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Immunity of home network devices to electromagnetic disturbances

Recommendation ITU-T K.93

ITU-T

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Immunity of home network devices to electromagnetic disturbances

Summary

The introduction of high-speed data services to customer premises that rapidly adopt new technologies allows the distribution of such data within customer premises. This is leading to a number of different wireless (e.g., wireless local area network, LAN, and digital enhanced cordless telecommunications, DECT) and wireline technologies (e.g., LAN and technologies designed to exploit existing telephone extension and power distribution wiring) to interconnect a variety of in-home electronic and electrical equipment (such as set top box, STB), and PCs. Many types of broadband services are provided on IP networks, such as voice over Internet protocol (VoIP), video on demand (VoD) and broadcasting. Moreover, the electromagnetic environment in the home will change due to this situation. Therefore, new electromagnetic compatibility issues may occur in a home network environment. Recommendation ITU-T K.93 aims to ensure normal operation of home networking devices and to provide a new additional immunity test method for broadband services, especially for devices that are sensitive to broadband interferences.

History

Edition	Recommendation	Approval	Study Group
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Keywords

Broadband impulsive conducted disturbance, home networks, QoS and xDSL.

FOREWORD

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Introduction

Along with the widespread use of the Internet, a number of broadband services, such as voice over IP (VoIP), music downloading, video on demand, and TV broadcasting over a telecommunication network, are provided by telecommunication operators and Internet service providers. These services require controlling quality of service (QoS) to ensure their reliability. Real-time services, such as Internet protocol TV (IPTV) or high-quality VoIP particularly require high quality performance.

On the other hand, there are many electric/electronic devices installed on customer premises that may be connected to networks. These devices may create an impulsive disturbance when they are turned on or off. In fact, quality degradation of IP-TV services caused by a repetitive impulsive disturbance has been reported by several telecommunication operators (see Appendices I-III of Recommendation ITU-T K.74). Therefore, new electromagnetic compatibility (EMC) problems caused by impulsive disturbances may occur in telecommunication networks.

Recommendation ITU-T K.93

Immunity of home network devices to electromagnetic disturbances

1 Scope

With the advent of Internet technologies, there are many telecommunication devices being used on customer premises. Therefore, new EMC problems may occur in such environments. These problems are caused by broadband disturbances, which are produced by electrical devices.

Many broadband services, such as Internet protocol TV and voice over IP, have been introduced to the home by telecommunication operators. These services require operators to be able to underwrite quality of service (QoS) levels, since both services are essentially streamed, and hence loss/delay of packets can be immediately apparent to the user as an interruption of the services. Resolving EMC issues of broadband services are one of the key factors for ensuring the QoS in home networks. Furthermore, use of the frequency band in the home is becoming wider and shifting to a higher frequency range.

This Recommendation provides an immunity test for home network devices against broadband disturbances. The purpose of this Recommendation is to ensure normal operation of telecommunication devices in home networks and to provide additional requirements that do not cover existing international standards. However, this Recommendation is not intended to replace or duplicate international/national regulations or laws.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T K.43] Recommendation ITU-T K.43 (2009), *Immunity requirements for telecommunication equipment*.

[ITU-T K.74] Recommendation ITU-T K.74 (2008), *EMC, resistibility and safety requirements for home network devices*.

[CISPR 24] CISPR 24:2010, *Information technology equipment – Immunity characteristics – Limits and methods of measurement*.
<http://webstore.iec.ch/webstore/webstore.nsf/ArtNum_PK/44481?OpenDocument>

[IEC 61000-4-4] IEC 61000-4-4 (2004), *Electromagnetic compatibility (EMC) – Part 4-4: Testing and measurement techniques – Electrical fast transient/burst immunity test – Basic EMC Publication Amendment 1 (2010).*
<http://webstore.iec.ch/webstore/webstore.nsf/ArtNum_PK/46341?OpenDocument>

[IEC 61000-4-6] IEC 61000-4-6 (2008), *Electromagnetic compatibility (EMC) – Part 4: Testing and measurement techniques – Section 6: Immunity to conducted disturbances, induced by radio-frequency fields.*
<http://webstore.iec.ch/webstore/webstore.nsf/ArtNum_PK/42065?OpenDocument>

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 AC power port [ITU-T K.43]: See clause 3.2.8 of [ITU-T K.43], ports in telecommunication equipment.

3.1.2 DC power port [ITU-T K.43]: See clause 3.2.8 of [ITU-T K.43], ports in telecommunication equipment.

3.1.3 home network device [ITU-T K.74]: A home network device is an electronic/electric equipment whose primary function is the distribution of data within the home, between the network termination point and one or more terminal devices.

3.2 Terms defined in this Recommendation

This Recommendation defines the following term:

3.2.1 wired network port: Point of connection for voice, data and signalling transfers intended to interconnect widely dispersed systems by direct connection to a single-user or multi-user communication network (for example, PSTN, ISDN, xDSL, LAN and similar networks).

NOTE – These ports may support screened or unscreened cables and may also carry AC or DC power where this is an integral part of the telecommunication specification.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

AC Alternating Current

AE Auxiliary Equipment

CDN Coupling Decoupling Network

CRC Cyclic Redundancy Check

DC Direct Current

DECT Digital Enhanced Cordless Telecommunications

EFT/B Electric Fast Transient/Burst

EMC Electromagnetic Compatibility

EMF Electromagnetic Field

EUT Equipment Under Test

FEXT Far End Crosstalk

INP Impulsive Noise Protection

IPTV Internet Protocol Television

ISDN Integrated Services Digital Network

LAN Local Area Networks

LCL Longitudinal Conversion Loss

PC Personal Computer

PLT Power Line Telecommunications

POTS Plain Old Telephone Service

PSTN	Public Switched Telephone Network
QoS	Quality of Service
RMS	Root Mean Square
SES	Severely Errored Seconds
STB	Set Top Box
STP	Shielded Twisted Pair
UTP	Unshielded Twisted Pair
VoD	Video on Demand
VoIP	Voice over Internet Protocol
xDSL	x-type Digital Subscriber Line

5 Background

The introduction of high-speed data services to customer premises that rapidly adopt technologies allows the distribution of such data on customer premises. This is leading to a number of different wireless (e.g., wireless LAN and DECT) and wireline technologies (e.g., LAN and technologies designed to exploit existing telephone extension and power distribution wiring) to interconnect a variety of in-home electronic and electrical equipment (such as STBs and PCs).

Moreover, telecommunication operators have introduced to homes many broadband services, such as Internet protocol TV (IPTV) and voice over IP (VoIP). These services require operators to be able to underwrite quality of service (QoS) levels, since both services are essentially streamed, and hence loss/delay of packets can be immediately apparent to the user as an interruption of the services. Resolving EMC issues of broadband services are one of the key factors for ensuring the QoS in home networks. Furthermore, use of the frequency band in the home is becoming wider and shifting to a higher frequency range.

These techniques introduce a new family of EMC issues, e.g., clarification of electromagnetic environment, cable characteristics, cabling on premises, immunity performance of services sensitive to interruption and immunity performance against wideband disturbances.

This work contributes to reduction in climate change by developing specifications that allow equipment to operate within a home network environment without disturbance. The availability of such equipment avoids the unnecessary manufacture and distribution of equipment to replace existing equipment thought to be faulty. It also reduces subsequent engineer visits required to resolve ongoing issues.

6 Immunity test method of broadband disturbance

6.1 Items to be tested

The EUT considered in this Recommendation shall comply with, at least, relevant immunity standards, such as [ITU-T K.43], [ITU-T K.74] or CISPR publications such as [CISPR 24].

6.1.1 Broadband impulsive conducted disturbances

This method is used to apply repetitive and isolated impulsive noise to xDSL ports of the EUT. The requirements for test level, burst duration and period for the two tests are given in Table 1.

The test procedure is based upon the CDN method defined and described in [IEC 61000-4-6], but with a signal generator replaced by a generator capable of producing a 1 ms burst of white noise every 10 ms or 8.3 ms for countries where the AC mains is 50 or 60 Hz, respectively (see Figure 1).

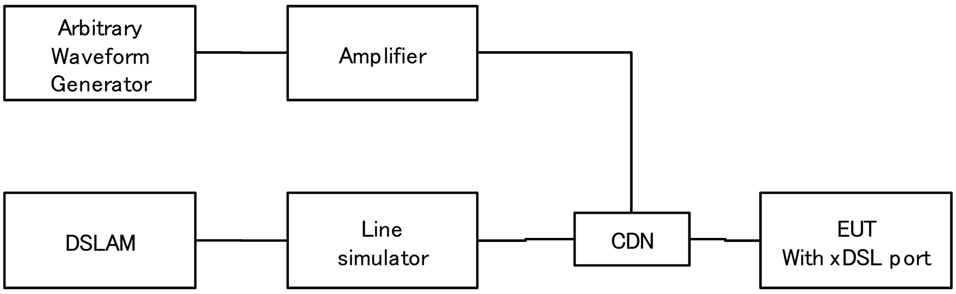


Figure 1 – Example block diagram of the test set-up

6.2 Test waveform

The white noise burst should be derived from a longer-sequence pseudo-random near-Gaussian white noise generator, band-limited to 30 MHz. The generator used for the bursts should have a crest factor of at least 4. The length of the sequence from which the noise bursts are taken should be at least 128k samples. An arbitrary waveform generator could be used to generate this waveform.

6.3 Test procedure

The insertion loss of the amplifier and CDN shall have a uniform frequency response that does not change by more than 3 dB over the frequency range that extends from 150 kHz to the highest frequency used by the DSL technology, or 30 MHz, whichever is the lowest. The CDN shall have an LCL of at least 60 dB over the same frequency range.

A level setting procedure similar to that of [IEC 61000-4-6] shall be used. The specified test level is established with a spectrum analyser having a peak detector and resolution bandwidth of 10 kHz and a video bandwidth of less than or equal to 10 Hz. The EUT port of the coupling device is connected in common mode through a 150 Ω to 50 Ω adapter to the spectrum analyser having a 50 Ω input impedance.

The test generator shall be adjusted to give the level specified in Table 1 No. 1.1 at the EUT port of the coupling device, using the set-up shown in Figure 8c in [IEC 61000-4-6].

Note that the relationship between the measured level in [dBµV] and the test level as defined in Table 1 No. 1.1 or 1.2 is given by:

Measured level [dBµV] = Test level [dBµV] – 27.6 dB[1)]

where:

27.6 dB = A1 + A2 + A3

A1 = 9.6 dB (150 Ω to 50 Ω converter loss)

A2 = 6 dB for EMF correction

A3 = 12 dB for the averaging caused by the video bandwidth reduction.

For the repetitive impulse test, the disturbance shall be applied for a period of 2 minutes. For the isolated impulse test, a minimum of 5 isolated impulses shall be applied with an interval of 60 seconds between successive impulses.

6.4 Test level

Test level of broadband impulsive conducted disturbance is given in Table 1.

Table 1 – Broadband impulsive conducted disturbance

No.	Test	Test specification		Unit	Performance criterion	Basic std.	Note
1.1	Repetitive impulse noise disturbance	Frequency ranges Test level	0.15-0.5 107	MHz $dB\mu V_{rms}$	A See clause A.4.2.1	[IEC 61000-4-6] See Note 2	See Note 3
			0.5-10 107-36	MHz $dB\mu V_{rms}$			
			10-30 36-30	MHz $dB\mu V_{rms}$			
		Burst duration Burst period	0.70 10	ms ms			
1.2	Isolated impulse noise disturbance	Frequency range Test level (peak) Burst duration	0.15-30 110 0.24 & 10 & 300 See Note 1	MHz dBµV ms	A See clause A.4.2.2	[IEC 61000-4-6] See Note 2	See Note 3
NOTE 1 – Burst duration of 8.3 ms or 10 ms can be selected by depending on a frequency of power system for a country. NOTE 2 – Methodology is in accordance with basic standard, with modification to signal source in line with clause 6.3. NOTE 3 – Applicable only to xDSL ports, see clause 6.3. For specific operating conditions, see clause A.3.2. The tests defined in this table shall be repeated using all burst durations.							

7 Immunity test method of impulsive disturbance

7.1 Specific EFT/B immunity test

Devices deemed to provide a service sensitive to impulsive disturbances would additionally comply with specific requirements in Table 2. The test level and criterion are listed in Table 2.

Appendix I gives important experimental results with which to consider the necessity of this test.

Table 2 – Specific immunity test level and criterion of EFT/B test

Test	Ports	Level	Unit	Duration, rep. freq., etc.	Basic std.	Criterion
Fast transients	Wired. DC	0.25	kV	100 kHz, 0.75 ms, 300 ms	[IEC 61000-4-4]	A See clause 8.1.1
	AC	0.25				

8 Performance criteria

8.1 General performance criteria

8.1.1 Performance criterion A

As a consequence of the application of the test, the communication function shall, as a minimum, operate without:

- increase in error rate above the figure defined by the manufacturer;

  NOTE – The manufacturer shall select the most appropriate performance measurement criteria for the product or system, for example, bit error rate, block error rate.

- requests for retry above the figure defined by the manufacturer;
- speed of data transmission rate below the figure defined by the manufacturer;
- protocol failure;
- loss of link.

8.1.2 Performance criterion B

Error rate, request for retry, and speed of data transmission rate may be degraded during test application. Performance degradation as described in criterion A is permitted provided that the normal operation of the EUT is self-recoverable to the condition immediately before test application.

8.1.3 Performance criterion C

Performance degradation as described in criteria A and B is permitted provided that the normal operation of the EUT is self-recoverable to the condition immediately before test application or can be restored after the test by the operator.

Annex A

Wireline data transmission or reception function

(This annex forms an integral part of this Recommendation.)

A.1 Applicability

This Annex is applicable to all functions related to the transmission and/or reception of data over a wireline connection. Examples of ports that exhibit these functions are Ethernet, LAN, ISDN, xDSL and PLT.

A.2 Definitions for use within this annex

A.2.1 dBm

The absolute level of a signal, calculated from 10 $\log_{10}(P)$

Where:

P = $1000V^2/|Z|$ and

V is the rms voltage given by unit "Volt" across a test impedance Z; e.g., if voltage is given by 1[mV], then V is 0.001[V].

NOTE – In telecommunication systems, Z is typically 600 Ω, and 0 dBm corresponds to approximately 775 mV.

A.2.2 dBm0

Absolute signal level in dBm, referred to a point of zero relative level.

NOTE – A digital signal at a level of 0 dBm0 is decoded to an analogue signal level of 0 dBm by an ideal decoder.

A.3 Mode of operation

A.3.1 General

A minimum test configuration consists of two pieces of equipment interconnected with manufacturer-specified physical cable. The cable shall be of a length representative of normal use or replaced with a line simulator. When a line simulator is used, at least 1 m of representative cable shall be placed between the line simulator and the EUT. The electrical disturbance signals shall be applied directly to the port or coupled into the 1 m cable, as appropriate to the test. The line simulator should not be placed in such a way that it would attenuate the disturbance signals. AE necessary to the data transmission function shall be included in the test configuration. Unused ports shall be treated according to the manufacturer's instructions.

The system shall be capable of delivering and receiving data at the specified nominal transmission rate.

Special software applications often improve the ability to test the wireline data transmission or reception function. These applications should be designed to repeatedly send and receive predetermined files or data packets. This approach allows easier comparison between the data communicated during the test and a known accurate copy of the information, to detect errors.

A.3.2 Specific to xDSL ports

Typical far end crosstalk (FEXT) impairment shall be differentially injected into the cable pair during testing along with Gaussian white noise equivalent to –140 dBm/Hz.

NOTE 1 – Further guidance can be found in [b-BBF TR-100] for ADSL2/ADSL2plus and in [b-BBF TR-114] for VDSL2.

Typically, the equipment shall be configured as shown in Figure A.1. The test equipment that is used for the EMC test is not shown in this figure.

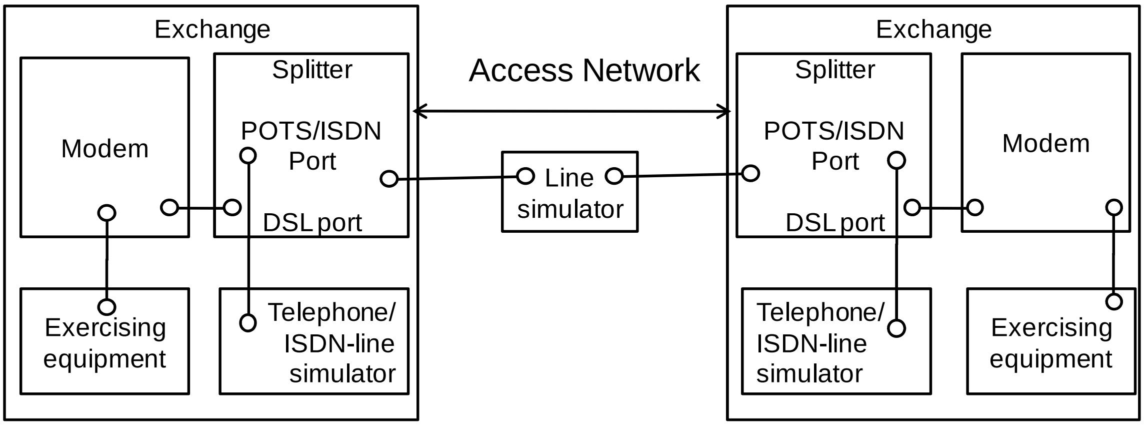


Figure A.1 – DSL access system configuration

For passband systems, such as ADSL and VDSL, the equipment under test typically comprises a DSL modem and splitter/filter via which the POTS/ISDN port is presented. The modem and splitter may be separate units or combined into one unit. The splitter and associated equipment shown in Figure A.1, are required only for systems that support this function, hence they are not needed for systems such as HDSL and SHDSL. Immunity testing shall be performed with the digital transmission system trained up and operating at its nominal transmission rate such that the full frequency spectrum used by the system is utilized. If the system can be operated in asymmetric and symmetric modes then the testing shall be carried out for each of these modes of operation. For ADSL and VDSL applications, ports shall be configured in rate adaptive mode. For HDSL and SHDSL, the data rate shall be set at 1 Mbit/s.

Further details can be found in the Recommendations given in Table A.1.

Table A.1 – ITU-T Recommendations for xDSL systems

ADSL	Recommendation ITU-T G.996.1: Test procedures for digital subscriber line (DSL) transceivers
	Recommendation ITU-T G.992.1: Asymmetrical digital subscriber line (ADSL) transceivers
	Recommendation ITU-T G.992.3: Asymmetrical digital subscriber line transceivers 2 (ADSL2)
	Recommendation ITU-T G.992.5: Asymmetric digital subscriber line 2 transceivers (ADSL2) – Extended bandwidth ADSL2 (ADSL2plus)
HDSL	Recommendation ITU-T G.991.1: High bit rate digital subscriber line (HDSL) transceivers
SHDSL	Recommendation ITU-T G.991.2: Single-pair high-speed digital subscriber line (SHDSL) transceivers
VDSL	Recommendation ITU-T G.993.1: Very high speed digital subscriber line transceivers (VDSL)
	Recommendation ITU-T G.993.2: Very high speed digital subscriber line transceivers 2 (VDSL2)

Tests shall be performed using cable lengths that result in the attenuation values given in Table A.2 or cable simulators that provide an equivalent line attenuation value (measured at 300 kHz) shall be used during testing.

Table A.2 – Attenuation values representing cable lengths

DSL format	Attenuation
ADSL/ADLS2	45 dB
ADSL2+	30 dB
ReADSL	70 dB
HDSL	35 dB
SHDSL	42 dB
VDSL	10 dB

Tests shall be performed with all access cable types supported by the EUT, i.e., STP and/or UTP. The cable type(s) used during test shall be recorded in the test report.

Other ports should be either terminated in their nominal impedance or connected to associated equipment that simulates the functional termination of the port.

NOTE 2 – The test levels were derived from a spectral power density (dBm/Hz) of –43 dBm/Hz,

where:

$$\text{Test level [dB}\mu\text{V]} = \text{Spectral power density [dBm/Hz]} + 150\ \text{dB}$$

where:

150 dB = A1 + A2 + A3

A1 = 40 dB (10 kHz bandwidth factor)

A2 = –10 dB (mW to V conversion for 100 Ω impedance)

A3 = 120 dB (V to µV conversion, i.e., 1 V=10^6 µV (120[dBµV]))

A.4 Performance criteria

A.4.1 General

Performance criterion A

As a consequence of the application of the test, the communication function shall, as a minimum, operate without:

- increase in error rate above the figure defined by the manufacturer;

  NOTE – The manufacturer shall select the most appropriate performance measurement criteria for the product or system, for example, bit error rate, block error rate.

- requests for retry above the figure defined by the manufacturer;
- speed of data transmission rate below the figure defined by the manufacturer;
- protocol failure;
- loss of link.

Performance criterion B

Error rate, request for retry and speed of data transmission rate may be degraded during the application of the test. Degradation of the performance as described in criterion A is permitted provided that the normal operation of the EUT is self-recoverable to the condition immediately before the application of the test.

Performance criterion C

Degradation of the performance as described in criteria A and B is permitted provided that the normal operation of the EUT is self-recoverable to the condition immediately before the application of the test or can be restored after the test by the operator.

A.4.2 Specific to xDSL ports

A.4.2.1 Performance criterion A, applicable for the test requirement defined in Table 1, No. 1.1

It is important that the modems should be able to train in the presence of the repetitive impulsive noise and minimize disruption to the end-user in the case that a repetitive impulsive noise source starts after the link has synchronized. Therefore the following procedure and performance criteria shall be applied to cover the latter case.

The impulsive noise protection (INP) setting for the DSL for this test shall be recorded in the test report and the maximum delay shall be set to 8 ms.

In the absence of impulsive noise: The manufacturer can select the class of INP to be used for the immunity test. According to the test results, the manufacturer should state this information in the technical documentation.

The modem shall operate without re-training at its target noise margin with a bit rate value depending on the line attenuation and the stationary noise being present on the line. (Actual value will be between the minimum and maximum bit rate values programmed in the port.)

The impulsive noise source shall then be applied at the required test level.

With the impulsive noise applied: The modem shall operate without re-training and without SES at the bit rate established prior to the application of the impulsive noise. CRC errors are tolerated during the test only as statistically related to the combination of data rate and bit error ratio over the test duration. No CRC error shall occur as related to the impulsive noises applied.

After the test, the noise margin value shall return to the target noise margin.

A.4.2.2 Performance criterion A, applicable for the test requirement defined in Table 1, No. 1.2

It is important that the modems should be able to withstand the occurrence of isolated impulsive noise events and minimize disruption caused to the end-user. Therefore, the following performance criteria shall be applied (Table A.3).

Table A.3 – Performance criteria against impulse duration

Impulse duration (ms)	Performance criteria
0.24	The application of the impulse shall not cause the DSL link to lose synchronization. No CRC errors are permitted.
8.3 or 10	The application of the impulse shall not cause the DSL link to lose synchronization. Up to 75 CRC errors after the five impulses have been applied are permitted. Selection of the duration depends on the frequency of AC mains in each country.
300	The application of the impulse shall not cause the DSL link to lose synchronization.

Performance criterion B

Degradation of the performance as described in criterion A is permitted in that errors are acceptable during the application of the test. However, the application of the test shall not cause the system to lose the established connection or re-train. At the cessation of the test, the system shall operate in the condition established prior to the application of the test without user intervention.

The above performance criteria do not apply to surge testing. For this test, the EUT shall operate as intended following the cession of the exposure.

Performance criterion C

Degradation of the performance as described in criteria A and B is permitted provided that the normal operation of the EUT is self-recoverable to the condition immediately before the test or can be restored after the test by the operator.

Appendix I

Experimental example of transparency between AC power port and Ethernet port

(This appendix does not form an integral part of this Recommendation.)

I.1 Electromagnetic disturbance entering toward Ethernet port

As results obtained from the field, an effect of any disturbances at Ethernet ports of telecommunication devices would depend on the transparency of a device between the AC power and an Ethernet port of those devices.

The common-mode voltage of the electromagnetic disturbance entering the Ethernet port, $V_{Ethernet}$ can be expressed as Equation I-1.

$$V_{Ethernet} = S_{21} \times V_{AC} \quad \text{(I-1)}$$

Where:

V_{AC} is defined as the common-mode voltage of the electromagnetic disturbance entering an AC power port of an IP-based communication device, and

S_{21} is the transmission factor between the AC power and the Ethernet port of that device.

In this appendix, the examination results of a transparency between the AC power and Ethernet ports of IP-based communication devices, such as PCs, HUBs, and STBs are given in order to clarify the level of disturbance at the Ethernet port.

I.1.1 Measurement set-up for transparency

Figure I.1 shows the measurement set-up to determine the transparency between the AC power and Ethernet ports of IP-based communication devices. The equipment under test (EUT) and auxiliary equipment (AE) are placed on an insulating support 0.1 m above the earth reference plane, as in the schematic set-up for the immunity to RF-conducted disturbances test in [IEC 61000-4-6]. The AC power cable of the EUT is connected to the coupling and decoupling network (CDN-M2), and the Ethernet cable of the EUT is connected to the CDN-T8.

The output port of the network analyser is connected to the CDN-M2 and the input port of the network analyser is connected to the CDN-T8 when the transmission factors (S_{21}) between the AC power and Ethernet ports of the EUT are measured. In this measurement set-up, the output and input voltage of the network analyser are equivalent to V_{AC} and $V_{Ethernet}$ in Equation I-1, respectively, and the transmission factor between the AC power and Ethernet ports is also equivalent to S_{21} in Equation I-1. The transmission factors have been measured in the frequency band from 0.15 to 80 MHz as well as that in the immunity test of [IEC 61000-4-6].

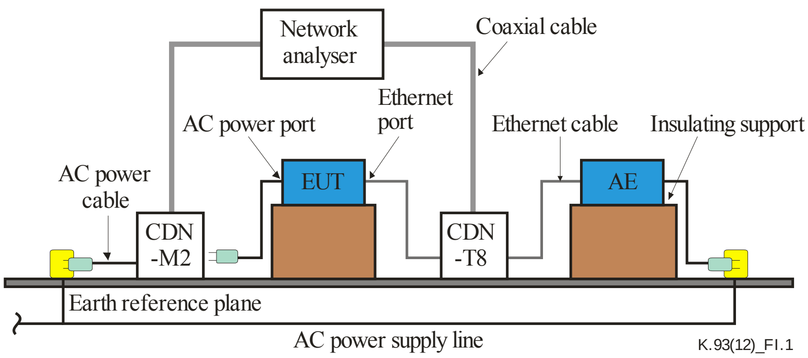


Figure I.1 – Measurement set-up for transparency

Various types of IP-based communication devices can be connected to the Ethernet ports of the telecommunication equipment on customer premises; therefore, the transmission factors for the 33 IP-based communication devices were examined and details are shown in Table I.1.

Table I.1 – Measured devices

IP series terminal	Enclosure	Number of models
Desktop PC	Metal (conductor)	3
Notebook PC	Plastic (insulator)	3
Switching HUB	Metal (conductor)	18
Switching HUB	Plastic (insulator)	8
STB	Plastic (insulator)	1

I.2 IP-based communication devices

Various types of IP-based communication devices can be connected to the Ethernet ports of the telecommunication equipment on customer premises, so transmission factors for 33 kinds of IP-based communication devices (Table I.1) were examined. As shown in Table I.1, three desktop and notebook PCs from different manufacturers were examined, because each of their components is different, such as the main frame of the body, motherboard, or AC adapter. One of the most distinctive components differentiating the desktop and notebook PCs is the material of their main frames. Moreover, 26 kinds of switching HUBs were also examined because they have one of the simplest structures among IP-based communication devices and may have a high transmission factor for electromagnetic disturbances in AC power supply lines. An STB has been examined as a representative video communication device.

Figure I.2 shows the measured transmission factors for 33 kinds of IP-based communication devices. Minimum transmission losses of all the devices are about 6 dB in the frequency band from 0.15 to 80 MHz. The transmission factor is related to the material of the main frame of the device, not the type of device.

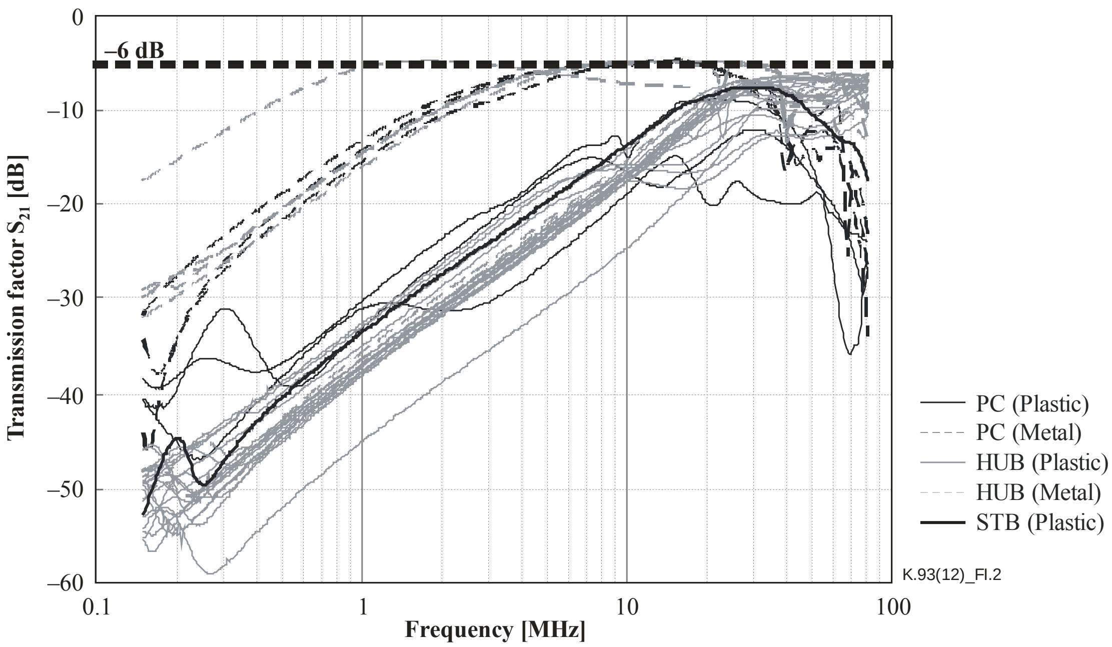


Figure I.2 – Measured transmission factors of IP-based communication devices

Figure I.3 shows the transmission factors for only those IP-based communication devices whose main frames are made of plastic. Figure I.3 shows that the transmission factors for such devices are almost the same, regardless of the type of device.

Figure I.4 shows the transmission factors for only those IP-based communication devices whose main frames are made of metal. The transmission factors for devices with metal frames can be classified into two groups, while those with plastic frames display almost the same characteristics. The transmission factor of group 2 below 10 MHz was 10 dB greater than that of group 1. The internal structures of the main bodies of the two groups were investigated in order to clarify the reason, finding that the earth plane in the motherboard of group 2 is connected to the frame earth of the main body and that of group 1 is not connected to it. Therefore, the transmission factors depend on the internal structure of the main bodies as well as the material of the main frames.

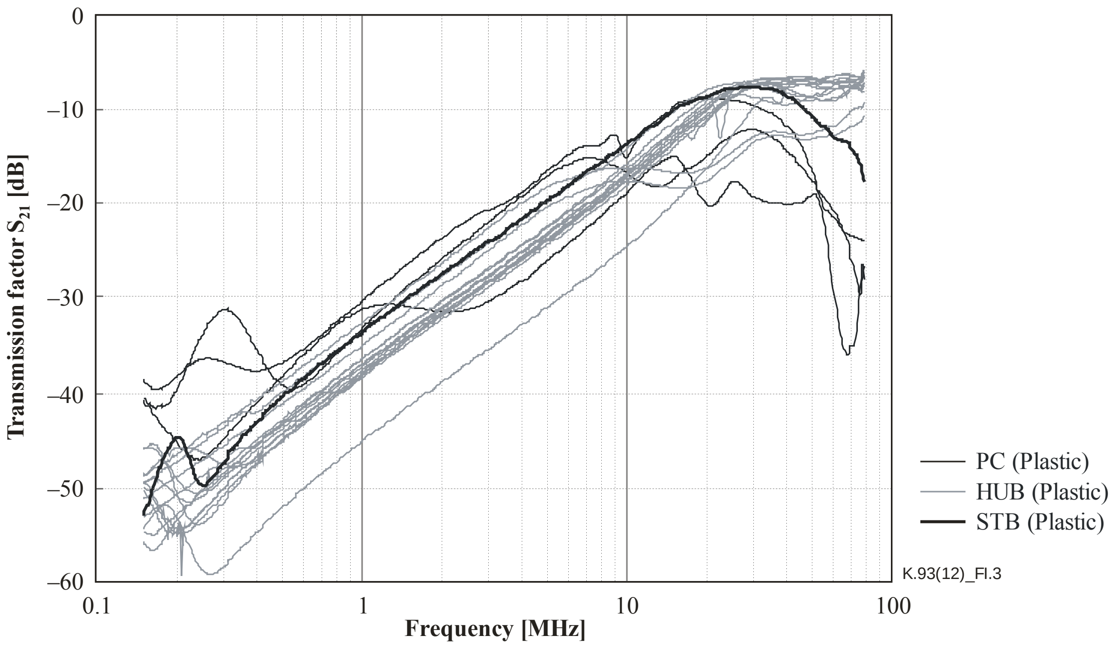


Figure I.3 – Measured transmission factors for devices with plastic frames

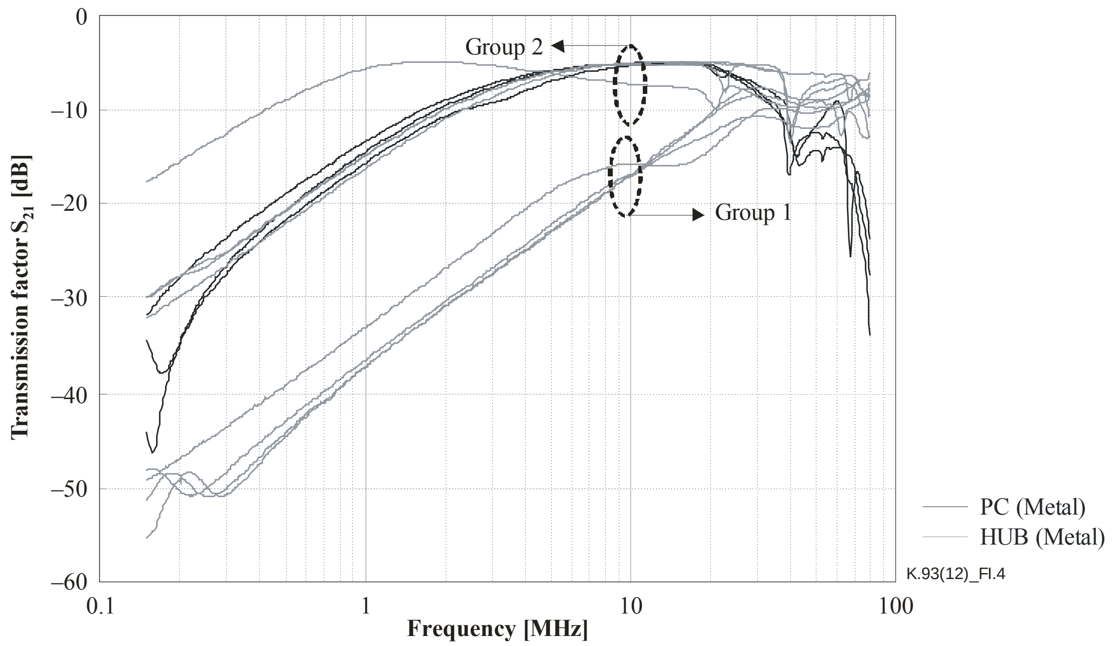


Figure I.4 – Transmission factors for devices with metal frames

I.3 Modelling of IP-based communication devices

The transmission factors for 33 kinds of IP-based communication devices were examined to clarify the potential for electromagnetic disturbances to affect their function via their Ethernet ports. The results show that the transmission factor between the AC power source and the Ethernet ports of IP-based communication devices depends on the material of their main frames and the internal structure of their main bodies. The measured IP-based communication devices can be categorized into three types for each structure (Figure I.5).

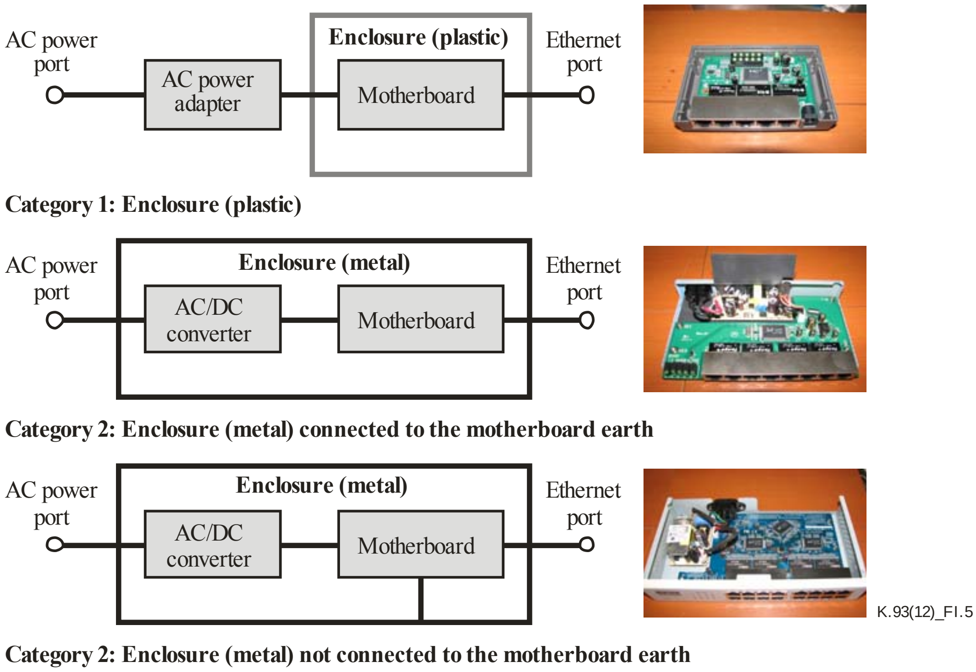


Figure I.5 – Categories of IP-based communication devices

In this appendix three categories of devices (Figure I.5) were classified by a Π-type equivalent circuit, as shown in Figure I.6.

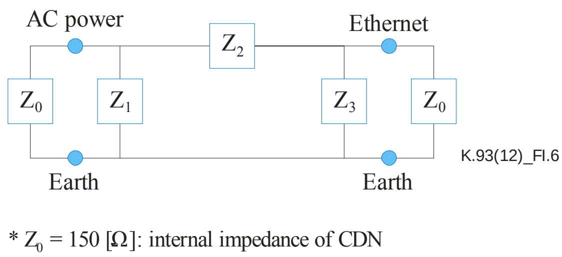
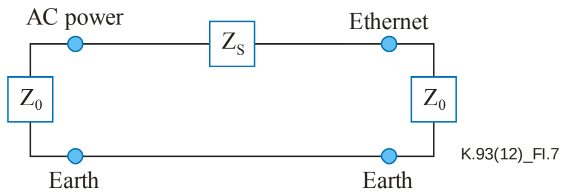


Figure I.6 – Π-type equivalent circuit for IP-based communication devices

In Figure I.6, Z_1 and Z_3 indicate the common-mode impedance at (respectively) the AC power and Ethernet ports of the EUT in Figure I.1. Z_0 is the internal impedance of the CDN, whose value is 150 Ω. Here, it is assumed that Z_1 and Z_3 are infinite because the distance between the EUT and the earth reference plane is great enough so the capacitance between them is negligible, and the measured S_{21} and S_{12} of each EUT are identical to each other because they represent essentially the same characteristic. Therefore, the Π-type equivalent circuit in Figure I.6 can be represented as the 2-terminal-pair network of series elements in Figure I.7, and F-parameters can be expressed by using Z_s as follows.



* Z_0 = 150 [Ω]: internal impedance of CDN

Figure I.7 – 2-terminal-pair network model of IP-based communication devices

$$F = \begin{pmatrix} A & B \\ C & D \end{pmatrix} = \begin{pmatrix} 1 & Z_s \\ 0 & 1 \end{pmatrix} \tag{I-2}$$

The relationships between F-parameters and S-parameters can be also expressed as Equations I-3 to I-6.

$$\frac{(1+S_{11})(1-S_{22})+S_{12}S_{21}}{2S_{21}} = 1 \tag{I-3}$$

$$Z_0 \frac{(1+S_{11})(1+S_{22})-S_{12}S_{21}}{2S_{21}} = Z_s \tag{I-4}$$

$$\frac{1}{Z_0} \frac{(1-S_{11})(1-S_{22})-S_{12}S_{21}}{2S_{21}} = 0 \tag{I-5}$$

$$\frac{(1-S_{11})(1+S_{22})+S_{12}S_{21}}{2S_{21}} = 1 \tag{I-6}$$

The relationship between S-parameters can be calculated from Equations I-3, I-5 and I-6 as follows.

$$S_{11} = S_{22} = 1 - S_{21} \tag{I-7}$$

Substituting Equation I-7 into Equation I-4, Z_s can be expressed by Z_0 and S_{21} because both S_{12} and S_{21} for the symmetrical network represent the same characteristic ($S_{12} = S_{21}$).

$$Z_s = Z_0 \frac{2(1-S_{21})}{S_{21}} \tag{I-8}$$

Figure I.8 shows the measured transmission factors S_{21} for each sample of the three models categorized in Figure I.5. Figure I.9 also shows the imaginary part of Z_s estimated from the measured S_{21} by using Equation I-8 for their models. As shown in Figures I.8 and I.9, the transmission factor S_{21} depends on the parasitic capacitance between the AC power and Ethernet ports of IP-based communication equipment because all the imaginary parts of Z_s for these models are negative. Comparing Figures I.8 and 1.4, below 10 MHz the transmission factor S_{21} of Category 1 is the smallest among the categories because the capacitive component becomes the most dominant factor for Z_s in Category 1. Below 10 MHz, the transmission factor S_{21} of Category 3 is the most undesirable because the inductive factor Z_s is increased by the connection between the earth plane of the motherboard and the frame earth. Therefore, the intensity of an electromagnetic disturbance that enters the Ethernet port will be a maximum when it is transmitted through a device whose main frame is made of metal and whose motherboard earth plane is connected to the frame earth of the main body.

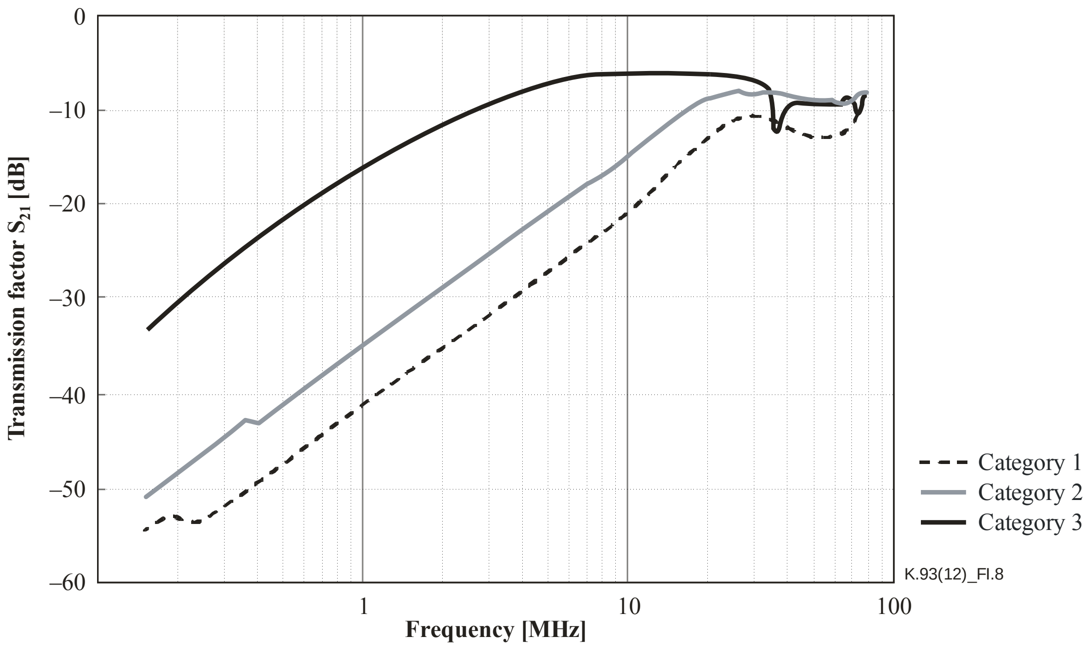


Figure I.8 – Transmission factors S_{21} for three categorized models

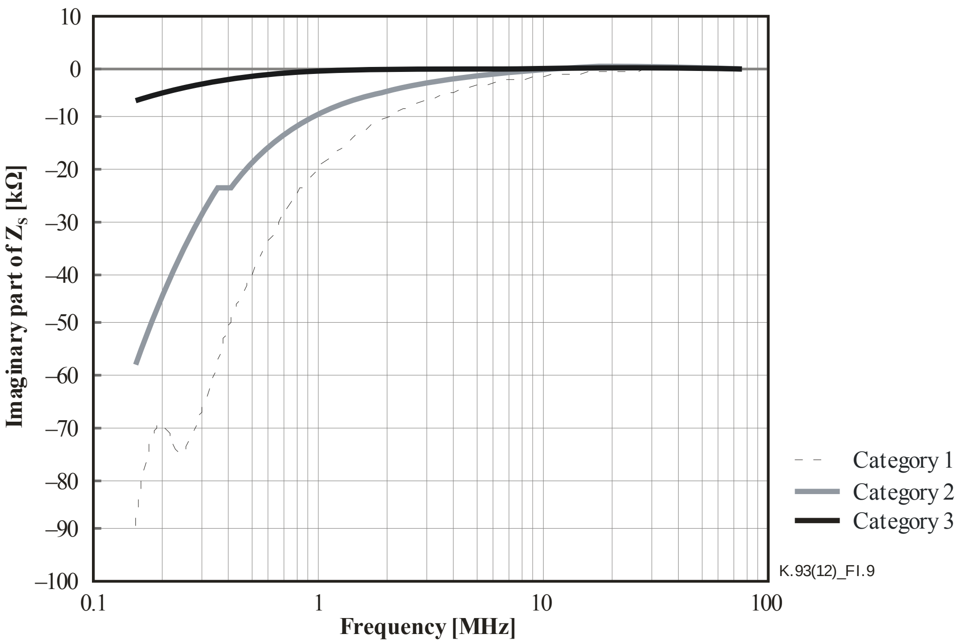


Figure I.9 – Imaginary part of Z_s estimated from the measured S_{21}

I.4 Conclusions

This appendix shows experimental results of the transparency between the AC power and the Ethernet port of IP-based communication devices, in order to clarify the interference levels and immunity requirements of the Ethernet port. The results indicate the following.

- The transparency between the AC power and Ethernet port of IP-based communication devices depends on the material of the main frames and the internal structure of the main bodies.
- The intensity of the electromagnetic disturbance that enters the Ethernet port of the telecommunication equipment is greatest when the electromagnetic disturbance is transmitted through an IP-based communication device whose main frame is made of metal and whose motherboard earth plane is connected to the frame earth of the main body.

- The maximum level of electromagnetic disturbance entering the Ethernet port of telecommunication equipment at frequencies from 0.15 to 80 MHz was about 6 dB lower than that injected into the AC power port of the IP-based communication device.

These results indicate that the immunity level required for the Ethernet ports of telecommunication equipment on customer premises may be for at least half of the intensity level of any electromagnetic disturbance from the AC power supply lines. Moreover, special immunity levels may be required to provide video and high-quality voice services because these services require low delays and low frame error rates.

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