Aug. 2, 1966 S. HOPFER 3,264,582

WIDE BAND SLAB LINE COAXIAL DIRECTIONAL COUPLER

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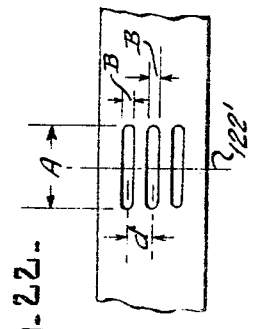



FIG. 22.

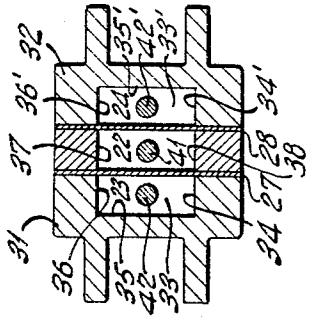



FIG. 3.

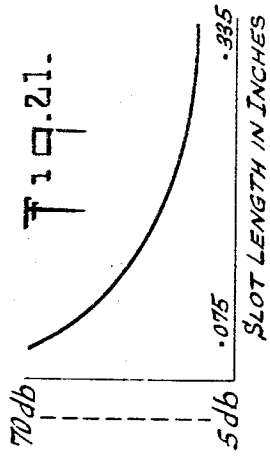



FIG. 21.

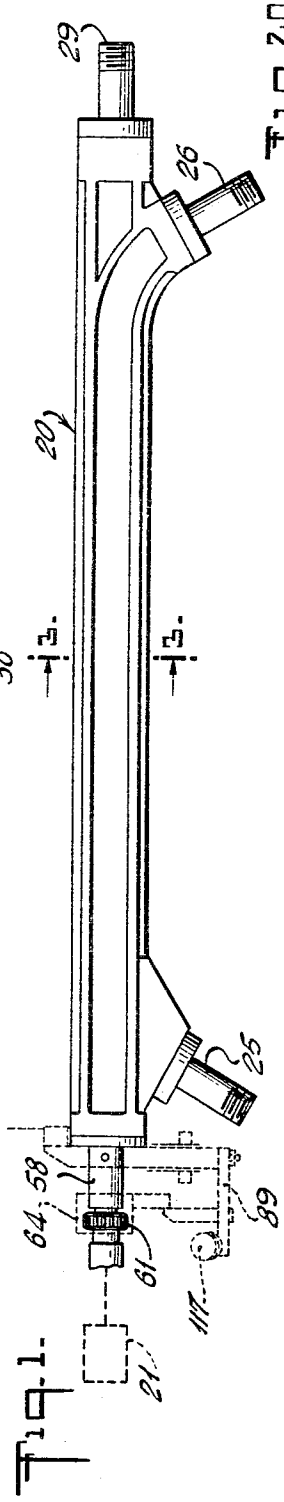



FIG. 1.

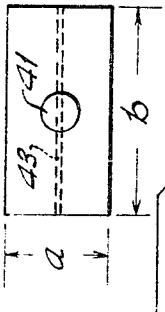



FIG. 20.




FIG. 2.

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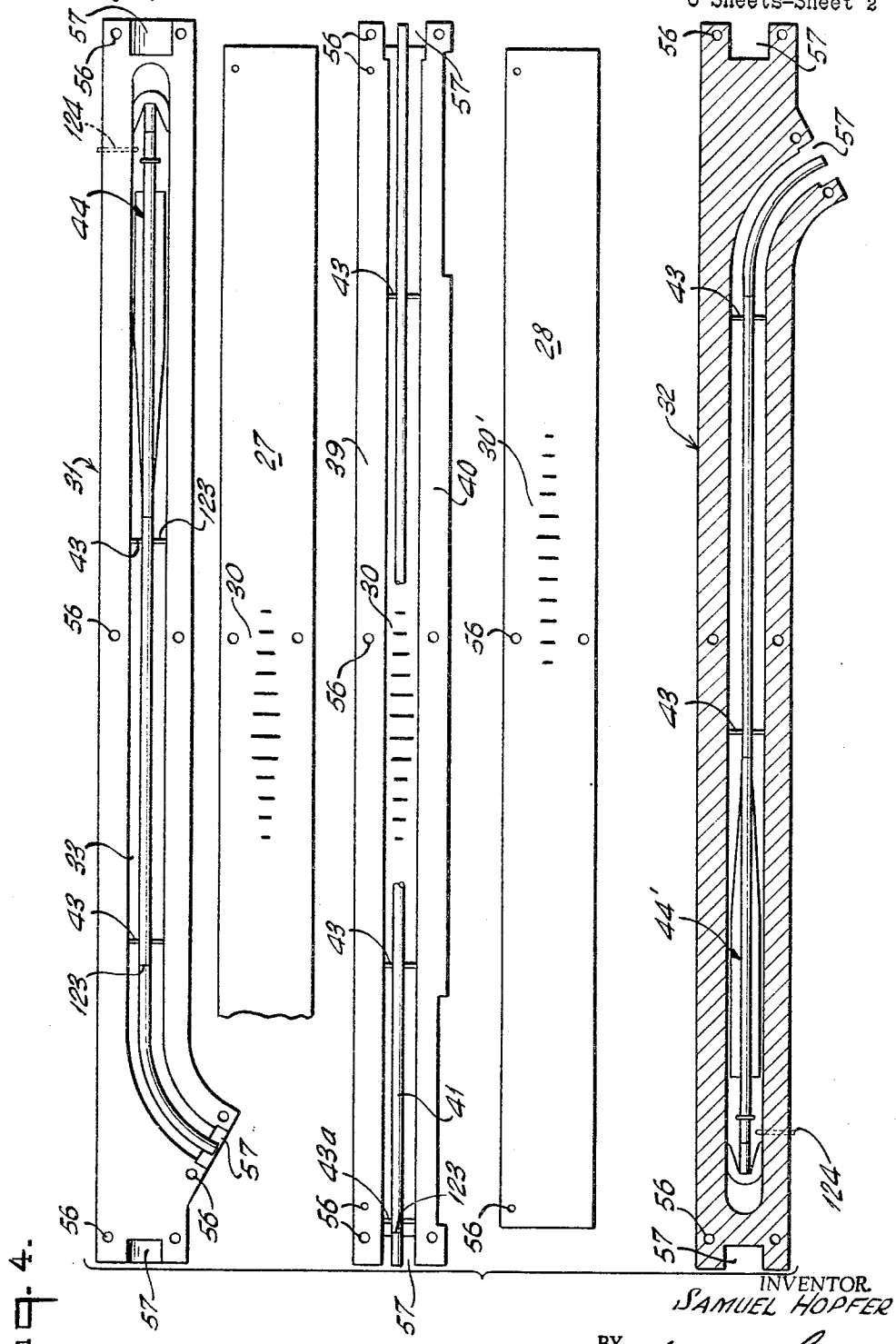



FIG. 4.

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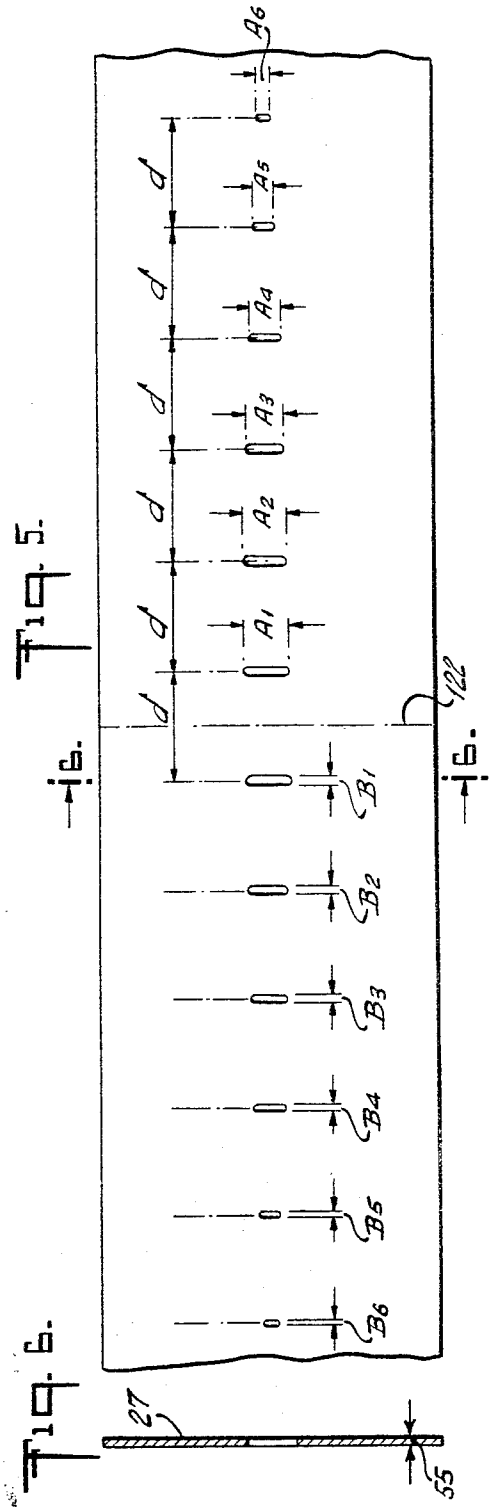



FIG. 5.

FIG. 6.

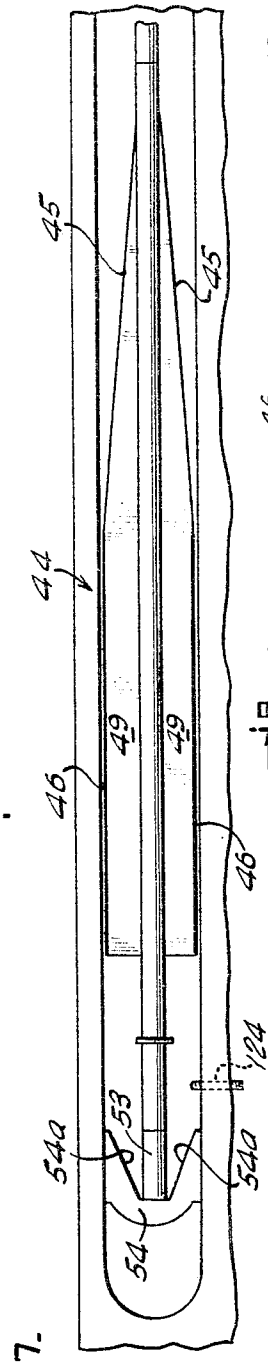



FIG. 7.

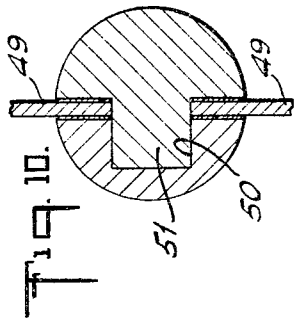



FIG. 10.

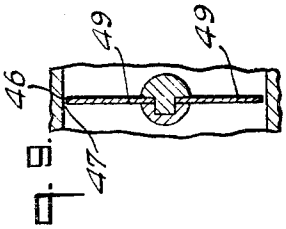



FIG. 9.

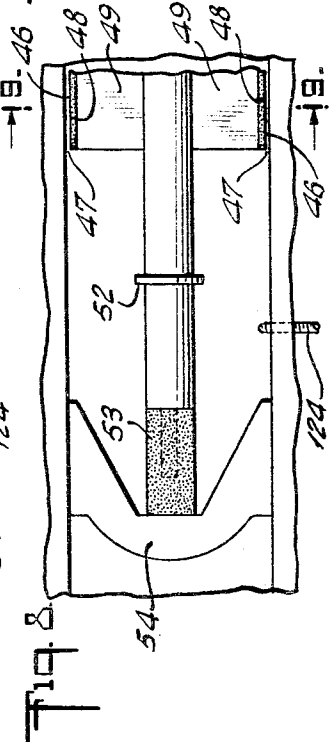



FIG. 8.

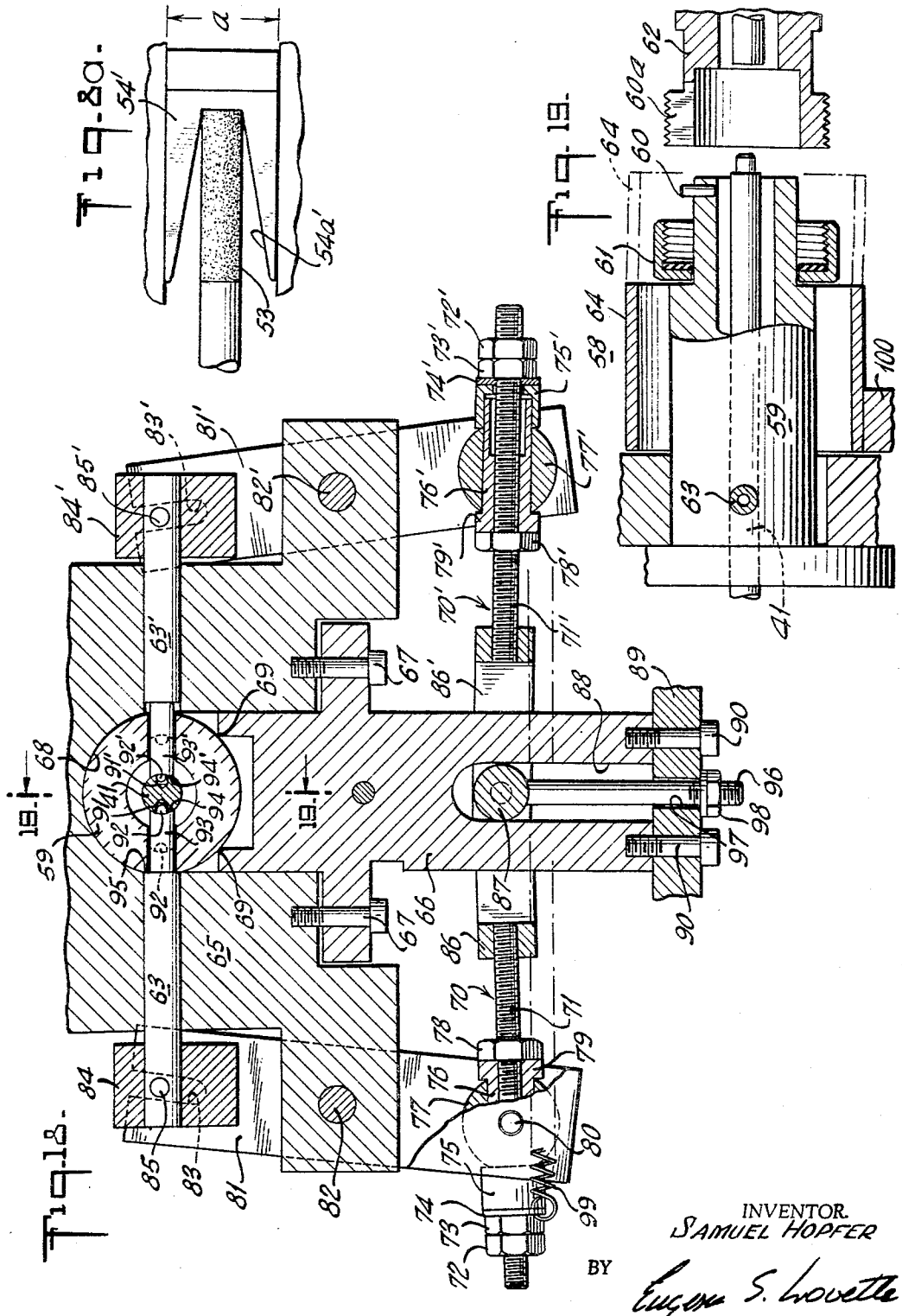
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WIDE BAND SLAB LINE COAXIAL DIRECTIONAL COUPLER

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Fig. 11.

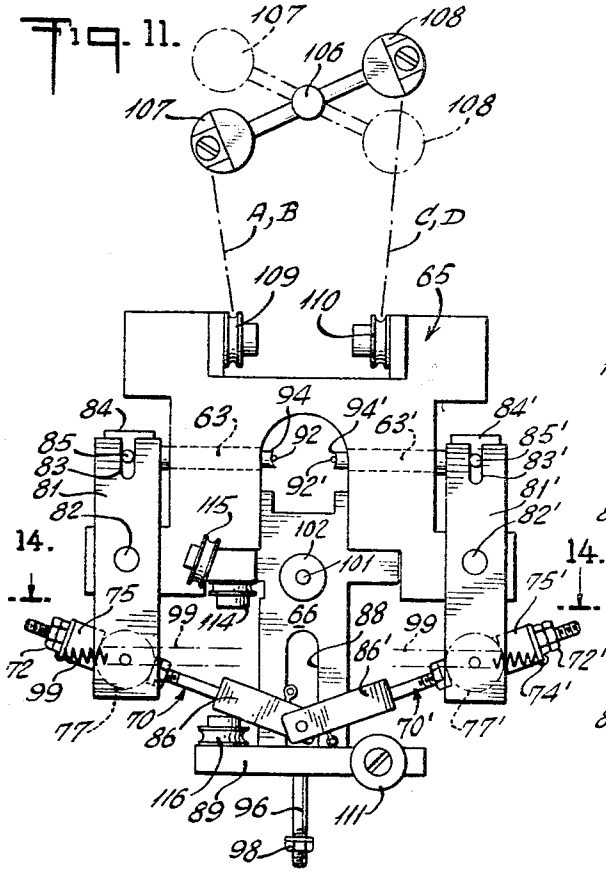



Fig. 12.

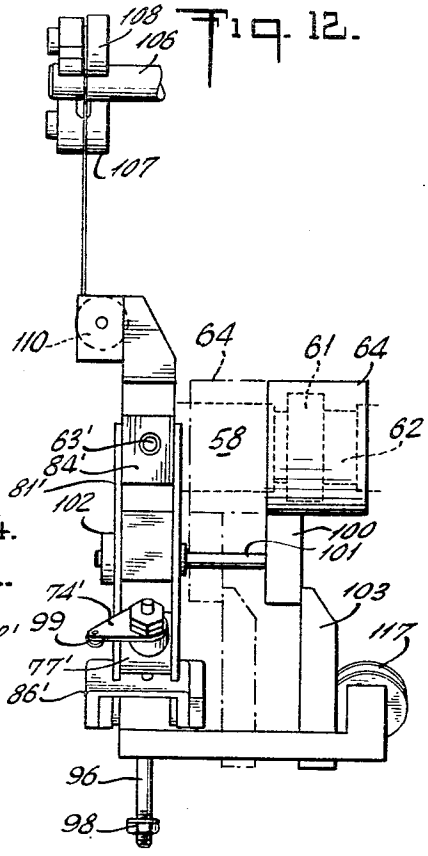



Fig. 13.

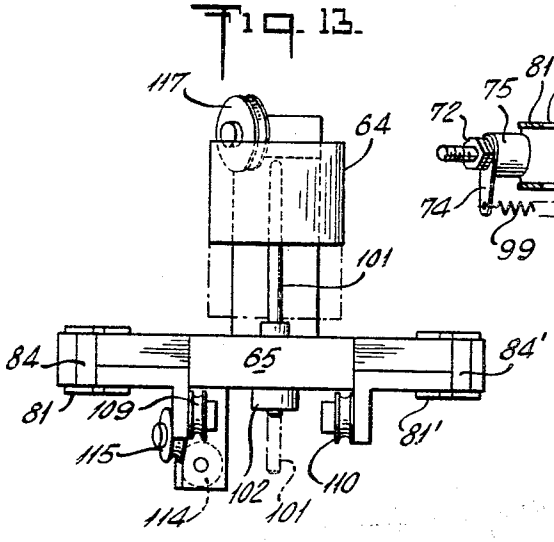
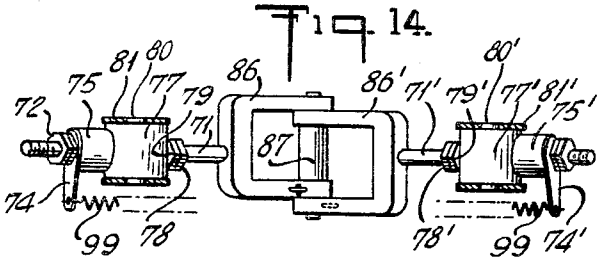



Fig. 14.




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Fig. 15.

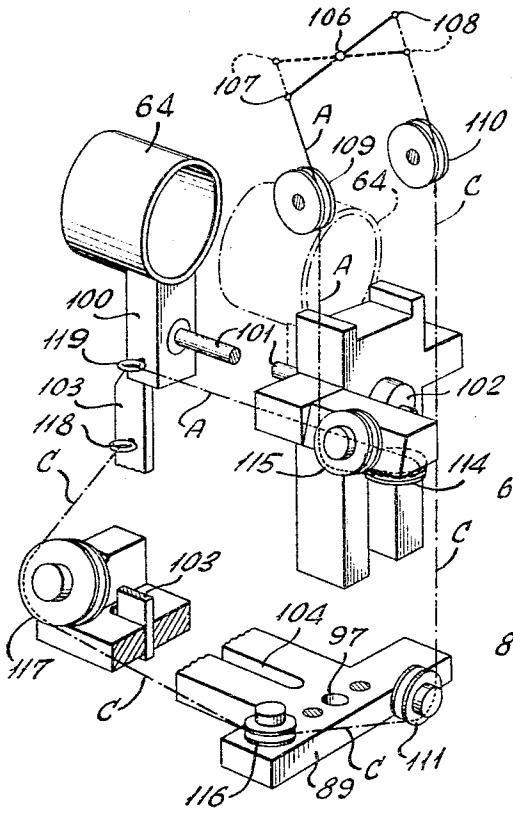



Fig. 16.

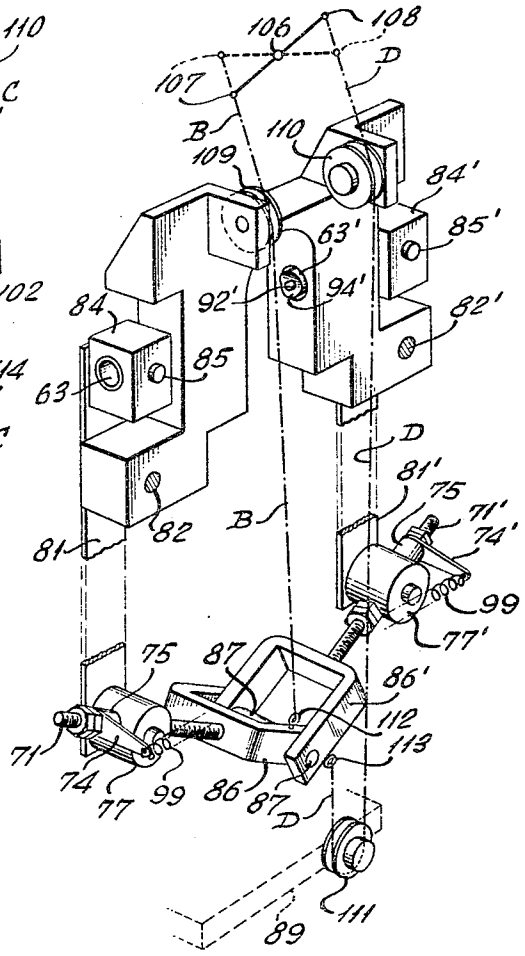
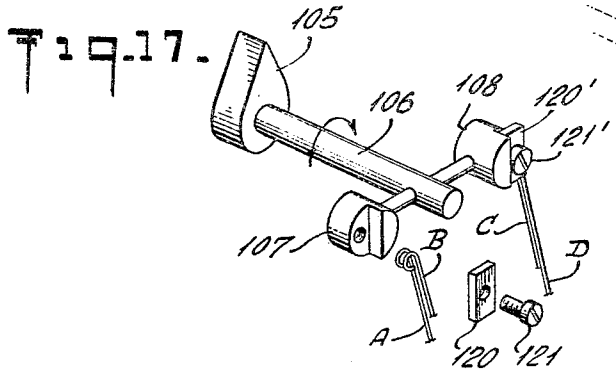



Fig. 17.




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United States Patent Office 3,264,582 Patented August 2, 1966



3,264,582

# WIDE BAND SLAB LINE COAXIAL DIRECTIONAL COUPLER

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Filed May 3, 1963, Ser. No. 277,930
1 Claim. (Cl. 333—10)

This invention relates to a broad band high directivity coaxial transmission line directional coupler, wherein a single directional coupler in accordance with the invention is capable of covering a frequency range from 3 to 10.5 kmc. with a directivity in excess of 30 db.

Broad band coaxial directional couplers known heretofore are limited in directivity to about 30 db at the upper ranges of frequency of about 5 kmc. At the higher frequencies, the directivity deteriorates rapidly whereby heretofore coaxial directional couplers covering the broad frequency range up to 10 kmc. are not available.

It is the principal object of the invention to provide a single coaxial directional coupler capable of covering the frequency range from about 3 to about 10.5 kmc. with directivities better than 30 db and, in particular, wherein such directional coupler lends itself to use in an automatic reflectometer system for operation over the foregoing range. In furtherance of the principal object, the directional coupler is made up of coupled transmissioned lines each characterized by a cylindrical inner conductor supported within an outer conductor having rectangular-shaped interior conductor walls.

It is a further object of the invention to provide a coupling mechanism for use in the directional coupler of the type contemplated herein, wherein such coupling mechanism is characterized by broad band high directivity operation; and, in particular, wherein the coupling mechanism consists of an array of narrow slots for effecting the composite broad band high directivity operation contemplated herein.

It is a further object of the invention to provide a broad band high directivity coaxial coupler incorporating means for supporting the inner conductors characterized by low VSWR characteristics compatible with the broad band low reflection operation demanded of the coupler. Inas much as the proposed structures contemplated herein for supporting the inner conductors are extremely fragile in comparison to conventional bead supports and thus cannot readily withstand the coaxial make and break connections to the directional coupler, it is a further object of the invention to associate such fragile inner conductor support means with relatively sturdy inner conductor clamping means, which latter means are temporarily applied to the inner conductor to support same rigidly while one is carrying out a coaxial make and break connection with the directional coupler.

It is a further object of the invention to provide broad band low reflection terminations in the auxiliary lines of the directional coupler, whereby the inherent high directivity characteristics of the coupler may be fully realized.

Further objects and advantages will become apparent from the following description of the invention taken in conjunction with the figures, in which:

FIG. 1 is a side elevation of a slab coaxial line directional coupler incorporating the principles of the invention;

FIG. 2 is a top view of FIG. 1;

FIG. 3 is a section through line 3—3 of FIG. 1;

FIG. 4 is an exploded view of the constituent parts of said slab line coupler and illustrates the assembly thereof at a plurality of stages; the bottom figure in FIG. 4 depicts one body part thereof in section;

FIG. 5 is an enlarged fragmentary plan view of a slab line wall and its coupling apertures;



FIG. 6 is a section taken along line 6—6 of FIG. 5;

FIG. 7 is a top view elevation of a terminating dissipating load employed in the auxiliary slab lines of said coupler;

FIG. 8 is a fragmentary enlargement of the terminating end of said load;

FIG. 8A shows a fragmentary enlargement of an alternative embodiment of the terminating end of said load;

FIG. 9 is a section through line 9—9 of FIG. 8;

FIG. 10 is an enlargement of the portion of FIG. 9 illustrating the means of supporting the load by the slab line inner conductor;

FIG. 11 is a front elevation of the interlock assembly in accordance with the principles of the invention claimed herein;

FIG. 12 is a side elevation of same illustrating the alternate positions of the protective hood in relationship to the connecting end of the directional coupler;

FIG. 13 is a top view elevation of FIGS. 11 and 12 also shows the alternate positions of the protective hood;

FIG. 14 is an elevational view taken in the direction of line 14—14 of FIG. 11 to illustrate the toggle structure of the interlock assembly;

FIG. 15 is a fragmentary and partly sectional view of the interlock assembly in perspective illustrating, in particular, the pulley system thereof for controlling the movement of the protective hood;

FIG. 16 is a fragmentary view of the interlock assembly in perspective illustrating, in particular, the pulley system thereof for controlling the movement of the inner conductor rigid clamp pins;

FIG. 17 is an exploded fragmentary view in perspective of the end of the pulley system showing its control knob for regulating the pulley system;

FIG. 18 is a section through the interlock assembly illustrating its operational relationship with respect to the coaxial device shown clamped to the interlock assembly;

FIG. 19 is a fragmentary section illustrating a coaxial adaptor at the test end of the directional coupler of FIG. 1; FIG. 19 also illustrates the connecting end of a matching adaptor for connection to said first adaptor in accordance with the principles of the invention;

FIG. 20 is a plan view of a cross-section of a slab line for the purpose of illustrating the dimensions thereof;

FIG. 21 is an experimental curve of slot coupling employed in the design of the slots constituting the coupling arrays; and

FIG. 22 illustrates an alternative embodiments of slots making up an array within the principles of the invention.

FIGS. 1 to 4 depict a high directivity bi-directional slab line coupler 20 in accordance with the principles of the invention. Coupler 20 is employed as a reflectometer, in particular, to measure the VSWR or reflection coefficient of a microwave frequency component 21. The device 21 under test is depicted by block diagram in FIG. 1 and may be a coaxial component or a wave guide component. A wave guide may be measured provided a suitable coax-to-wave guide adaptor is available to connect the wave guide component to directional coupler 20. Coupler 20 is made up of three axially coextending slab lines, i.e., main line 22 and two auxiliary lines 23, 24. Electromagnetic wave energy is supplied by a suitable source, not shown, to an input end coaxial connector 29 of coupler 20. The incident energy travels down main line 22 and is fed to the unit under test 21 which is coupled to the other end of line 22. Auxiliary line 23 is designed to provide an output signal proportional to the incident power at its output end coaxial connector 25. Auxiliary line 24 is designed to provide an output signal proportional to the reflected power at

its output end coaxial connector 26. The reflected signal is the power reflected back into main line 22 by device 21. Under normal conditions, the power fed into main line 22 is relatively small. Hence, the auxiliary lines 23, 24 are not too loosely coupled to main line 22.

Coupling from main line 22 to each auxiliary line is achieved by coupling means 30, 30' incorporated in the individual conductive walls 27, 28 common to respective pairs of slab lines 22, 23, and 22, 24. In particular, each coupling means 30, 30' involves a Tchebycheff array of twelve slots suitably dimensioned and displaced in the walls 27, 28. By the foregoing arrangement, each auxiliary line 23, 24 experiences a minimum directivity of 35 db over the frequency range of 3 to 10.5 kmc. A pair of matched crystals or other detector means, not shown, are coupled to the auxiliary line outputs 25, 26 for detecting power from the individual auxiliary lines 23, 24.

In basic construction, coupler 20 is made up of a pair of outer lengthwise conductive bodies 31, 32 of generally similar construction. Each body 31, 32 has a U-shaped lengthwise recess 33 defined by interior conductive walls 34, 35, 36. The primed numbers, such as 33', 34', 35', 36', etc., refer to components of auxiliary line body 2 and correspond to the unprimed like-numbered parts of auxiliary line body 31. The parallel surfaces 34, 36 and 34', 36' form the narrow dimension walls of slab lines 23, 24, respectively. When wall 27 is mounted over body 31, recess 33 is enclosed on four sides to define the slab line cavity for auxiliary line 23. Similarly, when wall 28 is mounted over body 32, recess 33' is enclosed to define the slab line cavity for auxiliary line 24. The confronting parallel surfaces of walls 35, 27 and 35', 28 form the wide dimension walls of slab lines 23, 24, respectively. Main slab line 22 is formed by the parallel confronting wide dimension surface of walls 27, 28 and the parallel confronting narrow dimension wall surfaces 37, 38. The latter walls are part of lengthwise conductive bodies 39, 40. Bodies 39, 40 are supported in lateral spaced apart relationship between walls 27, 28.

Each slab line has an axial inner conductor 41, 42, 42', respectively. The inner conductors are held in fixed axially centralized position by a plurality of thin nylon rods 43. Two rods are shown supporting each of the auxiliary line inner conductors 42, 42'. A third rod near the test end of line 22 is added to increase the support of inner conductor 41. The axes of rods 43 are parallel to the wide dimension walls of the slab lines. The three inner conductors are provided with holes and rods 43 are inserted therethrough for supporting the inner conductors. The inner conductors are secured to the respective supporting rods 43 by dielectric cement. The ends of rods 43 are secured by dielectric cement or other means to the opposed recess walls 34, 36; 34', 36'; and walls 37, 38. In addition, rods 43 do not extend across the coupling regions of the slab lines, but are located to the left and to the right of the coupling slots 30, 30'.

The three inner conductors are made of highly conductive light weight structure, such as seamless silver tubing to minimize the load weight on supporting rods 43 and to minimize line attenuation. For ease of fabrication, the three inner conductors are made in axial sections which are conductively secured end-to-end by conductive cement or other means. Slab line walls, such as 34, 35, 36, 37, 38, 34', 35' and 36', are preferably polished silver surfaces to provide highly conductive slab line boundaries.

Each of the closed ends of the individual auxiliary lines includes a well-matched terminating load, such as the tapered loads 44, 44'. Loads 44, 44' are of similar design and structure. Each load 44 is formed by a metalized film and, in particular, consists of a Mylar substrate having an evaporated metalized film, such as Nichrome, on one side thereof. The forward section of load 44 has tapered outer edges 45 extending axially a sufficient length along the slab line to match for the lowest frequency of operation. The rear section of load 44 has straight longitudinal edges 46 forming a very small uniform separation or gap 47 with the adjacent narrow dimension walls of the slab line. Gaps 47 are in the order of .005 to .01 inch. A conductive silver band 48 may be formed along the straight edges 46 of the load to increase the capacitance between the load and the ground walls in order to characterize the load less sensitive to frequency over the range of operation.

FIGS. 7 through 10 illustrate the method of attaching and supporting the elements constituting loads 44, 44' by the respective inner conductors of the auxiliary slab lines. Each load is actually formed of two Mylar-metalized leaves 49, 49 supported along their inner edges by a section of slab line inner conductor. The supporting portions of the inner conductors are sectioned in cross-section, wherein one section is grooved 50 and the other conductor section is tongued 51 to press-fit into the matching groove. The lengthwise inner side edges of leaves 49 are seated and conductively cemented between the adjacent walls of the conductor sections. The individual leaves 49 extend outwardly in a plane coinciding with the center line of the supporting inner conductor and parallel to the wide dimension of the slab line. The Mylar substrate is sufficiently stiff to maintain the foregoing flat and dimensional relationship.

An annular thin conductive disc 52 may be mounted on the slab line inner conductor to the rear of the load leaves 49 for improving the matching response of the load at the lower frequencies of operation. A cylindrical resistor 53 is butt-connected in series to the axial end of the slab line inner conductor. Resistor 53 serves to dissipate energy at the lower frequencies to D.C. In accordance with known practice, the slab line walls in the region of resistor 53 are tapered. The taper surfaces 54*a* are provided by a shorting plug 54 conductively cemented to the end of resistor 53 and to the pair of opposed adjacent slab line walls for the purpose of terminating the slab line.

The common coupling walls 27, 28 are preferably made of flat, rigid, extremely thin and highly conductive material. The cross-sectional thickness of walls 27, 28 depicted as 55 in FIG. 6, is made as thin as possible and yet characterized to retain perfect flatness without buckling or rippling. In one preferred embodiment, walls 27, 28 are made of beryllium copper of 4 mils thickness. Beryllium copper is chosen as wall material because it holds its rigidity and flatness for thin dimensions in the order of 4 mils and, further, because it permits the fabrication of coupling slots 30, 30' with high dimensional accuracies. The two beryllium copper walls are substantially identical except that the array of slots 30' are off-set to the right (FIG. 4) with respect to the location of the slots 30 in wall 27 to avoid having the loads 44, 44' extending into the area of the coupling slots 30, 30'.

In assembly, the individual innner conductors 42, 42' are attached to respective bodies 31, 32. Walls 27, 28 are placed over the recesses 33, 33' of the respective bodies. Conductive bodies 39, 40 are mounted on one of the foregoing assembled structures, such as wall 27, and then the other assembled structure is mounted over bodies 39, 40 to complete the assembly. The foregoing components are provided with suitably located positioning and securing holes 56 for mounting and securing one structure component against the next for proper assembly of coupler 20. In addition, bodies 31, 32, 39 and 40 are provided with undercuts and recesses 57 at the ends thereof to form mounting bores into which the coaxial connectors, such as 25, 26, 29 and 58, are seated and secured during the assembly of coupler 20. Reference member 58 depicts a coaxial adaptor secured to the test end of coupler 20 and is further described hereinafter. The outer shells of connectors 25, 26, 29 are conductively connected to the coupler ground walls and the inner conductors of connectors 25, 26, 29 are connected to the respective slab

line inner conductors in accordance with customary practice to allow connection to external electrical circuits. The output ends of auxiliary lines **23**, **24** are gradually bent on a radius to allow sufficient structural room for attaching the output connectors **25**, **26** at such ends.

A coaxial adaptor **58** is secured to the test end of coupler **20**. Adaptor **58** includes an outer conductive shell **59**, see FIGS. 1 and 19, conductively connected to the coupler ground walls. The outer end of shell **59** includes a fixed bayonet pin **60** and also has a threaded coupling nut **61** mounted thereon. Main line inner conductor **41** extends into shell **59** to the outer end thereof to define a coaxial male connection at such end for connection with a female adaptor **62**, shown in part in FIG. 19. The opposite end of female adaptor **62**, not shown, is suitably designed to connect directly to the unit **21** under test. In other words, the unit under test **21**, for example, a coaxial line connector, is attached to adaptor **62**, and the female connecting end thereof is equipped to connect directly to adaptor **58**. The connection is secured by coupling nut **61**. Female adaptor **62** will have a bayonet slot **60***a* engaged by bayonet pin **60**. When adaptors **58**, **62** are connected, bayonet pin **60** engages slot **60***a* to lock adaptor **62** against turning about its longitudinal axis. By the foregoing arrangement in cooperation with an interlock structure to be described hereinafter, inner conductor **41** and its support rods **43** are protected against deforming forces which might otherwise arise if a mechanical force, such as a turning force, is inadvertently applied to adaptor **62** when it is connected to adaptor **58**. The total mechanical support for inner conductor **41** at the test end is provided by nylon rods **43**, in particular, by rod **43***a* located at the coupler test end and also by the interconnected unit **21** under test and adaptor **58**. In other words, the unit under test and the interconnected adaptor **58** contribute to the mechanical support of slab line inner conductor **41** during the time the unit under test is coupled to coupler **20**. This arrangement provides sufficient support to hold inner conductor **41** axially centralized during measurement of unit **21** under test. When measurement of unit under test is completed, it is disconnected and replaced by another unit to be tested which is then connected to adaptor **58**. During such disconnect and connect phase of operation, the sole support for inner conductor **41** at the test end would be rod **43***a*. Rod **43***a* is not sufficiently strong to hold inner conductor **41** firmly in place; nor is rod **43***a* sufficiently strong to withstand the mechanical stresses and strains imposed thereon during such disconnect and connect phase of operation. Any appreciable stress or strain on inner conductor **41** during disconnect and connect will bend or deform rod **43***a*.

An arrangement is provided to prevent destruction of rods **43** and, in particular, rod **43***a*, by clamping inner conductor **41** with retaining pins **63**, **63'** during disconnect and connect operation; see FIGS. 11, 18 and 19. Pins **63**, **63'** are sufficiently strong to withstand mechanical strains and stresses imparted to the coupling structure at its test end during disconnect and connect operation to relieve nylon pins **43** of all mechanical loads during such time. The clamping actions of pins **63**, **63'** are correlated with the action of a hollow cylindrical protective hood **64**; see FIGS. 12, 15 and 19. Protective hood **64** is equipped to extend over adaptor **58** and, in particular, over the region of coupling nut **61** to prevent access thereto while unit **21** under test is being measured, whereby inadvertent disconnection of the unit under test and manipulation of adaptor **58** during such phase of operation is not possible. Correlated with this position of hood **64**, pins **63**, **63'** are retracted from the interior of adaptor **58** to avoid interference of the transmission of wave energy between coupler **20** and the unit under test.

During the connect and disconnect phase of operation, hood **64** is retracted to expose coupling nut **61** to permit disconnect and connect of unit **21** under test with respect to adaptor **58**. Correlated with this position of hood **64**, retaining pins **63**, **63'** are injected into adaptor **58** to grip conductor **41** firmly so as to relieve nylon rods **43**, in particular, nylon rod **43***a*, of all mechanical loads created by reason of disconnect and connect manipulations. The axes of retaining pins **63**, **63'** are perpendicular to the axes of rods **43**. The correlated operation of retaining pins **63**, **63'** and hood **64** are brought about by an interlock assembly made up of upper and lower frame members **65**, **66** secured by bolt means **67** (FIG. 18) to define a clamp; see FIGS. 11 to 19. Upper frame member **65** has a curved surface **68** equipped to match-fit against the O.D. of shell **59**, see FIGS. 1 and 18, when frame members **65**, **66** are clamped tight by bolt means **67**. Frame member **66** has clamp jaws **69** equipped for clamping against the lower portion of the shell surface when frame members **65**, **66** are made tight by bolt means **67**.

Interlock assembly includes a pair of similar toggle arms **70**, **70'**. Toggle arm **70** includes a threaded rod **71**. Rod **71** carries a pair of locking nuts **72**, **73**, a spring support **74**, a tubular sleeve **75**, a tubular bushing **76**, a cylindrical spool **77** mounted on bushing **76**, and a third locking nut **78**, FIG. 18. The I.D. of sleeve **75** is larger than the O.D. of threaded rod **71**; this is best seen in the sectioned assembly of toggle arm **70'**, and, in particular, note the corresponding and identical parts rod **71'** and sleeve **75'** in FIG. 18. Hence, sleeve **75** is free to be slidably positioned on rod **71**. The inner end of the bore section of sleeve **75** is enlarged to receive one end of bushing **76** therein; see the sectioned assembly for corresponding parts sleeve **75'** and bushing **76'**, FIG. 18. There is no axial abutting contact between sleeve **75** and bushing **76**; again, note corresponding parts **75'** and **76'** of toggle arm **70'**. Bushing **76** extends through the spool bore. The bushing bore I.D. at its outer end (the right end for bushing **76'**) is larger than the O.D. of the threaded rod **71** to slide therealong. However, the portion of the bushing bore I.D. at its other end (note the left end of bushing **76'**) is threaded to secure to the rod thread. The inner end of bushing **76** has an enlarged collar **79**. Nut **78** is threadedly drawn against collar **79**. The foregoing components are mounted on rod **71** so that collar **79** and the inner end of sleeve **75** are drawn against respective diametrically opposite sides of spool **77**. These components are suitably located along rod **71** and locked in position by locking nuts **72**, **73** and **78** to provide the toggle action described hereinafter. The axial ends of spool **77** have axial projections **80** secured to respective link arms **81** of a link structure. Link arms **81** are pivotally mounted and journalled to turn about rod means **82** supported therebetween. Rod means **82** is supported in frame member **65**. The upper ends of link arms **81** have open ended slots **83**. The outer end of retainer pin **63** has a head **84** fixed thereto and provided with axial projections **85** captivated and keyed to travel in respective ones of vertical link slots **83**.

The same arrangement exists for the other toggle arm **70'**. Accordingly, like parts for the latter toggle arm have primed reference numbers corresponding to the toggle components previously described. The inner ends of toggle arms **70**, **70'** are threadedly secured and soldered to respective yoke members **86**, **86'**. The bifurcated arms of yoke members **86**, **86'** are pivotally secured and journalled to the opposite ends of pivot means **87** to form a knuckle joint. Knuckle joint pivot means **87** is captivated and guided along a vertical track formed by slot **88** in frame member **65**. Slot **88** is closed at its lower end by a base plate **89** secured to frame member **66** by bolt means **90**.

Pins **63**, **63'** are captivated for axial slide movement in respective bores in frame member **65**, whereby each pin **63**, **63'** is aligned to engage a diametrically opposite side of inner conductor **41**. Inner conductor **41** has diametrically opposite holes **91**, **91'** each extending partway

into conductor 41. Each pin 63, 63' has a round tip end 92, 92' for easily finding and entering a respective hole 91, 91'. Pins 63, 63' have intermediate diameter sections 93, 93' provided with curved faces 94, 94' to match-fit against the diametrically opposite O.D. portions of inner conductor 41. Pin section 93' is longer than section 93, whereby pin shoulder 95' never abuts against the O.D. of shell 59. However, the shoulder 95 of pin 63 will abut against the O.D. of shell 59. The latter shoulder 95 serves as an anvil when it abuts the shell O.D. Curved face 94 also acts as an anvil when it abuts against the inner conductor O.D. Furthermore, the axial distance between shoulder 95 and curved face 94 is selected to centralize inner conductor 41 within adaptor shell 59 when inner conductor 41 is being clamped by pin faces 94, 94' during connect-disconnect operation.

Prior to clamping of inner conductor 41, pins 63, 63' including the inner tips 92, 92' thereof are withdrawn from the wave energy coaxial cavity of adaptor 58. In this position, pins 63, 63' are located within the structure of adaptor shell 59 as depicted in dotted outline of FIG. 18, to avoid interference with the transmission of wave energy by coaxial adaptor 58. When pins 63, 63' are at such retracted position, link structure 81 is at its maximum counterclockwise position about the axis of 82 and link structure 81' is at its maximum clockwise position about the axis of 82'. At this state of operation, knuckle joint 87 is at its lowest position along its vertical track 88. A stud 96 is secured to and carried by knuckle joint 87. Stud 96 passes freely through a hole 97 in base plate 89. Stud 96 carries a nut 98 fixed thereon at its lower end. Nut 98 acts as a limit stop to define the maximum upward travel of knuckle joint 87.

Retaining pins 63, 63' are inserted into inner conductor 41 to clamp same by applying a suitable force to toggle arm 70, 70' to raise knuckle joint 87 to its upper limit of travel, slightly above the horizontal line, for example, about 1/32 of an inch, as depicted in FIG. 18. Further upward travel of knuckle joint 87 is prevented by stop nut 98 striking the bottom of base plate 89.

When pins 63, 63' are forced to clamp inner conductor 41, the action is as follows. Link structure 81 is caused to turn clockwise about axis 82 as link 81' is caused to turn counterclockwise about axis 82'; this requires raising knuckle joint 87. The pin center tips 92, 92' readily find and enter into respective locating holes 91, 91' as pins 63, 63' converge upon inner conductor 41. When pin tips 92, 92' enter the locating holes 91, 91', inner conductor 41 is initially and somewhat loosely gripped for final clamping. Pin shoulder 95 anvils against the O.D. of shell 59. About this time or soon thereafter, curved face 94 of pin 63 anvils against the inner conductor O.D. Furthermore, about this time or soon thereafter the curved face 94' of pin 63', which has been located by its tip 92' finding hole 91' match-fits against the inner conductor O.D. and pushes said inner conductor over until both curved faces 94, 94' now tightly clamp the O.D. of inner conductor 41. The axial lengths of pin center tips 92, 92' are less than the axial depths of respective locating holes 91, 91' to permit the foregoing operation. The action of having one curved face 94 or 94' strike the inner conductor O.D. before other and the sequence of the individual parts of the pins 63, 63' engaging the respective parts of adaptor 58 are controlled by the location of the toggle arm components on their respective toggle rods 71, 71'. Upon completion of clamping, toggle knuckle joint 87 is now slightly above the horizontal center and is held there by a spring 99 under tension. The ends of spring are tied to respective spring supports 74, 74'. Spring 99 also serves to hold toggle arms 70, 70' at its lower limit position as well. The force of spring 99 is sufficient to hold the knuckle joint 87 and thus toggle arms 70, 70' at its respective upper and lower limits as set manually until an overriding external force is applied to the toggle mechanism.

Simultaneous with clamping of inner conductor 41, hood 64 is retracted to expose coupling nut 61. Hood 64 is supported by a small base 100. Base 100 includes a horizontal pin 101 equipped for slidable in and out motion with respect to a support bearing 102 in frame member 66. Base 100 has a depending tail member 103 captivated for slidable movement in a longitudinal guide track 104 in base plate 89, see FIG. 15. When hood 64 is in its position close to frame (dashed outline in FIGS. 12, 13 and 15 and solid outline in FIG. 19), coupling nut 61 is exposed. When hood 64 is in its forward position spaced relatively far from frame member 65, hood 64 is located over coupling 61 (nut is now threaded to adaptor 62, which in turn is connected to unit 21 under test) to prevent access to nut 61; this is depicted by the solid outlines in FIGS. 12, 13 and 15 and in dashed outline in FIG. 19. For this position of hood 64, retaining pins 63, 63' are withdrawn into the body of shell 59.

The foregoing simultaneous action of hood 64 and toggle arms 70, 70' is brought about by a pulley system controlled by a knob 105 (FIG. 17) carried by a turnable shaft 106. Shaft 106 carries dumbbell tie points 107, 108. It will be understood that shaft 106 is suitably journalled in some available stationary structure adjacent to coupler 20, whereby knob 105 is readily accessible to the person carrying out the test. The pulley system includes first and second pulleys 109, 110 journalled by frame member 65 for turning about a horizontal axis, A third pulley 111 is journalled by base plate 89 for turning about a second horizontal axis. A pair of tie members or eye loops 112, 113 are carried by respective yoke members 86, 86'. A fourth pulley 114 is journalled by frame member 66 to turn about a vertical axis. A fifth pulley 115 is journalled by frame member 65 to turn about an axis raised from the horizontal. In addition, two more pulleys 116, 117 are supported by base plate 89. Pulley 116 is journalled to turn about a vertical axis and pulley 117 is journalled to turn about an axis raised from the horizontal. Another pair of tie members or eye loops 118, 119 are carried by members 103 and 100, respectively. From FIGS. 13 and 15, it is seen that pulley 117 is behind tie point 118 regardless of the position of hood 64. Pulley cords of fixed length are designated as A, B, C and D. Cords A and B are tied to dumbbell 107 by a washer 120 and bolt 121. Cords C and D are similarly tied to dumbbell 108. Cord A extends down from dumbbell 107, around the front of pulley 109 and then underneath pulley 115, around the front of pulley 114 and then extends back and is tied to point 119. Cord B extends down from dumbbell 107, around the front of pulley 109, and is tied to the point 112 on yoke 86. Cord C extends down from dumbbell 108, around the front of pulley 110, underneath pulley 111, around pulley 116, underneath pulley 117 and is tied to point 118. Cord D extends down from dumbbell 108, around the front of pulley 110, underneath pulley 111 and is tied to point 113 on yoke 86'. Cords A, B, C and D are fixed in length. Accordingly, when shaft 106 is rotated about its axis, one dumbbell rises as the other dumbbell drops. This provides slack to one pair of cords, for example, C–D, as tension or pull is imparted to the other pair of cords A–B. The example assumes clockwise turning about shaft 106 as viewed in FIG. 17. Opposite turning applies to slack to cords A–B and tension to cords C–D. For example, if knob 105 is turned clockwise as viewed in FIG. 17, that is, looking into the back of knob 105, cords A–B are put up tension, whereas cords C–D are given slack. This means that with respect to hood 64, cord A is pulled up so as to pull hood 64 to its position spaced close to frame 65. This position exposes coupling nut 61. Since cord C is being relaxed for such turning, tie point 118, which is in front of pulley 117 as seen in FIG. 15, is being given cord slack to permit forward movement of hood 64. With

respect to toggle arms **70, 70'**, when cord B is pulled up, knuckle joint **87** is pulled to travel vertically up. This requides a slack to cord D to allow yoke **86'** to rise upwardly. It will be seen from an analysis of the pulley system, that converse turning of knob **105** moves hood **64** to its solid line position (FIGS. 15 and 16) and causes toggle arms **70, 70'** and thus knuckle joint **87** to drop to its lower limit point. Manual force on handle **105** is sufficient to override the spring tension (spring **99**) holding the pulley system in set position at its upper and lower limits. When toggle arms **70, 70'** are at low limit position, they do not abut against base plate **89**, see FIG. 11; this may be regulated by the fixed length of cords B, D.

As noted hereinbefore, the illustrated directional coupler **20** is designed to serve as a reflectometer for operation over a very wide band of frequency, i.e., 3 to 10.5 kmc. Since auxiliary line **23** is designed to sense the incident power, line **23** should exhibit high directivity in the direction of incident energy flow in main line **22**. Auxiliary line **24** is designed to sense reflected power. Hence, this line should exhibit high directivity in the direction of reflected energy flow (reflected by device **21**) in main line **22**. The method of broad band coupling proposed in FIG. 5 herein consists of an array of elongated coupling slots. An array of slots are employed for each coupling mechanism **30, 30'** to secure the high directivity characteristics sought herein. Array coupling is essentially in the forward direction, because coupling from successive slots of the array add in phase while coupling from such slots interfere destructively for energy flow in the reverse direction. In addition, coupling apertures provide a number of mechanical advantages, for example, they are relatively simple to fabricate, and they lend themselves to satisfactory control of dimensional tolerances.

In accordance with the invention, the individual coupling slots should not exhibit a strong reverse direction coupling characteristic, because if such situation existed, then further design and operational demands would be required of the array, i.e., it would have to overcome the aggregate effect of reverse coupling flow in the auxiliary lines. A circular aperture gives rise to excess coupling in the reverse direction close to 10 db. By applying Bethe's theory of coupling by small apertures, one can obtain for a TEM system with no field components in the propagating direction, a ratio for the forward coupling wave amplitude, F, with respect to the reverse coupling wave amplitude, R:

$$\left|\frac{R}{F}\right| = \left|\frac{1+P/M}{1-P/M}\right| \qquad (1)$$

where P and M are the electric and magnetic coupling polarizibilities. For the ratio of $P/M=0.5$ which corresponds to a circular aperture, the directivity is in the order of 9.5 db. In accordance with the principle of the instant invention, a coupling element is selected to exhibit a condition of $P/M$ very much greater than 1 or very much less than 1.

As illustrated in FIG. 5, elongated transverse slots were chosen for the coupling arrays **30, 30'** to realize the condition of $P/M<<1$. By choosing elongated slots with each slot having a dimensional ratio of $A/B=5$, where "A" is the long dimension of the slot and "B" is the narrow dimension of the slot, see FIG. 5, individual slot directivities of approximately 1.5 db are realized. A 1.5 db aperture directivity represents a considerable reduction of reverse coupling in comparison to coupling exhibited by the circular aperture.

The foregoing assumes a thin, flat interface between the coupled transmission lines. This condition is satisfied by the rectangular-shaped I.D. cross-section of the slab line outer conductors illustrated herein, which I.D. shape readily permits the use of flat common walls, such as **27, 28**. In addition, walls **27, 28** easily accommodate aperture type coupling elements.

It was found that for outer conductor I.D. ratio values of $a/b$ of as large as .52, where "$a$" is the narrow slab line wall dimension, as depicted in FIG. 20, and "$b$" is the wide slab line wall dimension, FIG. 20, that the characteristic impedance of such line is within 1% of value computed for the condition where the "$b$" dimension approached infinity. Other experimental investigations have shown that high modes will not propagate in such line below 11.5 kmc. In illustrated embodiment, the following I.D. dimensions were used for the outer conductor walls "$a$" and "$b$" for three slab lines **22, 23** and **24**; "$a$"=0.252 inch and "$b$"=0.492 inch. A circular O.D. diameter of 0.141 inch was employed for the inner conductors **41, 42** and **42'**. The dimension of the coupler inner conductor was chosen to match a conventional ⅜ inch coaxial line. At the end of the slab lines, there is a cross-sectional transition from its outer conductor rectangular-shape configuration to the outer conductor circular coaxial-shape configuration; the latter being formed by the coax connectors and adaptor **58**. Of particular significance, is the junction where the I.D. of the adaptor shell **59** meets with the rectangular I.D. of the main line outer conductor walls. The residual VSWR from this junction discontinuity is predominantly capacitive, and is substantially eliminated by providing an inductive undercut in center conductor **41** in the plane of the discontinuity.

As indicated hereinbefore, an array of narrow elongated slots are employed to produce an aggregate of destructive interference between the waves coupled into the auxiliary lines by each of the slots constituting the respective arrays for reversed direction of travel in said auxiliary lines. This comes about from the fact that the reverse direction waves coupled by the slots travel suitable lengths in the auxiliary line to achieve relative phases, whereby when all such reverse travel waves combine, there is cancellation. The phase relationship of the reverse waves so coupled change with frequenecy. By virtue of the design of the array of slots, the magnitudes of the individual waves coupled by the respective slots are regulated, whereby the aggregate of all the reversed coupled waves substantially cancel over the specified band of frequency operation. It will also be understood for forward direction travel in the auxiliary lines, all waves coupled therein from individual slots add in phase.

In accordance with known and developed theory, an analysis of the total reverse direction coupled wave to the total forward direction coupled wave indicates that optimum directivity conditions for the auxiliary lines obtain when the coupling slots of the respective arrays are arranged in a Tchebycheff fashion. The Tchebycheff array optimizes the minimum directivity for energy coupled into the auxiliary lines for a fixed length of coupling interaction between the coupled lines over a given range of frequency operation. In order for the array to function properly, it requires a slot design wherein the relative coupling between slots of the array remains constant with frequency over the band of operation. Relative constant coupling means herein that the ratios of the wave amplitudes coupled by individual slots of the array remain constant with frequency. In other words, although the wave amplitudes coupled by the individual slot will change with frequency, the wave amplitude of energy coupled by any one slot in the array in comparison to the wave amplitude coupled by any other slot of the array will remain constant with frequency. It will also be understood that the coupled wave amplitudes are directly proportional to the frequency of any size aperture as long as the parameters M and P are constant; and this latter condition is satisfied if the largest dimension of the individual slots is small compared to the wave length at the highest operating frequency. The foregoing criteria is observed in the selection of slot dimensions herein.

In setting forth the method of designing the aperture

slots making up arrays **30**, **30'**, only one of the arrays need be considered, since the dimensions employed for the coupling arrays are identical. The following design formulas are based upon the Tchebycheff analysis to determine the array configuration. The distance "*d*," see FIG. 5, between the center lines of adjacent slots is determined as follows:

$$\text{"}d\text{"}=\frac{c}{2(f_1+f_2)}=\frac{2.99\times10^{10}\text{ cm.}}{2(3.0+10.5)\times10^{9}}=1.1104\text{ cm.}=$$

.437 inch (2)

where $f_1$ is the lowest frequency of operation; $f_2$ is the highest frequency of operation, and $c$ is the phase velocity of the wave propagated in the slab line.

The following formula:

$$\text{"}D\text{"}=20\log T[(2n-1)(no)] \quad (3)$$

determines the minimum number of slots required for an array to achieve a desired minimum directivity for an auxiliary line where: "D" is the minimum directivity desired in db; "$T[(2n-1)(no)]$" are the tabulation of Tchebycheff polynomials and are known; $2n$ is the number of slots;

$$no=\frac{1}{\cos\pi\frac{f_1}{f_1+f_2}}=\frac{1}{\cos 40^\circ}=1.305$$

and $f_1$ and $f_2$ are 3 kmc. and 10.5 kmc., respectively, as defined hereinbefore. Upon establishing a desired operational directivity, for example, 35 db, one may solve for the value of $2n$ from Equation 3. In the illustrated embodiment, each array employs twelve slots.

Further computations consistent with Tchebycheff's theory provides that the relative coupling voltage amplitudes for a twelve slot array is in accordance with the normalized coupling coefficients of Table I:

*Table I*

| | |
|---|---|
| (*e*) 1=1 | (*e*) 7=42.07 |
| (*e*) 2=4.546 | (*e*) 8=34.690 |
| (*e*) 3=12.06 | (*e*) 9=23.127 |
| (*e*) 4=23.127 | (*e*)10=12.06 |
| (*e*) 5=34.690 | (*e*)11=4.546 |
| (*e*) 6=42.07 | (*e*)12=1 |

where (*e*)1 and (*e*)12 are the amplitude coefficients for the two small end slots: (*e*)2 and (*e*)11 are the amplitude coefficients for the adjacent slots next to the end slots, and so on, so that (*e*)6 and (*e*)7 are the coefficients for the two middle slots. As seen from the figures and Table I, the slots progressively increase in size starting with the smallest dimensional slots at the ends of the array and concluding with the largest size slots in the middle of the array. The figures and Table I also bear out the fact that each array is dimensionally symmetrical about the center line **122** of FIG. 5. Hence, it will be understood that the six slots to the right of center line **122** are identical to the respective six slots to the left of such center line upon folding the structure along line **122**.

Table I may be translated into actual slot dimensions; however, it is first necessary to assign a value to the total forward coupling at a given frequency. Table I shows that the ratio of the summation of all coupled amplitudes for the twelve slots in a forward direction to the coupled amplitude of one of the largest slots in a forward direction is:

$$\frac{2[(e)1+(e)2+(e)3+(e)4+(e)5+(e)6]}{42.07}=5.58 \quad (4)$$

The amplitude coefficients are added in the numerator of Equation 4 because we are considering forward direction coupled amplitudes and as noted hereinbefore, these amplitudes add in phase. It is assumed for the reasons before noted, that there is substantial cancellation for reversed direction coupling. It is only necessary to add the first six coefficients and multiply same by 2 because the array is symmetrical about center line **122**.

Equation 4 is a voltage amplitude ratio. A power amplitude ratio of same in db is 10 log $(5.58)^2$=14.92 db, which means that the total forward direction coupled power for the array is 14.92 db above the forward direction coupled power from one of the largest slots. Accordingly, if it is desired to couple a total power of −16 db at mid-frequency into an auxiliary line, for example, line 23, it then follows that each large slot will couple −(16 db+14.92 db)=−30.92 db into such line. The negative sign indicates power down from incident power in main line **22**. Hence, upon fixing the actual amount of coupling for one of the large slots, 30.92 db, one now may determine the slot dimensions from Table I and the curve of FIG. 21.

The curve of FIG. 21 was derived experimentally by measuring, at mid-frequency, various sample slots of different legnths A; but wherein all of the sample slots are characterized by the same dimensional ratio $A/B=5$ and plotting power coupled by each of the sample slots as a function of length A. Thus the power coupling curve of FIG. 21 now permits one to select a slot of particular size to achieve a given value of coupled power. For example, a value of coupled power is selected along the vertical coordinate and projected to the curve. The correlated value of length along the horizontal coordinate determines the slot length of a slot capable of such coupled power for $A/B=5$ and at mid-frequency. From the curve of FIG. 21, a slot having a length of .1881 inch will provide a coupled power of 30.92 db. The width of the slot is .0376 inch from the ratio $A/B=5$.

The dimensions of the other slots are determined as follows. Table I indicates that the voltage amplitude ratio of the largest slot to the next-to-largest slot is 42.07/34.69. Bearing in mind that the coefficients of Table I are voltage amplitude coefficients, the square of the ratio of (*e*)6/(*e*)5 gives the power ratio. The logarithm of the power ratio gives the power coupled by the largest slot above the second largest slot. Hence, this value of power in db added to 30.92 db will give the amount of power coupled by one of the second largest slots down from incident power in main line **22**. This value of power is applied to the curve of FIG. 21 to ascertain length of the second slot. The fixed ratio of $A/B$ will determine its width dimension. The same technique is used for the remaining slots of the array. It will also be noted that the ends of each slot are rounded by a radius equal to one-half of the "B" dimension of the slot.

The slots are formed with extreme accuracy in the walls **27**, **28**. Table II indicates the dimensions of the slots. Dimensions are given for only six slots because of symmetry of the arrays.

*Table II*

| Inches | Inches |
|---|---|
| A1=.1881 | B1=.0376 |
| A2=.1720 | B2=.0344 |
| A3=.1500 | B3=.0300 |
| A4=.1185 | B4=.0237 |
| A5=.0850 | B5=.0170 |
| A6=.0520 | B6=.0104 |

Another design condition concerns the thickness of coupling walls **27**, **28** continuing the slot apertures. Theoretically, the thickness dimension of the slots (dimension **55** in FIG. 6) also should be scaled in the same proportion as the dimensions "A" and "B" for the individual slot apertures, otherwise, the frequency responses of the coupling from the different slots will not be the same. However, for fabrication reasons, scaling the thickness of walls **27**, **28** is not practical. As an alternative, walls **27**, **28** are made of a uniform thickness in cross-section, but very thin and, in particular, as thin as fabrication

permits. As mentioned hereinbefore, walls **27, 28** are in the order of 4 mils thick; this minimizes the error introduced by not scaling thickness **55** to a negligible significance.

It is customary practice in a coaxial line structure to support the center conductor by sturdy dielectric bead structure. The use of such bead supports in coupler **20** would give rise to excessive reflections at the high frequency end of the operating band. Bead supports serve essentially two purposes, namely, (1) to support the inner conductor in coaxial relationship with respect to the I.D. of the outer conductor walls, and (2) to provide the center conductor with sufficient physical rigidity to counteract the deforming or destructive forces imposed upon such coaxial line structure when ones is effecting a make or break connection to same. In order to overcome the transmission line reflection limitations of the known dielectric bead supports, center conductors **41, 42** and **42'** of the individual slab lines are supported by thin cylindrical rod-like pins **43**, made of nylon or other suitable dielectric material. Pins **43** are positioned to lie in the weak field region of the wave propagated along the slab lines, whereby the pins intercept very little of the power flow. The diameter of pins **43** are in the order of .055 inch. As noted hereinbefore, the center conductors **41, 42, 42'** are provided with holes extending diametrically through same. Pins **43** extend through these holes. It has been found that this arrangement does not adversely affect the propagating characteristics of the slab lines, nor do they introduce adverse discontinuities. It is contended that the through holes in the inner conductors **41, 42, 42'** introduce shunt capacitance in addition to series inductance in the respective lines, whereby the combination is largely self-compensating in character over the specified wide range of operation. The foregoing arrangement of pins **43** to support the inner conductors **41, 42, 42'** satisfies the first-named function normally performed by the conventional bead supports.

One main aspect of the three lines is that these lines are dimensionally parallel to a very high degree of accuracy particularly along the interaction length of arrays **30, 30'**. Pins **43** contribute to such parallelism by preventing bowing of the respective inner conductors. To prevent inner conductor bowing, the pins **43** are located just to the left and right of the arrays **30, 30'** in the lines as seen from FIG. 4. Moreover, the end-to-end seams **123** for conductors **42, 42'** are just to the left and right of the adjacent pins **43**, in other words, in line **33**, the end-to-end conductor seams **123** do not occur between the pair of pins **43**. The same applies to line **33'**. Main line **22** has a continuous inner conductor **41** which makes an end-to-end seam **123** to the left of pin **43***a*. The other two pins **43** in line **22** are just to the left and right of the overall interaction length for arrays **30, 30'**. The foregoing is observed to minimize all possible inner conductor bowing. The break points **123** along the conductors **41, 42, 42'** also serve to take up axial play along the respective lines to prevent bowing. It is also desirable to locate the pins **43** along each line axially as close as possible to each other but without violating the foregoing restrictions to minimize the structural vibrational frequency of the slab lines.

It is also appreciated that pins **43** are extremely fragile and thus cannot withstand the physical forces, stresses or strains normally attending coaxial connection and disconnection to adapter **58** at the test end of coupler **20**, each time a different device under test is disconnected from the coupler **20** and replaced by connection of another device under test. It has been previously pointed out that such forces, stresses and strains, will readily deform or destroy pins **43**, although pins **43** are sufficiently strong to support the inner conductors in proper coaxial relationship in their respective slab lines when coupler **20** is propagating energy during test measurements. Consequently, to protect support pins **43**, the sturdy steel clamping pins **63, 63'** are employed in the manner previously described to satisfy the second-named function of the conventional bead supports. The interlock assembly including its pulley system, as illustrated in FIGS. 15 through 18, has been described hereinbefore for the purpose of teaching the features thereof including the correlated movement of support pins **63, 63'** and protective hood **64**. Said interlock structure including the pulley system thereof, is the claimed subject matter of a related copending application now United States Patent No. 3,210,698, issued October 5, 1965, in the name of Roger E. Doerfler and entitled Means for Supporting the Inner Conductor of a Coaxial Microwave Frequency Device.

To avoid all possible electrical interference or reflection discontinuities along the interaction length of each coupling array, which interaction length is

$$11d+.014 \text{ inch}=4.8174 \text{ inches}$$

coupler **20** is arranged so that both interaction lengths are unobstructed. It will be noted that even the thin dielectric support pins **43** are located to the left and to the right of the interaction length of each array to avoid obstructing same. In addition, each interaction length is off-set with respect to the other to avoid all possible mutual interference between same.

With respect to terminating loads **44, 44'** in respective auxiliary lines **23, 24**, it will be understood that these loads should be broad band well-matched low reflection devices for effectively absorbing all reverse coupling power propagated towards the closed ends of the auxiliary lines. For example, if there is reflection of power from loads **44, 44'** back towards the output sensing ends of either auxiliary lines, then the detection of signals at such sensing ends will not provide an accurate reflectometer ratio, whereby the reflectometer measurement will be subject to errors. With respect to the metalized film applied to one side of the mylar substrates of the loads **44, 44'**, these films characterized by a thickness less than skin depth and 180 ohms per squaer. The thin Nichrome resistive film load along **49, 49** is principally effective for high frequency dissipation. The thin resistive film is supported in the horizontal plane as shown to minimize the applicable tolerances because with the resistance film in such plane, the rate of attenuation is lower than if the film were in the vertical plane. An adjustable turning screw **124** may be carried by the narrow wall of each auxiliary line to the rear of the film load for matching at the low frequencies. A 50 ohm metalized film resistor was employed for cylindrical resistor **53** to provide effective low frequency to D.C. attenuation. Resistor **53** in cooperation with tapered walls **54***a, b* provides the low frequency matched termination. The tapered plug **54** oriented 90° from that shown in FIGS. 7 and 8 may be used in lieu of the first shown shorting plug to terminate the auxiliary lines. This alternative plug is shown in FIG. 8*a*.

FIG. 22 illustrates an array of a plurality of elongated narrow aperture slots having the long A dimensions thereof aligned in the direction of the transmission line axis. It is submitted that this type of array may be used in lieu of arays **30, 30'** in respective walls **27, 28**. A narrow elongated slot aligned as shown in FIG. 22 and having an $A/B$ dimensional ratio $\geqslant 6.67$ provides a $P/M$ ratio close to 1, about .95, and a theoretical directivity of better than 30 db in the reverse direction. This directivity is substantially independent of frequency as long as the slot dimensions A and B are very much less than the signal wave length for the highest frequency of operation. Hence, a single slot may be employed since it is hi-directivity in operation (in a reverse direction) except that the single slot shows low power gain. The A dimension of the slot may be determined by a curve similar to that of FIG. 21.

In FIG. 22, a plurality of such slots are employed to increase the power coupled into the auxiliary guides from

the main guide. It will be noticed that the transverse center lines 122' of all slots of the array are aligned and coincide. The voltage coupling amplitude of each slot is still a direct function of frequency, however, the aggregate directivity of the array does not deteriorate by use of a plurality of such slots to make up the array. The spacing "*d*" between the longitudinal slot center lines is selected large enough to prevent interaction between the individual slots.

It is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

In a broad band coaxial transmission line device having an outer conductor formed by interior conductor walls of a rectangular-shaped cross-section in the plane orthogonal to the axis of wave energy propagation along said line and an inner conductor supported in coaxial relationship with respect to said outer conductor, said line being characterized by a closed-terminated end, the combination defining a broad band low reflection terminating load comprising, a thin uniformly flat and relatively stiff dielectric substrate supported along diametrically opposite sides of said inner conductor, said substrate extending a finite axial length along said inner conductor, the plane of said substrate being parallel to opposed interior conductor walls of said outer conductor and coinciding with a plane substantially through a center line of said inner conductor, said substrate having a first section defined by outer edges tapering gradually so as to increase the planar area of said substrate, wherein the widest dimension of said first substrate section is closer to the closed terminating end of said line to present a gradually increasing tapered matching section with respect to wave energy propagated in a direction towards the terminating load, said substrate having a second section continuous with and to the rear of said first section, said second section being defined by straight outer edges forming a very small uniform longitudinal gap with respect to opposed interior conductor walls of said outer conductor, wave energy dissipating metalized film along said substrate less than the skin depth of the wave energy carried by said line for dissipating said wave energy, resistor means having an end connected electrically in series to the end of said inner conductor at the rear of said metalized substrate for dissipating wave energy at the low operating frequencies to D.C., shorting means conductivity connecting the other end of said resistive means electrically in series with the conductive walls of said outer conductor, said shorting means including conductive taper walls surrounding said resistor means for forming a taper shorting plug at the closed end of said coaxial line, and a band of highly conductive material along the outer longitudinally straight edges of said second section of substrate for rendering said load less sensitive to frequency.

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