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Identification cards — Contactless integrated circuit cards - Proximity cards — Part 2: Radio frequency power and signal interface

AMENDMENT 5
Bit rates of 3*fc*/4, *fc,* 3*fc*/2 and 2*fc* from PCD to PICC

Cartes d'identification — Cartes à circuit intégré - Cartes de proximité — Partie 2: Interface radio fréquence

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AMENDEMENT 5
Débits binaires de 3fc/4 et fc, 3fc/2 et 2fc de PCD vers PICC

Document type: International Standard
Document subtype: Amendment
Document stage: (30) Committee
Document language: E

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Foreword

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Amendment 5 to ISO/IEC 14443-2:2010 was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 17, *Card and personal identification*.

Identification cards — Contactless integrated circuit cards - Proximity cards — Part 2: Radio frequency power and signal interface

EDITORIAL remarks

Tables start with number 10

Table 1 Table 2 Table 3 Table 4 Table 5 Table 6 Table 7 Table 8 Table 9

Figures start with number 18

Figure 1 Figure 2 Figure 3 Figure 4 Figure 5 Figure 6 Figure 7 Figure 8 Figure 9 Figure 10 Figure 11 Figure 12 Figure 13 Figure 14 Figure 15 Figure 16 Figure 17

Amendment 5: Bits rates of 3*fc*/4, *fc*, 3*fc*/2 and 2*fc* from PCD to PICC

Page 3, Clause 4

Add the following symbols:

APV	Actual Phase Value
EPI	Elementary Phase Interval
etu	Elementary time unit
NPV	Nominal Phase Value
PH	maximum NPV
PL	minimum NPV
PNP	Previous Nominal Phase
PR	Phase Range
PSK	Phase shift keying
#	Number

Page 6 , 8.1.1

Replace paragraph with:

"The bit rate for the transmission during initialization and anticollision shall be *fc*/128 (~106 kbit/s).

The bit rate for the transmission after initialization and anticollision shall be one of the following:

— *fc*/128 (~106 kbit/s),

— *fc*/64 (~212 kbit/s),

— *fc*/32 (~424 kbit/s),

— *fc*/16 (~848 kbit/s),

— *fc*/8 (~1,70 Mbit/s),

— *fc*/4 (~3,39 Mbit/s),

— *fc*/2 (~6,78 Mbit/s),

— *3fc*/4 (~10,17 Mbit/s),

— *fc* (~13,56 Mbit/s),

— *3fc/2* (~20,34Mbit/s),

— 2*fc* (~27,12Mbit/s)."

Page 14

Add new subclause

"**8.1.2.4 Modulation for bit rates of 3*fc*/4, *fc, 3fc*/2 and 2*fc***

See 11.1"

Page 15

Add new subclause"

"**8.1.3.3 Bit representation and coding for bit rates of 3*fc*/4, *fc,* 3*fc/2* and 2*fc***

See 11.2"

Page 15, 8.2.1

Replace paragraph with:

"The bit rate for the transmission during initialization and anticollision shall be *fc*/128 (~106 kbit/s).

The bit rate for the transmission after initialization and anticollision shall be one of the following:

— *fc*/128 (~106 kbit/s),

— *fc*/64 (~212 kbit/s),

— *fc*/32 (~424 kbit/s),

— *fc*/16 (~848 kbit/s),

— *fc*/8 (~1,70 Mbit/s),

— *fc*/4 (~3,39 Mbit/s),

— *fc*/2 (~6,78 Mbit/s),

"

Page 23, 9.1.2

Add a subclause title:

"**9.1.2.1: Modulation for bit rates of *fc*/128, *fc*/64, *fc*/32, *fc*/16, *fc*/8, *fc*/4 and *fc*/2** "

Insert new subclause 9.1.2.2 with the following title and content:

"**9.1.2.2: Modulation for bit rates of 3*fc*/4, *fc,* 3*fc*/2 *and* 2*fc***

See 11.1"

Page 24, 9.1.3

Add a subclause title:
"**9.1.3.1 Bit representation and coding for *fc*/128, *fc*/64, *fc*/32, *fc*/16, *fc*/8, *fc*/4 and *fc*/2**"

At the end of the subclause, add a new subclause with the following title and content

"**9.1.3.2 : Bit representing and coding for bit rate of 3*fc*/4, *fc, 3fc/2 and* 2*fc***

See 11.2"

Create a new clause 11 as follows:

"

11 Bit rates of 3*fc*/4, *fc,* 3*fc*/2 and 2*fc* from PCD to PICC

For bit rates of 3*fc*/4, *fc*, 3*fc*/2 and 2*fc*, communication from PCD to PICC shall use the modulation principle of PSK of the RF carrier of the operating field.

11.1 Modulation for bit rates of 3*fc*/4, *fc*, 3*fc*/2 and 2*fc*

For bit rates of 3*fc*/4, *fc*, 3*fc*/2 and 2*fc*, information is encoded by PSK modulation of the RF carrier. The RF carrier is phase modulated by an NPV in degree at each etu. For each bit rate the length of an etu and the number of NPVs are specified in Table 10.

Table 10 — etu and # of NPVs

Bite rate	etu	# of NPV
3*fc*/4 (~ 10,17 Mb/s)	4/*fc*	8
***fc* (~ 13,56 Mb/s)**	4/*fc*	16
3*fc*/2 (~ 20,34 Mb/s)	2/*fc*	8
2*fc* (~27,12 Mb/s)	2/*fc*	16

The difference between 2 consecutive NPVs is defined as EPI, specified in Table 11 and illustrated in Figure 18.

Table 11 — EPI

Bite rate	EPI
3*fc*/4 (~ 10,17 Mb/s)	8°
***fc* (~ 13,56 *Mb*/s)**	4°
3*fc*/2 (~ 20,34 Mb/s)	8°
***2fc* (~27,12 Mb/s)**	4°

The difference between the P_H and P_L defines the phase range PR as illustrated in Figure 18.

The PCD and PICC shall respect the PR limits as specified in Table 12 and Table 13.

Table 12 — PR for PCD transmission

Bite rate	Minimum PR	Maximum PR
3*fc*/4, 3*fc*/2	54°	58°
fc*, 2*fc	58°	62°

Table 13 — PR for PICC reception

Bite rate	Minimum PR	Maximum PR
3*fc*/4, 3*fc*/2	52°	60°
***fc*, 2fc**	56°	64°

11.1.1 NPV Tolerances

The NPV phase modulation varies within inter-symbol interference (ISI) tolerances resulting in an APV. This is described in a constellation diagram with ISI_m and ISI_d as specified below and illustrated in Figure 19.

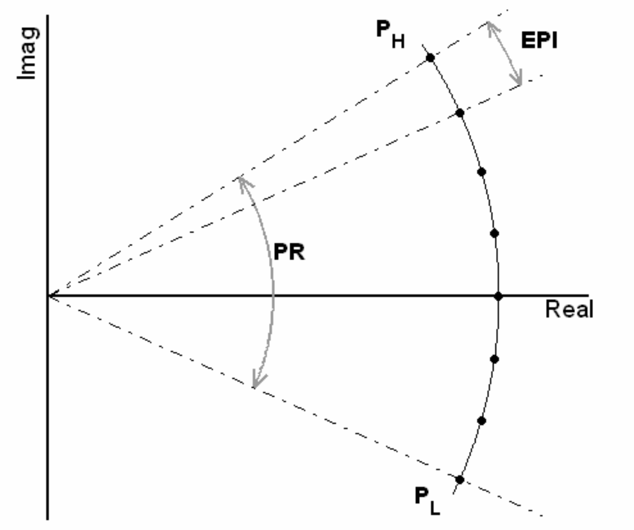

Figure 18 — Nominal constellation diagram

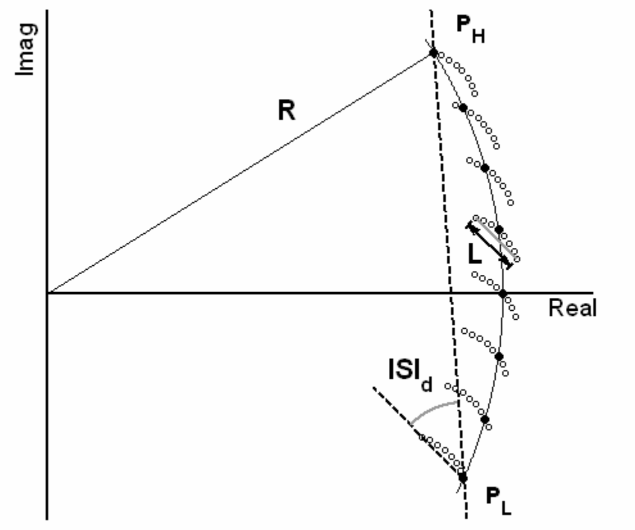

Figure 19 — Actual constellation diagram

NOTE NPVs are indicated with small filled spots. APVs are indicated with small circles

NOTE See Annex A for explanation on constellation diagrams. See Annex B for explanation on ISI.

L is the maximum distance of 2 APVs related to one NPV.

R is the signal amplitude of an NPV phase modulation.

ISI_d is the rotation in degrees of all APV modulations related to one NPV phase modulation. It is defined as the angle between the line through P_H,P_L and the line through the maximum distance of 2 APVs related to one NPV .

ISI_m is the ISI magnitude normalized to the EPI. ISI_m = arcsin(L/R)/EPI.

The PCD and PICC shall respect ISI_m limits for an APV as a function of ISI_d specified in Table 14 and Table 15. and illustrated in Figure 20.

Table 14 — ISI_m limits for PCD transmission

	Condition	Min	Max
ISI_m	abs(ISI_d) ≤ 90°	0	1.5 - abs(ISI_d)/90
	abs(ISI_d) > 90°	0	0,5

Table 15 — ISI_m limits for PICC reception transmission

	Condition	Min	Max
ISI_m	abs(ISI_d) ≤ 90°	0	1.6 - abs(ISI_d)/90
	abs(ISI_d) > 90°	0	0,6

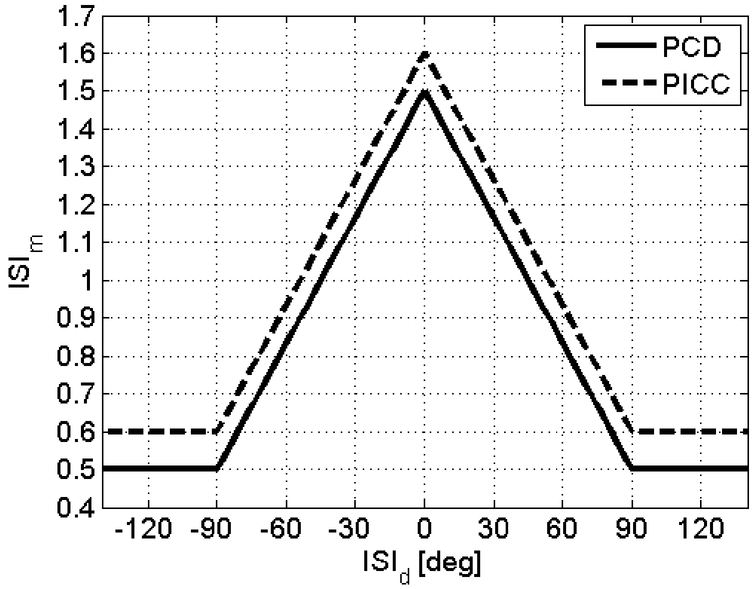

Figure 20 — ISI_m limits for PCD and PICC

11.1.2 Phase noise

APVs may also vary randomly due to phase noise.

The normalized differential phase noise (rms) shall be lower than 0,033 for PCD transmission and lower than 0,035 for PICC reception.

The normalized differential phase noise is the differential phase noise divided by EPI.

The differential phase noise is defined as the difference of two consecutive instantaneous phase noise values.

The instantaneous phase noise value is defined as the difference between the APV and the NPV during no phase modulation.

11.2 Bit representation and coding for bit rates of 3*fc*/4, *fc*, 3*fc*/2 and 2*fc*

For bit rates 3*fc*/4 and 3*fc*/2 binary information shall be transmitted from PCD to PICC in units of 8 logic levels, building an information symbol of 3 bits, LSB is transmitted first. The 8 logic levels are represented by 8 NPVs.

For bit rates *fc* and 2*fc* binary information shall be transmitted from PCD to PICC in units of 16 logic levels, building an information symbol of 4 bits, LSB is transmitted first. The 16 logic levels are represented by 16 NPVs.

Incomplete information symbols shall be stuffed with logic "0".

For end of communication, the PCD shall generate a sequence of 8 NPVs of -180°.

11.2.1 Bit representation and Coding for bit rates of 3*fc*/4 and 3*fc*/2

For start of communication the PCD shall generate a sequence of 140 NPVs starting with NPV of etu # 1 as specified in Table 16. The phase of the unmodulated RF carrier is defined as NPV = 0°.

Table 16 — start of communication for bit rates of 3*fc*/4 and 3*fc*/2

etu #	NPV	etu #	NPV	etu #	NPV	etu #	NPV	etu #	NPV	etu #	NPV	etu #	NPV
1	24 °	21	24 °	41	24 °	61	-24 °	81	-16 °	101	8 °	121	-24 °
2	24 °	22	24 °	42	24 °	62	24 °	82	24 °	102	32 °	122	32 °
3	-24 °	23	-24 °	43	-24 °	63	32 °	83	-16 °	103	8 °	123	-24 °
4	-24 °	24	-24 °	44	-24 °	64	8 °	84	-8 °	104	-16 °	124	32 °
5	24 °	25	24 °	45	24 °	65	-8 °	85	16 °	105	-16 °	125	-24 °
6	24 °	26	24 °	46	-24 °	66	16 °	86	-16 °	106	24 °	126	8 °
7	-24 °	27	-24 °	47	24 °	67	8 °	87	24 °	107	24 °	127	24 °
8	-24 °	28	-24 °	48	-24 °	68	-8 °	88	8 °	108	32 °	128	16 °
9	24 °	29	24 °	49	32 °	69	16 °	89	0 °	109	-16 °	129	0 °
10	24 °	30	24 °	50	32 °	70	8 °	90	32 °	110	0 °	130	16 °
11	-24 °	31	-24 °	51	-24 °	71	-16 °	91	16 °	111	32 °	131	24 °
12	-24 °	32	-24 °	52	8 °	72	32 °	92	32 °	112	-16 °	132	-8 °
13	24 °	33	24 °	53	-16 °	73	-24 °	93	-16 °	113	8 °	133	-24 °
14	24 °	34	24 °	54	24 °	74	16 °	94	-16 °	114	-8 °	134	0 °
15	-24 °	35	-24 °	55	-8 °	75	8 °	95	-24 °	115	-16 °	135	32 °
16	-24 °	36	-24 °	56	8 °	76	8 °	96	32 °	116	24 °	136	8 °
17	24 °	37	24 °	57	-16 °	77	-24 °	97	-8 °	117	24 °	137	8 °
18	24 °	38	24 °	58	16 °	78	-16 °	98	-24 °	118	24 °	138	16 °
19	-24 °	39	-24 °	59	16 °	79	0 °	99	8 °	119	16 °	139	8 °
20	-24 °	40	-24 °	60	16 °	80	-8 °	100	-24 °	120	-16 °	140	0 °

For transmission of binary information symbols, the PCD shall generate a NPV as specified in Table 17 as a function of the symbol to be sent and PNP.

For encoding the first symbol the PCD shall use PNP = 0° (last NPV of Table 16).

Table 17 — NPV encoding for bit rates of 3*fc*/4 and 3*fc*/2

Symbol MSB LSB	PNP	32°	24°	16°	8°	0°	-8°	-16°	-24°
000	NPV	32°	24°	16°	8°	0°	-8°	-16°	-24°
001		24°	16°	8°	0°	-8°	-16°	-24°	32°
010		8°	0°	-8°	-16°	-24°	32°	24°	16°
011		16°	8°	0°	-8°	-16°	-24°	32°	24°
100		-24°	32°	24°	16°	8°	0°	-8°	-16°
101		-16°	-24°	32°	24°	16°	8°	0°	-8°
110		0°	-8°	-16°	-24°	32°	24°	16°	8°
111		-8°	-16°	-24°	32°	24°	16°	8°	0°

For reception of binary information symbols, the PICC shall decode the information symbol as specified in Table 18 as a function of the received NPV and the PNP.

For decoding the first symbol, the PICC shall use PNP = 0°.

Table 18 — NPV decoding for bit rates of 3*fc*/4 and 3*fc*/2

NPV	PNP	32°	24°	16°	8°	0°	-8°	-16°	-24°
32°	MSB LSB	000	100	101	111	110	010	011	001
24°		001	000	100	101	111	110	010	011
16°		011	001	000	100	101	111	110	010
8°	Symbol	010	011	001	000	100	101	111	110
0°		110	010	011	001	000	100	101	111
-8°		111	110	010	011	001	000	100	101
-16°		101	111	110	010	011	001	000	100
-24°		100	101	111	110	010	011	001	000

NOTE: See Annex C for a description of all intermediate steps for encoding and decoding.

11.2.2 Bit representation and Coding for bit rates of *fc* and 2*fc*

For start of communication the PCD shall generate a sequence of 140 NPVs, starting with NPV of etu # 1 as specified in Table 19. The phase of the unmodulated carrier is defined as NPV = 0°.

Table 19 — start of communication for *fc* and 2*fc*

etu #	NPV	etu #	NPV	etu #	NPV	etu #	NPV	etu #	NPV	etu #	NPV	etu #	NPV
1	28 °	21	28 °	41	28 °	61	-4 °	81	32 °	101	-20 °	121	-28 °
2	28 °	22	28 °	42	28 °	62	-20 °	82	8 °	102	4 °	122	32 °
3	-28 °	23	-28 °	43	-28 °	63	-12 °	83	-28 °	103	-16 °	123	-28 °
4	-28 °	24	-28 °	44	-28 °	64	28 °	84	-16 °	104	28 °	124	32 °
5	28 °	25	28 °	45	28 °	65	16 °	85	12 °	105	32 °	125	-28 °
6	28 °	26	28 °	46	-28 °	66	-20 °	86	-16 °	106	8 °	126	4 °
7	-28 °	27	-28 °	47	28 °	67	-24 °	87	28 °	107	12 °	127	24 °
8	-28 °	28	-28 °	48	-28 °	68	24 °	88	16 °	108	20 °	128	16 °
9	28 °	29	28 °	49	32 °	69	-12 °	89	8 °	109	-24 °	129	0 °
10	28 °	30	28 °	50	32 °	70	-20 °	90	-20 °	110	-4°	130	20 °
11	-28 °	31	-28 °	51	-28 °	71	20 °	91	32 °	111	32 °	131	32 °
12	-28 °	32	-28 °	52	8 °	72	4 °	92	-12 °	112	-16 °	132	4 °
13	28 °	33	28 °	53	-12 °	73	16 °	93	4 °	113	8 °	133	-12 °
14	28 °	34	28 °	54	32 °	74	-8 °	94	4 °	114	-8 °	134	12 °
15	-28 °	35	-28 °	55	0 °	75	-16 °	95	-4 °	115	-12 °	135	-20 °
16	-28 °	36	-28 °	56	16 °	76	-16 °	96	-12 °	116	32 °	136	24 °
17	28 °	37	28 °	57	-8 °	77	16 °	97	16 °	117	-28 °	137	28 °
18	28 °	38	28 °	58	28 °	78	28 °	98	4 °	118	-24 °	138	-24 °
19	-28 °	39	-28 °	59	32 °	79	-20 °	99	-28 °	119	-28 °	139	-28 °
20	-28 °	40	-28 °	60	-28 °	80	-28 °	100	8 °	120	8 °	140	32 °

For transmission of binary information symbols, the PCD shall generate a nominal phase value NPV as specified in Table 20 as a function of the information symbol to be sent and the previously used nominal phase PNP.

For encoding of the first symbol the PCD shall use PNP = 32° (last NPV of Table 19).

Table 20 — NPV encoding for bit rates of *fc* and 2*fc*

Symbol MSB LSB	PNP	32°	28°	24°	20°	16°	12°	8°	4°	0°	-4°	-8°	-12°	-16°	-20°	-24°	-28°
0000	NPV	32°	28°	24°	20°	16°	12°	8°	4°	0°	-4°	-8°	-12°	-16°	-20°	-24°	-28°
0001		28°	24°	20°	16°	12°	8°	4°	0°	-4°	-8°	-12°	-16°	-20°	-24°	-28°	32°
0010		20°	16°	12°	8°	4°	0°	-4°	-8°	-12°	-16°	-20°	-24°	-28°	32°	28°	24°
0011		24°	20°	16°	12°	8°	4°	0°	-4°	-8°	-12°	-16°	-20°	-24°	-28°	32°	28°
0100		4°	0°	-4°	-8°	-12°	-16°	-20°	-24°	-28°	32°	28°	24°	20°	16°	12°	8°
0101		8°	4°	0°	-4°	-8°	-12°	-16°	-20°	-24°	-28°	32°	28°	24°	20°	16°	12°
0110		16°	12°	8°	4°	0°	-4°	-8°	-12°	-16°	-20°	-24°	-28°	32°	28°	24°	20°
0111		12°	8°	4°	0°	-4°	-8°	-12°	-16°	-20°	-24°	-28°	32°	28°	24°	20°	16°
1000		-28°	32°	28°	24°	20°	16°	12°	8°	4°	0°	-4°	-8°	-12°	-16°	-20°	-24°
1001		-24°	-28°	32°	28°	24°	20°	16°	12°	8°	4°	0°	-4°	-8°	-12°	-16°	-20°
1010		-16°	-20°	-24°	-28°	32°	28°	24°	20°	16°	12°	8°	4°	0°	-4°	-8°	-12°
1011		-20°	-24°	-28°	32°	28°	24°	20°	16°	12°	8°	4°	0°	-4°	-8°	-12°	-16°
1100		0°	-4°	-8°	-12°	-16°	-20°	-24°	-28°	32°	28°	24°	20°	16°	12°	8°	4°
1101		-4°	-8°	-12°	-16°	-20°	-24°	-28°	32°	28°	24°	20°	16°	12°	8°	4°	0°
1110		-12°	-16°	-20°	-24°	-28°	32°	28°	24°	20°	16°	12°	8°	4°	0°	-4°	-8°
1111		-8°	-12°	-16°	-20°	-24°	-28°	32°	28°	24°	20°	16°	12°	8°	4°	0°	-4°

For reception of binary information symbols, the PICC shall decode the information symbol as specified in Table 21 as a function of the received nominal phase value NPV and the previous received nominal phase PNP.

To decode the first symbol, PNP = 32° shall be used.

Table 21 — NPV decoding for bit rates of *fc* and *2fc*

NPV	PNP	32°	28°	24°	20°	16°	12°	8°	4°	0°	-4°	-8°	-12°	-16°	-20°	-24°	-28°
32°	MSB LSB	0000	1000	1001	1011	1010	1110	1111	1101	1100	0100	0101	0111	0110	0010	0011	0001
28°	Symbol	0001	0000	1000	1001	1011	1010	1110	1111	1101	1100	0100	0101	0111	0110	0010	0011
24°		0011	0001	0000	1000	1001	1011	1010	1110	1111	1101	1100	0100	0101	0111	0110	0010
20°		0010	0011	0001	0000	1000	1001	1011	1010	1110	1111	1101	1100	0100	0101	0111	0110
16°		0110	0010	0011	0001	0000	1000	1001	1011	1010	1110	1111	1101	1100	0100	0101	0111
12°		0111	0110	0010	0011	0001	0000	1000	1001	1011	1010	1110	1111	1101	1100	0100	0101
8°		0101	0111	0110	0010	0011	0001	0000	1000	1001	1011	1010	1110	1111	1101	1100	0100
4°		0100	0101	0111	0110	0010	0011	0001	0000	1000	1001	1011	1010	1110	1111	1101	1100
0°		1100	0100	0101	0111	0110	0010	0011	0001	0000	1000	1001	1011	1010	1110	1111	1101
-4°		1101	1100	0100	0101	0111	0110	0010	0011	0001	0000	1000	1001	1011	1010	1110	1111
-8°		1111	1101	1100	0100	0101	0111	0110	0010	0011	0001	0000	1000	1001	1011	1010	1110
-12°		1110	1111	1101	1100	0100	0101	0111	0110	0010	0011	0001	0000	1000	1001	1011	1010
-16°		1010	1110	1111	1101	1100	0100	0101	0111	0110	0010	0011	0001	0000	1000	1001	1011
-20°		1011	1010	1110	1111	1101	1100	0100	0101	0111	0110	0010	0011	0001	0000	1000	1001
-24°		1001	1011	1010	1110	1111	1101	1100	0100	0101	0111	0110	0010	0011	0001	0000	1000
-28°		1000	1001	1011	1010	1110	1111	1101	1100	0100	0101	0111	0110	0010	0011	0001	0000

NOTE: See Annex C for a description of all intermediate steps for encoding and decoding.

"

Add the following annexes:

"

Annex A
(INFORMATIVE)

Complex envelope and constellation diagram

In carrier-based transmission systems, the information-carrying component of the symbol $x(t)$ may be represented by the complex envelope $v(t)$:

$$x(\mathrm{t}) = \mathrm{v}(t)\cdot\exp(j\cdot 2\cdot\pi fc\cdot t) + \mathrm{v}^*(t)\cdot \exp(-j\cdot 2\cdot\pi fc\cdot t)$$

and $v^*(t)$ is the complex conjugate of $v(t)$, j is the imaginary unit and fc the carrier frequency.

For a purely ASK modulated signal, the argument (angle) of $v(t)$ would be constant over time and the information is coded in the magnitude of $v(t)$.

For a purely PSK modulated signal, the magnitude of v(t) would be constant over time and the information is coded in the argument of $v(t)$.

Note that passing the signal $x(t)$ through a band-limited channel would affect the complex envelope of $v(t)$. In some cases, a purely amplitude modulated signal might exhibit a varying phase component after the channel. Similarly, a purely phase-modulated signal generally exhibits some amplitude variations after passing through a band limited channel.

The complex envelope $v(t)$ is often plotted in the complex plane at the symbol sampling instants only, in what is called a constellation diagram. So, the complex values of $v(\mathrm{k}\cdot etu)$ are plotted (imaginary component versus real component), where k is a set of integer numbers and *etu* is the symbol time. All samples are plotted in the same diagram, without explicit time information. An example of such a diagram is found in Annex B figure B.1.

Annex B
(INFORMATIVE)

Inter-Symbol Interference

The bandpass characteristic of the PCD antenna resonator affects the complex envelope of the transmitted signal and, thus, gives rise to inter-symbol interference (ISI). The effect of such ISI can be seen when observing the constellation diagram of the transmitted signal: The ISI spreads every constellation point into an *ISI cloud* (the spreading of APVs), which has the same shape as the original constellation, a *size* depending on the channel bandwidth, and a *rotation* depending on the PCD tuning. These effects are depicted in Figure B.1 and B.2.

Figure B.1 shows intervals of ISI around the nominal (transmitted) phase values NPVs. Such intervals are a simplified view of the actual interference patterns which are visible two-dimensionally in Figure B.2 (the constellation diagram). The rotation of these clouds is caused by detuning of the PCD. In such detuned case, the line joining the extremes of these clouds form an angle ISI_d with respect to the line joining P1 and P4 (which corresponds to the original transmitted constellation points before channel filtering).

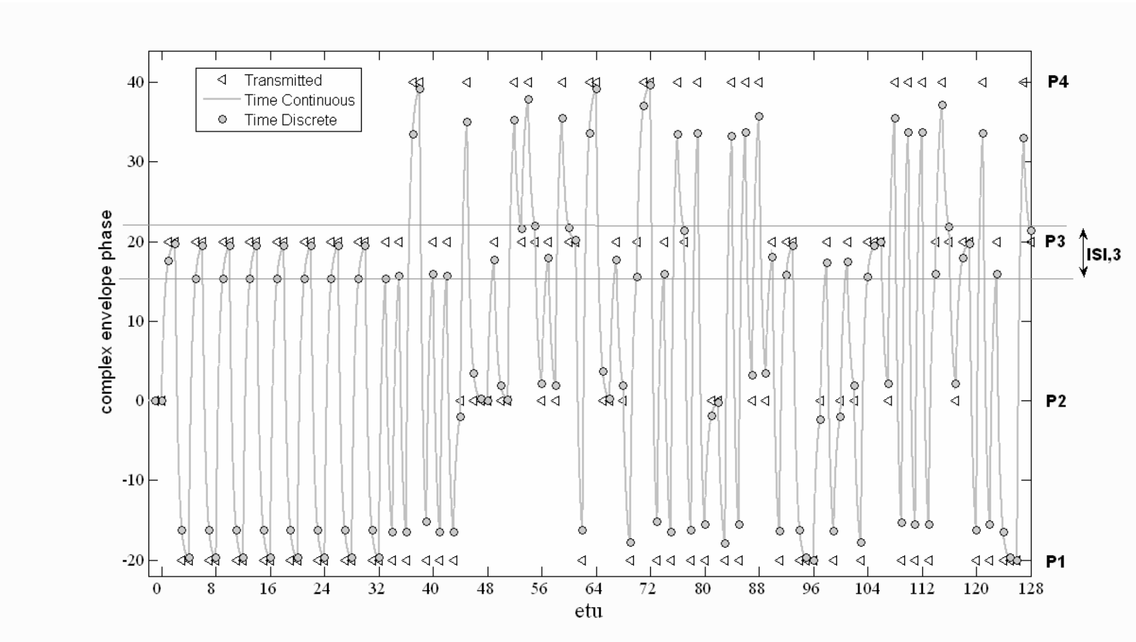

Figure B.1 — Example of inter-symbol interference due to a band-limited channel as a function of time

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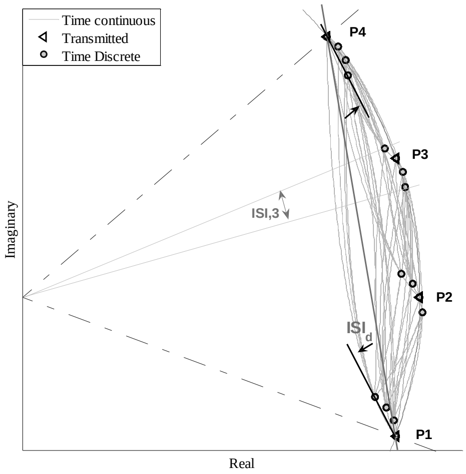

Figure B.2 — Example of inter-symbol interference due to a band-limited channel, the corresponding constellation diagram showing both amplitude and phase of the modulated carrier in continuous time.

Annex C
(INFORMATIVE)

The contents of Table 17, Table 18, Table 20 and Table 21 can be described by a chain of data transformation steps for bit rates of 3*fc*/4, *fc,* 3*fc*/2 *and* 2*fc* as shown in Figure 21.

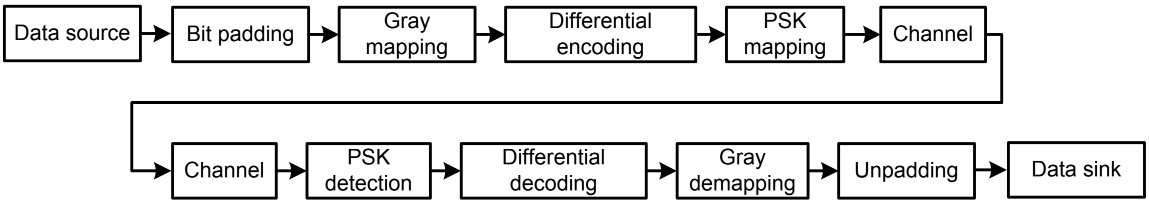

Figure 21 – Data transformation steps

The data transformation steps:

1) **Bit padding:** the source data is mapped to groups of 3bits or 4 bits, each group representing one information symbol. Incomplete information symbols are padded with ‘0’ in this step.

2) **Gray mapping:** the Gray mapping ensures that two successive symbols differ in only one bit. The source to Gray mapping is described in Table 22 and Table 23.

Table 22 –Gray mapping for bit rates of 3*fc*/4 and 3*fc/2*

Source data	Gray mapping out
000	000
001	001
010	011
011	010
100	111
101	110
110	100
111	101

Table 23 - Gray mapping for bit rates of *fc* and 2*fc*

Source data	Gray mapping out
0000	0000
0001	0001
0010	0011
0011	0010
0100	0111
0101	0110
0110	0100
0111	0101
1000	1111
1001	1110
1010	1100
1011	1101
1100	1000
1101	1001
1110	1011
1111	1010

3) **Differential encoding:** is defined as out(n) = (out(n-1) + in(n))mod(# of NPV))

4) **PSK mapping:** information symbols are mapped to NPVs according to Table 24 and Table 25.

Table 24 - PSK mapping for bit rates of 3*fc*/4 and 3*fc*/2

Output of Differential encoding	NPV
000	$\phi_0 + 32\,°$
001	$\phi_0 + 24°$
010	$\phi_0 + 16\,°$
011	$\phi_0 + 8\,°$
100	ϕ_0
101	$\phi_0 - 8\,°$
110	$\phi_0 - 16\,°$
111	$\phi_0 - 24\,°$

Table 25 - PSK mapping for bit rates of *fc* and 2*fc*

Output of Differential encoding	NPV
0000	ϕ_0 + 32 °
0001	ϕ_0 + 28 °
0010	ϕ_0 + 24 °
0011	ϕ_0 + 20 °
0100	ϕ_0 + 16°
0101	ϕ_0 + 12 °
0110	ϕ_0 + 8 °
0111	ϕ_0 + 4 °
1000	ϕ_0
1001	ϕ_0 - 4 °
1010	ϕ_0 - 8 °
1011	ϕ_0 - 12 °
1100	ϕ_0 - 16 °
1101	ϕ_0 - 20 °
1110	ϕ_0 - 24 °
1111	ϕ_0 - 28 °

NOTE NPVs are transmitted by the PCD over the channel, and received by the PICC.

5) **Channel:** the channel refers to the transmission medium (air interface).

6) **PSK detection:** the detected NPVs are mapped to binary information according to Table 24 and Table 25.

7) **Differential decoding:** is defined as out(n) = (in(n) – in(n-1)) mod(# of NPV).

8) **Gray demapping:** a replica of the source data is restored by Gray demapping according to Table 26 and

9) Table 27.

Table 26 - Gray demapping for bit rates of 3*fc*/4 and 3*fc*/2

Output of Differential decoding	Data replica
000	000
001	001
010	011
011	010
100	110
101	111
110	101
111	100

Table 27 - Gray demapping for bit rates of *fc* and 2*fc*

Output of Differential decoding	Data replica
0000	0000
0001	0001
0010	0011
0011	0010
0100	0110
0101	0111
0110	0101
0111	0100
1000	1100
1001	1101
1010	1111
1011	1110
1100	1010
1101	1011
1110	1001
1111	1000

10) Unpadding: the unpadding step removes the ‘0’s added in the padding step.

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