Lumped and Distributed Lattice-type LC-Baluns

Student paper

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Abstract **This paper presents two balun circuits derived from the lumped Lattice-type LC-balun. First the lumped LC-balun bridge elements are substituted by microstrip lines. This results in an improved performance at the 2nd and 3rd harmonic frequency for RF power amplifier output baluns. Secondly, the lumped Lattice-type LC-balun is extended to a dual band balun. Independent impedance transformation and balun conversion can be done at two different frequencies. The design equations are derived.**

I. Introduction

The lumped Lattice-type LC-balun (Fig. 1) was originally known from the early 1930's as antenna balun [1], [2], [3], [4].

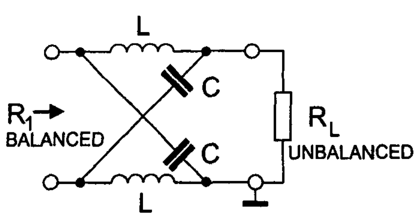

Fig. 1. Lattice-type LC-balun network.

This circuit transforms the balanced input into an unbalanced output by shifting the phase of one input port by +90° and the second input port by −90° and vice versa. Other balun concepts are based on a $\lambda/2$-transmission line ($\hat{=}$ 180°) added to a power divider or a filter structure. [5] shows a microstrip balun with a T-junction with two arms differing in their length by $\lambda/2$ and an even-mode suppression structure.

Baluns like these are required for push-pull amplifiers. As the structure proposed by [5] is rather large for a low dielectric constant ε_r, lumped LC-balun are widely used. Fig. 2 shows the schematics for a push-pull power amplifier usage. The lattice-type balun consists of two

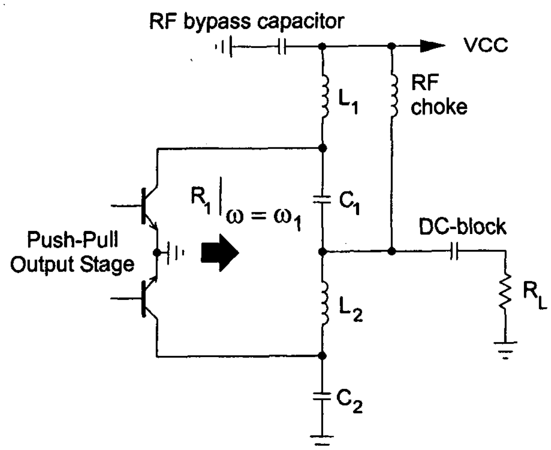

Fig. 2. Lumped LC-balun as push-pull type power amplifier output matching network.

inductances $L_1 = L_2$ and two capacitors $C_1 = C_2$. A RF-choke and a DC-block capacitor are used to feed the supply voltage. R_1 is the balanced input impedance of the bridge. Each collector is loaded by $R_1/2$. R_L is the load resistor, usually $50\,\Omega$. L and C can be calculated by

$$L_1 = L_2 = \frac{Z_1}{\omega_1} \quad (1)$$

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$$C_1 = C_2 = \frac{1}{\omega_1 Z_1} \quad (2)$$

where $Z_1 = \sqrt{R_1 \cdot R_L}$ is the characteristic impedance of the bridge. $\omega_1 = 2\pi f_1$ is the frequency of operation.

II. Microstrip line balun

The four lumped elements of the LC-balun in Fig. 2 can be substituted by transmission lines. We designed a balun where L1, L2 and C2 were substituted by transmission lines while C1 remains as a lumped element. Fig. 3 shows a balun layout for f = 2.4 GHz for a substrate with a thickness of 0.51 mm and an ε_r of 3.38. The radial stub is not necessary if it is replaced by a RF bypass capacitor. However, the radial stub is a good RF short-circuit [6], [7].

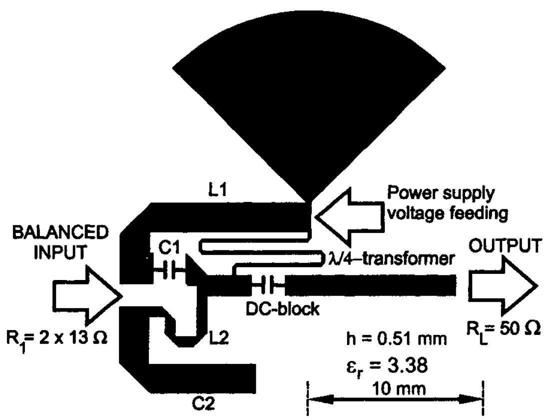

Fig. 3. Microstrip line balun for 2.45 GHz and a substrate with a thickness of 0.51 mm and $\varepsilon_r = 3.38$.

The necessary equations in addition to the Hammerstad [8] formulas are given by:

$$\omega L_1 = Z_0 \tan\theta \quad , \quad \theta \le \frac{\pi}{2} \quad (3)$$

$$\omega L_2 = Z_0 \sin\theta \quad , \quad \theta \le \frac{\pi}{2} \quad (4)$$

$$\omega C_2 = \frac{\tan\theta}{Z_0} \quad , \quad \theta \le \frac{\pi}{2} \quad (5)$$

with $\frac{\pi}{2} \triangleq \frac{\lambda}{4}$ and λ as wavelength [9]. Designing such a balun starts by calculating L and C using Eqn. 1 and Eqn. 2. Next step is the substitution of the lumped elements by transmission lines (Eqns. 3 - 5). C1 is not substituted for the reason, that a long transmission line larger than $\lambda/4$ would be necessary. This would lead to a narrow bandwidth and large outer dimension for low frequencies.

This balun structure shows several advantages to the standard LC-balun solution:

- Only one lumped element is required.
- The use of transmission lines gives two variables per element to adjust the outer dimensions. However this complicates the design procedure and requires simulation tools.
- The second harmonic load impedance shows very low input impedances while the third harmonic load impedance shows very high impedances. Especially for nonlinear operation this leads to high efficient amplifiers [10].
- The outer dimensions are significantly smaller than other microstrip based baluns [5].

Fig. 3 shows the layout of such a balun. It was designed for a center frequency of 2.45 GHz and a load impedance of 26 Ω. Fig. 4 shows the simulated results for fundamental, second and third harmonic frequency.

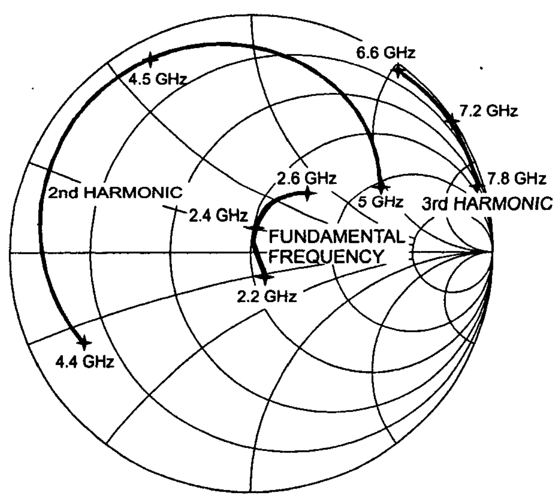

Fig. 4. Simulted results for the load impedance at the fundemental frequency of 2.45 GHz and the second and third harmonic frequency for $Z_0 = 26\,\Omega$.

This balun was tested with a 2.45 GHz power amplifier chip. The power amplifier is presented in [11]. Fig. 6

shows the frequency response of this module. The substrate parameters are $\varepsilon_r = 3.38$, $\tan\delta = 0.0027$ and the dielectric thickness is 0.51 mm. The metallization layers consist of 18 μm copper with a nickel diffusion barrier and 5 μm gold on top for bonding. The lumped capacitor C1 is a 1.2 pF 0805 AVX ACCU-P type capacitor (effective capacity $\approx$ 1.4 pF).

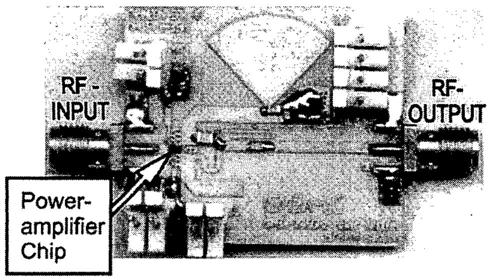

Fig. 5. Photograph of the power amplifier test-board including microstrip line balun (size: 36 x 29 mm^2).

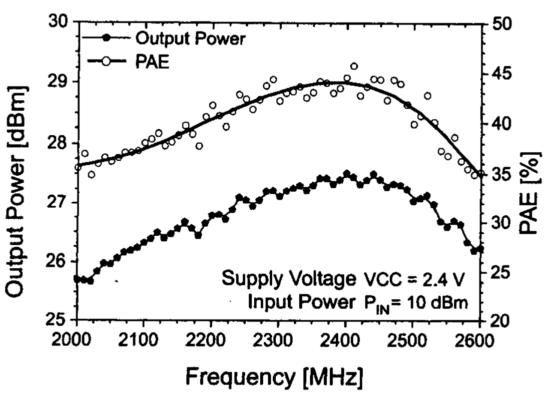

Fig. 6. Measured power amplifier frequency characteristic.

III. Dual Band LC-Balun

For dual band applications an extension to the standard LC-balun can be made: If the inductors are replaced by a parallel resonant circuit and the capacitors are replaced by a series resonant circuit in Fig. 1, then a lumped dual-band LC-balun, shown in Fig. 7, is available.

Using this as an output matching network for a push-pull type power amplifier leads to a schematic shown in Fig. 8. The circuit provides a balanced input impedance R_1 at $\omega_1 = 2\pi f_1$ and R_2 at $\omega_2 = 2\pi f_2$. Independent matching and balun conversion at two different frequencies can be done. L_S, C_S, L_P and C_P can be calculated by

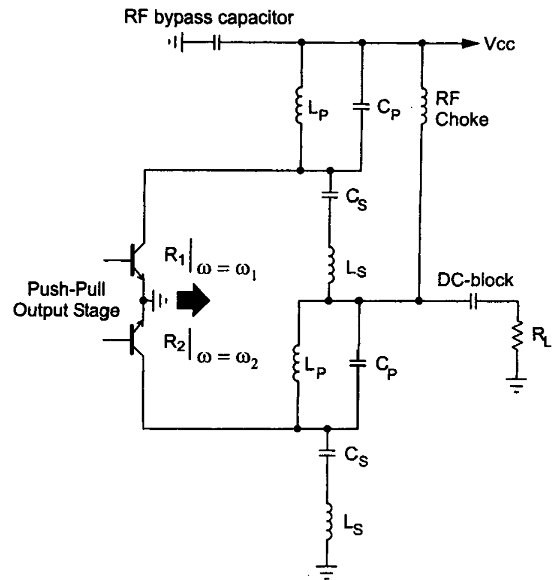

Fig. 8. Dual-band lumped LC-balun as push-pull type power amplifier output matching network.

$$L_S = \frac{\omega_1 \cdot Z_1 + \omega_2 \cdot Z_2}{\omega_2^2 - \omega_1^2} \tag{6}$$

$$C_S = \frac{\frac{\omega_2}{\omega_1} - \frac{\omega_1}{\omega_2}}{\omega_1 \cdot Z_2 + \omega_2 \cdot Z_1} \tag{7}$$

$$L_P = \frac{\left(\frac{\omega_2}{\omega_1} - \frac{\omega_1}{\omega_2}\right) \cdot Z_1 \cdot Z_2}{\omega_1 \cdot Z_1 + \omega_2 \cdot Z_2} \tag{8}$$

$$C_P = \frac{\omega_1 \cdot Z_2 + \omega_2 \cdot Z_1}{(\omega_2^2 - \omega_1^2) \cdot Z_1 \cdot Z_2} \tag{9}$$

where $Z_1 = \sqrt{R_1 \cdot R_L}$ and $Z_2 = \sqrt{R_2 \cdot R_L}$ are the characteristic impedances of the bridge at ω_1 and ω_2. R_1, R_2, Z_1 and Z_2 are assumed to be real valued. Note, that

$$\omega_2 = k\omega_1 \tag{10}$$

with k > 1. For example $\omega_1 = 2\pi\, 900$ MHz and $k = 2$, so that $\omega_2 = 2\pi\, 1800$ MHz, would be well suited for a GSM dual-band push-pull power amplifier.

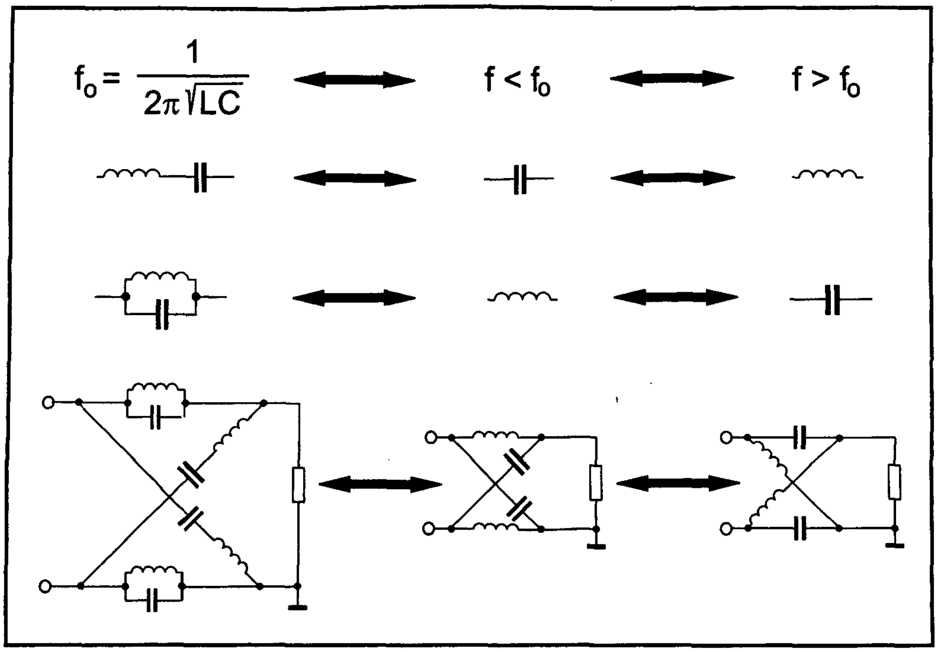

Fig. 7. Equivalent circuit of the dual-band LC balun vs. the frequency.

IV. Conclusions

Two balun circuits derived from the conventional LC-balun bridge are presented. The lumped LC-balun is transformed in a microstrip line balun for the use as a power amplifier output matching network. This results in a low impedance at the 2nd harmonic frequency and a high impedance at the 3rd harmonic frequency to improve the power-added efficiency (PAE). Finally, the lumped LC-balun is extended to a dual band balun. The design equations are derived. Independent impedance transformation and balun conversion can be done at two different frequencies.

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