TIME ALIGNMENT™ in loudspeakers

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Recently there has been a new interest in the performance of loudspeakers as it relates to the time vs. frequency domain. The amplitude vs. frequency response data of loudspeakers is relatively easy to obtain and "frequency response" curves are seen quite regularly in literature put out by manufacturers and in publications which review loudspeaker performance. However, data showing the performance of loudspeakers in the time vs. frequency domain is not as widespread. This is because the equipment which will allow time vs. frequency data to be produced is either very expensive or the tests, using less expensive equipment, are very time consuming. This article will attempt to describe a little of the history of investigations into the time domain, clarify the interrelationship of time and phase vs. frequency, and describe the Time-Align™ Technique as it applies to loudspeaker design.

The importance of having the different elements of a loudspeaker arranged to avoid a double sound or echo is certainly not a recent discovery. John Hilliard describes an event which occurred in 1934 while developing a theater sound system.[1] Dancer Eleanor Powell was rehearsing on a music stage. Hilliard and others could hear two distinct taps coming from the monitor loudspeaker as it reproduced the sound of her dancing feet. The high frequency driver of the two way monitor loudspeaker system was moved back until its acoustical position was essentially lined up with that of the woofer and the double taps could no longer be heard. Some experimenting to determine at what delay the echo could be heard was carried out. Depending upon the person making the judgment, a one to two foot path differential between the high frequency and low frequency drivers was determined as the point at which the echo could be just perceived. Hilliard states that a delay of 1 millisecond then became the criterion for future designs as the maximum allowable delay between drivers.

About eight-and-a-half years ago, Richard C. Heyser published a paper on phase and time delay characteristics of loudspeakers.[2] Anyone seriously interested in the subject should definitely read this article and others he has written dealing with the problems of loudspeakers related to performance characteristics in the time vs. frequency domain. Quoting from his 1969 article: "...the acoustic position of a loudspeaker should, on average lie behind its physical position by an amount that is some inverse function of its high frequency cutoff. The acoustical position of woofer will be further behind the physical transducer than that of a tweeter. This important fact is quite frequently overlooked by engineers who consider that spatial alignment of voice coils is sufficient to provide equal-time path signals from multirange loudspeakers." A further proof of this high frequency cutoff interrelationship to acoustical position is shown in a paper, by the author, given at the Audio Engineering Society Convention in May 1976.[3] In this case, the high frequency cutoff of a midrange driver was lowered in frequency by changing one component in the crossover network which was feeding it. The increase in time delay is clearly visible in Fig. 12 of this paper. This shows that the apparent acoustical position of this midrange driver is further back after the change in the network lowered its cutoff. The acoustical position of a driver is not only a function of its high frequency cutoff but of the cutoff network feeding it.

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The Definition of Time-Align™

Time-Align™ Technique, as applied to loudspeakers, is a real-time design method, utilizing proprietary instrumentation, which allows the acoustic output of a multi-way loudspeaker system to be adjusted so that the fundamental and overtones of a complex transient arrive at a listener's ears with the same time relationships they had in the electrical signal at the loudspeaker's input terminals. The time vs. frequency characteristics of the individual drivers of a multi-way loudspeaker system play an important role in determining the uniformity of the total time delay characteristics of the complete loudspeaker system. It would be well to point out that uniform time delay of a complete signal is not a bad thing. If it were, we would not enjoy recorded programs! We can play back performances which were recorded years before. It is at any instant in time, during the playback, that all of the complex overtones and the fundamental of a signal must be in the proper time relationship.

In designing such a Time-Aligned™ loudspeaker system, it is necessary that the time differential between various frequencies produced by a given driver, which is to be used in the system, be as small as possible. This requires that each driver be used only in what is called, by loudspeaker designers, its piston band. Of course, in any given design, the allowable tolerance of the time delay will determine the quality of the total system. This is similar to the effect upon quality, of the allowable amplitude vs. frequency response tolerance. At some point in the future it may be an ordinary thing for both the amplitude and time vs. frequency response plots of a loudspeaker to be shown, even on the same graph. This would most certainly be a very valuable way to display these interrelated characteristics.

After the individual time vs. frequency characteristics of each driver to be used in a particular loudspeaker system design are determined as being uniform, the design of the total system may begin. An interesting concept which may help to explain how a loudspeaker system is designed using the Time-Align™ technique is to compare it to splicing a magnetic tape recording. A good splice is virtually undetectable because the amplitude and time characteristics of the program at the point of the splice are very carefully matched. The same thing can also be said of the Time-Align™ technique as applied to loudspeaker design. Both the amplitude and time characteristics vs. frequency are carefully adjusted, with particular attention paid to splicing the time characteristics of any two adjoining frequency ranges. Thus, as the acoustic output of the driver covering the lower frequency portion of a given range of frequencies is reduced in amplitude by its network, the acoustical position of driver covering the next higher range of frequencies including the parameters of the network feeding it are adjusted to provide a virtually undetectable splice in both the amplitude and time vs. frequency domain.

Since there are both physical and electrical methods available which can be used to properly adjust the acoustical position vs. frequency and therefore the Time-Alignment™ of acoustical output of a multi-way loudspeaker system, it is worthwhile to look at some different loudspeaker systems which are Time-Aligned™. Figure 1 is a photograph of three Time-Align™ loudspeakers, manufactured by Sonic Energy Systems. The smallest, the TA-10, on the right, is a Bookshelf system employing a 25 cm (10 in.) woofer and a 3.8 cm (1.5 in.) tweeter. The physical offset between the woofer and tweeter in this system is less than that of the woofer and the midrange of the TA-12, shown as the middle system of Fig. 1. This is because the upper cutoff frequency of the 25 cm (10 in.) woofer is higher than the 30 cm (12 in.) woofer of the TA-12. This means that the acoustical position of the 30 cm (12in.) woofer is further back than that of the 25 cm (10 in.) woofer. Generally, the larger the diameter of a driver, the lower its cutoff frequency and therefore the further back its acoustical position, when compared to their physical positions. Since the cutoff characteristics of the network feeding a driver can also effect its cutoff, a smaller driver can have an acoustical position behind that of a larger driver if its cutoff is at a lower frequency. The method used to Time-Align™ the Sonic Energy Systems loudspeakers combined both the physical placement of the drivers relative to each other and the adjustment of the network parameters while looking at the acoustical output of each system in the amplitude vs. frequency and time vs. frequency domains. Both the physical locations and network parameters were adjusted simultaneously in real time.

Fig. 1—Time-Align™ loudspeakers by Sonic Energy Systems. Left to right: the Model TA-10F floor standing system with passive radiator, the Model TA-12 three-way floor system, and the Model TA-10 two-way bookshelf speaker system. All drivers in these systems are physically offset from each other in the front to back plane.

Fig. 2—The Sonex Model Two Loudspeaker System. This system uses two small bass drivers with a passive radiator in the rear for fast response. The physical offset between the bass and midrange drivers is less than between the drivers in Fig. 1.

Figure 2 shows the Sonex Model Two loudspeaker which, while designed using the same method described above, employs a different approach than usual for producing the bass frequencies. Two small diameter, 16 cm (6½in.) bass drivers are employed down to approximately 60 Hz where a rear mounted passive radiator takes over to produce the next lower octave to 30 Hz. Because of their small size and relatively high cutoff frequency, (about 3 kHz), the relative time delay characteristic, across the range which they are required to produce, is quite good. As can be seen, the relative physical offset between these two bass drivers and the midrange driver mounted above them, is relatively small. The trade off made in the design of the Sonex Model Two is to sacrifice high acoustical output capability for greater accuracy, especially in the time vs. frequency domain.

Figure 3 shows the Model 813 Time-Align™ Monitor by UREI (United Recording Electronics Industries) designed for use in recording studio control rooms. A recording studio monitor is required to produce high level acoustical output and to be efficient. The interesting point in this design is that it utilizes an Altec 604-8G dual concentric driver in which the high and low frequency producing elements are physically locked together. This precludes adjustment of the physical positions of the low and high frequency drivers which was part of the method used to adjust the acoustical position vs. frequency in the designs of Figs. 1 & 2. The method used to accomplish the Time-Alignment™ of the Altec 604-8G is purely electrical and uses a passive time delay network as well as a crossover network. The two networks are designed as a composite, once again using the real time method of the Time-Align™ technique. The second 38 cm (15in.) woofer in this system also receives its signal via a time delay/crossover network. Besides offering the 813 Time-Align™ Monitor as a complete system, UREI also supplies Time-Align™ crossover networks for the Altec 604-8G and the older 604-E.

Fig. 3—The UREI Model 813 Time-Align™ Monitor for use in studio control rooms. The 604-8G high and low frequency drivers are locked together and are, therefore, Time-Aligned™ by a passive time delay plus crossover network.

Because these networks can be substituted directly for the networks ordinarily used with the Altec 604-8G and 604-E loudspeakers, an interesting demonstration was conducted by UREI at the most recent Audio Engineering Society Convention (May 1977). By selecting between the Time-Align™ network and the network ordinarily used with each driver, the value of Time-Alignment™, if any, could be determined without changing the driver, enclosure, or position, thus allowing a really valid "apples to apples" comparison to be made. Tests conducted to determine "if phase is important" tend sometimes to cloud the issue. Usually, these tests are conducted to prove that phase is relatively unimportant. At the recent Audio Engineering Society Convention (May 1977), the author was told by two people independently, that they had been present at demonstrations in different parts of the world which were designed to show that phase was unimportant. Each said that they heard a clear difference between the two examples presented. The persons conducting the demonstrations proclaimed that no difference could be detected. In one case, no one said anything to the demonstrator. In the other case, people in the audience said they could hear the difference. In the second case, the demonstrator has since reduced the amount of "phase

Fig. 4—Relationship of the time delay vs. frequency for constant phase delays.

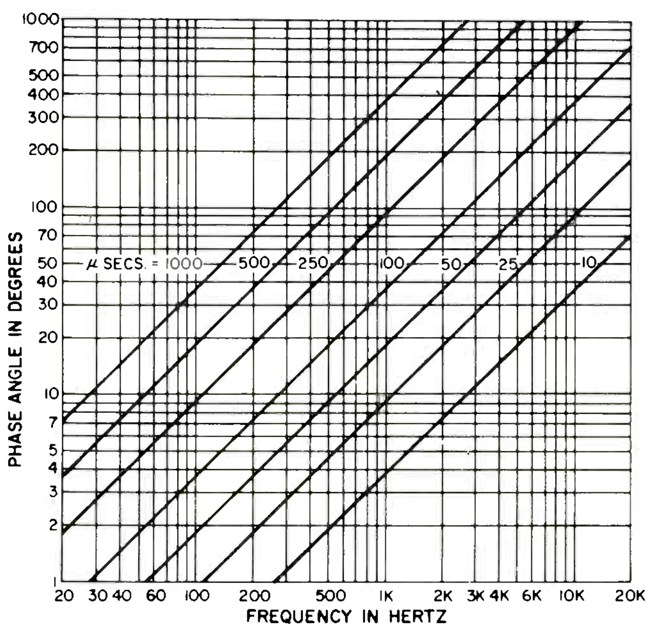
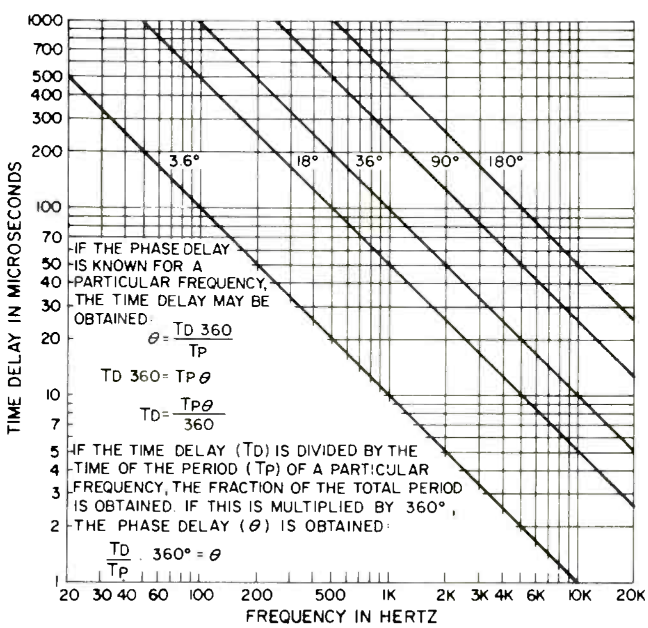


Fig. 5—Relationship of phase angle vs. frequency for constant time delays.



delay" which so far has still been detectable by some listeners.

Phase vs. Time

At this point, it would be worthwhile to show the relationship between phase and time as they relate to frequency. Since the term "Linear Phase" is used to describe certain loudspeakers, it might be well to clarify what is meant by this term. Most people would probably imagine that "Linear Phase" vs. frequency would mean that the phase at any given frequency would be the same value, and therefore linear. Figure 4 is a graph which relates the time delay vs. frequency for a constant or linear phase. As can be seen for a constant phase delay of 3.6°, the time delay varies from 500 microseconds at 20 Hz to 0.5 microseconds at 20 kHz. This is a time delay difference of 1000:1. Obviously, this is not what is meant by the term "Linear Phase". What must be meant is a linear change of phase vs. frequency. Another way of looking at this relationship is to compare two frequencies separated by a decade. The period of 1000 Hz is ten times as long as the period of 10 kHz. 10 complete cycles of 10 kHz can exist during the period of one cycle of 1000 Hz. This means that 10 kHz can go through 3600° while 1000 Hz goes through only 360°. Figure 5 is a graph of phase angle vs. frequency for a constant time delay. If all frequencies are delayed by the same amount of time, the phase will change linearly with frequency. For a constant time delay of 50 microseconds the phase delay at 100 Hz, 1000 Hz and 10 kHz will be 1.8°, 18° and 180° respectively. To be completely accurate in describing the desired condition, the term "Linear Phase" should be "Linear Phase Change."

During the demonstration of the Time-Align™ networks vs. the normal networks with the Altec 604-8G and 604-E loudspeakers, at the Audio Engineering Society Convention (May 1977), comparisons were made by having the demonstrator speak using a half inch condenser microphone. This microphone has a uniform time delay of about 10 microseconds which should not cause it to obscure the time information in normal speech. Lack of time offset between the low and high frequencies with a Time-Align™ network should allow the consonants, Ss, Ts, etc., to line up more accurately with the vowel sounds of speech. The reaction of listeners was quite dramatic. Of course, no claim is made that this was a scientific experiment. However, many people said that they were convinced that Time-Alignment™ was very worthwhile and that the reproduced speech was much more accurate with the Time-Align™ network. The fact that many recording companies have already expressed their desire to install Time-Aligned™ monitors in their control rooms may bode well for the future in terms of much clearer recordings with more judicious use of limiters, compressors, etc. Time will tell!

References:

1. J. Hilliard, "Historical Review of Horns Used for Audience Type Sound Reproduction", J.A.S.A., Vol. 59, No. 1, page 1, (Jan 1976).

2. R. Heyser, "Loudspeaker Phase Characteristics and Time Delay Distortion, Part 1", J.A.E.S., Vol. 17, No. 1, page 30, (Jan 1969).

3. E.M. Long, "A Time-Align™ Technique for Loudspeaker System Design", A.E.S. 54th Convention, May 1976, Preprint No. 1131.