

TRANSMISSION LINES

-THE REAL WORLD MEANS TO ENHANCED PERFORMANCE MONITORING



PMC was founded in 1991, with the objective of developing a new breed of monitor to deliver the extended frequency and greater resolution, increasingly desired by recording engineers working with programme material such as multi-channel film soundtracks and high bit, high bandwidth digital recording formats. These ambitions led the founding partners to Transmission Line theory and a substantial research and development programme in order to realise a TL based design that would produce consistent performance advances over conventional cabinet designs. It is an enterprise that has resulted in critical acclaim and considerable commercial success for an entire product range based on the application of TL principles, and that has earned the PMC a premium reputation in the most critical areas of the recording, mastering and television and film sound industries. PMC managing director and principal design engineer, Peter Thomas, examines the theory and the reality of TL design and why it works.

The birth of the Transmission Line speaker design came about in 1965 with the publication of A R Bailey's article in *Wireless World*, "A Non-resonant Loudspeaker Enclosure Design" (1) (Fig 1), detailing a working Transmission Line. Radford Audio took up this innovative design and briefly manufactured the first commercial Transmission Line loudspeaker. Shortly thereafter John Wright of IMF Electronics designed a range of Transmission Line designs and made them popular through his refinement and development of Bailey's theory. Although acknowledged as the father of the Transmission Line, Bailey's work drew on the work on labyrinth design, dating back as early as the 1930's. His design, however, differed significantly in the way in which he filled the cabinet with absorbent materials. Bailey hit upon the idea of absorbing all the energy generated by the bass unit inside the cabinet, providing an inert platform for the drive unit to work from; unchecked, this energy produces spurious resonances in the cabinet and its structure, adding distortion to the original signal.

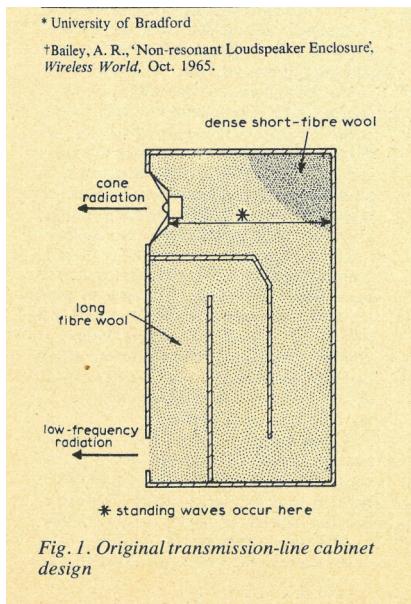


Fig. 1. Original transmission-line cabinet design

The Transmission Line (TL) is the theoretical ideal and most complex construction with which to load a moving coil drive unit. The most practical implementation is to fit a drive unit to the end of a long duct that is open ended. In practice, the duct is folded inside a conventional shaped cabinet with the open end of the duct usually appearing as a vent on the front of the cabinet. There are many ways in which the duct can be folded and Fig 1A illustrates one of PMC's typical layouts of a TL, as incorporated within a small two-way near-field design. The line is often tapered in cross-section to avoid parallel internal surfaces that encourage standing waves. Depending upon the drive unit and quantity – and various physical properties – of absorbent material, the amount of taper will be adjusted during the design process to tune the duct to remove irregularities in its response. The internal partitioning provides substantial bracing for the entire structure, reducing cabinet flexing and colouration. The inside faces of the duct or line, are treated with an absorbent material to provide the correct termination with frequency to load the drive unit as a TL. A theoretically perfect TL would absorb all frequencies entering the line from the rear of the drive unit but remains theoretical, as it would have to be infinitely long. The physical constraints of the real world, demand that the length of the line must often be less than 4 meters before the cabinet becomes too large for any practical applications, so not all the rear energy can be absorbed by the line. In a realized TL, only the upper bass is TL loaded in the true sense of the term (i.e. fully absorbed); the low bass is allowed to freely radiate from the vent in the cabinet. The line therefore effectively works as a low pass filter, another crossover point in fact, achieved acoustically by the line and its absorbent filling. Below this "crossover point" the low bass is loaded by the column of air formed by the length of the line. The length is specified to reverse the phase of the rear output of the drive unit as it exits the vent. This energy combines with the output of the bass unit, extending its response and effectively creating a second driver.

Phase inversion is achieved by selecting a length of line that is equal to the quarter wavelength of the target lowest frequency. The effect is illustrated in Fig 2, which shows a hard boundary at one end (the speaker) and the open-ended line vent at the other. The phase relationship between the bass driver and vent is in phase in the pass band until the frequency approaches the quarter wavelength, when the relationship reaches 90 degrees as shown. However by this time the vent is producing most of the output – Fig 3. Because the line is operating over several octaves with the drive unit, cone excursion is reduced, providing higher SPL's and lower distortion levels, compared with reflex and infinite baffle designs.

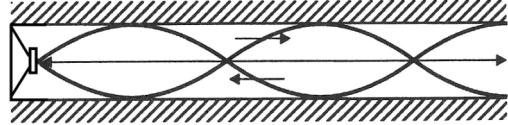
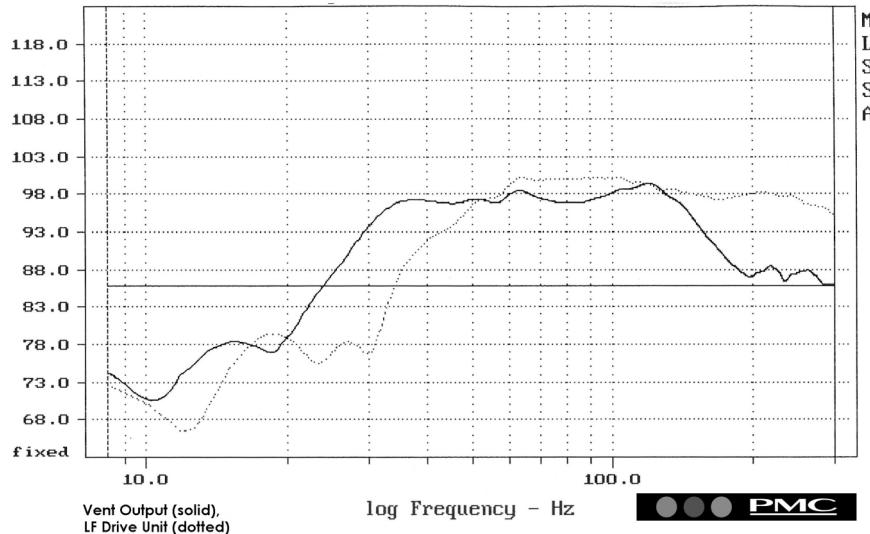


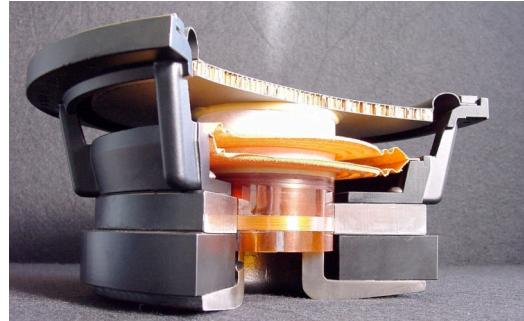
Fig 2



The calculation of the length of the line required for a certain bass extension appears to be straightforward, based on a simple formula (2), however the introduction of the absorption materials reduces the velocity of sound through the line, as discovered by Bailey in his original work. L Bradbury published his extensive tests to determine this effect in an AES Journal in 1976 (3) and his results agreed that heavily damped lines could reduce the velocity of sound by as much as 50%, although 35% is typical in medium damped lines. Bradbury's tests were carried out using fibrous materials, typically longhaired wool and glass fibre. These kinds of materials however produce highly variable effects that are not consistently repeatable for production purposes. They are also liable to produce inconsistencies due to movement, climatic factors and effects over time. High specification acoustic foams, developed by PMC with similar characteristics to longhaired wool, provide repeatable results for consistent production. The density of the polymer, the diameter of the pores and the sculptured profiling are all specified to provide the correct absorption for each speaker model. Quantity and position of the foam is critical to engineer a low pass acoustic filter that provides adequate attenuation of the upper bass frequencies, whilst allowing an unimpeded path for the low bass frequencies.

There are therefore two distinct forms of bass loading employed in a TL, which historically and confusingly have been amalgamated in the TL description. Separating the upper and lower bass analysis reveals why the TL has so many advantages over reflex and infinite baffle designs. The upper bass is completely absorbed by the line allowing a clean and neutral response. The lower bass is extended effortlessly and distortion is lowered by the line's control over the drive unit's excursion. One of the exclusive benefits of the TL design is its ability to produce very low frequencies even at low monitoring levels.

The complex loading of the bass drive unit demands specific Small-Thiele driver parameters to realise the full benefits of a TL design. Most drive units in the marketplace are developed for the more common reflex and infinite baffle designs and are usually not suitable for TL loading. To design a high efficiency woofer with extended low frequency ability, cones are usually extremely light and flexible with very compliant suspensions. Whilst performing well in a reflex design, these characteristics do not match the demands of a TL design. The drive unit is effectively coupled to a long column of air which has mass. This lowers the resonant frequency of the drive unit, negating the need for a highly compliant device. Furthermore, the control of this column of air requires an extremely rigid cone, to avoid deformation and consequent distortion. The lack of available suitable drive units provided the impetus for PMC to design a series of drivers employing a flat, 6mm thick diaphragm, manufactured from aerospace materials, that provides extraordinary stiffness, while maintaining a relatively low mass. Fig5



Over the past 35 years, various TL designs have come to market that have not always realized the true benefits of TL loading. Drive units with incorrect parameters have been employed, experience with line layouts and absorbent materials has been lacking and this has sometimes given rise to reservations regarding the performance of TL designs, compared to reflex and infinite baffle designs. The complexity of designing an accurate TL led PMC to invest in considerable R&D in order to develop the principle for a new generation of monitors, fully able to exploit the benefits of this technology. In house software and new measurement techniques have allowed the complexities of the TL design to be mastered and its performance benefits extended.

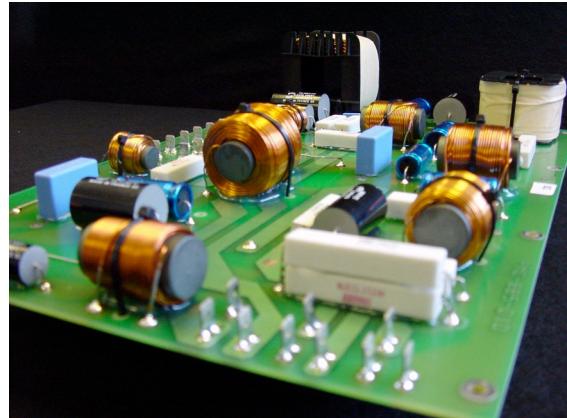
The extended frequency response, higher sound pressure levels and lower distortion afforded by TL's, separates them from reflex and Infinite baffle models. In addition, phase accuracy is superior to other moving coil designs, as a result of the absorption provided by the line in the upper bass range. The low frequency roll off at 12dB per octave matches the infinite baffle arrangement and avoids the large phase changes inherent in reflex designs.

It is sometimes claimed, as recently in the pages of this journal by John Watkinson, that the integrity of a monitor design stands or falls on the criterion of minimum phase response, providing the basis on which one would reject TL's in favour of infinite baffle designs. While it is an important concern, minimum phase response is clearly only one of several parameters that act to produce an accurate square wave. High SPLs, low distortion and usable bass extension are imperative in developing improved signal resolution and realistic lower signal reproduction, and the infinite baffle has

significant limitations in these areas. A "perfect" speaker would have both a perfect impulse response and a perfect frequency response, but then we are back in the theoretical realms of the infinitely long TL. In fact, the majority of loudspeaker engineers are agreed that acoustic phase responses have a small effect on the ear's ability to assess signal quality. As Floyd Toole commented in his AES Journal in 1986 (4)(5): "The advocates of accurate waveform reproduction, implying both accurate amplitude and phase responses are in a particularly awkward situation. In spite of the considerable engineering appeal of this concept, practical tests have yielded little evidence of listener sensitivity to this factor... the limited results lend support for the popular view that the effects of phase are clearly subordinate to amplitude response."

In support of this statement, electrostatic speaker designs, although possessing a remarkable ability to reproduce square waves, are not widely accepted as providing an accurate reproduction of transient bass signals, such as a kick drum in a studio environment. A speaker's low frequency extension, its rate of roll off, overall distortion and maximum output ability dominate our appreciation for accurate reproduction of low frequency instruments. Furthermore, on-axis response, off-axis dispersion and reduction of resonances within the response are more important issues to address in an overall speaker design.

Not only does PMC design its own bespoke bass units, it also manufactures custom midrange and high frequency domes to extend the limits of performance in its of monitor series. Integrated with Linkwitz-Riley 24 dB/Octave hand built crossovers, employing high end, close tolerance components, they provide highly accurate responses to over 60 degrees off axis, imperative in developing accurate stereo and surround sound imaging. The testament to PMC's TL approach is the use of our monitors by leading studios in all areas of music and sound production throughout the world, including many of the world's most renowned mixing and mastering facilities. Fig7



Distortion presents the major obstacle in monitoring high-resolution audio by eliminating fine detail at all ends of the spectrum. The greatest challenge for the loudspeaker designer in the 21st century is how to reduce this distortion ever further. Advanced Transmission Lines are one step further towards that goal.



Hospital Studios –The UK's 1st HDTV Central, London



Metropolis Studios – The UK's premier Recording and master facility, London

REFERENCES

- (1) A R Bailey, "A Non-resonant Loudspeaker Enclosure Design" Wireless World October 1965 P483-486
- (2) $\lambda = 344/4 \times f$ where f is the quarter wavelength frequency; 344m/s is the velocity of sound at 20 degrees C; λ is the length of the Transmission Line
- (3) L J S Bradbury "The Use of Fibrous Materials in Loudspeaker Enclosures" Journal of the Audio Engineering Society April 1976 P404-412
- (4) F E Toole "Loudspeaker Measurements and their Relationship to Listener Preferences" Journal of the Audio Engineering Society April 1986 P227-235
- (5) F E Toole Loudspeaker Measurements and their Relationship to Listener Preferences" Journal of the Audio Engineering Society May 1986 P335-336

Image 1	cutaway of PMC10 inch piston driver (para 6)
Image 2	PMC Linkwitz-Riley crossover board (para 11)
Image 3	Metropolis Studios
Image 4	The Hospital, Music Control Room
Image 5	Peter Thomas, MD and principal design engineer, PMC