

Intelligent transport systems — Continuous air interface, long and medium range (CALM) — Infra-red systems

ICS 03.220.01; 35.240.60

National foreword

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The UK participation in its preparation was entrusted to Technical Committee EPL/278, Road transport informatics, which has the responsibility to:

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- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep UK interests informed;
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Summary of pages

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Intelligent transport systems — Continuous air interface, long and medium range (CALM) — Infra-red systems

*Systèmes intelligents de transport — Interface d'air continue, gamme
longue et moyenne (CALM) — Systèmes à infrarouges*



Dedication

Exceptionally this International Standard is dedicated to the late Dipl. Ing. Helmut Strasser in grateful recognition of his leadership as the editor and project leader of ISO 21214, and for his commitment and services over more than a decade to meet the challenges of international standardization in the rapidly changing arena of ITS technology.

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 21214 was prepared by Technical Committee ISO/TC 204, *Intelligent transport systems*.

Introduction

This International Standard is part of a family of International Standards for CALM (continuous air interface, long and medium range) which determine a common architecture, network protocols and air-interface definitions for wireless communications using cellular second generation, cellular third generation, 5 GHz, millimetre, and infra-red communications. Other air interfaces may be added at a later date. These air interfaces are designed to provide parameters and protocols for broadcast, point/point, vehicle/vehicle, and vehicle/point communications in the ITS sector.

This International Standard determines the air interface using infra-red systems operating in the wavelength range at 850 nm.

The fast movement of information across the longer distances using wireless technology is functionally very different from the requirements definition for dedicated short range communication (DSRC). High volumes of data are required for purposes such as traffic information and management, video downloads to vehicles for tourist information and entertainment and navigation system updates, etc.

In order to support such services, transmitters need to be able to operate over long or medium range, and to be able to hand over a session from one transmitter to another.

These International Standards are designed to enable quasi-continuous communications, or communications of protracted duration, between vehicles and service providers, or between vehicles. As such they are complementary to dedicated short range, single point, technologies standardised in various regions of the world.

The CALM concept supports multiple bearer types (such as cellular, microwave, infra-red), where an option is proposed to offer user selection of preferred media, and to enable resumption of session interruptions (whether to change bearer media, service provider, or because of signal interruption or interference).

Some applications will have the requirement that communication sessions set up in a first communication zone may be continued in following communication zones; therefore “handover mechanisms” are included. Handover mechanisms need to be defined at two levels:

- Firstly, handover mechanisms within the same technology and service provider. These handover mechanisms are defined within the frequency-specific CALM International Standards.
- Secondly, handover mechanisms at the application level, for use where either the technology or the service provider changes. These handover mechanisms will be defined within the CALM architecture International Standard (ISO 21217), within the CALM networking protocols International Standard (ISO 21210) and within the CALM lower layer SAP International Standard (ISO 21218).

Applications include the update of roadside telemetry and messaging, internet, image and video transfer, infotainment, traffic management, monitoring and enforcement in mobile situations, route guidance, car-to-car safety messaging, maintenance management, and “yellow page” services. For medium- and long-range high-speed roadside/vehicle transactions such as on-board web access, broadcast and subscription services, entertainment, yellow page and booking transactions, etc., the functional characteristics of such systems require contact over significantly longer distance than is feasible or desirable for DSRC, and often for significantly longer connection periods – in some circumstances, continuous communication.

Intelligent transport systems — Continuous air interface, long and medium range (CALM) — Infra-red systems

1 Scope

This International Standard determines the air interface using infra-red systems at 820 nm to 1 010 nm.

It provides protocols and parameters for medium-range, medium- to high-speed wireless communications in the ITS sector using infra-red systems.

Such links are required for quasi-continuous, prolonged or short communications

- between vehicles and the roadside,
- between vehicles, and
- between mobile equipment and fixed infrastructure points,

over medium and long ranges.

Vehicles may be moving or stationary.

Wherever practicable, this International Standard has been developed by reference to suitable extant International Standards, adopted by selection. Required regional variations are provided.

Due account is given to, and use made of, any relevant parts of appropriate communications systems, such as global positioning systems (GPS), digital audio broadcasting (DAB), digital video broadcasting (DVB), radio local area networks (RLANs), digital data broadcasting (DDB), TETRA, FM subcarrier, mobile broadband systems (MBS, W-ATM), internet protocols, and dedicated short range communication (DSRC).

The International Standard:

- supports data rates of 1 Mbit/s up to 128 Mbit/s (it may support higher data rates);
- supports vehicle speeds up to a minimum of 200 km/h (closing speeds could be double this value);
- defines or references environmental parameters relevant to link operation;
- supports communication distances up to 100 m (it may support longer communication distances of 300 m to 1 000 m);
- supports latencies and communication delays in the order of milliseconds;
- is compliant to regional/national regulatory parameters;
- may support other regional/national parameters as applicable.

Application-specific requirements are outside the scope of this International Standard. These requirements will be defined in the CALM management and upper layer standards and in application standards.

Application-specific upper layers are not included in this International Standard, but will be driven by application standards (which may not be technology specific).

2 Conformance

Systems claiming conformance with this International Standard shall meet the specifications herein.

3 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 8802-11, *Information technology — Telecommunications and information exchange between systems — Local and metropolitan area networks — Specific requirements — Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications*

IEC 60050-845, *International Electrotechnical Vocabulary. Lighting*

IEC 60825-1, *Safety of laser products — Part 1: Equipment classification, requirements and user's guide*

4 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

4.1 General

4.1.1 broadcast window *BcW*

window used to broadcast information to slaves, even to those which have not yet performed the “registration process”

4.1.2 chip

smallest information unit communicated over the link

NOTE Depending on the chosen coding, one information bit may be represented by one or more consecutive chips.

4.1.3 communication profile

specific set of data rate, modulation and flow control

4.1.4 communication zone

spatial zone in which two CALM-IR units are able to communicate with acceptable performance

4.1.5 compatibility window *CmpW*

enables non-CALM-IR systems that follow certain rules to co-exist with a CALM-IR system without harmful interference

4.1.6 default data rate

data rate used in the “default communications profile”

4.1.7**default communications profile**

communications profile used unless another communications profile is successfully negotiated

4.1.8**flush byte**

8 bit sequence used to denote the end of the main body of the information to be transmitted using the $HHH(1,13)$ coding procedure

4.1.9**forward direction**

communication flow from master to slave

EXAMPLES forward link, forward window

4.1.10**frame length indicator*****Flen***

indicator is used to calculate the frame length from the last “slot index”

4.1.11**frame organisation table*****FOT***

table which carries all organisation data of the TDMA frame

4.1.12**free airtime indicator*****FATI***

indicator which signals that “free airtime” follows the current frame

NOTE This airtime may be used by units not being a slave of the current master to establish “secondary mastership”.

4.1.13**guard time** **T_G**

time period preceding a “command alert” (CA) in certain cases in order to allow the automatic gain control of the receivers to resettle

4.1.14 **$HHH(1,13)$ code**

special run length limited code with $d = 1$ and $k = 13$ used in the CALM-IR communications profiles 2 to 6

4.1.15**management window**

first window in a CALM-IR frame, which carries all organisation information for the current frame

4.1.16**master identifier*****MID***

code which uniquely identifies a CALM-IR master

4.1.17**multicast window*****McW***

window used for communication from master to multiple slaves, forward direction only

4.1.18**private window**

window which carries the information exchange between a master and a specific slave

4.1.19

registration phase

phase during which a master identifies devices newly entering its communication zone

4.1.20

slave

device that is under the control of another device

4.1.21

spare window

SpW

window, not allocated to a slave, which reserves airtime for any slaves registering during the current frame in order to enable the master to instantly allocate them a private window without the need for frame reorganisation

4.1.22

slot index

index used to count time slots

4.1.23

TDMA frame

time (division multiple access) structure based on a train of consecutive time slots (at least one)

4.1.24

time slot

subunit of a TDMA frame

4.1.25

temporary identifier

TempID

identifier used for addressing the slave device while it resides in the communication environment of the master

NOTE Each time the slave registers in a communication zone, a new *TempID* is created.

4.1.26

wake-up window

WuW

special case of a broadcast window which is used to “wake-up” sleeping units entering the communication zone of an active master

4.1.27

window

smallest addressable time span of a CALM-IR frame which may consist of one or multiple time slots

4.2 Optical parameters

4.2.1

radiant power

radiant flux

Φ_e

power emitted, transmitted or received in the form of radiation

NOTE 1 The unit is the watt (W).

NOTE 2 Adapted from IEC 60050 (845-01-24).

4.2.2 radiant intensity

I_e

quotient of the radiant flux $d\Phi_e$ leaving the source and propagated in the element of solid angle $d\Omega$ containing the given direction, by the element of solid angle

$$I_e = \frac{d\Phi_e}{d\Omega}$$

NOTE 1 Unit: W/sr (watts per steradian).

NOTE 2 Adapted from IEC 60050 (845-01-30).

4.2.3 irradiance

E_e

quotient of the radiant flux $d\Phi_e$ incident on an element of a surface containing a given point divided by the area dA of that element

NOTE 1 Unit: W/m².

NOTE 2 Equivalent definition. Integral, taken over the hemisphere visible from the given point, of the expression $L_e \cdot \cos\theta \cdot d\Omega$, where L_e is the radiance at the given point in the various directions of the incident elementary beams of solid angle $d\Omega$, and θ is the angle between any of these beams and the normal to the surface at the given point.

$$E_e = \frac{d\Phi_e}{dA} = \int_{2\pi\text{sr}} L_e \cdot \cos\theta \cdot d\Omega$$

NOTE 3 Adapted from IEC 60050 (845-01-37).

4.2.4 radiant exitance

M_e

quotient of the radiant flux $d\Phi_e$ leaving an element of a surface containing a given point divided by the area dA of that element

NOTE 1 Unit: W/m².

NOTE 2 Equivalent definition. Integral, taken over the hemisphere visible from the given point, of the expression, where $L_e \cdot \cos\theta \cdot d\Omega$ is the radiance at the given point in the various directions of the emitted elementary beams of solid angle $d\Omega$, and θ is the angle between any of these beams and the normal to the surface at the given point.

$$M_e = \frac{d\Phi_e}{dA} = \int_{2\pi\text{sr}} L_e \cdot \cos\theta \cdot d\Omega$$

NOTE 3 Adapted from IEC 60050 (845-01-47).

4.2.5 radiance

L_e

quantity (in a given direction, at a given point of a real or imaginary surface) (L_e ; L) defined by the formula

$$L_e = \frac{d\Phi_e}{dA \cdot \cos\theta \cdot d\Omega}$$

where

$d\Phi_e$ is the radiant flux transmitted by an elementary beam passing through the given point and propagating in the solid angle $d\Omega$ containing the given direction;

dA is the area of a section of that beam containing the given point;

θ is the angle between the normal to that section and the direction of the beam.

NOTE 1 Unit: W/sr.m².

NOTE 2 Adapted from IEC 60050 (845-01-34).

4.2.6 radiant intensity

I_e
quotient of the radiant flux $d\Phi_e$ leaving the source and propagated in the element of solid angle $d\Omega$ containing the given direction divided by the element of solid angle

NOTE Adapted from IEC 60050 (845-01-30).

4.2.7 steradian sr

dimensionless SI unit of solid angle

NOTE 1 The steradian is the solid angle of a cone which, having its vertex in the centre of a sphere, cuts off on the surface of the sphere an area equal to that of a square with sides of length equal to the radius of the sphere. [ISO 31-1:1992, 1-2.a]

NOTE 2 Usually the abbreviation "sr" is appended, although mathematically this is incorrect.

EXAMPLE

The unity solid angle, in terms of geometry, is the angle subtended at the centre of a sphere by an area on its surface numerically equal to the square of the radius (see Figure 1). Other than the figure might suggest, the shape of the area does not matter at all. Any shape on the surface of the sphere that holds the same area will define a solid angle of the same size.

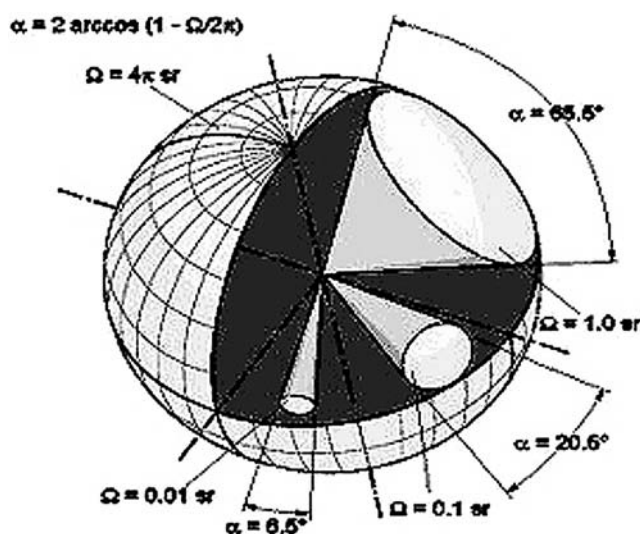


Figure 1 — Solid angle

Relation between distance r , irradiance E_e and intensity I_e

Using a single radiation point source, we get the following relation:

$$E_e = \frac{d\Phi_e}{dA} = \frac{I_e \cdot d\Omega}{dA} = \frac{I_e}{r^2} \left[\frac{W}{m^2} \right]$$

NOTE 3 Adapted from IEC 60050 (845-01-20).

4.2.8**luminous flux**

Φ_v

quantity derived from radiant flux Φ_e by evaluating the radiation according to its action upon the CIE standard photometric observer, for photopic vision

$$\Phi_v = K_m \int_0^\infty \frac{d\Phi_e(\lambda)}{d\lambda} \cdot V(\lambda) \cdot d\lambda$$

where

$$\frac{d\Phi_e(\lambda)}{d\lambda}$$

is the spectral distribution of the radiant flux and $V(\lambda)$ is the spectral luminous efficiency

NOTE 1 For the values K_m (photopic vision) and K'_m (scotopic vision), see IEC 60050 (845-01-56).

NOTE 2 Adapted from IEC 60050 (845-01-25).

4.2.9**luminous efficacy of radiation**

K

quotient of the luminous flux Φ_v divided by the corresponding radiant flux Φ_e

$$K = \frac{\Phi_v}{\Phi_e}$$

NOTE 1 When applied to monochromatic radiation, the maximum value of $K(\lambda)$ is denoted by the symbol K_m :

$K_m = 683 \text{ lm.W}^{-1}$ for $\nu_m = 540 \times 10^{12} \text{ Hz}$ ($\lambda_m \approx 555 \text{ nm}$) for photopic vision.

$K'_m = 1700 \text{ lm.W}^{-1}$ for $\lambda'_m \approx 507 \text{ nm}$ for scotopic vision.

For other wavelengths, $K(\lambda) = K'_m V(\lambda)$ and $K(\lambda) = K'_m V(\lambda)$.

NOTE 2 Adapted from IEC 60050 (845-01-55).

5 Symbols and abbreviated terms

For the purposes of this document, the following symbols and abbreviated terms apply.

<i>BcW</i>	broadcast window
CALM	continuous air interface, long and medium range
CFA	CALM-fast application
CME	CALM management entity
<i>CmpW</i>	compatibility window
CRC	cyclic redundancy check
<i>D</i>	beam axis, "bore-sight direction"
DAB	digital audio broadcasting
DDB	digital data broadcasting
DVB	digital video broadcasting
DSRC	dedicated short range communication
E_e	irradiance
E_v	illuminance
<i>FATI</i>	free airtime indicator
<i>FB</i>	flush byte
<i>FCIR</i>	fast-CALM infra-red packet format
FM	frequency modulation
IPv6	internet protocol version 6
<i>MID</i>	frame length indicator
<i>FOT</i>	frame organisation table
<i>F-Sync</i>	frame synchronisation signal
<i>HHH</i>	Hirt, Hassner, Heise (inventors of the <i>HHH(1,13)</i> code)
I_e	radiant intensity
<i>IR-CAL</i>	infra-red communication adaptation layer
<i>IR-MAE</i>	infra-red management adaptation entity
<i>IR-ME</i>	infra-red management entity
<i>K</i>	luminous efficacy of radiation
L_e	radiance
LLC	logical link control
MAC	medium access control (sometimes used as a synonym for MAC layer)
<i>McW</i>	multicast window
M_e	radiant exitance
<i>MID</i>	master identifier
<i>MnW</i>	management window
N_{frame}	number of time slots in a CALM-IR frame
$N_{\text{frame,max}}$	maximum number of time slots in a CALM-IR frame
$N_{\text{frame,min}}$	minimum number of timeslots in a CALM-IR frame
OBU	on-board unit

<i>PA</i>	preamble
<i>PL</i>	payload
<i>PP</i>	preamble period
PDU	protocol data unit
<i>PrW</i>	private window
RLL	run length limited code
RSU	roadside unit
SAP	service access point
<i>SpW</i>	spare window
sr	steradian
<i>STA</i>	start flag
<i>STO</i>	stop flag
T_{bit}	bit time (duration of one bit)
T_{chip}	chip time (duration of one chip)
T_{CWAIT}	waiting time of the slave for a reply to a proposed <i>TempID</i>
TDMA	time division multiple access
T_{DREG}	registration time-out
<i>TempID</i>	temporary ID
TETRA	trans-European trunked radio access (an ETSI standard for trunked radio networks)
$T_{F\text{-}Sync}$	duration of the <i>F-Sync</i> signal
T_{G}	guard time
T_{L}	lead time — time from the rising edge of the last pulse of a synchronisation signal (<i>F-Sync</i> , <i>W-Sync</i> , <i>CA</i>) to the rising edge of the first pulse of the following command, etc.
T_{Pfall}	optical pulse fall time
T_{Pon}	optical pulse on time
T_{Prise}	optical pulse rise time
T_{REG}	delay time before slave replies to a <i>MC-RRQ</i> or <i>MC-REN</i>
T_{RT}	waiting time of the master for a reply to its <i>MC-IDP</i>
T_{RW}	receiver window – time span around the allocated time slot when the receiver circuit shall be ready to detect a <i>W-Sync</i> signal
T_{RWAIT}	waiting time of the master for a reply to a <i>MC-RRQ</i> or <i>MC-REN</i>
T_{TempID}	<i>TempID</i> time-out.
W-ATM	wireless asynchronous transfer mode
<i>W-Sync</i>	window synchronisation pattern
<i>WuW</i>	wake-up window
Δ	elevation angle
θ_{H}	horizontal opening angle
θ_{V}	vertical opening angle
φ	azimuth angle
Φ_{e}	radiant power, radiant flux
Φ_{v}	luminous power or luminous flux

6 Requirements: transmitter and receiver parameters

6.1 Transmitter wavelengths and bandwidths

Table 1 — Infra-red transmitter parameter specification

Parameter name		Specification	
		Channel 870 (main channel)	Channel 970 (alternate channel)
TX1	Nominal transmitter wavelength	870 nm	970 nm
TX2	Transmitter pass band	820 nm to 910 nm	920 nm to 1 010 nm
TX3	Coherence length	< 1 mm	
TX4	Total radiated power	dependent on transmitter class (see 6.2)	
TX5	Minimum receiver in-band (RX2) radiated power	80 % of TX4	
TX6a	Radiated power below pass band	not specified	< 10 % of TX4
TX6b	Radiated power above pass band	< 10 % of TX4	not specified

NOTE Regarding parameter TX3:

$$l_c = \frac{\lambda^2}{\Delta\lambda}$$

where

l_c is the coherence length;

λ is the wavelength;

$\Delta\lambda$ is the bandwidth.

EXAMPLE $\lambda = 900 \text{ nm}$, $\Delta\lambda = 40 \text{ nm}$

$$l_c = \frac{(900 \text{ nm})^2}{40 \text{ nm}} \approx 20 \text{ }\mu\text{m}$$

6.2 Radiated power

6.2.1 Radiated power limits

Table 2 — Infra-red transmitter parameter limits

Parameter name		Specification
TX7	Maximum radiated intensity	According to IEC 60825-1
TX8	Maximum transmitted power within the range of visible light	Not limited by this International Standard ^a

^a Certain automotive standards may have limitations on this parameter.

6.2.2 Transmitter classes

The transmitter class shall be declared in the associated product specification and shall be organised as shown in Table 3.

Table 3 — Transmitter classes

Parameter	TX class															
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16
<i>TX4a</i> - Minimum radiant intensity [W/sr] (pulse peak value)	0,36	0,75	1,5	3	6	12	25	50	100	200	400	800	1600	3200	6400	12800

6.3 Receiver wavelengths and bandwidths

Table 4 — IR receiver parameter specification

Parameter name		Specification	
		Channel 870 (main channel) mandatory	Channel 970 (alternate channel) optional
<i>RX1</i>	Nominal receiver wavelength	870 nm	970 nm
<i>RX2</i>	Receiver pass band	835 nm to 905 nm ^a	935 nm to 1 005 nm
<i>RX4a</i>	Lower receiver stop band	≤ 805 nm	905 nm
<i>RX4b</i>	Upper receiver stop band	≥ 935 nm ^b	≥ 1 035 nm
<i>RX5a</i>	Receiver sensitivity in lower stop band	not specified	≥ 10 dB above <i>RX6</i>
<i>RX5b</i>	Receiver sensitivity in upper stop band	≥ 10 dB above <i>RX6</i> ^c	not specified
^a Receivers which are able to receive both channels employ an upper limit of 1 005 nm. ^b Receivers which are able to receive both channels employ an upper limit of 1 035 nm. ^c Not specified for receivers which are able to receive both channels.			

The manufacturer shall declare whether he implemented in the equipment only the mandatory main channel or as well the optional alternate channel.

6.4 Receiver class

The receiver class shall be declared in the associated product specification and shall be organised as follows:

Table 5 — Receiver classes

Parameter	RX class										
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11
<i>RX6</i> [mW/m²] Receiver sensitivity in boresight @ <i>RX2</i> , <i>RX8</i> , <i>RX9</i> and <i>RX11</i>	better than 32	better than 16	better than 8	better than 4	better than 2	better than 1	better than 0,5	better than 0,25	better than 0,12	better than 0,06	better than 0,03
<i>RX7</i> [mW/m²] Saturation limit in boresight	12 800	6 400	3 200	1 600	800	400	200	100	48	24	≤ 12
<i>RX8</i> Reference bit error ratio (B.E.R.)	10 ⁻⁶										
<i>RX9</i> Immunity to interference caused by natural optical radiation	≥ 1 120 W/m ² (sunlight spectral distribution)										
<i>RX10</i> [mW/m²] Wake-up sensitivity in boresight @ 500 kHz	better than 32	better than 16	better than 8	better than 4	better than 2	better than 1	better than 0,5	better than 0,25	better than 0,12	better than 0,08	better than 0,03
<i>RX11</i> Reference communication profile	Default communication profile										

The manufacturer shall declare the guaranteed sensitivity for all communication profiles implemented in the equipment.

7 Modulation and coding

7.1 Generic modulation parameters

7.1.1 Wake-up signal

In systems where receivers which have a “sleeping mode” are to be expected, the master has to send a “wake-up signal” in order to wake-up any “sleeping” slaves. The wake-up signal is to be transmitted in a “wake-up window”.

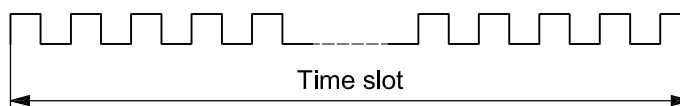


Figure 2 — Wake-up signal

Table 6 — Wake-up signal timing specification

Parameter name		Specification
<i>TX11</i>	Wake-up signal	Burst frequency: 500 kHz $\pm$ 1 %, duty cycle: 45 % to 55 %
<i>TX12a</i>	Max. allowed pulse rise time (optical)	200 ns
<i>TX12b</i>	Max. allowed pulse fall time (optical)	200 ns

7.1.2 Transmitter generic modulation parameters

Table 7 — Infra-red transmitter parameter TX10 specification

Parameter name		Specification
<i>TX10</i>	Tolerance of bit clock	0,1%

7.1.3 Receiver generic modulation parameters

Table 8 — Infra-red receiver parameter RX12 specification

Parameter name		Specification
<i>RX12</i>	Tolerance of bit clock	0,1%
NOTE	“Tracking” of the receiver clock or equivalent techniques are assumed in the sync. modes.	

7.2 Communications profiles

CALM IR employs a whole set of data rates and coding schemes, which have to be selected in dependence of the application and of the actual link quality.

Specific data rates and coding schemes constitute a “communications profile”.

The profiles given in Table 9 apply.

Table 9 — Communications profiles

Parameter	Profile						
	0 (base profile)	1 (default profile)	2	3	4	5	6
Data rate	1 Mb/s	2 Mb/s	8 Mb/s	16 Mb/s	32 Mb/s	64 Mb/s	128 Mb/s
Modulation	3/16 OOK-RZ	6/16 OOK-RZ	CIR-8 <i>HHH(1,13)</i>	CIR-16 <i>HHH(1,13)</i>	CIR-32 <i>HHH(1,13)</i>	CIR-64 <i>HHH(1,13)</i>	CIR-128 <i>HHH(1,13)</i>
Bit time T_{bit}	1 000 ns ± 1 %	500 ns ± 1 %	n.a.				
Chip time, T_{chip}	1 000 ns ± 1 %	500 ns ± 1 %	83,4 ns ± 6,6 ns	41,7 ns ± 3,3 ns	20,8 ns ± 1,6 ns	10,4 ns	5,2 ns
Optical pulse on time, T_{Pon}	190 ns ± 20 ns	190 ns ± 20 ns	83,4 ns ± 6,6 ns	41,7 ns ± 3,3 ns	20,8 ns ± 1,6 ns	10,4 ns	5,2 ns
Optical pulse rise time ^a , T_{Prise}	≤ 75	≤ 75	≤ 38 ns	≤ 19 ns	≤ 9 ns	to be added	to be added
Optical pulse fall time ^a , T_{Pfall}	≤ 75	≤ 75	≤ 38 ns	≤ 19 ns	≤ 9 ns	to be added	to be added
Format	Sync.						
MAC flow control	By MAC commands ("Block start", "Block end", "Packet start", "Packet end", "Start of control-block"),						
Forward error correction	Hamming $L = 12$, $D = 3$ ^b		none ^b				
Multiple error detection	Hamming $L = 12$, $D = 3$ ^b		CRC32				
NOTE Some of the parameters of profile 5 and profile 6 will be defined in future versions of this International Standard.							
^a Equipment employing several communications profiles shall conform with the most stringent values, irrelevant which profile is active at a given time.							
^b For details see Annex B.							

Further profiles may be added in the future.

7.3 Profile 0 (base profile) and profile 1 (default profile) modulation

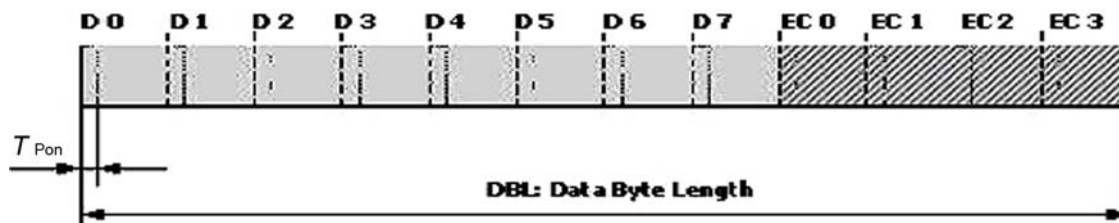


Figure 3 — Modulation of profiles 0 and 1

The coding and decoding rules for the communications profiles 0 and 1 are defined in Annex A.

7.4 Profiles 2 to 6

Profiles 2 to 6 do not employ forward error correction.

NOTE Burst errors at these dataspeeds are much more likely than single bit errors.

Burst errors are detected by the CRC.

The complete coding and decoding rules for the communications profiles 2 to 6 (e.g. modulation types CIR-8 to CIR-128) are given in Annex B.

8 Directivity and communication zones

8.1 Directivity parameters

For a directional communication with CALM-IR devices, a three-dimensional co-ordinate system (x_{CALM} , y_{CALM} , z_{CALM}) has to be constituted. The origin of the co-ordinate system corresponds to the source of the beam. The x -axis of the CALM-device corresponds to the forward direction of the vehicle.

Figure 4 shows the azimuth angle φ and the elevation angle δ of the beam axis D ("bore-sight direction") in relation to the x -axis ("main direction").

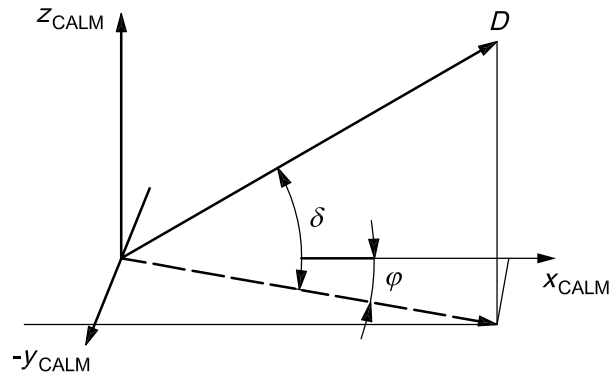


Figure 4 — Azimuth and elevation angle of the beam axis

Further parameters of directivity are the horizontal opening angle θ_H and the vertical opening angle θ_V , as detailed in Figure 5.

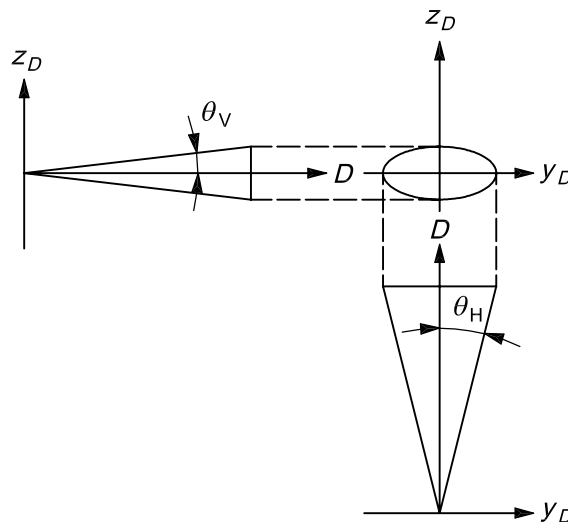


Figure 5 — Horizontal opening and vertical opening angles

Azimuth and elevation are measured according to Figure 4.

Openings are symmetrical to the beam axis D .

Valid horizontal openings θ_H encompass values from 0 degrees to 360 degrees.

Valid vertical openings θ_V encompass values from 0° to 360°.

The resolution of these angles is θ_{basic} ($\sim 1,5^\circ$).

8.2 Communication zones

8.2.1 Basic beam

A “basic beam” is defined as a beam (in arbitrary direction) with the minimum possible horizontal and vertical opening angles equal to the resolution $\theta_{\text{basic}} = 1,5^\circ$.

8.2.2 Communication zone construction

8.2.2.1 A CALM-IR communication zone with any “footprint” on the sphere “illuminated” by the “antenna array” may be defined by assigning a number of basic beams being a member of it.

Alternatively a CALM-IR communication zone with a regular, i.e. symmetrical, footprint may be defined by its associated directivity parameters: azimuth φ , elevation δ , horizontal opening θ_H , and vertical opening θ_V .

8.2.2.2 Any communication zone may be assigned a specific transmitter or receiver class independently from any other. The assignment of transmitter and receiver classes to communication zones is dynamically controllable.

8.2.2.3 Inside the communication zone, the transmitter class and the receiver class parameters as defined in Tables 2, 3, 4 and 5 apply.

NOTE 1 Any communication zone may be associated with the same “communications channel”, thus carrying identical communications streams.

NOTE 2 Alternatively any communication zone may be associated with a different “communications channel”, thus carrying different communications streams, independent of each other (dynamically controllable).

NOTE 3 Isolation between multiple communication zones is not defined by this International Standard.

8.2.3 Communication zone shortcuts

Shortcuts to speed up the direction control for predefined communication zones are defined in Tables 10 and 11.

Table 10 — Transmitter communication zones shortcuts

Zone		Parameter			
		φ [°]	δ [°]	θ_H [°]	θ_V [°]
FG	Forward general	0	30	90	90
FS	Forward straight	0	0	7,5	7,5
FR	Forward right	-18	0	9	7,5
FL	Forward left	18	0	9	7,5
BG	Backward general	180	30	90	90
BS	Backward straight	180	0	7,5	7,5
BR	Backward right	-156	0	21	7,5
BL	Backward left	156	0	21	7,5
GR	General right	-90	30	90	90
SR	Side right	-45	0	15	7,5
UR	Up right	-60	36	21	21
GL	General left	90	30	90	90
SL	Side left	45	0	15	7,5
UL	Up left	60	36	21	21
HS	Hemispheric	0	90	210	210
US	Up straight	0	42	21	21
DR	Disk-radiator	0	0	360	7,5

Table 11 — Receiver communication zones shortcuts

Zone		Parameter			
		φ [°]	δ [°]	θ_H [°]	θ_V [°]
FG	Forward general	0	30	90	90
FS	Forward straight	0	0	7,5	7,5
FR	Forward right	-18	0	9	7,5
FL	Forward left	18	0	9	7,5
BG	Backward general	180	30	90	90
BS	Backward straight	180	0	7,5	7,5
BR	Backward right	-156	0	21	7,5
BL	Backward left	156	0	21	7,5
GR	General right	-90	30	90	90
SR	Side right	-45	0	15	7,5
UR	Up right	-60	36	21	21
GL	General left	90	30	90	90
SL	Side left	45	0	15	7,5
UL	Up left	60	36	21	21
HS	Hemispheric	0	90	210	210
US	Up straight	0	42	21	21
DR	Disk-radiator	0	0	360	7,5

NOTE For the RSU, no communication zone is defined because it depends strongly on the geographical site.

9 Frames and windows

9.1 General structure

Clause 9 defines the CALM-IR framing, the window structure and window management.

The framing describes the CALM-IR TDMA scheme as a media access method for synchronised communication of multiple communication partners.

In one communication environment with two or more communication partners, there shall exist exactly one master, which controls the organisation of the TDMA sequence.

If no dedicated master exists, a procedure is provided to establish a new master.

Direct “slave to slave” communications require that one of the slaves act as a temporary master.

The CALM-IR frame consists of N_{frame} time slots and is defined and organised by the master.

The framing structure is defined by reserved signals which by definition can never occur in a data stream. This allows simple detection circuitry without the necessity to constantly supervise and analyse the data stream.

The following signals are used:

- *F-Sync* - frame synchronisation signal;
- *W-Sync* - window synchronisation signal;
- *CA* - command alert.

The patterns and the use of these signals are described and defined in the following sub-clauses.

9.2 Frame

9.2.1 Frame structure

A frame employs the following characteristics.

- The CALM-IR TDMA frame is generated by the master and starts with the *F-Sync* signal.
- The frame is either terminated by the *F-Sync* signal of the consecutive frame or, in the event that the option “free airtime” is used, with a *W-Sync* signal and the MAC command “free airtime” (*MC-FAT*).
- A frame is subdivided into time slots of duration T_S .
- The maximum length of the frame is $N_{\text{frame,max}}$ time slots, the minimum length is $N_{\text{frame,min}}$.
- A frame is organised in “windows” by means of window synchronisation signals, *W-Sync*.
- The CALM-IR TDMA frame contains at least one window.
- The maximum number of windows within one frame is a dynamic parameter and depends on the size of the windows.
- The very first window of a frame is always the management window, *MnW*.

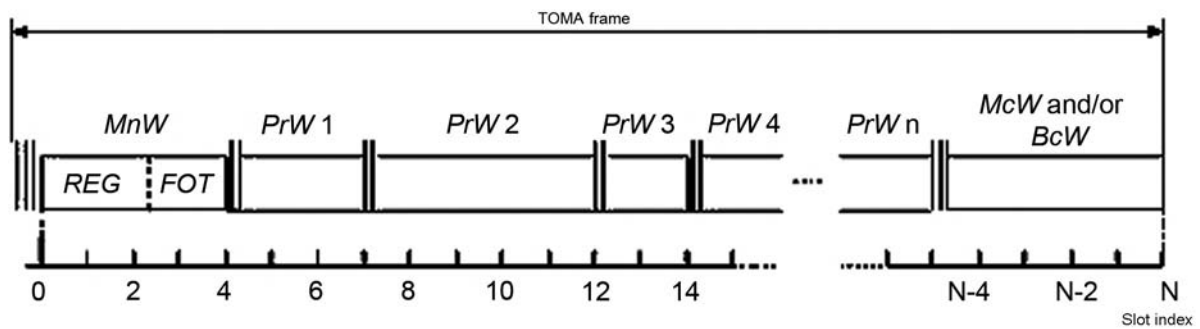
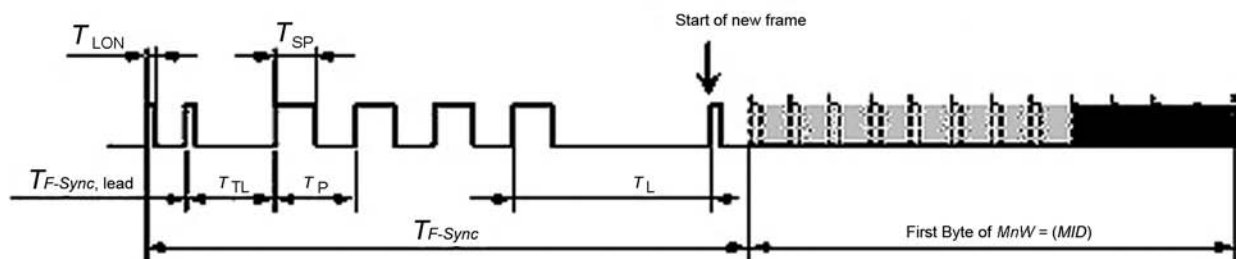


Figure 6 — An example CALM-IR frame structure

9.2.2 Frame synchronisation signal (*F-Sync*)

The frame synchronisation signal *F-Sync* is generated by the master at the beginning of a frame and has the pattern shown in Figure 6.

Figure 7 — Frame synchronisation signal (*F-Sync*)

All active slaves not in a “transmit state” shall be ready to recognise an *F-Sync* at all times as an *F-Sync* can also interrupt frames in progress, for example to prioritise emergency messages.

An *F-Sync* shall never be sent directly after a “receive state” of the master. In such a case, a guard interval of duration T_G shall be inserted before the sending of *F-Sync* in order to allow the receiver circuitry of all slaves to resettle.

9.3 Windows

9.3.1 Window structure and types

9.3.1.1 Frames are subdivided into communication windows by the window synchronisation signal *W-Sync* sent by the master.

9.3.1.2 Windows may carry forward information (master to slave) as well as return information (slave to master).

9.3.1.3 There exist the following types of window, which are defined in subsequent sub-clauses:

- management window, *MnW*;
- private window, *PrW*;
- multicast window, *McW*;

- broadcast window, BcW ;
- compatibility window, $CmpW$;
- spare window, SpW ;
- wake-up window, WuW .

9.3.1.4 The information flow within a window is controlled by MAC commands and can also be interrupted, in case of high priority events, by the communications partner employing the “right to send” (Token) using the signal command alert (CA) followed by a MAC command.

9.3.2 Window synchronisation (W -Sync)

9.3.2.1 The window synchronisation signal W -Sync is sent by the master at the beginning of all windows PrW , BcW , McW and WuW except the first window of the TDMA frame which is marked by the F -Sync.

9.3.2.2 Because of sometimes significant propagation delay times of the signal arriving from the slaves, it may happen that the master transmits the W -Sync even whilst still in the receive state. This is not allowed. Therefore the W -Sync may be transmitted slightly asynchronously with respect to the time slot index.

9.3.2.3 In order to account for this effect on the receiver side, the receiver circuitry shall be ready to detect the W -Sync not just at the beginning of the time slot allocated by the FOT , but from slightly before until slightly after the allocated time within the W -Sync receiver window, $T_{W\text{Receive}}$.

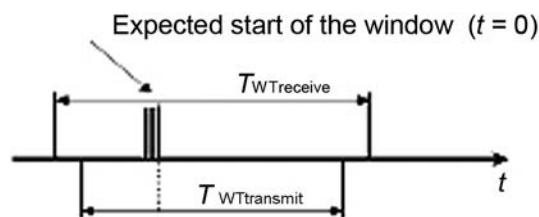


Figure 8 — Window synchronisation (W -Sync) receiver and transmitter window

9.3.2.4 In the event that a system is configured with the feature “free airtime”, the very last window (which may be either a MnW , a PrW , a McW or a BcW) shall be followed by a W -Sync and the MAC command MC -FAT.

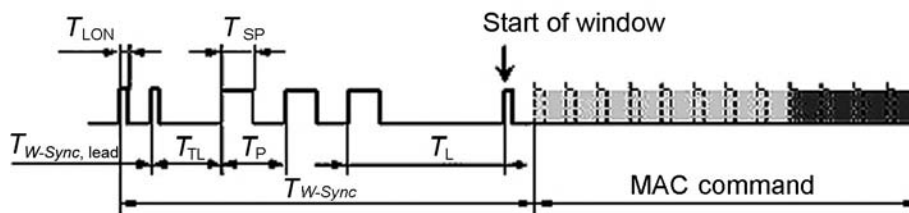


Figure 9 — Window synchronisation (W -Sync)

9.3.2.5 A W -Sync never shall follow directly after a “receive state”. In such case a guard interval of duration T_G shall be inserted before the sending of W -Sync in order to allow the receiver circuitry of the communications partner to resetttle.

9.3.3 Management window

9.3.3.1 The management window (MnW) is the first window in a CALM-IR frame and carries all organisation information for the current frame as described below.

9.3.3.2 The following occur within the management window.

- Slaves newly entering the communication zone are registered and allocated appropriate window parameters.
- Sufficient communication time is dynamically allocated to each slave.
- Care is taken that timing requirements for time-critical applications are met.
- Care is taken that required command response/reaction times are met.
- If necessary, time slots are re-arranged.
- Short broadcast messages are sent.

In the management window only the default communications profile shall be used.

9.3.3.3 The *MnW* follows immediately after the *F-Sync* signal. It is subdivided into the generic frame information, i.e. *MID*, *MID* and *FAT*, and optional MAC commands for registration (*MC-REG*) and organisation (*MC-FOT*, *MC-FOT U*, *MC-FOT S*, *MC-SUS*, *MC-SUA*); see Clause 12. The generic frame information is defined as follows.

9.3.3.4 The master identifier *MID* is the unique identifier of any CALM-IR communications master. It consists of a three byte integer which is composed of two parts.

9.3.3.4.1 The first part, the one byte class identity, gives information about the master: fixed roadside beacon, vehicle onboard unit, mobile enforcement, PDA or laptop, point-to-point link, etc.

MSB	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	LSB
M	F1	F0	S	K3	K2	K1	K0
1	Function of the master		Sub-master	Kind of master			

Figure 10 — Structure of the class identity code

Table 12 — Class identity codes

Bit Position	Value	Meaning	Description
M	1	Master identifier	Used in MAC address to distinguish slaves and masters
F1, F0	1, 1	Broadcaster	Indicates that the sender of the <i>MID</i> is a “broadcaster” only (for example a “talking traffic sign”. The broadcaster supports no registration of slaves.
	1, 0	Master	Indicates a normal master to which slaves may register
	0, 1	Pre master	Indicates a (normally mobile) unit which, besides being a slave to a master, can also assume the function of a master (usually of a moving cluster).
	0, 0	Internet access point	Indicates that the internet is accessible via the master
S	1	Flag: Active as secondary master	Indicates that the unit currently performs two functions at the same time: - it works as a slave versus a master (usually positioned in the infrastructure); - it works as secondary master, usually of a moving cluster.
	0	Flag: Active as master	Indicates that the unit currently works as the master of a usually moving cluster. In case this cluster comes into the communications zone of a master the unit assumes the function of a slave versus the master and as a secondary master versus the cluster and sets the flag to 1.
K3, K2, K1, K0		reserved for future use	If not used, set to 0

9.3.3.4.2 The second part is a 16 bit binary number which,

- in the event of a stationary master, shall be a fixed number identifying the master and is assigned during installation time;
- in the event of a temporary master, shall be a random number created by the device which wants to take the master function.

9.3.3.5 The frame length indicator *MID* gives the total length of the current frame in terms of available time slots as a one byte integer.

9.3.3.6 The free airtime indicator *FATI* gives the airtime following the last window of the current frame which is not used by the current master in order to allow other masters to build up a communications frame between two frames of the current master. The free airtime is given in terms of the number of time slots unused by the current master between two consecutive frames as a single byte integer.



Figure 11 — Example of free airtime

9.3.3.7 The coding and modulation during the management window is always according to the default profile.

9.3.4 Private window

9.3.4.1 Private windows carry the information exchange between a master and a specific slave. Private windows are allocated to a master/slave relation by using a temporary MAC Address called “temporary identifier” (*TempID*) which is created during the registration process and “published” in the *FOT* during the management window.

9.3.4.2 One slave may use more than one private window (*PrW*). To do this it must register again and a new *TempID* will be created and allocated to it.

9.3.4.3 Communications in a *PrW* starts by using the default communications profile. Upon negotiation with the master, any communications profile which both master and slave support, and which gives sufficient link quality, may be used for subsequent information exchange.

9.3.4.4 A *PrW* employs at least one information transfer phase in the “forward direction” and zero or more information transfer phases in the “return direction”.

9.3.4.5 Each *PrW* starts immediately after the window synchronisation signal *W-Sync* emitted by the master.

9.3.4.6 The window phase now starting transfers information from the master to the slave (“forward direction”).

9.3.4.6.1 Immediately after the synchronisation signal *W-Sync*, the master sends,

- in the event that a new message is to be transmitted, an appropriate MAC command;
- in the event that the information to be transferred is the remainder of an earlier message which did not fit in the slave’s last *PrW*, the MAC command “packet start” (*MC-PAS*).

9.3.4.6.2 The length of the information stream is signalled

- either inherently by the MAC command itself, or
- if the length is not inherently given by the MAC command,
 - in the event that all the information which is to be transmitted fits in the current window, by the MAC command “block end” (*MC-BLE*) after the data;
 - in the event that all the information which is to be transmitted does not fit in the current window and will be continued in a further *PrW* of the slave, by the MAC command “packet end” (*MC-PAE*) after the data.

NOTE All MAC commands which do not start immediately after a *W-Sync* have to be preceded by a command alert signal *CA*.

9.3.4.7 Now that the (first) transfer in the forward direction (master to slave) is finished, the (first) transfer from slave to master (return direction) starts.

9.3.4.7.1 After the recognition of the end of reception (described above), the slave has to wait a “guard time” T_G before it starts sending (this guard time allows the receiver on the other end of the link to re-establish correct thresholds).

9.3.4.7.2 The slave then sends an appropriate MAC command (preceded by a command alert *CA*).

9.3.4.7.3 The slave then transfers information towards the master (in the “return direction”) in exactly the same manner as described above for the “forward direction”.

9.3.4.8 Where the pre-assigned window size allows, the slave switches to its “receive state” and the master may again send information to the slave.

9.3.4.8.1 In such a case, the master starts the second transfer in the “forward direction” by waiting the guard time T_G and issuing an appropriate MAC command.

9.3.4.8.2 The further sequence is identical to that described above, until the window time expires or until none of the partners wants to exchange any more information.

9.3.5 Broadcast window

9.3.5.1 Broadcast windows (*BcW*) are used to broadcast information to all slaves within the communication zone of the “broadcaster”, even to those which have not yet performed the “registration process”.

NOTE Unregistered slaves can also receive and decode the *FOT*, and thus decode the frame and receive the broadcast window.

9.3.5.1.1 A frame shall contain zero or one broadcast window.

9.3.5.1.2 The broadcast window is addressed by a reserved *TempID* (see 11.2) in the frame organisation table *FOT*.

9.3.5.1.3 The broadcast window can have any position in the frame.

9.3.5.1.4 The broadcast window *BcW* employs only one information transfer phase, namely in “forward direction”.

9.3.5.1.5 In the *BcW* the default profile shall be used.

9.3.5.1.6 The *BcW* starts immediately after the window synchronisation signal *W-Sync* emitted by the master.

9.3.5.1.7 The window phase now starting transfers information from the master to the slave(s) (“forward direction”).

9.3.5.2 Immediately after the synchronisation signal *W-Sync* the master sends either

- the MAC command “block start” (*MC-BLS*) in case a new broadcast message is to be broadcasted, or
- the MAC command “packet start” (*MC-PAS*) if the following information is the continuation of an earlier broadcast message which did not fit in a single window.

9.3.5.3 The length of the information stream is signalled either

- by the subsequent MAC command “block end” (*MC-BLE*) in the event that all the information which is to be broadcasted fitted in the current window, or
- by the subsequent MAC command “packet end” (*MC-PAE*) in the event that all the information which is to be broadcasted does not fit in the current window and will be continued in a further broadcast window.

NOTE All MAC commands which do not start immediately after a *W-Sync* have to be preceded by a command alert signal CA.

9.3.5.4 As the slaves shall not respond in a *BcW*, the information transfer phase is now finished.

9.3.6 Multicast window

9.3.6.1 Multicast windows are used to transfer information to a certain group of registered slaves (within the communication zone of the “multicast”) which had been included in that group.

NOTE Procedures on how slaves are assigned to “multicast groups” are not defined in this International Standard.

9.3.6.2 Multicast windows are addressed by one of the reserved *TempIDs* allocated to multicasting (see 11.2) in the frame organisation table *FOT*.

9.3.6.3 A multicast window *McW* employs only information transfer phases in the “forward direction”.

9.3.6.4 In a *McW*, the communications profile which is set with the first MAC command of the multicast window shall be used (see below).

9.3.6.5 The multicast window *McW* starts immediately after the window synchronisation signal *W-Sync* emitted by the master.

9.3.6.6 The window phase now starting transfers information from the master to the slave(s) (“forward direction”).

9.3.6.6.1 Immediately after the synchronisation signal *W-Sync*, the master shall send, in each *McW*, the MAC command “set multicast profile” (*MC-SMP*) in order to signal to the slaves with which communications profile the information will be sent.

9.3.6.6.2 Subsequently, the master sends either

- the MAC command “block start” (*MC-BLS*) in case a new multicast message is to be sent, or
- the MAC command “packet start” (*PAS*) if the following information is the continuation of an earlier multicast message which did not fit in a single window.

NOTE All MAC commands which do not start immediately after a *W-Sync* have to be preceded by a command alert signal CA.