Signal Analysis

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Based on

Signal Processing with Free Software : Practical Experiments
F. Auger

soxi

soxi s1.mp3
soxi s1.mp3 > s1_info.txt

Input File
Channels
Sample Rate
Precision
Duration
File Siz
Bit Rate
Sample Encoding

Generating signals using sox

```
sox -n s1.mp3 synth 3.5 sine 440
sox -n s2.wav synth 90000s sine 660:1000
sox -n s3.mp3 synth 1:20 triangle 440
sox -n s4.mp3 synth 1:20 trapezium 440
sox -V4 -n s5.mp3 synth 6 square 440 0 0 40
sox -n s6.mp3 synth 5 noise
```

stat

Sox s1.mp3 -n stat
Sox s1.mp3 -n stat > s1_info_stat.txt

Samples read
Length (seconds)
Scaled by
Maximum amplitude
Minimum amplitude
Midline amplitude
Mean norm
Mean amplitude
RMS amplitude
Maximum delta
Minimum delta
Mean delta
RMS delta
Rough frequency
Volume adjustment

stats

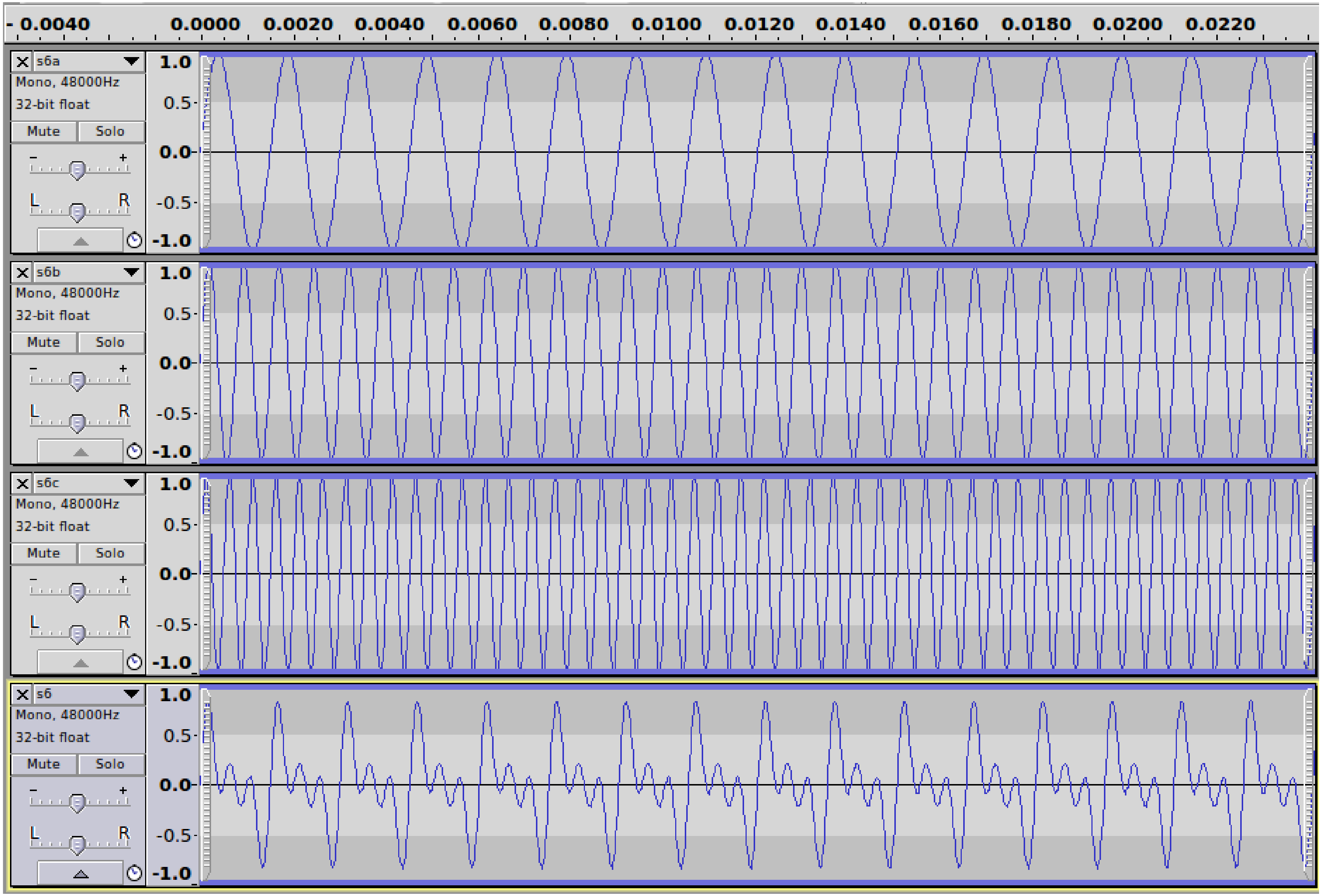
Sox s1.mp3 -n stats
Sox s1.mp3 -n stats > s1_info_stat.txt

DC Offset
Min level
Max level
Pk lev dB
RMS lev dB
RMS Pk dB
RMS Tr dB
Crest factor
Flat factor
Pk count
Bit-depth
Num samples
Length s
Scale max
Window s

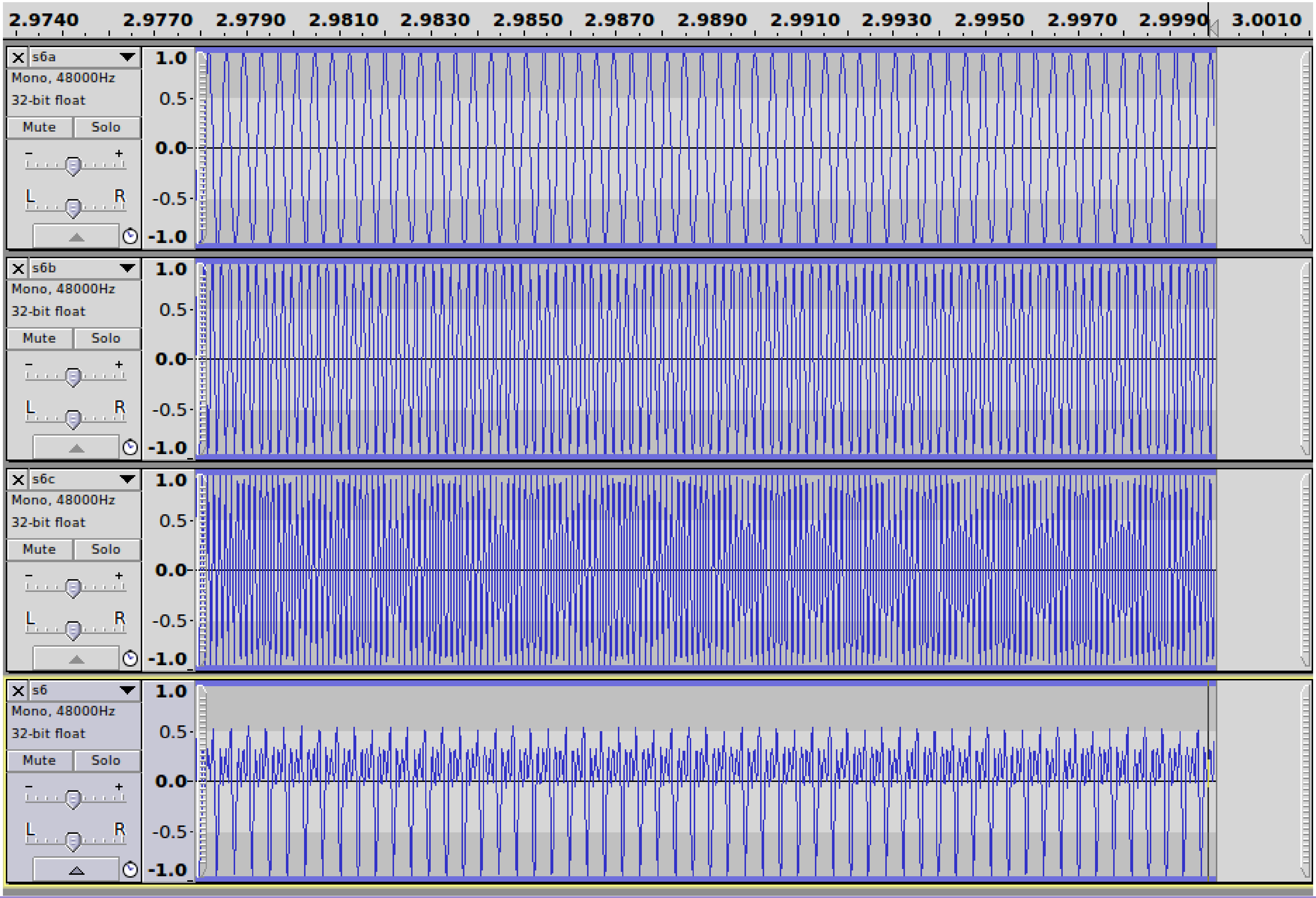
soxi

```
Sox -n s1a.wav synth 3 sine 660-2640
Sox -n s1b.wav synth 3 sine 1320-5280
Sox -n s1c.wav synth 3 sine 1980-7920
Sox -m s1a.wav s1b.wav s1c.wav s1.wav

sox s1.wav -n spectrogram          -o s1_sp1.png
sox s1.wav -n spectrogram -m       -o s1_sp2.png
sox s1.wav -n spectrogram -l       -o s1_sp3.png
sox s1.wav -n spectrogram –l -m -o s1_sp4.png
sox s1.wav -n spectrogram -l -m -S 0.5 -d 1.3 \
                                   -o s1_sp5.png
```

sox -m s1a.wav s1b.wav s1c.wav s1.wav – beginning



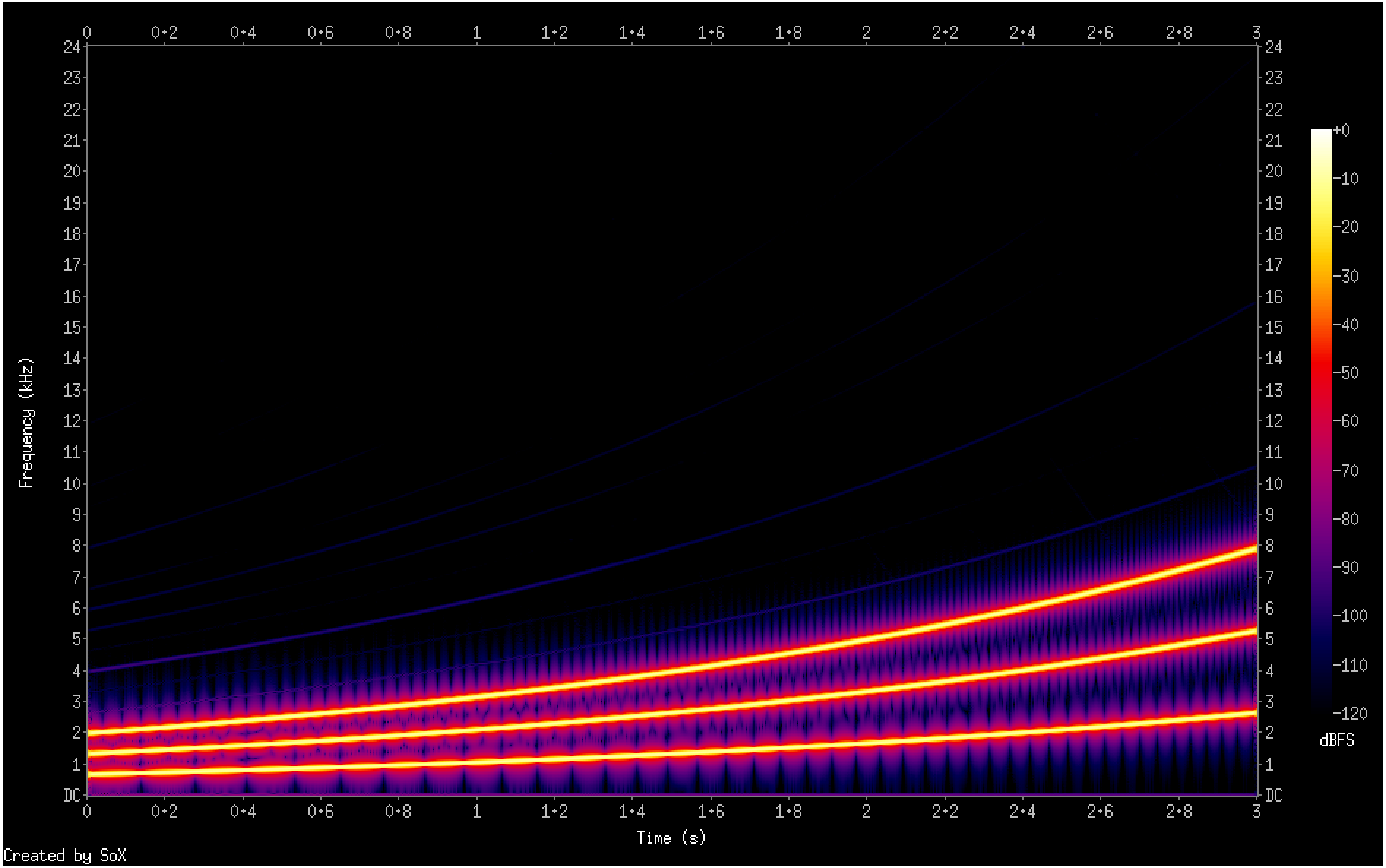
sox -m s1a.wav s1b.wav s1c.wav s1.wav – ending



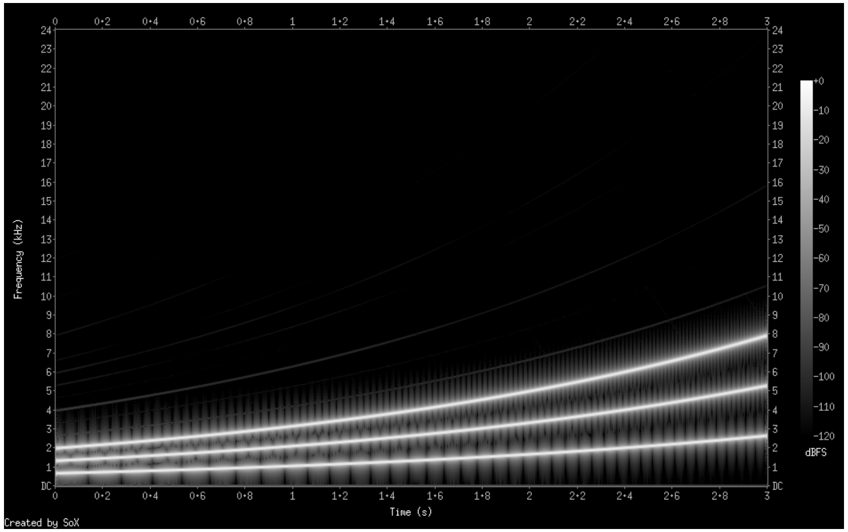
soxi

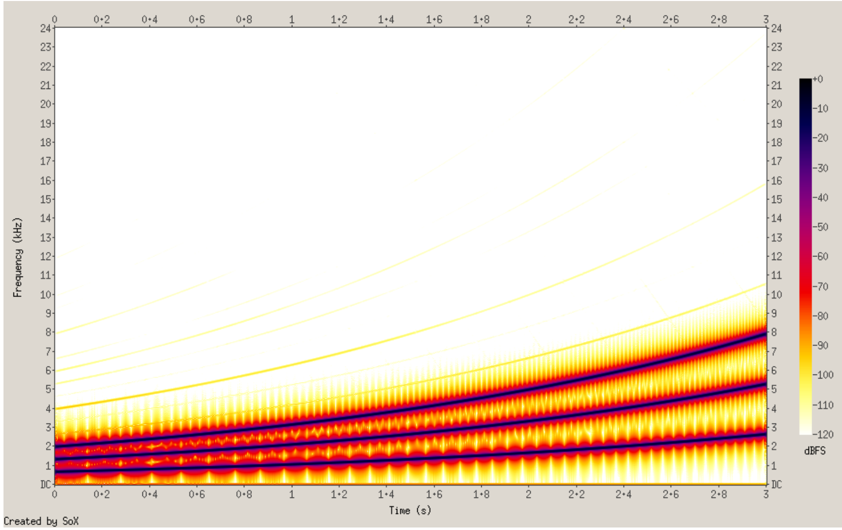
```
sox -n s1a.wav synth 3 sine 660-2640
sox -n s1b.wav synth 3 sine 1320-5280
sox -n s1c.wav synth 3 sine 1980-7920
sox -m s1a.wav s1b.wav s1c.wav s1.wav

sox s1.wav -n spectrogram          -o s1_sp1.png
sox s1.wav -n spectrogram -m       -o s1_sp2.png
sox s1.wav -n spectrogram -l       -o s1_sp3.png
sox s1.wav -n spectrogram –l -m -o s1_sp4.png
sox s1.wav -n spectrogram -l -m -S 0.5 -d 1.3 \
                                   -o s1_sp5.png
```

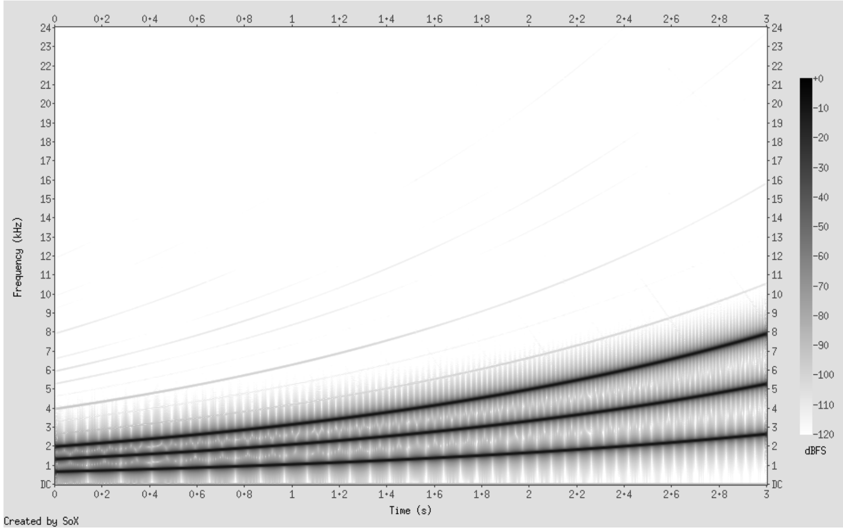
soxi

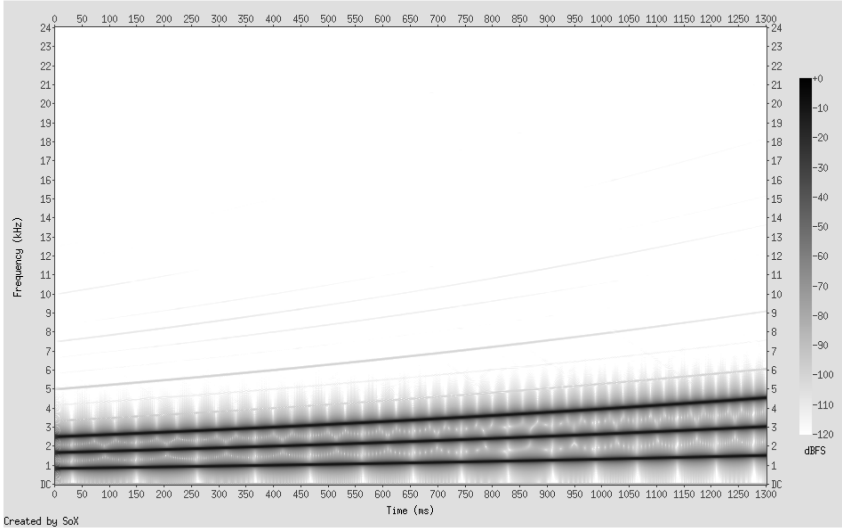


soxi


Frequency (kHz)
Time (s)
dBFS
Created by SoX


Frequency (kHz)
Time (s)
dBFS
Created by SoX

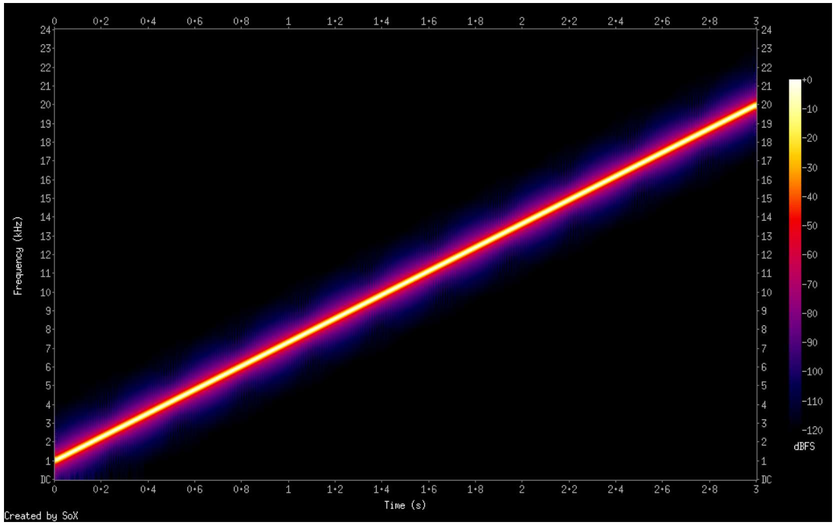

Frequency (kHz)
Time (s)
dBFS
Created by SoX

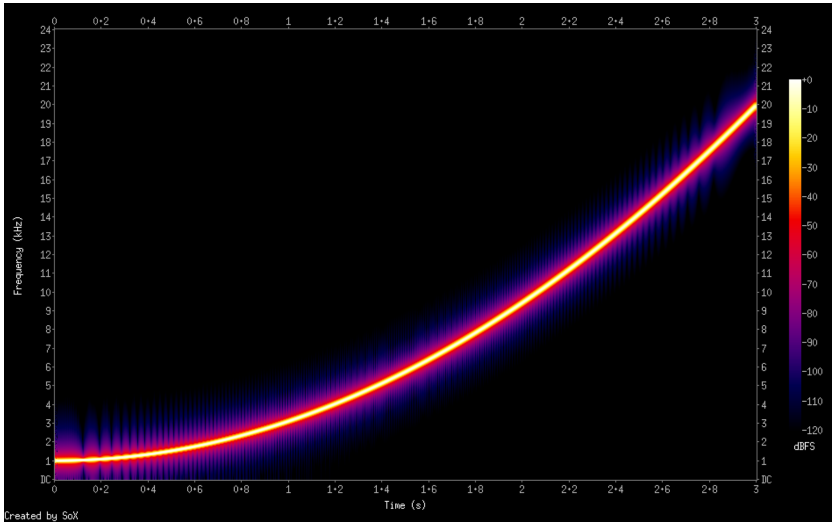

Frequency (kHz)
Time (ms)
dBFS
Created by SoX

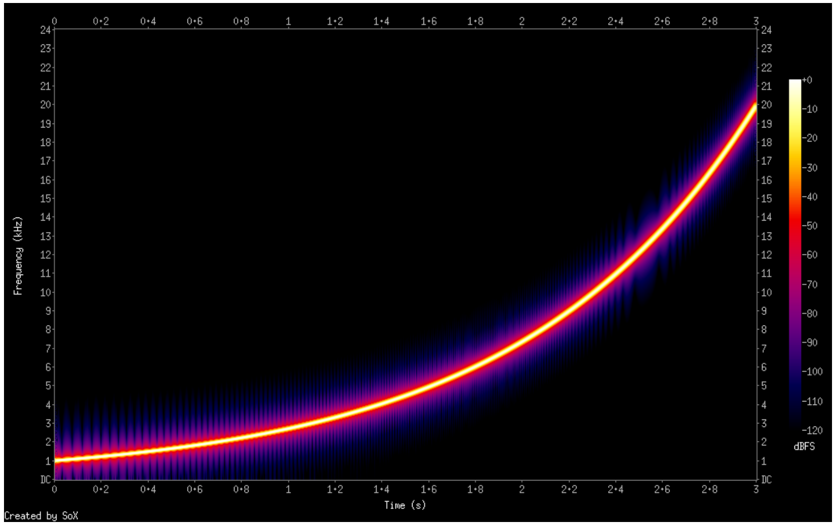
soxi

```
sox -n chirp1.wav synth 3 sine 1000:20000
sox -n chirp2.wav synth 3 sine 1000+20000
sox -n chirp3.wav synth 3 sine 1000/20000

sox chirp1.wav -n spectrogram -o chirp1_sp.png
sox chirp2.wav -n spectrogram -o chirp2_sp.png
sox chirp3.wav -n spectrogram -o chirp3_sp.png
```

soxi


Frequency (kHz)
Time (s)
dBFS
Created by SoX


Frequency (kHz)
Time (s)
dBFS
Created by SoX

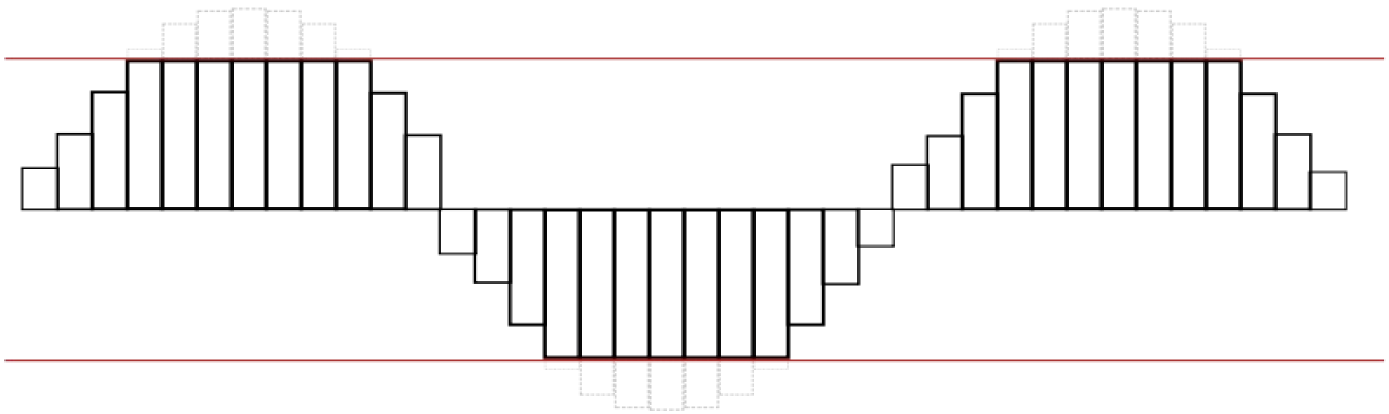

Frequency (kHz)
Time (s)
dBFS
Created by SoX

dbFS

Decibels relative to full scale (dBFS) is
a unit of measurement for amplitude levels in digital systems,
which have a defined maximum peak level.

The level of 0 dBFS is assigned to
the maximum possible digital level.
a signal that reaches 50% of the maximum level
has a level of −6 dBFS, which is 6 dB below full scale.

Conventions differ for root mean square (RMS) measurements,
but all peak measurements smaller than the maximum are negative levels.



https://en.wikipedia.org/wiki/DBFS

Sox **remix** usage examples

sox input.wav output.wav remix 6 7 8 0

creates an output file with four channels
where channels 1, 2, and 3 are
copies of channels 6, 7, and 8 in the input file,
and channel 4 is silent.

sox input.wav output.wav remix 1−3,7 3

the left channel is a mix-down of input channels 1, 2, 3, and 7
and the right channel is a copy of input channel 3.
when a range of channels is specified
the channel numbers to the left and right of the hyphen are optional
and default to 1 and to the number of input channels respectively

sox input.wav output.wav remix −

performs a mix-down of all input channels to mono.

http://sox.sourceforge.net/sox.html

Sox **trim** usage examples

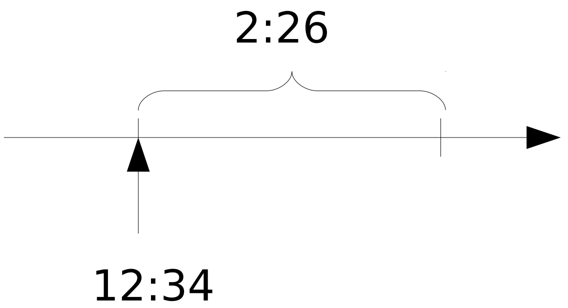
sox infile outfile trim 0 10

will copy the first ten seconds

play infile trim 12:34 =15:00 -2:00
play infile trim 12:34 2:26 -2:00

will both play from 12 minutes 34 seconds into the audio
up to 15 minutes into the audio (i.e. 2 minutes and 26 seconds long),
then resume playing two minutes before the end of audio.

$$\begin{array}{rr} & 15{:}00 \\ - & 12{:}34 \\ \hline & 2{:}26 \end{array}$$



http://sox.sourceforge.net/sox.html

Sox **-b** usage examples

For an input file, the most common use for this option is
to inform SoX of the number of bits per sample
in a ‘raw’ (‘headerless’) audio file.

sox −r 16k −e signed −b 8 input.raw output.wav

converts a particular ‘raw’ file to a self-describing ‘WAV’ file.

For an output file, this option can be used (perhaps along with −e)
to set the output encoding size.
By default, the output encoding size will be set to the input encoding size.
(providing it is supported by the output file type)

sox input.cdda −b 24 output.wav

converts raw CD digital audio (16-bit, signed-integer)
to a 24-bit (signed-integer) ‘WAV’ file.

http://sox.sourceforge.net/sox.html

Sox **dither** usage examples

dither [−S|−s|−f filter] [−a] [−p precision]

Apply dithering to the audio.
Dithering deliberately adds a small amount of noise
to the signal in order to mask audible quantization effects
that can occur if the output sample size is less than 24 bits.

With no options, this effect will add triangular (TPDF) white noise.
Noise-shaping (only for certain sample rates) can be selected with **−s**.

With the **−f** option, it is possible to select a particular noise-shaping filter
from the following list: lipshitz, f-weighted, modified-e-weighted, improved-e-weighted, gesemann, shibata, low-shibata, high-shibata.

Note that most filter types are available only with 44100Hz sample rate.
The filter types are distinguished by the following properties:
audibility of noise, level of (inaudible, but in some circumstances, otherwise problematic) shaped high frequency noise, and processing speed.

http://sox.sourceforge.net/sox.html

Sox **rate** usage examples (1)

the following two commands are equivalent:

sox input.wav −r 48k output.wav bass −b 24
sox input.wav output.wav bass −b 24 rate 48k

the rate option is more flexible
allows rate's other options and
allows the effects to be ordered arbitrarily

sox input.wav −b 16 output.wav rate −s −a 44100 dither −s

sox input.wav −b 24 output.aiff rate −v −I −b 90 48k

http://sox.sourceforge.net/sox.html

Sox **rate** usage examples (2)

sox input.wav −b 16 output.wav rate −s −a 44100 dither −s

default (high) quality resampling;
overrides: steep filter, allow aliasing;
to 44.1kHz sample rate;
noise-shaped dither to 16-bit WAV file.

−s ‘**steep filter**’ changes resampling band-width
from the default 95% (based on the 3dB point), to 99%.

−a option is given, then **aliasing/imaging**
above the pass-band is allowed.

http://sox.sourceforge.net/sox.html

Sox **rate** usage examples (3)

sox input.wav −b 24 output.aiff rate −v −I −b 90 48k

very high quality resampling;
overrides: intermediate phase,
band-width 90%;
to 48k sample rate;
store output to 24-bit AIFF file.

−M, **−I**, or **−L** option : **Minimum**, **intermediate**, or **linear phase response**
−p option : a **custom** phase response

Note that phase responses between 'linear' and 'maximum' (greater than 50) are rarely useful.

http://sox.sourceforge.net/sox.html

Sox **delay** usage examples

Delay one or more audio channels such that they start at the given position.

delay 1.5 +1 3000s

delays the first channel by 1.5 seconds,
the second channel by 2.5 seconds
(one second more than the previous channel),
the third channel by 3000 samples,
and leaves any other channels that may be present un-delayed.

The following (one long) command plays a **chime** sound:

```
play −n synth −j 3 sin %3 sin %−2 sin %−5 sin %−9 \
  sin %−14 sin %−21 fade h .01 2 1.5 delay \
  1.3 1 .76 .54 .27 remix − fade h 0 2.7 2.5 norm −1
```

and this plays a guitar chord:

```
play −n synth pl G2 pl B2 pl D3 pl G3 pl D4 pl G4 \
  delay 0 .05 .1 .15 .2 .25 remix − fade 0 4 .1 norm −1
```

http://sox.sourceforge.net/sox.html

Sox spectrogram

the audio is passed unmodified
through the SoX processing chain
to create a spectrogram of the audio

the spectrogram is rendered in a PNG file

- time in the X-axis
- frequency in the Y-axis
- magnitude in the Z-axis by the colour or the intensity

multiple channels are shown
from top to bottom starting from channel 1
(the left channel for stereo audio).

http://sox.sourceforge.net/sox.html

Sox spectrogram usage examples (1)

‘**my.wav**’ is a stereo file
‘**spectrogram.png**’ is a spectrogram

sox my.wav −n spectrogram

sox my.wav −n remix 2 trim 20 30 spectrogram

sox my.wav −n rate 6k spectrogram

http://sox.sourceforge.net/sox.html

Sox spectrogram usage examples (2)

* to analyze a smaller portion of the audio

sox my.wav −n remix 2 trim 20 30 spectrogram

only from the second (right) channel **2**
duration of 30 seconds starting from 20 seconds in **20 30**

* to analyze a small portion of the frequency domain
the rate effect may be used

sox my.wav −n rate 6k spectrogram

detailed analysis of frequencies **6k**
up to 3kHz (half the sampling rate)

http://sox.sourceforge.net/sox.html

Sox spectrogram usage examples (3)

sox my.wav −n trim 0 10 spectrogram −x 600 −y 200 −z 100

controls the size of the spectrogram’s X, Y, Z axes
600 by 200 pixels in size
the Z-axis range will be 100 dB

sox −n −n synth 6 tri 10k:14k spectrogram −z 100 −w kaiser

an analysis ‘window’ with high dynamic range is selected to
best display the spectrogram of a swept triangular wave.

http://sox.sourceforge.net/sox.html

Sox spectrogram usage examples (4)

append the following to the ‘chime’ command
in the description of the delay effect (above):

rate 2k spectrogram −X 200 −Z −10 −w kaiser

X-axis **200 pixels/second**

play −n synth −j 3 sin %3 sin %−2 sin %−5 sin %−9 \
sin %−14 sin %−21 fade h .01 2 1.5 **delay** \
1.3 1 .76 .54 .27 remix − fade h 0 2.7 2.5 norm −1

http://sox.sourceforge.net/sox.html

Sox spectrogram usage examples (5)

to control the appearance (colour-set, brightness, contrast, etc.)
and filename of the spectrogram; e.g. with

sox my.wav −n spectrogram −m −l −o print.png

a spectrogram is created suitable for printing on a ‘black and white’ printer.

−m : Creates a monochrome spectrogram (the default is colour).
−l : Creates a ‘printer friendly’ spectrogram with a light background
(the default has a dark background).

http://sox.sourceforge.net/sox.html

Sox spectrogram -d

−d duration
sets the X-axis resolution
such that audio with the given duration (a time specification)
fits the selected (or default) X-axis width.

sox input.mp3 output.wav −n spectrogram −d 1:00 stats

creates a spectrogram showing the first minute of the audio,
whilst the **stats** effect is applied to the entire audio signal.

See also −X for an alternative way of setting the X-axis resolution.

http://sox.sourceforge.net/sox.html

Sox spectrogram -x -X

−x num
Sets **the X-axis size** <u>in pixels</u>
Change the (maximum) **width** (X-axis) of the spectrogram
default value of 800 pixels [100 ~ 200000]. See also −X and −d.

−X num
X-axis **pixels/second**; the default is auto-calculated
to fit the given or known audio duration to the X-axis size, or 100 otherwise.
with −d, this option affects the width of the spectrogram;
otherwise, it affects the duration of the spectrogram.
[1 ~ 5000] need not be an integer.
a slight adjustment for processing quantisation reasons;
if so, SoX will report the actual number used
(viewable when the SoX global option −V is in effect). See also −x and −d.

http://sox.sourceforge.net/sox.html

Sox spectrogram -y -Y

−y num
Sets the **Y-axis size** in pixels (***per channel***);
this is the number of **frequency bins** used
N.B. it can be slow to produce the spectrogram
if this number is not one more than a power of two (e.g. 129).
By default the Y-axis size is chosen automatically
(depending on the number of channels).
See −Y for alternative way of setting spectrogram height.

−Y num
Sets the target **total height** of the spectrogram(s).
The default value is 550 pixels.
Using this option (and by default), SoX will choose a height
for individual spectrogram channels
that is one more than a power of two,
so the actual total height may fall short of the given number.
However, there is also a minimum height per channel
so if there are many channels, the number may be exceeded.
See −y for alternative way of setting spectrogram height.

http://sox.sourceforge.net/sox.html

Sox spectrogram -z -Z

−z num
Z-axis (colour) range in dB, default 120.
This sets the dynamic-range of the spectrogram
to be −num dBFS to 0 dBFS.
Num may range from 20 to 180.
Decreasing dynamic-range effectively
increases the ‘contrast’ of the spectrogram display,
and vice versa.

−Z num
Sets the upper limit of the Z-axis in dBFS.
A negative num effectively
increases the ‘brightness’ of the spectrogram display,

http://sox.sourceforge.net/sox.html

Sox spectrogram -q

−q num

Sets the **Z-axis quantisation**,
i.e. the number of different colours (or intensities)
in which to render Z-axis values.
A small number (e.g. 4) will give a ‘poster’-like effect
making it easier to discern magnitude bands of similar level.
Small numbers also usually result in small PNG files.
The number given specifies the number of colours to use inside the Z-axis range;
two colours are reserved to represent out-of-range values.

http://sox.sourceforge.net/sox.html

Sox spectrogram -w -W

−w name
Window: Hann (default), Hamming, Bartlett, Rectangular, Kaiser or Dolph.
By default, SoX uses the Hann window
which has good all-round frequency-resolution
and dynamic-range properties.
For better frequency resolution (but lower dynamic-range),
select a Hamming window;
for higher dynamic-range (but poorer frequency-resolution),
select a Dolph window.
Kaiser, Bartlett and Rectangular windows are also available.

- Hann (default)
- Hamming
- Bartlett
- Rectangular
- Kaiser
- Dolph

−W num
Window adjustment parameter.
This can be used to make small adjustments
to the Kaiser or Dolph window shape.
A positive number (up to ten) increases its dynamic range,
a negative number decreases it.

http://sox.sourceforge.net/sox.html

Sox spectrogram -s, -m, -h

−s
Allow slack overlapping of DFT windows.
This can, in some cases, increase image sharpness and
give greater adherence to the −x value,
but at the expense of a little spectral loss.

−m
Creates a monochrome spectrogram (the default is colour).

−h
Selects a high-colour palette-less visually pleasing
than the default colour palette,
but it may make it easier to differentiate different levels.
If this option is used in conjunction with −m,
the result will be a hybrid monochrome/colour palette.

http://sox.sourceforge.net/sox.html

Sox spectrogram -p -l -a -r

−p num
Permute the colours in a colour or hybrid palette.
The num parameter, from 1 (the default) to 6, selects the permutation.

−l
Creates a ‘printer friendly’ spectrogram
with a light background (the default has a dark background).

−a
Suppress the display of the axis lines.
This is sometimes useful in helping
to discern artifacts at the spectrogram edges.

−r
Raw spectrogram:
suppress the display of axes and legends.

http://sox.sourceforge.net/sox.html

Sox spectrogram -A -t text -c text -o file

−A
Selects an alternative, fixed colour-set.
This is provided only for compatibility
with spectrograms produced by another package.
It should not normally be used as it has some problems,
not least, a lack of differentiation at the bottom end which results
in masking of low-level artifacts.

−t text
Set the image title - text to display above the spectrogram.

−c text
Set (or clear) the image comment - text to display below
and to the left of the spectrogram.

−o file
Name of the spectrogram output PNG file,
default ‘spectrogram.png’.
If ‘-’ is given, the spectrogram will be sent to standard output (stdout).

http://sox.sourceforge.net/sox.html

Sox **stat** usage examples (1)

stat [−s scale] [−rms] [−freq] [−v] [−d]

Display time and frequency domain
statistical information about the audio.
Audio is passed unmodified through the SoX processing chain.

The **−s** option can be used to scale the input data by a given factor.
The default value of scale is 2147483647
(i.e. the maximum value of a 32-bit signed integer).
Internal effects always work with signed long PCM data
and so the value should relate to this fact.

http://sox.sourceforge.net/sox.html

Sox **stat** usage examples (2)

stat [−s scale] [−rms] [−freq] [−v] [−d]

The **−rms** option will convert all output average values
to ‘root mean square’ format.

The **−v** option displays only the ‘Volume Adjustment’ value.

The **−freq** option calculates the input’s power spectrum (4096 point DFT)
instead of the statistics listed above.
This should only be used with a single channel audio file.

The **−d** option displays a hex dump of the 32-bit signed PCM data audio
in SoX’s internal buffer.
This is mainly used to help track down endian problems
that sometimes occur in cross-platform versions of SoX.

http://sox.sourceforge.net/sox.html

Sox **stat** usage examples (3)

n is the duration of the audio in samples,
c is the number of audio channels,
r is the audio sample rate, and
x_k represents the PCM value (in the range −1 to +1 by default)
of each successive sample in the audio
Note that the delta measurements are not applicable for multi-channel audio.

Samples read	$n \times c$
Length (seconds)	n/r
Scaled by max amplitude	$max(x_k)$
Scaled by min amplitude	$min(x_k)$
Scaled by midline amplitude	$\frac{1}{2}(max(x_k)+min(x_k))$
mean norm	$\frac{1}{n}\Sigma\lvert x_k\rvert$

mean amplitude	$\frac{1}{n}\Sigma x_k$
RMS amplitude	$\sqrt{\frac{1}{n}\Sigma x_k}$
max delta	$max(\lvert x_k - x_{k-1}\rvert)$
min delta	$min(\lvert x_k - x_{k-1}\rvert)$
mean delta	$\sqrt{\frac{1}{n-1}\sum(\lvert x_k - x_{k-1}\rvert)}$
rough frequency	
volum adjustment	

http://sox.sourceforge.net/sox.html

Sox **stat** usage examples (4)

Max amplitude : The maximum samplevalue in the audio; usually this will be a positive number.
Min amplitude : The minimum sample value in the audio; usually this will be a negative number.
Mean norm : The average of the absolute value of each sample in the audio.
Mean amplitude : The average of each sample in the audio. If this figure is non-zero, then it indicates the presence of a D.C. offset (which could be removed using the dcshift effect).
RMS amplitude : The level of a D.C. signal that would have the same power as the audio's average power.
Rough frequency : in Hz
Volume Adjustment : The parameter to the vol effect which would make the audio as loud as possible without clipping. Note: See the discussion on Clipping above for reasons why it is rarely a good idea actually to do this.

http://sox.sourceforge.net/sox.html

Sox **stats** usage examples (1)

stats [−b bits|−x bits|−s scale] [−w window-time]

Display time domain statistical information about the audio channels; audio is passed unmodified through the SoX processing chain. Statistics are calculated and displayed for each audio channel and, where applicable, an overall figure is also given.

For example, for a typical well-mastered stereo music file:

```
             Overall      Left     Right
DC offset   0.000803 -0.000391  0.000803
Min level  -0.750977 -0.750977 -0.653412
Max level   0.708801  0.708801  0.653534
Pk lev dB      -2.49     -2.49     -3.69
RMS lev dB    -19.41    -19.13    -19.71
RMS Pk dB     -13.82    -13.82    -14.38
RMS Tr dB     -85.25    -85.25    -82.66
Crest factor       -      6.79      6.32
Flat factor     0.00      0.00      0.00
Pk count           2         2         2
Bit-depth      16/16     16/16     16/16
Num samples    7.72M
Length s     174.973
Scale max   1.000000
Window s       0.050
```

http://sox.sourceforge.net/sox.html

Sox **stats** usage examples (2)

DC offset, **Min level**, and **Max level** are shown, by default, in the range ±1.
−b (bits) to be scaled to a signed integer with the given number of bits;
for example, for 16 bits, the scale would be −32768 to +32767.
−x is similar to **−b** except in hexadecimal
−s scales by a given floating-point number.

Pk lev dB and **RMS lev dB** are standard peak and RMS level measured in dBFS.
RMS Pk dB and **RMS Tr dB** are peak and trough values for RMS level
measured over a short window (default 50ms).

Crest factor is the standard ratio of peak to RMS level (note: not in dB).

Flat factor is a measure of the flatness
(i.e. consecutive samples with the same value)
of the signal at its peak levels
(i.e. either Min level, or Max level).
Pk count is the number of occasions
(not the number of samples)
that the signal attained either Min level, or Max level.

http://sox.sourceforge.net/sox.html

Sox **stats** usage examples (3)

The right-hand **Bit-depth** figure is
the standard definition of bit-depth i.e.
bits less significant than the given number are fixed at zero.
the number of least significant bits
that are fixed at zero

The left-hand **Bit-depth** figure is
the number of most significant bits
that are fixed at zero (or one for negative numbers)
subtracted from the right-hand figure
(the number subtracted is directly related to Pk lev dB).

http://sox.sourceforge.net/sox.html

Sox **stats** usage examples (4)

For multi-channel audio, an **overall figure** for each of the above measurements is given and derived from the channel figures as follows:

- DC offset:
- maximum magnitude;
- Max level
- Pk lev dB
- RMS Pk dB
- Bit-depth
- maximum
- Min level
- RMS Tr dB
- minimum
- RMS lev dB
- Flat factor
- Pk count
- average
- Crest factor: not applicable.

```
                Overall      Left       Right
DC offset      0.000803  -0.000391   0.000803
Min level     -0.750977  -0.750977  -0.653412
Max level      0.708801   0.708801   0.653534
Pk lev dB         -2.49      -2.49      -3.69
RMS lev dB       -19.41     -19.13     -19.71
RMS Pk dB        -13.82     -13.82     -14.38
RMS Tr dB        -85.25     -85.25     -82.66
Crest factor          -       6.79       6.32
Flat factor        0.00       0.00       0.00
Pk count              2          2          2
Bit-depth         16/16      16/16      16/16
Num samples       7.72M
Length s        174.973
Scale max      1.000000
Window s          0.050
```

http://sox.sourceforge.net/sox.html

Sox **stats** usage examples (5)

Length s is the duration in seconds of the audio, and
Num samples is equal to the sample-rate multiplied by Length.
Scale Max is the scaling applied to the first three measurements; specifically, it is the maximum value that could apply to Max level.
Window s is the length of the window used for the peak and trough RMS measurements.

http://sox.sourceforge.net/sox.html

soxi

```
sox -n chirp1.wav synth 3 sine 1000:20000
sox -n chirp2.wav synth 3 sine 1000+20000
sox -n chirp3.wav synth 3 sine 1000/20000

sox chirp1.wav -n spectrogram -o chirp1_sp.png
sox chirp2.wav -n spectrogram -o chirp2_sp.png
sox chirp3.wav -n spectrogram -o chirp3_sp.png
```

soxi

```
sox -n chirp1.wav synth 3 sine 1000:20000
sox -n chirp2.wav synth 3 sine 1000+20000
sox -n chirp3.wav synth 3 sine 1000/20000

sox chirp1.wav -n spectrogram -o chirp1_sp.png
sox chirp2.wav -n spectrogram -o chirp2_sp.png
sox chirp3.wav -n spectrogram -o chirp3_sp.png
```

References

[1] F. Auger, Signal Processing with Free Software : Practical Experiments