ICs Boost Video Performance

New video ICs are making life easier for design engineers by integrating the functions once implemented with discrete components. The new products not only cost less and save space on the PC board; they offer better performance because the proximity of video functions on the IC reduces parasitic capacitance and its detrimental effect on bandwidth and other parameters. This article introduces basic video technology along with new, state-of-the-art video switches and their applications.

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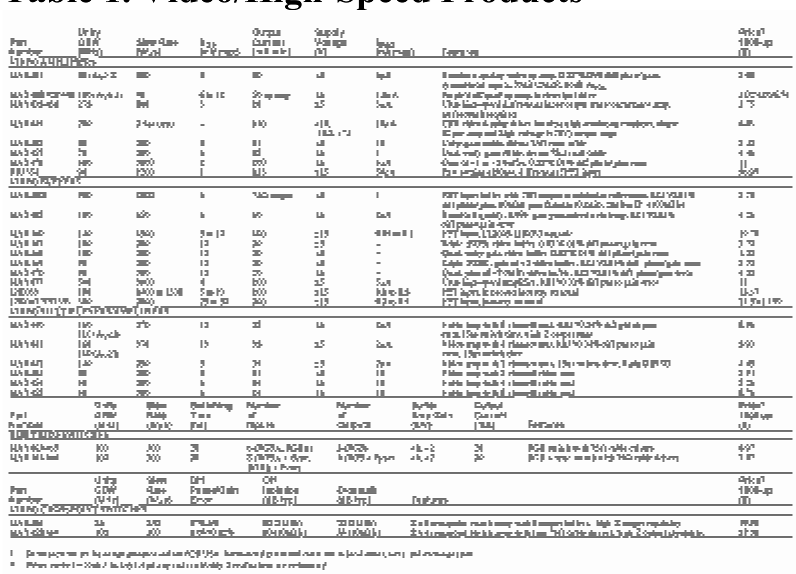
Table 1. Video/High-Speed Products



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Switching is a common requirement in video systems. Video editors must select one of several input signals on command, and other systems (broadcast studios, security and surveillance networks) must be capable of displaying multiple input signals on multiple monitors.

Traditional video switches are followed by a buffer amplifier in a separate package. Some applications include an input buffer as well, to isolate the signal sources and preserve bandwidth (**Figure 1a**). The resulting circuits require at least two or three packages, but recent video-switch ICs have absorbed the output buffer while precluding the need for an input buffer. This integration of functions lowers the package count to one, and by minimizing certain parasitic capacitances it also improves the electrical performance.

Monolithic vs. discrete switch/buffers

Distributed capacitance associated with the package, board, and switch make bandwidth preservation a difficult job in the traditional, discrete-IC video switch (**Figure 1b**). Switch capacitance CDS causes feedthrough that reduces OFF isolation. Cpb and Cpp, also associated with the switch, combine with source impedance RSOURCE (usually 75Ω) to produce a bandwidth-limiting pole. The finite source impedance also causes Cpp to produce coupling (crosstalk) between the two channels. Adding an input buffer as shown in Figure 1a eases the effect on bandwidth and crosstalk by substituting a low impedance for RSOURCE.

Referring again to Figure 1b, note that the switch output capacitance consists of Cpb and CCM in parallel, plus a differential-mode value (CDM) between the pins. These capacitances charge rapidly when the switch closes (turns on), but they discharge through a rapidly increasing switch resistance when the switch turns off. The resulting slow turn-off can produce unwanted artifacts at the boundary between images in a graphics display.

Switch on-resistance must be low enough to prevent distributed capacitance from limiting the signal bandwidth. A 75Ω switch with 10pF, for example, produces a rolloff to -3dB at $1/2\pi RC$ = 212MHz. But, switches with low on-resistance are physically large structures with unavoidably large values of junction capacitance CDG, CDS, and CSG. CDS undermines the isolation between source and output, and the other parasitics undermine the bandwidth. An input buffer can compensate for these effects, but (as mentioned) it adds a third package to the circuit.

The integrated approach combines switch and buffer in one package (**Figure 1c**). The switch can have higher on-resistance because the switch-to-amplifier capacitances (Cpb, CM, and CD) are smaller. In turn, the higher-resistance switch is physically smaller, and its lower-valued CDG, CDS, and CSG may eliminate the need for an input buffer. As a further advantage, switching transients and other performance parameters are specified for the switch/buffer combination as a single subsystem. Integration thus improves performance while saving board space.

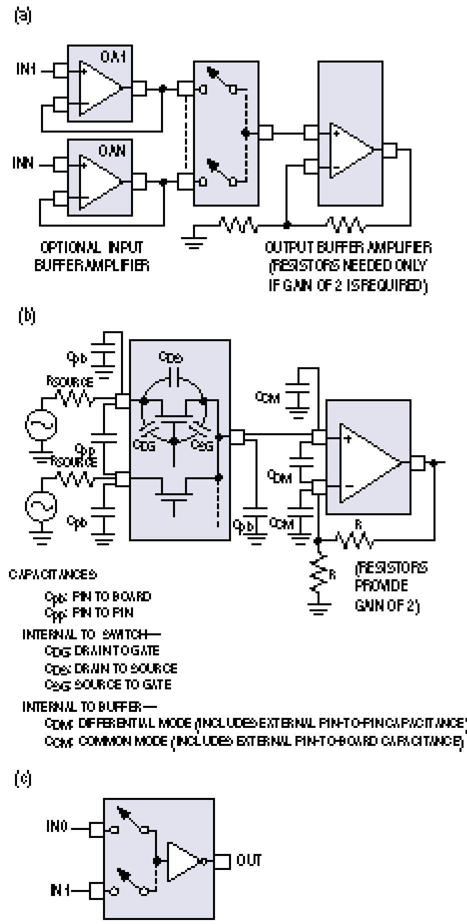

Figure 1. For a traditional video switch, the switch and buffers reside in separate ICs (a). Parasitic capacitances in the traditional switch limit bandwidth and provide paths for unwanted feedthrough and crosstalk (b). The integrated approach (c) improves performance by minimizing parasitics.

Circuit topology

A major concern in multiplexing video signals is the degree of isolation between the output and the non-selected input signals. Data sheets specify this isolation as "adjacent-channel crosstalk" and "all-hostile crosstalk." Integrated multiplexer-amplifiers perform well in this respect-most such devices provide isolation in excess of -60dB, which is sufficient for most NTSC and PAL systems.

A popular method for providing high isolation is the "T"switch (**Figure 2a**). Used in all CMOS "mux-amps" from Maxim, the T-switch preserves isolation by shorting to ground the feedthrough capacitance of S1: when the T-switch is on, S1 and S3 are closed and S2 is open; when the T-switch is off, S1 and S3 are open and S2 is closed. Thus, signals that would otherwise couple through CS are shorted to ground before reaching the output. The disadvantage-higher on-resistance due to S1 and S3 in series-is usually not a problem for the IC because intra-chip capacitances at the output of S3 can be kept very low.

An implementation of the T-switch in bipolar technology includes parallel npn transistors on one side of the buffer amplifier's differential input pair (**Figure 2b**). Turning on Q3 steers emitter current from Q1 and robs Q5 of base current. Q1 and Q5 turn off, disconnecting IN0 from the output stage. This action is similar to that of the T-switch, in which two off transistors (Q1 and Q5) are shorted to ground via Q3.

Similarly, turning off Q4 allows Q2 to act as an emitter follower, connecting IN1 to the output via Q6. The high input impedance and low input capacitance of this pnp emitter follower (Q2) negates the need for an input buffer amplifier. It also isolates the input signal from switching transients. The circuit's make-before-break action minimizes glitches (**Figure 2c**). Note that a break-before-make action would open both switches at the same time, floating the inputs to the output stage and causing a high-amplitude glitch as the output slews toward a supply rail.

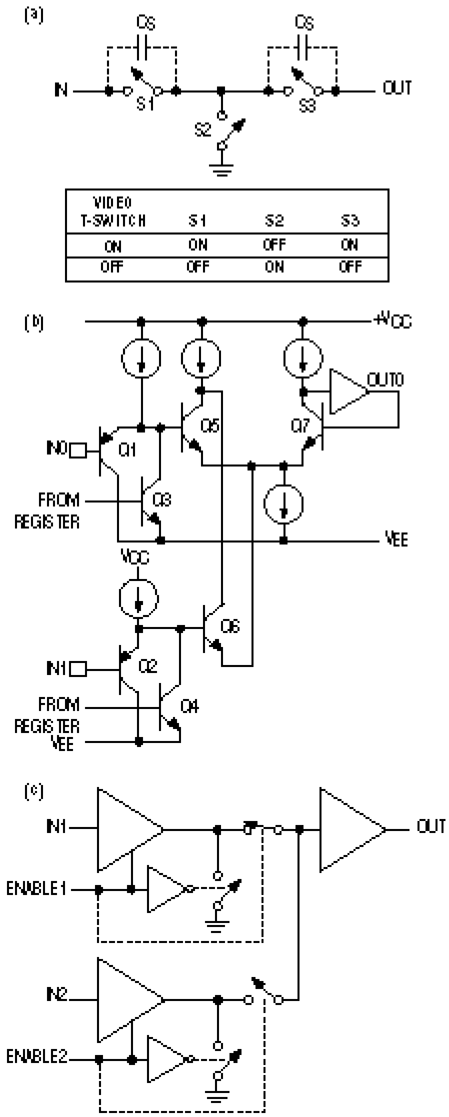

Figure 2. By shunting feedthrough currents to ground (through S2), the T-switch provides improvements of 6dB to 12dB in feedthrough and crosstalk (a). Implemented in bipolar technology, the T-switch configuration offers high input impedance and low input capacitance (b). Make-before-break action in the integrated T-switch minimizes glitches (c).

Mechanical switches usually avoid make-before-break action, because shorting the inputs together would disrupt the signals on those channels (the signals may be routed to other destinations besides the switches). This problem can't occur with bipolar switches from Maxim, because each switch is preceded by an internal unity-gain buffer.

T-switches are found in integrated-circuit multiplexers as well as IC switches. Maxim's MAX442, for example, combines a 2PST switch with an uncommitted, unity-gain-stable output amplifier in an 8-pin DIP or SO package. It switches one of two composite video signals to a single output, as required in a video editor or tape recorder. T-switches in the MAX442 assure -76dB minimum isolation and crosstalk, which is 6dB to 12dB lower than that of conventional switches.

Composite video vs. RGB

In video systems, "RGB" refers to the three electrical signals corresponding to the red, green, and blue components of an image. After correction and shaping, the RGB signals are encoded to produce chrominance (color) and luminance (brightness) signals. Then, combining the chrominance and luminance with sync and blanking signals produces a "composite" video signal (see **sidebar**). Thus, combining all video information in a single signal makes a convenient input for monitors, VTRs, and broadcast transmitters.

Composite signals allow single-channel transmission (especially convenient for broadcasting), but their complex encoding of chrominance and luminance information carries disadvantages. System nonlinearities, for instance, degrade the image by producing unavoidable crosstalk between the luminance and chrominance components. To control this problem, engineers seek to develop signal-processing electronics with minimal errors of differential gain (which affects color saturation) and differential phase (which affects hue).

Video signals in a broadcast studio may pass through many stages of editing and recording. To maintain fidelity in these applications, the studio video is best handled in a three-signal "component" format that eliminates the use of subcarriers with their crosstalk and noise problems. The original RGB can serve as component video, but advantages are realized by encoding RGB as YUV-i.e., the electrical analogs of luminance (Y) and the color differences B-Y (U) and R-Y (V) (see sidebar).

YUV requires less bandwidth than RGB: Equal amounts of picture detail reside in R, G, and B, but the YUV system conveys fine picture detail only in Y (U and V carry color information only). Bandwidths are approximately 4.2MHz for Y, 0.5MHz for U, and 1.5MHz for V, resulting in a lower overall bandwidth that can save costs. A video tape recorder, for example, needs three tracks to handle RGB video. For YUV, the VTR requires only two tracks-one for Y and one for U and V together.

YUV components have another advantage-the U and V signals are less subject to electronic gain error than are the RGB signals. Gain error in one RGB channel produces a wrong-colored image; gain error in the U or V channel produces only a small change in hue or saturation.

Many video cameras provide RGB outputs in addition to a composite output, and some commercial television monitors provide RGB inputs in addition to the composite input. YUV components are easily derived from RGB components with a resistive network called a matrix circuit.

Definitions

"Video" in this article refers to the approximate 4MHz to 6MHz analog signals that emanate from a video camera-i.e., baseband video in the context of broadcast television. "Graphics" refers to the resulting CRT display. (Note that the video signals for high-performance workstations and other graphics systems, generated by a computer and reconstructed with a D/A converter, can exceed 100MHz.) Other video terms are defined as follows:

NTSC (National Television Standards Committee) is the US agency that developed standard monochrome and composite-color waveforms for the US. NTSC signals are now used in the US, Japan, Canada, Mexico, and many other countries of the western hemisphere. Because these systems are sensitive to errors of differential gain and phase, Europeans once referred to NTSC as "Never The Same Color." Today's high-performance circuits have largely eliminated these problems.

PAL (Phase Alternate Line) is a transmission standard for color television developed by the Telefunken Company in Germany, partly as an answer to the shortcomings of NTSC. Though similar to NTSC, it includes a line-by-line alternation in phase for one of the two color-signal components, which minimizes the distortion due to differential phase error between the luminance and chrominance signals. PAL is used by the United Kingdom and most of Western Europe, except France.

SECAM (Sequential Couleur Avec Memoire) was developed in France, also as an alternative to NTSC. Luminance signals have the same format as those of NTSC and PAL, but the color-difference signals modulate two separate carriers that are transmitted on alternate lines. To restore the missing color information for a given line, SECAM receivers include a one-line memory element (1H delay). Today, SECAM is used in France and in some countries of the former USSR.

IRE (Institute of Radio Engineers) was a forerunner of today's IEEE. Today, the term represents an arbitrary unit for measuring relative amplitudes on a video signal. One hundred IRE units represents full scale (i.e., 1V on a monochrome signal or 0.714V on a color signal).

RGB (Red, Green, Blue) is a term that refers to the primary colors. A video camera resolves light into its RGB components and generates the corresponding analog voltages ER, EG, and EB. After gamma correction (which minimizes the visual effect of noise by assuring a logarithmic relation between signal amplitude and CRT brightness) the signals become ER', EG', and EB'. These are encoded to produce the luminance component "EY" (0.30ER' + 0.59EG' + 0.11EB'), and the chrominance components "EU" (ER' - EY) and "EV" (EB' - EY).

Component video refers to individual signal components such as the three found in an RGB or YUV system.

Composite video is an analog waveform suitable for transmission on a single channel. It is obtained by combining the chrominance and luminance signals with sync and blanking pulses.

Saturation is a term of perception (not subject to quantitative measurement) that refers to the intensity of a primary color. It corresponds to purity, which is an objective, measurable quantity.

Hue is a term of perception (not subject to quantitative measurement) that corresponds to a color's dominant wavelength, which is an objective, measurable quantity.

Color burst is a brief reference pulse of RF energy that is transmitted with every line of an NTSC signal. Because the color subcarrier (phase and amplitude modulated according to hue and saturation) and the color burst derive from the same signal, phase and amplitude distortion affect burst and subcarrier equally, and tend to cancel.

Differential gain and **differential phase** errors result from nonlinear characteristics in a video amplifier. Because the amplifier's gain and phase responses change slightly with signal level, variations in luminance affect the color subcarrier's gain and phase modulation. Differential gain error (DG) is a change in gain as the amplifier's dc output level swings from 0V to 1V, and differential phase error (DP) is a change in phase over the same range. DG (expressed in dB or %) affects color saturation in the CRT display, and DP (expressed in degrees) affects the hue.

Video editors

The substitution of video ICs for discrete-component circuitry, plus the growing importance of video for teleconferencing and related applications, has produced an expanding market for video ICs. One target for these products is the video editor.

Video editors accept one or more signals, which may be in different formats, from cameras, VTRs, computers, and other sources. After "editing" (rotating, translating, zooming, mixing, keying, wiping, etc.) the editor directs the signals to one or more VTRs or other systems. The video editor's electronics must pay close attention to dc as well as ac signal parameters.

In many cases, dc levels are unknown for the video editor's input signals. Each input, therefore, may include a dc-restore circuit that employs capacitive coupling to establish the zero (black) level. If this dc restoration is followed by switching, the subsequent amplifiers must have low dc offsets.

Two such devices-the MAX440 and MAX441 multiplexer/amplifiers (mux/amps)-illustrate the performance available with T-configuration switches. Each combines a unity-gain-stable, wideband output buffer with an 8-channel (MAX440) or 4-channel (MAX441) video multiplexer. The parts offer low input-offset voltages of ±2.5mV typical (1/4IRE), low values of differential gain and phase (0.04% and 0.03° respectively), and low feedthrough and crosstalk (-66dB).

The ICs' output-disable capability enables their use in larger multiplex arrays (**Figure 3**). Each EN input serves as a fourth address bit (A3), and the inverters insure that two amplifiers are not enabled simultaneously. With proper selection of the R1-R6 values you can add more MAX440s in parallel, up to a limit imposed by parasitic capacitance and feedthrough from the de-selected channels.

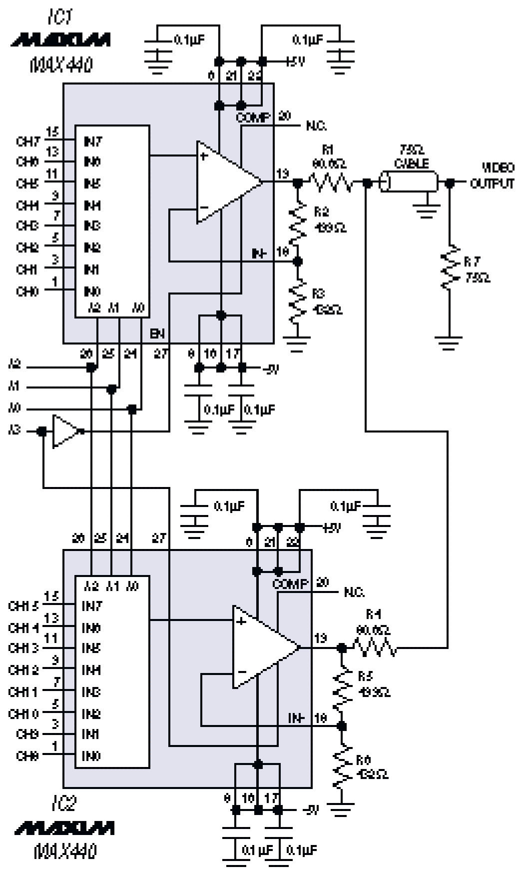

Figure 3. These mux/amp ICs can be combined as shown to form larger multiplex arrays.

Each back-termination resistor (R1 and R4) has been increased from 75Ω to 80.6Ω to compensate for the three resistors at the output of the disabled amplifier. In parallel with R1 or R4, these resistors produce the desired 75Ω termination value. The three resistors also form a divider with the active amplifier's output resistor. To compensate for this effect, the closed-loop gain of each amplifier is set slightly greater than 6dB. And to help minimize ringing, the amplifier outputs are joined at the cable end of R1 and R4-a connection that allows the resistors to isolate the enabled amplifier from the output capacitance of the disabled amplifier.

These circuits handle composite video, but many systems require switching of component video signals. To meet that need, Maxim has introduced the first switch/buffer ICs for RGB, YUV, YRGB, or RGB+SYNC applications (**Table 2**). MAX463-MAX466 devices switch from two sets of three inputs to one set of three outputs (3P2T) or from two sets of four inputs to one set of four outputs (4P2T). Each device contains an output driver with a fixed gain of one or two, which is capable of driving ±2V into a 75Ω back-terminated cable (150Ω load). And for buffering RGB, YUV, or other component video, the MAX467-MAX470 series includes triple and quad buffer amplifiers without the switches.

Table 2. Video switch/buffer ICs

Device	Description	Voltage Gain
MAX463	Triple switch & buffer	1
MAX464	Quad switch & buffer	1
MAX465	Triple switch & buffer	2
MAX466	Quad switch & buffer	2
MAX467	Triple video buffer	1
MAX468	Quad video buffer	1
MAX469	Triple video buffer	2
MAX470	Quad video buffer	2

The output buffers provide a combination of isolation and bandwidth that satisfies most video applications. By sandwiching each input and output pin between two ac-ground pins, the devices hold adjacent-channel crosstalk to 60dB at 10MHz. Their 100MHz bandwidths (90MHz for gain-of-two buffers) and 200V/µs slew rates (300V/µs for gain-of-two buffers) are difficult to achieve in discrete-component circuits. Wide bandwidth, low differential gain and phase error, and excellent gain and phase matching suit the MAX463-MAX470 devices for a wide range of component-video applications.

RGB video systems convey color information by amplitude only, so differential phase errors are unimportant. Gain and phase matching between channels, however, is important. **Figure 4** shows typical gain and delay matching for the MAX463-MAX470 devices.

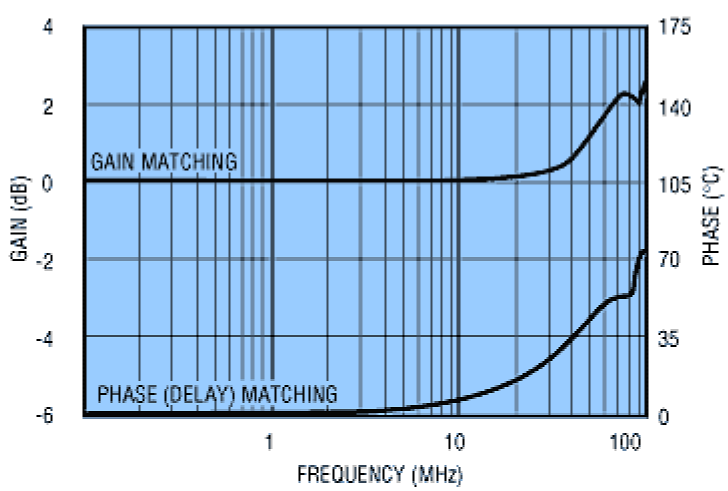

Figure 4. In the MAX463-MAX470 family of switch/buffer ICs, separate channels offer matched gain and phase over many megahertz of video bandwidth.

Many functions in a video editor are handled by high-speed digital circuits, which require close attention to layout issues such as power-supply decoupling and the minimization of ground and power-supply transients. See the last section (*Layout, grounding, and bypassing*) for guidance in these matters.

Security and surveillance systems

Multiple inputs and outputs are a common feature of most security and surveillance systems, as is the need to make arbitrary connections between a given input and one or more outputs. Cost is a major issue for the "crosspoint switches" developed for this purpose.

Maxim is currently the only manufacturer of integrated crosspoint switches (**Table 3**). These devices really shine as space savers: a 16x16 array (16 inputs and 16 outputs) consisting of four MAX456 ICs (not including cable drivers) replaces 256 discrete switches and at least 32 buffer amplifiers. The same array constructed with MAX458 or MAX459 crosspoints requires eight packages, but those versions also include the cable drivers.

Table 3. Maxim crosspoint switches

Device	No. of Switches	Technology	Gain	Differential Phase/Gain	Cable Driver
MAX456	8 x 8	CMOS	1	1.0°/0.5%	No
MAX458	8 x 4	Bipolar	1	0.5°/0.01%	Yes
MAX459	8 x 4	Bipolar	2	0.14°/0.13%	Yes

MAX458 and MAX459 switches can be programmed either in parallel mode or in serial mode, which is fully compatible with SPI™, QSPI™, and MICROWIRE™ standards for synchronous-data transmission. MAX458 and MAX459 outputs are disabled automatically at power-up. The disabled outputs assume a high-impedance state, except the MAX459's internal feedback (for achieving a gain of two) limits its output impedance to 1kΩ. Both devices can also be disabled on command, via software-a feature that enables the construction of switching arrays larger than 8x4.

CRT drivers

Moving up from the crosspoint switch to the CRT, we find another target for integration in video systems-the high-voltage CRT driver for high-resolution monitors. A new, monolithic variable-gain amplifier (Figure 5a) drives these monitors directly. Its internal preamp and high-voltage output driver provide a reliable, low-cost, and space-saving alternative to hybrids and discrete-component circuitry.

The IC's offset and variable-gain controls enable brightness and contrast adjustments. Its current-drive output provides for faster rise and fall times than those of a voltage-output device, and its TTL BLANK input disables the video signal by turning off the output current. The MAX445's 2.5ns rise time through 50V (**Figure 5b**) makes it ideal for driving the high-resolution displays (1280 x 1024 and 1530 x 1280) found in workstations and medical-imaging systems.

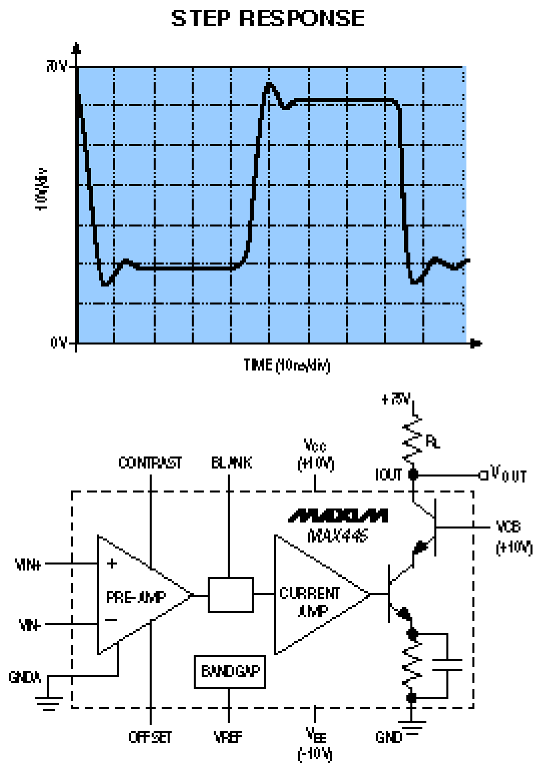

Figure 5. The current-drive output in this high-voltage amplifier drives high-resolution CRT monitors directly, with rise and fall times of 2.5ns.

Layout, grounding, and bypassing

Layout on the printed-circuit board is important for all analog circuits, but it is especially crucial for video and other high-speed circuitry. A choice of surface-mount over feedthrough components, for example, may seriously affect performance by altering the layout.

To realize the full ac performance specified for high-speed amplifiers, you should provide a large, low-impedance ground plane and pay close attention to the pc layout and power-supply bypassing. Multilayer boards are preferred. Place an unbroken ground plane on a layer without signal traces, in a way that provides shielding for the traces. All inputs and outputs should be connected through lines of constant impedance, so you might consider a review of stripline techniques.

The input capacitance CIN+ can limit the bandwidth in a buffer amplifier by forming a pole with the signal-source impedance RS. The pole can be defeated, however, by preventing current flow in CIN+. Buffer operation maintains the IN+, IN-, and OUT terminals at the same potential. Thus, surrounding IN+ with an ac "guard ring" driven by the buffer's output eliminates the current flow in CIN+ by removing voltage variations across it. Adjacent positions for IN+, IN-, and OUT simplify the guard-trace layout (**Figure 6**).

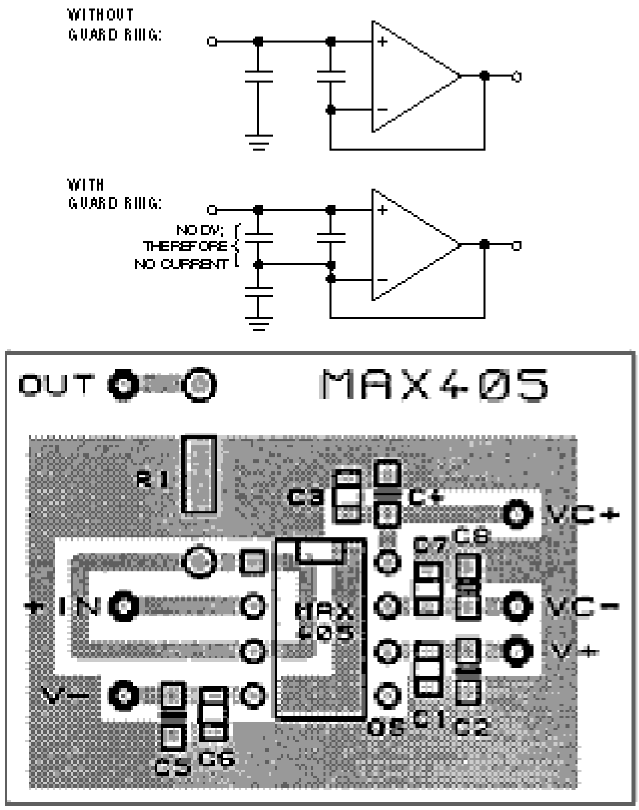

Figure 6. Surrounding this buffer amplifier's input (pin 2) with a guard ring driven by the output (pin 1) minimizes the effect of input capacitance on bandwidth.

You should bypass all power-supply pins directly to the ground plane with 0.1µF ceramic capacitors placed as close to the pins as possible, and keep the lead lengths as short as possible to minimize series inductance. For high-current loads, it may be necessary to include 10µF tantalum or aluminum electrolytic capacitors in parallel with the 0.1µF ceramics. Surface-mounted chip capacitors are ideal for this application.

To prevent unwanted coupling of signals, minimize the trace area at the circuit's critical high-impedance nodes, and surround each analog input with ac-ground traces. The analog inputs and outputs of Maxim switches are separated with such ac-ground pins (GND, VCC, and VEE), which minimize the parasitic coupling that causes crosstalk and amplifier instability. To further reduce crosstalk, connect the coaxial-cable shield to the ground side of the 75Ω termination resistor, at the ground plane.

Wherever possible, use Faraday shields that interpose the ground plane or another component between sensitive circuits and those that produce noise. Noise generators include the digital circuitry that operates as an interface to the systems processor and memory.

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