Driving Video Lines

When does a trace or a wire become a transmission line? Bandwidth, characteristic impedance, ESD, and shoot-through considerations for selecting the proper video driver, receiver, mux-amp, or buffer.

Engineers are aware they must match impedances to avoid reflections when driving transmission lines. This is especially true in video, with its wide range of component frequencies. While most applications span a few octaves, video covers six or more.

Only dissipative elements (resistors) can be relied on for matching[1] over such wide bandwidths. The use of resistors creates a loss. The driver must compensate with added gain. That's why most video drivers have a fixed gain of two[2], though some are settable. This allows long lines to be equalized, restoring their frequency response to the required bandwidth for the application.

It is obvious that coaxial and differential-pair cables are transmission lines. But when does a trace or a wire become a transmission line, and is this a problem in video design?

Bandwidth

The first information needed when designing or choosing a video driver is the bandwidth. Microscopically, video is a bit-stream, and the high-frequency end depends on the rise/fall time of the waveform. To reproduce the waveform with satisfactory fidelity, the upper -3db point should be between 0.35 to 0.50 over the rise/fall time[3] of the video signal, thus putting the high end of the video bandpass in the tens or hundreds of MHz. Macroscopically, video is an image, and to reproduce it we have to pass the rate at which it was sampled, or the frame rate. This sets the low end around 2.5 to 5Hz. AC coupling would require large capacitors, which is why most applications are DC coupled. It also means that the driver must sink and source current to the load, which is returned by the supply. Because of that, even DC-coupled drivers require large supply-bypass capacitors close by to avoid including the power supply trace in their design.

The size of the AC coupling caps can be reduced by "bootstrapping" the load, as shown in Figure 1. The gain is boosted at lower frequency by adding R_{fb}, which is shunted out at high frequency by the second coupling capacitor. This reduces the value of C_c, but you'll need two of them.

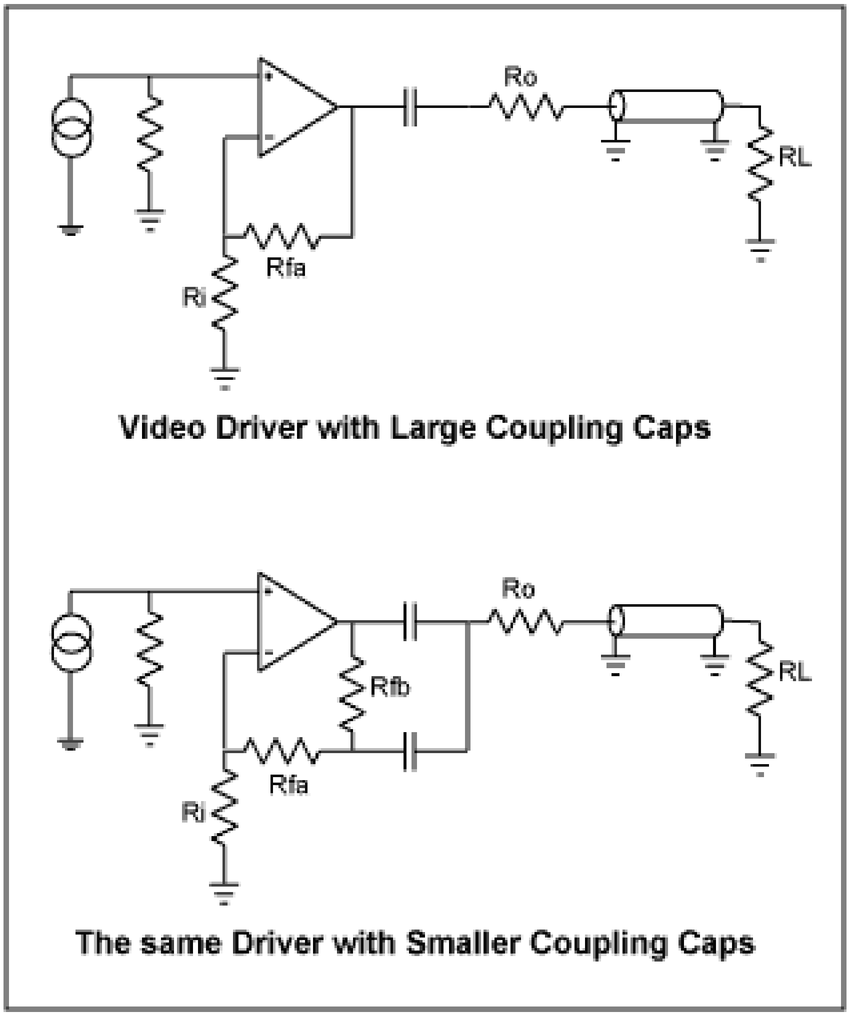

Figure 1. A method to reduce the size of the coupling capacitors by bootstrapping the load

The next question may sound odd, but how long is the line? A transmission-line's bandwidth depends on its length. For example, at 10MHz, 100ft of RG-59A has 1.1db IL (insertion loss), 200ft has 2.2db IL, and 300ft has 3.3db[4]. Depending on the length, NTSC or PAL video experiences little loss, but HDTV or SXGA video would be affected. To correct for this, the line is "equalized" to restore overall response to the necessary application bandwidth. The equalizer has an inverse-frequency characteristic, compared to that of the transmission line, to create a flat response at the end of the line. A simple equalizer can be built into the driver (Figure 2), as long as the equalization (blue line) is inside the GBW of the driver (red line). This requires more gain-bandwidth in the driver, but for fixed-length lines it's less expensive than a line receiver. To allow this, some drivers have settable, rather than fixed gain.

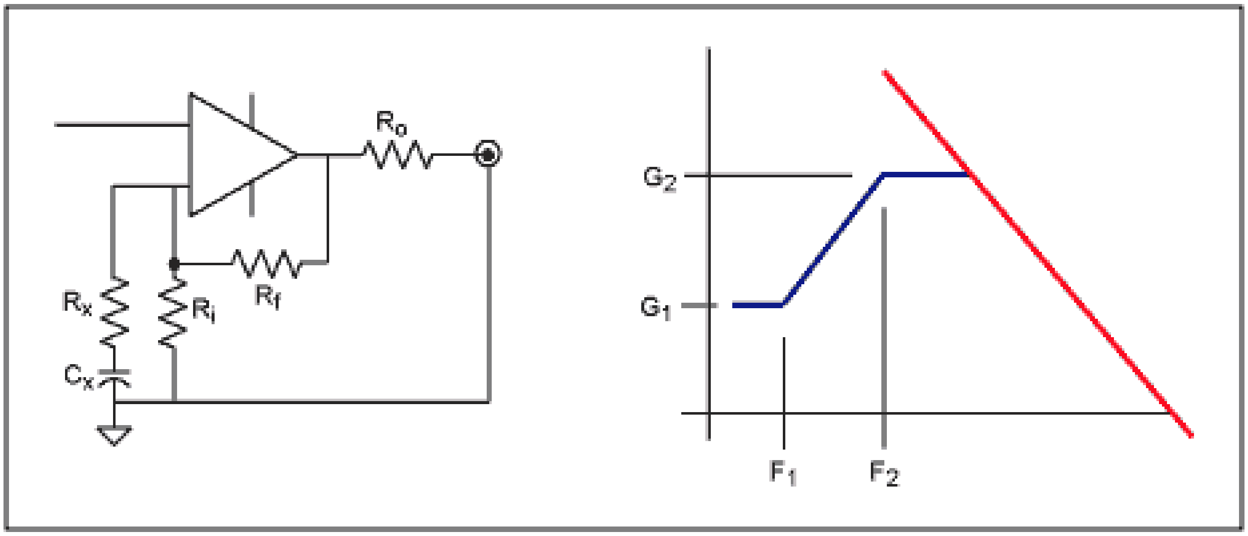

Figure 2. A simple R-C equalizer (pre-emphasis) is used to compensate for loss between F1 and F2.

Characteristic Impedance

Transmission lines have a characteristic impedance (Zo) with which they should be driven and terminated; and, in video, the most popular is the 75Ω coaxial cable. This give the 150Ω "back terminated" unit load the driver sees due to the series 75Ω source resistor, (Ro in Figure 2) and the 75Ω line. But what about "other lines"? PCB traces and wires: are they lines?

The Long and the Short of It

To determine if a trace or wire is a transmission line, we need to know its electrical length. That's given in terms of the rise/fall time of the video (tr) by[5];

$$L = t_r/(\Delta t/\Delta l)$$

Where, $\Delta t/\Delta l$ is the delay per unit length (see Table 1). As the length approaches about 1/6*L it starts to look like a "line". Before that, it doesn't have a characteristic impedance, only a reactance[6].

To get a scale of things, HDTV signals exhibit a rise-time of 20nsec, *so a trace has to be about 2ft long to be a transmission line*. Rise/fall times would have to approach 1-2nsec before PCB traces become transmission lines. Mainly, it's reactance that causes problems, narrow traces are series inductors, wide ones are shunt capacitors. Drivers are more tolerant of shunt capacitance than of series inductance.

Things to remember are:

- an inch of #20AWG wire has about 20nH of inductance
- an inch of 0.030 trace has 10nH
- and a sq inch of FR-4 has about 5pF of capacitance.
- inductance scales by length, capacitance by area.

Table 1. Typical Delay Times for Various Types of Transmission Lines

Transmission Line/Dielectric	Delay (picosec/in.)
Wire in Air (Vacuum)	85
Coax (RG-59A, 75Ω, 66% Propagation)	128
Coax (RG-58A, 50Ω, 66% Propagation)	128
Coax (RG-11A, 75Ω, 55% Propagation)	154
PC Board, Inside Trace (FR-4)	140
PC Board, Outside Trace (FR-4)	180

Another potential problem on PCB is the "via" that connects traces between layers. At high-frequency, a Pi filter[7] is formed which can "ring" on fast transitions. This is often seen in video-reconstruction-filter applications that originate from a narrow (high Zo) trace in a digital portion of a board. These signals have faster rise/fall times than video, usually set by the logic family used in the DAC. In such cases, it's best to keep the line short and terminate it as best you can. Then put a buffer or driver after the via.

Besides the length, a transmission line must be homogenous. This means it must be over a continuous return path. Even though a trace isn't a transmission line, failing to put a continuous ground under it can have subtle side effects. The first is that you can't get rid of the ringing usually followed by coax being soldered to the board. The second is cross-talk over and above what you expected, followed by more coax.

Although most PCB traces aren't transmission lines, they act as if they were. In this case, it's the return current. Don't route video lines over split planes or large gaps. It change the reactance causing ringing, and mixing ground currents causing cross-talk.

Differential Pairs

Twisted pairs, Category 3 to 6 are "Differential" transmission lines as opposed to the conventional single-ended coaxial cable. These lines have a characteristic impedance (Zo) between 100 to 150 ohms8. Typically, differential lines were used exclusively by digital signals like LVDS, but are increasing being used for analog signals; especially in existing infrastructures were coax is at a premium.

During the development of twisted pairs, two important properties were discovered; the first was the EMI radiated is lower than an equivalent coaxial cable, and the lines are less susceptible to external fields. The second was the importance of "balance" in attaining this improvement.

Just as single-ended coax cables must be properly terminated, so must differential pairs, but the signal paths must also be "balanced" or current flows outside the differential circuit[9] and it starts to act like a single-ended circuit. A good way to visualize this is the differential source is composed of two perfectly symmetrical single-ended ones so that the entire signal current flows in and out of the two sources outputs, and not through the ground they may be connected to. This fact has tremendous implications for EMC. A well-balanced and terminated differential circuit may improve radiation and susceptibility as much as 30-40dB compared to coax.

The property of balance is specified differently for the driver, receiver, and line. It is further complicated by the need to convert between single-ended and differential domains.

The driver/source/line is typically specified as having a property, usually called "Common Mode Balance[10]", "Longitudinal Balance[11]" or simply "Line Imbalance[12]". Although balance is associated with the source, it assumes a perfectly balanced, correctly terminated, differential load. This is typically between 20 to 40 dB in digital drivers limiting their performance, however analog circuits can improve this up to a theoretical 60db at 10MHz[13].

The receiver-side balance is determined by the common mode rejection ratio (CMRR). The CMRR can be quite large for even simple op amps (50-70dB), therefore the driver-side balance is the limiting factor. Assuming these are bipolar signals there has to be a quiescent point about which they swing, called the common mode voltage (CMV). Typically, this is half the supply voltage to optimize the Common Mode Input Voltage Range of the Receiver. Exceeding this range will distort the signal and possibly damage a part.

ESD and Shoot Thru

This isn't a video problem, but it does effect video drivers that are used to connect to an external load. To protect them, the output has shunt diodes to the supply and to ground to protect the driver from ESD originating outside the chassis.

New set-top boxes, video games, VCRs, DVDs and even TV sets have isolated (2-wire) chassis today, causing a potential problem called "shoot thru". Here the mains bypass capacitors called "Y Caps" charge and discharge the chassis to peak AC line potential. The chassis is also the video ground. As long as the driver is connected to equipment on that same AC line, nothing much happens, except to the well-grounded and unwary. Cable and satellite receivers have to be connected to earth-ground for operation and safety reasons. The most common connector for commercial video, the RCA jack, will likely connect the signal pin first. To avoid damaging the driver, there have to be shunt diodes at the input as well as the output.

Choosing A Driver, Receiver, or Buffer

Tables 2 and 3 show large-signal bandwidth (2Vp-p), slew rate, differential gain and phase, and supply voltage for Maxim's most popular video drivers, buffers, and receivers with single-ended and differential outputs.

A special subset of the video driver is the video-distribution amplifier (see Table 4). Built to drive multiple loads, they offer higher isolation, selectable outputs, fixed or settable gain and are often used in professional equipment.

Another subset of the video driver is the video mux-amp (see Table 5). Mux-amps combine a video multiplexer and a video line driver for routing video signals.

Table 2. Single-Ended Video Line Drivers and Buffers

P/N	No. of Amps	Operating Voltage (V)	-3dB LSBW (MHz)	Slew Rate (V/µs)	DP/DG (° /%)	Notes
MAX4450/1	1 / 2	+5, ±5	175	485	0.08/0.02	SC70/SOT23 Packages
MAX4350/1	1 / 2	±5	175	485	0.08/0.02	SC70/SOT23 Packages
MAX4380-4	1 / 2 / 3 / 4	+5, ±5	175	485	0.08/0.02	SC70/SOT23 Packages, Disable Available
MAX4389-96	1 / 2 / 3 / 4	+5, ±5	127	200	0.015/0.015	SC70/SOT23 Packages, Disable Available
MAX4012/16/18/20	1 / 2 / 3 / 4	+3.15 to +11	140	600	0.02/0.02	Disable Available
MAX4212/13/16/18/20	1 / 2 / 3 / 4	+3.15 to +11	180	600	0.02/0.02	Disable Available
MAX4214/15/17/19/22	1 / 2 / 3 / 4	+3.15 to +11	140	600	0.02/0.04	Gain of 2 Buffer, Disable Available

MAX4214/15/17/19/22	1 / 2 / 3 / 4	+3.15 to +11	220	600	0.02/0.04	Gain of 2 Buffer, Disable Available
MAX477	1	±5	200	1100	0.01/0.01	130MHz 0.1dB Gain Flatness

Table 3. Differential Video Line Drivers and Receivers

P/N	No. of Driver/ Receiver	Operating Voltage (V)	-3dB LSBW (MHz)	Slew Rate (V/µs)	DP/DG (° /%)	Notes
MAX435	Driver	±5	275	800	Not Specified	300µV Input Offset Voltage
MAX4142	Driver	±5	180	1400	0.01/0.01	Fixed Gain of 2V/V
MAX4147	Driver	±5	250	2000	0.03/0.008	Fixed Gain of 2V/V
MAX4447/8/9	Driver	±5	405	6500	0.01/0.02	Single-Ended Input
MAX436	Receiver	±5	275	800	Not Specified	300µV Input Offset Voltage
MAX4144/5/6	Receiver	±5	110	1000	0.03/0.03	Shutdown Mode
MAX4444/5	Receiver	±5	500	5000	0.05/0.07	Shutdown Mode

Table 4. Distribution Amplifiers

P/N	No. of Outputs	Operating Voltage (V)	-3dB LSBW (MHz)	Slew Rate (V/µs)	DP/DG (° /%)	Notes
MAX4135/6	6	±5	185	1000	0.1/0.1	0.1dB Gain Flatness to 40MHz

MAX4137/8	4	±5	185	1000	0.1/0.1	0.1dB Gain Flatness to 40MHz

Table 5. Video Mux-Amps

P/N	Inputs: Outputs	Operating Voltage (V)	-3dB LSBW (MHz)	Slew Rate (V/µs)	DP/DG (° /%)	Notes
MAX4310	2:1	+5, ±5	110	460	0.06/0.08	Unity Gain Stable
MAX4311	4:1	+5, ±5	100	430	0.06/0.08	Unity Gain Stable
MAX4312	8:1	+5, ±5	80	345	0.06/0.08	Unity Gain Stable
MAX4313	2:1	+5, ±5	40	540	0.09/0.03	Fixed Gain of 2
MAX4314	4:1	+5, ±5	90	430	0.09/0.03	Fixed Gain of 2
MAX4315	8:1	+5, ±5	70	310	0.09/0.03	Fixed Gain of 2

[1]*Wideband Circuit Design*, Carlin, ISBN0-8493-7897-4

[2] Although the terms are often interchanged, video buffers as opposed to video line drivers, usually have a gain of +1V/V.

[3]*High Speed Digital Design*, Johnson and Graham, ISBN 0-13-395724-1

[4]*Transmission Line Design Handbook* , Waddell, ISBN 0-89006-436-9

[5]*High Speed Digital Design*, Johnson and Graham, ISBN 0-13-395724-1

[6]*Wideband Circuit Design* , Carlin, ISBN0-8493-7897-4

[7]*Transmission Line Design Handbook* , Waddell, ISBN 0-89006-436-9

More Information

MAX4012: QuickView -- Full (PDF) Data Sheet -- Free Samples
MAX4135: QuickView -- Full (PDF) Data Sheet -- Free Samples
MAX4137: QuickView -- Full (PDF) Data Sheet -- Free Samples
MAX4142: QuickView -- Full (PDF) Data Sheet -- Free Samples
MAX4144: QuickView -- Full (PDF) Data Sheet -- Free Samples
MAX4147: QuickView -- Full (PDF) Data Sheet -- Free Samples
MAX4212: QuickView -- Full (PDF) Data Sheet -- Free Samples
MAX4214: QuickView -- Full (PDF) Data Sheet -- Free Samples
MAX4310: QuickView -- Full (PDF) Data Sheet -- Free Samples
MAX4311: QuickView -- Full (PDF) Data Sheet -- Free Samples
MAX4312: QuickView -- Full (PDF) Data Sheet -- Free Samples
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MAX4314: QuickView -- Full (PDF) Data Sheet -- Free Samples
MAX4315: QuickView -- Full (PDF) Data Sheet -- Free Samples
MAX435: QuickView -- Full (PDF) Data Sheet -- Free Samples
MAX4350: QuickView -- Full (PDF) Data Sheet -- Free Samples
MAX436: QuickView -- Full (PDF) Data Sheet -- Free Samples
MAX4380: QuickView -- Full (PDF) Data Sheet -- Free Samples
MAX4389: QuickView -- Full (PDF) Data Sheet -- Free Samples
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