



multi media manufacturer

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Manager's Guide to AV Design & Development

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High-Performance Balanced Audio Interface Design, Part 1

By Bill Whitlock

■ *Balanced interfaces, at least in theory, are immune to interference of all kinds. For 50 years, virtually all audio equipment used transformers at their balanced inputs and outputs. High noise rejection was taken for granted, while very few engineers understood the reason: the transformer's extremely high common-mode impedance—about a thousand times that of its solid-state "equivalents." Widespread misunderstanding of the meaning and underlying theory of balanced interfaces has resulted in all-too-common design mistakes and seriously flawed testing methods. Therefore, noise rejection in today's real-world systems is often inadequate, or at best, marginal. Traditional input stages will be discussed and compared. I will describe a novel IC that compares favorably to the best transformers. Other topics will include tradeoffs in output stage design, effects of non-ideal cables, and a design error called the "pin 1 problem."*

INTRODUCTION

"At present I give seminars and do consulting work. The seminars have changed over the years because I am always trying to provide better ways to describe the general issue of interference control. The buzzwords in the engineering community are still **grounding** and **shielding**. These are the words that attract attention and get students to sign up for a course. It is a trick because grounding is usually **not** the way to solve interference problems. It is important to know what grounding is all about, and then we can talk about the **real** issues.

A circuit diagram does not show physical size, relative position, physical spacing, or interconnection order. It says nothing about parasitics or loop area. The effects of long cables or of the power grid are not even suggested. The electrical nature of the facility is not represented. Yet with all this missing

information the engineer is supposed to function. It is a deep mystery to most, and the easy way out is to ignore it all until there is a problem."

—Ralph Morrison, *Solving Interference Problems in Electronics*, 1995, reprinted by permission of John Wiley & Sons, Inc.

High signal-to-noise ratio is a very important goal for most audio systems. However, AC power connections unavoidably produce ground voltage differences, magnetic fields, and electric fields. This makes the task of transferring an analog audio signal from one system component to another, while avoiding audible contamination, anything but trivial.

The dynamic range of a system is the ratio, generally measured in dB, of its maximum undistorted output signal to its residual output noise or noise floor. Fielder has shown that as much

as 120dB dynamic range might be required in high-performance sound systems in homes¹. The trend in professional audio systems is toward increasing dynamic range, fueled largely by increasing resolution in available digital converters.

Analog *signals* accumulate *noise* as they flow through system equipment and cables. Once noise is added to a signal, it's impossible to remove it without altering or degrading the original signal. Therefore, noise and interference must be *prevented* along the entire signal path. Of course, a predictable amount of random or "white" noise, sometimes called "the eternal hiss," is inherent in all electronic devices and must be expected. Excess random noise is generally a gain structure problem, a topic beyond the scope of this series.

Ground noise, usually heard in audio signals as hum, buzz, clicks, or pops, is generally the most noticeable and irritating. In fact, even if its level is significantly lower than background hiss, it can still be heard.

Ground noise is caused by ground voltage differences between the system components. Most systems consist of at least two devices that operate on utility AC power. Although hum, buzz, clicks, and pops are often blamed on "improper grounding," in most cases there is nothing improper about the system grounding. To ensure safety, all user-accessible connections and the equipment enclosure *must* be connected to the safety ground conductor of the AC power system. A properly installed, fully code-compliant AC power distribution system will develop small, entirely safe voltage differences between the safety grounds of all outlets. In general, the lowest voltage differences (typically less than 10mV) will exist between physically close

outlets on the same branch circuit, while the highest (up to a few volts) will exist between physically distant outlets on different branch circuits.

These normally insignificant voltages cause problems only when they exist between vulnerable points in a system—which is more unfortunate than improper. Users who don't understand its purpose will often defeat equipment safety grounding—a practice that is both illegal and extremely dangerous. *Safety must supercede all other considerations!*



Although UL-listed equipment supplied with a two-prong power cord is safe, its normal leakage current can still produce troublesome ground voltage differences. This topic, as well as unbalanced interfaces, is also beyond the scope of this series; both are under consideration for later articles.

Ground noise is very often *the* most serious problem in an audio system. As Bruce Hofer (Audio Precision's co-founder and principal analog design engineer) wrote: "Many engineers and contractors have learned from experience that there are far more audible problems in the real world than failing to achieve 0.001% residual distortion specs or DC-to-light frequency response"². Carefully designed and executed system grounding schemes

can reduce ground voltage differences somewhat but cannot totally eliminate them.

The use of "balanced" line drivers, shielded "balanced" twisted-pair cables, and "balanced" line receivers is a long-standing practice in professional audio systems. It's tantalizing to assume that the use of balanced outputs, cables, and inputs can be relied upon to eliminate such noise contamination. In theory, it is a perfect solution to the ground noise problem, but very important details of how to convert the theory to practice are widely misunderstood, even by experienced equipment designers. Therefore, many products might work perfectly on the test bench, but will become a headache when connected into a system.

Many designers, installers, and users believe grounding and interfacing is a "black art." College electrical engineering courses rarely mention practical issues of grounding. It's no wonder that myth and misinformation have become epidemic! Especially in the "high-end" segment of the audio industry, science, evidence, and common sense are often discarded in favor of religious zeal, marketing hype, and huge profits. Remember, the laws of physics have not changed!

I hold equipment manufacturers and their marketing departments responsible for most of the problems we will talk about. Having a DSP genius in the engineering department is nice, but someone needs to understand real-world analog interfaces if a manufacturer expects to have satisfied customers. "System friendly" inputs and outputs are just as important as "gee-whiz" features. **M³**

REFERENCES

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ment," *Journal of the Audio Engineering Society*, May 1995, pp. 322-339.

2. Hofer, Bruce, "Transformers in Audio Design," *Sound & Video Contractor*, 15 March 1986, p. 24.

Bill Whitlock was hired by transformer expert Deane Jensen to be chief engineer at Quad-Eight, at that time the world's premier custom console maker. Whitlock developed the Compumix fader automation system that was used by Neil Young, Ken Nordine, MGM, Warner Brothers, and many others worldwide. He moved on to Laser Images, where he designed automated electronics that were deployed at 20 of the world's best planetariums. Ongoing work led to development of a VHS-cassette-based four-channel digital audio and data recorder for which Whitlock was granted US Patent 4,030,129 in 1976.

In 1981, Capitol Records hired Bill as manager of electronic engineering. His department developed custom equipment used for recording, mastering, duplication, and quality control in Capitol/EMI plants around the world. He designed high-speed (64x) duplicator electronics, including HX Pro, for Capitol's XDR pre-recorded cassettes, which became quality benchmarks. His most am-

bitious project was to develop a system to record cassettes at high speed directly from digital masters (without an intermediary analog master).

In 1988, Bill and Deane Jensen began working together as a consulting team. Deane died in October 1989 and his will left financially-troubled Jensen Transformers to Bill. Fortuitously, he was asked to develop the Spatializer concept into both a consumer IC for Panasonic and a professional 3-D panning system for mastering. This income helped save Jensen. By 1994, Bill had become an expert on balanced interfaces and audio transformers. He started sharing his insights in his first lecture at a 1994 local AES workshop with Neil Muncy. This led to his landmark paper, published in the June 1995 **Journal of the AES**, and the invention of a novel balanced input circuit for which he was granted US Patent 5,568,561 in 1996.

In 2002, Bill conceived an innovative high-speed "feed-forward" AC power regulator. He was awarded US Patent 6,653,824, which is licensed to Pinnacle Power Quality Systems, makers of the ExactPower line-voltage regulator. Bill also has a patent pending on downward-compatible three-conduc-

tor (balanced) versions of RCA connectors, allowing migration of consumer interfaces to balanced without making existing equipment obsolete.

Bill has been a member of the Audio Engineering Society since 1966, presenting numerous papers and tutorial seminars. He is a member, and former chair, of AES standards committee working group SC-05-05, which authored AES48-2005: AES Standard on Interconnections, Grounding and EMC Practices. Bill also co-authored a major change to IEC standard 60268-3: Test Procedures for Balanced Inputs and Outputs of Audio Equipment, issued August 2000. He is also a senior member of the Institute of Electrical and Electronic Engineers. Since 1994, Bill has been writing and lecturing, authoring ongoing columns and dozens of articles for trade magazines, writing chapters for textbooks, and attracting more than 5,000 students to his seminars at industry trade shows, universities, trade schools, and private companies. As president and chief engineer of Jensen Transformers, Bill currently designs Jensen's audio, video, and other signal interfacing devices and handles much of Jensen's technical support. He also does consulting as time permits.