through port" is at the opposite end of the through stripline from the input port, an "adjacent port" is at the same end of the coupled stripline as the input port, and an "opposite port" is at the opposite end of the coupled stripline from the input port. If a coupler has multiple inputs, and thus more than one input port, more than one designation may apply to a single port. In the coupler shown in Fig. 1, if port A is the input port, port B is the through port, port C is the adjacent port, and port D is the opposite port.

The first and second parallel striplines 12, 14, the through and coupled striplines, respectively, have a specified, small spacing in a coupling region 26. Ports A-C are usually configured for connection to coaxial transmission lines and the outer conductor or ground for each coaxial line is connected to grounded body 28 of coupler 10. Port D terminates the second stripline 14 by interconnecting stripline 14 to the

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body 28 of coupler 10, which is at ground potential, through resistor 30.

Conventional TEM or quasi-TEM mode directional couplers provide contra-directional coupling. In
5 contra-directional coupling, energy applied to a first stripline at an input port is directionally coupled from the first stripline to the coupled stripline and appears at the adjacent port on the coupled stripline, with a greater amount of power appearing at the
10 adjacent port than the opposite port. For example, energy applied at port A of the first stripline 12 appears at port B of first stripline 12; however, some fraction of the energy will appear at port C of the second stripline 14. The amount of energy appearing
15 at port C of second line 14 depends upon the amount of coupling provided in the design of the coupler. Several factors, including the spacing between the striplines 12, 14, determine the amount of energy that may be transferred from the one line to the other.

20 The amount of coupling desired for forward power (power flowing in the port A-to-port-B direction) varies with the application. For example, a coupler used to split a signal would use tight coupling, i.e.,
25 a large amount of power would be coupled to the coupled stripline. Coupling values of 30dB to 3dB are typically encountered in practice, and coupling of 8dB or better (i.e., coupling values of 8dB to 0dB) is generally referred to as tight coupling.

30 The directivity of a coupler is calculated as the ratio of the power coupled to the adjacent port to the power coupled to the opposite port, expressed in dB. For example, directivity is an indication of the

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amount of power appearing at port D, as a fraction of the power appearing at port C, when power is applied at port A, and is a measure of the isolation between port A and port D. It is generally desirable to avoid the loss of power, and thus the ideal directional coupler will have an infinite value of directivity. Values of directivity usually range from 5dB to 30dB.

Directional couplers are useful devices for measuring reflected energy. This is accomplished by applying energy to port B and connecting a device under test at port A. Energy reflected by the device under test will flow in the port A-to-port-B direction and a known fraction thereof will appear at port C.

A conventional 3dB, TEM, air dielectric, stripline coupler is shown in the schematic diagram of Fig. 2A and in the cross sectional view of Fig. 2B. First and second striplines 36, 38 are provided between first and second ground planes 40, 42 and are surrounded by an air dielectric. The spacing d between the ground planes 40, 42 is approximately 0.045". In coupling region 39 each stripline 36, 38 has a thickness of 0.006" and a width w of 0.020", and the spacing S_1 between the striplines 36, 38 is 0.0025". The dimensions of this conventional coupler, except for the length of the coupled sections of striplines 36, 38, generally do not vary with frequency.

Each of the dimensions of a coupler affects performance; for the purpose of providing tight coupling at high frequencies, the stripline spacing S is one of the important factors. For conventional TEM mode and quasi-TEM mode coupling, tight coupling at high frequencies requires (i) a spacing S on the order of thousandths of an inch with tolerances of ten-

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thousandths of an inch, and (ii) high impedance striplines in the coupled region (high impedance striplines are provided by selecting the dimensions of the striplines in the coupled region). In general, for TEM mode and quasi-TEM mode coupling the impedance of the coupled sections of the striplines is approximately 90X, and increase of almost a factor of two (2) with respect to the 50X impedance of the remaining portions of the striplines and the first and second transmission lines.

Coupled striplines 12, 14 of some conventional directional couplers are constructed using metalized plastic layers similar to multi-layer printed circuit board. The metal is etched to form a desired conductor or circuit pattern. One type of coupler fabricated in this manner is a suspended substrate coupler in which the coupled striplines are suspended microstrips. A suspended coupler which operates as a quasi--TEM coupler is disclosed in Japanese Laid Open Application No. 62-114302 -- Miyazaki.

Very small, high-frequency geometries can be formed with suspended substrate couplers. However, until approximately 1984, it was believed that the maximum frequency which could be handled by coaxial couplers was 26GHz. This perceived limitation was related, at least in part, to the inability to manufacture components such as couplers with the small dimensions and tolerances required for frequencies above 26GHz. Tolerances on the order of approximately 0.0005" must be maintained for frequencies over 26GHz. Further, it has not been possible to make a coupler which provides coupling tighter than 3dB with conventional suspended substrate couplers.

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At higher microwave frequencies (above 20GHz), suspended substrate couplers offer low loss, relatively large size features, and precise impedance control. For frequencies above 26GHz, the transmission lines must comprise microstrips provided on both sides of the suspended substrate because single sided transmission lines suffer from dielectric surface modes. However, suspended substrate couplers suffer from poor performance, particularly poor directivity, at frequencies above 20GHz.

The directivity of suspended substrate couplers is, in general, very poor for frequencies below 20GHz (directivity values usually range from 5 to 15dB). At frequencies above 20 GHz the directivity of a suspended substrate coupler rapidly degrades further. In addition, conventional suspended substrate couplers suffer from losses due to, for example, line resistances and losses in the dielectric. At high frequencies these losses are more critical because losses generally occur per wavelength -- the shorter wavelengths associated with higher frequencies result in more loss per length of transmission line. One cause of losses in conventional suspended substrate contra-directional couplers is the need to provide the transmission lines with an increased impedance -- on the order of 90X -- in the coupling region in order to provide tight coupling.

SUMMARY OF THE INVENTION

It is, therefore, an object of the present invention to provide a coupler useful with microwave signals having frequencies of 26GHz and higher.

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A further object of the present invention is to provide a coupler which is useful at frequencies ranging from 40 to 60 GHz and beyond.

5 Another object of the present invention is to provide a directional coupler which operates at frequencies above 26GHz with low losses.

10 Another object of the present invention is to provide a directional coupler which provides tight coupling (a coupling factor of better than 8dB) and coupling tighter than 3dB.

Another object of the present invention is to provide a coupler in which performance is not effected by differing propagation velocities of odd and even mode signals.

15 These and other objects of the present invention are provided by a suspended substrate coupler which has a large spacing S (approximately an order of magnitude greater than the spacing for conventional couplers) between the coupled striplines and which is
20 operated in the forward coupling mode. In the forward coupling mode a signal applied to the through stripline at the input port (port A) is coupled to the coupled stripline and appears at the opposite port (port D), with more power appearing at the opposite
25 port than at the adjacent port. Tight forward coupling begins at frequencies of approximately 26GHz and coupling as tight as 1dB for signals of 40-60GHz, with directivity better than 10dB, is provided by such a coupler. In the suspended substrate coupler of the
30 present invention, the first and second transmission lines are suspended striplines spaced apart by a distance which is approximately an order of magnitude larger than the distance between the striplines in a

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conventional contra-directional couplers. Further, tight coupling is provided by transmission lines constructed to have a uniform impedance of $50X$, and therefore the need to use higher impedance transmission lines in the coupling region is eliminated.

An apparatus for coupling signals in accordance with the present invention, comprises: first and second transmission lines; means for providing signals having a frequency of approximately 26GHz or greater on said first transmission line; and a suspended substrate coupler for forward coupling said signals from said first transmission line to said second transmission line.

In accordance with the present invention, a method of operating a suspended substrate coupler to couple microwave signals in the forward direction, the coupler comprises first and second transmission lines, the opposite ends of the first transmission line being designated as ports A and B, respectively, and the opposite ends of the second transmission lines being designated as ports C and D, respectively, ports A and C being at corresponding ends of the first and second transmission lines, comprises the steps of: (a) applying a microwave signal having a frequency equal to or greater than 26GHz to port A; and (b) detecting power at ports B and D, where the amount of power detected at port D is at least approximately equal to the amount of power detected at port B.

BRIEF DESCRIPTION OF THE DRAWING

Fig. 1 is a plan view of a conventional directional coupler;

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Fig. 2A is a schematic diagram of a conventional, air dielectric, TEM mode, stripline, 3dB directional coupler;

5 Fig. 2B is a sectional view along line 2B-2B in Fig 2A;

Fig.3 is a schematic diagram of an apparatus for coupling signals including a suspended substrate directional coupler in accordance with the present invention;

10 Fig.4 is a sectional view a suspended substrate directional coupler in accordance with the present invention;

Fig.5A-C are graphs useful in explaining the operating characteristics of couplers in accordance with the present invention;

Figs. 6A-B are schematic diagrams of alternative embodiments of the present invention; and

20 Fig. 7 is a schematic diagram useful in describing an application of the directional coupler of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A directional coupler in accordance with the present invention will be described with reference to Figs. 3 - 7. The inventor of the directional coupler of the present invention has discovered that a
25 suspended substrate coupler having a large spacing between the coupled striplines has improved coupling characteristics for signals of approximately 26GHz or greater when operated in the forward coupling mode.
30 In particular, signals of 40 to 60 GHz are forward coupled with an unusually large amount of power being coupled, with good directivity, and with low losses.

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5 The forward coupling mode, as used herein, refers to the coupling of power from a signal input at an input port (e.g., port A) on a through stripline to the opposite port (e.g., port D) of the coupled stripline. Alternatively, if port B is the input port power is coupled to port C, if port C is the input port power is coupled to port B, or if port D is the input port power is coupled to port A. A forward coupler in accordance with the present invention is useful, with improved results, in many of the same applications where conventional contra-directional couplers are used, provided that the appropriate connections and isolation of the ports of the coupler are established.

10
15 The operation of a suspended substrate coupler in accordance with the present invention will be described with reference to Fig. 3. Signal source 44 provides microwave signals having frequencies of 26 GHz and higher to a first transmission line 46. First transmission line 46 and a second transmission line 48 are connected to coupler 50, and test/measurement devices 52, 54 are connected to transmission lines 46, 48, respectively. Coupler 50 includes first and second stripline conductors 56, 58 which are coupled in coupling region 57, first stripline 56 being inserted as a portion of first transmission line 46, and second stripline conductor 58 being inserted as a portion of second transmission line 48. Coupling region 57 has a length L , and first and second striplines 56, 58 have a spacing S_2 in the coupled region. Thus, signal source 42 is connected to port A (first end 72 of stripline 56), test/measurement device 52 is electrically connected to port B (second

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end 74 of stripline 56), and test/measurement device 54 is electrically connected to port D (second end 78 of stripline 58). Port C (first end 76 of stripline 58) is connected to ground in the embodiment illustrated in Fig. 3.

In operation, signal source 44 supplies signals at port A, and a portion of the power input at port A is transmitted by first stripline 56 to port B. In addition, a portion of the power input at port A is coupled from first stripline 56 to second stripline 58. The coupled power appears at port D. A small amount of power also appears at port C; however, coupler 50 has good directivity and the amount of power appearing at port C is negligible, or at least less than the amount of power appearing at port D.

As shown in Fig. 4, a suspended substrate directional coupler 50 in accordance with the present invention includes first and second ground conductive planes 52_{1-2} and a suspended substrate 70 provided between the ground planes 52_{1-2} . The suspended substrate is a dielectric, for example, alumina. Other dielectrics and the properties of various dielectrics are set forth in "Foundations for Microstrip Circuit Design", T.C. Edwards, John Wiley and Sons, 1981. First and second stripline 56, 58 are provided on the suspended substrate 70, and are each formed of first and second conductors 56_{1-2} , 58_{1-2} provided on opposed first and second surfaces 70a, b of suspended substrate 70.

First and second transmission lines 46, 48 (Fig. 3) are usually coaxial conductors. The ground shields of transmission lines 46, 48 are electrically connected to the first and second ground planes 52_{1-}

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2 of coupler 50, and the centerline conductors of first and second transmission lines 46, 48 are connected to first and second striplines 56, 58, respectively. First and second conductors 56₁₋₂, 58₁₋₂ of each of the first and second striplines 56, 58 are both connected to the centerline conductor of the respective first and second transmission lines 46, 48, so that striplines 56₁₋₂ are connected in parallel and so that striplines 58₁₋₂ are connected in parallel.

Each of the stripline conductors 56₁₋₂, 58₁₋₂ has a width W and a thickness T₁ which are related to provide an impedance of 50X for the striplines 56₁₋₂, 58₁₋₂. The distance S₂ between first striplines 56₁, 58₁ and between second striplines 56₂ and 58₂ ranges from approximately 0.01 to 0.05". This spacing S₂ is approximately an order of magnitude larger than the spacing between the first and second striplines in conventional contra-directional couplers. The length of the coupled sections of first and second striplines 56, 58 ranges from approximately 0.1 to 0.5 inches; the coupled sections are not required to be multiples of one-quarter wavelengths as in conventional couplers. The thickness T_s of substrate 70 may range from approximately 0.002 to 0.015 inches.

A coupler in accordance with the present invention has coupling versus frequency characteristics which are greatly different than those of conventional contra-directional couplers. The coupling for a directional coupler in accordance with the present invention becomes tighter as the frequency of the signals increases, without an apparent drop-off in coupling. On the other hand, a conventional contra-directional coupler has a bell-shaped coupling curve

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with the peak of the curve usually falling in the center of the frequency range for which the coupler is designed.

5 The slope of the coupling versus frequency curve for coupler 50 of the present invention can be controlled by changing the spacing S_2 of striplines 56, 58 and the length L of the coupled section of striplines 56, 58. It has been experimentally
10 determined that smaller spacings S and shorter coupled section lengths L create a steeper coupling versus frequency curve, making a coupler which is useful for a narrower range of frequencies; however, the tradeoff for a steep coupling versus frequency curve is poorer directivity.

15 On the other hand, experimental results have determined that a longer coupling length L and a larger coupling spacing S_2 yield a coupler having a broader frequency response and a shallower coupling versus frequency curve. Longer coupling lengths L of
20 the coupling region 57 yield improved directivity, but the increased length of striplines 56, 58 increases the losses which occur in coupler 50.

The inventor has determined that a coupler in accordance with the present invention which provides
25 3dB coupling at 40 GHz and tighter coupling at higher frequencies (with coupling as tight as 1dB at 60 GHz) can be fabricated utilizing a coupler having a ground plane spacing D of 0.045 inches, a dielectric having a thickness T_2 of 0.005 inches, parallel striplines 56,
30 58 having a spacing S_2 of 0.028 inches, and a coupling region 57 having a length L of 0.35 inches. The coupling versus frequency curve for a coupler having these dimensions is shown by curve A-D in Fig. 5A,

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which represents the coupling from port A to port D versus frequency. Curve A-B in Fig. 5A shows the losses for a signal transmitted from port A to port B, and curve A-C shows the directivity for this coupler. From Fig. 5A it can be seen that coupling of 3dB is achieved at 40 GHz, and that tighter coupling is achieved as frequency of the signal to be coupled increases from 40 to 60 GHz, and beyond.

Fig. 5B illustrates the coupling characteristics for couplers having a coupling length L of 0.300", spacings S_2 of 0.028" (plot I), 0.035" (plot II), and 0.050" (plot III), and a substrate thickness of 0.010". The losses for signals transmitted from port A to port B are illustrated by plots I'-III', respectively. Fig. 5C illustrates the coupling characteristics for couplers having a coupling length L of 0.300", spacings S_2 of 0.020" (plot IV), 0.028" (plot V), and 0.036" (plot VI), and a substrate thickness of 0.005". The losses for signals transmitted from port A to port B are illustrated by plots IV'-VI', respectively.

Parallel striplines 56, 58 in coupling region have been found to provide the best coupling. However, alternative arrangements of first and second striplines 56, 58 in the coupling region have been found to provide satisfactory coupling. Examples of alternatively arrangements for striplines 56, 58 are shown in Figs. 6A and 6B. Fig. 6A illustrates a single tapered coupling region 57, and Fig. 6B illustrates a dual tapered coupling region 57.

One example of an application for a coupler with the present invention is a multiplexer for signals having different frequencies. A multiplexer 76

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utilizing a coupler 50 in accordance with the present invention is shown in Fig. 7. In multiplexer 76, signal source 44 provides signals having a frequency ranging from 40 to 60 GHz at port A of coupler 50, and
5 signal source 80 provides signals having a frequency of 1-40 GHz at port C of coupler 50. The 40-60 GHz signals applied at port A are coupled to port D, and the 1-40 GHz signals applied at port C are transmitted to port D by second stripline 58. Accordingly,
10 signals having frequencies of 1 to 60 GHz appear at port D and may be detected by test/measurement device 54.

The coupler of the present invention does not appear to operate with odd and even modes as does a
15 conventional contra-directional coupler, and does not appear to operate as a TEM or quasi-TEM mode coupler, based on the fact that the coupling is not contra-directional. It is possible that the coupler operates in a waveguide coupling mode. However, the coupling
20 mechanism is not presently known.

The many features and advantages of the present invention will be apparent to those skilled in the art from the Description of the Preferred Embodiments. Thus, the following claims are intended to cover all
25 modifications and equivalents falling within the scope of the invention.

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CLAIMS

What is claimed is:

1. An apparatus for coupling signals, comprising:
first and second coaxial transmission lines;
first means for providing signals having a frequency of at least 26GHz on said first transmission line; and

second means for forward coupling said signals from said first transmission line to said second transmission line with a coupling factor of 8 dB or better.

2. An apparatus according to claim 1, wherein said second means comprises first and second suspended striplines inserted in respective ones of said first and second transmission lines.

3. An apparatus according to claim 1, wherein said second means comprises:

first and second substantially parallel ground planes;

a dielectric layer supported between said first and second ground planes, said dielectric layer having first and second opposed surfaces substantially parallel to respective ones of said first and second ground planes;

first and second suspended stripline conductors provided on respective ones of said opposed surfaces of said dielectric layer, said first and second suspended stripline conductors being electrically connected in parallel and electrically inserted in said first transmission line;

third and fourth stripline conductors provided on respective ones of said opposed surfaces of said dielectric layer, said third and fourth suspended

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stripline conductors being electrically connected in parallel and electrically inserted in said second transmission line, each of said third and fourth stripline conductors including a coupling section substantially parallel to and spaced a distance S from respective ones of said first and second stripline conductors.

4. An apparatus according to claim 3, wherein:
said coupling sections of said third and fourth stripline conductors have a length ranging from 0.1 to 0.5 inches and S ranges from 0.01 to 0.05 inches; and
said substrate has a thickness ranging from 0.002 to 0.015 inches.

5. An apparatus for coupling signals, comprising:
first and second transmission lines;
means for providing signals having a frequency of approximately 40-60GHz on said first transmission line; and
a suspended substrate coupler for forward coupling said signals from said first transmission line to said second transmission line.

6. An apparatus according to claim 5, wherein said second means comprises:

first and second substantially parallel ground planes;

a dielectric layer supported between said first and second ground planes, said dielectric layer having first and second opposed surfaces substantially parallel to respective ones of said first and second ground planes;

first and second suspended stripline conductors provided on respective ones of said opposed surfaces of said dielectric layer, said first and second

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suspended stripline conductors being electrically connected in parallel and electrically inserted in said first transmission line;

third and fourth stripline conductors provided on respective ones of said opposed surfaces of said dielectric layer, said third and fourth suspended stripline conductors being electrically connected in parallel and electrically inserted in said second transmission line, each of said third and fourth stripline conductors including a coupling section substantially parallel to and spaced a distance S from respective ones of said first and second stripline conductors.

7. An apparatus according to claim 6, wherein:

said coupling sections of said third and fourth stripline conductors have a length ranging from 0.1 to 0.5 inches and S ranges from 0.01 to 0.05 inches; and said substrate has a thickness ranging from 0.002 to 0.015 inches.

8. A directional coupler, comprising:

first and second substantially parallel ground planes;

a dielectric layer supported between said first and second ground planes, said dielectric layer having first and second opposed surfaces substantially parallel to respective ones of said first and second ground planes;

a first transmission line comprising first and second suspended stripline conductors provided on respective ones of said opposed surfaces of said dielectric layer;

a second transmission line comprising third and fourth stripline conductors provided on respective

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ones of said opposed surfaces of said dielectric layer, said second transmission line including a coupling section substantially parallel to and spaced a distance S from said first transmission line and having a length, the length of said coupling section and the spacing S being selected to provide a selected coupling coefficient versus frequency, so that microwave signals having a frequency of approximately 40-60GHz travelling on one of said first and second transmission lines are forward coupled to the other of said first and second transmission lines with a coupling factor of 3dB or better.

9. A directional coupler according to claim 8, wherein:

said first and second transmission lines have a uniform impedance of approximately 50X;

said coupling sections of said third and fourth stripline conductors have a length ranging from 0.1 to 0.5 inches and S ranges from 0.01 to 0.05 inches; and

said substrate has a thickness ranging from 0.002 to 0.015 inches.

10. An apparatus for directional coupling of signals, comprising:

means for providing signals having a frequency of greater than approximately 40 GHz; and

means for forward coupling signals, comprising:

first and second substantially parallel ground planes;

a dielectric layer supported between said first and second ground planes, said dielectric layer having first and second opposed surfaces substantially parallel to respective ones of said first and second ground planes;

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a first transmission line comprising first and second suspended stripline conductors provided on respective ones of said opposed surfaces of said dielectric layer;

a second transmission line comprising third and fourth stripline conductors provided on respective ones of said opposed surfaces of said dielectric layer, said second transmission line including a coupling section substantially parallel to and spaced a distance S from said first transmission line and having a length, the length of said coupling section and the spacing S being selected to provide a selected coupling coefficient versus frequency, so that microwave signals having a frequency of approximately 40-60GHz applied to an input port of one of said first and second transmission lines are coupled to the opposite port of the other of said first and second transmission lines with a coupling factor of 3dB or better.

11. A directional coupler according to claim 10, wherein said first and second transmission lines have a uniform impedance of approximately 50X.

12. A directional coupler according to claim 10, wherein:

said coupling sections of said third and fourth stripline conductors have a length ranging from 0.1 to 0.5 inches and S ranges from 0.01 to 0.05 inches; and said substrate has a thickness ranging from 0.002 to 0.015 inches.

13. A suspended substrate directional coupler for providing forward coupling of microwave signals having a frequency greater than 26GHz, comprising:

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first and second substantially parallel ground planes;

a dielectric layer suspended between said first and second ground planes, said dielectric layer having first and second opposed surfaces substantially parallel to respective ones of said first and second ground planes and a thickness ranging from 0.002 to 0.015 inches;

a first transmission line comprising first and second stripline conductors provided on respective ones of said opposed surfaces of said dielectric layer; and

a second transmission line comprising third and fourth stripline conductors provided on respective ones of said opposed surfaces of said dielectric layer, said second transmission line having a coupling section substantially parallel with and spaced a distance S ranging from 0.01 to 0.05 inches from said first transmission line, said coupling sections of said third and fourth stripline conductors have a length ranging from 0.1 to 0.5 inches.

14. A method of operating a suspended substrate coupler to couple microwave signals in the forward direction, the coupler comprising first and second transmission lines, the opposite ends of the first transmission line being designated as ports A and B, respectively, and the opposite ends of the second transmission lines being designated as ports C and D, respectively, ports A and C being at corresponding ends of the first and second transmission lines, comprising the steps of:

(a) applying a microwave signal having a frequency equal to or greater than 26GHz to port A; and

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(b) detecting power at ports B and D, where the amount of power detected at port D is at least approximately equal to the amount of power detected at port B.

15. A method of operating a directional coupler to couple microwave signals having a frequency greater than 26GHz in the forward direction, the coupler comprising first and second transmission lines, each transmission line comprising first and second stripline conductors provided on opposed surfaces of a suspended substrate, each transmission line having a first end and a second end, the transmissions lines having substantially parallel coupling sections, the first ends of the first and second transmission lines being designated as ports A and C, respectively, and the second ends of the first and second transmission lines being designated as ports B and D, respectively, comprising the steps of:

(a) applying a microwave signal having a frequency equal to or greater than 26GHz to port A; and

(b) detecting power at ports B and D, where the amount of power detected at port D is at least approximately equal to the amount of power detected at port B.

16. A method according to claim 15, further comprising the step of (c) isolating ports A and C.

17. A method according to claim 15, further comprising the step of (c) detecting power at port C, where the power detected at port C is at least 6dB less power than the power detected in said step (b).

18. A method according to claim 15, wherein said step (b) comprises detecting power at ports B and D,

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where the amount of power detected at port D is greater than the amount of power detected at port B.

19. A method of coupling microwave signals, comprising the steps of:

(a) providing first and second substantially parallel ground planes;

(b) providing a dielectric layer suspended between the first and second ground planes, the dielectric layer having first and second opposed surfaces substantially parallel to respective ones of the first and second ground planes;

(c) providing a first transmission line comprising first and second stripline conductors provided on respective ones of the opposed surfaces of the dielectric layer;

(d) providing an second transmission line comprising third and fourth stripline conductors provided on respective ones of the opposed surfaces of the dielectric layer, the third and fourth stripline conductors each having a coupling section having a length ranging from 0.1 to 0.5 inches, the first and second transmission lines each having a first end and a second end, the first ends of the first and second transmission lines being designated as ports A and C, respectively, and the second ends of the first and second transmission lines being designated as ports B and D, respectively;

(e) providing the coupling sections with a spacing of a distance S from respective ones of the first and second stripline conductors, where S ranges from 0.01 to 0.05 inches;

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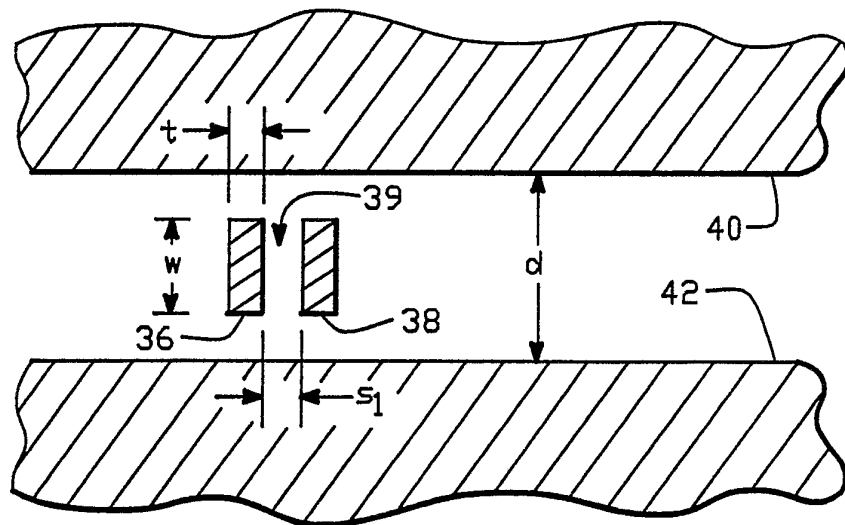
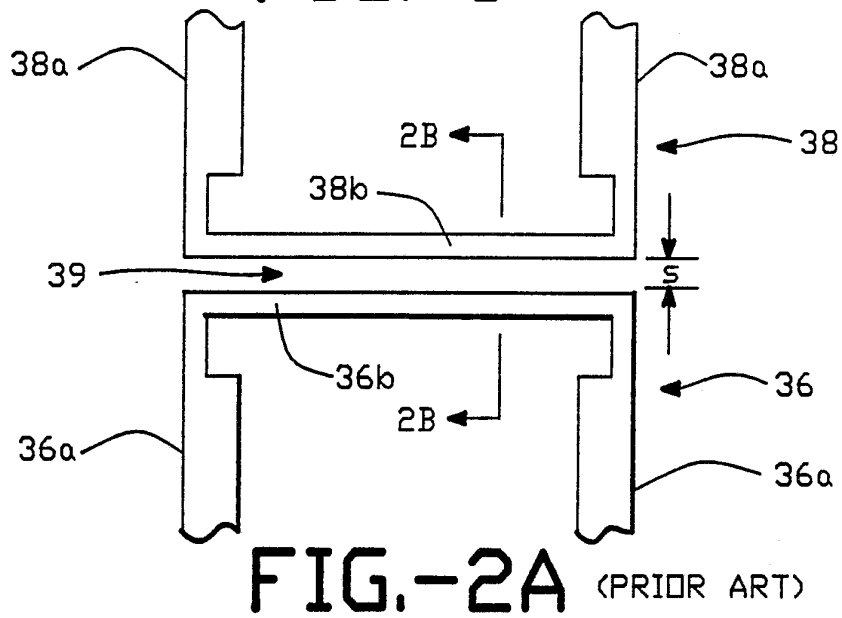
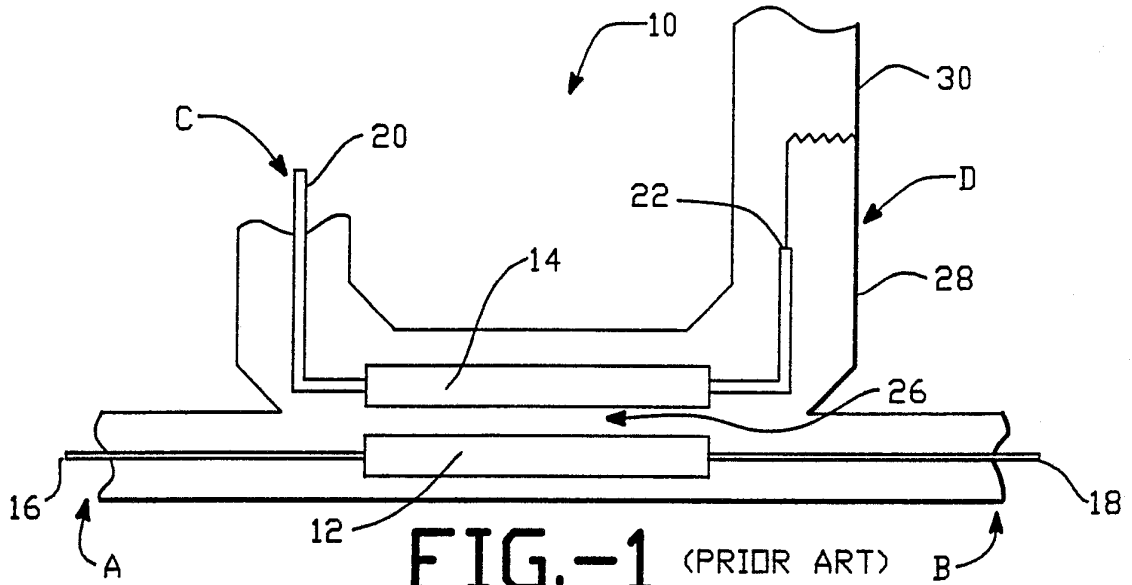
(f) providing microwave signals having a frequency greater than 26GHz at port A of said first transmission lines; and

(g) detecting power at ports B and D, where the amount of power detected at port D is at least approximately equal to the amount of power detected at port B.

20. A method according to claim 19, further comprising the step of (h) isolating ports A and C.

21. A method according to claim 19, further comprising the step of (h) detecting power at port C, where the power detected at port C is at least 6dB less power than the power detected in said step (g).

22. A method according to claim 19, wherein said step (g) comprises detecting power at ports B and D, where the amount of power detected at port D is greater than the amount of power detected at port B.



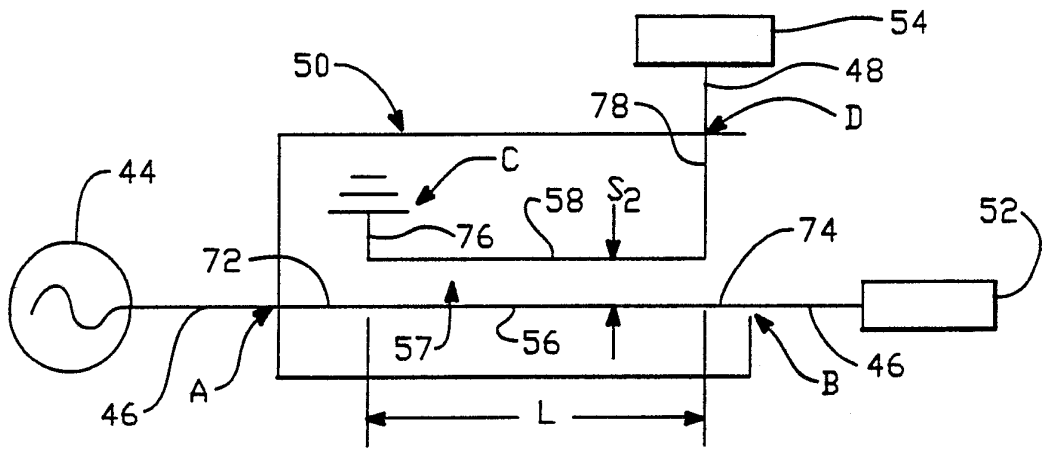


FIG.-3

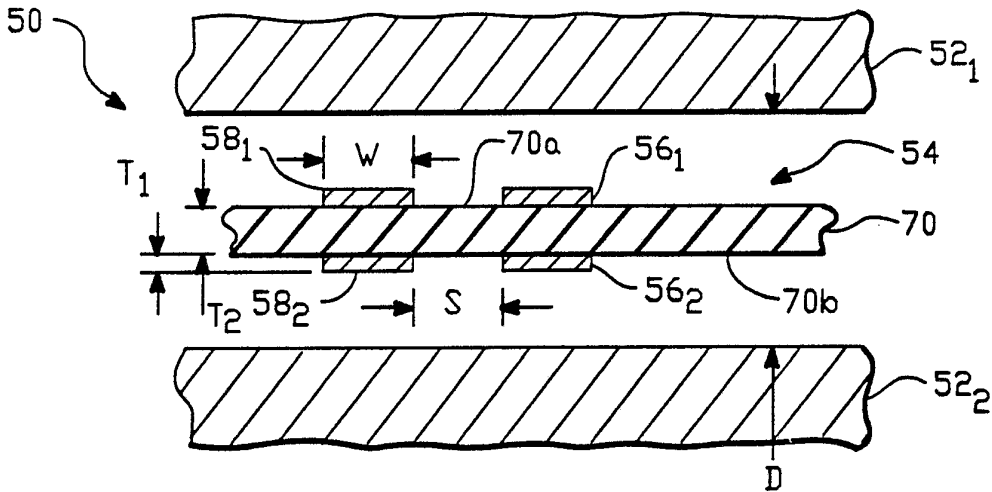


FIG.-4

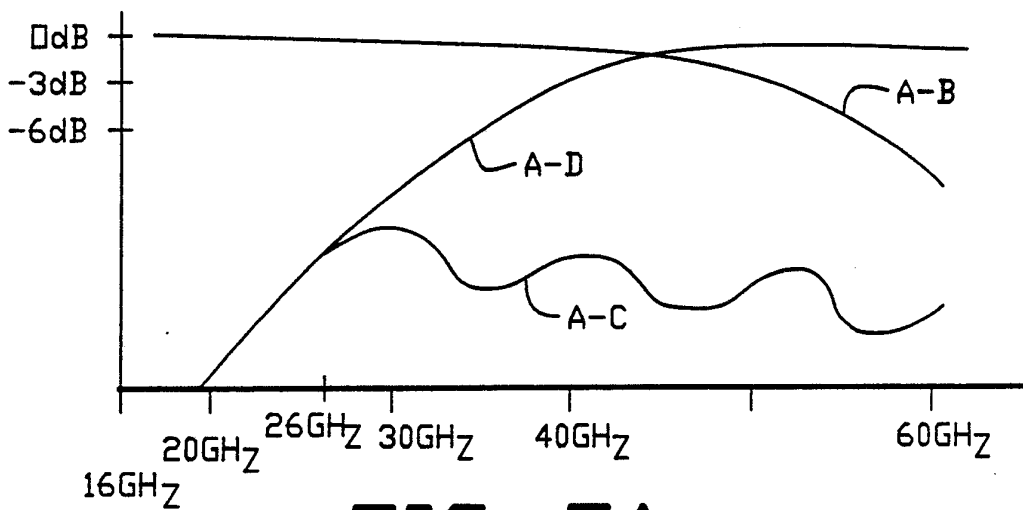


FIG.-5A

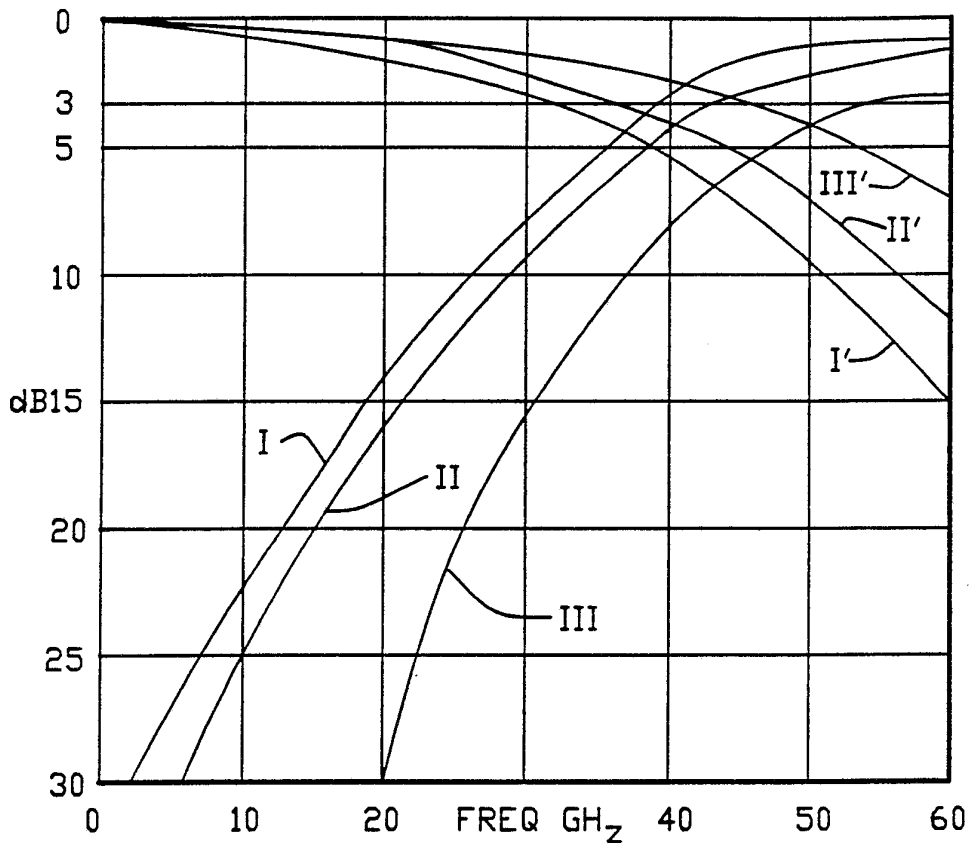


FIG.-5B

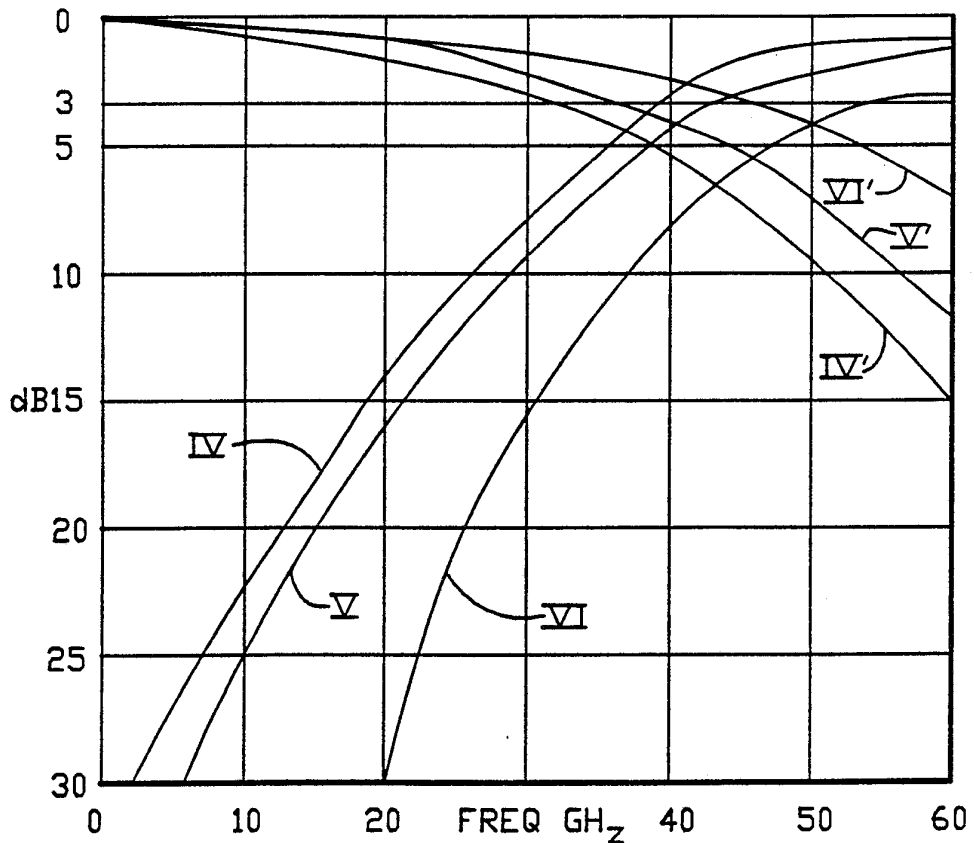


FIG.-5C

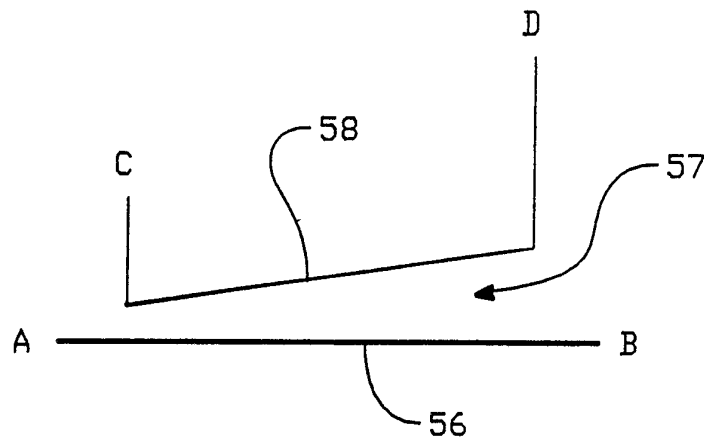


FIG.-6A

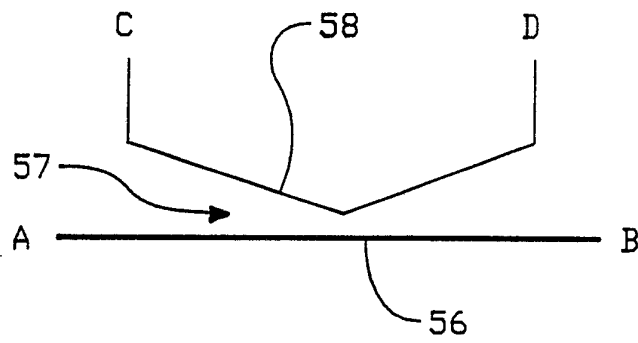


FIG.-6B

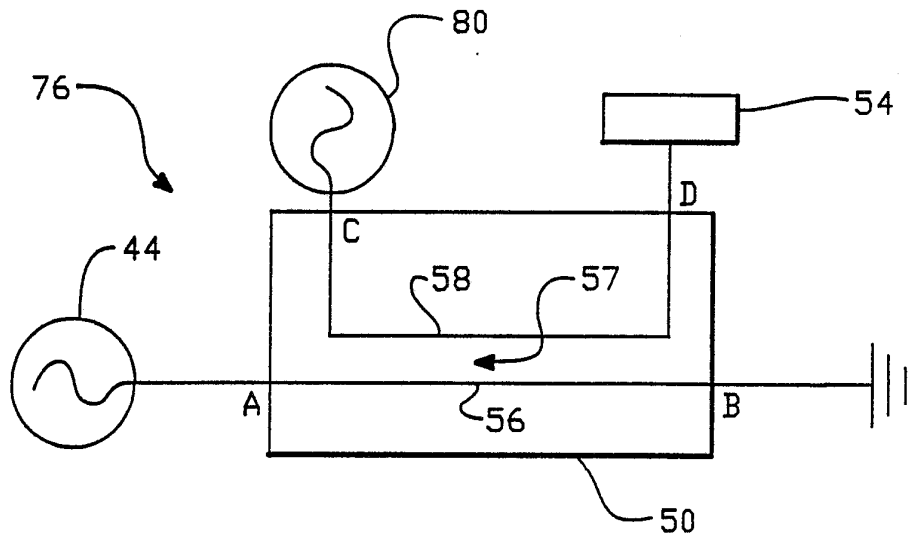
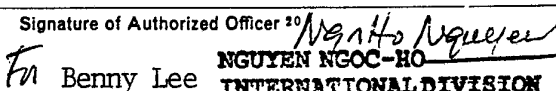


FIG.-7 SUBSTITUTE SHEET

INTERNATIONAL SEARCH REPORT

International Application No PCT/US90/03846

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ³		
According to International Patent Classification (IPC) or to both National Classification and IPC		
IPC (5): HO1P 5/18		
U.S.Cl.: 333/116		
II. FIELDS SEARCHED		
Minimum Documentation Searched ⁴		
Classification System	Classification Symbols	
U.S. Cl.	333/116,115,109	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched ⁵		
III. DOCUMENTS CONSIDERED TO BE RELEVANT ¹⁴		
Category *	Citation of Document, ¹⁵ with indication, where appropriate, of the relevant passages ¹⁷	Relevant to Claim No. ¹⁸
Y	US, A, 4,376,921 (DICKENS et al.) 15 March 1983 (Note col. 2, lines 7-42 for forward coupling)	1-22
Y	US, A, 3,621,478 (JOHNSON et al.) 16 November 1971 (Note col. 2, lines 9-17 for housing and coax connector)	1, 14
Y	JP, A 62-114301 (MITSUBISHI) 26 May 1987 (Note the abstract)	1-22
Y	JP, A 62-114302 (MITSUBISHI) 26 May 1987 (Note the abstract)	1-22
A	US, A, 4,459,568 (LANDT) 10 July 1984 (Note Fig. 2)	1-3, 5-7
A	US, A, 3,204,206 (HARMON) 31 August 1965 (Note Fig. 3)	1-3, 5-7 14
A	US, A, 4,571,545 (GRIFFIN) 18 February 1986 (Note Fig. 1)	14-22
A	US, A, 4,502,028 (LEAKE) 26 February 1985	14-22
<p>* Special categories of cited documents: ¹⁹</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"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)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> <p>"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</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"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.</p> <p>"&" document member of the same patent family</p>		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search ²	Date of Mailing of this International Search Report ²	
07 September 1990	07 DEC 1990	
International Searching Authority ¹	Signature of Authorized Officer ²⁰	
ISA/US	 NGUYEN NGOC-HO INTERNATIONAL DIVISION	