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Impedance-Transforming Lumped Element Two-Branch 90^0 Couplers in Case of Type C

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Abstract: - An impedance-transforming lumped-element (LE) two-branch 90^0 coupler is discussed in this paper. The LE coupler discussed here can be derived from a branch-line coupler consisting of one-quarter or three-quarters wavelength transmission-lines (that is, case of type C) and classified into five groups. Normally, the LE coupler needs 8 circuit elements. However, the existence of reduced LE couplers consisting of 6 circuit elements is shown in this paper during the process for deriving the five circuit groups. The circuit element values are given by terminal admittance y_{02} and power division ratio k^2.

Key-Words: - Impedance-transforming, Lumped-element, Two-branch, 90^0 coupler, 6 elements

1 Introduction

A branch-line (BL) 90^0 coupler is a kind of co-directional coupler that divides incoming signals into two output ports. The phase difference of the output signals is odd multiples of 90^0 [1], and the coupler is therefore important in the front end of transmitter/receiver systems [2], [3]. The fundamental circuit is composed of four quarter wavelength transmission-lines (TLs). The TL components occupy a large area on a printed circuit board and create dimensional problems in microwave integrated circuits, especially at frequencies below 10 GHz.

In recent years, lumped-elements (LEs) have become attractive in systems in which size-reduction techniques are important, since techniques for fabricating inductors and capacitors have improved even in the ultra-high frequency (UHF) band. Therefore, a capacitive coupled two-branch LE coupler was proposed by Gupta [4]. To achieve a wider bandwidth, broad-band matching design techniques were proposed by Vogel, Ohta, Chiang and Sakagami [1], [5]-[8].

Recently, an impedance-transforming LE two-branch 3-dB 90^0 coupler has been discussed [9]. Therefore, more general discussion, including the case of unequal power division, will be presented under the condition of Gupta's circuit model [10].

2 Two-Branch TL 90^0 Couplers

The circuit shown in Fig. 1 consists of four TLs of which normalized characteristic admittances are y_{b1}, y_T and y_{b2}. The normalized characteristic admittances at four terminals are 1 and y_{02}. The two lines between ports #1 and #4 and between ports #2 and #3 are called branch lines. The other two lines are called through lines.

2.1 Four realizations

Four cases are considered in terms of wavelength λ_0 of center frequency f_0.

Type A: The four TLs are all $\lambda_0/4$ in length.

Type B: The four TLs are all $3\lambda_0/4$ in length.

Type C: The two branch lines are $\lambda_0/4$ and the through lines are $3\lambda_0/4$ in length.

Type D: The two branch lines are $3\lambda_0/4$ and the through lines are $\lambda_0/4$ in length.

Type A is well known and is called a branch-line coupler [2].

2.2 Design values

In terms of S parameters, the ideal branch-line coupler must satisfy the following conditions at the center f_0:

$$S_{11}=S_{41}=0, \text{ and } |S_{21}| : |S_{31}| = 1 : k, \tag{1}$$

where k is the coupling factor.

The branch-line coupler admittances shown in Fig.1 are given by [10]:

$$y_{b1} = k,\ \ y_{b2} = ky_{02}, \text{ and } y_T = \{(1+k^2)y_{02}\}^{0.5}. \tag{2}$$

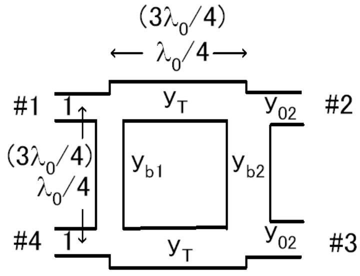


Fig. 1. Two-branch TL 90^0 coupler.

3 LE Realizations in the Case of Type C

When two-branch TL 90^0 couplers of types A and B are transformed into LE couplers, the circuit structure will be the same as that reported previously [5]. Therefore, we will discuss couplers of type C.

3.1 Equivalent transformation

A TL of line length $\lambda_0/4$ (or $3\lambda_0/4$) is shown in Fig. 2, where z_0 and y_0 are the normalized characteristic impedance and admittance, respectively. The single line can be transformed into π equivalents as shown in Fig.3 (a) and (b) [11]. The T equivalents are omitted here.

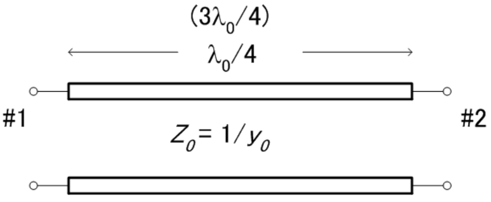


Fig. 2. A TL of $\lambda_0/4$ (or $3\lambda_0/4$).

(a) In case of $\lambda_0/4$. (b) In case of $3\lambda_0/4$.

Fig. 3. π equivalents, where l and c represent normalized inductance and capacitance.

3.2 Case of type C

When the relationship between Figs. 2 and 3 is applied to the circuit in the case of type C, the circuit shown in Fig. 4 can be obtained.

The series components are given by

$$c_T=y_T,\ l_{b1}=z_{b1},\ \text{and}\ l_{b2}=z_{b2}. \quad (3)$$

The shunt components are shown in Fig. 5 as P_1- and P_2-circuits, and the following equations hold:

$$cl|_{p1}= y_{b1}z_T=\{k^2z_{02}/(1+k^2)\}^{0.5} \quad \text{for } P_1\text{-circuit,} \quad (4)$$

$$cl|_{p2}= y_{b2}z_T=\{k^2y_{02}/(1+k^2)\}^{0.5} \quad \text{for } P_2\text{-circuit.} \quad (5)$$

In general, the shunt circuit can be classified into three cases.

Case 1 : $cl>1$, case of a capacitive circuit
Case 2 : $cl=1$, case in which c and l can be removed
Case 3 : $cl<1$, case of an inductive circuit.

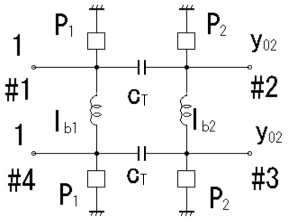
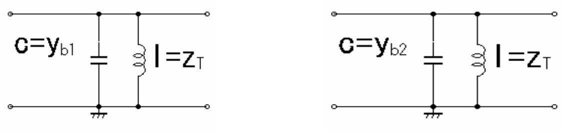


Fig. 4. LE Circuit of type C.



(a) P_1-circuit (b) P_2-circuit

Fig. 5. Shunt components in Fig. 4.

3.2.1 Case of $cl=1$

From the above three cases, cases 1, 2 and 3, a reduced element circuit, an LE coupler of 6 elements, can be expected.

From (4) under the condition of $cl=1$,

$$Z_{02}=1+k^{-2} . \quad (6)$$

From (5) under the condition of $cl=1$,

$$y_{02}=1+k^{-2} . \quad (7)$$

It is found from (6) and (7) that the LE coupler of 6 elements can be realized only in the case of impedance transformation under the condition of finite power division, and the P_1- and P_2-circuits can not be removed at the same time.

Now, let us show that the circuit shown in Fig. 4 can be classified into 5 groups.

3.2.2 Five circuit structures

From (4) and (5) and cases 1, 2, and 3, the following circuit structures and element values can be obtained:

(A) When $y_{02}>1+k^{-2}$, $cl|_{p1}<1$ and $cl|_{p2}>1$ hold. Fig. 6(a) shows the circuit in this case.

$$l_a=1/(y_T-y_{b1}) \text{ and } c_b=y_{b2}-y_T. \quad (8)$$

(B) When $y_{02}=1+k^{-2}$, $cl|_{p1}<1$ and $cl|_{p2}=1$ hold. The resultant circuit is shown in Fig. 6(b).

$$l_a=1/(y_T-y_{b1})=k. \quad (9)$$

(C) When $1/(1+k^{-2})<y_{02}<1+k^{-2}$, $cl|_{p1}<1$ and $cl|_{p2}<1$ hold. The resultant circuit is shown in Fig. 6(c).

$$l_a=1/(y_T-y_{b1}) \text{ and } l_b=1/(y_T-y_{b2}). \quad (10)$$

(D) When $y_{02}=1/(1+k^{-2})$, $cl|_{p1}=1$ and $cl|_{p2}<1$ hold. The resultant circuit is shown in Fig. 6(d).

$$l_b=1/(y_T-y_{b2})=k+k^{-1}. \quad (11)$$

(E) When $y_{02}<1/(1+k^{-2})$, $cl|_{p1}>1$ and $cl|_{p2}<1$ hold. The resultant circuit is shown in Fig. 6(e).

$$c_a=y_{b1}-y_T \text{ and } l_b=1/(y_T-y_{b2}). \quad (12)$$

3.2.3 Examples for the case of 2:1 power division

In the case of 2:1 power division, from (1) and (2), $k=y_{b1}=1/2^{0.5}$, $y_{b2}=ky_{02}$, and $y_T=(1.5y_{02})^{0.5}$. Therefore, the series components shown in Fig. 4 or Fig. 6(a)-(e) are determined using (3) as follows:

$$c_T=y_T=(1.5y_{02})^{0.5},\ l_{b1}=z_{b1}=2^{0.5}, \text{ and } l_{b2}=z_{b2}=2^{0.5}/y_{02}. \quad (13)$$

The shunt components are determined by (8)-(12) according to y_{02}.

In the following, calculated examples of 2:1 power division are presented for a 50-Ω system.

(A) Case of 50- to 10-Ω LE 90^0 coupler
Since $k=1/2^{0.5}$ and $y_{02}=5$, the circuit is given by Fig. 6(a). The element values are derived using (8) and (13):

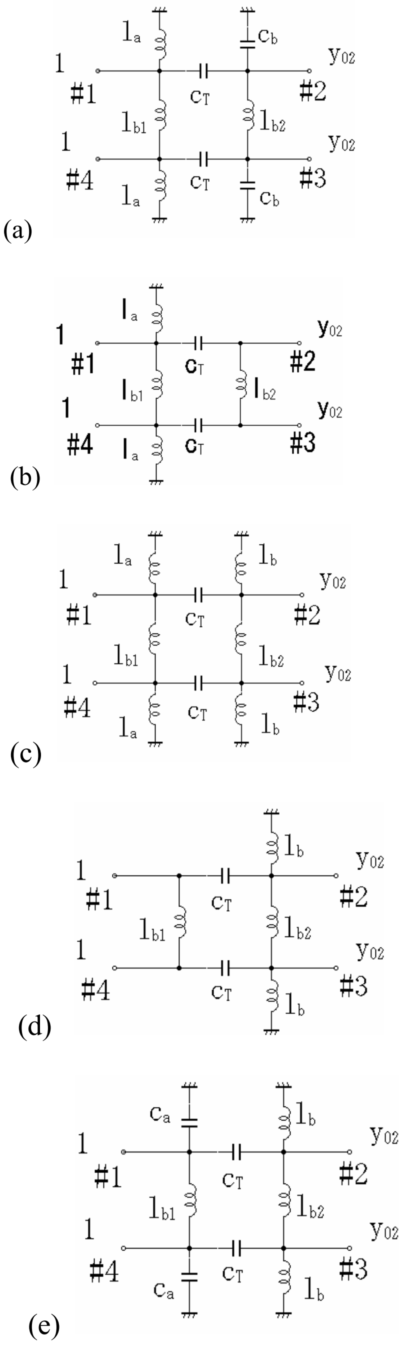


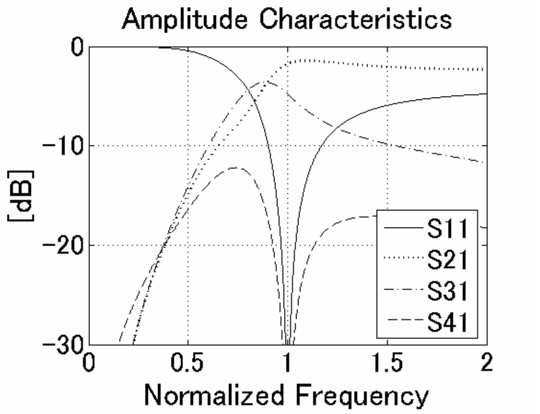
Fig. 6. Five circuit structures for arbitrary y_{02} and k.

$l_a=2^{0.5}/(15^{0.5}-1)$, $c_a=(5-15^{0.5})/2^{0.5}$, and $c_T=7.5^{0.5}$, $l_{b1}=2^{0.5}$, $l_{b2}=2^{0.5}/5$.

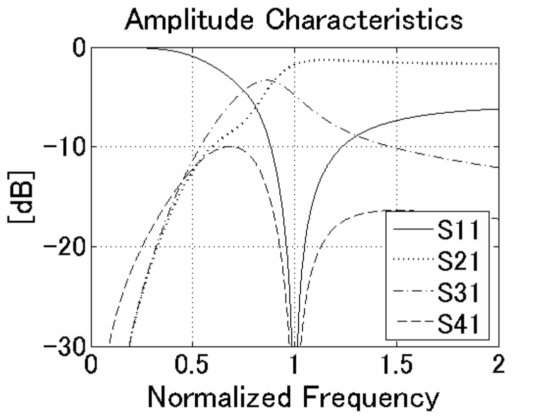
(B) Case of 50- to 50/3-Ω LE 90^0 coupler
Since $k=1/2^{0.5}$ and $y_{02}=3$, the circuit is given by Fig. 6(b). The element values are

$l_a=1/2^{0.5}$, and $c_T=4.5^{0.5}$, $l_{b1}=2^{0.5}$, and $l_{b2}=2^{0.5}/3$.

The frequency characteristics for the above two cases are shown in Fig. 7(a) and (b). The perfect input match, isolation, power transfer to port #2, 1.76dB, and power transfer to port #3, 4.77dB, are satisfied at the center frequency. Other examples are omitted.



(a) 50- to 10-Ω.



(b) 50- to 50/3-Ω.

Fig. 7. Frequency characteristics for y_{02}=5 and 3.

4 Conclusion

Impedance-transforming two-branch lumped element 90^0 couplers have been investigated by introducing two-branch 90^0 couplers consisting of one-quarter and three-quarters wavelength transmission-lines and Gupta's terminal conditions.

In this paper, the circuit structure is classified into five groups, and reduced lumped element 90^0 couplers have been presented, as shown in Fig.6 (b) and (d). It is proved that the reduced lumped element 90^0 couplers are realizable only in the case of impedance transformation, as seen from (6) and (7). Although the circuit models shown in Fig.6 (a), (c) and (e) were pointed out in [1], general and simple expressions for the lumped element values, which can be determined by the coupling factor k and terminal load y_{02}, have been presented for the first time. The circuit model for type D will be discussed in the near future.

References:

[1] R.W.Vogel, Analysis and design of lumped- and lumped-distributed-element directional couplers for MIC and MMIC applications, IEEE Trans., Microwave Theory Tech, Vol.40, 1992, pp.253-262.

[2] Y.Konishi, Microwave Integrated Circuits, Marcel Dekker, Inc., 1991.

[3] K. Itoh, Even harmonic type direct conversion receiver and its utilization for W-CDMA terminals, MWE 2001 Microwave Workshop Digest, 2001, pp.247-252.

[4] R.K.Gupta and W.J.Getsinger, Quasi- lumped-element 3- and 4-port networks for MIC and MMIC applications, IEEE MTT-S Digest, 1984, pp.409-411.

[5] I. Ohta, X.-P. Li, T.Kawai, and Y.Kokubo, A design of lumped-element 3 dB quadrature hybrids, Asia-Pacific Microwave Conf., 1997, pp.1141-1144.

[6] Y-C. Chiang and C-Y. Chen, Design of a wide-band lumped-element 3-dB quadrature coupler, IEEE Trans., Microwave Theory Tech, vol. 49, 2001, pp.476-479.

[7] I. Sakagami, K. Sakaguti, M. Fujii, M. Tahara and Y. Hao, On a Lumped Element Three-branch 3-dB Coupler with Butterworth and Chebyshev Characteristics, The 47th IEEE Inter. Midwest Symp. on Circuits and Systems, 2004, pp.III-21-III-24.

[8] I.Sakagami, Derivation of two- and three-branch lumped element codirectional couplers and their frequency characteristics, IEEE Inter. Symposium on Circuit and Systems, 2005, pp.5047-5050, Kobe.

[9] I.Sakagami and T.Wuren, Impedance-transforming lumped-element co-directional couplers and their circuit structure, Asia-Pacific Microwave Conf., Vol.3, 2005, pp.1434-1437.

[10] R.K.Gupta, S.E.Anderson and W.J.Getsinger, Impedance- transforming 3-dB 90^0 hybrids,IEEE Trans., Microwave Theory Tech, vol.35, 1987, pp.1303-1307.

[11] S.J. Parisi, 180°Lumped element hybrid,' IEEE MTT-S Symp. Dig., 1989, pp.1243-1246.