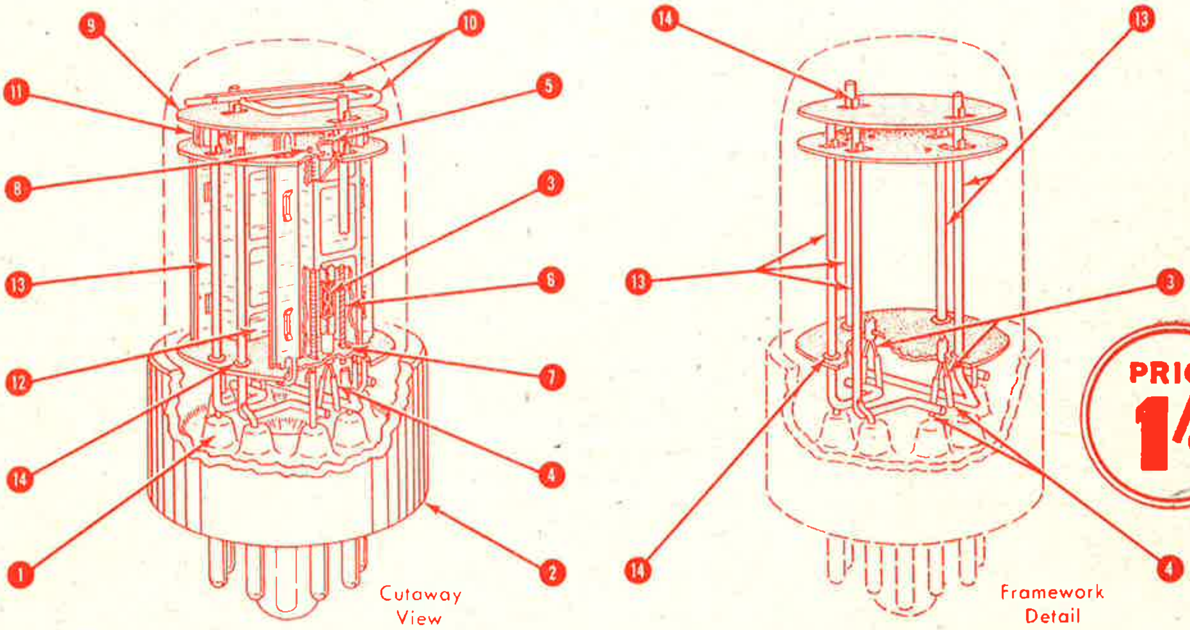
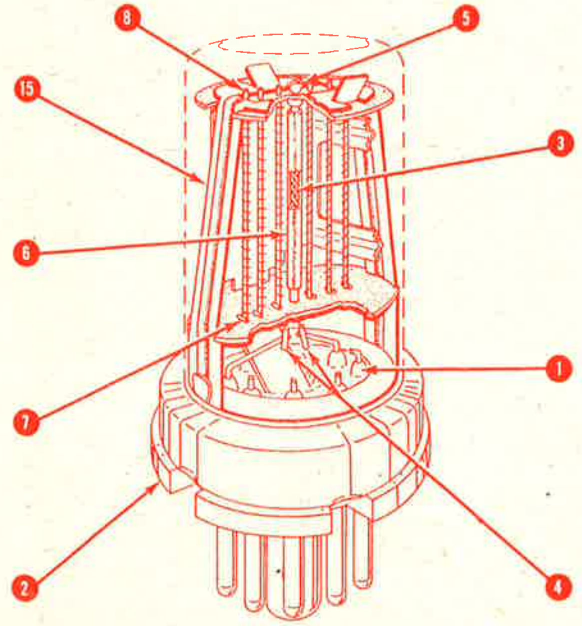
RADIOTRONICS

Volume 18 January 1953 No. 1



PRICE 1/-

RCA-5691 and RCA-5692, Twin-Triode Amplifiers



RCA-5693, Sharp-Cutoff Pentode

Design features of industrial-type tubes

1. A button stem is used so that leakage between stem leads is minimized.
2. Base material is non-hygroscopic to maintain good insulation between pins under adverse humidity conditions.
3. Heaters are made of pure tungsten for high mechanical strength.
4. Heaters are enclosed in sleeves to ensure a good mechanical and electrical bond between heater and heater lead.
5. Cathode sleeves are locked to mica insulators to restrict movement under vibration and shock.
6. Grids are plated to minimize variations in contact potential from tube to tube initially and in individual tubes during life.
7. Short cross members are welded to grid side rods to prevent vertical movement of the side rods.
8. Grid side rods fit tightly into mica insulators.
9. An extra mica insulator prevents getter material from creating leakage paths across insulators.
10. Two getters are used to insure good vacuum and long life.
11. Plates are rigidly held in mica insulators by ears wedged against the insulators.
12. Completely enclosed design of plates minimizes electron coupling between units.
13. Elements are held together in a secure assembly by five supporting rods.
14. Twelve reinforcing eyelets provide a firm bond between mica insulators and five supporting rods.
15. Integral "A-Frame" is used for strength.

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THE TELEVISION SIGNAL

1. Assigned television channels.

Television progress can best be measured in terms of the number of lines in the transmitted picture. The first television pictures had 24 or 48 lines, and then 60, 120, 180, 240, 343, 441, and, finally, the present standard of 525 lines. This increase in scanning lines, with the resulting improvement in picture quality, has of necessity, caused an increase in the video frequency bandwidth from about 30,000 cycles to approximately 4 megacycles. These high modulation frequencies make it necessary to transmit in the very-high frequency spectrum.

The frequency allocations for television specified by the Federal Communications Commission for frequencies from 54 to 216 mc are shown in chart form in Figure 3-1. It will be noted that twelve channels are located in this range of frequencies.

The first five channels assigned to television are considerably lower in frequency than the remaining seven channels and are often referred to as the low frequency channels, while the upper seven channels are referred to as the high frequency channels. All twelve of these channels have been assigned to commercial operation.

2. Arrangement of the television channel.

The standard television channel is 6 mc wide and contains both the video (picture) carrier and the audio carrier — the sound carrier being at a higher frequency than the video carrier, with a 4.5 mc separation between carriers.

Details of single television channel as transmitted are shown in Figure 3-2A. It will be noted that the video signal is amplitude modulated and takes up most of the channel width. The sound carrier is frequency modulated with a channel width of 50 kc, allowing a maximum deviation of ± 25 kc due to modulation.

A close inspection of Figure 3-2 will bring out the following pertinent facts:

(1) The picture carrier is placed 1.25 mc above the lower frequency limit of the channel.

(2) The sound carrier is placed .25 mc below the upper frequency limit of the channel, thus affording a 4.5 mc separation between carriers.

(3) The picture side-band components do not extend symmetrically on either side of the video carrier as might at first be expected but, instead, for reasons explained later, the upper frequency side-band extends approximately 4 mc above the video carrier while the lower frequency side-band extends approximately .75 mc below the video carrier.

(4) The flat portion of the video signal is approximately 4.75 mc wide, with a .5 mc guard-band located at the upper and lower edges of the video side-bands to prevent the video signal from going beyond the low frequency limit of the channel and to prevent the upper video side-band from interfering with the audio channel. The radiated power at the lower edge of the channel should not be more than 0.1 per cent. of the maximum amplitude of the carrier, and the radiated power of the upper video side-band at the sound carrier should also be limited to 0.1 per cent.

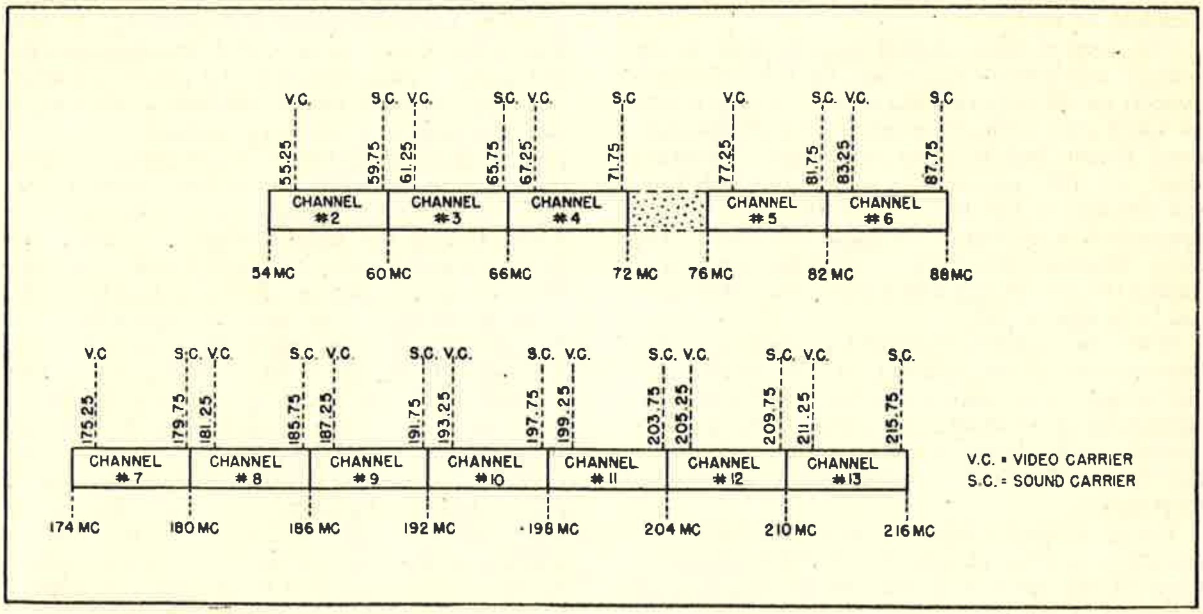

Fig. 3-1. Television channels.

(5) The relative radiated power for picture and sound is approximately the same.

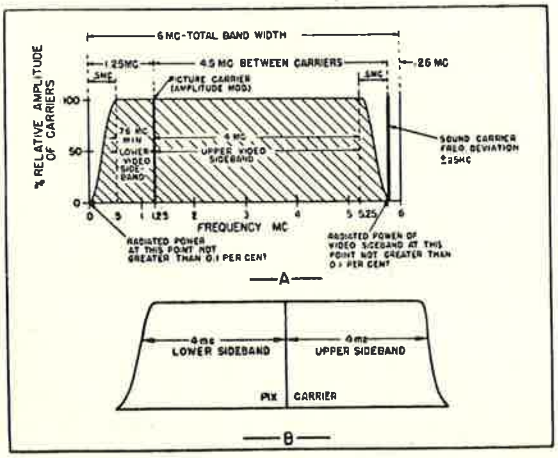

Fig. 3-2. Television and video side-bands.

3. Vestigial side-band operation.

As was brought out earlier in the text, it is necessary to have a very wide video bandwidth in order to transmit pictures having good definition. A bandwidth of approximately 4 mc is required to transmit and reproduce a picture having the maximum amount of detail available from our present 525 line standard.

If the conventional double side-band method of transmission were used, the video signal alone would have to occupy approximately 8 mc of the channel, as indicated in B of Figure 3-2, in order to transmit a picture which meets these standards.

Since the television channel is limited to 6 mc, both to accommodate a larger number of stations on the air and to relieve the bandwidth requirements of transmitting and receiving apparatus, it is obvious that the double side-band method of transmission cannot be used if a picture having good definition is to be transmitted. Some other method must therefore be used.

The method best adapted to television is the vestigial side-band method where the side-band components on the high side of the video carrier extend to where they normally would in the double side-band system, but in order to conserve frequency space in the television channel the side-band components on the low side of the video carrier extend only a fraction of the upper side-bands. The name "Vestigial Side-Band" is used because only a portion of one of the side-bands (the lower side-band) is transmitted.

With the vestigial side-band method of transmission, the system operates in the conventional double side-band manner for very low modulation frequencies up to about .75 mc and gradually passes through a transition to where it operates with carrier and single side-band for the higher modulation frequencies.

The reader might well ask why bother with transmitting a portion of one of the side-bands at all since all the modulation frequencies necessary are contained in just one of the side-bands. The answer is that technically the transmission of a single side-band is a very difficult problem since it is not possible to remove all the modulation components of the undesired side-band without producing undesirable phase shifts in the signal. Therefore, a compromise is made where all of the modulation components in the upper side-band are transmitted and only enough of the modulation components in the lower side-band are used to prevent undesirable phase shifts.

In order to properly make use of the vestigial side-band method of transmission, the receiver response must be such that the output of the video detector will be essentially the same for side-band components near the video carrier as well as for those far removed from the carrier. The details of how this is accomplished will be discussed in a later chapter, when the video i-f stages are described.

4. General description of the television signal.

As stated earlier in the text, the picture is scanned at both the camera tube and the picture tube by an electronic spot (beam of electrons) in a series of adjacent horizontal lines. The amount of detail reproduced is determined by the number of lines into which the picture is divided by the scanning process. After scanning the whole picture, the process must be repeated at a sufficiently rapid rate so as to produce the illusion of continuity of motion. This process is essentially the same so far as the effect upon the eye is concerned as that performed by the shutter on the familiar motion picture projector. The frequency at which the complete picture is scanned is the *frame frequency,* and is 30 times per second.

In order to conserve the bandwidth occupied by a television transmitter, it is desirable to keep the frame frequency as low as possible. Consequently, a device somewhat similar to that used in a motion picture projector, serves to increase the frequency at which the entire screen is illuminated. In using this device, known as interlaced scanning, described in Chapter 1, every other line of a picture is scanned, and after the whole picture has been scanned in this way, the lines in-between are scanned. This affects the eye, in-so-far as flicker is concerned, as though every line in the entire picture were scanned twice. This is true even though all the detail of the whole picture has been scanned only once. The flicker frequency under these conditions is twice the frame frequency, and is called the *field frequency.* Now, if anything other than a complete blur is to be obtained, it is necessary that the number of lines per frame, the order of scanning the lines, and the number of frames per second, be identical at the receiver and transmitter. Also, that identical synchronizing pulses be provided for the sweep circuits of the camera tube at the studio, and the picture tube in the receiver, so that the electron beams of both tubes will have the same relative position at any given instant. This is accomplished by means of the standard RMA television signal to be discussed in detail in subsequent paragraphs.

5. Polarity of transmission.

Television transmitters in this country are designed so that the passage of the camera scanning spot to a point of more light causes a decrease in the radiated power. The reason for using negative transmission, as contrasted to positive as used in England, is that experience has shown that negative transmission is less vulnerable to the visible effects of interference such as automobile ignition, etc. Since the polarity of transmission is negative, it follows, then, that white portions in a picture are produced by low power in the transmitted signal, and as black portions in the picture are approached the power in the transmitted signal is accordingly increased until a power level is reached in the picture signal, which is called the black level. This level represents a total absence of light in the picture.

6. Portion of signal amplitude devoted to synchronizing.

An axiom of television is that picture synchronism must be maintained even to the point where the picture signal is too weak to produce a useable image. Obviously, a signal is useless, irrespective of its strength, if the synchronizing portion of the wave fails to keep the picture at the receiver in synchronism with that at the transmitter. Therefore, sufficient transmitter amplitude must be assigned to the synchronizing portion of the picture signal to maintain proper synchronism between transmitter and receiver, and experience has shown that approximately 25% is a reasonable figure, with the synchronizing signals occupying the upper 25%. The peaks of the synchronizing pulses represent the maximum amplitude of the transmitted signal.

7. Transmission of black level.

Because of considerations which will be made obvious later, black in a scanned picture is represented by a definite carrier level, independent of the light and shade in the picture. This level has been fixed at a value of 75% of the maximum amplitude of the signal, and is maintained constant during transmission.

8. Review of scanning process.

The resulting composite signal of the electrical impulse from the camera tube and the horizontal and vertical synchronizing and blanking pulses is referred to as an "RMA Standard Television Signal". However, before considering the actual composition of this signal, it would be well to briefly review the scanning process used in reproducing the image upon the screen of the picture tube.

It is necessary for the spot starting at the top of the screen to travel uniformly across the screen of the tube from left to right by means of a waveform of voltage or current applied to the horizontal deflecting plates or coils, as the case may be. As the spot moves from left to right across the screen, its intensity varies in accordance with the picture impulses applied to the picture tube grid, tracing one line of the picture across the screen. When the right edge of the screen is reached, the control grid of the picture tube is biased beyond cut-off and the spot is extinguished or blanked out while the electron beam is moved back to the left-hand edge of the screen, placing it in position to trace another line of the picture. Extinguishing of the beam at this time is called horizontal or line blanking. The bias on the grid of the tube is then removed and the spot again moves across the screen from left to right as before. This process is repeated over and over, gradually moving toward the bottom of the screen by means of a much slower waveform of voltage or current applied to the vertical deflecting plates or coils, as the case may be, each horizontal line being slightly below the previous one, due to the pull of the much slower-moving vertical sweep.

After a certain number of horizontal lines have been traced in this way (one complete field), the control grid of the tube is biased to cut-off, and the spot is extinguished while it is being moved from the bottom to the top of the screen, placing it in position to start tracing the second field. The blanking of the spot at this time is called vertical blanking or field blanking. The bias on the picture tube is then removed, and the spot traces the horizontal lines contained in the second field, thus completing one frame of the picture.

Since one complete frame of a television picture consists of 525 horizontal lines, and since 30 complete frames appear on the screen of the picture tube every second, then the electron beam must trace 525 x 30 or 15,750 horizontal lines every second. In other words, the frequency of the horizontal sawtooth generator in the receiver must have a frequency of 15,750 cycles. Expressing this in microseconds we find that the total duration of one complete cycle of the horizontal sawtooth waveform is approximately 63.5 microseconds. On the other hand, the frequency of the sawtooth waveform for vertical deflection is much slower—being 60 cycles per second—and is based on the fact that in interlaced scanning the picture is partially scanned from top to bottom twice during each frame, and since there are 30 complete frames every second, the electron beam must move from top to bottom 30 x 2 or 60 times every second. This means that the frequency of the vertical sawtooth generator in the receiver must be 60 cycles per second. The total duration in microseconds of one complete cycle of the vertical sawtooth waveform is approximately 16,667 microseconds, as compared to only 63.5 microseconds duration of one complete horizontal cycle, thus allowing the horizontal sawtooth generator to go through 262.5 complete cycles during the time required for one complete cycle of the vertical sawtooth generator.

In order to generate a sawtooth waveform of current or voltage, special circuits are required which usually take the form of a blocking oscillator or multivibrator. We will not go into detail at this time as to the actual operation of these oscillators, except to bring out the fact that normally they are free-running—that is, their frequency is not constant, but varies considerably from the exact frequency of 15,750 cycles per second for the horizontal sawtooth oscillator or generator, and

60 cycles per second for the vertical sawtooth generator until such time as they are synchronized or locked in by synchronizing pulses.

Now, it is apparent that some means of controlling the frequency of these oscillators must be provided so that the horizontal oscillator will run at exactly 15,750 cycles per second, and the vertical oscillator will run at 60 cycles per second, so that both the horizontal and vertical deflection circuits in the receiver will be in synchronism with those used to scan the mosaic of the iconoscope or camera tube at the television studio. This is accomplished by providing synchronizing pulses in the video signal which will initiate the retrace portion of every cycle of each oscillator at the proper instant to maintain the frequency of each oscillator at the correct value.

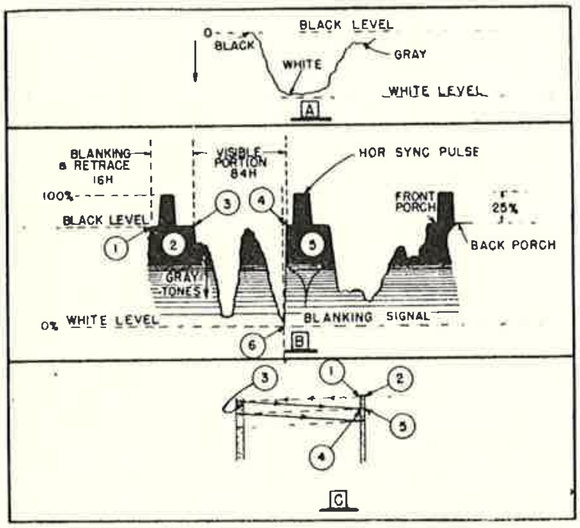

Fig. 3-3. Television signal.

9. Details of the video signal.

It will be recalled that the television transmitters in this country are designed for negative transmission; that is, the passage of the camera spot to a point of more light causes a decrease in radiated power, and the passage of the camera spot to a point of less light or a darker scene causes an increase in the radiated power of the transmitter. Figure 3-3A illustrates some of the characteristics of the picture signal used to modulate the carrier of a television transmitter. Starting at the left, the horizontal line represents the picture signal when a black portion of the scene is scanned and is called the black level, the light values corresponding to all other picture signals being referred to this level. It will be noted that as the brightness of the scene increases, the amplitude of the picture signal which modulates the carrier increases, but in a *negative* direction, until it reaches its maximum, when the scene is all white. Although the black level is represented as zero, it has a d-c potential which is approximately 75% of the amplitude of the unmodulated carrier, and the picture signal is, therefore, a pulsating voltage, which *always* varies in a negative direction from the d-c level, which is established by the black level. Such a modulating signal is said to have negative polarity. Thus, white in the scene will cause the least amount of power to be radiated, while black will cause approximately 75% of the maximum carrier power to be radiated.

In addition to the signal which contains the actual picture information, synchronizing pulses are provided at the end of each line to initiate retrace and to return the spot from the right-hand edge of the screen to the left-hand edge. These pulses occur in the blacker than black region of the signal, starting at the black level and rising 25% above it, thus occupying the upper 25% of the video signal which modulates the carrier. This is shown in B of Figure 3-3, which represents two successive lines of a scene with their associated horizontal synchronizing pulses. The maximum power radiated by the modulated carrier will be represented by the peaks of these synchronizing pulses. A very important point to note is that the maximum height of these synchronizing pulses above the blanking level is the same for each line, regardless of the character of the picture signal. Also, it is important to note that the signal does not immediately rise to the synchronizing level at the end of a line, but rises to the blanking level and remains there for a short interval. This short interval at the blanking level, which precedes the front or leading edge of the synchronizing pulse, is sometimes referred to as the "front porch" of the synchronizing pulse and serves as a buffer between the picture signal and the beginning of the synchronizing pulse, so that the character of the picture signal (whether it is light or dark) will not affect the line timing. If the frequency response of the transmitter and receiver were such that the blanking pulse could be transmitted without any slope, as indicated by the dashed line at (6) of B, Figure 3-3, then the front porch would not be necessary and the leading edge of the horizontal synchronizing pulse could be a continuation of the blanking pulse. However, since this would require an almost infinite frequency response, there is always a slight slope to the edges of the blanking pulse in practical transmitters and receivers, due to a loss of some of the higher frequencies contained in the edges of the blanking pulse. If the blanking pulse started near the white level, as shown at the end of the first line in B of Figure 3-3, this slope would cause the synchronizing pulse to occur at a different time than it would if the blanking pulse started near the black level as at the end of the second line. By having the leading edge of the horizontal synchronizing pulse occur a short time after the blanking pulse reaches the black level, as provided by the front porch, it does not matter where the blanking pulse starts, since the horizontal synchronizing pulse will always occur after the same time interval. At the completion of the horizontal synchronizing pulse there is another interval at the black level which is called the back porch. The purpose of this is to keep the picture blanked out until the spot has had a chance to return to the left side of the screen, at which time the blanking pulse is removed. The duration of the front porch is .02 H or approximately 1.27 μs, while the duration of the back porch is somewhat longer, being .06 H or approximately 3.8 μs. The maximum duration of the synchronizing pulse from leading-to-lagging edge is 5.08 microseconds.

Figure 3-4 represents the RMA Standard Television Signal. Diagrams A and B represent portions of a single frame and show video, blanking, and synchronizing signals in regions of successive fields. It will be noted that the black level divides the signal into two parts; voltages below this level represent the picture signal, as indicated at the left of diagram A, and those above the synchronizing. The black level is fixed at a value of approximately 75% of the maximum amplitude of the signal and is held constant during transmission. The remaining 25% of the signal amplitude above the black level is devoted to synchronization. Since all synchronizing signals are above this level, they cannot produce light in the received picture, and the signal is said to be in the black or "blacker than black" region.

At the left of diagram A, Figure 3-4, is represented the picture information contained in the scanning of four lines of the image, together with the periods during which the synchronizing and blanking signals are transmitted. The particular view represented starts as white at the left edge of the line-marked picture, and gradually increases to black near the centre, then gradually decreases to white at the right edge. Note, in particular, a dark or black portion in a scene is represented by a correspondingly high level in the picture signal as transmitted, while white in the scene is represented by a correspondingly low level in the signal. In other words, the polarity of transmission is such that as the amplitude of the picture signal increases, the corresponding brilliance in the picture at the receiver decreases, and vice-versa. As mentioned before, this is known as negative transmission, and is used for reasons explained earlier in the text. The maximum white level has been set 15% or less of the amplitude of the transmitted signal.

It should be noted that the video or picture information is interrupted for brief periods at the end of each line. During these periods, horizontal synchronizing pulses are transmitted which initiate the retrace portion of the horizontal sweep at the receiver, and thus control the timing of the spot's return to the left side of the picture tube. Since the amplitude of the video signal is in the black or "blacker than black" region while the spot is returning to the left side, that is, during line retrace, the retrace portion of the horizontal sweep will not be visible.

This action is shown in C of Figure 3-3, which shows the movement of the spot across the screen for the two lines shown in B of Figure 3-3. Starting at (1) in C, the spot will be extinguished by the blanking pulse (1) in B and will be moved back across the screen from right to left during the horizontal retrace which is initiated by the horizontal synchronizing pulse at (2). This is shown by the top dashed line in C. The spot is extinguished during this period, because the signal is in the black region (1) to (3) in B and C and, therefore, the horizontal retrace will not be visible. After the spot has reached the left-hand edge of the screen and has reached its normal velocity, the blanking pulse is removed at (3) and the spot again becomes visible as it traces a line across the screen from left to right, as indicated by the solid line. The intensity or brilliance of the line as the spot moves from left to right across the screen from (3) to (4) in B and C will vary in accordance with the picture signal and, for this particular line, it will start as grey at the left, gradually becoming white and then become black near the centre, gradually

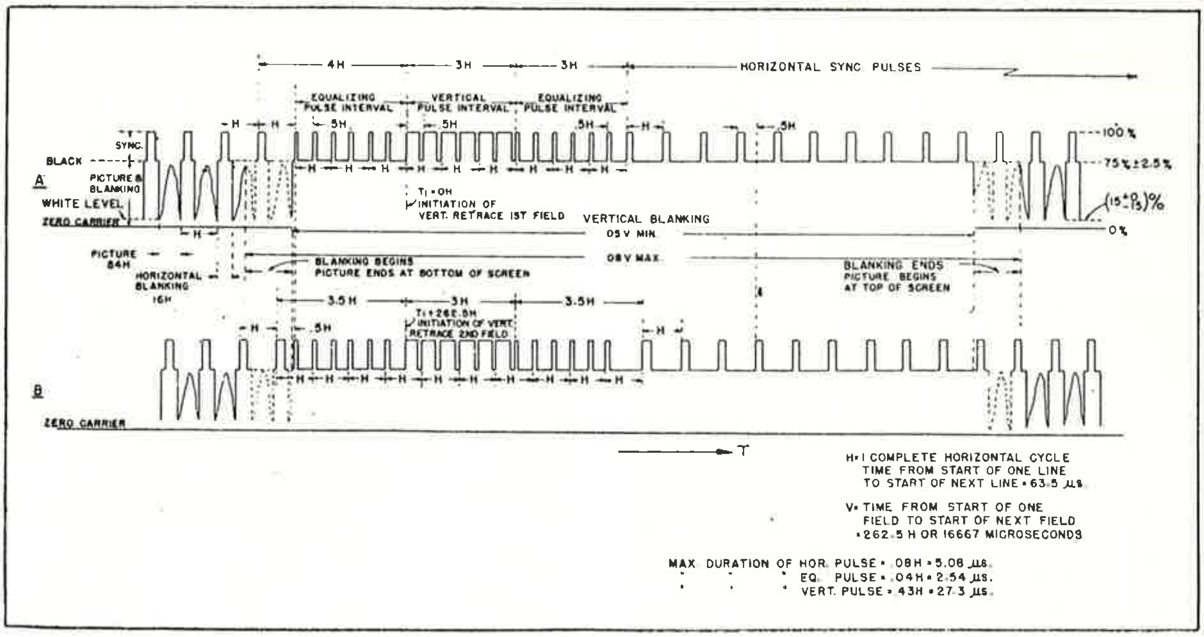

Fig. 3-4. The video signal wave.

becoming white again as it nears the right-hand edge. When point (4) is reached, the blanking pulse extinguishes the spot, and after a short interval the synchronizing pulse at (5) in B and C again initiates horizontal retrace, moving the spot back to the left-hand edge of the screen ready to trace another line of the scene as before. It should be noted that the spot is always extinguished during horizontal retrace, as indicated by the dashed lines, and, also, that a small portion of the beginning and end of the trace is also blanked out, as shown by the shaded area at the edges of the screen. The blanking of the trace at the right-hand edge is due to the front porch, and the blanking at the left-hand edge is due to the back porch for reasons mentioned previously. The visible portion of the sweep (3) to (4) occupies about 85% of the total time (approximately 54 microseconds), while retrace and blanking (1) to (3) occupy about 15% of the total time (approximately 10 microseconds).

Referring to Figure 3-4, it will be noted that the interval between the leading edge of one horizontal synchronizing pulse and the leading edge of the next horizontal synchronizing pulse is 1 H or 63.5 microseconds. This represents the time required for one complete cycle of the horizontal sweep. At the completion of the last visible line of each field which is marked "Blanking Begins, Picture Ends Near Bottom of Screen" in A and B, a series of six narrow pulses marked "equalizing pulses" are transmitted, followed by a series of six broad pulses marked "vertical pulses", which are followed by six more equalizing pulses. During the transmission of these pulses the amplitude of the signal is such as to always be in the black region, which, of course, again means that the spot of the picture tube is invisible. It will also be noted that the interval between the leading edge of every other equalizing pulse equals 1 H or 63.5 microseconds, as does the interval between the leading edge of every other vertical pulse in the vertical pulse group. This is done because the horizontal sweep oscillator in the receiver must be triggered once every 63.5 microseconds at all times in order to maintain line synchronization. The purpose of the six broad pulses in the vertical pulse group is to time or initiate the start of the retrace of the vertical sawtooth oscillator and move the spot from the bottom of the screen to the top. A single broad pulse could be used if vertical synchronization were the only consideration. But in order to maintain horizontal line synchronization during this period the vertical pulse is divided into six separate pulses, the leading edge of every other one being separated by 1 H or 63.5 microseconds, so that it will initiate horizontal retrace at 1 H intervals. The equalizing pulses serve two purposes. First, they maintain horizontal synchronization immediately preceding and following the vertical synchronizing pulse interval since the leading edge of every other one is spaced 1 H. However, if this were the only consideration, then ordinary horizontal synchronizing pulses could be used, but in order to have identical conditions preceding and following the vertical synchronizing pulses for successive fields so that perfect interlacing will occur, smaller pulses are used which are separated by .5 H instead of the 1 H separation used with horizontal synchronizing pulses. The exact function of the equalizing pulses will be considered later in connection with synchronizing circuits. A number of horizontal pulses follow the second set of equalizing pulses so that the horizontal oscillator will be properly timed when the vertical blanking is removed at the top of the picture.

The vertical, horizontal, and equalizing pulses have the same amplitude, but, as mentioned before, their duration or width is not the same. The duration of the horizontal synchronizing pulse is 5.08 microseconds, while that of each vertical synchronizing pulse is considerably longer, being 27.3 microseconds. The reason for this difference in width between the two pulses is to provide for their separation in the receiver by the waveform method of separation, which will also be considered in detail when the synchronizing circuits are discussed. The equalizing pulses are half as wide as the horizontal synchronizing pulses, and their duration is 2.54 microseconds.

The vertical blanking period is shown as occupying between .07 V and .08 V (V is the time from the start of one field to the start of the next). Since there are 60 fields per second, V is 1/60 of a second or 16,667 microseconds. The only result of the longer blanking interval is to slightly reduce the height of the picture, since more horizontal lines will be blanked out with the longer blanking period.

Because of the two-to-one interlace, the vertical synchronizing pulse groups occur twice per frame or 525 lines, as indicated in diagrams A and B of Figure 3-4. Accordingly, the interval between the initiation of vertical retrace on adjacent fields is 525/2 lines or 262.5 H. Figure 3-4 shows only the portion of the television signal near the vertical blanking regions for two successive fields or one frame, and it should be kept in mind that there is a continuation of the wave represented in the right-hand side of diagram A. This continues until 262.5 H has elapsed from the initiation of vertical retrace A to the initiation of vertical retrace in B, the last few lines preceding vertical retrace in B being shown on the left. After another 262.5 H has elapsed following vertical retrace in B, two successive fields have been completed, and the second frame is started at the point where the first started in A.

A close examination of A, Figure 3-4, reveals the fact that the initiation of vertical retrace and horizontal retrace are coincident at $T_1 = OH$ (occur at the same time) for this particular field, since the leading edge of the first vertical pulse in the vertical pulse group occurs exactly 4 H after a regular horizontal synchronizing pulse and, therefore, acts as a horizontal synchronizing pulse as well as a vertical pulse. However, for the field associated with diagram B, the initiation of of horizontal and vertical retrace is not coincident, since the leading edge of the first vertical pulse in the vertical pulse group occurs only 3.5 H from the last regular horizontal synchronizing pulse. The horizontal oscillator is not triggered by pulses at .5 H intervals; therefore, vertical retrace for this field will occur .5 H after the initiation of the horizontal retrace. In other words, initiation of vertical retrace for one field occurs at the end of a horizontal line, while initiation of vertical retrace for the following field occurs in the middle of a horizontal line. It is this important difference of half a line or approximately 32 microseconds between the triggering of the vertical and horizontal oscillators at the initiation of vertical retrace for one field and the simultaneous triggering of both oscillators for the other field that produces the condition of interlaced scanning.

10. Details of interlaced scanning.

To illustrate this more clearly, consider Figure 3-5, which shows the relationship between the horizontal sweep and the vertical sweep for two successive fields or one complete frame. For the sake of simplicity, assume ideal sawtooth waveforms for both the horizontal and vertical sweeps, that is, assume zero retrace time so that when the horizontal sweep reaches the right-hand edge of the screen, it snaps back instantly to the left side of the screen, and when the vertical sweep reaches the bottom of the screen it will snap back instantly to the top of the screen. It will also be assumed that the vertical retrace is initiated by the leading edge of the first vertical synchronizing pulse in each field. Actually, it is not, but this assumption will simplify the explanation considerably.

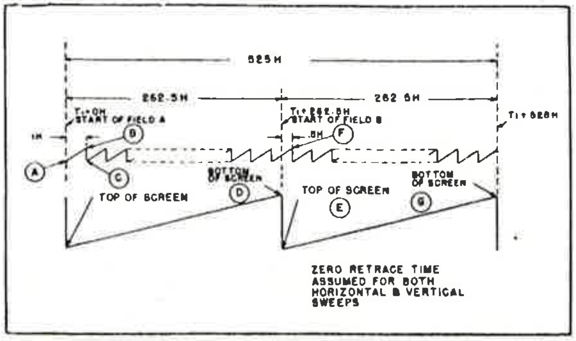

Fig. 3-5. Hórizontal and vertical sweeps.

Blanking will not be considered at this time, since it has no effect on the condition of interlace. Starting at T_1, which equals zero H, horizontal and vertical retrace are coincident, since at this point the vertical pulse occurs at a 1 H interval, and its leading edge will initiate horizontal retrace as well as vertical retrace, moving the spot to the top left of the screen, which places the spot in position to trace the first line of the first field. The actual movement of the spot across the screen is shown by Figure 3-6, which is correlated with Figure 3-5. Point A of Figure 3-6 corresponds to point A of Figure 3-5, etc. Due to the pull of the trace portion of the horizontal sweep, the spot will move from left to right across the screen until point B is reached, at which time horizontal retrace is initiated, immediately moving the spot back to the left-hand side of the screen to point C, and the spot is now in position to trace the second line of the first field. It is important to note that point B of Figure 3-6 is lower than point A, and that the solid line representing the first line of the first field has a certain definite slope. This slope is due to the downward pull exerted on the spot by the trace portion of the vertical sweep during the time that it was moving from left to right across the screen, and this pull was exerted on the spot for the duration of one horizontal line or 63.5 microseconds. Since we are considering ideal waveforms with zero retrace time, the spot snaps back instantly from point B to point C, when horizontal retrace is initiated, and point C will be on the same level as point B, since the spot is assumed to move from B to C in zero time. From point C the trace portion of the horizontal sweep again moves the spot from left to right, tracing the second line of the first field until it reaches the right side of the screen and the cycle is again repeated over and over until the spot reaches the bottom of the screen at point D. When point D is reached, the spot will have traced exactly 262.5 horizontal lines as indicated by Figure 3-5. Referring to the standard RMA signal, Figure 3-4, it will be noted that after 262.5 H have elapsed, T_1 plus 262.5 H, the leading edge of the first vertical synchronizing pulse in B occurs and will initiate vertical retrace, starting the second field. As indicated in Figure 3-6, the spot will move immediately (assuming zero retrace time) from the bottom of the screen, point D, to the top of the screen, point E.

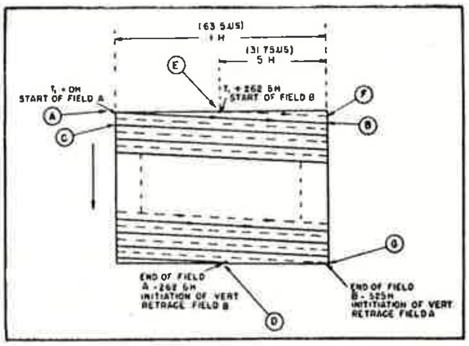

Fig. 3-6. Raster of a picture tube.

Since the vertical synchronizing pulse for this field occurs in the middle of a horizontal sweep cycle, as indicated in Figure 3-5, it will not initiate horizontal retrace and the spot will be in the centre when it reaches the top of the screen (point E) ready to start the first line of the second field. As the remainder of the trace portion of the horizontal sweep moves the spot across the screen toward the right-hand edge of the screen, the pull of the vertical sweep will move the spot down to point F, Figure 3-6, and the condition of interlace is produced since point F is exactly half-way between the top of the screen and point B. This is so because the first line of both fields start at the top of the screen, but since the duration of the first line of the second field is only half as long as for the first line of the first field, it is apparent that the downward pull of the vertical sweep will move the spot down twice as far as in the case of the first line of the first field, as it does for the first line of the second field, and, therefore, all the lines of the first field and the second field will be equidistant apart as indicated by Figure 3-6, where the solid lines represent the first field and the dashed lines the second field. At the completion of the last line of the second field at point G, Figure 3-5, 525 lines will have been traced, thus completing one frame. At point G, the complete cycle is repeated, horizontal and vertical retrace again being coincident, and the spot is again at point A, ready to start the first line of the first field for the second frame. This action is repeated over and over at the rate of 60 fields per second or 30 complete frames per second.

In the preceding explanation of how interlacing occurs, idealized sawtooth waveforms were considered, however such an ideal is not obtained in practice and a certain amount of time is consumed during the retrace period, as was pointed out earlier in the text. The only effect of this retrace time, as far as the horizontal sweep is concerned, is to make the duration of the trace portion of the sweep less than it would otherwise be with an ideal sweep with zero retrace time. This can best be illustrated by referring to Figure 3-7. As shown, the duration of the trace will be from A to B if no time is lost during retrace, but will only be from A to C if, let us say, 15% of the sweep cycle is consumed by the horizontal retrace in moving the spot back to the left edge of the screen. The spacing between lines is the same for both cases, as shown by Figure 3-7, and therefore the retrace time has no effect on interlacing but only reduces the duration of the trace. During the retrace period, as mentioned before, the spot is extinguished so that it will not be visible while moving from right to left back across the screen.

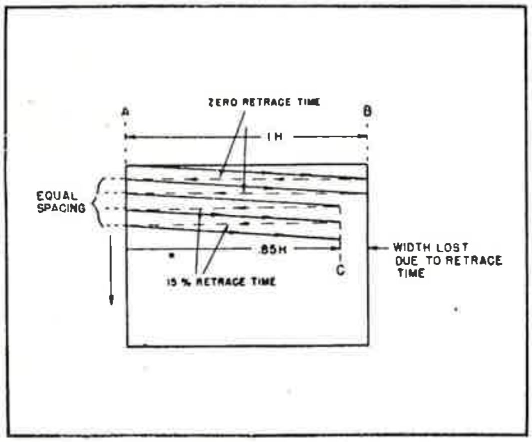

Fig. 3-7. Horizontal trace.

The effect of the retrace time in the vertical sweep is to reduce the trace portion of the vertical sweep, and instead of having 262.5 lines sweep across the screen from top to bottom for each field, as in Figure 3-6, where zero retrace time was assumed, about 12 of these lines will be consumed during vertical retrace while the spot is moving from the bottom to the top of the screen, and will reduce the total number of useful horizontal lines somewhat. In Figure 3-8 only a few of the horizontal lines consumed during vertical retrace are shown, but it serves to illustrate the movement of the spot across the screen in travelling from the bottom to the top. It will be noted that the slope of the lines is considerably greater than when the spot was moving toward the bottom of the screen, due to the rapid change in the vertical sweep voltage during vertical retrace. The lines in Figure 3-8 are dashed to illustrate the fact that the spot is extinguished during the time that it is moving from the bottom to the top of the screen. The time consumed during vertical retrace will not affect interlacing, provided that vertical retrace occurs at the same instant for each successive field, and that the time consumed during vertical retrace is the same for each field. As mentioned before, the only effect of the vertical retrace time is to reduce the number of horizontal lines moving in a downward direction, and thus reduce the number of visible lines.

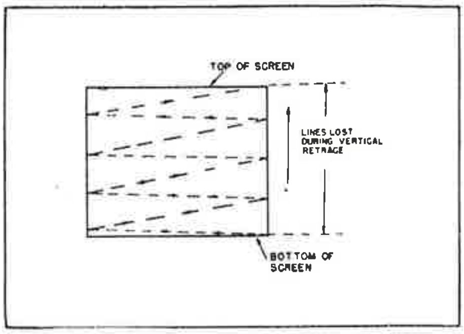

Fig. 3-8. Inactive horizontal lines.

11. Details of line and field blanking.

In the preceding paragraphs no attempt was made to consider line blanking and field blanking in detail. As mentioned before, the spot is extinguished during the time that it is moved from right to left during the horizontal retrace period, and this extinguishing of the spot is known as line blanking. In practice, it consumes about 16% of the horizontal sweep cycle. The spot is also extinguished during the time that it is moved from the bottom to the top of the picture during vertical retrace, and this is known as field blanking. In practice, it consumes about 7% of the vertical sweep cycle.

Figure 3-9 illustrates the relationship between the horizontal and vertical sweeps and line and field blanking. Starting at A, the spot is extinguished by the field blanking signal somewhat before the initiation of the vertical retrace which occurs at $T_1 = 0H$. At the initiation of vertical retrace, the spot will be at the bottom of the screen, and during the vertical retrace period it will move back and forth across the screen as it goes toward the top of the screen. If the spot were not extinguished during this period, a number of horizontal lines in the upward direction (retrace lines) would appear on the screen and would interfere with the lines in the downward direction which occur during the trace portion of the vertical sweep — therefore, the need for the line blanking signal during the vertical re-

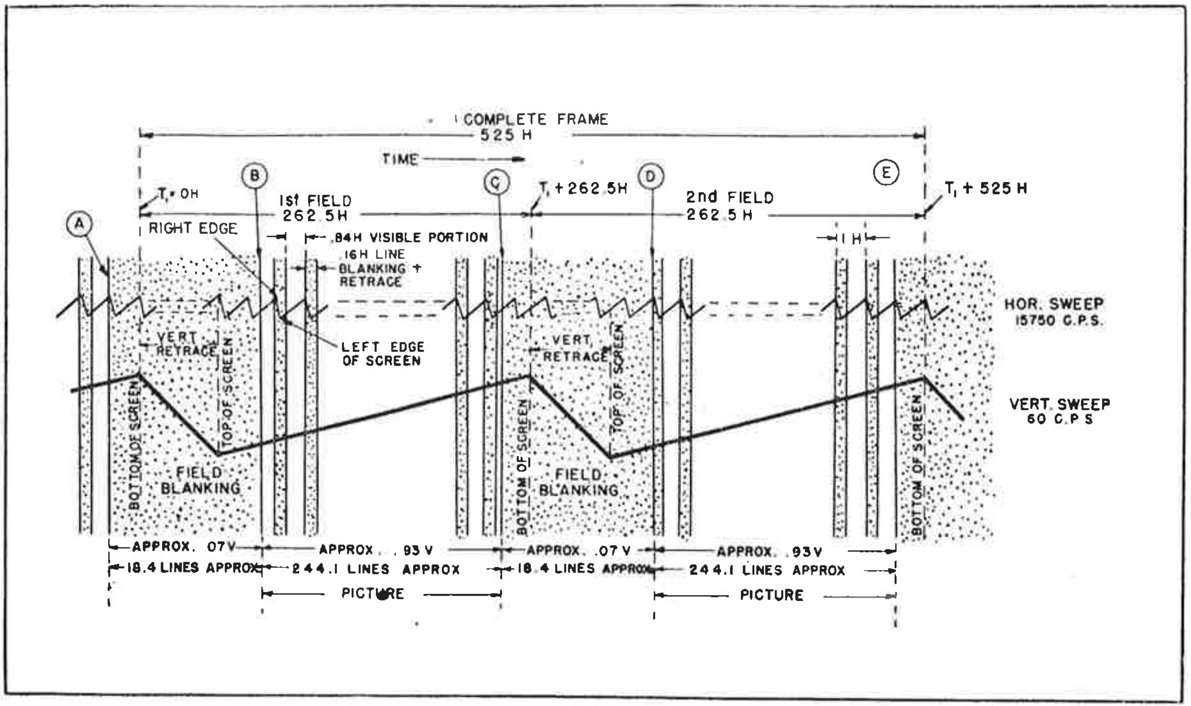

Fig. 3-9. Sweeps and blanking within a frame.

trace period. At the completion of the vertical retrace, the spot will be at the top of the screen, ready to trace lines in the downward direction. The field blanking signal, however, is not removed immediately after the completion of vertical retrace, but remains for a short time after, as shown at point B of Figure 3-9, so that the spot can gain its normal velocity in moving toward the bottom of the screen, thus blanking out any non-linearity at the start of the vertical sweep. The duration of the field blanking period is .07 V minimum to .08 V maximum, and for the minimum blanking time the horizontal sweep will have completed approximately 18.4 cycles. In other words, approximately 18.4 horizontal lines will have been blanked out during the field blanking period. These lines are referred to as inactive lines, since they are not active in reproducing the picture.

When the vertical blanking signal is removed at point B, the spot will be moving toward the right near the top of the screen, and remains visible until it nears the right edge of the screen, at which time the spot is again extinguished, but this time by a horizontal blanking signal which occurs just before the initiation of the horizontal retrace by a horizontal synchronizing pulse which moves the spot from the right edge to the left edge of the screen. As shown by Figure 3-9, the horizontal blanking signal remains for a short time after the horizontal retrace is completed, and is not removed until after the spot has gained its normal velocity in moving from left to right across the screen to trace another visible line of the first field. It should be noted that the duration of the horizontal retrace and line blanking consumes 16% of the horizontal sweep cycle, and that the spot is visible for 84% of the horizontal sweep cycle. This action continues, with the spot tracing visible horizontal lines from left to right and being extinguished just before and after each horizontal retrace period until the spot has traced approximately 244 visible lines. At this time the spot will be near the bottom of the screen, due to the downward pull of the vertical sweep when the field blanking signal again occurs at point C and the spot is again extinguished just before the initiation of vertical retrace for the next field. Shortly after the completion of vertical retrace for the second field, the field blanking signal is removed to point D, however, since a horizontal retrace occurs at this time the spot will remain extinguished until after the horizontal retrace is completed. The same scanning process is repeated for the 2nd field until approximately 244 visible lines have been traced on the screen, when field blanking again occurs at point E (which corresponds to point A in the 1st field), just before the initiation of vertical retrace for the next field, 525 lines after the start of the first field at T_1 = OH, thus completing one frame. Although each frame consists of 525 lines, only about 488 of them are visible on the screen of the picture tube, due to the fact that approximately 37 lines are blanked out during the two field blanking intervals per frame. The lines that are not blanked out are referred to as active lines, since they are the ones that actually trace the picture on the screen. The lines that are blanked out are called inactive lines, since even though the spot moves across the screen the lines are not visible, due to the action of the blanking signal on the grid of the picture tube in extinguishing the spot.

The actual movement of the spot, together with the effect of line and field blanking on the picture tube screen is shown by Figure 3-10. The solid lines represent the movement of the spot across the

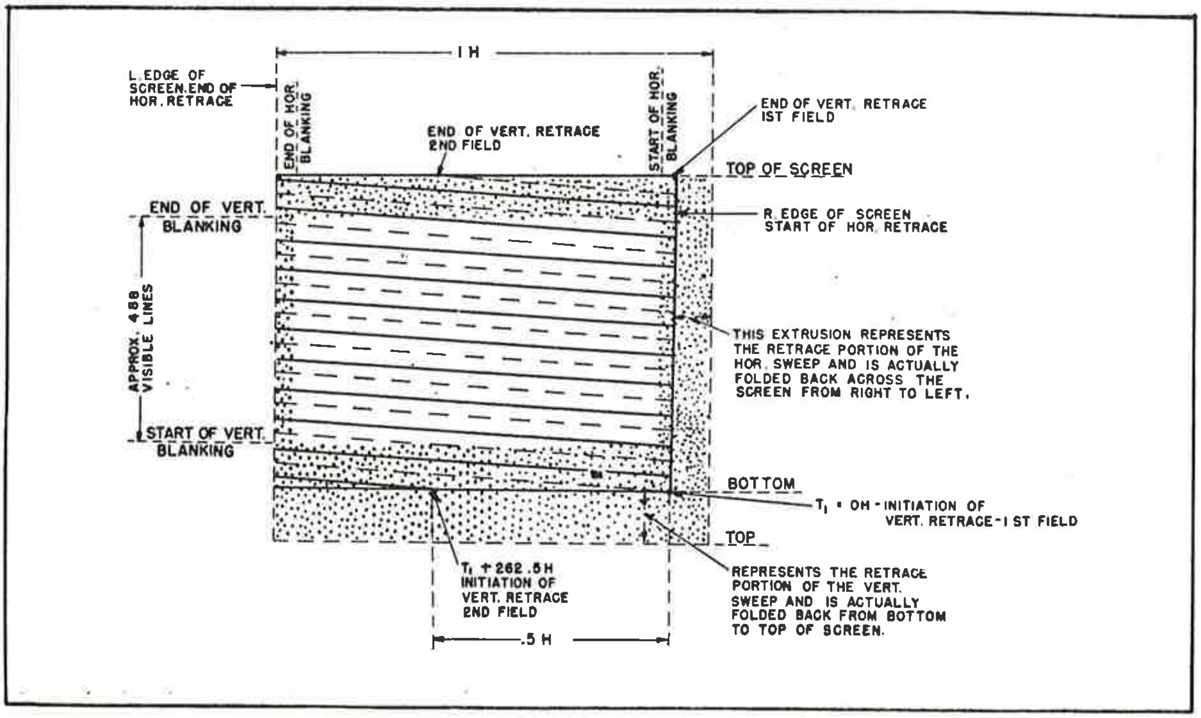

Fig. 3-10. Effect of blanking on picture size.

screen from left to right in a downward direction during the first field, while the dashed lines represent the movement of the spot from left to right for the second field. For simplicity, the movement of the spot in the upward direction which occurs during vertical retrace and the movement of the spot from right to left during horizontal retrace is not shown. Instead, the horizontal retrace interval is shown by an extrusion to the right of the screen to indicate that the retrace portion of horizontal sweep is actually folded back across the screen from right to left, while the spot is extinguished and the vertical retrace interval is shown by an extrusion at the bottom of the screen to show that the vertical sweep is actually folded back from the bottom to the top of the screen, while the spot is extinguished by the field blanking signal. The shaded portions at the top and bottom of the screen represent field blanking, while the shaded portions at the left and right edges of the screen represent line blanking.

As shown by the shaded portion near the bottom of the screen, field blanking begins a few lines before the initiation of vertical retrace for either field. Initiation of vertical retrace occurs at the very bottom of the screen. Vertical retrace for either field ends at the top of the screen. Vertical retrace for either field ends at the top of the screen, but field blanking remains for several lines, as shown by the shaded portion at the top of the screen. With a 7% field blanking period, approximately 488 visible lines will appear between the end of the shaded area at the top (removal of field blanking) to the beginning of the shaded area at the bottom (beginning of field blanking).

The shaded area at the right of the screen represents horizontal blanking which takes place just before the spot reaches the extreme right edge of the screen, at which time horizontal retrace is initiated, moving the spot back across the screen from right to left, as indicated by the extrusion on the right side of the screen. Horizontal retrace ends at the left edge of the screen, but horizontal blanking remains for a short time after the spot starts moving from left to right across the screen, as shown by the shaded area at the left of the screen.

The start of vertical retrace for the first field occurs at the bottom right-hand corner of the screen, and if we assume that the horizontal retrace also occurs at this point, and if an exactly even number of horizontal lines occur during vertical retrace, then the spot will be at the upper right-hand corner of the screen, at the end of vertical retrace. However, immediately after the spot reaches the top-right of the screen, horizontal retrace occurs, moving the spot to the left edge of the screen slightly down from the top ready to trace the first line of field 1 in the downward direction, as shown by the first solid line in Figure 3-10. After the completion of 262.5 lines following the initiation of vertical retrace for the first field, the spot will be at the bottom of the screen exactly .5 H away from the start of the first field, when vertical retrace for the second field occurs. The same number of lines will occur during vertical retrace for the second field as for the first field and the spot will, therefore, be at the top of the screen exactly .5 H away from the right-hand edge at the end of vertical retrace for the second field. Immediately after the spot reaches the top of the screen, it will move toward the right-hand side of the screen for .5 H, as shown by the dotted line, and will be spaced exactly .5 H away from the solid line, which is the desired condition for interlaced scanning. The spot will again be at the lower right-hand corner of the screen, 262.5 lines after the start of the second field, and one frame will have been completed.

12. Summary of Chapter III.

1. Picture carrier is 1.25 mc above lower frequency limit of channel.
2. Sound carrier is .25 mc below the upper limit of channel.
3. Separation between carriers is 4.5 mc.
4. Vestigial side-band method of transmission is used.
5. Response of video i-f channel is 50% down at the i-f frequency, corresponding to the picture carrier.
6. The flat portion of the video signal as transmitted is 4.75 mc wide, with the upper side-band flat out to 4 mc from the carrier and dropping off to zero at 4.5 mc from carrier. The lower side-band is flat out to .75 mc and drops off to zero at 1.25 mc from carrier.
7. The maximum deviation frequency of the sound carrier is ±25 kc.
8. The relative radiated power for picture and sound is approximately the same.
9. Number of fields per frame = 2.
10. Lines per frame = 525.
11. Lines per field = 262.5.
12. Number of fields per second = 60.
13. Number of frames per second = 30.
14. Polarity of transmission is negative.
15. Approximately 25% of signal amplitude is devoted to synchronizing signals.
16. Black level is fixed at 75% of maximum amplitude. White in picture is set at 15% or less of maximum amplitude.
17. Frequency of horizontal sawtooth sweep = 15,750 cycles per second.
18. Duration of one complete horizontal sweep cycle = 63.5 microseconds.
19. Duration of trace portion of horizontal sweep cycle = approximately 57.5 microseconds (varies with retrace time in receiver).
20. Duration of retrace portion of horizontal sweep cycle = approximately 6 microseconds (varies in receivers).
21. Duration of horizontal retrace and blanking = .16 H or 10.16 microseconds.
22. Duration of visible portion of horizontal trace = .84 H or 53.34 microseconds.
23. Frequency of vertical sawtooth sweep = 60 cycles per second.
24. Duration of one complete vertical sweep cycle = 16,667 microseconds.
25. Duration of trace portion of vertical sweep cycle = approximately 15,834 microseconds (varies with retrace time in receiver).
26. Duration of retrace portion of vertical sweep cycle = approximately 833 microseconds (varies in receivers).
27. Duration of vertical retrace and blanking 0.7 V minimum and .08 V maximum where V = 262.5 H. Approximately 1,270 microseconds.
28. Approximately 19 horizontal lines blanked out during the vertical retrace and blanking period. These are called the inactive lines.
29. All synchronizing pulses are above the black level (blacker than black).
30. Horizontal sweep cycle starts at each 1 H interval or each 63.5 microseconds. Controlled by a synchronizing pulse.
31. Duration of horizontal synchronizing pulse approximately 5.08 microseconds.
32. Duration of "front porch" of horizontal synchronizing pulse approximately 1.27 microseconds. Duration of back porch approximately 3.8 microseconds.
33. There is a 1 H or 63.5 microsecond separation between leading edges of horizontal synchronizing pulses.
34. Vertical sweep cycle is initiated once every 262.5 H or 16,667 microseconds.
35. Six vertical pulses occur during vertical synchronizing pulse interval of 190.5 microseconds.
36. Leading edge of every second vertical pulse is separated by 63.5 microseconds to maintain horizontal synchronizing during vertical retrace.
37. Duration of each vertical synchronizing pulse = 27.3 microseconds.
38. Six equalizing pulses precede and follow the vertical synchronizing pulse interval to insure identical conditions at the start of successive fields.
39. Duration of equalizing pulse = 2.54 microseconds.
40. Leading edge of every second equalizing pulse is separated by 1 H or 63.5 microseconds.
41. All synchronizing pulses have the same amplitude.
42. Synchronizing pulses are separated from video by amplitude clipping.
43. Horizontal and vertical synchronizing pulses are separated from each other by waveform method of separation.
44. Interlacing occurs due to the .5 H difference between the start of successive fields.
45. There are approximately 485 visible or "active lines" per frame.
46. There are approximately 38 invisible or inactive lines per frame due to field blanking.
47. The vertical or field blanking period blanks out the last few lines near the bottom of the screen, the lines occurring during vertical retrace and the first few lines at the top of the screen.
48. Horizontal blanking blanks out a portion of each horizontal line at both edges of the screen and the retrace.

Increasing Tube Reliability In Industrial Circuits

By **D. G. Koch,** **Tube Department, Radio Corporation of America, Harrison, N.J.**

A single tube failure in industrial electronic equipment may cost the equipment user hundreds of times the price of the tube. Tube failures often are caused by improper equipment design practices, particularly in cases where receiving-type tubes are used in industrial applications. Considerable progress has been made in programs aimed at increasing tube reliability in industrial circuits. Of particular importance are the ways in which the circuit designer may prolong the life of the tubes.

More industrial-type tubes are now available to equipment designers — tubes designed for specific industrial applications. Often, however, new circuit applications require particular tube characteristics which are as yet available only in receiving-type tubes. When these tubes are used, special care must be taken to insure reliability in operation. Receiving-type tubes are designed for use in home instruments, where it is unlikely that they will be subjected to extremes of temperature, to excessive shock and vibration, or to various other severe environmental or operating conditions encountered in industrial equipment.

In cases where it is necessary to use receiving-type tubes in industrial circuits, certain equipment design practices may be employed to increase reliability. Many such practices will be discussed in this article. All of them are important to the designer.

Range of tube characteristics.

Practical considerations, such as production speeds, testing problems and material costs, often fix the range of tube electronic characteristics at ± 20 to 40 per cent. of design-centre values. Even on special industrial types, where tighter controls and premium materials are economically feasible, characteristics may have tolerances of ± 10 to 20 per cent. These tolerances are caused largely by variations in dimensions of internal parts and in chemical properties of inner tube surfaces. The tolerances also reflect some unavoidable shifting of characteristics from one manufacturing lot to the next.

In a particular high-impedance triode, for example, typical manufacturing tolerances are in the order of ± 1 per cent. on coated cathode diameter; ± $1\frac{1}{2}$ per cent. on grid diameter; and ± 2 per cent. on plate diameter.

A cumulative variation in characteristics of ± 5 to 10 per cent due solely to such tolerances on parts can exist in an appreciable number of these tubes.

Tube characteristics are also affected by such factors as degree of activation of the cathode over its length; contact potential between grid and cathode; and tendency toward secondary emission. And since complete stabilization of all tubes by pre-burning is not practical, wide variations in initial characteristics are normal. For example, because traces of metallic or gaseous contaminants on electrode surfaces affect contact potential, it is impractical to control the grid contact potential to limits closer than ± 0.3 volts.

Because characteristics do vary from tube to tube, and also because many tube characteristics change during life, it is well to design circuits for operation over a wide range in tube characteristics. Life tests on a typical tube show that its average life is increased $2\frac{1}{2}$ times if the acceptable change in transconductance is doubled. And the average life is increased 5 times if the acceptable change in plate current is doubled.

From the standpoint of reliability, however, the equipment designer is more interested in per cent. survival of tubes than in average tube life. For example, he would rather know that all tubes will last 1,000 hours than know the average life is 5,000 hours with a few tubes failing before 1,000 hours and a few lasting longer than 10,000 hours. Unfortunately, the latter case is closer to actual experience. In general, the survival of tubes in operation is typified by Fig. 1, in which the curve follows an exponential law after 2,500 hours.

The effect of wider tolerances for tube characteristics on survival is illustrated in Fig. 2. Per cent. survival vs. hours of operation is plotted for maximum allowable transconductance changes of 10 and 40 per cent. respectively. If the desired reliability criterion is survival of 80 per cent. of the tubes, it can be seen that a transconductance limit of 10 per cent. change yields 1,000 hours' life, while a limit of 40 per cent. change yields 9,000 hours' life. Often, tube life may be further extended by providing means of adjusting circuit conditions, at least initially.

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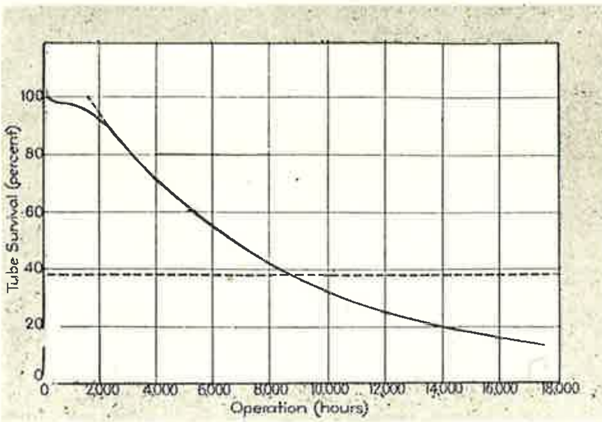

Fig. 1 — Survival curve of a filamentary triode-type tube. Average life is the point at which 37 per cent. of the tubes are still operative.

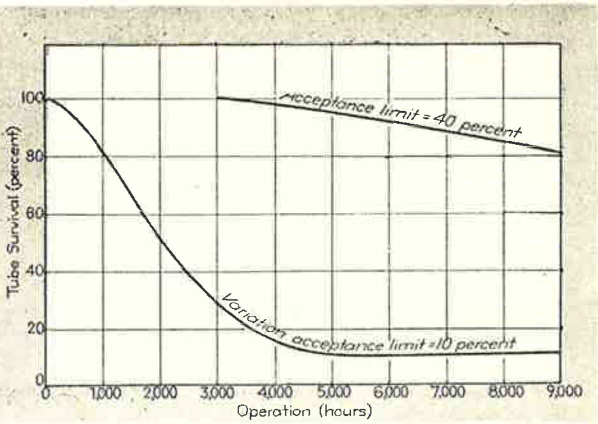

Fig. 2 — Typical survival curves for tubes in which variations of 10 and 40 per cent. in transconductance are allowable. Circuits should be designed for wider variations in tube characteristics.

Pre-burning and tube selection.

Tube failures may occur in significant number during the early hours of life. Many of these failures are caused by opened welds or shorted elements. Other early failures are caused by sudden shifts in tube characteristics to values outside acceptable limits. To improve tube reliability, many industrial users pre-burn tubes for 50 to 100 hours under conditions simulating intended applications to stabilize characteristics further and also to eliminate early mechanical failures. Tubes designed specifically for industrial service often receive a similar 50 hours' stabilizing burn-in as part of the standard manufacturing processing. Pre-burning of all mass-produced tubes is, of course, impractical.

To get a desired range of tube characteristics an equipment designer sometimes is tempted to select, from available stocks, tubes having tolerances closer than tube manufacturers provide. If the quantity of tubes involved is sizable, however, this practice can be costly. Furthermore, there is no assurance that the yield of tubes with the desired range of characteristics will be maintained in future production. Such an arrangement also poses tube replacement problems for the equipment user.

In industrial service, successful operation of a circuit often depends on some tube characteristic for which there is no published information. In such cases, the tube manufacturer can advise the equipment designer as to how closely a given tube type does maintain the desired characteristic. The tube manufacturer may suggest another type in which the critical characteristic is controlled more closely.

Maximum tube ratings.

Maximum tube ratings set by tube manufacturers are the limits within which tubes must be operated for satisfactory performance. Ratings for receiving-type tubes, in general, are not as conservative as those for industrial types. Therefore, when receiving-type tubes are used in industrial circuits where longer life is desired, maximum ratings must be re-evaluated.

When several maximum ratings are given it is not wise to assume that one rating (for example, plate voltage) may be exceeded, provided that a corresponding reduction is made in the other ratings. The first maximum rating reached should set the limits for all other conditions.

The operating frequency is another factor to be considered. When tubes are operated at high frequencies, the internal tube losses increase, reducing efficiency and, therefore, permissible maximum input. Dielectric losses in the glass stem between lead wires may increase sufficiently at high frequencies to raise the glass temperature and hasten electrolysis failure. Rectifiers operate at high temperatures and high inverse voltages and, therefore, are particularly susceptible to electrolysis. At high frequencies, dielectric losses in the glass envelope near points bombarded by stray electrons may increase sufficiently to overheat the glass, causing cracks or evolution of gas from the glass envelope. In all cases, therefore, the permissible tube dissipations for maximum reliability are lower for operation above some critical frequency.

Envelope temperature.

Tube life may often be extended by maintaining envelope temperatures at low values. This is especially important in power-output types because of their higher plate and heater dissipations. The temperature rise of the envelope may be limited by: (1) reduction of total tube dissipation; (2) provision for improved ventilation; and, (3) maintenance of low ambient temperatures. In general, the envelope temperature of small receiving-type power tubes should be kept below 175°C for increased reliability.

The tube envelope, as well as other glass and metal surfaces within the tube, holds by adsorption and absorption small amounts of gases. If released during tube operation, these gases cause poor performance.

In receiving-tube processing, the degassing process includes heating of all parts to drive off gases, mechanical evacuation of the tube by high-vacuum pumps, and chemical cleanup of gases within the tube by gettering materials. All but minute quantities of adsorbed gas are removed from the glass envelope. The complete removal of adsorbed gas from the glass envelope would require hours of baking at temperatures of 250° to 300°C, which is impractical for high-volume receiving types. If, during subsequent tube operation, envelope temperatures equal or exceed those used on exhaust, some of the remaining adsorbed gases will be liberated. A limited amount of these gases can be absorbed by the gettering material, but excessive gas evolution results in minute traces of free gas in the tube.

The presence of free gas in a tube can be undesirable for a number of reasons. The gas molecules may become ionized due to collisions with electrons during tube conduction. These ionized molecules migrate to the negative electrodes in the tube. Those travelling to the control grid are equivalent to an electron flow from the grid, and produce across any grid circuit resistance a voltage drop which tends to increase the flow of cathode current. In addition, if ions arriving at negative grids are sufficiently energized, they knock out electrons and cause reverse or secondary emission from the grids.

Gas ions arriving at the cathode may dislodge cathode coating material by bombardment. Furthermore, because the hot cathode has a great affinity for gas, ions arriving at the cathode combine with the free barium, so that emission is gradually reduced. Thus, envelope temperature is more critical for tubes having smaller cathode areas.

The envelope temperature is a function of the heat generated within the tube, the envelope size, and the ambient temperature. The relationship of envelope temperature to total power dissipation for tubes of various sizes operating in air of normal room temperature (approximately 30°C) is shown in Fig. 3.

The temperature of the plate and screen electrodes of tubes results primarily from the conversion into heat of the energy of electrons arriving at these electrodes. Typical operating temperatures for the plate and screen electrodes of power pentodes are of the order of 400 to 450°C. Plate temperatures for triode types range from 300 to 400°C, depending upon the power input. Any increase above these temperatures results in envelope temperatures which are increasingly troublesome. In addition, the probability of release of residual gases from the parts is increased.

The ambient temperature can be controlled by good ventilation, using blowers if necessary. Reductions in envelope temperature have been obtained with miniature and subminiature tubes by the use of close-fitting metal jackets thermally connected to the chassis so that the chassis serves as a heat-radiating surface or by shields designed to cool the envelope with convection currents. When a solid bond to the chassis is not made, the use of conventional metal shields around tubes can raise envelope temperature as much as 50°C. To promote heat radiation, plated shields should be avoided and surfaces surrounding the tube unpolished.

Cathode temperature.

For long life, oxide-coated cathodes must be operated at recommended temperatures. For most tube types, ±5 per cent. of rated value is the maximum allowable heater-voltage variation for long life. Because industrial electronic equipment often must operate with varying line voltages, regulation of heater voltage should be considered.

At cathode temperatures above recommended values, evaporation of free barium from the cathode surface is accelerated, and cathode emission decreases with time to values insufficient for certain applications. This effect is most serious in the case of power-output and rectifier types, where normal cathode temperature is relatively high to provide the abundant emission required for satisfactory performance.

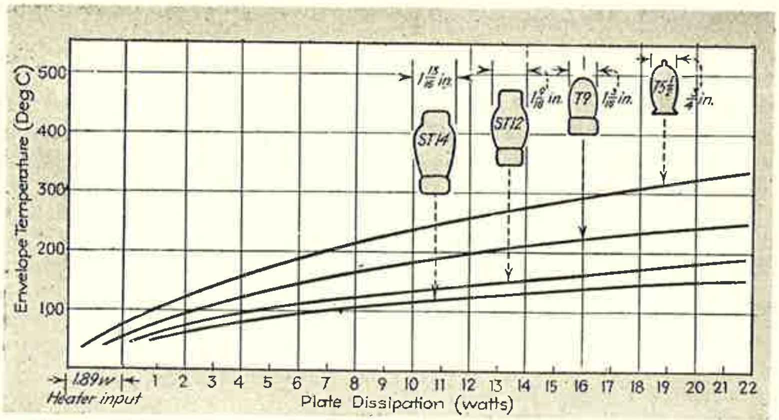

Fig. 3 — Envelope temperatures as a function of input power for various sizes of glass tubes. Excessive temperature can shorten the life of any tube and is a more critical problem in the smaller-envelope sizes.

Elevated cathode temperatures cause the deposition of vaporized emitter materials on tube electrodes such as grids or plates, or on surfaces of glass or mica insulators. Such deposits increase the tendency of electrodes to become emitters during operation, and may cause undesirable reverse currents to flow. If such currents flow in a grid circuit containing high resistance, the voltage drop produced often upsets normal functioning of the tube. Higher cathode temperatures in turn cause higher operating temperatures of other electrodes and increase the possibility of reverse emission. Deposits of emitter material on insulating surfaces may give rise to noise or faulty insulation between electrodes.

On the other hand, when the cathode is operated below recommended temperature, emission decreases and may go below the safe limit required to maintain desired tube characteristics over a long period of operation, especially in applications requiring high peak current or power. A phenomenon known as sparking may result from the emission becoming confined to localized spots of high current density in the cathode.

A more common effect of low-temperature operation is poisoning of the cathode because of gas absorption. The lower the cathode temperature, the more readily it absorbs gas. Very small amounts of oxygen or carbon monoxide poison a cathode (i.e., drastically reduce its emission).

If voltages are applied to other electrodes while the cathode is below operating temperature, ion bombardment of the cathode may cause permanent damage to the cathode coating. After the cathode has reached operating temperature, the electron cloud surrounding it neutralizes ions arriving there and prevents damage to the coating. Thus, where equipment is subject to many cold starts, the life may be extended by applying electrode voltages only after a cathode warm-up.

Grid resistance.

In the present stage of the tube-manufacturing art, grid currents of the magnitude of one microampere may be present in receiving-type tubes. The designer, however, can frequently compensate for this grid current by using the smallest practicable value of grid resistance. This precaution is necessary because excessive grid resistance may produce "run-away" tubes. Whatever negative grid current exists flows through the grid resistor, causing a shift in bias that is proportional to the value of resistance. For instance, a negative grid current of one microampere through a grid resistance of one megohm decreases the negative bias by one volt. The bias shift tends to increase plate current.

A larger plate current increases ionization collisions and thus ion current to the grid, which, therefore, swings even less negative. If grid resistance is too large, this effect may be cumulative, so that plate current reaches destructive values.

Negative grid currents may result from ionization of residual gases, grid emission, or leakage across insulation inside the tube or externally across the tube base.

An additional reason for reducing grid resistance is that high grid resistance increases the susceptibility of the circuit to the pick-up of undesired voltages. Transformer coupling between stages of amplifiers is often advantageous for obtaining low d.c. grid resistance. Usually, the grid resistance should be kept under 200,000 ohms for power-output types and under 2 megohms for all other types. Cathode-resistor bias, by virtue of its effective degeneration, may be used to minimise the harmful effects of larger grid resistances.

Operation of heaters.

When full heater voltage is applied to a cold heater, the heater assembly is subjected to thermal shocks and strains caused by expansion and unequal heating of the heater wire. Expansion causes physical abrasion against the cathode, especially near the cathode ends. During warm-up, strain is also placed on the heater welds at the stem leads. A high rate of on-off switching may cause heater failure due to fatigue.

In many installations it is possible to maintain continuous operation, and thus to reduce the frequency of switching. Or, by applying or removing heater voltage gradually when the equipment is turned on or off, heater failures can be virtually eliminated.

In general, low-voltage (6.3 v) and high-current (300 milliamp or more) heaters, because of their heavier wire, are better than high-voltage or low-current heaters for reliability.

Under certain conditions, series-string operation may represent very severe service. For purposes of illustration, a conventional receiver uses types 12BA6, 12BE6, 12AV6, 50B5, and 35W4 with all heaters connected in series. If the heaters are all at room temperature, then at the instant voltage is applied to the heaters a current of the order of 6.5 times the "hot" current flows through the heater string. The 12 v heaters have lower thermal inertia, and so they show a more rapid increase in heater resistance and temperature than do the 50B5 and 35W4. As a result, initially most of the line voltage appears across the three 12 v heaters.

The curves of Fig. 4 show that within the first second after voltage is applied to the heater string, the voltage across the 12AV6 rises to 31.5 volts, while the voltage on the 35W4 and the 50B5 remains well below rated values for five seconds or more. The effect on the 12AV6 heater voltage of replacing part of the series string with a resistor is shown in Fig. 5. Replacing the 12BA6 with an 89-ohm resistor reduces the peak heater voltage on the 12AV6 by 20 per cent. Replacing the 35W4 with a 247-ohm resistor reduces the peak voltage by approximately 30 per cent. to 21 volts. In addition the rate of rise of heater voltage is decreased as the series resistance is increased, further reducing thermal shock to the heater.

The effects of series-string operation are aggravated by the fact that the temperature is not uniform along the length of the heater, but may be concentrated in small sectors such as the uncoated sections of wire near the stem lead welds.

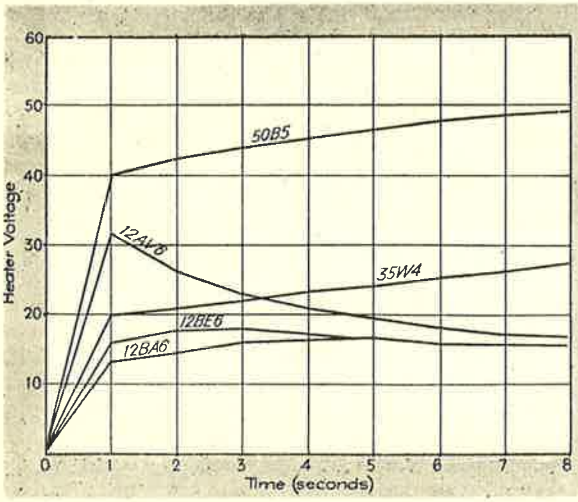

Fig. 4 — Initial heater-voltage surges in series-string operation of five different receiving tubes. Type numbers of tubes are indicated on the curves.

On tube types having a cathode of small mass and low thermal inertia, the heater temperature may rise to a value that will cause sintering of the heater insulation.

If series-string operation is unavoidable for particular applications, the following will improve reliability.

1. Use tubes with less than 300 milliamp heater current.
2. The total heater voltage of slow-heating types should be less than half the total string voltage. Limit the surge voltage across any heater to less than twice the rated value.
3. A resistor should be used in series with the heater string to make up at least 15 per cent of the load.
4. Series-parallel combinations should be avoided. A resistance in parallel with part of the heater string increases voltage surges. For instance, if a resistor is used across a 150-milliamp heater to include it in a 300-milliamp string, the 150-milliamp heater passes a greater current initially than it would in a 150-milliamp string. If possible, high-current heaters should be used in one string and low-current heaters in another.

Standby and cutoff operation.

During vacuum-tube operation, a layer known as the inter-face gradually forms between the cathode base metal and the cathode coating. If, however, the tube operates for long periods of time while biased beyond cutoff, this inter-face layer may take on characteristics equivalent to those of a cathode resistor of a few hundred ohms shunted by a capacitance of 0.01 microfarad, resulting in faulty circuit performance.

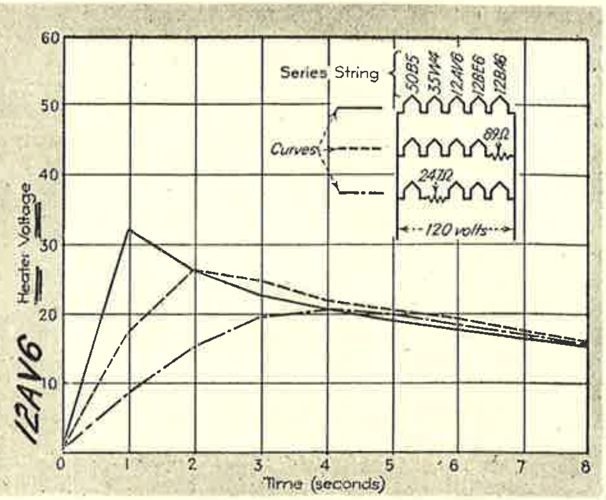

Fig. 5 — Curves illustrating the effect of inserting resistance in series with a heater string. Legend at top right identifies the curves.

In some cases, cutoff life is as little as 5 per cent. of average conduction life. However, if the minimum cathode current can be maintained greater than 0.5-1.0 milliamp, harmful effects of the interface layer can usually be avoided satisfactorily.

Some cathodes exhibit this interface characteristic and others do not, depending to a large degree upon the composition of the cathode base metal. Because receiving-type tubes are designed for the requirements of radio service, where cutoff operation is not a problem, these types may not have a satisfactory "cutoff-life" characteristic. Several industrial tube types are made with relatively "inactive" cathodes to improve performance in applications where cutoff life is important.

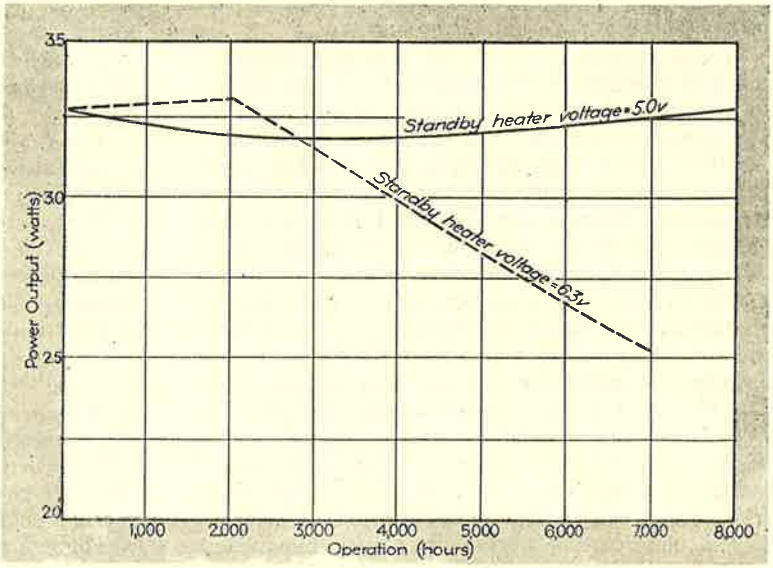

Fig. 6 — Effect on life of reduced heater voltage during standby operation of a typical receiving tube. If such usage is needed, tube life can be extended by applying reduced heater voltage during standby.

Standby or heater-only operation produces effects similar to those of cutoff operation, and should be avoided where possible or at least restricted to short periods of time. If standby operation is required, tube life may be extended, as demonstrated in Fig. 6, by operating the heater at reduced voltage during standby.

Shock and vibration.

Conditions of shock and vibration may cause a tube to fail by shifting its characteristics, by causing a short between elements, or by causing an open circuit in one of the elements.

Receiving tubes are generally not designed or tested to withstand unusual shock or vibration. Tubes designed for industrial service, however, incorporate features that make them less susceptible to shock and vibration failure. There is a limit, nevertheless, to how far tube design can accommodate shock and vibration and still provide desired electrical characteristics. Beyond this point shock and vibration must be reduced or eliminated by suitable shock mounting of equipment and tube sockets. Much can be done even with standard tubes by proper shock mounting. All electrical connections to a shock-mounted socket should be flexible or the purpose of the shock mounting may be defeated. If vibrations are air-borne, damping of the tube with lead may be required.

Noise and hum output.

Although most industrial applications do not require critical limitations on noise or hum output, several methods may be used to reduce tube noise or hum where necessary. Electro-magnetic and electrostatic fields set up within the tube envelope by the heater may produce a hum voltage in the tube output circuit. Such hum can be nullified by a hum-balancing potentiometer connected across the heaters with the centre-tap connected to ground. Often sufficient balance is obtained merely by connecting the heater transformer centre-tap to ground.

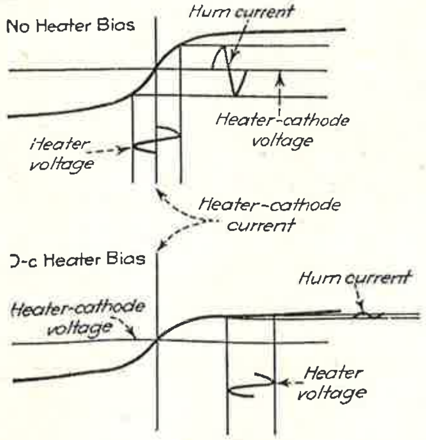

Fig. 7 — Resistance characteristics of heater insulation material, showing effect of d.c. heater bias on hum. Leakage of current through the heater insulation can have undesirable effect on operation.

Hum output may also be caused by leakage through the heater insulation material. As shown in Fig. 7, the resistance of the insulation varies with d.c. bias, the lowest value of resistance occurring within a volt or two of zero bias.

When a heater-cathode type tube is operated with cathode-resistor bias, it is possible that leakage through the insulation between the a.c. operated heater and the cathode will be sufficient to develop voltage across the cathode resistor. The undesirable effects of such a voltage can be avoided if the cathode resistor is bypassed with a capacitor of 25 microfarads or more. If bypassing is not possible, a d.c. bias of 5-60 v positive or negative applied between heater and cathode shifts the operating point to the relatively flat portion of the curve, as shown in Fig. 7, and the hum current is reduced considerably.

The undesirable characteristic known as microphonism must also be considered in high-gain amplifier design. A tube is microphonic when, with no input signal, it gives rise to an output voltage while it is being lightly tapped with a felt mallet. Microphonism is a resonant effect. The microphonic output is the result of resonant vibration of some internal tube structure. If the microphonic tube is acoustically coupled to the audio output of the amplifier of which it is part, sustained oscillation may result. Tube manufacturers have gone to extensive measures to control microphonic characteristics of critical tube types. But in spite of all precautions, some microphonic tubes undoubtedly will appear good during testing and pass inspection.

Shock-mounting the socket will isolate the tube from the chassis as a source of vibration or shock. If the acoustic feedback is through the air, other components may be placed in the air path between the acoustic output and the tube, and the sound reproducer may be moved farther away. Where space is at a premium, the tube vibration may be damped by such means as weighting the critical tube with a cylinder of lead. Noises known as thumps, clicks or pops may be detected by testing, and tubes exhibiting these noises can be removed from critical stages and used in the less critical later stages.

Socket design.

Industrial electronic equipment is often expected to operate at elevated temperatures, in corrosive, humid, or dusty atmospheres, and under conditions of vibration. Good tube-socket design can improve circuit performance and reliability in such cases.

Tube sockets should be made of the best dielectric materials. The metal parts should be plated with corrosion-resistant material such as nickel. The socket contacts should grip the tube pins firmly without putting a physical strain on the rest of the tube structure, such as the glass stem of miniatures. In some cases, the use of shields that lock to the base of the tube is required to keep the tubes secure in the sockets.

The use of heavy wiring for connections to the tube socket terminals promotes longer life in some cases by reducing the temperature of leads within the tubes.

If leads run too hot, rectifiers will have shorter life due to electrolysis of the glass between the leads. In certain tubes such as power-output tubes, where grid temperatures tend to run high, heavier electrical connections are used between the grid and the stem leads to reduce the grid temperature and to prevent grid emission. In such cases, good thermal conductivity of the socket contacts and of the wiring to the grid may help.

Tube maintenance.

The designer of industrial electronic equipment should consider the problem of maintenance, including availability of replacement tubes, frequency of tube maintenance routines, and the manner of testing tubes. Ease of maintenance is often a key to reliable operation.

A common practice in industry is the replacement of tubes on a periodic schedule regardless of their condition. It is doubtful that this method insures any greater reliability, because tube failures in operation follow a logarithmic pattern (Fig. 1), with some tubes failing in a few hours and others lasting several thousands of hours. The automatic replacement schedule neither eliminates early failures nor obtains the benefit of the better tubes having long useful life.

In general, tube failures may be classified as sudden or gradual. The sudden failures are due to such causes as shorts between elements and open elements, and usually occur early in life. They are unpredictable, but may often be reduced by a preburning operation before actual use in equipment.

Most tube failures, however, are due to the gradual decrease in emission or transconductance, and can be detected before performance is below minimum requirements by periodic tube checks. Preferably these checks should consist of measurement of tube performance in actual operating equipment. To facilitate such tests, the designer should provide easy access to tube sockets or special testing connections brought out to convenient terminals. The tests should indicate the margin of safety remaining in critical operating characteristics.

A refinement of this technique is the "Marginal Checking" system in use on at least one large electronic computer. This system consists of changing operating conditions (such as supply voltages, signal levels, etc.) in such a manner that the computer will misperform if tubes of marginal performance are present. Additional means are provided for making such checks on small sections of the computer to localize a failure rapidly.

Industrial tube designs.

Circuit reliability can best be obtained by using the available industrial-type tubes whenever possible. Examples of such tubes are the RCA-5691, 5692, and 5693. This Radiotronics cover shows many special features have been incorporated in the industrial types to insure reliability in specific industrial applications.

Long life is also built into these special tubes as the result of: (1) designing the cathode to operate at relatively low temperatures; (2) maintaining exacting control during processing to prevent deposit of cathode materials on other electrodes; (3) using pure-tungsten heaters provided with sleeves to give long heater life with frequent "on-off" switching; (4) inspecting each assembly for adherence to rigorous specifications; (5) rating the tubes conservatively; (6) using inactive cathode base metal for good cutoff life.

All industrial tubes are given a stabilizing 48 hour aging before testing. Tests are made for more characteristics and to tighter limits than on receiving types. For example, the published characteristics state that the maximum value of reverse grid current is 0.2 microamp for type 5691 and 5692 and 0.1 microampere for type 5693.

These features combine to make a tube having a minimum life of 10,000 hours, exceptionally uniform and stable characteristics, and resistance to shock and vibration.

New RCA Releases

Radiotron — 12BF6 is a multi-unit miniature tube of the heater-cathode type containing two diodes and a medium-mu triode in one envelope. It is intended primarily for use as a combined detector, amplifier, and avc tube in automobile radio receivers operating from a 12-volt storage battery.

The characteristics of the triode unit are such that it can be impedance-coupled or transformer-coupled to the output stage. In either case, the triode unit can supply more than ample output with low distortion to drive a pair of 12V6-GT's operating at maximum plate voltage in the output stage of automobile receivers.

Radiotron — 5726 is a high-perveance, miniature twin diode especially useful as a detector in circuits utilizing wide-band amplifiers. Constructed to give dependable performance under shock and vibration, this "premium" version of the 6AL5W is particularly suited for use in mobile and aircraft equipment.

The two, sturdy, coiled heaters used in the 5726 are internally connected in series to provide fail-safe operation in applications which require that burnout of either heater will make the heaters of both units simultaneously inoperative. These heaters employ pure tungsten to provide long life under conditions of frequent on-off switching.

The "premium" quality of each 5726 is assured during manufacture by rigid controls and rigorous tests.