INTRODUCTION TO THE ”APPLE" SYSTEM

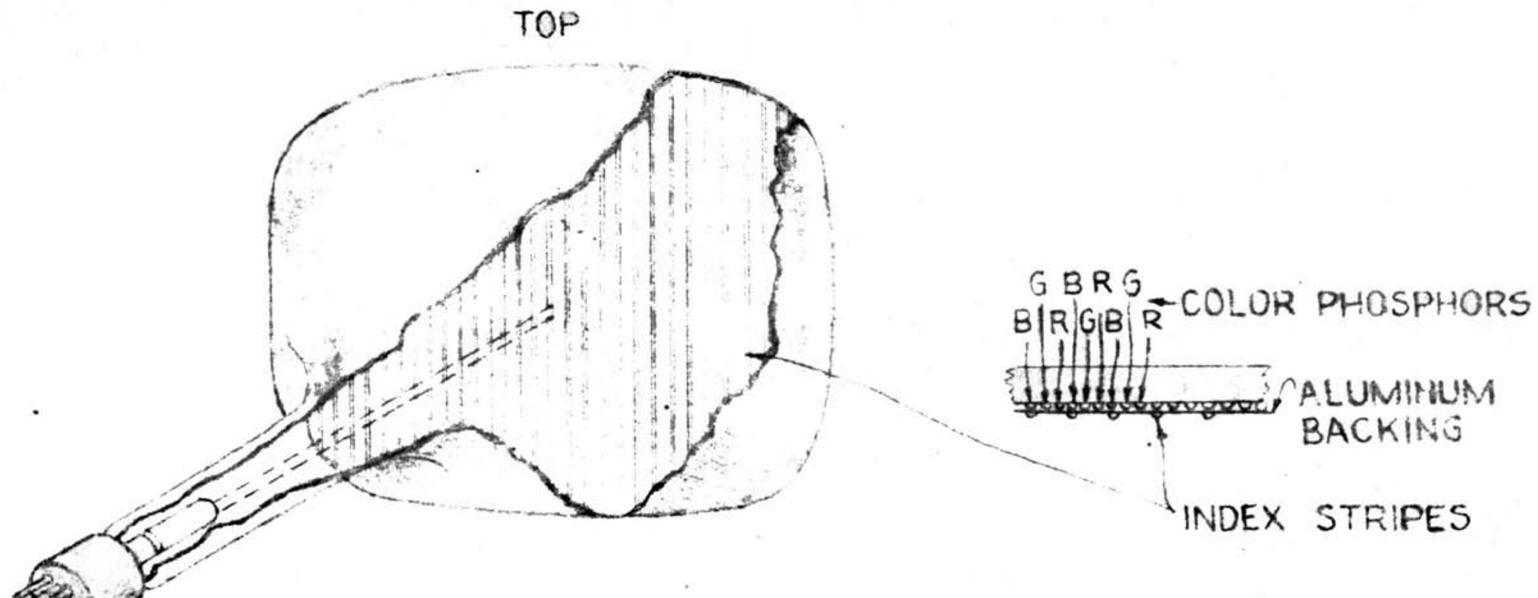
An understanding of the "Apple" system of color television reception is greatly aided by the following ultra simplified review of the color television signal properties.

The complete color television signal has three basic picture components, all of which are transmitted simultaneously on a single carrier with the aid of a sub-carrier. One component is primarily a light and dark, or luminance evaluation of the picture. Two components make up the chrominance or color signal. The first of these is saturation which we might call the intensity of the color in a particular spot in the picture. The second is hue which can be termed the color value of the spot. For example, consider a single light blue spot in a picture. Blue color with no white content is saturated blue. Blue with some white is a pastel or light blue. White in turn is formed by approximately equal amounts of red, green and blue. Thus, since a pastel shade of blue would require a certain amount of white, than that particular spot would require a basic amount of red, green, and blue to form the white level, plus a relatively large amount of blue to create the exact blue shade desired. From these facts, we can see that the color signal for a particular spot on the screen must simultaneously contain the information regarding which color or colors, how much brilliance or intensity of each, and (since a particular spot in the picture corresponds to a particular instant of time), exactly when.

THE APPLE RECEIVER

The following report is discussion about the principles of operation of an apple receiver. The material for this report was supplied by the “Engineering Services Division."

C. P. COMEAU



Section thru Face Plate

Apple Tube Showing Gun and Beam Positions

At the transmitter the hue and saturation values of the chrominance component are simultaneously impressed on the subcarrier, in a form which can be interpreted as phase and amplitude modulation, respectively. In addition, the luminance or monochrome evaluation of the scene is transmitted in the form of a wide band, amplitude modulated signal Just as is the present day black and white information.

From this basic information about the color television signal, it would seem that if we have a picture tube on the face of which is painted alternating vertical phosphor stripes of red, green, blue, red, green, blue and so on, it would only be necessary to sweep a bean across the tube in the conventional black and white manner, turning it off and on at the proper time and in the proper amount to reproduce the transmitted picture. That is to say, when the beam is pointed at the red stripe, the transmitted signal is analyzed for red signal and the beam is varied from zero to full brilliance accordingly. When the beam is pointed at the green stripe the green signal is used, and so forth.

In the Apple receiver which we will use as our example, the color information is sampled in sequence, that is, first red, then green, then blue and so on at the rate of approximately 7.4 million <u>sets</u> (or triplets) of color impulses per second. Such is the basic simplicity of the "Apple" system.

There are, of course, many reasons why such ultra simplification cannot be achieved in practice. Let us take a look at some of these.

1. Sweep linearity.

   Any deviation from absolute linearity in the sweep (i.e., the sweep traveling faster or slower than normal) will result in the beam lagging behind or running ahead of its proper synchronous position and hence producing incorrect color information on the face of the tube.

2. Physical spacing of the color lines.

   Any deviation from absolutely accurate location of the color lines would likewise mean that the instantaneous beam location would be incorrect, producing the wrong color.

3. Start and stop position of each line. Obviously, even if the linearity were correct and the spacing right, If the beam happened to start a sweep incorrectly, say on blue if it should have been red, all colors on that particular line in the picture would be wrong.

4. Width of picture.

   Incorrect picture width likewise would produce incorrect color renditions since that would mean incorrect sweep speed and incorrect start or stop position.

5. Focus.

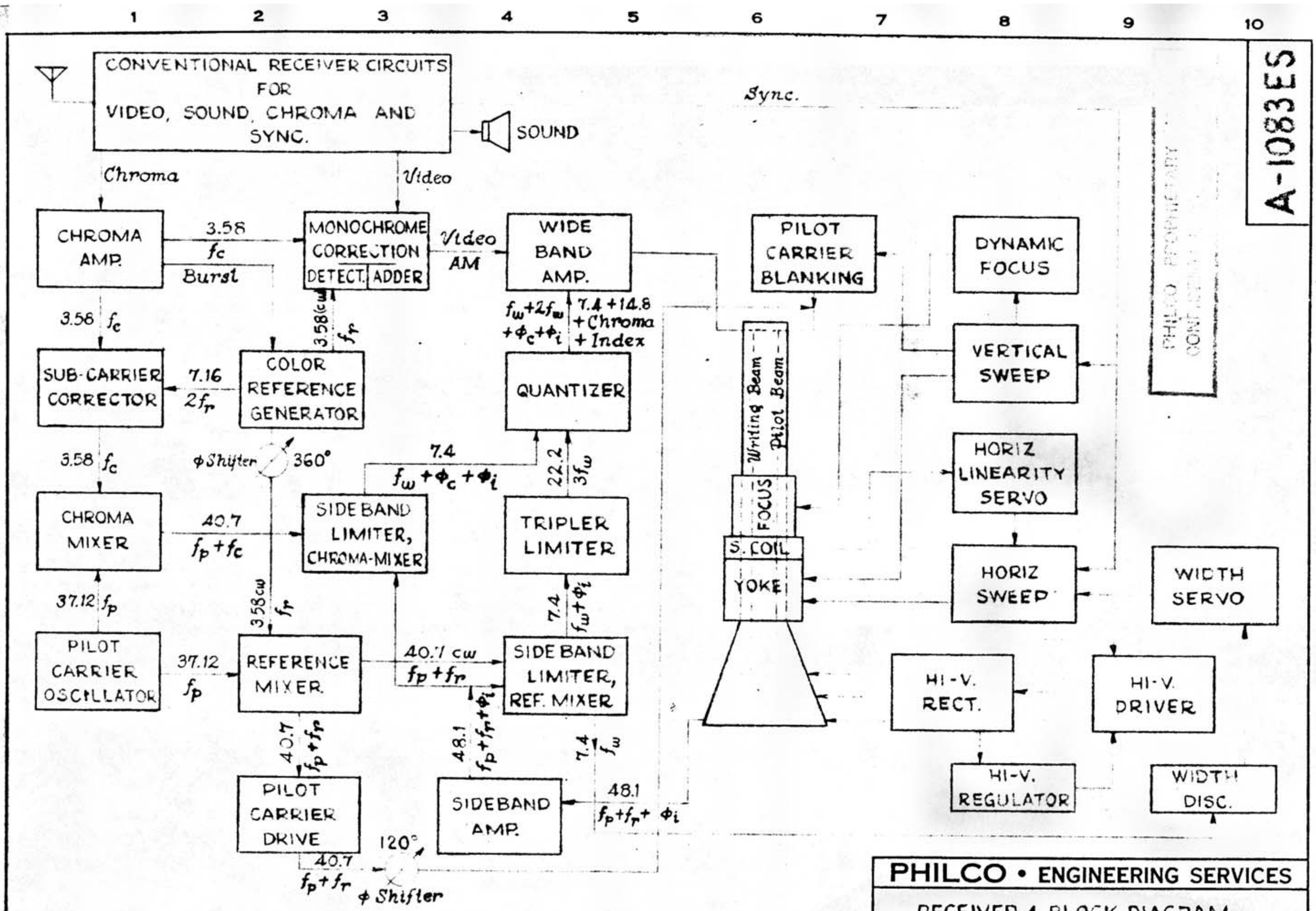
   if the focus deviates from correct, the beam could erroneously strike two or more color lines simultaneously, causing incorrect color reproduction.

It is possible to overcome the most troublesome of these difficulties if we can devise a method of constantly monitoring the position of the "writing beam" at the picture tube face. If we could, for example, create a distinct impulse each time the beam swept past one particular color stripe, it would be possible to compare this instantaneous location of the beam with the picture signal (which contains the information of where the beam <u>should</u> <u>be</u> at that instant). This would provide us with the information needed to correct the position of the beam, or, equally effective and much easier in practice, to advance or retard the timing of the picture signal to agree with the instantaneous position of the beam.

Accordingly, in the Apple tube, the vertical phosphor lines are laid down on the inside of the tube face. Then a layer of electrically conducting material transparent to electrons is placed over them. Next, an "index" stripe is laid over the position of each stripe of one of the colors. (In the Apple tube it is the red stripe.) The material used, magnesium oxide, is chosen for its high secondary emission properties. The ”transparent" material between the phosphor lines and the index stripe is a conventional aluminum screen backing. With this physical setup, when the beam of electrons sweeps past the red stripe, secondary emission from the magnesium oxide behind the red stripe causes an increased current flow in the aluminum layer. This then is an "index" signal which can be capacitively coupled to give us the required constant monitoring of the beam position.

In practice it has been found that attempting to use the writing beam to also provide the monitoring information has many drawbacks. It has been found much more practical to provide a separate "pilot beam". The pilot beam is of relatively low electron density and the tube construction accurately positions it vertically with respect to the writing beam. Since it is acted upon by the same sweep and focusing fields, it is (to a high degree) locked accurately in time and space synchronization with the writing beam.

In order to separate the position information developed by the pilot beam from the picture information of the writing beam, it is necessary to "mark" one of the beams in some way. This is done by intensity modulating the pilot beam at a ”pilot carrier" radio frequency rate. The writing beam, of course, is modulated with the full picture information. A wholly new signal is generated by secondary emission which occurs when the beams pass over the index stripe. The frequency of this new signal obviously depends upon the number of stripes passed over per unit time. In the case of the 21 inch Apple tube, a little arithmetic indicates that this



A-1083ES

f_c = Chroma Frequency
f_p = Pilot Oscillator Frequency
f_r = Color Reference Frequency

f_w = Writing Frequency
ϕ_i = Index Phase
ϕ_c = Chroma Phase

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RECEIVER 4 BLOCK DIAGRAM
SHOWING SIGNAL PATHS

DRAWN	DATE	CHECKED	APPROVED	
EH	10-5-54			A-1083ES
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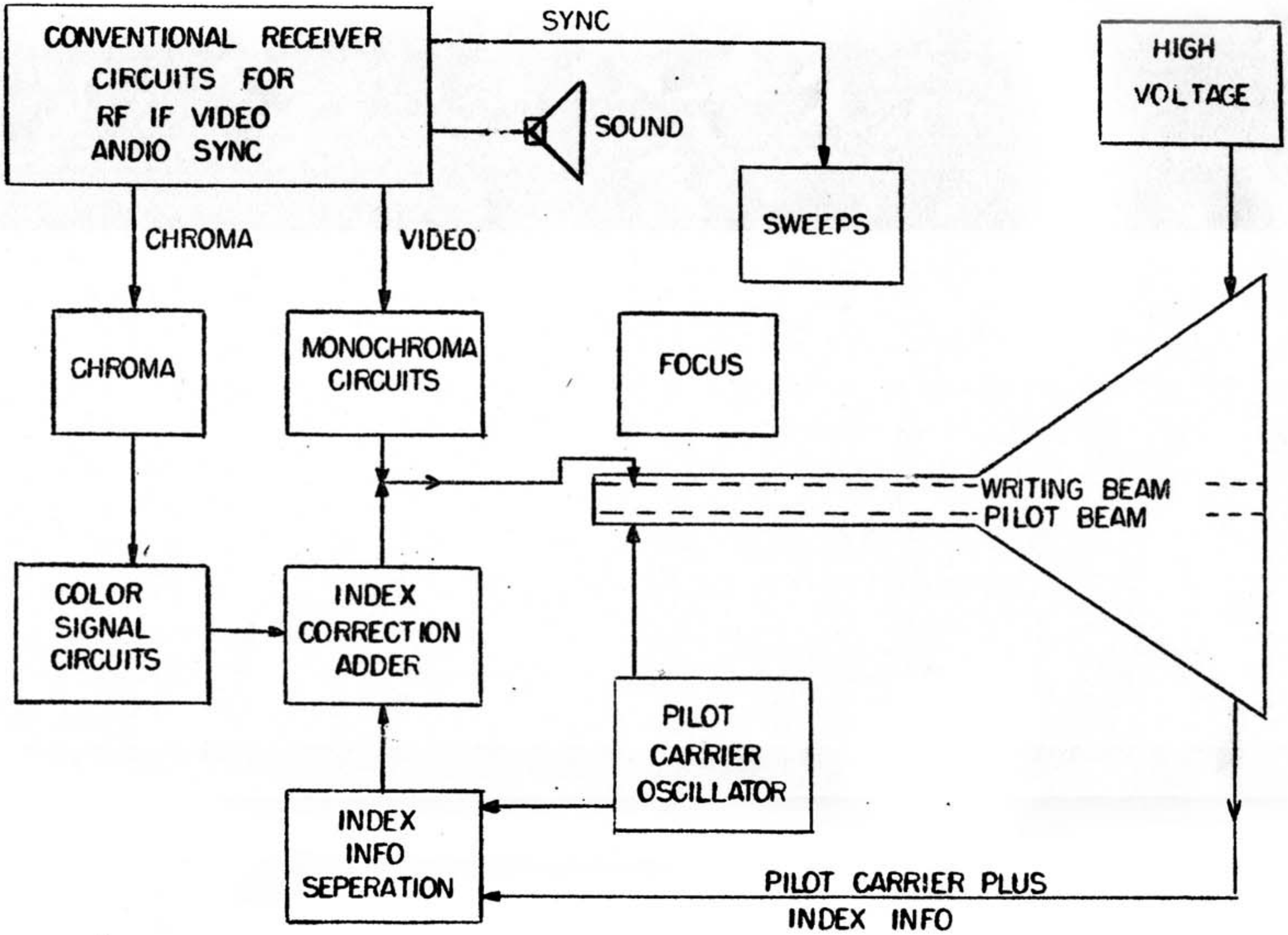
A. E. P., INC.

frequency is approximately 7.4 megacycles (the distance from index stripe to index stripe is .051 inches, the length of one horizontal line is about 20 inches, and the unblanked length of time required for one horizontal sweep is approximately 53 microseconds). Obviously then, the pilot carrier frequency, modulated with this index 7.4 mc., signal also exists at the index signal pickup point. This is the signal in which we are interested and which we shall use. In effect, this signal is phase modulated by the error-position information. That is to say, if the beam deviates from the correct writing speed, this will be reflected in a leading or lagging phase shift in the index signal and hence in the "pilot plus index" output. In turn, we can in effect, examine the phase of the writing chrominance signal and that of our signal, and advance or retard the chrominance signal to agree with the beam position.

″APPLE" SYSTEM DESIGN PHILOSOPHY AND FEATURES

Now that we have established an acquaintance with the Apple system, we are in a position to take a little closer look at the details and technical features which distinguish it from other systems. The Apple System belongs to that broad class of systems usually referred to as Index - or Position-Using Systems. We may further sub-classify it from the nature of its scanning or indexing procedure as belonging to the perpendicular scanning group. A separate sub-class of systems could conceivably be evolved using parallel scanning, but we are concerned only with the system which has been brought to its present state of development under the code name "Apple".



SIMPLIFIED APPLE RECEIVER DIAGRAM

In order to obtain a better understanding of the Apple system, it will be helpful to follow the several signal paths involved in obtaining the Apple display. If we first consider the circuits in a general way, and then reconsider them with additional attention to detail, the explanation can be followed to whatever degree of technical detail is desired by the individual reader. Accordingly, let us assume that whatever circuits may be necessary to produce a beam current in the Cathode Ray Tube have been furnished and are in operating condition. Focus, sweep, high voltage and other auxiliary circuits will be assumed to be functioning. A convenient place to start our discussion is at the origin of the pilot beam. As is apparent from inspection, the index information occurs at approximately the same frequency as the writing information. We cannot use the writing beam in a non-pilot beam system to provide the index information without encountering contamination of the writing signal with the index signal, and vice versa. Similarly, when using a pilot beam, unless it is processed in some way to distinguish it, contamination between the two beans must result. Now it is true that systems can be visualized and circuits proposed which could possibly overcome these difficulties and which would make single beam and non-carrier pilot beam operation possible. Extensive work in this field leads us to the conclusion that neither of these two possibilities offer hope of immediate utility. In some respects both of them require utilization of materials and/or techniques which are not yet commercially feasible. For these reasons we choose to modulate the pilot beam with a carrier frequency to provide a frequency difference between the index (time position) information and the color line repetition period (which must be matched to the color frequency supplied by the receiver signal.)

The physical structure of the Apple tube is one which provides a clean division between the two primary screen functions. The first of the functions, of course, is to produce light emission at the three primary colors. The second, and equally important, is to produce by secondary emission, beam position information. Let us take a closer look at the method of accomplishing the second function.

When the pilot beam is scanned at approximately a uniform velocity across the secondary emission function which has been physically built into the screen structure, a sampling process takes place in which the pulses (at pilot carrier frequency) of beam current provide varying amounts of secondary yield. The amount depends on the emission surface and field gradient conditions which the pulses encounter at a particular spot on the screen structure. As far as the fundamental component is concerned, this can be thought of as a simple mixing process in which the equivalent emission frequency is mixed or beat with the pilot carrier fundamental component. Other beats which take place are discriminated against in the succeeding amplification process.

In discussion of Apple processes it is well to keep in mind that mixing processes involve phase as well as frequency relations. in particular, when two signals are mixed, the phases of the two signals are additive in the upper sideband, and subtractive in the lower sideband. This property is important In processing color and index signals because the color television signal intelligence is largely dependent upon phase relationships of the various signals.

Let us examine more closely the beat which we intend to use to furnish the information about the beam position changes. (Where they may be helpful to some readers, we will include specific frequencies used in a typical developmental receiver.) The signal then is basically a carrier at the pilot oscillator frequency (1), 37.12 mc, beat with the reference frequency (2) (3.58 mc). The sum is used as the pilot beam frequency (3), 40.7 mc. At the CRT Screen this is mixed with the generated index signal (4), 7.4 mc, producing (among others) sum and difference frequencies (5), 48.1 mc and 33.3 mc.

To attempt to amplify all the important frequencies involved would require an amplifier having a very wide band pass or a "comb-type" amplifier with three principal responses. Fortunately; we can apply single-side band, suppressed-carrier principles here and select only one band for amplification. In practice, we will select the upper side band (6), 48.1 mc.

In the amplifier we will limit off all amplitude modulation components, since it is only the phase information in which we are interested. Our new signal (7) has a constant amplitude, is phase. modulated with index information, and has a frequency of 48.1 mc.

One of the advantages of carrier suppression in the sideband amplification process now becomes apparent. The sideband information must be recovered by some form of carrier re-insertion, synchronous detection or basically, by heterodyne mixing techniques. If the reinserted carrier is itself first phase and amplitude modulated with the color signal from the transmitter, then the mixing action will result in an output with a sideband component which combines the phase position information with the phase chroma information supplied by the received signal.

To accomplish this we could mix together the pilot carrier frequency, (37.12 mc, unmod.) and the color (chroma) signal, (3.58 mc PM and AM) selecting the upper sideband (40.7 mc) which will now be modulated with the phase and amplitude chroma information.

However, this signal would not be exactly correct for our purposes. The Apple tube has equally spaced color lines. This requires a color signal wherein the three colors are spaced 120 degrees phasewise, whereas the NTSC signal is not so constituted. A very simple process known as negative sequence vector addition enables us to overcome this problem. We can perform mixing operation in which we control the amplitude of any one color with respect to the other two, at subcarrier level, and thereby produce a new subcarrier containing the desired 120 degree color information relationship.

A convenient way to do this is to mix together the chroma signal (3.58 mc. + chroma) and a controlled amount of second harmonic (7.16 mc.) from the reference generator, in the sub-carrier corrector. The difference beat will then be a 3.58 mc. chroma signal corrected to equi-anqle characteristics. When this beat is mixed with the pilot carrier oscillator output, and the sum frequency then heterodyned with the sideband amplifier output, the resultant detected signal will contain the chroma phase as well as the index phase information.

In practice it has been found that there is still another modification of the picture signal which will yield some improvement in picture colorimetry. Complementary colors are created from equal amounts of two primaries; yellow from green and red, cyan from green and blue, and magenta from red and blue. Thus a yellow signal would turn the beam on when the beam was centered between the red and green stripes. Not only is such exactness difficult to adhere to in practice, but also between the stripes is a guard stripe, unproductive of any color. Thus any yellow (or cyan of magenta) signal would produce a less intense output than was intended because of part of the beam striking bare glass. We can improve this somewhat by effectively dividing all complementary signals into two equal primary signals, letting the signal level remain or drop as the beam passes over the bare area between primary color stripes. We do this in a circuit chain called the quantizer.

The quantizing circuit is shown in the Apple Receiver block diagram (Page 5[1]), However, since Research does not use quantization as such, further discussion of it will not be made here.

It is interesting to note here that loss of any of the signals -- pilot carrier, color reference carrier, color signal, or sideband output -- results in zero output of color information to the writing beam. This means that a normal black and white picture will automatically be seen. No action is required on the part of the observer.

The resultant signal (7.4 mc. + 14.8 mc. + chroma and index phase) will be exactly right to fit the color signal to the screen line structure, as long as the two beams remain very closely aligned vertically, and the signal delay in the loop is small. Under these conditions an essentially constant but not absolutely matched scan will produce completely acceptable color rendition. Of course, the system will have zero color error only if the loop delay is zero, or if the sweep scan is absolutely synchronous, producing a constant color repetition rate. Zero loop delay is naturally impossible, while an absolutely constant sweep speed is economically not a desirable design goal. The compromises which must be worked out in the circuit design are such as to keep the errors acceptably small and the costs equitably distributed among the various components affecting loop performance.

It can be shown that any change in the carrier oscillator phase affects all colors equally and that therefore a single adjustment of carrier oscillator phase will compensate for phase shift in the various carrier signal paths. It is also interesting that although carrier oscillator frequency drift will cause the sideband amplifier to be operated off its center frequency, it will not directly affect the color signal.

The signal loop is completed by taking the resultant signal (10) containing index and chroma information, adding the monochrome information, and amplifying and applying the complete signal to the writing beam.

"SOME CIRCUIT AND COMPONENT DESIGN CONSIDERATIONS"

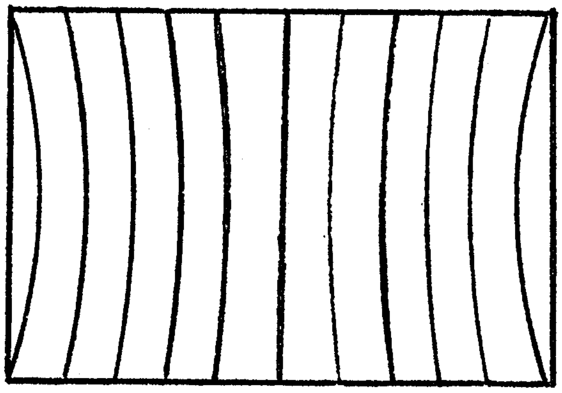
For our third look at the Apple system, let us concern ourselves with some general design requirements behind the various portions of the loop.

We have earlier mentioned some of the problems involved In obtaining accurate scanning, such as focus, picture dimensions and linearity, etc. Associated with these problems are certain circuits and techniques which contribute to their solution.

Stabilization of sweep linearity and hence scan velocity is presently accomplished by means of a "servo" loop. A sampling coil in the deflection yoke makes it possible to monitor the rate of change of horizontal deflection flux. Any deviation from a constant rate results in a deviation in the uniform sweep. This information is used to control the impedance of the damping circuit and hence the instantaneous horizontal yoke current. Inaccurate sweep width affects the writing and index frequency since it changes the number of triplets (or index stripes) scanned each sweep. Absolute width control relative to the color line structure may be obtained by monitoring either the sideband frequency (or the writing frequency), since inaccurate sweep width directly affects the index frequency rather than its phase. It may also be determined by measuring the flyback pulse (assuming the high voltage to remain constant). Although both methods are currently in use, the former is used in our example receiver.

The high voltage regulation requirements are those essential to maintaining good focus in all parts of the sweep, (especially with a servo controlled sweep width) throughout the normal tube life. A focus control is used to adjust the focus dynamically with the vertical position of the spot compensating for astigmatic yoke effects on the spot shape.

The problem of securing accurate vertical alignment of the two beams over the entire raster was difficult of original solution, but once solved, the necessary circuit and component accuracy are relatively simple production problems. For example, the length of each beam's travel from the center of deflection is different at the corners of the screen than at the center. Therefore, the relative positions of the two beams will vary, as shown, in exaggerated form, in Fig. 2. This pin cushion effect is of relatively little interest in black and white receivers, but in the Apple tube, unless the color and index stripes are curved to match this pincushioning, the colorimetry will be affected. In turn, sweep width and linearity must be compensated to agree with this line structure.



° pilot beam
x writing beam

beam displacement by
pincushion effect.

Since the scan is fundamentally at right angles to the color lines, no color inaccuracy will result from minor variations in vertical separation of the beams. Variations in horizontal alignment, however slight, must be eliminated or minimized. Pains are taken with the gun orientation in the color picture tube as the first step in securing accurate beam alignment. Further steps involve the yoke and the focuser assemblies.

The yoke requirements are twofold. It must have anastigmatic properties, such that focus at the sides of the raster is essentially as accurate as that in the center area. Its pincushion distortion must be uniform, reproducible and of simple order, readily matched by a feasible color line structure. The yoke properties currently employed are such as to minimize the need for horizontal dynamic focus by accepting vertical astigmatism for all spot positions left or right of tube center, to obtain essentially zero horizontal astigmatism. (Vertical errors in beam shapes and orientation will not produce color errors.) The focus unit must be extremely uniform to produce very low central area astigmatism and virtual freedom from coma and other lens distortions. In order that vertical dynamic focus can be applied without affecting the vertical alignment of the two beams, it is desirable that the focus assembly be (essentially) of the non-rotating type. Both E.M. and P.M. units have been used. The present beam orientation is such as to be best suited to a two ring focus unit currently in wide use.

Some of the other auxiliary problems are associated with the CRT drives. Prevention of crosscoupling or transmu between the two beams is one of these. Electron space coupling is extremely small because of the unique tetrode design. To maintain this low value of beam interactions, the circuit design must avoid high driving point impedances and large external capacity coupling.

Since the pilot beam current is only of the order of 10 microamperes, and for optimum index signal must operate at approximately a 180 degree conduction angle, some means of maintaining these operating conditions should be provided against changes in the tube cut-off voltage on the pilot beam grid, due either to tube cycling, tube aging or variations in the screen grid or cathode voltages. In addition, for optimum contrast, the pilot beam current should be minimum on low illumination portions of the picture. It can be increased during bright portions, minimizing the likelihood of contamination of the index information by the increased writing beam current. This modulation of the pilot carrier with picture brightness information can increase contrast up to 10 db over what can be achieved without such modulation. In the receiver used as an example, performance has been satisfactory without such pilot carrier modulation, and this refinement may not be economically desirable.

Now let us consider some of the general design considerations peculiar to the side band amplifier.

The principal information which we are seeking in the sideband component is the phase modulation spectrum associated with it. It is this phase modulation of the side band component which gives us a measure of the instantaneous beam position and, of course, beam velocity. It is interesting to note that because of the repetitive nature of the television signal, there are two principal envelopes on the phase modulation; one occurs at a 15 kc or line repetition rate, the other, of course, is the 60 cycle vertical rate. The 15 kc envelope essentially defines the linearity of the horizontal scan, while the 60 cycle envelope contains principally pin cushion and other vertical width correction terms. The problem of determining bandwidth is somewhat more complicated than that of the usual amplifier. We are not interested in the amplitude components and will limit them off, but we must preserve all of the phase modulation sidebands which are significant to the position information. A simplified concept is to assume that we have a single frequency vector which is moving at a certain variable rate over the phase versus frequency slope of the sideband amplifier transfer characteristics. This is a satisfactory arrangement if the changes occur very slowly and the phase sidebands occur very close to the original frequency. For rapid changes, however, we must be more particular. It can be seen that the primary requirement on the sideband amplifier then, other than the obvious one of sufficient gain, is to provide a passband phase-wise in which instantaneous frequency changes all suffer the same phase delay. Conventional amplifier theory and signal transmission requirements normally require constant time-delay amplifiers. It has been necessary to consider the effect of interstage networks and network combinations which produce arrested phase characteristics or phase slopes having dynamic characteristics of a negative sign, Following amplification, it is necessary to limit the amplitude changes in the sideband component which occur from one part of the tube to the other so that these can have substantially no effect on the color writing currents applied to the phosphors of the tube. A problem with limiters of this type is the avoidance of phase distortions at and beyond the limiting threshold. It is usually necessary, for example, to so arrange the pole diagrams that all limiters operate with the pole at band center so that changes in the damping on this pole do not change the center-frequency phase slope materially.

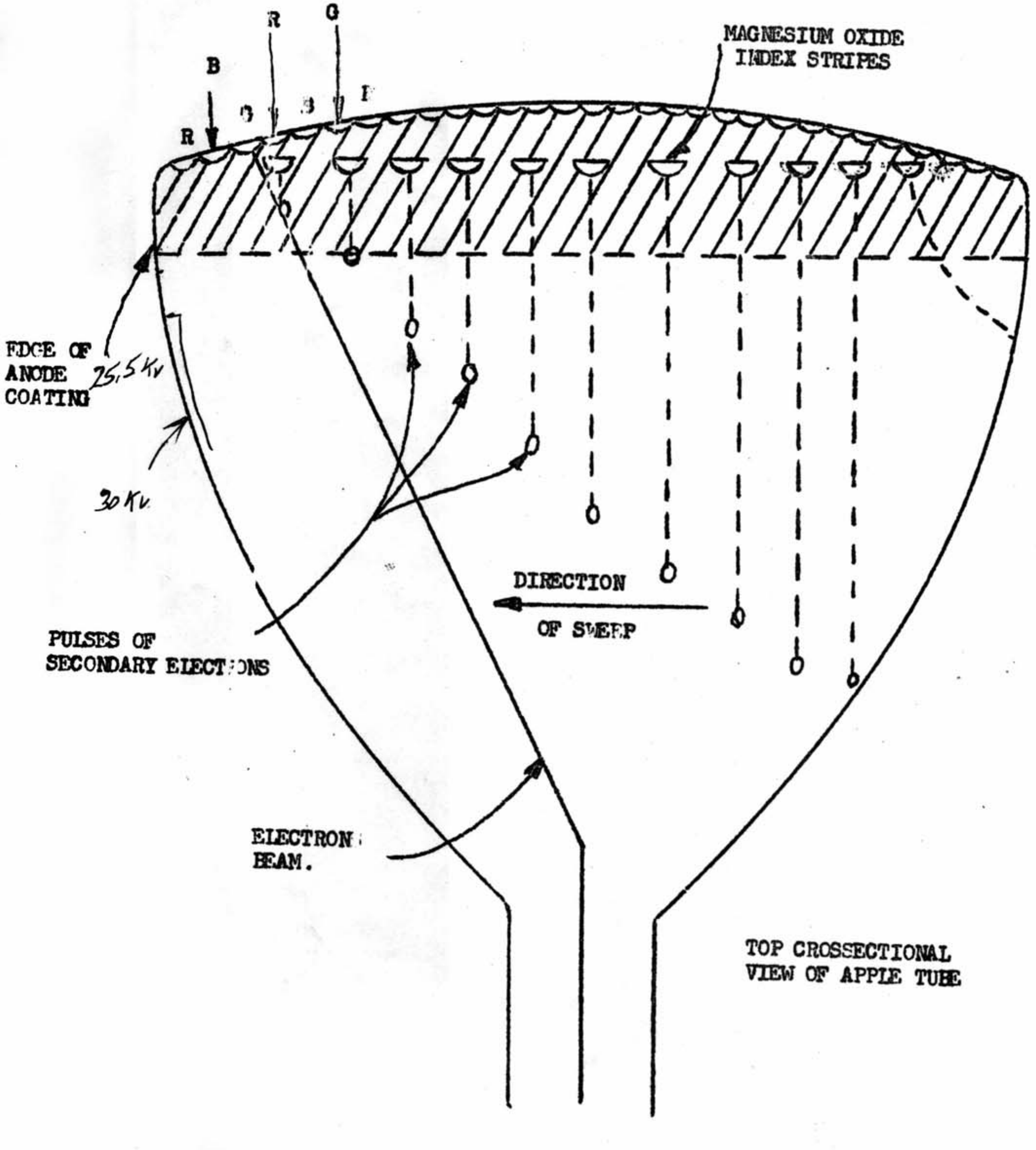
The reasons for the present choice of operating frequencies is certainly an item of interest in any general study of the Apple System. Since writing frequency affects tube construction, it appears that it should be chosen first. A frequency much less than 6 megacycles will not be adequate to reproduce all of the information in a color broadcast. On the other hand, it can be shown that the color saturation obtainable at a given brightness is inversely proportional to the writing frequency. (This is rather obvious, as a matter of fact, if we consider that a lower writing frequency means fewer, but wider, color stripes, with an attendant higher brightness, for a given spot size-beam current combination and comparable saturation.) Writing frequencies between 5 1/2 and 8 megacycles have been explored and the present recommendation of 7.4 megacycles as the nominal writing frequency is the result of compromising many of the subjective parameters involved. This is essentially independent of picture tube size if the deflection angles remain constant. Next we can say that the sideband frequency should be an odd harmonic of one-half the writing frequency. This will center the acceptance band of the side band amplifier between harmonics of the writing frequency, thus minimizing index contamination by writing signals.

The choice of a sideband frequency midway between the 6th and 7th harmonics of the writing frequency is also a compromise. We want to place the sideband frequency as far above the writing frequency as possible so as to encounter as little harmonic power as possible. On the other hand, amplifier stability, internal interference, external interferences such as television and other VHF broadcast signals and noise figure limitations of practical circuitry lead us to select a reasonably low frequency. Moreover, the important sideband characteristic is phase, and this becomes an increasingly troublesome problem at higher frequency.

In this examination of the Apple system principles, we have first considered in a very general way the basic ideas involved. We then examined in more detail the signal loops and some of the processes used in achieving the high quality color picture of which the system is capable. Lastly, we have considered some of the reasons behind the more interesting and unconventional components, processes and circuits which make the Apple system work.

We are now in a position where detailed examination of the important circuits can profitably be made.

Secondary emission ~~volts~~ current waveform is nearly a sine wave



TOP CROSSECTIONAL VIEW OF APPLE TUBE