

[54] **BROADBAND BALUN**  
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[58] Field of Search..... **333/26, 34, 84 M, 333/21 A**

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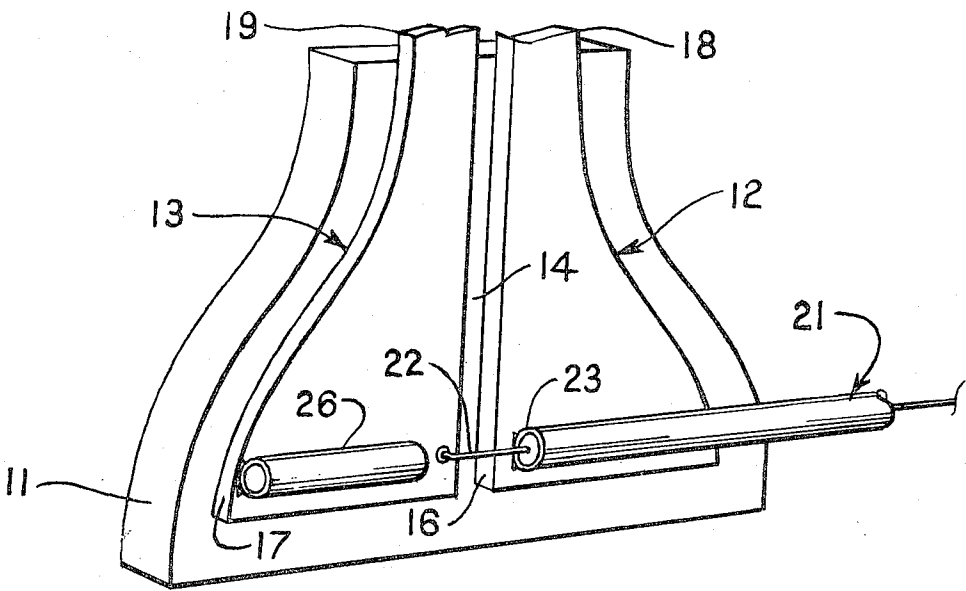
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[57] **ABSTRACT**  
A balun comprised as electrical leads forming a slot line and having a tapered configuration to provide a matching impedance to an asymmetrical conducting system such as coaxial cable, strip-line, microstrip, etc. Broadband impedance matching is achieved between symmetrical and asymmetrical electrical transmission systems.

**5 Claims, 5 Drawing Figures**



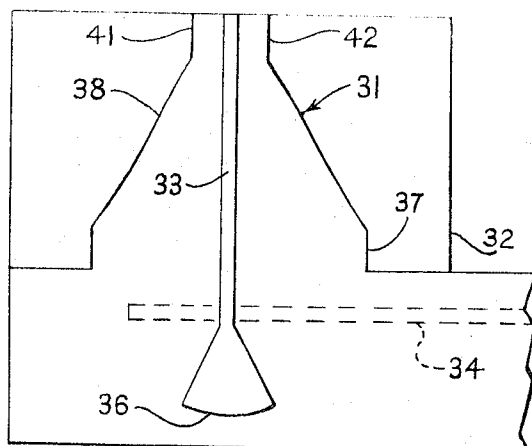
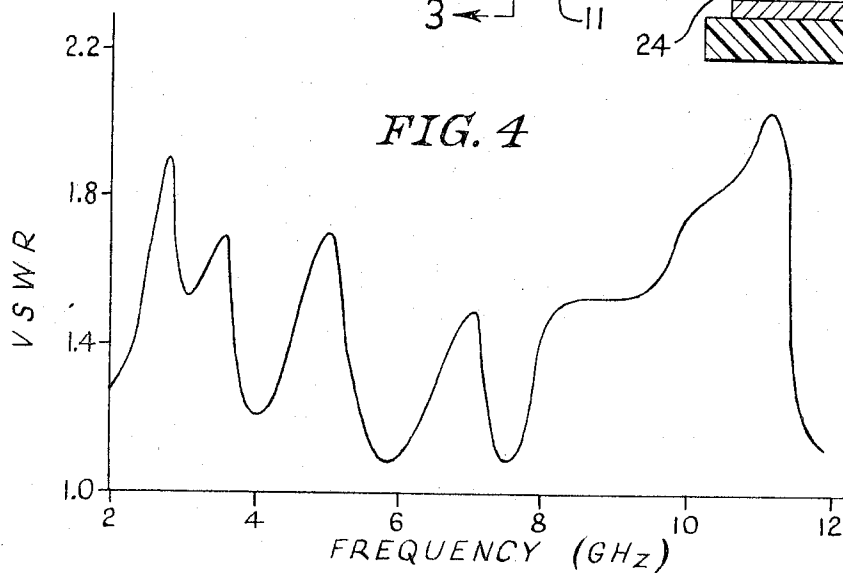
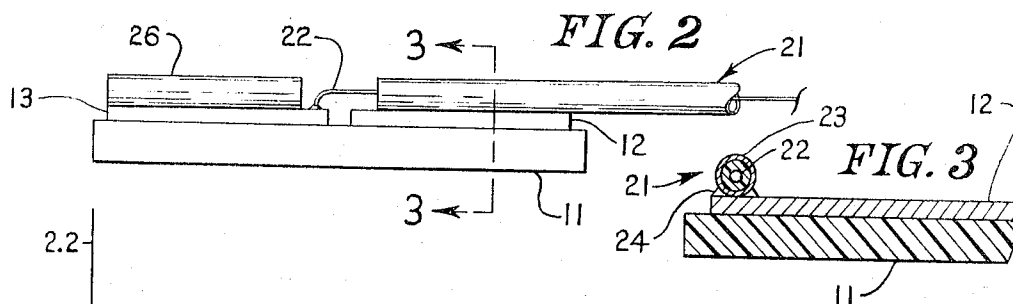
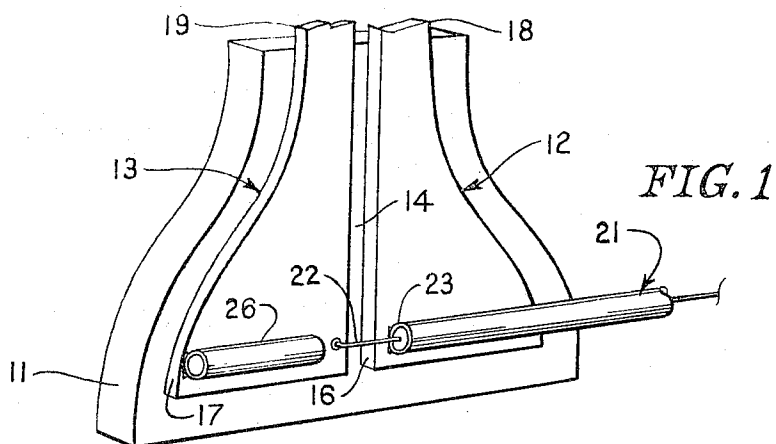


FIG. 5

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## BROADBAND BALUN

## BACKGROUND OF INVENTION

In various high frequency applications it is necessary to transfer electrical energy from a symmetrical transmission line to an asymmetrical transmission line, i.e., between a circuit or line including two conductors that are electrically symmetrical with respect to a neutral or ground point and a line or circuit that is electrically unsymmetrical with respect to its ground point. As an example, coaxial transmission lines commonly employed for the transmission of high frequency power are asymmetrical or unsymmetrical and an antenna such as a dipole radiator comprising two elements extending in opposite directions from the neutral point and fed at that point is a symmetrical or balanced circuit. Devices for accomplishing the transition between balanced and unbalanced or symmetrical and unsymmetrical systems such as those noted above are commonly termed baluns.

Particularly in the field of wide band radar systems and space communications systems, there has been experienced a need for well matched wide band antennas; and a limitation in antenna designs, particularly in wide band microwave applications, has been a balun structure. It is recognized that a variety of different balun structures have been proposed and certain of these are widely employed in the art. In this respect note, for example, U.S. Pat. Nos. 2,517,968 and 2,517,969 to Brown, 2,925,566 to Jasik, and 3,357,023 to Hemmie. In general baluns provide a good impedance match over only a relatively narrow frequency bandwidth; usually less than 2:1. There has been developed a truly broadband balun described in Proceedings of the IRE, Feb., 1960, in an article entitled "100:1 Bandwidth Balun Transformer" by Duncan and Minerva. However, it is noted that the cost of manufacture of this device is quite high and, furthermore, that the size thereof is large enough to preclude its utilization in many applications.

The present invention provides a truly broadband balun having a usable bandwidth of at least 10:1 in a device of small size and low cost of manufacture.

## SUMMARY OF INVENTION

The present invention provides a balun capable of transforming an unbalanced transmission mode into a balanced two wire mode over a wide frequency band. The invention is particularly applicable for the connection of circuitry to antennas, although it is not limited to this application.

In structure the present invention may be comprised as a pair of conductors formed as conducting layers upon a solid dielectric substrate with a slot separating the conductors on the substrate. The conductors are formed with a wide base end normal to the slot therebetween and both taper inwardly toward the slot away from the base end to a second end whereat the narrow parallel conductors extend from the substrate for engagement with a two wire line. An asymmetrical transmission line such as a coaxial cable is adapted to be connected across the conductors on the substrate at the base end of the conductors and this connection is made by both physically and electrically connecting the sheath of the coaxial cable across the base of one of the conductors on the substrate and extending the central conductor of the coaxial cable across the slot between

the conductors into electrical and physical engagement with the other conductor on the substrate. The balun is configured to establish an impedance at the base end of the conductors thereof substantially equal to the characteristic impedance of the coaxial line connected thereat. The tapered configuration of the balun conductors provides for increasing the impedance to a desired value at the two wire line connection thereto without the introduction of discontinuities in the transformation.

Alternative configurations may be formed without a dielectric and also the base of the conductors may be coupled to stripline, microline or the like instead of coaxial cable.

A bandwidth of 10:1 or greater is achievable with the broadband balun of the present invention.

## DESCRIPTION OF FIGURES

The present invention is illustrated as to a particular preferred embodiment thereof in the accompanying drawing wherein:

FIG. 1 is a perspective view of a broadband balun formed in accordance with the present invention;

FIG. 2 is an end elevational view of the balun of FIG. 1;

FIG. 3 is a partial sectional view taken in the plane 3—3 of FIG. 2;

FIG. 4 is a graph of VSWR vs. frequency for a balun formed in accordance with the present invention; and

FIG. 5 is a plan view of a slotline to microstrip balun in accordance with the present invention.

## DESCRIPTION OF PREFERRED EMBODIMENT

Considering now a preferred embodiment of the present invention as illustrated in FIGS. 1 to 3 of the drawing, there will be seen to be provided a solid dielectric substrate 11. Although the substrate is not essential to the invention, it provides a convenient way of supporting the balun and also serves to concentrate electromagnetic fields close to the balun and avoid interaction thereof with the surrounding environment. Upon a surface of this substrate there is provided a layer of electrically conductive material in the form of first and second conductors 12 and 13 respectively. These conductors are separated by a slot 14 extending through the conductive layer to the substrate, as illustrated. The conductors 12 and 13 are each formed with wide base ends 16 and 17 respectively and each of the conductors have at least the outer edges thereof tapered inwardly, somewhat as illustrated. The conductors 12 and 13 have narrow second ends 18 and 19 respectively extending from substrate 11 for connection to a conventional flat two wire system. The taper of the conductors 12 and 13 may, for example, be a linear taper or a Tchebycheff taper, as set forth in an article entitled "A Transmission Line Taper of Improved Design," by R.W. Klepenstein, appearing in the Proceedings of the IRE, Vol. 44, pp. 31-35, January, 1956, or any other taper which provides a good impedance match over a large frequency band.

The purpose of the taper or reduction in width between the base ends and second narrow ends of the conductors 12 and 13 is to provide for a change in impedance from the base ends of the conductors to the second narrow ends thereof. It is herein provided that such impedance variation shall be accomplished with-

out reflection of high frequency energy passed through the conductors.

The improved broadband balun of the present invention is adapted for connection or coupling to an asymmetrical transmission line such as coaxial cable 21. The coaxial cable, as illustrated, is comprised as a central conductor 22 surrounded by a concentric electrically conducting sheath 23 with a dielectric between the central conductor and sheath. As illustrated in the drawings, the coaxial line or cable 21 is extended across the base of the first conductor 12 and the sheath 23 is physically and electrically connected to the conductor 12 as by means of a solder or conducting epoxy 24. The cable sheath 23 is terminated at the slot 14; however, the central conductor 22 extends from the sheath across the slot 14 into electrical connection with the conductor 13. Assuming that the coaxial cable 21 is an input line, it will be appreciated that the TEM mode of transmission thereof launches a wave onto the conductors 12 and 13 at the base thereof to thus transmit the wave longitudinally on these conductors. With the base width of the conductors 12 and 13 being of sufficient magnitude so as to be capable of being considered infinite widths for the purposes hereof, it may be considered then that the coaxial cable is actually coupled to a slot line formed by the conductors 12 and 13. It is to be appreciated that slot line transmission is known in the art and in this respect reference is made to an article entitled "Slot-line — An Alternative Transmission Medium for Integrated Circuits" by S. B. Cohn, 1968 IEEE G-MTT International Microwave Symposium Digest, pp. 104-109. Energy is transmitted in what may be termed a TE mode in slot line inasmuch as there exists a transverse electric field but the magnetic field is in a plane perpendicular to the slot and forms closed loops at half wave intervals. The conventional 50 ohm characteristic impedance of the coaxial line can be closely matched by slot line through an appropriate choice of slot width, dielectric depth and dielectric constant.

The present invention furthermore provides for a variation of this "input" impedance of the balun by tapering of the conductors 12 and 13 so as to reduce the widths thereof toward the second end of the balun. This then provides for a transition between slot line and flat two wire line upon the substrate. At the second or upper end of the balun, as illustrated in FIG. 1, the transition is complete and the impedance of the two wire line formed by the upper ends 18 and 19 of the conductors may, for example, be of the order of 150 to 200 ohms for matching the impedance of a high frequency antenna to be energized through the balun. The taper of the conductors 12 to 13 may, as noted above, be a linear taper, a Klopfenstein taper, or any other configuration which produces an impedance variation while eliminating reflections.

With regard to physical dimensions and choice of materials for construction of the present invention, it is noted that the conductors 12 and 13 may be formed by printed circuit techniques upon the dielectric substrate 11. Thus, for example, the substrate may be formed of Teflon Fiberglas with the conductors formed of copper or, again for example, the conductors may be formed of a gold-chrome on an alumina substrate. In practice the physical size of the balun may be quite small and in S band or X band the width of the conductors on the substrate may, for example, be of the order of 1/2 inch

with a thickness of the order of hundredths or thousandths of an inch and the substrate having a thickness of the order of 0.10 inch. It is noted to be possible to calculate the base impedance of the balun by slot line techniques and it is further noted by way of information that actual input impedance of the balun at the coaxial line is normally about two-thirds of calculated impedance.

A broadband balun in accordance with the present invention was formed upon a 1/16 inch thick Teflon impregnated Fiberglas having a 0.0014 inch thick copper cladding on one surface with the base width of 1 inch of conducting layer and length of 1.5 inch. The conducting layer tapered to a width of 0.180 inch and the slot width was 0.050 inch. A coaxial cable of 0.141 inch OD was connected as shown in FIG. 1. This device provided a 50 ohm to 150 transition over a broad bandwidth without reflections.

Referring to FIG. 4, there will be seen to be shown a plot of voltage standing wave ratio vs. frequency in GHz. It will be seen from FIG. 4 that for the particular balun tested a standing wave ratio less than two is obtained over a frequency range of 6:1. In practice the present invention is capable of providing a bandwidth in excess of 10:1, again with a minimum VSWR. It will be seen that the present invention overcomes the complexities of the prior art in the provision of a truly broadband balun. The present invention furthermore presents a very simple device having small size and being very inexpensive of manufacture. As noted above, printed circuit techniques may be employed to form the balun itself.

As a further refinement of the above described embodiment of the present invention, there may be provided across the base 17 of the second conductor 13 a coaxial cable sheath 26. This sheath 26 is electrically connected to the second conductor 13 but does not contain a central conductor. This then provides not only a physical symmetry but also an improved impedance matching between the coaxial cable and the conductors 12 and 13 of the balun. Although the theory of the improvement attained by provision of this additional coaxial sheath is difficult to establish, it has been established by experimental testing that a substantial improvement is afforded thereby. Improved impedance matching results from the complete configuration illustrated in FIG. 1 and including the coaxial sheath 26 connected across the base of the second conductor 13. A further increase in bandwidth is also attained in this manner.

As noted above, the present invention is adapted to match impedances between symmetrical and unsymmetrical transmission lines without reflections. The change in impedance between an unsymmetrical transmission line and a symmetrical transmission line as afforded by the present invention may comprise either an increase or decrease in impedance and a wide variety of different types of asymmetrical transmission lines may be employed with the present invention. It will be appreciated that certain physical variations in the invention are employed to accommodate different types of asymmetrical transmission lines. In this respect reference is made to FIG. 5 wherein there is illustrated an example of microstrip coupling to the improved broadband balun of the present invention. A conductive layer 31 is provided upon a dielectric base 32 with a slot 33 formed in the conductive layer. The lower por-

tion of the conductive layer 31 provides the wide conductor of a microstrip transmission line completed by a thin trace or conductor 34 disposed on the opposite side of the dielectric plate 32 from the conductive layer 31, as illustrated. The microstrip line extends transversely of the slot 33 and the trace 34 extends past the slot approximately one quarter wavelength. This then provides an open circuit termination of the microstrip line. The slot extending perpendicularly to the microstrip trace also extends past the trace 34 approximately one quarter wavelength with this last quarter wavelength possibly being formed as a segment of the circle, as indicated at 36. This type of slot termination is known in the art and provides an improvement in broadband termination. It is, however, noted that the slot may merely extend as a straight slot a quarter wavelength beyond the microstrip trace 34.

It will be appreciated that the lower portion of the conductive layer 31 on the dielectric plate 32 comprises a slot line transmission line and the conductive layer extends upwardly from the microstrip line at 37 to completely establish this type of slot line transmission line. The conductive layer 31 is then tapered inwardly as indicated at 38 in extension away from the microstrip to provide a smoothly varying impedance increase along the conductors formed by the layer 31. At the top of the dielectric plate 32 the conductive layer is reduced to a nominal width on each side of the slot 33 to thus form a flat two wire line as conductors 41 and 42 which may then be connected to the input terminals of an antenna for example. There will be seen to be provided upon the upper surface of the dielectric plate 32 a transition from slot line to flat two wire transmission line by decreasing the width of the conductors forming this slot line so as to consequently achieve an increase in impedance. The particular taper or configuration of the decreasing width of the conductive layer 31 from slot line to conductors 41 and 42 of the flat two wire line may comprise any desired configuration eliminating reflections such as for example a linear taper, a Klopfenstein taper or the like.

Electromagnetic waves traversing the microstrip are coupled to the slot line in FIG. 5 to thus travel on the conductive layer 31 of the balun out the flat two wire line of the conductors 41 and 42. In this embodiment the impedance variation from microstrip to flat two wire line increases. The majority of applications to which the present invention has been put calls for an increase in impedance from an asymmetrical system to a symmetrical system and thus the invention is so illustrated. It is, however, possible for the balun of the present invention to provide a decrease in impedance from an asymmetrical system to a symmetrical system by inverting the tapered portion of the balun. Transition from a waveguide to a two wire line would require such an impedance change.

Although the present invention has been described with respect to particular preferred embodiments thereof, it is not intended to limit the invention to the details of description or illustration.

What is claimed is:

1. A broadband balun comprising,
  - a dielectric substrate,
  - a conductive layer on a single side of said substrate separated by a slot into first and second conductors, said conductors each being tapered from a maximum width at the base end to a small width at an opposite end,
  - a coaxial cable disposed transversely across the base end of said first conductor with the cable sheath electrically contacting the first conductor and the central cable conductor extending across said slot into electrical contact with said second conductor, and
  - a second coaxial cable sheath mounted across the base of said second conductor in electrical contact therewith.
2. The balun of claim 1 further defined by the thickness of said substrate, the width of said slot and the width of said first and second conductors at the base thereof being dimensioned to establish an impedance substantially equal to the characteristic impedance of said coaxial cable, and the conductor width decreasing away from the base to a dimension establishing an impedance substantially equal to the impedance of a load to be connected across the conductors at the ends away from the base.
3. The balun of claim 1 further defined by said first and second conductors extending from said substrate at the opposite end of the conductors from said base as a two wire line.
4. A broadband balun comprising,
  - a solid dielectric substrate,
  - a conductive layer upon a first surface of said substrate and separated by a slot into first and second conductors, said conductors having maximum widths at a base end thereof with such widths being sufficient to establish said conductors as a slot line conductor and said conductors tapering inwardly toward the slot away from the base end to an opposite end whereby the impedance increases from the base end to the opposite end, and
  - a coaxial cable having a sheath about a central conductor, said sheath extending across the base of said first conductor in electrical contact therewith, and said central conductor extending from said sheath across said slot into electrical contact with said second conductor.
5. The balun of claim 4 further defined by a second coaxial cable sheath only extending across the base of said second conductor in electrical contact therewith.

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