Design Method of a Dual Band Balun and Divider

°Jung-Hyun Sung*, Geun-Young Kim**, Seok-Ho Son*, Hyo-Jong Lee*, Young-Joo Song, Yong-Woo Jeong, Hyung-Sik Park, Dal Ahn

Division of Information Technology Engineering, Soonchunhyang Univ., R.O.Korea
**School of Information and Communication, Tamna Univ., R.O.Korea
*Micro-Radio Wave Technologies Ltd, R.O.Korea
E-mial : dahn@ramrec.sch.ac.kr

Abstract — **This paper presents the design method and performance characteristics of a dual band balun. The design method for dual band balun is based on the lumped element equivalent circuit of quarter-wave transformer. By employing the proposed configuration and the derived formulas, dual band balun are designed, simulated, and manufactured. The proposed design method and equivalent circuit can make it easy to adapt to designing dual band balun and divider of ceramic multi-layer chip type. The dual band balun and divider are applied to wireless communication system.**

I. INTRODUCTION

The need for dual band components increases with the increase in the use of multi band mobile phones. Baluns are used to form a good transition from an unbalanced transmission line into a balanced transmission line with equal magnitude and phase difference of 180 degrees. Another purpose of a balun is impedance matching. Optimum power is transmitted with the least insertion loss only when the load is matched to the transmission line. This is particularly true for such impedance sensitive components as antennas and low noise amplifiers.[1][2] We had presented in earlier papers 2~4GHz broadband microstrip baluns with two λ/4 stubs and one λ/4 transformer for a single band balun.[3] In this paper, we present design method and simulation of equivalent circuit for a dual band balun and divider. We were also able to verify that the equivalent circuit with lumped elements, such as wound inductors and chip capacitors, would produce satisfactory results in two different frequency bands. Our theory could be used in the design of baluns and dividers with multi-layer ceramic configurations.

II. DESIGN THEORY

Fig.1 shows the equivalent circuit of a balun using transmission lines. In order for the circuits to produce electrical characteristics of a balun, these circuits must have electrical length of $\theta = \lambda/4$, $\phi = -\lambda/4$.

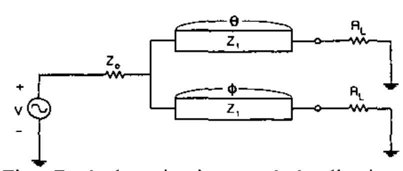

Fig.1 Equivalent circuit transmission line in a balun

Since the reflection coefficient is zero at the input port, characteristic impedance Z_1 of a quarter wavelength transformer is expressed in eq.(1).

$$Z_1 = \sqrt{2Z_0 \cdot R_L} \qquad (1)$$

Each quarter wave transmission line can be represented by π-type equivalent circuit using even-odd mode analysis as shown in Fig.2.[4][5][6]

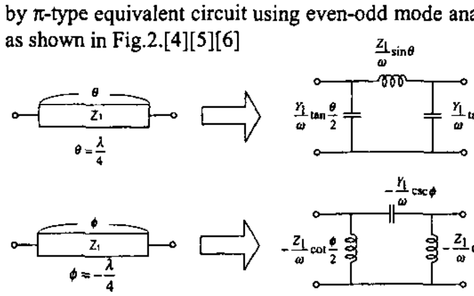

Fig. 2 π-type equivalent circuit for a quarter wavelength transformer.

Each of equivalent circuits produces the high band pass and low band pass characteristics. As the susceptance at the center frequency is zero, the final equivalent circuit is as shown in Fig. 3. In the final equivalent circuit the insertion loss at center frequency is -3dB with ± 90 degree phase difference. Subsequently, phase difference is 180 degrees over the operating frequency range.[5][6]

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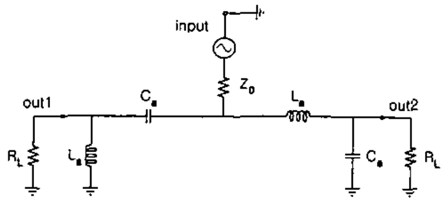


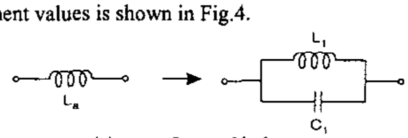
Fig. 3 Final equivalent circuit for a balun

For the equivalent circuit as shown in Fig.1 to perform over dual frequency bands, the elements must meet the conditions set forth in Table I.

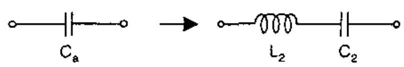
TABLE I
Condition for elements in dual band balun

	f_1 (Frequency 1)	f_2 (Frequency 2)
θ	+ 90 °	- 90 °
ϕ	- 90 °	+ 90 °

As we can see in Table I, the elements must satisfy +90 degrees and –90 degrees in frequency 1 and –90 degrees and +90 degrees in frequency 2. The transform of element values is shown in Fig.4.



(a) transform of inductor



(b) transform of capacitor

Fig. 4 Transform of elements

The transformed element values can be derived at by equation (2) and (3) with invariable impedance. The value of L_a and C_a can be derived at from the impedance value of the transformer.

$$j\omega L_a = \frac{-j}{\omega_0 C_1 (\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega})} \tag{2}$$

$$\text{where } \omega_0 = \frac{1}{\sqrt{L_1 C_1}}$$

$$\frac{1}{j\omega C_a} = j\omega_0 L_2 (\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}) \tag{3}$$

$$\text{where } \omega_0 = \frac{1}{\sqrt{L_2 C_2}}$$

Thus, the final equivalent circuit of a dual band balun is shown in Fig.5.

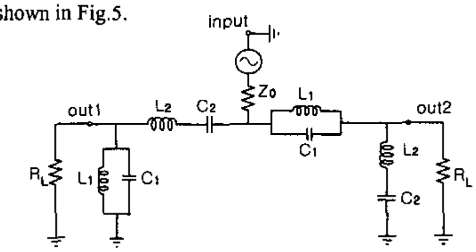


Fig. 5 Final Equivalent circuit of a dual band balun.

Based on the above, we can also achieve a final equivalent circuit for dual band divider as in Fig.6.

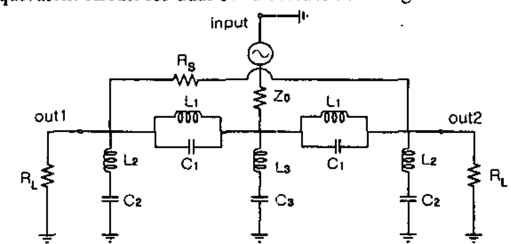


Fig. 6 Final Equivalent circuit for a dual band divider.

III. SIMULATION

Designs and simulations were carried out for dual band balun and divider by the design methods described above. The design specification is shown in Table II and III at the frequencies f_1 and f_2.

TABLE II. Design conditions for dual band Balun

Center Frequency	500.0 ± 50 MHz	1000.0 ± 50MHz
Unbalanced Impedance	50 Ω	50 Ω
Balanced Impedance	50 Ω	50 Ω

TABLE III. Design condition for dual band divider

Center Frequency	500.0 ± 50 MHz	1000.0 ± 50MHz
Port Impedance	50 Ω (-3 dB)	50 Ω (-3 dB)

Results of the simulation for dual band balun are shown in Fig.7~8. As shown in Fig.7~8, magnitude is -3dB and phase is ±90 degrees at each center frequency.

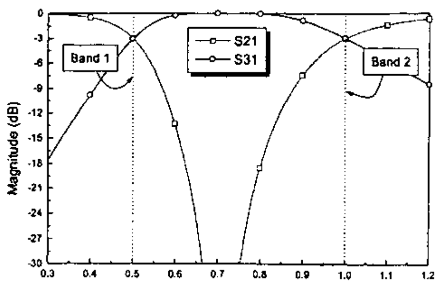


Fig. 7 Magnitude simulation in a dual band balun.

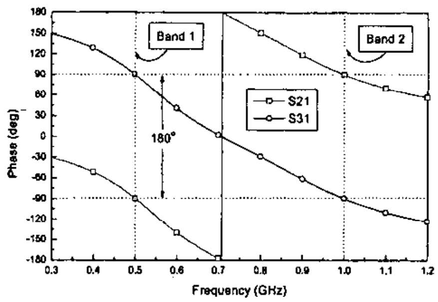


Fig. 8 Phase Simulation in a dual band balun

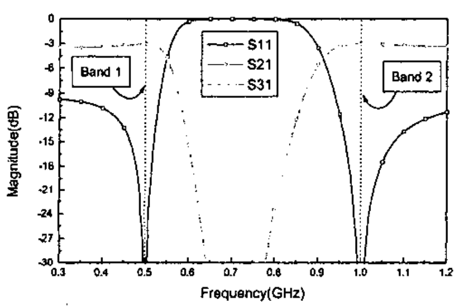


Fig. 9 Magnitude Simulation in a dual band divider.

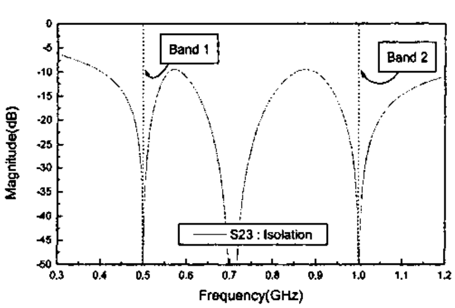


Fig. 10 Isolation simulation in a dual band divider.

Simulation results for dual band divider are shown in Fig. 9~10. We can see from these simulations that the dividing ratio is -3dB and that the isolation for each port is greater than -15dB.

IV. Fabrication and Experimental Results

A dual band balun and divider were made based on the aforesaid simulations. Fig.11 and Fig.13 show magnitude at -3±0.3dB at the center frequencies of 0.5GHz and 1GHz. Shown in Fig.12 is the phase of the dual band balun and in Fig.14 isolation characteristics of the dual band divider. Shown in Fig.12, phase difference at the output ports are 180 degrees with less than a five percent error. This could become smaller if adjustments and modification are made to the transmission lines of the substrate. Fig.14 shows that the isolation in dual band dividers are less than -15dB. Fig.15 and 16 are photo graphs of dual band balun and divider made with wound inductors and chip capacitors soldered on microstrip substrates.

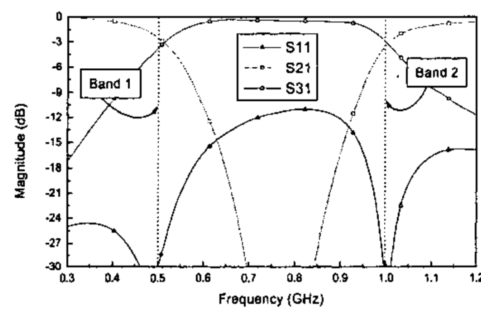


Fig. 11 Measured magnitude results of a dual band balun

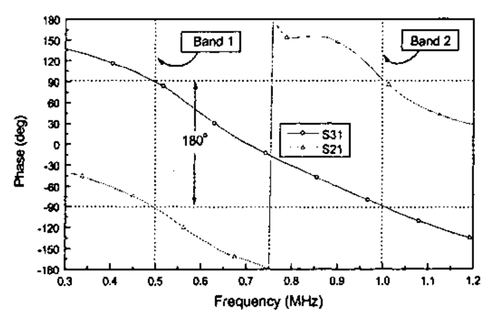


Fig. 12 Measured phase result of a dual band balun.

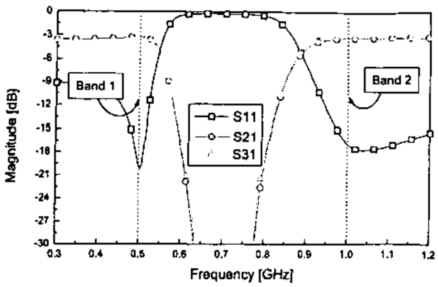


Fig. 13 Measured magnitude result of a dual band divider.

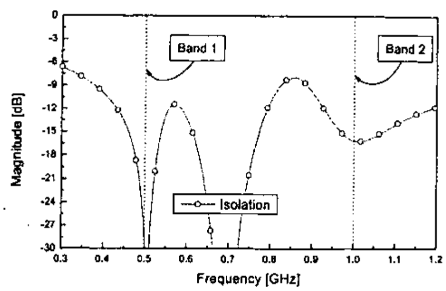


Fig. 14 Measured isolation result of a dual band divider.

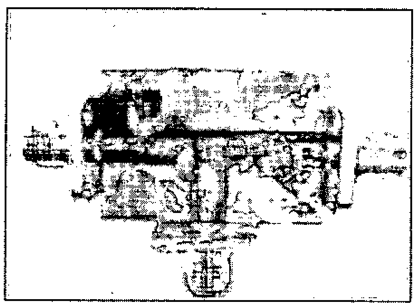


Fig. 15 Photograph of a dual band balun

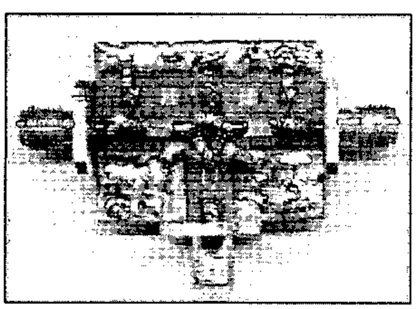


Fig. 16 Photograph of a dual band divider.

V. CONCLUSION

In this paper, we have proposed a simple equivalent circuits and design methods for dual band baluns and dividers. We have also illustrated the results of simulations based on the new and simple equations in Fig. 7~10. From the simulations, we could observe that the circuit designs produce –3dB magnitudes and ±90 degree phase difference in both center frequencies. We have also fabricated dual band baluns and dividers using lumped element equivalent circuits, mounting wound inductors, and chip capacitors. 50 Ohm impedance at the output ports were designed, and Fig.11~14 show the measured results. The magnitudes were measured at –3±0.3dB at the center frequencies, and the phase difference between output ports were measured at 180 degrees with lower than five percent error rates, thus proving that it is feasible to design and fabricate a dual band balun and a divider in single component. It is worth noting that the components mounted on the equivalent circuits in Fig. 5 are capable of being embedded in the inner layers of a multi-layer structure. Consequently, the design of dual band baluns and dividers as presented in this paper can be applied in the design of chip baluns and dividers, other passive components to be fabricated in chips and through LTCC processes applied in the design and modulation of passive components.

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