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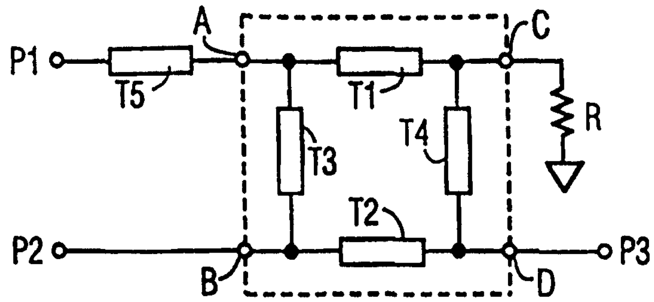
(54) Title: COMPACT LOW-LOSS MICROWAVE BALUN

(57) Abstract

A microwave balun is constructed by combining a four-transmission-line branch-line coupler with a single-transmission-line delay element. This construction results in a simplified, compact arrangement for combining first and second signals applied to respective first and second ports, phase shifted by 180°, and providing the combined signal at a third port. The balun is a reciprocal device and may be operated in reverse with a signal applied to the third port to obtain outputs at the first and second ports.



Compact low-loss microwave balun

The invention relates to a microwave transformer device and, in particular, to a balanced-to-unbalanced transformer device. This type of device is commonly referred to as a balun.

A balun is often used when it is desired to couple a balanced system or device to an unbalanced system or device. A typical example is the coupling of a two-line (balanced) circuit, such as a cellular telephone circuit, to a single-line (unbalanced) circuit, such as an antenna circuit. Another example is as a signal splitter/phase shifter for use with a balanced mixer.

In some uses, such as in portable cellular telephones, it is important that a balun meet three criteria. It must be compact, have a minimum insertion loss, and have a narrow passband to minimize power wastage. Although prior art baluns are known which accomplish one or two of these objectives, none are known which satisfactorily accomplish all three.

It is an object of the invention to provide a balun which accomplishes all three of the above-mentioned objectives.

In accordance with the invention, a balun is constructed by combining a branch-line coupler with a delay element that is coupled to a first input of the balun. The branch-line coupler includes: first and second inputs; first and second outputs; a first delay element having a characteristic impedance of $Z_0/\sqrt{2}$ and coupling the first input to the first output through a phase shift of 90°; a second delay element having a characteristic impedance of $Z_0/\sqrt{2}$ and coupling the second input to the second output through a phase shift of 90°; a third delay element having a characteristic impedance of Z_0 and coupling the first and second inputs through a phase shift of 90°; and a fourth delay element having a characteristic impedance of Z_0 and coupling the first and second outputs through a phase shift of 90°. The delay element coupled to the first input of the balun comprises a fifth delay element having a characteristic impedance of Z_0 and coupling the first input of the branch-line coupler to the first input of the balun through a phase shift of 90°. An impedance means having a characteristic impedance of Z_0 terminates the first output, the second input of the branch-line coupler comprises a second input of the balun, and the second output of the branch-line coupler comprises an output of the balun.

In a preferred embodiment of the invention, the balun is formed in microstrip or stripline, to simplify construction. In order to conserve space, especially for baluns operating at frequencies corresponding to wavelengths of significant size with respect to the balun itself, each of the transmission line means comprises a meandering conductive pattern formed on a dielectric substrate, and the transmission line means are disposed in close proximity to each other. To ensure that the coupling between adjacent portions of the conductive patterns uniformly affects the phase shifts of each of these patterns, the patterns are arranged such that there is at least one linear transmission line segment disposed between each meander pattern and each adjacent meander pattern, and such that the meander patterns of the first, second, third and fourth transmission line means are arranged symmetrically with respect to each other.

Fig. 1 is a schematic illustration of a balun in accordance with the invention.

Fig. 2 is a top view (not to scale) of a preferred embodiment of the balun which is illustrated schematically in Figure 1.

Fig. 3 is a graph illustrating phase shift characteristics of the balun of Fig. 2.

Fig. 4 is a graph illustrating insertion loss characteristics of the balun of Fig. 2.

Fig. 5 is a graph illustrating passband characteristics of the balun of Fig. 2.

The balun illustrated schematically in Figure 1 comprises a branch-line coupler, including four interconnected transmission lines T1 - T4, a fifth transmission line T5, and a resistive termination impedance R. The branch-line coupler, which is shown enclosed within a dashed-line box, is a symmetrical device having two pairs of ports A,B and C,D. Either pair of ports may serve as inputs, while the other pair serves as outputs.

In the illustrated embodiment, ports A and B serve as inputs, while ports C and D serve as outputs. Input A is coupled to output C through transmission line T1, which has a characteristic impedance of $Z_0/\sqrt{2}$ and an electrical length of $\lambda_0/4$ to provide a phase shift of 90°. The symbol λ_0 represents that wavelength corresponding to an operating frequency band having a center frequency f_0. Input B is coupled to output D through transmission line T2, which has a characteristic impedance and electrical length equal to that of T1. Input A is coupled to input B through transmission line T3, which has a characteristic impedance of Z_0 and an electrical length of $\lambda_0/4$ to provide a phase shift of 90°. Output C is coupled to output D through transmission line T4, which has a characteristic impedance and electrical length equal to that of T3.

The balun has first and second input ports P1 and P2 for receiving respective first and second input signals and a single output port P3 for providing an output signal. The first input port P1 is coupled to input A through transmission line T5, which has a characteristic impedance of Z_0 and an electrical length of $\lambda_0/4$. Input B and output D serve as the second input port P2 and the output port P3, respectively, of the balun. Output C is terminated to ground through the impedance R, which has the characteristic impedance Z_0.

Figure 2 illustrates a physical embodiment of the balun shown schematically in Figure 1. The balun comprises a dielectric substrate S having the transmission lines formed in microstrips on one side and having a ground plane formed on an opposite side (which is not visible in Figure 2). Preferably the substrate comprises a thin dielectric material, such as alumina, to minimize the overall size of the balun. Each of the five transmission-line strips T1 - T5 has a width/height ratio that determines its characteristic impedance and an overall length corresponding to a phase shift of 90°. To minimize the surface area of the balun, each of the transmission-line strips is formed in a meander pattern. The resistive impedance R illustrated in Figure 2 is a chip resistor electrically connected between first and second conductive layers. The first conductive layer L_1 is disposed on top of the chip and is electrically connected to the port C by means of a pair of electrical leads. The second conductive layer L_2 is disposed on one side and the bottom of the chip and is soldered to a conductive layer L_3 which is electrically connected via a through hole H to the ground plane on the opposite side of the substrate S.

In each of the meander patterns forming one of the transmission lines, adjacent linear segments forming the patterns are spaced apart by at least the width of the line segments and the number of bends is minimized. This minimizes coupling between different portions of the line, which coupling increases the line length required for a given phase shift. Further, the meander patterns for the transmission lines T1 and T2 are substantially identical, and those for the transmission lines T3 and T4 are substantially identical. Also, these four meander patterns are arranged symmetrically with respect to each other and are separated from each other by linear segments of the transmission lines which are not included in the meander patterns..

Table I lists the dimensions and impedances of each of the microstrip transmission lines T1 - T5 illustrated in Figure 2. Note that the lengths of each of these lines is approximately 17% longer, than would be required for straight lines, to compensate for right-angle corner bends and inter-line coupling. The substrate thickness is 381 μm and the conductive patterns forming the transmission lines are 5μm-thick gold layers.

Table I

	T1	T2	T3	T4	T5
Width (μm)	688	688	361	361	361
Length (μm)	36770	36770	37870	37870	37870
Impedance (Ω)	35	35	50	50	50

In operation, the balun combines signals applied to the input ports P1 and P2, phase shifted by 180°, and provides the combined signal at output port P3. The operating characteristics of the preferred embodiment described above are illustrated in the graphs of Figures 3, 4 and 5.

Figure 3 illustrates the phase shift of the signal applied to port P1 relative to that applied to port P2 as detected at port P3. Note that over a bandwidth Δf_1 the phase shift varies by $\pm$ 5° and over a bandwidth Δf_2 the phase shift varies by $\pm$12°. For the exemplary balun illustrated in Figure 2 and having the above-described dimensions, the center frequency and bandwidths are:

$$f_0 = 905 \text{ MHz}$$
$$\Delta f_1 = 30 \text{ MHz}$$
$$\Delta f_2 = 60 \text{ MHz}$$

Figure 4 illustrates the respective insertion losses of the balun attributable to the signal path from P1 to P3 with P2 terminated (indicated by a rectangular symbol), and attributable to the signal path from P2 to P3 with P1 terminated (indicated by a cross symbol). The difference between the two insertion losses represents the degree of attenuation imbalance between the two paths. Note that the insertion loss from the input port P1 to the single output port P3 is almost flat over the entire illustrated frequency range. As a favourable consequence, transmission line T5 may be lengthened or shortened to compensate for too low or too high of a delay through the branch-line coupler without significantly affecting the degree of imbalance at any frequency.

Figure 5 illustrates the return loss (ratio of reflected power to incident power) at each port with the other ports terminated. The return loss at port P1 is indicated by a rectangle symbol, that at port P2 is indicated by a cross symbol, and that at port P3 is indicated by a diamond symbol. Note that over the entire bandwidth Δf_1 the return loss is lower than -20 DB.

Although one specific example of a microstrip balun in accordance with applicant's invention is has been described, numerous alternative embodiments are possible. For example, if multiple substrates are available the balun can be constructed in multilayers with different ones of the transmission line conductors being disposed on different ones of the substrates. This would both decrease the width and length of the space required for the balun and minimize coupling effects between different ones of the transmission lines.

As additional alternatives, the balun could be formed in stripline (with the microstrip conductors disposed between opposing ground planes) or by discrete components that are electrically connected to form a lumped-element equivalent of the balun.

CLAIMS

1. A microwave balun comprising:

- a) a branch-line coupler having:

1. first and second inputs;

2. first and second outputs;

3. a first delay element having a characteristic impedance of $Z_0/\sqrt{2}$ and coupling the first input to the first output through a phase shift of 90°;

4. a second delay element having a characteristic impedance of $Z_0/\sqrt{2}$ and coupling the second input to the second output through a phase shift of 90°;

5. a third delay element having a characteristic impedance of Z_0 and coupling the first and second inputs through a phase shift of 90°;

6. a fourth delay element having a characteristic impedance of Z_0 and coupling the first and second outputs through a phase shift of 90°;

- b) a fifth delay element having a characteristic impedance of Z_0 and coupling the first input of the branch-line coupler to a first input of the balun through a phase shift of 90°; and

- c) impedance means having a characteristic impedance of Z_0 terminating the first output;

said second input of the branch-line coupler comprising a second input of the balun and said second output of the branch-line coupler comprising an output of the balun.

2. A microwave balun including a dielectric substrate supporting a conductive layer forming a ground plane and further supporting:

- a) a conductive pattern defining a branch-line coupler, said coupler having:

1. first and second inputs;

2. first and second outputs;

3. first transmission line means having a characteristic impedance of $Z_0/\sqrt{2}$ and coupling the first input to the first output through a phase shift of 90°;

4. second transmission line means having a characteristic impedance of $Z_0/\sqrt{2}$ and coupling the second input to the second output through a phase shift of 90°;

5. third transmission line means having a characteristic impedance of Z_0 and coupling the first and second inputs through a phase shift of 90°;

6. fourth transmission line means having a characteristic impedance of Z_0

and coupling the first and second outputs through a phase shift of 90°;

- b) fifth transmission line means having a characteristic impedance of Z_0 and coupling the first input of the branch-line coupler to a first input of the balun through a phase shift of 90°; and

- c) impedance means having a characteristic impedance of Z_0 terminating the first output;

said second input of the branch-line coupler comprising a second input of the balun and said second output of the branch-line coupler comprising an output of the balun.

3. A microwave balun as in claim 1 or 2 where at least the branch-line coupler is formed in stripline.

4. A microwave balun as in claim 1 or 2 where at least the branch-line coupler is formed in microstrip.

5. A microwave balun as in claim 2 where at least one of the transmission line means comprises a meander conductive pattern formed on the dielectric substrate.

6. A microwave balun as in claim 2 where at least the first, second, third and fourth transmission line means each comprise a conductive pattern formed on the dielectric substrate and including a meander pattern and a linear segment, said meander patterns being arranged adjacent to each other and at least one of said linear segments being disposed between each meander pattern and each adjacent meander pattern.

7. A microwave balun as in claim 2 where at least the first, second, third and fourth transmission line means each comprise a conductive pattern formed on the dielectric substrate and including a meander pattern including adjacent linear segments having a predetermined width which are spaced apart by at least said width.

8. A microwave balun as in claim 6 or 7 where the meander patterns of the first, second, third and fourth transmission lines are arranged symmetrically with respect to each other.

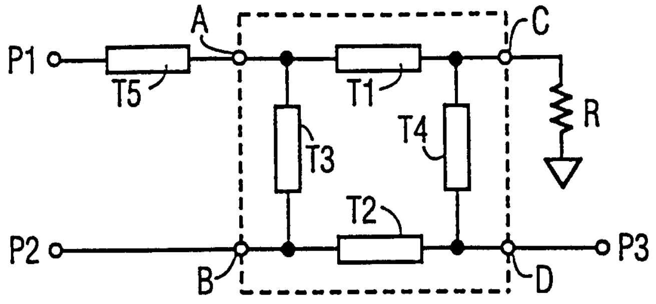


FIG.1

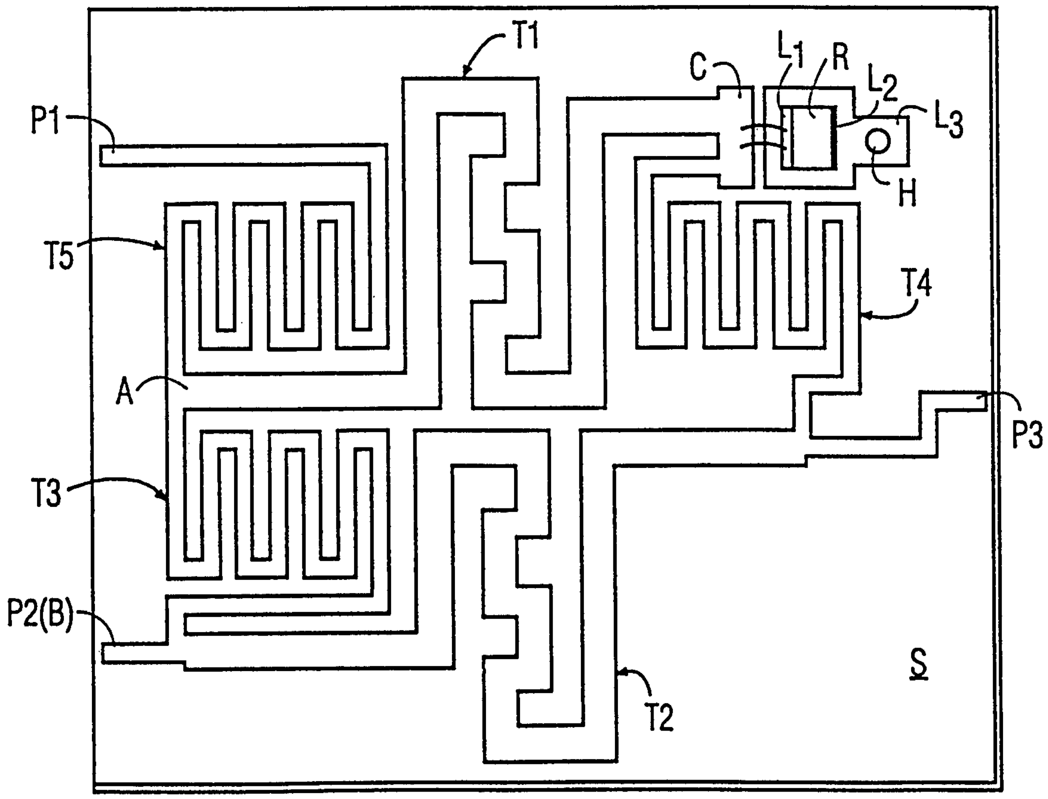


FIG.2

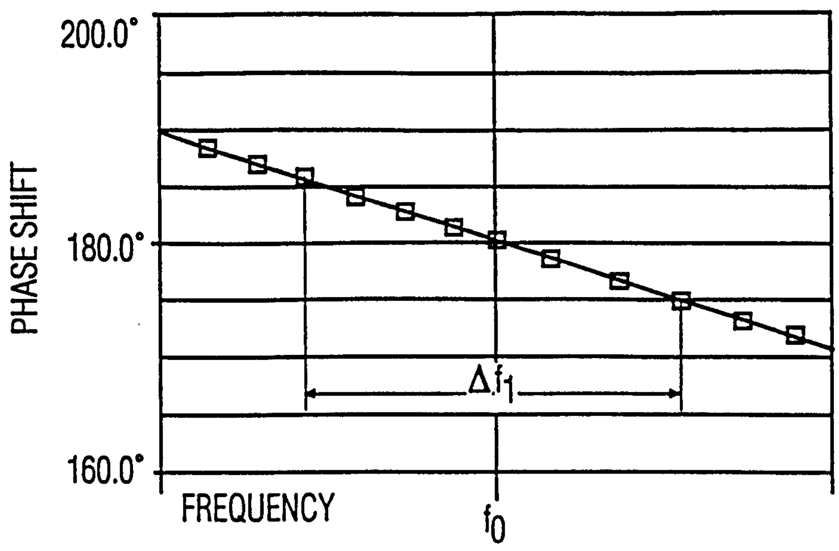


FIG.3

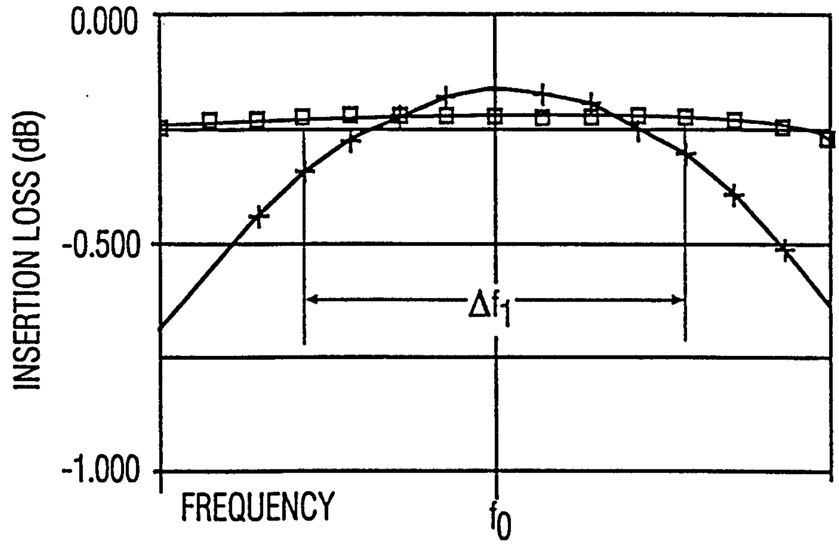


FIG.4

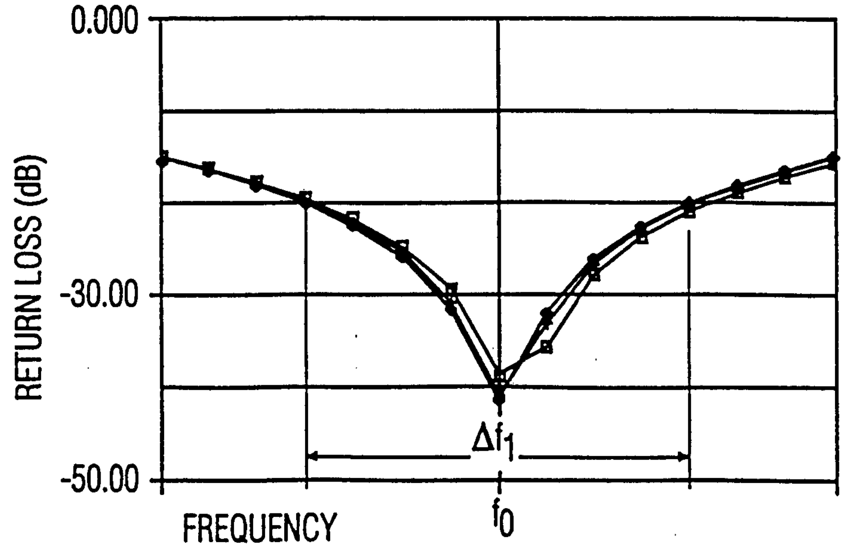


FIG.5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB 94/00383

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H01P 5/18
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H01P, H03H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB, A, 2110882 (THE MARCONI COMPANY LIMITED), 22 June 1983 (22.06.83), column 1, line 5 - line 53, figure 1	1-4
	--	
X	DE, A1, 2144985 (SIEMENS AG), 15 March 1973 (15.03.73), page 2, line 17 - page 3, line 4, figure 1	1-3
	--	
A	US, A, 3754197 (EDWARD G. CRISTAL), 21 August 1973 (21.08.73), column 9, line 4 - column 10, line 12	5-7
	--	

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" erlier document but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 March 1995	29 -03- 1995
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Göran Magnusson Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

Information on patent family members

25/02/95

International application No.

PCT/IB 94/00383

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
GB-A- 2110882	22/06/83	EP-A- 0080859 US-A- 4492939	08/06/83 08/01/85
DE-A1- 2144985	15/03/73	NONE	
US-A- 3754197	21/08/73	NONE	