AN/2WR/HSC-XTCSS/2 March 2003

1 Introduction

The Hexadecimal Sequential Code (HSC) is a coding format for sequential tone signalling systems. HSC permits address codes, instruction codes and data blocks to be exchanged on an unrestricted basis between all units in a network, thus providing the key to the design of fully integrated base/mobile/personal communications schemes. HSC is also compatible with the frequencies and protocols used for international '5-tone' selective call (SelCall).

This document describes the coding rules and tone parameters for HSC, from which a 'closed code' protocol is used. This protocol specifies that each sequence of information characters is preceded and terminated by a 'boundary' character. A boundary character may be 'notones', representing the beginning or end of a code sequence of a flag character, denoting the partition between information of one class (address) and information of another class (data or instructions).

HSC allows data and addresses to be signalled without cross-aliasing, different length addresses to be used in a common network, and confers virtual immunity to noise or voice falsing of addresses.

XTCSS is an additional control feature, which could be supported on any 2-Way Radio System, so long as it supports HSC. Any device from any vendor can support XTCSS so long as it supports HSC.

The HSC and XTCSS feature can be implemented in the following CML devices:

CML Device	HSC Capable	XTCSS Feature
CMX803	Yes	Software Implementation
CMX823	Yes	Software Implementation
CMX828	Yes	Software Implementation
CMX881	Yes	Software Implementation
CMX882	Yes	Built in
CMX883	Yes	Built in

1.1 Contents

1.2 What is HSC and Where is it Used

HSC could be used in any radio data system where selective communication is required. Typical examples would be:

- Pagers
- Data communications to mobile units
- Vehicle tracking – via GPS data feedback

HSC is the coding system normally used for SELCALL. A number of audio tones are transmitted sequentially as a continuous group. These differing tones are easily detected by audio filters or by computer software.

A tone set comprises of several tones. This could also include an R (repeat) tone and a G (group) tone. The reason for the repeat tone is that the specification prohibits sending a continuous frequency for longer than a defined period. Therefore the code ‘12334’ is sent as ‘123R4’. The group tone is used so that a group of 10 or 100 (for example) devices could be called at the same time. All 100 devices/stations with the code 12300 to 12399 could be called by sending the code 123GR. The other tones can be used for a variety of uses, one of the most common being to mute or un-mute the receiver loudspeaker.

The last tone in the set is sometimes used for a status function according to the users predefined code. In a transport scenario, if the driver enters a relevant number into his radio, the base station controller can call the mobile unit and get a automatic update of the drivers status without using the radio channel for more than a couple of seconds. For example:

- ‘0’ – Driver not available
- ‘1’ – Driver travelling to pickup point
- ‘2’ – Parcel Picked up
- ‘3’ – Returning to base

There are several tone signalling systems used. The most common are “EEA”, “CCIR”, “ZVEI” and the “Modified ZVEI” systems. These systems define the actual frequency and period to be used for each digit. Summary details are given below.

2 HSC Coding

2.1 HSC General Description

The HSC format employs up to 17 tone frequencies to signal code characters drawn from the Hexadecimal (base 16) alpha numeric code table. Codes are transmitted as a sequence of single tones representing a series of alphanumeric characters. A sequence of characters may represent an address code, an un-addressed data block or an address code with data appended.

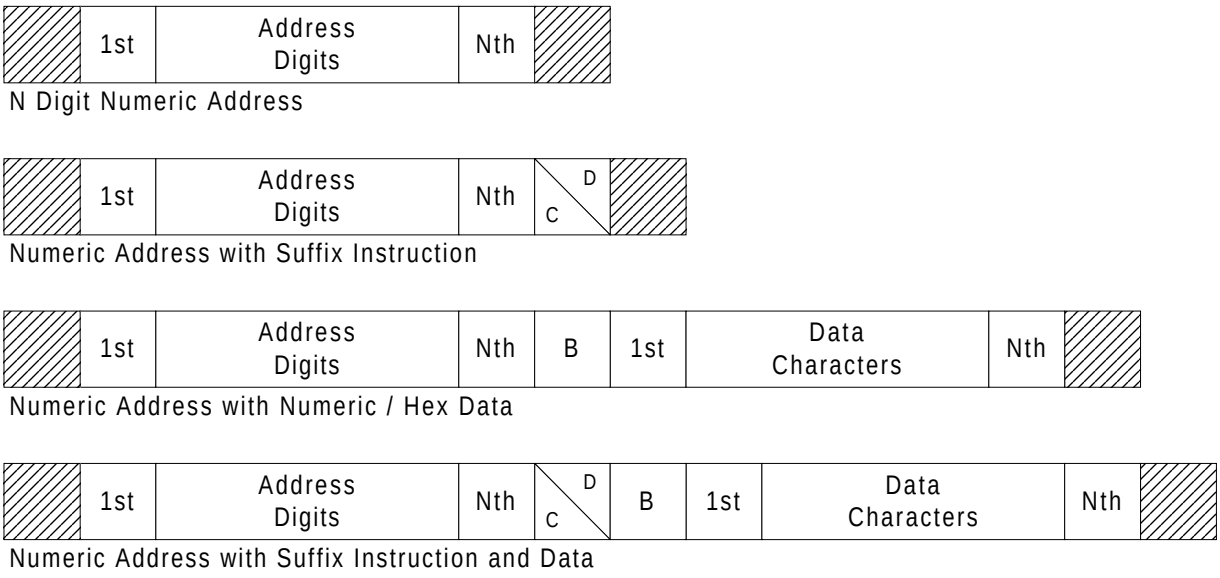

Figure 1 - HSC Coding Format

2.1.1 Code Formats

According to application requirements, the code format may be:

A) HEXADECIMAL TONE CODED (XTC) with a capacity of 16 information levels per character. This format employs the full character set 0 through to the 9 and A through to the F and is particularly suited to signalling applications based on 4 bit words and µP HEX code characters.

B) QUADRADECIMAL TONE CODED (QTC) with a capacity of 14 information levels per character. In this format, characters E and F are dedicated to signalling

protocols and have no information capability. QTC is optimised for selective calling applications and is compatible with the '5-tone' formats in current use. Through its efficient and secure coding structure, QTC allows high-level data coding to be easily added to existing selective call systems.

2.1.2 HSC Character Set

The ten numbers and six letters in the HSC character set are assigned to the following code functions:

Character	HSC Function
'0' through to the '9'	Decimal digit value. Used for numerical address codes and as a decimal value in data codes.
'A'	Address Group character. Represents all decimal values 0-9 when transmitted as an address code character. Has alphabetical value when used in a data sequence.
'B'	Data prefix character. Always the first character in any sequence forming a data code.
'C' and 'D'	Address code suffixes. Used for auxiliary functions when transmitted immediately following the last address digit. Invalid for inclusion in an address code. Have alphabetical values when used in data sequence.
'E' (QTC)	Repeat character. Represents 'same value' as preceding character in any code sequence. Invalid as first digit of an address code.
'E' (XTC)	Has alphabetical value when used in a data sequence. Invalid for inclusion in an address code.
'F' (QTC)	NOTONE character. In signal terms it represents 'no transmission' or invalid tone frequencies.
'F' (XTC)	Has alphabetical value when used in a data sequence. Invalid for inclusion in an address code.
$\overline{\text{CHAR.}}$ (XTC)	NOTONE flag. Represents absence of all format characters. In signal terms it represents 'no transmission' or invalid tone frequencies.

2.2 Character Tone Table

Format characters		Binary	Tone Frequency (Hz)			
XTC	**QTC**	**Code**	**CCIR**	**EEA**	**ZVEI**	**EIA**
0	0	0000	1981	1981	2400	600
1	1	0001	1124	1124	1060	741
2	2	0010	1197	1197	1160	822
3	3	0011	1275	1275	1270	1023
4	4	0110	1358	1358	1400	1164
5	5	0101	1446	1446	1530	1305
6	6	0110	1540	1540	1670	1446
7	7	0111	1640	1640	1830	1587
8	8	1000	1747	1747	2000	1728
9	9	1001	1860	1860	2200	1869
A	A	1010	2400	1055	2800	2151
B	B	1011	930	930	810	2433
C	C	1100	2247	2247	970	2010
D	D	1101	991	991	886	2292
E		1110	873	873	740	N/A (4)
F		1111	1055	2400	680	N/A
	E	1110	2110	2110	2600	459
(2) X		N/A	2110	2110	2600	N/A
	F	1111	NOTONE	NOTONE	NOTONE	NOTONE
(3) CHAR	(1)	FLAG	NOTONE	NOTONE	NOTONE	N/A

Notes

1. No equivalent code character exists for the format.
2. X is not a character; it is a transmission coding function relating to consecutive identical characters encoded. The preceding character is invalid.
3. CHAR. is equivalent to all characters absent, e.g. tri-state 'open' or similar flag condition.
4. XTC format is not accommodated by the EIA tone set

Abreviations – SelCall Systems and Standards:	
EIA -	Electronics Industries Association - United States
ZVEI -	Zentralverband der Electrotechnischen Industrie - West Germany
CCIR -	Comite Consultatif International de Radio United Kingdom / Scandinavia / World Wide Marine Applications
EEA -	Electronic Engineering Association - United Kingdom

2.2.1 Tone Frequencies

The character tone frequencies given in the HSC Character Tone Table are based on the ZVEI, CCIR, EEA and EIA standards specified by various countries for '5-tone' selective calling.

These standards each specify ten frequencies, representing digits 0 through 9, and include an eleventh tone to signal a 'repeat' digit. A twelfth tone is sometimes specified for 'Group Call' and '2nd address' purposes. The HSC tone-sets include tones appropriate to each standard, together with the additional frequencies required for XTC/QTC operation. These additions are logical extensions of each national tone-set.

2.2.2 Frequency Tolerance

The frequency tolerance on each transmitted tone shall comply with limits specified for the national standard, which are:

ZVEI	-	f_c	± 1.5%
CCIR	-	f_c	± 8Hz
EEA	-	f_c	± 1%
EIA	-	f_c	± 0.1%

f_c = Centre Frequency

2.2.3 Tone Duration

The duration of each transmitted tone in a code sequence is specified by the national standard. These values are:

ZVEI	-	70ms	± 15ms
CCIR	-	100ms	± 10ms
EEA	-	40ms	± 4ms
EIA	-	33ms	+ 0.5 / -0ms

The tone periods specified for a national standard relate to normal address code transmissions. Longer tones, or modified tolerances, are sometimes employed for special purposes. The time frame for consecutive code elements is not material to HSC code security and tone periods of non-standard length may be transmitted where appropriate.

2.2.4 Tone Transmission

Tones are transmitted as individual single frequencies. Tones are transmitted sequentially, without inter-tone gaps, until the code sequence is complete. Where an inter-tone gap is unavoidable, the gap duration shall not exceed the maximum time permitted in the national specification or 15mS, whichever is less.

Each consecutive tone in a code transmission shall have a different frequency. Where a code contains identical consecutive characters the 'repeat' tone, frequency E or X, shall be substituted to ensure compliance with the rule. As an example, code 11122 shall be transmitted as code 1E12E or 1X12X depending on the format. Frequencies E(QTC) and X(XTC) are identical.

Consecutive code transmissions shall be separated by an interval during which no tones are transmitted. This interval shall not be less than the maximum tone decoder response time for NOTONE (character F or CHAR) or such longer interval as may be specified for a START condition (see HSC Decoding Rules).

Where transmissions are designed to be compatible with national '5-tone' protocols, the inter-code gap shall not be less than the maximum 'decoder reset time' specified for the standard, or such longer time, as the standard shall determine.

Values for maximum inter-tone gap and minimum inter-code gap specified for each national standard are:

	Max Intertone Gap	**Min Intercode Gap**
ZVEI	15ms	140ms
CCIR	7.5ms	290ms
EEA	4ms	100ms
EIA	NIL	33ms

2.2.5 Tone Decoder Characteristics

An HSC tone decoder shall decode single valid character tones from the HSC tone set. According to the format used (XTC/QTC) each valid character tone in the format set shall be decoded, regardless of the sequence in which tones are applied.

A valid character tone shall be one having a frequency falling within the maximum tone decode bandwidth specified for the tone set. A valid tone shall have a duration not less than the minimum tone period specified for the tone set.

An invalid tone shall be one having a frequency falling outside the maximum tone decode bandwidth specified for the tone set or, where a maximum decode bandwidth is not specified, having a frequency error equal to or greater than the 'not decode' bandwidth specified by the national standard.

The tone decode bandwidths applicable to each national standard are as follows:

	Tone Decoder Bandwidth	
	Min 'Decode' BW	**Max 'Not Decode' BW**
ZVEI	f'o ± 2%	f'o ± 4.5%
CCIR	f'o ± 1%	f'o ± 3%
EEA	f'o ± 1%	f'o ± 3%
EIA	f'o ± 16Hz	

The decoder shall decode an input condition in which no valid tone from the format tone set is present at the input, and where this condition has been continuously maintained for a maximum preceding interval of time. The qualifying time interval shall be grater than the maximum permissible inter-tone gap duration, but shall not exceed the minimum transmitted tone duration specified by the national standard.

2.3 HSC Transmission Encoding Rules - Address Codes

The addressing codes for encoding an HSC transmission are as follows:

- An address code transmission shall comprise N sequential tones, representing decimal number N digits in length. N may be any number suitable to the signalling system organisation.

- An address code transmission may be a unique numerical code, or a Group code representing a multiple number of numerical codes.

- Only numeric tones 0 through to the 9 shall be used in an address code, except in the case:
    - Tone E/X is used to signify a repeat digit in the case of codes containing identical consecutive digits. Tone E/X is invalid as the first digit of an address code.
    - Tone A is transmitted as a substitute address digit, representing all numeric values 0 through to the 9, in Group code transmissions.

- Tone A may be transmitted as a substitute address digit in one or more positions in an address code. Where tone A is substituted in two or more consecutive code positions, the repeat tone (E/X) shall be used to ensure transmission of consecutively different frequencies.

- Examples of address codes (N=5) are given below.
  Tone E signifies E or X according to the format used.

Numerical Addresses

Character Tones	**Address Code**
12345	12345 (unique address)
29E5E	29955 (unique address)

Group Addresses

Character Tones	**Address Code**	
1234A	10 addresses	(12340 - 12349)
1A345	10 addresses	(10345 - 19345)
1A3A5	100 addresses	1(1_9) 3 (0-9) 5
29AE5	100 addresses	(29005 - 29995)
AEAEA	All call	(00000 - 99999)

- A quiescent period, during which no transmission takes place, shall immediately precede transmission of the first digit in an address code. This period shall have a minimum duration Tq, where Tq is the maximum NOTONE decoder response time specified for the tone set, or such longer duration as the START condition for HSC address decoding may require (see HSC Decoding Rules).

- A quiescent period of minimum duration Tq shall immediately follow transmission of the Nth tone in an address code, except in the case:
  A) An Address Suffix digit immediately follows the Nth address digit
  B) The Data Prefix digit immediately follows the Nth address digit

2.4 Address Suffix Codes

The following rules apply to the address code suffix:

- An address code may have a suffix digit immediately following the Nth address digit. One or more consecutive suffix digits may be employed for extending address coding or other functional purposes.

- Only character tones C and D are valid as Address Suffix digits, except in the case:
  A) Tone E/X is used to signify a repeat digit in the case of identical consecutive suffix digits.
  B) Tone E/X is invalid as the first digit in an Address Suffix.

- A quiescent period (Tq) shall immediately follow transmission of the Nth Address Suffix digit, except in the case where the Data Prefix digit immediately follows the Nth Address Suffix digit.

2.5 Address Code Transmissions

Examples of valid address code transmissions are given below, and include examples of the use of Address Suffix and Data Prefix digits. The number of address digits has no significance in the example and may be any required value. Address codes of different lengths are valid for a common signalling system. The asterisk (*) denotes a quiescent transmission period in accordance with the rules.

Tone Transmission

123	3 digit address
12345	5 digit address
12345C	Address with Suffix Digit C
12345CDE	Address with Suffix Digit CDD (QTC format)
12345B - -	Address with Data Prefix (data not shown)

2.6 Data Codes

The Data Code rules apply as follows:

- A data code transmission shall comprise 1+N sequential tones, representing an 'N character' sequential code. N may be any required number.

- The first tone in any data transmission shall be tone B, representing a Data Prefix digit. It shall be valid for a data transmission to comprise tone B only (N=0).

- The 1st through to the Nth data tones may be any format characters transmitted in any required sequence, except that:
  A) In the case of the QTC format set, character F is invalid as a data character.
  B) Tone E/X shall be used to signify a repeat digit in the case of transmissions including identical consecutive characters.

- A quiescent period of minimum duration Tq shall immediately precede transmission of the Data Prefix tone, except in the case:
  A) A Nth address digit immediately precedes the Data Prefix digit, or
  B) A Nth Address Suffix digit immediately precedes the Data Prefix digit. A quiescent period of minimum duration Tq shall immediately follow transmission of the Nth data tone.
  C) Examples of the valid data code transmissions are given below:

Un-Addressed Transmission

Tone Transmission	**Data Code**
B123	123
BFXFX	FFFF (XTC format)
BE12	B 12 (QTC format) E12 (XTC format)
BX12	B12 (XTC format)

Addressed Transmission (N = last numerical address digit)

Tone Transmission	**Data Code**
- - - NB1A2B	1A2B (appended to address)
- - - NCB234	234 (appended to Address Suffix)
- - - NB	No data (signifies ‘nil data’)

2.7 HSC Decoding Rules

These rules relate to the decoding of HSC character sequences obtained from an HSC tone decoder.

2.7.1 Address Decoding

- Address decoders shall adopt a START condition on receipt of a NOTONE character. A minimum period for which the NOTONE character shall be present before a START condition is adopted may be imposed if required. In the START condition the decoder awaits receipt of consecutive characters in accordance with the numeric address code sequence.

- Address code decoders shall recognise as 'valid', a sequence of characters in which the first through to the Nth characters are received in the correct consecutive sequence corresponding to the address code, and where a valid termination is received immediately following the Nth address character. Valid address code terminations are:
  A) a NOTONE character
  C) a DATA Prefix character

- Address code decoders shall recognise as invalid any sequence of characters in which:
  A) Character of incorrect numeric value is received at any position in the numeric address code sequence.
  B) An alphabetical character is received at any position in the numeric address code sequence, except where characters E and A are valid in accordance with the rules.
  C) A NOTONE character is received at any 2nd through to the Nth position in the numeric address code sequence.
  D) The Nth address character is not followed immediately by a valid termination.

2.7.2 Address Suffix Decoding

- A suffix character, or a coded sequence of suffix character, may be appended to the numeric address of an address code decoder. Address suffix characters shall be considered to form a coded extension to the numeric address.

- Address suffix characters may be decoded according to CLOSED CODE or OPEN CODE rules.

- CLOSED CODE decoders shall recognise as valid a sequence of characters in which the 1st through to the Nth characters are received in the correct consecutive sequence corresponding to the numerical address and suffix code, and where a valid termination is received immediately following the Nth suffix character.

- OPEN CODE decoders shall recognise as valid a sequence of characters in which the 1st through to the Nth characters are received in the correct consecutive sequence corresponding to the numerical address and suffix code. Receipt of the Nth coded suffix character shall represent valid completion of the suffix code without further qualification or termination.
- Two or more alternative suffix codes may be appended to one numerical address. Alternative codes may have different lengths (number of characters.)

- It shall be valid for receipt of a valid termination to substitute for the first character in a coded address suffix and to represent valid termination of the preceding numerical address code.

- Address code decoders shall recognise as invalid any sequence of address suffix characters in which:
  A) A character other than C or D is received at any position in a coded suffix sequence, except where a character E (QTC) is valid in accordance with the rules.
  B) A NOTONE character is received at any position in a coded suffix sequence.
  C) In the case of CLOSE CODE address suffix decoders, the Nth code suffix character is not followed immediately by a valid termination.

- Where two or more suffix codes are appended to one numerical address code, each shall be considered an alternative code. A condition that invalidates one code shall not inhibit correct completion of an alternative code.

- On detection of an invalid character/condition at any position in an address or suffix sequence, address decoders shall adopt an INHIBIT state. In the INHIBIT state further character decoding is inhibited until a valid START condition is received.

2.7.3 Data Decoding

- Data decoders shall recognise as a valid Data Prefix the first character B to be received following receipt of a NOTONE character. It is valid for characters NOTONE and B to be received in immediate consecutive sequence or to be separated by one or more intervening characters.

- Data decoders shall recognise as valid Data Characters any 1st through to the Nth sequence of characters in which the 1st character immediately follows the DATA Prefix and the Nth+1 character in the first NOTONE character to be received following the Data Prefix.

- The first through to the Nth Data Characters may include any characters in the alphanumeric format set, except that character E (QTC) shall signify repetition of the immediately preceding character. Character E is valid in any 1st through to the Nth position in the sequence.

2.7.4 Data Sequence Decoding

- Data Sequence decoders shall adopt a START condition on receipt of a valid Data Prefix character. In the START condition, the decoder awaits receipt of consecutive Data Characters in accordance with a predetermined coded sequence.

- Data Sequence decoders shall recognise as valid a sequence of Data Characters in which the 1st through to the Nth characters are received in the correct consecutive coded sequence, and where a NOTONE character is received immediately following the Nth coded character.

- Data Sequence decoders shall recognise as invalid any sequence of Data Characters in which:
  A) A character of incorrect value is received at any point in the coded sequence
  B) A NOTONE character is received at any 1st through to the Nth position in the coded sequence
  C) The Nth coded character is not followed immediately by a NOTONE character.

- On detection of an invalid character/condition at any position in the coded sequence, Data Sequence decoders shall adopt an INHIBIT state. In the INHIBIT state further character decoding is inhibited until a valid START condition is received.

3 XTCSS

XTCSS is a state-of-the art (squelch) signalling format, employing both sub-audio (CTCSS) and in-band (XTC) signalling concurrently. This method offers more than twice as many privacy codes as standard CTCSS operation and completely eliminates interference caused by other traffic on the channel (quiet operation). Any device from any vendor can support XTCSS so long as it supports HSC.

Additionally the XTCSS signalling can be employed as an over-air control for such features as voice scrambling and voice compression. With reference to Figure 2, the XTCSS command sequence that precedes speech could be used to set the receiving device to whatever parameters the transmitting device is set to. This could be realised by the developer creating a lookup table relative to all the controllable features within a system. The 2nd two hexadecimal control tones (within the sequence of 4 tones) could be related to several individual features (when converted to binary) that could be switched on or off with relative ease. When a transmission is initiated the transmitting system generates the appropriate hexadecimal code to set the receiving device with no intervention of the user, thus creating a quick set up process and/or improved security communication system.

XTCSS is fully compatible with both conventional and enhanced CTCSS signalling operations and can implement the 'All Call Code' and 'All Codes Monitor' functions.

XTCSS signalling offers:

- 'Quiet' Operation using sub-audio and in-band signaling
- Over-air configuration
- Ability to 'ignore' non-XTCSS Signals on same channel
- Additional privacy codes (99 'private' addresses)

The HSC and XTCSS feature can be implemented in the following CML devices:

CML Device	HSC Capable	XTCSS Feature
CMX803	Yes	Software Implementation
CMX823	Yes	Software Implementation
CMX828	Yes	Software Implementation
CMX881	Yes	Software Implementation
CMX882	Yes	Built in
CMX883	Yes	Built in

The devices listed above offer standard and advanced signalling, which provides a flexible operation for CTCSS, DCS and XTCSS.

For the CMX881, 882 and 883 devices, these features can be evaluated using the CML EV8810 Evaluation Kit. Information for this kit can be located on line at the CML web site.

Figure 2 shows an example of an RF transmission using a special CTCSS tone (64.7Hz) and XTCSS hexadecimal 4-byte code before and after the audio channel is opened.

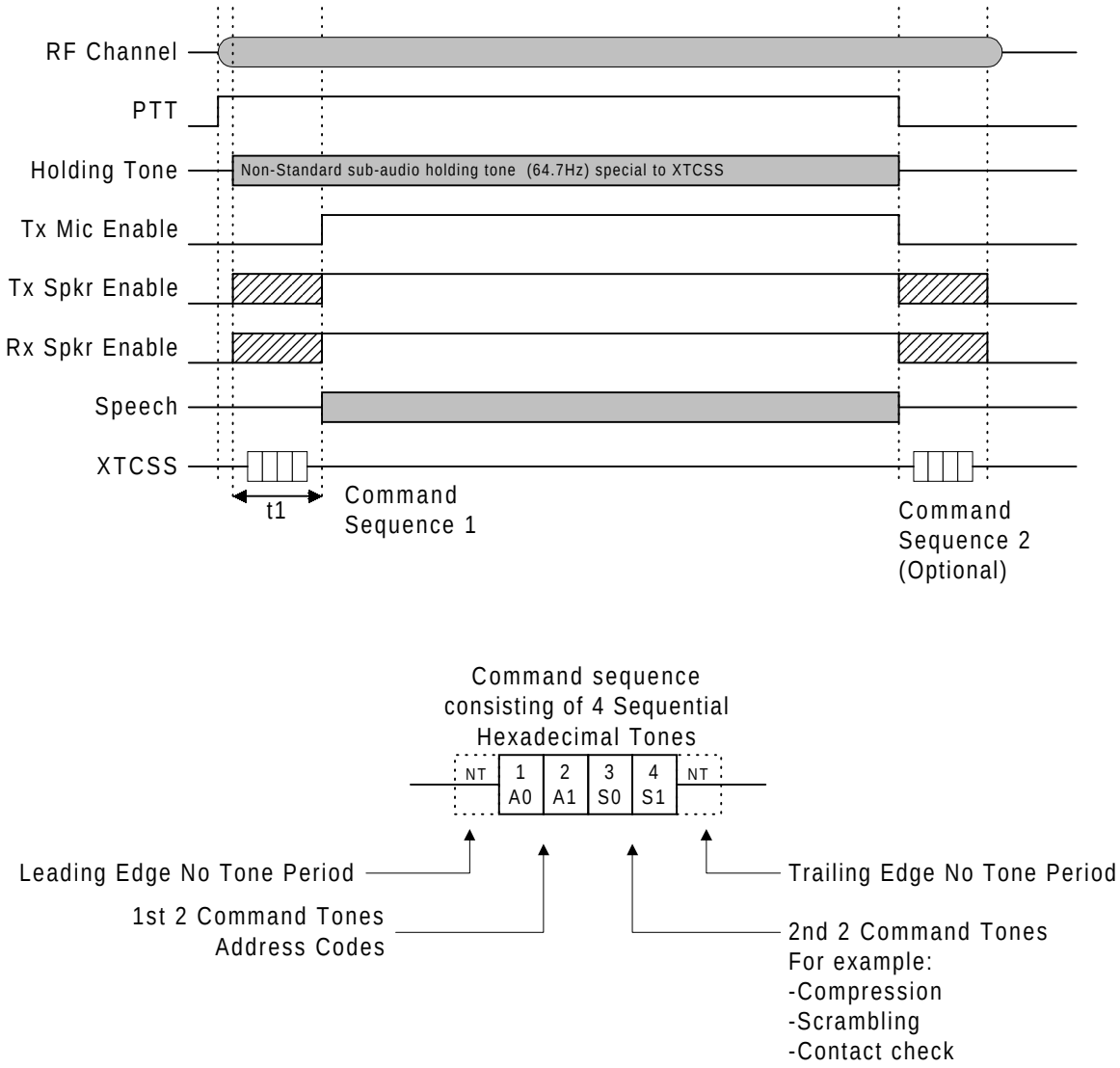

Figure 2 – HSC Transmission using XTCSS and a Holding Tone

Notes:

- Timing Specifications are not defined.
- It is left up to the designer to decide on the best timing, based on the application, system reaction and performance of the RF link.
- The HSC code could be used as an in band audio confidence and roger bleep, but if the transmitting microphone is not disabled then it may corrupt the HSC data.
- Period t1 is the minimum time in which the transmitting microphone has to be disabled so the HSC is not corrupted.
- To stop the transmitting user talking too early (before the Tx mic is enabled), the transmitting radio could produce a confidence bleep thus discouraging the user from talking until the mic is enabled.

- The hatched area is optional. This would allow the radios to produce a confidence and roger bleep.

4 Conclusion

This document describes the coding rules and tone parameters for HSC, from which a 'closed code' protocol can be implemented. This protocol specifies that each sequence of information characters is preceded and terminated by a 'boundary' character.

The following CML devices can be used in HSC and XTCSS applications:

- FX803 – Audio Signaling Processor
- CMX823 - Programmable Paging Tone Decoder
  Example systems and tones include:
  - Motorola Quick Call series GE groups A, B and Zetron.
  - Reach and Plectron 2-tone radio paging.
  - Motorola 5/6-tone paging.
  - EIA, CCIR, ZVEI1 and EEA tone sets used for HSC radio paging and SELCALL.
- FX828 – CTCSS / DCS / SELCALL Processor
- CMX881 – Analogue / Trunking Baseband Processor
- CMX882 - FRS / MURS / GMRS /PMR466 Baseband Processor + GPS Data Transport
- CMX883 - FRS / MURS/ GMRS/ PMR446 Baseband Processor

www.cmlmicro.com

For FAQs see: http://www.cmlmicro.com/products/faqs/index.htm

For a full data sheet listing see: http://www.cmlmicro.com/products/datasheets/download.htm

For detailed application notes: http://www.cmlmicro.com/products/applications/index.htm

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