VOICE COIL
THE PERIODICAL FOR THE LOUDSPEAKER INDUSTRY

*Article prepared for www.audioXpress.com*

# *Voice Coil* Interviews Dr. Earl Geddes

*By Steve Mowry*

Earl R. Geddes was born in 1951 in Detroit, Mich., to a second-generation Ford Motor engineer. When he wasn't singing in rock 'n' roll bands, he was playing with and building the band's equipment. Earl became addicted to this pastime, which later evolved into a passion. This passion naturally led to the loudspeakers which remain today the weak link in the audio chain.

Earl earned his BS and MS in physics at Eastern Michigan University, after which he went on to the graduate program in acoustics at the Pennsylvania State University for his Ph.D., which he received in 1980. He wrote his thesis on the "Low Frequency Sound Field Statistics in Non-rectangular Rooms" using the Finite Element Method. He specialized in numerical methods in acoustics, a topic that he is still interested in today.

After graduation, Earl worked for the Ford Motor Company as a specialist in acoustics working on audio systems, passive and active noise control, and sound quality perception. In 1991 he won the Henry Ford Technological Achievement Award for his work in redefining the sound quality goals for automobiles.

Dr. Geddes left Ford in 1992 as a Senior Engineering Consultant to work as Technical Director for Knowles Electronics in Chicago, Ill., the major supplier of transducers to the hearing aid industry. While working at Knowles, he collaborated on research into sound quality and psychoacoustics for hearing aids with Dr. Lidia Lee, then at Northern Illinois University. They were married in 1995. Lidia and Earl continue to do fundamental research in sound quality perception.

Earl left Knowles in 1996 and returned to Ford's Electronics Division, which shortly thereafter become Visteon. Visteon had licensed his patent for the acoustic lever, which he intended to put into production. With the collapse of the economy after 9/11 (and the acoustic lever project), Earl took a buyout from Visteon to work as a consultant full time.

Since 2001 Lidia and Earl have run GedLee LLC in Novi, Mich., where they have produced two books (*Audio Transducers* and *Premium Home Theater*), performed numerous psychoacoustical studies, filed several patents, and (based on proprietary technology) designed and built the Summa loudspeaker.

**Steve Mowry**: Which of your papers do you consider to be the most significant and why?
**Earl Geddes**: Clearly the foremost would be my paper on waveguides. This paper basically overturned about 80 years of horn theory and replaced it with an entirely new concept, one that is significantly more accurate and which has led to a revolution in the use of waveguides for loudspeakers.

Second, I would consider Lidia's and my papers on the perception of distortion as breakthroughs. While people have talked about this topic for a long time and many had hypothesized that what we found would be true, no one had actually done the work to prove it. I think that in years to come this work will be duplicated many times over, as it is already being done by people such as Alex Voishvillo at JBL.

The paper that Lidia and I just did on the perception of very small time delayed signals, such as would occur for diffraction in a waveguide or off a cabinet edge, is also enlightening for its proof that these effects are strongly dependent on the playback sound pressure level. The ear appears to mask these effects at low levels, while they rapidly become perceptible at higher SPLs. This basically puts much of the previous work on the perception of diffraction and very early reflections into a questionable light since playback level was seldom a controlled or control variable.

**SM**: Could you describe your new distortion paradigm?
**EG**: Lidia and I showed that it is not the amount of waveform modification for some special test signal that is relevant to the subjective perception of a nonlinearity. These classical tests (THD and IMD) were shown to be completely uncorrelated with the subjective perception of the underlying nonlinearity—in essence, as a metric of sound quality they were meaningless.

The true root cause of the nonlinear distortion problem is the shape of the nonlinearity transfer characteristic, an intrinsic property of the system itself. THD and IMD are simply symptoms of the problem, not the problem itself. We

showed that the rate of change of the nonlinearity transfer characteristic curve, and the location of these changes, were the relevant factors.

Of great interest is the fact that the types of nonlinearities that occur in loudspeakers are fairly benign, while an amplifier can easily exhibit the types of nonlinearity that are highly audible. The THD and IMD numbers, as currently used, simply don't have any direct relevance to the perception of the underlying problem.

As I said before, we have also learned that the perception of diffraction is highly dependent on the playback level—this means that our *perception* of certain acoustic aberrations is actually nonlinear. These types of audible distortions do occur quite readily in loudspeakers, while they are virtually nonexistent in electronics.

Given all of this recent information, it appears that one should be looking for completely different things when judging the sound quality of electronics and loudspeakers. The evolution of a fairly common set of metrics for both of these systems (often using irrelevant metrics) was probably not a good thing. Basically, it may well be that we have been looking at the wrong things for all these years.

**SM**: What is different regarding the SUMMA's horn design?

**EG**: The Summa does not actually use a "horn," but instead uses a "waveguide." This difference is more than simply semantic. A horn, by definition, is developed from the "horn equation" of Webster in the 20s. In the early 90s I published several papers that showed that this equation has some serious limitations (one might even say errors) in it that prevent its use in the development of the next generation of directivity controlling devices (the true function of a modern waveguide). The horn equation works fine for the calculation of the impedance of a horn, but it is wholly inadequate at determining the directivity of such a device.

I went on to develop a different mathematical approach to the problem which was free from the assumptions that Webster had used, which had led to the limitations in his equations. The sets of equations that I derived are free from the limitations and assumptions about how the wave travels in the device and allow for a far better—more exacting—analysis of devices for wavefront control. Since an entirely new set of equations was used, I thought that a new term was needed to differentiate "horns" (as defined by Webster) from "waveguides" (as defined by Geddes). Unfortunately, the marketplace seems to have picked up the term "waveguide" and is applying in places where my original usage of the term does not apply.

Fundamentally a waveguide looks like a horn, but the contours are different. The differences can even appear to be small, but where the contour makes the most difference is where they differ the most.

The significant part of this new development, however, was the fact that the waveguide equations predict the existence of a form of wave propagation that is not allowed by Webster's equation—the Higher Order Modes, or HOM. These waves certainly do exist in horns; it's just that with Webster's equation one cannot predict them and hence cannot seek to control (minimize) them. The recent psychoacoustical studies that Lidia and I did on diffraction points to the fact that the HOM are significant contributors to the sound quality degradation of a horn or waveguide.

In the Summa speakers as they are now known, the waveguide is designed to minimize the generation of HOMs, thus improving the sound quality of these systems. Further investigations have shown that the use of a sound absorbing plug, what I jokingly call the "*HOMless*" device (patent pending), offers a further reduction in HOM propagation. The foam plug (which is made from open-cell polypropylene) actually absorbs the HOM and mouth reflections/diffraction far more than the direct wavefront, thus yielding a net gain in sound quality through a net reduction in HOM content and mouth reflections. The improvement in sound quality is really quite spectacular, elevating the compression driver driven waveguide to a level of sound quality not seen before in these directivity controlling devices.

**SM**: Do you have any plans for SPEAK?

**EG**: SPEAK was never a moneymaker for me, I actually only sold it because I used it in my own design work and so I may as well sell it. I have no plans to further its development, however. I still use it regularly for first cut design trials of new concepts. It's quite useful for these very early design studies; however, as things progress we move the design into another set of software tools that I have developed that allows for a sort of "hardware in the loop" development.

**SM**: Why do you feel that displacement related nonlinearity is insignificant in a loudspeaker?

**EG**: I would say that it can easily be made to be insignificant, but it can also be made to be significant through choices in the system design. Several recent subjective studies, as well as a lot of personal experiences, have led me to conclude that in a good system design, displacement related nonlinearities do not enter into the subjective perception of the system. This is not to say that in a different system design these factors won't be perceptible, only that it is not a big problem to design a system with existing drivers such that the drivers' cone displacement nonlinearities do not enter into the picture. Many studies of nonlinear distortion have shown that THD levels as high as 20% can be completely inaudible—given that fact, what's the point in designing to reduce these numbers? There is simply no correlation between THD and subjective assessment.

Nonlinear distortion in the loudspeaker can certainly be an issue in some areas of audio, most notably automotive audio where one is forced to use speakers that are really too small, operating over a very wide bandwidth, and so on. But in applications that are not so restricted by size, weight, and number of drivers, designing out driver nonlinearities is not difficult.

**SM**: What about temperature as a dominant source of nonlinearity?

**EG**: Temperature effects are a serious issue even in well-designed loudspeakers. One need only look at the voice coil

resistance change in actual operation to realize how much the fundamental parameters of the system can change with input power. The subjective effect of these changes has not been studied to any great extent and we intend to do that because there are things that can be done to minimize these temperature effects—such as the voice coil wire metal composition (the addition of a small amount of nickel to copper dramatically reduces the thermal coefficient, unfortunately it also raises the resistivity). Finding the proper wire compositions and driver design need to be determined, but that's a straightforward design issue.

**SM**: Loudspeaker technology seems to be lagging behind other industries. Is this a reason why? Have we been going in the wrong direction?
**EG**: I clearly think that the loudspeaker industry—mostly the consumer side—has created a situation where sonic improvements in loudspeakers are not seen as a good investment. In an environment where it is marketing that sells speakers—not sound quality—a loudspeaker company will almost always spend its money where it nets the greatest returns—marketing. There has not been a lot of work on loudspeaker sound quality in the last ten years, except for a few companies, most notably Harman.

Most loudspeakers are designed and tuned by ear and sold by marketing (which marketing would have us believe is the correct way to do it). In this scenario there is little need for any real technical developments and, at this stage of the technology (mature), technical advances become expensive to research and develop. Bottom line: no real advances occur except by people like me who pursue new technology through sheer diligence—no one funded my work in waveguides, for example.

**SM**: Why did you abandon your patent *"Transducer Motor with Low Thermal Modulation*?"
**EG**: Actually it was not abandoned; it was rejected as being "obvious" over Button in his patent on a similar invention. Of course, I did not agree with this, but I lacked the resources to fight it. Adding a small percentage of nickel to the copper in the voice coil windings is so simple that it seems obvious, but no one has actually done it. At any rate, the technique is now in the public domain, so go for it!

**SM**: Are you doing any teaching or do you plan to conduct course(s) at a university?
**EG**: I am the chair of the ALMA education committee and I have taught some courses in loudspeaker design and signal processing for them, but my knowledge is really too specialized for a university.

**SM**: Where do you see the loudspeaker industry in ten years?
**EG**: That's a tough question because we don't know what we don't know, so there is no way to tell whether tomorrow's technology won't be completely different than today's. I do have my doubts about the trends in "digital transducers," because this will not be as easy to do in the mechanical world as it is in the electrical one. I do think that waveguides, like those in our products, will become more popular since they solve some very real problems found in horns. I also think that this new class of waveguides will work even better with new compression driver designs.

**SM**: Do you miss working at the Ford Motor Company?
**EG**: Well, these days, no. I have a lot of friends and neighbors who work there and at the moment things are not that much fun for them. I did enjoy it when I worked there and it was a great opportunity to learn some skills that I would not have had otherwise. Ford had a lot of respect for highly technical people—a feature that a lot of companies don't have—and a very disciplined design approach that I admire to this day.

**SM**: If I said, "Earl Geddes has a bit of an ego but he knows a lot," how would you respond?
**EG**: I've heard this before. Perhaps it would be better to not have an ego (as if that were true of anyone), but I'll be happy if people just recognize the "he knows a lot" part.

**SM**: You said to me some time ago that the Chinese loudspeaker companies do not hire consultants; they utilize sheer numbers and diligence. Has this changed or will this change?
**EG**: It hasn't changed that I can see. You go to a factory and they still have lots and lots of people, but very little technical expertise. My book on loudspeakers has sold at least a thousand copies worldwide, and yet, I have sold only a single copy in China. Given the large quantities of loudspeakers designed and built there, one would expect that if they were really serious about technical competence that they would be studying the available literature. Sure, the book is only in English, but I do sell a very large percentage of my books into non-English speaking countries. Chinese engineers can usually read English, and math is math.

The Chinese appear to be mostly interested in being the low-cost provider of commodity drivers and systems with little value-added content. Consultants are not very useful in this situation.

Will this change? I suspect that it will have to or the loudspeaker industry in China will move elsewhere, just as it already is, to Thailand, for instance.

**SM**: Do you see the migration of engineering and new product development functions following manufacturing to Asia and especially to China?
**EG**: I see the trend to migrate manufacturing into China as slowing down and perhaps even turning around until such time as the Chinese seriously ramp up their technical capabilities. Virtually no one that I know has found that they can manufacture in China without having significant non-local technical expertise on site. This raises the true cost of the manufacturing substantially. To me, the environment is much more attractive in Thailand.

As to a migration of the engineering function, this is not likely to occur short term because of the substantial lack of qualified Chinese engineers. There simply are not that many talented audio engineers in China and engineers in all disci-

plines are in high demand. Other sectors of the marketplace that are not so focused on the low-end of their markets will tend to draw the better engineers into them. It's going to be a while before this situation changes. Even in Thailand engineers are in short supply. It seems like, in Asia, the Japanese (and maybe the Koreans) were the only ones to take engineering seriously enough many years ago as would be required to be world class today. In China, the Cultural Revolution cost them several generations of lag behind the rest of the world in technology.

**SM**: What do you consider to be the most important design criteria for a loudspeaker: linearity, bandwidth, ease of manufacture, cost. . . ?
**EG**: I see cost versus performance as a central issue, especially in the pro market. Current prices of the components are just about as low as they will ever be. Drivers are pretty much a commodity, but the prices on completed systems scale price with performance at a very steep slope—as if the components were a precious resource. This occurs because of the lack of high performance in the market—again due to the priority of marketing over performance. In the professional world the costs for premium performance are way out of line. This market segment is going to see some significant competition in terms of price at the premium performance level as companies become better at making high performance systems at reasonable costs.

On the more technical issues, I think that the marketplace has virtually ignored the polar response issues. Even when this is a design requirement, the actual performance in this regard is poor, and seldom is adequate polar performance data ever supplied. DI and polar charts at specific frequencies do not show the required data. We use polar maps that show all frequencies at all angles simultaneously—unfortunately, this can only be done in one plane at a time. However, with several plots in different planes, the whole picture becomes evident.

I think that having a smooth and nearly flat polar response map is more important than the axial response graphs that seem to be the most important criteria in the marketplace. Bandwidth, to me, is basically assumed; it has to be what the application requires, and this varies from application to application. I think too often too much midrange performance is sacrificed for an extended low end to meet some spec sheet claim. Better, in our opinion, is to make the main speakers have reasonable low end (but not extended at the sake of the mids), and then to extend the low end, when required, through subs—the more the better. Spacing subwoofers around the room dramatically improves the smoothness of the low-frequency response field. This is why we offer so many sub designs and bandwidths—some six in all.

Given the design philosophy (highly directional controlled directivity), larger systems and drivers are required. This approach tends to make the excursion linearity requirements a negligible factor because the cones in the woofers (and compression drivers) are not required to have very large excursion requirements. The subs all have acoustic low-pass filtering via their bandpass designs and as such also tend to solve the basic linearity problem through the design philosophy. In our systems driver linearity is simply not an issue.

Linearity only becomes an issue when one is pushing the envelope of system size toward the extremely small. There are customers who request this size constraint, but we try and make them aware of the trade-offs of small systems, and they usually opt for the slightly larger size with substantially better sound quality. Current marketing claims would have customers believe that there is no trade-off between size and sound quality—they can have both. We don't try and sell this concept because it's not correct.

**SM**: How do you envision the role of the AES and ALMA in the globalization of the loudspeaker industry?
**EG**: These organizations need to make the end users aware of the need for good loudspeakers if good sound system quality is to be achieved. In the marketplace customers are told that the speakers are a matter of personal taste, that there are no absolutes or correct choices, and this is simply not correct. Fundamental work in showing the relationship between the perception of a loudspeaker and its design objectives will show that there is a strong correlation between perception and design and that good designs will always achieve a better overall customer acceptance than poor ones. It is all a matter of education, which is a principal part of both the AES and ALMA.

But the manufacturers need to get behind these organizations with their support both financially and with active participation. The companies need to recognize that marketing alone cannot achieve long-term success and that true design for sound quality is the only way to ensure long-term stability in the loudspeaker business.

**SM**: Other than yourself, who is conducting significant research into improving sound reproduction?
**EG**: I think I most respect Floyd Toole for his foundational work in perception, although Dr. Toole is not really a loudspeaker designer. Harman makes some fine products, but I think that their cost and pricing structure is not sustainable in the longer term.

In the world of loudspeaker systems design, I'd have to say that there is a real shortage of highly skilled people. I'm not trying to short-change or insult anyone, but I have just not found a loudspeaker systems designer who has a strong grasp of all the issues in room acoustics, transducer design, and psychoacoustics. Many people have one or two of these talents, but very few have all three—no one of these three factors can be ignored without sacrificing the quality of the system design and the final perception of that system by the customer.

## COMMENTS

I cannot say that I concur with all of Earl Geddes' comments; however, I do admire his frankness and the courage demonstrated in "speaking his mind." This is obviously a man driven by his passion and believes strongly in what he does.

His critique of China and the technical capability of the loudspeaker industry overall may be embedded with controversy, but I hope this will draw attention to a very real industry deficiency. *VC*