From September 2004 *High Frequency Electronics*

Balanced Circuits: A Review of Their Operation and Behavior

This tutorial review of balanced circuits covers the basic structure and compares them with single-ended circuits in terms of performance advantages and design challenges

Balanced circuits are undergoing a renaissance among engineers designing today's cost-conscious, highly-integrated products. RF, microwave and optical circuits are all seeing greater implementation in balanced topologies than has been seen in recent years. This short tutorial note offers a review of balanced circuits.

Balanced CIrcuit Defined

A balanced circuit is one in which the reference is not ground, but an inverted version of the signal itself—like the classic push-pull circuit with two inputs, each equal in amplitude but with a 180 degree phase difference. Unlike many historic push-pull circuits, which typically comprise two single-ended circuits, a true balanced circuit will have no ground reference in the signal path, with the necessary decoupling of bias voltages symmetrical with respect to ground.

This is illustrated in Figure 1, using a simple 3-section lowpass filter as an example. Figure 1(a) is the familiar single-ended topology. Figure 1(b) shows two filters arranged in push-pull, but each still having a ground reference. Figure 1(c) shows the fully balanced version.

Although the push-pull circuit of Figure 1(b) is generally considered to be balanced, the distinction between it and the ground independent version of Figure 1(c) illustrates a key reason for current interest in balanced circuits, as explained next.

Why Balanced Circuits?

The primary reason for the recent rekindled interest in balanced circuits can be summed up in two words: *via holes*. Integrated circuits have a ground plane that lies below the substrate, while active and passive devices are fabricated on top of the substrate. To obtain a ground reference for single-ended circuits, multiple via holes must be created to make connection between the top and bottom layers. This adds to the cost and complexity of the IC, with the added problem that each via hole has a finite inductance.

At higher frequencies, such as 5 GHz WLAN, the problem is significant. With devel-

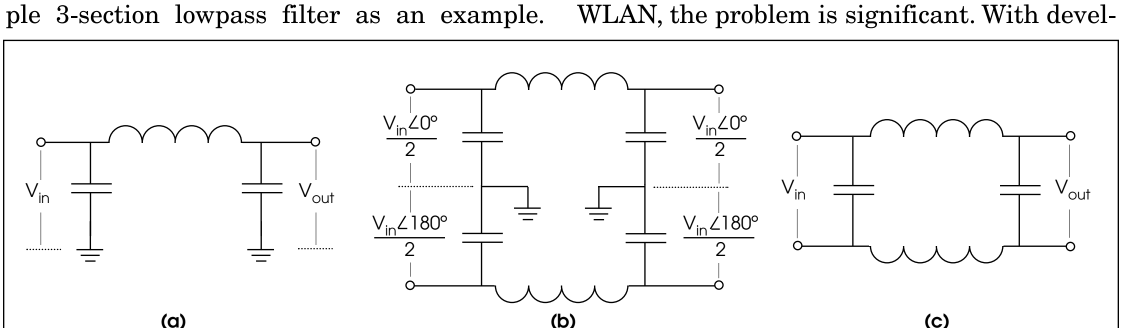

Figure 1 · Evolution from single-ended to balanced topology: (a) A single-ended 3-section filter; (b) Two such filters in push-pull; and (3) A fully balanced filter.

oping technologies at even higher frequencies, alternative topologies like coplanar waveguide and balanced circuits are essential.

A fully balanced circuit can be constructed with via holes located only at the edges of the IC, where the chip must have an interface to the package and external circuitry, whether balanced or not.

Another advantage of balanced circuits is the ability to construct them on an insulated substrate such as sapphire or glass. Without the need for a ground reference, a thin layer of semiconductor material sufficient to fabricate the necessary active and junction devices can be deposited, and passive components can be created with metallization directly on the substrate. Since the substrate has better dielectric properties than silicon, GaAs and other materials, the passive components will have much higher Q than those fabricated on a typical semiconductor substrate.

In addition to the elimination of the direct inductance of via holes, balanced circuits also have lower parasitic inductance and capacitance. The balanced topology effectively divides parasitic capacitances in half (as long as the layout is symmetrical) since they now appear in series, like the ground-referenced push-pull capacitors of Figure 1(b).

Design Challenges

The majority of design difficulties with balanced circuits are in the interfaces to the unbalanced "real world" of microstrip and coax. Narrowband balanced-to-unbalanced (balun) circuits are relatively straightforward, but broadband baluns are much more difficult. Some of the most common balun techniques are shown in Figure 2(a-d).

For many years, active devices have been used in current-mirror circuits [Figure 2(a)] to provide balanced signals for internal IC operation, providing generally good performance. They are less common in MMICs than in general purpose baseband and IF RFICs, but are getting renewed attention as a microwave design option.

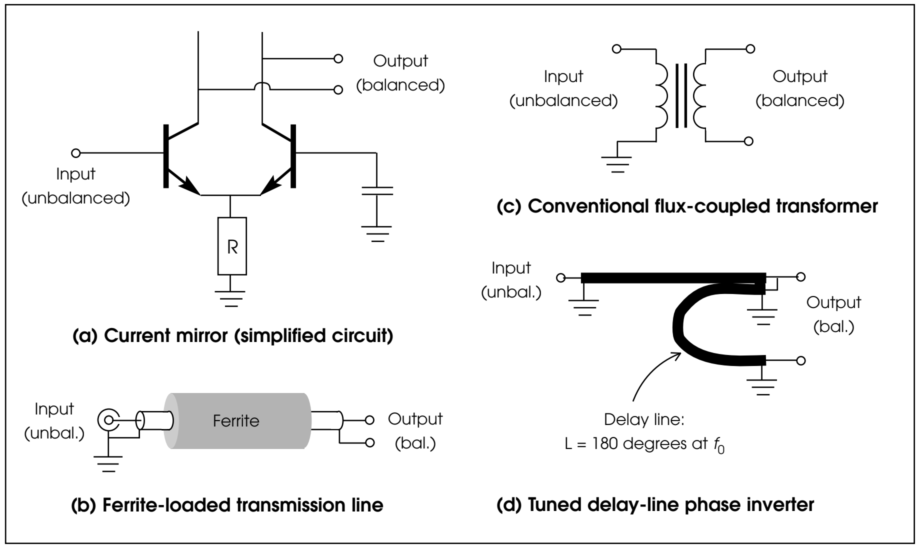

Figure 2 · Some design options for interfacing between balanced circuits and unbalanced external circuits.

Passive baluns with broadband performance are usually transmission line structures. At lower frequencies, ferrite-loaded transmission line transformers [simplest version shown in Figure 2(b)] can provide multi-octave performance, but with an upper frequency limit around 100 MHz where the physical length of the transmission lines becomes an appreciable fraction of a wavelength, degrading the performance. Baluns covering a few hundred kHz to 50 MHz with good balance and very low loss can be constructed.

If some additional loss can be tolerated, tightly-coupled conventional transformers [Figure 2(c)] wound on ferrite or iron powder cores can provide similar bandwidth, although they cannot match the power-handling of transmission line transformers.

Tuned transmission line balun structures are relatively easy for narrowband applications at VHF and above [Figure 2(d)]. Cascaded structures can obtain bandwidths of octaves or even decades, but with greatly increased complexity and the requirement for tight control over mechanical symmetry to maintain amplitude and phase balance.

Measuring Balanced Circuits

Another significant challenge with balanced circuits is accurate measurement of typical performance parameters. The same issues that apply to all balanced circuits apply to the input and output circuits of test instruments. Currently, two practical options are being used for connections to balanced circuits: a balun with adequate performance for the frequencies involved, or two well-matched single-ended channels that can be used in push-pull to create the equivalent of a balanced system.

The difficulties of making good baluns was noted previously, and the challenges of making two identical generator or detector channels in a spectrum analyzer, network analyzer or other instrument are obvious.

Summary

Balanced circuits are important in today's microwave ICs, simplifying fabrication and reducing parasitics. However, they require additional engineering effort to interface them to unbalanced external circuits.