TIA STANDARD

Project 25

Phase 2 Two-Slot Time Division Multiple Access Physical Layer Protocol Specification

TIA-102.BBAB **July 2009**

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Foreword

(This foreword is not part of this standard.)

This document has been published by the Telecommunications Industries Association (TIA) in accordance with the terms and conditions provided for in a Memorandum of Understanding (MoU) executed by and between the TIA, the Association of Public-Safety Officials (APCO), the National Association of State Telecommunications Directors (NASTD), and the various agencies of the Federal government (FED).

This TIA standard is being promulgated and will be maintained by the TR-8.12 (Two-Slot TDMA subcommittee) and working groups under the sponsorship of the Telecommunications Industry Association. This document has been published as a *TIA Standard* because it contains useful technical information on emerging digital techniques for Land Mobile Radio Service.

The P25 Two-Slot TDMA Standard, which includes definition of the P25 two-slot TDMA common air interface, is being developed by the APIC TDMA Task Group and TIA TR-8.12 to be consistent with the APCO Project 25 Statement of Requirements adopted by the Project 25 Steering Committee. This standard uses the APCO Project 25 Statement of Requirements dated October 17, 2008 as input guidance to capture the relevant user needs requirements.

This physical layer protocol specification provides a standard for the definition and control of the transmission of digital information utilizing a two-slot TDMA modulation format within a 12.5 kHz bandwidth physical radio channel.

The TIA makes no claims as to the applicability of the information contained in this document for any purpose although it is believed that the information will prove to be invaluable to implementers and operators of P25 two-slot TDMA equipment. Some aspects of the specifications contained in this document may not have been fully operationally tested; however, a great deal of time and good faith effort has been invested in the preparation of this document to ensure the accuracy of the information it contains. While all reasonable efforts have been made to ensure the accuracy of this document, it should be understood that significant work remains to fully develop the standard series and this document will be updated as necessary.

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1. Introduction

This standard specifies the physical layer protocol for the definition and control of the transmission of digital information using a two-slot Time Division Multiple Access (two-slot TDMA) modulation format within a 12.5 kHz bandwidth physical radio channel. As described below, this standard is included in the suite of Project 25 (P25) standards that defines the P25 Phase 2 Two-Slot TDMA Standard.

Specifically, this standard defines the physical layer, or Open Systems Interconnection (OSI) Layer 1, protocol including the modulation scheme used for the P25 Two-Slot TDMA Common Air Interface (CAI). The P25 Two-Slot TDMA CAI, designated U_{m2}, is the P25-defined interface between P25 fixed/base station equipment and P25 radios (i.e., P25 subscriber units (SUs)) as shown in Figure 1 and described further below.

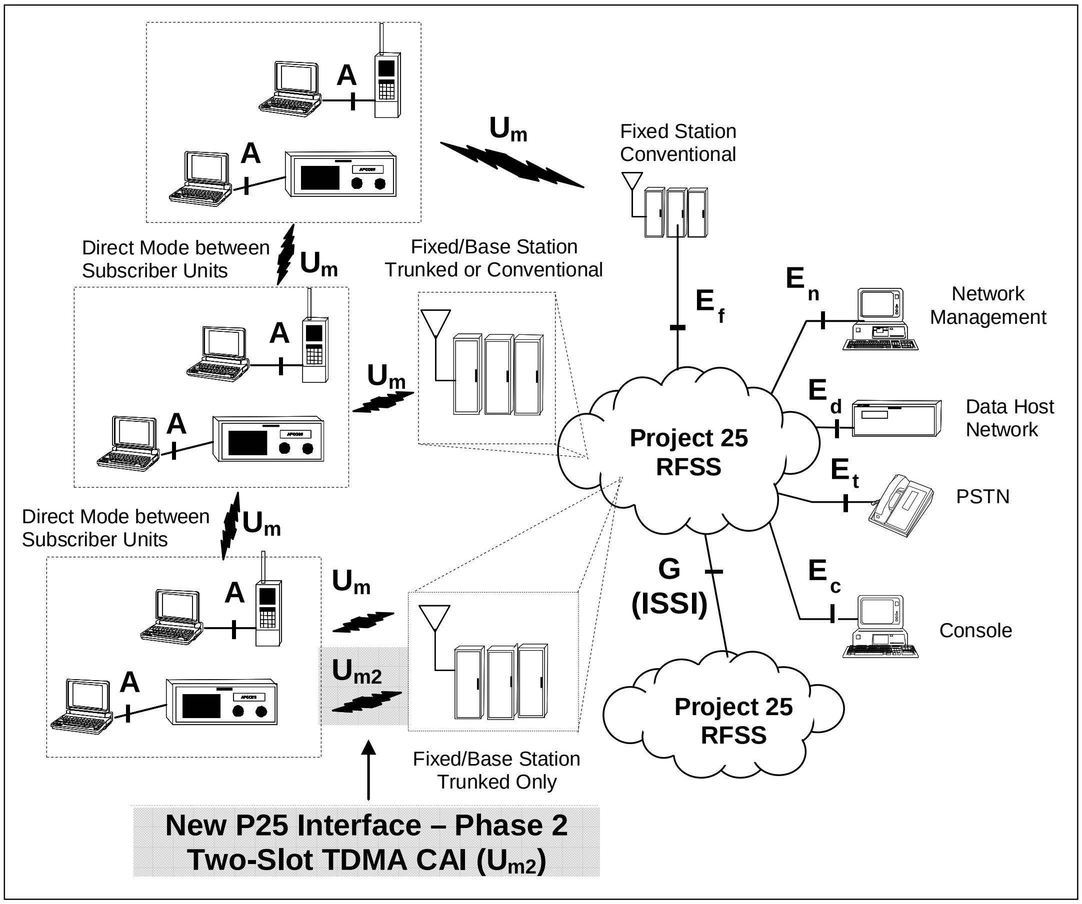

Figure 1 Representative P25 Phase 2 System Model Illustrating Support of the New Phase 2 Two-Slot TDMA CAI (U_{m2}) and the Phase 1 12.5 kHz FDMA CAI (U_m)

This document is organized as follows. Clause 1 introduces the standard. Clause 2 describes the scope of the standard and provides supporting information (i.e., overview, revision history, references, and glossary). Clauses 3, 4, and 5 specify, respectively, the transmission format, modulation scheme, and structure of the different types of bursts for the P25 Two-Slot TDMA Physical Layer CAI Protocol Specification defined by the standard. An informative annex provides information on H-D8PSK modulation.

2. Scope

The scope of the P25 Phase 2 Two-Slot TDMA Standard, which includes this standard (see [3]), has been established taking into account the P25 Phase 2 6.25 kHz CAI requirements defined in [4]. In this regard, the P25 Phase 2 Two-Slot TDMA Standard defines an additional type of P25 CAI interface, the Phase 2 Two-Slot TDMA CAI, which is shown as U_{m2} in Figure 1. (See [3] and [4] for background information concerning the Phase 1 and Phase 2 P25 interfaces shown in Figure 1.) The U_{m2} interface is the P25-standardized CAI that supports P25 trunked voice and data service between P25 fixed/base station equipment provided as part of a trunked P25 Radio-Frequency Subsystem (RFSS) and P25 Subscriber Units (SUs) implementing the P25 Two-Slot TDMA Standard. The OSI Layers 1, 2, and 3 are the specified scope of the standardization of the U_{m2} interface. This standard defines OSI Layer 1 for the U_{m2} interface.

This standard has been developed taking into account that SUs implementing the P25 Phase 1 Standard (using the P25 Phase 1 CAI, U_m, shown in Figure 1) for trunked voice and data service be supported by P25 RFSSs that implement the P25 Phase 2 Two-Slot Standard (using the P25 Phase 2 Two-Slot TDMA CAI). This is a key P25 system requirement for the P25 Two-Slot TDMA Standard (see [3] and [4]) that enables:

- System interoperability among multiple manufacturers’ P25 Phase 1 and Phase 2 equipment.

- Operational migration from a P25 Phase 1 12.5 kHz FDMA CAI-based system to a P25 Phase 2 Two-Slot TDMA CAI-based system.

- SU roaming for trunked voice services within and among P25 Phase 1 and P25 Phase 2 systems according to network operator requirements.

This standard has also been developed taking into account that implementation of the P25 Phase 2 Two-Slot TDMA Standard supports use of the P25 dual-rate vocoder. In particular, this standard has been developed to support use of the P25 half-rate vocoder (see [1] and [3]).

2.1 Overview

The function of the P25 two-slot TDMA CAI physical layer is to convey information through the physical radio channel while contending with various channel impairments such as noise, interference, multi-path, fading, and delay distortion. The definition of the two-slot TDMA CAI physical layer protocol involves specification of:

- Transmission formats
- Modulation
- Pulsed transmission ramp-up and ramp-down
- Burst structure.

This standard specifies Harmonized-Continuous Phase Modulation (H-CPM), which is used for the uplink, and Harmonized-Differential Quadrature Phase Shift Keyed Modulation (H-DQPSK), which is used for the downlink. H-CPM allows for the continued use of non-linear amplifiers in subscriber equipment. H-DQPSK is used in base stations and requires linear amplifiers.

2.2 Revision History

Version	Date	Description
ISSUE 1.0	9/3/08	Initial draft of Two-Slot TDMA harmonized PHY introduced into TR8.12.
ISSUE 1.1	10/1/08	Second draft of Two-Slot TDMA harmonized PHY introduced into TR8.12 moving H-D8PSK to informational annex.
ISSUE 1.2	10/15/08	Third draft of Two-Slot TDMA harmonized PHY introduced into TR8.12 with some editorial corrections.
ISSUE 1.3	12/15/08	Fourth draft of Two-Slot TDMA harmonized PHY introduced into TR8.12 with a new Figure 1, some editorial changes, a revised normalization constant and a patent identification page.
ISSUE 1.4	4/2/09	Fifth draft of Two-Slot TDMA harmonized PHY with changes to resolve editorial letter ballot comments.

2.3 References

The following documents contain provisions that, through reference in this text, constitute provisions of this document. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this document are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. American National Standards Institute (ANSI) and TIA maintain registers of currently valid national standards published by them.

2.3.1 Normative references

[1] PN-3-3633-AD1 Draft TIA-102.BABA-1 (Project 25 – Half Rate Vocoder Addendum)

[2] PN-3-0380 Draft TIA-102.BBAC (Project 25 – Two-Slot TDMA MAC Layer Protocol Specification)

2.3.2 Informative references

[3] PN-3-0349 Draft TSB-102.BBAA (Project 25 – Two-Slot TDMA Standard Overview)

[4] APCO P25 Statement of Requirements, October 17, 2008

2.4 Glossary

2.4.1 Acronyms and abbreviations

APCO	Association of Public-Safety Communications Officials, International
CAI	Common Air Interface
CPM	Continuous Phase Modulation
DQPSK	Differential Quadrature Phase Shift Keyed
H-CPM	Harmonized-Continuous Phase Modulation
H-DQPSK	Harmonized-Differential Quadrature Phase Shift Keyed
IQ	In phase Quadrature phase
ISCH	Interslot Signaling Channel
kbps	Kilo Bits Per Second
LLR	Log-Likelihood Ratio
MAC	Media Access Control
MLSE	Maximum Likelihood Sequence Estimator
MSB	Most Significant Bit
OSI	Open Systems Interconnection
P25	Project 25
PAR	Peak to Average Ratio
PDU	Protocol Data Unit
PSTN	Public Switched Telephone Network
RFSS	Radio Frequency Subsystem
SU	Subscriber Unit
TDMA	Time Division Multiple Access
U_m	Air Interface reference point
U_{m2}	Air Interface reference point for Project 25 Phase 2 Two-Slot TDMA

3. Two-Slot TDMA Transmission Format

The two-slot TDMA transmission format for inbound H-CPM and outbound H-DQPSK emission is the same except for the first and last 10 symbols (6 symbols of ramp-guard and 4 symbols of pilot) of a burst:

– Inbound: ramp up and ramp down periods as shown in Figure 2.

– Outbound: an Interslot Signaling Channel (ISCH) logical channel is emitted at the beginning and end of a burst (i.e., the ISCH occurs at the equivalent location in the ‘outbound’ burst as the ramp, guard and pilot portions for the ‘inbound’ direction). This is shown in Figure 2.

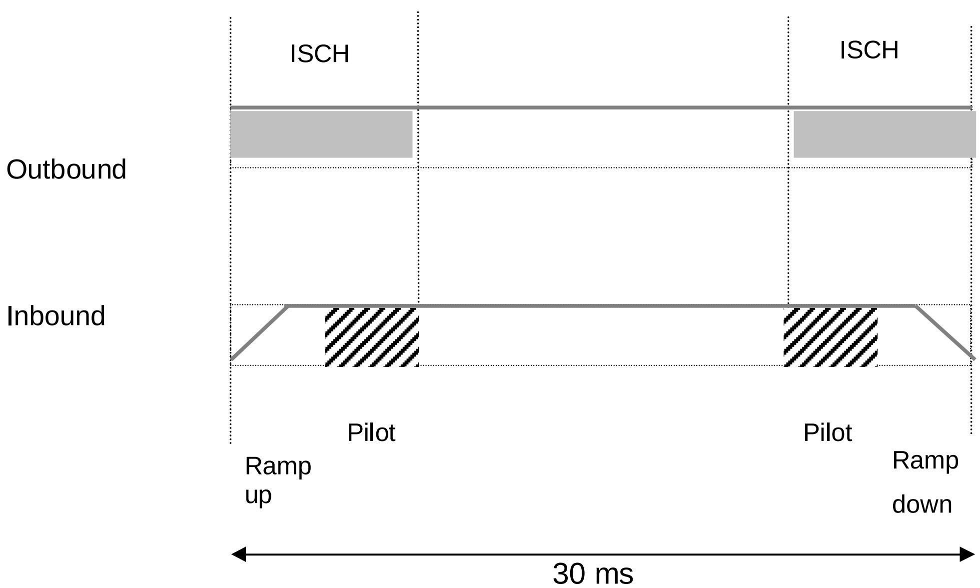

Figure 2 Inbound and Outbound 30 ms Slot

Moreover,

– The outbound emission is never bursty and a replacement burst defined in [2] is transmitted in the other TDMA slot when only one TDMA slot is used.

– The inbound emission is always in two-slot TDMA mode.

Figure 3 shows the two-slot TDMA aspect from inbound point of view (two SUs). Two communications can be transmitted on the same radio channel by multiplexing time between two users. The outbound corresponds to downlink where both communications appears on the same radio channel without discontinuity. The purpose of transmitting downlink MAC Idle PDUs when only one TDMA channel is used, is to ensure the SUs can always “hear” the downlink and associated control channels (i.e., the ISCH).

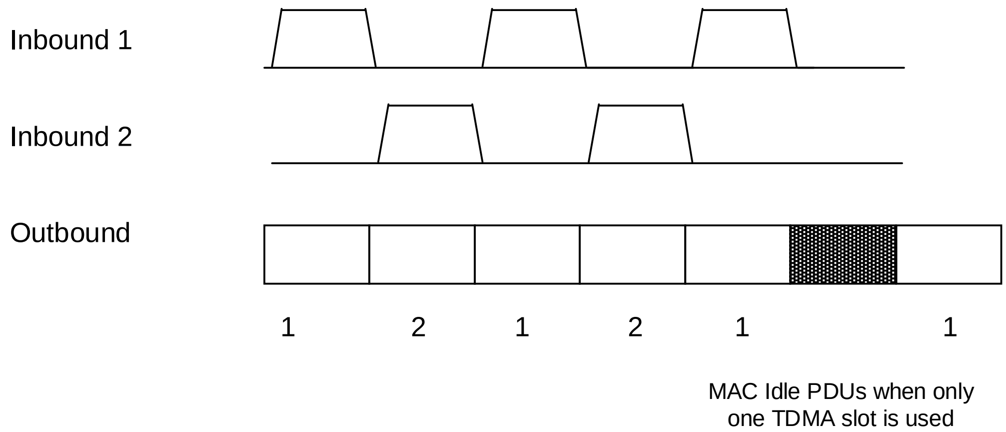

Figure 3 Example of Inbound and Outbound Transmission

4. Two-Slot TDMA Modulation

The uplink modulation operates at 12 kbps with a quaternary modulation derived from continuous phase modulation (CPM).

The core downlink modulation operates at 12 kbps with a quaternary modulation derived from π/4-DQPSK.

Both modulations use the quaternary alphabet: M=4, $I \in \{\pm 1, \pm 3\}$ with a symbol rate = 6000 symbols/sec.

The bits are mapped to symbols as shown in Table 1.

Table 1 Bit to Symbol mapping for H-CPM and H-DQPSK modulation

Input bits to modulation [b1 b0]		Quaternary Symbol
[0 1]	$\rightarrow$	+ 3
[0 0]	$\rightarrow$	+1
[1 0]	$\rightarrow$	-1
[1 1]	$\rightarrow$	- 3

The convention is that the first bit in the frame is the MSB.

4.1 H-CPM Uplink Modulation

The uplink modulation is a form of CPM operating at 12 kbps, defined in this standard as harmonized-continuous phase modulation (H-CPM). H-CPM is distinguished from normal CPM by the specific modulation parameters λ, h, and L.

Two conceptual methods for generating CPM are shown in Figure 4 where g(t) is the frequency pulse filter, q(t) is the phase pulse filter, both defined in equation (3), and $\phi(t, \mathbf{I})$ is the phase signal which carries the information defined in equation (2).

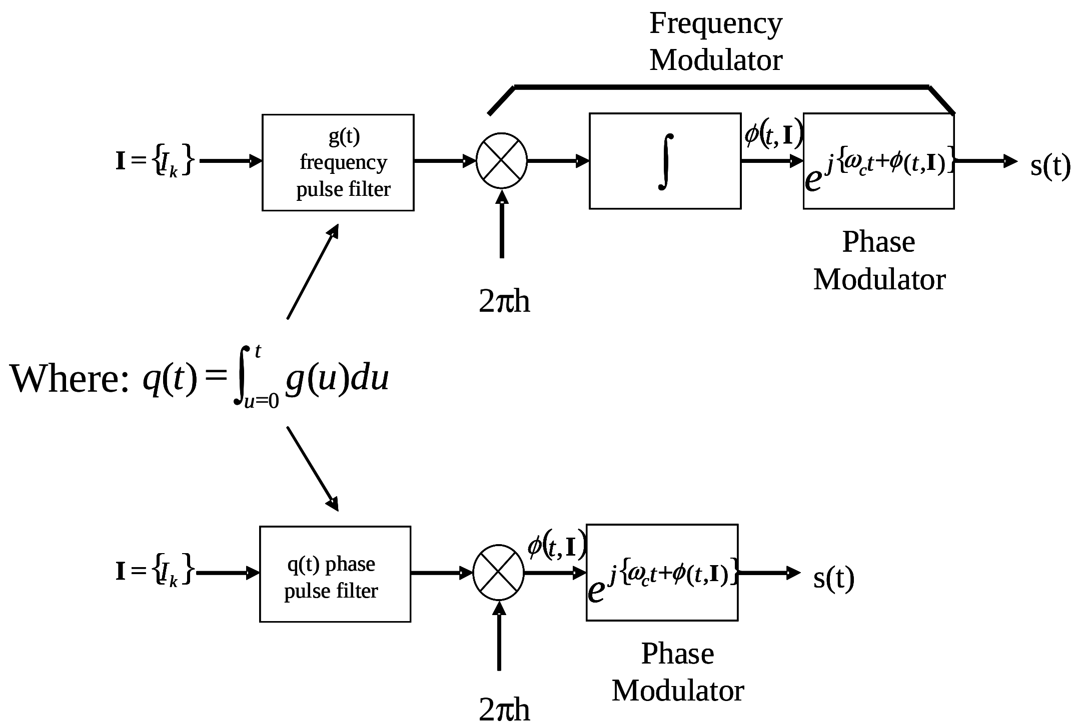

Figure 4 Two Conceptual Methods for Generating CPM

4.1.1 General formula for CPM

The general formula for CPM, at baseband, is the following:

$$s\,(t) = \sqrt{\frac{E_S}{T}}\exp\left(j\phi(t,\mathbf{I})\right) \qquad (1)$$

Where:

E_S =energy of a modulation symbol

T=symbol period.

The phase signal $\phi(t,\mathbf{I})$ carries the information (the sequence of data symbols occurring up to time t, $\mathbf{I}=\{I_k\}$) and is obtained as follows (with k as the index of the summation and n being the final value to sum over in equation (2)).

$$\phi(t,\mathbf{I}) = 2\pi h\sum_{k\le n} I_k q(t-kT) \qquad \mathrm{nT} < \mathrm{t} \le (\mathrm{n}+1)\mathrm{T} \qquad (2)$$

Where:

h = modulation index

q(t) = phase smoothing response of H-CPM, which satisfies:

$$q(t) = \begin{cases} 0 & \text{for } t < 0 \\ 1/2 & \text{for } t > LT \end{cases}$$

L = pulse response length in symbols.

Complete definition of the phase pulse for H-CPM, q(t), over the full range from t=0 to LT is given in the next section.

4.1.2 Characteristics of H-CPM modulation

H-CPM modulation has a phase pulse, q(t), defined by integrating the frequency pulse, g(t), as shown in equation (3).

$$q(t) = \int_0^t g(u)du, \text{ with}$$

$$g(t) = \begin{cases} \frac{1}{G}\left\{\text{sinc}\left[\frac{\lambda}{T}\left(t - \frac{LT}{2}\right)\right]\cos^2\left[\frac{\pi}{LT}\left(t - \frac{LT}{2}\right)\right]\right\} & t \in [0, LT] \\ 0 & elsewhere \end{cases} \tag{3}$$

Where: *sinc(t)=sin (πt)/(πt).*

H-CPM shall use the modulation parameters of λ=.75, h=1/3 and L=4.

Note: G is a normalization factor (G=4.3455e-4 for a symbol rate=6000 symbols/sec) such that:

q(t) = 1/2 for $t \geq LT$.

The frequency and phase pulses of H-CPM are normalized waveform shapes and are shown in the upper section of Figure 5. The bottom portion of Figure 5 shows the phase pulse for each symbol, I_k.

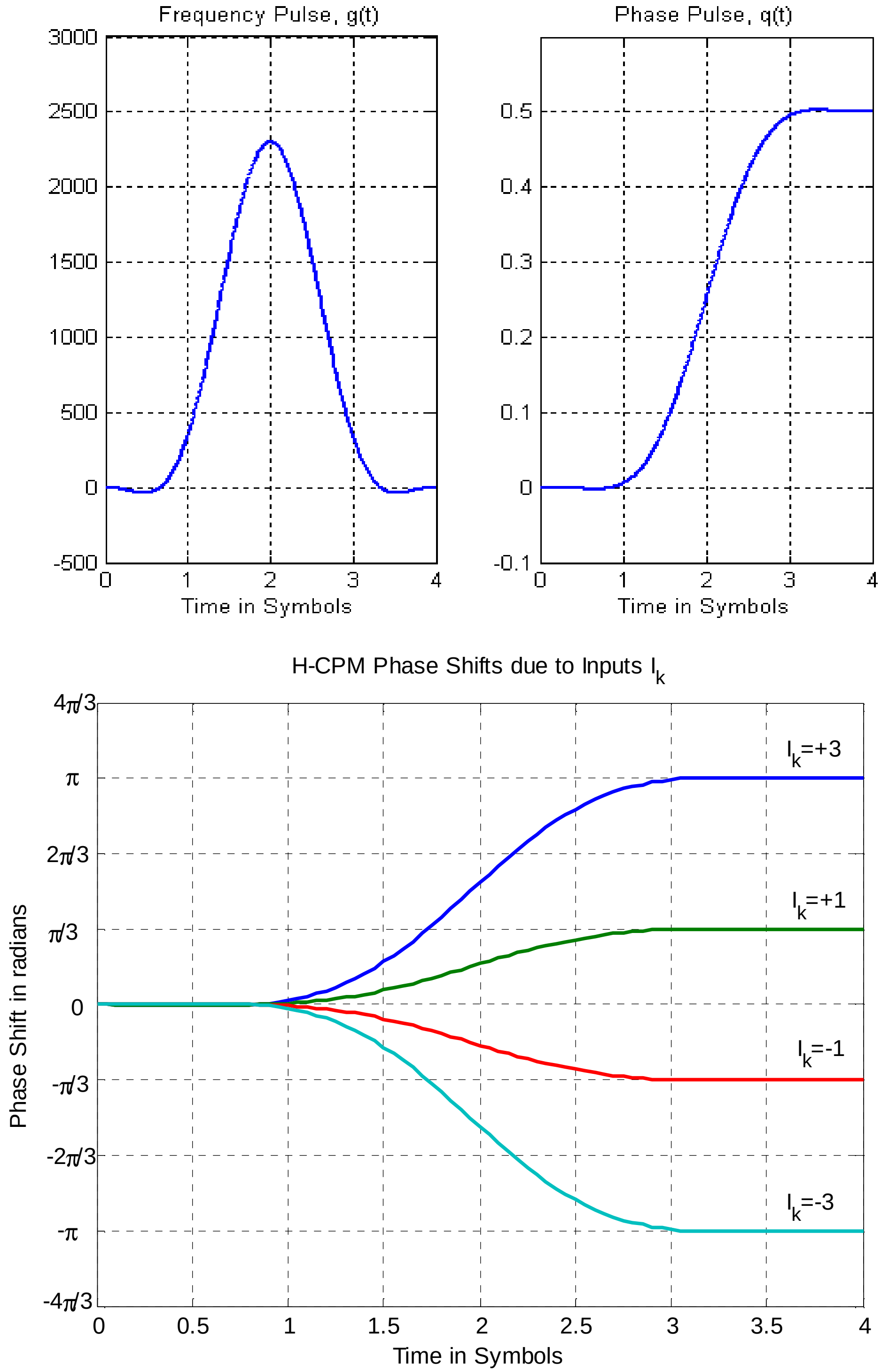

Figure 5 Frequency and Phase Pulses for H-CPM

4.1.3 H-CPM demodulation

A method for demodulating H-CPM using a maximum likelihood sequence estimator (MLSE) is shown below in Figure 6 where *r(t)* is the received signal, ***r**(t)* is a vector of samples of the received signal over a symbol period, $c_k(t)$ is the channel estimate for state k and $\boldsymbol{M}_k(t)$ is the matched filter for state k. The matched filters to use in the demodulator for creating the branch metrics are derived from the parameters of H-CPM modulation. Note that a state as depicted in Figure 6 is expressed as a combination of the phase state, θ_n, obtained from the history of symbols up to n-L and the correlative state, obtained from the symbols from n-L+1 up to n-1 (i.e., $\sigma_n=\{\theta_n, I_{n-1},\ldots,I_{n-L+1}\}$).

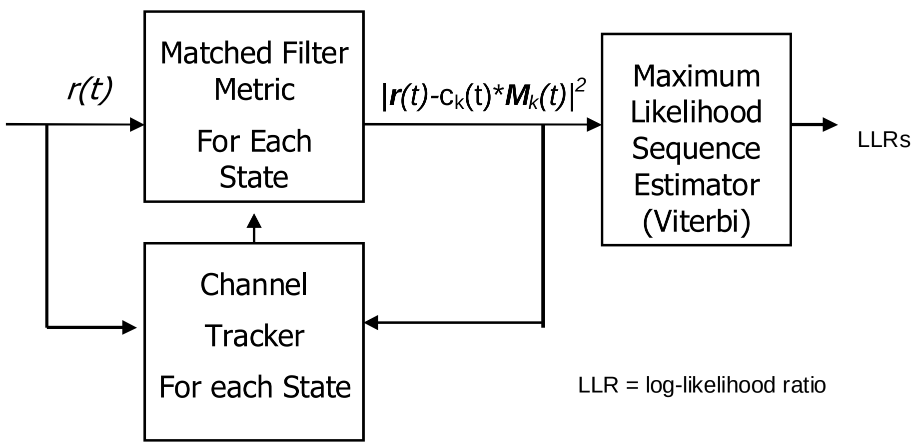

Figure 6 MLSE Demodulator for H-CPM

The soft information, log-likelihood ratios (LLRs), that is calculated in the demodulator is used by the error correction and detection algorithms for estimating the most likely bit sequence from the received set of data.

The particular method to generate the LLR values is dependent on the technology used for demodulation but should provide information on a bit–by-bit basis as to the likelihood of the bit being a 1 or 0 with the magnitude providing a confidence measure for the information provided by the demodulator.

4.2 H-DQPSK Downlink Modulation

The downlink modulation is a form of $\pi/4$ differential quadrature phase shift keyed modulation (DQPSK) operating at 12 kbps. Harmonized-DQPSK is distinguished from normal $\pi/4$ DQPSK by application of an IQ filter, h(t), defined below.

A conceptual block diagram of $\pi/4$ DQPSK modulation is shown in Figure 7 for input symbols $I \in \{\pm 1, \pm 3\}$.

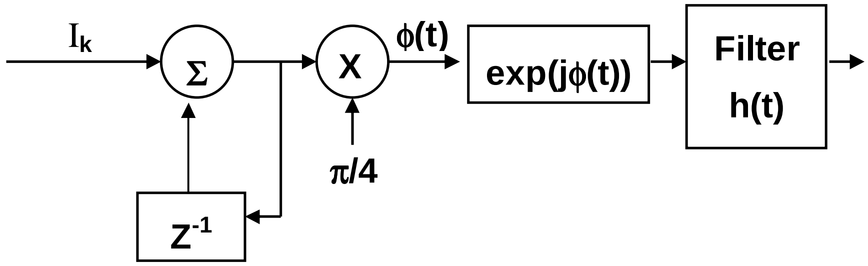

Figure 7 Conceptual π/4 DQPSK Modulation Block Diagram

4.2.1 General formula for H-DQPSK

The general formula for H-DQPSK modulation, at baseband, is the following:

$$s(t) = \int \sqrt{\frac{E_s}{T}} \exp\left(j\phi(\tau, \mathbf{I})\right) h(t-\tau)\, d\tau \tag{4}$$

Where:

$$\phi(t, \mathbf{I}) = \pi / 4 \sum_{k \le n} I_k \qquad \mathrm{t} \le \mathrm{n} \tag{5}$$

and

E_s= energy of a modulation symbol

T= symbol period.

The filter h(t), which band-limits the IQ data, may use a raised cosine frequency response (α=1) with a magnitude response that is 6 dB down at the one-sided BW of 3.6 kHz as given in equation (6).

$$\begin{aligned} &H(f)=(1+\cos(\pi f/f_h))/2 && \text{for } 0 \le f < f_h \\ &H(f)=0 && \text{for } f \ge f_h \\ &\text{Where: } f_h=2{*}BW \\ &BW=3.6\ \text{kHz} \end{aligned} \tag{6}$$

4.2.2 H-DQPSK demodulation

A method for demodulating π/4 DQPSK using differential phase detection is shown below in Figure 8.

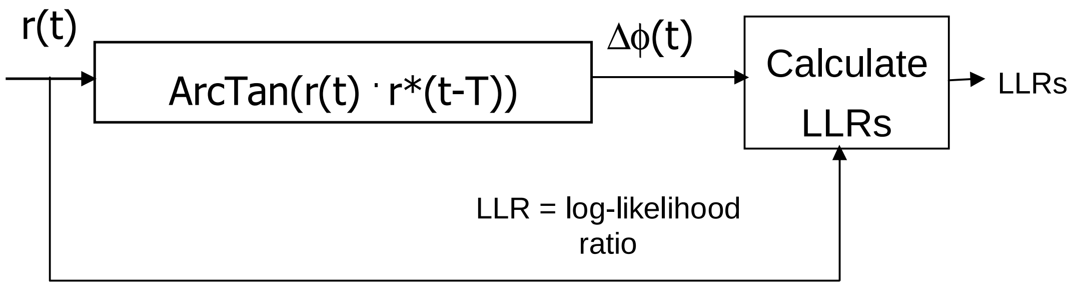

Figure 8 Demodulator for H-DQPSK

The soft information (log-likelihood ratios, LLRs) that is calculated in the demodulator is used by the error correction and detection algorithms for generating the most likely bit sequence from the received set of data.

The particular method to generate the LLR values is dependent on the technology used for demodulation but should provide information on a bit-by-bit basis as to the likelihood of the bit being a 1 or 0 with the magnitude providing a confidence measure for the information provided by the demodulator.

4.3 Ramping

For inbound bursts, a total of 2 ms of time is reserved as "Guard" time to allow for power ramping and propagation delay protection. The modulation burst is centered in the 30 ms time slot, with 1 ms of the "Guard" time at the beginning of the burst and 1 ms at the end of the burst as shown in Figure 9.

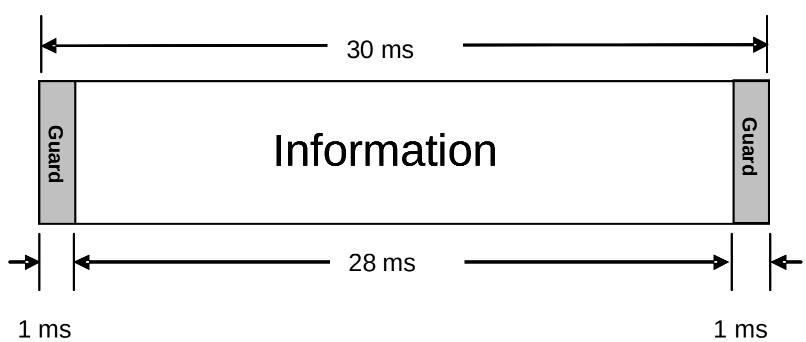

Figure 9 Inbound Burst Guard Time Allocation

Of the 2 ms of "Guard" time, a minimum of 0.8 ms shall be allocated for propagation delay protection while the remaining time up to 1.2 ms shall be allocated for power ramp up and ramp down. Note that overlapping of the ramps is allowed as long as the portion of the waveform containing useful information located in the center portion of Figure 9 (including data, synchronization and pilot sequences) remains unaffected.

Figure 10 shows the case where the ramps, which are shown generically in the figure as linear ramps, are set to 1.2 ms, the maximum allowed by the standard. Note that the full extent of the transmitted burst in this case is actually slightly longer than the 30 ms slot length.

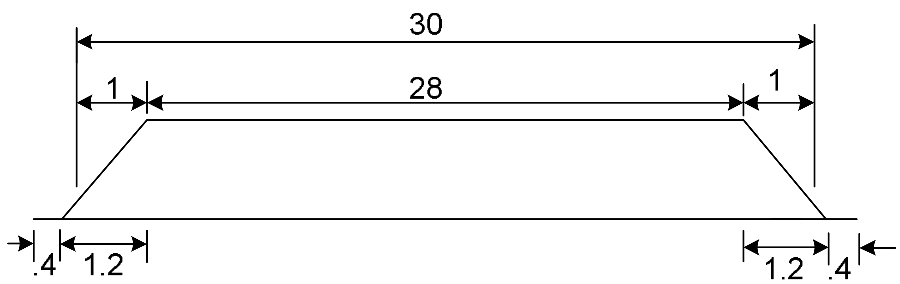

Figure 10 Burst with 1.2 ms Ramps (Times in ms)

Figure 11 shows the overlap for two successive bursts as would be seen at the base station receive antenna if the two transmitting SU radios were at the same distance from the base station antenna.

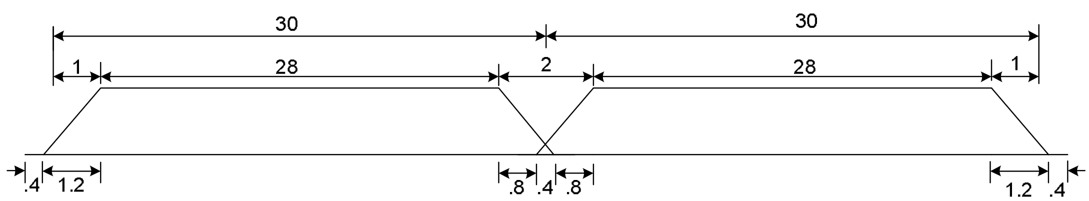

Figure 11 Successive Bursts with 1.2 ms Ramps with no Propagation Delay (Times in ms)

As can be seen from the Figure 11, there is only a small overlap of 0.4 ms between the two successive bursts for this ramp length, and this overlap does not affect the information which is transmitted in the center 28 ms of the bursts.

Figure 12 shows the amount of overlap when the maximum amount of propagation delay is inserted into the first burst while no delay is present in the second burst. This is the expected timing for the scenario where the SU transmitting the first burst is at maximum distance from the base station antenna while the SU transmitting the second burst is essentially in the same location as the base station antenna.

Overlapping of the ramps more than the amount illustrated in Figure 12 due to a very near SU and a very far SU on the same frequency channel will start to affect the useful information in the adjacent slot and is therefore undesirable.

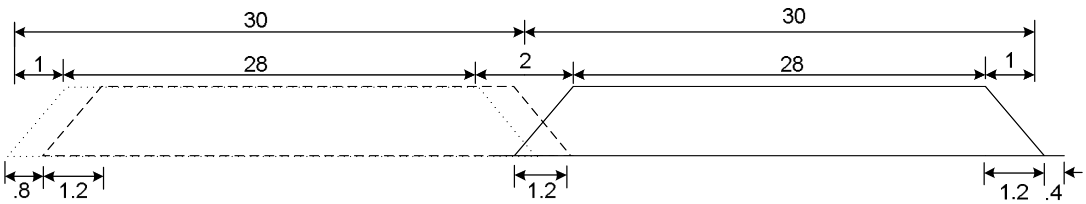

Figure 12 Successive Bursts with 1.2 ms Ramps with 0.8 ms of Propagation Delay (Times in ms)

In Figure 12, the burst shown with dotted lines indicates the non-delayed position of the burst while the dashed line shows the burst delayed by 0.8 ms. From this figure it can be seen that even with this amount of delay added to the first burst that the ramp reaches zero before the useful information in the second burst begins, which is located in the center 28 ms of the second burst.

5. Two-Slot TDMA Burst Structure

In all the burst structures described below, timing refers to the beginning of the radio slot, and each part of the burst contains an integer number of symbol durations (i.e., an integer multiple of 166.67 μs).

5.1 Normal Burst

This type of burst will be used for voice, data and signaling information.

The duration of the burst is 30 ms, which corresponds to 360 bits for a transmission rate of 12 kbps, or 180 quaternary symbols.

5.1.1 Outbound format

For the outbound, ISCH sequences are inserted between two contiguous bursts as shown in Table 2.

Table 2 Bit/symbol structure of the Normal Burst (outbound format)

1.67ms	*26.67ms*	*1.67ms*
20 bits / 10 symbols	**320 bits/ 160 symbols**	**20 bits/ 10 symbols**
ISCH	*information*	*ISCH*

5.1.2 Inbound format

The symbols corresponding to INTERSLOT_FILL1 and INTERSLOT_FILL2 fields are shown in for illustrative purposes. The formal definitions of these fields are given in 5.1.2.1. Pilot symbol sequences are defined in [2].

Table 3 Bit/symbol structure of the Normal Burst (inbound format)

1ms	*.67ms*	*26.67ms*	*.67ms*	*1ms*
INTERSLOT_FILL1	**PILOT_NB1**	**Information bits**	**PILOT_NB2**	**INTERSLOT_FILL2**
6 symbols	**4 symbols**	**320 bits /160 symbols**	**4 symbols**	**6 symbols**
0 0 0 0 0 0	*pilots*	*information*	*pilots*	*0 0 0 0 0 0*

5.1.2.1 Interslot Fill sequences

The Interslot Fill sequences specify the value of the symbols being presented to the modulator during the time period allocated to the ramp up, ramp down and propagation guard. These sequences are not modulated; a zero value is attributed to these sequences.

The following specifies the Interslot Fill sequences with signed symbols notation:

INTERSLOT_FILL1 = 0 0 0 0 0 0

INTERSLOT_FILL2 = 0 0 0 0 0 0.

Annex A H-D8PSK Modulation (Informative)

A.1 H-D8PSK Downlink Modulation

A standard modulation protocol option for increased simulcast performance on the downlink is a form of π/8 differential phase shift keyed modulation (D8PSK) operating at 12 kbps with a symbol rate of 4000 symbols/sec. Harmonized-D8PSK is distinguished from normal π/8 D8PSK by application of an IQ filter, h(t), defined below.

The mapping of bits to symbols for H-D8PSK is shown below in Table A.1.

Table A.1 Bit to Symbol mapping for H-D8PSK modulation

Input bits to modulation [b2 b1 b0]		Quaternary Symbol
[0 1 0]	→	+7
[0 1 1]	→	+5
[0 0 1]	→	+3
[0 0 0]	→	+1
[1 0 0]	→	-1
[1 0 1]	→	-3
[1 1 1]	→	-5
[1 1 0]	→	-7

A conceptual block diagram of π/8 D8PSK Modulation is shown in Figure A.1 below for input symbols $I \in \{\pm 1, \pm 3, \pm 5, \pm 7\}$.

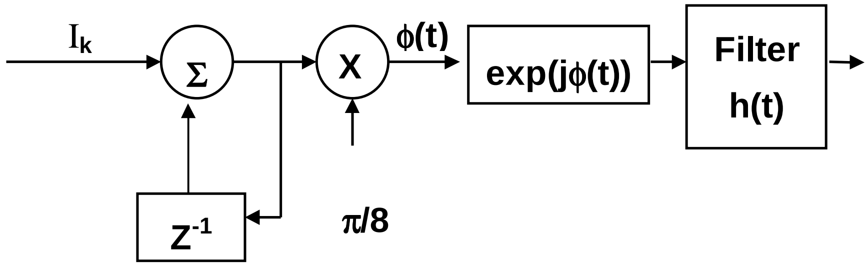

Figure A.1 Conceptual π/8 D8PSK Modulation Block Diagram

A.1.1 General formula for H-D8PSK

The general formula for H-D8PSK modulation, at baseband, is the following:

$$s(t) = \int \sqrt{\frac{E_s}{T}} \exp\left(j\phi(\tau, \mathbf{I})\right) h(t-\tau) d\tau \qquad (7)$$

Where:

$$\phi(t, \mathbf{I}) = \pi / 8 \sum_{k \le n} I_k \qquad t \le n \qquad (8)$$

and

E_s= energy of a modulation symbol

T= symbol period.

The filter h(t), which band-limits the IQ data, may use a raised cosine frequency response (α=1) with a magnitude response that is 6 dB down at the one-sided BW of 3.6 kHz. A BW of 2.5 kHz as given in equation (9) may be used so that the peak to average ratio (PAR) of the H-D8PSK modulation is approximately 2.5 dB, which matches that of H-DQPSK.

$H(f)=(1+\cos(\pi f/f_h))/2$ for $0 \le f < f_h$

$H(f)=0$ for $f \ge f_h$

Where: $f_h=2*BW$

BW=2.5 kHz (9)

A.1.2 H-D8PSK Demodulation

A method for demodulating π/8 D8PSK using differential phase detection is shown below in Figure A.2.

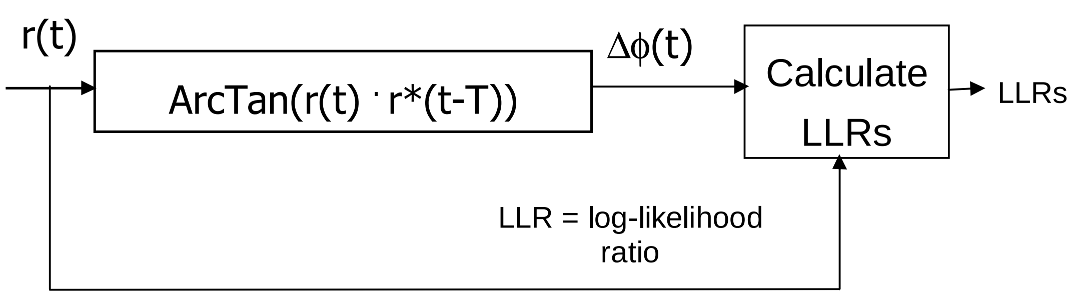

Figure A.2 Demodulator for H-D8PSK

The soft information (log-likelihood ratios, LLRs) that is calculated in the demodulator is used by the error correction and detection algorithms for generating the most likely bit sequence from the received set of data.

The particular method to generate the LLR values is dependent on the technology used for demodulation but should provide information on a bit-by-bit basis as to the likelihood of the bit being a 1 or 0 with the magnitude providing a confidence measure for the information provided by the demodulator.

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