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## AMP UPDATE

With reference to John Stewart's article "Crowhurst's Twin-Coupled Amp" published in the Sept. ′05 issue, congratulations for the well-written topic full of details and tables. However, unless I'm missing something, it lacks data on the bandwidth figures. In addition, I would like to know whether, by using higher quality output transformers, the performance improves—and to what extent.

*Atto E. Rinaldo*
*Italy*

**John Stewart responds:**
I should have included some information on the bandwidth of the amplifier, so here it is.

Frequency response when using internal balanced negative feedback, as per Crowhurst:

| | | |
|---|---|---|
| At 10W | 1dB down | 35Hz and 33kHz |
| | 3dB down | 27Hz and 47kHz |
| At 1W | 1dB down | 9.6Hz and 36kHz |
| | 3dB down | 7.4Hz and 48kHz |

But there is breakup in the signal at the low-frequency end. At 1W that happens at 15Hz, while at 10W breakup is at 40Hz. More iron would help a lot, as you would expect.

Here is more information to show how the circuit responds to a full loop NFB connection, just as you would see in an ordinary amp. Refer to Figure 8, the Alternative Front End in the article. Set the input for differential operation. From the amplifier 8Ω output a 10k resistor is connected to the grid end of R4, a 1k resistor at the amplifier front end. This includes the output transformer and results in about 12dB of NFB at 1kHz. The damping factor is increased considerably. I measured it to be 17 at 1kHz.

Frequency response when using alternative negative feedback

| | | |
|---|---|---|
| At 10W | 1dB down | 35Hz and 40kHz |
| At 1W | 1dB down | 10Hz and 60kHz |

The low-frequency limit is set again by the iron in the output transformers.

However, they do seem to work well beyond the Hammond spec of 150Hz to 15kHz. I've not yet tried better-quality output transformers, but I intend to do that as soon as I can find time.

In all of the measurements, I found about a 0.5dB rise at something like 15kHz.

Thank you for your comments and interest in this project.

## TRANSMISSION LINES

Rick Schultz is to be applauded for continuing his "TLs for Dummies" articles—exploring TL-space using George Augspurger's transmission line modeling software and distilling it so you can quickly come up with a reasonable—if not optimum—TL design for any given driver ("Alpha Transmission Lines," Aug. ′03 *aX* and "Omega Quarterwave Reflex," Oct. ′05 *aX*). I found the alphaTL very useful, and my brother is really enjoying the alphaTLs I built to replace the ones he has been using for the last 30 years (we didn't call them alphaTLs back then).

But Rick does a disservice to the community—and those whom he acknowledges (I am somewhat disappointed that I got no acknowledgment for executing the drawing of the omega QWR published in *aX*.)—with his claim that his omega quarter-wave reflex is a unique design and subject to full intellectual property protection. As I pointed out to Rick when I reviewed his work prior to publication, this TL is no different than what has, over the past four years, become commonly known as a Mass Loaded Transmission Line—ML-TL for short.

George Augspurger, in his presentation at the 1999 AES conference, suggested a straight TL with an offset driver and restricted terminus, i.e., an ML-TL. The popular Zigmahornet (an ML-TL) predates King's and Augspurger's work. Greg Monfret (a.k.a. GM) brought us the first highly visible ML-TL (and I believe coined the term to differentiate it from Martin King's TL-TQWT terminology) with his RS40-1354 ML-TL at Atlanta DIY 2001.

Martin King has published a number of incredibly well-documented ML-TL projects (from sims through builds with measurements) dating back to shortly after this, and the many, many (you could probably say hundreds) ML-TL configurations for specific drivers that GM has suggested (GM says he built his first one in 1969). I would guess that literally thousands of ML-TLs have been built by DIYers in the last few years. A number of representative designs can be seen at **http://www.planet10-hifi.com/boxes.html.** A number of the projects in Martin King's Transmission Line gallery are ML-TLs (**http://www.quarter-wave.com/Gallery/Gallery.html**), and Bob Brine's FT-1600s is one of the most widely implemented and successful ML-TLs (**http://geocities.com/rbrines1/Pages/FT-1600_MkII/Main.html**). The last two sites plus mine (**http://www.t-linespeakers.org/**) contain much information on successfully implementing quarter-wave designs.

Rick Schultz was a regular visitor to online forums over the evolution, discussion, and sharing of these designs, so is well aware of them. His methodology to design them is certainly unique, but the design is not.

I would also suggest that any DIYer or commercial designer wishing to build an ML-TL could—using Augspurger's TLwrx software or Martin King's even more versatile MathCAD worksheets—design an ML-TL more fully optimized for a specific driver. Thanks to the generous efforts of many DIYers, including those already mentioned, many designs for many drivers are already freely available.

*David Dlugos*
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**Rick Schultz responds:**

David Dlugos certainly deserves credit for Fig. 14, along with my sincere apology. His credit improperly dropped during my edits of the manuscript.

I expected Xpress Mail would receive questions concerning adjustments and TSP-derived quarterwave design. I am gratified by the apparent acceptance of the essential portions of "Omega Quarterwave Reflex."

Mr. Dlugos' letter can be distilled into two good questions.

1. Is there naming precedent for the design I described?
2. What, if anything, is protected?

Mr. Dlugos understands the history and development of quarterwave design better than anyone I know. Mr. King's ML-TQWT naming credit is almost certainly accurate. I have every confidence in Mr. Dlugos' report of first use of "mass-loaded Transmission Line" (ML-TL) by Mr. Monfret© 2001.

Mr. Dlugos reports it has taken four+ years of evolution to develop a generally accepted ML-TL. I fondly recall forum discussions with Martin, GM, Dave, Thorsten, Godzilla, ron, hitsville, James, and others. The difference between ML-TL evolution versus growth from "Rhinos" through "alpha Transmission Lines" to "Omega Quarterwave Reflex" is the difference between iterative modeling versus cookbook design.

The punctuated evolution of ML-TL design began shortly after "Rhinos" was published. "Rhinos" shows how an unstuffed aperture-loaded parallel cabinet (predating ML-TL) and an unstuffed, aperture-loaded reverse-tapered cabinet (a -tqwt) work.

"Rhinos" expressly discusses the quarterwave and reflex actions of the pipes. At the time, "I was astonished when I first saw the frequency response. [fQ shifts] about one-half octave below [pipe length resonance]!" That was news in 1999.

"Quarterwave reflex" is not used in the 1999 article. I had no concern with naming precedent then. The term ML-TL has come into general use since. I offer the new term to separate iterative modeling from my cookbook approach. Time will tell whether ML-TL and Quarterwave Reflex can stand side by side.

Mr. Dlugos says, "His methodology is certainly unique." This is a high compliment, especially considering the source. This also answers the second question above.

King and Augspurger are protected if a software program or loudspeaker design is derived using their computational models. Likewise, producing and selling software or loudspeakers derived from "Let's build one" and related graphs are protected.

Copying the article, in whole or in part, or using the published equations is copyrighted. OQR cannot be posted on the Internet, quoted or reproduced in print or in cyber-space in any way. OQR may have no economic value, but it is the first of its kind and therefore protected.

Because OQR contains the first discussion and explanation of the distinctive pulse-shaped impedance curve, I believe protection extends to that curve in the context of quarterwave loudspeakers.

**David Dlugos responds:**

To use Rick's term, the pulse-shaped impedance curve is simply the characteristic impedance curve of a box transitioning from a standard vented box to an aperiodic box. The bottom hump of the saddle-shaped impedance curve becomes smaller as more damping is added—to the port in the case of a BR or the whole line in the case of a TL (aka quarter-wave resonator). This was discussed and explained by Augspurger in his AES paper (see figure 7a) at AES 107, and I was also able to dig up a paper published in 1956 by Ted Jordan in *Wireless World* that shows and discusses essentially the same thing.

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Regarding Rick Schultz's "Omega Quarterwave Reflex" article, I was pleased and excited to see a TL speaker design article in *aX*, having built several TLs and modeled more potential TL designs than I can recall. I read it and its addendum on the *aX* website with great interest. The ΩQR design process is easy to follow and will likely allow many people to build a satisfactory design. Still, I have issues with many of the suppositions, conclusions, and claims presented in the article.

First, consider what the ΩQR is and is not. In my opinion, it's essentially a specific case of an ML-TL whose ultimate performance has been limited by restricting the use of three important design parameters: driver location, stuffing length along the line, and relative aperture size. There is nothing really unique about the ΩQR's design in terms of the resulting performance. And, the process does not necessarily—and, I believe, may infrequently—result in an optimally performing design as claimed. Its only real benefit is its ease of application; no computers are necessary.

The author placed much emphasis on the resulting impedance characteristic, comparing it to an over-stuffed TL and an un-stuffed TL and why it indicated superior performance to both. He went so far as to describe an EKG sinus rhythm waveform as being similar in shape to the impedance curve shape of the ΩQR. Why this EKG-waveform similarity is useful or important is not clear. From my viewpoint, it seems this analogy was used not for technical or scientific purposes, but simply to impress the reader.

As the author stated, all TL-type designs will have a pair of impedance peaks before stuffing is added. When stuffing is added, the magnitudes of both peaks will be reduced, with the peak occurring at the lower frequency decreasing more in magnitude than the other peak. If enough stuffing is added, the lower peak can be made to completely disappear, making the TL perform much like a sealed enclosure. Nevertheless, there is nothing special about the shape of the ΩQR's impedance curve; it shows only that the performance characteristics will lie somewhere between a typical vented system and a sealed system. Its impedance curve shape does not necessarily indicate superior or optimum performance, just a different performance.

Locating the driver along the line according to the "20%" rule of thumb is generally a good rule *when you can't model the expected results*, but my extensive modeling with a variety of drivers and a variety of TL designs clearly shows a different location is often needed. Sometimes 25% is better, sometimes 15% is better, and sometimes somewhere in between or even outside of those values gives superior results. You just can't limit yourself to using 20%. With Internet access to readily available and easy-to-use modeling programs, such as those on Martin King's website, there's no reason to restrict a design's potential performance (or to just hope the performance will be good).

Restricting the stuffing length to the first 67% of the line's length will not ensure optimum performance. That may be too long or too short. Many of my modeled designs have worked better by stuffing just the first 50% or so of the line. Additionally, it's sometimes necessary to modify both the length and density of the stuffing to achieve optimum results. Again, it's not difficult to acquire and use modeling software, so why limit your design?

The author made a comment on the shape of the aperture's SPL response on either side of its peak stating, in so many words, that because the response sloped up or down at 12dB/octave on both sides, this defined the *system* as being 2$^{nd}$ order! An aperture response is only part of the system response. All TLs, no matter their configuration, are 4$^{th}$-order systems. That's not to say the *system* response in the first octave or two below f3 can't or won't be more gradual, even 2$^{nd}$ order, but the SPL system responses of all TLs will become 4$^{th}$ order as frequency approaches zero.

Making the aperture's area fairly small with respect to the line's area is not the only way, nor is it necessarily the best way to make the system response be flatter and deeper. You can make the line longer or taper it, both of which will deepen the response because the line's ¼-wavelength resonant frequency will be lowered, while tapering will also flatten the response. Making the enclosed volume larger will also deepen the response.

While reading the author's analogy between TLs and the movement of the radio antenna on his car as he drove along a highway, I found it contrived yet vaguely familiar. In a quick check on Martin King's website I re-read his paper describing the enclosure design of an ML-TL for a Lowther driver.

In that paper Martin visualized using a yardstick with one end clamped to a table to illustrate what happens when the free end of the yardstick is plucked. The yardstick's vibration was analogous to the air velocity in a TL. Further, Martin discussed how the yardstick's vibrational patterns would change if its length was increased or decreased, or if a weight was applied to the loose end. The similarity between Mr. Schultz's antenna analogy and Martin's yardstick analogy is curious, to say the least, *and Martin's was written in 2003.*

Never one to not at least try yet another documented TL design process, I designed and modeled an ΩQR for my favorite 8″ woofer, a Peerless 831709, following the author's design process. I then compared the modeled performance to the modeled performance for my current TLs using the same woofer. I used the same Mathcad-based programs from Martin King for both models.

The T/S parameters I used are the average values for the pair of Peerless drivers I'm using, which were broken in and measured for me by the good folks at Madisound. The parameter values are:

| | |
|---|---|
| fs = 21.8Hz | Qms = 2.36 |
| Qts = 0.334 | Re = 5.52Ω |
| Vas = 8139 in$^3$ | Le = 0.56mH |
| Sd = 33 in$^2$ | Bl = 7.04 |
| Qes = 0.389 | |

For the ΩQR cabinet, stuffed with AcoustaStuf, the calculations resulted in a line length of 100″, Sx of 106.4 in$^2$, Sa of 10.64 in$^2$, a stuffing density of 0.56 lb./ft$^3$ for the first 67″ along the line, and the driver's center located at 20″ from the closed end of the line. For convenience I modeled the cabinet with an Sx of 105 in$^2$ and an Sa of 10.5 in$^2$, making the cabinet's internal dimensions 10.5″ W × 10″ D × 100″ H.

Three graphs of the modeled ΩQR performance are shown in **Fig. 1**. (Figures are located at

**www.audioXpress.com**

Once there, click on the current issue and follow the link title "articles and addenda.") The red line in **Fig. 1A** is the system's SPL output (ignore the dashed blue line). The red line in **Fig. 1B** is the woofer's SPL output, and the dashed blue line is the aperture's SPL output. Finally, the red line in **Fig. 1C** shows the system's impedance curve (again, ignore the dashed blue line).

Now consider how the performance of the same woofer in my TL-based 3-way speaker compares. For convenience, just call my system the SigmaTL, which is a three-way system with the Peerless 831709 working into a 12:1 tapered TL. At the closed end of the line the cross-sectional area is 70 $in^2$, and it tapers to 6 $in^2$ at the open end of the line. The line is 69″ long and stuffed with AcoustaStuf for the first 36″ from the closed end at a density of 1 $lb./ft^3$. The driver is located 16% of the line's length from the closed end. **Figure 2** contains the three performance graphs that resulted from the modeling process.

Now, consider the comparable graphs, one pair at a time. For the ΩQR you can see from **Fig. 1A** that f3 is about 27Hz, whereas for the SigmaTL (**Fig. 2A**), f3 is about 37Hz. Clearly, the ΩQR has a performance advantage over the SigmaTL in this response area.

Looking higher in frequency, above 300Hz both response curves are pretty much identical with very small-amplitude "ripples," but from the knees in their response curves up to 300Hz, the response of the SigmaTL is much flatter than that of the ΩQR. Staying with **Figs. 1A** and **2A** and looking at the slopes of the curves below their knees, the ΩQR rolls off at a faster rate than the SigmaTL. Neither the ΩQR nor the SigmaTL can be called or is a 2nd-order *system*, however.

Comparing **Figs. 1B** and **2B** shows the beneficial effects of the small aperture size in the ΩQR in reducing harmonic ripples in the system response shown in **Fig. 1A**. Still, both system responses are quite good, and almost identical, above 300Hz or so.

The graph of system impedance in **Fig. 1C** shows the "sinus" waveform discussed by the author for the ΩQR. In **Fig. 2C** it's clear the lower-frequency impedance peak has been almost completely suppressed as compared to **Fig. 1C**, but this only means that the rolloff rate of the SigmaTL's response below its knee will be slower.

Which system is better? Well, if your only concern is how low f3 is, clearly the ΩQR is better, but think about cabinet size for a moment. The ΩQR's cabinet would enclose 6$ft^3$ of volume and be over 8′ tall! Even if the line were folded once, the cabinet's dimensions would end up around 1′ wide by almost 2′ deep and would be over 4′ tall. That's a really big box!

How big is the actual cabinet for my SigmaTL? I built this as a two-box system, so the woofer has its own dedicated cabinet for the TL. Its volume is only ~1.5$ft^3$ with external dimensions of 11.5″ W × 27″ H × 14.75″ D (the SigmaTL box does not have a rectangular shape and has internal baffles to fold the line several times, so using these dimensions to estimate its internal volume would not be appropriate).

Except for sound effects, such as the tromping of dinosaur feet through the jungle, or pipe organs perhaps, how much of the music we listen to requires an *anechoic* f3 much below 40Hz? I can't speak for anyone else, but my musical tastes certainly don't. And don't forget, room gain effects usually add in quite a bit of boost in this region.

If I wanted a much lower system f3 and could live with a somewhat larger cabinet, I would stick with a tapered TL. For instance, I'd increase the SigmaTL's cabinet volume by about two-thirds to ~2.5$ft^3$, while keeping the line length, line taper, and stuffing distance/density the same.

Call this one the DeltaTL. Its modeled system SPL response is shown in **Fig. 3**. Not only is the f3 of 30Hz comparable to the 27Hz f3 of the ΩQR response shown in **Fig. 1A**, the DeltaTL's overall system SPL response is much smoother and flatter. And, the DeltaTL's cabinet volume and size would still be much smaller than those of the ΩQR.

While I believe the performance abilities and uniqueness of the ΩQR were overstated, I was bothered even more by the self-important tone of the article and the author's failure, in my opinion, to fully acknowledge the work of others before him. Anyone reading the article who does not generally know much about transmission line speaker systems or their established designers might easily conclude the author did much more original thinking and work than I believe he actually did. His acknowledgments of the extensive contributions from George Augspurger and Martin King in this field, from which the ΩQR design was "derived," were grossly inadequate.

In all fairness, I must give Mr. Schultz credit for developing the mathematical expressions and graphs that define the ΩQR design and defend his proprietary rights to them, but I can't imagine he honestly believes any of this has enough originality to be patented.

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**Rick Schultz responds:**

It pleases me to see reference to Mr. King. He is a pioneer in quarter-wave design. His MathCAD-based modeling tool is the best freeware for pipe design.

"Omega Quarterwave Reflex" is written as a follow-up to "alpha Transmission Lines" (*aX* 9/2003) and "Rhinos" (*Speaker Builder* 5/99). Please consider them together. I acknowledge Mr. King and Mr. Dlugos in "alpha Transmission Lines" and do not repeat the acknowledgment in the current article. I consider them both cyber-friends. See more at **http://www.quarter-wave.com/** and **http://www.t-linespeakers.org/**, respectively. Sorry, I don't have a website.

Mr. King and Mr. Augsurger are engineers by trade, and this brings great value to quarterwave design. Mr. King's articles and discussions rely heavily on calculus. Mr. King says on his site, "If a new user invests a few hours working with one of the simple transmission line worksheets, I believe they become proficient MathCAD users very quickly. Unfortunately a few users are never comfortable with MathCAD and abandon the worksheets."

A user needs nine TSP or similar engineering parameters, not all of which are readily available. I re-examined his "Classic Transmission Line Alignment Tables," which help the beginner determine length, cross-section using several tapers, and driver placement based on ⅓ length. The user changes them and speculates over aperture size until a good pipe is revealed. Every iteration yields several new graphs.

The writer modeled a nice design for his speaker. I have no idea how much iteration it took to come up with his design.

My OQR "cookbook" model requires three TSP and three readings from one simple graph. With a little algebra, OQR quickly delivers a complete aperture loaded pipe that can be constructed with a good performance. OQR reduces guesswork and predicts cabinet dimensions.

The King and Augspurger models produce graphs. With less input, my model delivers recommended pipe characteristics. Because King's and Augspurger's goals and outcomes are different from mine, comparing them as the writer does is imprudent. Apples and oranges.

A pipe builder could start with OQR to get a good pipe and then move on to use Mr. King's or Mr. Augspurger's modeling software. Speculate on tweaks and adjustments until the definitive, ultimate pipe is designed.

Naming or categorizing quarterwave pipes is the source of much confusion. Before I proceed to address some of the writer's other issues, I need to explain the state of the art as I perceive it. As you can probably tell, I like to organize things into a

| | parallel sides | tapered |
|---|---|---|
| open | Transmission Line | TQWT |
| aperture loaded | Quarterwave Reflex | ML-TL, -tqwt |

useful system.

I believe quarterwave pipes should be categorized by two characteristics: sides and loading.

Driver placement is important but not crucial.

My two articles discuss Transmission Lines and Quarterwave Reflex. For the rest of the readers, ML-TL means "mass-loaded Transmission Line." A TQWT is a "tapered quarterwave tube." It is narrow at the closed speaker end and wide open at the other end.

I started using the term "-tqwt" on fullrangedriver.com several years back. It means the taper of the TQWT is reversed. The closed end is wide while the open end is small.

I have clearly and repeatedly said TL and QR have parallel sides and are not tapered. My comments and assertions pertain to a parallel-sided quarterwave design, whether a TL or QR. I stand by what I have written.

The writer describes a -tqwt in his letter. His pipe is very good. Many of his comments are correct with respect to his -tqwt. IMHO, -tqwt is the best quarterwave design possible. I think -tqwt and aperiodic speakers are the two best cabinet designs overall.

Challenging the value of OQR by presenting a -tqwt that is tapered, shorter, and more densely stuffed is inequitable. It would take an entire article to explain how and why his -tqwt is different and better than an OQR. (I have only sketched an outline for an article in my head. It will have to wait until after an article concerning stuffing adjustment.)

I will address three tapered system characteristics briefly: impedance curve, stuffing location, and driver placement. I was not explicit when describing stuffing and driver placement in OQR, but believe it is a good time to get the full explanation into print.

Driver placement is a function of cabinet *volume* above and below the speaker. I mean volume from driver to open end versus driver to closed end. The rule for parallel pipes applies to tapered pipes. A 5:1 volume ratio sets driver location.

This immediately implies two things. If the closed end is larger than the open end (the writer's -tqwt), the driver must move toward from the closed end. Second, the steeper the taper, the more the driver moves. A steep 12:1 taper requires more movement than a 3:1 taper. Mr. Kittinger's 16% location seems on target, though I did not do the calculation.

Next, the same basic principle applies to stuffing. The volume of stuffing at the closed end is about twice the volume of empty space at the aperture end. Denser stuffing may allow for some variation, but the 2:1 volume ratio is generally reliable.

I hope these two pointers save time for iterative modelers.

The impedance curve of the OQR is a telltale electrical characteristic. It does not indicate superior performance. It does indicate optimum design. You can over-stuff an OQR to flatten the curve or under-stuff to be more like a bass reflex, but why would you? When the pulse-shape curve is present, the design is right. There indeed is something special about the OQR impedance signature.

Mr. Kittinger flames, I fail ". . . to fully acknowledge the work of others before [him]." I went to great lengths in "alpha Transmission Lines" to properly credit the long history of quarterwave design. The history came from Mr. Dlugos, Steven E. Schoenherr (**http://history.acusd.edu/gen/recording/loudspeaker.html**), and my own reading of patents and articles. Mr. Kittinger finds my acknowledgments "grossly inadequate."

Flames continue, ". . .[readers] might easily conclude the author did much more original thinking or work than I believe he actually did." My first paragraph claims this is the first quarterwave design based solely on TSP and not rules of thumb. As one example, I assert fs/Qts is a more reliable predictor of length than the old rule of thumb. If one driver has fs = 40 and Qts = 0.5 and another has fs = 80 with Qts = 1.0, the pipe for each should be the same length?

That is original, specific, and new. Before last month, this thought did not appear in print or any form of public discussion. The placement-volume and stuffing-volume relationships for both tapered and parallel pipes within this letter are news.

My article ends by stating the individual adjustments are nothing new. What is new is bringing the adjustment together with TSPs into one design model. I welcome a discussion of prior quarterwave designs derived from TSPs.

P.S. Yes, a yardstick with a lump of clay is similar to an antenna with a golf-ball thingy. Yes, to some degree we have ripped off prior ogies. Of course mine was partially contrived. *aX*