# EMC of Ready-Made Connecting Devices (RMCDs)

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## Abstract

Connecting elements such as so-called "Ready-Made Connecting Devices" (RMCDs) are integral components of electronic systems in their function as data and power transmitting hardware.

Currently, regional regulations e.g. European Union (EU) directives consider RMCDs as passive components and therefore as not EMC relevant. Nevertheless, an unwanted function of RMCDs is the transport of electromagnetic interference from and towards the connected electronic systems. Additionally, RF disturbances may occur by electromagnetic radiation between RMCD and the environment and vice versa depending on their electromagnetic characteristics. Thus they become EMC relevant from a practical point of view.

Using the example of HDMI cable assemblies with different shielding qualities, emission measurements on finished HDMI video systems show that the current CISPR emission limits cannot be met if the screening quality of the applied cable assembly is not sufficient. The screening effectiveness of the applied cable assemblies are tested with a standardized test procedure and the results are correlated to the emission measurement.

Thus, a clear evidence is that RMCDs are EMC relevant for completed systems and since standardized test procedures for the EMC of cable assemblies are available EMC regulations should be adapted accordingly to ensure the EMC of working systems in the field.

**Keywords:** RMCD; EMC, HDMI, cable assembly, radiated emission, coupling attenuation, screening attenuation, transfer impedance

## 1. Introduction

In view of the coexistence of traditional cable-based communication applications and an increasing number of wired network ports of multimedia equipment and new wireless communication services, EMC characteristics are becoming more and more important. EMC of devices and components shall be designed to avoid harmful interferences or disturbances between different applications.

This applies especially to cable assemblies respectively RMCDs for the connection of all kind of electronic components.

Cable assemblies can be of coaxial, balanced or hybrid construction. Currently, cables and assemblies are not in the scope of the EMC Directive of the EU, because according to their understanding cables are "passive". Therefore, no regional EMC requirements exist. However, reality is quite different.

This paper gives an overview over common EMC problems of "Ready-made connecting devices", shows the relation between cable qualities and emission characteristics of HDMI cable assemblies, provides some measurement data and describes standardized measurement methods of common EMC measurements of balanced cable assemblies

## 2. EMC environment

Compliance with the applicable regional regulations is mandatory for the use of the terrestrial frequency spectrum. This is not the case with cable connections / cable networks. It is assumed that there is no harmful interference if the same frequencies are used for both terrestrial and wired signal transmission in the same location at the same time.

Unfortunately, cables have some properties that are responsible for unwanted radiation emissions, as well as for limited immunity to electromagnetic fields of wanted emissions by radio services when the cable is used for signal transmission.

Important EMC characteristics are transfer impedance, screening attenuation for coaxial cables and coupling attenuation (including the symmetry) for twisted pair cables, [1], [2], [3]. Depending on the signal level on the cable, a certain limit for screening and / or coupling attenuation is required for trouble-free system operation.

A well-known interference situation in Germany is CATV versus aeronautical radio services. Cable networks use the same frequency for television signals and aeronautical radio service. Due to poorly shielded cables and / or poorly manufactured connectors, emissions were observed, that were more than 50 dB above the limit, [4]. Although analogue signal transmission is no longer used, limits are exceeded considerably also by digital CATV signal transmission. The majority of EMC issues in CATV applications is caused by poorly shielded TV receiver leads.

In the meantime, some new types of high data link connections have been developed, e.g. USB and HDMI.

For these cable connector configurations, the EMC characteristics are also important. Unwanted emissions can disturb radio services as well as multimedia applications, at least if existing CISPR limits are exceeded.

Due to the capability of the new digital radio systems like channel coding and error correction, in most cases EMC issues don't mean that signal reception is completely impossible but the presence of EMI will decrease the transmission rate. The EMC characteristic of the cable is also important for EMC tests of products. Depending on the cable quality, the same product can fail or pass the test procedure.

That is the case for both, emission as well as immunity requirements and it especially happens to products in the scope of CISPR 32 and CISPR 35. EMC requirements are available for some types of cable assemblies, e.g. coaxial cable assemblies of IEC 60966-2-n series and for balanced patch cords of IEC 61935-2-n and EN 50288-2-n series, but not for hybrid assemblies like HDMI cables.

# 3. Types of Ready-Made Connecting Devices

## 3.1 General

Ready-made connecting devices usually consist of a cable of a certain length with a connector on one or on both ends. Cables can be of coaxial, balanced or hybrid construction, they may be unshielded or contain one or even more than one screens. For good EMC behavior an overall screen is required.

The conductive shell shall be able to contact the cable overall screen over the complete circumference with low contact resistance respectively with low impedance.

## 3.2 Coaxial cable assemblies

Coaxial assemblies are the most common type of cables for RF signal transmission. With respect to EMC requirements, a lot of different qualities are available on the market, see table 1. That applies to the type of shielding (double, triple) as well as to the junction to the connector. Unfortunately, this is not visible and also the price is not an indicator for the quality. Only a clear classification system with EMC requirements could be helpful for the user. Here, the most important parameter is the screening attenuation. The value for a good cable can be greater than 100 dB whereas for a bad one it might be less than 30 dB. This has an important impact on the EMC behavior of the whole system.

**Table 1 – Screening classes for coaxial cable assemblies according to EN 60966-2-n series**

| Screening-class | 5 - 30 MHz | 30 -1000 MHz | 1 GHz – 2 GHz | 2 GHz – 3 GHz |
|---|---|---|---|---|
| A++ | 0.9 mOhm/m | 105 dB | 95 dB | 85 dB |
| A+ | 2,5 mOhm/m | 95 dB | 85 dB | 75 dB |
| A | 5 mOhm/m | 85 dB | 75 dB | 65 dB |
| B | 15 mOhm/m | 75 dB | 65 dB | 55 dB |
| C | 50 mOhm/m | 75 dB | 65 dB | 55 dB |

IEC SC 46A and CLC 46XA have established screening classes for coaxial cables and cable assemblies which are standardized as IEC 60966-2-n series, see table 1. IEC 60966-2-n series includes construction details as well as requirements for transmission characteristics and EMC limits.

It is recommended by different service providers to use at least screening class A for interference free TV reception.

## 3.3 Balanced cable assemblies

Balanced cable assemblies such as patch cords with RJ 45 connectors are widely used, e.g. for the connection of personal computers (PCs) to a local area network (LAN). Basic patch cords exhibit a coupling attenuation of about 35 dB or less, mainly due to the poorly shielded connector. Cords with better screened connectors are available, e.g. for industrial applications.

Balanced cable assemblies are standardized as IEC 61935-2-n series and EN 50288-2-n series. IEC 61935-2-n series and EN 50288-2-n series include construction details as well as requirements for transmission characteristics and EMC limits, see table 2.

**Table 2 - Coupling attenuation of balanced data cables and assemblies acc. to IEC 61156-n series**

| Coupling att. type | Freq. range/requirement | Frequency range/requirement |
|---|---|---|
| | 30 to 100 MHz | 100 to 1 000 MHz, [dB] |
| Type I | $\geq$ 85 dB | $\geq 85 - 20 \times \lg 10\ (f/100)$ |
| Type Ib | $\geq$ 70 dB | $\geq 70 - 20 \times \lg 10\ (f/100)$ |
| Type II | $\geq$ 55 dB | $\geq 55 - 20 \times \lg 10\ (f/100)$ |
| Type III | $\geq$ 40 dB | $\geq 40 - 20 \times \lg 10\ (f/100)$ |

## 3.4 Hybrid cable assemblies

Hybrid cable assemblies like USB, HDMI etc. contain different kinds of cables, e. g. coaxial and/or balanced cables for RF signal transmission and insulated wires for power supply and low frequency signal transmission. Preferably, they should contain an overall screen of braid or foil/braid construction.

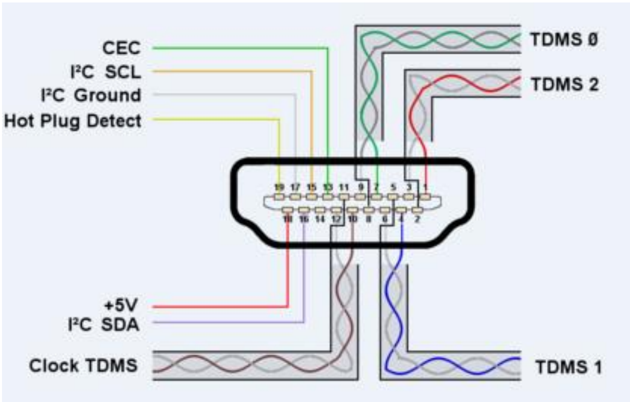



**Figure 1. Assignment of the contacts of an HDMI device socket (wikipedia)**

Requirements for the interfaces of hybrid cable assemblies are well described by different industrial standards or by different consortia, see e.g. https://www.hdmi.org/. Standards for RMCDs from official standardization organizations like IEC or CENELEC do not exist yet. Neither exist requirements for EMC test procedures or EMC limits

Examples of different manufacturing qualities regarding the connection of the cable screen to the shell of the applied connectors are shown in the figures 2a and 2b.

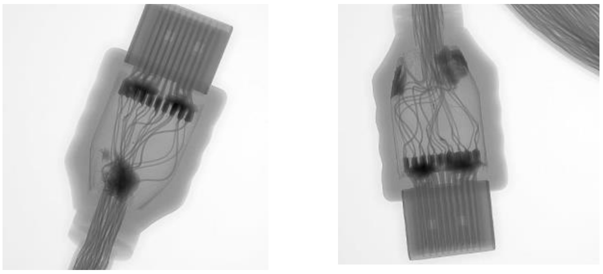


**Figure 2a. X-ray images of HDMI connectors with poor screen connection (Vestel EMC laboratory)**

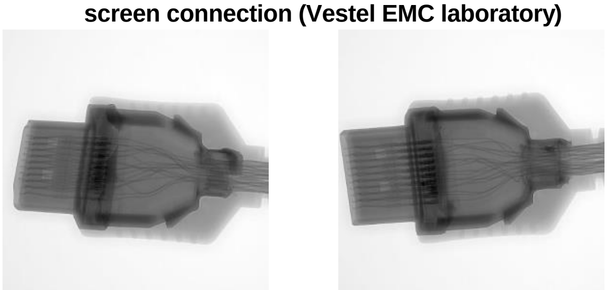


**Figure 2b. X-ray images of HDMI connectors with good screen connection (Vestel EMC laboratory)**

To get sufficient EMC behavior, the connection of an overall screen of an assembly shall be applied over the complete circumference of the connector shell with low contact impedance.

## 4. Test procedures

### 4.1 Radiated emissions

Radiated emission measurements are usually carried out according to CISPR 16-2-3 (2016 or 2019). CISPR 16-2-3 describes measurement methods from 9 kHz up to 18 GHz. The measurement test site can be a SAC or an OATS up to 1 GHz and a FAR, a SAC, an OATS or aFSOATS above 1 GHz.

The precondition is a typical set up and an operation mode like the intended use for the equipment as well as for the cables, especially for the signal shape and level on the cables. The whole system has to meet the required limits.

Probably the EMC test result of the most equipment in the scope of CISPR 32 (EN 55032) and CISPR 35 (EN 55035) is impacted by the cable quality as well as by the cable arrangement. One requirement in CISPR 32 is: “In addition, during prescan measurements, the arrangement of the DUT, the arrangement of the local AE and the placement of cables shall be varied within the range of typical and normal placement to attempt to determine the cable arrangement giving the **maximum emission level.**

**Table 3 - Requirements of CISPR 32 for radiated emissions up to 1 GHz for Class B equipment (table A.4)**

| Table clause | Frequency range [MHz] | Measurement | | Class B limits [dB(µV/m)] |
|---|---|---|---|---|
| | | Distance [m] | Detector type/ bandwidth | OATS/SAC (see table A.1) |
| A.4.1 | 30 - 230 | 10 | Quasi Peak/ 120 kHz | 30 |
| | 230 - 1000 | | | 37 |
| A.4.2 | 30 - 230 | 3 | | 40 |
| | 230 - 1000 | | | 47 |
| Apply only table clause A4.1 or A4.2 across the entire frequency range | | | | |

Thus, the equipment manufacturers and the equipment distributors are very interested that a good cable assembly quality is reliably available on the market.

Class B requirements of CISPR 32 are intended to offer adequate protection to broadcast services within the residential environment. Class A requirements are intended for products used in industrial environment. Note that all equipment contain broadcast receiver(s) is considered to be Class B equipment.

Table 3 shows only the requirements given in CISPR 32 (in Europe EN 55032, resp.) for radiated emissions up to 1 GHz for Class B equipment. These requirements are used in the emissions measurements result shown in Chapter 5. Limits up to 6 GHz can be found in CISPR 32.

### 4.2 Screening effectiveness of cables and cable assemblies

The quantities describing the screening effectiveness of coaxial and balanced cables and assemblies is the transfer impedance $Z_T$ in the lower frequency range up to about 100 MHz and the screening attenuation aS in the upper frequency range from 30 MHz upwards, depending on the length of the device under test (DUT).

The transfer impedance $Z_T$ [mΩ/m] is defined as quotient of the longitudinal voltage $U_1$ induced to the inner circuit by the current $I_2$ fed into the outer circuit or vice versa, (see IEC 62153-4-1 respectively IEC 62153-4-3).

The screening attenuation $a_S$ is defined as the logarithmic ratio of the input power $P_1$ to the maximum radiated power $P_{r,max.}$

Screening attenuation: $a_S = 10 \lg (P_1/P_{r,max})$

The screening effectiveness of balanced cables, connectors and assemblies is described among other parameters by the coupling attenuation $a_C$ which takes into account both, the unbalance attenuation $a_U$ of the pair (differential mode) and the screening attenuation $a_S$ of the screen (common mode).

Coupling attenuation: $a_C = 10 \cdot \lg (P_{diff}/P_{com}) + 10 \cdot \lg (P_{com}/P_{r,max})$

The unbalance attenuation $a_U$ of a balanced pair describes in logarithmic scale how much power couples from the differential mode to the common mode and vice versa. It is the logarithmic ratio of the input power in the differential mode $P_{diff}$ to the power which couples to the common mode $P_{com}$:

Unbalance attenuation: $a_U = 10 \cdot \lg (P_{diff}/P_{com})$

Measuring of coupling attenuation of balanced cables with triaxial test set-up is described in IEC 62153-4-7 and IEC 62153-4-9.

Hybrid cable assemblies like HDMI cables consist of different signal cable cores as well as of different balanced respectively symmetrical pairs for data transmission and clock signals. It is assumed that EMC emissions of HDMI assemblies at higher frequencies are mainly caused by the balanced pairs, where a high coupling attenuation value $a_C$ of the pair is an indication of good EMC performance.

### 4.3 Triaxial test procedure

The triaxial test method according to IEC 62153-4-3 and IEC 62153-4-4 for measuring transfer impedance and screening attenuation was originally designed for communication cables and connectors. Meanwhile, also the measurement of coupling attenuation of balanced cables and assemblies with triaxial test set-up is described in IEC 62153-4-7 and IEC 62153-4-9, [5], [6].

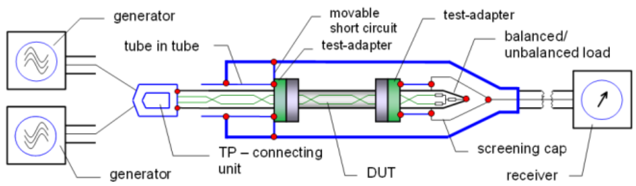



**Figure 3. Coupling attenuation measurement of a balanced cable assembly acc. to IEC 62153-4-7 - principle**

IEC 62153-4-7 is currently under revision to allow balunless measurements up to 3 GHz.

To measure coupling attenuation (as well as unbalance attenuation) a differential signal is required.

The differential mode signal may be obtained with a 4-port vector network analyzer (VNA) having two generators with a phase shift of 180° using mixed mode S-parameters. The S-parameter Ssd21 (differential feeding, single ended measurement) represents the coupling attenuation.

To connect the unbalanced ports of the VNA with the balanced device under test (DUT) a TP-connection unit with high RF performance is required. Furthermore, appropriate test adapters with high RF performance are needed.

## 4.4 HDMI Test adapter for triaxial test set-up

To measure transfer impedance and screening or coupling attenuation on balanced cable assemblies, appropriate test adapters are required, see figure 2. The test adapters will influence the test result and may limit the sensitivity of the test set-up.

They shall be prepared as carefully as possible.

For investigation of HDMI cable configurations using the triaxial test method, two different dedicated test adapters have been designed and characterized in measurements applying a 4-port vector network analyzer. As shown in Figure 3, for triaxial test method according to IEC 62153-4-7 one test adapter on the generator side (see Figure 4 and 5) and one test adapter on the receiver side are required.

It is important to note that the adapter on the receiver side acts as a termination of the cable under test and therefore the clock and signal pins of the HDMI connector are terminated with 50 Ohm SMD resistors.

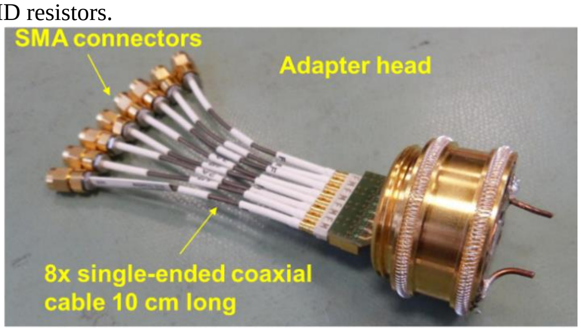



**Figure 4. HDMI adapter head for usage on the generator side (Rosenberger)**

In order to indicate the applicability of the design adapters to the triaxial method several measurements have been performed in the frequency and time domain.

The used set-up is depicted in Figure 4. As described there, in the first step the VNA is calibrated up to the measurement cable ends using the short-open-load-thru calibration method and mechanical 2.92 mm coaxial standards.

In the next step, for observation of the S-parameters of the head and the termination adapters, one 8-port coaxial adapter and a short piece of HDMI cable have been used.

One side of this short HDMI cable is clumped inside of the 8-port adapter and on the other side a HDMI jack is used for plugging it to the HDMI adapters.

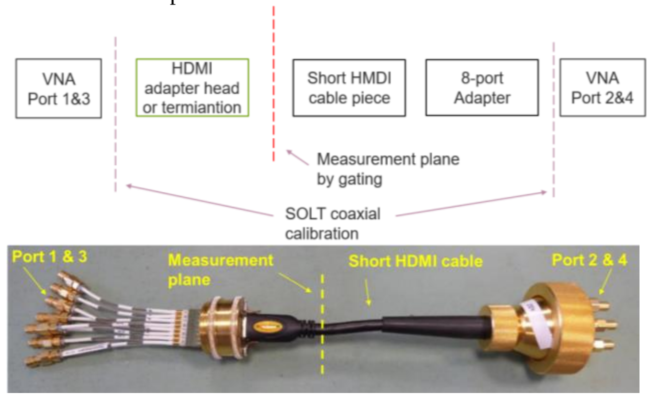



**Figure 5. Measurement set-up used for characterization of the HDMI adapter head and for the HDMI adapter termination (Rosenberger)**

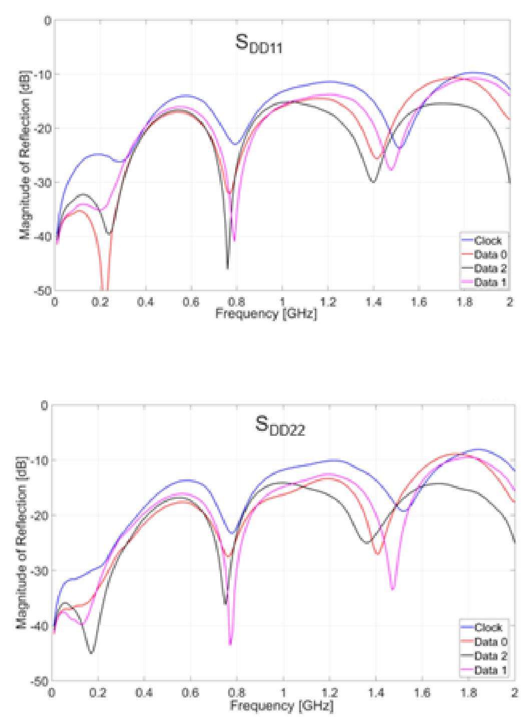



**Figure 6. Measured reflection of the HDMI adapter head looking from port pair 1&3 (Sdd11) and from port pair 2&4 (Sdd22)**

This measurement set-up allows the investigation of the head and termination adapters as mated pair. Applying time domain gating one can remove the influence of the short HDMI cable and the 8-port adapter on the reflection loss and therefore the reflection loss of the HDMI adapter only might be observed. For comparison, the reflection parameters with and without time domain gating are shown in Figure 6 and 7.

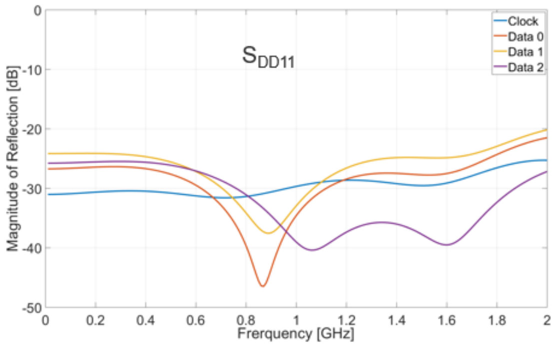



**Figure 7. Gated reflection parameters of the HDMI adapter head looking from port pair 1&3 (Sdd11)**

The gated reflection parameters of the adapter termination obtained from the measurements are shown in Figure 8.

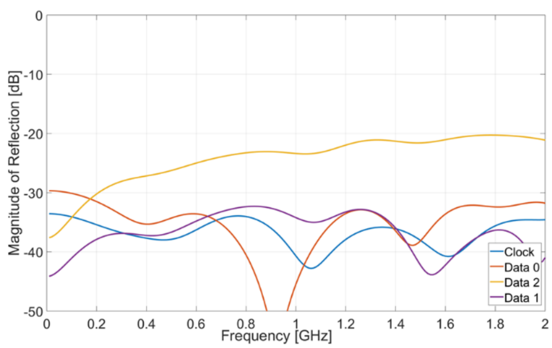
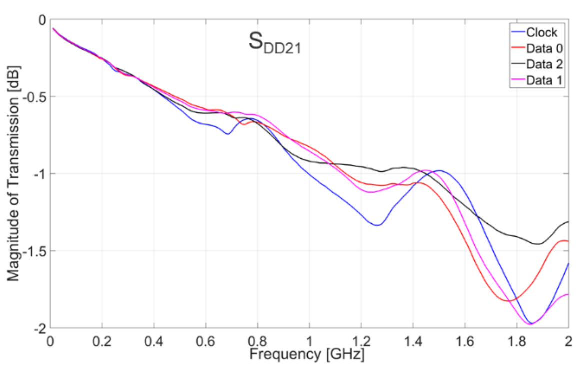



**Figure 8. Gated reflection parameters of the HDMI adapter termination looking from port pair 2&4 (Sdd11)**

The transmission losses of the used measurement set-up (8-port adapter + short HDMI cable) cannot be removed using time domain gating. For this purpose, microprobe measurements have been performed where the probe tips have been connected directly to the footprint of the HDMI connectors on the PCBs. Looking at Figure 9, it is obvious that the main transmission loss is induced by the short HDMI cable and the 8-port adapter.



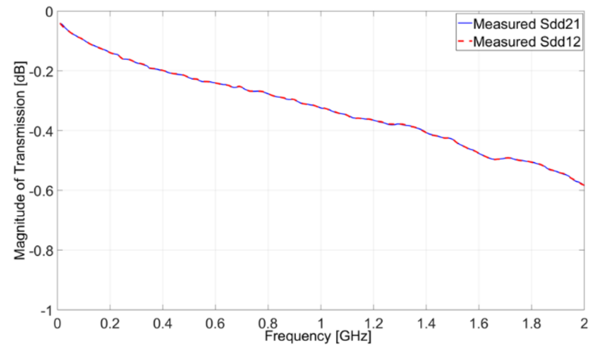




**Figure 9. Transmission loss of the HDMI adapter head**

These two measurement procedures allowed the characterization of the designed HDMI head and termination adapters. The main characteristics obtained from the studies are summarized in the tables below.

**Table 4 - Limits of the adapter head parameters**

| Adapter head characteristics | *10 MHz to 0.6 GHz* | *0.6 GHz to 1 GHz* | *1 GHz to 2 GHz* |
|---|---|---|---|
| Differential return loss, (Z0 = 100 Ω) | > 21 dB | > 21 dB | > 18 dB |
| Differential transmission loss | < 0.25 dB | < 0.35 dB | < 0.6 dB |
| Common-mode return loss (Z0=25 Ω) | > 4 dB | > 4 dB | > 4 dB |
| Common-mode transmission loss | < 0.23 dB | < 0.32 dB | < 0.6 dB |
| Unbalance attenuation, near end, (Scd11) | > 30 dB | > 25 dB | > 20 dB |
| Unbalance attenuation, far end, (Scd21) | > 30 dB | > 30 dB | > 20 dB |

**Table 5 - Limits of the adapter termination parameters**

| Adapter termination characteristics | 10 MHz to 0.6 GHz | 0.6 GHz to 1 GHz | 1 GHz to 2 GHz |
|---|---|---|---|
| Differential return loss, (Z0 = 100 Ω) | > 25 dB | > 20 dB | > 20 dB |
| Common-mode return loss (Z0 = 25 Ω) | > 9 dB | > 4 dB | > 4 dB |
| Unbalanced attenuation, near end, (Scd11) | > 25 dB | > 25 dB | > 25 dB |

## 5. Measurements

To assess the impact of the quality of HDMI cables radiated emission measurements according to EN 55032 (CISPR 32), [8], and measurements of coupling attenuation according to IEC 62153-4-9 respectively IEC 62153-4-7 were performed and test results were compared.

**Figure 10. Test configuration for radiated emission measurement (Vestel EMC lab)**

The test configuration for radiated emission measurements contains a LG TV set and an Apple TV box. Different HDMI cables were used for the connection of these devices. All other ports were left open.
The signal provided by the Apple TV box was a moving color bar signal and the maximum picture resolution was used [8], [9].

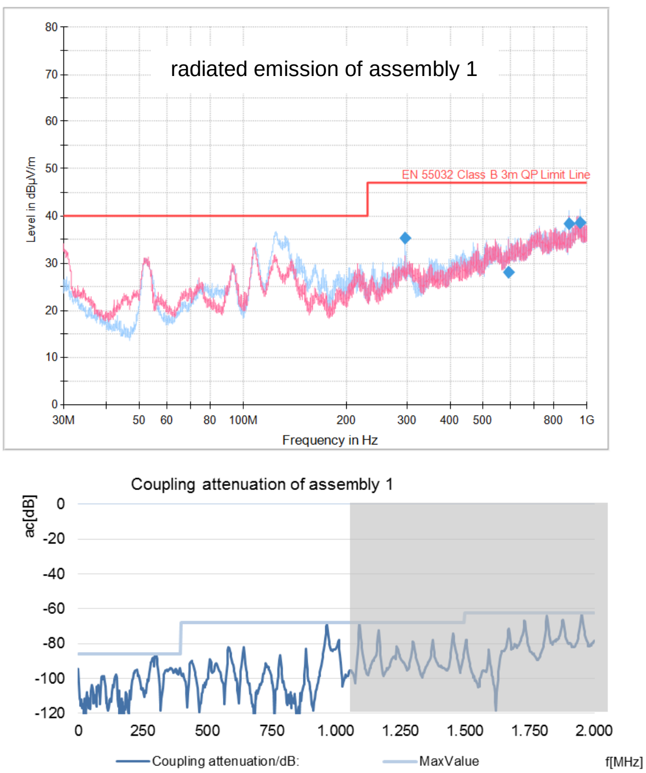



**Figure 11. Radiated emission and coupling attenuation of HDMI assembly 1**

The maximum values of the measured coupling attenuation of assembly 1 are outside the diagram range of the radiated emission measurement in the frequency range up to about 400 MHz.

With roughly calculation the coupling attenuation is about 68 dB as an average in the range of about 400 MHz up to 1 GHz. The highest measurement value of the radiated emission measurement is 38.5 dBµV/m, i.e. at first approach, the source field could be about 106,5 dBµV/m.

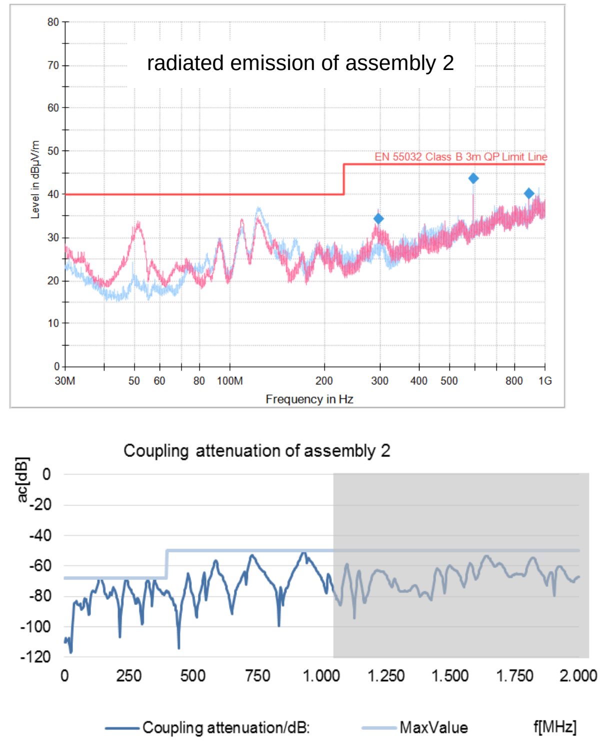



**Figure 12. Radiated emission and coupling attenuation of HDMI assembly 2**

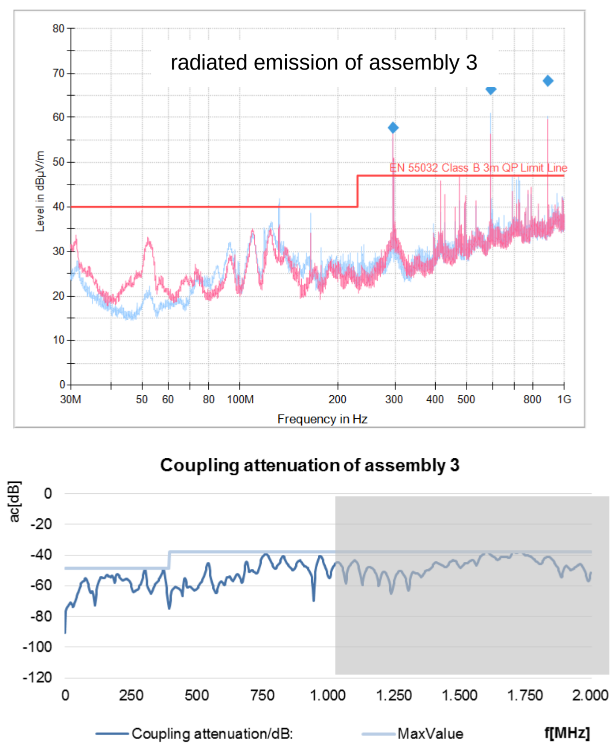



**Figure 13. Radiated emission and coupling attenuation of HDMI assembly 3**

In the range of about 400 MHz up to 1 GHz the coupling attenuation of assembly 2 is about 50 dB. The highest value of the radiated emission measurement is 43.7 dBµV/m, i.e. at first approach, the source field could be about 93,7 dBµV/m.

In the range of about 400 MHz up to 1 GHz the coupling attenuation of assembly 3 is about 38 dB. The highest measurement value of the radiated emission measurement is 68,3 dBµV/m, i.e. at first approach the source field could be about 98,3 dBµV/m.

It is clearly shown that the level of the unwanted emissions of the test configuration increases if the coupling attenuation decreases. That is nearly in the same level range and demonstrates the relation between cable EMC quality and the level of the emissions. There is also an impact of the EMC quality of the EUT ports as well as the EMC quality of the whole EUT. But the quality of the cable has significantly more impact.

## 6. Conclusions and outlook

In this paper, the influence of cables on the level of unwanted emissions is shown using the HDMI cable as an example. That is also valid for other types of cables that are used for the transmission of high frequency signals, e.g. USB.

At this time, the EMC requirements of cables only play a secondary role. However, the impact of the cables contributing to the emissions is visible and is increasingly changing the way we look at this issue.

Now the European EMC Directive is under revision. One of the aims in this process is to extend the scope of the directive in such a way that, among other things, cables are explicitly identified. This would make it necessary to bring up a mandate for standardization activities and demand a binding standard for cables.

Another approach is in use in the Netherlands. They introduced a voluntarily certification scheme KEMA Keur that is accepted by the manufacturers and by the consumers/users. Unfortunately, that is not the case in other countries.

The consumer is mostly price driven. But the price is not even an indicator for the quality and also the outer appearance like golden screen and pins of the connector give no evidence on the actual EMC quality.

Therefore, it seems to be the best way to develop EMC requirements for all relevant types of cables and refer to this standard in EMC standards such as CISPR 32 as well as in user manuals. That gives the opportunity for the manufacturer to use this cable quality to pass the EMC product requirements as well for the users for an undisturbed use of the products.


## 7. Acknowledgments

Special thanks to Mark Arthurs (Sony) and Cem Cengiz Keskin (Vestel EMC Laboratory) for providing the radiated emission measurements and for valuable advice and discussion.


## 8. References


[1] IEC TS 62153-4-1, Metallic communication cable test methods - Part 4-1: Electromagnetic compatibility (EMC) - Introduction to electromagnetic screening measurements

[2] IEC 62153-4-7, Metallic communication cable test methods - Part 4 - 7: Electromagnetic compatibility (EMC)

[3] IEC 62153-4-9, Metallic communication cable test methods - Part 4 - 9: Electromagnetic compatibility (EMC) - Coupling attenuation of screened balanced cables, triaxial method

[4] Coaxial Cable Television Interference to Aviation Systems, Eurocontrol report from 2001-03-15

[5] Thomas Hähner, Bernhard Mund, & Thomas Schmid, History and recent trends of Triaxial test procedure, Proceedings of the 67th IWCS Conference, Providence, RI, US, October 2018

[6] Thomas Hähner, Bernhard Mund, & Thomas Schmid, Screening effectiveness of unscreened balanced pairs, EMC Barcelona 2019

[7] M. Kotzev, T. Schmid, M. Schwaiger, Time and frequency domain analysis of an 8-port adapter for multiconductor cable screening measurements, EMC Europe 2018

[8] Mark Arthurs, Cem Cengiz Keskin, Radiated emission comparision report, Sony/Vestel EMC Laboratory

[9] Sezgin Hilavin1, Cem Cengiz Keskin, Analysis of Repeatability and Uncertainty Issues in Radiated Emission Tests Regarding HDMI Ports, Proc. of the 2016 International Symposium on Electromagnetic Compatibility - EMC EUROPE 2016, Wroclaw, Poland, September 5-9, 2016

## 9. Authors

After having successfully completed his apprenticeship as Radio- and TV Technician in 1979, **Ralf Damm** received his diploma in Telecommunications- and Microprocessor-Technologies at FH Giessen-Friedberg.In 1987 he joined bedea Berkenhoff & Drebes GmbH, working with electronic development of fibre optic components. In 2018 the bedea cable division has changed to bda connectivity GmbH. Later he was responsible for sales and supports for data communication networks and structured cabling. He is now member of the cable R&D department and responsible for sales & support of the CoMeT product line.

**Kurt Hemmerlein** started as Technician responsible for the measurement apparatuses for the German TV studio in 1979. In 1991, he moved to the German Federal Office for Post and Telecommunication (later Regulatory Authority and now the Federal Network Agency) as Employee. The area of work was the EMC of radio receivers. In 2010 he finished a postgraduate studies successful and is now responsible for EMC issues for multimedia equipment and cable networks. Kurt is member of CISPR/SC/I, CENELEC TC 210 and TC 209 and several national Committees.

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Bernhard Mund has been in the cable business since 1985 when he joined the cable manufacturer bedea Berkenhoff & Drebes GmbH in Asslar, Germany.

In 2018 the bedea cable division has changed to bda connectivity GmbH. Formerly being R&D Manager of communi-cation cables, he is now head of the RF- and EMC test engineering department.

Besides his work for bda, Bernhard Mund has been contributing for more than 30 years in national and international standar-dization organizations.

He has served as Chairman of the German committee UK 412.3, Koaxialkabel as well as Secretary of IEC SC 46A, Coaxial cables and of CLC SC 46XA, Coaxial cables, among other standardization activities in different committees and working groups e.g. of the IEC TC 46 family.

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Thomas Schmid was granted for the 1906 IEC Award in recognition of his outstanding technical contribution in developing, writing and finalizing TC 46’s IEC 62153-4 series (Metallic communication cable test methods – Electromagnetic compatibility).