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Monitor Deflection Circuits

THIS MONTH, WE'LL ADDRESS THE BASIC PRINCIPLES OF OPERATION OF THE HORIZONTAL-DEFLECTION SYSTEMS USED IN MONITORS. WHILE MOST PEOPLE WITH ANY FAMILIARITY WITH TV OR MONITOR OPERATION OR REPAIR HAVE SOME VAGUE idea of how these circuits work (probably just enough to be dangerous), many of their assumptions are incorrect or at least very incomplete. In addition to monitors, TVs (direct-view as well 3-CRT and light-valve projection types), tube-based video cameras (*e.g.*, vidicon), and other magnetically-deflected CRT devices also use the same techniques.

Note that vertical-deflection circuits are much less complex due to the lower scan rate (*e.g.*, 50 to 120 Hz as compared to 15.734 kHz for an NTSC TV or up to 120 kHz or more for a high-resolution computer monitor). Most of the control and output drive circuitry is contained in a special vertical chip in modern equipment.

TVs and most computer and video monitors depend on the use of similar (at least in concept) circuit configurations to generate several outputs:

• Current waveform required in the deflection yoke coils of the CRT for linear sweep of the electron beam to create a high quality (geometry and linearity) picture. This is close to a sawtooth but not quite.

• CRT high voltage (20 to 30 kV or more) as well as other related voltages—focus and screen (G2).

• Various auxiliary power and signals for other subsystems of the equipment (low voltage, CRT filament, feedback, etc.).

How It Works

Although there are many variations, the basic operation of the horizontal-deflection/high-voltage power-supply circuits in most TVs, monitors, and other CRT displays is very similar.

To better understand how the deflection circuit works, regard the flyback transformer as an inductor. The airgap stores energy, some of which might be tapped off during flyback by secondary rectifiers (*e.g.*, vertical deflection, signal circuits, and high-voltage supplies) and non-rectified loads (*e.g.*, filament supply), but those have hardly any influence on the basic working principles.

The scenario described next is only true in the steady state—the first few scans are different because the picture-tube capacitance is still discharged.

A very simplified circuit is shown in Fig. 1. Note that many components needed to create a practical design have been omitted for clarity.

We begin our adventure at the end of the scan—called retrace—when the flyback period begins.. At the end of the scan, current is flowing through the flyback primary to horizontal-output transistor (HOT) Q1. At the start of the flyback period, Q1 turns off. (This must be done in a controlled manner—not just a hard shutoff to minimize stresses on the HOT—but that is another story). Since current in an inductor cannot change instantaneously, the current is diverted into the snubber capacitor, C1. The inductance of the flyback primary (L1) and C1 forms a resonant circuit so that the voltage climbs on C1 as the current goes down. At its peak, this voltage will be 1000 V to 1500 V. Snubber capacitor C1 now begins to discharge in reverse through the primary of L1 (back into the B+ supply—the filter capacitor will stabilize the B+ output) until its voltage (and also the collector-emitter voltage of the HOT) reaches 0.

If there were no damper diode (D1), that voltage would go negative and continue to oscillate as a damped sinusoid
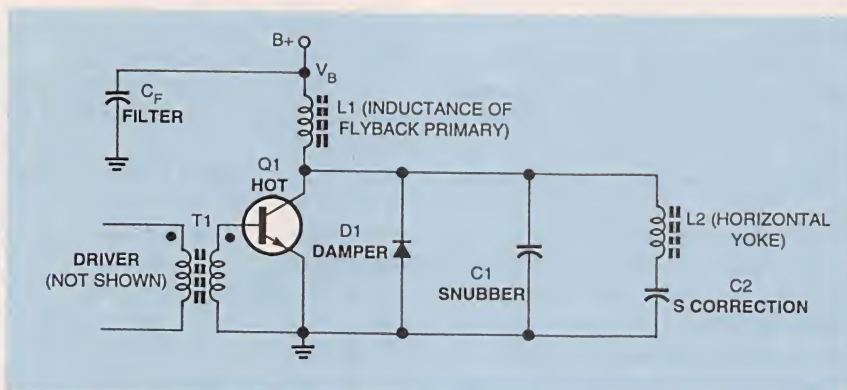

FIG. 1—A VERY SIMPLIFIED SCHEMATIC of a monitor's horizontal-deflection/high-voltage power-supply circuits is shown here. Note that many components needed to create a practical design have been omitted for clarity.

due to the resonant circuit formed by L1 and C1 (and the other components). However, D1 turns on as the voltage goes negative and diverts the current through it, clamping the voltage near 0 ($-V_F$ for the diode).

Note that in inexpensive or small screen TVs, damper-diode D1 may be built into the HOT. That's also true for some monitors that don't have any circuitry for E/W correction (more on that later).

The steps we've just described perform the flyback function of quickly and cleanly reversing the current in L2 (and, as we will see, the deflection yoke as well). The full flyback (and yoke current) are now flowing through the forward-biased damper diode, D1.

Therefore, at the beginning of scan, the damper diode (forward biased) carries the bulk of the current from the yoke and flyback. The nearly constant voltage of the B+ across L1 results in a linear ramp of current through the damper diode since it is still negative and decreasing in magnitude.

At approximately mid-scan, the current passes through zero and changes polarity from minus to plus. As it does so, the damper diode cuts off and the

HOT picks up the current (with a voltage drop of $+VCE_{sat}$). Current is now flowing out of the B+ supply.

Note that the base-drive to the HOT must have been switched on at some time before this point!

During the second half of the scan, the HOT current ramps up approximately linearly. That is again due to the

nearly constant voltage of B+ across the inductance of the flyback primary.

Near the end of scan, the HOT turns off and the cycle repeats.

Thus, the current in the flyback (ignoring the yoke components) is a nearly perfect sawtooth. The ramp portion is quite linear due to the essentially constant B+ across the flyback primary's
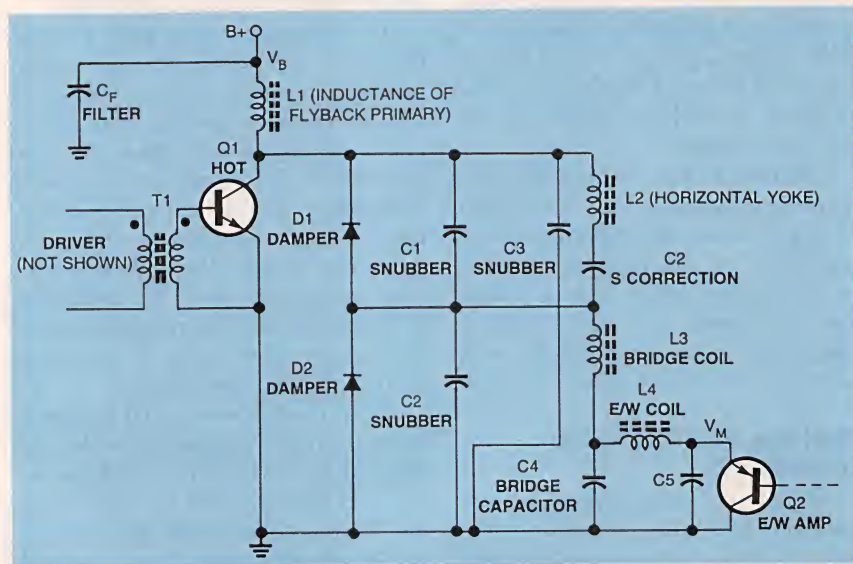

FIG. 2—HERE THE E/W CORRECTION circuit has been added to the power supply of Fig. 1. Again, note that this is a simplified schematic.

inductance. The current waveform can be easily viewed on an oscilloscope with a high-frequency current probe. I'll even tell you how to build one safely for next to no cost in a future installment!

The voltage across the collector-emitter junction of the HOT is a half sinusoid pulse during the flyback (scan retrace) period and close to zero at all other times (-V_F of the damper diode during the first half of scan; +VCE_{sat} for the HOT during the second half of scan).

Caution: Without a proper high-frequency, high-voltage probe, it is not possible or safe to observe this point on an oscilloscope with full B+. However, where the equipment can be run on a Variac, this clean pulse waveform can be observed at very reduced B+. Excessive ringing or other corruption would indicate a problem in the flyback, yoke, or elsewhere.

The current through Q1 and D1 is several amps peak-peak. There's a lot of power circulating here, making this a **dangerous** circuit in every way!

The Deflection-Yoke Connection

So, you ask: "Why can't the yoke just be placed in series or parallel with the flyback primary?" There are several reasons including:

• The desired yoke current is not quite a sawtooth, but includes two major corrections: S and E/W (described below). These cannot be applied easily with such a configuration.

• The flyback also generates the HV and secondary output voltages, and the primary current might then be affected by these and change as a function of beam current (picture brightness) or audio level (although feeding the audio amplifiers from HOT windings is not common anymore).

The yoke in series with a capacitor (S-correction) and other components are placed across the collector-emitter junction of the HOT. That, in effect, forms a variable power supply (analogous to the constant B+) that is used to compensate for the various problems of scanning a nearly flat screen.

What Are S, E/W, and N/S Correction?

Those terms actually refer to the various corrections to deal with what is normally called scan linearity and pincushion distortion. Most larger TVs and nearly all high-quality monitors will
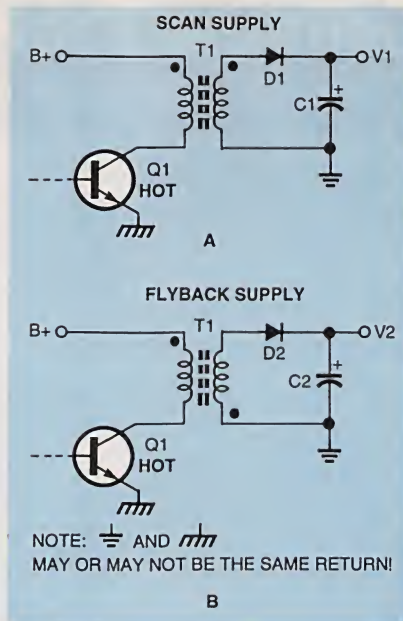

FIG. 3—THE CIRCUIT IN A is just a typical example of an auxiliary supply derived from a scan rectifier. The circuit in B is an example of the use of a flyback rectifier.

have various user and internal controls to optimize the corrections for each scan rate (multiscan monitors).

Because the screen of most CRTs is relatively flat (even those not advertised as flat), any picture tube would naturally have serious linearity problems and pincushion distortion if there were no corrections applied. The spot will move faster near the edges and corners of the screen because the same angular speed translates to a larger linear speed.

S-Correction Circuit Operation

The first correction to apply, in both directions, is S-correction. By simply putting a capacitor in series with each coil, the sawtooth waveform is modified into a slightly sinewave shape (the top and bottom are somewhat squashed). This reduces the scanning speed near the edges. Linearity over the two main axes should now be good. When we add in the yoke components (only the horizontal deflection coil and S-correction capacitor or S-cap are shown in Fig. 1) conditions are only slightly more complex.

First, consider what would happen if instead of the S-cap, the yoke were connected to B+ like the flyback. In that case, the total current would divide between the flyback primary and the yoke. It would still be a sawtooth as described above. Of course, component values would need to be changed to provide the

proper resonant circuit behavior.

That's called "tuning of the flyback capacitor." The goal is to get the proper duration of the flyback pulse, matching the blanking time of the video signal, and to achieve the proper peak flyback voltage, matching the V_{CES} specification of the HOT with a reserve of about 20%. That's two conditions, requiring two degrees of design freedom. There are three freedoms: supply voltage, flyback capacitor, and yoke inductance.

With the S-cap and yoke wired as shown in Fig. 1, the inductance of the yoke and S-cap form a low-pass filter such that the voltage on the S-cap will be a smoothed version of the pulses on the HOT collector (similar in effect to the B+ feeding the flyback but not a constant value). The average value of the S-cap voltage will be positive.

The S-capacitor together with the yoke inductance forms a resonant circuit whose frequency is tuned lower than the line frequency. It has the effect of modifying the sawtooth current into a sinewave shape. This is called "S-correction." It reduces the scanning speed at the left and right edges of the screen.

The value of the S-cap can be selected so that the voltage varies in such a way as to squash the current sawtooth by the appropriate amount to largely compensate for the fact that the electron beam scans a greater distance with respect to deflection angle near the edges of the screen.

Think of it this way: When the scan begins, the yoke current is at the maximum value in the direction to charge the S-cap. The voltage across the S-cap is causing the current to decrease, but the S-cap is also gaining charge, so the rate of decrease is increasing. At the time the current passes through 0, the S-cap is charged to its maximum. The current now reverses direction, retracing its steps. This is an example of a portion of a resonant circuit. The voltage on the S-cap is varying by just the right amount to compensate for the geometry error.

For multiscan monitors, S-caps must be selected for each scan range since the timing varies with scan rate. These are only approximate corrections, but are good enough for most purposes. MOSFET or relay circuits are used to select the correct combination of S-correction capacitors for each range of scanning frequencies.

As an example, consider a multiscan monitor that supports VGA (31.4 kHz,

800 × 600 at 56 Hz (35 kHz), and 800 × 600 at 60 Hz (38 kHz):

For good geometry between 31, 35, and 38 kHz, two discrete values for the S-cap are barely enough. Actually a third value optimized for 35 kHz would be better. If there is only one S-cap and it is optimized for 38 kHz, then at 31 kHz you will be using a too large an angle of the sine (of the resonant frequency between the S-cap C and the deflection coil inductance). Possibly even more than 180 degrees, making the current fold back. Apart from an obvious geometric distortion, there is also increased risk of HOT failure because you're operating too close to the resonant frequency.

E/W Correction-Circuit Operation

There are also N/S and E/W errors, meaning that near the corners the scanning speed is still too large. To a large extent the N/S errors can be corrected by a suitable yoke-coil design. For smaller tubes (90 to 100 degrees types) that could also take care of E/W errors. However, for larger (110 degrees) or high-quality tubes, electronic E/W correction is required. E/W errors are what cause the well-known pincushion effect.

E/W correction is modulation (which implies multiplication) as a function of the vertical-beam position. The amplitude of the horizontal-deflection current is modulated with a parabola waveform that is derived from the vertical-deflection circuit. That squeezes the top and bottom lines back into the left and right screen borders.

This is how the diode modulator for E/W correction works (refer to Fig. 2 as we proceed):

The deflection supply B+ gives a constant voltage V_B. At the output of the E/W amplifier there is a variable voltage V_M. Because there can not be an average voltage over any coil, the average voltage over the deflection circuit (L2 + C2) is $V_B - V_M$. The scanning width is proportional with this voltage. Modulating V_M as a field-frequency parabola that is higher for the top and bottom lines causes the scanning width to be reduced for the corners of the screen.

The required field-parabola waveform is derived from the field-deflection circuit. Amplitude and DC-level are adjustable as needed for correcting pincushion distortion and setting the screen width.

The E/W amplifier usually has a PNP emitter follower only, because it must only sink current and dissipate a bit of power. Coils L3 and L4 ensure that the E/W amplifier sees no line-frequency. The "bridge" components, L3 and C5, resemble the deflection coil with its S-correction capacitor and carry the large amplitude alternating current. The L3/C5 circuit is tuned to approximately the same frequency as the L2/C2 circuit.

Capacitors C1, C3, and C4 must be tuned so that EHT is independent of V_M and peak voltage over D2/C2 is high enough but not too high when Q2 is off. Capacitor C4 is usually a small (approximately 1 nF) ceramic capacitor mounted close to the HOT (Q1); it also suppresses EMI. Flyback capacitors are critical components. Wrong types may overheat and burn. Bad contacts here or elsewhere in the deflection circuit might arc and also cause fire.

There are many variants to this circuit, e.g. for dynamic S-correction. Multi-sync monitors need added circuitry to make the EHT independent of the line frequency (if there is not a separate EHT supply, that is).

If the E/W modulator fails, you will see that the top and bottom lines will be much too wide. There are several parts that could have failed. It's usually not too difficult to find why there's no parabola. If you have partial loss of E/W modulation, notably in the extreme corners, then you should suspect the tuning of the three flyback capacitors that belong to the diode modulator circuit. That's a specialist job...

S-Correction Problems

So, then, what are the problems associated with the S-Correction capacitor, and what are their symptoms? Here goes:

• An open S-cap will result in no horizontal deflection—a vertical line.

• A shorted S-cap will likely load down the B+ possibly resulting in a blown fuse or other power supply components.

• An S-cap that changed value (or in the case of a multiscan monitor, selected to be the wrong value) will result in distortion at the left and right sides of the screen. If it is too low, the picture will be squashed towards the edges. If it is too high, the picture will be stretched towards the edges.

Note that this is not the same as what is commonly called linearity, which

would likely affect only one side or gradually change across the screen.

Horizontal-Linearity Correction

Since there is a non-zero resistance associated with the components (mainly coil losses) in the yoke circuit (yoke winding, ESR of S-cap, etc.), the world is not quite as ideal as one would hope. Without compensation, that resistance would result in non-linearity of the picture—it would tend to be squashed on the right side as the resistance saps energy from the yoke circuit.

The waveform becomes a damped sinewave, which will be "undamped" by restoring energy during the flyback.

One way to deal with this is to add a magnetically biased saturable inductor in series with the horizontal-deflection yoke. That inductor is called the linearity coil.

Its core is magnetically biased near the point of saturation such that the inductance decreases with increasing current, and that helps to stretch the right-hand side of the scan. In other words, during the scan the coil saturates so that the inductance decreases. At the end of scan there is practically no voltage left over the linearity coil, so that the deflection coil gets maximum voltage.

E/W Correction Problems

The common name for the adjustment controls is likely to be "Pincushion Amp" and "Pincushion Phase." They affect the E/W correction circuits. Pincushion Amp adjusts the amplitude of the correction signal. Pincushion Phase adjusts where the correction is applied on the vertical scan.

Problems in the E/W correction circuits will show up as follows:

• Failure of the E/W correction circuit will result in very noticeable pincushioning distortion of the vertical edges.

• Excessive E/W correction will result in barrel distortion of the vertical edges.

• A bad power supply derived from the flyback could also result in similar symptoms due to ripple or lack of power to the pincushion circuitry.

N/S and E/W Circuit Differences

While the desired effects are largely the same—modulate the amplitude of one component of the deflection circuit (H or V) by the other (V or H), the implementations of the N/S and E/W circuits

will differ substantially. The reasons should be obvious: The line frequency is much higher than the field frequency.

E/W correction is easy—the lower frequency modulates the higher frequency. That reduces to simple amplitude modulation. Well, simple in principle. The line circuit is a high-energy circuit. That's why the diode modulator circuit has been invented for this application. It allows an energy exchange between the line-deflection circuit and a pseudo deflection circuit.

N/S correction is difficult—the higher frequency modulates the lower frequency. It can be done with sort-of amplitude modulation by using a "transductor." This is not a transformer but a component with 2 coils and a saturable core where the current through 1 coil modulates the inductance of the other coil. If there are tuned parts in the circuit, then the correction will be highly sensitive to line-frequency variations.

It can also be done with a regular transformer by injecting a strong signal (from an amplifier) with line-frequency components into the field-deflection circuit.

Either way, it's an expensive solution that should be avoided by designing the deflection coils so that the picture tube needs no active N/S correction.

Deflection Derived Power Supplies

Several types of auxiliary power may be obtained from the flyback, somewhat as a byproduct of the deflection-system operation.

Although not always well known, the coupling factor with the primary is decent for a flyback transformer, and so there can be scan rectifiers as well as flyback rectifiers.

• Scan power is obtained during the forward stroke as with a "normal" transformer. Energy is transferred while the HOT/damper diode is conducting. The output rectifier is oriented so that current flows during scan time (dots on the transformer winding match). See Fig. 3A.

Scan rectifiers make no use of the stored magnetic energy; they load the primary directly during the scan part. They do not cause an increase of the stored magnetic energy, so a heavy load is not a problem.

• Flyback power is obtained from the stored energy in the flyback transformer's inductance when the HOT shuts off. The output rectifier is orient-

ed so that current flows at flyback time (dots on the transformer windings oppose). See Fig. 3B.

Unlike scan rectifiers, flyback rectifiers (especially the EHT) draw from the stored magnetic energy. When the secondary load increases, the magnetization current will also increase. Ultimately this will cause saturation of the ferrite core. Excess beam current is a common cause for this and should be avoided by the beam-current limiter. The advantage of a flyback rectifier is that it provides 7 times more volts per winding than a scan rectifier.

• AC power (usually only for the filament or a feedback signal) flows during both scan and flyback.

EHT (High-Voltage) Generation

The EHT (Extra High Tension or HV to the CRT) is generated from a secondary winding on the flyback transformer having several thousand turns of very fine wire. Being a flyback supply, the actual output voltage is many times what would be calculated based on turns ratios alone. The HV rectifier consists of a stack of silicon diodes with a total PIV rating of 50 KV or more. Because the flyback pulse is so narrow, the rectifier diode will conduct only a short time. Thus the peak current in the winding will be quite high, resulting in a significant voltage drop when loaded. The internal impedance of the EHT source is in the order of 1 megohm, so with a load of, for example, 1 mA, the EHT will drop 1000 V = -3%. Usually the EHT voltage is far from stable; a 10% drop is quite normal.

If the EHT voltage drops, then the electrons will be accelerated less and will move through the deflection field at a lower velocity. As a result they will be easier to deflect by the magnetic field, and the picture size will grow. Without special measures, brighter pictures will be larger. The way to prevent that is to feed some EHT information or beam-current information to the deflection circuits, reducing the deflection current amplitude a bit for bright pictures. For horizontal deflection, that is done by the E/W modulator. This technique is called anti-breathing.

Sets with raster-correction-free picture tubes don't have an E/W modulator. There the correction might be done by means of a power resistor in series with the B+ supply. A large beam current causes more power consumption; this

lowers the B+ supply voltage and thus reduces the line-deflection current. That also reduces the EHT even further, but the deflection current has a stronger effect on the picture width than the EHT. Better methods exist as well.

The EHT information is also used to protect the flyback transformer from overload. As the load increases, the average primary current rises. Ultimately it may reach a level where the transformer core may go into saturation. This causes large peak currents in the HOT, which might lead to destruction. To prevent that, some EHT information is fed to the contrast controller to automatically reduce the picture brightness whenever the white content is too high. That is called the average beam-current limiter.

A failure in the video path, like a video output amplifier stuck at 0 V, causes a high beam current that will not react to the contrast controller. In that case, the beam-current limiter will not work; and the set should switch off automatically, usually within a few seconds after applying power. When the cathodes heat up, you'll see an even picture with diagonal retrace lines, and then it will switch off.

"Real-World" Circuits

Don't expect to find the circuits shown this month to be staring you in the face when you get your *Sams' Photofacts* or service manual. There are a semi-infinite number of variations on this basic theme. Some of them will, to put it mildly, appear quite obscure (or to put it more positively, creative) at first.

You might see all sorts of additional passive components as well as transformers for generating additional voltages not provided by the flyback. There could be diodes in places you would think would be impossible. Therefore, to really understand even approximately how each design works could require some head scratching—but the basic operation of them all seems to be very similar.

Wrap Up

That's it for now. Next time we will continue our discussion of deflection-system operation with some information about horizontal-output transistors and deflection system problems. Until then, check out my Web site: www.repairfaq. org. I welcome comments (via e-mail please at sam@stdavids.picker.com) of all types and will reply to requests for information. See you next time!

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