APPLICATION NOTE

CAT-5 Video Transmission: Troubleshooting and Equalization

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Introduction

CAT-5 cable provides an enormous cost benefit over coax. The average cost of 100 meters of CAT-5 cable is $20 while the average cost of 100 meters of Coax cable could easily exceed $240. Furthermore, wiring is reduced from a bulky, hard-to-manage bundle of 3 cables to 1 easily-pulled cable. Additionally, CAT-5 cable has a 4th twisted pair available, which can be used for audio, timing or control signal transmission.

This paper provides in-depth information on component video standards and amplifier characteristics necessary to achieve those standards. The trade-offs of differential line driver and receiver topologies are discussed in detail. This paper also presents an array of common video problems along with an explanation of the source and a suggested solution. This array includes: ghosting, color matching, common-mode noise, power-supply noise, mismatches in channel timing and equalization.

With a focus on CAT-5, extra effort is spent in the discussion of video equalization techniques, an inevitable result of the lower bandwidth of the cables. While circuit specifics are presented, they involve manual tuning to compensate for the exact length of the cable used. Since manual tuning requires professional installation, two new systems based on automatic cable compensation are also presented.

Video Example - SXGA

We have chosen to discuss the main aspects of a video system with respect to the SXGA video standard. Table 1 presents key parameters of 76Hz SXGA video signal so we can calculate the bandwidth and slew rate needed in the driver and receiver amplifiers. If not provided, the signal bandwidth is calculated with the Equation 1:

$$BWS = (1/2)(K \bullet AR \bullet (VLT)^2 \bullet FR) \bullet (KH)/(KV) = 51.9MHz \quad \text{(EQ. 1)}$$

where BWS = Signal bandwidth

K = Kell factor, Visual information is lost when video information passes during the retrace rather than the active portion of the scan line. Assuming 30% of the visual information is loss, K = 0.7.

AR = Aspect ratio (the display width divided by display height) = 1.33

VLT = Total number of vertical pixels = 1067

FR = Frame rate or refresh rate = 76

KH = Ratio of total horizontal pixels to active pixels = 1720/1280 = 1.34

KV = Ratio of total vertical lines to active lines = 1.04

TABLE 1. PARAMETERS OF SXGA VIDEO STANDARD

PARAMETER	VALUE
Active Horizontal Pixels	1280
Active Vertical Pixels	1311
Total Horizontal Pixels	1720
Total Vertical Pixels (VLT)	1067
Frame Rate (FR)	76Hz
Horizontal Rate	81.1kHz
Pixel Rate	139.5Mpixels/second
Signal Bandwidth (BWS)	51.9MHz

The signal bandwidth is calculated to ensure adequate system bandwidth. When choosing an amplifier, remember that the reported bandwidth is measured as the half-power point, also known as the 3dB frequency. The 50% loss of power at this frequency is not acceptable in any part of the video signal bandwidth. Therefore, it is customary to determine the 0.1dB bandwidth of the amplifiers chosen for the drivers and receivers of the video system. The correlation between 3dB bandwidth and 0.1dB bandwidth will depend on the number of poles in the amplifier. A single-pole amplifier needs to have a reported 3dB bandwidth of 337MHz (~6.5 times more than 51.9MHz) to have sufficient 0.1dB bandwidth. A multiple-pole amplifier (including most modern high-speed amplifiers) must have a 3dB bandwidth of at least 156MHz (~3 times more than 51.9MHz) to ensure the proper 0.1dB bandwidth.

The second crucial characteristic is slew rate. The slew-rate can be calculated from the signal amplitude and pixel rate. To maintain video signal integrity for a pixel rate of 139.5MHz and a swing of ~1V transition during ¼ of a clock period:

$$\text{Slew Rate} = 1/(1/4*\text{Pixel Time}) = 1/(1/4*(1/139.5MHz)) = 558V/(\mu s) \quad \text{(EQ. 2)}$$

Therefore, the video driver and receiver must have bandwidth in excess of 337MHz (worst case) and slew rate greater than 558V/µs.

CAT-5 Cable Characteristics

Standard CAT-5 cable consists of 4 twisted pairs of AWG 24 cable, which has a characteristic impedance of 100Ω. The DC resistance is 10Ω/100m with a capacitance of 4.6nF/100m. One important characteristic of SXGA video transmission is high frequency cable attenuation, which increases exponentially over frequency and distance. Figure 1 shows the effects of signal frequency and cable length on the signal attenuation. As Figure 1 illustrates, the losses within CAT-5 cable are significant at 51.9MHz, the calculated signal bandwidth of SXGA.

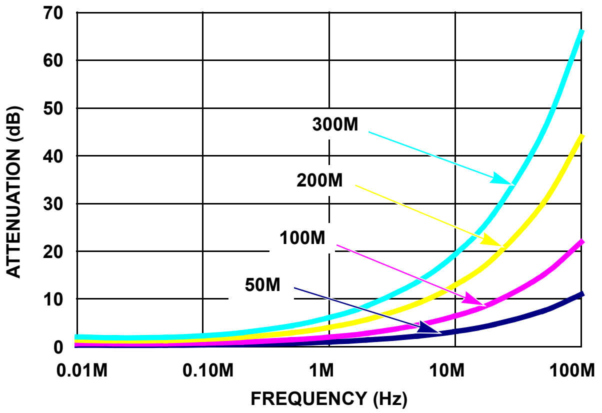


FIGURE 1. CAT-5 CABLE ATTENUATION CHARACTERISTICS

Differential Line Driver Topologies

Figure 2 illustrates a standard differential input and output line driver system built with discrete operational amplifiers. The differential output driver doubles the output voltage swing – while the resistors R_F and R_G determine the circuit voltage gain with Equation 3:

$$V_{OUT}/V_{IN} = 1+2\bullet R_F/R_G \qquad \text{(EQ. 3)}$$

High noise rejection such as 60Hz power line interference is accomplished by amplifying only the differential input voltage signals and not amplifying the common-mode input voltage. The only real disadvantage of this circuit is the required differential input signal sources.

Typically, signals originate in single-ended rather than differential form. Converting single-ended signals to differential mode prior to line transmission reaps the benefit of high common-mode noise reduction. The circuit in Figure 3 provides a very simple way to generate a differential output signal from a single-ended input signal using two operational amplifiers; the upper amplifier is non-inverting while the bottom is inverting.

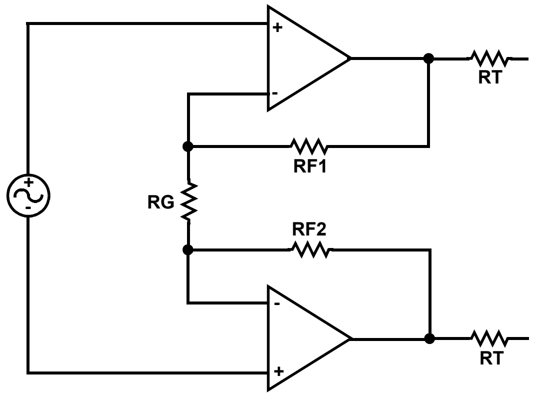


FIGURE 2. DIFFERENTIAL LINE DRIVER WITH DISCRETE AMPLIFIERS

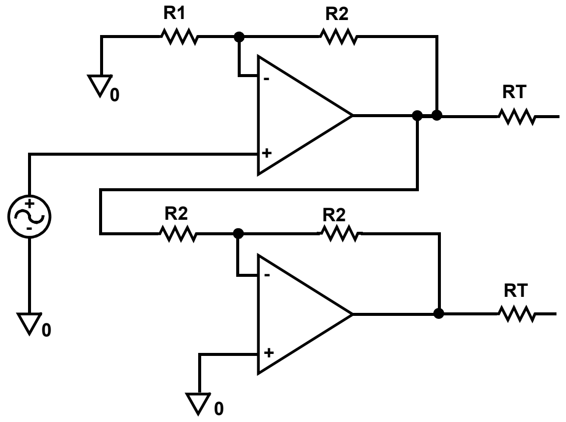


FIGURE 3. SINGLE-ENDED TO DIFFERENTIAL LINE DRIVER

Note the amplifiers in Figure 3 have different feedback ratios (closed-loop gain) which results in different bandwidths for voltage feedback amplifiers. The difference in bandwidth causes higher frequency signal mismatch and can lead to distortion.An integrated solution will ensure proper matching and the EL5177 is available. It is a differential output amplifier with a bandwidth of 550MHz, a slew rate of 1100V/µs, and can accept single or differential inputs. This device is internally compensated for a stable closed-loop gain of +1 and the gain is set by an external R_F and R_G while the common mode output voltage is controlled by a reference pin.

Differential Line Receiver Topologies

Figure 4 shows a differential to single-ended converter implemented with high-speed amplifiers. The advantage is both a very high input impedance and very high common mode rejection achieved with simplicity. Bandwidth mismatch of the two amplifiers introduces the possibility of high-frequency distortion. The differential gain is determined by R_1 and R_2 resistors with the relationship:

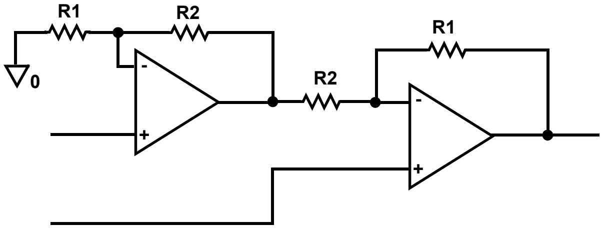


FIGURE 4. DIFFERENTIAL TO SINGLE-ENDED CONVERTER, GAIN = $1 + R_1/R_2$

An integrated, balanced receiver solution, the EL5175, provides the complement to the integrated driver, the EL5177. It takes the differential signal from the CAT-5 cable and provides a single-ended output within a 550MHz bandwidth and 622V/µs slew rate.

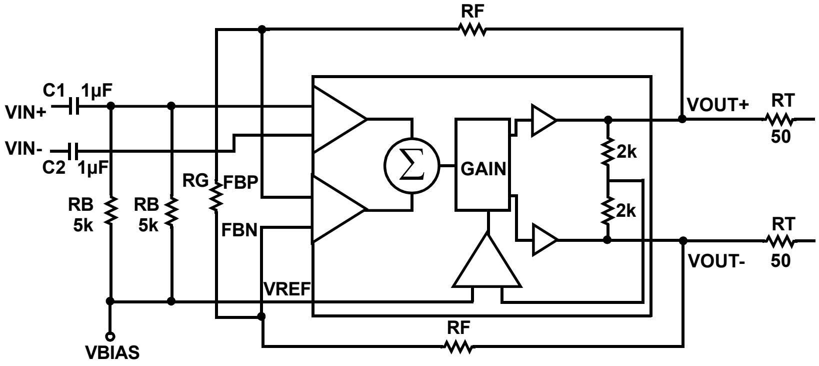


FIGURE 5. CAT-5 CABLE TERMINATION SCHEME (DRIVER SIDE)

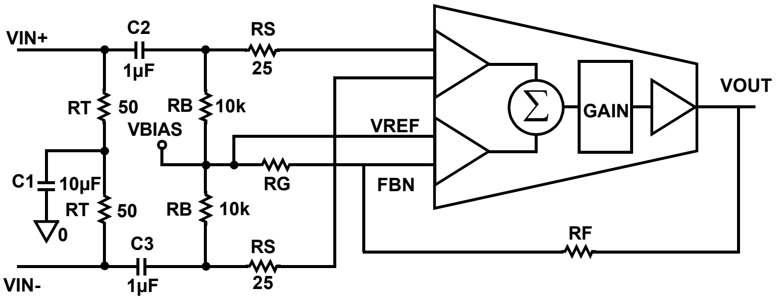


FIGURE 6. CAT-5 CABLE TERMINATION SCHEME (RECEIVER SIDE)

Common Video Problems and Solutions

Video systems can experience a myriad of problems. Many of those problems are uncovered and explained in the following paragraphs. Solutions are presented as space allows. The issue of equalization, brought about by the attenuation inherent in CAT-5 cable, is discussed in detail.

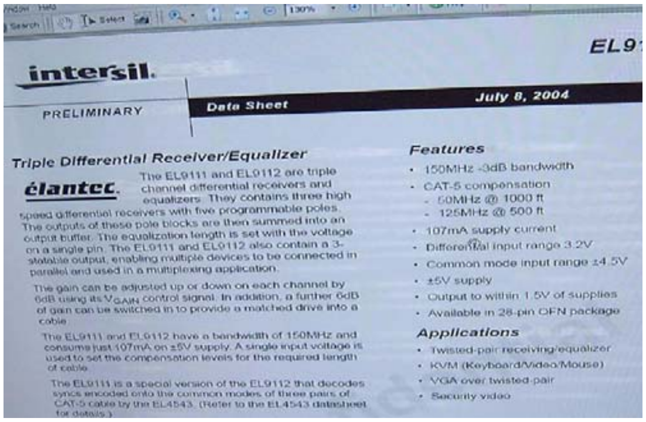
Video Problem 1: Ghosting

Ghosting occurs when a circuit does not have proper termination. Improper termination causes ringing, which appears as additional images after the original image. It always occurs horizontally and to the observer's right—following the path of the video signal.

To avoid reflections and maintain integrity of the input video signals, each stage must be properly terminated. The characteristic impedance of a standard CAT-5 cable is 100Ω which is split into two 50Ω resistors for driving the line differentially. Figures 5 and 6 show the termination schemes on the driver and receiver sides.

C_1 and R_T of the receiver form a low pass filter to reject high frequency common-mode noise on the cable. Capacitors isolate DC voltage differences in the ground potential of the driver and receiver systems. A small resistor Rs isolates the input capacitance of the receiver from the PCB trace inductance to avoid any resonance at the amplifier inputs.

Some video systems do not have a negative supply available and require single supply operation. The above circuits also show the implementation of single supply operation.



Triple Differential Receiver/Equalizer

The EL9111 and EL9112 are triple channel differential receivers and equalizers. They contains three high speed differential receivers with five programmable poles. The outputs of these pole blocks are then summed into an output buffer. The equalization length is set with the voltage on a single pin. The EL9111 and EL9112 also contain a 3-statable output, enabling multiple devices to be connected in parallel and used in a multiplexing application.

The gain can be adjusted up or down on each channel by 6dB using its V_{GAIN} control signal. In addition, a further 6dB of gain can be switched in to provide a matched drive into a cable.

The EL9111 and EL9112 have a bandwidth of 150MHz and consume just 107mA on ±5V supply. A single input voltage is used to set the compensation levels for the required length of cable.

The EL9111 is a special version of the EL9112 that decodes syncs encoded onto the common modes of three pairs of CAT-5 cable by the EL4543. (Refer to the EL4543 datasheet for details.)

Features

- 150MHz -3dB bandwidth
- CAT-5 compensation
  - 50MHz @ 1000 ft
  - 125MHz @ 500 ft
- 107mA supply current
- Differential input range 3.2V
- Common mode input range ±4.5V
- ±5V supply
- Output to within 1.5V of supplies
- Available in 28-pin QFN package

Applications

- Twisted-pair receiving/equalizer
- KVM (Keyboard/Video/Mouse)
- VGA over twisted-pair
- Security video

FIGURE 7. EXAMPLE OF WHITE GHOSTING ON A WEB PAGE

Video Problem 2: Color Mismatch

Color mismatch is the effect of a difference in gain or offset of the R, G, and B channels. This offset can be adjusted manually with resistive dividers or additional op amps. An integrated solution is available in the EL9111.

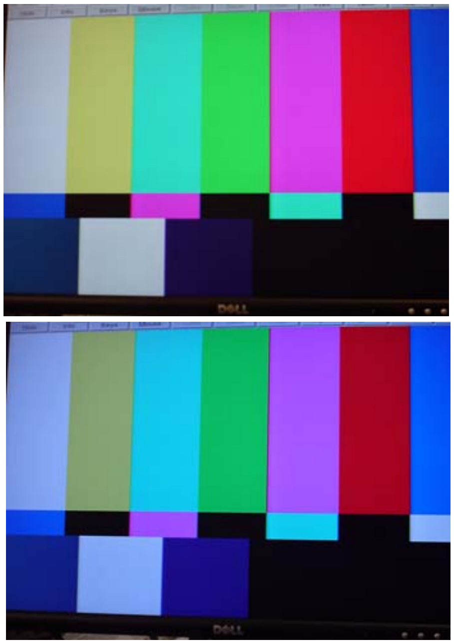


FIGURE 8. EXAMPLES OF COLOR MISMATCH. THE SCREEN ON THE BOTTOM HAS EXCESS BLUE

Video Problem 3: Common-mode Noise

Since the horizontal and vertical sync information is typically transmitted as a common-mode signal, common-mode noise can cause a loss of synchronization. An example of delay in horizontal sync is shown in Figure 9. Figure 12 shows a circuit to eliminate it. The sum of all of the common-mode signals is gathered at the amplifier at the bottom and fed back as a reference to each of the signal line.

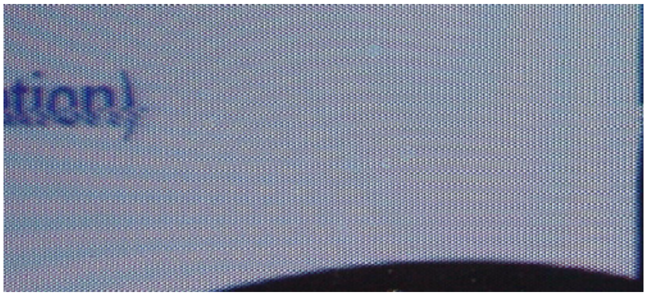


FIGURE 9. EXAMPLE OF LOSS OF HORIZONTAL SYNCHRONIZATION

Video Problem 4: Power Supply Noise

Power supply noise appears as a repetitious disturbance in the video picture. As the power supply is effectively raised and lowered, the gains of the amplifiers are altered. This commonly causes the striping that appears in the following figures. To avoid this unwanted behavior, use a higher quality voltage regulator to power the amplifiers and bypass all ICs as close to the power pins as possible.

FIGURE 10. EXAMPLES OF POWER SUPPLY NOISE

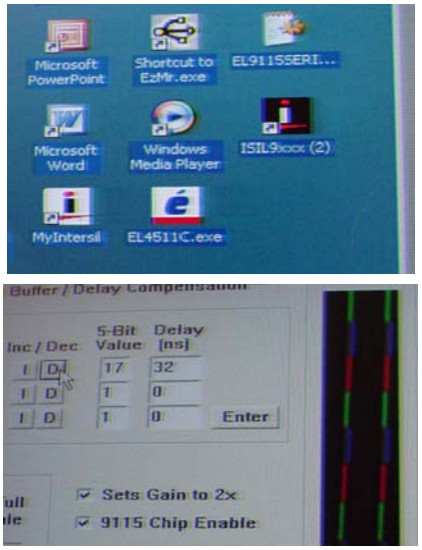


FIGURE 11. EXAMPLES OF CHANNEL TIMING MISMATCH

Video Problem 5: Channel Timing Mismatch

If the R, G, and B signals are mismatched with respect to time, they will cause a blurring of the signal. In Figure 11, the left side shows each of the color signals and blue is late with respect to the others. This causes an offset in the overlay of the three colors. In Figure 11, look at the icons on the right where the blue has been overcompensated and is appearing first, causing the other colors to appear as a trailing edge.

This usually signifies a mismatch in line length, either within the cable or the printed circuit board. An analog delay line can be added to delay early signals, but must be tuned for the given circuit. An integrated solution is available, the EL9115, which will insert a specific delay into any or all of the three video signals. In fact, we used it to offset the blue signal and create these images.

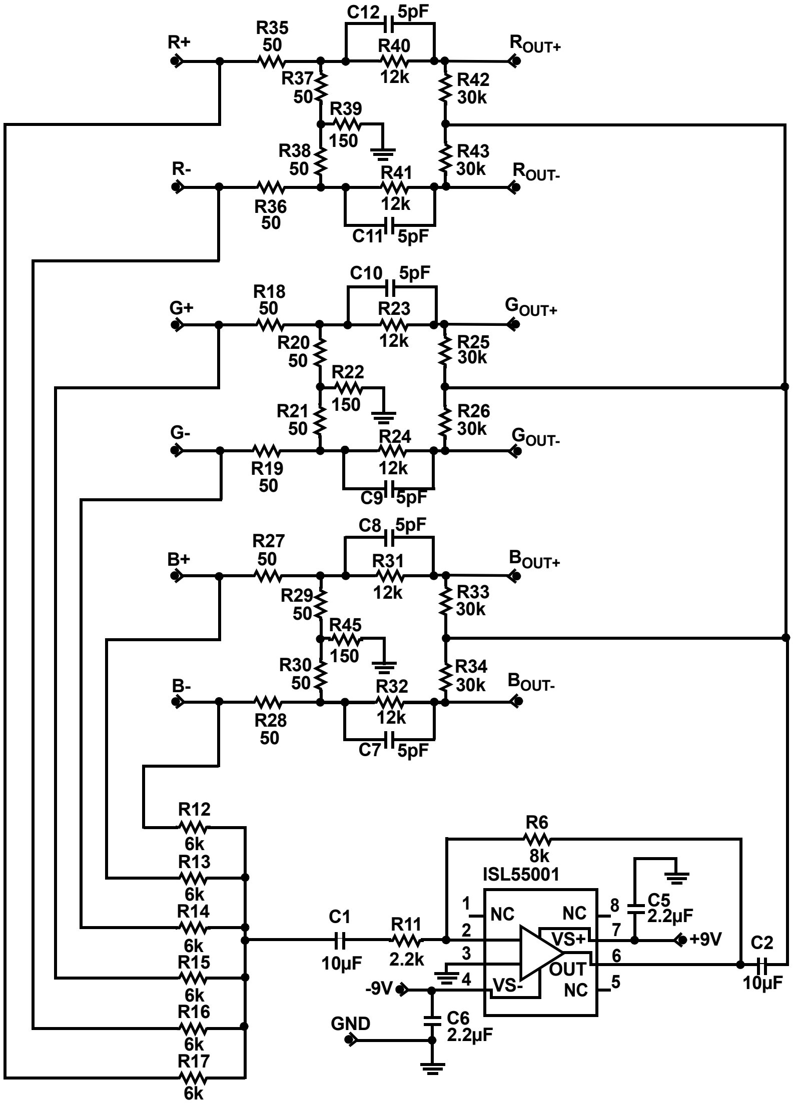


FIGURE 12. COMMON-MODE FEEDBACK CIRCUIT TO CORRECT SYNCHRONIZATION PROBLEMS

Video Problem 6: Equalization

Equalization issues are unavoidable when using CAT-5 cable. Since the cable attenuates some of the signal bandwidth, the high frequency signals will be distorted. This causes the smearing apparent in Figure 13. Compensation is needed to rectify the high frequency losses of the system. This compensation can be provided at the driver (before entering the cable, predistortion) or at the receiver (after going through the cable.

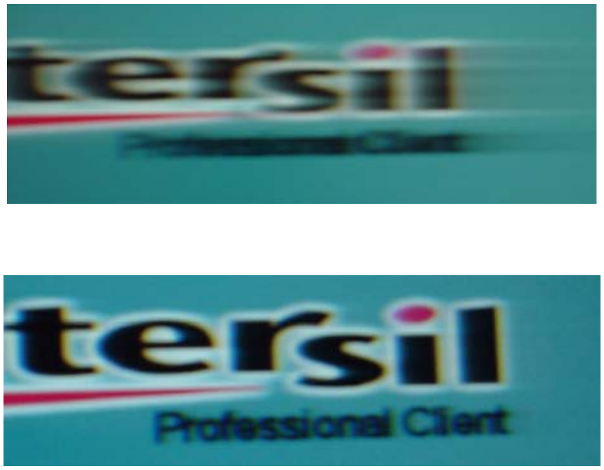


FIGURE 13. VIDEO SIGNAL WITH SMEARING (TOP) AND WITHOUT SMEARING (BOTTOM)

VIDEO EQUALIZATION STRATEGIES: PRE-EQUALIZATION VERSUS POST-EQUALIZATION

Figure 14 shows a very simple method of pre-equalizing the line with the inclusion of a parallel 1.6nF capacitor with the termination resistor. The 1.6nF capacitor shorts the 50Ω termination resistor at high frequencies and allows a larger amount of signal on the line. The resistor-capacitor combination is a single pole high pass filter with a zero at 2MHz. The maximum achievable gain at high frequency is limited to 6dB. In this scheme, cable parasitic capacitance appears at the amplifier output and can lead to oscillation.

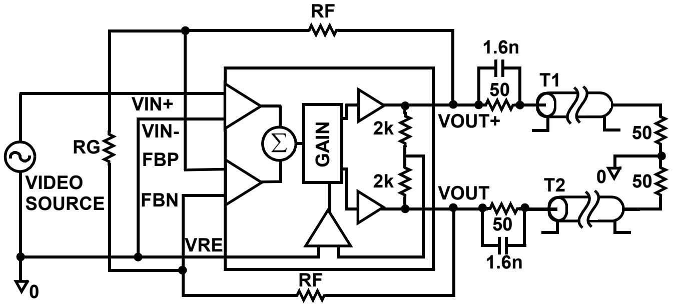


FIGURE 14. SINGLE-POLE PRE-EQUALIZATION SCHEME

Figure 15 shows a 3 pole compensation circuit using a 1GHz bandwidth high slew rate amplifier. The circuit is configured around the gain setting resistor that places the poles at 1.2MHz, 15MHz and 100MHz respectively. The amount of high frequency compensation is determined by the resistance. The capacitor and resistor combinations set the pole frequencies. Theoretically, this circuit can be used for both pre and post equalization. In practice the line driver slew rate and output swing limit the pre-equalization performance; for instance, a 1V 60MHz input signal becomes a 12.6V 60MHz signal at the line driver output requiring approximately a 5kV/µS slew rate. This would require a factor of 10 increase in slew rate. Therefore, this circuit should always be implemented in a post-equalization configuration where the incoming high frequency signal is low in amplitude.

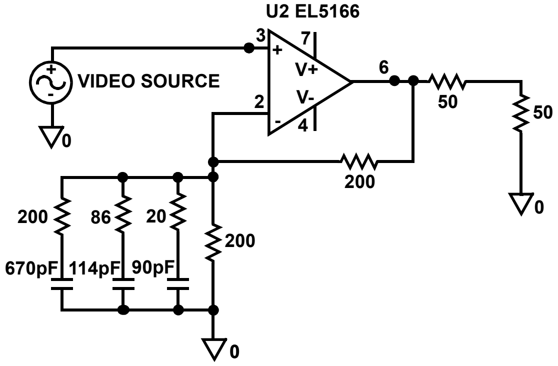


FIGURE 15. 3 POLE POST-EQUALIZATION SCHEME

A third solution is the EL9110, a differential line receiver with an integrated CAT-5 cable compensation network. Since the frequency-dependent losses are preprogrammed into the amplifier, a control voltage allows the amplifier to compensate for the cable loss.

Figure 16 shows a comparison of 100 meter CAT-5 cable attenuation and the frequency responses of the 3 cable compensation circuits. The 1.6pF//R_{OUT} compensation circuit works well up to 10MHz. The frequency response of the 3 pole compensation circuit comes very close to matching the CAT-5 cable attenuation. The EL9110, with V_{GAIN} set to 0.24V, compensates for signal frequencies up to 100MHz.

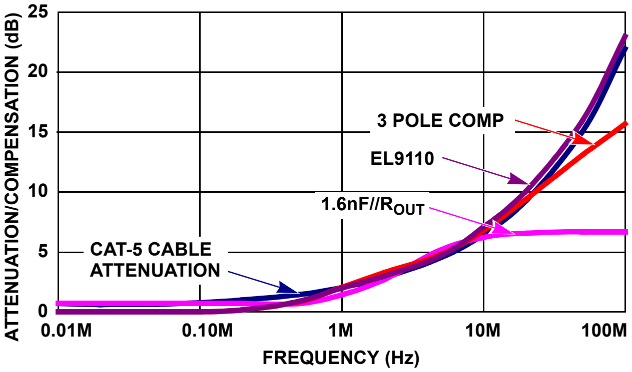


FIGURE 16. 100m CAT-5 CABLE ATTENUATION AND COMPENSATION

Automated Equalization - Step-Response Solution

With the acquisition of an IC internally programmed with the frequency-dependent losses of CAT-5 cable, an automated system can be constructed to provide the gain voltage. We offer two methods for determining this gain input and therefore the amount of compensation necessary to offset cable losses. The first is a digital solution using the non ideality of a step response.

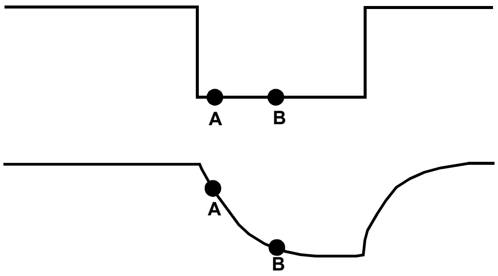


FIGURE 17. COMPENSATED (ABOVE) AND UNCOMPENSATED (BELOW) SYNC TIPS

In a properly compensated receiver; the edges are square. In a grossly under compensated receiver, the edges are soft and indistinct due to the cable's attenuation of the high frequency components. The rest of the video signal suffers equally, but the sync tip shows the effect of under compensation most dramatically.

Consider the points labeled "A" and "B" in Figure 17. In a properly-compensated receiver, the sync tip is flat, and the slope between points A and B is roughly zero. Without compensation, the sync tip is not flat and there is a negative slope between points A and B. The slope of the line between these two points can be used to measure the compensation

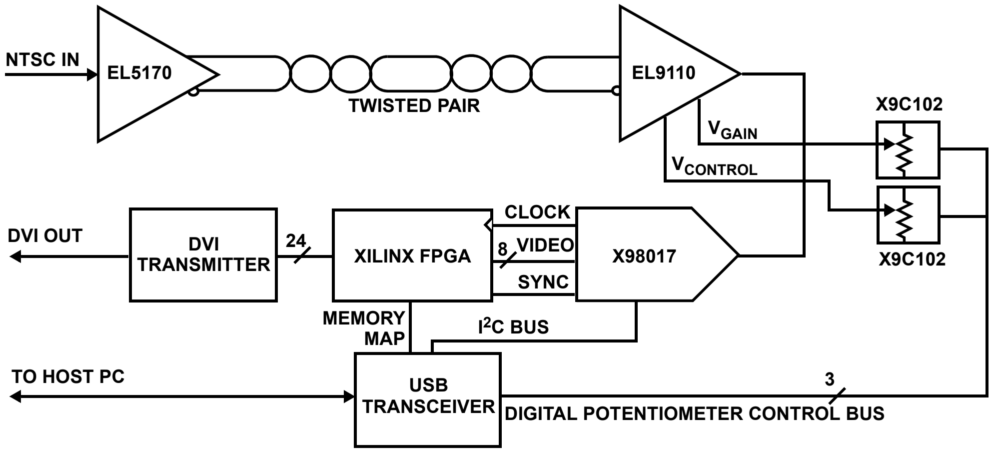


FIGURE 18. AUTOMATIC EQUALIZATION LOOP BLOCK DIAGRAM

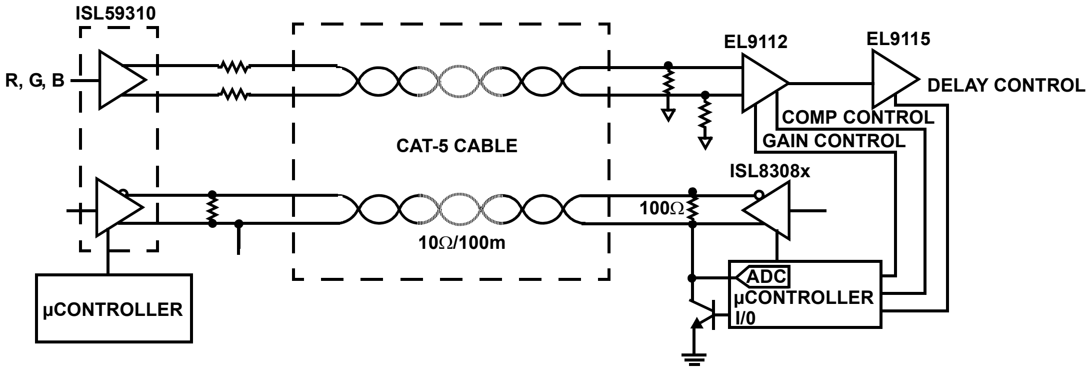


FIGURE 19. AUTOMATIC EQUALIZATION CIRCUIT USING RESISTANCE MEASUREMENT OF LINE

quality and provides a means to develop an auto-equalization loop.

The analog transmission line is comprised of an EL5170 twisted-pair transmitter, CAT-5 cable, and EL9110 single channel receiver and equalizer. The EL9110's gain and equalization settings (V_{GAIN} and $V_{CONTROL}$) are controlled digitally with two X9C102 digitally-controlled potentiometers.

Automated Equalization – Resistive Method

In the method shown in Figure 19, the fourth pair of wires is used to calculate the loss of the CAT-5 cable. Since the loss of CAT-5 cable is 10Ω per 100 meters and the total loss incurred typically remains less than 100Ω, a resistive divider is formed to calculate the length. Figure 20 demonstrates the resistor-divider set-up on the fourth pair of wires. This fourth pair is driven on both ends. The driver also has the ability to disconnect from the line when set for high impedance.

After the driver (left side) is set to provide a constant 5V, the ISL8308x has its output set for high impedance. With a transistor acting as a switch, the resistive divider shown in Figure 20 is created. The voltage read by the microcontroller will reveal the line loss using Equation 4:

$$V_{MEASURED} = 5V \bullet [R_{LINE} / (2 \bullet R_{LINE} + 100\Omega)] \qquad \text{(EQ. 4)}$$

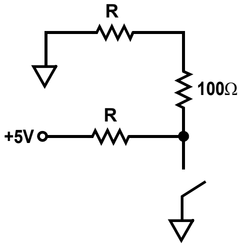


FIGURE 20. RESISTIVE DIVIDER FORMED ON 4TH PAIR OF CAT-5 WIRES FOR MEASURING LENGTH

A microcontroller is configured to read this voltage and send the appropriately scaled voltage to the gain input of the ISL9112 line receiver. Since the ISL9112 includes specialized compensation for CAT5 cable loss, the calibration is complete and the system is operational.

Conclusion

CAT-5 cable provides a low-cost option for transmitting video signals. Many potential problems are discussed along with suggestions and solutions. Emphasis on equalization, including two complete automated systems, gives multiple options for compensating high frequency losses.

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