

XIII. PROCESS ANALYSIS AND SYNTHESIS

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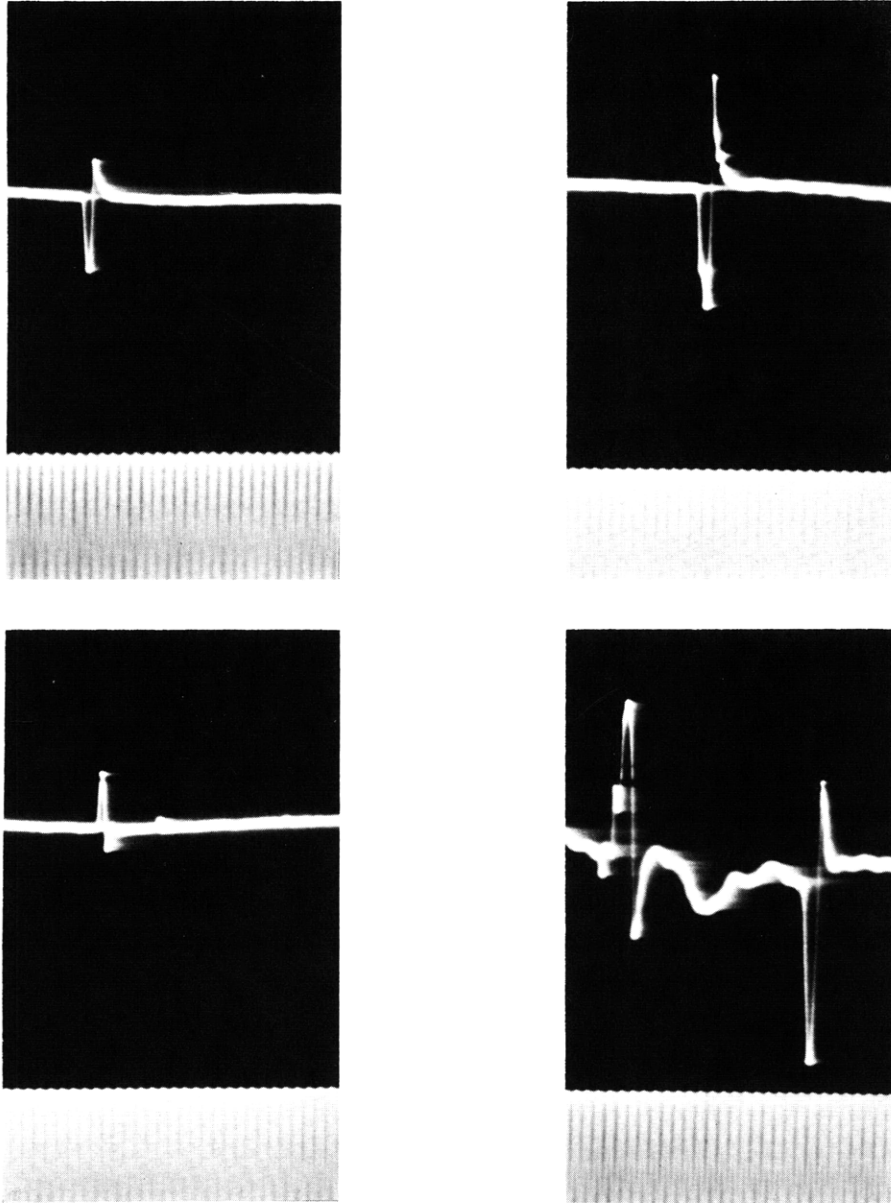
A. A LINEAR FILTER FOR THE REDUCTION OF PULSIVE RECORD NOISE

A Master's thesis (1) was undertaken to develop a technique for the reduction of pulsive record noise by using a method of time-domain synthesis proposed by M. V. Cerrillo (2, 3). The fundamental theory for this research arose from the properties of incomplete linear operators employed in Cerrillo's method. Signal-noise separation was attempted by performing the linear operation of prediction on the signal and a nulling operation on the noise. The convolution integral was the basic analytical tool for describing the system operations. The analysis procedure led to the solution of the kernel of the convolution integral, which is the impulse response of the desired system. The synthesis was then performed by realizing the kernel for prediction by means of time-domain approximations. This technique was applied to the cancellation of pulsive record noise by Cerrillo in 1953. It was the objective of the thesis research to continue the study of the nature of pulsive record noise, and to determine the extent to which nulling should be possible.

Two methods for synthesizing the system as window-function distributions (1, 4) on a tapped delay line were investigated. The first method, which employed a single window-function distribution for prediction, was unsuccessful by virtue of the prohibitive tolerances imposed on the window-function parameters. The tolerance problem, however, was eliminated by using a second method, which employed window-function distributions that performed the operation of differentiation of various orders, rather than prediction itself. Although experimental results were not obtained, it was shown theoretically that such a system is feasible. An error analysis was derived in order to determine appropriate design specifications.

Observations of the pulsive noise indicated that simulation could be obtained with the null functions used for prediction. It was determined that the shape of the noise depended on many factors – the type of cartridge, the position of the tone arm, the shape and wear of the needle, and the shape of the "nick" (a flaw in the record groove that causes pulsive noise). The extent to which these factors affect the quality of the filter should be determined experimentally because it would be very difficult to determine it analytically. Figure XIII-1 shows examples of the typical noise pulses. The average value of the ratio of the first lobe to the second was 2.5:1. The zero crossings occurred at 100- μ sec intervals.

The measurement of success in reducing the pulsive noise will be, for the most part, subjective. Since the filter has a finite perception time and does not completely null the noise, there will be a residual pulse of noise transmitted through the whole system.



Note: Time axis is calibrated by peaks of 5000-cps sine wave below each pulse.

Fig. XIII-1. Noise pulses that may be filtered.

"System," in this sense, refers to the record, the high-fidelity components, the listening environment, and the human ear. If the music retains its fidelity while the noise is reduced, the system is functioning properly.

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References

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B. ELECTRONIC CURVE TRACING

In several fields of endeavor, notably in the fields of pattern recognition, identification techniques, map reading, print reading, pattern cutting, and analog computation, there is a need for a machine that has the ability to follow a prescribed curve automatically. Study of several of the early curve followers reveals that most of them have been constructed for specific purposes. The machine described here is a more general prototype device that will be useful, perhaps with some modification, in many different applications.

The class of curves considered here is limited to arbitrarily positioned, two-dimensional closed curves. The interior of a given curve is completely blackened and contains no holes; thus the curve is represented by a black and white silhouette. A silhouette is presented in the form of a transparency; that is, a silhouette is formed by first drawing the contour of the closed curve on a piece of transparent material and then blackening the interior portion of the curve. The contour of the curve is traced by automatically controlling the position of a very narrow beam of light that shines on the boundary of the silhouette.

No special care is needed in preparing a silhouette for tracing because the only requirements are that the region exterior to the curve will readily transmit light, and that the interior region will not pass light as easily as the exterior region does. Thus the light that passes through the transparency is quantized into two states that are determined by the position of the light beam relative to the boundary of the silhouette. Therefore, any degree of blackening used in shading the silhouette is permissible if it permits a reasonable answer to the question, "Is the light beam interior or exterior to the curve?"

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Assuming that the first objective, which is automatically tracing the curve, is satisfactorily carried out, what useful information does this operation provide? As the beam of light traverses the contour of the curve, the tracing machine supplies the Cartesian (X and Y) coordinates of the curve as a function of the peripheral distance (S) along the curve. Since the displacement (S) is an undefined function of time (t), the X and Y coordinates are also arbitrary but related functions of time. This arbitrariness can be eliminated by controlling the displacement of the tracing spot along the curve in a given manner – for example, by linear motion. A linear displacement with time implies that the curve is traced by a light spot that moves with constant peripheral speed along the contour of the silhouette. This particular mode of tracing is advantageous if it is desired to compute from X and Y coordinates an additional descriptive quantity such as the curvature of the curve, or its reciprocal, the radius of curvature. Furthermore, it provides a common element on which to base comparison if the object is to study a given set of curves. Because of its desirable features, the tracing machine described here employs the method of following a curve with constant peripheral speed.

1. The Elementary Curve Follower

As a first approach to electronic curve tracing, the elementary curve follower shown in Fig. XIII-2 is presented. The machine employs an electrostatically deflected cathode-ray tube, used in conjunction with a lens system, and a phototube that are similar to the components of flying-spot scanners. The cathode-ray tube serves as the automatically controlled light source that traces the contour of the curve. A very small, bright spot of light is generated on the inside face of the cathode-ray tube but because of dispersion resulting from the light traveling through the glass of the tube and the intervening air, the spot arrives at the transparency greatly enlarged. If the curve is to be traced accurately, the size of the tracing spot must be small compared with any important detail of the curve; therefore, a focusing lens is needed to focus the spot in the

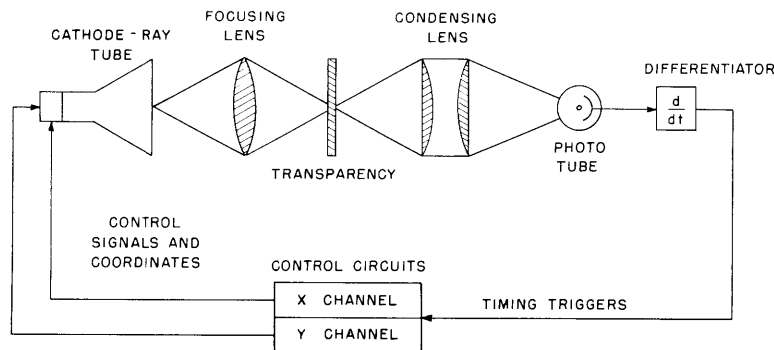


Fig. XIII-2. Elementary curve follower.

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plane of the transparency. Even though the spot is in focus at the transparency, the spot may fall anywhere in the plane of the transparency, and after passing through it the light again disperses. Since the photosensitive cathode of the phototube has a limited size, a condensing lens must be used to collect all of the transmitted light and direct it to the sensitive area of the photocathode.

Because of the nature of the silhouette, the intensity of the light that passes through the transparency has either a high or a very low value; the value depends upon whether the tracing spot is exterior or interior to the curve. Thus, the phototube current is a two-state quantity; a maximum for high light intensities and a minimum approaching the "dark" current for low intensities. Each time the tracing spot crosses the boundary of the curve, the phototube current changes state. A differentiator operating on the output of the phototube converts the quantized video information into positive and negative trigger pulses, one of which occurs each time the spot crosses the curve. The resulting trigger pulse train serves as a timing reference that is used to instruct the electronic control circuits to compute and supply a positioning signal to the deflection plates of the cathode-ray tube. Thus, the elementary curve tracer electronically traces the curve.

Obviously, the machine as described here is over-simplified (a more sophisticated device is required for a practical curve tracer) but our description presents the basic ideas involved. To begin with, nothing has been said about what causes the light spot to cross the boundary of the curve or why it should even do so. For another point, the X and Y control channels seem to be fine examples of the well-known "black box." The answers to these points and others will become evident as the basic idea is developed.

2. Searching for the Curve

Since the silhouette is arbitrarily positioned in the plane of the transparency, the curve must be located before its contour can be traced. Therefore, two distinct modes of operation are required of the machine: searching for the curve and tracing the curve. The searching mode is conveniently implemented with the use of a spiraling light spot that seeks out the silhouette, as shown in Fig. XIII-3. The light spot spirals inward, searching for the silhouette, and at the first intersection with the boundary of the curve, the intensity of the light that passes through the transparency drops to a minimum, thereby causing an abrupt change in the phototube current. The differentiator operating on the output of the phototube provides a trigger pulse to inform the control circuits that the curve has been "found." Acting on this instruction, the machine automatically holds the coordinates (X_0, Y_0) of the curve at the point of intersection, and then switches the operation to the tracing mode. A spiral sweep is easily generated by applying to the X and Y deflection plates of the cathode-ray tube sine and cosine signals of the same fixed sinusoidal frequency and exponentially decaying amplitude.

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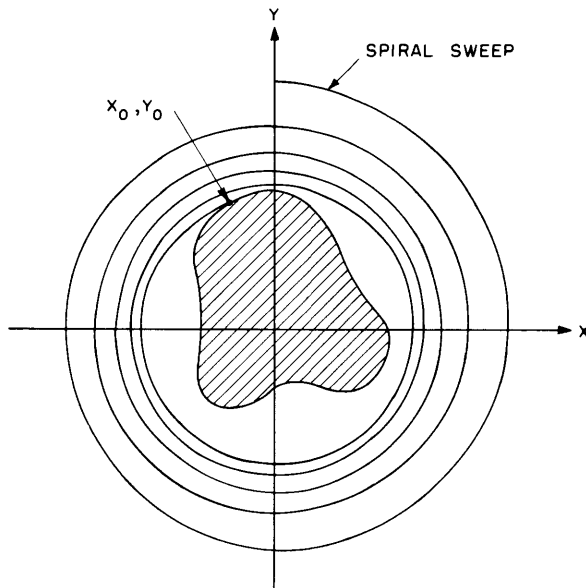


Fig. XIII-3. Searching for the curve.

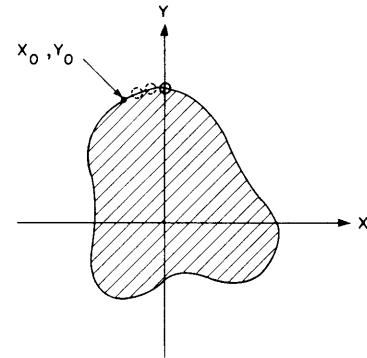


Fig. XIII-4. Tracing the curve.

3. Tracing the Curve

The problem of tracing the periphery of the curve can be separated into two distinct operations: (a) the tracing spot must be kept centered on the boundary of the silhouette; and (b) the spot must be caused to move with constant speed along the curve. Both of these operations can be implemented by causing the tracing spot to rotate in a circular path which thus describes a circle. The mean circle diameter is assumed to be small compared with any important detail of the curve; furthermore, the speed of rotation of the spot is large compared with its speed of translation along the curve. Thus the silhouette is pictured, as shown in Fig. XIII-4, as being traced out by a very small high-frequency circle centered on the curve and moving slowly with constant speed along the curve. A circle is, of course, easily generated by the addition of sine and cosine signals of small amplitude to the X and Y coordinates.

As the tracing spot moving on a circle crosses the boundary of the silhouette into or out of its blackened interior, the phototube output changes abruptly from a high value to a low value, or vice versa. Thus, the differentiator output contains a positive trigger pulse each time the spot crosses the curve moving outward, and a negative trigger each time it crosses the curve moving inward. The resulting trigger pulse train serves as a timing reference for the automatic positioning and translation of the circle.

Ideally, the circle should be centered on the curve with its diameter tangent to the curve. However, without a restoring force, it would tend to drift away to an uncentered

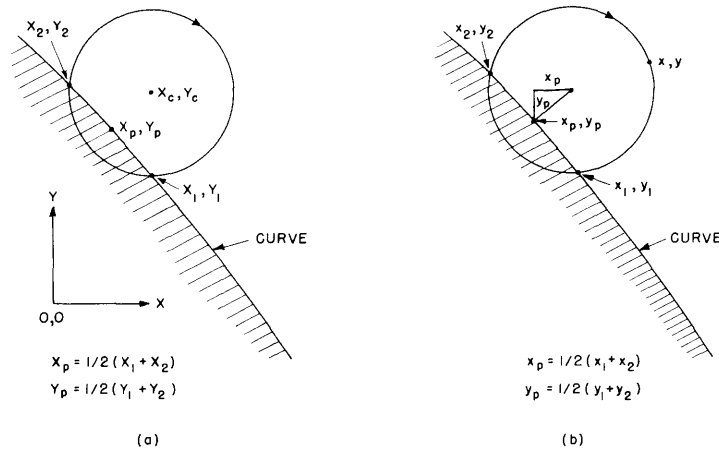


Fig. XIII-5. Centering the circle.

position where it would intersect the curve as a chord rather than as a diameter. This situation is shown in Fig. XIII-5a. To center the circle on the curve, a point (X_p, Y_p) on the chord halfway between its ends must coincide with the center (X_c, Y_c) of the circle. The X component $(X_p - X_c)$ and the Y component $(Y_p - Y_c)$ of the error between these two points can each be applied to a zero-position-error servo system to force the points to coincide. But we are dealing with a very small circle that is, in general, many circle diameters removed from the origin of coordinates. The X and Y component errors are, then, the difference of two very large numbers that are approximately equal in magnitude. Obviously, the error committed in computing such a difference could easily be as large as, or larger than, the error itself; therefore, this is an unsatisfactory method. However, if we think of the circle as a small perturbation about its center that is considered as an average value, the center of the circle can be used as a new origin of coordinates for errors. Therefore, for purposes of computing errors, it is sufficient to deal only with the sine and cosine parts of the total X and Y coordinates, which are given by

$$X = X_c + x$$

$$Y = Y_c + y$$

where X_c, Y_c are the coordinates of both the curve and the center of the circle. The coordinates x, y represent a point on the circle measured with respect to the center of the circle that is taken as a translating origin of coordinates (see Fig. XIII-5b).

The error coordinates (x_1, y_1) and (x_2, y_2) of the ends of the chord are obtained by sampling the amplitude of the sine and cosine signals each time the tracing spot crosses the boundary of the curve. A point on the chord halfway between

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its ends has the error coordinates:

$$x_p = \frac{1}{2} (x_1 + x_2)$$

$$y_p = \frac{1}{2} (y_1 + y_2)$$

and these can be easily computed by a simple electronic adding circuit. Since the center of the circle has error coordinates 0, 0, the x and y component errors are x_p and y_p . If these errors are integrated and added to the total X and Y coordinates, they will tend to cause the circle to be centered on the curve.

Because of the effects of the rotational and translational velocities of the tracing spot, the curve is actually traced in helical fashion, as shown in Fig. XIII-6a in which the tracing rate is shown to be faster than the normal rate. However, if the circle frequency is many times higher than the frequency of tracing around the silhouette, one complete curl of the helix translates such a small distance during its duration that it appears almost circular. For this desired situation, as shown in Fig. XIII-6b, the curve is traced by a closely spaced succession of circles. Of course, if the tracing speed is not constant, the curve is traced by an irregular succession of circles and helical curls, as shown in Fig. XIII-6c.

If we consider a slow, constant tracing speed, and that the circle is already centered on the curve as shown in Fig. XIII-7, then a diameter of the circle is tangent to the curve with the point of tangency at the center of the circle. For a fixed circle diameter, the tangent is a line segment of constant length but changing direction, as the circle moves along the contour. Thus, the tangent has all of the characteristics of the velocity vector of a point moving along a two-dimensional space curve with constant speed. In fact, the fixed length of this vector is proportional to the magnitude of the constant tracing speed, and its sense is in the direction of immediate translation. The x and y components ($x_1 - x_2$ and $y_1 - y_2$) of this vector always add vectorially to a constant length, and if each component is integrated and added to the X and Y voltages, a net displacement

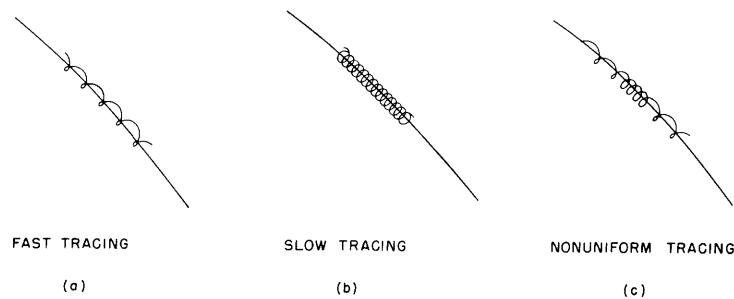


Fig. XIII-6. Some tracing modes.

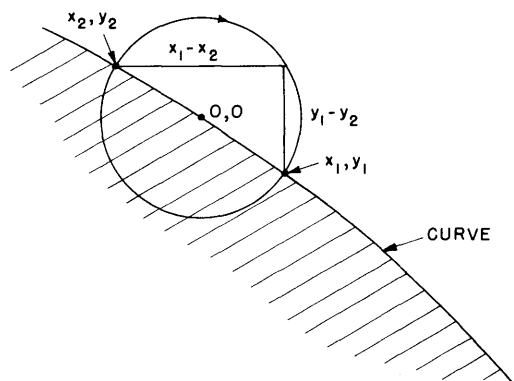


Fig. XIII-7. Components of constant speed.

will result in the computation of the tangent's components; but this error should be negligible because the circle moves at a slow, constant translational speed relative to its speed of generation.

4. The Electronic Curve Tracer

Figure XIII-8 is a block diagram of a practical system for instrumenting the electronic curve tracer. The new system retains the basic scheme of the elementary curve follower, and the methods that were presented previously for searching for and tracing the curve are also used. The major additions to the system are the spiral-sweep generator, the circle generator, the pulse generator, and modifications to the X and Y control channels.

The cathode-ray tube, the optical system, the phototube, and the differentiator each function as those previously described for the elementary curve follower. The beam of light from the cathode-ray tube is focused in the plane of the silhouette and after it passes through the transparency, it is refocused on the photocathode of the phototube. Each time the spot of light moving on the tracing circle crosses the boundary of the silhouette, the phototube current changes state and a trigger pulse appears at the output of the differentiator. A negative trigger occurs at time t_1 when the tracing spot crosses the curve while moving inward toward the blackened interior of the silhouette, and a positive trigger occurs at time t_2 when the spot moving outward again crosses the curve.

The trigger pulse train consisting of alternate negative and positive triggers from the differentiator serves as a timing reference for the pulse generator, the block diagram of which is shown in Fig. XIII-9. A negative trigger, $T(t-t_1)$, occurring at $t = t_1$ causes three outputs of the pulse generator. A rectangular pulse, $P(t-t_1)$, occurring at $t = t_1$, another pulse, $P(t-t_1^+)$, occurring at $t = t_1^+ = t_1 + 1.2 \mu\text{sec}$, and a trigger pulse, $T(t-t_1^+)$, all result from the negative trigger, $T(t-t_1)$. A positive trigger, $T(t-t_2)$,

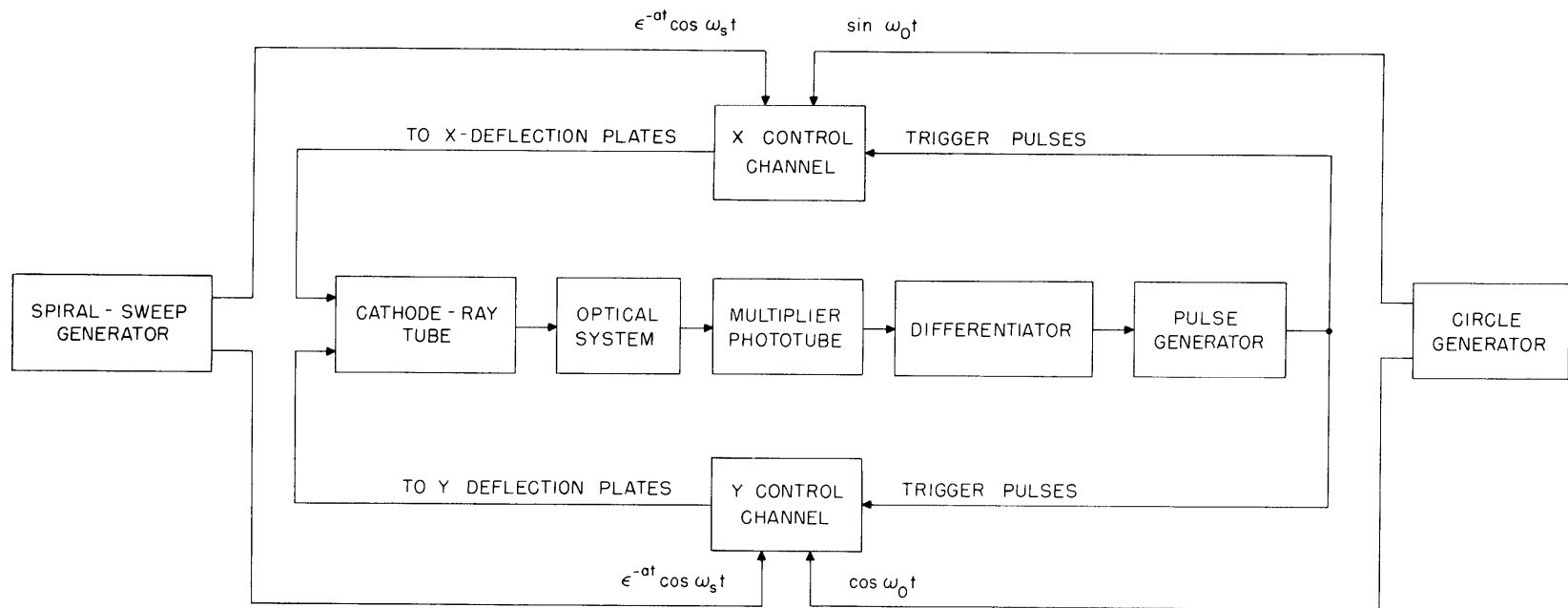


Fig. XIII-8. Electronic curve tracer.

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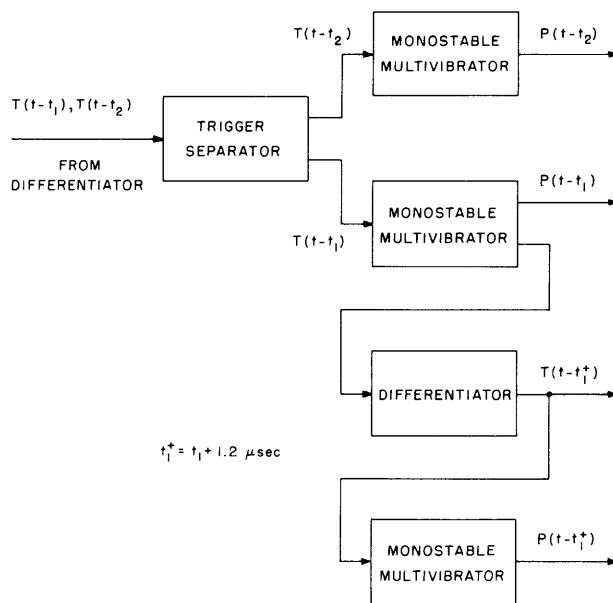


Fig. XIII-9. Pulse generator.

occurring at $t = t_2$, produces a rectangular pulse, $P(t-t_2)$, at the output of the pulse generator. All four outputs of the pulse generator are positive pulses and serve as a timing reference for the X and Y control circuits. The specific use of these pulses will become evident from the discussion of the operation of the curve tracer.

The X and Y control channels constitute the computing center of the curve tracer. There all of the pertinent information is gathered and operated upon to automatically direct the light source to trace out the contour of the curve. Both the X and the Y control channels are driven by the same timing pulses from the pulse generator; the X channel is driven by the sine components of the circle and spiral-sweep generators; and the Y channel is driven by the cosine components. The control circuits operate on these driving functions in an analog manner and compute from them the coordinates of the curve and the necessary positioning signals for tracing the curve. These signals are then supplied to the deflection plates of the cathode-ray tube to close the loop and complete the system. Since the X and Y control channels are identical, except for their respective driving functions, only the block diagram of the X control channel is shown (Fig. XIII-10).

5. Operation of the Curve Tracer

Because of the similarity of design and operation of the X and Y control channels (except for their respective inputs), a discussion of the operation of both channels would involve a large amount of duplication. Therefore we shall limit our discussion to the

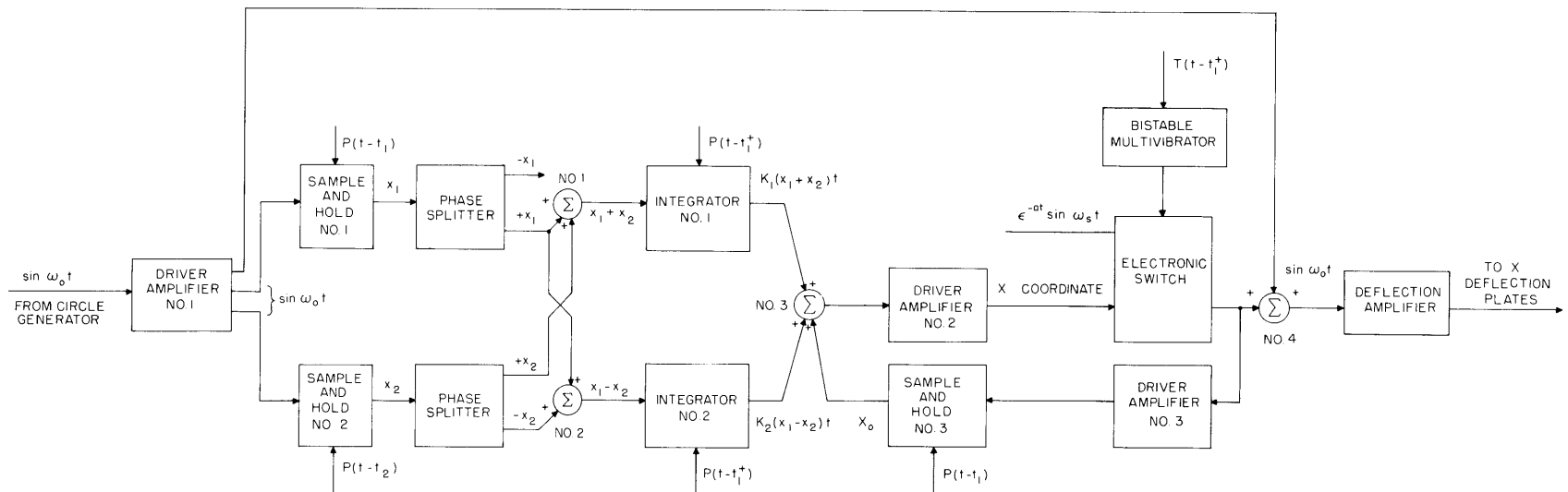


Fig. XIII-10. X control channel: ω_0 = circle radian frequency;
 ω_s = sweep radian frequency; α = envelope damping
 constant.

X control channel and the parts or operations of the curve tracer that are shared by both channels. For the Y control channel the only necessary changes are to replace X with Y and the sine components of the circle and spiral sweep generators with the cosine components. Refer to Figs. XIII-8, XIII-9, and XIII-10 during this discussion.

Before the curve tracer commences to operate, it is at rest in the tracing mode; that is, the circuits are set for the tracing operation but neither searching nor tracing is proceeding and the system is in stand-by condition. At any desired time, a manually operated switch is closed to initiate the searching mode. The closing of the switch changes the state of the electronic switch in the X control circuit (Fig. XIII-10) and permits the spiral-sweep signal to feed through the electronic switch and onto the deflection plates of the cathode-ray tube. The inwardly spiraling spot of light from the cathode-ray tube searches for the silhouette in the manner shown in Fig. XIII-3. The searching mode continues until the light spot first crosses the boundary of the silhouette into its blackened interior. At the time (t_1) of crossing the curve, the phototube current drops to a minimum and causes the differentiator to provide a negative trigger pulse $T(t-t_1)$. Immediately after being triggered, the pulse generator (Fig. XIII-9) emits a rectangular pulse $P(t-t_1)$, and one pulsewidth later emits another pulse $P(t-t_1^+)$ and a trigger pulse $T(t-t_1^+)$. The trigger $T(t-t_1^+)$ changes the state of the electronic switch and ends the searching mode.

Before the searching ceases and the tracing begins, it is necessary to store the initial coordinate (X_0) of the point of intersection of the light spot with the curve. This is done by sampling the value of the spiral-sweep signal at the time of intersection (t_1) and holding this value in sample-and-hold circuit No. 3 of the X-control channel. This action is initiated by the pulse $P(t-t_1)$, and is completed in one pulsewidth (1.2 μ sec). At this time, the trigger $T(t-t_1^+)$ from the pulse generator changes the state of the electronic switch and starts the tracing mode. At the same time, the pulse $P(t-t_1^+)$ discharges the integrators, and thus removes any residual information that might be left in them.

The initial coordinate now feeds around and through the electronic switch and holds the light spot fixed, except for a perturbation caused by the tracing circle, the sine component of which is added to the coordinate at the output of the electronic switch. At the time of initial intersection, the pulse $P(t-t_1)$ also causes sample-and-hold circuit No. 1 to sample the value (x_1) of the sine component of the circle and to hold this value. The integrators No. 1 and No. 2 immediately act on this value and start supplying a positioning correction to the light spot by means of the adding circuit at the input to the electronic switch.

Meanwhile, the tracing spot is moving on a circle in the blackened interior of the silhouette, and is being translated a very small distance along the curve. At approximately one-half the period of the circle sinusoid after the initial intersection, the tracing spot again crosses the curve and emerges into the transparent portion of the silhouette.

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At this time, (t_2) , the phototube current jumps to a maximum value that causes the differentiator to provide a positive trigger pulse $T(t-t_2)$. This trigger is converted, by means of the pulse generator, into a rectangular pulse $P(t-t_2)$. This pulse then causes sample-and-hold circuit No. 2 to sample the value (x_2) of the sine component of the tracing-circle sinusoid. The system now has enough stored information to compute an error (x_1+x_2) proportional to the x component of the error in centering the circle on the curve (see Fig. XIII-5) and a value (x_1-x_2) proportional to the x component of constant tracing speed along the curve (see Fig. XIII-7). These components are computed and supplied individually as inputs to the integrators.

Integrator No. 1 provides a positioning correction for centering the circle on the curve, and integrator No. 2 provides the x component of linear translation along the curve. Each integrator has a separate gain control, so that independent adjustment of the speed of centering and tracing is available. These signals are added to the initial coordinate (X_0) , and their total sum is the instantaneous coordinate (X_c) of the curve and also the center of the tracing circle.

At approximately the time of completion of one circle after the initial intersection, the tracing spot again crosses the curve into the interior of the silhouette. This action at time t'_1 causes sample-and-hold circuit No. 3 to sample the new initial coordinate of the curve, which is the value X_0 plus the sum of the signals from the integrators. One pulsewidth later (after t'_1), the integrators are again discharged in order to avoid redundant information and a resulting discontinuity of the tracing spot. When this operation is completed, the system repeats its operations and the tracing of the curve proceeds automatically.

J. J. Jones

References

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