Balun Design

In the design of mixers, push-pull amplifiers, baluns are used to link a symmetrical (balanced) circuit to a asymmetrical (unbalanced) circuit.

Baluns are designed to have a precise 180-degree phase shift, with minimum loss and equal balanced impedances. In power amplifiers loss of symmetry will degrade efficiency and the symmetrical port must be well isolated from ground to eliminate parasitic oscillations.
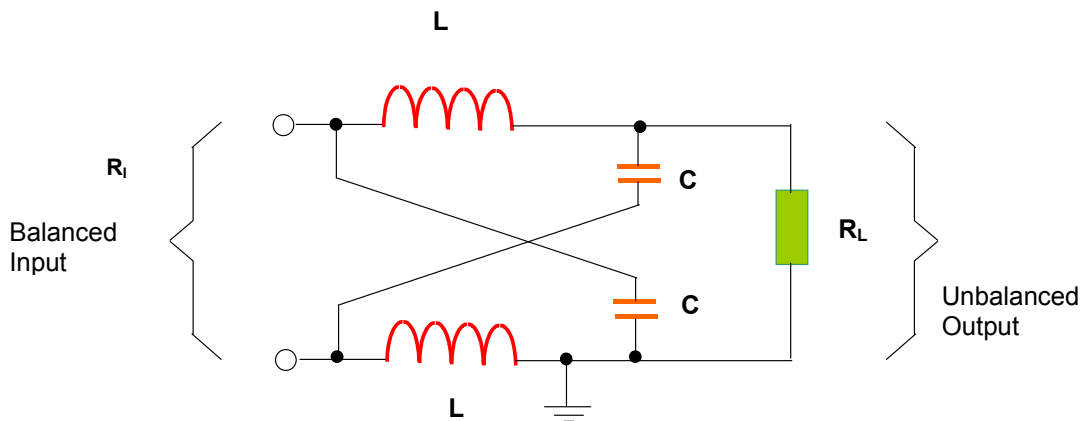
The basic construction/design of a balun consists of two 90-degree phasing lines that provide the required 180-degree split, and this involves the use of λ/4 and λ/2.

A wire-wound transformer provides an excellent balun. Miniature wirewound transformers are commercially available covering frequencies from low kHz to beyond 2GHz. They are often realised with a centre-tapped secondary winding, if grounded this provides a short circuit to even-mode (common-mode) signals whilst having no effect on the differential (odd-mode) signal.

Wire-wound transformers are more expensive than the printed or lumped element baluns described below, which find greater adoption in practical mixer designs. It should be noted that most of these lumped element and printed baluns do not provide the centre-tapped ground to even mode signals and this fact must be accounted for in the mixer design.

(1) L-C Balun

This design is essentially a bridge and is known as a 'lattice-type' balun. It consists of two capacitors and two inductors, which produce the ± 90 degree phase shifts. The diagram below (Figure 1) shows the circuit diagram of the Balun.
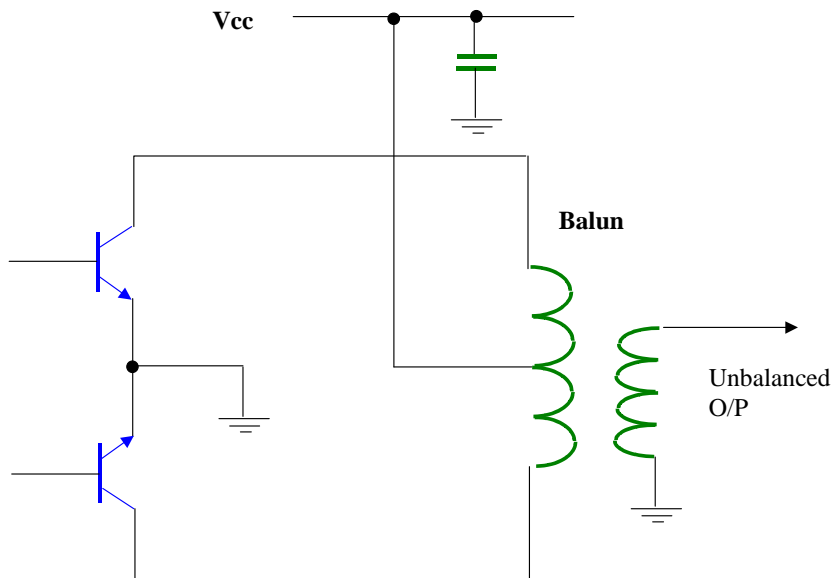

Figure 1 Schematic diagram of a L-C lumped balun.

At operating frequency

$$\omega = 2\pi f \quad \text{and} \quad Zc = \sqrt{R_I.R_L}$$

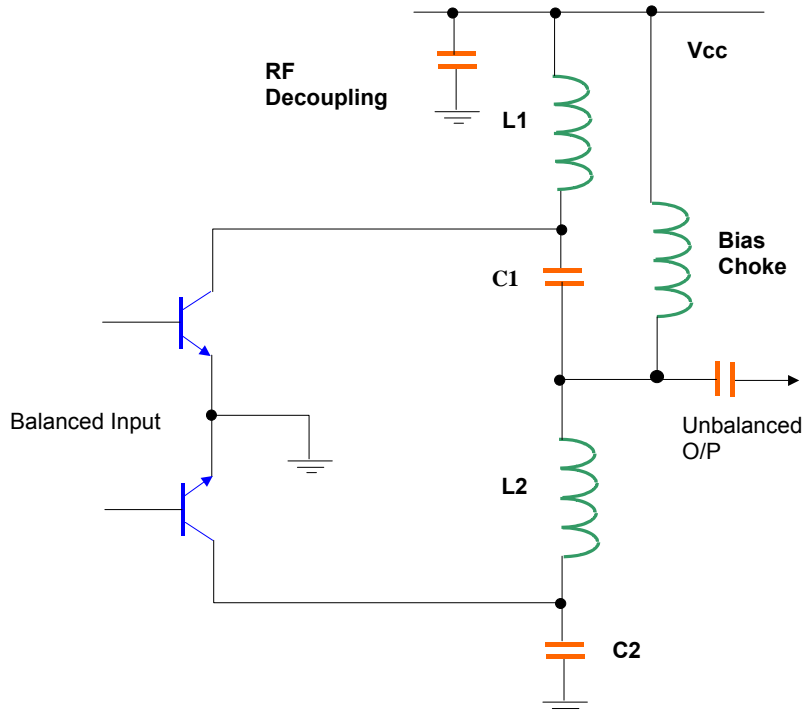$$L = \frac{Zc}{\omega} \quad ; \quad C = \frac{1}{\omega.Zc}$$

When designing this circuit make sure that the operating frequency is well below the self-resonant frequencies of the components and take account of pad capacitances.

One of the main applications of this circuit is on the output of a push-pull amplifier, which provides a balanced signal and we want to convert to a single un-balanced output. Normally a wound toroid style of balun is used as shown in Figure 2.

Figure 2 Use of a wire-wound balun on the output of a push-pull amplifier stage to provide a balanced to unbalanced conversion.

However, it may be convenient especially at chip level to realise the wound transformer type balun, with the previously described lumped balun as shown in Figure 3.
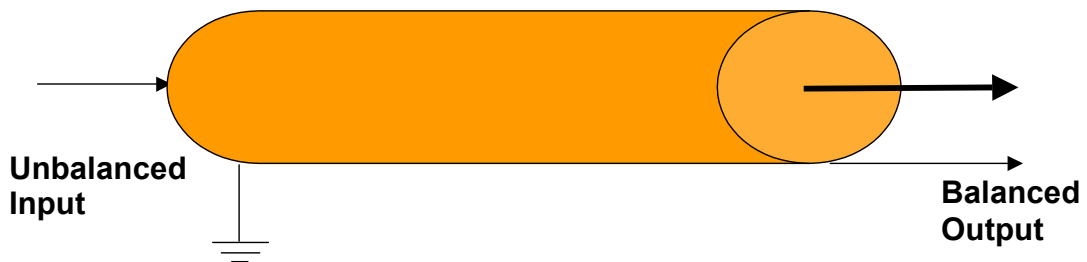

Figure 3 The balanced to unbalanced transformation can achieved by using lumped components instead of a wound transformer.

(2) Transmission Line

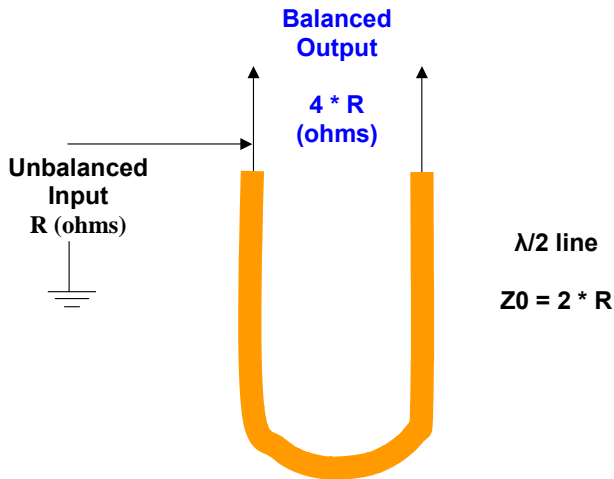This balun can be realised from a λ/4 length of line or coax as shown in Figure 4:

(a) 1:1 Coaxial Balun

Figure 4 Coaxial balun realised from a quarter length of coaxial cable, and gives a 1:1 impedance transformation.

If we require an impedance transformation of 1:4 then we can utilise the coaxial balun as shown in Figure 5.

(b) 1:4 Coaxial Balun

Balanced Output

4 * R (ohms)

Unbalanced Input
R (ohms)

λ/2 line

Z0 = 2 * R

Figure 5 Coaxial balun realised from a quarter length of coaxial cable, and gives a 1:4 impedance transformation

(3) Microstrip

There are a wide-range of printed/micro-strip balun topologies they have the advantage of being inexpensive, realised as they are on the Printed Circuit Board (PCB) or Microwave Integrated Circuit (MIC) substrate. On the downside they can be quite large, particularly at lower RF frequencies. The rat-race coupler is commonly used at microwave frequencies for bandwidths of up to around 10-20%.

Un-balanced Input

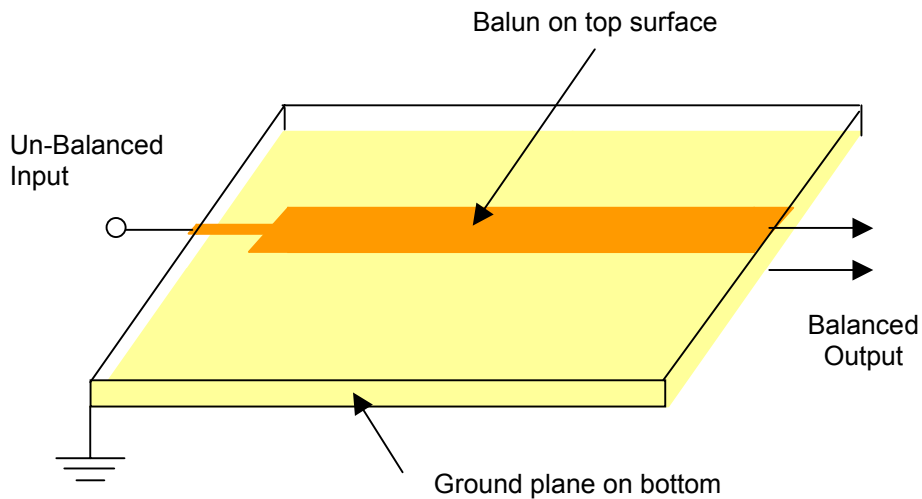Balanced Output

Figure 6 Simple coupled line balun

The simplest printed balun is the coupled line balun, also called a parallel-line balun shown in Figure 6. The structure is a quarter of a wavelength long at the centre frequency. It is capable of bandwidths of over an octave, provided the coupling between the lines is high enough. In practice this is not normally the case for the simple edge coupled balun shown in Figure 7.

Figure 7 Coupled line balun using multiple coupled lines

A more practical approach is to use multiple coupled lines as shown in Figure 7 or, where multi-layer substrate processing is available, to adopt a broad-side coupler topology as in Figure 8.
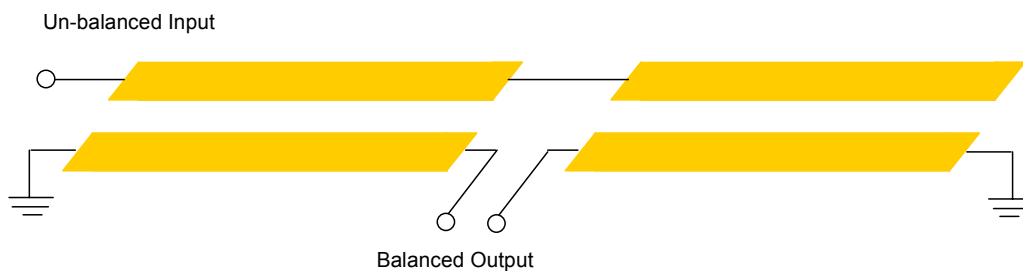
This broadside-coupled implementation is often referred to as a parallel plate balun.

Figure 8 Coupled line balun, using broadside coupler structure

An improvement on the parallel-line balun is a printed version of the "Marchand Balun". This is derived from the co-axial balun, described by Nathan Marchand in 1944 . The printed version of the Marchand balun is shown in its simplest form in Figure 9.
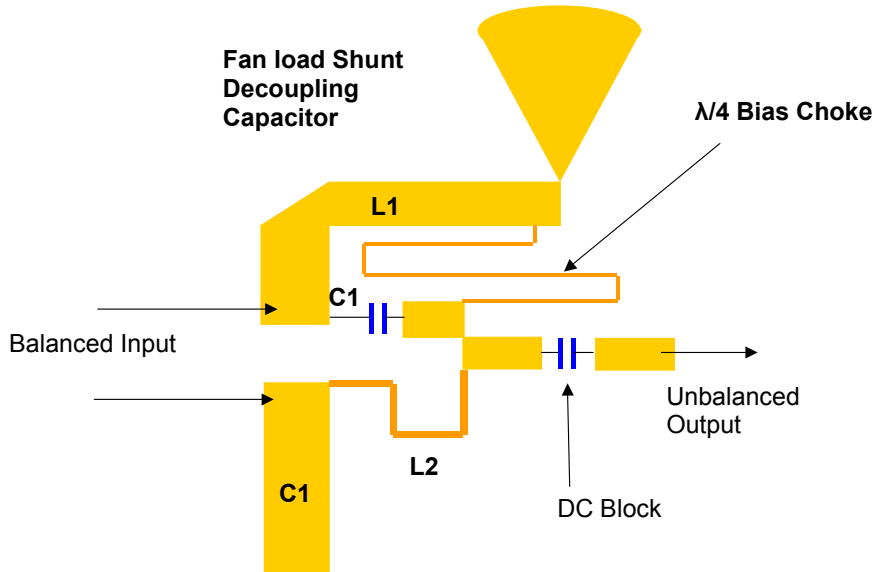
This is more tolerant to low even mode impedance (low coupling ratio) than the parallel line balun and has a wider bandwidth.

Figure 9 Printed Marchand Balun

As with the parallel line balun, improved performance is obtained if multiple planar section are used or if a broadside coupling topology is adopted. One draw back to using these printed baluns at lower RF frequencies is their size. As with the parallel line and Marchand baluns, the use of broadside, rather than edge, coupling will yield tighter coupling and improved performance.

Finally we can realise the LC balun type balun using microstrip techniques. Here we are using the microstrip equivalents of capacitors and inductors as shown in Figure 10.

Figure 10 LC balun type balun using micro-strip techniques to realise capacitors and inductors.

Shunt Capacitors to ground, are realised a low impedance (ie wide track) open circuit stubs, while inductors are realised as high impedance lines (very narrow tracks). The fan load also acts as a shunt capacitor to ground providing RF de-coupling of the network at RF frequencies.