



On Cables and Connections

A discussion by Dr. J. Kramer

We are frequently asked - "what length of cable can I use for a specific application?" Seemingly a simple question, but the answer is quite complicated.

Basically, cables connecting different types of equipment should ideally behave as "shorts", meaning that the output from the receiving device should be as if it is connected directly to the transmitting device. Unfortunately, they don't. Connecting cables have their own characteristics, which they impose on the signals they carry. An ideal cable should behave as an ideal "transmission line", having no effect on the signal. Nevertheless, cables behave otherwise.

Two major factors play an important role in signal deterioration due to poor cables:

1. First, cables do not behave as ideal transmission lines with known impedance due to flaws in cable design and production. Sometimes the impedance of the cable is simply not as stated on the cable.
2. Second, due to imperfection in cable design, stray (parasite) capacitance and inductance appear along the cable and they have an adverse effect on signal quality.

The longer the cables used the more adverse effects they have on the signals being transmitted. Better cables alleviate this problem. A very popular cable used for video is "RG-59" type. For short distances - a meter or two - this cable is fine, and the signals, which emerge, look as if they were connected directly by an ideal short. At composite video frequencies, up to 10 MHz, the high frequency loss of this cable is about 3 dB after 100 meters. Therefore, deterioration is not apparent even at 20 meters. However, at 300 MHz, (the frequencies encountered in high-resolution or digital video) the loss at 100 meters is close to 20 dB, which is disastrous to the signal. When using SDI (Serial Digital) signals, at 270 Mbits/sec, a loss of 40 dB may occur at 300 meters. This represents a signal deterioration of 99% (down to 1% of the original signal!)

Rules-of-thumb to prevent cable problems:

- Use the best cables you can afford.
- Use the shortest cables possible.
- Check that impedance of the cable really matches your application.
- Check the connectors on the cables. Poor quality connectors may have worse effects than the cables themselves.
- Use appropriate amplifiers if needed.
- Keep cables away from sources of interference - electric motors, mains cables, transmitters, triac operated equipment (light dimmers) etc.

Cable length and quality:

- For composite video, PAL or NTSC, RG-59 cable can be used for distances of up to 20 meters between the video source and the acceptor. No signal deterioration should show on the screen. For longer distances, up to 30 meters, use RG-11 type cable. For still longer distances, better cables should be used, such as Belden 8281 or Belden 1694A (which are also suitable for SDI signals). Those cables extend the range by 50% and more.
- For s-Video (Y/C, Super-VHS and Hi-8), standard, inexpensive cables allow operating distances of 5-7 meters. Very little deterioration is apparent. At this distance lower quality cables would show color "smear" and blurred images. Better than standard quality cables will show no deterioration whatsoever. The quality of the s-Video connector, often overlooked, plays a very important role in final signal quality.
- Analog component video signals - whether Y, R-Y and B-Y or RGB should be treated very carefully. If the origin of the component video signal is a VCR or a camera, in order to maintain good quality (especially for the "Y" signal), RG-59 cables are suitable for up to 10 meters. For longer distances, up to 20-25 meters, a better cable should be used - either RG-11 or an appropriate Belden cable (see above). Component signals such as RGB signals from computer graphics sources should be treated as computer sources (see below.).
- Computer graphics cards generating VGA, Super-VGA or XGA signals need a different approach, depending on resolution. Standard, commonly available VGA cables are suitable for 640x480 resolution at distances of up to 1.5 meters. At 800x600, such cables are suitable for distances of not more than 80 centimeters. They are not suitable for use at higher resolutions. Special VGA/XGA cables should be used for resolutions of 1024x768 and above. The best quality cables of the packed-in-one-sleeve type are suitable for up to 10 meters, albeit with some apparent deterioration. When computer graphics or other high frequency component signals are used, the compound output should be transmitted over coax cables which are divided into individual, separately sleeved lines, of one of the types mentioned above. For

VGA/XGA signals, 5 cables are needed for setups of Red, Green, Blue, Horizontal Sync and Vertical Sync, and four cables are needed for setups with Red, Green, Blue and Composite Sync. Three cables are needed for setups either with Red, Blue, Green+Sync or when the composite sync signal is superimposed on all signals (Red Green and Blue).

Solving cable related problems:

The problems cable generate that can be completely or partially solved divide into several categories:

- General signal loss and attenuation due to incorrect impedance characteristics. If you feed a long cable with 1-Volt composite video, you may find on the far end only about 0.9 Volts.
- High frequency losses due to the wrong capacitance and inductance. Such high frequency loss in video shows up as loss of color, from color smears to up to full color loss, loss of picture resolution and loss of fine details.
- Standing wave and reflection effects due to impedance mismatch between circuit and cable. The visible result of this problem is the "ringing" effect, where ghost lines appear on vertical image transitions, thus upsetting image integrity.

When longer distances are needed:

As we have seen, cable lengths impose limitations in all formats. The available solutions are as follows, assuming that the best cables and connectors are used:

- Use line amplifiers to extend the range.
- Use twisted pair transmitters and receivers for longer ranges.
- Use fiber-optic transceivers to extend the range even further.
- Use RF transmission (microwave or HF) or satellite uplink for very long distances.

Line Amplifiers

Line amplifiers overcome the following shortcomings of long cable installations:

- Loss of overall signal level.
- Loss of high frequency signals due to stray capacitance and inductance.
- Mismatch of cable impedance.

Line amplifiers should be installed as close as possible to the video source to achieve the best signal to noise ratio.

Line amplifiers are equipped with several controls or trimmer adjustments to control signal level. Some are for boosting and compensating for overall signal loss. Others control high frequency losses, and are called EQ (Cable Equalization) or HF (High Frequency) controls. EQ controls apply a variable, frequency dependent amplification to the signal, to "straighten" the tilted frequency response curve of the cable. In this way, the distortions of the cable can be eliminated.

Line amplifiers cure source impedance mismatch by driving the cable with an accurate impedance drive.

Line amplifiers differ in their functions, depending on their use:

- Line amplifiers for composite video have simple controls, as mentioned above.
- Line amplifiers for S-Video (Y/C) have separate controls for Y and C. Sometimes Y/C line amplifiers have additional controls such as Chroma phase control.
- Line amplifiers for twisted-pair setups have simple controls similar to those for composite.
- Line amplifiers for component video, RGB or VGA/XGA signals are more complicated. For example, in the case of VGA/XGA, one control must adjust three different signals.
- Line amplifiers for SDI (Serial Digital) video have two-correction circuitry built-in: cable compensation and reclocking. Digital signals, besides being attenuated, become jittery when using long cables and the reclocking circuitry time-base corrects them.

With a reasonable quality line amplifier, effective operation range may be multiplied by a factor of from 2-10, depending on the format and cable used. It is not uncommon to find installations with video lines running 300 meter, using high quality cables and one or more line amplifiers inserted in series.

Line amplifiers may be cascaded. Inserting a line amplifier every 80 meters in a composite video setup is quite common. In component or Y/C setups, line amplifiers should be inserted closer together, 40 meters or so, though good cables must be used.

To transmit high resolution computer graphics signals over long distances, the best way is to split the compound VGA/XGA cable to RGB coax cables, as explained above, and use coax line amplifiers. If this is not possible, bear in mind that a line amplifier should be inserted in the signal path every 10 meters maximum, and this only when very high quality cable is used.

When long distance line-amplification is used, ground-related problems such as hum and ground loops often arise. This is due to different ground potentials between the local and remote locations. Ground isolation and differential amplification is often needed to cure the ground-related problems.

The twisted-pair solution:

Twisted pair may be the most appropriate solution to transmit composite video signals over long distances, of 100 meters up to 1km. Such a system includes a twisted pair video or AV transmitter which converts video into a twisted-pair, differential input, balanced format. On the receiving end, a twisted-pair receiver converts the twisted pair signal back to a standard video signal.

Any type of twisted pair or dual-wire cables can be used because, in most cases, the transmitter can force the impedance of the twisted-pair cable to match that of the transmitter. However, the twisted pair solution is dependent on wire quality. Low quality twisted pair wires, which have high capacitance or are over-shielded, limit the effective range of the system. Twisted-pair is also less prone to ground related problems.

Twisted pair setups linking distances of 500 meters between source and acceptor are quite common. Line amplifiers specially designed for twisted pair applications extend the range of operation. The rule of thumb is that when a system performs well at 500 meters, a line amplifier inserted at that point effectively doubles the operating distance.

Twisted pair works well for composite video where bandwidths approach 5 MHz. A good quality, color-rich signal is obtained on the far end. This system is not suitable for Y/C, Component video or VGA signals, due to the high-frequency nature of those signals.

The fiber-optic solution:

For operating distances of over 1km, fiber optic is recommended. It converts electric signals to beams of light, and transmits them over an optic fiber. The beam of light is usually infrared and can have different wavelengths. A fiber optic system includes a transmitter and a receiver. The transmitter converts the electric signal to a light beam, and the receiver converts the light beam back into an electric, such as video, signal.

There are two types of optic fiber, multi-mode and single-mode. Using multi-mode systems with transmitter, optic fiber and receiver, the useful distance for analog composite video is up to 5km. Using single-mode, this range may be extended to up to 25km. For still longer distances, special transmitting elements create an intense laser beam which can be carried by the appropriate optic fiber for 50km or more. Line amplifiers may be used with fiber optics as well, but they are far more complicated.

The RF solution:

Microwave transmitter / receivers, or satellite communication transceiving systems can extend the range of transmission to many kilometers, but this is different technology and will therefore not be discussed here.

Problems related to audio wires:

As mentioned above, transmitting audio signals over long distances can also create a host of problems. The audio system may transmit low power signals (line, Mic or balanced) or high power signals, such as those used in standard loudspeakers. Audio cabling system and design is far less sensitive to impedance matching problems than it is in video.

The main difficulties in audio cabling are as follows:

- High capacitance audio cables can overload the driving amplifier, and thereby cause instability and oscillations.
- Audio cables may pick up noise and interference which will result in poor signal quality and bad signal to noise ratio.
- Cable impedance problems cause signal loss and deterioration.
- Cable resistance and the loss of the high dumping factor of the amplifier can degrade the amplifier's output quality.

All these problems can be solved satisfactorily.

Dealing with high capacitance audio wires:

High capacitance audio wires may create signal deterioration and instability in the output amplifier stage. To avoid these problems, the output amplifier stages should use stable amplifier chips, with appropriate output resistors isolating the amplifier from the adverse effect of the cable.

The load on the cable should be high (low impedance) and the driving amplifier should be able to "pump" current into the cable. The printed circuit board design around the amplifier should eliminate PCB induced instability.

Dealing with noise pickup:

Electric noise may be picked up by long wires, thereby causing audio signal quality to deteriorate. The problem is more severe when low-level signals such as microphone generated signals are involved.

There are two solutions to this problem:

- ❑ One solution is to use good quality cables with proper shielding. The shielding substantially reduces noise pickup. This solution for line-level signals is appropriate for up to 10 meters, provided the cables are not adjacent to electric noise sources (see above).
- ❑ The other solution, commonly used in broadcast applications, is to use a balanced-wire system. A typical system uses a three-wire assembly - two wires carry the signal in opposite polarities, and the third is the ground-reference and/or shield wire. This way a very clean signal is obtained at output, though at the cost of more complicated electronic circuitry. When using the balanced-wire system, the line level signal's range may be effectively extended by up to 100 meters, again, provided the cables are not adjacent to electric noise sources (see above).

Microphone level signals of a few milli-volts are more sensitive to external interference. The effective range of low level microphone signals in a balanced-wire system is 10-15 meters (ten times better than when using simple, unbalanced shielded wires).

A very common trick is used nowadays in order to improve signal to noise ratio. The signal level is elevated in order to elevate the signal to noise ratio. This trick is based on the assumption that interference is constant. In the past, audio/video signal levels of 1 Volt were normal. Today, signal levels of 6-30 Volts, travelling on balanced audio wire systems, are very common.

Signal loss and deterioration due to cable impedance:

Cables impose specific impedance in a signal path. Sometimes, the resistance part of this compound impedance is too large and creates a voltage divider with the load impedance. The result is signal level deterioration. Active amplifying circuitry compensates for signal level changes where signal gain, either at the receiver end or, preferably, at the transmitter end, can be fine-tuned by the user, using internal or external controls. In some cases, some specific frequency bands within the audio signal spectrum are attenuated due to cable capacitance. It is usually the high frequency range which is effected. To overcome this problem, a tone-affecting amplifier or an audio equalizer should be inserted in the signal path.

Dealing with amplifier output quality degradation due to cable resistance

In an amplifier-loudspeaker system, the cables leading to the amplifier, if not heavy enough, create a voltage divider with the resistance of the loudspeaker reducing signal level. This problem can be dealt with by using the volume control of the amplifier. A much worse problem is the depreciation of the amplifier's damping factor due to cable resistance. This results in lower quality and "muddiness" in the sound. Using heavy-conductor, low capacitance wires overcomes this problem.

A final word

Cables and long distance operation can be problematic, but understanding the nature of the problems, accurately identifying one's needs and using the tips above will help in getting a good job done, even from a remote location.