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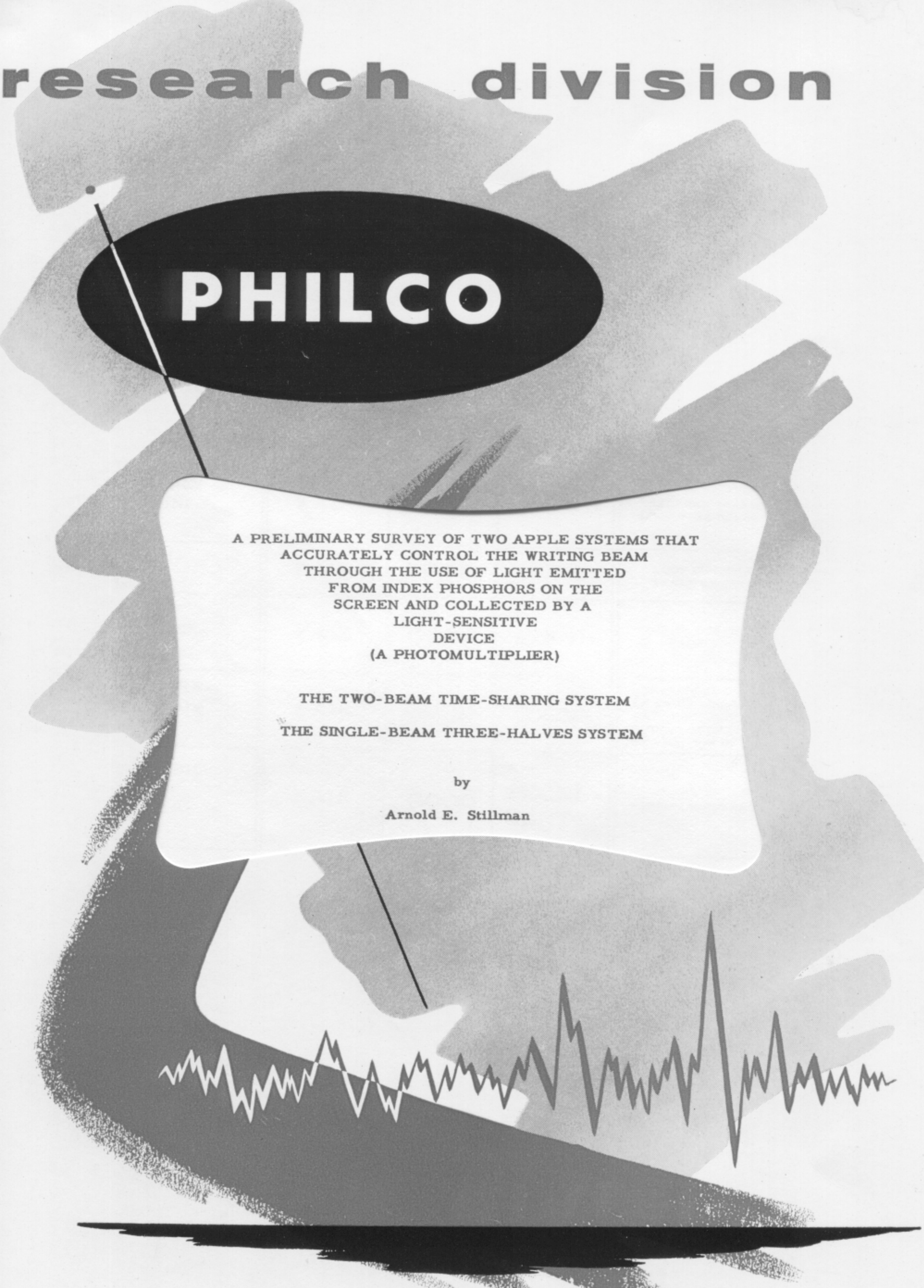

A PRELIMINARY SURVEY OF TWO APPLE SYSTEMS THAT
ACCURATELY CONTROL THE WRITING BEAM
THROUGH THE USE OF LIGHT EMITTED
FROM INDEX PHOSPHORS ON THE
SCREEN AND COLLECTED BY A
LIGHT-SENSITIVE
DEVICE
(A PHOTOMULTIPLIER)

THE TWO-BEAM TIME-SHARING SYSTEM

THE SINGLE-BEAM THREE-HALVES SYSTEM

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LIMITED CIRCULATION

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TABLE l. A SUMMARY

System Characteristics	Present Apple	Time-Sharing System	Three-halves System	Responsible Components or Underlying Factors
READING-WRITING INTERACTION	GOOD	GOOD	*	LOOP CIRCUITRY TUBE-SCREEN DESIGN
AVAILABLE BRIGHTNESS AND SATURATION	GOOD	GOOD	GOOD+	BEAM CURRENT TO WHICH IT CAN BE DRIVEN BEFORE IT BECOMES UNSTABLE. REQUIREMENTS ON THE DESIGN OF THE GUN WHICH PREVENT VERY SMALL SPOT SIZE.
COLOR ACCURACY	GOOD-	GOOD	GOOD-	COLOR REGISTRY. PILOT CARRIER. WHITE POINT. BLACK LEVEL. DRIVE WAVEFORMS. READING-WRITING INTERACTION
EASE OF ACHIEVING COLOR UNIFORMITY	FAIR	GOOD	GOOD+	TRACKING. TRANSIT TIME. SWEEP LINEARITY. LOOP TIME DELAY. INDEX REGISTRY
CIRCUIT COMPLEXITY	FAIR	GOOD+	GOOD-	LOOP CIRCUITRY. HIGH-VOLTAGE SUPPLY. SWEEP CIRCUITS
CATHODE RAY TUBE COMPLEXITY	FAIR	GOOD	GOOD+	FUNNEL COATINGS. TYPE OF SCREEN. NUMBER OF BEAMS
STRICT REQUIREMENTS ON COMPONENTS	FAIR	GOOD	FAIR+	TOLERANCES ON. PLACEMENT AND THICKNESS OF INDEX LINES. CRT COATING. GUN ASSEMBLY. PHOTOMULTIPLIER TUBE. INDEX PHOSPHOR. SWEEP CIRCUITS WITH GOOD LINEARITY. REGULATION OF HIGH VOLTAGE
NONSUSCEPTIBILITY TO NOISE AND INTERFERENCE	FAIR	GOOD	EXCELLENT	RANDOM NOISE AND EXTERNAL INTERFERENCE
EASE AND STABILITY OF ADJUSTMENT	FAIR	GOOD	GOOD	NUMBER AND EASE OF FACTORY ADJUSTMENTS. NEED FOR AND EASE OF READJUSTMENTS IN THE FIELD. SIMPLICITY OF ELECTRON-OPTICAL ADJUSTMENT
POTENTIAL COST REDUCTION	FAIR	GOOD	GOOD	CHASSIS AND TUBE MATERIAL COST NOT INCLUDING LABOR. BURDEN OR MARKUP

This table is a summary of opinion about the three systems as of January 28. 1957; information not known now may serve to alter these ratings at some future time. Each rating is an average of ratings made by the members of the color group. The ratings, "GOOD." "FAIR," "EXCELLENT," are all commercially acceptable. They are not necessarily listed in order of importance,

* This particular characteristic is still under investigation to determine its commercial acceptability; it is known to be worse in this system than in either of the other two systems.

LIGHT UTILIZATION

The index beam, secondary emission Apple system promises to be the leader in its field when full production is reached. Its price will be competitive; its general picture quality better than that of its nearest rival, the shadow-mask system. However, these facts, very encouraging of course, only begin to paint the picture of Apple potentiality.

During the last 4 years, research has concentrated on reducing Apple costs and increasing Apple quality both by improving present Apple and by studying other promising systems. From this research has come the realization that writing-beam control through the use of light-emitting index phosphors can accomplish both these results (see Table 1). Let us then, before describing in some detail the particular light-utilizing systems as well as present Apple, consider and compare to present Apple (where such comparison is relevant) those things which are intrinsic to light utilization regardless of the particular Apple system in which it is used.

Controlling the writing beam with instructions that travel at the speed of light rather than at the speed of an electron (basically determined by a 3 kv potential in present Apple) simplifies and improves many aspects of the Apple system by virtue of the fact that with control of the writing beam based on light, transit-time variation is in terms of multiples of the ideal transit time of a photon (. 0005 microsecond); with control based on secondary electrons, variation is in terms of multiples of a much longer ideal* time (determined by the speed of an electron falling through a 3 kv potential); therefore, variations are not significant in light Apple, and demand no special compensations:

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* Ideally, all the photons in the light systems or all the electrons in present Apple spend the same respective amounts of time in getting from the screen to the photoelectric cell in the former, the sides of the CRT in the latter, and accomplish this transit in the shortest time interval that the particular system allows Actually, in the light systems the light from certain phosphor stripes does not go in its entirety at a single instant to the photoelectric cell, but may bounce from the sides of the tube several times before it is entirely collected. In both types of systems, the geometrical relationship of the area of collection to the position on the screen from which the photons or electrons are emitted will force certain groups of electrons or photons to travel paths longer than the ideal.

Displaced index is unnecessary; revisions in the tube screens are simplified. Any high voltage which gives adequate spot size may be used; this voltage may be changed at any time without changing the CRT in any way. The regulation of high voltage is necessary only in regard to spot size or line-width changes, either of which may be regulated independently Any possibility of hue variance from one area of the screen to another caused by opacity of the index material to electrons is eliminated if the index phosphor stripes are located behind black guardbands.

Light-utilizing systems are free from interference caused by local sources of radiation; present Apple is sensitive to radiation near and at the frequency of its 48. 1 mc sideband amplifier (47 to 50 mc); certain P. T. C. transmitters use 48 mc.

Present Apple, to provide an impetus to secondary electrons leaving the screen, must have two high voltages (27 kv and 30 kv), and, in order to prevent variations in transit time with voltage variation, 1 high-voltage-regulator tube with its associated components is required to control the difference voltage. Light Apple needs only one high voltage and, therefore, does not require this tube with its associated components. A high-voltage supply of 27 kv in light Apple will provide a picture of the same brightness as present Apple (the CRT current being the same in both cases).

In light Apple very high-gain amplification is easy to achieve and is not subject to interference. The photomultiplier tube provides this amplification with dynodes (internal to it). Since the photomultiplier is sensitive only to light, the requirements for shielding and prevention of cross coupling are reduced substantially.

The light Apple CRT does not require the difficult-to-achieve chrome oxide coating (at present providing production difficulties) of the present Apple CRT nor any others of similar difficulty: Only an aluminum coating is used. No external coatings are necessary as in present Apple to reference the tuned circuit of the screen to ground; the external silver coating now used is not necessary for light Apple CRTs. These factors, of course, represent decreases in tube cost, complexity and rejection rate.

Good index phosphors for light systems are believed to be available (fair index phosphors are in use now); we do not believe that these phosphors will present any new problems in CRT processing.

Testing the light Apple CRT is simpler than testing the present Apple CRT, since the index and color stripes are laid down in constant phase relationship in light Apple CRTs.

Whether or not it has registered index can be known immediately on a completed light Apple CRT since a misregistry causes a change in hue on a blank raster; most misregistry would also be visually apparent on the unsealed face plate It is unnecessary to measure light Apple CRTs for transit time, screen mixing, or charging effects (concomitant to the chrome oxide band in present Apple).

Slightly less sweep power per unit CRT current is required in light Apple than in present Apple for a raster of the same size and same brightness; 2 percent of sweep power is saved in light Apple systems.

Since precautions to prevent shorting out the index signal are unnecessary (a threat in present Apple because of the complexity of coatings), and interference from local transmission is not a problem, a simplified CRT mount may be used in light Apple systems.

Another advantage, the result of several advantages already mentioned, is that light Apple systems vary in performance very much less than present Apple if one appropriate CRT is substituted for another.

We have not mentioned every advantage of light utilization; there are more. No disadvantages are listed because, so far no basic ones have become evident. At this time, we cannot assign a strict dollars-and-cents value to the advantages; however, we can state that every indication leads us to believe that they will provide, with further development, economy for light systems, economy greater than that expected of standard Apple.

The Photomultiplier

The economy, as well as feasibility, of light Apple hinges on the photomultiplier. The photomultiplier must be inexpensive; it should have a good degree of sensitivity, and it must be capable of amplifying the current originated by the photons it collects. Of course, it must fulfill the demands placed on any vacuum tubes such as good tube lifetime and uniformity of initial characteristics as well as any special demands, stemming from particular-system characteristics.

At the present time there is no photomultiplier in production that exactly fulfills all the demands of either of the 2 light systems to be considered here. The Time-sharing system has tried the RCA 931A photomultiplier tube, which amplifies with dynodes constructed within it in a nest-like fashion. Its photosensitive cathode is recessed in the center of the "nest" from where it cannot collect photos with any great efficiency. This tube fulfills the economy and amplification requirements, but in this system it is not able to collect enough photons excited by the index beam to help overcome the signal-to-noise ratio difficulty* (discussed below); further, it is not good enough from the standpoint of tube lifetime and uniformity of initial characteristics (some tubes are bad before they are placed in a set); actually, for light-system purposes this is a poorly produced tube of inefficient design (not suitable for either of the 2 light systems at present).

Dumont makes by hand 2 photomultiplier tubes (6291 and 6292) with a fully accessible photosensitive cathode, which fulfills many of the demands of both systems, but does not fulfill the demand of economy. However, mass production should enable this uncomplicated tube to meet this requirement.

At present, the Time-sharing system makes use of the RCA 5819 photomultiplier tube; the Three-halves system, 2 small Dumont 6365 photomultiplier tubes. Neither one of these types fulfills the economy demand; two 6365s are needed to fulfill the amplification requirement; the 5819 just barely meets this requirement.

Slight modifications of the photomultiplier tube (a specially designed tube) will enable loop simplification and concomitant cost reduction in both light systems.

Now, we describe, for the purpose of more specific comparison and illumination, present Apple and the two light-utilizing systems <u>in terms of their essential characteristics</u>, limiting the circuit description in the interest of brevity mainly to the index loop of each and components closely related to the loop, since there is little or no difference in the circuitry of the three systems except in the index loop of each, the rest of the circuitry being standard Apple receiver circuitry.

PRESENT APPLE

Present Apple, a 2-beam system with the good indexing stability intrinsic to such systems (index beam and writing beam), controls the writing beam through the utilization of electrons emitted from index phosphor stripes under the excitation of the index beam, and collected

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* A better photomultiplier (in conjunction with a gate) is not the only inexpensive solution to this difficulty. An ultraviolet window in the CRT or a better index phosphor would also eliminate the difficulty (in conjunction with a gate).

by a sideband amplifier primarily sensitive to 48. 1 mc (range of sensitivity: 47 to 50 mc). The index beam and writing beam are vertically aligned so that the variation in the space between them (caused by poor convergence and the effect of the yoke) cannot cause indexing failure; tracking difficulties are compensated for in the screen geometry. There are two high-voltage supplies, 27 kv and 30 kv; a chrome oxide insulating band separates the aluminized screen at 27 kv from the carbon collector coating around the sides of the tube at 30 kv; it is the difference in potential provided by these two supplies which determines the speed of index-phosphor electrons leaving the screen. If the index and color phosphor stripes were laid down on the screen with a uniform phase relationship within each group of primary colors (triplet) over the entire face of the tube, transit-time-delay variation (e.g., the electrons traveling from the center of the screen cannot reach their destination as quickly as those from the edges) at the speed of an electron under the impetus of a 3 kv potential would cause serious color error. Of course, the index and color phosphor triplets are laid down not with a uniform phase relationship within each triplet but with a varied relationship that eliminates transit-time-delay variation difficulties as well as tracking-error difficulties (see Table 1).

The Loop, Functioning (see Figure 1)

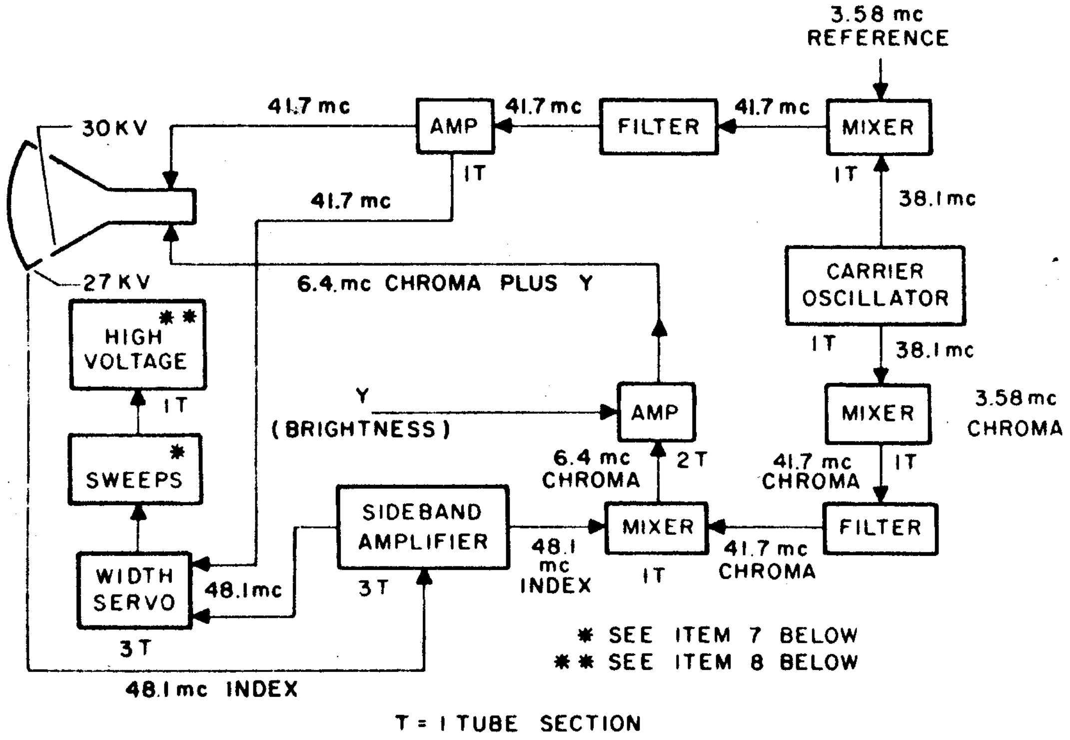

FIGURE 1. The index loop of present Apple (receiver 7).

1. The carrier oscillator has two outputs of 38. 1 mc (1 tube section).
2. A mixer receives 1 of the outputs, heterodyning it to the 3. 58 mc reference signal (1 tube section).
3. A filter receives the resultant 41. 7 mc, eliminating unwanted sidebands from it.
4. The 41. 7 mc is amplified and placed on the index-beam grid of the CRT (1 tube section); both the index beam and writing beam pass over triplets at a 6. 4 mc rate.
5. The resultant 48. 1 mc index is taken from the screen by a sideband amplifier and amplified (3 tube sections); there are two outputs from this amplifier.
6. A width servo receives one of the 48. 1 mc outputs (3 tube sections); this width servo also receives 41. 7 mc from the amplifier of Item 4.
7. Virtually D. C. flows from the width servo to the sweeps in order to keep the average index frequency constant. (The sweeps are similar and use the same number of tube sections in present Apple, the Time-sharing system and the Three-halves system; therefore, in the interest of simplicity, they are not shown in the diagrams of the 2 latter systems, and for fair comparison are not assigned any tube-section value here or in the diagram of Figure 1.)
8. The high-voltage gets its power from the sweeps (1 tube section). The high-voltage supply uses one tube section more than the Time-sharing system or the Three-halves system; for simplicity, the high-voltage supply is not shown in the diagrams of these systems; however, to compare fairly, it is necessary to assign a tube-section value of 1 to the high-voltage supply of present Apple.
9. The second output of the carrier oscillator of Item 1 is heterodyned to the 3. 58 mc chroma signal by a mixer (1 tube section).
10. The resultant 41. 7 mc chroma and unwanted sidebands enter a filter where the unwanted sidebands are eliminated.
11. A mixer then receives the 41. 7 mc chroma, heterodyning it to 48. 1 mc index from the sideband amplifier of Item 5 to give 6.4 mc chroma (1 tube section).
12. An amplifier amplifies the 6. 4 mc chroma; at this point brightness (Y) information is added. The picture is written with the amplified 6. 4 mc chroma plus Y (2 tube sections).

THE TIME-SHARING SYSTEM

Preliminary development of the Time – sharing system already has brought its desirability to a level comparable to or better than that of present Apple (see Table I). At this early stage of development time delay in the index loop is about the same, and so is the numbers complexity of vacuum tubes required for the loop; the future holds promise of substantial reductions both in loop time delay and the number and complexity of vacuum tubes; these reductions will represent an increase in quality and a decrease in costs.

The Time – sharing system is a two-beam (writing beam and index beam) system (with the good indexing stability intrinsic to such systems) similar to the present Apple system, except in two particulars. One, of course, is the use of the photomultiplier, the changes that this permits and the benefits derived therefrom; the other is the elimination of index-information contamination (caused by the writing beam exciting the index phosphors) by gating the photomultiplier as well as selecting the desired information with a sideband amplifier primarily sensitive to a single frequency In the Time-sharing system, the index beam and writing beam are focussed so that when the index beam is impinging on an index phosphor stripe, the writing beam is halfway between 2 index phosphor stripes and vice-versa (see Figure 2). The index beam is above the writing beam; its position is so little removed from a vertical relationship with the writing beam that for all practical considerations of tracking problems they do have a vertical relationship as in present Apple.

If the index phosphor used in the system had a fast decay time, the gating circuit could eliminate all of the information derived from photons emitted by the index phosphor stripes under the stimulus of the writing beam (see Figure 3). At the present stage of development, the gating circuit is not able to accomplish this, and admits the slight amount of noise that this system exhibits in one color, randomly in one or more small areas of the screen, because the photon emission of the present index phosphor does not decay fast enough; there is overlapping of index-beam information and writing-beam misinformation; the gate accepts

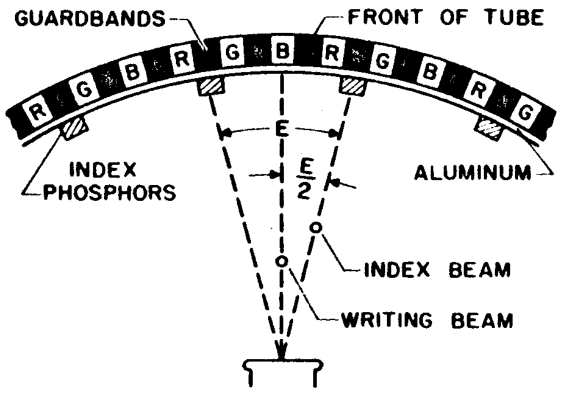

FIGURE 2. The screen of the Time-sharing system.

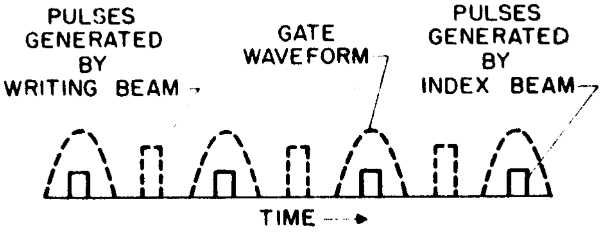

FIGURE 3. The gating of pulses from index phosphors with a fast decay time.

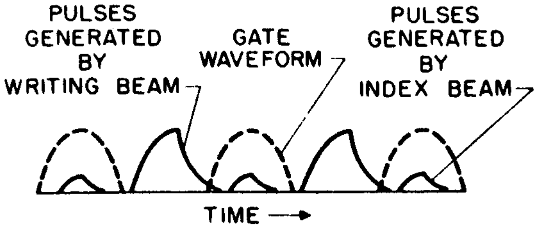

FIGURE 4. The gating of pulses from present index phosphors.

some D. C. originated by the writing beam (see Figure 4).

To simplify the description of the function of the loop of this system, we assume that the system has the screen of Figure 2, which has one index phosphor stripe for every trip-let of primary colors, even though this screen is not in use yet. (This screen may be put in use in the near future.} Everything that is said of a system with this screen is true (except for the exact frequencies designated) of the system in use at present which has one index phosphor stripe behind the guardband between red and green in every other color triplet.

The Loop, Functioning (see Figure 5)

1. The carrier oscillator places the 27 mc index beam on the CRT screen (1 tube section); both the index beam and writing beam pass over triplets at a 6 mc rate.

2. Photons at the resultant sideband of 21 mc are collected (see Item 5 below) and amplified by a photomultiplier (1 tube section).

3. The 21 mc from the photomultiplier is further amplified (2 tube sections)

4. The amplified 21 mc is fed to a mixer which receives 27 mc from the carrier oscillator of Item 1 (1 tube section).

5. The resultant 6 mc is amplified (1 tube section); this 6 mc is used to gate the photomultiplier so that only photons at the 21 mc sideband are collected.

6. A third output of the carrier oscillator of Item 1 is heterodyned to the 3. 58 reference signal to give 30. 58 mc reference (1 tube section).
This in turn is heterodyned to the 3. 58 mc chroma signal to give 27 mc chroma (1 tube section).

8. The 27 mc chroma is fed to a mixer (1 tube section) that receives an amplified 21 mc from the amplifier of Item 3.

9. The resultant 6 mc chroma is amplified (1 tube section); brightness information (Y) is added to the amplified 6 mc chroma through an adder; 6 mc chroma plus Y writes the picture.

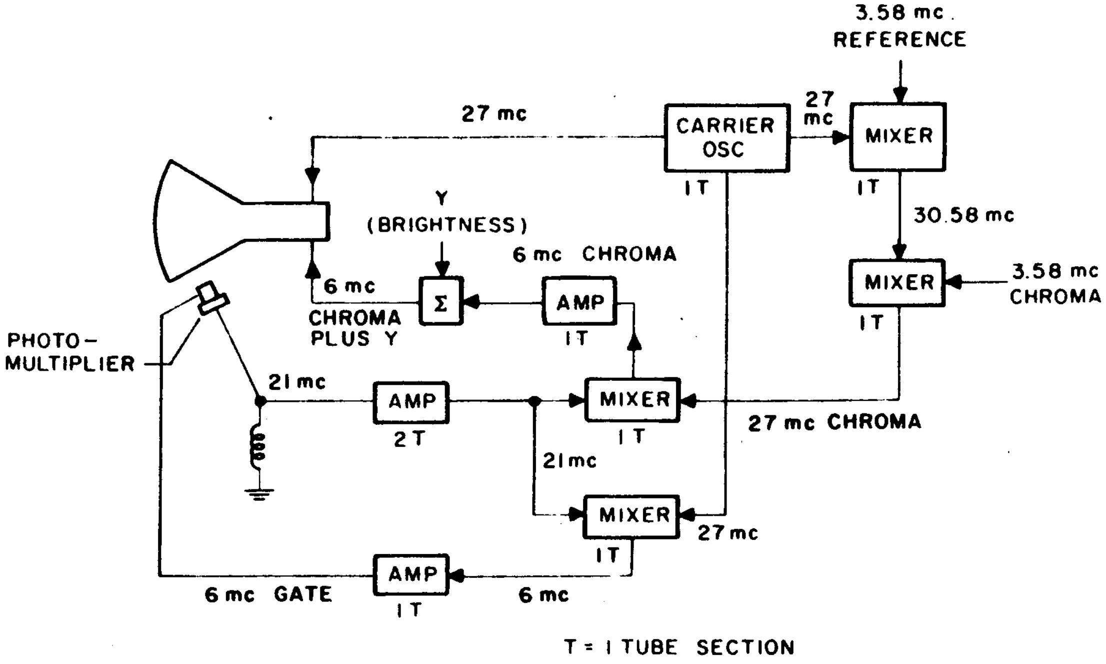

FIGURE 5. The index loop of the Time-sharing system.

THE THREE-HALVES SYSTEM

Of course, many problems are solved or alleviated by having a single-beam system, but what new problems are incurred? Preliminary development has placed the potential desirability of the Three-halves system a notch above that of either present Apple or the Time-sharing system (see Table 1). Time delay in the index loop is slightly more than that of either of these 2 systems; the number and complexity of vacuum tubes is about the same in the 3 systems since the light systems are at an early stage of development; however. the future holds promise, for the Three-halves system as well as for the Time-sharing system, of substantial reductions both in time delay and the number and complexity of vacuum tubes, and concomitantly, an increase in picture quality and reduction in costs.

The Three-halves system is a single-beam, light-utilizing Apple system, participating in all the benefits of light utilization, in which a single beam writes the picture and excites the index phosphor stripes (located behind blue and behind guardbands adjacent to blue and behind every other guardband between red and green), producing photons (see Figure 6). These photons are collected by a photomultiplier, enabling the loop to properly control the writing beam, i.e., the gun is controlled so that the correct amount of writing-beam electrons reaches the screen at a given time. The nature of the loop (elaborated upon below) is such that when serious index deficiencies are present in the screen the following can happen, although in most cases these deficiencies would be visible to the naked eye or uncovered by a simple test and presumably would be basis for rejection of the tube before it got into a receiver:

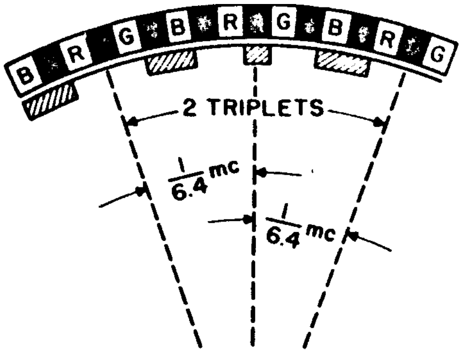

FIGURE 6. The screen of the Three-halves system.

a. No visible result; the time delay of the loop or other factors have accommodated the deficiency.
b. Loss of color for a line or part of a line; however, the luminance remains correct. This defect is not visible at all times, but it occurs in the same place at all times.
c. Change of color with or without change of luminance for a line or part of a line. These defects are not visible at all times, but they occur in the same place at all times.
d. Quickly recovers. A small gray blemish or blemish of wrong color is just barely evident.

To sum up: it takes a lot of index deficiency to upset this system (pinholes or small deficiencies won't do it and in many instances extensive index deficiencies won't either), but when this system is upset it is in more trouble than present Apple or the Time-sharing system are when upset.

The Nature of the Loop

This system is one of a class of systems in which freedom from reading-writing interaction is built into the screen: over a series of a few successive index stripes, the contamination by the writing signal of the signal from some of these stripes is cancelled out by the contamination by the same writing signal of the index signal from the remainder of the index stripes in the succession No two successive triplets have the same index arrangement; systems in which the number of index stripes is equal to or a submultiple of the number of triplets cannot cancel out contamination in the manner indicated.

However, this class of systems suffers from ambiguity unless special precautions are taken: the loop cannot distinguish which position of a small number of alternative positions the writing beam is impinging upon a given instant unless a separate set of stripes is provided, whose sole function is to resolve this ambiguity. In the Three-halves system, these special index stripes are located behind every blue phosphor. When a critical index deficiency exists, the Three-halves system cannot resolve ambiguity: it writes wrong colors or wrong luminance or both.

Black Level

Black level deserves some thought, too. In the Three-halves system, unlike in the Time-sharing system or present Apple, the writing beam cannot be turned off to manifest by its absence, black. If it were, index emission would be lost, and the loop would turn off, upsetting the system. At present, black level is maintained in this system with a D. C. restorer (a diode) which, does not allow the gun to put forth less than a certain amount of electrons; in production models, a keyed clamp (1 vacuum tube) or similar device would be used since the D. C. restorer is effective with only one program at a time and must be reset for other programs. The black level can be maintained in this system at values equivalent to those of the Time-sharing system or present Apple where the light concomitant to the index beam, which, of course, is never turned off, determines the black level.

The Loop, Functioning (see Figure 7)

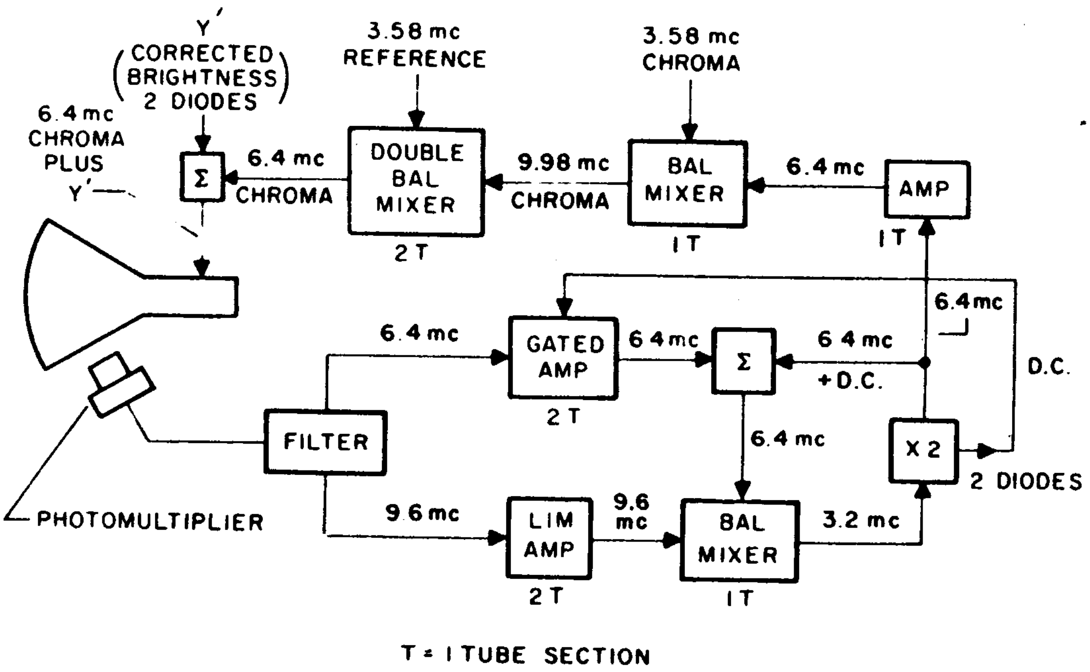

FIGURE 7. The index loop of the Three-halves system.

1. Photons emitted from the index phosphor stripes under the excitation of the 6. 4 mc writing beam are collected by a photomultiplier tube, which amplifies the current originated by the photons (1 tube section).

2. From this tube, the current enters a filter where it is divided into a 6. 4 mc component and a 9. 6 mc component.

3a. A limiter-amplifier raises the 9. 6 mc to 90 volts (2 tube sections).

3b. The 6. 4 mc is controlled by a gated amplifier (2 tube sections). D. C. from the doubler of Item 5 to the gated amplifier instructs the gate that there is a 6. 4 mc output from the doubler. In this case, the gated amplifier turns off the 6. 4 mc from the filter. The absence of D. C. instructs the gate to turn on the 6. 4 mc from the filter.

4. The 9. 6 mc is then heterodyned to 6.4 mc from an adder (see Item 5 below) to give 3. 2 mc plus D. C. by a balanced mixer (1 tube section).

5. The 3. 2 mc plus D. C. is then converted to 6. 4 mc plus D. C. by a doubler (2 diodes); the gated amplifier of item 3b receives the D. C. from this doubler (X2); an adder (Σ) receives the 6. 4 mc plus D. C. from the doubler and 6. 4 mc from the gated amplifier of Item 3b; the balanced mixer of Item 4 receives 6. 4 mc from the adder: thus the loop is kept turned on.

6. The 6.4 mc from the doubler is amplified (1 tube section).

7. Another balanced mixer heterodynes the amplified 6.4 mc to the 3. 58 mc chroma signal to produce 9. 98 mc chroma (1 tube section); unwanted sidebands and carriers are eliminated.

8. The 9. 98 mc chroma is then heterodyned to the 3. 58 mc reference signal by a double balanced mixer to produce 6. 4 mc chroma (2 tube sections); unwanted sidebands and carriers are also eliminated here.

9. An adder adds a corrected (2 diodes) brightness signal (Y') to the 6. 4 mc chroma; 6. 4 mc chroma plus Y' writes the picture.

THE DIRECTION OF FUTURE RESEARCH ON LIGHT SYSTEMS

Information (e.g., drive waveform information) gained as a result of research on present Apple or gained from any other source will be utilized in the improvement of light systems. Consideration will be given to the following projects:

Research Common to Both Systems

Prescribe new mask accommodated to the index-frequency variations of a tube with only one coating.

Experiment with prediction circuits.

Procure suitable photomultiplier tubes.

Develop A. G. C. circuits for photomultiplier tubes.

Conduct experiments on putting the index phosphor stripes in front of the aluminum.

Generally simplify the circuits.

Procure improved index phosphors.

Research on the Time-sharing System

Study noise performance to ensure that index phosphors, photomultipliers and light-collecting apparatuses are adequate.

Change to a fundamental frequency CRT.

Research on the Three-halves System

Shorten loop time delay.

Improve screen quality to remove blemishes, noise in the index and any half-frequency components.

Start indexing a sufficient distance around the side of the tube.

Study color transients to determine whether or not they are inherent to the system.

Study guns that take advantage of having only one beam.

Study ambiguity failures to determine subjectively how objectionable they are and to determine what tolerances are required in CRT manufacture to eliminate them.

Compare semi-ambiguous and fully ambiguous systems.