Draka

Application of coaxial cables in a HD studio

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A cable manufacturer studies video cable's influence on the video quality during transmission. In a studio, where signals are generated, it is important to either eliminate or minimize influences on signal degradation. The manufacturer's contribution also provides calculations and background information to the relevant standards.

Introduction

Which physical and electrical characteristics are influential to the transmission of video signals and thus decisive for the quality of a transmission? This article will look at the following parameters, production and environmental influence:

- characteristic impedance
- reflection
- attenuation
- screening attenuation

During the production process of studio cables, the mechanical tolerances need to be kept as tight as possible. Mechanical deviations of the inner conductor, the insulation (dielectric) and the outer conductor lead to signal reflections, either local ones or, in the worst case, to frequency dependent reflection peaks (structural return loss), if occurring at regular intervals.

Signals are generated in the studio and it is there, during transmission, where these deviations can have critical consequences for the transmission characteristics. Mechanical deviations lead to deviations of the characteristic impedance and thus a mismatched transmission line. In a matched status, the losses through the transmitting medium are at their lowest.

Of significant importance is the choice of the right connectors. They definitely shall harmonize with the cable. The corresponding information and reference lists are available from the cable and connector manufacturers.

Characteristic impedance

How is the characteristic impedance defined? The characteristic impedance Z represents the ratio of the voltage wave proceeding in one direction to the current wave running into the same direction. At any point x of the cable, the characteristic impedance has the same value (independent of the cable length):

$$U_{(x)} = Z \cdot I_{(x)}$$

Termination of a cable to its characteristic impedance Z, affords the best transmission characteristics:

- largest power transfer
- lowest losses
- no energy reflection at the cable end

What is the characteristic impedance of a coaxial cable dependent on?

1. Its physical dimensions, i.e. the diameter of the inner and outer conductor

2. the dielectric

3. the frequency

Above approximately 5 MHz the characteristic impedance has a constant real value:

$$Z \xrightarrow{f \to \infty} \mathrm{Re}(Z)$$

As mentioned before, the characteristic impedance of a cable is determined by the diameter of the inner conductor d and the inner diameter of the outer conductor D, measured above the dielectric, as well as the choice of the dielectric and it's foaming (air bubbles), if any:

$$Z \approx 60\ \Omega \ln \frac{D/d}{\sqrt{e^{(1-s)\ln(\varepsilon_{r,PE})}}}$$

This means that during the manufacturing process of the cable all parameters must be simultaneously kept constant in order to achieve lowest tolerances regarding the deviation of the characteristic impedance in the cable.To ensure this, a precise combination of wire preheating, nitrogen and material supply, temperature control, speed control of the extruders and regulation of the winders s necessary. Furthermore, there are stringent requirements regarding the constancy of the line speed and a well-defined cooling process. Also the prevention of any vibration of the inner conductor when being placed into the extruder is paramount. When these parameters are met, an accuracy of $75\ \Omega < \pm 1\%$ characteristic impedance can be achieved.

How are the terms "return loss, local reflection, and reflection-coefficient" defined?

The reflected electromagnetic waves are a factor for the homogeneity of the cable. Usually, the voltage ratio "a" from the forward to the backward moving wave (returning to) is indicated as return loss in dB (20 log|a|). For a frequency range of up to 1 GHz this approximately means:

- 17 dB poor value
- 30 dB good value

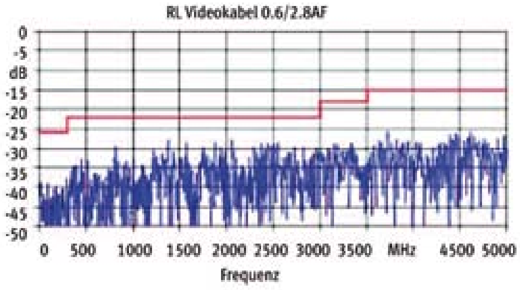

Figure 1 Measurement of return loss

The reflected electromagnetic waves represent the heterodyne of all reflected waves: these, which are reflected at the point of discontinuities of the transmission line (deviation from the characteristic impedance).

The second reflection is to be understood as follows: If the reflected electromagnetic waves are being reflected from a discontinuity again, this causes a small part of the wave to move - with a little delay - in the direction of the main signal.

The local reflection is the reflection at a discontinuity not occurring at regular intervals (variability of the characteristic impedance). The reflection coefficient r is the amplitude ratio from the backward to the forward moving wave.

Thus, the reflection coefficient r is between $-1 \leq r \leq 1$. The following exceptions apply for a cable termination with Z_x:

r = 0	matching	$Z_x = Z_0$
r = 1	open circuit	$Z_x = \infty$
r = -1	short circuit	$Z_x = 0$

These changes in dimensions, of RF cables, during the manufacturing process, represent inconsistency i.e. deviations from the characteristic impedance. Small periodic irregularities of the characteristic impedance - i.e. discontinuities at regular intervals – lead to additional reflections.

The consequences are:
- resonances at certain frequencies
- changes of the attenuation values

Randomly occurring, small variations of the characteristic impedance cause reflections that do not add in phase and so do not have any virtual influence on the return loss. Local variations are measured with a Time Domain Reflectometer. This is called TDR measurement. Both periodic and statistically occurring discontinuities can be expressed as a reflection coefficient. With the TDR measurement, the reflection coefficient is usually indicated in percent.

Mismatch

A deviation from the characteristic impedance always means a mismatch, which leads to reflections. A classic example of reflection and mismatch and its effects can be simulated with a studio monitor. For this purpose, a monitor with a switchable 75 ohm input impedance is needed. If the input of the monitor is not terminated, the monitor shows the effects of mismatches (misinterpretation of the signal displayed in respect of chrominance and luminance, etc.).
Local deviations of the characteristic impedance in the cable occurring at regular intervals are also risky and unwanted. If, for example, these frequency dependent deviations (reflection peaks) occur at so-called key frequencies, they can have a considerable impact. Especially with triax cables: special key frequencies are of particular importance for the transmission.

Attenuation "α"

What is the difference between attenuation and effective attenuation?
Attenuation is the ratio of input voltage to output voltage, at the termination of the cable, with its characteristic impedance. The effective attenuation describes the situation with a "not quite" homogeneous cables where the characteristic impedance is not the same at every point of the cable. It also comprises and includes reflection losses, which are caused by so-called discontinuities in the cable (reflections). Furthermore, additional deviations between the characteristic impedance of the cable and the transmitters/receivers are of importance. The attenuation (Figure 2) of a coaxial cable is a parameter for the occurring losses and consists of the following:

1. Frequency dependent resistance loss B: Deriving from the resistance losses of the conductors. Due to the skin effect, the part of the attenuation

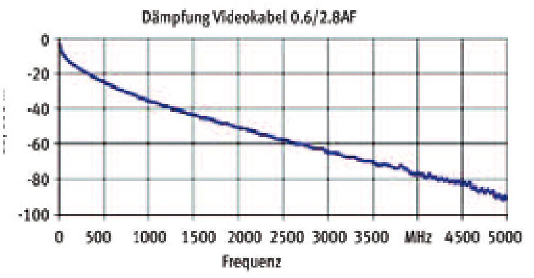

Figure 2 Progression of attenuation of a coaxial cable

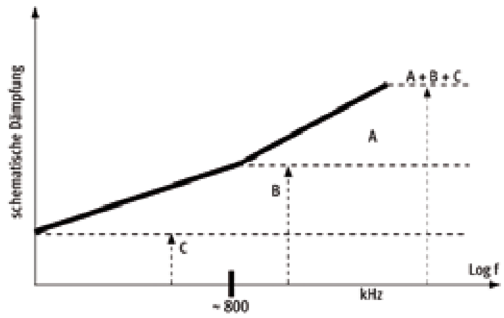

Figure 3 Ratio between leakage attenuation (A), resistance attenuation (B) and frequency independent resistance loss (C)

deriving from the conductors is inversely proportional to the diameter of the conductor. From approx. 800 kHz, it increases with the root of the frequency.

2. Leakage attenuation A: Due to losses in the dielectric of quantity and angle tan δ (friction losses with the re-orientation of polar elements in the alternating field). The leakage attenuation increases proportionally to the frequency.

3. Frequency independent resistance loss C: Due to ohmic losses only. Figure 3 shows the ratio between:

A = leakage attenuation
B = frequency dependent resistance loss
C = frequency independent resistance loss

Attenuation of cables and their transmission lengths

The maximum transmission length of a cable mainly depends on the attenuation values at the frequencies to be considered. With video cables, the attenuation values are determined by the:

- diameter of the inner conductor and its construction,
- braid (braid angle and diameter in proportion to the diameter of the dielectric),
- foil construction, thickness of the Al layer and
- dielectric losses at high frequencies (dissipation factor tan δ).

Maximum transmission length

On the occasion of the World Cup 2006, and the then required HDTV signal 1080i, a number of tests have been conducted (manufacturers of cables, devices, broadcasting vans, etc.) in respect of the transmission length.

Measurement equipment for the calculation of the maximum transmission length

The following equipment has been used for the measurement of the maximum transmission length:

- Source: Tektronix TG 2000, alternatively TG 700
- Wave form monitor: Tektronix WFM 700, alternatively WFM 8300

With these measurements certain conditions were applied:

- Laboratory conditions (constantly low humidity, constant ambient temperature, etc.)
- new, optimum condition of the assembled cables
- cables and connectors are harmonized

An independent institute also tested the application length and determined the maximum value of the known 0.6/2.8AF at 90 m. Therefore, this is what mainly defines the maximum transmission length.
If these physical conditions are actually the same with different manufacturers, then the electrical characteristics are the same. Very often thin inner conductors are compared to thicker inner conductors. This is not acceptable; the same dimensions have to be compared, always. These measurements (Table 1) are so-called applied transmission lengths. Here, assembled cables are being measured and assessed under laboratory conditions.

Cable type	Maximum cable lenght measured with HD1080i
0.6/2.8AF	90 m
0.8/3.7AF	120 m
1.0/4.8AF	140 m
1.4/6.6AF	200 m
1.6/7.3AF	240 m

Cable type	Maximum cable lenght measured with HD1080p
0.6/2.8AF	80 m
0.8/3.7AF	110 m
1.0/4.8AF	130 m
1.4/6.6AF	170 m
1.6/7.3AF	210 m

Table 1 Measured maximum transmission lengths

Equalizer and maximum transmission length

The measured maximum transmission lengths can vary depending on the device and the manufacturer of the same. This is due to the different hardware and generations of equalizer that are available. Sometimes different equalizers may be applied in one device.

SMPTE versus applied maximum transmission length

SMPTE describes a different approach.

SMPTE 292M

Whereas with SDI (SMPTE 259M) it was 30 dB maximum attenuation at half clock frequency; it is 20 dB maximum attenuation with HDTV (SMPTE 292M) (Table 2) – Standard: SMPTE 292M, signal: 1080i and 720p (1.5 Gbit/s).

The specification of the standard is: 20 dB maximum attenuation at half clock frequency (1.5 Gbit/s → 0.750 GHz).

$$\alpha = Af + B\sqrt{f} + C$$

$$L_{max} = \frac{20dB/100m}{\alpha_{750MHz}[dB/100m]} \cdot 100$$

Standard cable type	Calculated transmission length Draka Communications
0.6/2.8AF	66 m
0.8/3.7AF	91 m
1.0/4.8AF	112 m
1.4/6.6AF	144 m
1.6/7.3AF	161 m

Tabelle 2 Calculated maximum transmission lengths according to SMPTE 292M

SMPTE 424M

The specifications in respect of the 1.5 Gbit/s signal (SMPTE 292M) are identical to those of the 3 Gbit/s signal (SMPTE 424M). The maximum transmission length for 3 Gbit/s according to SMPTE 424M (calculated transmission length) is shown in Table III (standard: SMPTE 424M, signal: 1080p/50 and 1080p/60 for 3 Gbit/s HD). The specification of the standard is: 20 dB maximum attenuation at half clock frequency (3 Gbit/s → 1.5 GHz).

$$L_{max} = \frac{20dB/100m}{\alpha_{750MHz}[dB/100m]} \cdot 100$$

The question remains which maximum transmission length is the correct one? Is it the calculated maximum transmission length according to SMPTE or is it the transmission length obtained by testing?

Typ	Attenuation at 1.5 GHz in dB as per data sheet	Calculated transmission length in m according to SMPTE 424M
0.6/2.8AF	43,2	47
0.8/3.7AF	31,3	64
1.0/4.8AF	24,9	80
1.4/6.6AF	19,6	102
1.6/7.3AF	16,9	119

Tabelle 3 Calculated maximum transmission lengths according to SMPTE 424M

Temperature influence on the attenuation

In practice, climate-induced variances of temperature and humidity, as well as aging and other influences, have their effects. Attenuation is dependent on temperature, and manufacturers state the attenuation of their cables at 20°C (see data sheet). With a rising temperature the attenuation increases by approx. 0.2%/°C (with chemically foamed PE up to a maximum of 0.27%/°C).

Equalizer and hardware

In addition, different application lengths might be achieved due to equalizers from different manufacturers – but also because of different generations produced by one and the same manufacturer. The correct customized transmission length is determined by many factors. On the one hand, these are the devices with different hardware which are applied, and on the other hand the cables with the corresponding dimensions and the appropriate connectors. If, in addition, the non negligible effects like humidity, aging and temperature influences are taken into consideration, then only the transmission length as defined by the SMPTE remains an alternative.

Screening attenuation

Electromagnetic interferences disturbing the transmission system from outside mainly influence the spatially most extensive transmission element, the cable! If interfering signals heterodyne the wanted signal, this might lead to misinterpretation of the signal or even an interruption of the signal flow. Whereas with analogue signals, interferences from the outside are identified as drop-outs; and, too-long transmission lines, a change of the signal level in the picture: there are only two situations with digital transmission: picture or no picture.

Increased, better, screening attenuation (Figure 4) the higher the interference resistance. In the frequency range of approx. 135 MHz (clock frequency of SDI), a screening consisting of an aluminium double-laminated foil plus braid has up to 30 dB better screening attenuation than a double braided cable. Compared to a single braided cable it is even higher, by 40 dB.

Conclusion

Generally speaking, the growing application of 1080i and 1080 p signals respectively leads to increasing requirements on studio cabling. In this context, the natural losses of high frequency signals on transmission lengths over 60 m and the effects on the signal quality connected therewith cannot be neglected. However, connectors have to be considered as a source of error in order to ensure a smooth and free-of-loss studio operation.

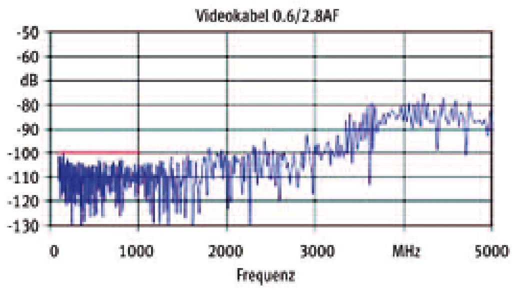

Figure 4 Screening attenuation

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