Breaking Sound Barriers

WHITE PAPER - WIDEBAND

THE NEED FOR EXTENDED HIGH FREQUENCY BANDWIDTH - OR WHY YOU NEED A SUPERTWEETER

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INTRODUCTION

We are all used to the concept of a subwoofer, used to extend the low frequency response of a loudspeaker system for added realism. A SuperTweeter in effect does the same thing, but at the other end of the audible spectrum, extending the frequency range of the loudspeaker several octaves above the accepted limit of human hearing. The result is increased tonal accuracy of instruments and improved transient response, with perceived benefits even at bass frequencies. These effects have been apparent to all listeners to the Tannoy SuperTweeter so far, but the sceptical may wish to ask a number of questions:

- Is there any musical information above 20kHz, the accepted upper limit to human hearing?
- If so, is this energy perceptible?
- How can the SuperTweeter improve reproduction of the whole audio band, even low frequencies?
- Does it benefit all source material?

To address these questions amongst others, we will first look at the energy spectrum of some musical instruments, before considering the effect of bandwidth on phase response and harmonic relationships, with special emphasis on the Dual Concentric. We will then examine some aspects of the human hearing mechanism.

THE NATURE OF MUSICAL INSTRUMENTS

Fig. 1 shows the accepted frequency range of musical instruments. In addition to the fundamental frequency, a higher bandwidth is required to reproduce the overtones or harmonics. It is these harmonics that give instruments their character. Without them, all instruments would sound like a sine wave test signal. There is also a family of pitchless instruments, such as the cymbal or triangle. In all cases, energy is seen to extend to 15kHz. This ties up neatly with work done by Snow in 1931 [1], which showed that the perfect reproduction of orchestral music required an upper frequency limit of 14kHz.

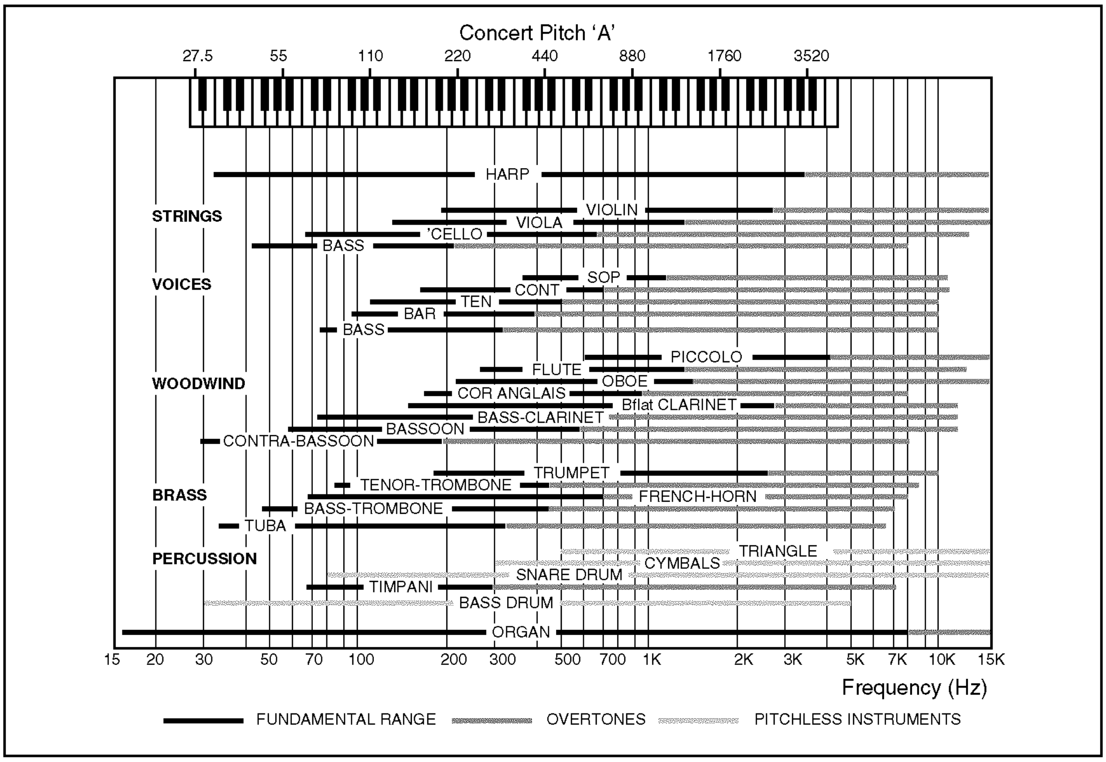


Fig. 1 The Frequency Range of Musical Instruments

That was accepted wisdom then, and identical information is still being reproduced in many modern text books. A quick measurement with a spectrum analyser shows that this is clearly not the case, but few researchers have considered the true bandwidth of musical instruments or investigated the in depth mechanism of human hearing at high frequencies.

The most thorough investigation into spectra we cite is that of Boyk [2], and we reproduce some of his figures with permission. Fig. 2 shows the spectral content of a trumpet, with a particular type of mute. There is considerable energy above 20kHz, as can be seen, the level of which does not drop into the noise floor until 100kHz. A similar result is found with instruments from the other musical families, with the violin and oboe showing energy above 40kHz. Even sibilants in speech were found to have energy above 40kHz.

It is the pitchless instruments, such as members of the percussion family that generate the greatest amount of ultrasound. The cymbal crash (Fig. 3) gave 40% of its energy above 20kHz, while the triangle was found to have a healthy output at 100kHz (Fig. 4).

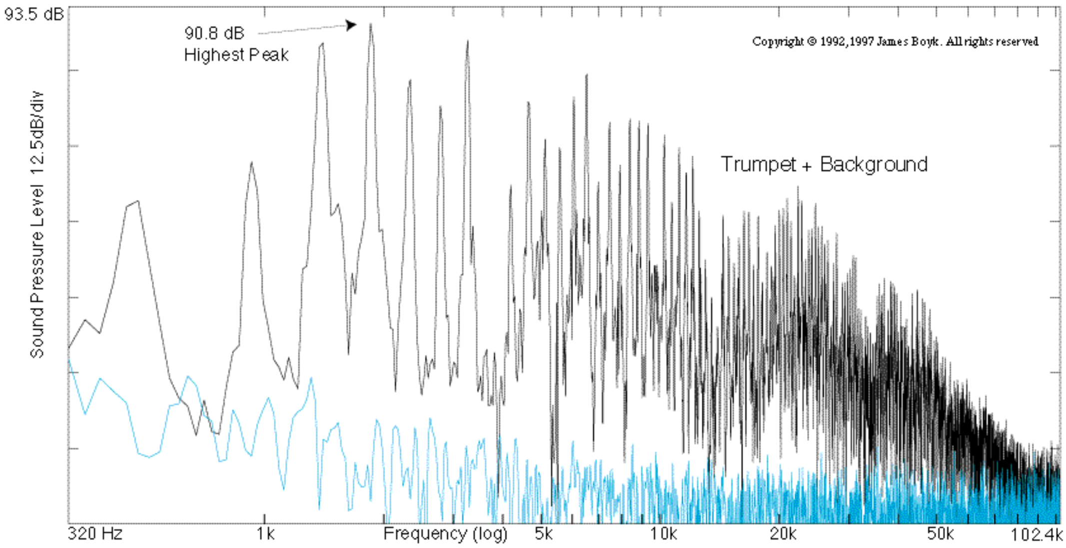


Fig. 2 Spectral Energy from Trumpet

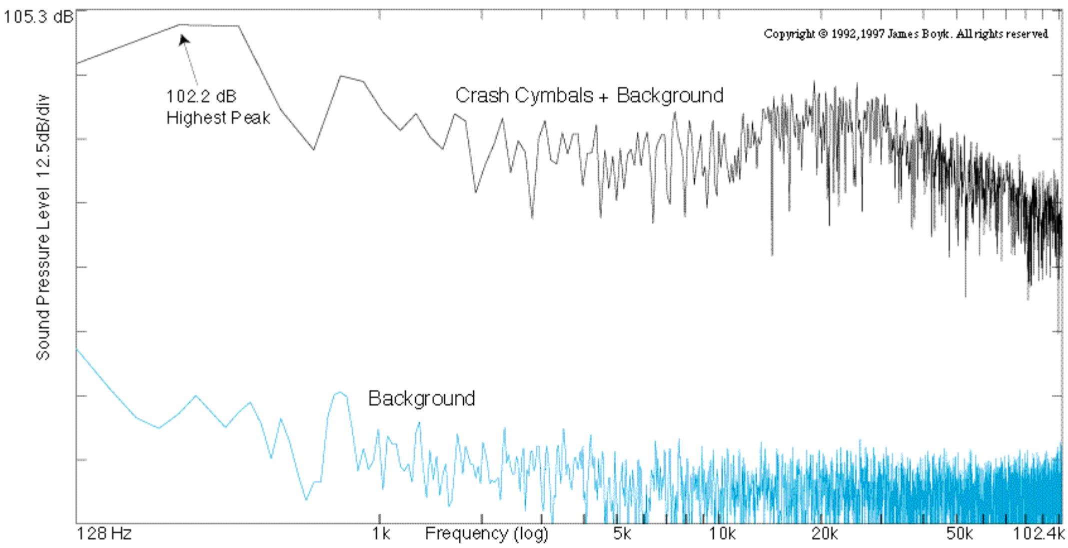


Fig. 3 Spectral Energy from Cymbals

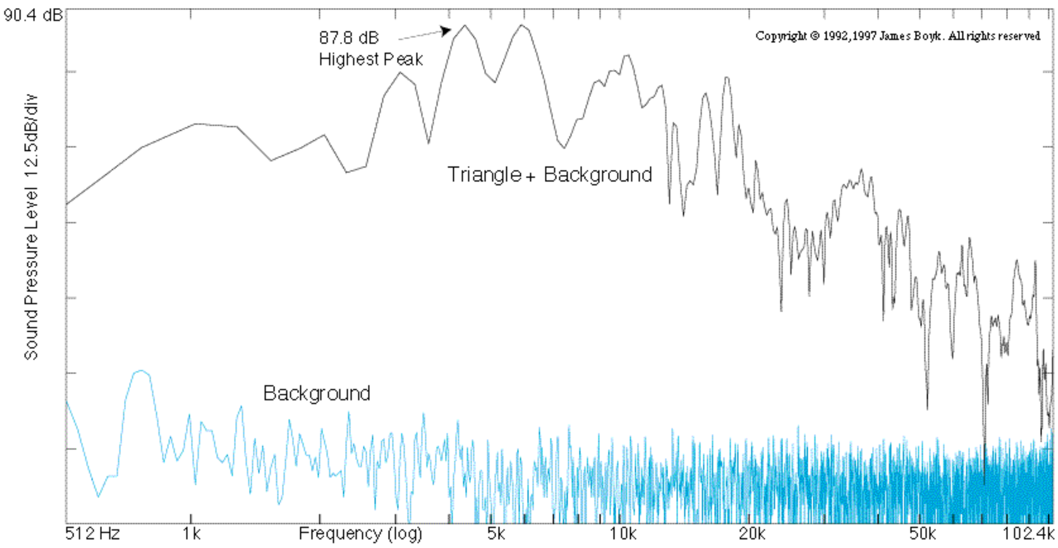


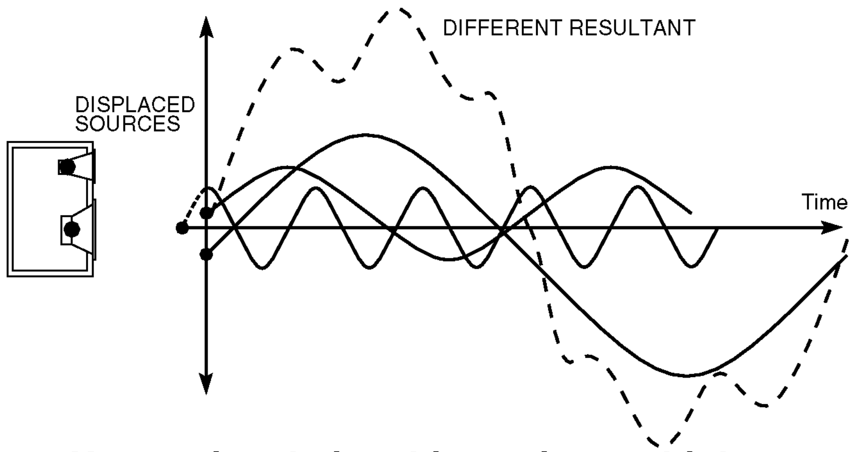
Fig. 4 Spectral Energy from Triangle

ABOUT HARMONICS, PHASE & THE DUAL CONCENTRIC

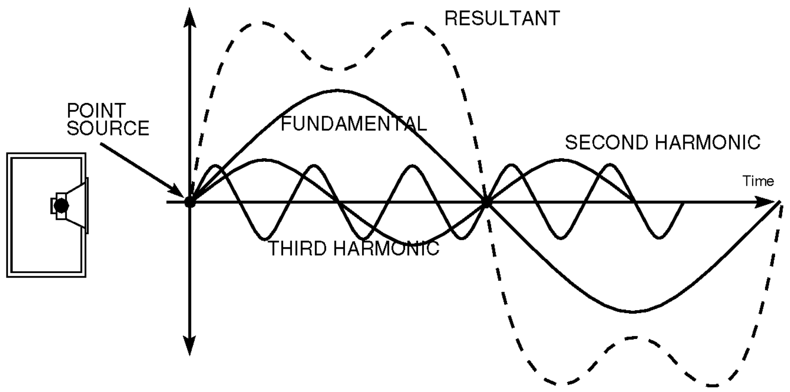
Over the frequency range that a Dual Concentric operates, it does a far better job of preserving the harmonic content of instruments compared with a conventional discrete drive unit arrangement. This is because the low and high frequency sounds are generated from the same point in space (point source), and there are no time and phase differences between harmonics below and above the crossover point, as with discrete speakers.

Also the relationship in amplitude of fundamental and harmonics is accurately preserved both on axis and at points off axis. In a normal room, the majority of sounds perceived by the human ear are reflections generated by the off axis response of the speaker. The even off axis response of the Dual Concentric means that the reflected energy has the same harmonic structure as the direct on axis energy. This is illustrated in Fig. 5

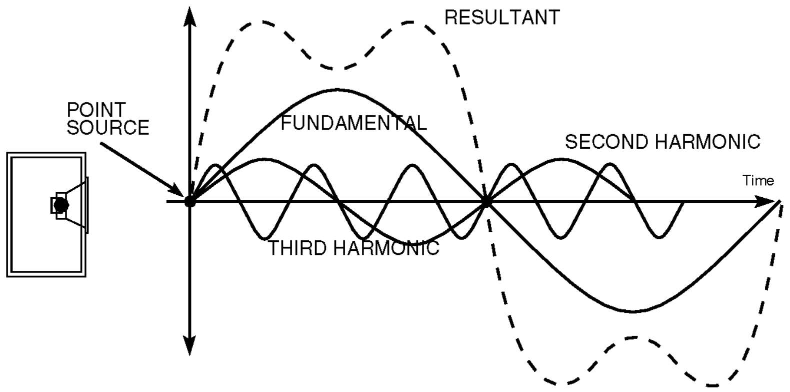
The other element of the Dual Concentric that is a function of its point source nature, is that it provides linear phase response. Every loudspeaker or audio device exhibits a low pass filter function [3], and consequently act as a frequency independent time delay in the pass band, otherwise known as a linear phase response. However, with discrete drive units that are not time aligned, severe phase errors occur in the pass band, while the Dual Concentric offers an almost ideal linear phase response (Fig. 6). This better preserves the harmonic relationship of instruments and improves the transient performance. Note though that the phase response does deviate from the ideal at very high and very low frequencies. This is a natural result of the high and low frequency roll off points of the system. To reduce the low frequency phase error, we would add a subwoofer, which does more than just add bass. It is this reduction of phase error we believe is one of the main benefits of a well integrated subwoofer. Music with no apparent bass content will sound more natural when this error is removed.



Harmonic relationships using multiple sources



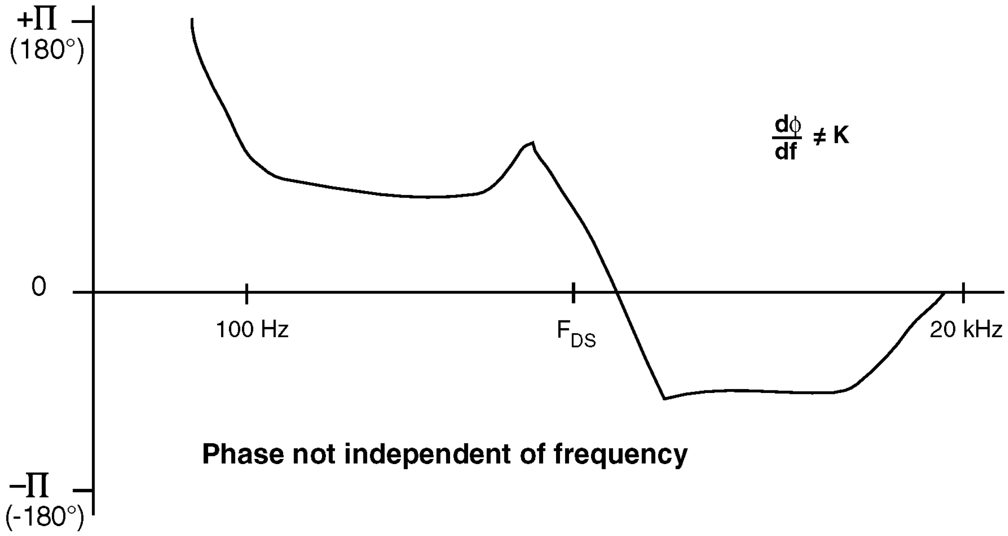
Harmonic relationships preserved using a single point source



Harmonic relationships preserved using a single point source

Fig. 5 How the Dual Concentric Preserves Harmonic Relationships

Phase Response of a Typical Discrete Non-aligned System



Phase Response of a Typical Tannoy Dual Concentric System

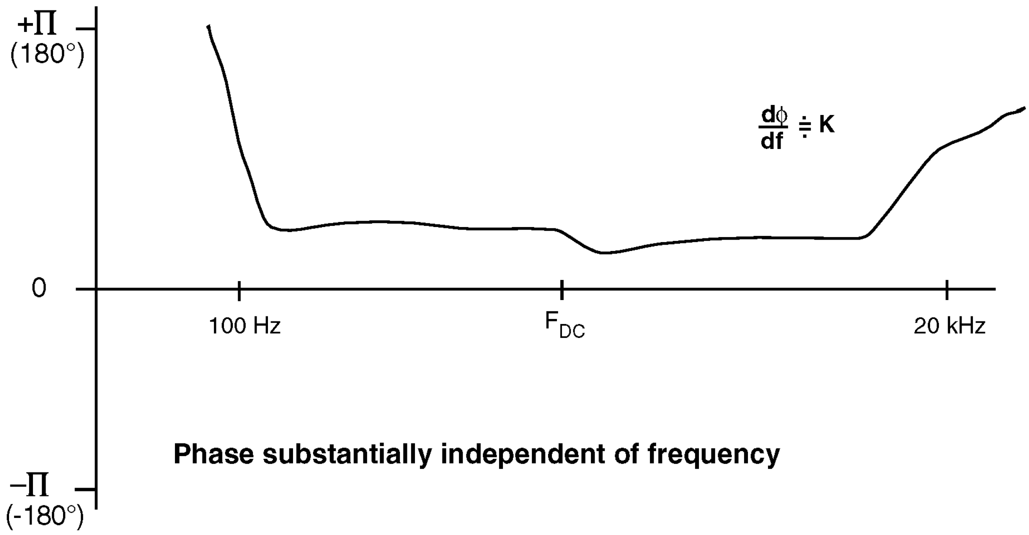


Fig. 6 Dual Concentric Phase Error Compared to a Discrete System

Likewise, the addition of a SuperTweeter, time aligned to the acoustic centre of the Dual Concentric, will reduce the high frequency phase error by moving the low pass roll off point much higher, typically –6dB @ 54kHz, -18dB @ 100kHz. So even if we ignore for now the perception of sound above 20kHz, the addition of a SuperTweeter will better preserve the harmonic relationship between instruments. To illustrate this, Fig. 7 shows the phase error with both a 20kHz roll off and a 54kHz roll off. There is clearly less phase error not just a high frequencies, but as low as 5kHz also.

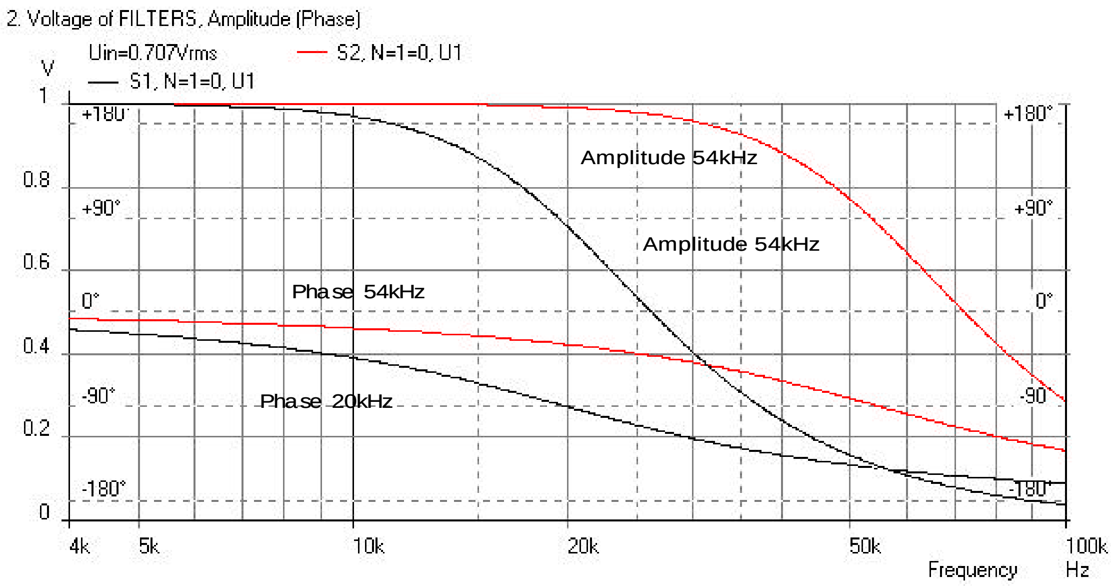


Fig. 7 Addition of SuperTweeter Gives Less Phase Error

HUMAN PERCEPTION OF ULTRASOUND

So far we have considered how the addition of a SuperTweeter improves the phase and transient performance of a loudspeaker, especially a Dual Concentric, in what is traditionally known as the audible band up to 20kHz. We know that musical instruments have energy up to and beyond 100kHz, but can we perceive it?

Japanese researchers Oohashi et al [5] conducted experiments with wide bandwidth material to 60kHz, whereby a SuperTweeter could be either switched in or out. By monitoring the subjects' brainwave activity and noting subjective scores under blind conditions, they concluded that the listeners were indeed responding to the ultrasonic components in the music.

A further paper [6], concluded that profoundly deaf subjects relied on ultrasonic detection in their discrimination of speech and tones. They concluded the mechanism was through bone conduction, probably to a small organ in the inner ear called the saccule, which is effectively wired to the cochlea, the organ responsible for hearing as we know it.

During development of the SuperTweeter, an interesting result was noted. We were trying to cancel a 10dB peak in the response at 30kHz, electrically in the crossover network. For the measurements, we used a pseudo- random digital noise sequence, with 100kHz bandwidth. The presence or absence of this peak could readily be discriminated by listeners, even under blind conditions. There was however no change in the measured frequency response below 28kHz, further supporting the above research.

CONCLUSIONS

In this White Paper we have shown that musical instruments produce energy well above the generally considered limit of human hearing. Research has shown that we are capable of responding to this energy, justifying the addition of a SuperTweeter where wide bandwidth sources are used. Even with conventional CD sources, the addition of a SuperTweeter reduces phase error and improves transient performance significantly below 20kHz. This leads to increased tonal accuracy at all frequencies, as the harmonics of instruments are not distorted in time. This benefits any high quality loudspeaker, but especially the Dual Concentric, with its superior time alignment in the first place. It should be stressed though, that even with the addition of a SuperTweeter, the Dual Concentric still acts effectively as a coincident point source, as it is still responsible for generating the vast majority of musical information.

We expect our source material and audio electronics to be of wide bandwidth and have excellent tonal and transient accuracy. There is now no reason for the loudspeaker to be considered the weak link in the chain in this respect.

ACKNOWLEDGEMENTS

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