THE 16-1 SOUND SPATIALIZER
A REAL-TIME MIDI SPATIALIZATION PROCESSOR

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ABSTRACT
A description is given here of a newly developed microprocessor-based audio spatializer device, designed to assist composers and performers in the simulation of moving sound sources and the creation of sound environments. The device has 4 channels, reassignable for the processing of 4 pseudo-sources on 2 speakers, 2 pseudo-sources on 4 speakers, or 1 pseudo-source on 8 speakers. In one, two, or three-dimensional space, it uses spatialization algorithms that numerically optimize array audio parameters such as amplitude, position, phase, Doppler shift and reverberation. A function of programmable speaker location while the unit is running, the internal position program is generated and read from an internal position sequence, it can be extensively controlled through arbitrary manipulation of MIDI parameters for real-time live applications or for synchronization.

INTRODUCTION
Sound localization and the simulation of moving sound sources have long been subjects of extensive study in the fields of computer graphics and signal processing, leading to a variety of experimental set-ups such as the 1971 Linhart & Kowalski system (1971).

The virtual sound field of a simple loudspeaker produces a virtual pseudo-source of sound with a variable location through fixed physical sound sources (speakers).

These systems have achieved a good measure of success and point to new ways of dealing with audio reproduction that can create a more realistic and lifelike sound environment surrounding the listener. Unfortunately, such systems have up to now remained confined to a few research laboratories and involve a prohibitive amount of equipment for individual or small organizations potentially interested in them. Also, they usually require a large amount of digital processing that cannot be performed in real-time, and while they can create striking spatial illusions, their placement is often highly dependent on fixed speaker and listener positions.

We set out two years ago to develop a spatialization system that would function in real-time, be affordable, portable, and flexible enough to be useful in a variety of situations. Given the speed limitations and high cost of current digital signal processing technology, it became clear that we would have to depart from a purely digital approach to achieve the above. The solutions we chose first, to use a hybrid system, in which analog audio processing is controlled by a dedicated computer; and second, to provide ways for that system to incorporate additional electronic parameters such as digital delays and reverberation into its processing.

The use of analog processing naturally has its limitations; still, it was found that interesting spatial effects could be achieved through the manipulation of the audio signal amplitude, position and phase, especially when combined with digitally generated frequency shifting and reverberation. Although it cannot produce highly localized spatial images, it provides a spatial sound dynamic that adds a significant dimension to musical composition, and is also less demanding in practical use on speaker and listener positions.

ARCHITECTURE OF THE 16-1:
The device that resulted from this project, named the 16-1 Sound Spatializer, consists of three main components:
1) A spatial coordinate generator that lets the user define spatial locations and trajectories.
2) A physical program that translates these coordinates into audio parameters that simulate the desired pseudo-sources.
3) An audio processor that routes the various audio outputs and controls of the device and performs the actual audio signal manipulation.

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The Spatial Coordinating Generator:
The user defines pseudo-source locations by specifying coordinates in a two, two or three-dimensional vectorial space mapped into the physical space where the spatialization is taking place. Each coordinate varies from 1 to 79, with 54 corresponding to the central position, the reference point for calculations. Coordinates can be entered in three different ways:

1-By two potsticks for manual play.
2-By an internal position sequencer that can record and playback patterns of movement, allowing sequences to be edited, combined, reversed and speeded up or down.
3-By an external interface that allows spatialization data to be recorded and played back on an external medium, through one of two ports:
   - an Audio Port to use one track of a tape recorder.
   - a MIDI Port (The MIDI implementation of the device is elaborated in a further paragraph, as it opens up many new possibilities).

The Spatiotemporal Processors:
Programmed into the SS-1 are a number of spatialization algorithms which are selected through six different operation modes. Their function is to calculate the optimal values of available audio parameters to simulate sound pseudo-sources at the locations defined by the user, handling from 1 to 4 sound pseudo-sources on systems of 2 to 8 speakers. Each algorithm combines a number of the following techniques:

- A direction simulation technique based on interaural intensity difference (IID) and time delay (ITT) involving the variation of amplitude ratios to obtain a perceptually linear scale between pairs of speakers, as described in numerous articles such as Leaky (1949), Beethoven (1975), Bernstein (1977).
- A distance simulation technique based on the variation of the cross-correlation coefficient between two channels through phase shifting of the signal, as described by Y. Furukawa, Nature & Science (1979).
- A panoramic sound-field synthesis technique involving a 90° phase shifting of the signal, based on the mathematical work of Gershman (1973).
- Control of the global pseudo-source amplitude to help simulate distance.
- Control of the reverberation-to-direct signal ratio to help simulate distance. This is done by coupling a regular reverber unit to the SS-1.
- Simulation of Doppler frequency shifting for moving pseudo-sources. This is done by coupling a regular voltage-controllable digital delay to the SS-1.

The algorithms also take as input the location of each speaker in the playback system, specified by coordinates as with the pseudo-sources. This has valuable consequences as it allows the transportation of pre-
proposed works to different performance after a spatialization composition made on the SS-1 can be played back intact on sys-
teams with speakers in different locations or even with a different number of speakers, by simply reconfiguring the description of their configuration.

The Analog Audio Processor:
The SS-1 has four audio inputs and eight audio outputs, interconnected through a matrix of analog gates, VCA's, inverters, and a precision phase differentiation network (PPDN). These elements, controlled by the numerical processor, are rearranged according to the selected operation mode:

* Mode 1: plays 4 pseudo-sources on sets of 2 speakers, in 1 dimension.
* Mode 2: plays 2 pseudo-sources on sets of 2 to 4 speakers, in 2 dimensions.
* Mode 3: plays 1 pseudo-source on a set of 2 to 4 speakers, with seven processing.
* Mode 4: plays 1 pseudo-source on a set of 2 speakers, in 3 dimensions.
* Mode 5: plays 1 pseudo-source on a set of 3 to 6 speakers, in 3 dimensions.
* Mode 6: bypasses the spatialization al-

THE MDH IMPLEMENTATION:

MDH (Musical Instrument Digital Interface) is a communication protocol that was originally designed to connect different synthesizer keyboards together. Its widespread accep-
tance as a standard has led to its use in all kinds of digital instruments and proces-
sors. The SS-1 is the first spatialization processor we know of to be equipped with MDH. Its implementation is particularly exten-
sive, as any SS-1 parameter (pseudo-source location, sequence speed, sequence trigger, scale, distance, etc.) can be assigned to most MDH parameters (continuous controllers, pitch control, etc.) with programmable scaling and offset. The complete signal path of the device is assigned to Program numbers and recalled through MDH Program Changes.

Basically, MDH can be used in two ways with the SS-1:

1-To control it from a micro-computer based MDH sequencer, for synchronization pur-
poses. In this way, spatialization data is written to a new track of the sequencer, along with whatever other musical informa-
tion present on other tracks. The SS-1 uses an internal data interpolation tech-
nique to reduce the amount of memory needed for its recording.

2-To control it from a MIDI keyboard. Pre-
viously unavailable effects are made possi-
bile by such a direct interaction between musical performance and spatialization.

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Further inquiries regarding the SS-1 and its commercial availability can be referred to the author.

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