

Multi-User Frequency-Hopping Underwater Acoustic Communication Protocol

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<ftp://ael.whoi.edu/pub/fhfsk.pdf>

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Release Notes for Version 1.0

The initial release is intended to provide a complete description of the following portions of the specification:

- The segmenter.
- The data frame structure.
- Error correction coding.
- Modulation.
- Frequency-hop patterns.

At this time the supervisory frame description is for informational purposes only and is not intended for implementation until after July, 2000. The supervisory frame descriptions constitute a Request for Comment from interested developers.

Interim testing is expected to be conducted as follows with respect to bands and user identification:

- A modem pair is programmed to use one pre-selected frequency band.
- A modem pair is programmed to use one pre-selected hopping pattern.

Interim testing among modems from different organizations is expected to be conducted as follows with respect to bidirectional communication in the near-term:

- One modem is configured as receiver. One or more other modems are programmed to transmit datagrams at low duty-cycle.
- One modem is programmed to initiate transactions (unit 0). All other modems are configured as slaves and transmit only when they are addressed by unit 0.

Other protocols will be established and documented after use of the physical layer is validated among different organizations.

Release Notes for Version 1.01

Changes in this version include a reduced width for Band C:

- The upper edge of Band C is lowered.
- The hopping patterns for Band C are changed to 7 and 13.
- The number of sync bits for Band C are changed to 21 and 26.

Release Notes for Version 1.02

Changes in this version include a modification to the hopping pattern used for acquisition. The pattern for the synchronization sequence for user i is now changed to the pattern $i + 3$ for the 7 hop sequence and $i + 6$ for the 12 hop sequence. This imposes a practical limit of 3 users for the 7 hop case and 6 users for the 13 hop case (per frequency band).

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Part I

Physical Layer Description

1 Introduction

This document describes a standard for low-rate, multi-user communication in the underwater acoustic environment.

1.1 Scope

The principal characteristics of the standard include:

1. Data framing of variable length information segments with header information and CRC for error detection.
2. Error-correction coding utilizing a rate 1/2 convolutional code.
3. Symbol rates of:
 - (a) 160 symbols per second
 - (b) 80 symbols per second
4. Three frequency regimes:
 - (a) 7.6 to 12 kHz
 - (b) 12.5 to 17 kHz
 - (c) 23 to 27 kHz
5. Low-coincidence frequency hopping patterns which provide code-division multiple-access and channel clearing time in multipath environments.

Section 2 describes the frame structure and error correction methods in detail. Frequency hop FSK modulation is described in section 3. Section 4 discusses the protocols proposed under this standard.

In addition, a Matlab toolbox has been written to demonstrate and document the physical layer of the system. The Matlab modules include the segmenter, the error-correction coding and frequency-hop modulation layers. The toolbox is summarized in Appendix A and it outlines the capabilities of the ECC, modulation and demodulation tools.

2 Frame Structure and Encoding

Frames can be of two types: supervisory and data. A data frame is used purely for data transfer, while a supervisory frame is used in all other cases, e.g. to request a connection, to set up the details of the data transfer and to set the link parameters. The supervisory frames are discussed in section 4.

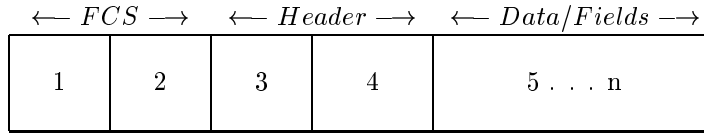


Figure 1: Frame Structure in Bytes, n=36, 68, 260

2.1 Segmenter

The segmenter works with data units of maximum size 16128 bytes. Each unit is broken up into frames of length l , where l can take on the following discrete values: 256, 128, 64 or 32 bytes based on the data rate chosen. A 2 byte header and a 2 byte Frame Check Sequence (FCS) are prepended to each frame. Figure 1 shows an overview of the frame structure. A maximum of 63 frames can be concatenated together to form a single packet for error-correction coding and modulation. If a frame consists of less than l bytes of data, it is zero-padded to the defined frame size and a header bit is accordingly set.

While the segmenter is capable of supporting different frame sizes, for the purposes of this initial release only the 32 byte option is considered.

2.2 Frame Definition

In a data frame, the entire contents of the frame, from byte 5 onward, consist of data. In a supervisory frame, additional fields, flags and information are provided in formats determined by the protocol chosen, thus there can be several types of supervisory frames as required by the different protocols.

2.3 Frame Header

The header consists of 16 bits, with field assignments as shown in Figure 2. Each of these field assignments is described in the following sections.

2.3.1 Fields 1 and 2: Acoustic Node Source/Destination Address

Bits 8 to 11 are assigned as destination address, while bits 12 to 15 are assigned for source addressing. The address at the physical layer is intended to allow the lowest layer at the receiver accept or reject data frames received at the center frequency, data rate and coding method set at a particular receiver. The 0000 destination is reserved for the base node in a system. The 0001 destination is reserved for broadcast. While a network may consist of many more nodes than 15, at the physical layer only 15 will be configured such that they will receive each others packets.

2.3.2 Field 3: Frame number

Bits 2 through 7 are reserved for frame numbers. Frame number 0 is interpreted as a supervisory frame and numbers 1 through 63 are interpreted as data frames.

full	ACK	framenum	destid	srcid
0	1	2-7	8-11	12-15

Figure 2: Header Structure, in Bits

2.3.3 Field 4: Acknowledgement Bit

Bit 1 is reserved for Acknowledgement, 'ACK'. If set, an ACK is requested when the receiver correctly decodes the packet. The definition of the response to a packet received with the ACK bit set is located in the supervisory frame definition section in Part II.

2.3.4 Field 5: Frame Full Bit

Bit 0, if set, signifies that the frame is completely full of data destined for the data layer. If not set, it indicates that the frame is padded to make it the standard size. If this bit is set then byte number 5 contains an eight bit number which indicates how many bytes of actual data are present in the frame.

2.4 Frame Check Sequence

A 16-bit cyclic redundancy-check (CRC) is appended on to the frame and used as a Frame Check Sequence. The CRC used is the CCITT standard, with a generator polynomial $g(x) = x^{16} + x^{12} + x^5 + 1$, and a minimum distance, $d_{min} = 4$, over block lengths of upto 32752 symbols [1]. The CRC protects both the data and the header.

2.5 Encoder

After the data is formed into blocks with the header and CRC, each frame is whitened using a pseudorandom noise (PN) sequence, convolutionally coded, then bit-interleaved.

2.5.1 Data Whitening

The data is whitened using an m -sequence which is generated using a shift register of length 11 and a generator polynomial $g(x) = 1 + x^2 + x^{11}$. The shift register is initialized with a one and 10 zeros. The whitening sequence generated in this fashion is XOR'd with the data prior to encoding with the convolutional code.

2.5.2 Convolutional Code

The whitened frame is convolutionally encoded using the same code as is employed in the IS-95 CDMA standard, a rate-1/2 encoder with constraint length 9 [2]. The

generator polynomials are

$$g_1(x) = 1 + x + x^2 + x^3 + x^5 + x^7 + x^8$$

$$g_2(x) = 1 + x^2 + x^3 + x^4 + x^8$$

Prior to encoding 8 zeros are appended to the data as a tail for the convolutional encoder. These bits are discarded at the receiver.

2.5.3 Interleaver

The encoded frame is then block-interleaved using an interleaver depth of 40 symbols. This separates consecutive errors by greater than four constraint lengths.

The encoded data is padded to an even number of 40 symbol blocks, then formed into a matrix with 40 columns and n rows. The interleaver operates by then reading out the data columnwise to achieve the 40 symbol spacing.

3 Frequency-Hop Modulation

The modulation method is binary (one-of-two) frequency-shift keying (FSK) with frequency hopping.

3.1 Symbol Rates and Frequency Separation

The symbol rates are chosen to be integer multiples of each other and allow for an even number of A/D samples using common clock rates. Symbol rates of 80 and 160 sps are used for all three frequency bands. The symbol durations corresponding to the two rates are 12.5 and 6.25 milliseconds respectively. At the 80 symbol per second rate the separation between frequencies is fixed at 160 Hz. At the 160 symbol per second rate the separation is 320 Hz.

3.2 Signaling Bandwidth

The bandwidth occupied by the signals is defined by the number of hops in each hopping table and the frequency bin separation. The number of hops is 7 or 13, depending upon the symbol rate. The upper band edges are calculated based on this and listed in Table 1.

3.3 Shaping

This standard does not define a time-domain weighting function for the transmitted signal.

3.4 Frequency Bands

There are three frequency bands defined in this specification. The bandwidth is approximately 4 kHz for all bands. Band A is intended for compatibility with underwater telephone transducers (i.e. the UQC). The bands are summarized in Table 1 where F_l denotes the carrier of the lowest frequency bin and F_h is the highest carrier frequency. The total bandwidth is slightly larger than $F_h - F_l$ and is also different for each of the two symbol rates.

Band	Rate sps	ΔF Hz	Hops	Synch Bits	F_l Hz	F_h Hz	T_{clear} sec
A	160	320	7	21	7680	11840	0.0375
A	80	160	13	26	7680	11680	0.150
B	160	320	7	21	12800	16960	0.0375
B	80	160	13	26	12800	16800	0.150
C	160	320	7	21	23040	27200	0.0375
C	80	160	13	26	23040	27040	0.150

Table 1: Frequency Bands and Summary Information

Band	Model Number	Type	Manufacturer
A	SB31CT	Omni	EDO
	SP23LT	Conical	EDO
	249-10 Series	Toroidal	EDO
	ITC-3167	Hemispherical	ITC
	ITC-3013	Hemispherical	ITC
	ITC-3148	Hemispherical	ITC
	ITC-2044	Toroidal $\pm 35^\circ$ @9.5 kHz	ITC
	AT-12xx	Omni	Benthos
	TC-1010	Omni	RESON
	TC-1032	Conical, $\pm 30^\circ$ @10 kHz	RESON
	TC-1035	Toroidal, $\pm 35^\circ$ @9.5 kHz	RESON
	TC-1037	Conical, $\pm 30^\circ$ @10 kHz	RESON
B	AT-18A1	Conical $\pm 30^\circ$ @18 kHz	Benthos
	AT-18AT	Omni	Benthos
	AT-18DT <i>3 ring</i>	Toroidal $\pm 20^\circ$ @18 kHz	Benthos
	249-17 Series	Toroidal	EDO
	6969-3500 <i>2nd resonance</i>	Omni	EDO
	ITC-3001	Conical $\pm 14^\circ$ @17.5 kHz	ITC
C	ITC-6137	Toroidal $\pm 14^\circ$ @24 kHz	ITC
	ITC-2089	Toroidal $\pm 38^\circ$ @25 kHz	ITC
	AT-27BT	Omni	Benthos

Table 2: Transducer and manufacturer list for each of the three bands.

The channel clearing time is a function of the number of hops and the symbol duration. The clearing time is defined as the period from the end of a symbol in a particular bin to the start of the next symbol in that same bin. The values for T_{clear} for each of the bands and rates is also listed in the table.

Commercial transducers identified as fitting these bands are listed in Table 2 as a convenience. In no way does this listing recommend or suggest any suitability of these transducers for any application but is instead a reference for the implementer. Some of the transducers listed here require electrical tuning or pre-emphasis to optimize the bandwidth.

3.5 Hopping Sequences

Two different hopping sequences are defined. Their selection depends upon the symbol rate as described in Table 1. There are $q - 1$ sequences of length q where q is a prime number. These sequences provide a minimum number of coincidences (exactly one with any other sequence) and may be generated as follows:

$$V_m = (v_{m,1}, v_{m,2}, \dots, v_{m,q})$$

m							
1	0	1	2	3	4	5	6
2	0	2	4	6	1	3	5
3	0	3	6	2	5	1	4
4	0	4	1	5	2	6	3
5	0	5	3	1	6	4	2
6	0	6	5	4	3	2	1

Table 3: Sequences for $q = 7$

m													
1	0	1	2	3	4	5	6	7	8	9	10	11	12
2	0	2	4	6	8	10	12	1	3	5	7	9	11
3	0	3	6	9	12	2	5	8	11	1	4	7	10
4	0	4	8	12	3	7	11	2	6	10	1	5	9
5	0	5	10	2	7	12	4	9	1	6	11	3	8
6	0	6	12	5	11	4	10	3	9	2	8	1	7
7	0	7	1	8	2	9	3	10	4	11	5	12	6
8	0	8	3	11	6	1	9	4	12	7	2	10	5
9	0	9	5	1	10	6	2	11	7	3	12	8	4
10	0	10	7	4	1	11	8	5	2	12	9	6	3
11	0	11	9	7	5	3	1	12	10	8	6	4	2
12	0	12	11	10	9	8	7	6	5	4	3	2	1

Table 4: Sequences for $q = 13$

$$v_{1,k} = k - 1$$

$$v_{m,k} = v_{1,p+mr}$$

where $k = mp + r$ under \mathbf{N} , $1 \leq m \leq q - 1, k \leq q$, and operators as defined under $\text{GF}(q)$.

The $q = 7$ and $q = 13$ cases are tabulated in this document ($m = 0$ results in zero vector as a trivial case, which is excluded from the tables).

The tables are used as follows. User 1 employs the base pattern and sequentially steps through the bin pairs where bin pair one corresponds to the two lowest frequency bins defined in Table 1. User 2 employs pattern 2 and so on.

3.6 Packet Timing Acquisition

Timing acquisition of a data packet is done using a prescribed sequence of data bits modulated according to the hopping pattern assigned to a particular user. The number of bits used for synchronization is shown in Table 1. In all cases an integer number of passes through the hopping table are used. The actual data to be modulated is simply a section of a pseudo-random sequence. The sequence used for generation of the data used to modulate the synchronization pattern is based on the shift-register sequence of length 10 which uses the polynomial $g(x) = 1 + x^2 + x^{10}$. The initial 10 outputs from the shift register are discarded and starting at the 11th point the data is segmented for each users pattern.

Thus the first user in the 7 hop system uses 21 synchronization bits which are the 11th through the 32nd bit from the shift register. User 2 uses the next 21 bits, and so on. The same sequence is employed for all of the different hopping patterns. The data bits for each hopping sequence and each user are tabulated in several include files for use with C programs, and in a Matlab file as well.

The hopping pattern for synchronization is different than that used for data. This reduces the correlation between the data and synchronization portions of a packet. The hop sequence for the data for user i is row i from the hopping table. The hop sequence for the synchronization bits is row $i + 3$ for the 7 hop case and row $i + 6$ for the 13 hop case. Thus a maximum of 3 users are supported per frequency band for the 7 hop case (160 sps) and a maximum of 6 users for the 13 hop case (80 sps).

Part II

Communications Protocol

4 Communications Protocol Overview

This version of the document defines only the mechanisms for generating a packet of data and modulating it in a particular band for a particular user. Communications protocols will be added to this document in the future. These include:

- *Negotiated transfer.*
- *Negotiation for rate.*
- *Negotiation for user number assignment.*
- *etc.*

What follows is a draft of portions of the supervisory frame definitions.

4.1 Supervisory Frames

A frame is to be interpreted as supervisory when the Frame Number (bits 2-7 in the header) is zero. The supervisory frame contains additional pre-defined fields to indicate its structure. The supervisory frame type number is an 8 bit integer contained in byte 4 within the structure shown in Figure 1.

Supervisory frames are always exchanged at the currently defined data rate for a given protocol. Supervisory frames are always 32 bytes in length.

4.1.1 Supervisory Frame Types

For the purposes of this specification only a limited number of supervisory frames are defined. These frames are intended for use in setting up a link and transferring information about modem capabilities. The defined groups of Supervisory Frames are listed in Table 5.

The Discovery and Level 1 Link Protocol Groups are described in this document. The Level 2 Link Protocol refers to network activity and includes functions such as exchange of routing tables. The Acoustic Navigation Group will be defined in a companion document.

4.1.2 Supervisory Frames for Discovery and Monitoring

The Supervisory Frames used for purposes of Discovery and Monitoring are listed in Table 6.

Range	Functional Group
0-3	Reserved
4-15	Discovery and Monitoring
16-31	Level 1 Link Protocol
32-47	Level 2 Link Protocol
48-56	Acoustic Navigation
56-63	Reserved
63-255	Open and Undefined

Table 5: Supervisory Frame Group List

Frame Number	Function
4	Capability Query
5	Capability Acknowledgement
6	Capability/Services/Protocol Broadcast
7	Status Query
8	Status Response

Table 6: Supervisory Frames for Discovery and Monitoring (4-15)

4.1.3 Capability Query Frame

A Capability Query Frame is defined by the Supervisory Frame Number 4. No other bits in the frame are used.

4.1.4 Capability Acknowledgment Frame

The acknowledgement to a capability query contains information regarding the modem manufacturer, hardware and firmware versions and frequency band capability within the frame. This information is listed in Table 7.

The assignments for manufacturer ID are contained in Table 8. A manufacturer may request an ID using the contact listed at the front of this document. Product ID numbers and firmware revision numbers are not defined or used under this protocol. Protocols which utilize this information will contain the appropriate definitions.

4.1.5 Supervisory Frames for the Level 1 Link Protocol

The Level 1 Link protocol which utilizes Supervisory Frames 16-31 supports the following functions:

1. Positive or Negative acknowledgement of a single data frame.
2. Link setup, data transfer, retransmissions and link closure of multiple data frames.

Bit Fields	Function
0-7	Manufacturer ID
8-15	Manufacturer Product ID
16-23	Firmware Revision Number
24	Band A Transmit Capability 0/1
25	Band A Receive Capability 0/1
26	Band B Transmit Capability 0/1
27	Band B Receive Capability 0/1
28	Band C Transmit Capability 0/1
29	Band C Receive Capability 0/1
30	reserved
31	reserved
32	Source Level Control Capability 0/1
33-39	reserved
40-47	reserved for future FSK capability definitions
48-55	reserved for future PSK capability definitions
56-63	reserved for future Direct-Sequence capability definitions

Table 7: Field Definitions for Capability Acknowledgment Frame

ID	Name
0	Reserved
1	Woods Hole Oceanographic Institution
2	Benthos
3	Florida Atlantic University/Edgetech
4	Delphi
5	LinkQuest
6	SPAWAR (Developmental)
7	Lockheed (ARCI)
8	NUWC (UUV)
9	NUWC (Ranges)
10	ORCA (France)
11	MARCONI (France)
12	INFREMER (France)
13	THOMSON SINTRA (France)
14	DERA (UK)
15	University of Newcastle (UK)
16	NDRE (Norway)
17	Simrad (Norway)

Table 8: Manufacturer ID Definitions

Frame Number	Function
16	Acknowledgement and Negative Acknowledgement
17	Data Transfer Request from Initiator
18	Data Transfer Grant to Initiator
19	Data Transfer Abort

Table 9: Supervisory Frames for Level 1 Link Protocol (16-31)

Field Definitions for ACK and NACK	
Bit Fields	Function
0-7	Starting frame number
8-15	Number of frames acknowledged using this supervisory frame
16	ACK/NACK for frame n , 0 indicates the frame is good.
17	ACK/NACK for frame $n + 1$
18	ACK/NACK for frame $n + 2$
\vdots	\vdots

Table 10: Field Definitions for ACK and NACK

Supervisory Frames used in Level 1 Link Protocol are listed in Table 9.

The ACK/NACK packet serves as an indicator from the recipient to the source that the data previously transferred is correct, incorrect or missing. This packet is used with two of the Level 1 Protocols. Upon receipt of this frame by the originating modem the data transfer is considered:

1. Complete, if the frame or frames were received correctly.
2. Incomplete, re-transmission is to be performed if one or more frames were received incorrectly.

The bit-level definitions for Supervisory Frame 16, used for Acknowledgement and Negative Acknowledgement are defined in Table 10.

References

- [1] Wicker, Stephen B., *Error Control Systems for Digital Communication and Storage*, Prentice-Hall, 1995.
- [2] Peterson, Roger L., R.E. Ziemer, and D. E. Borth, *Introduction to Spread Spectrum Communications*, Prentice-Hall, 1995.

A Matlab Frequency Hop Toolbox

The toolbox includes the functions required to break up a block of data into frames and then encode those frames for transmission. In addition, the toolbox provides all the functions necessary to take demodulated data from the frequency-hop receiver and decode it back to frames.

The frequency hop modulation and demodulation tools include the facilities to add synchronization bits to data frames, modulate the data to passband, then demodulate using a matched-filter bank. The tools are provided as examples only and it is not intended that actual implementations copy the methodology used here, which is provided only for demonstration.

Demonstration of a method for performing timing acquisition is also provided. This function is called `fhacq.m`.

A.1 Using the Toolbox

The toolbox is supplied as a reference for the standard presented in this document. The operations described in the previous sections are provided as Matlab functions in order to allow validation of actual implementations. These tools are thus used to both document the standard and to provide a means for checking the compliance of a given system with the standard.

The functions are contained in one directory for easy use. However, it must be added to the users' matlab path in order to execute the functions from another directory.

A.2 MEX files

Several functions are provided only as C source code, not in m-file format. These functions include the Viterbi decoder, the metric table generator and the CRC function. While these functions have been compiled for Linux systems and are provided, users of other operating systems will need to compile these functions for their system. Type `help mex` at the Matlab prompt for more information. Check the README file in `src/vit` within the distribution for additional information. After the mex files have been compiled for your system place them in the distribution directory.

The soft-decision Viterbi decoder is from a publicly available web site maintained by Phil Karn. This software may be used under the terms of the GNU Public License.

A.3 Demonstrations

The complete structure of the standard may be observed by studying the file `fskdemo.m`. To run a demonstration of one of the 6 possible band and rate combinations a set of parameter files have been created. Simply invoke the name of one of the parameter files, for example `fhfsk_a_160` and then type `fskdemo`. The scripts leave all of their output in the workspace to be examined by the user.

A.4 Toolbox Contents

The contents of the toolbox include the functions listed below.

```

% Multi-User Frequency Hopping Communication Toolbox
%
% Version 1.02  May 25, 2000
%
% Segmenter
%
% mkframe      - makes frames, given data
% rdframe      - unpacks data/header info, given frames
% rdheader     - unpacks a header word to the header info
% paddata      - pads data
% crc          - 16 bit CRC generator (mex)
%
% Error Correction
%
% whitenframes - whiten a frame using PN sequence
% encodeframes - convolutionally encode and interleave frames
% decodeframes - de-interleave and viterbi decode frames
% conv_encode  - convolutional encoder
% conv_decode  - Viterbi decoder function
% vit29_decode - (2,1,9) Viterbi decoder (mex)
% mettab       - metric table generator (mex)
% interleave   - fixed-length block interleaver
% mlgen        - Maximal-Length sequence generator
%
% Frequency-Hopping FSK
%
% fhmod        - modulate data to passband
% fhdemod      - demodulate and apply filter bank
% fhacq        - timing acquisition for FH sequences
% fsk2prob     - convert binary FSK to probability metric
% isnr         - calculate SNR of FSK filter bank output
%
% Utilities
%
% bit2word     - convert a stream of bits into words
% word2bit     - convert a word into a stream of bits
% oct2bin      - Convert an octal number into binary
% bin2sym      - convert packed binary data to symbols
% sym2bin      - convert symbols to binary data
%
% Demonstrations
%
% fhfsk_a_160  - generate and demodulate Band A, 160 sps
% fhfsk_a_80   - generate and demodulate Band A, 80 sps

```

```
% fhfsk_b_160 - generate and demodulate Band B, 160 sps
% fhfsk_b_80  - generate and demodulate Band B, 80 sps
% fhfsk_c_160 - generate and demodulate Band C, 160 sps
% fhfsk_c_80  - generate and demodulate Band C, 80 sps
% fskdemo     - utility script for above demos
%
% Mat Files
%
% sync        - matrices of synchronization bits
%              (pn7 and pn13)
% table7c     - 7 element hop matrix
% table13c    - 13 element hop matrix
%
% (C) 2000 Woods Hole Oceanographic Institution
% Contributions by S. Singh, M. Grund, L. Freitag, M. Johnson,
% M. Stojanovic, R. Suzuki and D. Kilfoyle.
```

B Include Files

The prime-number based hopping tables are in the file `include/tab.h`. The tables are in the form of static variables. The shortest table is shown below as an example.

```
unsigned char **tab7 = {
    { 0, 1, 2, 3, 4, 5, 6},
    { 0, 2, 4, 6, 1, 3, 5},
    { 0, 3, 6, 2, 5, 1, 4},
    { 0, 4, 1, 5, 2, 6, 3},
    { 0, 5, 3, 1, 6, 4, 2},
    { 0, 6, 5, 4, 3, 2, 1},
};
```

The synchronization data bits are also available as a set of three files. Two of the files contain the sync data bits encoded as bytes, the other file (`sync.h`) contains the same data, but packed into words for a more compact representation. The file `sync7.h` is shown below. All of the files are in the same directory.

```
unsigned char **sync7 = {
    {0,1,1,0,0,1,0,0,1,1,0,1,1,1,1,1,1,0,0,1,0},
    {0,0,0,1,0,0,0,0,0,1,1,1,1,0,1,1,1,1,1,0,0},
    {0,1,1,1,1,1,0,0,0,1,1,0,0,1,1,0,1,1,1,0,0},
    {1,0,1,1,1,0,1,0,1,0,1,0,1,1,1,1,0,1,0,1,1},
    {0,1,0,1,1,1,1,0,1,0,0,0,1,1,1,1,1,0,1,0,1},
    {1,0,1,0,0,1,1,0,0,1,1,1,0,1,1,1,0,1,1,0,0},
    {0,0,0,1,1,1,1,1,0,0,0,0,0,0,1,0,0,0,1,1,1},
}
}
```