Sept. 8, 1970 R. M. HONDA ET AL 3,528,041

BROADBAND DOUBLE RIDGED WAVEGUIDE BALUN

Filed Dec. 30, 1968 2 Sheets-Sheet 1

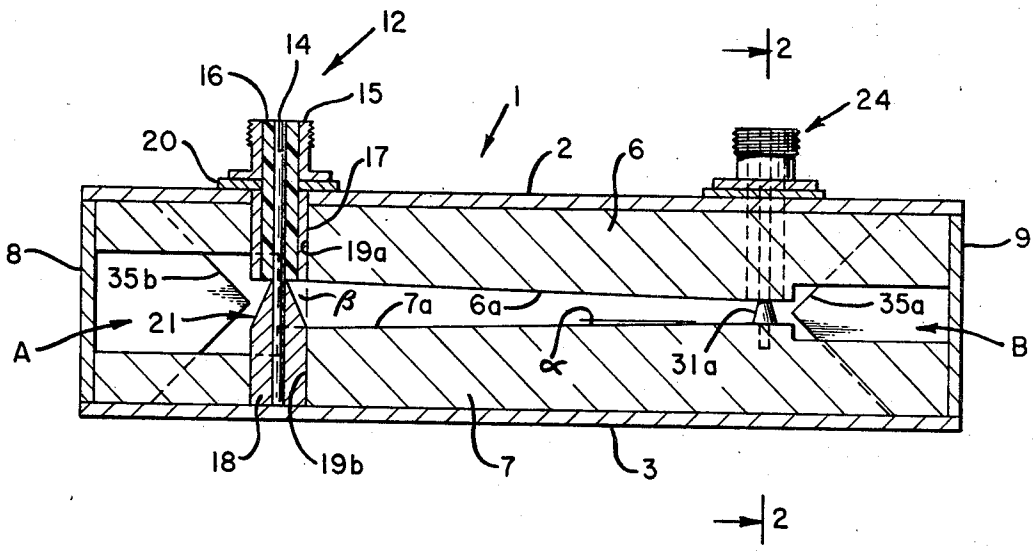


FIG-1

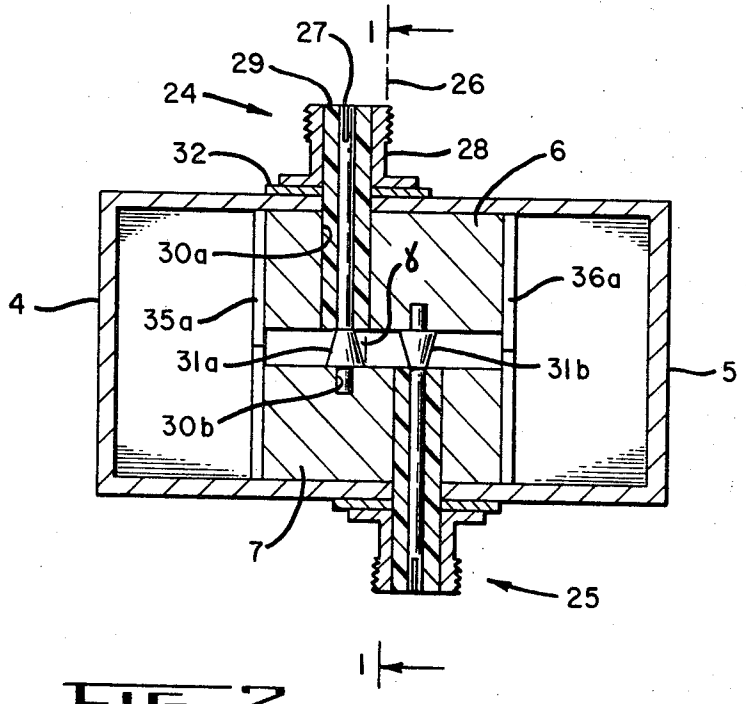


FIG-2

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2 Sheets-Sheet 2

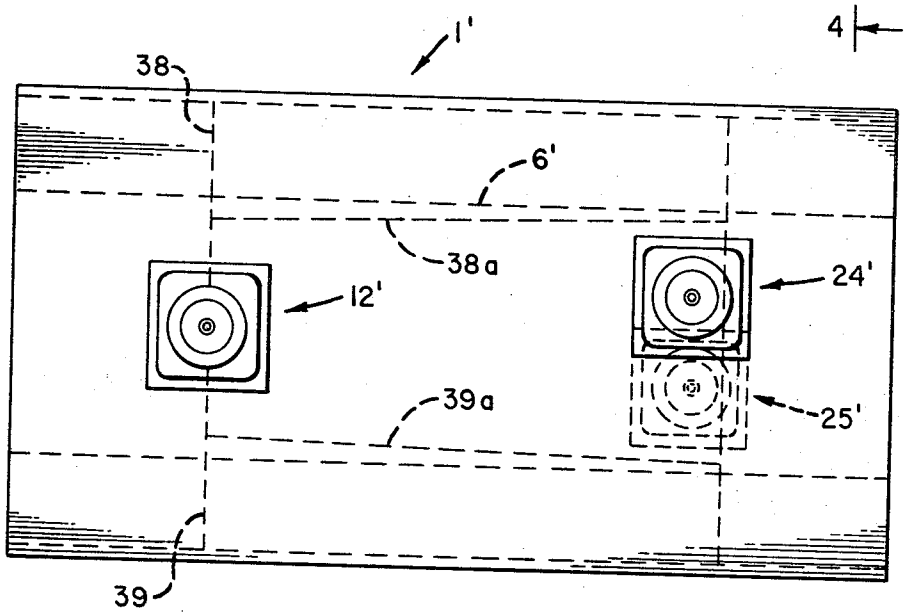


FIG-3

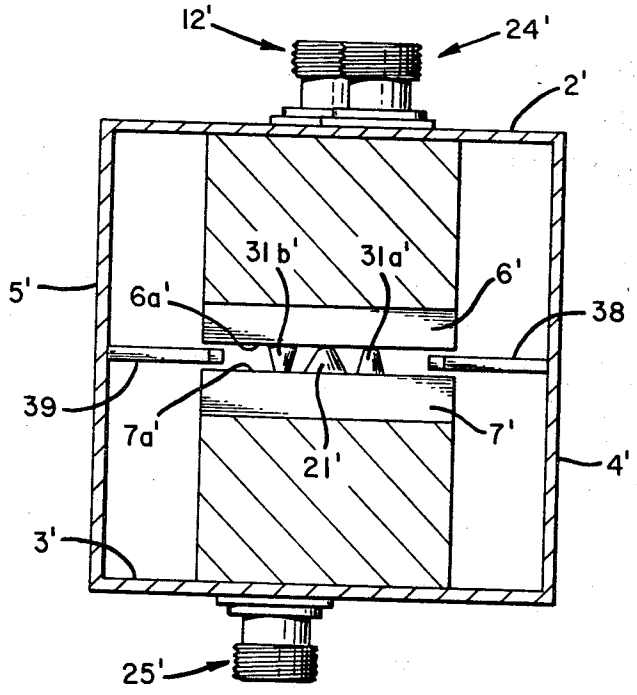


FIG-4

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BROADBAND DOUBLE RIDGED WAVEGUIDE BALUN

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U.S. Cl. 333—26 10 Claims

ABSTRACT OF THE DISCLOSURE

This balun includes a length of doubly ridged rectangular waveguide that is dimensioned to support TE_{10} mode propagation of electromagnetic waves and is short circuited at both ends. Adjacent one end of the waveguide, a first coaxial probe is centered in and short circuited across the waveguide at the top of one ridge. Adjacent the other end of the waveguide, second and third coaxial probes are spaced equidistant from the center line of the waveguide and in the same plane transverse to the direction of propagation of electromagnetic waves in the waveguide. The latter probes are short circuited across the waveguide at the tops of opposite ridges so as to couple to and from the waveguide equal amplitude signals that are 180° out-of-phase.

BACKGROUND OF INVENTION

This invention relates to transmission of electromagnetic wave signals and more particularly to a balancing unit (balun) for coupling signals between an unbalanced system and a balanced two wire system.

Baluns are often employed to couple signals on the two-wire output of a balanced antenna to an unbalanced coaxial transmission line connected to a receiver. Antennas are presently available that operate over frequency bands that are several octaves wide. Conventional baluns, however, operate over limited bandwidths that are nominally less than an octave wide and they are difficult to balance. A strip transmission line balun having octave bandwidth operation is also available, but it has a relatively high voltage standing wave ratio in the order of 2:1. Also, it radiates energy at the abrupt junction between the balanced and unbalanced lines so that a very high fringing field is produced which makes it sensitive to its surroundings. This degrades the antenna radiation patterns and skews the antenna beam off the bore sight axis.

An object of this invention is the provision of an improved balun.

Another object is the provision of a balun that operates over a broad band of frequencies.

Another object is the provision of a balun that is rugged and simple to construct.

SUMMARY OF INVENTION

These and other objects are accomplished in accordance with this invention by locating a first coaxial coupling circuit in a length of doubly ridged waveguide that is short circuited at both ends and supports a mode of propagation of electromagnetic wave signals in which there is one-half cycle of sinusoidal variation of the intensity of the electric field over the width of the waveguide. The first coaxial circuit couples signals between the waveguide and an unbalanced coaxial transmission line. Second and third coaxial coupling circuits are spaced from the first circuit in the direction of propagation of electromagnetic waves in the waveguide and are located in the same plane transverse to the direction of propagation. The second and third circuits are symmetrically located about the center line of the waveguide and are oriented therein to couple between the waveguide and a balanced system equal amplitude signals that are 180° out-of-phase. The adjacent surfaces of the ridges are tapered between the first and second circuits in order to match the impedances in the waveguide at the coupling circuits. In a modified form of D.C. through the waveguide walls and conductor **18** invention, a second pair of ridges are located in the waveguide orthogonal to the first ridges. The ends of the second ridges extend into the gap between the first ridges and are tapered over their lengths between the first and second circuits.

DESCRIPTION OF DRAWINGS

FIG. 1 is a side section view, taken through the center line of the waveguide, of a balun embodying this invention;

FIG. 2 is a section view taken along line **2—2** of FIG. 1;

FIG. 3 is a top plane view of a balun embodying a modified form of this invention; and

FIG. 4 is a section view taken along line **4—4** in FIG. 3.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring now to FIGS. 1 and 2, the balun comprises a length of rectangular waveguide **1** having top and bottom broad walls **2** and **3** and narrow side walls **4** and **5**. Ridges **6** and **7** extend over the length of the waveguide and are electrically connected and mechanically secured to the broad walls **2** and **3**, respectively, by brazing or screws (not shown). The ends of the waveguides are short circuited by plates **8** and **9** which are also electrically connected and mechanically secured to the waveguide by brazing or screws (not shown). The waveguide and ridges are dimensioned to support the TE_{10} mode of propagation of electromagnetic wave signals which is characterized by one-half cycle of sinusoidal variation of the intensity of the electric field over the width of the waveguide. Although a rectangular waveguide is shown in FIGS. 1 and 2, circular and square waveguides, as well as coaxial transmission line, also support a similar propagation mode.

A first coaxial probe coupling circuit **12** is centered in broad wall **2** proximate plate **8** for exciting the TE_{10} mode of propagation in the waveguide and for coupling signals between an unbalanced coaxial transmission line (not shown) and the waveguide. Probe **12** comprises a center conductor **14** which is insulated from outer conductor **15** by a dielectric sleeve **16**, and a pair of cylindrical conductors **17** and **18**. Conductors **14**, **17** and **18** and the dielectric sleeve are coaxial and located in the bore **19** extending through broad wall **2** and the ridges. Conductors **17** and **18** are rigidly secured in the bores **19***a* and **19***b* in ridges **6** and **7**, respectively, by brazing. A support plate **20** having a central opening therein coaxial with the bores **19** is rigidly secured to broad wall **2** by brazing. Outer conductor **15** may, by way of exam-

ple, be an OSM 204 coaxial connector that is secured to plate 20 by screws (not shown).

The end 21 of conductor 18 is shaped like a truncated conic that tapers from a large diameter adjacent the plane surface of the ridge 7 to a smaller diameter in the plane of the surface of ridge 6. These surfaces of the ridges are parallel to broad walls 2 and 3 over the breadth of conductors 17 and 18.

Center conductor 14 is rigidly secured in the central opening in conductor 18 by brazing. Since conductor 14 is electrically insulated from connector 15 and conductor 17 by the dielectric sleeve 16, the center conductor 14 and the outer conductor 15 of the first probe 12 are effectively short circuited at the surface of ridge 7.

Second and third coaxial probe coupling circuits 24 and 25 are located in the broad walls 2 and 3, respectively, of the waveguide proximate plate 9. These probes are spaced equidistant from and on opposite sides of the waveguide center line 26 in the same plane that is parallel to the shorting plates and transverse to the direction of propagation of electromagnetic waves in the waveguide. Probes 24 and 25 are similar and therefore only probe 24 will be described in detail.

Referring now to FIG. 2, probe 24 comprises a center conductor 27 which is insulated from an outer conductor 28 by a dielectric sleeve 29. Conductor 27 and sleeve 29 are coaxial and located in a bore 30 extending through ridge 6 and into ridge 7. The end of conductor 27 in the bore 30*b* is mechanically and electrically connected to ridge 7 by brazing. The circumference of the section 31*a* of conductor 27 is shaped like a truncated conic which tapers from a large diameter adjacent the plane surface of ridge 7 to a smaller diameter in the plane of the surface of ridge 6. These surfaces of the ridges are parallel to broad walls 2 and 3 over the breadth of the center conductor sections 31. A second support plate 32 having a central opening therein coaxial with the bore 30 is rigidly secured to broad wall 2 by brazing. Outer conductor 28 may, by way of example, also be an OSM 204 connector that is secured to plate 32 by screws (not shown).

Consider that the magnitudes of the characteristic impedances of probes 12, 24 and 25 are all the same value. Since probes 24 and 25 are electrically connected in parallel across the waveguide, the waveguide impedance in the transverse plane of these probes is only half the waveguide impedance at probe 12. In order to properly match the waveguide impedances at the probes, it is necessary to smoothly vary the value of the waveguide impedance between the impedance values at probes 12 and 24. As illustrated in FIG. 1, this is accomplished by tapering the opposite facing surfaces of ridges 6 and 7 between probes 12 and 24 to linearly vary the ratio of the height of the waveguide to the separation of the ridges while maintaining the ratio of the width of the waveguide to the width of the ridges constant.

It is also necessary to insure that propagation of electromagnetic waves is between probe 12 and probes 24 and 25 and away from the adjacent shorting plates 8 and 9, respectively. This is accomplished by reducing the heights of the ridges between the transverse planes through the probes 12 and 24 and the adjacent shorting plates to form cavities A and B, respectively, in these areas. The cavities have characteristic impedances much greater than the waveguide impedance at the adjacent probes. Resistance cards 35 and 36 are bonded to the side walls of the ridges in the cavities to absorb electromagnetic signals in these areas.

As stated above, probes 24 and 25 are electrically and mechanically the same except that the slopes of the tapers of the circumferences of probe sections 31*a* and 31*b* are of opposite sign. Thus, since probe sections 31*a* and 31*b* are spaced the same distance on opposite sides of center line 26 in the same transverse plane, signals coupled from the waveguide by probes 24 and 25 are of equal amplitude and 180° out-of-phase.

When it is desirable to operate a ridged waveguide balun over a broad band of frequencies, the spacing between the ridges is small. Because of this small spacing, it is difficult to provide a taper of the surfaces 6*a* and 7*a* of the ridges to properly match the waveguide impedance at probe section 21 to the impedance at probe sections 31. The modified form of this invention illustrated in FIGS. 3 and 4 includes a second pair of ridges 38 and 39 which are useful in matching the waveguide impedances at the probes. Similar components in the embodiment of FIGS. 1 and 2 are indicated in FIGS. 3 and 4 by primed reference characters.

As shown in FIG. 4, the waveguide has a square cross section. The surfaces 6*a*′ and 7*a*′ of ridges 6′ and 7′, respectively, are parallel to the waveguide walls 2′ and 3′ over their entire length. The ridges 38 and 39 project from the waveguide walls 4′ and 5′, respectively, to which they are rigidly secured. The ends of ridges 38 and 39 project into the gap between ridges 6′ and 7′. The opposite facing surfaces 38*a* and 39*a* of the second pair of ridges are linearly tapered between the transverse planes through probes 12′ and 24′ in order to match the waveguide impedances at these probes.

By way of example, a balun similar to that shown in FIGS. 1 and 2 that was built and successfully operated and tested as the feed for a conical spiral antenna had the following dimensions and characteristics:

Waveguide 1:
- Length—4.0 inches
- Width—1.872 inches
- Height—0.872 inch

Ridges 6 and 7:
- Width—0.749 inch
- Height:
  - Minimum—0.376 inch
  - Maximum—0.406 inch
- Taper angle α—0°45′

Cavity A:
- Length—0.742 inch
- Height—0.480 inch
- Ridge 7 height—0.309 inch

Probe section 21:
- Center line spacing—0 inch
- Diameter—0.260 inch
- Taper angle β—41°11′

Probe sections 31*a* and 31*b*:
- Center line spacing—0.126 inch
- Taper angle γ—14°2′

Cavity B:
- Length—0.742 inch
- Height—0.254 inch
- Ridge 7 height—0.309 inch

Spacing between probes 12 and 24—2.276 inches
Operating frequency band—2.5–5.0 gHz.
Voltage standing wave ratio—$<$1.5:1

This balun did not include resistance cards 35 and 36 adjacent the cavities. The balun operated over an octave bandwidth which was defined as the band of frequencies over which the voltage standing wave ratio (VSWR) was less than 1.5:1. The amplitude unbalance between the output signals of probes 24 and 25 was less than 0.25 db. The phase difference between these signal differed from 180° by less than 2°. This balun would operate over a broader frequency band if a higher VSWR was acceptable.

Another balun including resistance cards adjacent the cavities and similar to the embodiment of the invention illustrated in FIGS. 1 and 2 was also built and tested. It was dimensioned to operate over a 6:1 bandwidth between 1.8 and 12.0 gHz. with a VSWR of less than a 2:1. The amplitude unbalance between the outputs of probes 24 and 25 was less than 0.65 db for this balun. The phase difference between these signals differed from 180° by less than 5°.

What is claimed is:

1. A balun for coupling electromagnetic wave signals between an unbalanced system and a balanced two-wire system comprising

a waveguide having a finite length, having two pairs of opposite walls which are orthogonal, and having a longitudinal axis,

a first pair of ridges in and symmetrical with respect to a centerline of said waveguide, each ridge of said first pair being electrically connected to a different wall of one of said pairs of opposite walls,

said ridged waveguide being dimensional to support the TE_{10} mode of propagation of electromagnetic waves along said axis which is characterized by an electrical field perpendicular to said axis and between opposed surfaces of said first ridges,

a pair of conductive plates electrically connected to and short-circuiting opposite ends of said waveguide,

a first coaxial probe coupling electromagnetic wave energy between said waveguide and the unbalanced system, said first probe extending into said waveguide and oriented for exciting said TE_{10} mode of propagation therein, and

second and third coaxial probes coupling electromagnetic wave energy between said waveguide and the balanced system; said second and third probes being located in the same plane transverse to said axis and axially spaced from said first probe, being spaced the same distance on opposite sides of a centerline of said waveguide, and extending into said waveguide and oriented for exciting said TE_{10} mode of propagation therein.

2. The balun according to claim 1 wherein the opposed surfaces of said first ridges are tapered over at least a portion of their lengths between said first and second probes.

3. A balun for coupling electromagnetic wave signals between an unbalanced system and a balanced two-wire system comprising

a waveguide having a finite length, having two pairs of opposite walls which are orthogonal, and having a longitudinal axis,

a first pair of ridges in and symmetrical with respect to a centerline of said waveguide, each ridge of said first pair being electrically connected to a different wall of one of said pairs of opposite walls,

said ridged waveguide being dimensional to support the TE_{10} mode of propogation of electromagnetic waves along said axis which is characterized by an electrical field perpendicular to said axis and between opposed surfaces of said first ridges,

a pair of conductive plates electrically connected to and short-circuiting opposite ends of said waveguide,

a first coaxial probe coupling electromagnetic wave energy between said waveguide and the unbalanced system, said first probe extending into said waveguide and oriented for exciting said TE_{10} mode of propagation therein, and

second and third coaxial probes coupling electromagnetic wave energy between said waveguide and the balanced system; said second and third probes being located in the same plane transverse to said axis and axially spaced from said first probe, being spaced the same distance on opposite sides of a centerline of said waveguide, and extending into said waveguide and oriented for exciting said TE_{10} mode of propagation therein,

the opposed surfaces of said first ridges being tapered over at least a portion of their lengths between said first and second probes,

each of said coaxial probes comprising

an outer conductor electrically connected to a wall of said one pair of walls,

a center conductor coaxial with said outer conductor, and

a dielectric sleeve coaxial with and electrically insulating said center and outer conductors from each other,

said center conductor extending across the gap between the opposite facing surfaces of said first ridges and being electrically connected to only one of said first ridges at the surface thereof, the circumference of said center conductor being tapered between the opposed surfaces of said first ridges,

said center conductors of said second and third probes being electrically connected to opposite first ridges at the surfaces thereof and having tapers that are of the opposite sign between the opposed surfaces of said first ridges.

4. The balun according to claim 3 wherein the height of a portion of the first ridges between each shorting plate and the adjacent probe is less than the height of the first ridges between said first and second probes.

5. The balun according to claim 4 including a resistance card adjacent to the ridge cavity between a shorting plate and the adjacent probe.

6. The balun according to claim 4 wherein the walls of said waveguide are parallel to said axis and the opposed surfaces of said first ridges are parallel to the walls of said one pair of opposite walls over the breadth of said probes.

7. A balun for coupling electromagnetic wave signals between an unbalanced system and a balanced two-wire system comprising

a waveguide having a finite length, having two pairs of opposite walls which are orthogonal, and having a longitudinal axis,

a first pair of ridges in and symmetrical with respect to a centerline of said waveguide, each ridge of said first pair being electrically connected to a different wall of one of said pairs of opposite walls,

said ridged waveguide being dimensional to support the TE_{10} mode of propagation of electromagnetic waves along said axis which is characterized by an electrical field perpendicular to said axis and between opposed surfaces of said first ridges,

a pair of conductive plates electrically connected to and short-circuiting opposite ends of said waveguide,

a first coaxial probe coupling electromagnetic wave energy between said waveguide and the unbalanced system, said first probe extending into said waveguide and oriented for exciting said TE_{10} mode of propagation therein,

second and third coaxial probes coupling electromagnetic wave energy between said waveguide and the balanced system; said second and third probes being located in the same plane transverse to said axis and axially spaced from said first probe, being spaced the same distance on opposite sides of a centerline of said waveguide, and extending into said waveguide and oriented for exciting said TE_{10} mode of propagation therein, and

a second pair of ridges in said waveguide, each ridge of said second pair being electrically connected to a different wall of the other one of said pairs of opposite walls and extending into the gap between opposed surfaces of said first ridges, the opposed surfaces of said second ridges being tapered over at least a portion of their lengths between said first and second probes.

8. The balun according to claim 7 wherein said waveguide has a square cross section.

9. The balun according to claim 8 wherein each of said coaxial probes comprises

an outer conductor electrically connected to a wall of said one pair of walls,

a center conductor coaxial with said outer conductor, and

a dielectric sleeve coaxial with and electrically insulating said center and outer conductors from each other,

said center conductor extending across the gap between the opposed surfaces of said first ridges and being electrically connected to only one of said first ridges at the surface thereof, the circumference of said center conductor being tapered between the opposed surfaces of said first ridges,

said center conductors of said second and third probes being electrically connected to opposite first ridges at the surfaces thereof and having tapers that are of the opposite sign between the opposed surfaces of said first ridges.

10. The balun according to claim 9 wherein the height of the first ridges between each shorting plate and the adjacent probe is less than the height of the first ridges between said first and second probes.

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U.S. Cl. X.R.

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