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Quantifying Accuracy of Balanced Circuits

Balanced circuits have existed for a very long time, having first been developed to reduce noise and crosstalk in telephone circuits. Implementation in push-pull amplifiers was another early use, simplifying output coupling to open-wire balanced feeders used in many antenna systems. As unbalanced coaxial lines replaced balanced lines, the ability of balanced circuits to reduce even-order harmonics became the primary factor for their use.

In addition to classic push-pull designs, other circuits take advantage of topologies that use the anti-phase properties of balanced circuits to provide cancellation of unwanted signals. Applications include hybrid couplers that provide isolation between ports, and the well-known double-balanced mixer that offers isolation at RF and LO frequencies, easing post-mixer filtering requirements.

Recently, balanced circuits have become popular for dealing with the difficulty of maintaining a low impedance ground plane in microwave MMICs. With very low ground (or *common mode*) currents, the performance of the ground plane in a balanced circuit has much less effect on performance than in an unbalanced design.

How Good is the Balance?

To examine the quality of a balanced circuit—the magnitude of the imbalance—we'll use Figure 1, a balanced circuit connected to a balanced load. The source and load are shown as split elements that include the midpoint potential of each, which in practice may be either a physical or virtual ground.

The balance error is the common mode voltage differential between the source side and the load side of this circuit.

First, let's look at the effect of amplitude error. As an example, let use a 1.0 volt source with a 1 dB difference between V_1 and V_2, thus:

$$V_1 = 0.89 \cdot V_2$$
$$V_1 + V_2 = 1$$

Solving these two equations, we determine that:

$$V_1 = 0.471 \text{ volts}$$
$$V_2 = 0.529 \text{ volts}$$

Since the "ground" potential on the load side is simply half the total voltage, or 0.5 volts, the difference (common mode voltage) can be shown as:

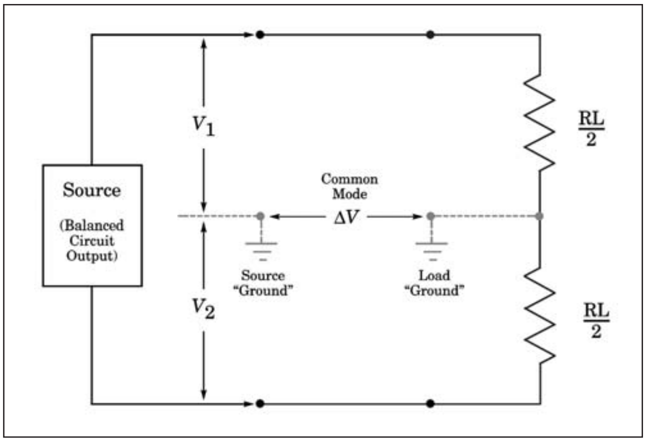

Figure 1 · A balanced circuit, showing the ground potential (virtual or physical) of the source and load and the common mode path.

$$\Delta V = 0.529 - 0.5 = 0.029 \text{ volts}$$

or –30.8 dB relative to the 1.0 volt source.

The same exercise can be done for phase error. With the same 1.0 volt source signal level and each branch having equal amplitude, a 20° phase difference between V_1 and V_2 results in $\Delta V = 0.015$ volts, or –36.5 dB relative to the 1.0 volt source.

What Accuracy is Required?

For either common mode rejection or anti-phase cancellation, the required accuracy depends on the application. Different designs have varying sensitivity to the level of common mode voltage (and current). Distortion, harmonic levels and stability are all factors that can be affected by deviations from ideal balance.

A general purpose amplifier with moderate gain and AC coupling to prior and following stages will not need the highest performance. But a high gain, high dynamic range CATV line amplifier or a precision instrumentation amplifier may require 50 dB or more common mode rejection. A good source for additional insight on common mode rejection performance is the literature on classic operational amplifiers.

In circuits using the anti-phase cancellation property of balanced circuits, the change in rejection is much more sensitive to balance accuracy than with common mode rejection. The same 1 dB amplitude difference noted earlier results in just 19 dB cancellation. Also, some topologies have two or more interconnected balancing devices that multiply the error, requiring even greater accuracy.