Converting single-ended video to differential video in single-supply systems

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Introduction

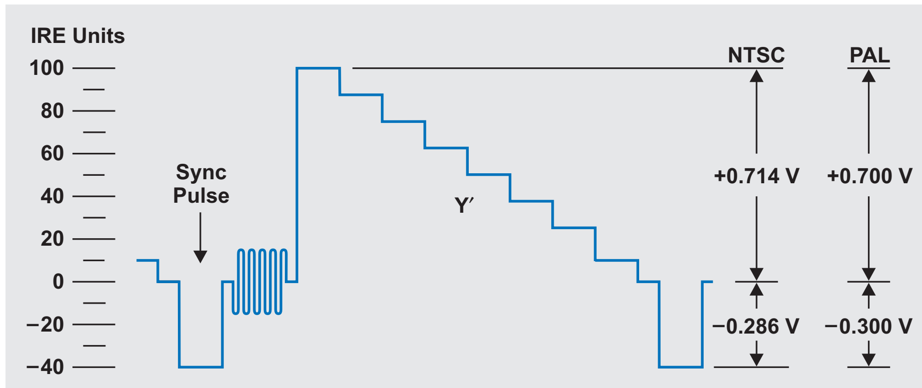
Video signals are commonly encoded, decoded, and processed as single-ended, but it is often desirable to convert them to differential for transmission over cables. A good example is a security system where cameras are placed in various locations and the video feeds are routed back to a central location for observation and storage.

Because of its inherent resistance to noise, differential transmission has been used for many years in telephone lines and professional audio. Assuming noise is coupled equally into the differential transmission line(s), it shows up at the receiver as a common-mode signal that is rejected.

With single-supply devices becoming more and more common these days, it is nice to design the line-drive circuit to be single-supply as well. In single-supply systems, the signal levels are shifted to fit within the supply voltage, and the bias levels need to be accounted for so as not to cause unwanted offsets in the output. These tasks are aside from the normal ones like setting gains, choosing the type of line termination, and allowing for adequate bandwidth and slew rate.

Single-ended-output operational amplifiers or fully differential amplifiers (FDAs) can be used to convert single-ended video signals to differential. The purpose of this article is to show how to use an FDA to convert single-ended video signals to differential to drive a Cat 5 cable with double termination in a single-supply system. It is assumed that the reader is familiar with FDA concepts and use. For more information on FDA fundamentals, please see Reference 1.

Figure 1. SD composite video baseband signal (CVBS) showing grayscale



Typical video parameters

Figure 1 shows a composite video baseband signal (CVBS) showing grayscale that is often used with standard-definition (SD) video. SD video characteristics typically follow the analog-signal standards established for the NTSC or PAL television broadcast systems. The total peak-to-peak output voltage is specified to be 140 IRE = 1 V_{PP}, with only the sync and luminance (Y′) where the sync pulse is negative. With chrominance information added, a fully modulated composite video signal is about 1.23 V_{PP}. To support the negative pulse, split-supply ($\pm V_S$) operational amplifiers can be used, or AC coupling where the DC levels are restored at the receiver. Using a split supply or AC coupling requires more components and is more costly. DC coupling can lower cost, but moving to DC-coupled signals that support a single supply requires level shifting the signal. For example, the data sheet of the Texas Instruments (TI) TMS320DM368 video processor specifies video-buffer output voltages ranging from 0.35 V to 1.35 V with a 75-Ω load. In this way, a 1-V_{PP} video signal can be supported with a shift in bias level and is acceptable in consumer video.

Other higher-definition video formats like enhanced-definition (ED) and high-definition (HD) do not encode as much different information into one line as SD. They use multiple lines with signals of varying duration and transition speed depending on the video content and specification.

So video signals are pulse-oriented by nature, and amplifiers and transmission media need to have excellent pulse characteristics to properly reproduce them. Because of this, it is standard practice to use double termination of the transmission line. In double termination, the amplifier driving the line is designed to have the same output impedance as the characteristic line impedance, and the receiver is designed to have the same input impedance as the characteristic line impedance. With this configuration, reflections from pulse edges are minimized and the best signal integrity is maintained. Since operational amplifiers are ideally voltage sources, their outputs have very low impedance (near 0 Ω), and matching the output impedance is easily done by adding a series output resistor. This output resistor, in conjunction with the input impedance of the receiver, gives a 6-dB loss that is inherent in double termination. To make up for the loss, it is common practice for video buffers to be designed to have a gain of 2 V/V (6 dB) so the overall gain from video source to load is 1 V/V (0 dB).

Category 5 (Cat 5) cabling is very common and used widely for computer local-area networks (LANs), but it is also used to carry other signals such as telephone, video, and audio. Most Cat 5 cables are low-cost and unshielded and use a twisted-pair design with differential signaling for noise rejection. The nominal characteristic impedance of Cat 5 cable is 100 Ω.

Circuit analysis

Proposed circuit #1

A first proposed circuit for converting a single-ended video signal from a single-supply video source like the TMS320DM368 to drive a differential line might be as shown in Figure 2. The function of the various elements is as follows:

V_{S+} is the power supply to the amplifier; and the negative supply input, V_{S-}, is grounded.

V_{IN} is the input from the TMS320DM368 video source, ranging from 0.35 V to 1.35 V.

R_G and R_F are the main gain-setting resistors for the amplifier. For a gain of 2 V/V, $R_F = 2R_G$.

V_{OUT+} and V_{OUT-} are the differential output signals from the FDA. They are 180° out of phase and are level shifted to the common-mode output voltage, V_{OCM}.

The two R_O resistors are selected to match the characteristic line impedance, Z_O. For Z_O = 100 Ω, R_O = 50 Ω.

R_L is the resistor selected to match Z_O. For Z_O = 100 Ω, R_L = 100 Ω.

At first look the circuit in Figure 2 might appear to be acceptable, but closer inspection shows it needs some work. This circuit does not provide a 75-Ω load for the TMS320DM368 video buffer, so the buffer output voltages will not be correct. When driven from a video source like the TMS320DM368, whose video-buffer output range is 0.35 V to 1.35 V, the output signals from this circuit will have a differential offset equal to the common-mode voltage of the video signal times the gain and will be level shifted to V_{OCM}. Calculations show that the Figure 2 circuit output will have a 1.7-V differential offset. To correct the offset, R_G on the undriven side of the FDA must be split and biased to make a Thevenin equivalent of R_G on the driven side of the FDA. The Thevenin-equivalent input voltage equals the common-mode voltage from the video source; i.e., $V_{TH} = V_{IN\_CM}$.

Figure 2. Proposed circuit #1 for converting single-ended video signals to differential

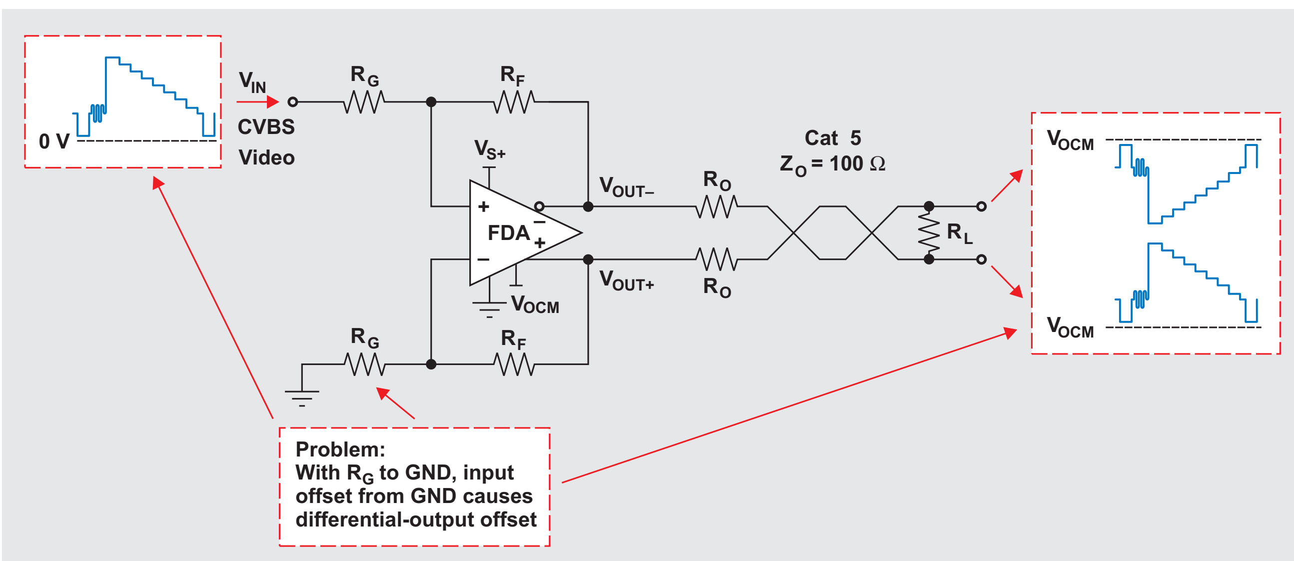
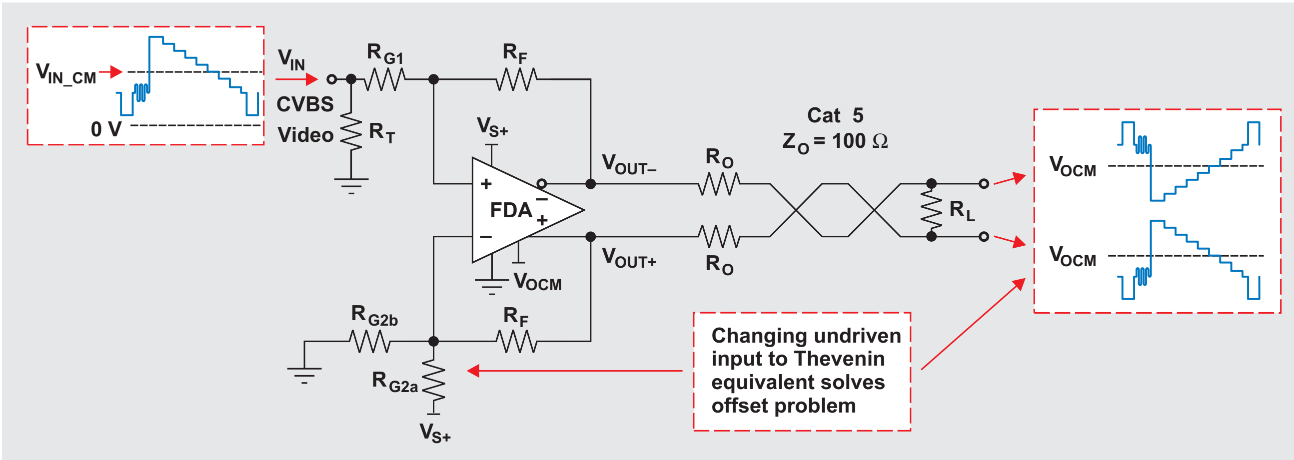


Figure 3. Proposed circuit #2 with corrected differential-output offset



Proposed circuit #2

A second proposed circuit for converting a single-ended video signal from a single-supply video source like the TMS320DM368 to drive a differential line is shown in Figure 3. In this version, the circuit is improved to correct the offset in circuit #1 by adding R_T for a 75-Ω input termination and changing R_G on the undriven side of the FDA to be the Thevenin equivalent of the driven side, with $V_{TH} = V_{IN\_CM}$. The function of the components is the same as before, with R_G on the undriven side replaced by R_{G2a} and R_{G2b}. An analysis and a simulation of circuit #2 follow.

Analysis of circuit #2

For analysis of circuit #2 in Figure 3, it is assumed that the FDA is an ideal amplifier with infinite gain and no offset. One goal of the design is to make the undriven side of the FDA a Thevenin equivalent of the driven side. This is working backwards from the normal way to use the theorem, converting the simpler form of the driven side to a more complex circuit on the undriven side.

The first step is to set the parallel sum, $R_{G2a} \parallel R_{G2b} = R_{TH}$, where $R_{TH} = R_{G1} + R_S \parallel R_T$. This can be written in equation form as

$$R_{TH} = R_{G1} + \frac{R_S \times R_T}{R_S + R_T}. \quad (1)$$

R_S equals 75 Ω and is the output impedance of the TMS320DM368 video buffer. R_T equals 82.5 Ω and is the resistance required to make the input impedance of the amplifier circuit equal 75 Ω. For detailed information on how to select R_T and R_{G1} for proper termination and gain, see Reference 2.

The second step is to set $V_{TH} = V_{IN\_CM}$, where

$$V_{IN\_CM} = \frac{V_{IN(min)} + V_{IN(max)}}{2}. \quad (2)$$

The required V_{TH} is easy to analyze by using Figure 4 and is calculated by

$$V_{TH} = V_{S+} \times \frac{R_{G2b}}{R_{G2a} + R_{G2b}}. \quad (3)$$

For completeness before going on, assuming the device has been set up per the foregoing, the gain from single-ended input to differential output is set by

$$G = \frac{V_{OUT\pm}}{V_{IN}} = 2 \times \frac{R_F}{R_{TH}} \times \frac{R_T}{R_S + R_T}. \quad (4)$$

Each single-ended output is half the differential output and is level shifted to V_{OCM}:

$$V_{OUT+} = V_{IN} \times \frac{R_F}{R_{TH}} \times \frac{R_T}{R_S + R_T} + V_{OCM}$$

$$V_{OUT-} = -V_{IN} \times \frac{R_F}{R_{TH}} \times \frac{R_T}{R_S + R_T} + V_{OCM}$$

Figure 4. Thevenin equivalent (V_{TH}) analysis diagram

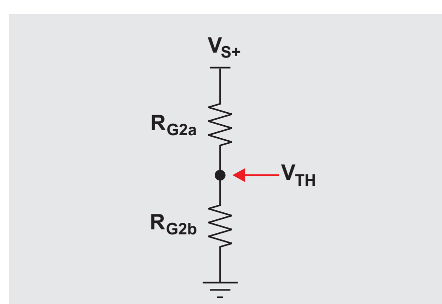
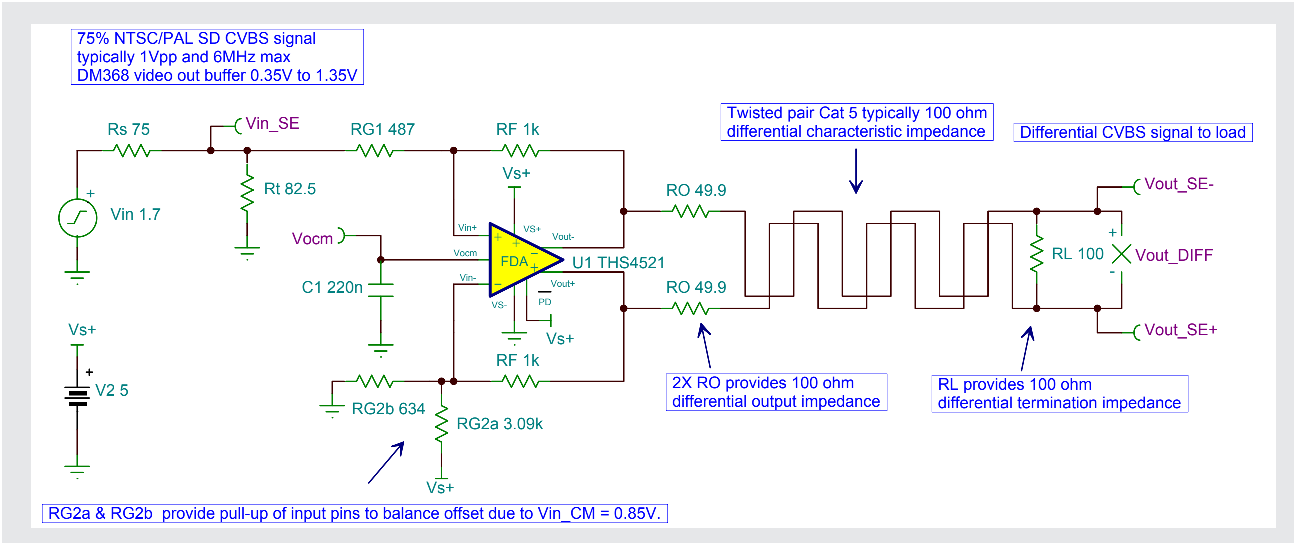


Figure 5. TINA-TI™ example circuit



To find the unique values of R_{G2a} and R_{G2b} that will satisfy the design, Equations 1 and 3 need to be rearranged and solved simultaneously. One approach yields

$$R_{G2a} = R_{TH} \times \frac{V_{S+}}{V_{TH}}. \quad (5)$$

This value can then be used to find

$$R_{G2b} = \frac{R_{G2a} \times R_{TH}}{R_{G2a} - R_{TH}}. \quad (6)$$

Calculation example for circuit #2

For this example of how to use circuit #2, it is assumed that the input signal is from the TMS320DM368, with a signal output range of 0.35 V to 1.35 V. Cat 5 cable is used, so R_O = 50 Ω and R_L = 100 Ω for double termination. The TI THS4521, an FDA with a single +5-V supply, was chosen for this example.

The THS4521 data sheet recommends that R_F be equal to 1 kΩ. To provide 75-Ω input termination and a value for G of 2 V/V (6 dB), R_{G1} can be set at 487 Ω and R_T at 82.5 Ω per Reference 2. These values can be used in the following equations to calculate the remaining resistor values.

Using Equation 1:

$$R_{TH} = R_{G1} + \frac{R_S \times R_T}{R_S + R_T} = 487\ \Omega + \frac{75\ \Omega \times 82.5\ \Omega}{75\ \Omega + 82.5\ \Omega} = 526\ \Omega$$

Using Equation 2:

$$V_{IN\_CM} = \frac{V_{IN(min)} + V_{IN(max)}}{2} = \frac{0.35\ V + 1.35\ V}{2} = 0.85\ V$$

Using Equation 5:

$$R_{G2a} = R_{TH} \times \frac{V_{S+}}{V_{TH}} = 526\ \Omega \times \frac{5\ V}{0.85\ V} = 3096\ \Omega$$

Using Equation 6:

$$R_{G2b} = \frac{R_{G2a} \times R_{TH}}{R_{G2a} - R_{TH}} = \frac{3096\ \Omega \times 526\ \Omega}{3096\ \Omega - 526\ \Omega} = 634\ \Omega$$

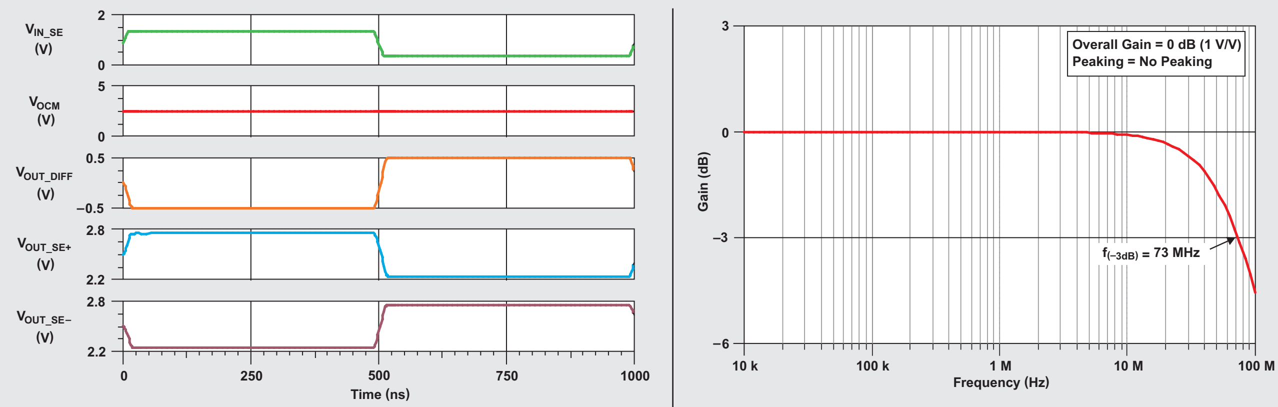
The nearest standard 1% values, 3.09 kΩ and 634 Ω, are used in the following simulation.

Simulation with TINA-TI™ software

It is always a good idea to simulate a proposed circuit to catch errors and verify that any assumptions are valid. Figures 5 and 6 show the result of a transient and frequency analysis performed with TINA-TI™ software. The simulation shows no unwanted offsets in the transient response with the output level shifted to V_{OCM} = 2.5 V, and the AC frequency response shows that gain to the load is 1 V/V (0 dB) as desired.

To see the TINA-TI simulation of this circuit, go to http://www.ti.com/lit/zip/slyt427 and click Open to view the WinZip directory online (or click Save to download the WinZip file for offline use). If you have the TINA-TI software installed, you can open the file THS4521_SE_to_DIFF_for_Cat5_video_drive.TSC to view the example. To download and install the free TINA-TI software, visit www.ti.com/tina-ti and click the Download button.

Figure 6. TINA-TI™ simulation results of example circuit



(a) Transient simulation with a 1-MHz square wave and V_{IN_SE} = 0.35 to 1.35 V

(b) Simulation of AC frequency response from V_{IN_SE} to V_{OUT_DIFF}

Conclusion

The THS4521 is an excellent choice for converting standard-definition (SD) or enhanced-definition (ED) video signals from single-ended to differential in single-supply applications. Table 1 shows the most stringent NTSC and PAL video-buffer requirements of SD and ED versus THS4521 specifications. The THS4521 meets them all.

The THS4521 is capable of working for this application with a supply as low as +2.5 V. This, along with its low quiescent current and power-down capability, makes it ideal for remote, portable, and battery-powered devices.

Table 1. NTSC/PAL SD/ED video-buffer requirements versus THS4521 specifications

SPECIFICATION	0.1-dB BANDWIDTH (MHz)	SLEW RATE (V/µs)
NTSC/PAL CVBS Video	6	38
NTSC/PAL ED Video	12	53
THS4521 (V_S = 3.3 V)	20	420

References

For more information related to this article, you can download an Acrobat® Reader® file at www.ti.com/lit/*litnumber* and replace "*litnumber*" with the **TI Lit. #** for the materials listed below.

Document Title **TI Lit. #**

1. James Karki, "Fully-differential amplifiers," Application Report. sloa054d
2. Jim Karki, "Input impedance matching with fully differential amplifiers," *Analog Applications Journal* (4Q 2008) slyt310

Related Web sites

amplifier.ti.com
www.ti.com/sc/device/THS4521
www.ti.com/sc/device/TMS320DM368

TINA-TI example:
www.ti.com/lit/zip/slyt427

To download TINA-TI software:
www.ti.com/tina-ti

TI Worldwide Technical Support

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TI Semiconductor Product Information Center Home Page
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India	1-800-425-7888
Indonesia	001-803-8861-1006
Korea	080-551-2804
Malaysia	1-800-80-3973
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