April 14, 1964 J. T. COLEMAN 3,129,393

BALUN TRANSFORMER WITH VARIABLE TRANSFORMATION RATIO

Filed March 30, 1961 2 Sheets-Sheet 1

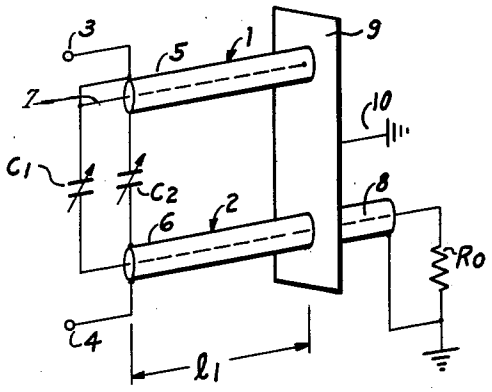


FIG 1

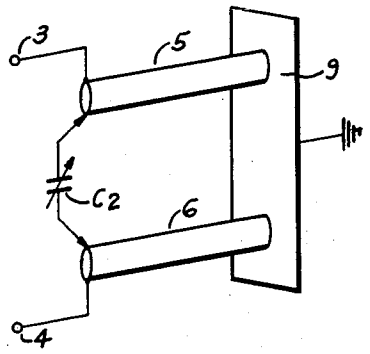


FIG 2

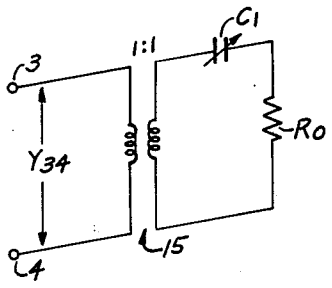


FIG 3

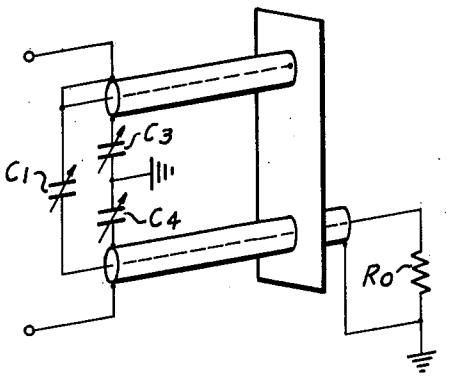


FIG 4

INVENTOR.
JAMES T. COLEMAN
BY Lawrence & Shrago.

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BALUN TRANSFORMER WITH VARIABLE TRANSFORMATION RATIO

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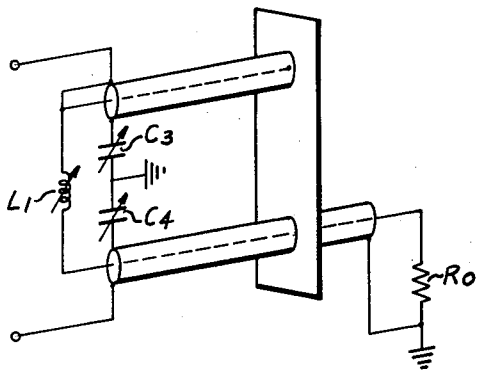


FIG 5

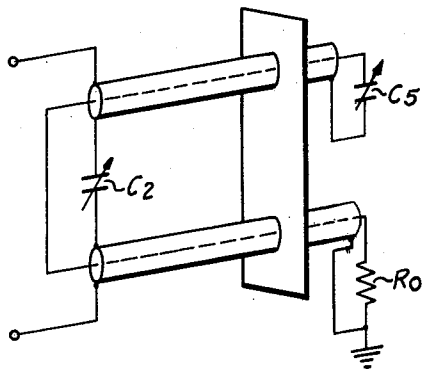


FIG 6

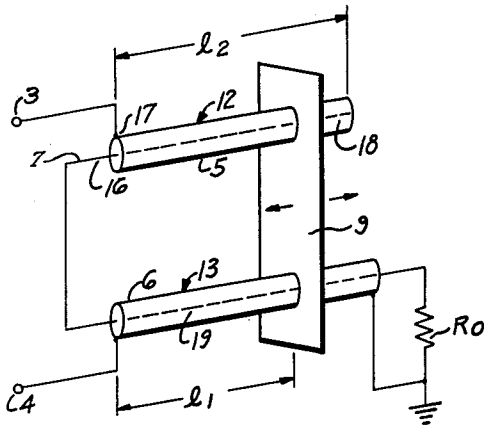


FIG 7

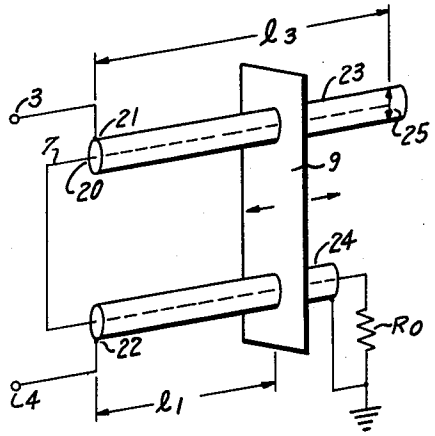


FIG 8

INVENTOR.
JAMES T. COLEMAN
BY Louis L Shrago

United States Patent Office 3,129,393 Patented Apr. 14, 1964

3,129,393
BALUN TRANSFORMER WITH VARIABLE TRANSFORMATION RATIO

James T. Coleman, Moorestown, N.J., assignor, by mesne assignments, to the United States of America as represented by the Secretary of the Navy

Filed Mar. 30, 1961, Ser. No. 99,646
11 Claims. (Cl. 333—26)

The present invention relates generally to apparatus for and methods of coupling radio frequency energy from a balanced to an unbalanced circuit, or vice versa, and more particularly to a balun transformer which possesses an impedance transformation capability.

In numerous radio frequency circuit configurations, it is necessary to couple a balanced radio frequency source which may, for example, comprise a transmitter embodying tubes arranged in a push-pull manner to an antenna via a relatively low impedance unbalanced line, such as a coaxial cable whose outer conductor is at ground potential. Such an energy transfer cannot be made directly because neither electrical connection of the balanced line is grounded and direct connection to the coaxial cable would immediately remove one side of the balanced line, shorting it to ground.

Devices for permitting the above radio frequency energy transfer are available in the prior art and have been variously called "chokes," "bazookas," "line balanced converters" and "baluns."

Besides the need for converting from a balanced or symmetrical condition to an unbalanced or asymmetrical condition, these circuits usually require an impedance matching operation to insure maximum efficiency of the over-all system. To perform these complementary functions, some of the conventional baluns have been designed to incorporate as an integral component thereof a mechanical tuning feature. However, relatively involved and critical adjustments must be made with these devices to cover only a limited frequency range. Also, some of the typical prior art arrangements for carrying out the impedance matching operation introduce an undesirable reactance component into the electrical system which destroys its unity power factor and prevents substantially perfect resistive transformations.

It is accordingly a primary object of the present invention to provide apparatus for coupling an unbalanced circuit to a balanced circuit, or vice versa, which also permits the impedances of both circuits to be matched for efficient energy transformation.

Another object of the present invention is to provide a balanced to unbalanced energy transformer circuit which has a variable transformation ratio for impedance matching purposes.

A still further object of the present invention is to provide a balun transformer having a variable transformation ratio.

A still further object of the present invention is to provide a variable transformation balun transformer whose physical dimensions are only a small fraction of the wave length of its operating frequency.

A still further object of the present invention is to provide a balun transformer whose transformation ratio can be continuously varied via electrical means.

A still further object of the present invention is to provide a balun transformer which can match both resistive and reactive loads to the signal generating source.

A still further object of the present invention is to provide a balun transformation circuit whose (Q) is low enough for achieving fairly wide bandwidth operation.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same

becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

FIG. 1 is a schematic circuit diagram of one embodiment of the present invention wherein changes in the transformation ratio are accomplished by a pair of variable capacitors;

FIG. 2 is a simplified drawing of part of the system of FIG. 1 showing only one loop of the balun transformer;

FIG. 3 is an equivalent circuit of FIG. 1 for facilitating an explanation of the operating behavior of the invention;

FIG. 4 illustrates an alternative embodiment of the present invention which is closely related to the system of FIG. 1;

FIG. 5 is an alternative construction wherein part of the tuning of the transformer is done by an inductive reactance;

FIG. 6 shows an arrangement which permits the electrical tuning adjustments to be made outside the high energy field area;

FIG. 7 is a schematic view of an alternative embodiment of the invention wherein mechanical means are employed to change the impedance transformation ratio; and

FIG. 8 shows a distributed parametric equivalent of FIG. 1 for ultrahigh frequency use.

Referring now to FIG. 1, a balun transformer arrangement constructed according to the present invention is seen to consist of a pair of parallelly disposed, electrically similar coaxial lines **1** and **2** of unequal lengths. In the particular case selected for illustration, a radio frequency signal derived from a source balanced with respect to ground is coupled to an unbalanced load. Accordingly, terminals **3** and **4**, which are directly connected to the left-hand ends of outer conductors **5** and **6** of these coaxial cables, serve as the input connections of the transformer. Terminal **3** is also connected to the left-hand end of inner conductor **7** of coaxial line **1**, and this line is terminated at its other end in a short circuit formed by part of the surface of conducting plate **9**. This plate, normally called a "shorting plate," is grounded at its midpoint **10** and establishes an electrical connection to the outer conductor of coaxial line **2**. Coaxial line **2** extends through and beyond this plate and the load, as represented by resistor R_0, is connected between the right-hand terminal end of inner conductor **8** and ground. The right-hand terminal end of outer conductor **6** is likewise grounded in accordance with the unbalanced mode of operation. It would be pointed out at this time that the electrical length of coaxial line **1**, as measured from its left-hand end to shorting plate **9**, is only a very small fraction of a quarter wave length of the operating radio frequency.

At the input side of the apparatus, a first variable capacitive reactance, provided by condenser C_1, is connected between the inner conductors **7** and **8**; while a second variable capacitive reactance, provided by condenser C_2, is connected between the confronting portion of the left-hand ends of the outer conductors **5** and **6**. It will be recognized, of course, that in the receiving mode of operation resistor R_0 would be replaced with an input circuit and the output taken across terminals **3**, **4**.

In order to understand the principles of operation of the above circuit, reference may now be had to FIG. 2, which shows only the input loop of the balun transformer as viewed from terminals **3** and **4**. Thus, with a balanced radio frequency source connected across these terminals, a current path may be traced from terminal **3** down the outer and inner conductors **5** and **7** of line **1** to and across shorting plate **9** and back to terminal **4** via the outer conductor only of coaxial line **2**, disregarding for the time being the effect of capacitor C_2. The impedance looking

into these terminals is that of a short-circuit transmission line because of the conducting path established by plate 9. This impedance, as is well known, is

$$Z_{34}=jZ_0 \tan \beta l_1 \quad (1)$$

with Z_0 the characteristic impedance of the two-conductor line formed by the outer conductors,

$$\beta=\frac{2\pi}{\lambda}$$

with λ the free space wave length of the radio frequency energy in meters and l the length of the line in meters, In the case of a lossless line, this impedance is thus seen to be a pure inductive reactance. When capacitor C_2 is taken into account, this impedance is paralleled with a variable capacitive reactance. The admittance across these terminals can be stated as

$$Y_{34}=\frac{1}{jZ_0 \tan \beta l_1}+j\omega C_2 \quad (2)$$

which can be rewritten as

$$Y_{34}=-j\frac{1}{Z_0 \tan \beta l_1}+j\frac{1}{X_{C_2}} \quad (3)$$

Considering once again the behavior of the system of FIG. 1, the radio frequency current path in the second loop may be traced from the ungrounded side of load resistor R_0 through the inner conductor 8 of line 2, variable capacitor C_1, the inner and outer conductors 7 and 5, respectively, of line 1 to shorting plate 9, and then across this plate down along the outer conductor 6 of line 2 to the left-end terminating edge thereof, and thence, via the inner surface of this same outer conductor back to the grounded side of the load resistor. Thus, the system behaves as a very tightly coupled one-to-one ratio transformer. It would be pointed out at this time that no load current flows between the shorting plate to the grounded side of the load resistor because of the potential equality existing between these points brought about by the balanced configuration.

The balun transformer of FIG. 1 may be represented by the equivalent circuit of FIG. 3. The admittance Y_{34} appears across the primary winding of an ideal transformer 15 and the series combination of capacitor C_1 and the load resistance R_0 appears across the secondary winding. In the following mathematical presentation, the coaxial line 2 will be considered as being terminated in its characteristic impedance R_0 and the electrical length of the short-circuited transmission line l_1 as being only a small fraction of $\lambda/4$.

The impedance of the series combination of C_1 and R_0 is

$$Z=R_0-jX_{C_1} \quad (4)$$

which can be rewritten in polar form as

$$Z=\sqrt{R_0^2+X_{C_1}^2}\,\underline{|-\theta} \quad (5)$$

The admittance of this combination is the reciprocal of the above impedance, that is,

$$Y=\frac{1}{Z}$$

and substituting for Z in this last relationship we obtain

$$Y=\frac{1}{\sqrt{R_0^2+X_{C_1}^2}}\,\underline{|\theta} \quad (6)$$

which can be expressed as

$$\frac{\cos\theta}{\sqrt{R_0^2+X_{C_1}^2}}+j\frac{\sin\theta}{\sqrt{R_0^2+X_{C_1}^2}} \quad (7)$$

but

$$\text{Cos}\ \theta=\frac{R_0}{\sqrt{R_0^2+X_{C_1}^2}} \quad (8)$$

and

$$\text{Sin}\ \theta=\frac{X_{C_1}}{\sqrt{R_0^2+X_{C_1}^2}} \quad (9)$$

and substituting these last two relationships in Equation 7 we obtain (10).

$$Y=\frac{R_0}{R_0^2+X_{C_1}^2}+j\frac{X_{C_1}}{R_0^2+X_{C_1}^2} \quad (10)$$

The ideal transformer places the admittance Y in parallel with the admittance Y_{34} when the circuit is viewed from the balanced terminals 3, 4 and, consequently, these admittances can be combined as

(11)

$$Y+Y_{34}=\frac{R_0}{R_0^2+X_{C_1}^2}+j\frac{X_{C_1}}{R_0^2+X_{C_1}^2}-j\frac{1}{Z_0 \tan \beta l}+j\frac{1}{X_{C_2}}$$

Now, if the sum of the last three terms in Equation 11 is set to equal zero by tuning the two variable capacitors, then only the real part of the admittance, that is, the conductance G, appears across terminals 3, 4 in the form of

$$G=\frac{R_0}{R_0^2+X_{C_1}^2} \quad (12)$$

and the load resistor R_0 is now transformed into

$$R'_{\text{Load}}=\frac{R_0^2+X_{C_1}^2}{R_0} \quad (13)$$

$R'_{\text{Load}} \geqq R_0$ which is, of course, equal to or greater than R_0.

From a study of the above mathematical analysis, it will be undertsood that a pure resistive load can be made to appear across the balanced terminals, that the magnitude of this resistance can be widely varied by selecting different values of C_1 and that throughout these changes a unity power factor can be maintained by similar adjustments to C_2. By the same token, a low input impedance circuit connected to the unbalanced side of the balun transformer can have its magnitude continually increased and made to appear in balanced form at the other side of the apparatus.

A slight variation in the circuit of FIG. 1 is shown in FIG. 4. Here, the variable capacitive reactance connected across the outer conductors 5 and 6 takes the form of a series combination of two variable condensers C_3 and C_4. Each of these components, of course, has half the reactance of C_2 or twice the capacitance because of their series relationship and the midpoint of the series combination is grounded. This configuration gives a better circuit balance than that realized with the arrangement of FIG. 1.

Another variation of the original circuit is schematically depicted in FIG. 5 and, in this particular modification, the variable capacitive reactance C_1 is replaced with a variable inductive reactance L_1. The series combination of capacitors C_3 and C_4 is still maintained; however, they are made large enough to make Y_{34} capacitive for this case.

In FIG. 6 there is schematically illustrated a modification similar to that of FIG. 1 wherein the coaxial line 1 does not terminate in a short circuit but extends through plate 9 and is terminated in a variable capacitive reactance, C_5. In order to avoid the necessity of any mechanical tuning, variable capacitive reactance C_2 is again connected across the outer conductors of the coaxial lines at the balanced ends thereof. Hence, in this configuration, too, all the tuning is done by electrical means, namely, condensers C_2 and C_5. The purpose of placing the C_5 at the extremity of coaxial line 1 is to permit the tuning to be made outside of the high radio frequency field area.

In FIG. 7 there is illustrated a balun transformer circuit wherein the tuning is accomplished by moving shorting bar 9 to different positions along the outer conductors 5

and 6 of coaxial lines 12 and 13. In this particular configuration, the mechanical tuning feature eliminates the need of variable condenser C_2 which otherwise would be required across outer conductors 5 and 6. Likewise, the variable capacitive reactance provided by condenser C_1 is here represented by a transmission line equivalent in the form of the open-circuited coaxial line 12 of length l_2. In regards to this last substitution, it is well known that such an open-circuited transmission line presents a capacitive reactance if it is less than a quarter wave length long at the operating frequency. It is this characteristic which provides the system with the capacitive reactance previously supplied by condenser C_1 in the second loop of the transformer as depicted in FIG. 3. It would be observed that with l_2 less than a quarter wave length a capacitive reactance appears between terminals 16 and 17 of the apparatus and that the $-jX_{C_1}$ term of expression (4) is now $-jZ_{o1} \cot \beta l_2$ where Z_{o1} is the characteristic impedance of coaxial line 12. The admittance across terminals 3, 4 can now be rewritten as

$$Y_{34}=\frac{1}{jZ_{o2} \tan \beta l_1} \tag{14}$$

where Z_{o2} is now the characteristic impedance of coaxial lines 12 and 13 between outer conductors. The matching performance of the transformer now becomes

$$R'_{Load}=\frac{R_o^2+(Z_{o1} \cot \beta l_2)^2}{R_o} \tag{15}$$

and for unity power factor

$$\frac{Z_{o1} \cot \beta l_2}{R_o^2+(Z_{o1} \cot \beta l_2)^2}=\frac{1}{Z_{o2} \tan \beta l_1} \tag{16}$$

It will be appreciated that for proper operation of the balun transformer l_1 and l_2 are adjusted to satisfy Equations 15 and 16.

In designing the apparatus of FIG. 7, the values of R'_{Load} and R_o would be known and Z_{o1} selected so as to give convenient values of l_2 over the operating frequency range. Also, Z_{o2} would be selected for convenient values of l_1 over this same frequency range; hence, the precise relationship of l_1 and l_2 would be defined. The above expressions from a physical viewpoint are good to the case where l_1 is about equal to the space in between centers of coaxial lines 12 and 13. This relationship will give the shortest dimension for l_1. It would be noted that with the apparatus of FIG. 1 l_1 can be much smaller than the aforementioned length, attaining values of about $\lambda/30$. The reason for this being that condenser C_2 makes coaxial lines 1 and 2 of FIG. 1 appear electrically longer.

FIG. 8 shows a balun transformer designed for ultra-high frequency operation employing only transmission line components. This apparatus is a distributed parametric equivalent of the transformer of FIG. 1 and, like the arrangement of FIG. 7, it employs a movable shorting plate 9 to tune the transformer. The required inductive reactance across terminals 21 and 22, the left-hand ends of the outer conductors of coaxial lines 23 and 24, is achieved by shorting bar 9 which maintains the length l_1 at a value less than $\lambda/4$, as is well known. Likewise, the electrical length of coaxial line 23, as determined by the axial position of internal shorting bar 25 and as represented by dimension l_3, is kept between $\lambda/4$ and $\lambda/2$ in order to present capacitive reactance between terminals 20 and 21. The last requirement, of course, comes about from the well-known fact that a shorted transmission line between $\lambda/4$ and $\lambda/2$ acts as a pure capacitive reactance. One of the noteworthy advantages of the arrangement of FIG. 8 is that the variable matching property can be used at very high frequencies, such as 600 mc./s. where $\lambda/4$ is 4.92 inches. Another characteristic which recommends the configuration of FIG. 8 is found in the fact that the short-circuited termination employed with coaxial line 23 is much easier to construct than the open-circuited termination of coaxial line 12 in FIG. 7.

At this point, it would be mentioned that the apparatus of FIGS. 1, 4, 5 and 6 may be preferred over the other structures because of the availability of vacuum variable capacitors whose parameters can be varied over considerably wide ranges. For example, units made by the Jennings Radio, of Palo Alto, California, have a capacitance range from 25 to 450 mfd. By resorting to such lumped variable electrical components, the physical size of the balun can be greatly reduced, reaching dimensions which are as short as $\lambda/30$. And l_1, for example, in the arrangement of FIG. 1 can be made at least as small as the separation between coaxial lines 5 and 6 as measured between line centers.

If desired, the inner conductor 7 of coaxial line 1 in FIGS. 1, 4 and 5 can be eliminated without altering the performance of the balun transformer. Capacitor C_1 would then be connected between the left-hand end of inner conductor 8 of coaxial line 2 and the outer conductor 5 of coaxial line 1.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. A balun transformer comprising, in combination, a pair of coaxial lines of unequal length, a conducting plate connecting the outer conductors of said coaxial line together at a given distance from one end of each coaxial line, said conducting plate being grounded and short-circuiting the inner and outer conductors of the shorter coaxial line at the other end thereof, means connecting the inner and outer conductors of the shorter coaxial line together at said one end thereof, first and second variable capacitors, said first capacitor being connected between the inner conductors of said coaxial lines at said one end thereof, said second capacitor being connected between the outer conductors of said coaxial lines at said one end thereof, means for coupling a radio frequency signal across the outer conductors of said coaxial lines at said one end thereof, the output of said transformer being taken across the inner and outer conductors of the longer coaxial line at the other end thereof.

2. A balun transformer having a variable transformation ratio comprising, in combination, first and second coaxial lines, a first variable capacitor connected across the inner conductors of said coaxial lines at one end thereof, a second variable capacitor connected across the outer conductors of said coaxial lines at said one end thereof, means for connecting the inner and outer conductors of the first coaxial line together at said one end thereof, means for coupling a radio frequency signal across said second variable capacitor, a conducting plate connected between the outer conductors of said coaxial lines at a distance l_1 from said one end thereof, said distance l_1 being less than one quarter of the wave length of said radio frequency signal, said conducting plate being grounded and short-circuiting the inner and outer conductors of said first coaxial line at the other end thereof, means for grounding the outer conductor of the second coaxial line at the other end thereof, and means for taking an output signal between the inner and outer conductors of said second coaxial line at the other end thereof.

3. A balun transformer comprising, in combination, a pair of metallic tubular members of unequal length, the longer member of said pair having a concentric conductor disposed therein, a first variable capacitor connected between one end of the shorter tubular member and one end of said conductor, a second variable capacitor connected between said one end of the shorter tubular conductor and that end of the longer tubular conductor which is adjacent said one end of said conductor, a con-

ducting plate joining said first and second tubular members together, said plate and said tubular members forming a short-circuited transmission line, means for feeding a radio frequency signal between said one end of said shorter tubular member and that end of said larger tubular conductor which is adjacent said one end of said conductor, means for grounding said conducting plate, means for taking an output signal from across the other end of said concentric conductor and the other end of said shorter tubular member.

4. A balun transformer comprising, in combination, first and second coaxial lines, means for connecting the inner conductors of said coaxial lines together at first ends thereof, means for coupling a radio frequency signal across the outer conductors of said coaxial lines at said first ends, a conducting plate connecting the outer conductors of said coaxial lines together, said plate being movable along said outer conductors whereby said plate and said outer conductors form a short-circuited transmission line of length l_1, means for grounding the outer conductor of the first coaxial line at the second end thereof, a load connected between the inner and outer conductors of said first coaxial line at the second end thereof, said second coaxial line terminating in an open circuit at the second end thereof and having a length which is less than a quarter wave length of said radio frequency.

5. A balun transformer comprising, in combination, first and second coaxial lines of unequal length, a first variable capacitor connected between a first end of the outer conductor of the shorter coaxial line and a first end of the outer conductor of the longer coaxial line, means for connecting the inner conductors of said coaxial line together at said first ends, means for coupling a radio frequency signal across the outer conductors of said coaxial lines at said first ends thereof, a conducting plate connecting the outer conductors of said coaxial lines together at a distance l_1 from said first ends thereof, said distance l_1 being less than a quarter wave length of the radio frequency energy connected across the outer conductors at said first ends thereof, a second variable capacitor connected between the inner and outer conductors of the shorter coaxial line at the second end thereof, and a load connected between the inner and outer conductors of the longer coaxial line at the second end thereof, and means for grounding the outer conductor of the longer coaxial line at said second end thereof.

6. A balun transformer comprising, in combination, first and second coaxial lines of unequal length, means for coupling a radio frequency signal across corresponding first ends of the outer conductors of said coaxial lines, means for connecting the inner conductors of said coaxial lines together at said first ends, a conducting plate connecting the outer conductors of said coaxial lines together, said conducting plate being movable along said outer conductors thereof to form in combination with said outer conductors a short-circuited transmission line of variable length, means for short-circuiting the inner and outer conductors of the longer coaxial line at variable distances from the second end of said coaxial line, a load connected between the inner and outer conductors of said shorter coaxial line at the second end thereof, the length of the short-circuited transmission line being less than one quarter wave length of said radio frequency energy and the distance from the first end of the longer coaxial line and the location of the short circuit being between one quarter and a half wave length of said radio frequency energy.

7. A balun transformer comprising, in combination, first and second coaxial lines, means for connecting the inner conductors of said coaxial lines together at one end thereof, means for coupling a radio frequency signal across the outer conductors of said coaxial lines at said one end thereof, a conducting plate connecting the outer conductors of said coaxial lines together, said plate being movable along said outer conductors whereby said outer conductors and said plate form a short-circuited transmission line of length l_1, said length l_1 being less than a quarter wave length of said radio frequency signal, means for grounding the outer conductor of the first coaxial line at the other end thereof, a load connected between the inner and outer conductors of said first coaxial line at the other end thereof, said second coaxial line being open at its other end and having a length l_2 which is less than a quarter wave length of said radio frequency signal.

8. A balun transformer having a variable transformation ratio comprising, in combination, a first and second hollow conductor, a concentric conductor disposed within said first hollow conductor, a first variable capacitor, said first variable capacitor being connected between a first end of said concentric conductor and a first end of said second hollow conductor, means for coupling a radio frequency signal between a first end of said first hollow conductor and said first end of said second hollow conductor, said first end of said concentric conductor and said first end of said first hollow conductor being coadjacent, second and third variable capacitors, said second capacitor being connected between said first end of said first hollow conductor and ground potential, said third variable capacitor being connected between said first end of said second hollow conductor and ground potential, a conducting plate bridging said first and second hollow conductors at a distance l_1 from the first ends of said hollow conductors, said distance l_1 being less than a quarter wave length of the frequency of said radio frequency signal, means for connecting the second end of said first hollow conductor to ground potential and a load connected between the second end of said concentric conductor and ground potential.

9. A balun transformer having a variable transformation ratio comprising, in combination, a first and second hollow conductor, a concentric conductor disposed within said first hollow conductor, a variable inductance, said variable inductance being connected between a first end of said concentric conductor and a first end of said second hollow conductor, means for coupling a radio frequency signal between a first end of said first hollow conductor and said first end of said second hollow conductor, said first end of said concentric conductor and said first end of said first hollow conductor being coadjacent, first and second variable capacitors, said first capacitor being connected between said first end of said first hollow conductor and ground potential, said second variable capacitor being connected between said first end of said second hollow conductor and ground potential, a conducting plate bridging said first and second hollow conductors at a distance l_1 from the first ends of said hollow conductors, said distance l_1 being less than a quarter wave length of the frequency of said radio frequency signal, means for connecting the second end of said first hollow conductor to ground potential and a load connected between the second end of said concentric conductor and ground potential.

10. A balun transformer comprising, in combination, first and second tubular members of unequal length, said first tubular member being shorter than said second tubular member, concentric conductors disposed within said first and second tubular members, means interconnecting a first end of said first tubular member and a first end of the concentric conductor disposed therein, a variable capacitor connected between a first end of said second tubular member and said first end of said first tubular member, a second variable capacitor connected between said first end of said first tubular member and a first end of the concentric conductor disposed within said second tubular member, means for coupling a radio frequency signal across said first end of said first tubular member and said first end of said second tubular member, a conducting plate connecting said first and second tubular members together at a distacne l_1 from said first ends of

said tubular members, the second end of the concentric conductor disposed within said first tubular member connected to said conducting plate, said conducting plate being grounded at its midpoint and closing the second end of said first tubular member, means for grounding the second end of said second tubular member, and means for connecting a load between said second end of said second tubular member and the second end of the concentric conductor disposed therein.

11. An arrangement as defined in claim 10 wherein the distance l_1 is less than a quarter wave length of the radio frequency energy connected across the first ends of said tubular members.

No references cited.