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A BALUN APPARATUS AND METHOD OF DESIGNING SAME

Field of the Invention

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Generally, this invention relates to baluns, and, more specifically, to a balun apparatus and a method of designing same.

Background of the Invention

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Typically in radio frequency (RF) communications systems, it is advantageous to use a balanced antenna. A balanced antenna reduces the RF current on the housing and other parts of the radio equipment, and the antenna is less susceptible to being detuned or being blocked by the operator. When connecting a balanced antenna with an unbalanced RF circuit the interface between the antenna and the unbalanced circuit requires a device called a balun.

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In circuit technology, an unbalanced system is defined as one in which two conductors are at different potentials with respect to ground. One of the conductors is often at the ground potential. The capacitance with respect to ground of each of the two conductors is then different, consequently, the current in the two conductors may be different. A balanced system is one in which the potential of each of the two conductors are respectively above and below ground potential by the same magnitude. FIG. 2 is an illustration of a simplified model of how currents are defined by a balanced and an unbalanced mode. In a RF transmit communication system, the source is the transmitter and the load is the antenna. Any configuration of currents I_a and I_b can be expressed as a combination of common mode and differential mode currents. Both the common mode and differential mode currents are determined by currents generated by either a balanced or an unbalanced source. The common mode current, shown as I_{Ca} and I_{Cb} in FIG. 2, have

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equal magnitude and equal phase. Consequently, the common mode currents contribute nothing to the intended operation of the load, or antenna, and are usually dissipated in heat. The differential mode currents, I_{Da} and I_{Db} , are equal in magnitude and opposite in phase, consequently, they
5 manifest the power into the intended load. The source and the load losses of the common and the difference or differential modes can be represented as a circuit, as shown in FIG. 3. For balanced loads such as balanced antennas, the intended or desirable mode is the differential mode, and the unintended or undesired mode is the common mode. By maximizing the
10 impedance of the common mode load, the currents and the loss associated with the common mode currents will be minimized.

A balun permits connection between a balanced system and an unbalanced system in such a way that the potentials to ground, and the currents in the two parts of the balanced structure are equal in magnitude
15 and opposite in phase. In the past, balun transformers and transmission lines or bazooka baluns have been used to perform the balun function for an antenna feeder in a communication device used in a RF communication system. A balun transformer effectively performs the balun function, however, for use in such devices as portable radiotelephones, a balun
20 transformer is large and absorbs power. Typically about 0.7 dB of power is lost through a balun transformer, thus, significantly reducing the amplitude of signal transmitted between the transceiver and an antenna. Second, a bazooka balun, or transmission line, requires more than two conductors, or two conductors and a sleeve about those two conductors to
25 perform the balun function. This bazooka balun requires very large physical space for a sleeve within a communication device.

Often, communication devices, such as a portable radiotelephone, are required to be physically small and less power-consuming than other non-portable or stationary communication devices. Thus, it is desirable in a
30 portable radiotelephone to have an efficient transfer of power between the transceiver and the antenna, and to have a small physical size. Thus, it

would be desirable to have an efficient and small balun device for transferring signals between a balanced antenna and unbalanced circuitry within a transceiver in a communication device.

Brief Description of the Drawings

5 FIG. 1 is an illustration in block diagram form of an electrical circuit in the prior art.

 FIG. 2 is an illustration of a theoretical source and load, and their related currents.

 FIG. 3 is an illustration of a theoretical source and loads having a common mode load and a differential mode load.

10 FIG. 4 is an illustration in block diagram form of a circuit in accordance with the present invention.

 FIG. 5 is an illustration in block diagram form of a radio communication system in accordance with the present invention.

15 FIG. 6 is an illustration in graph form of the periodic cycles of common mode current for a differential load.

 FIG. 7 is an illustration in graph form of the periodic cycles of common mode currents for a dipole antenna.

 FIG. 8 is an illustration of a Smith chart describing common mode impedances and currents.

20 FIG. 9 is a flow chart illustrating a method of designing a balun device in accordance with the present invention.

Description of a Preferred Embodiment

5 A preferred embodiment of the present invention encompasses an RF communication device, specifically, a radiotelephone having diversity antennas, such as model number TH541, available from Motorola, Inc. In this particular radiotelephone, the physical size constraints are severe, particularly concerning the space available between a transceiver and an antenna; the radio receiver being an unbalanced load circuit and the antenna being a balanced source circuit. Since the electrical connection between the receiver and the antenna is an unbalanced-to-balanced connection a balun is required. A traditional balun, as discussed in the prior art, would be impractical because of the physical constraints. Thus, the balun function is performed by using a transmission line of minimum transverse dimensions and a predetermined length between the receiver and the antenna.

10 FIG. 4 is an illustration in block diagram form of a circuit in accordance with the present invention. The circuit 400 contains an unbalanced circuit 401, a transmission line of length "L" 403, and a balanced circuit 405. Here the unbalanced circuit 401 is coupled to the balanced circuit 405 through a transmission line 403 having a length "L" which is determined as part of the present invention is an implementation of the present invention in a portable radiotelephone.

20 FIG. 5 is an illustration in block diagram form of a radio communication system which may employ the present invention. In the system, a remote transceiver 513 sends and receives radio frequency (RF) signals to and from mobile and portable radiotelephones contained within a fixed geographic area served by the fixed site transceiver 513. The radiotelephone 500 is one such radiotelephone served by the fixed site transceiver 513.

30 While receiving signals from the fixed site transceiver 513, the radiotelephone 500 uses a main antenna 511 and a diversity antenna 515 to

couple the RF signal and convert the RF signal into an electrical RF signal. The electrical RF signal is received by the radio receiver 503, for use within the radiotelephone 500. The receiver 503 outputs a symbol signal for use by the controller 505. The controller 505 formats the symbol signal into
5 voice or data for the user interface 507. The user interface 507 typically contains a microphone, a speaker and a keypad.

Upon the transmission of RF signals from the radiotelephone 500 to the remote transceiver 513, the controller 505 formats the voice and/or data signals from the user interface 507. The formatted signals are input into the
10 transmitter 501. The transmitter 501 converts the data into electrical RF signals. The electrical RF signals are converted into RF signals and output by antenna 511. The RF signals are received by the remote transceiver 513.

As discussed earlier, the receiver 503 is an unbalanced load circuit and the diversity antenna 515 is considered a balanced source circuit for the
15 purpose of the present invention. The transmission line 517 of length "L" is designed such that the common mode impedance is very high, and that the differential impedance is equal to that of the receiver and antenna circuits 503, 515. The requirements for a highly efficient antenna are to maximize the impedance of the common mode, and to match the impedance of the
20 differential mode to the source and load. There are two basic parameters that affect the common mode impedance while maintaining the differential mode impedance as a match to the source; namely, the lateral size and the length of the transmission line. The lateral size or transverse dimensions of the transmission line (width and thickness) should be reduced to a minimum
25 size, making the effective common mode inductance and impedance of the transmission line as high as possible. If the lateral dimensions are scaled properly, then the differential mode impedance can be maintained for any set of dimensions. The limit of this approach is that the dimensions become unmanufacturable, and the electrical loss in the differential mode becomes
30 unacceptable.

A second method of increasing the common mode impedance while maintaining the differential mode impedance is to select a length of transmission line to be an integral number of half wavelengths from an open end. Referring now to FIG. 6, the common mode current, illustrated as wave 601 goes through periodic cycles along its length. There are common mode current minima at end point 603, point B 605, and point D 607. Likewise, there are common mode current maxima at point A 609, point C 611, and point E 613. A similar pattern of common mode currents appears when the transmission line, such as transmission line 517, is terminated in a dipole antenna, such as the diversity antenna 515 of FIG. 5. Referring to FIG. 7, the common mode current for a transmission line terminated in a dipole antenna is shown. Again, minima occur at point B 701, and point D 703. Likewise, maxima points occur at point A 705, point C 707, and point E 709. When a dipole antenna is added to the transmission line, the common current pattern, as illustrated in FIG. 7, shifts such that the first current minimum is at a point one quarter wavelength from the antenna feed point; determining the location of the other current minima. This effect can also be seen if the effective common mode impedance is plotted as a function of length from the end of the transmission line, as illustrated in FIG. 8. FIG. 8 shows the points A, C and E as shorts or very low impedance points directly across from the high impedance points, B, and D. The Smith chart of FIG. 8 appears as a spiral that circumvents the chart several times. If a transmission line 517 is chosen to have a length ending at points B or D, then the common mode impedance would be very high and the power going into the common mode will be small, as desired in the case of the preferred embodiment.

The frequency of operation and the phase velocity determine the wavelength on the transmission line. The wavelength is equal to the phase velocity divided by frequency. For air, the phase velocity is equal to the speed of light. For other media, the phase velocity is equal to the speed of light divided by the square root often designated as $\text{Sqrt}()$, of the effective

dielectric constant of the media, often designated as ϵ_r . For the common mode case the phase velocity is near that of free space, for the differential mode case the media is the flexible printed circuit material with a dielectric constant of 3.4. This will reduce the phase velocity to $1/\text{Sqrt}(\epsilon_r)$ or 0.55 times that of light in free space. These phase velocities are indeed quite different for the two cases. For the difference mode, the desire is to reduce reflections on the transmission line, such that the impedance is essentially independent of the length of the transmission line. However, for the common mode, the impedance is intentionally made to be very dependent upon the length and then the length is selected for the maximum impedance.

In order for these phenomena to be used to realize a balun function on a transmission line, the transmission line must be designed for each particular application using the design flow chart illustrated in FIG. 9. First, at function block 903, one designs an unbalanced circuit and a balanced circuit without any considerations of the connections therebetween. In the preferred embodiment, the balanced circuit is a dipole antenna used as the diversity antenna 515, as illustrated in FIG. 5. When designing a dipole antenna, it may be designed without a feedline for its desired frequency band. In the preferred embodiment, the desired frequency band for the antenna is 810-830 MHz (Megahertz). Second, at function block 905, one provides an unbalanced circuit. In the preferred embodiment, the receiver 503 of FIG. 5 is considered the unbalanced circuit. Third, at function block 907, one chooses a balanced transmission line for coupling between the balanced circuit and the unbalanced circuit. The transmission line should have a differential mode impedance equal to that of the source and a very high common mode inductance. The differential mode impedance often designated as Z_o , generally is defined using the equation

$$Z_o = 377 * \text{thickness} / (\text{width} * \text{Sqrt}(\epsilon_r))$$

If the source impedance, Z_s , and the load impedance are equal, then the differential impedance is made equal to them.

For unequal source and load impedances, the transmission line will be more complex, such is the case in our preferred embodiment.

5 The length L to traverse the distance between the antenna and receiver has a differential mode phase length greater than the length needed to implement an impedance transformer, designated as L_t . This length is one quarter wavelength and is often designated as $(\lambda/4)$. Therefore we have designed an inline (series) pair of transmission lines that perform the two
10 functions required, namely:

- 1) rejection of the common mode load, and
- 2) transformation of the antenna source impedance, Z_s , to match the receiver load impedance, Z_l .

Before coupling the transmission line to the load circuit, choose the
15 proper length " L_r " of the transmission line 517 that gives a common impedance much greater than the source impedance. In the preferred embodiment, the length, L , needed to reject the common mode, designated as L_r , is greater than the length needed for transformation, designated as L_t . Consequently, an additional length or excess length,
20 designated as L_e is required. This can be expressed in the equation below:
 $L_t + L_e = L_r$.

The excess length would have the characteristic impedance of either the source or the load. Therefore, the excess length is chosen to have a characteristic impedance of the higher impedance of Z_s or Z_l .

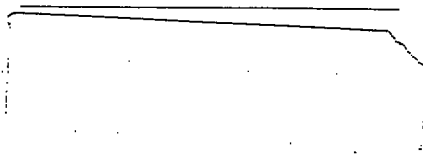
25 The transformer section of the transmission line has a length L_t which is defined by the frequency of interest and having a phase length of one quarter of a wavelength which may also be expressed as 90° which is $\lambda/4$. This phase length can be found using the earlier text provided. In the preferred embodiment the impedance of the load, Z_l , is equal to 50Ω and
30 the dipole antenna has an impedance of 12Ω . Thus, a transmission line was chosen having a differential mode impedance for L_e , of 50Ω and a

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transformer, L_t , section of 25Ω . This transformer matches the antenna source impedance, Z_s , of 12Ω to the receiver load impedance, Z_l , of 50Ω .

5 By choosing the proper length " L_r " of the transmission line, a balun function is realized. Although the transmission line is now limited to a predetermined length " L_r ", additional circuitry or components such as transistors, or additional transmission lines or coaxial cable are no longer necessary, thus reducing the physical size constraints required for realizing a balun function.

10 What is claimed is:



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5 1. A balun apparatus coupled between a balanced circuit and an unbalanced circuit, the balanced and unbalanced circuits transmitting and receiving in a common mode and a differential mode, the balun apparatus comprising:

a first conductor having a first length; and

10 a second conductor having a second length equal to the first length and the second conductor parallel to the first conductor, the second conductor separated from the first conductor by a first distance, the first conductor and the second conductor used to form a first transmission line having a first impedance for the differential mode transmissions, the first conductor and the second conductor used to form a second impedance for the common mode transmissions.

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2. A balun apparatus of claim 1 using planar metal strips for the first conductor and for the second conductor.

5 3. A balun apparatus of claim 2 using flexible plastic material to provide the separation of the first conductor from the second conductor.

10 4. A balun apparatus of claim 1 wherein the first and the second conductor further comprise an impedance transformer having an arbitrary ratio, the impedance transformer is realized with the use of quarter-wavelength transformers.

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5. A radio communication device comprising:

a balanced antenna having a first common mode impedance and a first differential mode impedance;

5 an unbalanced radio receiver having a differential load impedance; and

a transmission line coupled between a terminal of the balanced antenna and a terminal of the unbalanced radio receiver, the transmission line having a first conductor, a second conductor each conductor having a predetermined length and separated by a first distance from each other,

10 additionally, the transmission line having a second common mode impedance and a second differential mode impedance, the first common mode impedance and the second common mode impedance forming a common mode input impedance and the first differential impedance and the second differential mode impedance forming a differential mode input

15 impedance, the common mode input impedance being substantially larger than the source impedance, the differential input impedance is substantially matched to the source impedance.

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6. The radio communication device of claim 5 using a planar metal strip for the first conductor and for the second conductor.
- 5 7. The radio communication device of claim 6 using flexible plastic material to provide the first distance between the first conductor and the second conductor.
- 10 8. The radio communication device of claim 5 wherein the first conductor and the second conductor further comprise an impedance transformer having an arbitrary ratio.
9. The radio communication device of claim 8 wherein the impedance transformer is realized with the use of quarter-wavelength transformers.

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10. A method of designing an antenna system comprising the steps of:
providing an antenna having a first common mode impedance and a
first differential mode impedance;
5 providing an unbalanced circuit having a first source impedance; and
choosing a balanced transmission line for coupling between the antenna
and the unbalanced circuit, the balanced transmission line having a first
length, a second common mode impedance and a second differential mode
impedance, such that together the first and the second common mode
10 impedance is substantially larger than the source impedance and together the
first and the second differential impedance are substantially matched to the
source impedance.

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