

A Quadraphonic Oscilloscope Display Technique*

DONALD L. PATTEN

Shure Brothers, Inc., Evanston, Ill.

A technique has been developed which allows visual analysis of the sound field created by the four channels by use of an oscilloscope. The oscilloscope display contains quadraphonic channel balance, phasing, separation, spread, and overall-directionality information. This technique should be of special interest to the recording engineer and anyone doing analysis of the various matrix systems. Analysis of a few representative displays, theory of the circuitry, and typical installations are discussed.

INTRODUCTION: The recording engineer is very familiar with the use of an oscilloscope to monitor audio signals in stereo systems. This paper describes a technique that allows an oscilloscope to be used for monitoring audio signals in quadraphonic systems. The resulting oscilloscope displays contain information on phasing, channel separation, directionality, and channel balance.

A simple circuit has been developed which permits an oscilloscope to be connected to the speaker lines or the 600-ohm program lines of a quadraphonic system. This paper covers the development of this technique, the theory of operation, and a description of the circuit utilized. Following circuit information is a section on analysis of typical audio patterns produced by this display system with emphasis on channel balance and phasing.

CIRCUIT DEVELOPMENT

One important use for an oscilloscope is in monitoring modulation while cutting stereo master records. In this case the oscilloscope is connected to the left and

right channels of the cutting system. The oscilloscope then displays both channels, revealing the lateral (in phase) and vertical (out of phase) information. The requirement for the oscilloscope in monitoring stereo is that it have both horizontal and vertical (*X* and *Y*) inputs, one for each channel. Therefore, in a quadraphonic display it would seem necessary to have an oscilloscope with four inputs.

Starting with a Tektronic model 503 oscilloscope which has four inputs (differential *X* and *Y*) and a rough idea of what the display ought to look like (Fig. 1), diodes were placed between the audio source and the scope inputs. The object was to be able to move the oscilloscope trace in four different directions, away from the center of the screen. The diodes allowed a positive input signal to move the trace in four directions: up, down, left, and right. Each of these could represent a channel of a quadraphonic system. Tilting the scope on its side by 45 degrees produced four display directions (left up, left down, right up, and right down) which began to sound (and look) like quadraphonic sound.

A rotational matrix was added between the input diodes and the oscilloscope to electrically rotate the display by 45 degrees, permitting the oscilloscope to be used in its upright position (Fig. 2).

* Presented May 3, 1972, at the 42nd Convention of the Audio Engineering Society, Los Angeles.

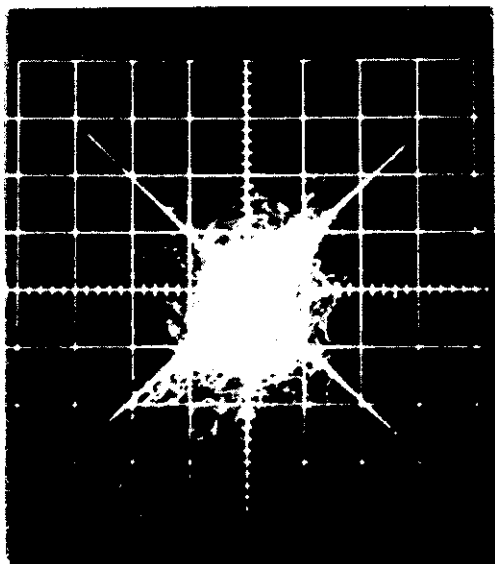


Fig. 1. Typical quadraphonic display.

CIRCUIT DESCRIPTION

The input diodes are germanium rather than silicon, chosen for lower turn-on voltage and "soft" knee characteristics. The rotational matrix resistors are all equal, and a value of 5 kilohms, $\frac{1}{2}$ watt was chosen to provide bridging input impedances that could monitor either 600-ohm program or speaker lines. The resistors should be matched to within 1% to avoid skewing the display. With two adjacent central resistors mismatched in the matrix (one 10% high and the other 10% low in value) and all the others exact, the angular displacement error is 17 degrees.

The oscilloscope output voltages $+H$, $-H$, $+V$, and $-V$ are developed across the central matrix resistors. The oscilloscope responds to the differential voltage for each axis, X and Y . An oscilloscope with only single-ended inputs could be used if a pair of differential

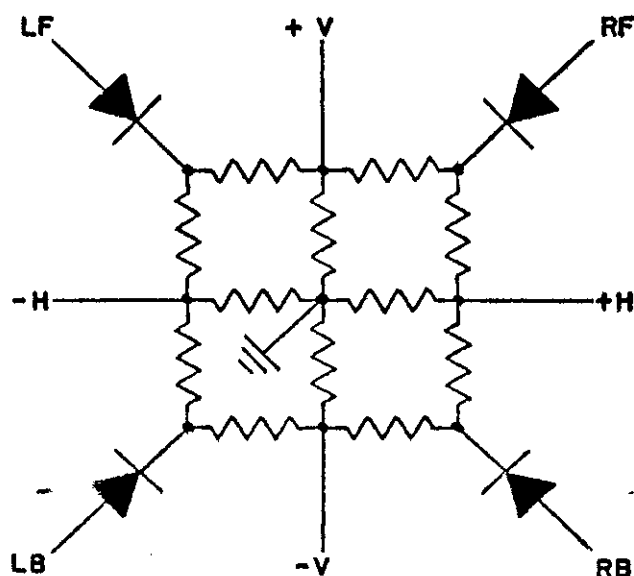


Fig. 2. Schematic of diode matrix network with inputs left front, right front, left back, and right back and outputs $+V$, $-V$, $+H$, and $-H$.

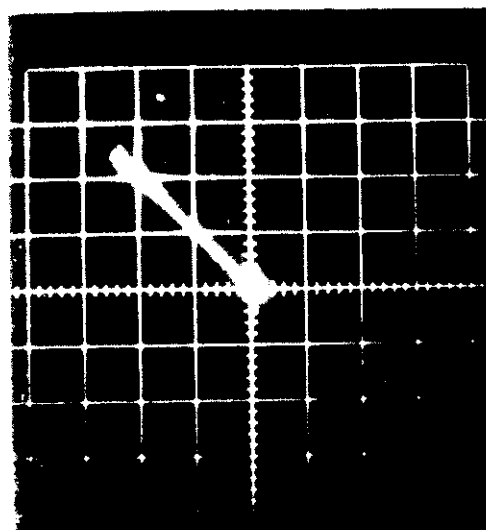


Fig. 3. Display with only a left front input.

amplifiers were added between the matrix outputs and the oscilloscope inputs [1]. A mathematical analysis of the diode-rotational matrix appears in the Appendix.

CIRCUIT OPERATION

The quadraphonic signals at the four inputs to the diode-matrix circuit cause the oscilloscope trace to be displaced away from the center of the cathode-ray tube.

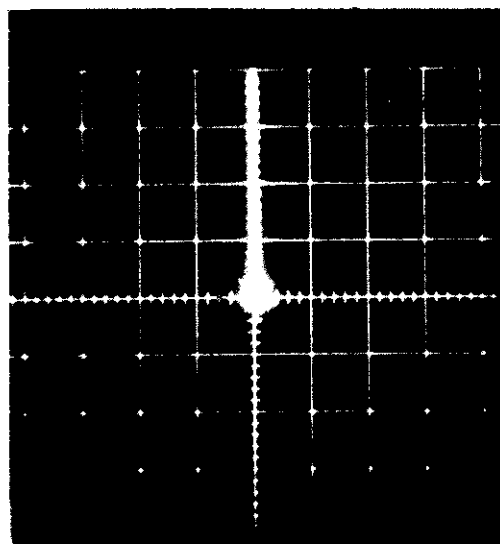


Fig. 4. Display with identical left front and right front inputs (in phase, mono).

The direction of the deflection is determined by the relative strength of the input signals present, and the amplitude of deflection is determined by the amplitude of the input signals. With only one channel driven at a time, a vector is traced on the cathode-ray tube from the origin to one of the "corners" of the screen. The vector length represents the signal amplitude, while the direction denotes which of the four input channels (left front, left back, right front, right back) is being excited (Fig. 3). The four independent vectors (left front, etc.) form

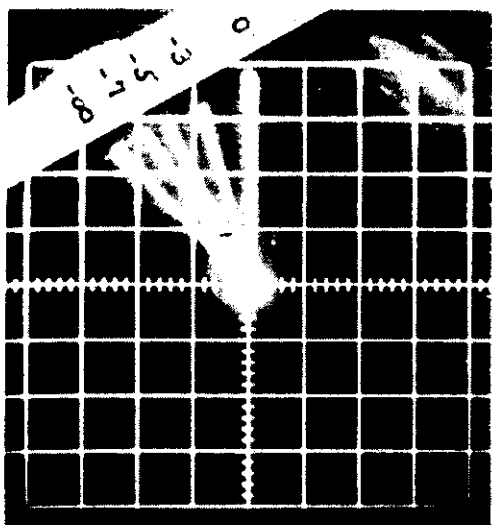


Fig. 5. Display with in-phase left front and right front inputs. The shift toward the left front is produced by reducing the right front input from 0 dB to -3 dB, -5 dB, -7 dB, and off.

dividing lines separating the display area into four quadrants. These quadrants are front, back, left, and right (Fig. 1). To display a vector in a quadrant requires that the adjacent channels that form that quadrant have simultaneous signals present. To display a front-oriented sound requires the same signal to be present on both the left front and right front inputs (Fig. 4).

If the input signals are not equal, the display will shift toward the stronger channel. Fig. 5 illustrates the shift with five vectors representing input signals starting with equal level (0-dB reference) and shifting toward the left front by reducing the right front channel input to -3 dB, -5 dB, -7 dB, and off. This shift can be predicted mathematically and is covered in the Appendix.

With the same input signal present on both the left front and right front inputs, but 180 degrees out of phase, the result is a V shaped pattern (Fig. 6). This pattern is due to the half-wave rectification of the input signals by the input diodes. Consider a pair of out-of-

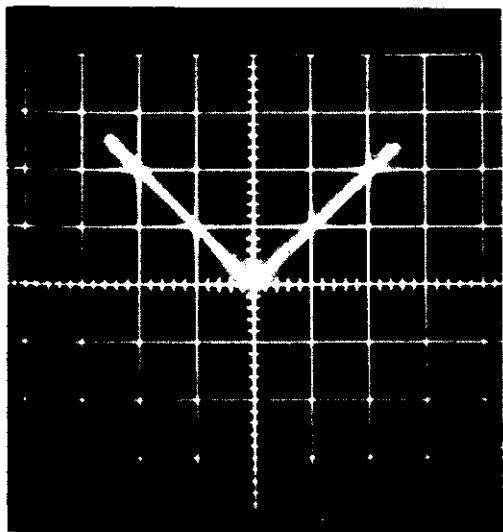


Fig. 6. Display with identical but out-of-phase left front and right front inputs.

phase sine-wave input signals that are half-wave rectified (Fig. 7). Note that at an instant in time when one signal has a positive value, the other is zero. The display circuit regards this input pair as two unrelated inputs occurring at different times and the output displays as two vectors representing the inputs being driven. Note that if full-wave rectification were employed, the phasing information would be lost (Fig. 7). Since the system is phase sensitive, it is possible to use it to check for various phase shifts. Fig. 8 shows patterns with different phase angles between 0 and 180 degrees.

To display four independent audio signals in only two independent directions requires a small compromise. This display technique requires the audio input signals to be rectified, as previously described; and while full-wave rectification destroys phase information, half-wave rectification only provides information on the positive half of the signal. For sinusoidal signals no information is lost in half-wave rectification because the negative half of the signal has the same information as the positive half. For impulsive signals, such as those from percussive instruments, some information is given up with half-wave rectification because the first half-cycle amplitude is greater than the amplitude of successive half-cycles. The tradeoff for preserving phasing information is the loss of some amplitude information.

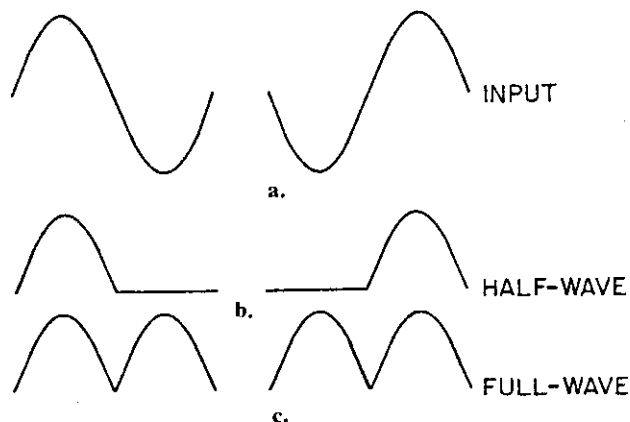


Fig. 7. a. Out-of-phase input sine waves. b. Half-wave rectified output. c. Full-wave rectified output. Note that full-wave rectification destroys the phase information.

TYPICAL DISPLAYS

Fig. 1 is a typical display of a normal quadraphonic tape source. Note the X pattern in the oscillograph, formed by the discrete input channel vectors. It has been noted that the more discrete a quadraphonic source is, the more pronounced the X.

Fig. 9 is a typical display of a quadraphonic recording made in a concert hall with four microphones and no interchannel mixing. Note the strong X pattern indicating good channel separation.

Fig. 10 is a display from a quadraphonic tape that looks more like three channels than four. It would appear that this was made from a reprocessed two-channel master, with the back channels being derived from a mono mix that was delayed and with reverberation added. In this display the X pattern is replaced by a Y pattern.

Figs. 4 and 6 show the differences between mono

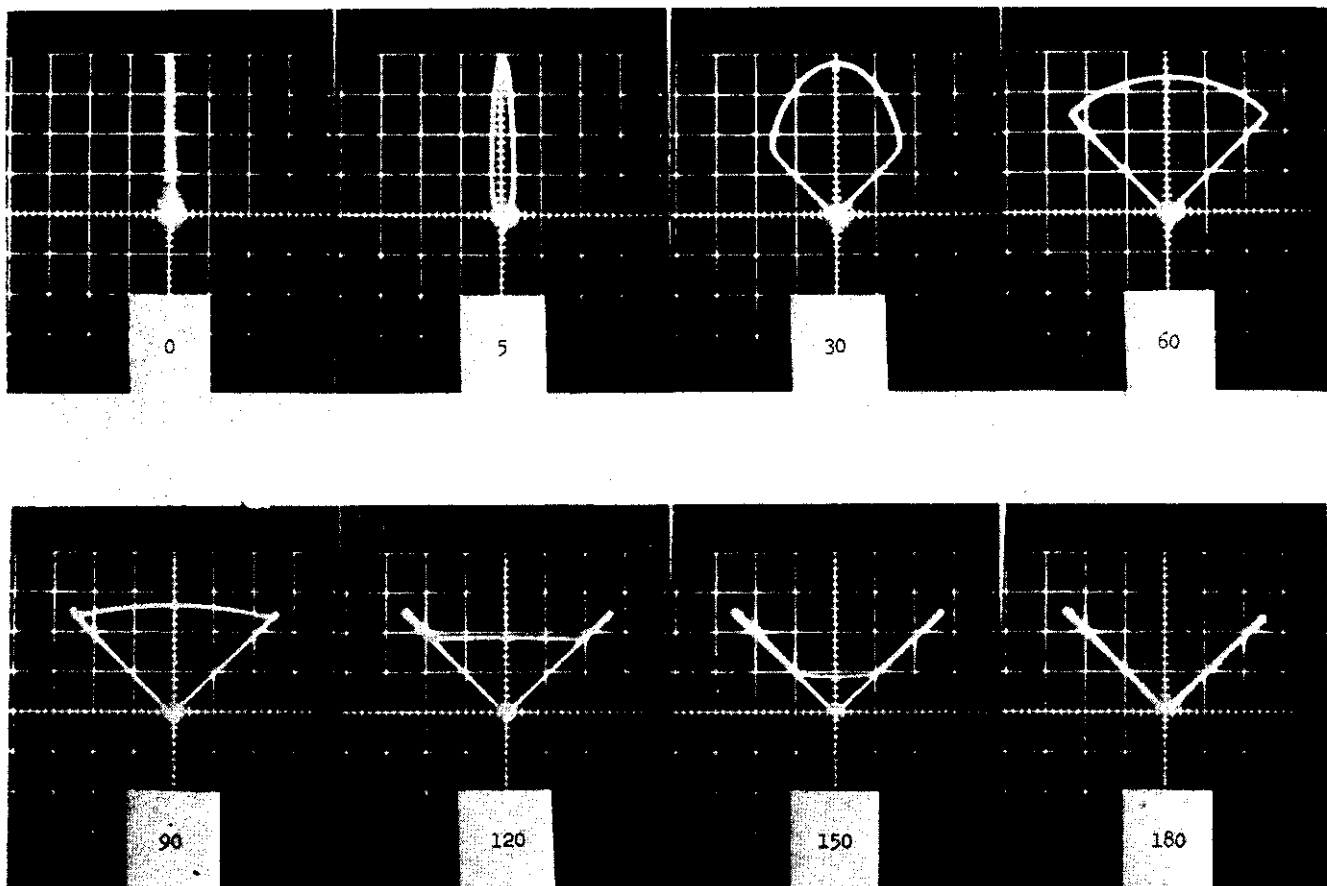


Fig. 8. Displays with equal amplitude left front and right front inputs, but with different phase angles.

in-phase and out-of-phase signals with no other signals present. In this case phase information is easily identified. With normal program material phasing information is subtle.

Fig. 11 is a display from a quadraphonic tape with mono front information and proper phasing. Fig. 12 is a display of the same passage with the phase reversed on the left front channel. Note the lack of front quadrant information in the out-of-phase oscillograph.

Fig. 13 is a display from a solo instrument in a

concert hall. The oscillograph shows the front and back channels out of phase and a phase shift of approximately 90 degrees between the left and right channels. This condition was due to the hall acoustics, microphone spacing, and the note being played.

FUTURE INVESTIGATIONS

With this display technique it is easy to monitor quadraphonic recordings or evaluate 4-2-4 matrix en-

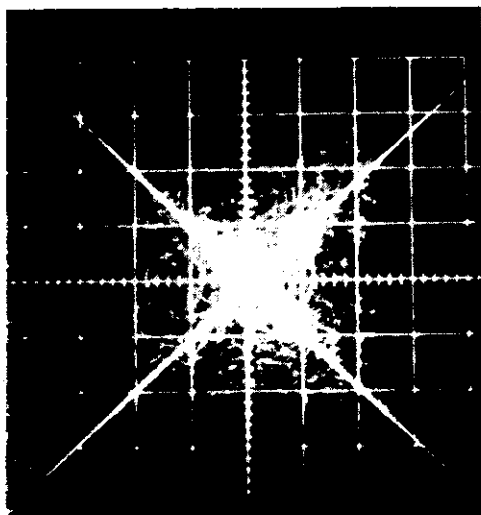


Fig. 9. Display of quadraphonic recording with good separation.

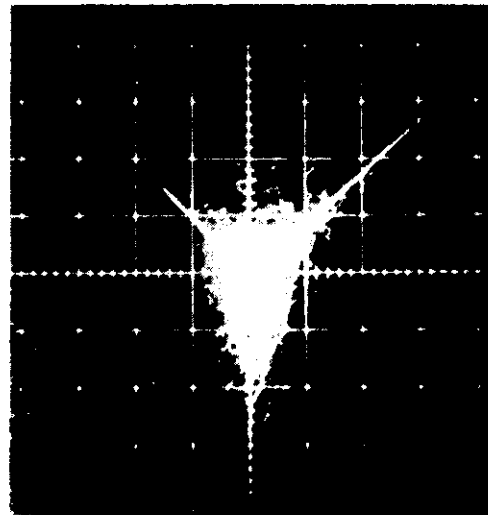


Fig. 10. Display of quadraphonic recording that was probably made from two-channel master.

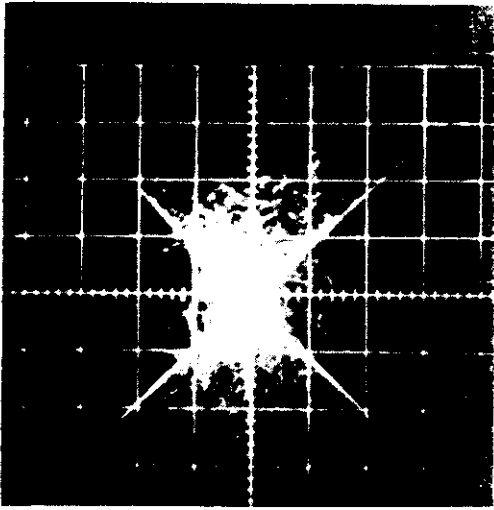


Fig. 11. Display of quadraphonic recording with mono in-phase front information.

coding systems. Fig. 14 is a typical pattern produced by one of the popular matrix systems. This matrix encoding system has the characteristic of the back channels 180 degrees out of phase with each other. Note the complete absence of material in the back quadrant.

This display system should be extremely valuable to the recording engineer for making quadraphonic recordings and also to equipment manufacturers for analyzing the various matrix systems.

APPENDIX

The algebraic solution to the diode rotational matrix can be accomplished by any of a number of techniques. Inspection of the network reveals the following: four voltage sources, four diodes, twelve resistances, and nine nodes. The problem is to solve for the output voltages to the oscilloscope inputs, given the above information. If a set of loop currents could be found, the output voltages would easily follow.

Using a topological approach for finding the loop currents, it is noted that sixteen branches and nine nodes

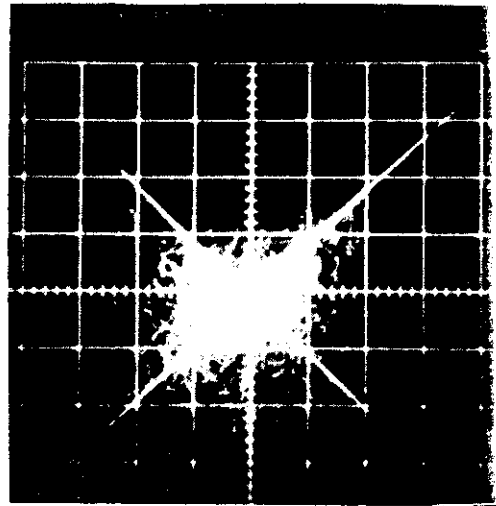


Fig. 12. Display of same passage as Fig. 11, but with left front phase reversed. Note loss of front quadrant information.

are in the network (Fig. 15). This requires eight linearly independent currents ($16 - 9 + 1$) and leads to eight equations with eight unknowns.

The eight loop equations may be written by inspection if matrix notation is used. Choice of current loops is important to ensure independence. Using the notation $V = ZI$, the following matrix set of equations was written:

$$\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix} = \begin{bmatrix} 4 & -1 & 0 & -1 & 2 & 0 & 0 & -1 \\ -1 & 4 & -1 & 0 & -1 & 2 & 0 & 0 \\ 0 & -1 & 4 & -1 & 0 & -1 & 2 & 0 \\ -1 & 0 & -1 & 4 & 0 & 0 & -1 & 2 \\ 2 & -1 & 0 & 0 & W & 0 & 0 & 0 \\ 0 & 2 & -1 & 0 & 0 & W & 0 & 0 \\ 0 & 0 & 2 & -1 & 0 & 0 & W & 0 \\ -1 & 0 & 0 & 2 & 0 & 0 & 0 & W \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \\ I_7 \\ I_8 \end{bmatrix}$$

Each row of the set represents a single-loop equation such as

$$V_1 = Z_1 I_1 + Z_2 I_2 + Z_3 I_3 + Z_4 I_4 + Z_5 I_5 + Z_6 I_6 + Z_7 I_7 + Z_8 I_8.$$

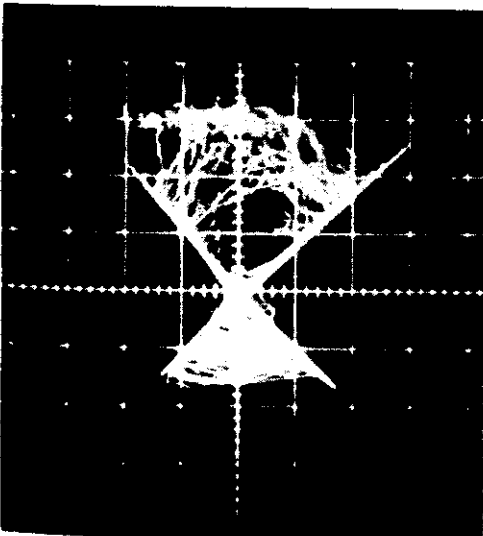


Fig. 13. Display from solo instrument in concert hall.

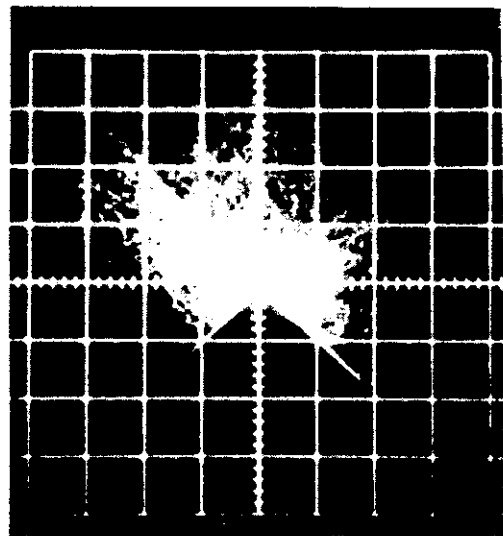


Fig. 14. Display from popular matrix system. Note that back quadrant shows no in-phase information.

Table I.

	Inputs				Outputs		Vector		Notes
	Left Front	Right Front	Left Back	Right Back	X	Y	R	θ	
A	1	1	0	0	0	.44	0.44	0	0 dB
B	1	0.71	0	0	-0.12	0.38	0.40	17	-3 dB
C	1	0.56	0	0	-0.18	0.35	0.39	27	-5 dB
D	1	0.45	0	0	-0.22	0.32	0.39	35	-7 dB
E	1	0	0	0	-0.29	0.29	0.40	45	$D=0 \& 10^3$
F	1	0	0	0	-0.26	0.26	0.37	45	$D=0.1 \& 10$
G	1	1	0	0	0	0.44	0.44	0	$D=0 \& 10^3$
H	1	1	0	0	0	0.43	0.43	0	$D=0.1 \& 10$
I	1	0	0	0	-0.18	0.34	0.38	62	$R_{-11}=1.1, R_{+r}=0.9$
J	1	1	0	1	0.17	0.17	0.24	-45	3 inputs
K	1	1	1	1	0	0	0	0	4 inputs

Rows A to E are data for the input signals shown in Fig. 5. Rows E to H are data for ideal diodes versus real diodes. Row I is the data for mismatched central matrix resistors; note the change in the vector angle θ from the ideal case, row E. Rows J and K are the data for three and four inputs; note in the case of four inputs that the output is zero. The zero output represents sound in the center of the listening room.

To simplify the impedance matrix, all resistors were scaled down and set equal to one, and the diodes are included as element D (Fig. 15).

The diagonal impedance matrix term W represents the loop impedance for each input diode current loop. Each loop includes two resistors and one input diode. Letting D represent the diode impedance, the loop impedance equation is $W = 2 + D$. The value of D is either low ($D \ll 1$) if conducting, or high ($D \gg 1$) if back biased. For the computer analysis, the values chosen for D were 0 and 1 000 000 for the conducting and nonconducting states, respectively.

A check was made using D values of 0.1 and 10 and the output voltages changed less than 10%. This indicates that the use of real diodes in the network introduces only a small error when compared to the ideal diodes used in the computer analysis.

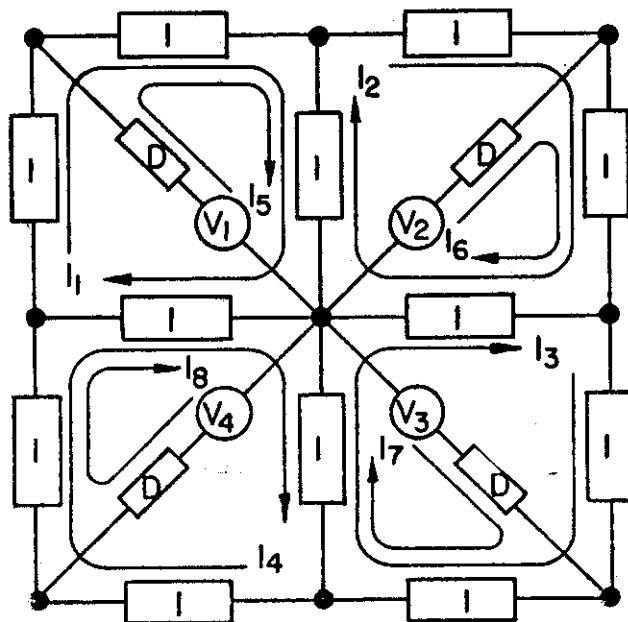


Fig. 15. Schematic diagram of analysis network.

The output voltages to the oscilloscope inputs are the differential voltages developed across the central matrix horizontal and vertical elements. The scope responds to the difference between the differential inputs. With X and Y denoting the resultant oscilloscope display voltages for the horizontal and vertical axes, respectively, the following equations result:

$$X = (I_1 + I_2 - I_3 - I_4 + I_5 - I_6) 1$$

$$Y = (I_1 - I_2 - I_3 + I_4 + I_5 - I_7) 1$$

where 1 represents the impedance of the central matrix elements. With the two oscilloscope display voltages known, simply converting them to polar coordinates completely specifies the display vector, both in magnitude and angle.

It should be noted that the phasing display information can also be predicted by the above analyses. In this case it is necessary to plot the output locus, one point at a time. The instantaneous input voltages are used to determine a point on the oscilloscope display whose location is set by the polar output information giving the distance from origin R and its bearing θ .

Table I lists the computer-derived outputs for various input signal combinations. Each row represents one set of inputs and outputs. X and Y represent the differential oscilloscope input signals and R and θ represent the vector in polar form with magnitude R and angle θ . The angular reference was chosen as the Y axis with counterclockwise rotation as positive.

ACKNOWLEDGMENT

The author would like to thank the Heath Company and his colleagues at Shure Brothers, Inc., for their assistance in the preparation of this paper.

REFERENCE

- [1] D. L. Patten, "Quadraphonic Oscilloscope Display," *db Mag.* (June 1972).