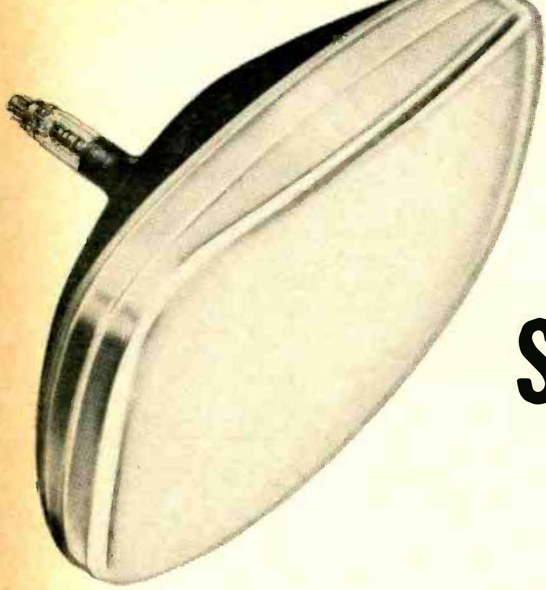


Some entirely new approaches to sweep circuit design must be made before reasonably priced, large-screen transistor TV sets make their appearance. Here are the design details.

SEMICONDUCTOR SWEEPS FOR LARGE-SCREEN TV

BY DON LANCASTER

THE fundamental limitation to an all-semiconductor 24- or 27-inch TV set has been the high cost of the transistors used in the sweep circuits, particularly the horizontal output stage. This last limitation to large-screen, solid-state television is about to be swept away, as indicated by the large number of recent technical articles dealing with this specific problem.

Three Major Approaches

There are now three major new approaches to the semiconductor sweep problem, all of which are radically different and all of which promise to make the horizontal output stage a low-cost, high-efficiency, and highly reliable circuit. These three methods differ markedly in their approach to the problem and in the actual semiconductors used. One new approach uses a gate controlled switch (GCS) in a very high efficiency, straightforward circuit. The second method makes use of conventional transistor circuitry but uses transistors of new price and performance capability. The final method employs a silicon controlled rectifier (SCR) in an unusual circuit configuration that eliminates the need for a conventional horizontal oscillator and driver and combines the power and flyback transformers into one multiwinding transformer.

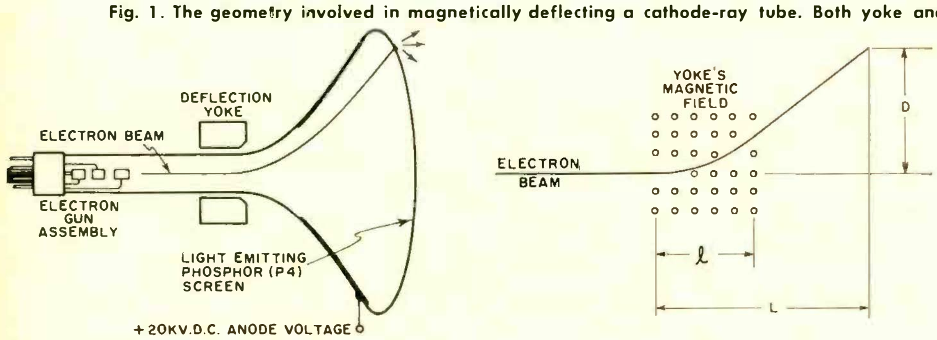
The advantages to be gained in an all-semiconductor TV are quite numerous. Today, the tube-type horizontal sweep circuits account for a major percentage of service problems and produce more heat than any other single circuit area. Further, because these circuits are the bulkiest and heaviest, they are in direct conflict with the set designer's ultimate goals of extreme portability and picture-on-the-wall, "two-dimensional" television sets. The tube-type sweep requires high-voltage supplies, in excess of that obtainable directly from the 117-volt line (without the use of doublers, etc.) or from 12-volt batteries compatible with portability. For these reasons, major design emphasis is being placed on this area by virtually every set manufacturer.

Basic Principles

The geometry and mathematics involved in a magnetically deflected CRT is shown in Fig. 1. As the electron beam enters the strong yoke-produced magnetic field, a force is created which is both at right angles to the beam and the field. This force deflects the electrons, and the electron beam assumes a circular path over the field length. Upon leaving the magnetic field, the beam again has no forces acting upon it, except for the anode voltage, and so assumes a straight-line path toward the screen. The stronger the magnetic field, the more the beam will be deflected by the yoke. As the over-all screen size increases, the required magnetic field for full deflection also increases. The increase would be a linear one, except that the brightness goes down as the screen size goes up. (This is because the electron beam spends less time on any phosphor area.) When increasing screen size, the high voltage must also be upped to maintain constant brightness. As CRT anode voltage goes up, the deflection sensitivity goes down. This means that the amount of deflection current provided must disproportionately increase with increasing screen size. Doubling the screen size approximately triples the required current for deflection. (The energy stored in a deflection yoke at any time is given by $W = \frac{1}{2}LI^2$ where W is stored energy in joules (watt-sec.), L is yoke inductance in henrys, and I is yoke current in amperes.)

Before we go into the exact mechanism of the horizontal deflection circuit, it is obvious that the energy stored in the yoke at maximum deflection must somehow be switched by the deflection circuit to collapse the field and return the

Fig. 1. The geometry involved in magnetically deflecting a cathode-ray tube. Both yoke and high voltage play important roles.



THE DEFLECTION D IN CENTIMETERS IS GIVEN BY

$$D = 2.96 \times 10^7 \frac{\ell L B}{\sqrt{V_a}}$$

WHERE:
ℓ = YOKE LENGTH, CM
L = YOKE TO SCREEN LENGTH, CM
B = YOKE FLUX DENSITY IN WEBERS/MTR^2
V_a = D.C. ANODE VOLTAGE, VOLTS

beam to its initial position. Doubling the screen size means three times the current, which in turn means *nine* times the stored energy! Here is why the deflection problem exists. To increase screen size slightly requires a radical increase in the deflection-circuit capabilities.

Small-screen TV's have been here for some time, using relatively low-cost transistors in circuits that are very much the same as conventional tube sweeps. But to date, as screen size has been increased, the switching and breakdown requirements of the output transistor have made it cost-prohibitive above a 15-inch, or at best, a 19-inch screen. Actually, transistors can handle any deflection problem with ease; it is done all the time in military CRT radar displays at about $85 per transistor.

A basic sweep circuit is shown in Fig. 2 and consists of a constant voltage source, an inductor, a switch, and a load resistor. The basic circuit behavior of an inductance states that $V=L(\Delta I/\Delta T)$ where V is the voltage on the inductor terminals, L is inductance in henrys, ΔI is the change in current in amperes, and ΔT is the change in time in seconds.

If we rearrange the equation by dividing by L, we g $V/L=\Delta I/\Delta T$ which says that if V is constant and L is co stant, the change in current in any time interval must al be constant. This is a linear current ramp. In Fig. 2, when the current ramp reaches the desired maximum value, the switch is opened momentarily, and the energy stored in the inductor is rapidly dissipated in load resistor R_L. The linear current produces a linear magnetic field which produces a linear sweep from the center to an edge of the CRT. (Differences in curvature of the beam and the tube face are taken into account by varying the spacing of the individual yoke windings.) Closing the switch once again starts a linear current ramp. The timing of the switch determines the period of the saw-tooth waveform, while the voltage and the inductance determine the slope.

There are two serious shortcomings of this simple sweep; namely, the extreme dissipation required in the load resistor R_L and the fact that the sweep is not symmetrical. Since no power is consumed by the inductance, it ought to be possible by a fancy switching scheme to *use the same energy over again* instead of "throwing it away" at the end of each cycle. Obviously we must make up system losses, but these would be trivial compared to the dissipation in R_L. It also ought to be possible to make the sweep symmetrical so that it can sweep from extreme left to extreme right when acting on a normally centered electron beam. A capacitor and a diode replace R_L in the practical sweep of Fig. 3.

As before, when the switch is closed, the inductance is driven by a constant voltage (V), and a linear ramp of current is produced. At the end of the sweep (maximum current in the yoke), the switch is opened. The circuit now consists of a series LC circuit with a return path being provided by the constant voltage supply. This circuit is highly oscillatory and at this particular instant, maximum positive current is flowing in the inductor. A quarter cycle later, all the stored energy is in the capacitor, and the yoke current is zero. Another quarter cycle later, the maximum *negative* current is flowing in the inductance and the stored energy in the capacitor is zero. So far, the voltage at point "A" has always been positive and diode D has always been back-biased. The negative current flowing in the inductor will try to force point "A" negative, which in turn *forward* biases damper diode D, effectively shorting out C. The oscillatory circuit no longer exists. All that remains is an inductor with negative current flowing in it connected to a positive constant voltage source. This produces a current ramp that subtracts from the maximum negative inductor current. This continues until the inductor current reaches zero. At this instant, switch S is once again closed, and the cycle repeats. Diode D disconnects as soon as point "A" begins to swing positive, and the sweep has gone through one complete cycle.

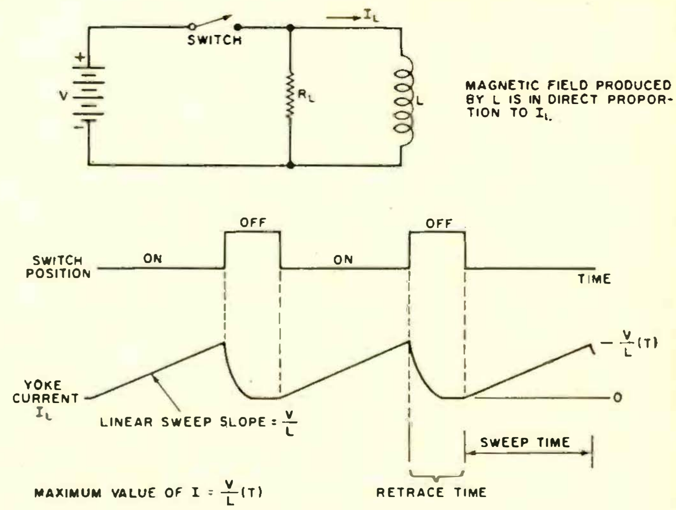


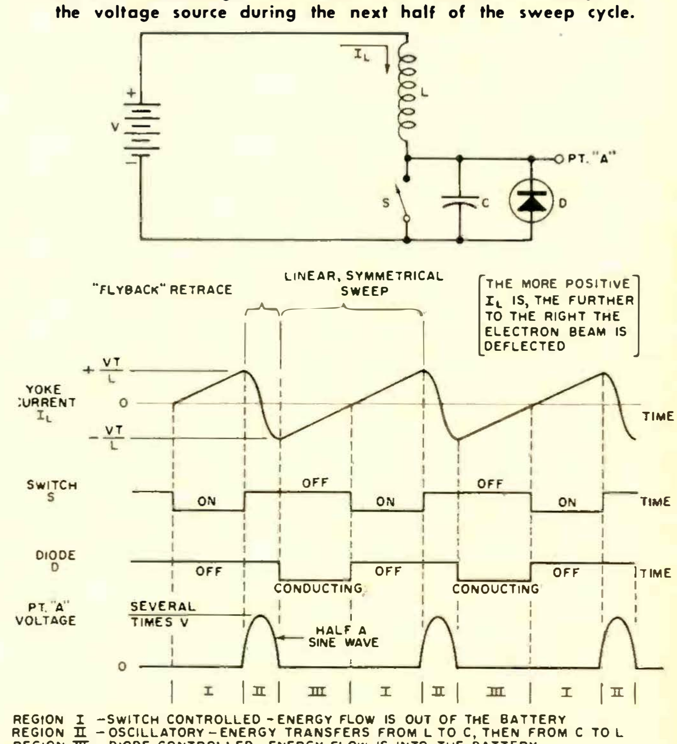
Fig. 2. Simple sweep circuit and the resulting basic waveforms.

osure, there is no current in the l, and the electron beam is cen- d, the electron beam is deflected to the right until the switch is opened at maximum deflection. The electron beam now rapidly returns to the extreme left side of the tube, and as the damper diode turns on, begins a sweep from extreme left to center. Upon reaching center, the cycle begins anew. The beam is blanked during the retrace period.

From an energy standpoint, starting with zero deflection, energy is first removed from the supply and allowed to build up in a linear manner producing a linear magnetic field. When maximum deflection is reached, the energy is transferred to a capacitor and then returned "backwards" to the inductor. The energy is then returned to the supply in a linear manner. Fig. 3 also shows the waveforms involved.

In terms of actual horizontal requirements, there are 15,570 horizontal sweeps per second, giving a total sweep time of about 63 microseconds. Of this, about 11 microseconds are reserved for retrace ("flyback") time. The LC resonance must have a half-period of about 11 microseconds, which

Fig. 3. A lossless symmetrical sweep only borrows energy from the constant-voltage source, and then returns this energy to the voltage source during the next half of the sweep cycle.



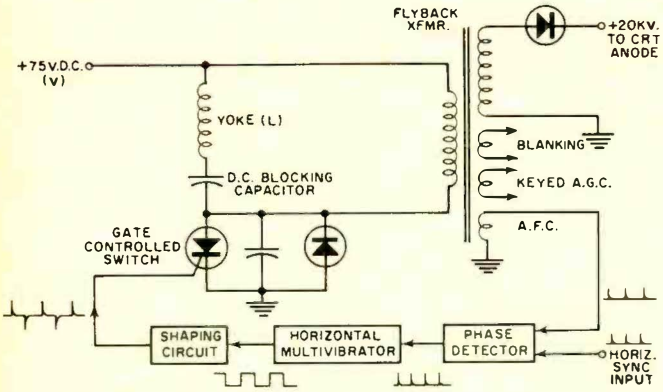


Fig. 4. A gate-controlled switch horizontal sweep takes advantage of the high blocking voltage (600 v.) and low "on" forward drop (1.2 v.) of the gate-controlled switch (GCS).

corresponds to a frequency of about 46 kilocycles. In actual circuits, there is an advantage to making the yoke-capacitor resonance exactly three times the sweep frequency.

The average deflection power drain of a 23-inch tube would be about 150 watts, were this energy not returned to the supply each cycle. The horizontal output stage must be capable of handling this power. In addition, the switching va. characteristics are much more severe since the circuit is highly reactive. A 1500-va. switching capability is required for a 19-inch tube deflection, and the requirement can go as high as 5 kva. on large-screen, large-deflection angle CRT's. The va. switching capability of a semiconductor is defined as the maximum blocking voltage multiplied by the maximum saturated current that the semiconductor switch can handle over a certain mode of turn-on.

Gate Controlled Switch Circuit

The first of the new sweep techniques uses a gate controlled switch, a new semiconductor that operates similarly to an SCR but with the added feature that it can be very rapidly turned *off* as well as on by a gate pulse. Turn-off times of less than a microsecond are typical. The high-current capacity, rapid switching, and low drive levels make the GCS very attractive for this application. Even more attractive is the high blocking-voltage capability, typically 600 volts or more for this device. Fig. 4 shows a GCS controlled sweep that uses a 75-volt d.c. power supply. The circuit is essentially the same as the basic sweep of Fig. 3, the GCS replacing the mechanical switch. The d.c. blocking capacitor in series with the yoke does not interfere with normal sweep operation but does prevent any shift of the normally centered electron beam due to a d.c. offset in the yoke. The transformer (flyback) also does not interfere with normal operation but borrows some of the stored energy during the retrace time, steps it up, rectifies it, and uses it for the 20 kv. or so of CRT anode voltage. Additional windings on the flyback transformers are used for sync phase comparison, blanking, and a.g.c. Protection must be given the "B+" supply lest a drive failure occur that would leave the GCS in the *on* state. This consists of two capacitors and a resistor, omitted in Fig. 4 in the interest of simplicity.

Transistor Circuits

A second approach to the sweep problem uses newly available power transistors in essentially the same circuit. Considerably lower supply voltages must be used because the breakdown characteristics of most transistors are substantially lower than the GCS, typically 100 or 120 volts. The high blocking capability is required during retrace, when the capacitor voltage (point "A," Fig. 3) can get up to three or four times the supply voltage due to series-resonant build-up. A higher current circuit results when providing the same energy control at lower voltages; consequently, the switching transistors must, of necessity, be of the high-current type.

The circuit is now possible because of the tremendous advances in power transistors. Silicon power transistors are now becoming reasonable enough in price to make their better temperature performance highly desirable. New means of constructing germanium transistors have substantially reduced leakage and improved thermal properties. New technologies have also raised the maximum frequency response and the minimum switching time considerably. (*Editor's Note: In addition, recently announced silicon transistors are available with breakdown voltages around 400 volts. These should make possible more conventional circuit designs.*)

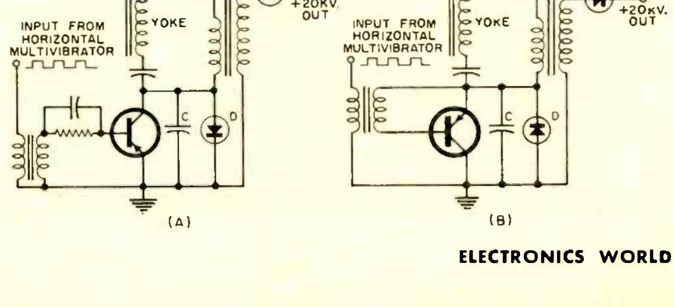
The most significant parameter in a switching power transistor is its "safe area." This is the region on the transistor V_c-I_c characteristics where switching can reliably take place without any fear of latch-up or thermal runaway. The normal safe area of these transistors is quite small when compared to the entire V_c-I_c plot. The new technologies have considerably fattened the safe area; in some transistors, it is possible to switch over any load-line path within the total V_c-I_c curve. ... omical transistors can be used. ... amount of circuit protection. ... transistors are shown in Fig. 5. One uses a -12 volt supply, suitable for battery operation. The second uses a high-voltage *p-n-p* transistor upside down and operating from a $+36$ volt supply.

SCR Switching Circuits

The final new approach to the sweep problem is extremely interesting. A conventional high-speed SCR is used to produce the horizontal switching, operating directly from the rectified power line. An unusual feature of this circuit is the combination of the flyback transformer and power transformer into a single high-frequency, multiwinding transformer. Since the transformer is a high-frequency one, little iron is required, and only small amounts of filtering are needed for the rectified d.c. power. In addition, the conventional horizontal oscillator and driver are not required and are replaced by simpler circuitry. The amount of set-cost and weight reduction this circuit could provide is considerable. The circuit has been successfully used on a 23-inch, 114-degree, 19-kilovolt tube and shows high promise of being quite economical for any screen size or deflection angle.

The circuit is the exact opposite of all previously used TV sweeps. The sweep *starts* with the retrace and then produces a linear ramp. Sync pulses are delayed to get video and sweep back together. All the energy required for the sweep cycle is supplied to the cricuit *during* retrace; the circuit then produces a linear sweep while returning the energy. The returned energy is used to power the rest of the set, and the circuit is automatically self-timing. Only a sweep start pulse must be provided the SCR, as it turns itself off later in the cycle. This eliminates the requirement for a horizontal multivibrator or other oscillator. Less linearity correction is required because the sweep is one continuous trace, unlike the crossover produced in the center-screen portion of normal sweeps. (*Continued on page* 74)

Fig. 5. (A) Conventional transistor sweep using 12-v. and a high-current transistor. (B) Using a special high-voltage transistor in upside-down circuit allows use of 36-v. supply.



Semiconductor Sweeps

(*Continued from page* 32)

the basic circuit is shown in Fig. 6. A series-resonant circuit is connected directly across the d.c. supply. At the start of the sweep, L starts to charge C, and the high-"Q" circuit starts to resonate. In a quarter cycle, C has charged to twice the line voltage, and the current through L is zero. Slightly past this resonance peak, the SCR is pulsed on with a gate pulse. A new, highly resonant circuit is now formed between the yoke and C. (The yoke inductance is much smaller than L.) C very rapidly starts discharging and building up the yoke field to the point of maximum deflection. Slightly past this point, th[illegible] verse current direc[illegible]

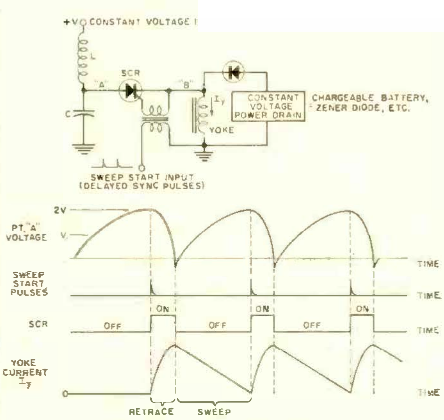


Fig. 6. The SCR horizontal sweep circuit begins by retracing and all sweep energy is provided during the retrace time. No horizontal oscillator is required in this case since this circuit is self timing.

to continue. This reverse current turns *off* the SCR, and the two halves of the circuit are once again separate. The left half of the circuit once again begins charging C for a new cycle. The right half of the circuit consists of an inductance (the yoke) connected to a constant voltage source *that can absorb energy*. (Assume it is a zener or battery for the present.) The energy in the yoke begins flowing into the supply (actually a drain) in a linear manner, producing the required linear sweep. The sweep continues until there is zero field in the yoke, and the cycle then repeats. The minor fact that the circuit seems to be sweeping backwards is easily eliminated by reversing the yoke leads.

There are two impracticalities to this simplified circuit; namely, the non-symmetrical sweep produced and the requirement for a power drain. These problems are eliminated in the practical circuit of Fig. 7. The yoke current is returned to the power supply *via* a diode and filter arrangement; the rest of the set and the sweep itself form the required power drain. A transformer is added to make the sweep a symmetrical one. This same transformer is the flyback transformer *and* the set power transformer; the entire "B+" requirement for the rest of the set forms the power drain. Any required supply voltage can be provided by changing the number of transformer turns. Additional windings may be added to the transformer for horizontal phase locking, blanking, and a.g.c.

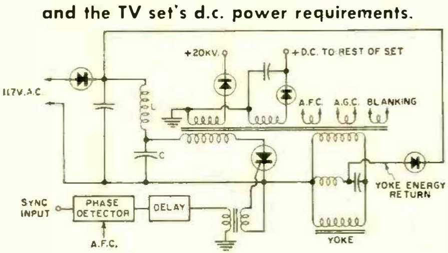
This new circuit could eliminate most of the horizontal circuitry, most of the conventional power supply, and reduce the set's weight and cost.

Optimum Supply Voltage

At present, there exists considerable controversy over what constitutes an optimum supply voltage for a transistorized television, and the manufacturers seem to be choosing up sides for a [illegible] battle on this issue. Direct-line [illegible] is the most economical, but [illegible]ired safety considerations are elaborate, and very high voltage transistors would have to be used in some circuits. The median (24-80 volt) supplies are optimum from a transistor standpoint but require a transformer supply. As supply voltage goes down, the average supply currents go up to provide the same power. This increases the size, cost, and weight of the filter capacitors needed in the supply. Finally, there remain the advantages of the 12-volt supply; namely, the compatibility with batteries and portable operation. These advantages are offset by very high filtering costs (during a.c. operation) and by high current levels required in the power circuits.

Since the choice of a horizontal sweep is intrinsically tied to the choice of supply voltages, no realistic comparison of the three new sweep techniques can be made until the supply question is resolved. All three circuits are capable of solving this critical problem.

Fig. 7. A practical SCR sweep uses a special transformer to produce both sweep and the TV set's d.c. power requirements.



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