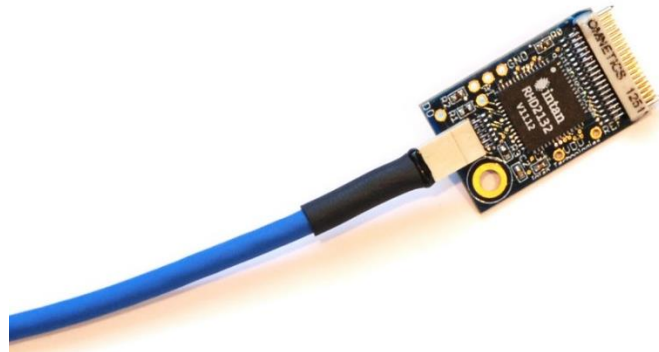


RHD

Application Note: Data File Formats

19 September 2013; updated 28 April 2022



This application note describes the file formats used by the Intan recording controller or the RHD USB interface board to save acquired waveforms to disk. While Intan provides some m-files for reading saved data files into MATLAB, some users may wish to write their own software to access this information. This document provides the necessary information for parsing these files. The software supports multiple file format options (selected by clicking the “Select File Format” button), and each of these formats will be described in a following section.

Data Types

Most of the data types described in this document will be familiar to those with rudimentary programming experience. The following table summarizes the data types referenced in this document:

NAME	DESCRIPTION	RANGE
uint16	unsigned 16-bit integer	0 to 65,535
int16	signed 16-bit integer	-32,768 to 32,767
uint32	unsigned 32-bit integer	0 to 4,294,967,295
int32	signed 32-bit integer	-2,147,483,648 to 2,147,483,647
single	32-bit single-precision floating point number	$\pm 3.4 \times 10^{\pm 38}$ with 7-digit accuracy
double	64-bit double-precision floating point number	$\pm 1.7 \times 10^{\pm 308}$ with 15-digit accuracy
QString	length-prefixed Unicode string (see below)	0 to 2,147,483,647 Unicode characters
ASCII String	ASCII unsigned 8-bit char array ending with 0	No length limit
Name Array	ASCII unsigned 8-bit char array	Exactly 5 characters

All numbers are saved to disk with “little endian” byte order. That is, the least-significant byte is written first and the most-significant byte is written last. MATLAB reads data in little endian format by default.

Some text fields are not stored as null-terminated strings as is common in the C family of languages. Rather, they are stored as length-prefixed strings using the **QString** style from the open-source Qt framework for C++. In the **QString** format, each string begins with a 32-bit unsigned number (**uint32**) that indicates the length of the string, in bytes. If this number equals 0xFFFFFFFF, the string is null. A series of 16-bit (2-byte) Unicode characters follows, and there is no special character to indicate the end of the string.

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The following MATLAB function reads a **QString** from a file identifier `fid` and translates it into a MATLAB-format string `a`:

```
function a = fread_QString(fid)

a = '';
length = fread(fid, 1, 'uint32');
if length == hex2num('ffffffff')
    return;
end
length = length / 2; % convert length from bytes to 16-bit Unicode words
for i = 1:length
    a(i) = fread(fid, 1, 'uint16');
end

return
```

Standard Intan RHD Header

All Intan RHD data file formats make use of the Standard Intan RHD Header which is described in this section. This header contains records of sampling rate, amplifier bandwidth, channel names, and other useful information.

Each file containing a Standard Intan RHD header has a filename ending with the `.rhd` prefix. These are a binary files that begin with the following file type and version information.

DATA TYPE	NAME	DESCRIPTION
uint32	Intan RHD Header identifier	This “magic number” always has a value of 0xC6912702 to indicate a traditional Standard Intan RHD Header.
int16	Data file main version number	These two integers indicate the version of the data file (e.g., v1.2 would be encoded by a 1 followed by a 2).
int16	Data file secondary version number	

Next is a block of data containing global sampling rate and amplifier frequency parameters.

single	Sample rate	Amplifier sample rate (units: Samples/s)
int16	DSP enabled?	0: DSP offset removal high-pass filter was disabled 1: DSP offset removal high-pass filter was enabled
single	Actual DSP cutoff frequency	DSP offset removal high-pass filter cutoff frequency (units: Hz)
single	Actual lower bandwidth	Amplifier analog high-pass filter cutoff frequency (units: Hz)
single	Actual upper bandwidth	Amplifier analog low-pass filter cutoff frequency (units: Hz)
single	Desired DSP cutoff frequency	User-requested DSP offset removal filter cutoff frequency (units: Hz)
single	Desired lower bandwidth	User-requested amplifier high-pass filter cutoff frequency (units: Hz)
single	Desired upper bandwidth	User-requested amplifier low-pass filter cutoff frequency (units: Hz)

The RHD chips are not always capable of achieving the precise cutoff frequencies specified by the user, so both the values requested in the GUI and the actual values realized on the chip are saved.

The next parameter records the state of the software-implemented 50/60 Hz notch filter in the GUI during recording. This notch filter is never applied to saved data, but this information may be used to re-apply the notch filter to recorded data, if desired. (The m-file `read_Intan_RHD2000_file.m` re-implements this notch filter on amplifier data that was saved with the filter enabled.)

int16	Notch filter mode	0: Software notch filter was disabled 1: Software notch filter was enabled and set to 50 Hz 2: Software notch filter was enabled and set to 60 Hz
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Next are two floating-point numbers indicating the latest user-requested electrode impedance test frequency and the impedance test frequency actually realized on the RHD chip.

single	Desired impedance test frequency	Electrode impedance test frequency last requested by user (units: Hz)
single	Actual impedance test frequency	Closest realizable electrode impedance test frequency (units: Hz)

In the “Configure” tab of the Intan GUI, there are three general-purpose text fields that may be used to enter notes on particular recording sessions. The contents of these text fields are saved here.

QString	Note 1	User text from the “Note 1” field in the “Configure” tab in the GUI.
QString	Note 2	User text from the “Note 2” field in the “Configure” tab in the GUI.
QString	Note 3	User text from the “Note 3” field in the “Configure” tab in the GUI.

Versions 1.1 and later support saving on-chip temperature sensor readings. The following number is saved in these versions, indicating the number of temperature sensors recorded. This number is typically equal to the number of RHD chips plugged into the SPI ports, or zero if the temperature recording option is disabled. Note that some file formats do not support saving temperature sensor data; in those formats, this number will always be zero.

int16	Number of temperature sensors	Number of temperature sensor channels saved in file. This number is set to zero if the option for saving temperature data is not selected.
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Version 1.3 and later saves the “board mode”. This integer is set by hardware in the RHD USB interface board or Intan Recording Controller. Currently, a board mode of zero indicates that the on-board ADCs operate over a range of 0-3.3V; a board mode of one indicates that the on-board ADCs operate over a range of $\pm 5.0V$. The Intan Recording Controller has a board mode of 13. This indicates that the ADCs (Analog In ports) operate over a range of $\pm 10.24V$.

int16	Board mode	Integer ranging from 0-15 indicating global properties of the hardware used to acquire the data.
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Version 2.0 and later (supported only by the 512- or 1024-channel Intan Recording Controller) saves name of the channel used for digital re-referencing. The waveform from this channel may be added to other amplifier channels to undo the effects of digital re-referencing, if desired. If hardware referencing was selected, this string is set to “n/a”.

QString	Reference channel name	Native channel name of the channel used as digital reference (e.g., “A-001” or “H-123”). If hardware referencing was selected, this string is set to “n/a”.
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The next number indicates the number of “signal groups” present in the data file. This number is typically equal to seven: Port A, Port B, Port C, Port D, Board ADC Inputs, Board Digital Inputs, and Board Digital Outputs. If a 1024-channel Intan Recording Controller was used, this number will be equal to 11: Ports A – H, Board ADC Inputs, Board Digital Inputs, and Board Digital Outputs.

int16	Number of signal groups in data file	Each “signal group” includes all signals from a particular SPI port or the USB board ADC inputs or digital inputs. There will typically be seven signal groups representing the six items listed under “Ports” in the GUI, plus Board Digital Outputs.
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For each signal group, the following “signal group header” is saved, along with a description of each channel in the signal group.

QString	Signal group name	e.g., “Port B” or “Board Digital Inputs”
QString	Signal group prefix	e.g., “B” or “DIN”
int16	Signal group enabled?	0: disabled 1: enabled
int16	Number of channels in signal group	Total number of channels in signal group
int16	Number of amplifier channels in signal group	Of the total number of channels in the signal group, the number that are amplifier channels
	List of channels	See below

Immediately following a signal group (before the remaining signal group headers) is a list of channel descriptions. If a signal group is enabled **and** has more than zero channels, then for each channel the following information is saved.

QString	Native channel name	e.g., “B-013” or “DIN-15”
QString	Custom channel name	e.g., “MyTetrode3-4” or “TTLSensor” renamed by user
int16	Native order	The original numerical order of this channel in the GUI display (e.g., the native order of amplifier channel B-013 is 13).
int16	Custom order	The numerical order of this channel as it appears on the GUI, after possible reordering by the user.
int16	Signal type	0: RHD2000 amplifier channel 1: RHD2000 auxiliary input channel 2: RHD2000 supply voltage channel 3: USB board ADC input channel 4: USB board digital input channel 5: USB board digital output channel
int16	Channel enabled?	0: channel disabled 1: channel enabled
int16	Chip channel	RHD2000 channel number (0-31)
int16	Board stream	USB board data stream (0-7); each data stream supports up to 32 channels. Each RHD2164 chips use two data streams. Each RHD2216 chip uses an entire data stream.
int16	Spike Scope voltage trigger mode	0: trigger on digital input 1: trigger on voltage threshold
int16	Spike Scope voltage threshold	Spike voltage threshold (units: microvolts)
int16	Spike Scope digital trigger channel	USB board digital input channel used for spike trigger (0-15)
int16	Spike Scope digital edge polarity	0: trigger on digital falling edge 1: trigger on digital rising edge
single	Electrode impedance magnitude	Last measured impedance magnitude (units: Ohms)
single	Electrode impedance phase	Last measured impedance phase (units: degrees)

Even non-amplifier channels will contain fields for Spike Scope trigger parameters and electrode impedance data, but these fields will contain default values that may be ignored.

The Spike Scope feature in the GUI is used only to aid in viewing neural spikes; the software saves full waveforms, not just spikes. However, the user-specified thresholds set in the Spike Scope are saved for each channel, so it would be relatively easy to write a script to isolate action potentials based on these thresholds (e.g., for compressing saved data files after recording).

This concludes the Standard Intan RHD Header contents. Typical headers consume very little disk space (a few KB) even for large numbers of enabled channels.

Traditional Intan File Format

This file format saves all types of waveforms (RHD2000 amplifier channels, auxiliary channels from RHD chips, chip supply voltages, USB board ADC inputs, and USB board digital inputs) to one file, along with the Standard Intan RHD Header described above. Only enabled channels of each type are saved. To keep individual file size reasonable, a new file is created every N minutes, where N is an integer that is specified by the user. New filenames are created by appending a date and time stamp to a base filename provided by the user. Each file contains both a Standard Intan RHD Header and approximately N minutes of saved data. These .rhd data files may be read into MATLAB using `read_Intan_RHD2000_file.m`, which is provided on the Intan Technologies web site.

This file format includes an option to save the temperature sensor readings from each RHD chip attached to the USB interface board.

Immediately following the Standard Intan RHD Header in each data file is the waveform data. The traditional Intan file format saves waveforms in “data blocks” corresponding to the `Rhd2000DataBlock` object (or `RHD2000DataBlockUsb3` object) in the C++ code. Each data block contains data from N amplifier samples, where **N = 60** for the 256-channel RHD USB interface board and **N = 128** for the 512-channel and 1024-channel Intan Recording Controllers. The new RHX software uses **N = 128** with both systems.

Each data block is organized as follows:

N × int32	Amplifier sample time index	Sequential integers (e.g., 0, 1, 2, 3...) with zero marking the beginning of a recording or a trigger point. Time indices can be negative to denote pre-trigger times. Divide by the amplifier sampling rate (in Samples/s) to get a time vector with units of seconds. The use of an <code>int32</code> data type means that this number will not “roll over” until total recording times exceed 19.8 hours with the maximum sample rate of 30 kS/s, or 29.8 hours with a sample rate of 20 kS/s.
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For each enabled RHD2000 amplifier channel, N ADC samples:

N × uint16	Electrode voltage	Units: ADC steps. To convert to electrode voltage in microvolts, first subtract 32768 then multiply by 0.195.
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For each enabled RHD2000 auxiliary input channel, N/4 ADC samples. (The Intan GUI software samples the RHD2000 auxiliary inputs at one-fourth the sampling rate of the amplifiers.)

N/4 × uint16	Auxiliary input voltage	Units: ADC steps. To convert to volts, multiply by 0.0000374.
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For each enabled RHD2000 supply voltage channel, one ADC sample. (The Intan GUI software samples the RHD2000 supply voltage once per data block.)

1 × uint16	Supply voltage	Units: ADC steps. To convert to volts, multiply by 0.0000748.
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For each enabled RHD2000 temperature sensor channel, one ADC sample. (The Intan GUI software samples the RHD2000 temperature sensor once per data block.) The GUI calculates a running average of temperature sensor readings over a window of approximately 100 ms to improve sensor accurate.

1 × int16	Temperature sensor reading	Units: 0.01°C per step. To convert to °C, divide by 100.
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For each USB interface board ADC channel, N samples:

N × uint16	Board ADC input voltage	Units: ADC steps. To convert to volts: If board mode = 0, multiply by 0.000050354. If board mode = 1, subtract 32768 and multiply by 0.00015259. If board mode = 13, subtract 32768 and multiply by 0.0003125.
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If **any** USB interface board digital inputs are enabled, unsigned 16-bit integers record N samples from **all** digital inputs 0-15. If no digital inputs are enabled, these samples are not recorded.

N × uint16	Board digital inputs	All 16 digital inputs are encoded bit-by-bit in each 16-bit word. For example, if digital inputs 0, 4, and 5 are high and the rest low, the uint16 value for this sample time will be $2^0 + 2^4 + 2^5 = 1 + 16 + 32 = 49$.
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The m-file `read_Intan_RHD2000_file.m` includes code to extract the bit-by-bit information from these 16-bit words into individual digital waveforms.

“One File Per Signal Type” Format

This file format creates a subdirectory using the base filename provided, plus a date and time stamp. Global information is saved in a Standard Intan RHD Header file, and all waveform data is saved in separate raw data files. Although the raw data files are divided by signal type (i.e., one file for all amplifier channels, another file for all auxiliary input channels, etc.), the file sizes can grow large quickly: If 64 amplifier channels were recorded at 20 kS/s for one hour, the amplifier data file would be 9.2 GB in size.

The raw data files written in this format are compatible with the NeuroScope open-source software for data viewing and analysis. (See <http://neuroscope.sourceforge.net> for more information on this third-party software.)

When using this file format, the following data files are written to the subdirectory:

Standard Intan RHD Header file: `info.rhd`

This file contains the data listed in the Intan RHD Standard Header described above: sampling rate, amplifier bandwidth, channel names, and other useful information. The information in this file may be read into MATLAB data structures using `read_Intan_RHD2000_file.m`, which is provided on the Intan Technologies web site.

Timestamp data file: `time.dat`

This file contains `int32`-type sequential integers (e.g., 0, 1, 2, 3...) corresponding to sample times indices, with zero marking the beginning of a recording or a trigger point. Time indices can be negative to denote pre-trigger times. Divide by the amplifier sampling rate (in Samples/s) to get a time vector with units of seconds.

The following MATLAB code reads a timestamp data file and creates a time vector with units of seconds:

```
fileinfo = dir('time.dat');
num_samples = fileinfo.bytes/4; % int32 = 4 bytes
fid = fopen('time.dat', 'r');
t = fread(fid, num_samples, 'int32');
fclose(fid);
t = t / frequency_parameters.amplifier_sample_rate; % sample rate from header file
```

The use of the `int32` data type means that this number will not “roll over” until total recording times exceed 19.8 hours with the maximum sample rate of 30 kS/s, or 29.8 hours with a sample rate of 20 kS/s.

Amplifier data file: `amplifier.dat`

This file contains a matrix of ADC samples from all enabled RHD2000 amplifier channels in `int16` format. For example, if four amplifier channels are enabled, data will be written in the following order:

`amp1(t), amp2(t), amp3(t), amp4(t), amp1(t+1), amp2(t+1), amp3(t+1), amp4(t+1), amp1(t+2), amp2(t+2), ...`

To convert to electrode voltage in microvolts, multiply by 0.195.

If no amplifier channels are enabled in the GUI, this file will not be written.

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The following MATLAB code reads an amplifier data file and creates an electrode voltage matrix with units of microvolts:

```
num_channels = length(amplifier_channels); % amplifier channel info from header file
fileinfo = dir('amplifier.dat');
num_samples = fileinfo.bytes/(num_channels * 2); % int16 = 2 bytes
fid = fopen('amplifier.dat', 'r');
v = fread(fid, [num_channels, num_samples], 'int16');
fclose(fid);
v = v * 0.195; % convert to microvolts
```

Auxiliary input data file: auxiliary.dat

This file contains a matrix of ADC samples from all enabled RHD2000 auxiliary input channels in **uint16** format. To convert to volts, multiply by 0.0000374.

Although the Intan software samples the RHD2000 auxiliary input channels at one-fourth the rate of the amplifiers, each auxiliary input sample is repeated four times in this file so that this data may easily be aligned with the timestamp vector in the **time.dat** file.

If no auxiliary input channels are enabled in the GUI, this file will not be written.

The following MATLAB code reads an auxiliary input data file and creates a waveform matrix with units of volts:

```
num_channels = length(aux_input_channels); % aux input channel info from header file
fileinfo = dir('auxiliary.dat');
num_samples = fileinfo.bytes/(num_channels * 2); % uint16 = 2 bytes
fid = fopen('auxiliary.dat', 'r');
v = fread(fid, [num_channels, num_samples], 'uint16');
fclose(fid);
v = v * 0.0000374; % convert to volts
```

Supply voltage data file: supply.dat

This file contains a matrix of ADC samples from all enabled RHD2000 supply voltage sensor channels in **uint16** format. To convert to volts, multiply by 0.0000748.

Although the Intan software samples the RHD2000 auxiliary input channels at one-sixtieth the rate of the amplifiers, each supply voltage sample is repeated sixty times in this file so that this data may easily be aligned with the timestamp vector in the **time.dat** file.

If no supply voltage channels are enabled in the GUI, this file will not be written.

The following MATLAB code reads a supply voltage data file and creates a waveform matrix with units of volts:

```
num_channels = length(supply_voltage_channels); % supply channel info from header file
fileinfo = dir('supply.dat');
num_samples = fileinfo.bytes/(num_channels * 2); % uint16 = 2 bytes
fid = fopen('supply.dat', 'r');
v = fread(fid, [num_channels, num_samples], 'uint16');
fclose(fid);
v = v * 0.0000748; % convert to volts
```

Board ADC input data file: analogin.dat

This file contains a matrix of ADC samples from the analog inputs on the USB interface board, in **uint16** format. To convert to volts, multiply by 0.000050354. (If the board mode is not equal to zero, other scaling values may apply.)

If no board ADC input channels are enabled in the GUI, this file will not be written.

The following MATLAB code reads a board ADC input data file and creates a waveform matrix with units of volts:

```
num_channels = length(board_adc_channels); % ADC input info from header file
fileinfo = dir('analogin.dat');
num_samples = fileinfo.bytes/(num_channels * 2); % uint16 = 2 bytes
fid = fopen('analogin.dat', 'r');
v = fread(fid, [num_channels, num_samples], 'uint16');
```

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```
fclose(fid);  
v = v * 0.000050354; % convert to volts
```

If the data file was generated by an Intan Recording Controller, use the following scaling instead:

```
v = (v - 32768) * 0.0003125; % convert to volts (Recording Controller)
```

Board digital input data file: digitalin.dat

This file contains samples of digital inputs 0-15 on the USB interface board, in **uint16** format. All 16 digital inputs are encoded bit-by-bit in each 16-bit word. For example, if digital inputs 0, 4, and 5 are high and the rest low, the **uint16** value for this sample time will be $2^0 + 2^4 + 2^5 = 1 + 16 + 32 = 49$.

If no board digital input channels are enabled in the GUI, this file will not be written. If **any** USB interface board digital inputs are enabled, the **uint16** numbers in this file record data from **all** digital inputs 0-15.

The following MATLAB code reads a board digital input data file and creates vector of 16-bit words:

```
fileinfo = dir('digitalin.dat');  
num_samples = fileinfo.bytes/2; % uint16 = 2 bytes  
fid = fopen('digitalin.dat', 'r');  
digital_word = fread(fid, num_samples, 'uint16');  
fclose(fid);
```

Individual digital inputs can be isolated using the **bitand** function in MATLAB:

```
digital_input_ch = (bitand(digital_word, 2^ch) > 0); % ch has a value of 0-15 here
```

Board digital output data file: digitalout.dat

This file contains samples of digital outputs 0-15 on the USB interface board, in **uint16** format. All 16 digital inputs are encoded bit-by-bit in each 16-bit word. For example, if digital outputs 0, 4, and 5 are high and the rest low, the **uint16** value for this sample time will be $2^0 + 2^4 + 2^5 = 1 + 16 + 32 = 49$.

If the “Save Digital Outputs” box is not checked in the Select File Format dialog, this file will not be written.

The following MATLAB code reads a board digital output data file and creates vector of 16-bit words:

```
fileinfo = dir('digitalout.dat');  
num_samples = fileinfo.bytes/2; % uint16 = 2 bytes  
fid = fopen('digitalout.dat', 'r');  
digital_word = fread(fid, num_samples, 'uint16');  
fclose(fid);
```

Individual digital outputs can be isolated using the **bitand** function in MATLAB:

```
digital_output_ch = (bitand(digital_word, 2^ch) > 0); % ch has a value of 0-15 here
```

Spike data file: spike.dat

This file contains the timestamp and channel name of each spike that has been detected during recording. If snapshots have been saved, then each spike entry also includes the raw, unscaled data of that spike’s snapshot.

The file begins with a header containing metadata about the recorded data, which is subsequently appended to spike-by-spike for each spike event that occurs.

Header

DATA TYPE	NAME	DESCRIPTION
uint32	Intan Spike File identifier	This “magic number” always has a value of 0x18F8474B to indicate an Intan Spike File (saved in One File Per Signal Type format).
uint16	Spike File version number	Which version this Spike File format follows
ASCII String	Base Filename	Base filename of recording session and time/date

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ASCII String	Native channel names	Comma-separated list of all enabled amplifier native channel names
ASCII String	Custom channel names	Comma-separated list of all enabled amplifier custom channel names
single	Sample rate	Amplifier sample rate (units: Samples/s)
uint32	Pre-detect samples	Number of samples preceding a spike event to include in a snapshot
uint32	Post-detect samples	Number of samples following a spike event to include in a snapshot

Individual Spike Data (repeats until the end of the file)

DATA TYPE	NAME	DESCRIPTION
Name Array	Native channel name	Which channel this spike occurred on. Note: not null-terminated like the strings in the header, because this string is always exactly 5 characters
int32	Timestamp	Integer timestamp at which this spike occurred, with zero marking the beginning of the recording. Divide by the amplifier sampling rate (in Samples/s) to get a time with units of seconds.
uint8	Spike ID	With future releases of Intan software, could be expanded to assign a specific ID to a certain spike type. Currently, any non-zero ID indicates a spike.

If spike snapshots were saved, immediately following a spike's ID:

DATA TYPE	NAME	DESCRIPTION
N x uint16	Snapshot electrode voltage	Short snapshot of the waveform on which the spike was detected, where N is 'Pre-detect samples' + 'Post-detect samples'. Units: ADC steps. To convert to electrode voltage in microvolts, first subtract 32768 then multiply by 0.195.

The following MATLAB function reads a spike data file into a struct array containing each spike's name, timestamp, spike ID, and (if saved), snapshot:

```
function spikes = read_spike_data
total_bytes = dir('spike.dat').bytes;
fid = fopen('spike.dat', 'r');
if fread(fid, 1, 'uint32') ~= 0x18F8474B
    fprintf(1, 'Invalid magic number\n');
    return;
end
version_number = fread(fid, 1, 'uint16');
base_filename = readString(fid, 0);
native_channel_names = readString(fid, 0);
custom_channel_names = readString(fid, 0);
sample_rate = fread(fid, 1, 'single');
pre_detect_samples = fread(fid, 1, 'uint32');
post_detect_samples = fread(fid, 1, 'uint32');
N_snapshot = pre_detect_samples + post_detect_samples;

bytes_remaining = total_bytes - ftell(fid);
spike_struct = struct( ...
    'native_channel_name', {}, ...
    'timestamp', {}, ...
    'spike_id', {}, ...
    'snapshot', {} );
spikes = struct(spike_struct);
spikes_index = 1;

while bytes_remaining > 0
    spikes(spikes_index).native_channel_name = readString(fid, 5);
    spikes(spikes_index).timestamp = fread(fid, 1, 'int32');
    spikes(spikes_index).spike_id = fread(fid, 1, 'uint8');
```

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```
if N_snapshot > 0
    spikes(spikes_index).snapshot = (fread(fid, N_snapshot, 'uint16') ...
        - 32768) * 0.195;
end
bytes_remaining = total_bytes - ftell(fid);
spikes_index = spikes_index + 1;
end
end

% Read a string. For null-terminated strings, num_chars should be 0. For
% known-length string, num_chars should be the length of the string.
function this_str = readString(fid, num_chars)
last_read_byte = 1;
read_bytes = [];
if num_chars == 0
    while last_read_byte ~= 0
        last_read_byte = fread(fid, 1, 'uint8');
        read_bytes = [read_bytes last_read_byte];
    end
    this_str = char(read_bytes(1:end-1));
else
    read_bytes = fread(fid, num_chars, 'uint8');
    this_str = char(read_bytes);
end
end
```

“One File Per Channel” Format

This file format creates a subdirectory using the base filename provided, plus a date and time stamp. The subdirectory contains separate files for each waveform recorded by the RHD controller; if 256 amplifier channels are connected to the system, then 256 individual amplifier data files will be written. This file format has the advantage of maintaining reasonable individual file sizes even for long recordings (a one-hour recording session at 30 kS/s would generate a 216 MB file for each enabled channel) while not dividing particular waveforms between multiple files.

When using this file format, the following data files are written to the subdirectory:

Standard Intan RHD Header file: info.rhd

This file contains the data listed in the Intan RHD Standard Header described above: sampling rate, amplifier bandwidth, channel names, and other useful information. The information in this file may be read into MATLAB data structures using `read_Intan_RHD2000_file.m`, which is provided on the Intan Technologies web site.

Timestamp data file: time.dat

This file contains `int32`-type sequential integers (e.g., 0, 1, 2, 3...) corresponding to sample times indices, with zero marking the beginning of a recording or a trigger point. Time indices can be negative to denote pre-trigger times. Divide by the amplifier sampling rate (in Samples/s) to get a time vector with units of seconds.

The use of the `int32` data type means that this number will not “roll over” until total recording times exceed 19.8 hours with the maximum sample rate of 30 kS/s, or 29.8 hours with a sample rate of 20 kS/s.

The following MATLAB code reads a timestamp data file and creates a time vector with units of seconds:

```
fileinfo = dir('time.dat');
num_samples = fileinfo.bytes/4; % int32 = 4 bytes
fid = fopen('time.dat', 'r');
t = fread(fid, num_samples, 'int32');
fclose(fid);
t = t / frequency_parameters.amplifier_sample_rate; % sample rate from header file
```

RHD Application Note

Amplifier data files

Each amplifier data file has a filename that begins with **amp** followed by the SPI port letter and channel number. For example: **amp-A-000.dat**, **amp-C-063.dat**, or **amp-D-027.dat**.

Each amplifier data file contains the consecutive ADC samples from one enabled RHD2000 amplifier channel in **int16** format. To convert to electrode voltage in microvolts, multiply by 0.195.

The following MATLAB code reads an amplifier data file and creates an electrode voltage vector with units of microvolts:

```
fileinfo = dir('amp-B-003.dat');
num_samples = fileinfo.bytes/2; % int16 = 2 bytes
fid = fopen('amp-B-003.dat', 'r');
v = fread(fid, num_samples, 'int16');
fclose(fid);
v = v * 0.195; % convert to microvolts
```

Auxiliary input data files

Each auxiliary input data file has a filename that begins with **aux** followed by the port and auxiliary channel: **AUX1**, **AUX2**, or **AUX3**. (If a dual-chip amplifier board is used, **AUX4**, **AUX5**, and **AUX6** may be present.) For example: **aux-A-AUX1.dat**, **aux-B-AUX3.dat**, or **aux-C-AUX2.dat**.

Each auxiliary input data file contains the consecutive ADC samples from one enabled RHD2000 auxiliary input channel in **uint16** format. To convert to volts, multiply by 0.0000374.

Although the Intan software samples the RHD2000 auxiliary input channels at one-fourth the rate of the amplifiers, each auxiliary input sample is repeated four times in this file so that this data may easily be aligned with the timestamp vector in the **time.dat** file.

The following MATLAB code reads an auxiliary input data file and creates a waveform vector with units of volts:

```
fileinfo = dir('aux-C-AUX1.dat');
num_samples = fileinfo.bytes/2; % uint16 = 2 bytes
fid = fopen('aux-C-AUX1.dat', 'r');
v = fread(fid, num_samples, 'uint16');
fclose(fid);
v = v * 0.0000374; % convert to volts
```

Supply voltage data files

Each supply voltage data file has a filename that begins with **vdd** followed by the port and MISO channel: **VDD1** (or **VDD2** if a dual-chip amplifier board is used). For example: **vdd-A-VDD1.dat**, **vdd-B-VDD1.dat**, or **vdd-D-VDD2.dat**.

Each supply voltage data file contains the consecutive ADC samples from one enabled RHD2000 supply voltage sensor channel in **uint16** format. To convert to volts, multiply by 0.0000748.

Although the Intan software samples the RHD2000 auxiliary input channels at one-sixtieth the rate of the amplifiers, each supply voltage sample is repeated sixty times in this file so that this data may easily be aligned with the timestamp vector in the **time.dat** file.

The following MATLAB code reads a supply voltage data file and creates a waveform vector with units of volts:

```
fileinfo = dir('vdd-D-VDD1.dat');
num_samples = fileinfo.bytes/2; % uint16 = 2 bytes
fid = fopen('vdd-D-VDD1.dat', 'r');
v = fread(fid, num_samples, 'uint16');
fclose(fid);
v = v * 0.0000748; % convert to volts
```

RHD Application Note

Board ADC input data files

Each board ADC input data file has a filename that begins with **board-ADC** followed by the channel number. For example: **board-ADC-00.dat**, **board-ADC-01.dat**, or **board-ADC-07.dat**.

Each board ADC input data file contains the consecutive ADC samples from one enabled analog input on the USB interface board, in **uint16** format. See the **Traditional Intan File Format** section above for instructions on converting this data to volts.

The following MATLAB code reads a board ADC data file and creates a waveform vector with units of volts:

```
fileinfo = dir('board-ADC-00.dat');
num_samples = fileinfo.bytes/2; % uint16 = 2 bytes
fid = fopen('board-ADC-00.dat', 'r');
v = fread(fid, num_samples, 'uint16');
fclose(fid);
v = v * 0.000050354; % convert to volts (only valid if board mode == 0)
```

If the data file was generated by an Intan Recording Controller, use the following scaling instead:

```
v = (v - 32768) * 0.0003125; % convert to volts (Recording Controller)
```

Board digital input data files

Each board digital input data file has a filename that begins with **board-DIN** followed by the channel number. For example: **board-DIN-00.dat**, **board-DIN-01.dat**, or **board-DIN-15.dat**.

Each board digital input data file contains the consecutive binary samples from one enabled digital input on the USB interface board, in **uint16** format. Each **uint16** value in these files will be equal either to 0 or 1.

The following MATLAB code reads a board digital input data file and creates a waveform vector:

```
fileinfo = dir('board-DIN-07.dat');
num_samples = fileinfo.bytes/2; % uint16 = 2 bytes
fid = fopen('board-DIN-07.dat', 'r');
din07 = fread(fid, num_samples, 'uint16');
fclose(fid);
```

Board digital output data files

Each board digital output data file has a filename that begins with **board-DOUT** followed by the channel number. For example: **board-DOUT-00.dat**, **board-DOUT-01.dat**, or **board-DOUT-15.dat**.

Each board digital output data file contains the consecutive binary samples from one digital output on the USB interface board, in **uint16** format. Each **uint16** value in these files will be equal either to 0 or 1.

The following MATLAB code reads a board digital output data file and creates a waveform vector:

```
fileinfo = dir('board-DOUT-00.dat');
num_samples = fileinfo.bytes/2; % uint16 = 2 bytes
fid = fopen('board-DOUT-00.dat', 'r');
dout00 = fread(fid, num_samples, 'uint16');
fclose(fid);
```

Spike data files

Each spike data file has a filename that begins with **spike** followed by the channel number. For example: **spike-A-000.dat**, **spike-A-001.dat**, or **spike-B-037.dat**.

This file contains the timestamp of each spike on this channel that has been detected during recording. If snapshots have been saved, then each spike entry also includes the raw, unscaled data of that spike's snapshot.

The file begins with a header containing metadata about the recorded data, which is subsequently appended to spike-by-spike for each spike event that occurs on this channel.

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Header

DATA TYPE	NAME	DESCRIPTION
uint32	Intan Spike File identifier	This "magic number" always has a value of 0x18F88C00 to indicate an Intan Spike File (saved in One File Per Channel format).
uint16	Spike File version number	Which version this Spike File format follows
ASCII String	Base Filename	Base filename of recording session and time/date
ASCII String	Native channel name	This channel's native channel name
ASCII String	Custom channel name	This channel's custom channel name
single	Sample rate	Amplifier sample rate (units: Samples/s)
uint32	Pre-detect samples	Number of samples preceding a spike event to include in a snapshot
uint32	Post-detect samples	Number of samples following a spike event to include in a snapshot

Individual Spike Data (repeats until the end of the file)

DATA TYPE	NAME	DESCRIPTION
int32	Timestamp	Integer timestamp at which this spike occurred, with zero marking the beginning of the recording. Divide by the amplifier sampling rate (in Samples/s) to get a time with units of seconds.
uint8	Spike ID	With future releases of Intan software, could be expanded to assign a specific ID to a certain spike type. Currently, any non-zero ID indicates a spike.

If spike snapshots were saved, immediately following a spike's ID:

DATA TYPE	NAME	DESCRIPTION
N x uint16	Snapshot electrode voltage	Short snapshot of the waveform on which the spike was detected, where N is 'Pre-detect samples' + 'Post-detect samples'. Units: ADC steps. To convert to electrode voltage in microvolts, first subtract 32768 then multiply by 0.195.

The following MATLAB function reads a single channel's spike data file into a struct array containing each spike's timestamp, spike ID, and (if saved), snapshot:

```
function spikes = read_spike_data
filename = 'spike-A-000.dat'; % Change this string to read different channels
total_bytes = dir(filename).bytes;
fid = fopen(filename, 'r');
if fread(fid, 1, 'uint32') ~= 0x18F88C00
    fprintf(1, 'Invalid magic number\n');
    return;
end
version_number = fread(fid, 1, 'uint16')
base_filename = readString(fid, 0)
native_name = readString(fid, 0)
custom_name = readString(fid, 0)
sample_rate = fread(fid, 1, 'single')
pre_detect_samples = fread(fid, 1, 'uint32');
post_detect_samples = fread(fid, 1, 'uint32');
N_snapshot = pre_detect_samples + post_detect_samples;

bytes_remaining = total_bytes - ftell(fid);
spike_struct = struct( ...
    'timestamp', {}, ...
    'spike_id', {}, ...
    'snapshot', {} );
```

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```
spikes_index = 1;

while bytes_remaining > 0
    spikes(spikes_index).timestamp = fread(fid, 1, 'int32');
    spikes(spikes_index).spike_id = fread(fid, 1, 'uint8');
    if N_snapshot > 0
        spikes(spikes_index).snapshot = (fread(fid, N_snapshot, 'uint16') ...
            - 32768) * 0.195;
    end
    bytes_remaining = total_bytes - ftell(fid);
    spikes_index = spikes_index + 1;
end
end

% Read a string. For null-terminated strings, num_chars should be 0. For
% known-length string, num_chars should be the length of the string.
function this_str = readString(fid, num_chars)
last_read_byte = 1;
read_bytes = [];
if num_chars == 0
    while last_read_byte ~= 0
        last_read_byte = fread(fid, 1, 'uint8');
        read_bytes = [read_bytes last_read_byte];
    end
else
    read_bytes = fread(fid, num_chars, 'uint8');
end
this_str = char(read_bytes);
end
```

Handling Large Data Files

The Intan Recording Controller supports up to 1024 amplifier channels, plus several other analog and digital inputs, that may be sampled up to 30 kS/s/channel. This can quickly create enormous data files. The example MATLAB code shown above reads entire raw data files into memory, but it is also possible to read particular segments of data from a file using the MATLAB commands `fseek`, `ftell`, and `frewind` to move to specified positions in a file. Then `fread` may be used to read a subset of the data in the file beginning at that point. Similar functions are available in C++ and other programming languages.