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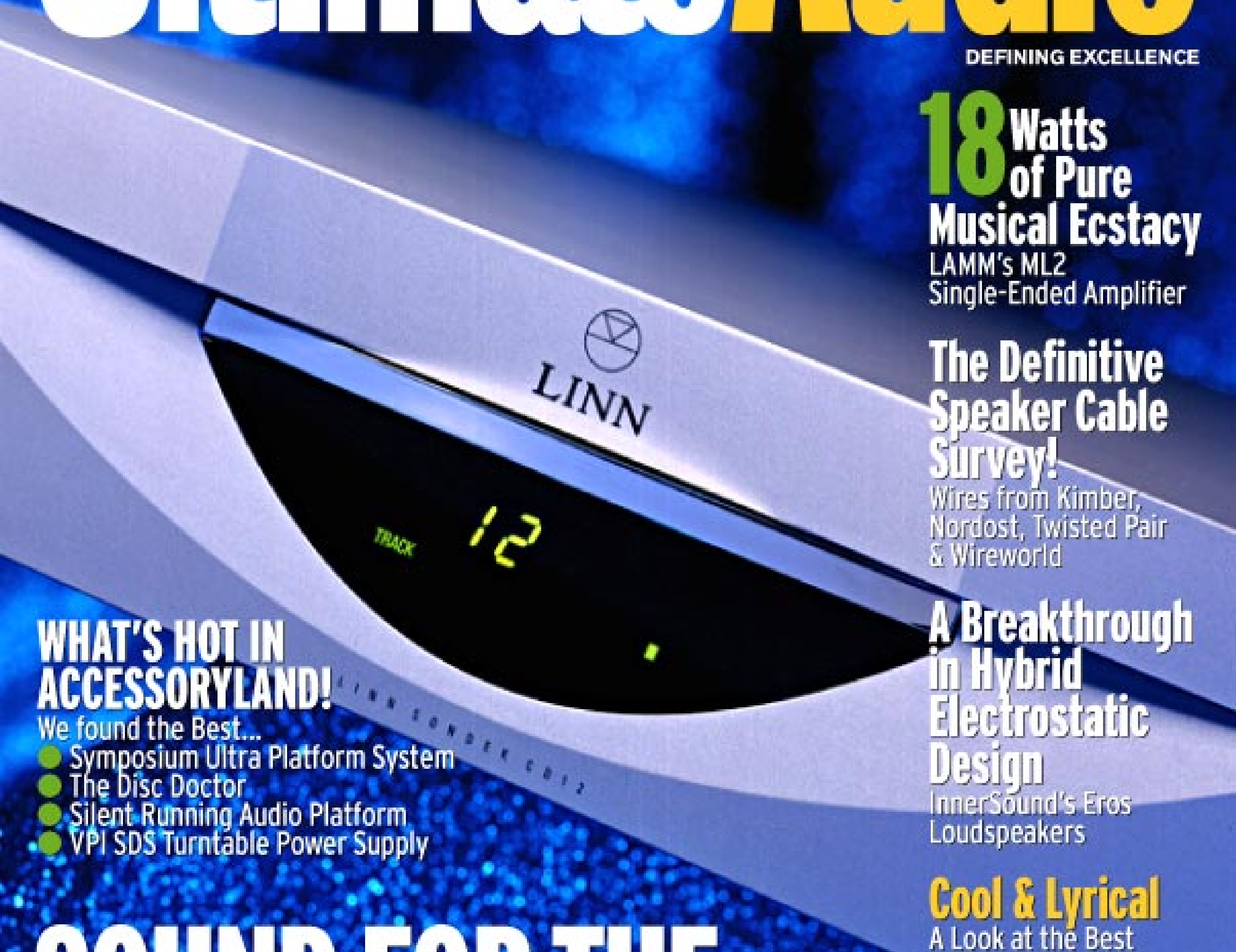

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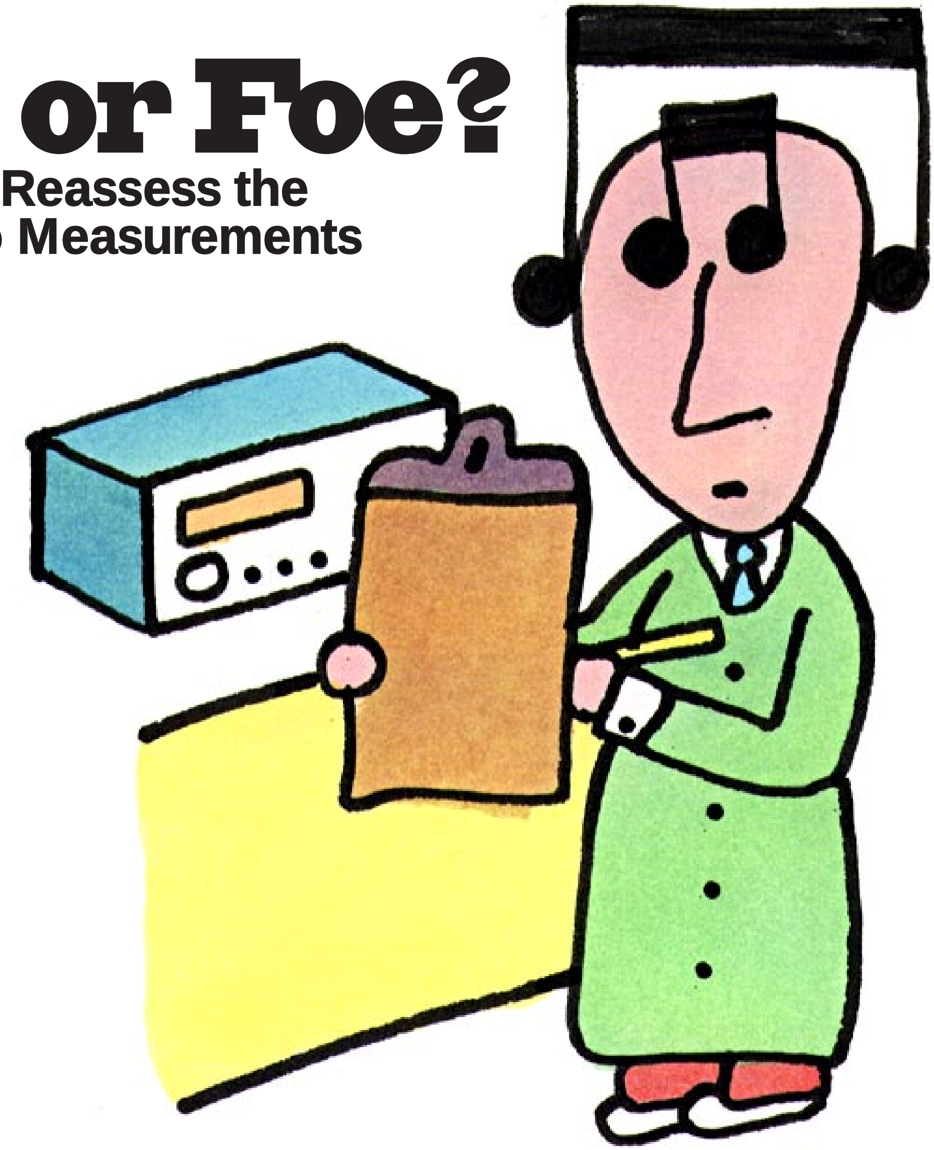
Friend or Foe?

High End Designers Reassess the Importance of Audio Measurements

BY MYLES B. ASTOR



Revolution was in the air. Rebelling against the establishment was the in thing to do in the '60s. It was a time of social turmoil and the birth of new ideas. A time for distrust of the establishment—and in the case of audio, of test measurements. And there were good reasons back then not to trust the measurements. This was an era when J. Gordon Holt, the founder of *Stereophile* magazine recalls, "Everyone selling audio equipment lied about their measurements. Published specs were not accurate." Eventually this resulted in magazines being entrusted with corroborating manufacturer-supplied test data and, in the long run, the standardization of measurements.

Holt led the revolt against using only audio measurements to evaluate audio equipment. Serving as chief equipment tester for *High Fidelity* magazine, he was becoming increasingly frustrated with its editorial policy. Holt believed that *High Fidelity* was only paying lip service to the sound of components. After all, audio equipment couldn't reproduce life-like music; so why even care? Holt was disturbed in particular by his observation that "two amplifiers that measured close to each other sounded dramatically different." The realization that measurements have little relationship to sound quality didn't come as "an epiphany," Holt recalls, but rather something he had experienced over the years. So as with most revolutions, changes were more of a gradual evolution.

Holt eventually left *High Fidelity* magazine and joined Weathers, where he was entrusted with writing their dealer's newsletter. Over time, the demand for Weathers' newsletter by customers outstripped that of dealers. So in 1963, Holt, with a background in journalism and a love of audio (and music) since age 14, decided to take the plunge and launch his own newsletter titled *Stereophile*.

Holt was quick to point out that the Hirsch-Houck newsletter was the first audio newsletter, not *Stereophile*. All similarities between the two publications, however, ended there. Reviews in the Hirsch-Houck newsletter were based entirely upon measurements and, as JGH observed, " really didn't tell us anything we didn't already know."

Stereophile was far from an overnight success. Holt recalls the initial "lukewarm" reaction to the newsletter. There were few letters of congratulation (like you see regularly published in today's magazines). Audiophiles discovered the newsletter over time. And so the subjectivist school of audio reviewing was born—and the battle between objectivist (lovingly known as "obs") and subjectivist ("subs") camps was born.

Like in the '60s, there's still an intense sense of distrust between the two camps. Part of this is the realization that today's standard static bench tests were selected to make audio equipment look its best. Probably the most infamous examples of measurements leading us down the garden path were the horrible sounding, triple naught distortion amplifiers of the '70s. Why is it that tube gear, with decidedly poorer measurements than transistor-based equipment, is growing in popularity? Even more recently, there's the digital audio debacle.

Yet today's leading high-end audio designers haven't given up hope that they will eventually find a set of measurements that correlates with what we hear to aid in the design of audio equipment. As Holt noted in the '60s, "Observations have gone far beyond our ability to explain," and, "We haven't found any measurements to describe what we are hearing." Forty years later, we're still struggling with these issues. Will the next millennium bring us any closer to the answer? We've approached a cross-section of high-end audio's leading electronic, speaker and cable designers to find out what they think; we asked them:

● What technical measurement comes the closest to predicting the sound of a piece of electronics or speakers, and why?

ILLUSTRATION BY STUART GOLDBERG

● At what point in the design of a component do you switch from using measurements to listening?

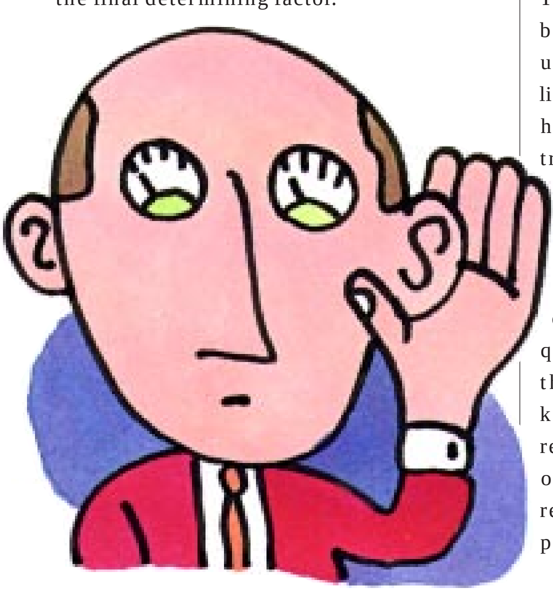
● Finally, do you think we will ever see the day when we have a set of measurements that will accurately predict the sound of a component?

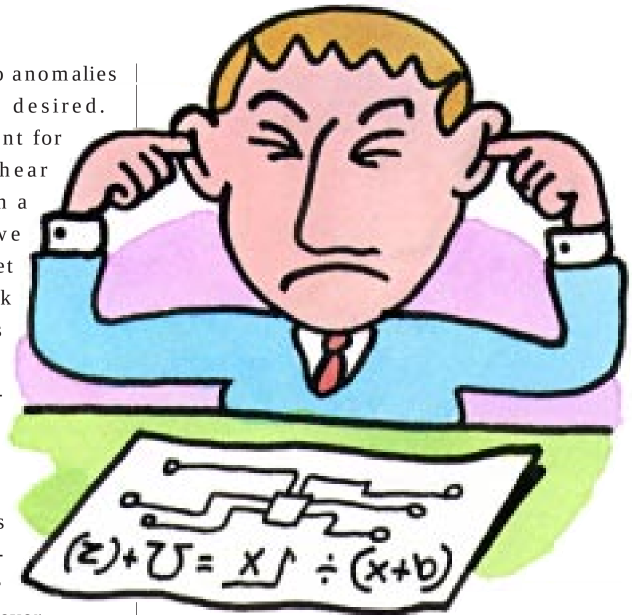
Here's the initial installment of their thoughts on the subject of whether there's been any progress in correlating test measurements with sound quality of audio equipment.

George Cardas, CEO, Cardas Audio

A cable's ability to replicate a waveform, such as a square or triangle, is one measure I use. High resolution programmable oscilloscopes can find the "thumb print" of many audible anomalies. FFT analysis and harmonic distortion testing can also be a predictor of anomalous behavior. There is a very interesting AES paper presented by Jon Risch at the latest AES convention, in which he explains a system for measuring cable distortion using a TEF-20 and a PHI series of tones (AES Preprint #4803, "A New Class of In-Band Multitone Test Signals," AES website, http://www.aes.org). It clearly shows differences between cable and cabling systems, such as bi-wiring. His system plots harmonic distortion in cable current transfer. I am now working on a commercial implementation for this system.

Correlating measurements with audible performance is part of a continuing, evolutionary process. My designs are well-formed internally before the prototype runs. Usually the results are very close to expectations. In the final analysis, I find that I switch back and forth constantly, but listening is always the final determining factor.





Correlating measurements to anomalies is easy, if that is all that is desired. However, having a measurement for all the different sounds we hear would be like trying to establish a measurement for all that we smell or see. We have a good set of tools now, if you can work with a TEF-20 and Jon Risch's program or really understand a Tektronix TDS 350 or other programmable scope. With these tools we can predict that a component will sound bad or possibly even "not so bad." As far as a measurement for "awesome" or "state-of-the-art" or "this is the best system I have ever heard"—listen to the music!

Bio Notes: George Cardas has a gift for mathematics and electronics, and a love of music. He holds several U.S. Patents for cable stranding, pressure differential microphones and connector designs. George loves working with other designers, "helping musicians reproduce their music."

Keith Herron, President, Herron Audio

Two fellows I knew in the late '60s used an oscilloscope kit, built with 10% tolerance parts at best, to inform a prominent local musician that she was off-pitch. Although the words she used to rebuke them may have been off-color, she was likely not off-pitch. I have often marveled at the fact that two pieces of audio equipment with similar frequency response specifications, as provided by the manufacturer, could sound totally different. One might sound warm and lush, and the other cold and analytical. This type of dichotomy would lead many to believe that measurements in general, unless gross differences were evident, have little meaning. Possibly the real problem is, however, that many specifications are like trying to measure the width of a human hair with a yardstick.

Maybe the sensitivity of our ears to frequency response has been drastically underestimated. We recognize the voices of people we know by often subtle frequency variations in their voices, even over the telephone. This suggests that we are keenly sensitive to relative frequency response variation. This could also explain our ability to hear minute frequency response differences between audio components when compared using speakers with gross frequency response variations.

One problem we encountered early in the development of our VTPH-1 phono stage was that seemingly identical units exhibited a variation in unit-to-unit characteristic sound. To find the cause of this variation we designed a piece of test equipment capable of measuring the RIAA response of each unit to an accuracy of one millibel (0.01 dB). Graphs were made of a number of units and compared to listener evaluations done in a number of audio systems after each listening session. The most highly rated units were always the ones with the most accurate RIAA response. Listener ratings of units could be reversed by altering the response curves between units. Listeners often heard differences on the order of 3 millibels (0.03 dB).

After reviewing these results, it becomes clear that specifications of plus and minus 0.5 dB have very little meaning when comparing audible colorations between various pieces of audio gear. It also comes as no surprise that a frequency response variation on the order of decibels at 100 kHz would be audible, since it usually means that there is a response variation of several millibels in the 5, 10 and 20 kHz (audible) range.

Another often confusing measurement is distortion. Why is it that tube amplifiers often have much higher distortion figures, yet often sound cleaner than many solid stage designs? Many triode tube circuits produce second harmonic distortion that rises percentage-wise in a way that is linear with output. As the output signal increases, so does the distortion. Odd order distortions exhibited by these configurations, although minute at low level, increase by the square of the output level. The bottom line is that the distortion can diminish to infinitesimal levels at very small signal levels, and that's where the detail and life of the signal is. Many bipolar transistor solid-state designs, on the other hand, have distortion percentage levels that are seemingly small but constant from very small signal levels to near full output. If distortion measurements are made at near full power for both tube and transistor equipment, the higher distortion figures of the tube equipment will be misleading since most of the "life" in real and recorded music takes place at very low levels, where the distortion is very low.

After hearing this brief discussion on the importance of frequency response and distortion, one might think that flat frequency response and low distortion are all that are necessary in a good sounding audio design. I wish it were that simple. Designing a product with flat frequency response and low distortion figures is a good place to start, but these parameters don't guarantee very much. Measurements, as we are currently doing them on the one millibel level, fail to tell us why capacitors, resistors, wire, power supplies, board layouts and circuit configurations sound different. Although we have a number of theories and models on the sonic behavior and nature of individual parts, there is no guaranteed measurement beyond tolerance and known quantities such as dialectric absorption to predict a sonic fingerprint. These aspects comprise the bulk of the design work and are currently based on experience and a lot of experimentation.

I suspect we will need to measure at much much higher resolution—possibly using an electron microscope rather than a yardstick—in order to predict the sonic personality of individual and combined parts. Although there has been considerable improvement in the area of measurement equipment and technique with some very useful results, it is hard to imagine a measurement procedure that will disclose the true audible value of a piece of audio gear. Possibly it will occur at the same time that a camera is contrived capable of measuring the perceived value of a painting.

Bio Notes: Keith Herron is the owner and principal designer at Herron Audio. A graduate of Iowa State University and a Registered Professional Electrical Engineer, he formerly served as director of research and development for Ampeg, Crate, and Audio Centron. He combines a strong background in electronics, mathematics, physics and music with a keen ear and an open-minded analysis of audio equipment design. He describes himself as an audiophile, a lover of music, and a "former" musician.

Siegfried Linkwitz, VP, R&D, Audio Artistry

I would have to say that measurement of the speaker's frequency response is the technical measurement that comes closest to predicting the sound of a loudspeaker. If you see a graph of a 20 to 20,000 kHz ±2 dB on-axis, anechoic response, you can be fairly sure that the speaker has a smooth sound characteristic. However, this information alone does not necessarily imply that the sound is neutral, transparent and dynamic, and that it would display those characteristics in your room.

First of all, it takes more than the anechoic on-axis response to describe the sound you hear. When you listen in a room, your ears not only receive the on-axis sound but also, with a slight delay, the sound that has bounced around in your room and been modified by it. Thus, the anechoic response must also be measured at angles up to at least ±60 degrees horizontally and ±15 degrees vertically off-axis, in order to assess the contribution of sound radiation in these directions to the overall sound, when the speaker is placed in a room. Simply averaging the different anechoic responses over a "listening window" or normalizing them to the on-axis response is not as relevant a description as is plotting the actual frequency response curves at different angles on the same graph.

The other half of the equation, which is also related to a speaker's frequency response, is its phase response. The phase response can be grossly different for two speakers, even though the magnitude of their corresponding frequency response may be similar. Interpreting the audible significance of a system's phase response curve is even more difficult than assessing the subjective impact of a particular amplitude response. Instead of looking just at the phase response, you can look at a speaker's step response. It highlights the effects of phase shift, but primarily in the higher frequency range. However, I am not convinced that the typical amounts of phase shift due to crossovers that are observed in these higher frequency regions have audible effects. On the other hand, I am convinced that phase shift is very important at the low frequency end of the spectrum.

Keep in mind that I have merely touched upon a few aspects of frequency response measurements that give an indication about the final sound of a speaker in your listening room. Many other important measurements require careful execution and interpretation during the design of a great speaker. For instance there's measurements of non-linear distortion in drivers, cone excursion capability, resonances in drivers and cabinets, and the critical room/speaker interaction.

After all of these factors have been evaluated in light of their audible significance, and after inadequate design parameters have been modified wherever possible, then it is time to listen. I listen in my living room at great length and with a wide variety of source materials, including my own DAT recordings. It is difficult to find genuinely neutral sound reference material-and I consider it mandatory to regularly attend live concerts to hear unamplified instruments. The listening sessions may lead to touch-ups or refinements of the fundamental speaker design, but the correlation between the set of measurements that I use and the audible results is very strong. I am also constantly working on refining those measurements, based on a study of the psychoacoustics of hearing and my own perceptions.

Bio Notes: Siegfried Linkwitz designs dipole-type loudspeakers for Audio Artistry, pursuing a love for music and realistic sound reproduction that started as a hobby more than 30 years ago. He recently retired from Hewlett-Packard Co. after working for 37 years in research and development of test equipment for radio frequency and microwave measurements.

Howard Mandell, President, Altis Audio

I think the single most important measurement in any digital processor or drive is the total amount and type of jitter in the signal. Jitter causes noise which infiltrates the playback and can cause very deleterious effects. It can manifest itself as white noise, harshness, bright highs or just simply bad timing of the music. This means that the pace and timing of the performance could, in fact, be compromised. We feel that jitter should be kept to well below

2 picoseconds.

We stop designing by measurements once we have completed the first layout and completed board. Then we begin to listen. We listen to different filter coefficients, different timing signals and different capacitors, just to name a few criteria. We also listen to make sure the layout of the PC boards has been fully optimized. This could result in the moving of one or more components for better sound. For example, the crystal oscillator might have to be moved to keep the noise of this device from infiltrating the analog signal. Things like this have to be studied carefully.

Personally, I don't think we will ever be able to design using only measurements. I think they can only take you so far. They can get you close but, the final realization of any design is in the listening. We take our units to many people to hear them in many systems before the product ever sees the light of day. I think the products that sound like music are ones that not only make use of good measurements, but also make use of the human experience. After all, listening to music is a human experience.

Bio Notes: Howard Mandel has been involved in the design and manufacture of digital products for many years. He founded Altis Audio eight years ago in an attempt to build a more realistic sounding digital processor than was available at the time. The company has grown and now serves audiophiles worldwide.

Nelson Pass, President, PASS Laboratories

The standard bench measurements (frequency response, harmonic distortion content, speed, damping factor, *etc.*) all provide useful feedback in the design process. Their importance occurs in the context of a given topology and hardware, where the numbers help you dial in the "sweet spot" and speed the process of subjective evaluation.

It is nevertheless possible to have a product that measures well but doesn't sound so good. It is still a mystery as to how this could be, but there it is. My experience is that there is a reasonable correlation between sound and measurement for simple Class A circuitry with minimal or no feedback. This relationship seems to disappear when the circuit becomes complex or has a lot of non-linearity corrected by feedback.

Most audio design is a long, iterative process. We go back and forth from listening to measurement until eventually we decide to ship it. At that point, we hope we have gotten it completely right, and occasionally we have.

That is a matter of opinion. I have seen pieces in *Stereo Review* and elsewhere stating outright that measurements have already adequately defined performance and that the subjectivists are fooling themselves. The opposite viewpoint is stated just as dogmatically. Both sides are emotional, and neither side is particularly reasonable.

Obviously, reality sits somewhere in between. Some measurements do tell you something about the sound, but not very reliably, and there are clearly some phenomena going on that are not being measured. On the other hand, I have witnessed blind tests where the participants could not hear a difference, or heard wild differences that could not have existed.

Me, I don't care that much; in fact, I find the subject kind of boring. We build amplifiers that sound good and measure reasonably well and don't break. If you want to get a machine to listen to them for you, be my guest!

Bio Notes: Nelson Pass received his graduate degree in physics from the University of California-Davis and founded Threshold Electronics in 1974. He sold Threshold Electronics in 1987 and founded PASS Labs in 1991. Perhaps best known for his Class A design amplifiers and single-ended transistor amplifiers, Pass holds eight U.S. patents on audio circuits.

Jeff Rowland, President and Chief Designer, Jeff Rowland Design Group

There is definitely a close relationship between test measurement (specifications) and subjective sound quality. However, current testing procedures commonly used in audio development, manufacturing and the audio press are inadequate to properly correlate and relate measurements with subjective experience.

Many well-meaning critics hold that so far as an audio component measures "perfect" in certain areas, the audio component will not have a "sound of its own," and it will be indistinguishable from a component with similar measurements. The measurement criteria usually involve flat frequency response, insignificant static and dynamic non-linearities, high input impedances, low output impedances, low noise and crosstalk levels, *etc.* Yet these common notions fail to uncover the actual performance potentials of complete audio systems.

The speed and processing abilities of current computer-interfaced testing equipment enable Jeff Rowland Design Group (JRDG) to perform tests which were impossible a few short years ago. Among the most important tests for musical reproduction accuracy is the Fastest procedure developed by Audio Precision, Inc. This test will uncover wide band, dynamic non-linearities in DUT's (devices under test) previously unexposed by twin-tone IMD (intermodulation distortion) and THD + N (total harmonic distortion plus noise) testing procedures. A composite of either 32 or 64 discrete tones, non-harmonically spaced throughout the 20 to 20 kHz bandwidth, is introduced to the DUT inputs. The DUT outputs are routed back into the computer interfaced analyzer, which sharply attenuates each of the 32 or 64 original tones. The resulting intermodulation (sum and difference) tones of the original tones are then integrated and displayed for analysis and/or continuing product development. Note that this test signal more accurately represents a musical signal due to its high content of discrete frequencies. Any non-linearities present in the DUT directly create a multitude of spurious difference frequencies, which fall throughout the lower amplitude ranges of the entire audio spectrum, significantly limiting and compressing the usable dynamic range. A poor result on this test correlates to the common listening experience of dynamic range compression, congestion, loss of detail and obscuration of the silence and harmonic integrity in music as the material becomes increasingly complex.

Another overlooked area of testing is evaluation of the DUT in a radio frequency interference (RFI) environment. Thorough testing and analysis of RFI, immunity in audio equipment is increasingly important due to the proliferation of telecommunication devices and computers throughout the world. This testing involves injecting minute amounts of continuous or multi-tone RF signals into the input, output, AC mains, and chassis of the DUT. The output of the DUT is analyzed much the same as above. Poorly designed equipment which under common lab tests can measure fine, will escape this particular scrutiny. In a metropolitan environment, for example, multiple RF signals can be demodulated within the input circuitry of poorly designed audio equipment. The resulting sum and difference frequencies will manifest throughout the audio frequency range and create an obscuring effect upon the musical signal much in the same manner as mentioned above.

The act of transferring an audio signal from one system component to another without audible degradation is very difficult. The existence of significant ground voltage differences and the resulting noise currents that flow between system components must be considered in the system as a whole. Carefully designed and executed system grounding schemes can reduce these problems but not eliminate them. Audio equipment that may display excellent test results in isolation can fail miserably in a typical audio system configuration.

The degree of isolation and immunity from these undesirable effects and their resulting problems is indicated by the CMRR (common-mode-rejection-ratio). (Note that balanced interconnection schemes are referred to in this discussion. Single-ended interconnected systems, by their inherent design limitations, can never overcome the problems discussed here.) Very few manufacturers give specifications relating to CMRR; the audio press fails to test for this important test parameter altogether. To make matters worse, most audio designers who do test for CMRR do so by driving the opposite phase inputs shorted together, which is both unrealistic and misleading. Tests which account for slight source impedance mismatching between opposite signal phases, a reality in all audio systems, are rarely done. Noise rejection in a balanced system has nothing to do with signal amplitude symmetry, erroneously regarded as an asset. Noise rejection has everything to do with the balance of common-mode impedances. Unfortunately, this is rarely accommodated for in equipment design or mentioned in performance specifications.

Audio hardware and interconnect cables are sensitive to mechanical vibration (microphonics). Sound energy, transferred through structural and air mediums, can significantly impact the performance of all audio equipment in many domestic environments. Again, equipment sensitivity to this condition is rarely tested in manufacturing or considered during the design process.

In conclusion, if more thorough testing procedures would be implemented at the design, manufacturing and reviewing stages within a product life cycle, definite correlations could be made between technical specifications and subjective critiques. However, this is not generally the case today. The result is confusion and a distrustful attitude towards technical tests altogether. Our hope is that more designers and reviewers will explore many of the test and measurement possibilities that are now possible.

For a detailed discussion on this topic, see the JRDG website, www.jeffrowland.com.

Bio Notes: Jeff Rowland's involvement in consumer electronics began in 1980, when he designed and manufactured a line of audio power amplifiers, preamplifiers and electronic crossovers, under the company name of Rowland Research. Recognition of his unique approach to audio amplifier design led to worldwide acceptance and distribution of a complete line of amplifiers and preamplifiers in 1986 under the current name of Jeff Rowland Design Group, Inc. Mr. Rowland has provided innovative solutions to design problems, such as his pioneering implementation of balanced circuitry (1986), transimpedence topologies (1988), preamp remote control (1988), low-resonance chassis design (1992), and battery power supplies for audio applications (1992), transformer interfacing (1995), and high power integrated circuit applications (1997). He is currently involved in the design of ultra-low distortion, high efficiency, modular amplifiers for stereo and multichannel audio applications.

Jim Thiel, President, Thiel Audio

No single measurement predicts the sound of a loudspeaker, because there are several separate aspects of speaker performance. I think the most important measurement is frequency response which, in principle, can predict the tonal character of a speaker, including overall balance and lack of colorations. Keeping in mind that it cannot predict the other performance aspects of imaging, clarity and dynamics, frequency response can predict many important attributes of speaker performance.

There is, however, a big difference between predicting performance in theory and doing so in practice. Interpreting frequency response measurements is tricky and complicated. For example, it can be difficult to differentiate between a relatively benign diffraction effect and a resonance effect that is quite deleterious. Even interpreting the overall octave-to-octave balance from measurement is error prone, since response imperfections are usually on the order of 1 or 2 dB, whereas the ear can detect errors of a fraction of a dB if over an octave or more.

Listening is a necessary method of evaluating speakers because of the difficulties of interpreting measurements. The ear and brain can sort out the different sonic effects to determine whether a measured effect is a major or minor problem, and can also untangle all the imperfections to determine the tonal balance. The ear's great sensitivity makes it an indispensable tool for evaluation.

I usually develop a product by first engineering everything possible from calculations, simulations and measurements. After the product is developed to the point that it would seem to be finished as far as measurements are concerned, I begin the design phase that includes listening. On first listening the product might sound good, but it often has significant problems, and it never sounds great. This phase of identifying imperfections—by listening and solving them with the help of measurements-involves a great deal of listening time and is a critical design phase for determining whether the final product will be truly exceptional.

The personal computer has allowed great improvements in speaker measurements during the last 20 years. Although we now have much more information easily available to us, the improvements have not facilitated prediction of sonic character. Extrapolating this trend, I don't predict that measurements will replace listening as an evaluative tool in the foreseeable future.

Bio Notes: Jim Thiel is a co-founder, co-owner, and product design engineer at Thiel Audio. Thiel pioneered the principle of time and phase accuracy in loudspeakers with the use of sloped baffles, coaxial driver mounting, and phase coherent crossover network design. His loudspeaker designs have been frequently honored by the audio industry and international press, earning 12 "Speaker of the Year" awards and 15 International Consumer Electronics Show "Design and Engineering" awards over Thiel's 20-year history.

Next issue, Part II: More insights into the subject of audio measurements, and an examination of the tools at the designer's beckoning. ◉