# Compact half-wave balun using microstrip and lumped-element artificial transmission lines

**Conference Paper** · May 2012

DOI: 10.1109/ICMMT.2012.6229909



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# Compact Half-wave Balun Using Microstrip and Lumped-Element Artificial Transmission Lines

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*Abstract*- **In this paper, a compact two-section half-wave balun using artificial transmission lines is presented. The developed balun comprises four sections of artificial transmission lines, including two sections realized with lumped chip capacitors and via holes. The theoretical performance of the proposed balun is verified through circuit simulations and measurements of a fabricated prototype at 0.9 GHz. The proposed balun exhibits excellent return loss, insertion losses and phase characteristics over the operational frequency band. The measured return loss of input port remain above 11dB over a bandwidth from 0.8 GHz to 1 GHz, while in this frequency range the amplitude imbalance varies from -0.48 dB to 0.37 dB, and the phase difference of 177° to 180°. Measurements show a good agreement with the corresponding simulations.**

## I. INTRODUCTION

Three-port baluns are key components in balanced microwave circuit such as mixers, frequency multipliers, push-pull amplifiers. Most balun configurations employ either distributed or lumped elements. Various types of distributed baluns have been reported, such as coupled-line Marchand balun [1], the quarter-wave coupled-line balun [2,3] , the N-section half-wave balun [4,5] . Many of these structures, however, are not well suited for wireless operation in low frequency bands. Since distributed baluns consist of sections of transmission lines or coupled lines which often 1/2 or 1/4 wavelength long at operational center frequency. Unfortunately, these structures always occupy large areas, especially in low frequencies. Therefore, for low frequency applications, the 1/2 or 1/4 wavelength lines can be replaced by artificial transmission lines [6] to become more compact.

In recent years, artificial transmission lines [6] have been reported, and many microwave components using artificial transmission lines have been realized, such as branch-line couplers [7] , power dividers [8] and antennas [9]. However, the lines with low impedance can't be easily realized by artificial transmission lines because of required too high capacitance. Therefore, the artificial transmission lines with lumped elements to be designed to solve the problem. Consequently, this paper presents a novel balun structure employing artificial transmission lines with both lumped elements and distributed mirostrip. Besides, addition of lumped elements greatly reduced the required areas of microstrip parallel-plate capacitors.

## II. THEORY OF ARTIFICIAL TRANSMISSION LINES

### *A. Conventional Artificial Transmission Lines*

Recent years, C. Wang [6] has proposed the concept of conventional artificial transmission lines, which consist of microstrip structures of interdigital capacitors, meandered-line inductors and parallel-plate capacitors. The layout and equivalent circuit of a unit of conventional artificial transmission line are given in Fig.1. The design and methodology of such kind of conventional artificial transmission lines have been presented in details in [6].

Referring to transmission line theory, a unit of artificial transmission line can be equivalent to the circuit of Fig.1 (b) and its characteristic impedance $Z_{ATL}$ and propagation constant $\beta_{g,ATL}$ of each unit of artificial transmission line is determined by

$$Z_{ATL} = \sqrt{L_{tot} / C_{tot}} \tag{1}$$

$$\beta_{g,ATL} = \omega\sqrt{L_{tot} \cdot C_{tot}} \tag{2}$$

Where $L_{tot}$ and $C_{tot}$ are equivalent total inductance and capacitance for a unit of artificial transmission line, respectively, and $\omega$ is the working angle frequency. According to the equivalent circuit in Fig.1 (b), $L_{tot} = L_1 + L_2 + L_3$, $C_{tot} = C_{l1} + C_{l2} + C_{l3} + C_{l4} + C_{p1} + C_{p2} + C_{p3} + C_{p4} + C_{s1} + C_{s2} + C_{s3} + C_{s4}$. These expressions show that changing $L_{tot}$ and $C_{tot}$ can adjust characteristic impedance and propagation constant of artificial transmission lines by adjusting the interdigital capacitors, parallel-plate capacitors, and meandered-line inductors.

Therefore, the required physical dimensions of artificial transmission lines are substantially reduced especially at low frequencies, whereas its electrical properties remain the same, when compared with conventional structures of microstrip transmission lines. Hence, the artificial transmission lines would be find more and more applications to satisfying imperative needs of miniaturized microwave components and devices.

978-1-4673-2185-3/12/$31.00 

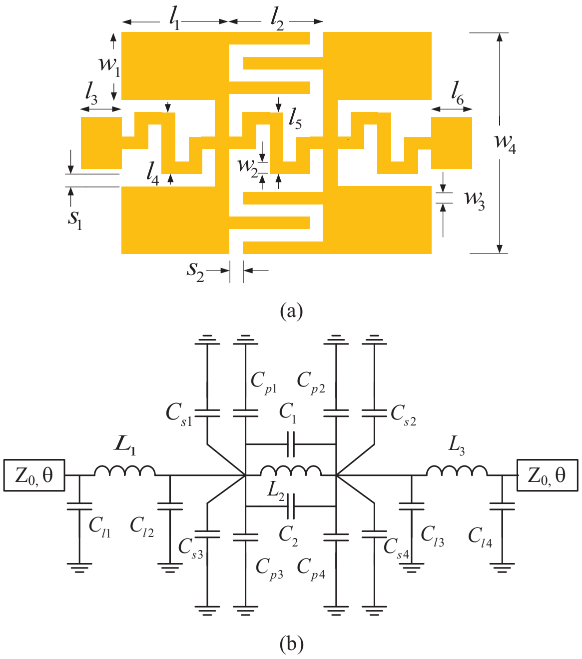


Fig.1. Unit cell of artificial transmission line (a) Layout (b) Equivalent circuit.

## B. *Artificial Transmission Lines With Lumped Elements*

However, the conventional artificial transmission lines mentioned above can only satisfy the general demand of realizing lines with characteristic impedance between 30 Ω and 100 Ω. Since the conventional artificial transmission line would be encounter its limitation in the dimensions of corresponding parallel-plate capacitors with too high capacitance when the characteristic impedance is too low. Therefore, in order to design low characteristic impedance line, the artificial transmission line can be ameliorated by applying lump elements such as chip capacitors in place of distributed microstrip capacitors, whereas its electrical properties remain the same as the conventional artificial transmission lines.

The ameliorated artificial transmission lines can be applied to low characteristic impedance lines which are hardly realized by conventional artificial transmission lines, such as the line with characteristic impedance ranged from 10 Ω to 30 Ω. In this ameliorated structure, a chip capacitor and a metalized edged via hole with radius 0.3 mm are applied to substituting the microstrip parallel-plate capacitors and microstrip interdigital capacitors as shown in Fig. 2. Capacitances of chip capacitors are also approximately calculated by (1) and (2). In reality, the capacitance of chip capacitor almost amounts to the value of the calculated total capacitance taken off the parasitic capacitance of meandered-line inductors.

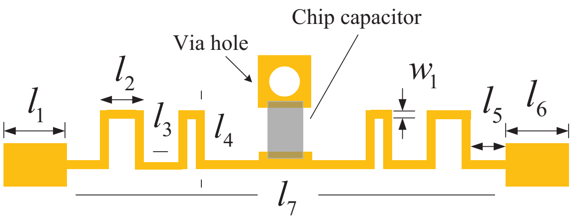


Fig. 2. The ameliorated artificial transmission line with lumped capacitor.

## III. Circuit Design

For simple operation, we have chosen the topology of two-section half-wave balun to be implemented with artificial transmission lines to verify the theory analysis. An N-section half-wave balun [4,5] comprises several half wavelength transmission lines paralleled by quarter wavelength sections. The series of half-wave transmission lines can achieve the phase shift of 180 degrees required for balun operation. And the quarter wavelength sections play a role in impedance transformation. However, this kind balun inherently isn't a broad band design since the half-wave and quarter-wave transmission line holds only at the center frequency. The more the half wavelength sections are applied, the broader the balun bandwidth is, as the more sections can give more paths for power to transmit. To this kind of balun the key point of design is properly choosing the line impedance of the half-wave and quarter-wave line to achieve good amplitude balance and impedance matching, and thereby to obtain the best performance.

For simplicity, the topology of two-section balun is adopted to realize its performance with artificial transmission lines. In optimized process with ideal model for microstrip lines of ADS software, the focus of consideration is bandwidth of amplitude balance, since this kind balun is destined to operate in natural narrow band. At the input port, single-stub matching network is added to attain good impedance matching to load impedance of input port. As a result, the optimized values of impedances for the two-section balun structure are $Z_1 = Z_3 = 50\Omega$, $Z_2 = 25\Omega$, $Z_{trans1} = Z_{trans2} = 50\Omega$, with the notation as given in Fig. 4.

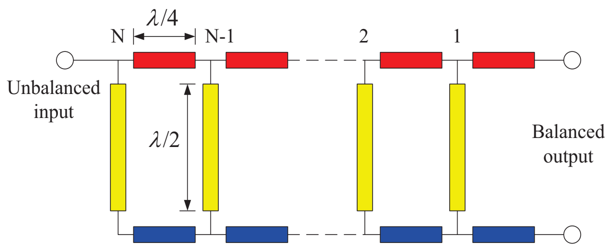


Fig. 3. The topology of N-section half-wave balun.

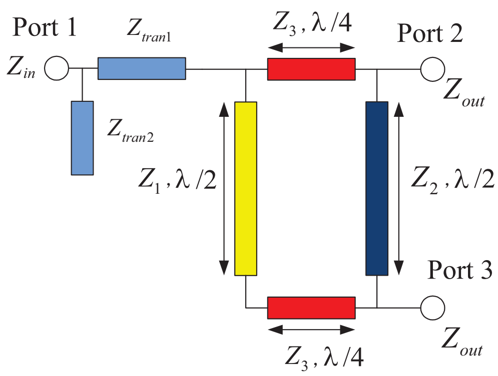


Fig. 4. The proposed topology of two-section half-wave balun.

The practical design operation of this two-section half-wave balun is performed by a full-wave EM simulation software IE3D. The lines of $Z_1$ = 50Ω with 90 degrees phase shift are realized by conventional artificial transmission lines. For each part of the design, such as interdigital capacitors, parallel-plate capacitors, meandered-line inductors, can be simulated out its capacitance and inductance by software of IE3D. Based on (1) and (2), the calculated total capacitance and inductance can be obtained, that is 5.56 pF and 13.89 nH. Therefore, what we should to do is varying each capacitor and inductor to achieve total calculated capacitance and inductance. Eventually, the parameters of the artificial transmission line of $Z_1$ are given in details in Table I with the notation marked in Fig.1 (a).

The lines of $Z_2$ = 25Ω are practically designed by software of IE3D using artificial transmission lines with lumped elements. And the design method is similar to the design of artificial transmission line of $Z_1$ = 50Ω, and the difference is that interdigital capacitors and parallel-plate capacitors are replaced by lumped capacitors. Obviously, the process of varying capacitance and inductance becomes more simple and easy when compared with designing conventional artificial transmission lines, which only needs varying the lumped capacitors and meandered-line inductors. By (1) and (2), the total calculated capacitance and inductance is 11.11 pF and 6.94 nH. Besides, the capacitance of the lumped capacitor is 6 PF (size code: 0603). The specific dimensions of the artificial transmission lines of $Z_2$ = 25Ω is shown in Table II using the notation signed in Fig. 2.

In practice, the proposed two-section half-wave balun based on artificial transmission lines was implemented on a F4B-2 substrate with $\varepsilon_r$=2.65 and height $h$=1 mm at a designed frequency of 0.9 GHz. In addition, the photo of the fabricated balun is shown in Fig. 5 with total area of 0.14 $\lambda_g$× 0.16 $\lambda_g$, where $\lambda_g$ is the guided wavelength on the substrate at 0.9 GHz. The fabricated balun is about 14% of a balun realized by conventional microstrip lines without folded lines of the same topology.

TABLE I

DIMENSIONS OF ARTIFICIAL TRANSMISSION LINES OF $Z_1$ (UNIT: MM)

| Impedance | $l_1$ | $l_2$ | $l_3$ | $l_4$ | $l_5$ | $l_6$ |
|---|---|---|---|---|---|---|
| | 4.9 | 2.8 | 2.7 | 4 | 7.2 | 2.7 |
| $Z_1$ | $w_1$ | $w_2$ | $w_3$ | $w_4$ | $s_1$ | $s_2$ |
| | 4.8 | 0.4 | 0.4 | 14.4 | 0.4 | 0.2 |

TABLE II

DIMENSIONS OF ARTIFICIAL TRANSMISSION LINES OF $Z_2$ (UNIT: MM)

| Impedance | $l_1$ | $l_2$ | $l_3$ | $l_4$ | $l_5$ | $l_6$ | $l_7$ | $w_1$ |
|---|---|---|---|---|---|---|---|---|
| $Z_2$ | 0 | 1.6 | 1.6 | 1.2 | 0.7 | 0.6 | 13.6 | 0.4 |

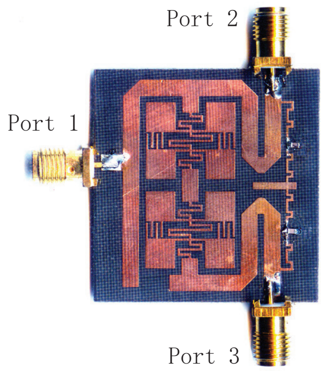


Fig. 5. Photo of the fabricated two-section half-wave balun.

## IV. SIMULATION AND EXPERIMENTAL RESULTS

The simulated and measured results (by an Agilent N5230A vector network analyzer) of the proposed two-section half-wave balun are plotted in Fig. 6 and Fig. 7. Fig. 6 shows the measured versus the simulated return loss for port 1, showing good agreement between the two. When at 0.9 GHz, the measured return loss is 26.7 dB. From less than 0.73 GHz to above 1.01 GHz, the measured return loss is above 10 dB, indicating the circuit at input port is well matched, especially around 0.91 GHz with a minimum value of $|S_{11}|$ = -29.5 dB. Also Fig.6 shows that both the measured $|S_{21}|$ and $|S_{31}|$ remain below -3 dB and above -4 dB from 0.78 GHz to 1.01 GHz, with $|S_{21}|$ = -3.19 dB and $|S_{31}|$ = -3.54 dB around 0.9 GHz, resulting in insertion losses of 0.19 dB and 0.54 dB respectively for each of the output branches.

Fig. 7 shows the measured and simulated differential output phase and amplitude of the two-section half-wave balun, with excellent agreement between simulations and measurements. The flat differential output phase of 177° to 180° has a 180° ± 3° bandwidth of 0.22 GHz from 0.80 GHz to 1.02 GHz. While the differential amplitude has ±0.5 dB bandwidth of 0.23 GHz from 0.80 GHz to 1.03 GHz, varies from -0.48 dB to 0.37 dB. The agreement between measurements and simulations verified the theory analysis.

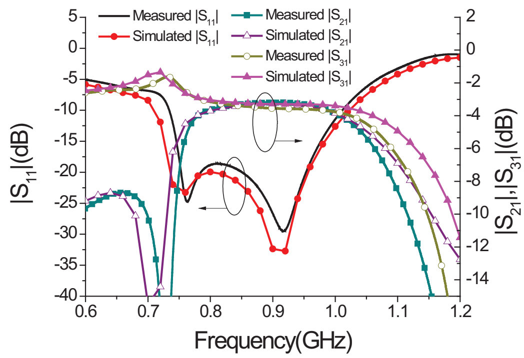


Fig. 6. Measured and simulated S-parameters.

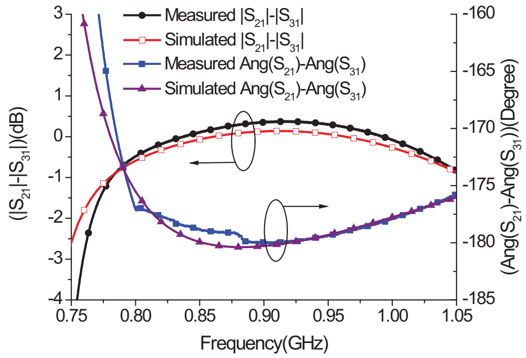


Fig. 7. Measured and simulated differential magnitude and phase.

## V. Conclusion

A miniaturized lumped and distributed two-section half-wave balun has been presented. It employs four sections of artificial transmission lines with two chip capacitors. Also, the requirement for impedance transformation at input port has also been considered. The balun achieved 0.5 dB amplitude balance and 180 ± 3 degrees phase balance, with return loss above11 dB from 0.8 GHz to 1 GHz. These results demonstrate that the miniaturized balun are highly suited for wireless communication applications, which require compact structures.

## Acknowledgment


This work was supported in part by NSFC 60971051 and Sichuan Youth Foundation 09ZQ026-016.


## References


[1] H.R. Ahn, and S. Nam, “New design formulas for impedance-transforming 3-dB Marchand baluns,” *IEEE Microw. Theory Tech.*, vol. 59, no.11, pp.2816-2823, 2011.

[2] B. Sewiolo, M. Hartmann, B. Waldmann, and R. Weigel, “An ultra-wideband coupled-line balun using patterned ground shielding structures,” *IEEE Radio Wirel. Symp.*, pp. 459-462, 2008.

[3] C. Liu, and W. Menzel, “Braodband via-free microstrip balun using metamaterial transmission lines,” *IEEE Microw. Wirel. Comp. Lett.*, vol.18, no.7, pp. 437-439, 2008.

[4] R. Sturdivant, “Balun designs for wireless, mixers, amplifiers and antennas,” *Applied Microw.*, pp.34-44, summer 1993.

[5] M. Basraoui, and S.N. Prasad, “Wideband, planar, log-periodic balun,” *1998 IEEE MTT-S Int. Microw. Symp. Dig.*, vol. 2, pp. 785-788, 1998.

[6] C.W. Wang, T.G. Ma, and C.F. Yang, “A new planar artificial transmission line and its applications to a miniaturized butler matrix,” *IEEE Trans. Microw. Theory Tech.*, vol.55, no.12, pp. 2792-2801, 2007.

[7] C.W. Wang, T.G. Ma, and C.F. Yang, “Miniaturized branch-line coupler with harmonic suppression for RFID applications using artificial transmission lines,” *IEEE MTT-S int. Microw. Symp.*, pp.29-32, 2007.

[8] W. Huang, C. Liu, L. Yan, and K. Huang, “A miniaturized dual-band power divider with harmonic suppression for GSM applications,” *J. of Electromagn. Waves and Appl.*, vol.24, no.1, pp. 81–91, 2010.

[9] R.C. Hua, C.W. Wang and T.G. Ma, “A planar quasi-Yagi antenna with a new microstrip-to-CPS balun by artificial transmission lines,” *Antennas and Propag. Society Int. Symp.*, pp.2305-2308, 2007.