Design Approach for Multi-Channel Sound Reinforcement Systems

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Abstract

A unique design approach to multi-channel sound reinforcement systems has been developed and implemented in several applications. This design approach utilizes a combination of PC based signal processing and routing along with speaker clusters and distributed delay speaker systems to provide discrete sound arrivals and imaging from the primary speaker sources to all seats in the audience area.

Introduction

The desire to implement multi-channel sound in reinforcement applications has long been a desire of systems designers. There have been several traditional approaches to implementing multi-channel systems including discrete speaker clusters – either left and right clusters, or left, center, right clusters; or alternating stereo clusters. While all three of these approaches provide some effectiveness, there are some significant limitations of these approaches. This paper describes a unique design approach made practical only recently with the advent of modern PC based and stand alone digital signal processing systems.

Sound System Design Goals

It might be useful to first identify what are some specific sound system design goals. We will refer to these design goals to help evaluate the strengths and weaknesses of the more traditional multi-channel design approaches, and our matrixed left-center-right system approach.

- Consistent Sound Level Coverage – We want to provide even and consistent sound level coverage to all seats as closely as possible.
- Consistent Tonal Response – The tonal characteristics should be consistent at all seats within the venue.
- Discrete Sound Arrivals – Each sound source should provide a single discrete event without multiple source arrivals offset in time.
- Accurate Stereo Imaging – Stereo imaging should be accurate to the physical layout of the stage so that various sources can be localized to their physical location.

Within the scope of this paper. we will be concerned with these design goals. Other goals that are assumed to be applicable here, as with any other design include: Adequate SPL for the program, adequate frequency response for the program, the system is appropriate for the program and the venue, and of course, that the system cost fall within the design budget.

Design Paradigm Comparison

The following chart summarizes the comparison between the three more traditional systems design approaches and the matrixed left-center-right system design approach.

Design Criteria	Matrixed LCR w/ dist delay	Alternating LR	Discrete LR	Standard LCR
Even Sound Coverage	Superior coverage from all three sources utilizing distributed delayed devices and matrix-summed speaker components.	Can provide good coverage, but will fall off towards the sides and back of the room without distributed delayed devices.	Poor overall coverage since each channel only covers a portion of the room.	Can provide good coverage, but will fall off towards the sides and back of the room without distributed delayed devices.
Even Tonal Response	Smooth tonal response at all seats utilizing well behaved system components and distributed delayed devices and short distances to listeners.	Difficult to achieve without distributed delayed devices.	Difficult to achieve without distributed delayed devices.	Difficult to achieve without distributed delayed devices.
Discrete Direct Arrivals	Single discrete direct sound arrival from each of the three sources. Distributed delayed speakers and matrix-summed devices signal aligned.	Multiple direct arrivals for any given mono source (speech and vocal, percussion) smears sound in time.	Multiple direct arrivals for any given mono source (speech and vocal, percussion) smears sound in time.	Single discrete direct sound arrival from each of the three sources.
Accurate Stereo Imaging	Not as good as alternating LR for direct sound arrival offset (at the sides of the room), but if mixed carefully, provides nice imaging to a large portion of the seating area.	Good stereo imaging within the coverage area, though some areas will have inverted panning and localization.	Stereo imaging will be accurate, but will not be percieved due to differences in sound level from sources.	Not as good as alternating LR for direct sound arrival offset (at the sides of the room), but if mixed carefully, provides nice imaging to a large portion of the seating area.

With the only exception that the left and right channel arrivals can be substantially different at seating locations off to either side of the room, the matrixed LCR system provides improved system performance.

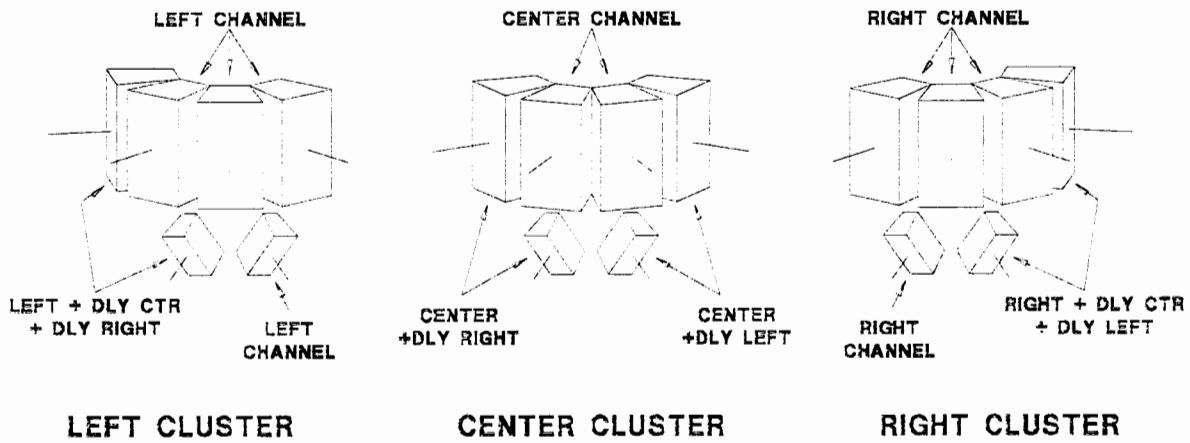
Matrixed Left-Center-Right with Distributed Delay Speaker System Design Theory

The system uses a combination of discrete speaker clusters for primary sources and distributed delay speakers for support. Several things make this design approach unique:

First, some of the various components of each of the primary clusters may be used as support delay speakers for the other sources. In each case where this is done, a discrete delayed signal is summed into the audio feed for that particular device and combined with the primary audio signal source. For example, the far outside mid/high section of the right side speaker cluster will

not only receive the primary right channel sound, but it will also receive a center channel feed that is delayed (with reference to the center cluster) and summed back in with the right channel sound feed. In this way, the right side speaker of the right cluster will act as a delayed side fill speaker for the center cluster. This approach is followed on several of the components of each of the main clusters.

The following graphic summarizes this approach and which signals are distributed to each of the system components.



The other unique design item is that each of the distributed delay speakers are supplied with discrete delayed signals from each of the primary sources, and then summed together and routed to each speaker. This provides a discrete delay speaker from each of the primary sources that is signal aligned for coordinated sound arrivals.

This design approach can also be thought of as if there were three different systems, each with distributed delay devices. The following graphical sequence outlines the approach for the center cluster and its delay support devices, and the left cluster and its delay support devices. The right channel is similar in design to the left channel.

Each component that is involved within the center channel signal chain is delayed with reference to the center cluster. This provides a very coherent sound distribution from that source. In the same way, each of the side cluster components are signal aligned with reference to each of the side clusters.

Design Process

Once the design concepts are understood, the design process can begin. First, a single mono center cluster speaker system with delay devices is developed that meets accepted design criteria. Consideration is given to aiming and location of speakers, and speaker device selection that will provide acceptable pattern control and direct sound to the desired locations in the room. Signal delay considerations are taken into account as well.

The next step is to develop a left (or right) channel system design that if used alone, will meet the same accepted design criteria including coverage, output level, etc. If proper components are chosen, several of the center channel and opposite channel components can be easily used as distributed delay devices for the system.

Signal processing for this system can be rather complex and is only practical utilizing today's flexible digital signal processing systems. The signal flow block diagram shown on the last page describes the primary components of the digital signal chain. Additional processing for various types of systems design techniques can be used and implemented in the DSP signal chain as well.

Also shown is the block diagram is the delay processing setup for the delay speakers. The primary sources - left, center and right channels are connected to a multi-tap delay device. Discrete delay outputs are fed into a mixer and summed along with the remaining two channels delayed signals and routed to the amplifier for each delay speaker. With this approach, each delay speaker must have its own processor output and amplifier.

Implementation

Implementation of the system is not unlike a single channel system. Individual sub-systems and components are adjusted and equalized as normal. Signal level balancing can be a little tricky. The key to system setup is to put a single input signal into one of the processor input channels, and set delays and levels as if it were a stand alone system. The procedure is repeated for the other channel systems. Delays are measured for each individual signal chain (along with a precedence effect delay) and implemented for that signal.

In order to achieve good stereo imaging when very close to either side cluster, it is recommended that the amplifier driving the inward firing speakers in the side clusters be increased in level by about 3dB. This will provide improved imaging when off to one side or the other and directly in front of one of the side clusters.

Frequency shading of cluster components, low frequency directivity array systems, and other cluster design techniques can be used with this design approach as well. Greatly improved results can be achieved with carefully designed clusters.

Limitations

Left / Right channel localization is very effective with this design approach. Discrete sound arrivals with minimal time smearing (from each of the primary sources) is achieved. However, the primary limitation to this system is the time difference in sound arrivals from various primary sources at the extreme sides of the room. At the left side of the room, the right channel sound can arrive significantly later than the direct left channel sound. Because of this limitation, the audio mix must be setup to minimize the negative effects caused by this difference in arrival time.

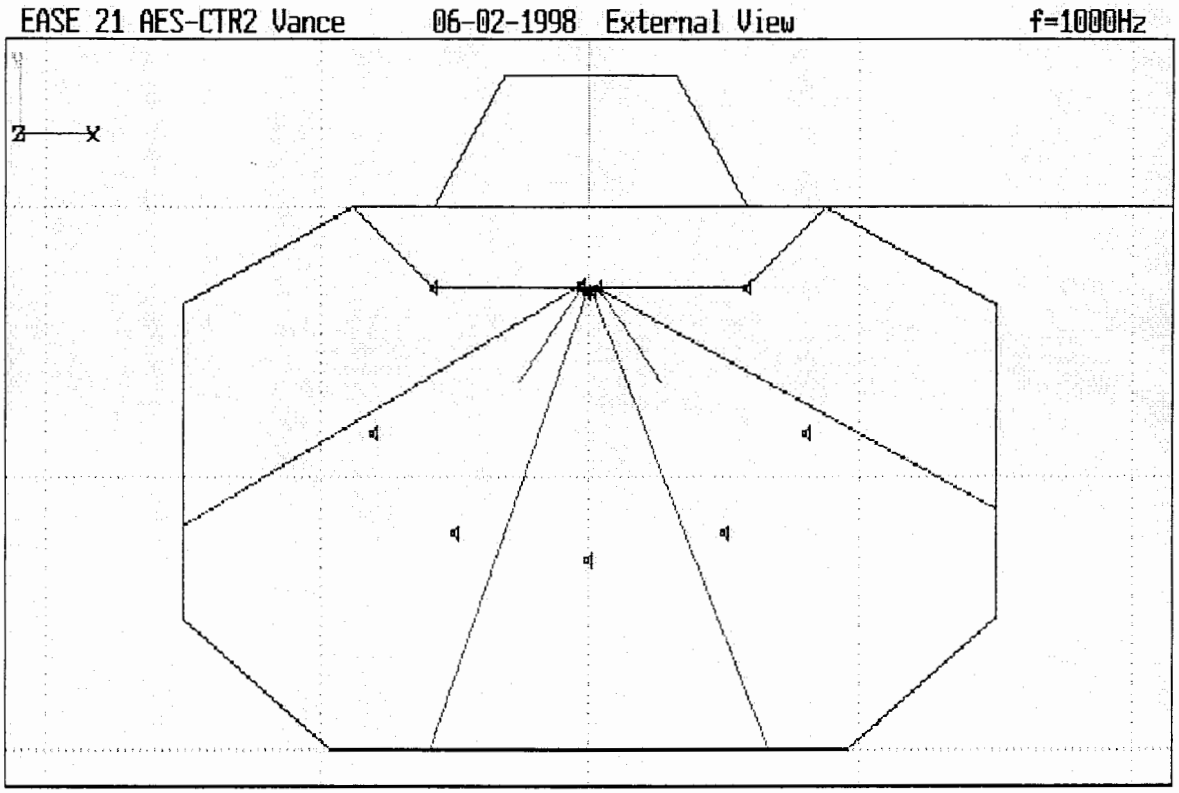
For example, the best approach to mixing on this sort of system is to route audio signals to either the left and right systems, OR the center channel system, but never to both. Vocals, percussion, rhythm instruments (such as electric bass) that will suffer a lack of clarity when played through multiple sources should all be routed to the center channel. Piano, strings, ensemble vocals, choir, etc. can be routed to the left and right channels and mixed appropriately. However, it is recommended that every instrument or source that is routed to the left and right channels is derived from a stereo microphone pair and each of the channels is hard panned left and right.

Problems arise when very percussive sources are routed to multiple clusters. This produces a smearing of sound over time effect that is counterproductive to the clarity.

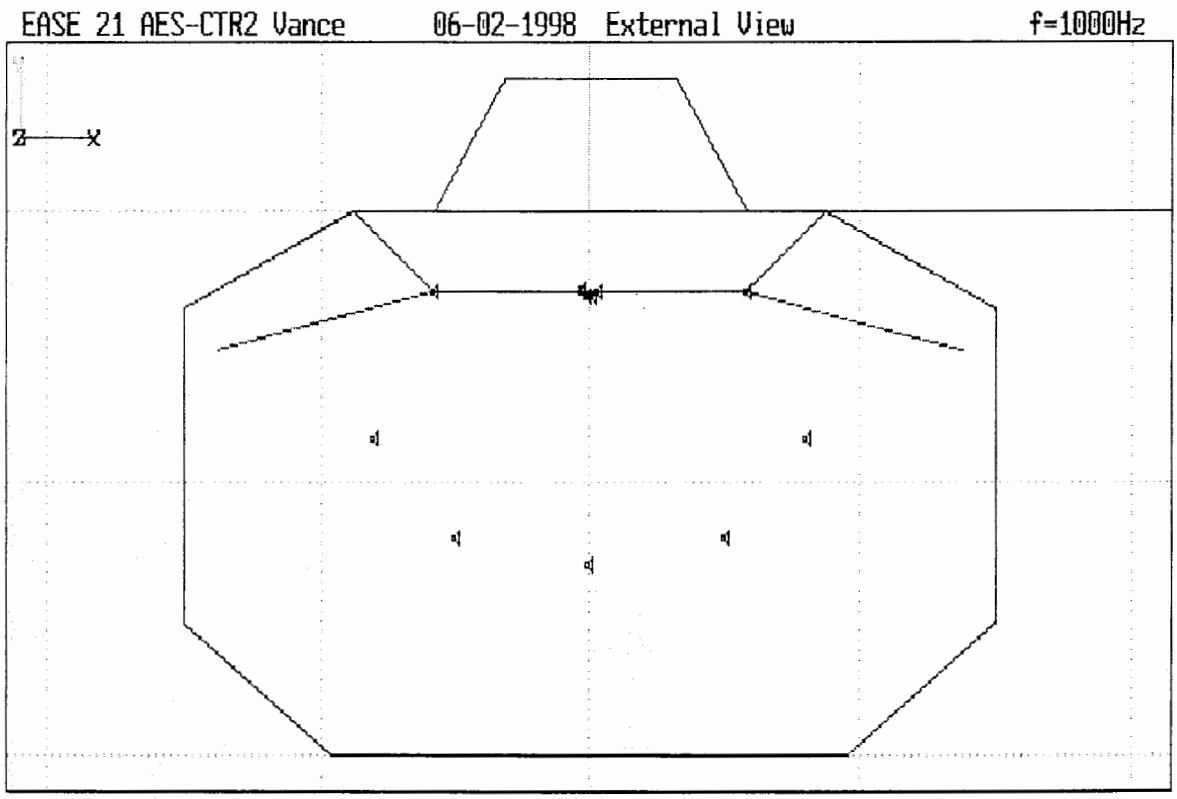
Conclusion

If properly designed, implemented, and operated, this systems design approach can provide dramatic multi-channel sound with excellent imaging to most seats in a audience area. The

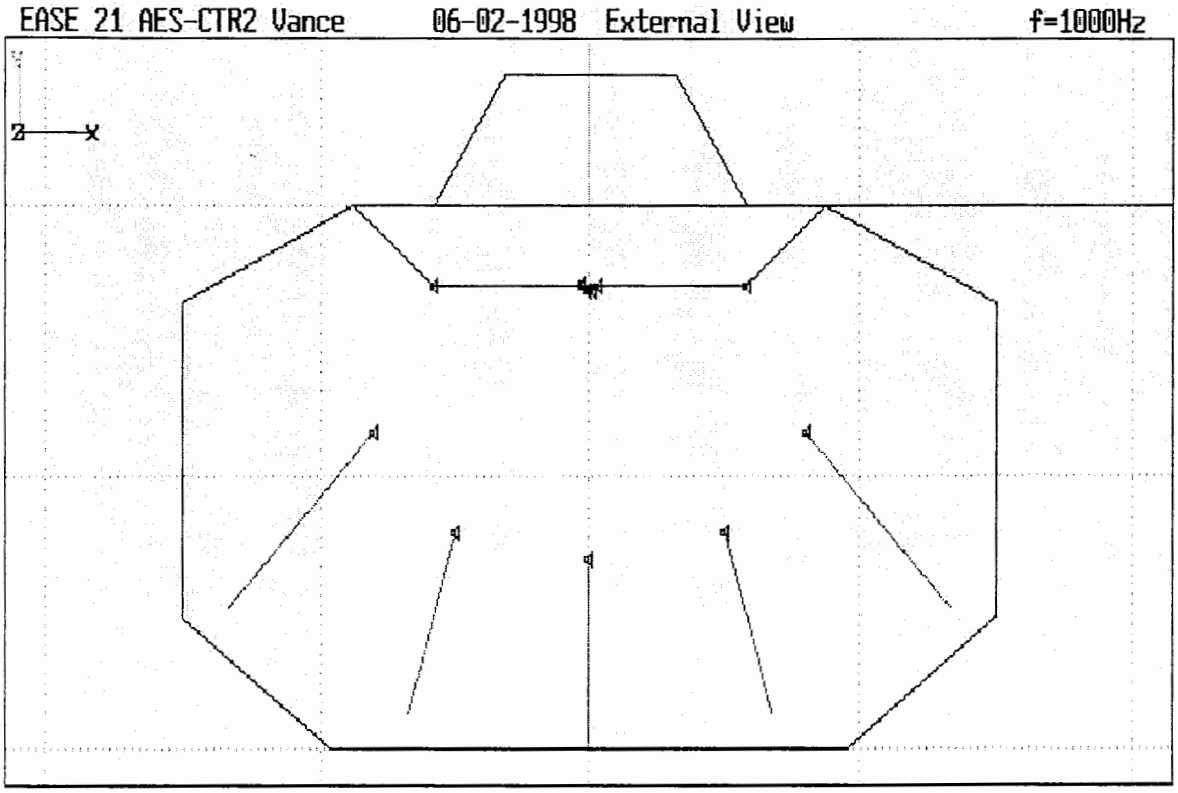
improvement from having coherent sound from each of the three primary sources is significant and provides an improved listening experience. Proper design, implementation, setup and use of this system is critical to it working well.



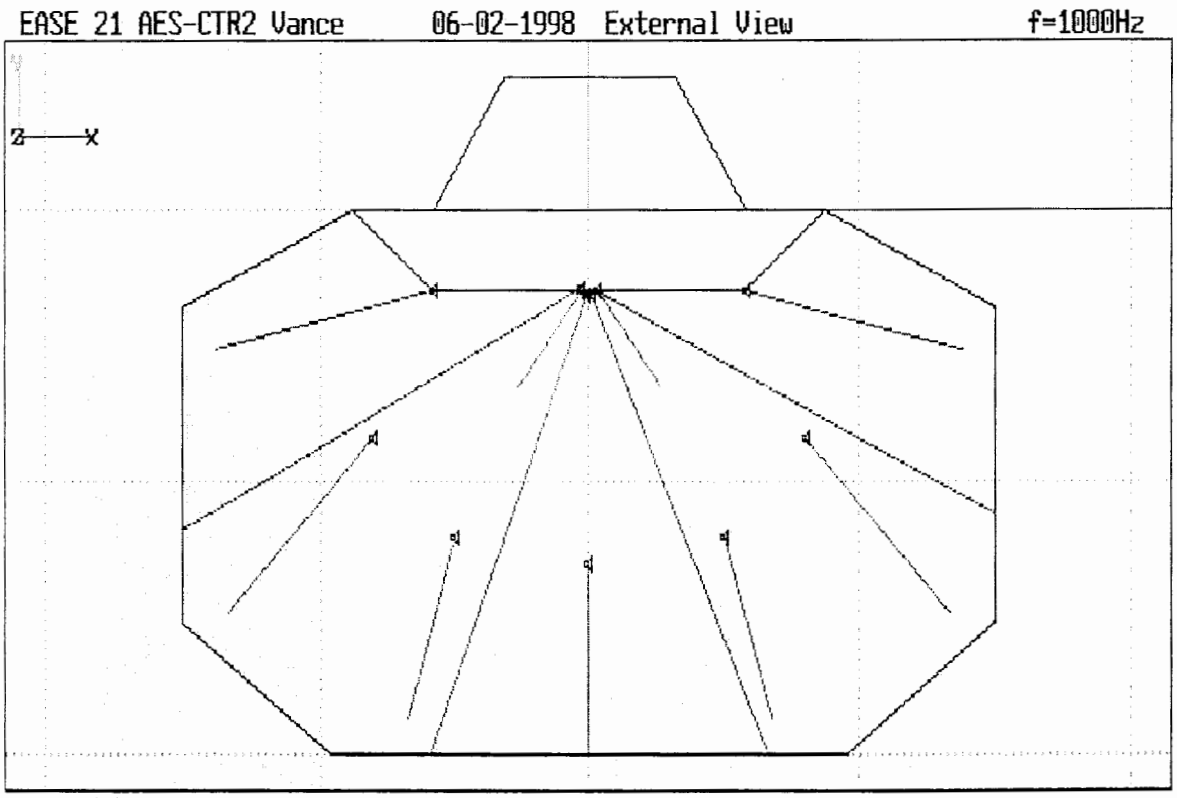
Center cluster main speaker location and aiming.



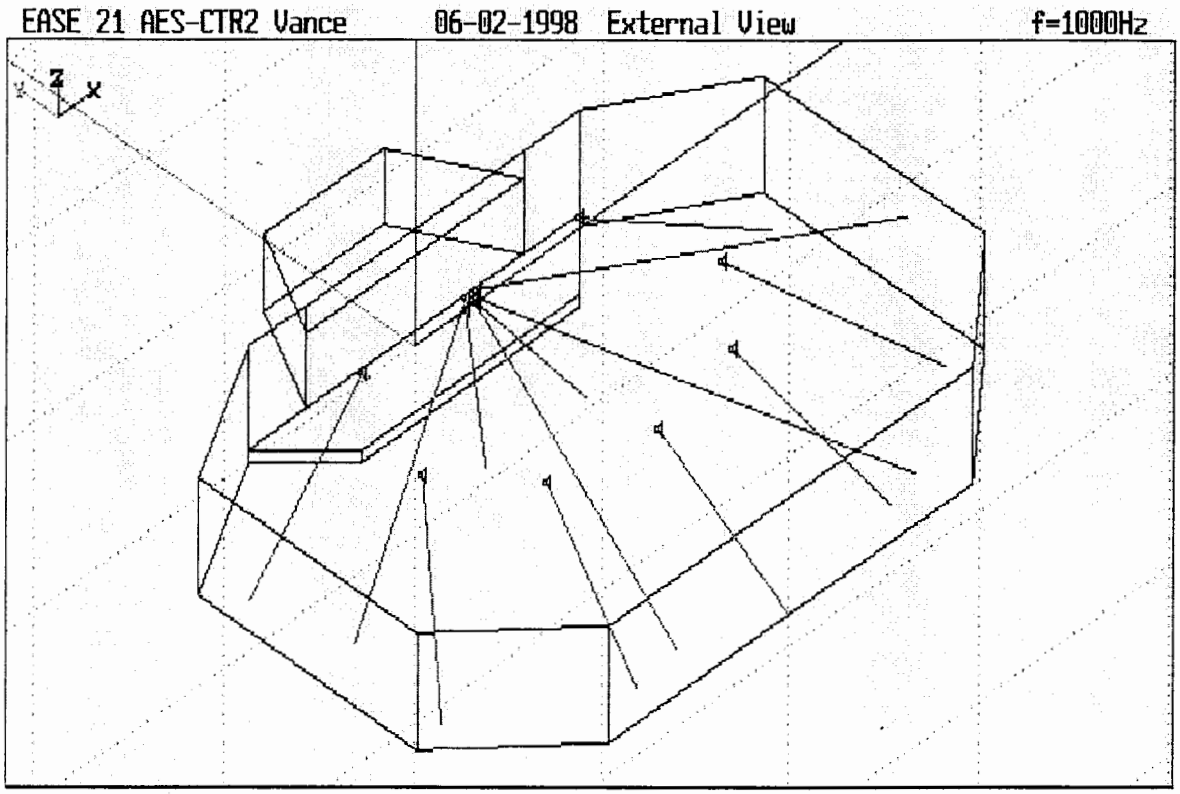
Side fill components for center cluster.



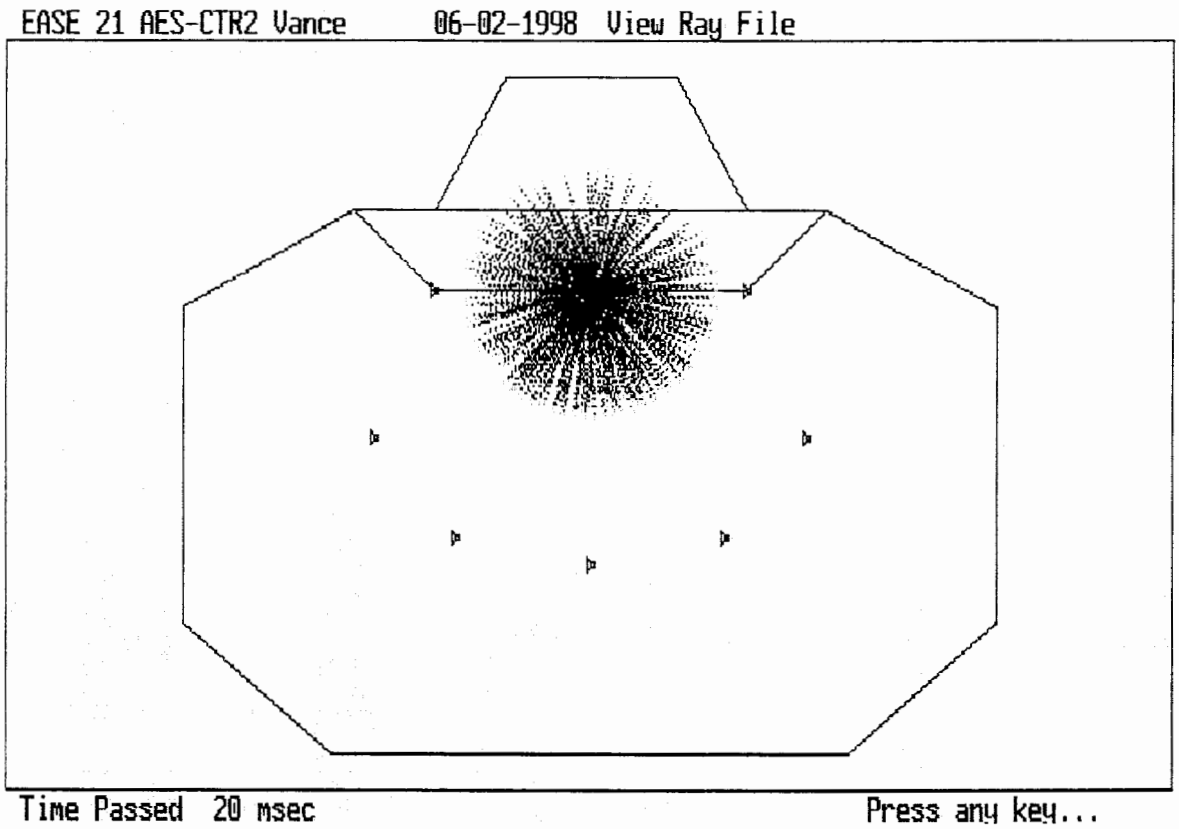
Delay speakers for center cluster.



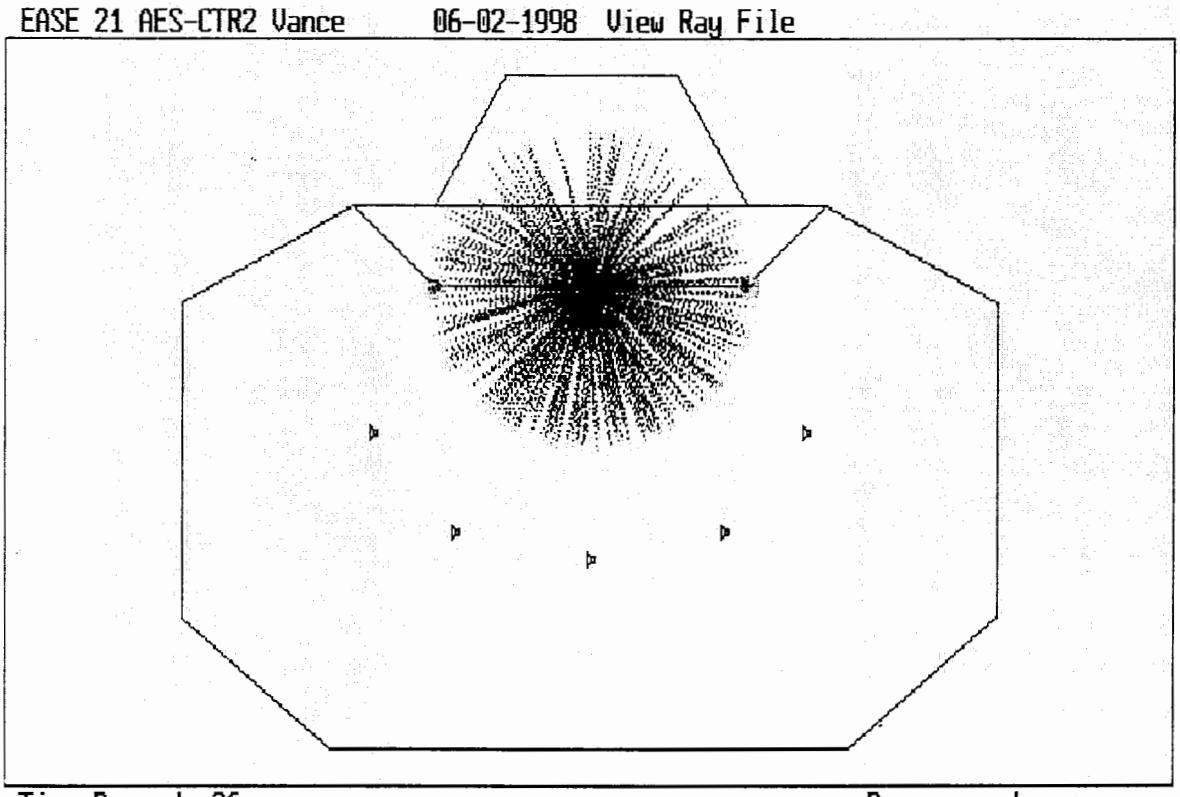
All center cluster primary and distributed delay components.



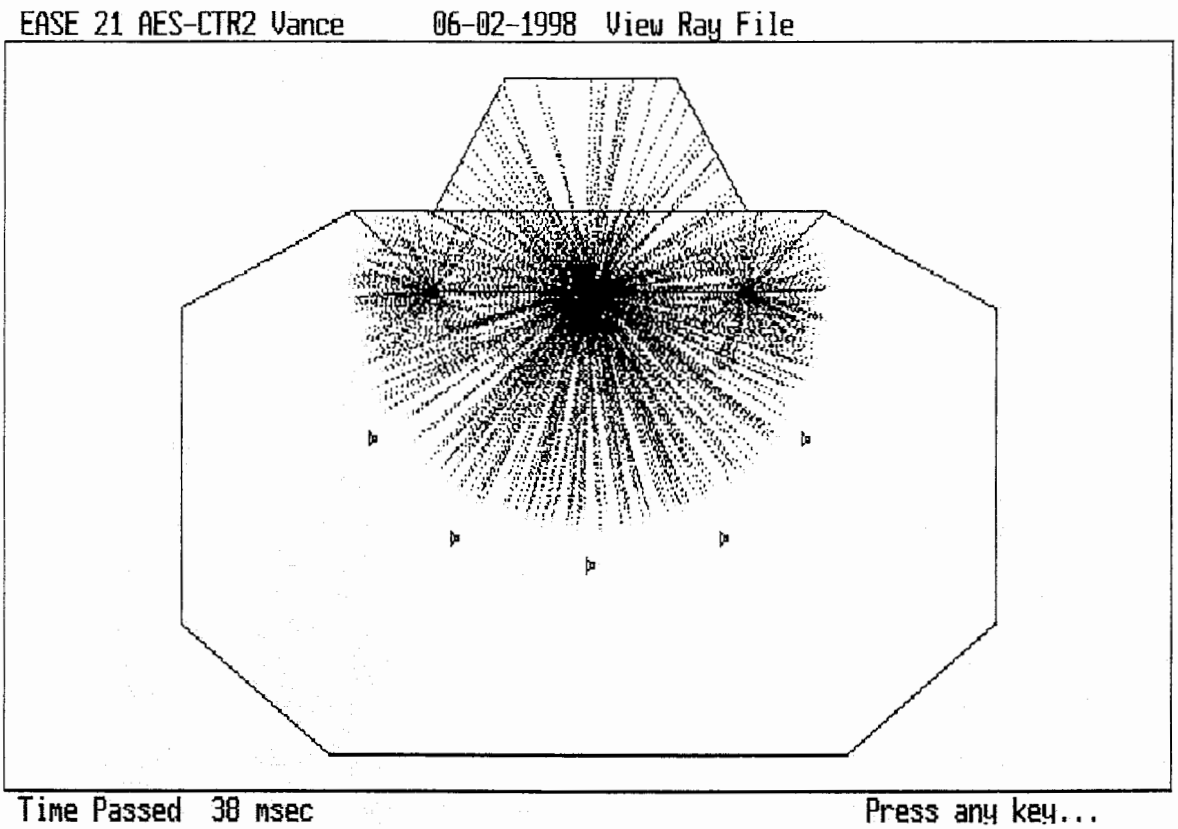
All center cluster primary and distributed delay components.



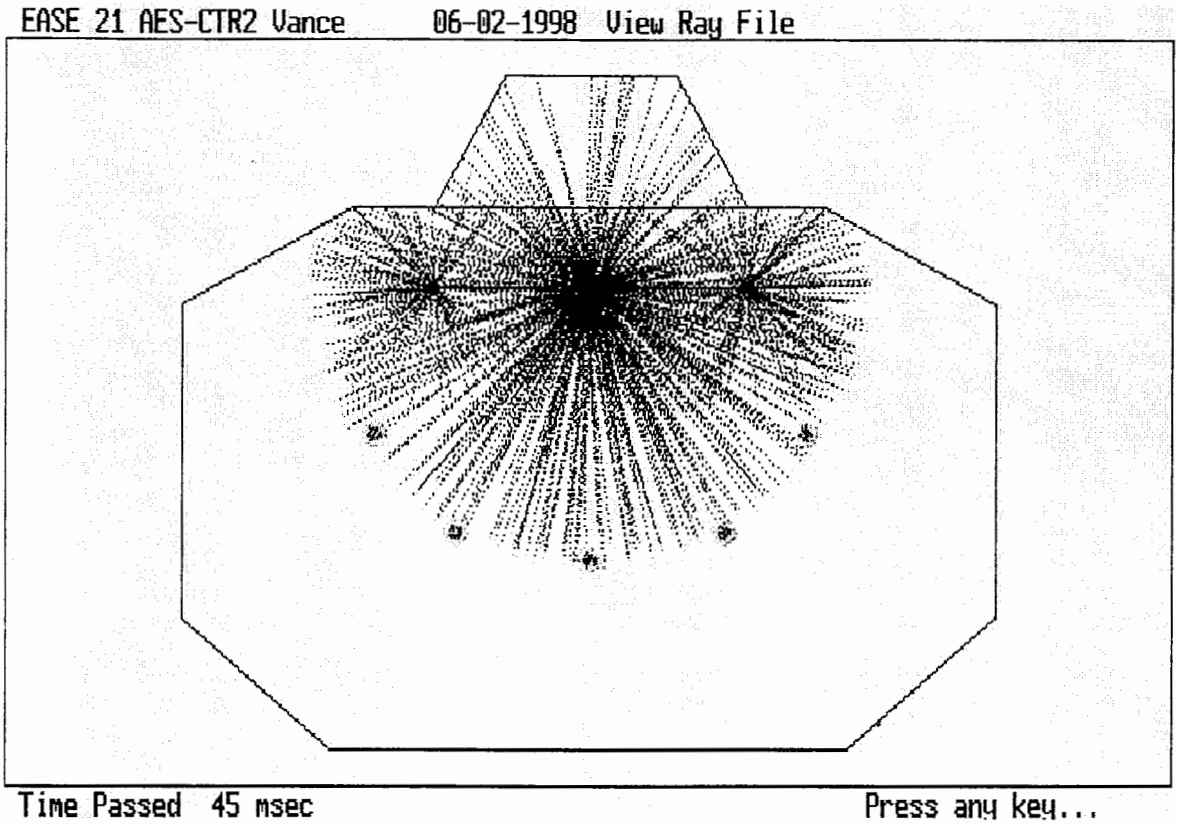
Center channel speakers and components at 20 mS.



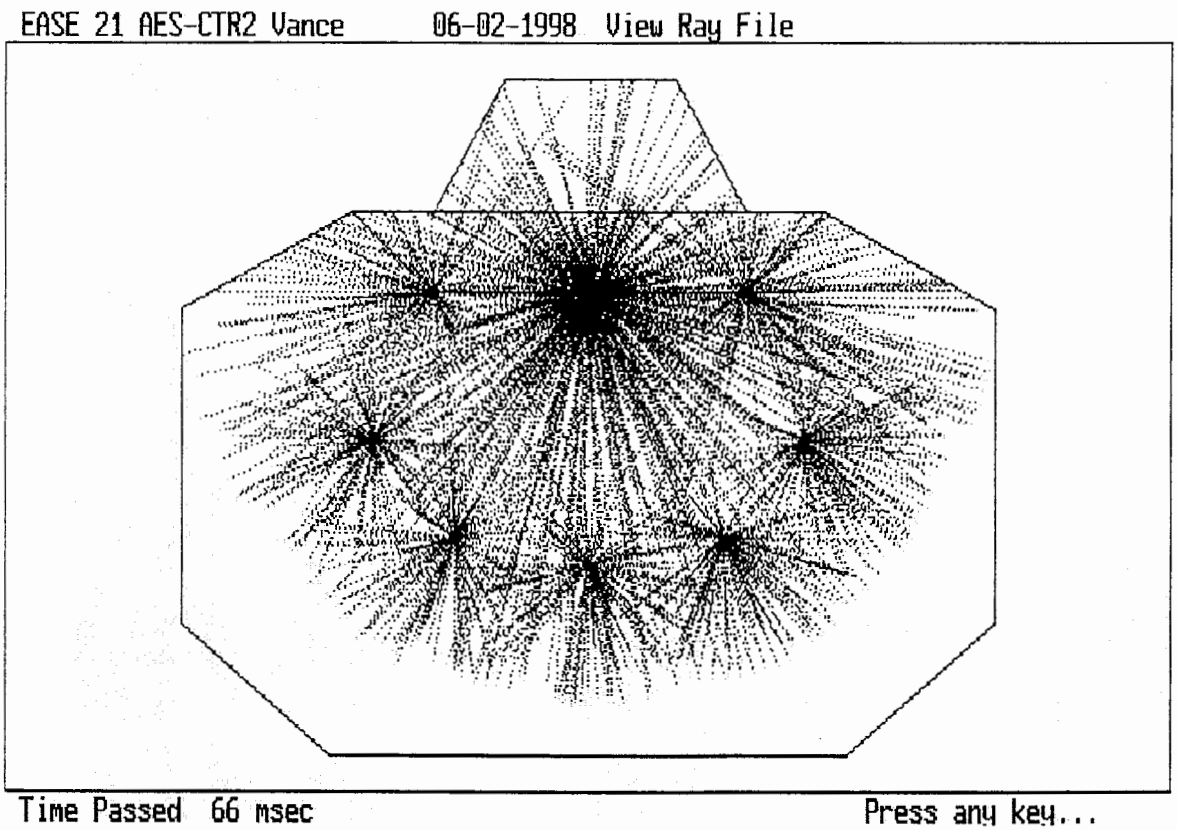
Center channel speakers and components at 26 mS. Side fill delay speakers now active.



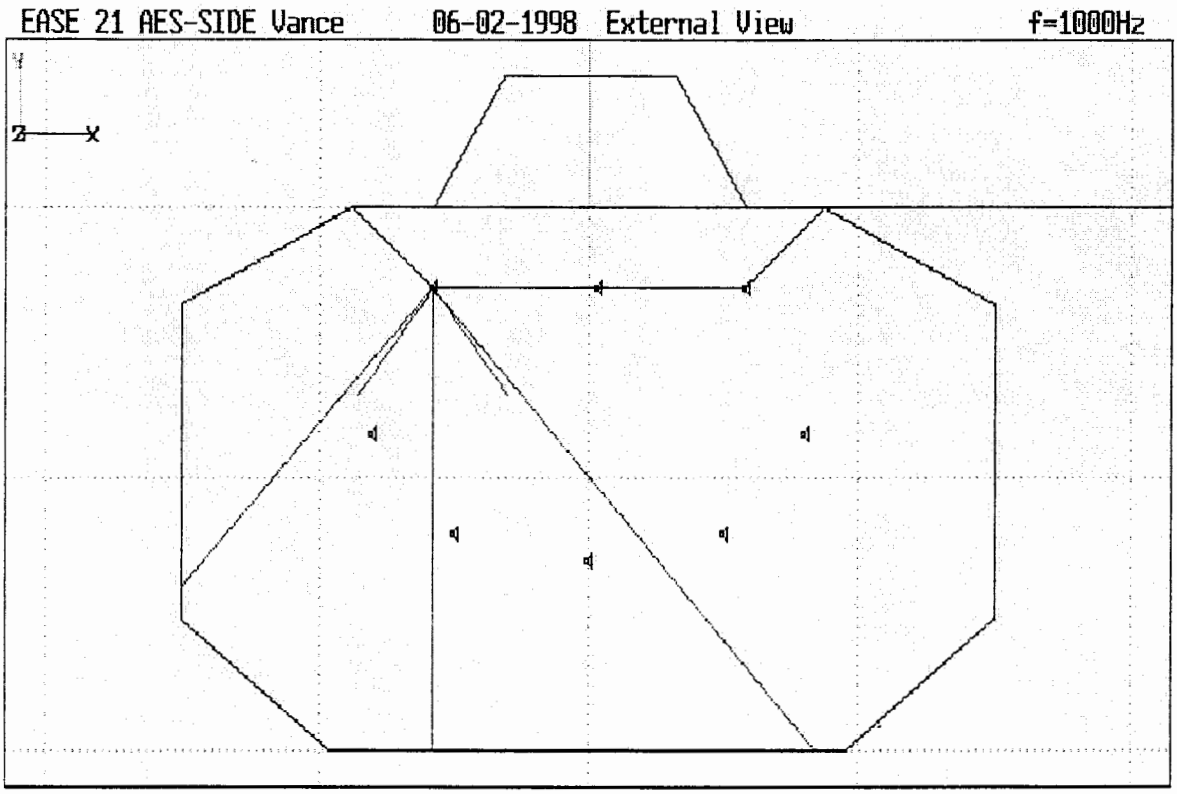
Center channel speakers and components at 38 mS. Side fill delay speakers now active.



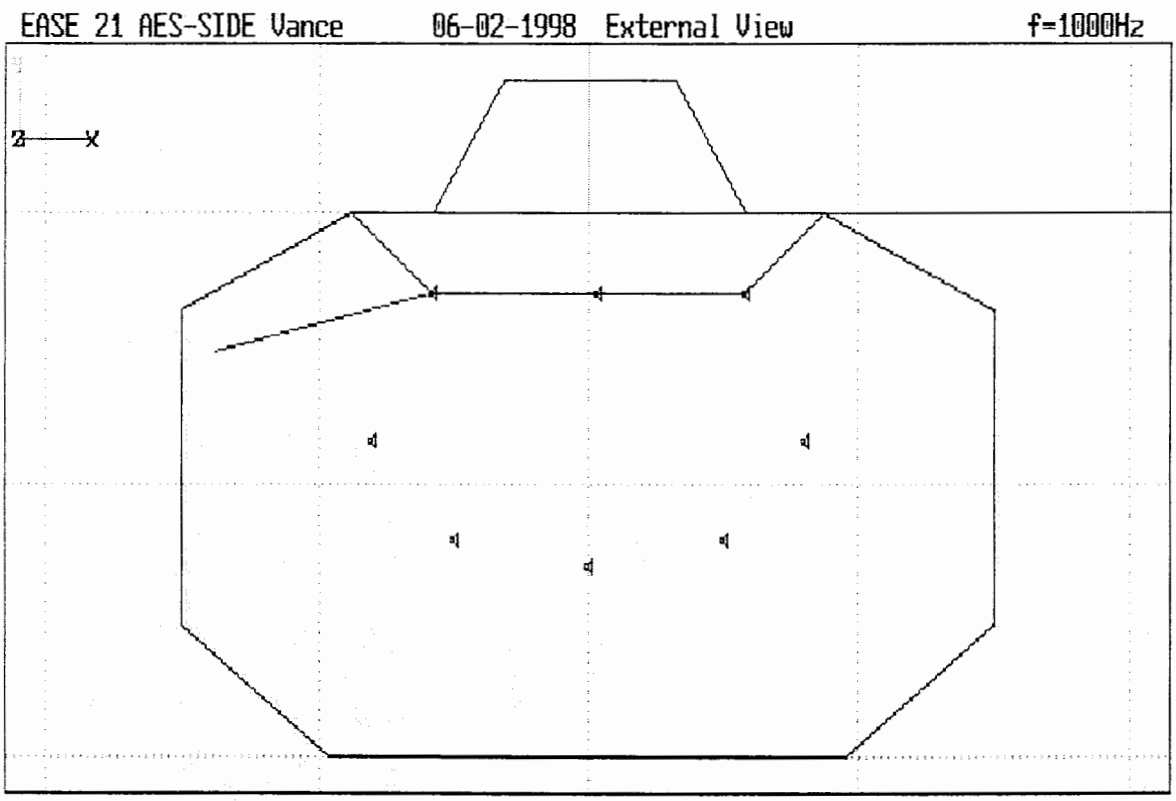
Center channel speakers and components at 45 mS. Delay speakers now active.



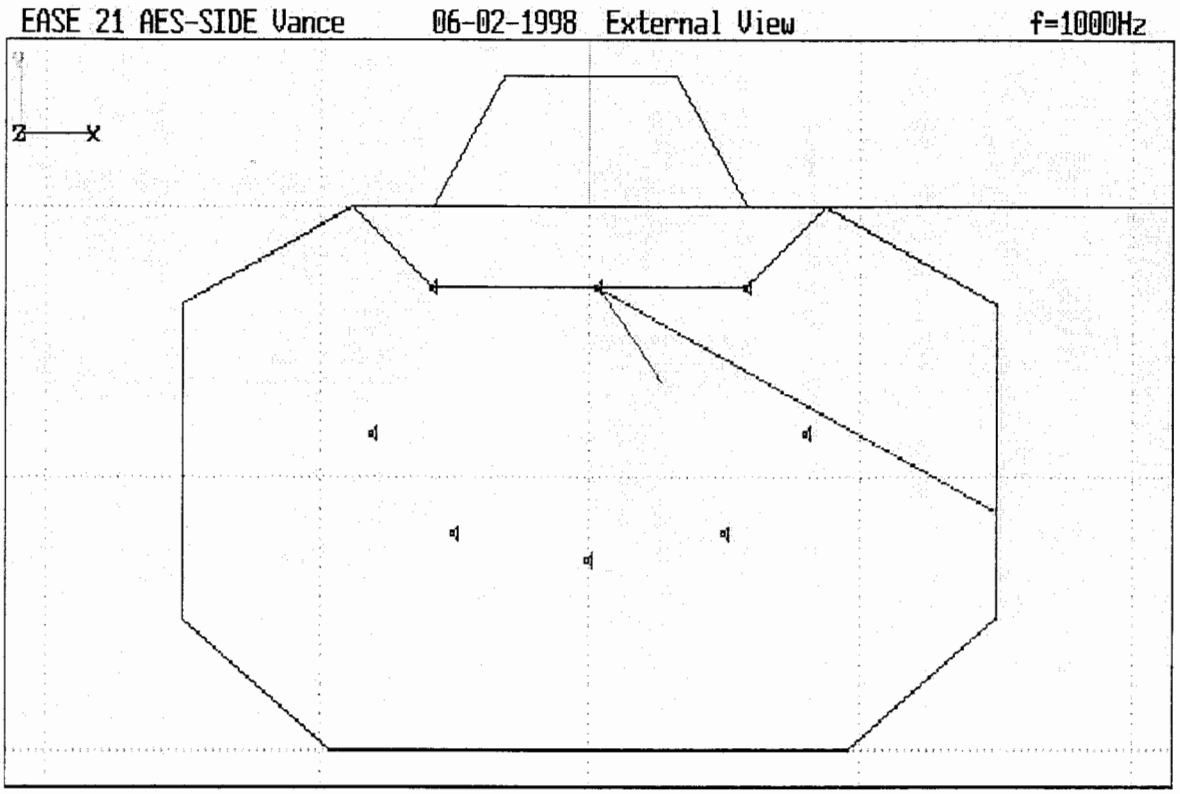
Center channel speakers and components at 66 mS. All speakers now active.



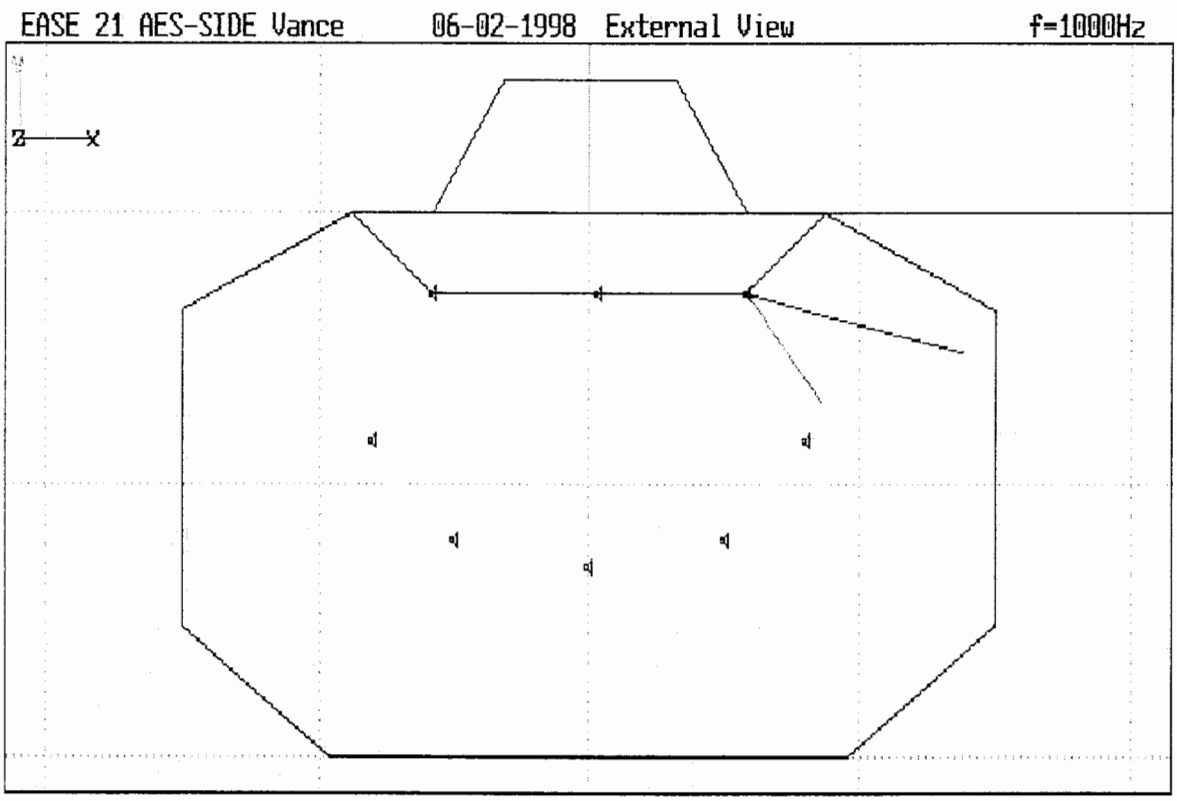
Left cluster main speaker location and aiming.



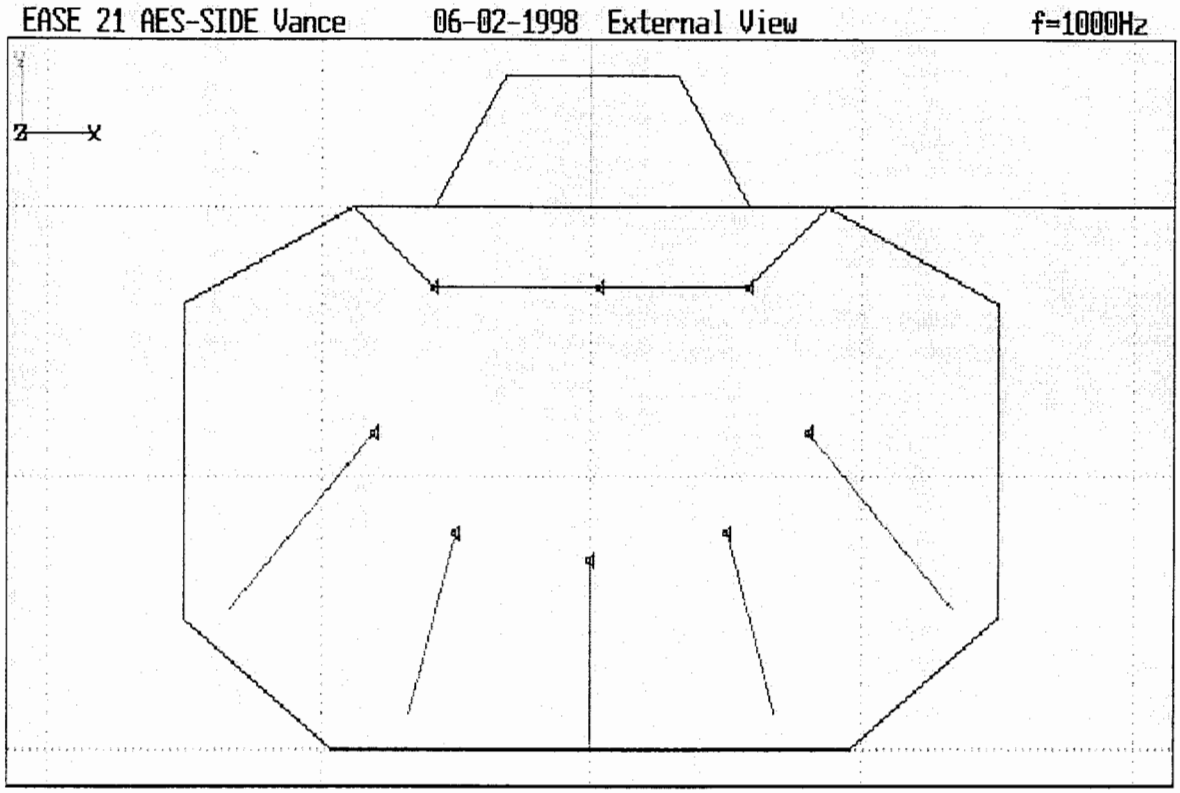
Side fill components for left cluster.



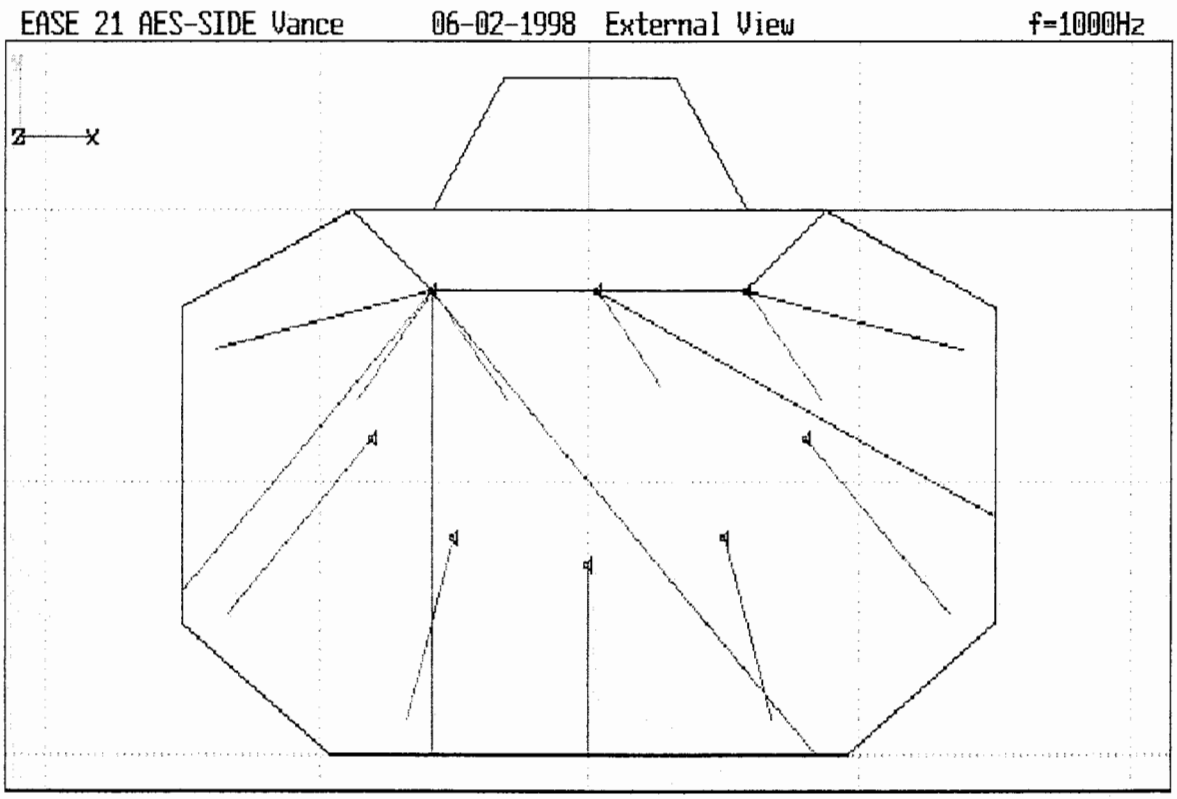
Center delay fill components for left cluster.



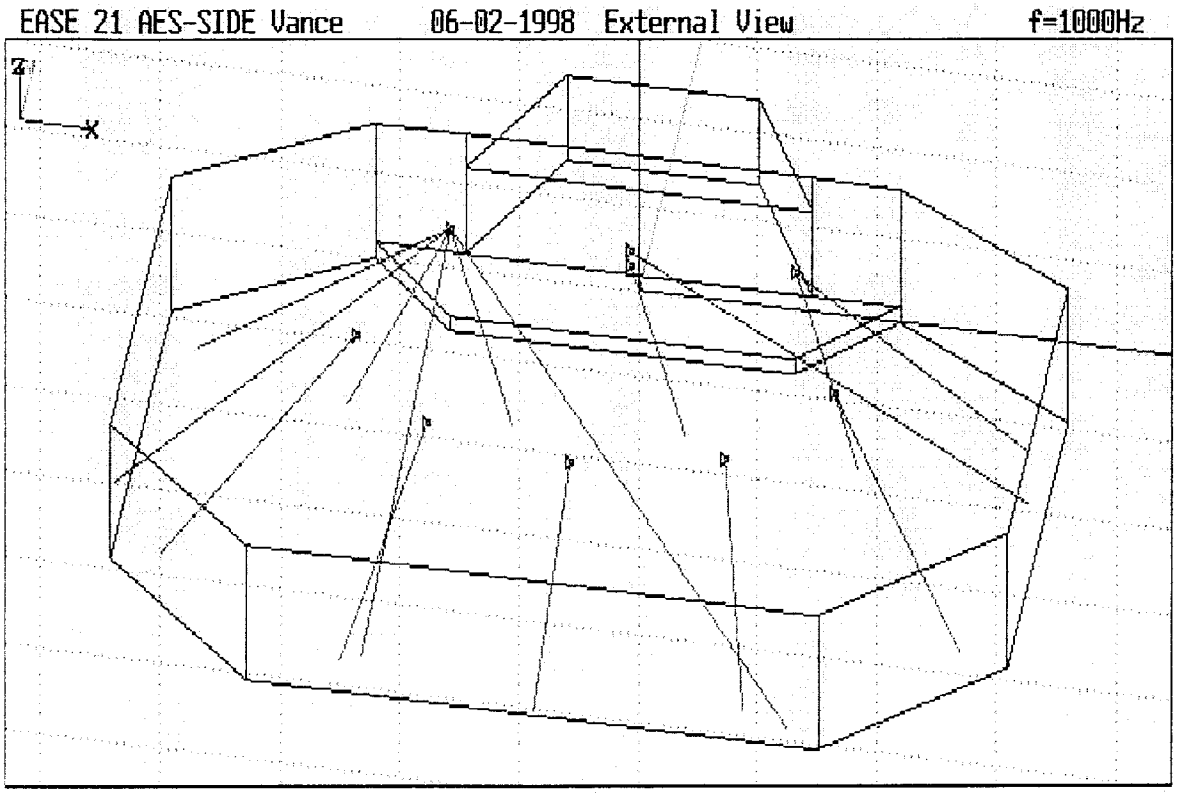
Right side delay fill components for left cluster.



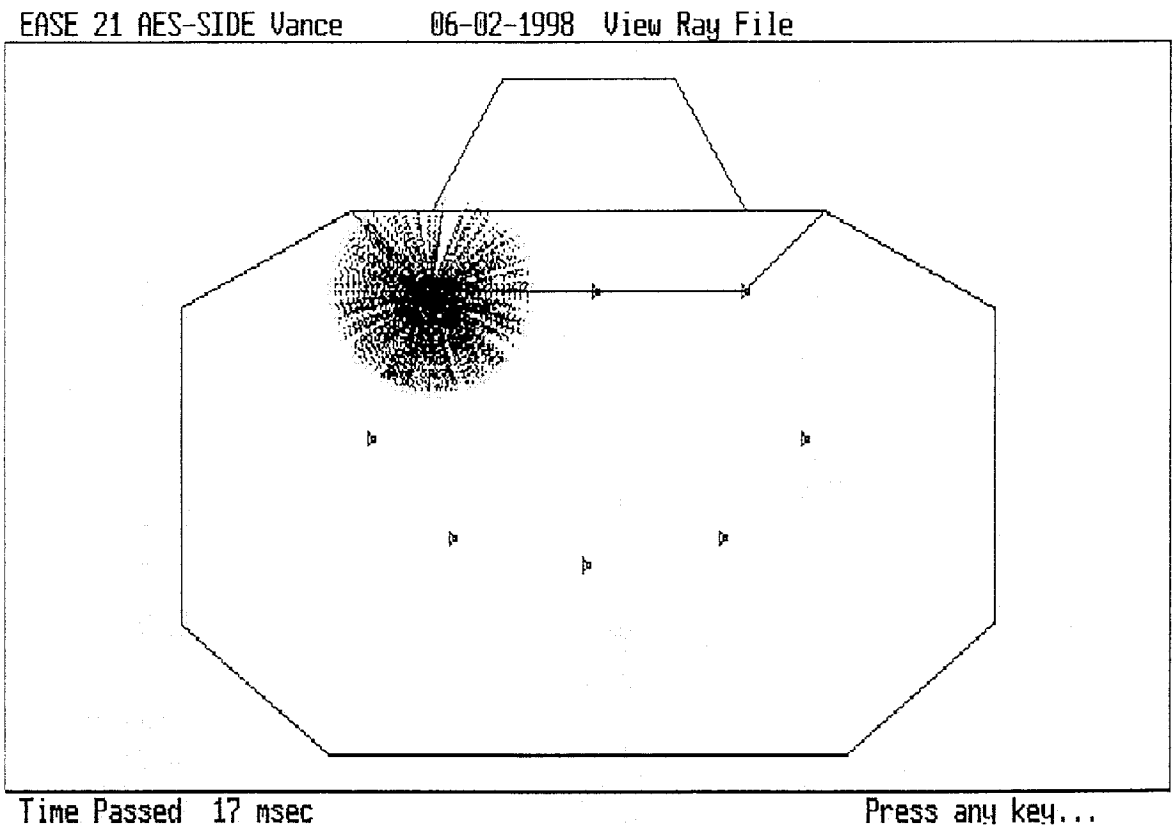
Delay speaker components for the left cluster.



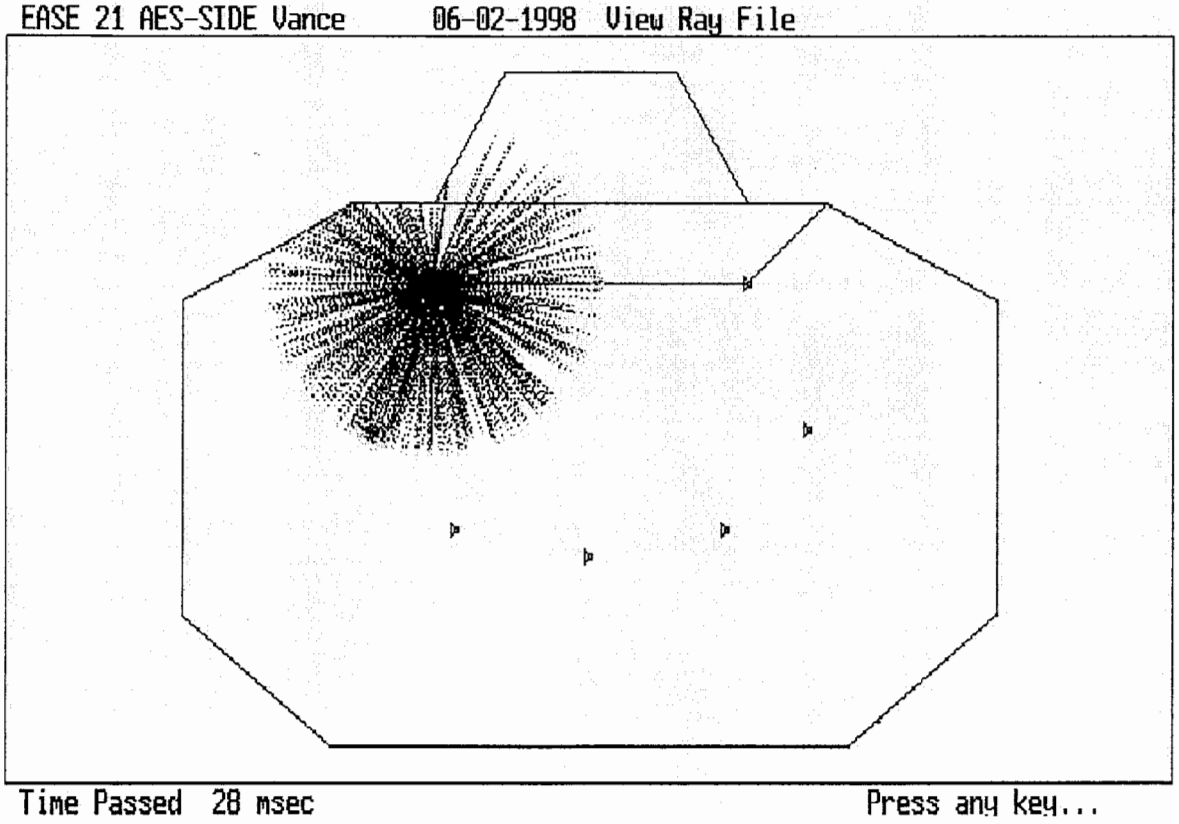
All left cluster primary and distributed delay components.



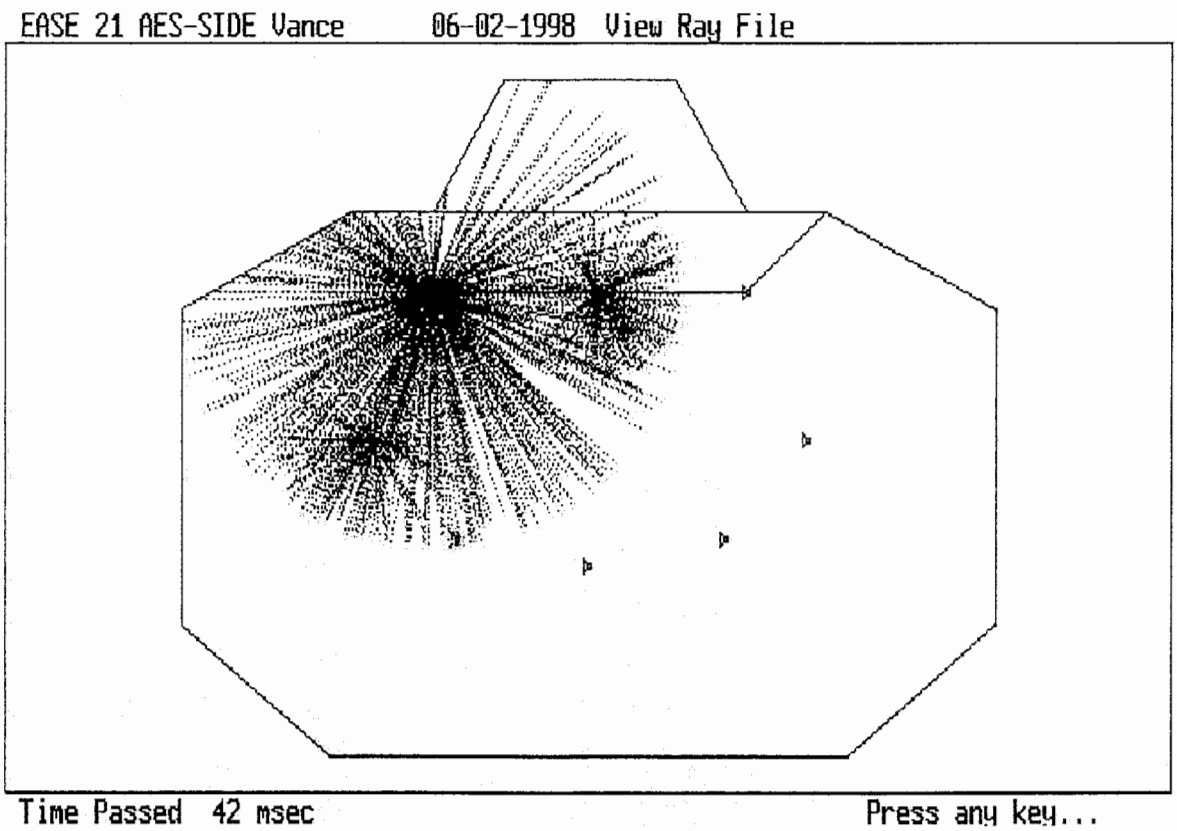
All left cluster primary and distributed delay components.



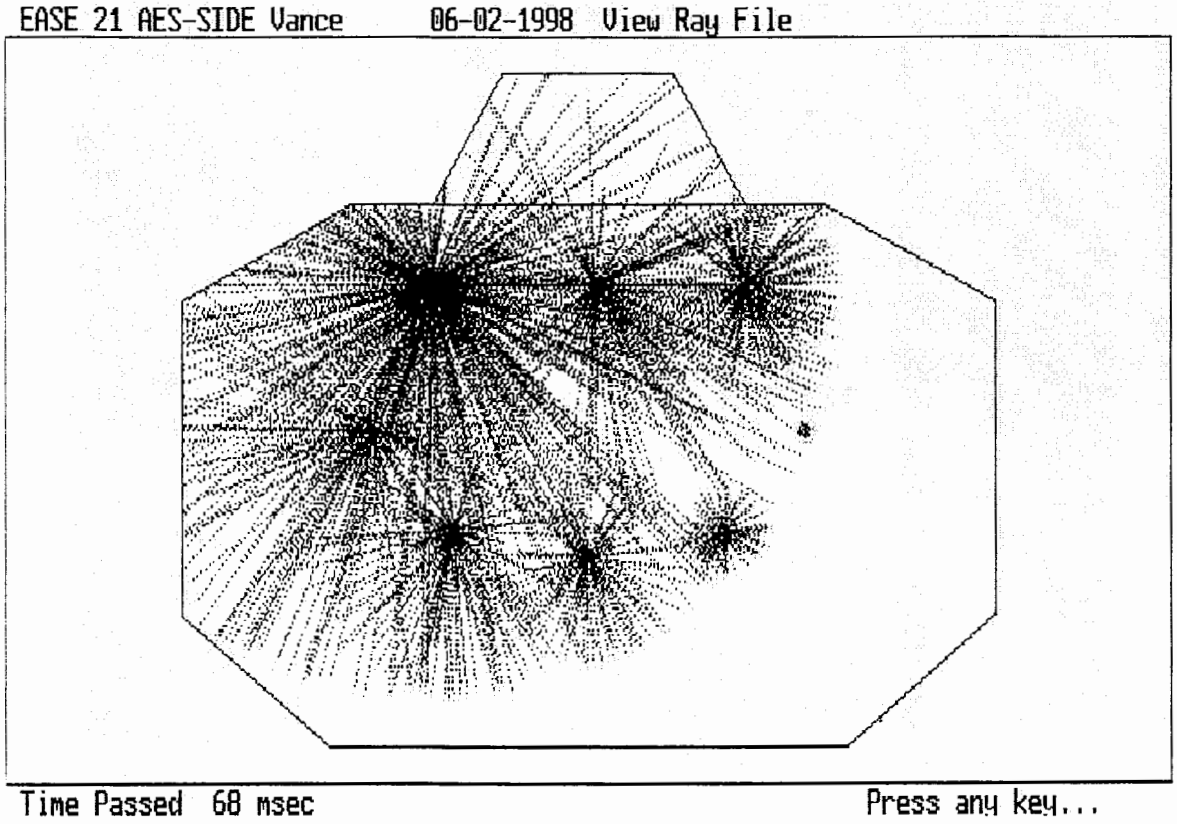
Left channel speakers and components at 17 mS.



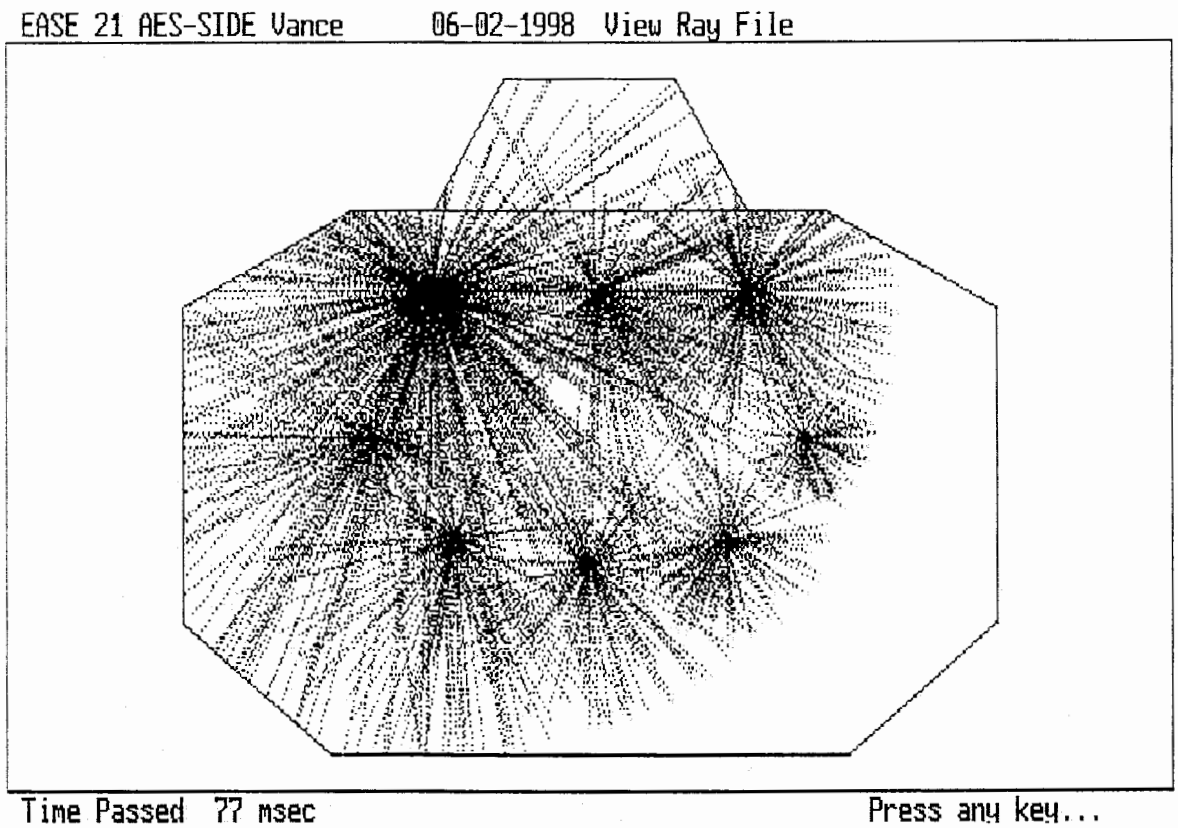
Left channel speakers and components at 28 mS. First delay speakers now active.



Left channel speakers and components at 42 mS. Center channel delay fill and second delay speakers now active.

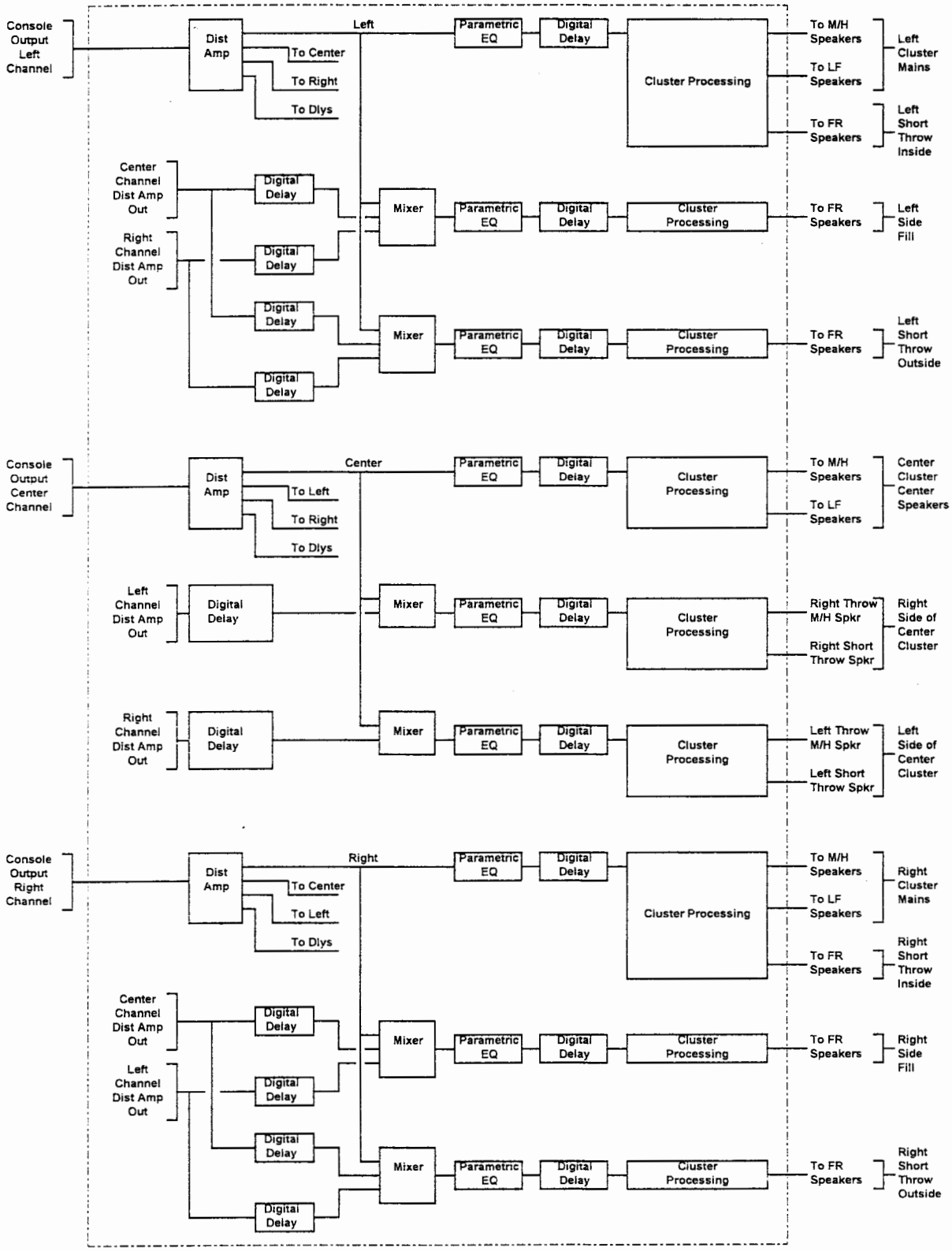


Left channel speakers and components at 68 mS. All delay speakers now active.



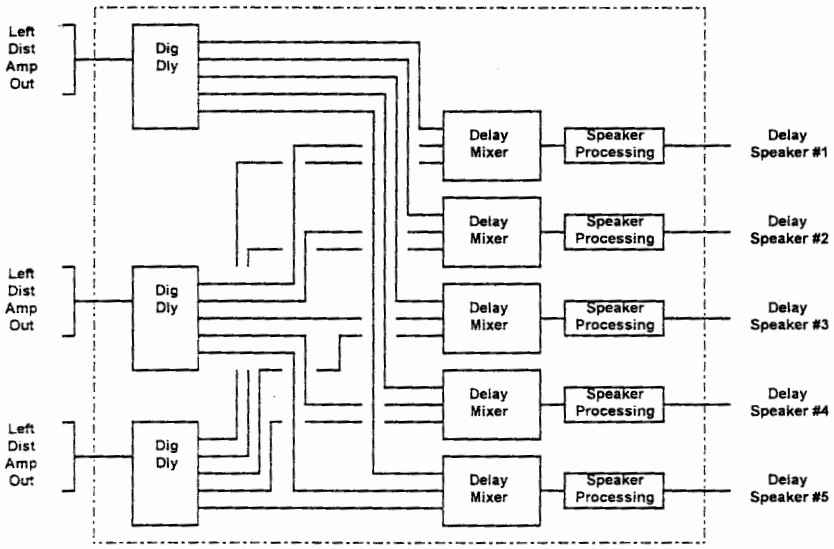
Left channel speakers and components at 77 mS. All delay speakers now active.

Digital Signal Processing Block



Signal Processing Block Diagram

Delay Speaker Digital Signal Processing Block



Signal Processing Block Diagram