Visual Correlates of Acoustical Parameters
as displayed with a
Scanned Raster, Tri- Colour Cathode Ray Tube

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In searching for new methods of presenting visual patterns in conjunction with musical sounds I have devised a system based on intensity modulation of colored light as displayed on the screen of a tricolor CRT (cathode ray tube). Much of the system is identical to portions of a standard color television receiver and since a minimum amount of peripheal circuitry is required to adapt audio sugnals for display it seems feasible that receivers could be commercially produced with sound display built in. There are distinct relationships between the displayed pattern and certain acoustical parameters such as amplitude and frequency. It is possible to catalogue the correlations and use them as a basis for developing an array of images which may be scored much in the same way that acoustical parameters are scored in musical compositions.

The following discussion begins with a description of the scanned raster display and an analysis of acoustically based patterns. Circuitry used in my experiments is described, and finally a simple visual score is developed along with the MUSIC 5 computer synthesis of the score.

Scanned raster systems.

A standard television picture is produced by scanning the area of the CRT screen horizontally and vertically. The sequence used is to scan one line horizontally and then proceed vertically to scan the next line. Scanning normally occurs from left to right across the screen and from top to bottom down the screen.

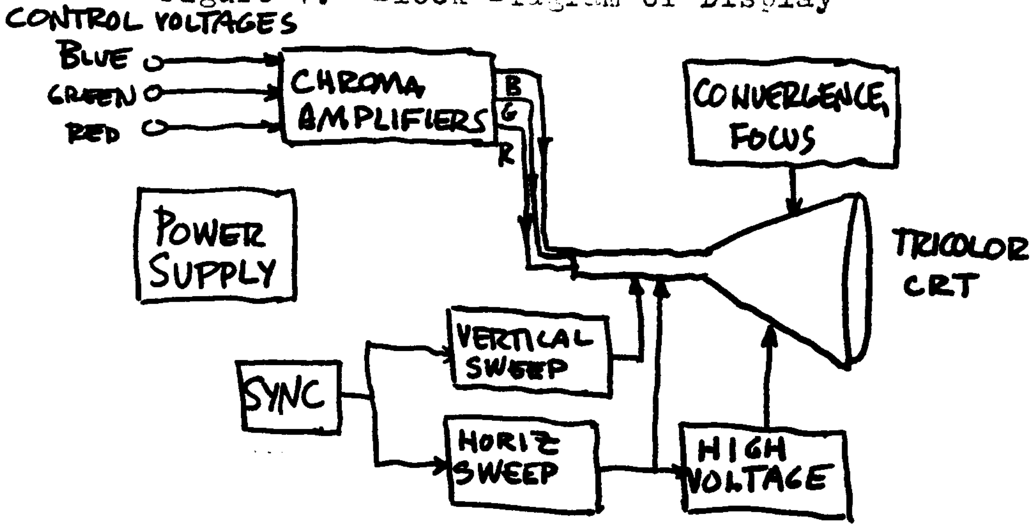
NTSC (National Television System Committee) standards have established the United States broadcast picture. This picture consists of 525 horizontal lines with an ideal resolution of about 500 elements per line. A vertical scanning frequency of 59.94 Hz and a horizontal scanning frequency of 15.734 kHz are specified. These frequencies are nominally refered to as 60 Hz and 15.75 kHz respectively. Furthermore, the scanning is interlaced with a ratio of 2:1. This means that in any given vertical scan only ½ the total lines are scanned. The following vertical scan covers the other lines so that two vertical scans or <u>fields</u> are required to produce a complete picture or <u>frame</u>. (The need for interlacing arises from the need to reduce picture flicker which is perceptible at field rates of 30 Hz.)

Considering the time domain we see that the duration of a line is about 63.5 usec (micro-seconds) while the duration of a field is about 16.67 milli-seconds. Not all of the scanning time is used for producing a visual portion of the picture. Synchronizing and retrace reduce the actual times used in producing an image to 52 usec for a line and 15.5 msec for a field.

Finally, a conversion from the time domain to the spatial domain occurs at the CRT. An aspect ratio of 4:3 sets the width of the picture at a value 4/3 the height of the picture. In the CRT used in my experiments the width of the screen is 20" and the height is 15". Thus, in the horizontal direction 2.6 usec corresponds to 1" of length. Likewise, 1 msec corresponds to 1" of length in the vertical direction.

The portions of the television receiver required for the display are indicated in figure 1.

Figure 1. Block Diagram of Display



Producing patterns.

The key to understanding production of patterns rests in knowing both the amplitude and time-nature of the modulating signal and how these parameters interact with the scanned raster. Let us consider the problem of analyzing these interactions.

In an optical system interference patterns result which contain nodes and antinodes in the observation plane at points which are related by integral multiples of the wavelength of light involved.

Similarly, stationary patterns result on the screen of the CRT when the modulating signal frequency is an integral multiple of the scanning frequency.

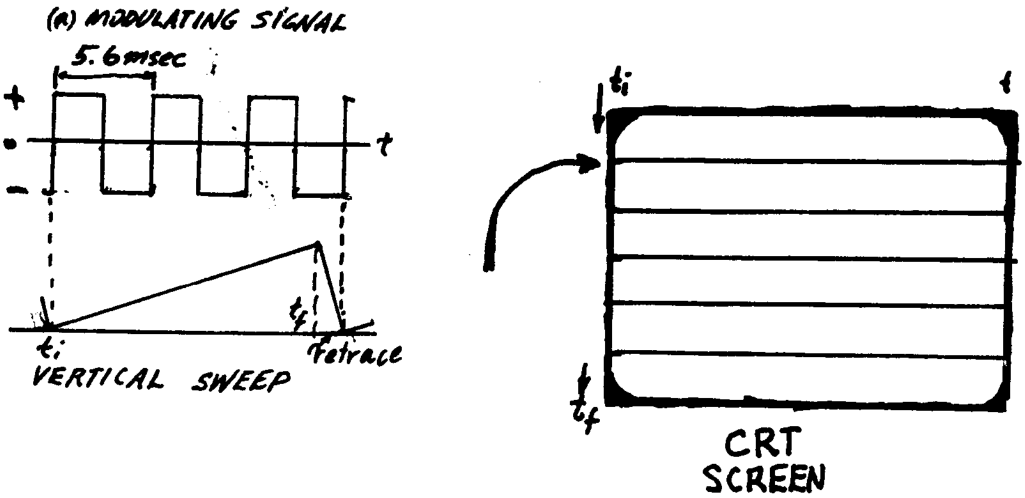
Consider a 180 Hz square wave modulating the red chroma channel. During each field the modulating signal goes through three cycles. Refer to figure 2. Since positive excursions of the square wave turn the chroma on and negative excursions turn the chroma off the resultant pattern consists of three red horizontal bars equal in dimensions and equally spaced on the screen of the CRT, as seen by an observer. If the frequency of the square wave is exactly 179.82 Hz (three times the vertical scanning frequency) the pattern will remain stationary. If the frequency is slightly higher than 180 Hz the pattern will move upward on the screen while if the frequency is slightly lower than 180 Hz the pattern will move downward on the screen.

It is possible to accurately predict the dimensions of the pattern on the screen. For the 180 Hz square wave the period is about 5.6 msec. The chroma channel is on for 2.3 msec assuming a symmetric wave. Since 1 msec corresponds to 1" in the vertical direction the pattern should consist of red bars 2.3" wide and extending across the screen. Between each color bar will be a black bar of width 2.3". Alternatively, it is possible to consider the number of lines which are produced. A 2.3 msec on time of the chroma corresponds to (2.3 msec)/(63.5 usec per line) or about 36 lines. Due to interlacing these 36 lines are spread over a distance of 72 lines . To find the width of 72 lines multiply the fraction (number of lines)/ (total lines) by the height of the screen:

$$(72/525)(15'') = 2''$$

which agrees with the 2.3" calculated above.

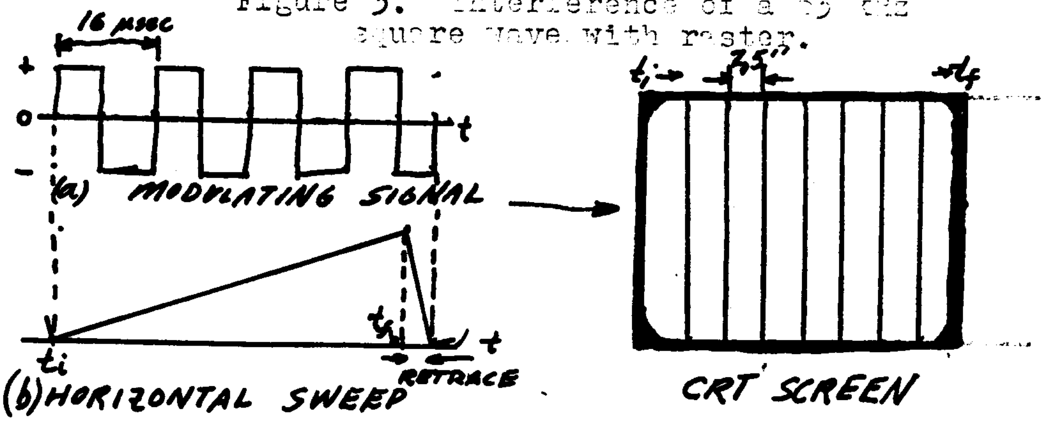
Figure 2. Interference of 180 Hz square wave with raster.



Patterns produced by other frequencies can be predicted in a similar fashion. For most audio frequencies the patterns will be horizontal in geometry. In order to achieve vertical patterns modulating frequencies above the horizontal scan frequency are required. It will be useful to consider this case even though it will normally not be encountered with audio frequencies.

As the frequency of the modulating signal is increased the patterns will shift from horizontal lines, to diagonal lines, to finally vertical bars at frequencies which are integral multiples of the horizontal scan frequency. At low frequency the period of a waveform is many lines so that the pattern appears to be horizontal. At high frequencies, greater than 16 kHz, the period of a waveform is only a fraction of the period of a line so that the patterns appear to be vertical. Figure 3 outlines the pattern produced by a 62.936 Hz square wave intensity modulating a chroma channel. This frequency is four times the horizontal scan frequency.

Figure 3. Interference of a 63 kHz square wave with raster.



To summarize to this point in the discussion, by intensity modulating the chroma channels of a tri-color CRT using frequencies in the audio range it is possible to produce patterns which bear predictable relationship to the frequency of the audio signal. Certain frequencies produce stable patterns of horizontal or vertical bars although audio frequencies produce primarily horizontal bars.

The simple case of a steady-state square wave is useful in explaining pattern production. There are many other parameters which can be considered and thus provide flexibility in producing patterns. The perceived combination of various portions of red, blue, and green light result in all colors of the spectrum. In addition, the saturation of [illegible] can be varied continuously [illegible] to produce many colors on the screen.

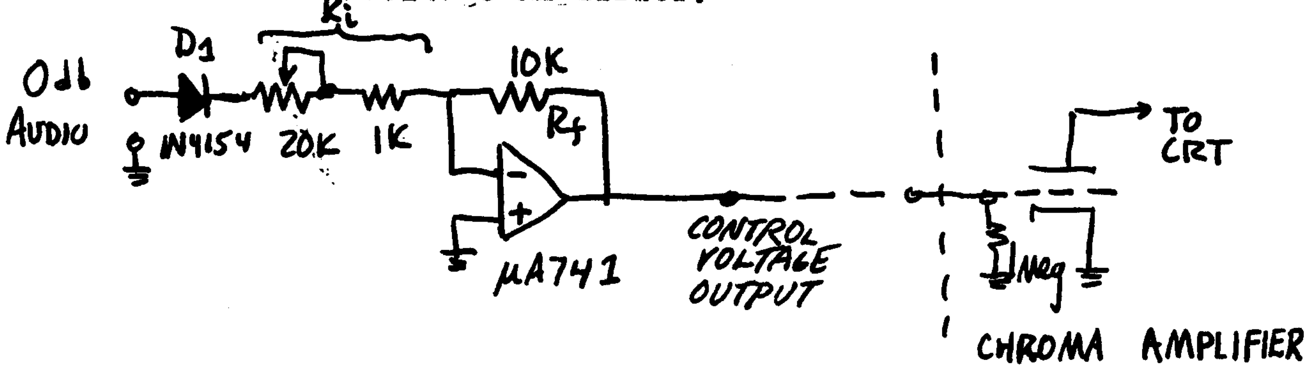
Various harmonic contents affect the pattern in that the instantaneous amplitude of the waveform is determined by the combination of each harmonic at that time. Thus there is a correlation between the timbre of a musical sound and the outline of the pattern produced by the sound on the screen. The square wave, which has as a first derivitave delta functions, produces a pattern with crisp, sharp outlines. That is, in a neighborhood of the outline, the intensity remains constant at one of two values, zero or some fraction of the saturated intensity. A sine wave has as its first derivative a continuous function, the cosine, so that the outline of the pattern produced by a sine wave is indistinct, or hazy. Other waveforms can be observed and the nature of the pattern outlines can be recorded for use in setting the texture of the pattern.

Circuits

The musical material used as a source for the patterns is recorded on magnetic tape. The chroma amplifiers are such that they operate essentially as voltage controlled amplifiers. The input impedance is 1 megohm and 0 volts produces a black screen. As the voltage is made negative the intensity of the color increases until it reaches a maximum at a control voltage of -4 volts. The input circuit must amplify nominal 0 db signals from the tape playback to a level necessary for operating the chroma amplifiers. 0 db corresponds to peak signals of 1 volt so a gain of 4 is required. Negative portions of the input signal should not be amplified. If a positive signal is fed to the chroma amplifier triode, current is drawn from the source and a voltage controlled condition no longer exists.

The amplifier circuit shown schematically in figure 4 is used to transform the audio signals into chroma control voltages.

Figure 4. Audio signal to control voltage amplifier.



A Fairchild uA741 operational amplifier is used as the active element. The amplifier is in the inverting configuration with the gain magnitude set by R_f and R_1. A portion of R_1 is made variable to allow the actual gain to be varied from about -½ to -10. The input diode D_1 is a silicon signal diode which allows only the positive portions of the input signal to be amplified. Although the basic circuit is simple a few additions provide a number of signal processing conditions to be utilized in producing a pattern thus providing flexibility in use of the sound material. For example, addition of a non-inverting input to the amplifier allows two chroma channels to be driven by opposite portions of the AC signal waveform. Also, since positive voltages to the non-inverting input will tend to cancel the effects of positive voltages at the inverting input it is possible to differentially modulate a chroma channel with two different signal sources. By providing several inputs to each chroma channel of both inverting and non-inverting types it is possible to mix several sources in the chroma channels and thus cause a great deal of color mixture on the screen of the CRT. A matrix switch allows each input to be connected to one of several sources. Besides using strictly audio signals to modulate the chroma channels there are digital circuits which can be used to blank out or to reinforce portions of the pattern. Additional pattern forms become available since the whole screen need not be used for one pattern. A complete schematic of an experimental system is shown in figure 5.

Notation.

For the sake of generality I will describe the essentials of a notational system. Such a system might be useful in communicating particular patterns to other displays as well as providing insight into the essential parameters which are perceived. There are basically three independent parameters to work with: intensity of light, wavelength of light, and time intervals. The wavelength of the emitted light can be one of three values established by the quantum nature of the phosphors used on the CRT screen. The wavelengths typically used are 700, 5[illegible], and 4[illegible] millimicrons and correspond to red, green, and blue light. The additive process of color mixing allows a wide variety of hues to be produced with these three wavelengths. The intensity of each channel

channel varies as the magnitude of the control voltage applied to that channel. Time intervals need to be considered of both large and small magnitude, from 10^{-6} seconds to 10^{3} seconds or more. The nature of the scanned raster is such that images are created and sustained in time. At any one instant there is but a portion of a whole image being produced. However, integration of the scanned pattern by the neural and psychological processes involved in human sight make it possible for a viewer to perceive a continuum of images. One need be concerned with time intervals which relate to elements in the line, that is intervals with orders of magnitude of 1 usec. When dealing with audio signals it suffices to specify the frequency and duration of the modulating signals.

The ideal graphic score could be realized in three dimensions with color as a parameter. Specifying amplitude and frequency as functions of time is sufficient to define a pattern. However it is convenient to score time and frequency as separate functions of time, with color as a parameter.

As an example of notation and computer realization of the audio portion of a pattern consider the following. A score is to consist of a sequence of tones. These tones shall be the frequency 59.94 Hz and its first 9 harmonics. Each tone shall have duration of ten seconds with three seconds of silence between each tone. After five seconds of each tone, there shall be a linear increase in frequency by 3% of the initial frequency, followed by a linear decrease in frequency to -3% of the initial frequency, and finally, a linear increase in frequency to the initial frequency. In addition, the envelope of the tone shall have an a linear attack time of 2 seconds, a linear decay time of 5 seconds, and a sustain level of 33 db.

Each tone should produce a stationary pattern on the screen for 5 seconds and then the pattern should shift upward, the downward, and finally upward and back to rest at its initial position. After these patterns are recorded they will be montaged onto a stereo tape. The final sequence of tones will not necessarily be the sequence which was generated. A score for the generating routine is notated in figure 6. The computer program is attatched.

Conclusions.

What has been described in the preceding is the beginnings of a system which will enable abstract video patterns to be produced as well as enable concrete, prerecorded or live video signals from cameras to be modified. It is difficult to predict where this work will lead, but its manifestations might prove as useful to understanding visual processes as the manifestations of electronic music have proved to be to understanding hearing.