A rotator for X/Y oscilloscope displays

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A simple and relatively inexpensive electronic circuit is described that will generate the Cartesian coordinates of a rotated display for both the X- and Y-axes of a conventional oscilloscope type of display monitor. The device will rotate the display through fixed angles and possesses the merits of very low intrinsic noise and extremely high speeds of response. It is particularly suited for computer control of stimulus orientation in psychophysical investigations of spatial contrast vision.

In most studies of spatial contrast vision, a modified version of the television technique (Campbell & Green, 1965) is utilized to provide the stimulus display. In a domestic television receiver, a slow sawtooth sweep is applied to the electron beam in the vertical (downward) direction and a higher frequency sawtooth is applied to the beam in the horizontal direction. Intensity modulation is synchronized, with the higher frequency horizontal sweep providing modulation along the length of the individual raster scan lines.

The modified version of this technique that is commonly used in spatial contrast displays utilizes a low-frequency sawtooth sweep in the horizontal direction with a higher frequency sawtooth or triangular waveform applied in the vertical direction. Intensity axis modulation is then synchronized with the onset of the horizontal (low-frequency) sweep to provide vertically oriented unidimensional patterns for inspection by experimental observers.

In many investigations of spatial contrast vision, it is desirable for the experimenter to be able to control the orientation of the stimulus. Various methods have been proposed for achieving this aim. Fairly simple mechanical methods can be used that rotate the body of the display itself (e.g., Georgeson, 1975) or the virtual image of the display (e.g., Heeley, 1978). Such methods are extremely cumbersome, and changes in stimulus orientation that are both rapid and accurate are not easily obtained. Alternatively, the display may be viewed through a Dove prism, thus utilizing optical rotation. This, however, restricts the field of view and severely constrains the observer's viewing position. As with the mechanical methods previously discussed, rapid rotation of the image is difficult to achieve. Further, none of these methods lends itself particularly well to control of stimulus orientation by a computer.

The ideal system uses electronic means to rotate the display present on the face of the monitor without having to introduce any mechanical displacement of

that display. If the display utilizes electromagnetic deflection, similar to that employed in domestic television sets, then rotation of the deflection coil will rotate the display on the screen. (This is the approach used in the special-purpose displays designed by Robson and Joyce of the Physiological Laboratory, Cambridge, England). Alternatively, for the more commonly used commercially available displays that use electrostatic deflection, such as the range of Tektronix and Hewlett-Packard monitors, modified horizontal and vertical sweep signals can be created that correspond to the Cartesian axes of a rotated display.

These vectors are $x' = x \cos \theta + y \sin \theta$ and $y' = y \cos \theta - x \sin \theta$, where x' and y' are the new signals that are to be applied to the X and Y inputs of the display, respectively, x and y are the original horizontal and vertical sweep signals (note that both of these must be bipolar if the display is to rotate about the central point), and θ is the angle through which the display is to be rotated. Note that for orientations intermediate between the horizontal and the vertical, x' and y' contain elements of both the original x and y sweep signals.

Shapley and Rosetto (1976) presented a technique for deriving these vectors by analog means. The original X and Y signals were passed through four-quadrant analog multipliers in which they were multiplied with control signals that defined $\sin \theta$ and $\cos \theta$. In this implementation, the control signals could be obtained either from a sin/cosine potentiometer for manual control or from an equivalent external source such as digital-to-analog converters. The results of the analog computations were then summed by operational amplifiers to generate the signals x' and y' , and these new signals were applied to the X and Y inputs of the display.

Several problems were encountered during attempts to apply this and allied techniques. It was necessary to rotate a raster scan display on a Tektronix 606A monitor. The horizontal sweep was a 100-Hz sawtooth, and the vertical sweep was a 200-kHz triangular wave, both of ± 1.0 -V amplitude driving a 50-ohm terminated load. These signals are of comparatively low amplitude, and even when the highest specification of Analog Devices modular multipliers are used, the intrinsic noise level at

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the outputs are unacceptably high. The effects of this noise are particularly noticeable on the X sweep. If the X sweep signal is increasing in voltage, the addition of a noise component will have the effect of shifting the relative spatial positions of the vertical scan lines on the display. In particular, a small negative-going noise component decreases the separation of successive vertical sweeps. When the noise component is sufficiently great, successive vertical sweeps may become superimposed. This introduces a spurious local modulation of the brightness of the display and is clearly unsatisfactory if any form of contrast detection experiment is contemplated. In the present implementation, there was a 2,000-line resolution. With a 2.0-V peak-to-peak horizontal sweep, this "folding over" of the vertical raster lines can be caused by a noise signal of only 1.0 mV. In a sample of six modular multipliers, the average noise level far exceeded this value.

Identical noise problems were encountered when proprietary digital vector generators or synchro resolvers were used (e.g., Analog Devices DTM 1717; O.E.C. 6125A). These operate in a fashion similar to the technique of Shapley and Rosetto (1976) to produce all (O.E.C.) or half (Analog Devices) of the values x' and y' . The noise problems are to be expected, as (particularly in the case of the Analog Devices module) they utilize internally the same silicon die for the multiplier section as is used in their "off-the-shelf" range of multipliers. They have a much more limited bandwidth than separate multipliers, and they are extremely expensive.

The problems of noise may be partially solved by a change in the multiplication process. The equations for x and y may be rearranged. A ramp signal is the integral over time of a step change in voltage:

$$G(t) = \int_0^t f(t) \times dt,$$

where $f(t)$ is the step change in voltage and τ is the time limit of the integration.

A typical result desired from the multiplication process is:

$$\begin{aligned} g(t) &= \sin \theta \times G(t) \\ &= \sin \theta \times \int_0^t f(t) \times dt. \end{aligned}$$

Rearranging, we have:

$$g(t) = \int_0^t \sin \theta \times f(t) \times dt.$$

This implies that the multiplication can be applied to the step change in voltage prior to the integration. The resulting step change, whose amplitude is a function of the sin or cosine of the radial angle of rotation, can then be passed through a conventional Miller integrator

circuit to generate the required ramp. The integrator is effectively a low-pass filter and will therefore remove most of the noise whose frequency is higher than the integration period.

This technique is a considerable improvement over that of Shapley and Rosetto (1976), but it still necessitates the use of four expensive modular multipliers and suffers from unacceptable noise levels despite the theoretical advantages. An alternative approach was therefore sought that more closely met the requirements of the proposed experiments.

In a large number of psychophysical experiments on spatial contrast vision (and, in particular, those that were under consideration), the variation in stimulus orientation is required only as an independent experimental variable. It is therefore not really necessary to have very fine resolution in the orientation domain. For example, a sufficiently fine sampling of orientations would be to select 15-deg intervals within a single quadrant of 90 deg. This was considered more than adequate for the present purposes.

The present circuit forms the products $x \times \sin \theta$, $x \times \cos \theta$, $y \times \sin \theta$, and $y \times \cos \theta$ by the use of resistive ladders. These "ladders" are tapped at intervals and connect to analog multiplexers. The intervals are arranged so as to correspond to sine products in 15-deg steps. As only one quadrant of rotation is being considered, the resistive ladders read as sine products in a descending direction and cosine products in an ascending direction. The signals from the multiplexers are buffered and summed at the differential inputs of the display to provide the vectors x' and y' .

CIRCUIT DESCRIPTION

A block diagram of the device and its interconnections is shown in Figure 1. The laboratory computer outputs through a conventional I/O port a digital number that corresponds to the required angle of rotation. As the orientation sampling is in this case at 15-deg intervals within one 90-deg quadrant, only seven possible stimulus orientations may be selected and, therefore, only the three lowest of the digital data lines are used. The digital output control "word" is latched by the STRB pulse from the I/O port onto the control bus internal to the circuit. The X and Y sweep signals are applied to two identical resistor ladders (as described earlier), from which seven "taps" emerge that are connected to the four analog multiplexers. The multiplexers are, in fact, contained within only two integrated circuits, as each integrated circuit comprises two identical "eight-in-one" devices that share a common digital control circuit. Thus one is used for selecting the X terms and one is used for selecting the Y terms, providing effective electrical isolation of the high-frequency Y and low-frequency X signals.

The internal digital control bus from the latch is

Figure 1. Block diagram of the display rotator and interconnections to raster scan generators and laboratory computer.

connected in parallel to the multiplexers to provide the required addressing. The control word determines which of the seven analog "taps" from the resistor ladder is connected to the output of the multiplexer. The four multiplexer outputs are buffered, and the outputs from the buffers are used to drive the differential inputs of the display monitor.

Commercially available Tektronix modular function generators (500 series) are used for the X and Y sweep generators. The Y sweep is enabled (gated) by a signal from the X sweep generator that is high when the horizontal ramp signal is running. This gating signal is also connected to an input port of the computer as the FLYBACK pulse shown in the diagram. The computer senses the falling edge of this pulse and updates the orientation control word during the flyback interval as required. The computer also provides a SYNCH pulse to the ramp generator to synchronize the onset of the display sweep with the commencement of the luminance modulation signal from the Z-axis digital-to-analog converters (not shown).

A circuit diagram of part of the device for the X products and the control circuitry common to both the X and Y is shown in Figure 2. The binary control word is latched conventionally (74273), with the latch strobe pulse being derived from the computer output strobe via

the 7416 open collector inverter and the top data bit (D7). The latch signal is therefore D7 .AND. STRB. This top data bit is used as a "device select," as more than one device uses the digital control bus.

The latch is also connected to a manual and "power on" reset circuit formed by a momentary closure toggle switch and a simple resistor-capacitor (RC) network. The RC network ensures that the latch is initialized in the clear state (corresponding to a vertical stimulus orientation) when the power is first applied. The reset line is held "low" until the 10-microF capacitor is fully charged via the 1-kohm resistor. The 100-ohm resistor in series with the manual switch provides a current limit for the discharge of the capacitor when the manual reset is activated.

Not shown in the figure is a simple LED address decode circuit that is useful in setting up and testing the circuit. The analog X and Y signals are applied to the two identical resistor ladders, each of which has a total impedance of 1.0 kohm. The relevant intermediate values are shown in Figure 2. Each element of the ladder comprises a high-quality metal oxide fixed resistor in series with a 10-ohm 20-turn cermet trimmer. The analog multiplexers are Analog Devices AD7507. The circuitry for the Y channel is exactly the same as that shown in the figure for the X.

Figure 2. Circuit diagram of the rotator. The arrangement of the Y resistor ladder and its connections to the Y product multiplexers is identical to that shown for the X products. The output buffer stages differ for the X and Y products (see text).

The buffers are somewhat different for the two parts of the circuits. In the case of the X components, the Motorola 1438 high-power buffer driven by a 531 low-noise operational amplifier is used to drive the 50-ohm terminated lines. However, the bandwidth of these devices was too limited for the higher frequency Y signals. A more suitable device was found to be the National LH0033 "Damn Fast Buffer." This has an enormous bandwidth and very low intrinsic noise.

The rotator was designed to drive a monitor with differential inputs. The trigonometric terms that were required were $X \times \sin \theta$ applied to the Y- input, $-X \times \cos \theta$ applied to the X- input, $Y \times \sin \theta$ applied to the X+ input, and $Y \times \cos \theta$ applied to the Y+ input of the monitor. An inversion stage was therefore required for the term $X \times \cos \theta$. This was achieved by connecting the relevant 531 operational amplifier as an inverter with an input impedance of 100 kohm.

The minimum loading imposed on the resistor ladders by the buffer stages is 100 kohm, and this has no measurable effect on values determined for the ladder statically. The ladders were thus set up by trimming the various stages to the required values as indicated by a five-digit digital ohmmeter. The circuit has required no adjustment over a 2-year period of use.

No spurious electrical noise is present on the display,

and the high bandwidth of the Y buffer stage means that the circuit is suitable for very high-frequency signals. The analog multiplexers are sufficiently fast in their response to easily allow updating of the stimulus orientation during the 100-microsec flyback duration.

MODIFICATION OF THE CIRCUIT

In the absence of differential inputs on the display, the summation of components can be achieved by using operational amplifiers prior to the final line driving buffers. In this case, the final buffer stages would have to be the LH0033 type, as high-frequency Y components would be present in both the x' and y' vectors.

The number of orientations that can be selected can easily be extended by increasing the number of "taps" on the resistor ladders and using more multiplexers. The outputs of the multiplexers (e.g., two for $X \sin \theta$, giving 16 possible orientations) could then be resistively summed at the virtual earth of the buffer stage input. Operation would still be restricted to one quadrant.

Operation in all four quadrants is possible if the resistor networks are driven from either end by anti-phase signals. In the present implementation, the sweep signal, either X or Y, is applied to one end of the resistor ladder, with the other end grounded. If, however, the

ground (earth) is removed and replaced by the antiphase signal ($-X$ or $-Y$, as the case may be), which has been suitably derived from an inverting stage, then rotation of the stimulus will take place over a range of 360 deg. The "tapping" points for the sin and cosine products must, however, be maintained in the correct quadrature.

Resolution finer than 15 deg/step may be obtained by simply inserting a fixed resistor in the middle of the ladders. In this case, the range of orientation variation will be more or less restricted to a region near the vertical, depending on the size of the resistor that is inserted. The larger the resistor, the more restricted will the range of angular variation become.

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