Balanced Measurement of Unbalanced Circuits

“The world is going differential!! What can we do??” is the latest quote heard peeping around the barnyard. An obvious response is to develop a whole new line of balanced measurement systems to deal with fully differential circuits. If we dig a little deeper, we can demonstrate that fully balanced measurement systems are preferred for all measurements—not just the latest differential amplifiers, mixers, filters, and oscillators. Furthermore, we don't have to reinvent everything. Balanced measurements are old, and we can borrow a few mature techniques from low frequency engineering.

The Most Basic Electrical Measurement Tools are Balanced

Figure 1 is a Simpson VOM. It is a relic from an earlier era when Electrical Engineers were expected to know what was inside their tools and the implications of spec’s like “20,000 ohms per volt.” The Simpson VOM is a fully differential, balanced measurement tool. It has two leads, and the bakelite case ensures that there is no inadvertent third ground connection. Each lead has the same high impedance to ground, and when making AC measurements, the leads may be reversed with no change in the measurement. Let's use the Simpson VOM to introduce the vocabulary of balanced measurements.

Definitions:

Balanced: two conductors with identical impedances to ground
Differential voltage: voltage between the two conductors
Differential current: equal and opposite currents in two conductors
Differential impedance: impedance between the two conductors

Balanced and Differential Sources

We may also define balanced and differential sources as the complement to balanced, differential measurement instruments. An example at DC is a AA cell. It has two connections, each has a very high impedance to ground, voltage is measured between the two ends, all current that flows out one end flows into the other end, and it has a low impedance between the two ends. Either end may be connected to ground, and any number may be connected in series or parallel. Nearly ideal low-frequency balanced, differential AC sources may be built using transformers.

High Frequency

High Frequency in this context means that phase shift along transmission lines is significant. One electrical degree is on the order of 1 meter at 1 MHz. When a transmission line is many electrical degrees long, reflected signals will constructively and destructively interfere with signals traveling from the source to the load, causing standing waves on the line. An understanding of transmission line theory and tools such as the Smith Chart must be used at high frequencies. Reflections and standing waves are generally ignored in audio engineering. A differential source has by definition 180,000 degrees of phase difference between the two conductors. A one degree phase error on a 1 volt differential source means that 10 millivolts is unaccounted for.
An Ideal High Frequency System

\[ R = Z_0 \]

\[ 2 \cos(2\pi ft) \text{ volts} \]

\[ 1 \cos(2\pi ft - \beta \ell) \text{ volts} \]

An Ideal High Frequency Measurement

\[ R = Z_0 \]

\[ 2 \cos(2\pi ft) \text{ volts} \]

Typical High Frequency System with Strays

\[ R = Z_0 \]

\[ 2 \cos(2\pi ft) \text{ volts} \]

Ramifications Chapter 2 verse 6 ...and every such circuit that is built shall not behave as predicted by the wise, nor by their texts, nor yet by their great engines of prediction, and they shall be humbled and brought low before their peers.
The Dangerous Fictional Symbol:

Ideal Coax: Solid conducting block with hole; perfectly conducting center rod

Lossless, all energy travels in EH Fields in space between rod and block

Still OK

Not any more
A Simple Model of the Coax Problem

Coax Drive with unbalanced Load.

Maybe OK

Not Good

Generally Not Good
Two Well-Known Cures

Widely used from 0.1 Hz through about 10 MHz

Example: Jensen Transformer

Useful from 100 Hz to 100 GHz and beyond

Example: Ferrite Sleeve Balun; H-4