Jan. 31, 1961 G. J. E. GOUBAU 2,970,284

WAVEGUIDE-TO-COAXIAL LINE TRANSDUCER

Filed July 3, 1958

3 Sheets-Sheet 1

FIG. 1

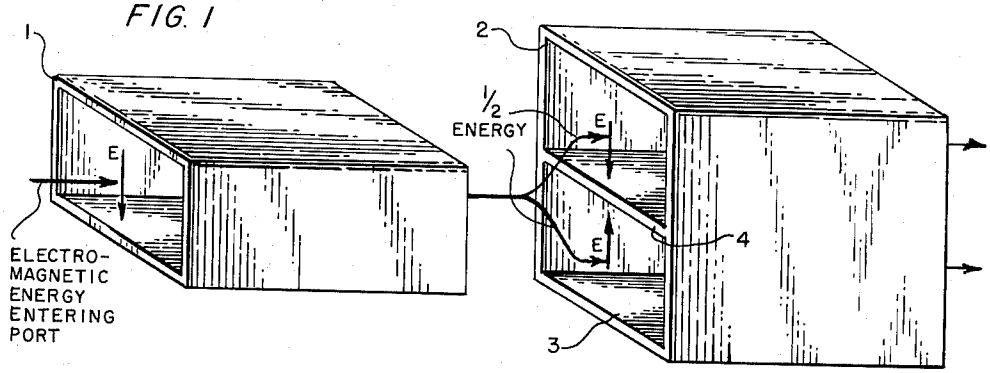


FIG. 2

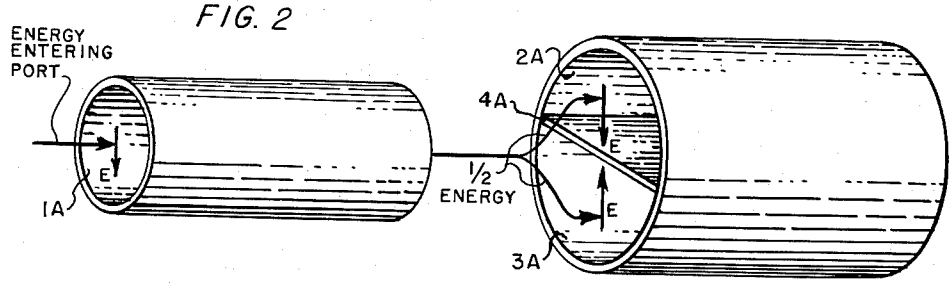
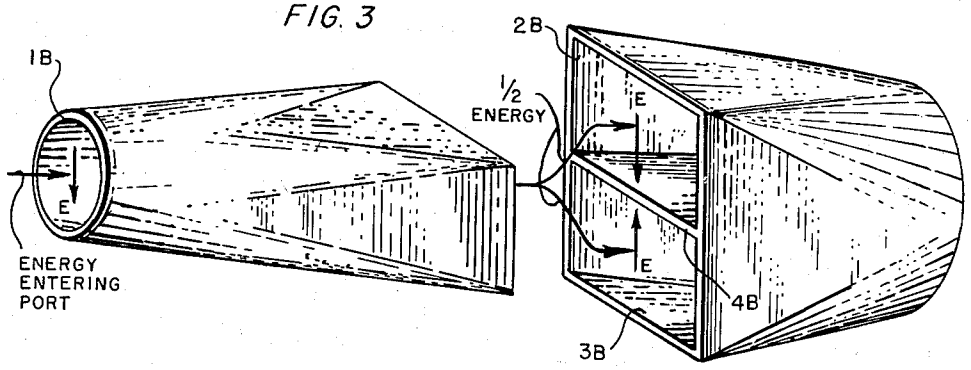


FIG. 3



INVENTOR,
GEORG J. E. GOUBAU.

BY Harry M. Saragovitz

ATTORNEY.

Jan. 31, 1961 G. J. E. GOUBAU 2,970,284

WAVEGUIDE-TO-COAXIAL LINE TRANSDUCER

Filed July 3, 1958

3 Sheets-Sheet 2

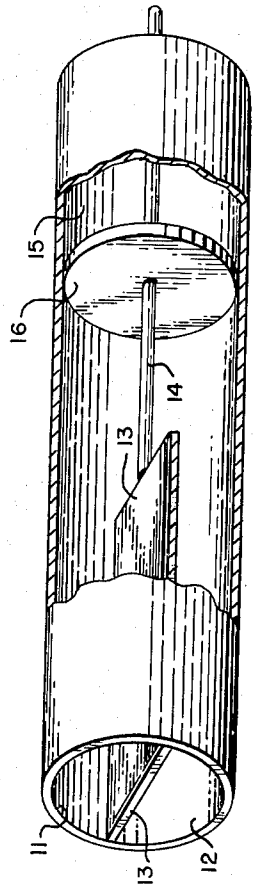


FIG. 5

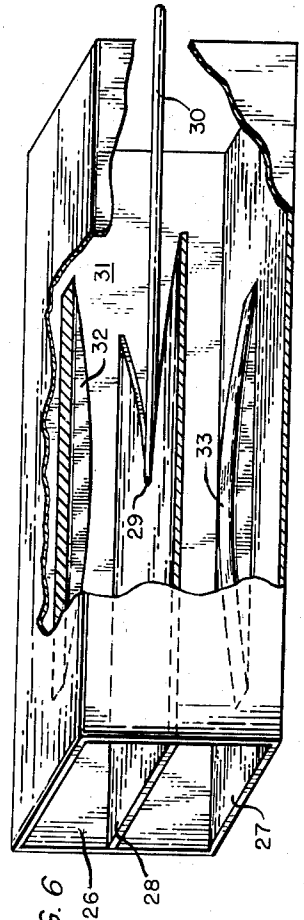


FIG. 6

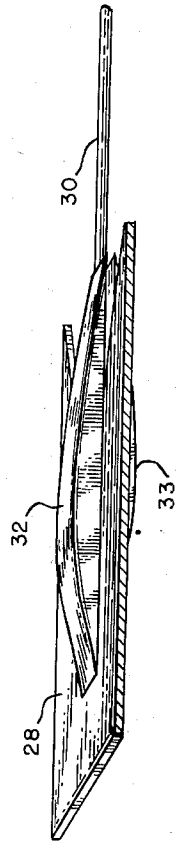


FIG. 7

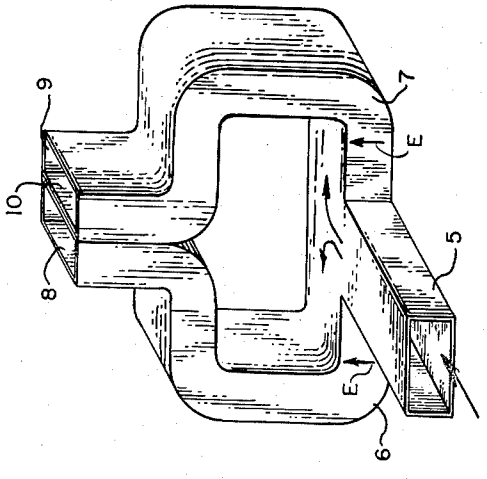


FIG. 4

INVENTOR,
GEORG J. E. GOUBAU.

BY Harry M. Saragovitz

ATTORNEY.

Jan. 31, 1961

G. J. E. GOUBAU

2,970,284

WAVEGUIDE-TO-COAXIAL LINE TRANSDUCER

Filed July 3, 1958

3 Sheets-Sheet 3

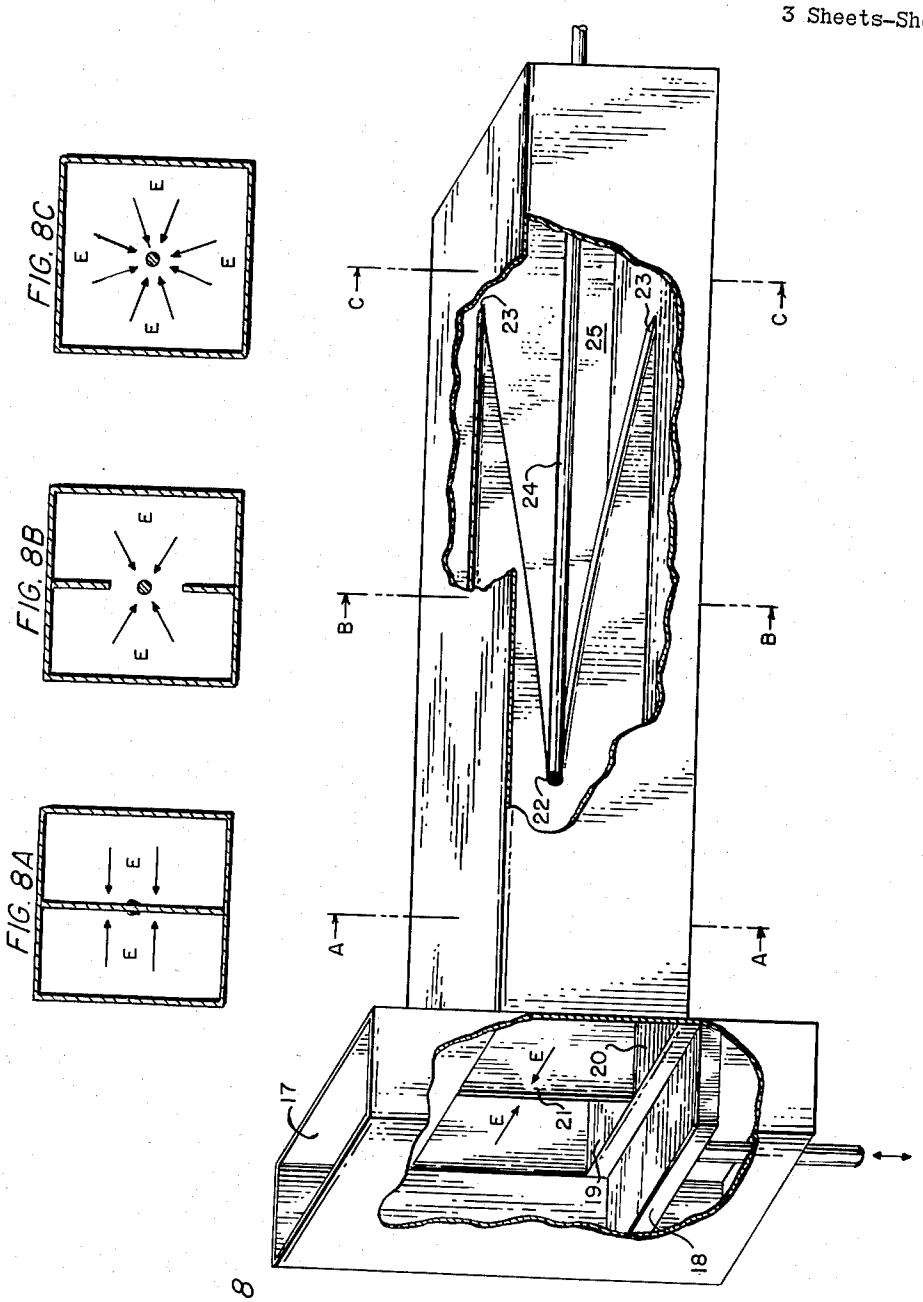


FIG. 8

INVENTOR,
GEORG J. E. GOUBAU.

BY Harry M. Saragovitz

ATTORNEY.

United States Patent Office 2,970,284 Patented Jan. 31, 1961

2,970,284

WAVEGUIDE-TO-COAXIAL LINE TRANSDUCER

Georg J. E. Goubau, Eatontown, N.J., assignor to the United States of America as represented by the Secretary of the Army

Filed July 3, 1958, Ser. No. 746,571

1 Claim. (Cl. 333—34)

(Granted under Title 35, U.S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the Government for governmental purposes, without the payment of any royalty thereon.

The invention relates to guided electromagnetic wave transmission systems and particularly to transducers for use in such systems to couple electrically transmission devices or lines having impedances of different types and values, such as a waveguide line and a coaxial line.

The transducers of the invention were specifically devised for use with lines of the so-called surface wave transmission type such as disclosed in applicant's U.S. Patent No. 2,685,068, issued July 27, 1954, for which they are particularly adapted, although they are not limited to such use. The surface wave transmission line (SWTL) is suitable for the propagation of electromagnetic wave energy in the high frequency range above about 50 megacycles per second because of its extremely low attenuation over a wide band of frequencies in this range and extremely high power carrying capacity (H. H. Barlow "The Relative Power-Carrying Capacity of High Frequency Waveguides," Proc. IEE (London), Part E, vol. 90, pp. 21–27, January 1952). As described in the aforementioned patent, the SFTL comprises an elongated conductor such as a wire, adapted to propagate electromagnetic wave energy along its outer surface because of special conditioning of that surface, for example, by the provision of a dielectric coating thereon, so as to reduce the phase velocity and thereby concentrate the field of the transmitted wave adjacent the conductor.

A SWTL is in effect a transmission device with coaxial terminations, and if it is used in combination with a waveguide transmission system requires a special adaptor for properly electrically coupling it to waveguide terminals in that system. The standard adaptors which have been provided for this purpose, which are usually designed for connecting 50-ohm cables, are not particularly suitable because they tend to reduce the usable frequency bandwidth of the SWTL. Since the impedance of the surface wave is in the order of 200 to 300 ohms, the launchers provided for exciting the surface wave in the SWTL must take care of an impedance transformation having a ratio of 5:1 or more. This not only increases the cost of the launchers but also reduces their efficiency because of inherent transformation losses. Even more important is the fact that the coaxial termination of the standard adaptors limits the power-handling capacity of an associated surface wave transmission line particularly in the centimeter-frequency range where the physical dimensions of the coaxial terminations are quite small.

One object of the present invention is to provide an adaptor for coupling a surface wave transmisison line with coaxial terminations to the waveguide terminals in a waveguide transmission system, which will not have the above-mentioned disadvantages of the prior art adaptors for this purpose.

A general object is to improve transducers for electrically coupling transmission devices or lines having terminating impedances of different types and values in a high frequency signal wave transmission system, from the standpoint of providing a more efficient transfer of the high frequency signal wave power between them while minimizing reflections at the junction point tending to increase power losses.

A related object is to provide at relatively low cost efficient impedance matching at frequencies in the ultra-high or super-high frequency ranges, for example, at frequencies in the order of 500 megacycles per second, between a coupled waveguide line and another line having a coaxial termination.

A more specific object is to provide efficient electrical coupling between a waveguide line and a surface wave or other transmisison line having a coaxial termination in a high frequency signal wave transmision system without appraciably reducing the power-handling capacity of the coupled lines in the system.

The transducers in accordance with the invention for attaining these objects comprise two tandem-connected portions of different constructions. Both portions are three-port line junctions but one of them, to be referred to hereinafter as the "input" junction, has three waveguide ports and the other, to be referred to hereinafter as the "output" junction, has two waveguide ports and one coaxial port. The input junction operates to divide the electromagnetic signal waves entering an input waveguide port into two equal wave energy portions and to propagate these portions separately through different ones of its two output ports consisting of two substantially straight sections of hollow-pipe waveguide of identical cross-sections and having one side wall in common, with the electric fields of the propagated wave energy portions oppositely directed with respect to the common wall.

The two input ports of the output junction are formed by two parallel sections of hollow-pipe waveguide with identical cross-sections and having one side wall in common. These two waveguide sections are also identical in cross-section width, and are respectively connected directly to the two output waveguide ports of the input junction so as to receive the propagated wave energy portions from the input junction. The output junction operates to combine these wave energy portions and to form a coaxial wave mode. The formation of this coaxial wave mode is achieved by cutting away a portion of the common wall of the adjacent waveguide section constituting the two input ports of the output junction and effectively extending the center of this wall to the output end of the transducer, by the attachment thereto of a longitudinally extending cylindrical conductor or wire to provide the inner conductor of the coaxial output port of which the extended outer walls of the two waveguide sections form the outer conductor. This coaxial output port provides a high output impedance for the transducer and is adapted for direct connection to the coaxial termination of the surface wave or other transmission line or device to be electrically coupled through the transducer to a waveguide line.

One feature of the invention is the gradual cutting away of the common wall of the two adjacent waveguide sections of the output junction, for example, in tapered fashion, to provide a gradual transformation of the electric field of the propagated wave energy, in order to increase the effective frequency bandwidth of the coaxial output portion of the transducer.

Other features and objects of the invention will be apparent from the following complete description thereof when it is read in conjunction with the several figures of the accompanying drawing respectively illustrating dif-

ferent embodiments of transducers in accordance with the invention or portions of them, in which:

Figs. 1, 2 and 3 show diagrammatically the general construction of three different embodiments of the input junction of a transducer in accordance with the invention, utilizing sections of waveguides with different cross-sectional configurations for forming the input and output ports;

Fig. 4 shows a perspective view of a fourth embodiment of the input junction, employing a H-plane, T-type waveguide junction in its input;

Figs. 5 and 6 show perspective views, partially broken away to show structural details, of different embodiments of the output junction of a transducer in accordance with the invention;

Fig. 7 shows a perspective view of a modification in accordance with the invention of a portion of the output junction of Fig. 6;

Fig. 8 shows a perspective view of an embodiment of a complete transducer in accordance with the invention, in which the coaxial output port of the output junction is derived in part from the rectangular waveguide sections forming the input ports of that junction; and

Figs. 8A, 8B and 8C are cross-sectional views along the lines A—A, B—B and C—C, respectively, of Fig. 8, showing the wall construction and the field transformation at different points along the transducer.

Fig. 1 shows a three-port input junction of a transducer in which the input port **1** comprises one section of hollow-pipe waveguide of rectangular cross-section and the two output ports **2** and **3** electrically coupled thereto comprise two substantially straight sections of hollow-pipe waveguide of identical rectangular cross-sections, having a common side wall **4**. In Fig. 2, the input port **1A** of the three-port input junction shown therein comprises a section of hollow-pipe waveguide of circular cross-section and the two output ports **2A** and **3A** coupled thereto comprise two substantially straight sections of hollow-pipe waveguide of identical semi-circular cross-section, having a common side wall **4A**. Fig. 3 shows how the circular and semi-circular cross-section of hollow-pipe waveguide used for the input and output ports, respectively, in the input junction of Fig. 2 can be obtained by gradual deformation of waveguides of rectangular cross-section. As indicated on each of the figures, the input junction of Figs. 1, 2 or 3 operates to divide the electromagnetic wave energy entering the input port **1**, **1A** or **1B** into two equal energy portions which because of the particular orientation of the cross-sections of the connecting waveguides are propagated separately through a different one of the two output ports **2** and **3**, **2A** and **3A**, or **2B** and **3B**, with the electrical fields E of the propagated wave energy portions oppositely directed with respect to the common wall **4**, **4A** or **4B**.

The particular embodiment of the transducer of the invention shown in Fig. 4 employs the well known H-plane, T-type waveguide junction in its input. As shown, this junction comprises an input arm **5** comprising a straight section of hollow-pipe waveguide of rectangular cross-section forming the stem of the T and two branch arms **6** and **7** consisting of two hollow-pipe waveguides of identical rectangular cross-sections connected at a common point to the output of the input arm **5**, and forming the cross-arm of the T. This junction with the identical cross-sections of the arms **5**, **6**, and **7** oriented as shown operates to divide the electromagnetic wave energy entering the junction through its input arm **5** into two equal energy portions which are separately propagated into different ones of the output arms **6** and **7** with their electric fields E oppositely directed. The extensions of the two branch arms **6** and **7** are bent inwardly as shown until near their output ends the adjacent walls combine so as to provide two straight sections **8** and **9** of waveguide having a common wall **10**, constituting the two output ports of the input junction, similar to the two output ports **2** and **3** in the embodiment of Fig. 1 and operating in similar manner.

Fig. 5 shows one embodiment of the output junction of a transducer in accordance with the invention, in which the two input ports **11** and **12** are formed by two parallel straight sections of hollow-pipe waveguide of identical cross-sections of semi-circular configuration, having one sidewall **13** in common. In Fig. 5, a portion of the outer wall of the waveguide sections **11** and **12** is broken away to show more clearly how the coaxial output port of the output junction is constructed. As indicated, part of the common wall **13** is removed and replaced by a cylindrical conductor or wire **14** attached at one end to the center of the common wall and extending longitudinally to the output end of the transducer. The conductor **14** forms the inner conductor of the output coaxial line section or port **15** for propagation of the coaxial wave mode, the outer conductor of which is provided by the extension of the outer walls of the two waveguide sections forming the input ports **11** and **12** of the output junction, to the ouptut end of the transducer. The dielectric disc **16** attached at a selected point along the cylindrical conductor **14** in the interior of the coaxial line output port **15** is used to compensate for the impedance discontinuities which occur at the junction of the conductor **14** and the common wall **13** by causing a reflection of equal amount and 180 degrees out-of-phase therewith, and thereby to effect complete transformation energywise of the waveguide modes entering through the input ports **11** and **12** into the coaxial wave mode leaving the output coaxial line section or port **15**.

Although the dimension of the output coaxial line section or port **15** usually would be sufficiently large so that this section can transmit the unwanted waveguide mode of the type TE_{11}, the formation of which would limit the size and thus the power-carrying capacity of the coaxial portion in standard waveguide-to-coaxial transducers, this mode would not be excited in the output junction of Fig. 5 because of the opposite orientation of the electric fields of the propagated wave energy with respect to the common wall **13**.

Fig. 8 shows one embodiment of a complete transducer in accordance with the invention adapted for producing an increase in the effective transmission frequency bandwith of the output junction. Referring to that figure, the input junction of the transducer shown therein has an input port **17** formed by a single section of hollow-pipe waveguide of rectangular cross-section, open at one end and closed at the other by an axially movable plunger **18**, and two output ports **19** and **20** respectively formed by two substantially straight sections of hollow-pipe waveguide of identical rectangular cross-section and having one side wall **21** in common. As shown, the inputs of the two waveguide ports **19** and **20** are electrically coupled to the input waveguide port **17** through a suitable opening in one sidewall of the latter at a point intermediate its ends, and the cross-sections of the three waveguide ports **17**, **19** and **20** are suitably oriented with respect to each other so that the electromagnetic wave energy propagated over the input guide or port **17** and fed into the branch waveguide sections or output ports **19** and **20** will be split into two equal energy portions which will be respectively separately propagated over a different one of these sections with the electric fields E of the propagated wave energy portions oppositely directed with respect to the common wall **21** of these sections, as indicated in the figure by the direction of the arrows so designated. The two input ports of the output junction of the transducer shown in Fig. 8 comprise the extended portions of the two waveguide sections **19** and **20** of identical rectangular cross-sections. The coaxial output section or port of the output junction is formed in the following manner.

The full common wall **21** of the waveguide sections **19** and **20** extends only to a point **22** a distance in the

order of a wavelength from the junction of that wall with the input guide 17. Beyond this point, the portion of the common wall 21 above and below a common center line are cut away gradually in tapered fashion as shown. The taper preferably begins from the middle of the wall and extends to the output end of the transducer, or, as shown, to the point 23 along the length of the guides 19 and 20, a short distance from the output end of the transducer where all portions of the common wall 21 are eliminated and only the extensions of the outer walls of the guides 19 and 20 remain. A cylindrical rod or wire 24 having one end connected to the center of the common wall 21 at the point 22 and extending longitudinally to the output end of the transducer, forms the inner conductor, and the extended outer walls of the two waveguide sections 19 and 20 the outer conductor of an output coaxial line portion or port 25 of the transducer. The gradual (tapered) cutting away of portions of the common wall 21 in the manner described results in an increase in the bandwidth of the output junction. In this manner, a more gradual transformation of the electric field of the propagated waves can take place as illustrated by the field patterns shown in Figs. 8A, 8B and 8C.

The field transformation which takes place in the transducer when the electromagnetic wave energy propagates from a cross-section A-A where the two wave energy portions are separated by the common wall 21, through the region where the wall 21 is cut away in tapered fashion so that a varied amount of coupling occurs between the two energy portions, to the coaxial output of the transducer, is illustrated in the cross-sectional views of the transducer at different point shown in Figs. 8A, 8B and 8C. The impedance matching produced by the transducer of Fig. 8 between a waveguide line connected to the open end of the input guide 17 and any line with coaxial termination connected to its coaxial output end 25 can be improved by proper positioning of the plunger 18 in the other end of the input guide 17.

Further improvement in the electrical coupling provided by a transducer in accordance with the invention can be obtained by reducing the phase velocity of the waves in the waveguide sections to a velocity which is only a little higher than the velocity in the coaxial line section of the output junction. One method of accomplishing this is illustrated in Fig. 6 applied to an output junction employing waveguides 26, 27 of identical rectangular cross-section having a common wall 28, for the two input ports, which common wall is cut away gradually in tapered fashion along its length beyond the point 29. A cylindrical conductor 30 extending longitudinally from the center of wall 21 at point 29 to the end of the transducer forms the inner conductor of the output coaxial line section or port 31 of which the extended outer walls of the waveguide sections 26 and 27 form the outer conductor. The required relation between the phase velocities of the propagated waves in the waveguide and coaxial line sections of the output junction is obtained by the use of similar metal ridge members 32, 33 in the interiors of the rectangular waveguide sections 26 and 27, which extend from the waveguide sections into the coaxial line section and taper off gradually in both directions. The ridge members 32, 33 may be located opposite to the common wall 28 and attached to the outer walls of the guides 26 and 27, respectively, as shown in Fig. 6, or may be attached to opposite sides of the common wall 28, as illustrated in the detail view of Fig. 6 showing only the ridges 32, 33, the common wall 28 and the cylindrical conductor 30 forming the inner conductor of the output coaxial line section or port. Instead of the metal ridge members, spaced dielectric slabs (not shown) in the interiors of the two waveguide sections 26, 27 may be used for accomplishing the same purpose.

The parallel waveguide sections used for forming the input and output ports of the input punction and the input ports of the output junction and for deriving the coaxial output port of the output junction of the transducer, may have configurations other than those illustrated in the embodiments of the transducer of the invention shown in Figs. 1 to 8. Also, although only the use of the transducers of the invention for transferring electromagnetic wave power in the direction from a waveguide line to a line having a coaxial termination has been described above, it is to be understood that they are also applicable for transferring electromagnetic wave power in the opposite direction, that is from a line with coaxial termination to a waveguide line.

When a surface wave transmission line is one of the lines coupled by a transducer in accordance with the invention, the cylindrical conductor forming the inner conductor of the coaxial output port of the transducer would be connected to the elongated conductor of the SWTL, and the output end of the outer walls of the extended waveguide sections forming the outer conductor of that output port would be connected to the waveguide horn or other surface wave launching means such as described in the above-mentioned patent, or the surface wave conductor may serve as conductor 30 of the coaxial section.

Various other modifications of the transducer arrangements illustrated and described which are within the spirit and scope of the invention will occur to persons skilled in the art.

What is claimed is:

A transducer for electrically coupling a waveguide line to another line having a coaxial termination comprising two tandem-connected line junctions one having three waveguide ports and the other two waveguide ports and one coaxial line port, the waveguide ports of said other junction being respectively connected in wave transmission relation with a different one of two of the waveguide ports of said one junction through two sections of hollow-pipe line of identical cross-section having a common sidewall between them, the connection between the three waveguide ports of said one junction being such that the electromagnetic energy entering one port of that junction from said waveguide line is split into two equal portions which are respectively propagated through different ones of said two sections to the other two waveguide ports thereof with their electric fields oppositely directed with respect to said common wall, said common wall being partly eliminated beyond a point a given distance from the waveguide end of the transducer and a cylindrical conductor is connected to the center of that wall at said point and extending longitudinally to the coaxial line end of the transducer to form the inner conductor of said coaxial line port, the extended outer walls of said line section forming the outer conductor of said coaxial line port, the partial elimination of said common wall beyond said point being provided by cutting away that wall in tapered fashion on opposite sides of a center line to provide a more gradual transformation of the oppositely phased electric fields to increase the effective frequency bandwidth, the tapered cut beginning at the center point to which said cylindrical conductor is attached and extending lengthwise to the opposite outer edges of the common wall near the coaxial line end of the transducer, impedance matching between the coupled lines being provided by the use of a similar metal ridge section in the interior of each of said hollow-pipe waveguide sections attached to corresponding wall thereof at a point opposite the common wall, which ridge sections taper off gradually longitudinally in both directions, to reduce the phase velocity of the waves in the waveguide portions of the transducer to a velocity which is only a little higher than that in the coaxial line portion of the transducer.

(References on following page)

References Cited in the file of this patent

UNITED STATES PATENTS

2,659,054	Alford	Nov. 10, 1953
2,792,551	Smith	May 14, 1957
2,817,835	Worthington	Dec. 24, 1957
2,878,453	Elliott	Mar. 17, 1959
2,924,797	Robertson	Feb. 9, 1960

FOREIGN PATENTS

623,770	Great Britain	May 23, 1949

OTHER REFERENCES

Ragan: "Microwave Transmission Circuits," vol. 9, MIT Radiation Laboratory Series, copyright May 21, 1948 (pages 360–361 relied upon).