Optimized Design of Unique Miniaturized Planar Baluns for Wireless Applications

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***Abstract*—The high frequency balun network has proven to be an important component in the design of certain RF and microwave system topologies—especially in wireless communications system architectures. This letter describes the optimized design of planar balun circuits which operate in the 900-MHz wireless frequency band. The designs are an outgrowth of extensive in-depth computer analysis and fabrication and testing of a multiplicity of circuit realizations. A novel feature of these designs is their compact size which is almost *one sixteenth* that of conventional quarter wavelength-coupled line designs. Size reduction and excellent coupling are effectively obtained by novel use of discrete capacitors.**

***Index Terms*—Balun, compact, hybrid, microstrip, wireless.**

Figures

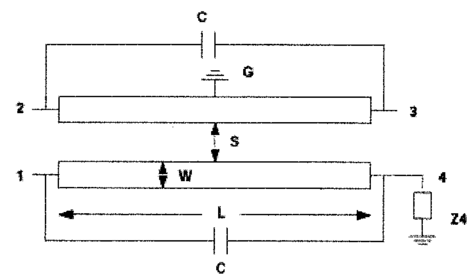

Fig. 1. Distributed balun realization.

I. Introduction

BALUN circuits are important components in many wireless communication systems where they are employed in balanced to unbalanced circuitry, realizing components such as multipliers, mixers, and power amplifiers. Additionally, as wireless technology advances toward more compact system architectures, all constituent system components require integratable realizations and significant reduction in size and power consumption.

One approach satisfying this requirement utilizes planar circuit technology; however, traditional design approaches require quarter wavelength planar lines which would be prohibitively large for lower gigahertz range applications.

Accordingly, this paper presents the results of an extensive in-depth investigation for the design of compact low gigahertz range planar baluns which are optimized for small size, excellent phase and amplitude balance, very good coupling levels ($\sim$4 db), and low VSWR at input and output ports. These optimized designs have emerged subsequent to theoretical analysis, extensive in-depth computer analysis, and *fabrication* and *testing* of dozens of balun circuit realizations.

The primary development contained in the following is a balun realization which is a *planar* structure of approximately one sixteenth the size of the conventional quarter wavelength design. Two design variations are presented which provide performance that is optimized over the various device geometrical parameters. The designs possess superior VSWR, excellent coupling, and significant fabricational advantages.

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II. Balun Circuit Realization

The balun circuit realization shown in Fig. 1 has been developed to provide the equivalent performance of the traditional wire wound balun widely utilized at these frequencies while providing a planar geometry for ease of fabrication. This circuit consists fundamentally of two planar transmission lines coupled electromagnetically in the standard manner [1]. As shown in Fig. 1, the input is at port 1, the coupled planar line is grounded midway between ports 2 and 3, and port 4 is terminated in impedance Z_4 (the authors have performed detailed studies leading to the utilization of Z_4 to optimize the coupling and VSWR of the overall balun circuit). Due to the requirements of various current wireless system applications, significant size reduction is necessary to employ the planar concept, and this is achieved primarily in the balun design by use of capacitors between ports 1–4 and 2–3, as shown in Fig. 1 (by allowing the lumped capacitors to increase the effective length of a distributed line, we can shorten the physical length. This concept for producing compactness is discussed in considerable detail theoretically, via simulation and by experiment in reference [3]). Without these capacitors, to achieve sufficient coupling for balun action (3-db coupling and 180° differential phase) would necessitate prohibitively small spacing (S) between the lines and require quarter wavelength line lengths $(L = \lambda_0/4)$.

To synthesize this configuration for highly efficient performance requires considerable balun geometry and impedance (Z_4) optimization. Specifically, for an optimum printed circuit board thickness and dielectric constant, computerized circuit synthesis is required to derive the optimum coupled line length (L), capacitance (C), coupled line width (W), spacing (S),

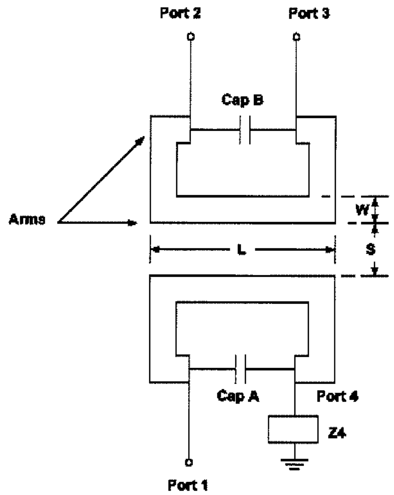


Fig. 2. Balun circuit ($L = 255$ mils, $W = 16$ mils, $S = 8$ mils, $CAP\ A = CAP\ B = 6.8$ pF).

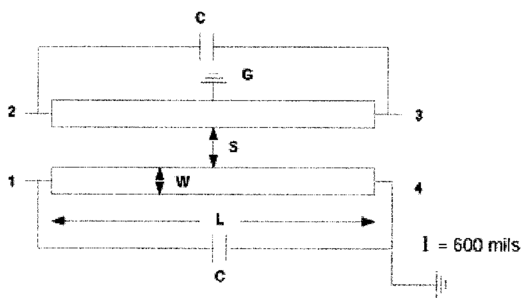


Fig. 3. Model 1 hybrid balun design ($L = 255$ mils, $S = 8$ mils, $W = 16$ mils, $C = 6.8$ pF).

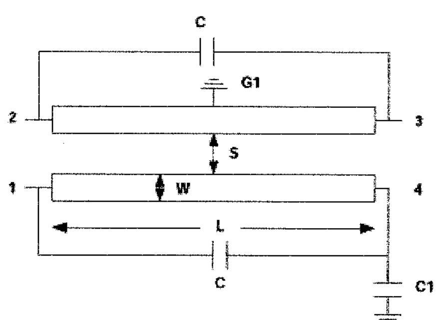


Fig. 4. Model 2 hybrid balun design ($L = 255$ mils, $S = 8$ mils, $W = 16$ mils, $C = 6.8$ pF, $C1 = 1.4$ pF).

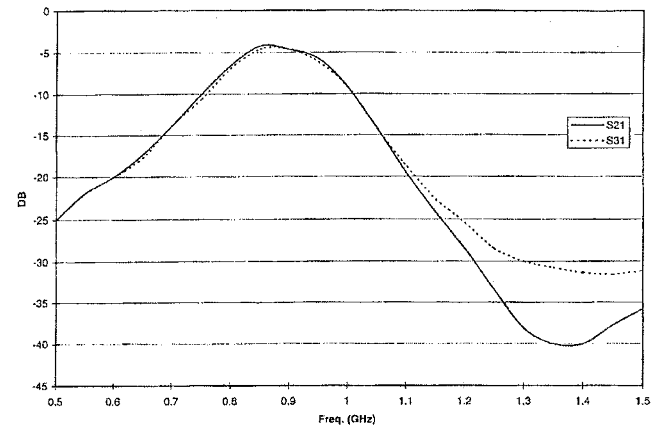


Fig. 5. Model 1 balun: measured coupling at output ports.

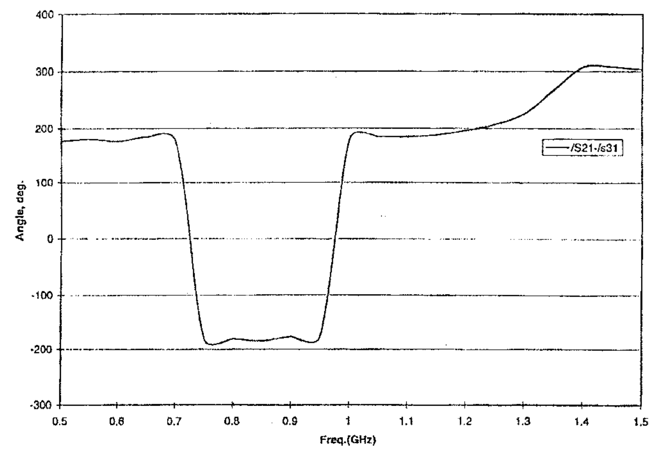


Fig. 6. Model 1 balun: measured phase balance.

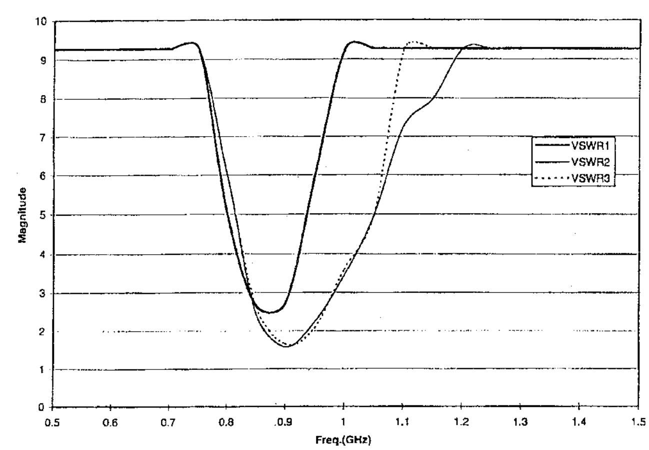


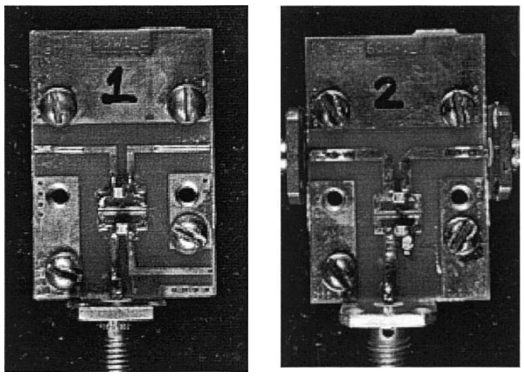
Fig. 7. Model 1 balun: measured VSWR at input and output ports.

and impedance Z_4. To achieve this objective, considerable effort was directed toward the synthesis of the final physical circuit realization shown in Fig. 2 [2].

This paper presents two *optimal* designs (Model 1 and Model 2) as shown in Figs. 3 and 4, where pertinent dimensions are indicated and both models have been designed and realized utilizing microstrip material with $\in_r = 4.1$ and substrate thickness $H = 30$ mils.

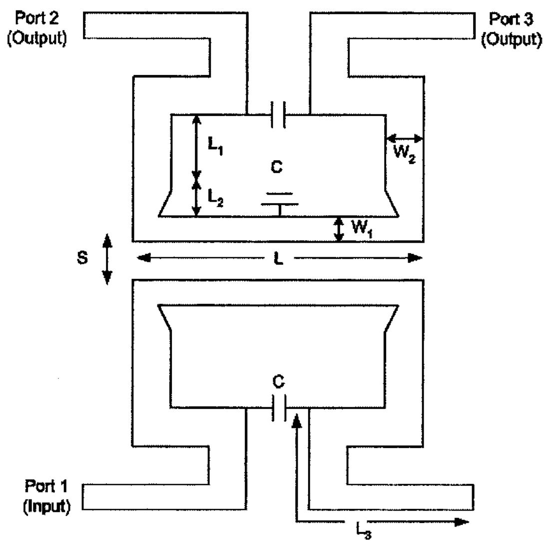
III. Performance of Balun Models

Two specific planar balun model realizations obtained as a result of the optimization process, are shown with dimensions in Figs. 3 and 4. These circuits, designed to operate in the 900-MHz wireless frequency band, were *fabricated* on circuit board having $\in_r = 4.1$ and substrate thickness of 30 mils. While both realizations have the same optimized length (L), linewidth (W), spacing (S), and capacitance (C), these model realizations differ in topology in that realization 1 has a short circuited transmission line of length $l = 600$ mils at port 4 while realization 2 has a capacitor $(C1)$ as the load at port 4. More specifically, Model 1 has $L = 255$ mils, $S = 8$ mils, $W = 16$ mil, $CAP\ A = CAP\ B = 6.8$ pF and $L = 600$ mils

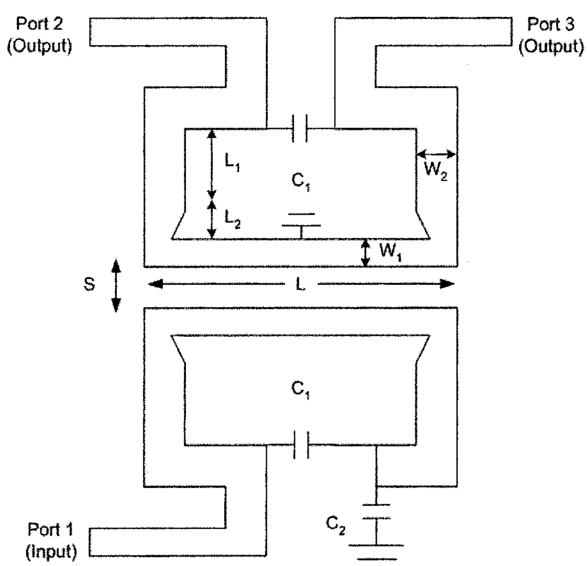


(a) (b)

Fig. 8. (a) Photograph of Model 1 balun; (b) photograph of Model 2 balun.



(a)



(b)

Fig. 9. (a) Diagram of Model 1 balun; (b) diagram of Model 2 balun.

(see Fig. 2). Model 2 has the same dimensions and capacitors except Z_4 is a capacitor $C1 = 1.4$ pF.

TABLE I
COMPARISON OF SIMULATED AND MEASURED PARAMETERS OF MODEL 1 BALUN AT 900 MHz

	$\|S_{21}\|$,dB	$\|S_{31}\|$,dB	$\angle S_{21}$-S_{31}deg	VSWR1	VSWR2	VSWR3
Simulated	-3.5	-3.5	180.4	1.5	2.6	2.6
Measured	-4.4	-4.6	180.2	2.6	1.6	1.7

TABLE II
COMPARISON OF SIMULATED AND MEASURED PARAMETERS OF MODEL 2 BALUN AT 900 MHz

	$\|S_{21}\|$,dB	$\|S_{31}\|$,dB	$\angle S_{21}$-S_{31}deg	VSWR1	VSWR2	VSWR3
Simulated	-3.5	-3.5	180.2	1.2	2.5	2.5
Measured	-3.9	-4.2	176.0	1.2	2.6	2.9

TABLE III
MEASURED PARAMETERS OF WIRE-WOUND BALUN AT 900 MHz

	$\|S_{21}\|$,dB	$\|S_{31}\|$,dB	$\angle S_{21}$-S_{31}deg	VSWR1	VSWR2	VSWR3
Measured	-4.0	-4.0	180.0	1.8	3.5	3.3

The frequency response of these circuits is presented in Figs. 5–7 for circuit 1 and circuit 2. These figures show, respectively, the coupling to two ports (1 to 2 and 1 to 3), phase balance, and VSWR performance at the input and the 2 output ports. Fig. 8(a) and (b) are photographs of circuit models 1 and 2, respectively. Fig.9(a) and (b) are those circuit model diagrams.

Tables I and II give measured and simulated results for each realization while Table III gives similar *measured* performance of a commercial wire-wound balun used for wireless applications.

Based on these results, it may be seen that excellent performance has been achieved over the frequency band of interest. While the commercial wire-wound balun achieves equivalent coupling values, the designs presented in this paper possess superior VSWR, excellent coupling, and significant fabrication advantages.

IV. CONCLUSION

This letter has presented the results of the optimized design of two planar 180°-hybrid balun circuits realized in the 900-MHz wireless frequency band. The designs are unique in that they are extremely compact in size while providing excellent performance and easier fabrication capability in comparison with traditional and wire-wound devices operating in the same frequency range.

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