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A TIME-ALIGN TECHNIQUE FOR LOUDSPEAKER SYSTEM DESIGN

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It has become increasingly apparent that the design parameters of a loudspeaker system must not only produce a smooth amplitude vs. frequency response, they must also produce a uniform phase and time characteristic. The ability to see the effects of parameter adjustments in the amplitude, phase, and time vs. frequency characteristics of a loudspeaker system, as the adjustments are being made is discussed.

I. INTRODUCTION

The main purpose of this presentation is to discuss a new method of designing loudspeaker systems which allows the effects of time variations to be seen and adjusted in a more direct manner than previously possible. The Time-Align Technique uses a new instrument which will be briefly described. This instrument provides a test signal which is used to align the loudspeaker system in the time domain. The total Time-Align Technique also includes the simultaneous alignment of the loudspeaker in the amplitude vs. frequency domain. However, before beginning, it would be of value to present the case for the importance of time variations.

II. THE IMPORTANCE OF TIME (PHASE)

Since the early 1930s the importance of eliminating gross driver alignment errors has been known and appreciated.(1). For small time errors, a learning process is probably involved.(2)(3)(4) This correlation between listening preferences and learning was a phenomenon discovered years ago with regard to bandwidth. In recent years, the importance of time (phase) in sound reproduction has become a matter of increasing discussion. Arguments with respect to the relative importance of time (phase) have become more prevalent. (5)(6)(7)(8)(9)(10) One of these investigations (11) mentions de Boer's "phase rule" which seems to be equivalent to the minimum phase phenomenon discussed by Heyser.(12)(13)

Some investigations into the effect of time (phase) changes on the timbre of complex tones were carried out using headphones. The possibility of time (phase) errors being introduced by the headphones has not been widely discussed but can be seen to exist in the data presented in some reports. (14)(15)(16) Another problem in determining the effects of time (phase) changes upon timbre, that of noise masking, has been studied. (17)

I. METHODS OF OBTAINING TIME (PHASE) DATA

In recent times, pulse testing techniques for the determination of loudspeaker (and other transducer) characteristics, has become popular.(18)(19) Various methods are available to allow time (phase) information to be derived from pulse measurements. A method of measuring the phase or group delay characteristics of phonograph cartridges has been described which is easily adaptable to the testing of loudspeakers. However, deriving time (phase) information from pulse response requires considerable equipment including computer processing.(20)(21) A method of obtaining phase information which uses sweep techniques has been described. (22)(23) Although phase meters have been available for many years, direct phase measurement of loudspeakers has been difficult. Phase meters which allow a chart record to be made of loudspeaker phase response have recently been described.(24)(25) It has been determined that the delay function is better described by time data.(26) This data can be derived from the phase measurement by mathematical manipulation.(12)(27) From time data it is easy to derive the equivalent distance since it is a direct function of the velocity of sound. The derivation can be used to describe the difference in time of arrival of sound from the various drivers of a multi-way loudspeaker system.(28) Having decided that time (phase) is an important characteristic of loudspeaker systems and worthy of consideration, quantification of the amount of detectable variation is naturally of interest.(9)(29)(30) During investigations of the detectability of small variations of phase, the importance of the absolute phase or polarity (+ or -) of the acoustic output was also discovered to be of importance.(10)(29)(31) In determining the relative spacing between drivers of a multi-way loudspeaker system it has been thought that the distance might be estimated.(32) Another approach is to calculate the amount of physical offset between drivers assuming a certain theoretical transfer function for each driver. This is based upon individual driver phase measurements. The crossover network transfer function must also be considered.(33) As Heyser has pointed out, the acoustic position of a driver relative to its physical position is some inverse function of its high frequency cutoff.(12) This will be verified later.

The interaction of the changing phase of loudspeaker driver acoustic output and crossover network phase characteristics has been described previously.(34)(35)

IV. TIME-ALIGN TECHNIQUE

A. Instrumentation

The technique to be described was developed because the above methods seemed indirect and time consuming. The Time-Align Technique permits the spatial alignment of drivers and the simultaneous adjustment of the crossover network with instantaneous visual display of the resulting acoustic output in either the time or frequency domain. A key to the Time-Align Technique is a newly developed Time-Align generator. A block diagram of this generator is shown in Figure 1. A pulse is generated which is a direct function of the ramp generator. As the pulse time duration is varied, the ramp rate varies in direct ratio. This allows the ramp to be used as the drive to the X axis of a display unit. The pulse passes to an output amplifier and from this output is available as a test signal. A derived sync pulse is also available to synchronize the normal sweep mode of an oscilloscope. The ramp is passed through a delay unit. This allows the time of the X axis of the display to be delayed by an amount equal to the transit time of the sound from the loudspeaker to the microphone.

Figure 2. shows the Time-Align generator connected to the basic measuring system. Because the ramp which drives the X axis of the display is delayed by the amount of time required by the sound to travel from the loudspeaker to the microphone, the acoustic output pulse displayed on the Y axis (channel 1) remains stationary when the pulse rate is varied. The displayed picture also remains basically unchanged in position and size. Any variations in pulse shape and/or position are due to variations in the time (phase) characteristics of the drivers and/or crossover network. This means that the effects of changes in the driver to driver spacing and crossover network parameters can be seen as they are being made. Because the X axis ramp drive is synchronized to the acoustic pulse on Y axis channel 1, and there is a delay between the ramp and the pulse output of the amplifier displayed on Y axis channel 2, this display will vary as the pulse duration is changed. However, this is merely a reference display. It is not affected by driver spacing or crossover network changes.
Figure 3 shows a more complete diagram of the equipment used for the Time-Align Technique. The addition of the 20Hz to 20,000Hz sweep generator and the frequency response tracer allows the immediate effects of changes in driver spacing and crossover network parameters to be viewed in the amplitude vs. frequency domain. The graphic level recorder and synchronized oscillator allow permanent records to be made.

The square wave generator allows the acoustic response to square waves to be viewed and photographed. The variable delay unit is in addition to the ramp delay unit which is an integral part of the Time-Align generator. This allows variations in phase to be viewed under dynamic conditions as an X-Y display. A 45^{o} straight line indicates perfect alignment of the acoustic output as received by the microphone with respect to the input to the loudspeaker system. The input to the amplifier may be any of the five sources shown.

Figure 4 shows a special mechanical assembly which facilitates the initial determination of optimum driver to driver spacing. Drivers may be moved in the X,Y, and Z planes.

B. Measurements

Figure 5a shows the display of an acoustic output pulse and the reference pulse. Figure 5b is the amplitude vs. frequency response. These were obtained by a combination of a crossover and a midrange and highrange driver. Figure 6a is the display of an acoustic output pulse of the same combination but with the polarity of the highrange driver reversed. Figure 6b is the amplitude vs. frequency response. For clarity, the difference between the amplitude vs. frequency response data of Figures 5b and 6b are shown in Figure 7. Notice the time smear in the acoustic pulse of Figure 6a. The time scale is identical for the acoustic output pulse and the input reference pulse. Both drivers were aligned with their mounting flanges in line. The time smear is due to blending the acoustic outputs of two drivers whose physical positions lie in the same plane, but whose acoustic positions are mis-aligned.

Adjustments were made on the spacing between the drivers and modifications were made to the crossover network. Figure 8a and 8b and Figure 9a and 9b represent the results of these changes. Figure 9 is for a polarity reversal of the highrange driver. The time smear in the acoustic output pulse has been reduced. Figure 10 shows the difference in the amplitude vs. frequency domain due to the polarity reversal of the highrange driver. Figure 11 is an acoustic output and reference input square wave at 3300 Hz, which is at the crossover frequency.

It is most interesting that, while the acoustic output pulse responses in the amplitude vs. time domain, as represented by Figures 8a and 9a, are very different, the amplitude vs. frequency responses, as compared in Figure 10, are very similar. A brief glance at the data presented in Figures 8 through 10 might cause one to conclude that, since Figure 10 shows the amplitude vs. frequency differences to be very small, changes in the amplitude vs. time domain as represented by the pulse response in Figures 8a and 9a, are unimportant. It must be pointed out that the test signal used to obtain the data of Figure 10 was a slowly swept sine wave. The pulses of Figures 8a and 9a were the result of a fundamental frequency and its harmonics occuring simultaneously. The difference in the acoustic output pulses of Figures 8b and 9b, due to the polarity reversal of the highrange driver, is audible. The modifications which produced the combination of driver spacing and crossover network parameters, for which polarity reversal of the highrange driver makes such little difference in the amplitude vs. frequency domain, was made possible by viewing changes in the amplitude vs. time domain using the Time-Align Technique. It is impossible to show, in this presentation, the subtle detail which can be seen in the amplitude vs. time display while slowly varying the driver positions.

There are many other aspects of the Time-Align Technique which are being investigated. One phenomenon mentioned by Heyser (12) is that the acoustic position of a driver should lie behind its physical position by some distance which is a function of its high frequency cutoff. This is verified by Figure 12. The delayed pulse is the result of decreasing the high cutoff of a driver by adjusting the crossover network. This points up another fact that might be overlooked. Some designers might be tempted to merely line up the voice coils of the various drivers of a loudspeaker system. Figure 12 points up the fact that not only are the acoustic positions of the drivers not identical with the voice coil positions, but that the adjustments of crossover network parameters to achieve a blended acoustic output, will vary the acoustic positions.

Two other points are worthy of mention. First, the minimum allowable variation in driver spacing is a function of the time spread of each individual driver in a system.(36) Second, when making subjective determinations of quality with respect to time smear, the quality of the program material, with respect to its own time smear, is of great importance.(36)(37)

V. SUMMARY

Subjective judgements of the quality of loudspeaker systems which are designed with attention to the time coherence of the acoustic output, have reported the great sense of depth in the reproduction of stereo programs.(38)(39) This correlates with the reverse situation where the unnatural spread of instruments in spatial depth has been noted as an effect of time smear.(36)

The Time-Align Technique has been presented as a means for achieving loudspeaker system designs which are capable of producing a time coherent acoustic output. The same results might be achieved by other methods but they are much more tedious and time consuming. The main advantage of the technique presented is the relative ease with which a complete Time-Align loudspeaker system can be engineered.

Acknowledgements

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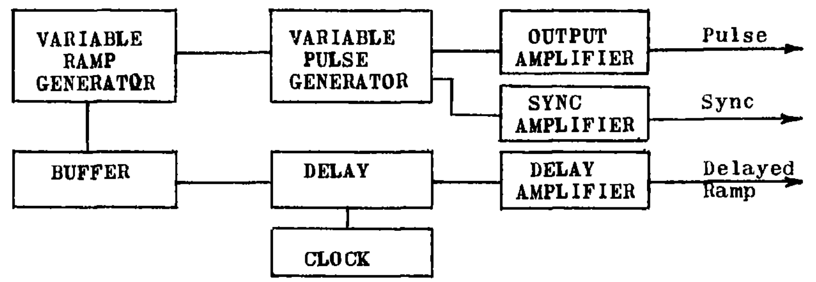

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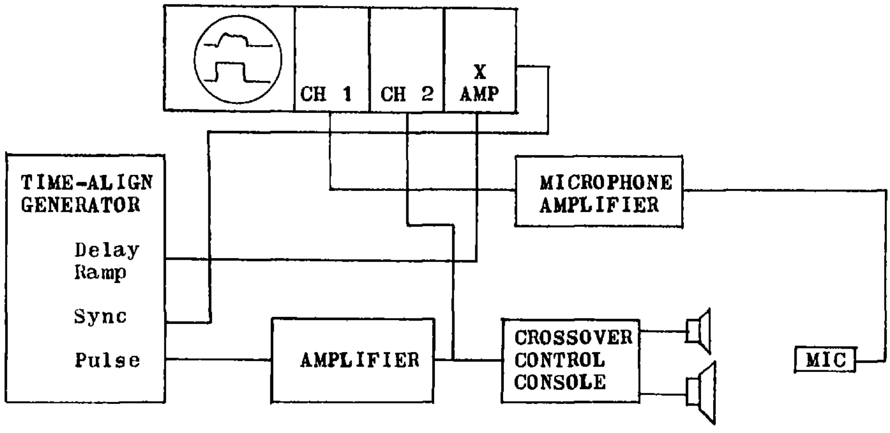

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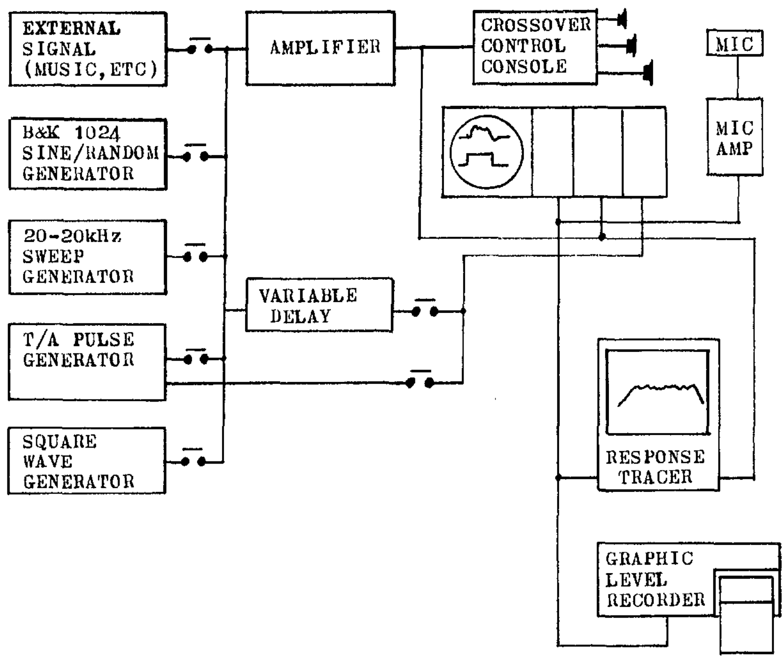

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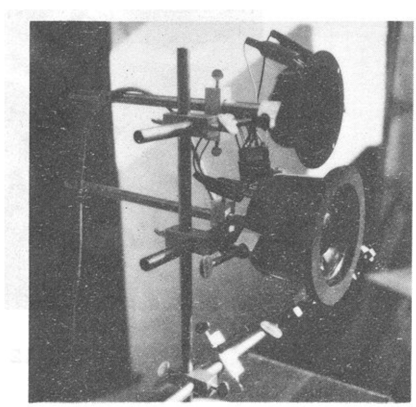

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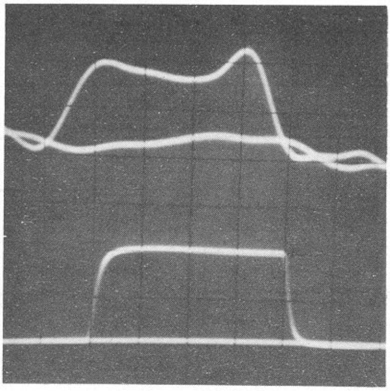

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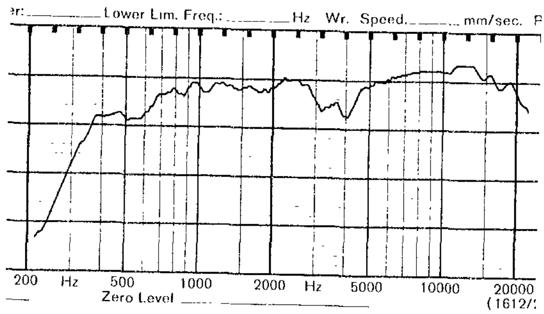

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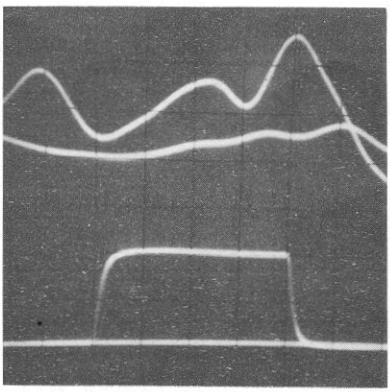

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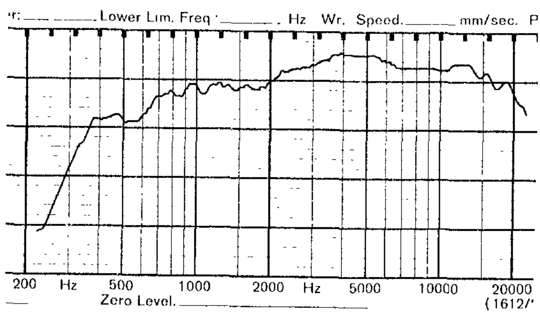

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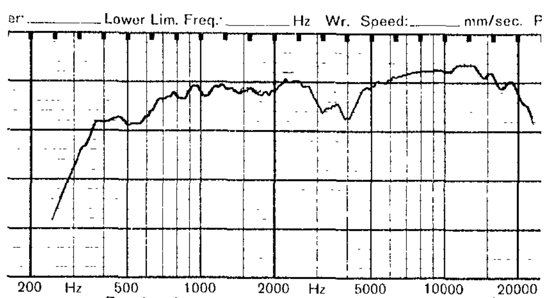

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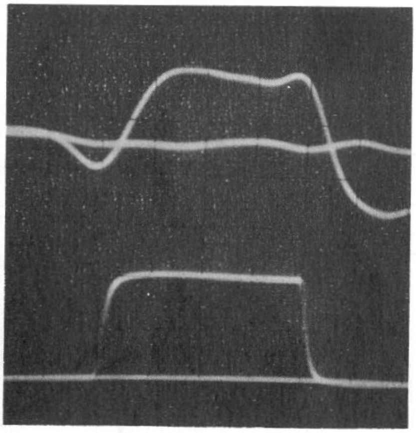

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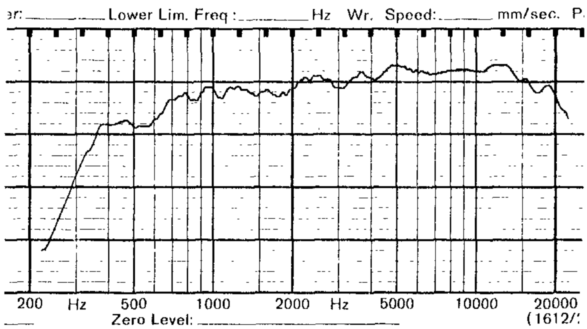

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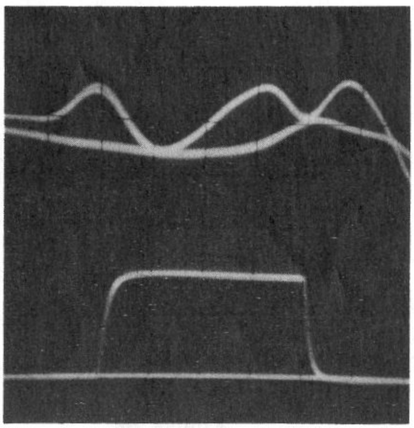

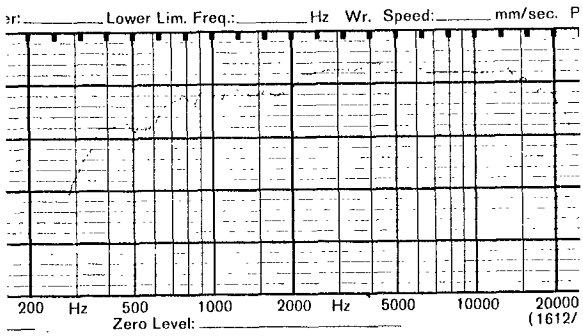

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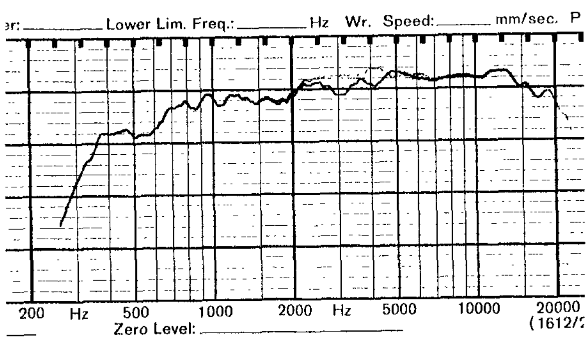

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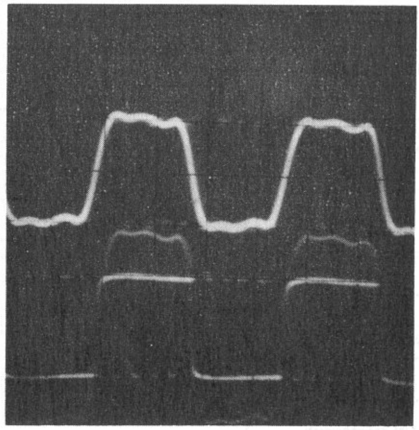

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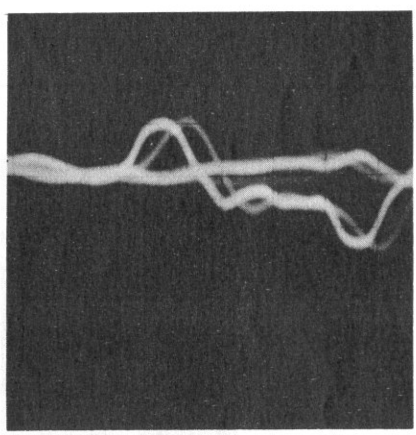

FIGURE 12