

Audio Quantization and Resampling Report

Część 1 (sin_)

Kwantyzacja:

Dla 4-bitowej kwantyzacji widać znaczące zniekształcenia zarówno w czasie, jak i w widmie — widoczne spłaszczenia i ograniczenie zakresu. Od 8-bitów jakość wizualna jest już akceptowalna, ale na wykresach widmowych wciąż widać lekką degradację (brak płynności). Przy 16 i 24 bitach sygnały praktycznie nie różnią się od oryginału.

Decymacja:

Przy decymacji w widmie pojawiają się szpilki zamiast ciągłego widma – typowy efekt aliasingu. Od kroku 6 widać wyraźne różnice w dziedzinie czasu (zmniejszenie liczby próbek w okresie).

Interpolacja:

Interpolacja to w praktyce bardzo podobna operacja do decymacji - jeśli oryginalny sygnał był próbkowany z 48 kHz, to interpolacja do 2 kHz oznacza dokładnie to samo co decymacja o kroku 24 (48/2). Tak samo 8 kHz odpowiada decymacji 6 itd. Można to zauważyć w tabeli: pary interpolacji i odpowiadającej im decymacji dają dokładnie tę samą maksymalną amplitudę widmową. Interpolacja ma lepszą jakość przekształcenia. W przeciwieństwie do decymacji, gdzie widmo staje się zestawem ostrzych szpilek, interpolacja generuje widmo, które wygląda jak normalna funkcja - gładka i ciągła, czyli interpolacja radzi sobie lepiej z aliasingiem. Dodatkowo, metoda kubiczna wypada lepiej niż liniowa - jej widma wyglądają na bardziej łagodne.

Sygnal 8kHz:

Ponieważ sygnał był próbkowany z częstotliwością 48 kHz, jego okres wynosi dokładnie 6 próbek.

Przez to:

Decymacja 6, 12 i 24 oraz interpolacje do 2kHz, 4kHz, 8kHz i 16kHz dawały sygnał całkowicie zerowy (ze słabym wzrostem – prawdopodobnie fluktuacje interpolacji).

W przypadku interpolacji 2kHz/4kHz/8kHz, zawsze wybierana była ta sama połowa okresu, więc efekt to liniowo płaski sygnał

Dla 16kHz wybierane są co 3 próbki, czyli co półokresu — pojawia się więc zmienność dodatnia/ujemna.

Dla 11999Hz i wyżej efekt już nie występował (dlatego, że próbki przestają się pokrywać z regularnym wzorcem oryginału)

Też warto zaznaczyć, że nawet jeżeli by ten sygnał nie miał takiej charakterystyki okresowości przy interpolacji i decymacji, to i tak prawdopodobnie byłby problem z przekształczeniem ponizej progu Nyquista (czyli 8kHz dla tego sygnału). Dlatego decymacji 10 (czyli 4.8kHz), wskazano dominantna częstotliwość jako 1600Hz, a przy interpolacji 11999Hz – 3999Hz.

Dla sygnału sin_combined.wav, maksymalne częstotliwości na widmach zmieniały się zależnie od typu modyfikacji, co pokazuje złożoność sygnału i wpływ różnych technik na detekcję częstotliwości dominujących.

Część 2 (sing.):

Dla pliku low1 kwantyzacja 4-bitowa daje bardzo niską jakość — słyszać dużo szumu i zniekształceń. Natomiast już przy 8-bitach brzmienie staje się akceptowalne. Przy decymacji kroki 4 i 6 nadal pozwalają rozpoznać oryginalny głos, natomiast przy kroku 10 dźwięk staje się głęboki i cichy, a przy kroku 24 — kompletnie niezrozumiałы, losowy. Interpolacja do 4 kHz brzmi praktycznie identycznie jak decymacja 24, przy 8 kHz jest lepiej, ale nadal cicho. Dopiero od 11999 Hz jakość jest wyraźnie lepsza, a przy 16 kHz praktycznie identyczna z oryginałem.

Dla pliku medium2 obserwacje są podobne, jednak degradacja jakości następuje szybciej. Nawet przy decymacji 4 jakość jest już wyraźnie

obniżona, a przy kroku 6 głos brzmi jak z bardzo starego urządzenia. Dla kroków 10 i 24 dźwięk staje się niemal niezrozumiały. Interpolacja daje bardzo zbliżone efekty — im niższa częstotliwość, tym gorsza jakość, dokładnie odpowiadająca decymacji o równoważnym stopniu.

Dla pliku high1 kwantyzacja 4-bitowa daje najgorszy efekt spośród wszystkich plików — zniekształcenia są najbardziej słyszalne. Już przy decymacji 4 jakość wyraźnie spada, a od kroku 6 pojawiają się nienaturalne dźwięki. Przy 10 i 24 sygnał jest kompletnie zniekształcony. Interpolacja zachowuje się podobnie jak w poprzednich przypadkach i daje te same wnioski: jakość mocno koreluje z odpowiadającą jej decymacją.

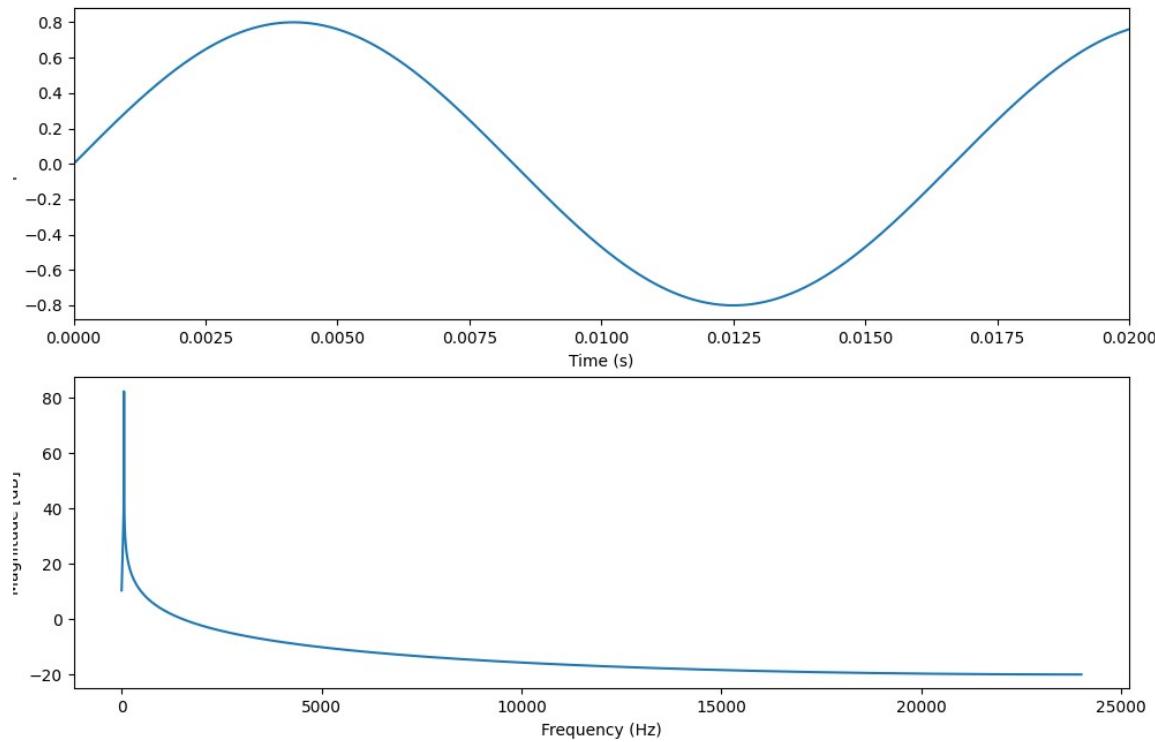
File: sin_60Hz.wav

Modification	Max Frequency (Hz)	Max Amplitude (dB)
Original	60.06	82.33
4-bit quant	60.06	82.37
8-bit quant	60.06	82.33
16-bit quant	60.06	82.33
24-bit quant	60.06	82.33
Decimation 2	60.01	79.65
Decimation 4	60.01	73.62
Decimation 6	60.02	70.10
Decimation 10	60.03	65.67
Decimation 24	60.06	58.06
linear interp 2000Hz	60.06	58.05
cubic interp 2000Hz	60.06	58.05
linear interp 4000Hz	60.03	64.08
cubic interp 4000Hz	60.03	64.08
linear interp 8000Hz	60.02	70.10
cubic interp 8000Hz	60.02	70.10
linear interp 11999Hz	60.02	73.62
cubic interp 11999Hz	60.02	73.62
linear interp 16000Hz	60.01	76.12
cubic interp 16000Hz	60.01	76.12
linear interp 16953Hz	60.01	76.63
cubic interp 16953Hz	60.01	76.63
linear interp 24000Hz	60.01	79.65
cubic interp 24000Hz	60.01	79.65
linear interp 41000Hz	60.06	82.32
cubic interp 41000Hz	60.06	82.32

Visualizations

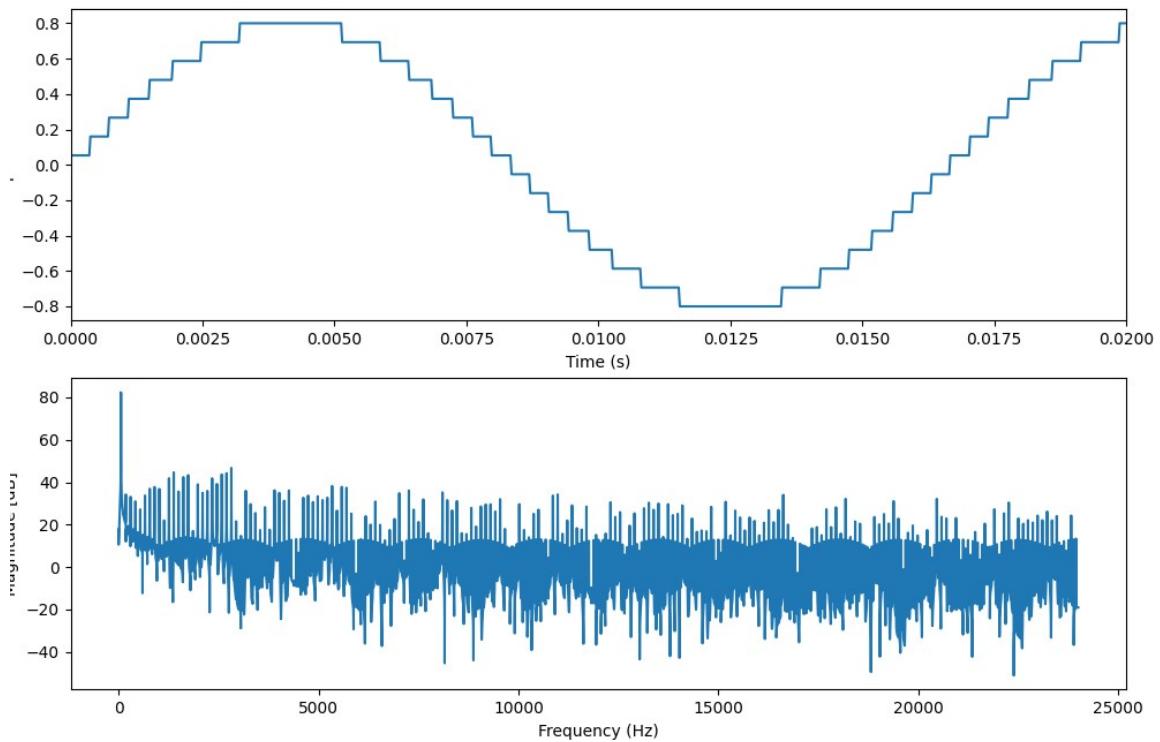
Original

Time margin [0, 0.02]



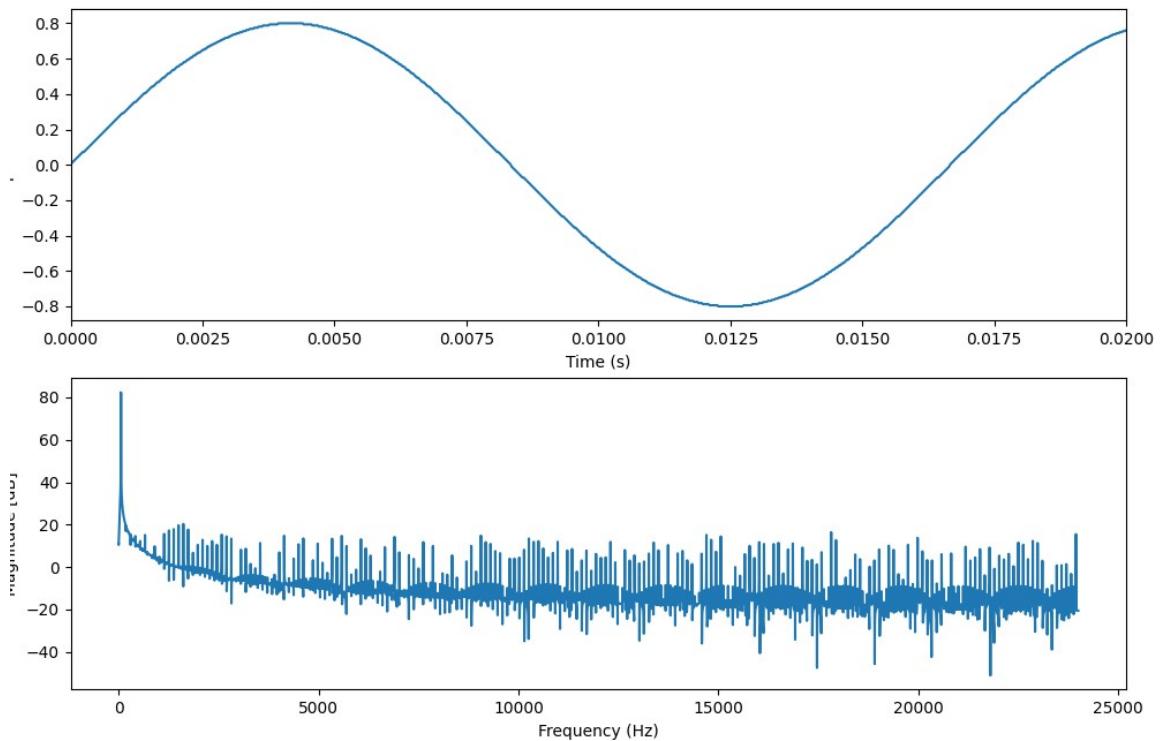
4-bit quant

Time margin [0, 0.02]



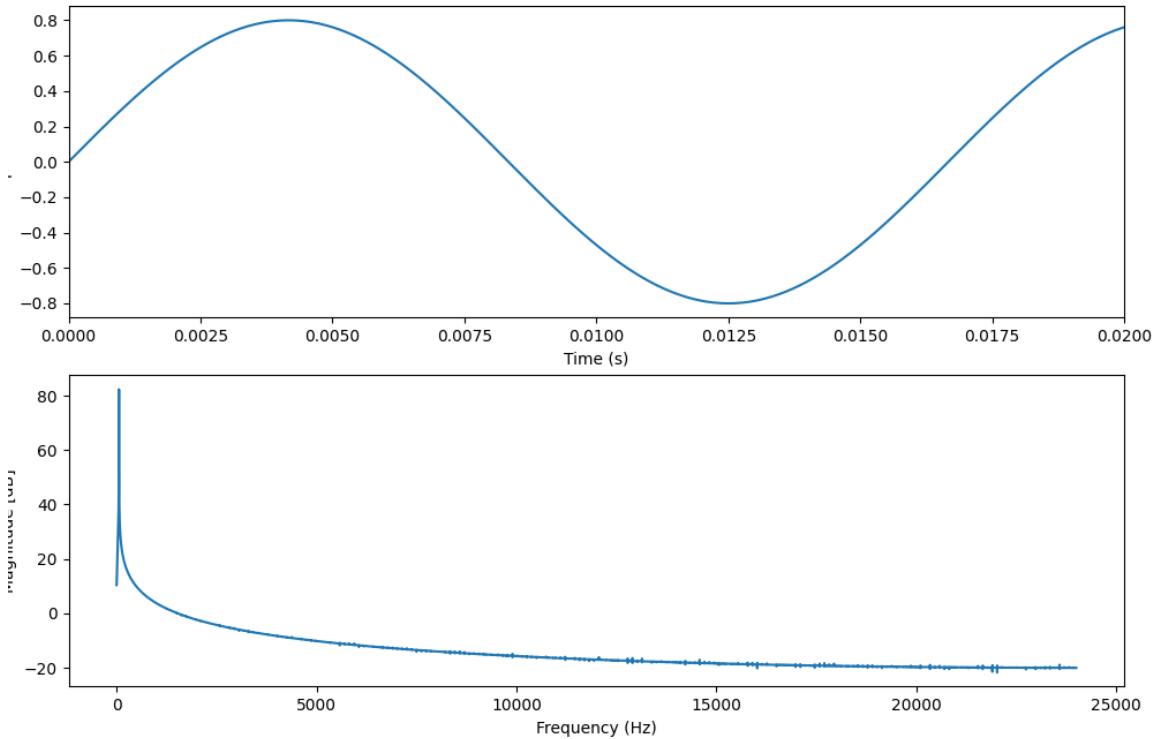
8-bit quant

Time margin [0, 0.02]



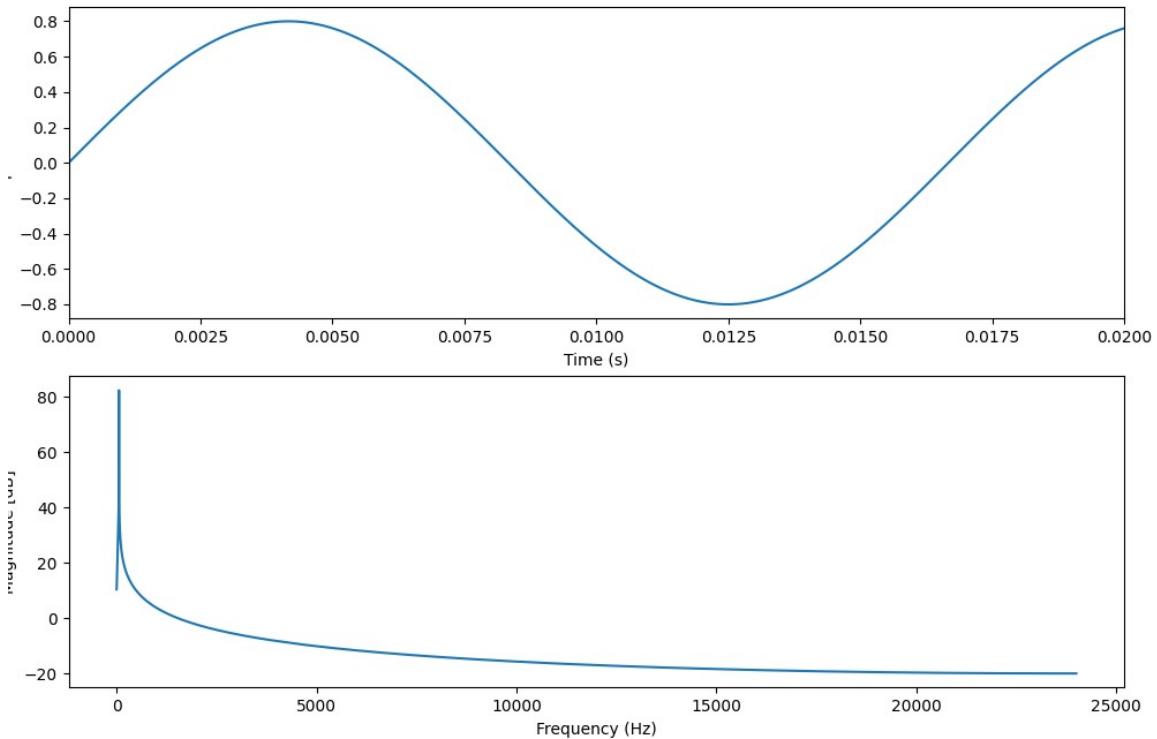
16-bit quant

Time margin [0, 0.02]



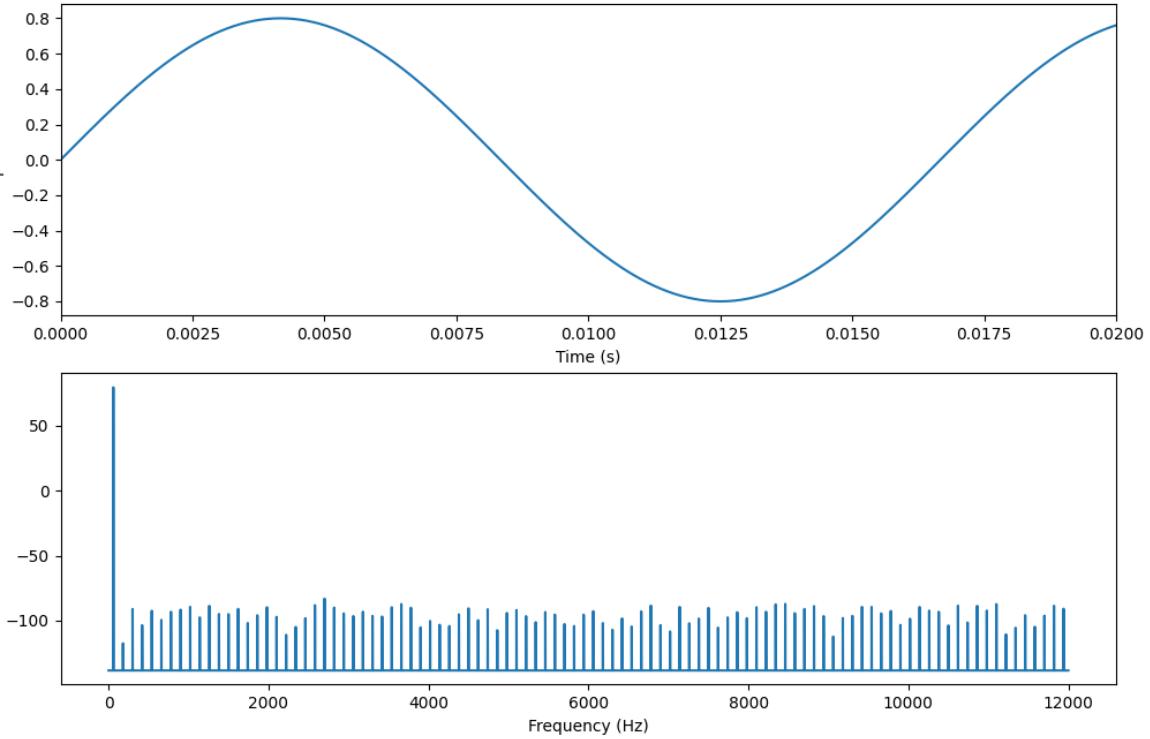
24-bit quant

Time margin [0, 0.02]



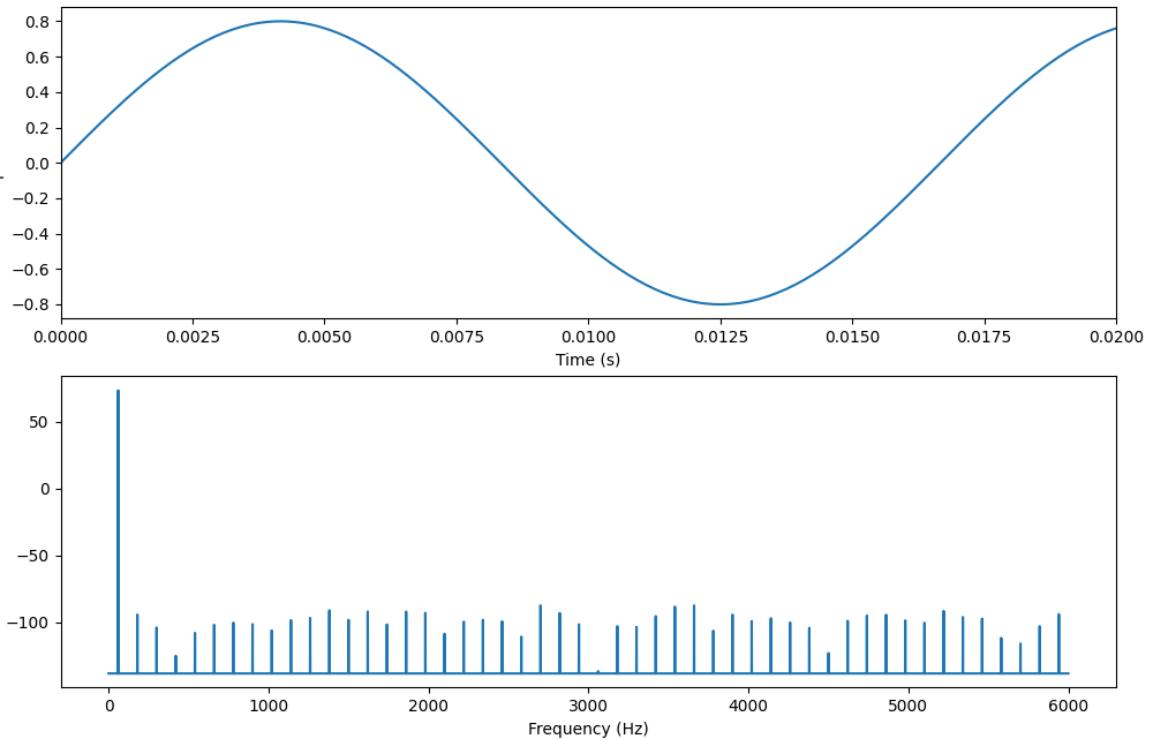
Decimation 2

Time margin [0, 0.02]



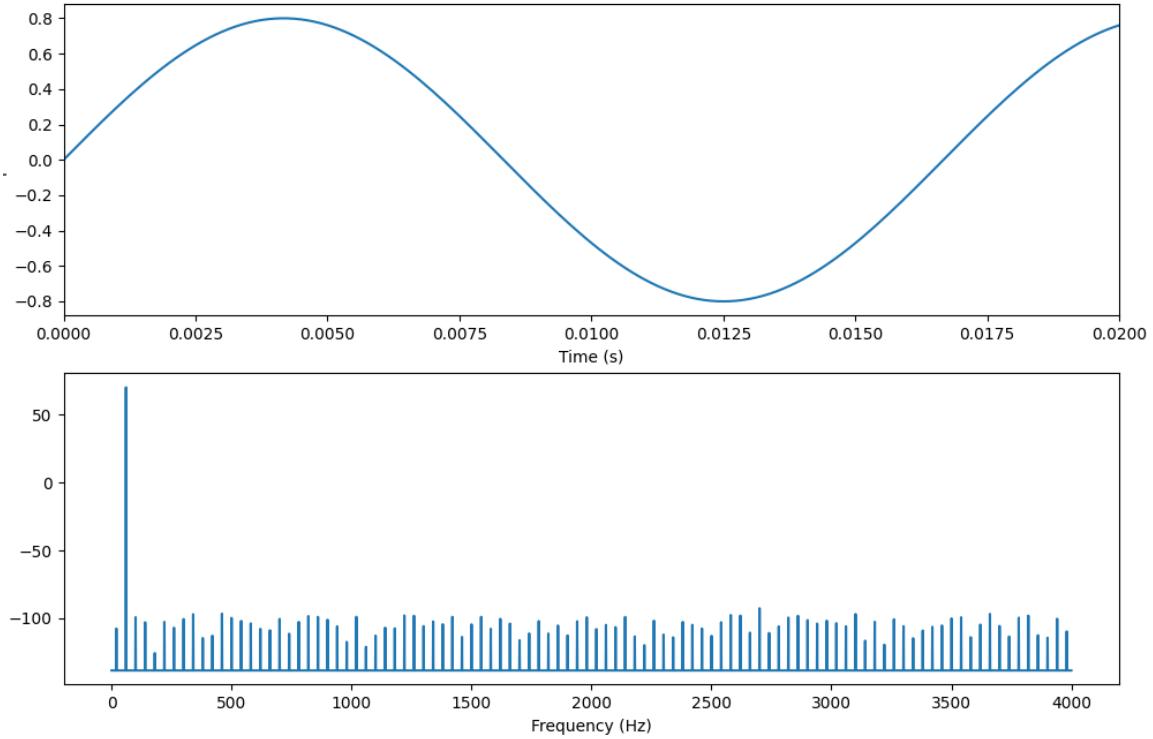
Decimation 4

Time margin [0, 0.02]



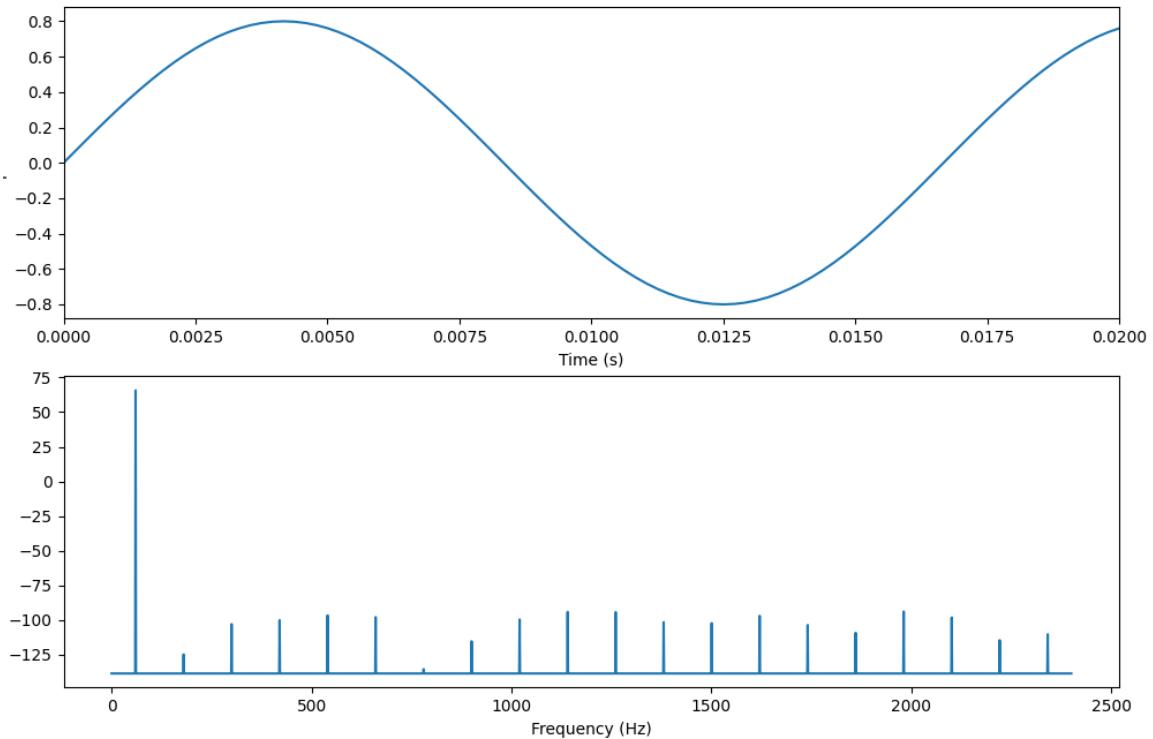
Decimation 6

Time margin [0, 0.02]



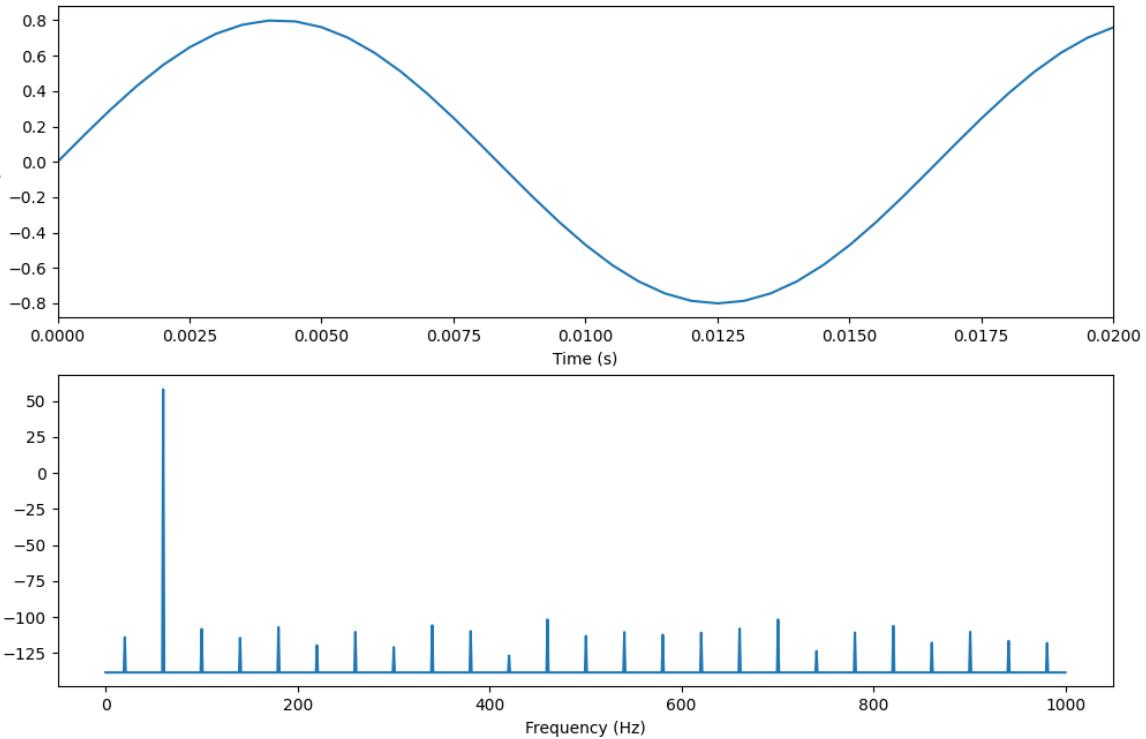
Decimation 10

Time margin [0, 0.02]



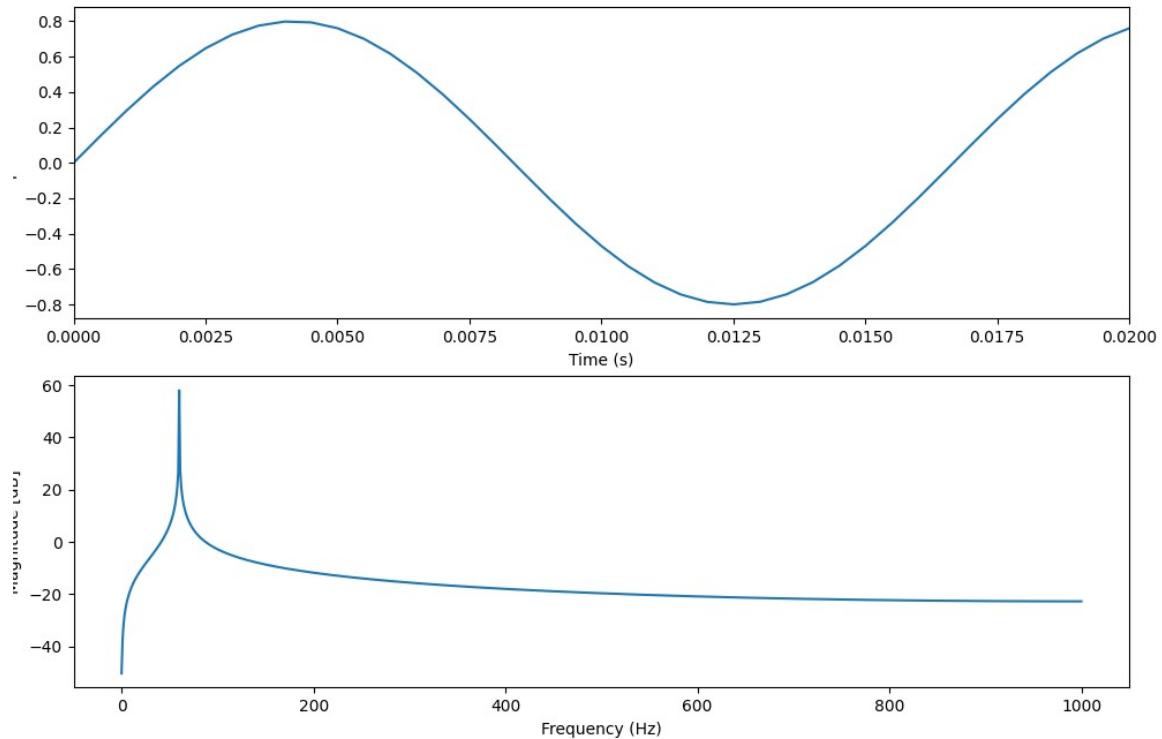
Decimation 24

Time margin [0, 0.02]



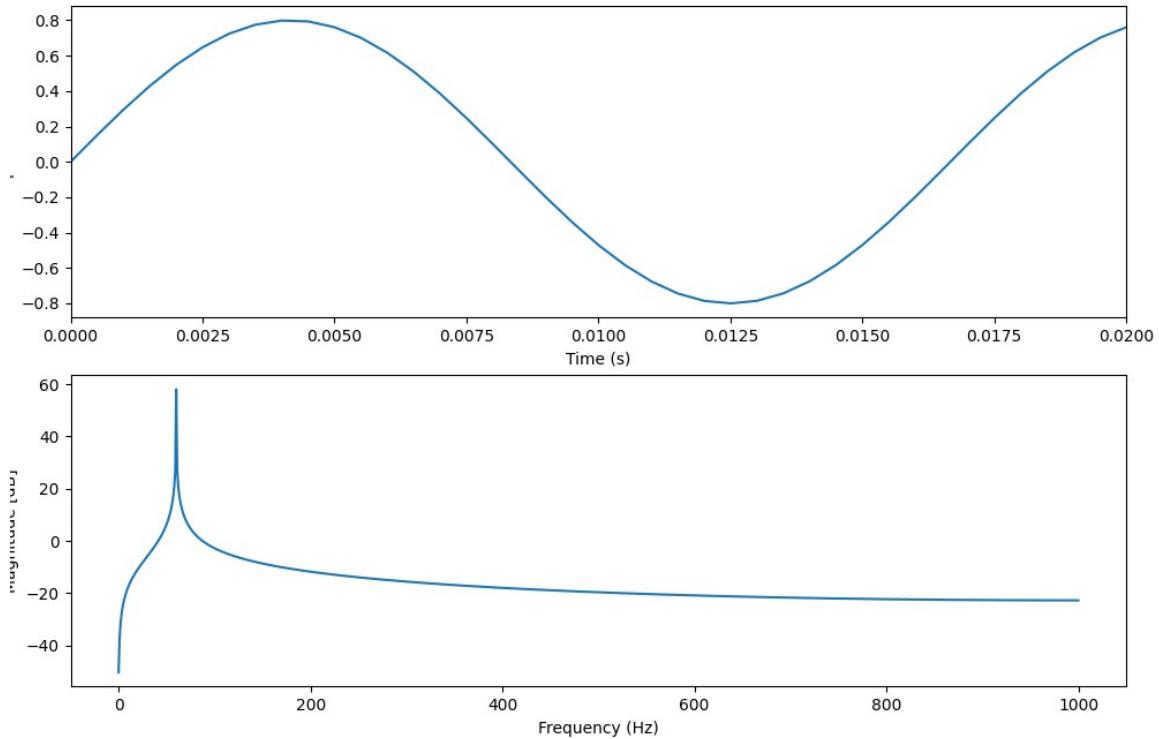
linear interp 2000Hz

Time margin [0, 0.02]



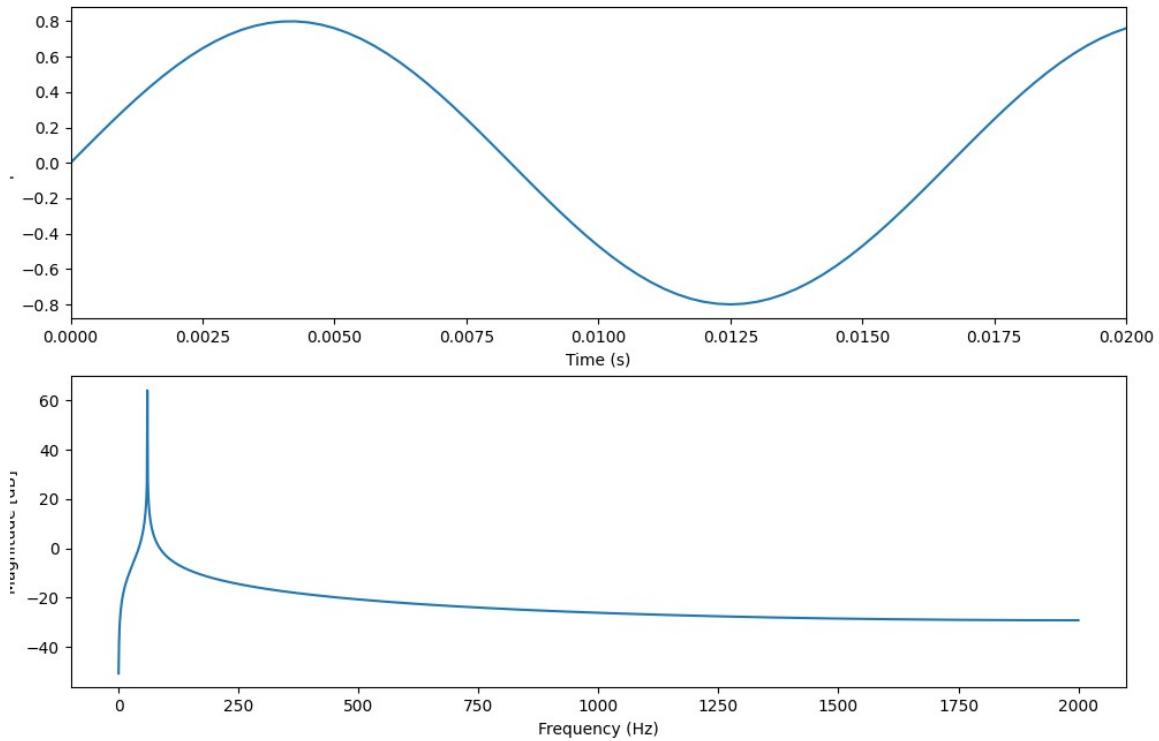
cubic interp 2000Hz

Time margin [0, 0.02]



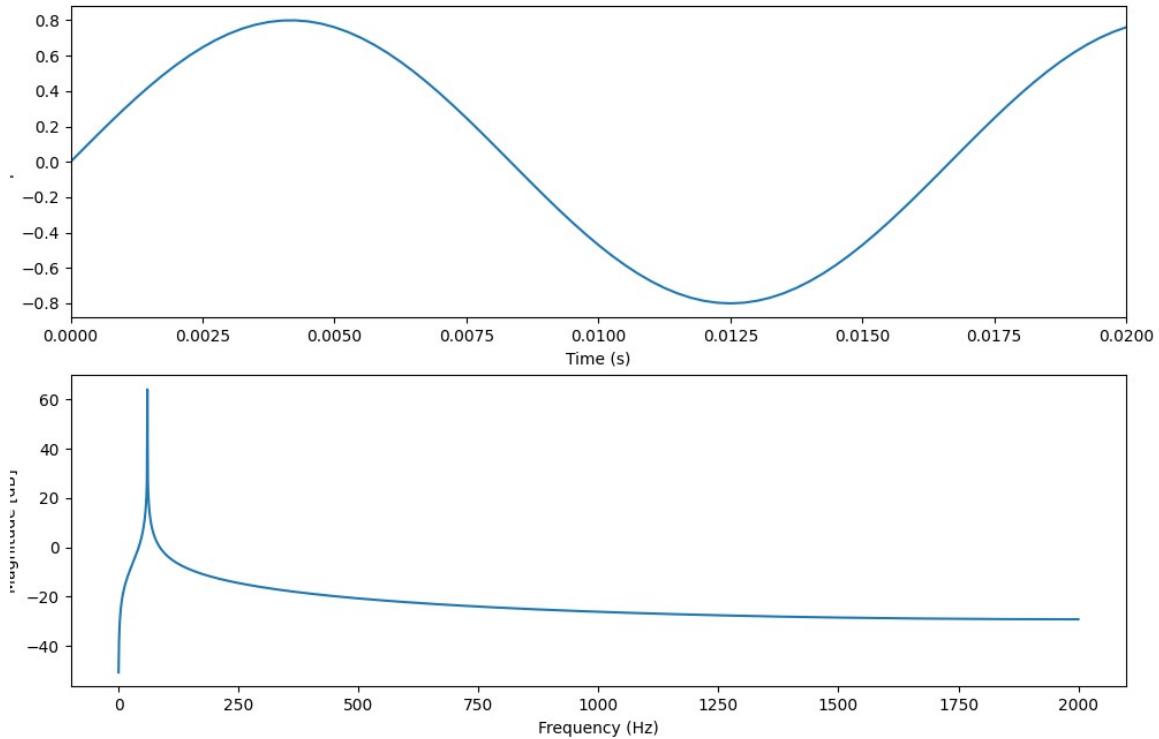
linear interp 4000Hz

Time margin [0, 0.02]



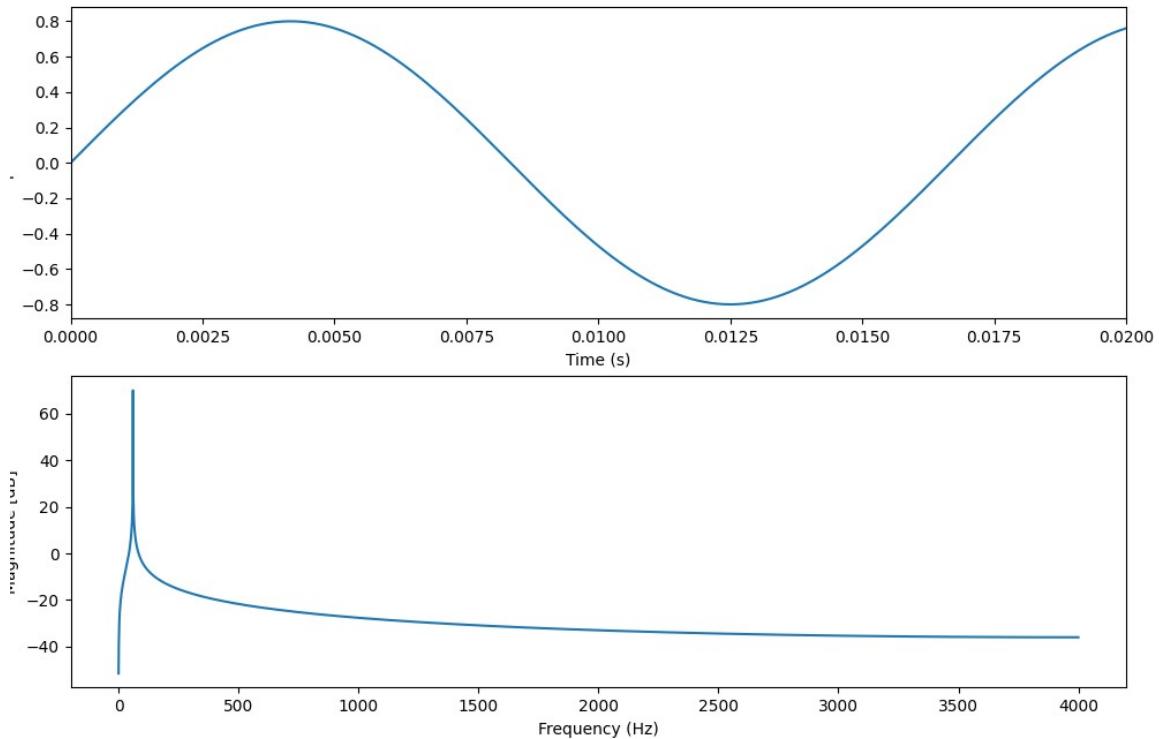
cubic interp 4000Hz

Time margin [0, 0.02]



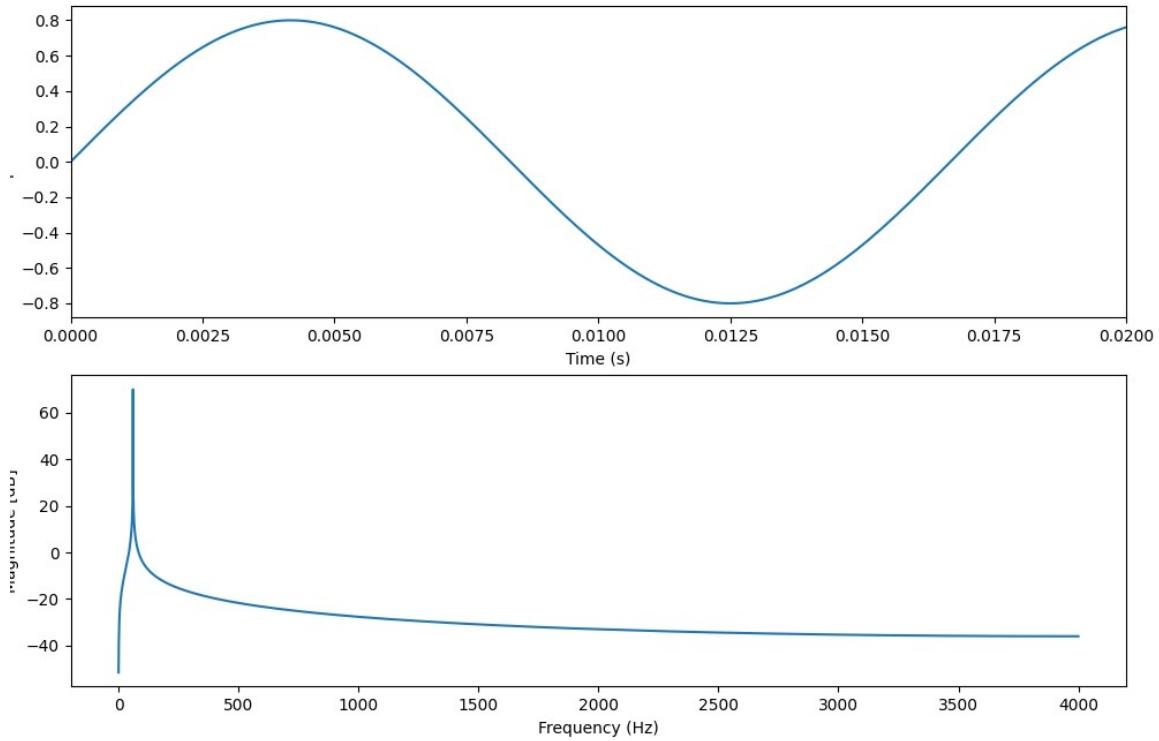
linear interp 8000Hz

Time margin [0, 0.02]



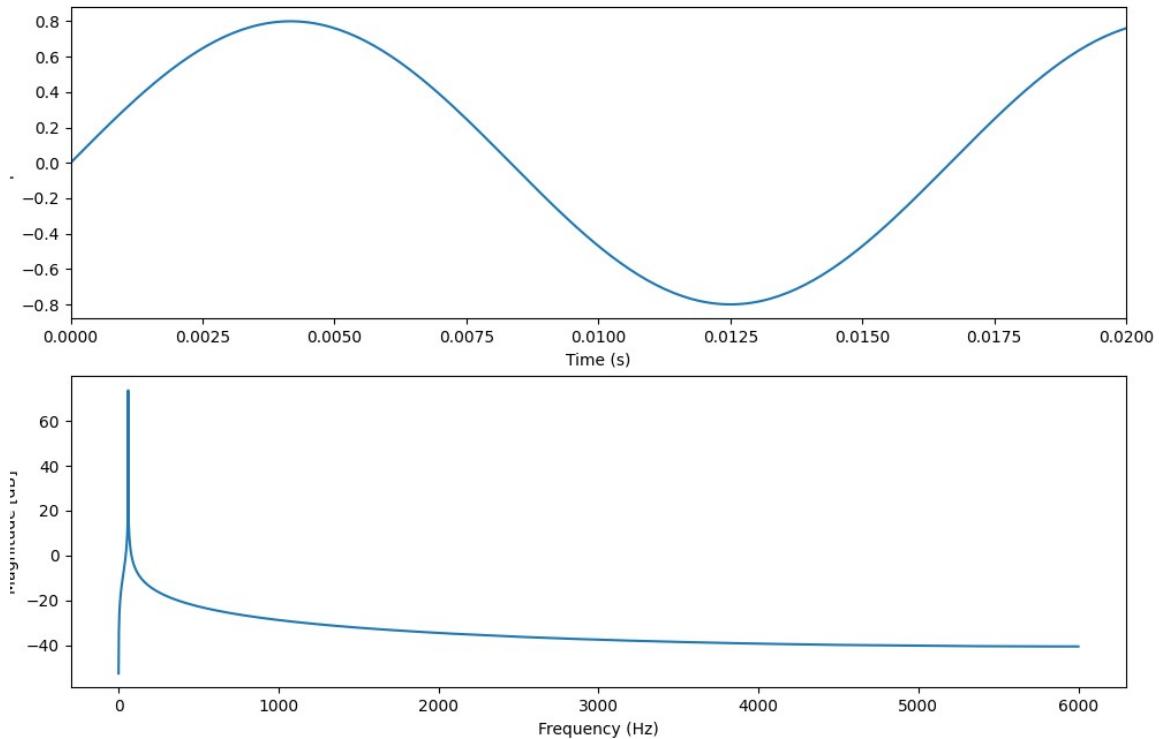
cubic interp 8000Hz

Time margin [0, 0.02]



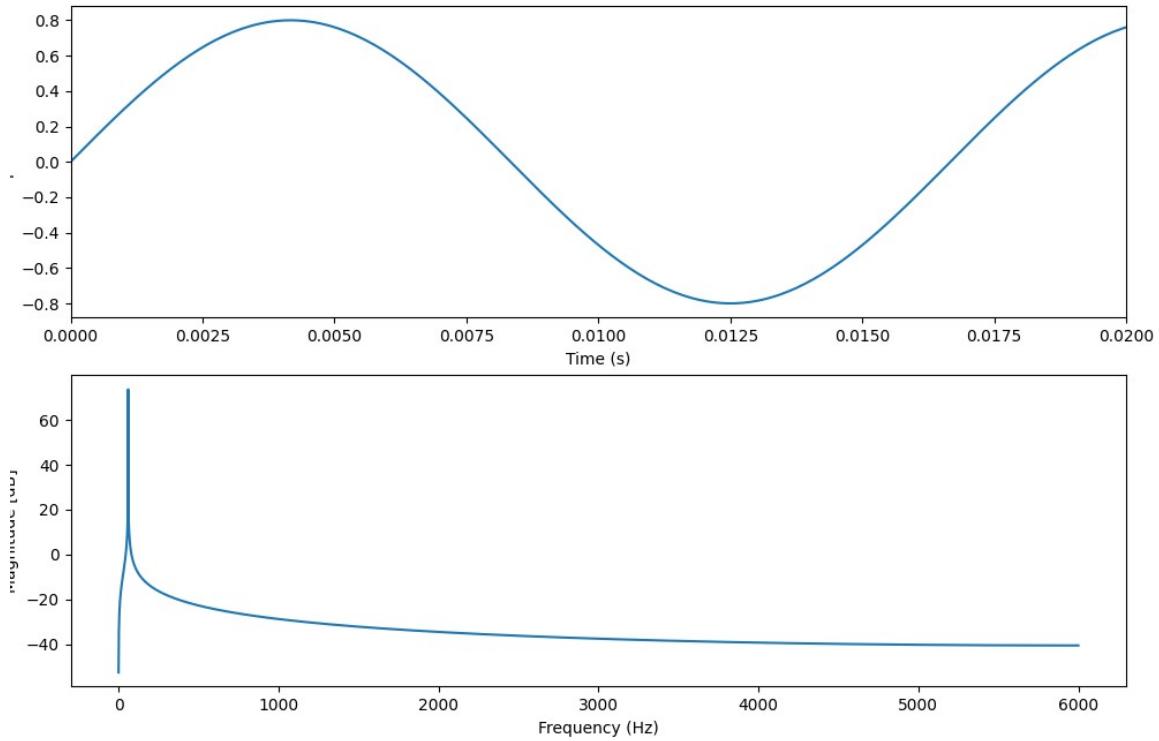
linear interp 11999Hz

Time margin [0, 0.02]



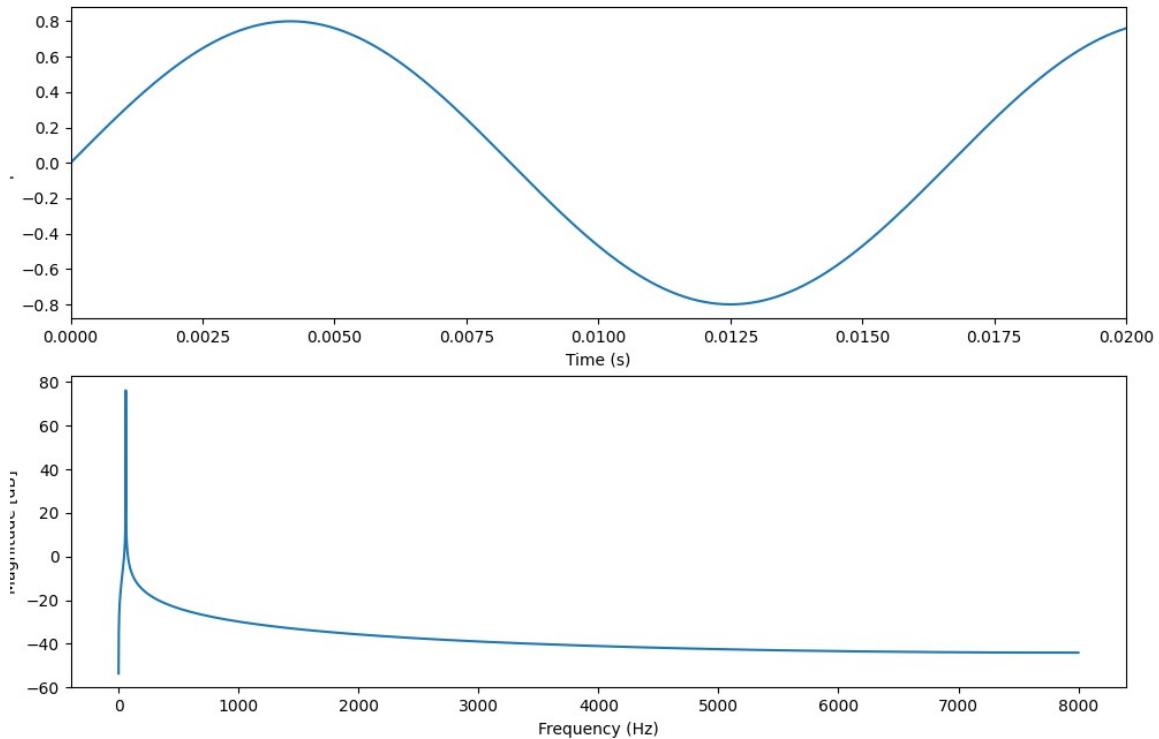
cubic interp 11999Hz

Time margin [0, 0.02]



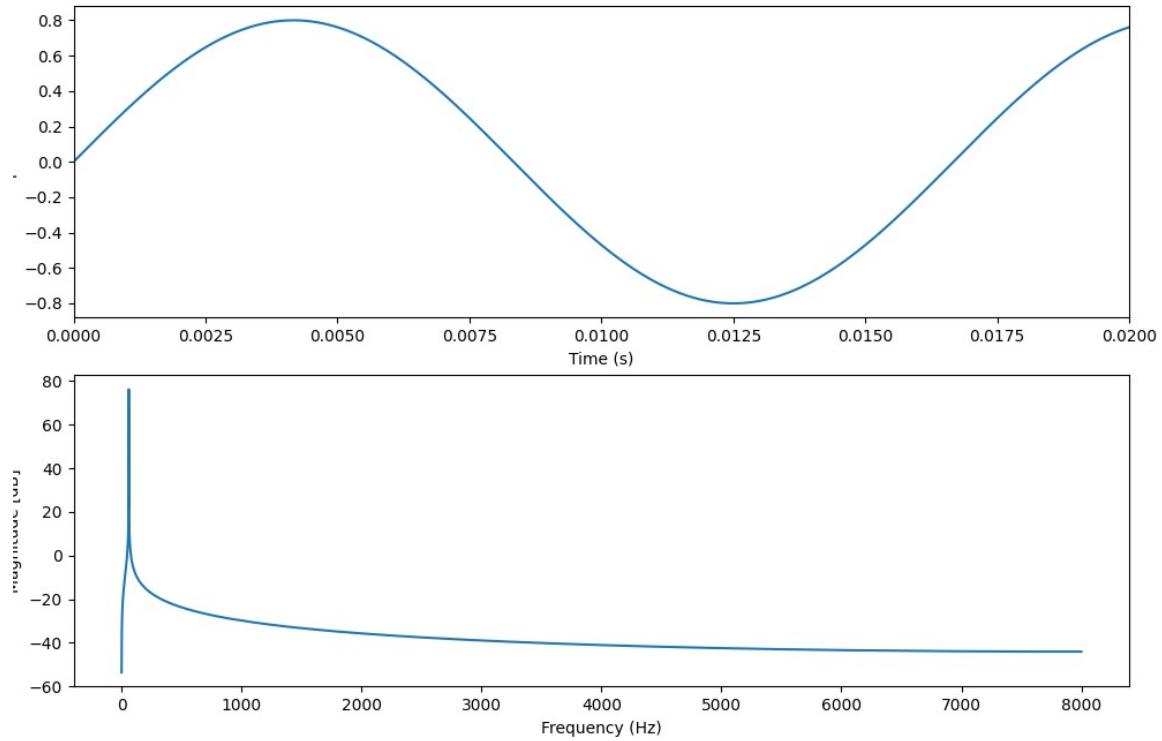
linear interp 16000Hz

Time margin [0, 0.02]



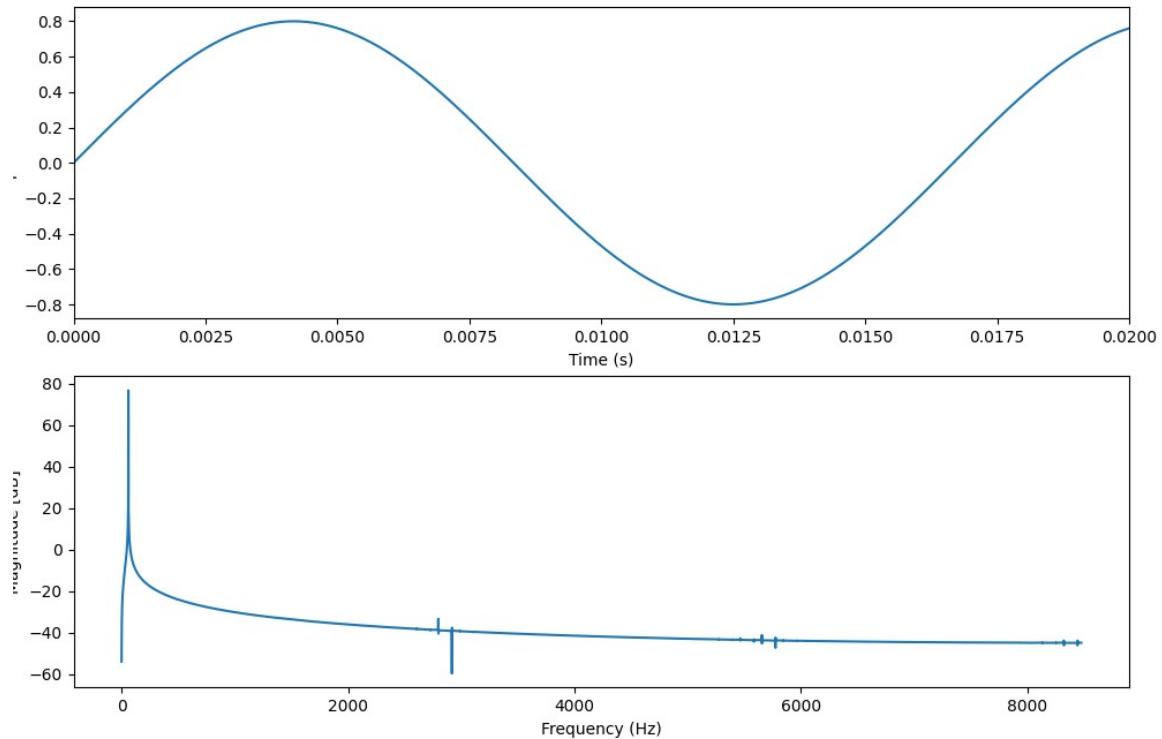
cubic interp 16000Hz

Time margin [0, 0.02]



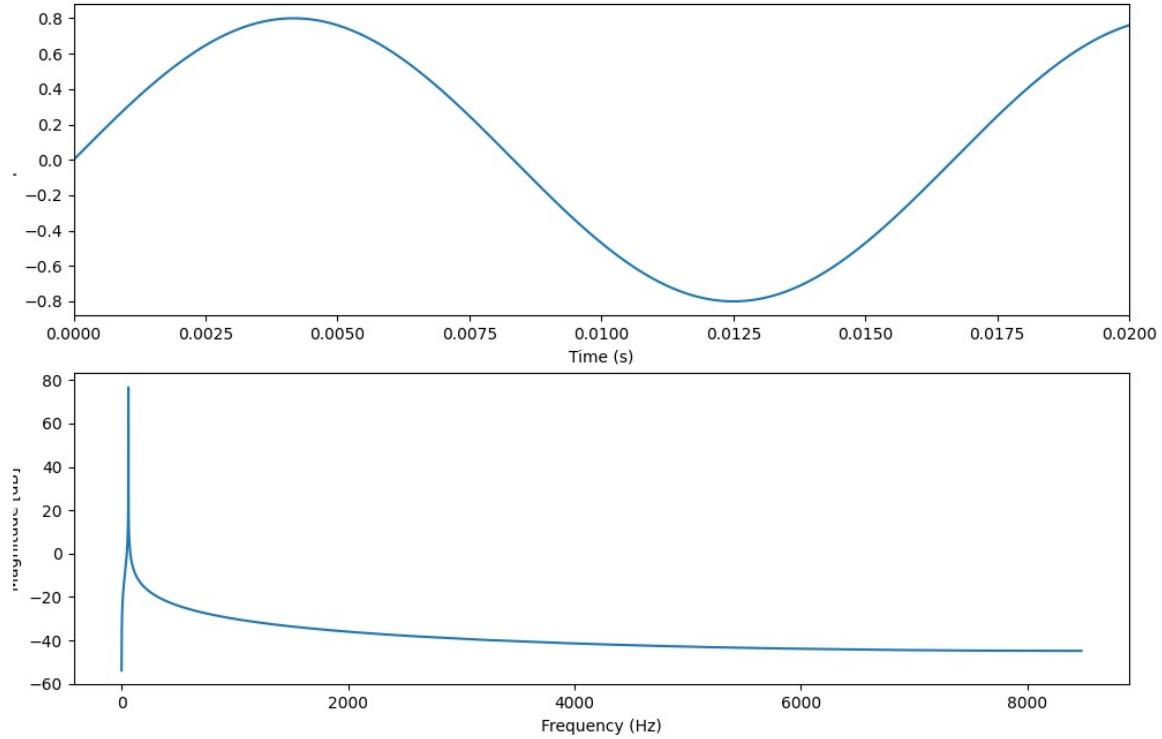
linear interp 16953Hz

Time margin [0, 0.02]



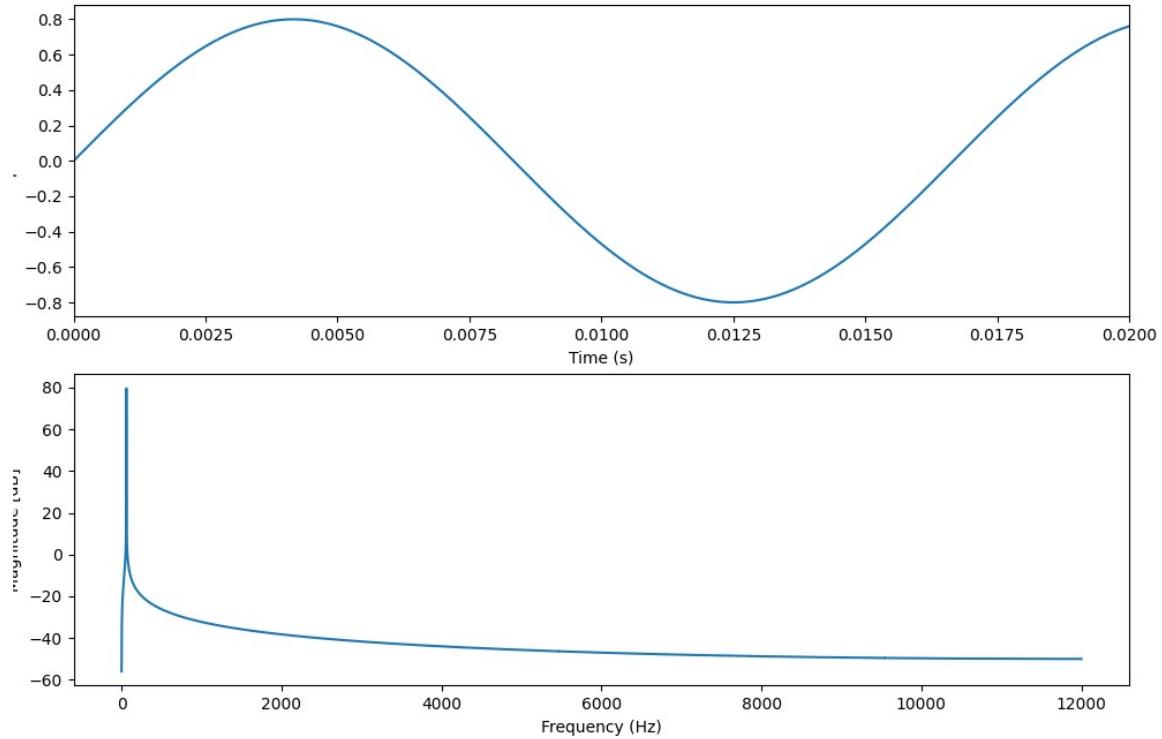
cubic interp 16953Hz

Time margin [0, 0.02]



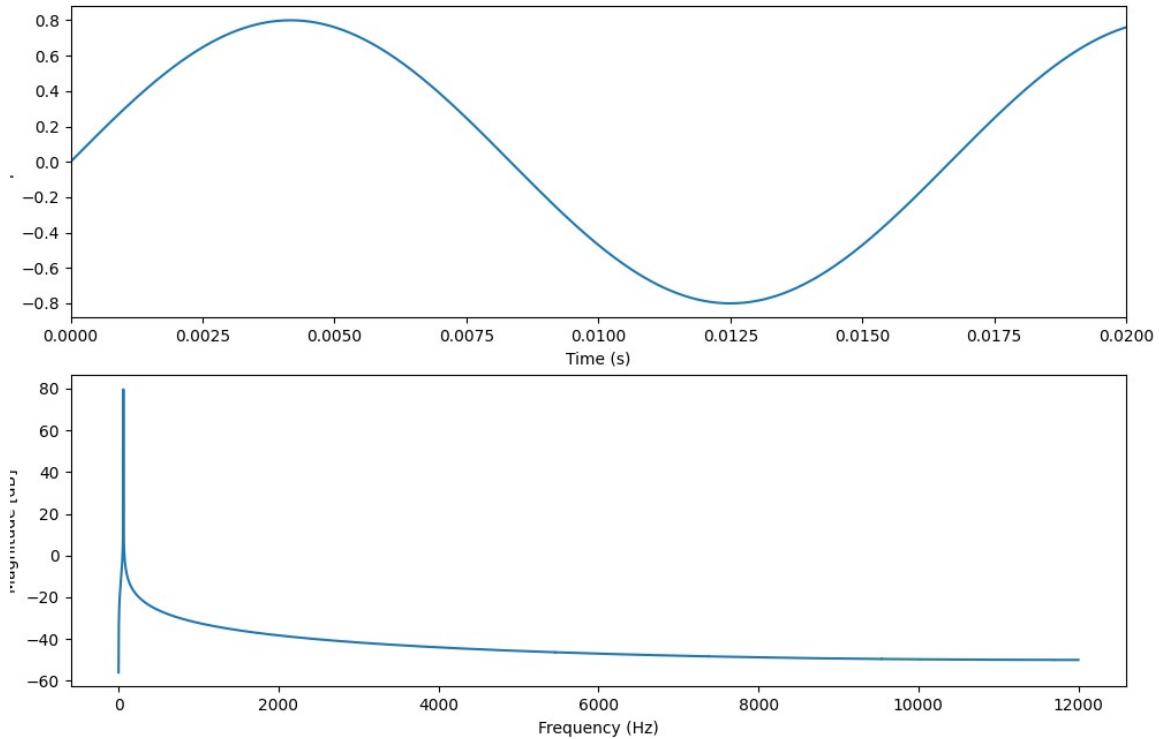
linear interp 24000Hz

Time margin [0, 0.02]



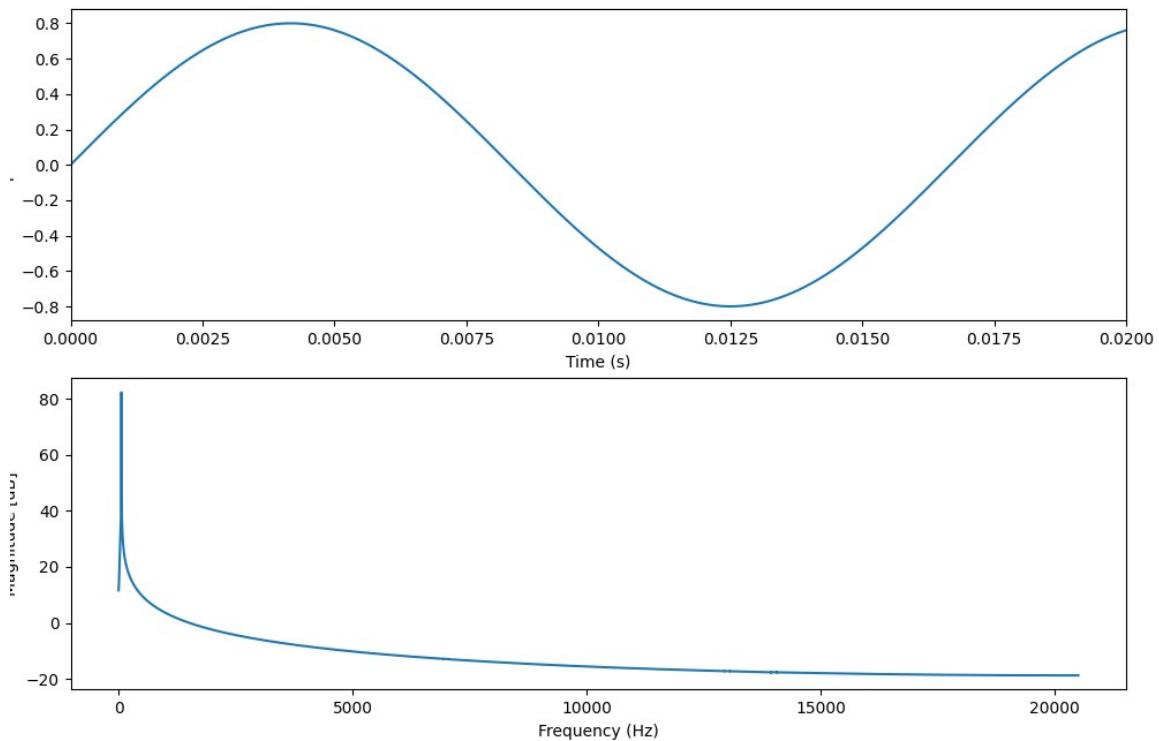
cubic interp 24000Hz

Time margin [0, 0.02]



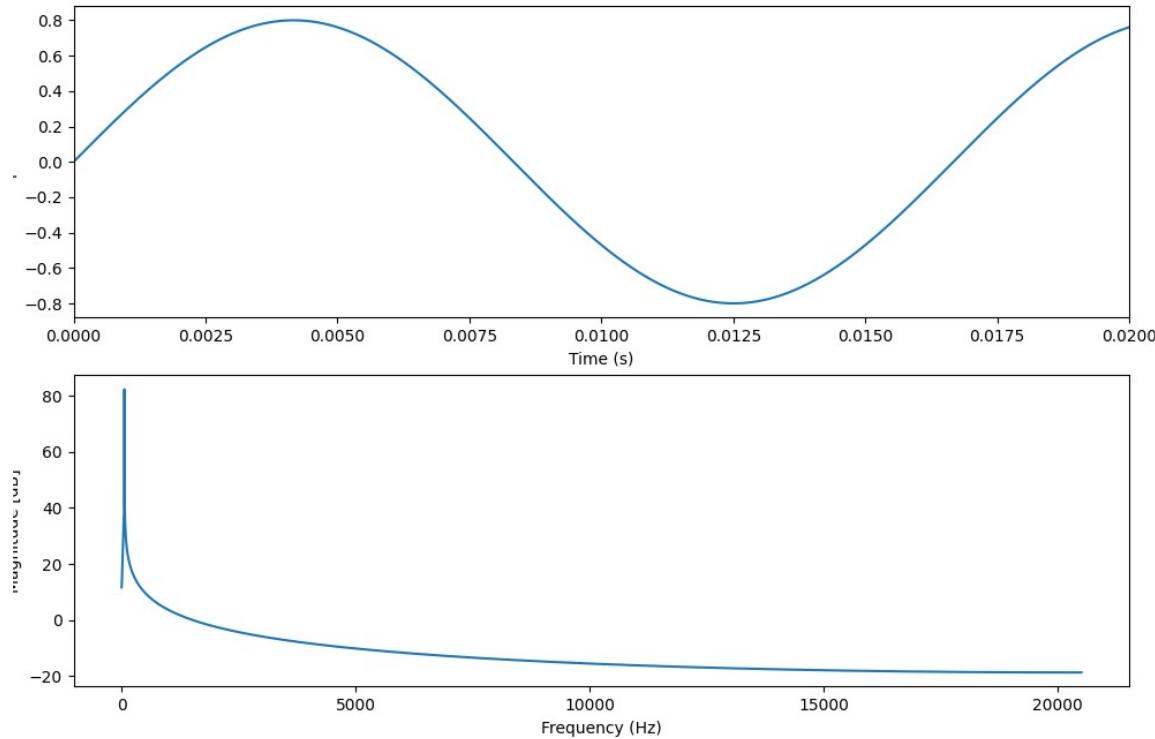
linear interp 41000Hz

Time margin [0, 0.02]



cubic interp 41000Hz

Time margin [0, 0.02]



File: sin_440Hz.wav

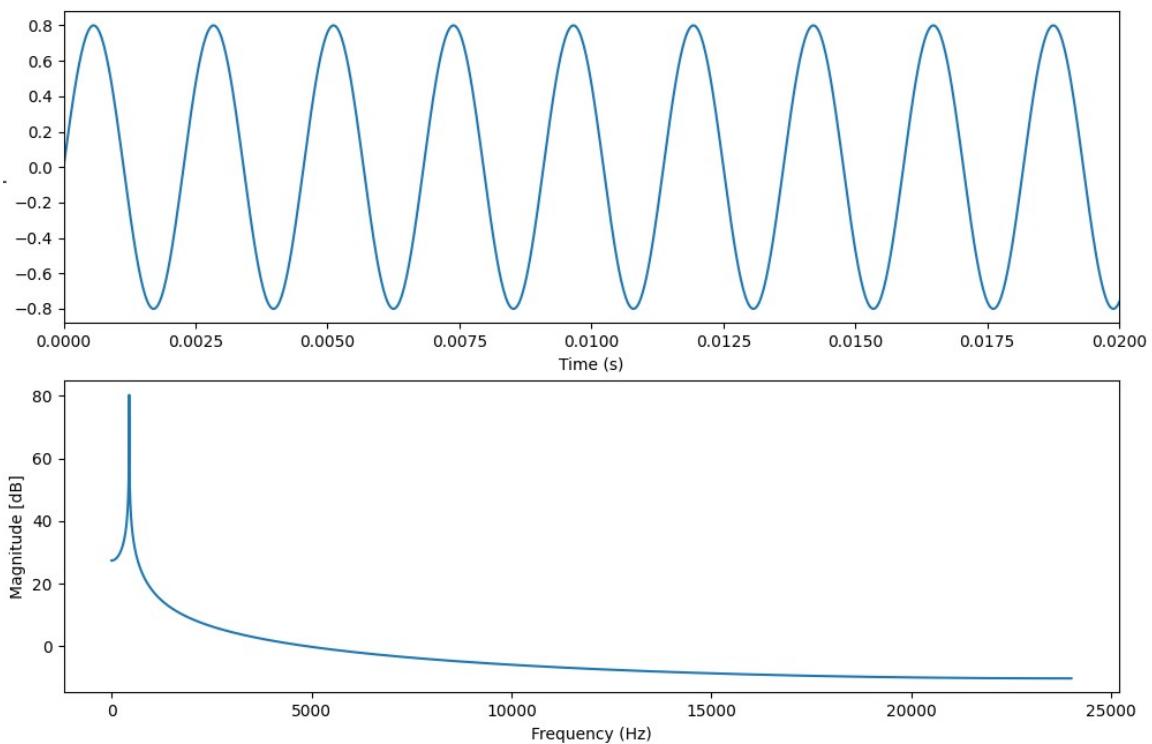
Modification	Max Frequency (Hz)	Max Amplitude (dB)
Original	439.48	80.26
4-bit quant	439.48	80.31
8-bit quant	439.48	80.26
16-bit quant	439.48	80.26
24-bit quant	439.48	80.26
Decimation 2	440.04	79.65
Decimation 4	440.07	73.62
Decimation 6	440.11	70.10
Decimation 10	440.18	65.67
Decimation 24	440.44	58.06
linear interp 2000Hz	440.44	57.41
cubic interp 2000Hz	440.44	57.41
linear interp 4000Hz	440.22	63.93
cubic interp 4000Hz	440.22	63.94
linear interp 8000Hz	440.11	70.07
cubic interp 8000Hz	440.11	70.07
linear interp 11999Hz	440.11	73.61
cubic interp 11999Hz	440.11	73.61
linear interp 16000Hz	440.06	76.12
cubic interp 16000Hz	440.06	76.12

linear interp 16953Hz	440.08	76.62
cubic interp 16953Hz	440.08	76.62
linear interp 24000Hz	440.04	79.64
cubic interp 24000Hz	440.04	79.64
linear interp 41000Hz	440.46	80.60
cubic interp 41000Hz	440.46	80.61

Visualizations

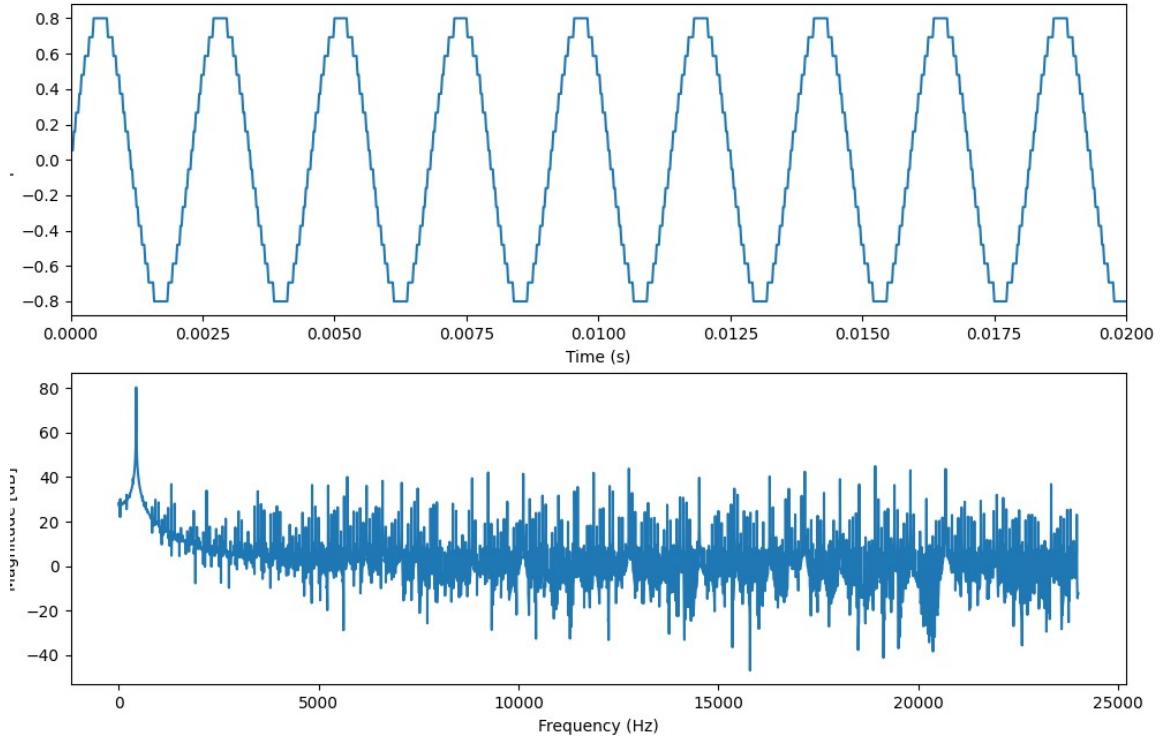
Original

Time margin [0, 0.02]



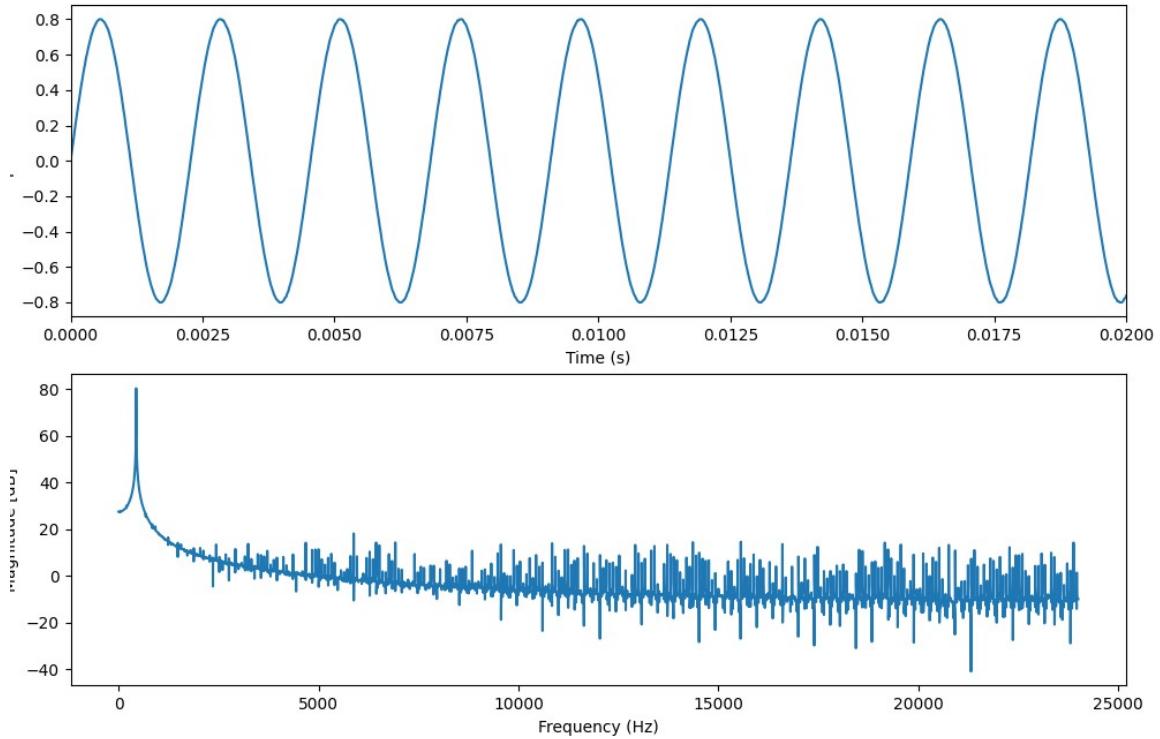
4-bit quant

Time margin [0, 0.02]



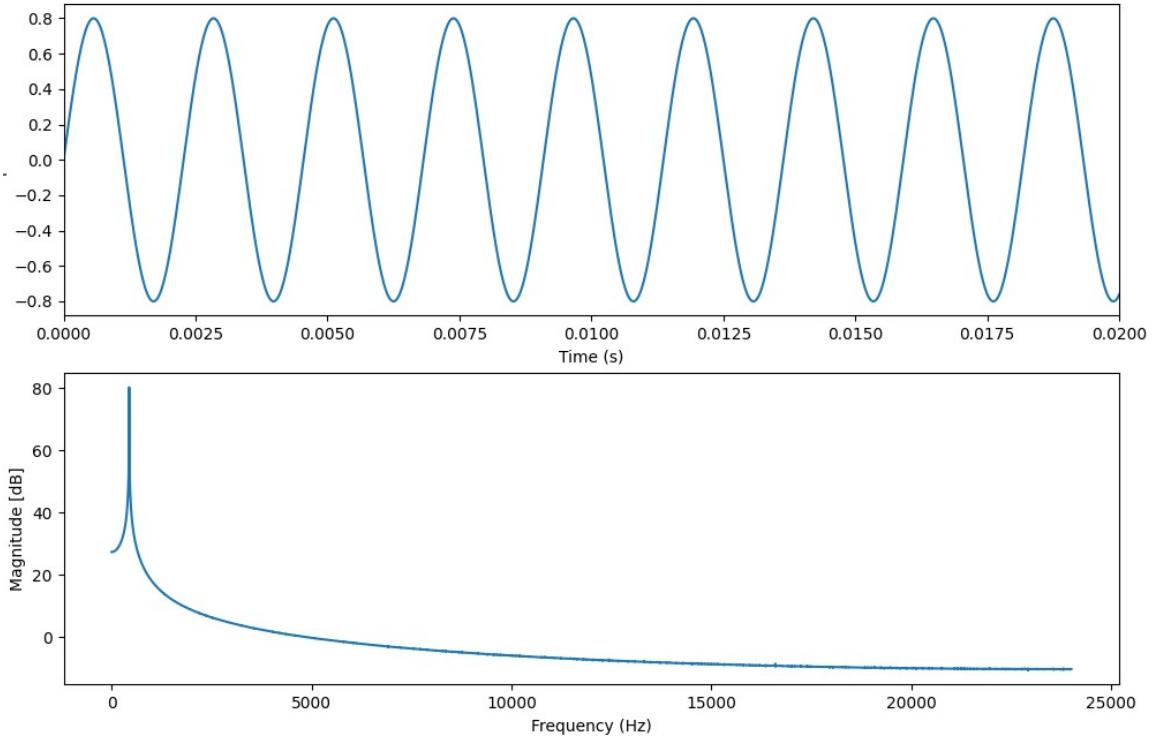
8-bit quant

Time margin [0, 0.02]



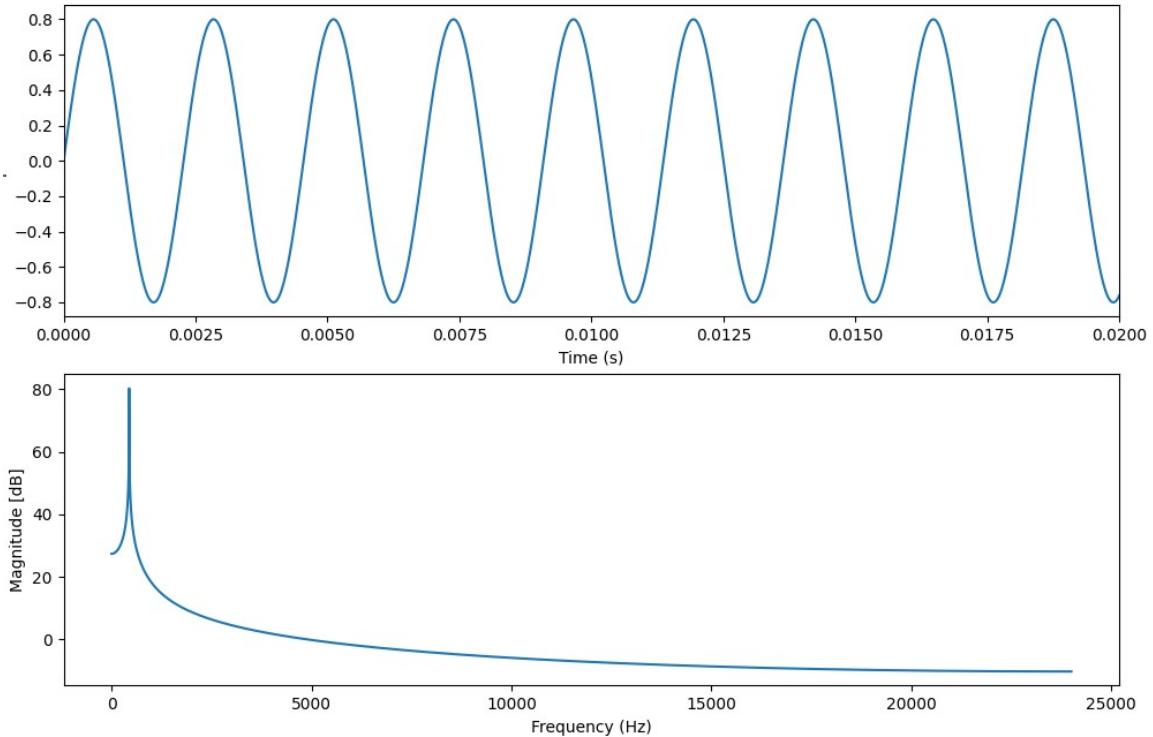
16-bit quant

Time margin [0, 0.02]



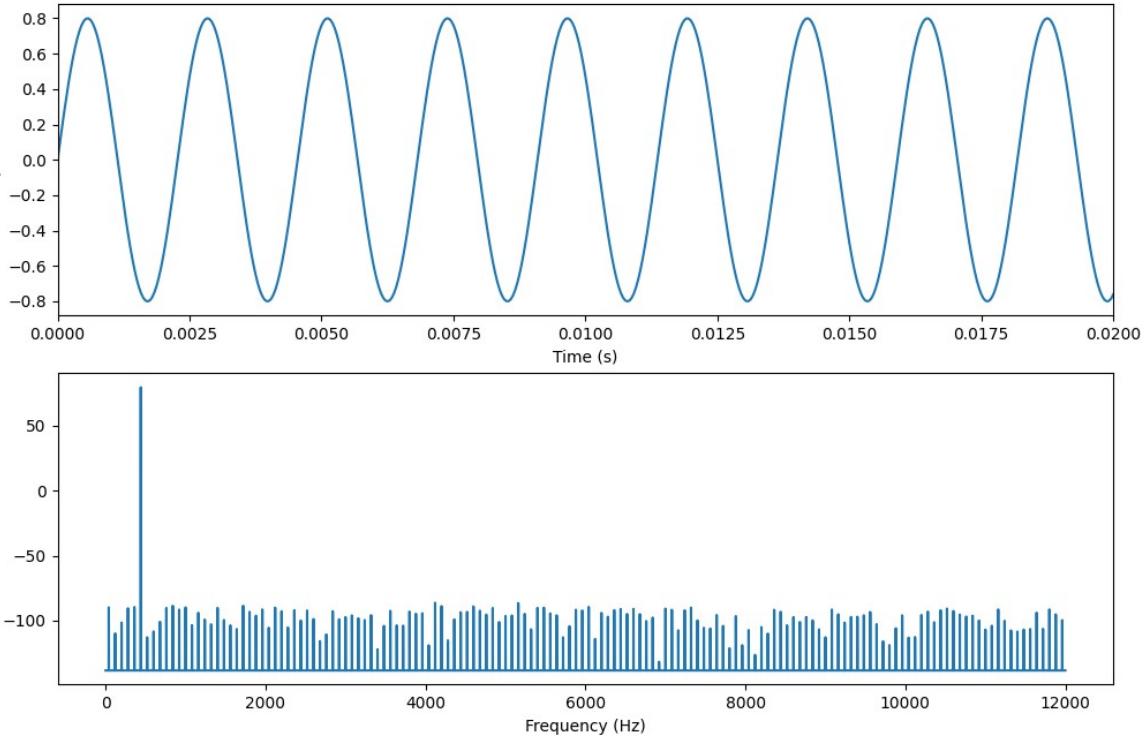
24-bit quant

Time margin [0, 0.02]



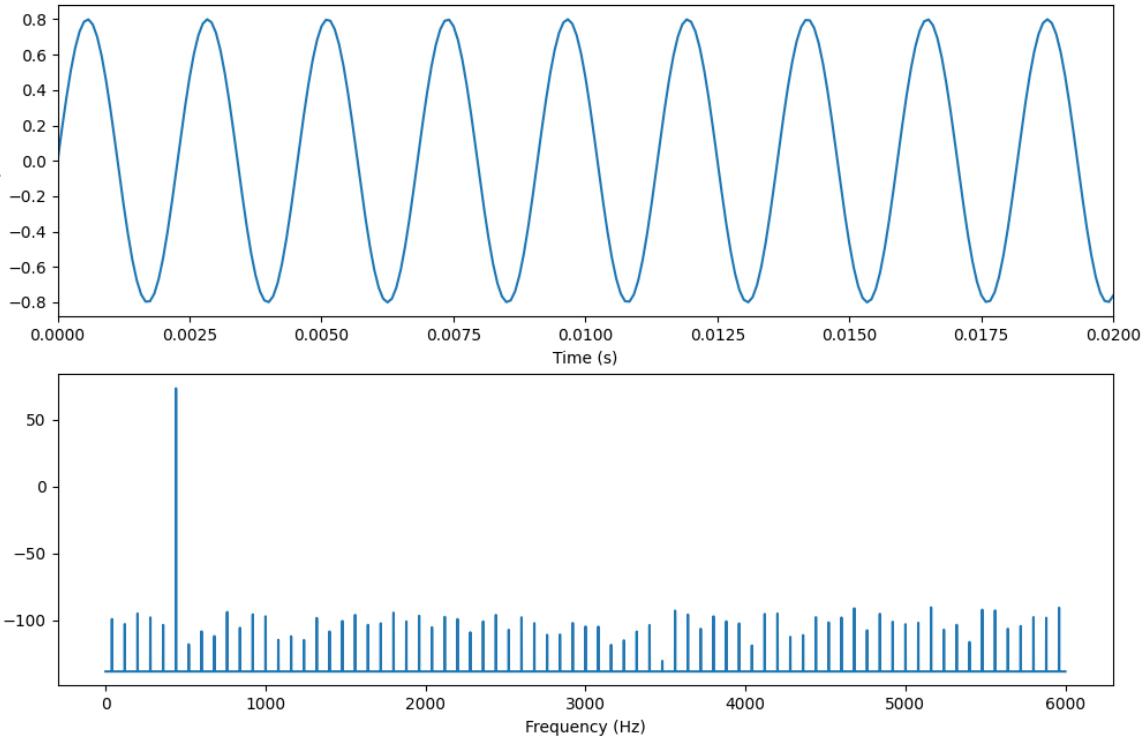
Decimation 2

Time margin [0, 0.02]



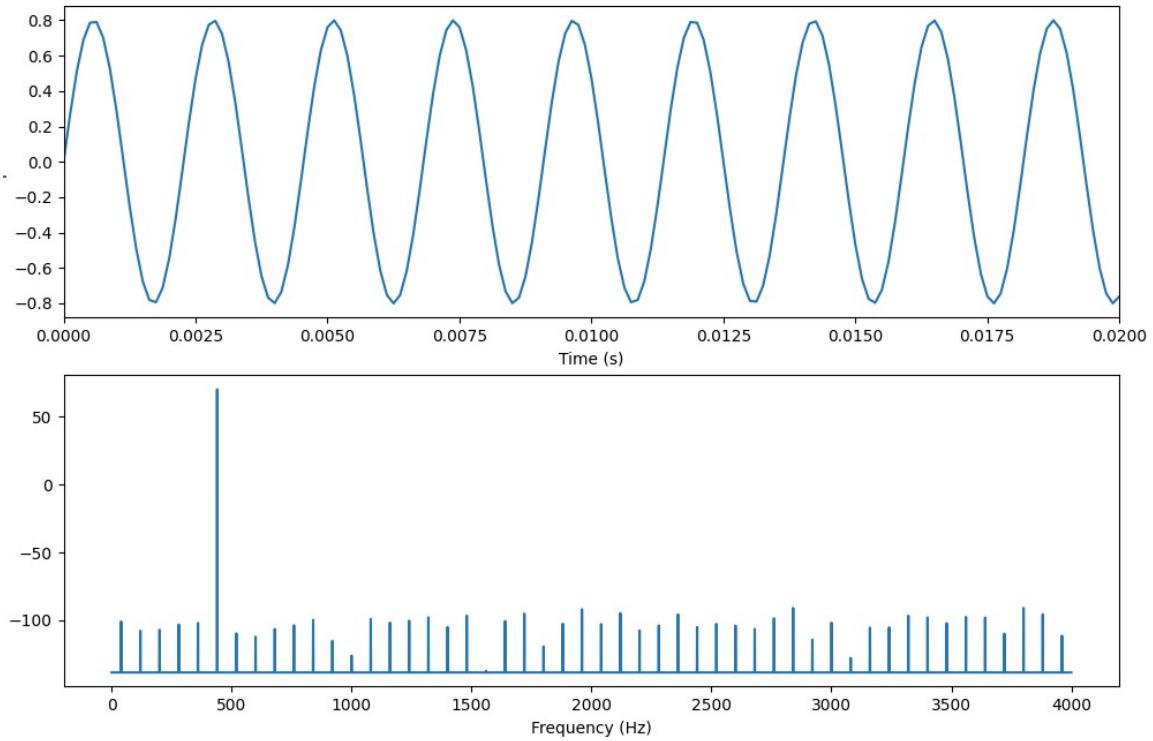
Decimation 4

Time margin [0, 0.02]



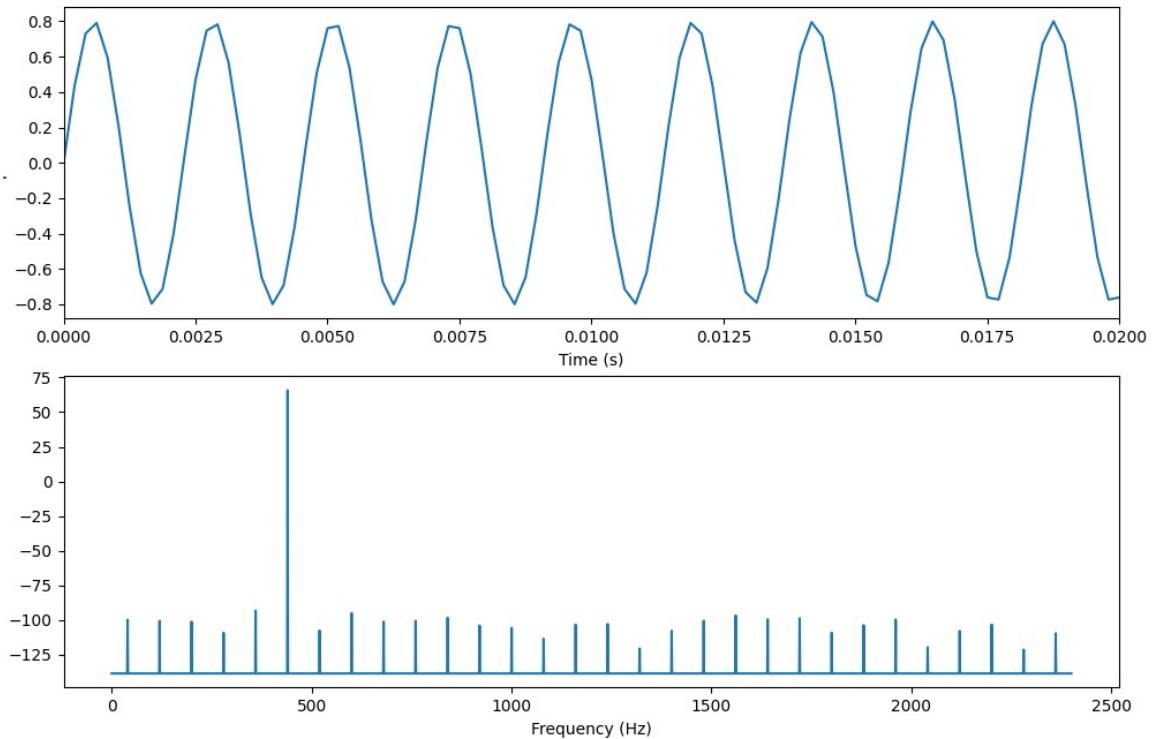
Decimation 6

Time margin [0, 0.02]



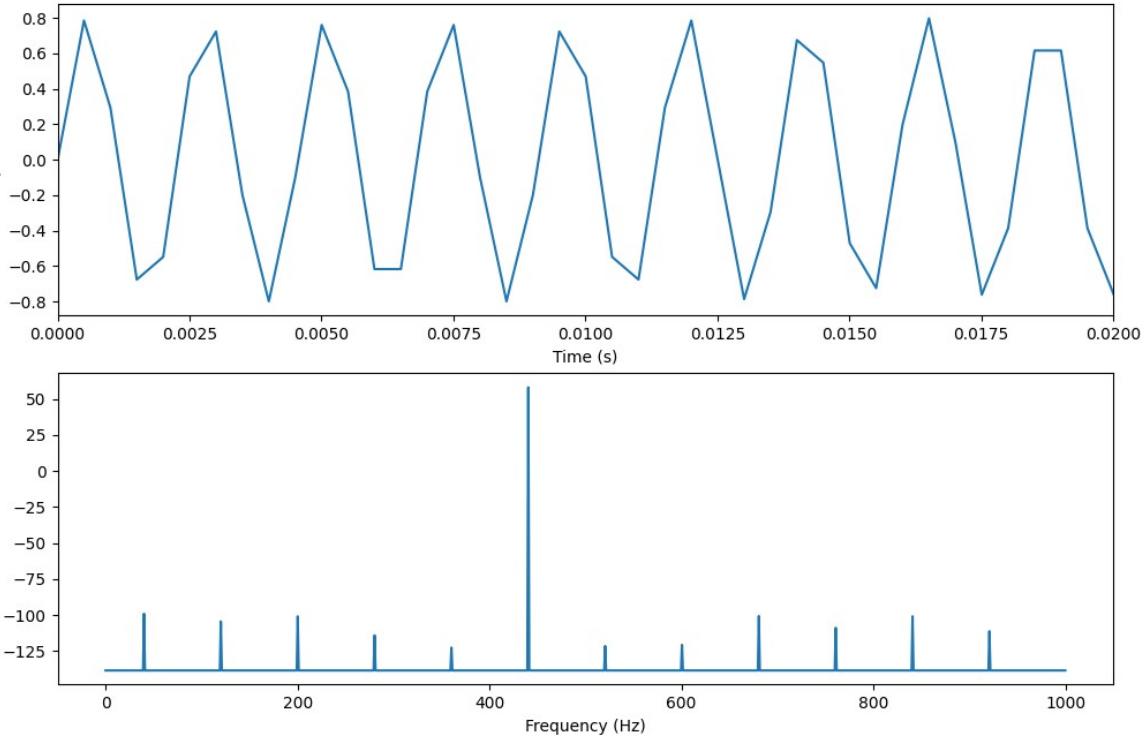
Decimation 10

Time margin [0, 0.02]



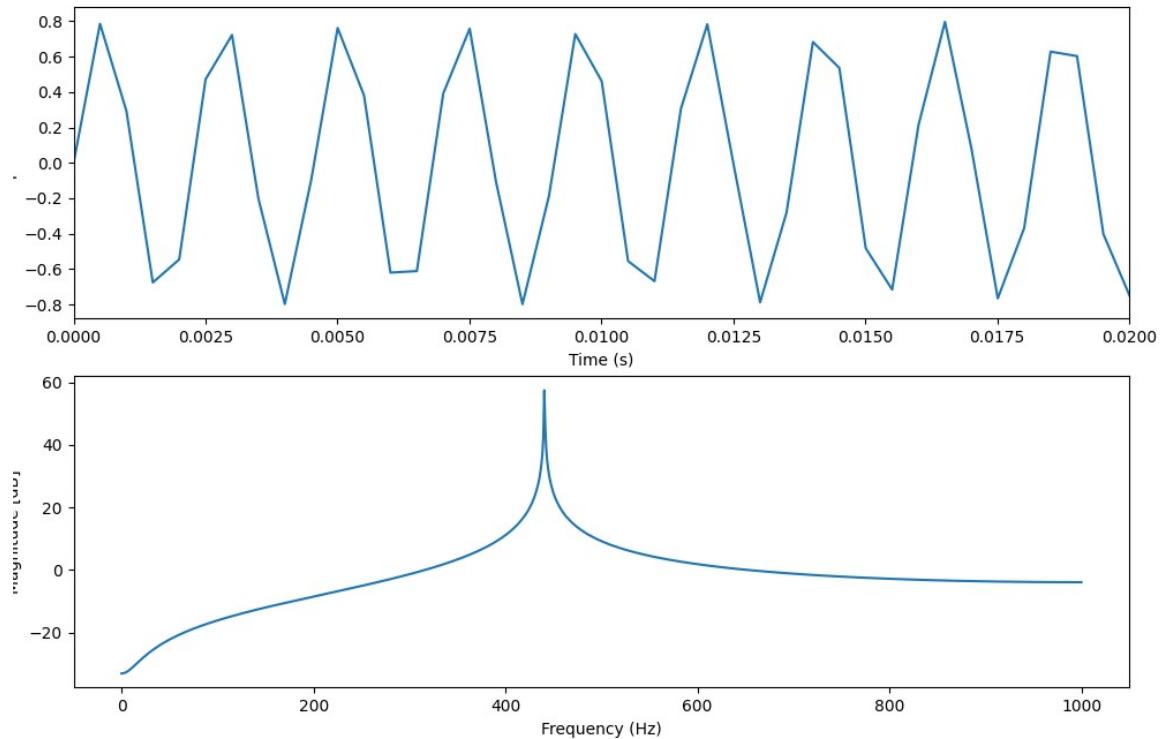
Decimation 24

Time margin [0, 0.02]



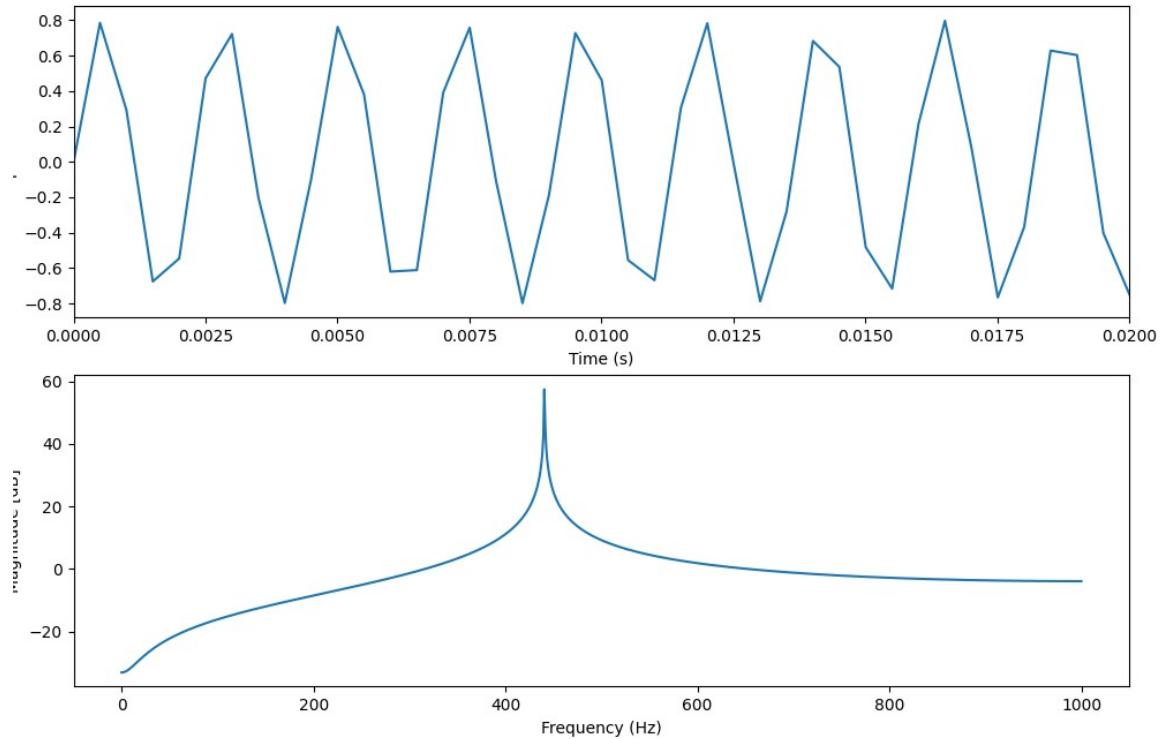
linear interp 2000Hz

Time margin [0, 0.02]



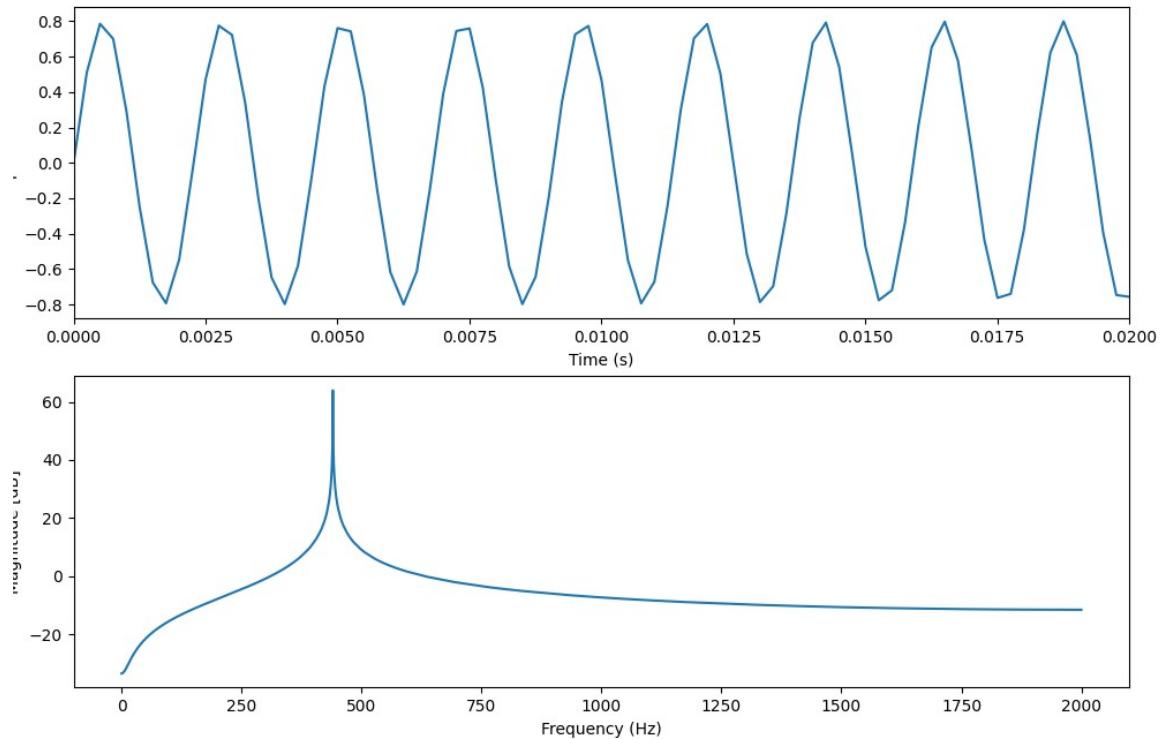
cubic interp 2000Hz

Time margin [0, 0.02]



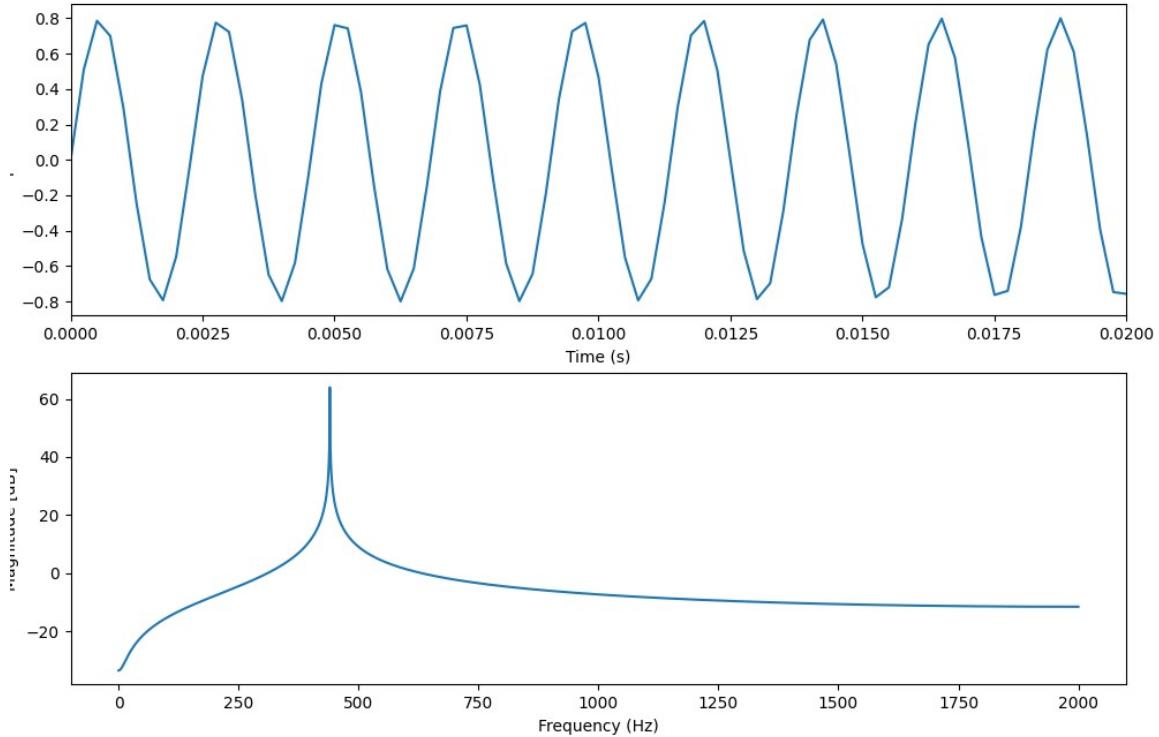
linear interp 4000Hz

Time margin [0, 0.02]



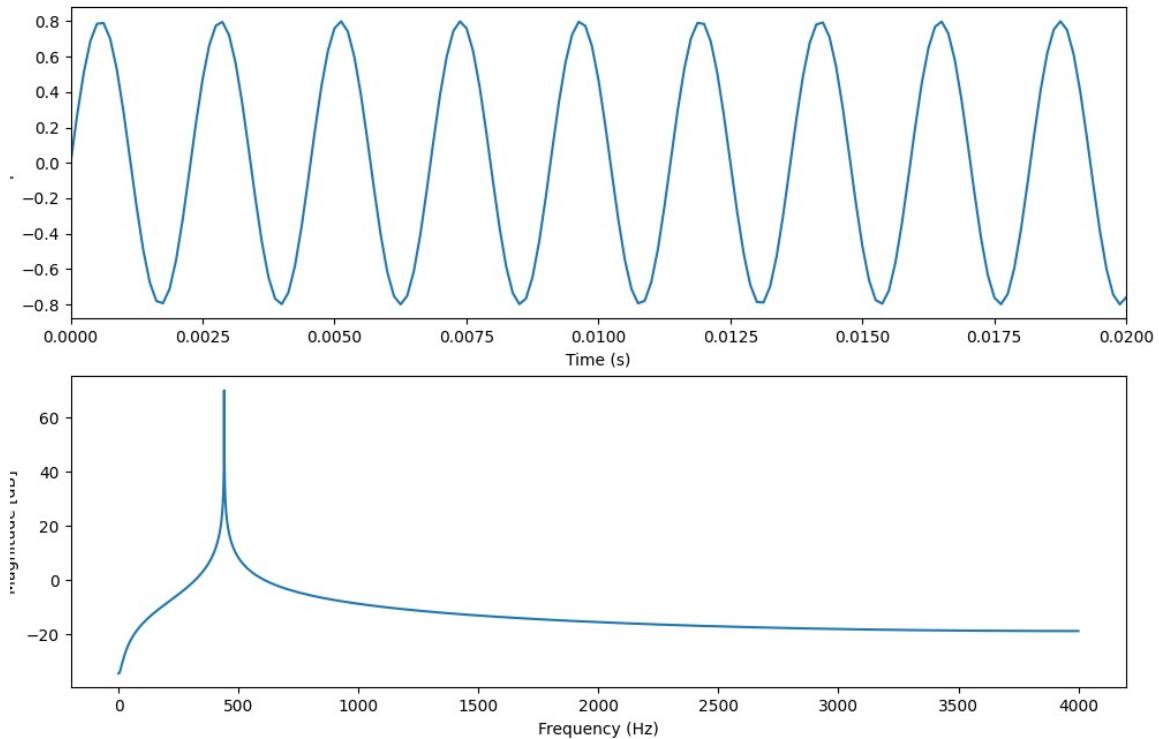
cubic interp 4000Hz

Time margin [0, 0.02]



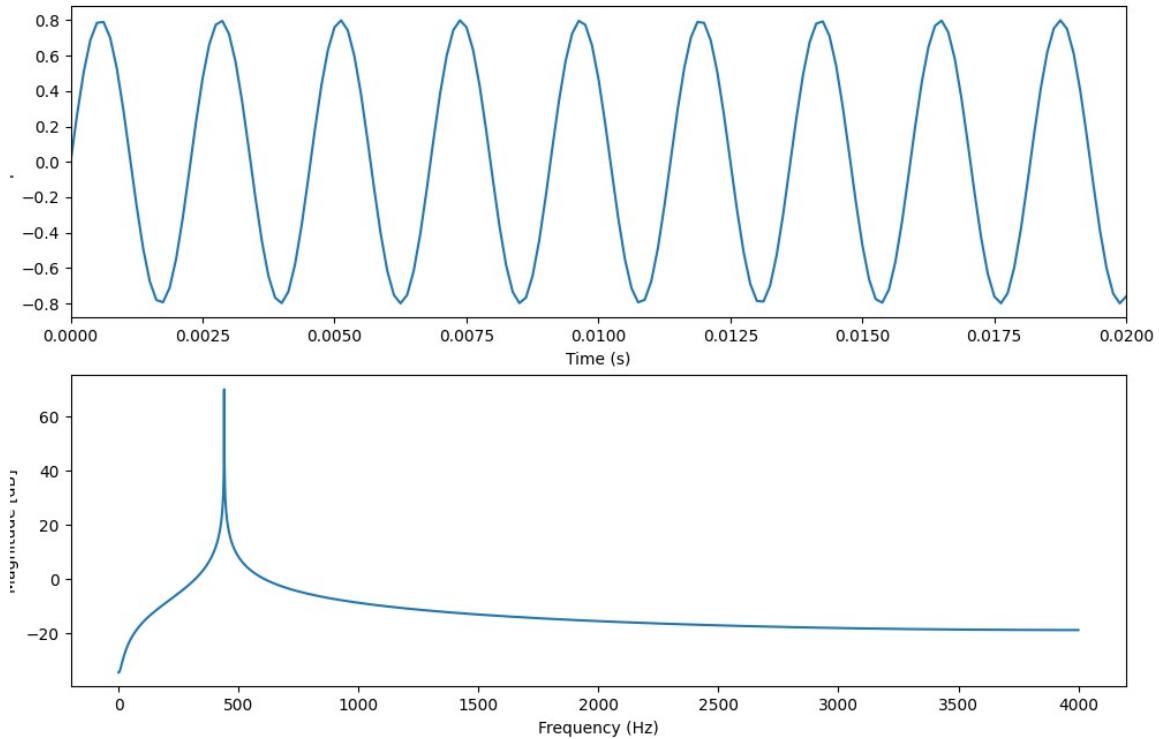
linear interp 8000Hz

Time margin [0, 0.02]



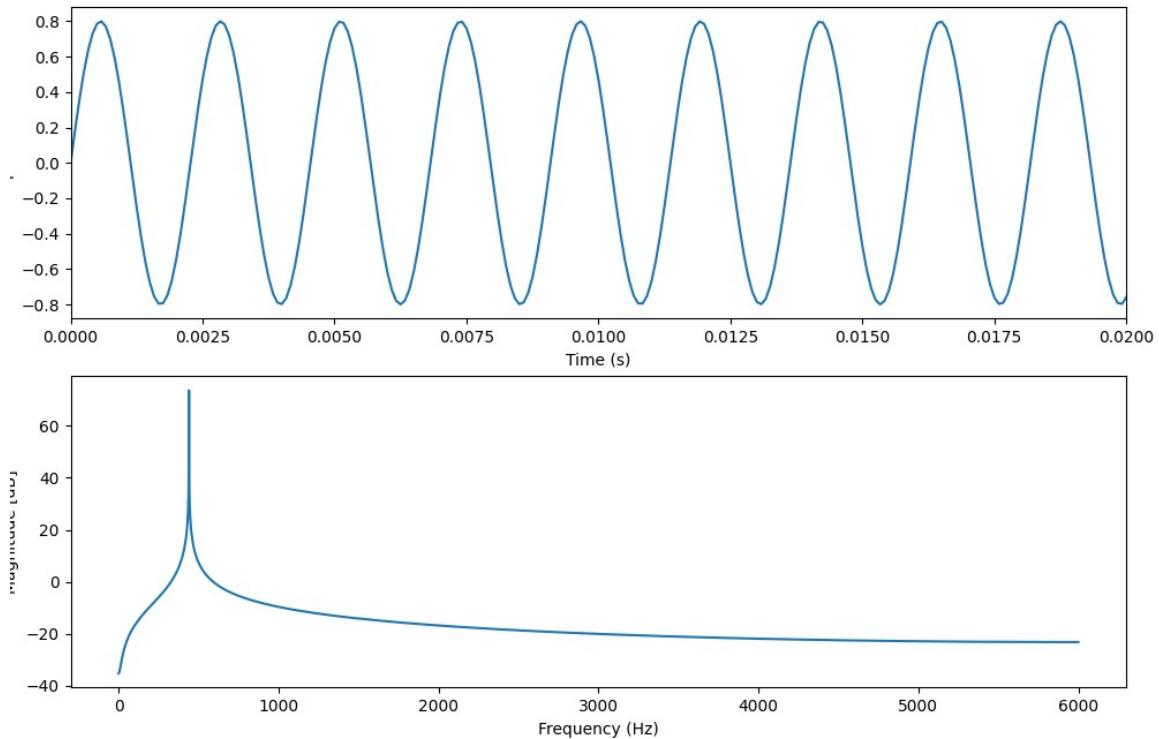
cubic interp 8000Hz

Time margin [0, 0.02]



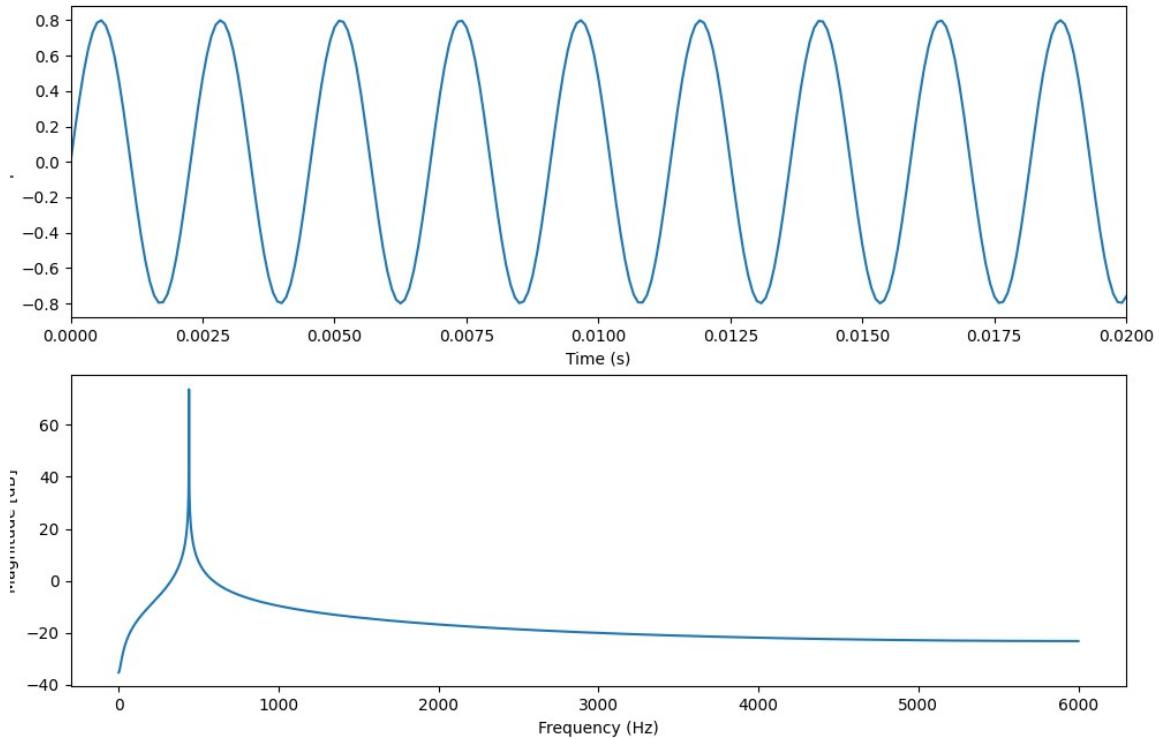
linear interp 11999Hz

Time margin [0, 0.02]



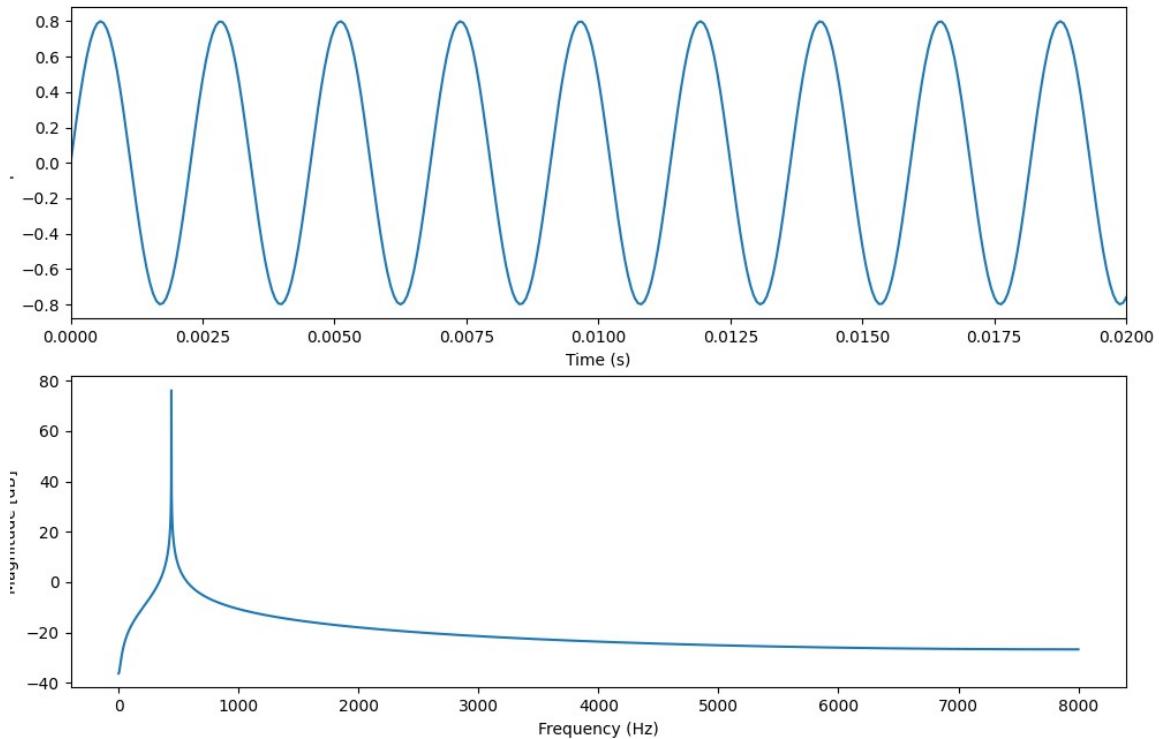
cubic interp 11999Hz

Time margin [0, 0.02]



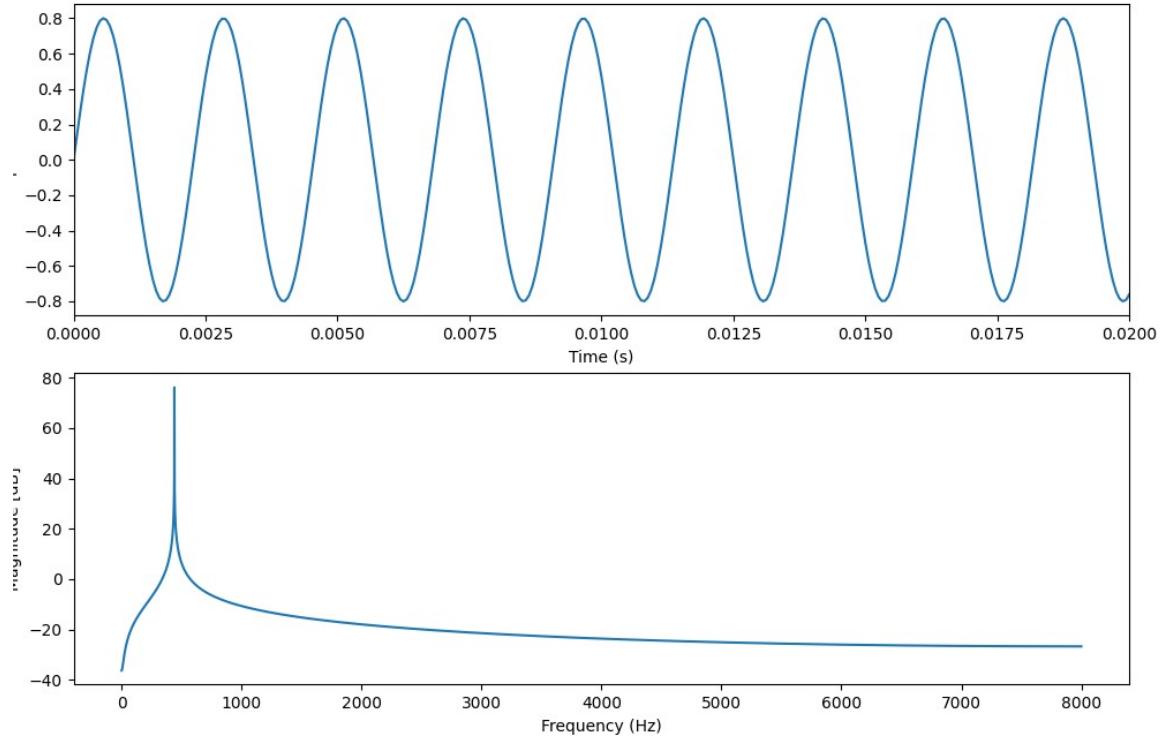
linear interp 16000Hz

Time margin [0, 0.02]



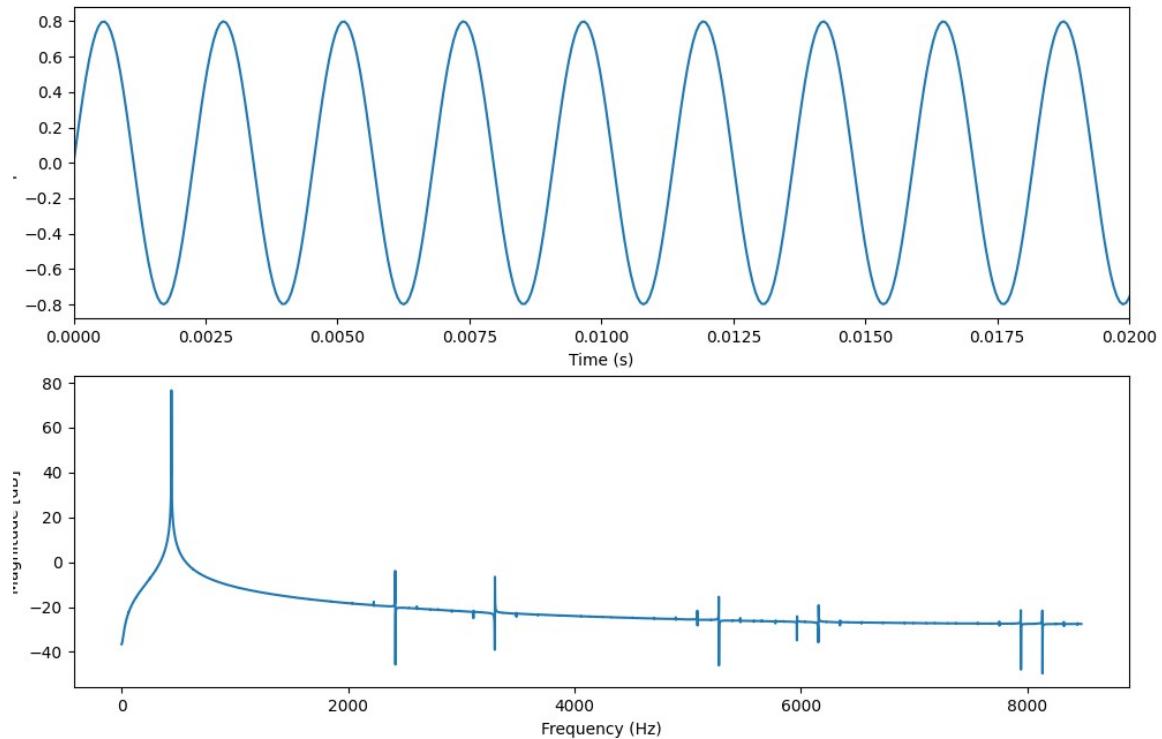
cubic interp 16000Hz

Time margin [0, 0.02]



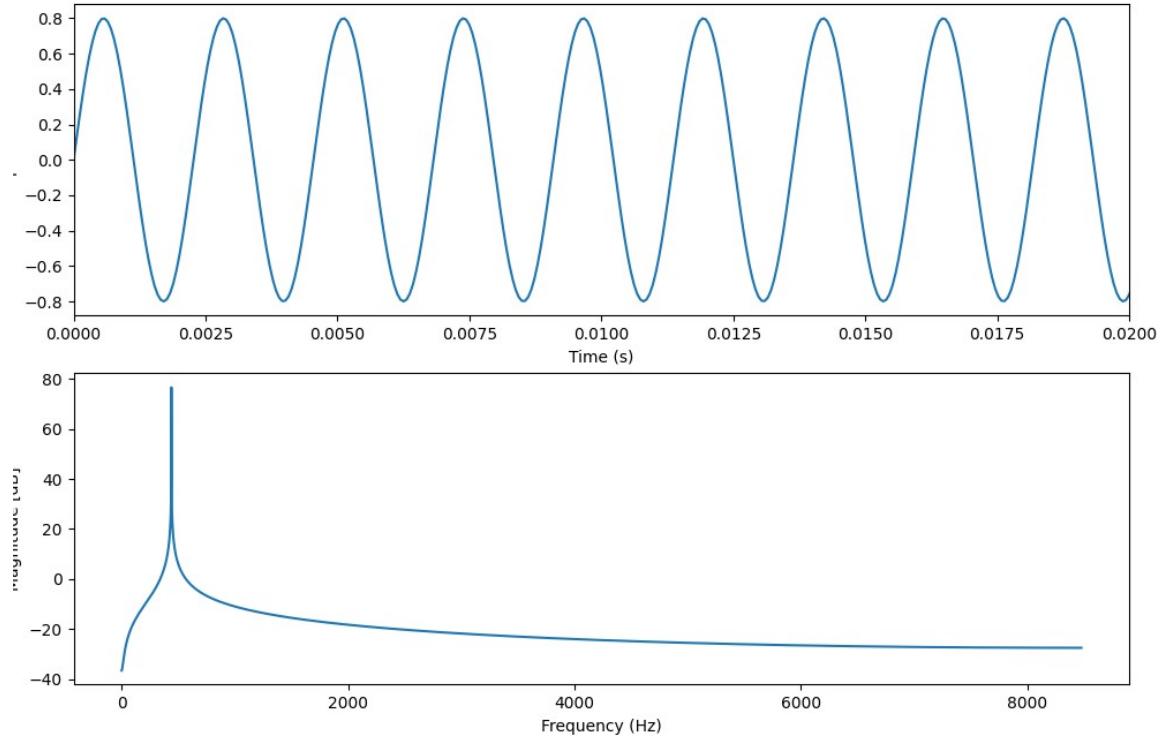
linear interp 16953Hz

Time margin [0, 0.02]



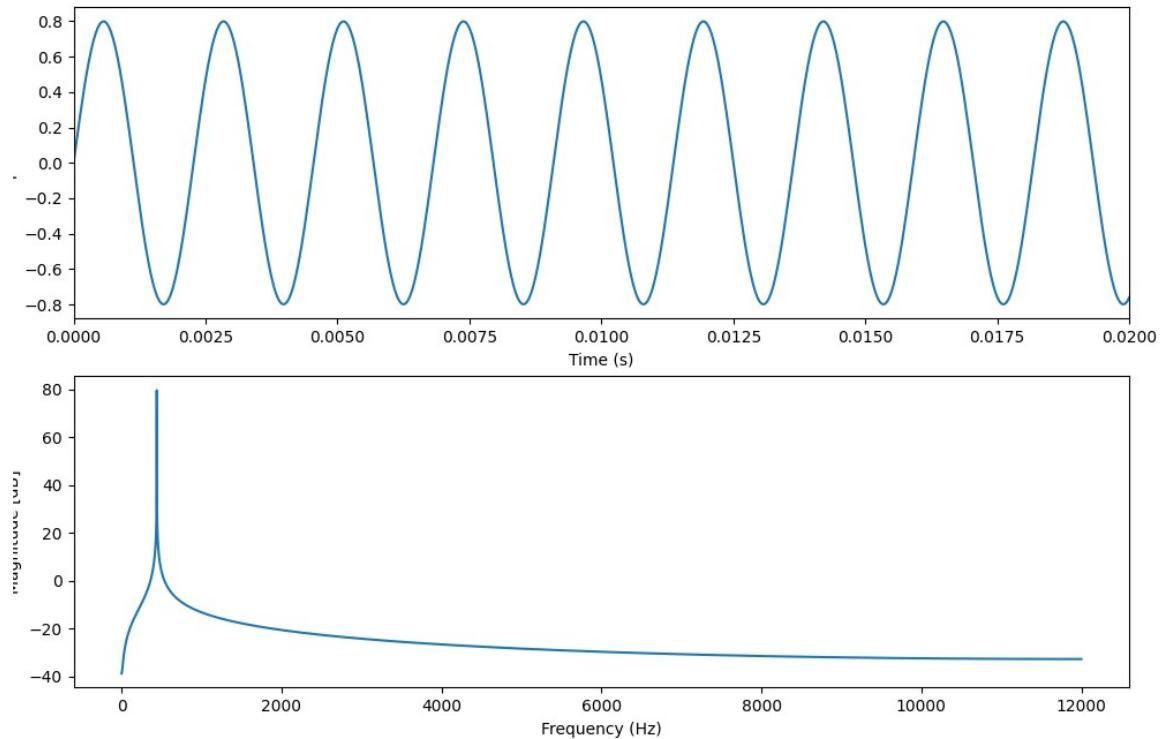
cubic interp 16953Hz

Time margin [0, 0.02]



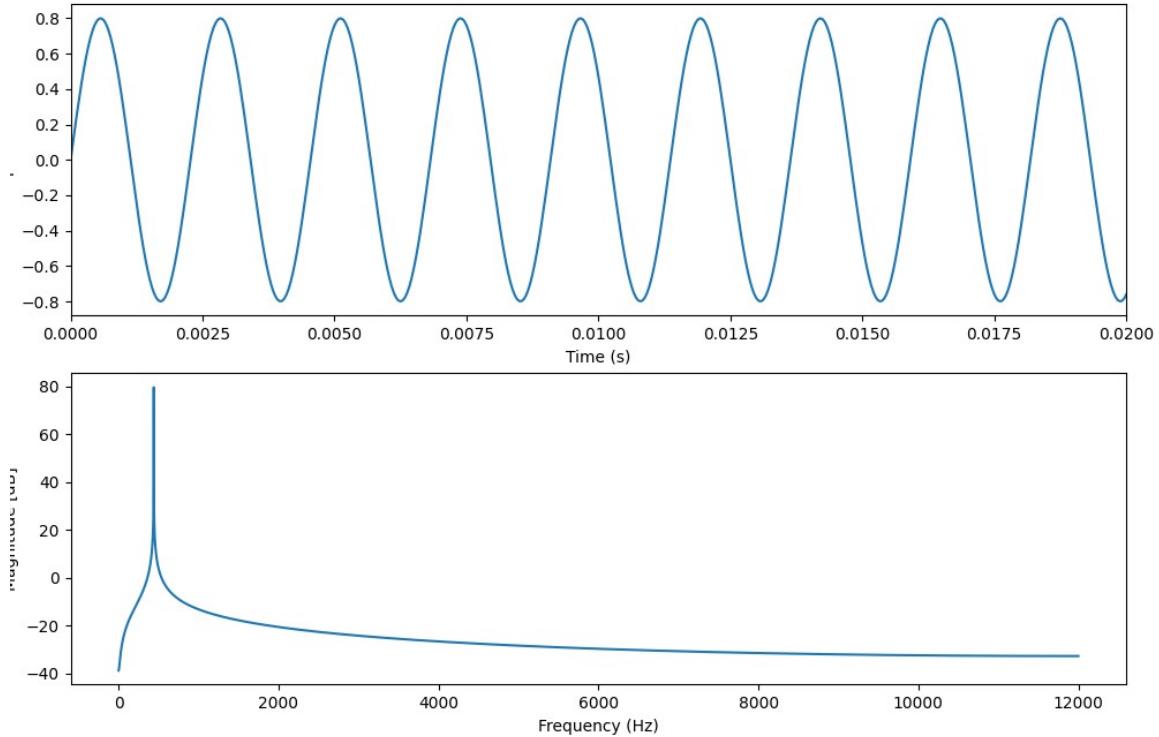
linear interp 24000Hz

Time margin [0, 0.02]



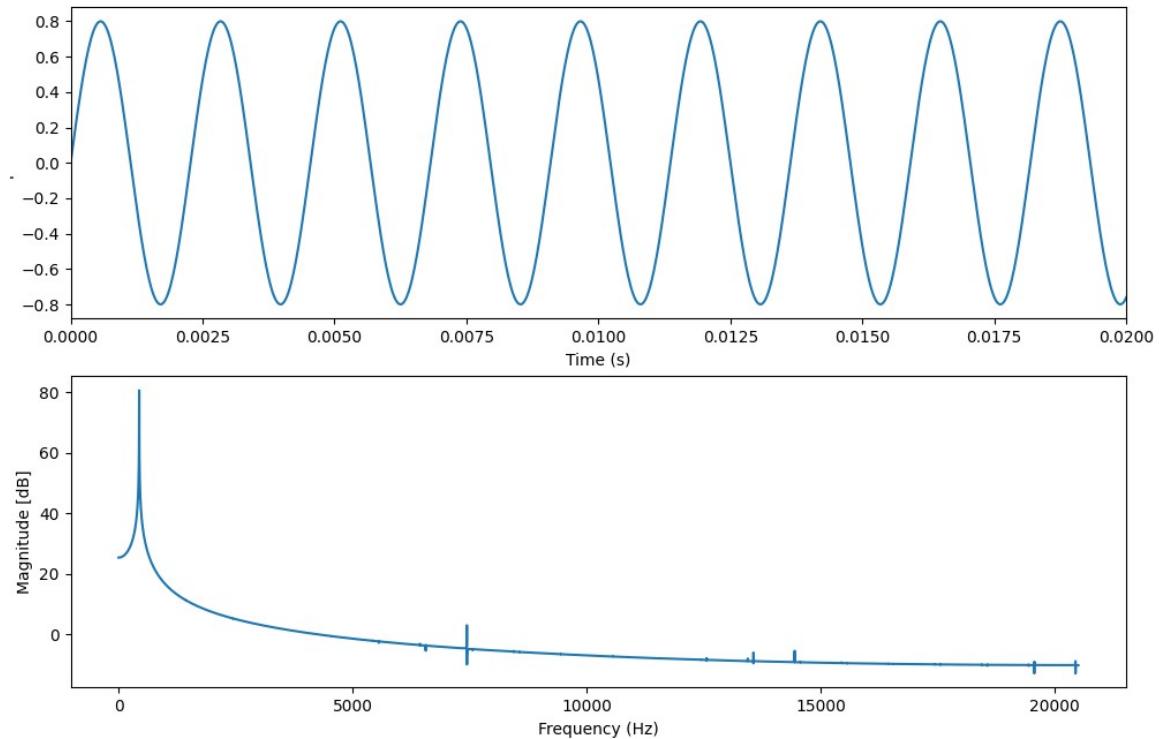
cubic interp 24000Hz

Time margin [0, 0.02]



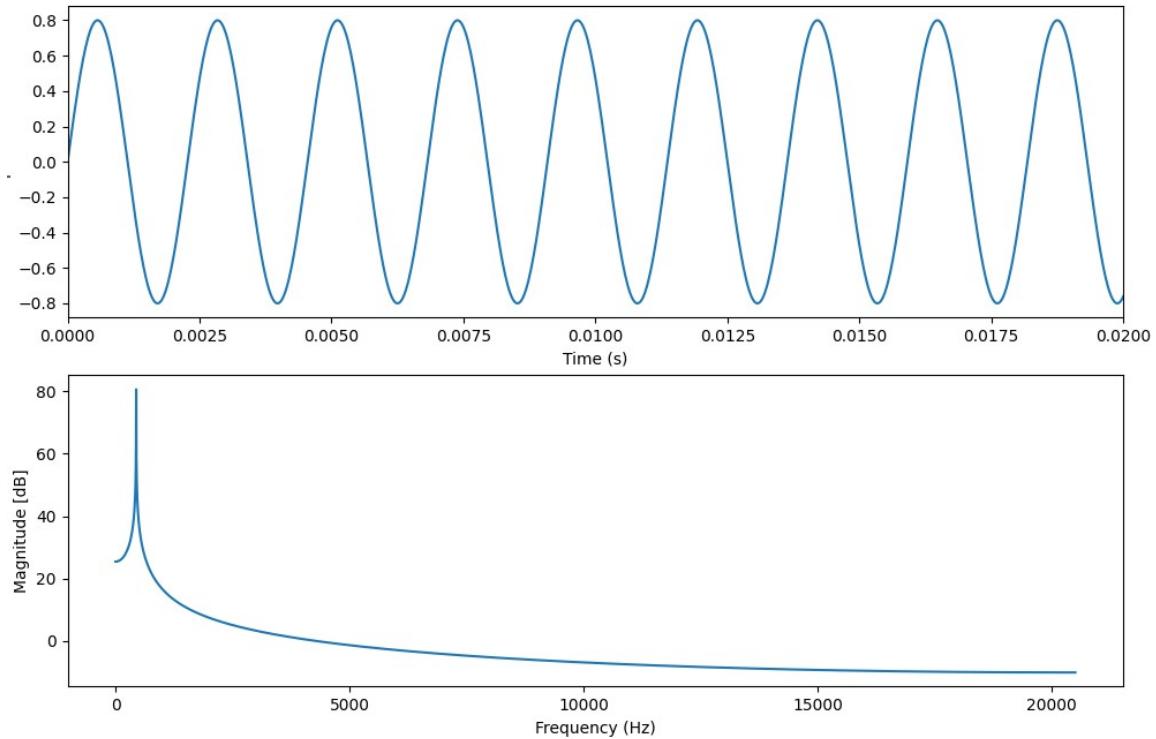
linear interp 41000Hz

Time margin [0, 0.02]



cubic interp 41000Hz

Time margin [0, 0.02]



File: sin_8000Hz.wav

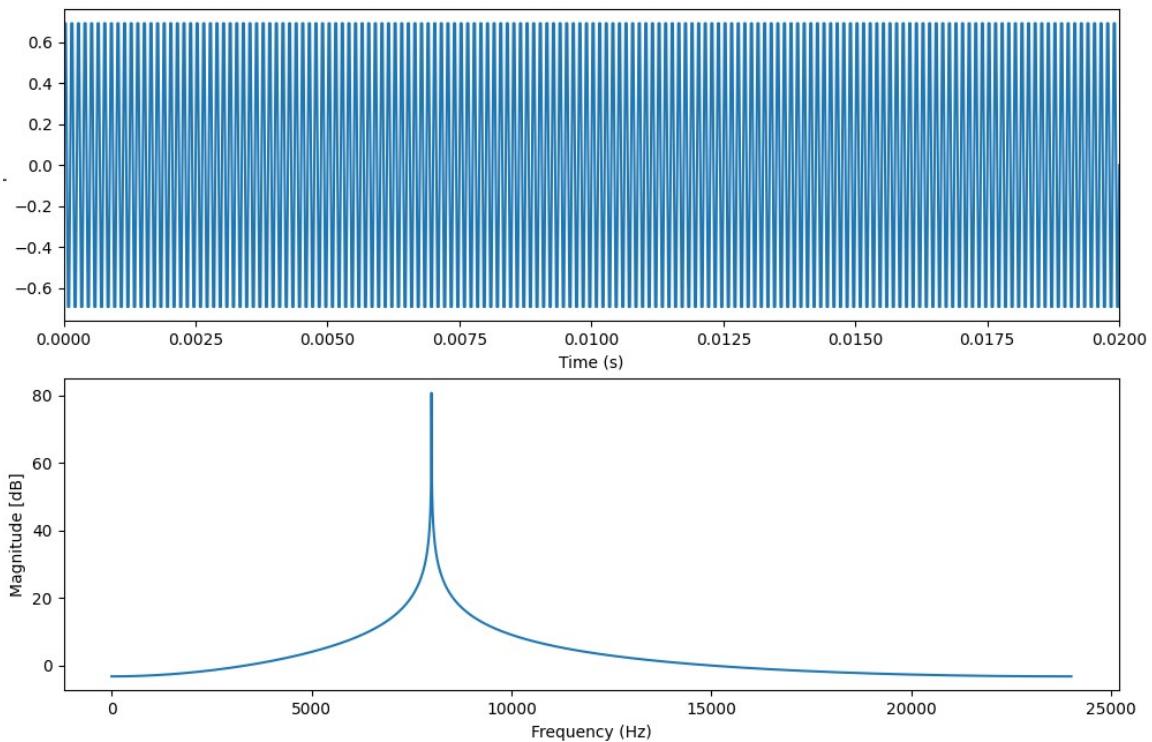
Modification	Max Frequency (Hz)	Max Amplitude (dB)
Original	8000.00	80.70
4-bit quant	8000.00	80.70
8-bit quant	8000.00	80.70
16-bit quant	8000.00	80.70
24-bit quant	8000.00	80.70
Decimation 2	8000.67	79.65
Decimation 4	4000.67	73.62
Decimation 6	0.00	-138.47
Decimation 10	1600.67	65.67
Decimation 24	0.00	-138.47
linear interp 2000Hz	4.00	56.96
cubic interp 2000Hz	4.00	57.74
linear interp 4000Hz	2.00	63.07
cubic interp 4000Hz	2.00	63.86
linear interp 8000Hz	1.00	69.31
cubic interp 8000Hz	1.00	70.09
linear interp 11999Hz	3999.00	68.91
cubic interp 11999Hz	3999.00	69.68
linear interp 16000Hz	8000.00	66.41
cubic interp 16000Hz	8000.00	67.19

linear interp 16953Hz	8001.42	74.45
cubic interp 16953Hz	8001.42	75.23
linear interp 24000Hz	8000.67	78.40
cubic interp 24000Hz	8000.67	79.22
linear interp 41000Hz	8000.79	80.84
cubic interp 41000Hz	8000.79	81.62

Visualizations

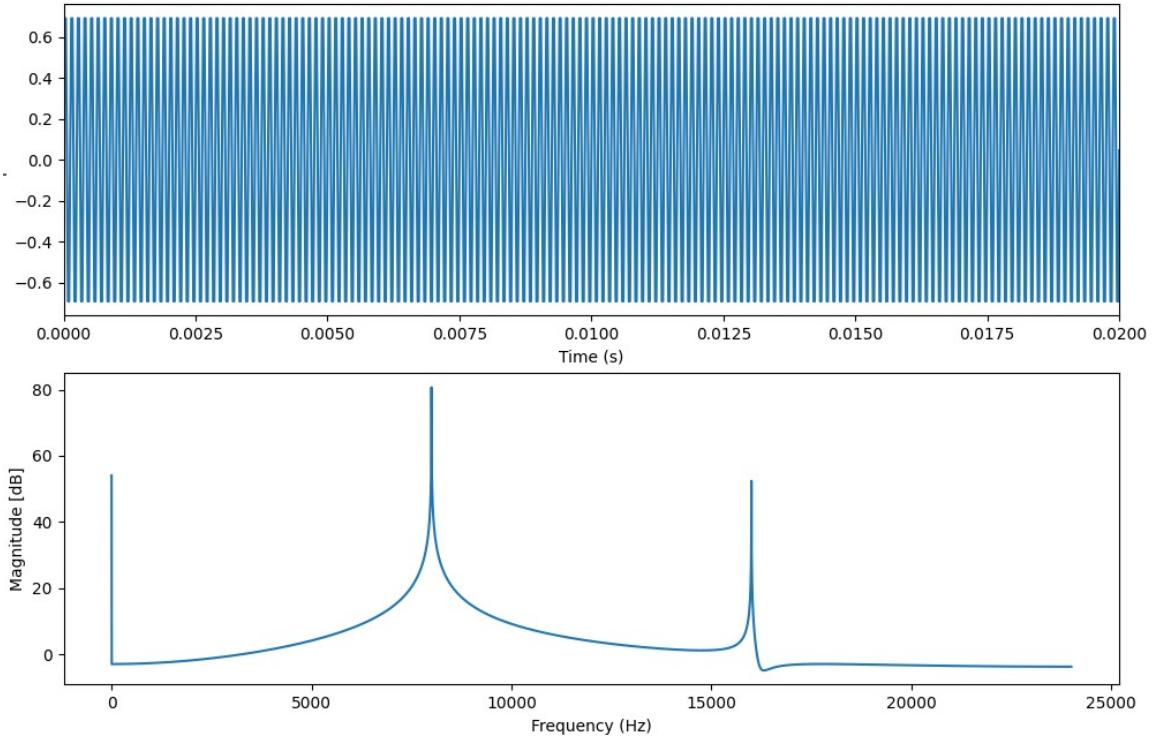
Original

Time margin [0, 0.02]



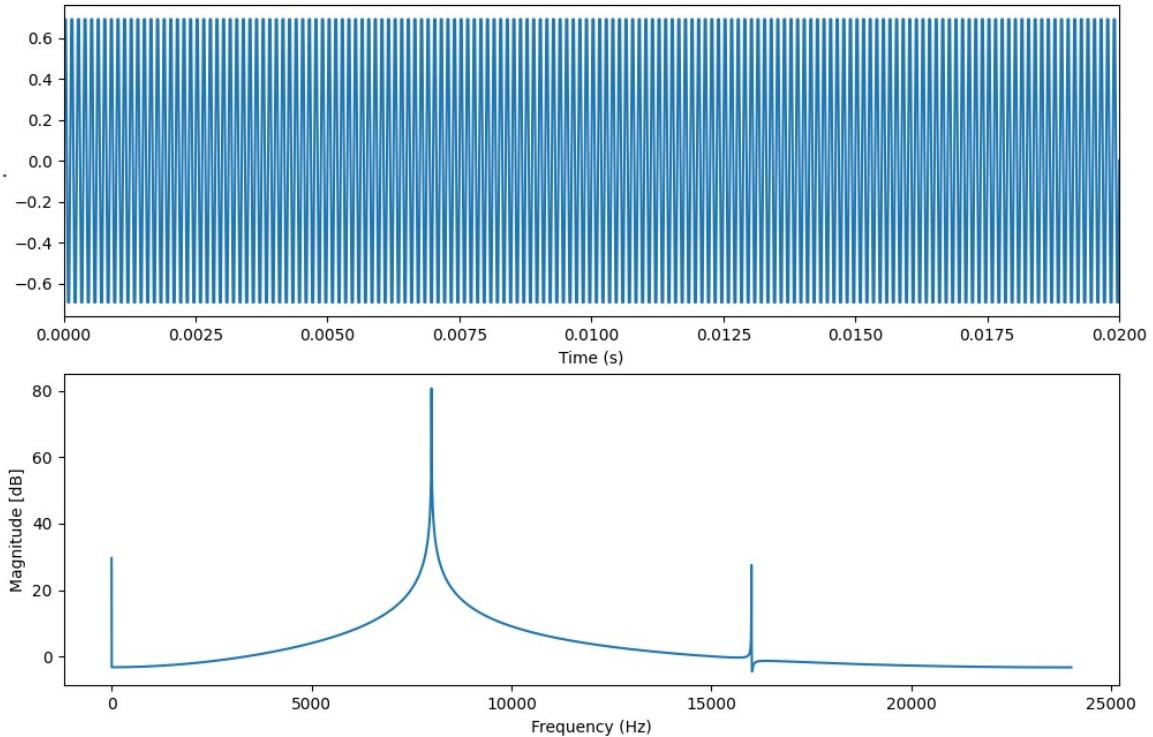
4-bit quant

Time margin [0, 0.02]



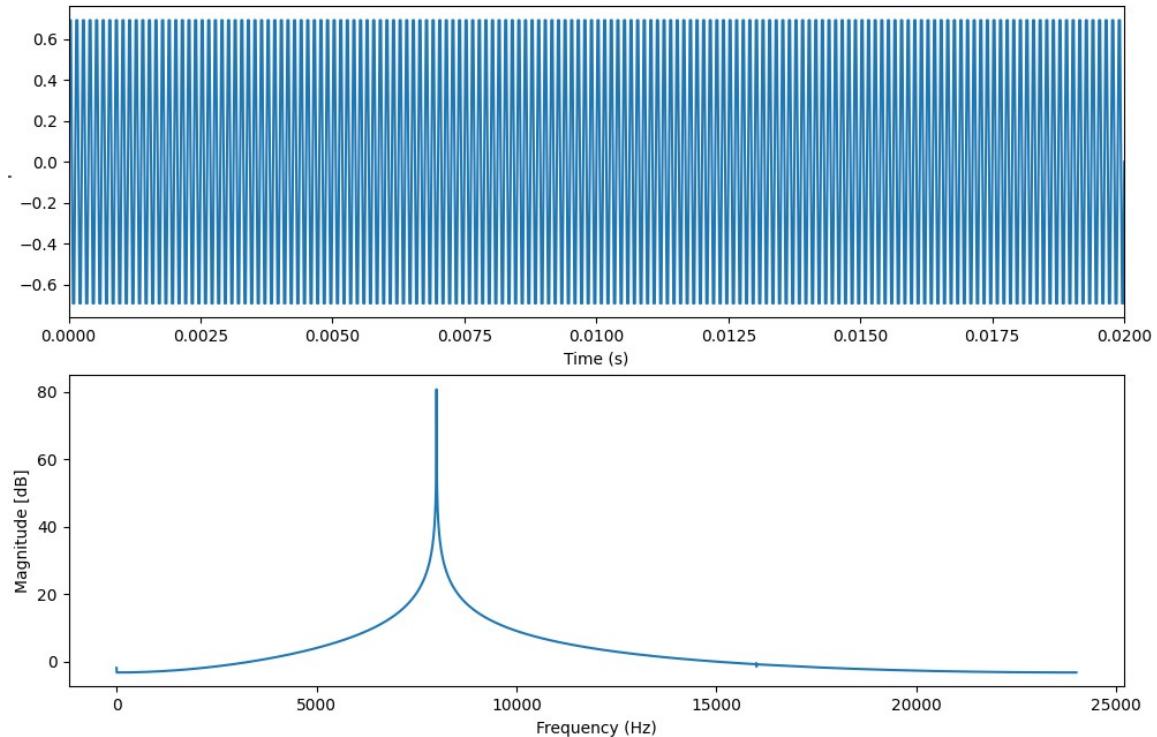
8-bit quant

Time margin [0, 0.02]



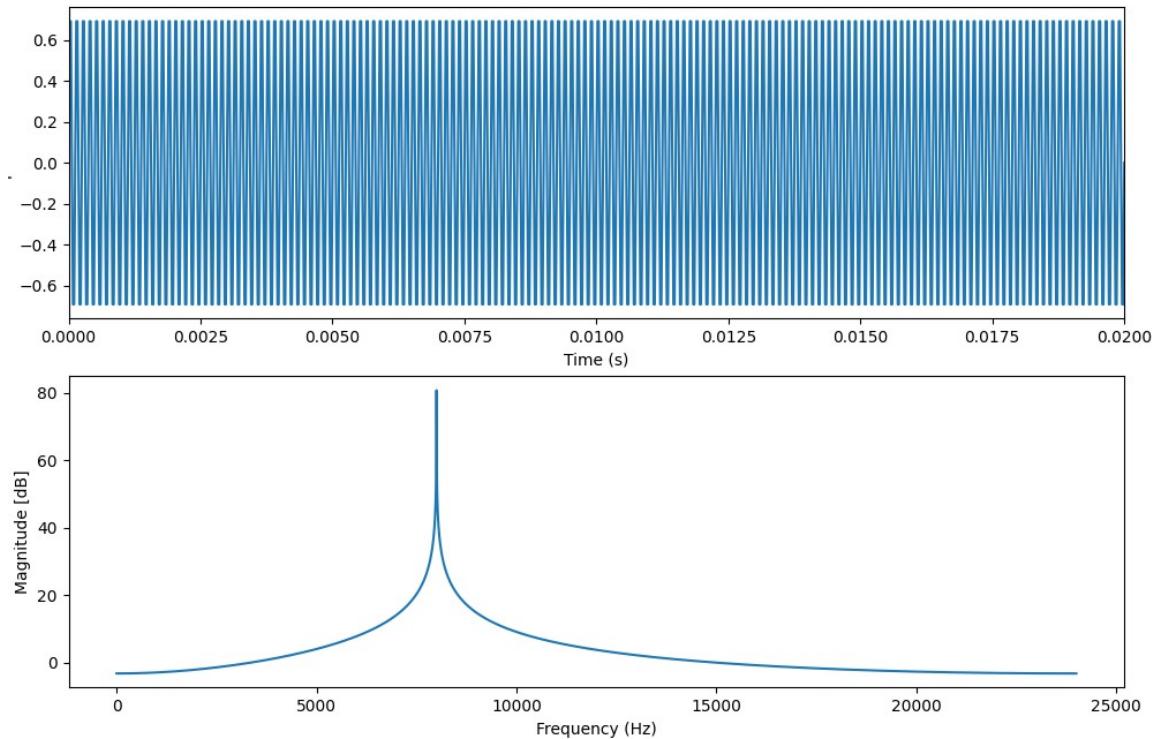
16-bit quant

Time margin [0, 0.02]



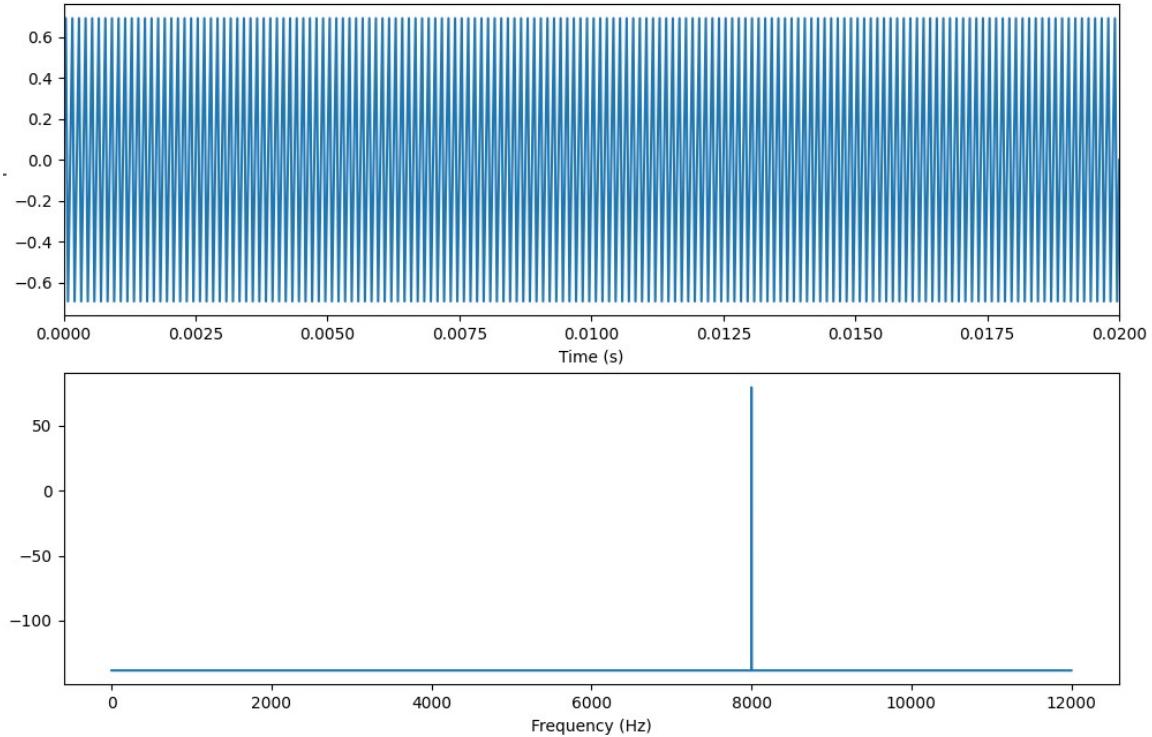
24-bit quant

Time margin [0, 0.02]



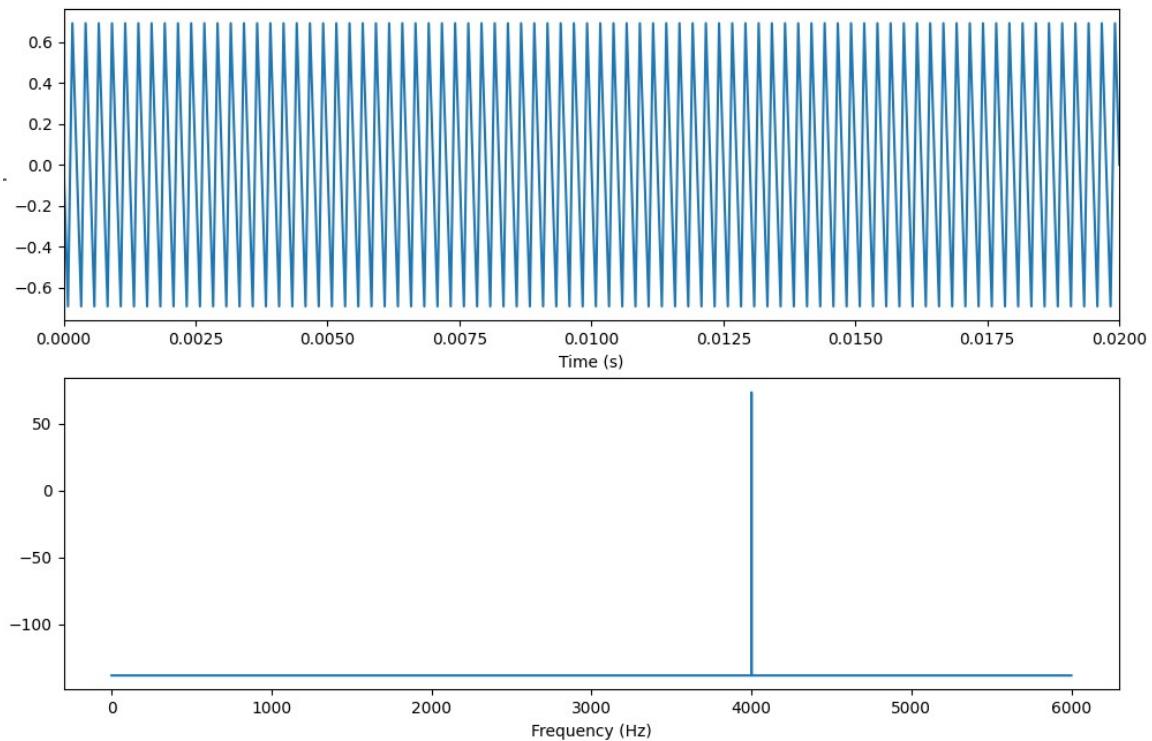
Decimation 2

Time margin [0, 0.02]



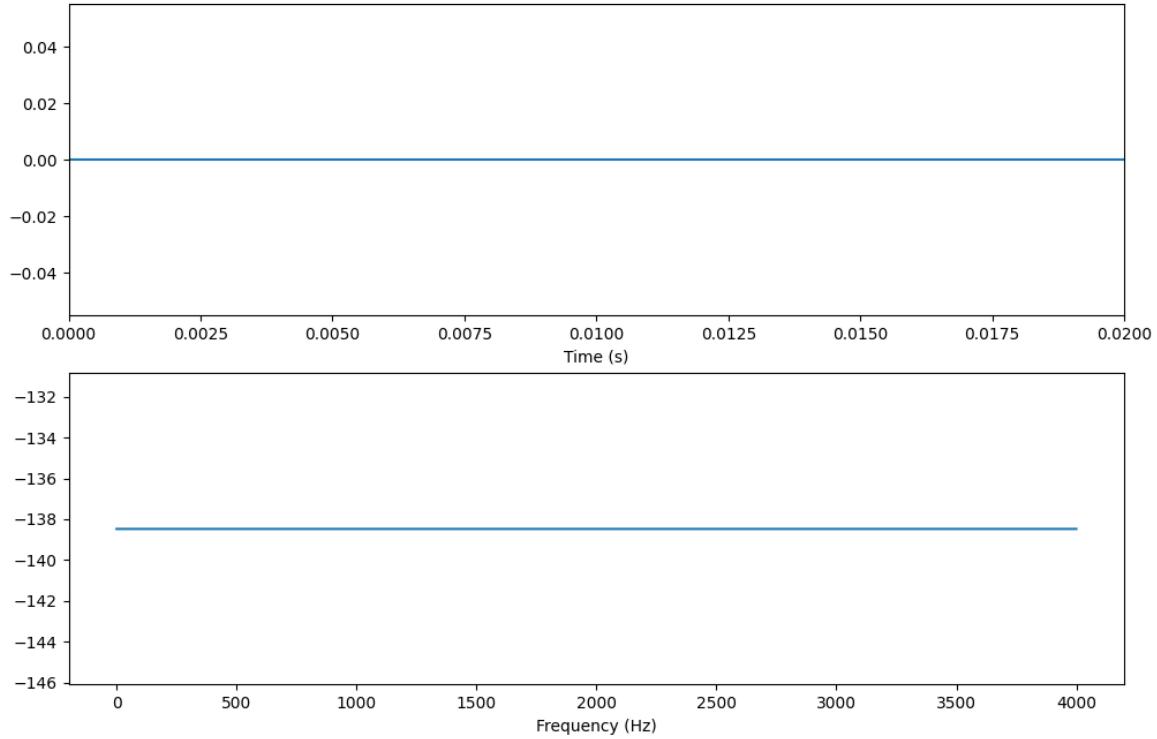
Decimation 4

Time margin [0, 0.02]



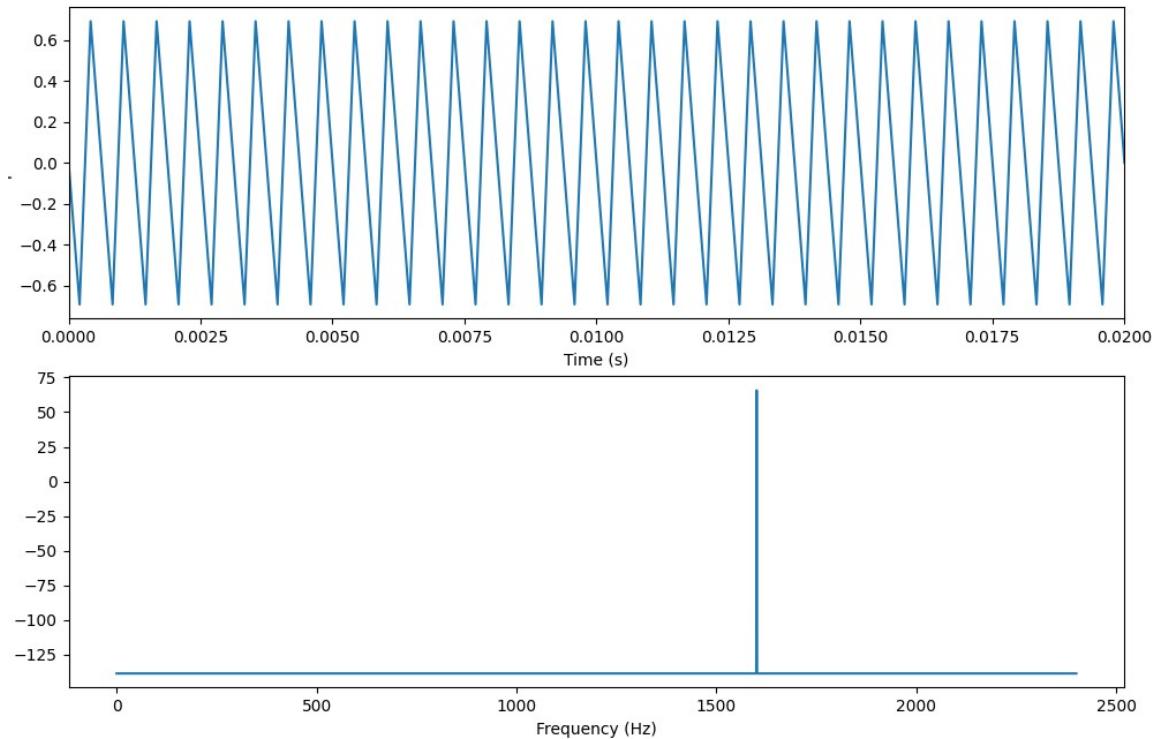
Decimation 6

Time margin [0, 0.02]



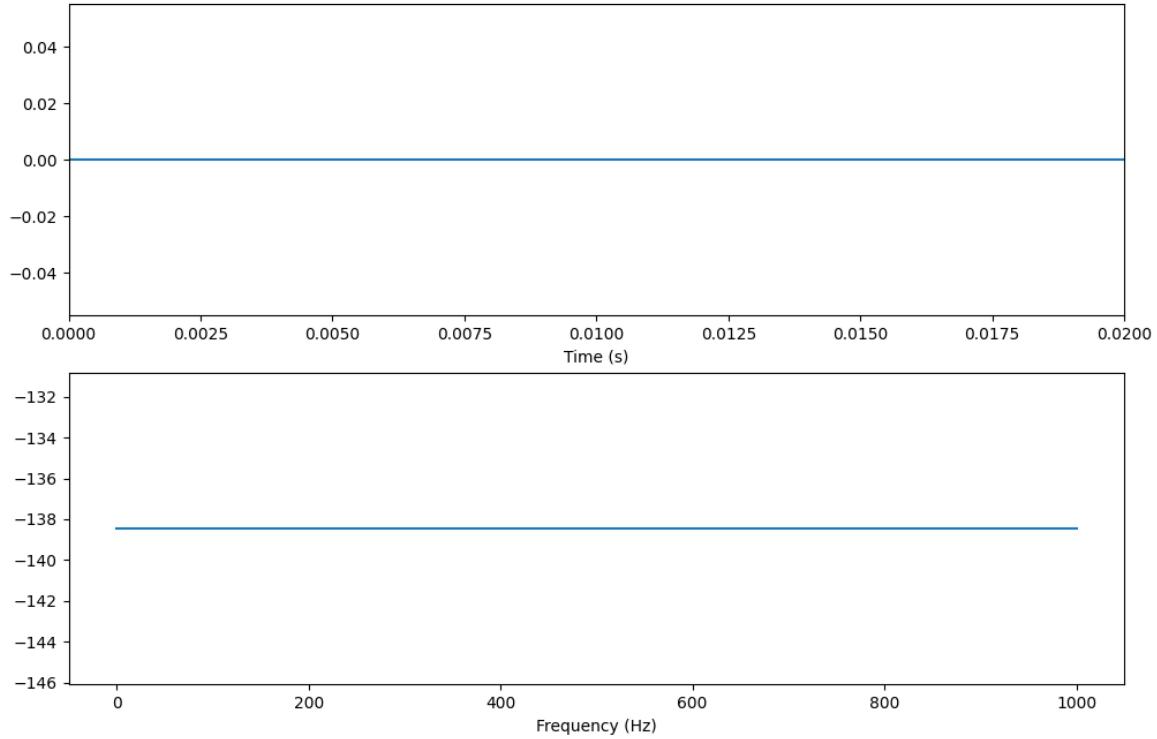
Decimation 10

Time margin [0, 0.02]



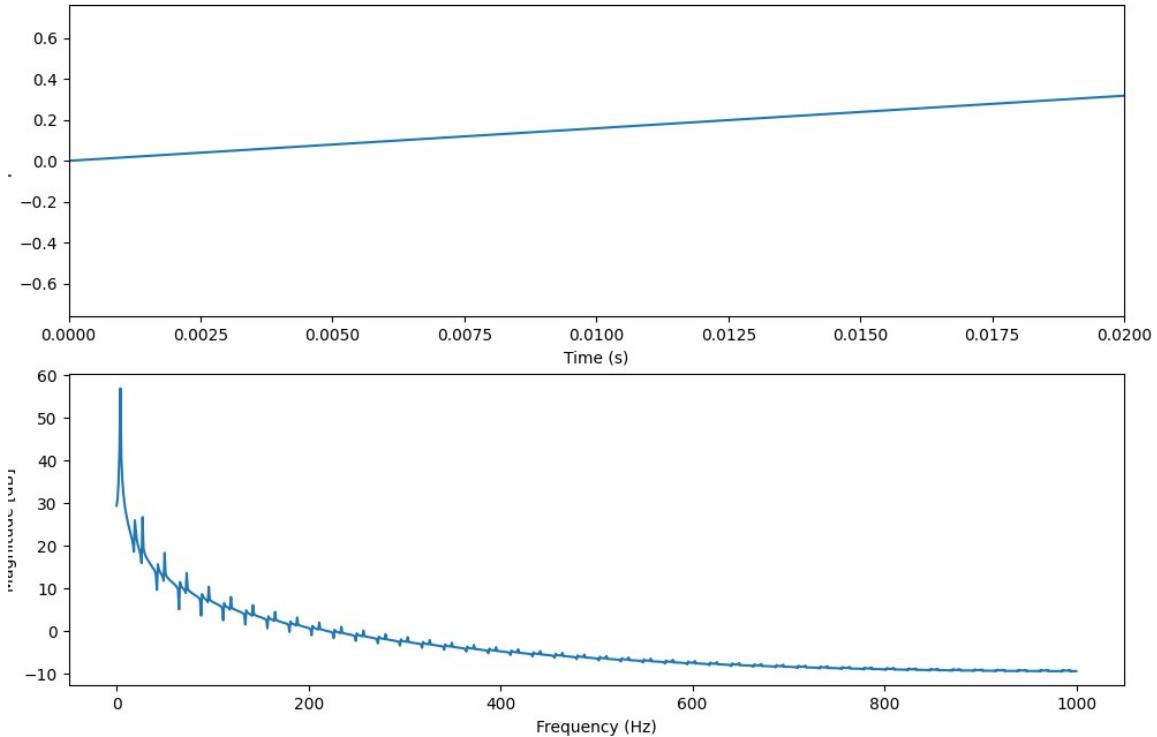
Decimation 24

Time margin [0, 0.02]



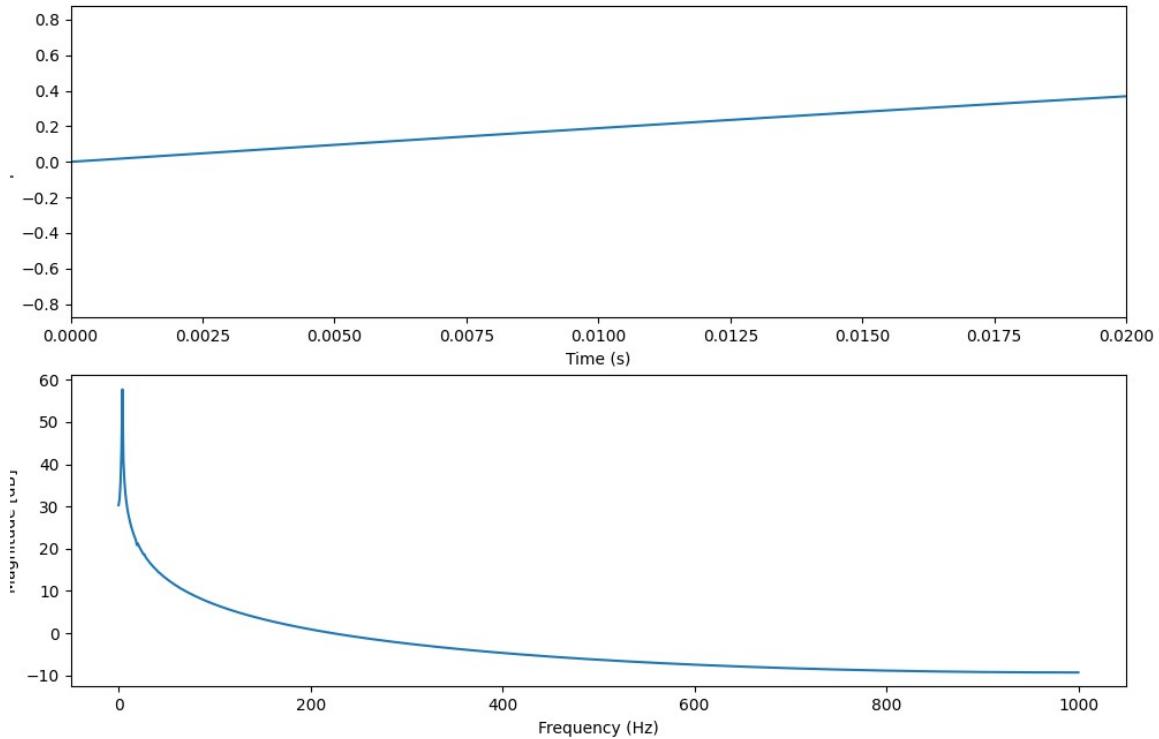
linear interp 2000Hz

Time margin [0, 0.02]



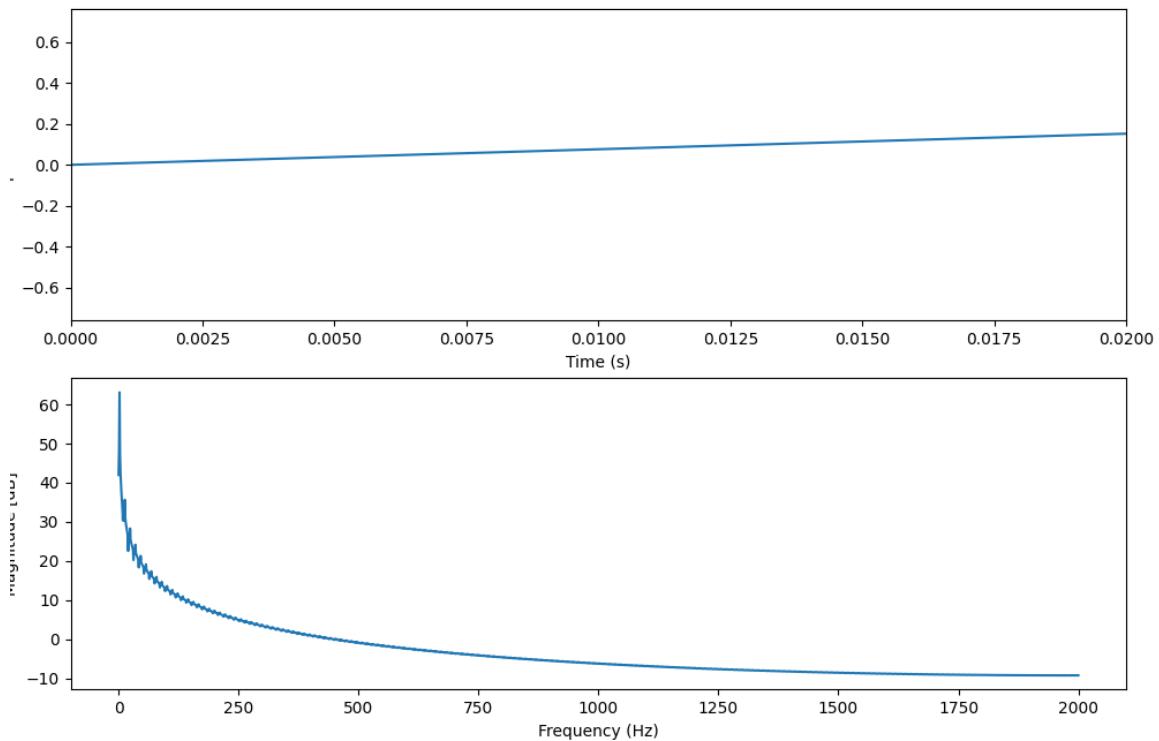
cubic interp 2000Hz

Time margin [0, 0.02]



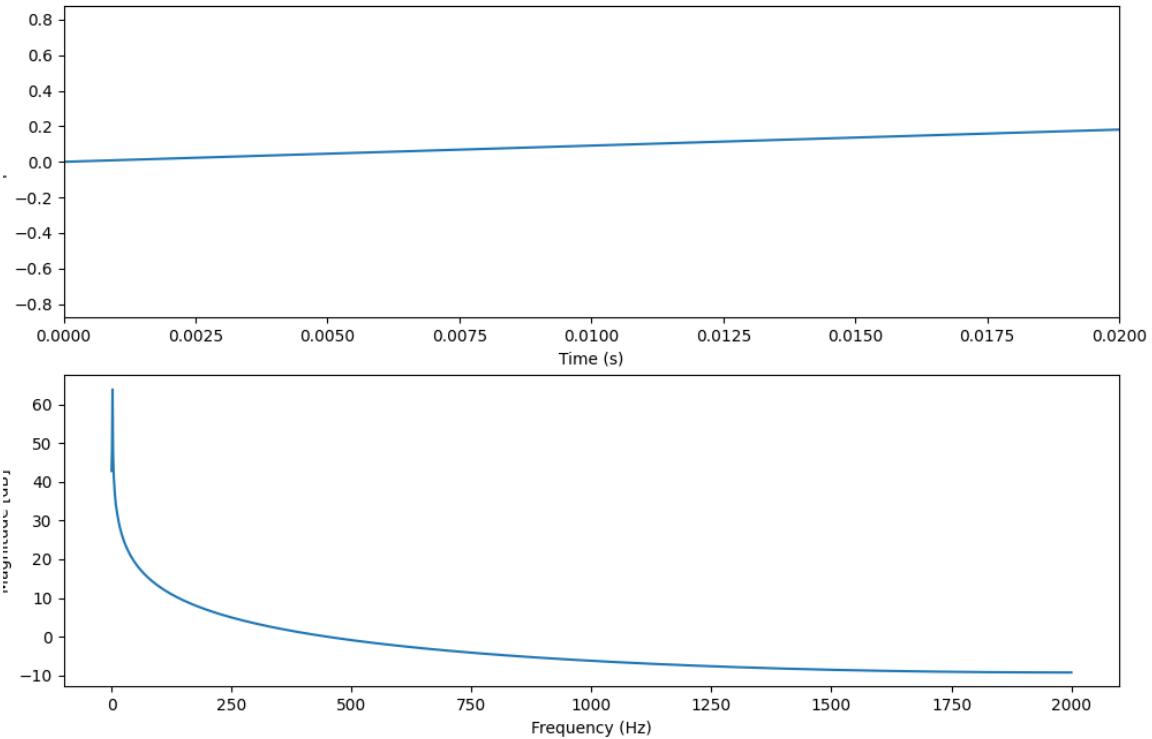
linear interp 4000Hz

Time margin [0, 0.02]



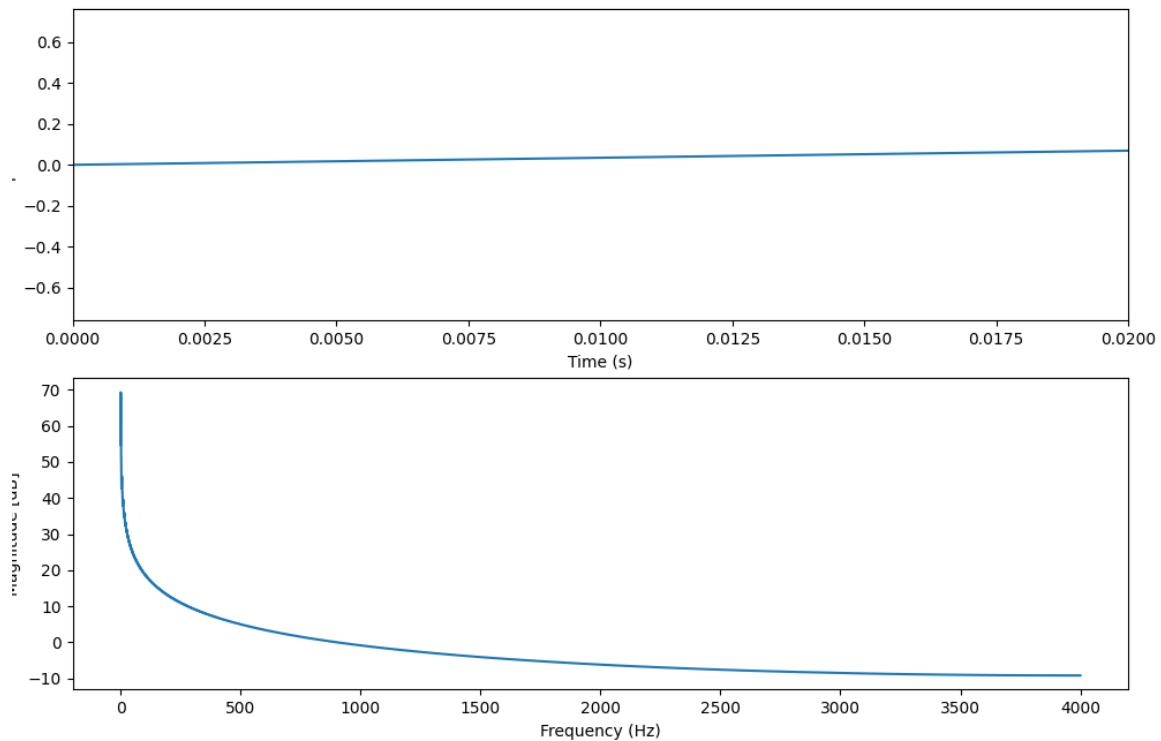
cubic interp 4000Hz

Time margin [0, 0.02]



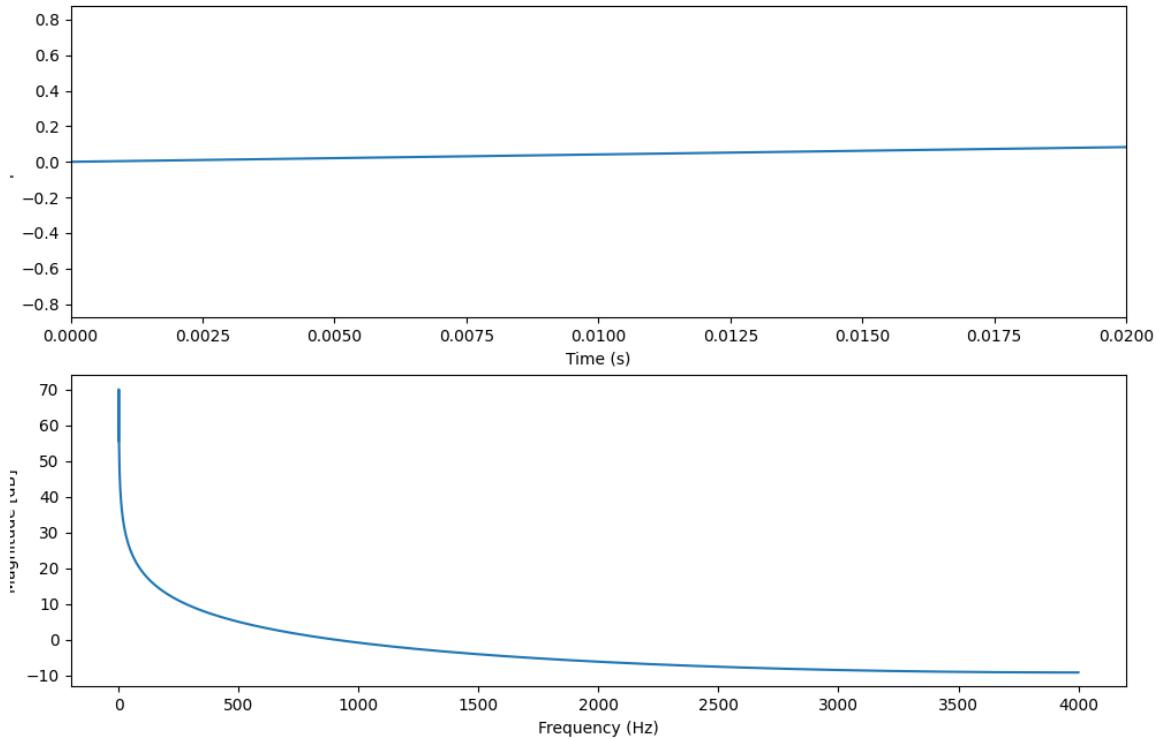
linear interp 8000Hz

Time margin [0, 0.02]



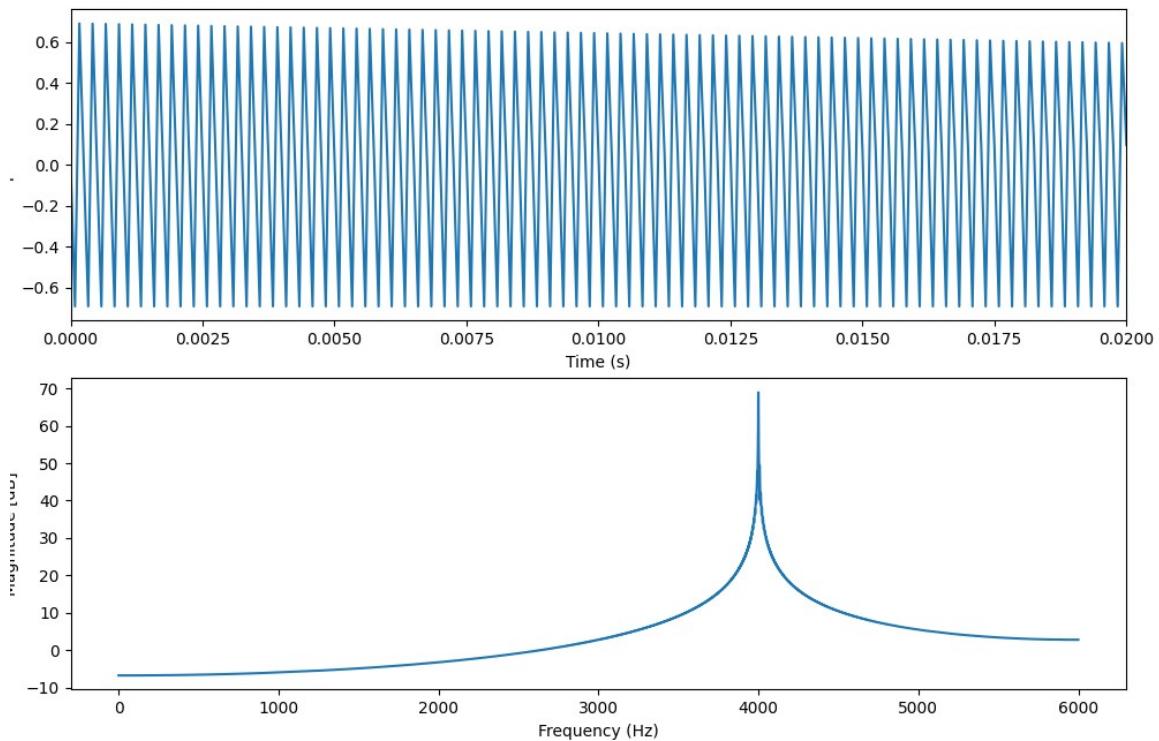
cubic interp 8000Hz

Time margin [0, 0.02]



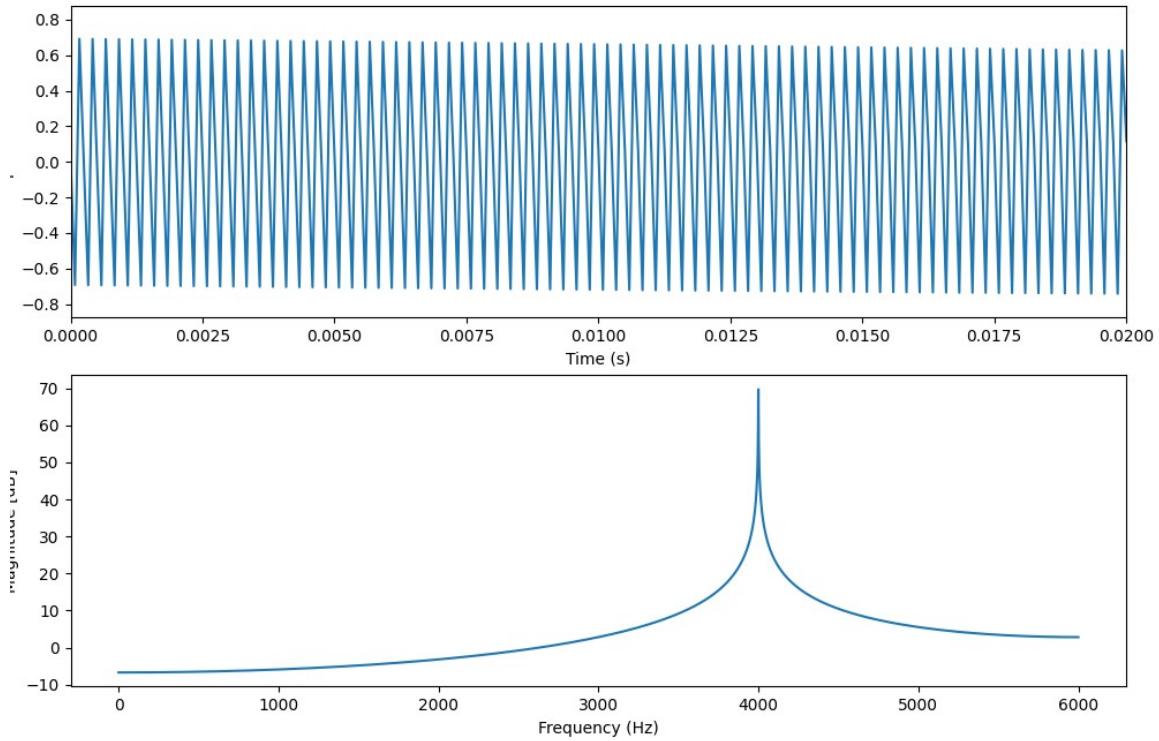
linear interp 11999Hz

Time margin [0, 0.02]



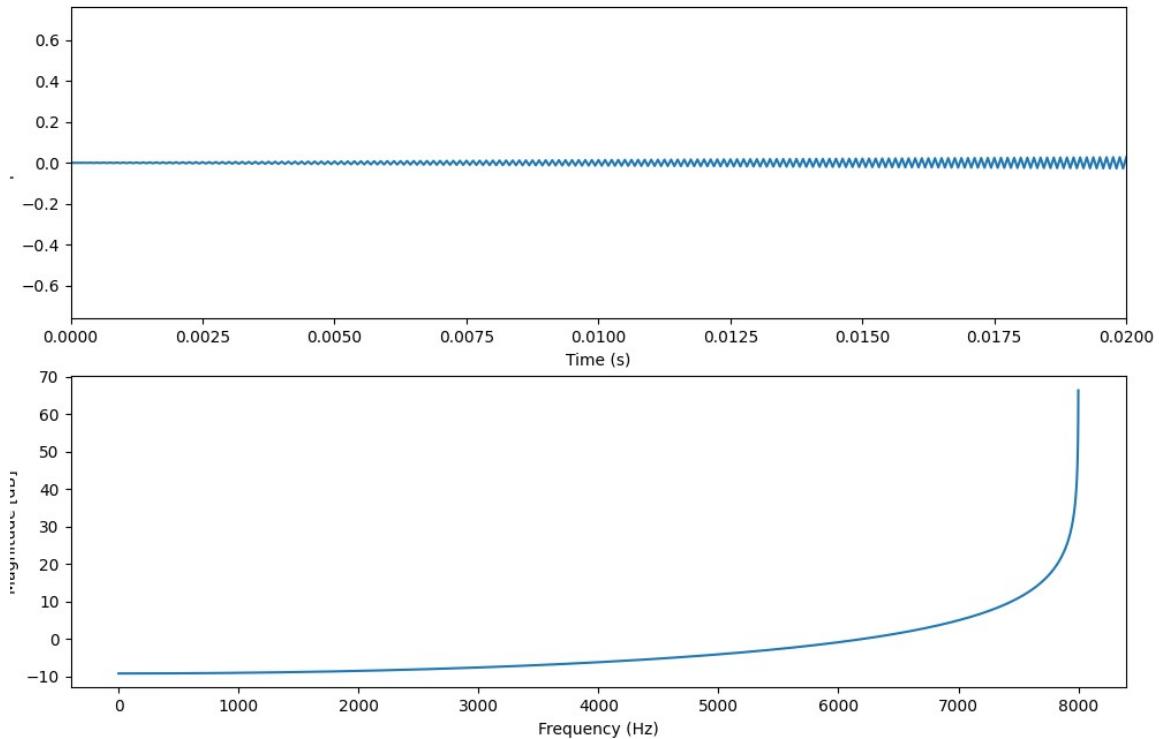
cubic interp 11999Hz

Time margin [0, 0.02]



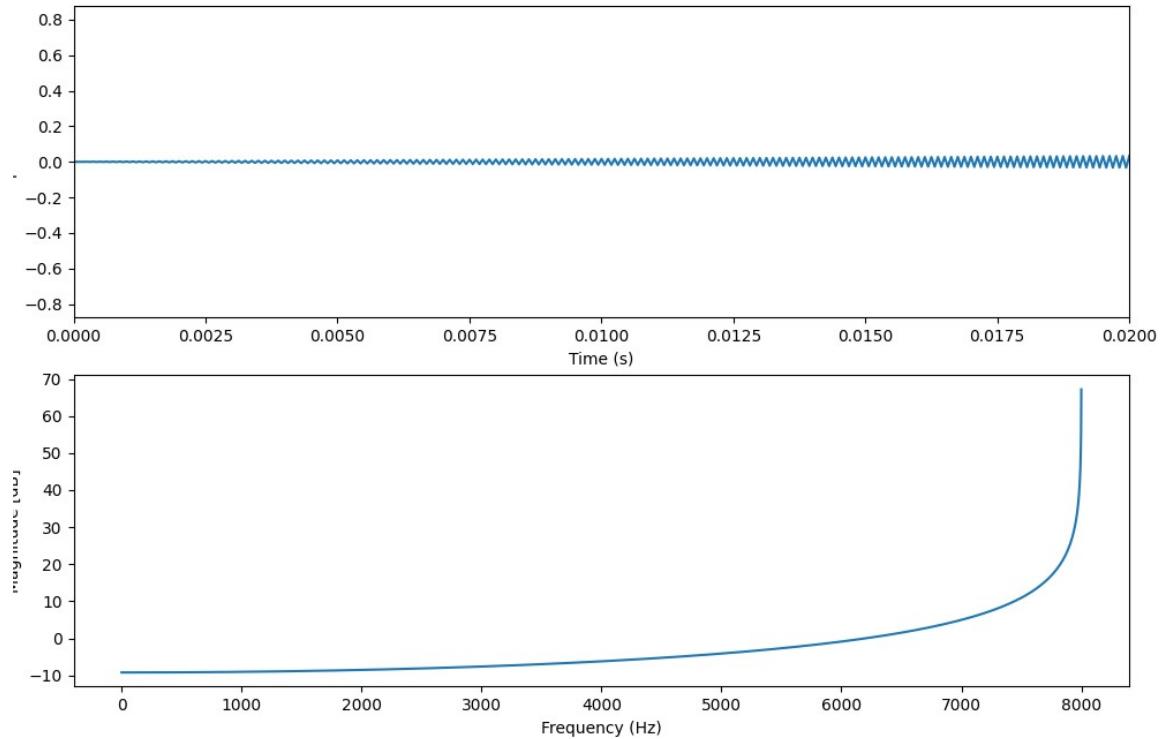
linear interp 16000Hz

Time margin [0, 0.02]



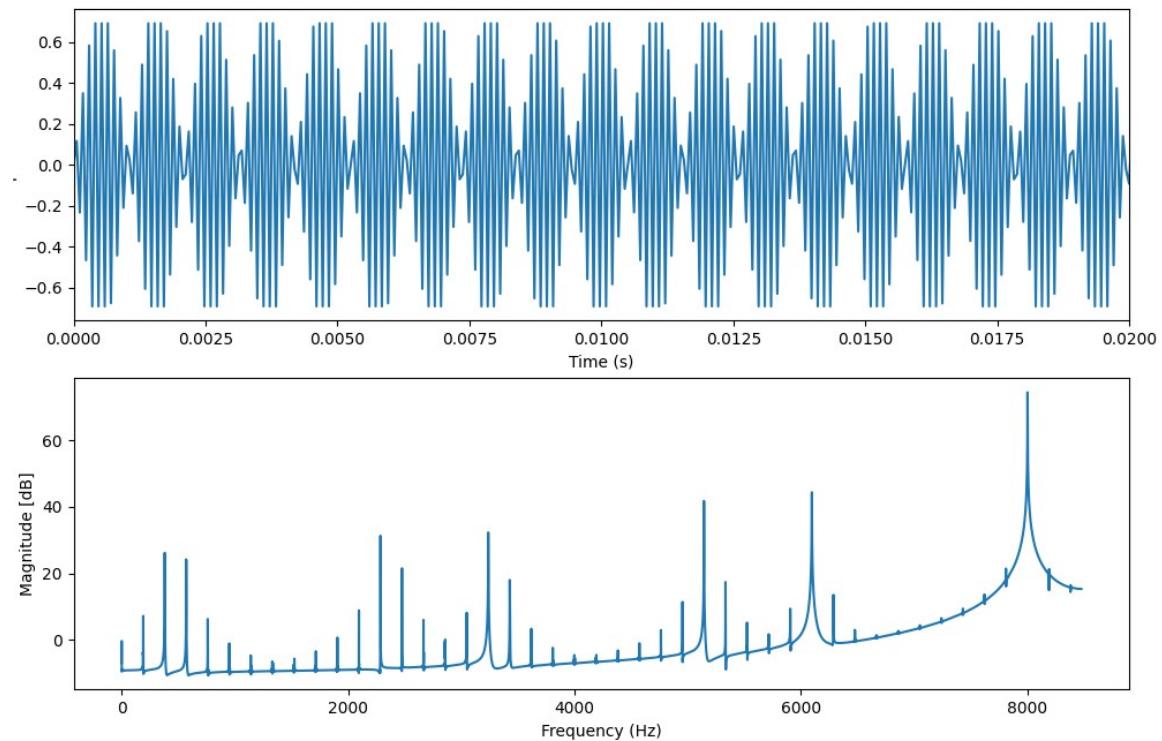
cubic interp 16000Hz

Time margin [0, 0.02]



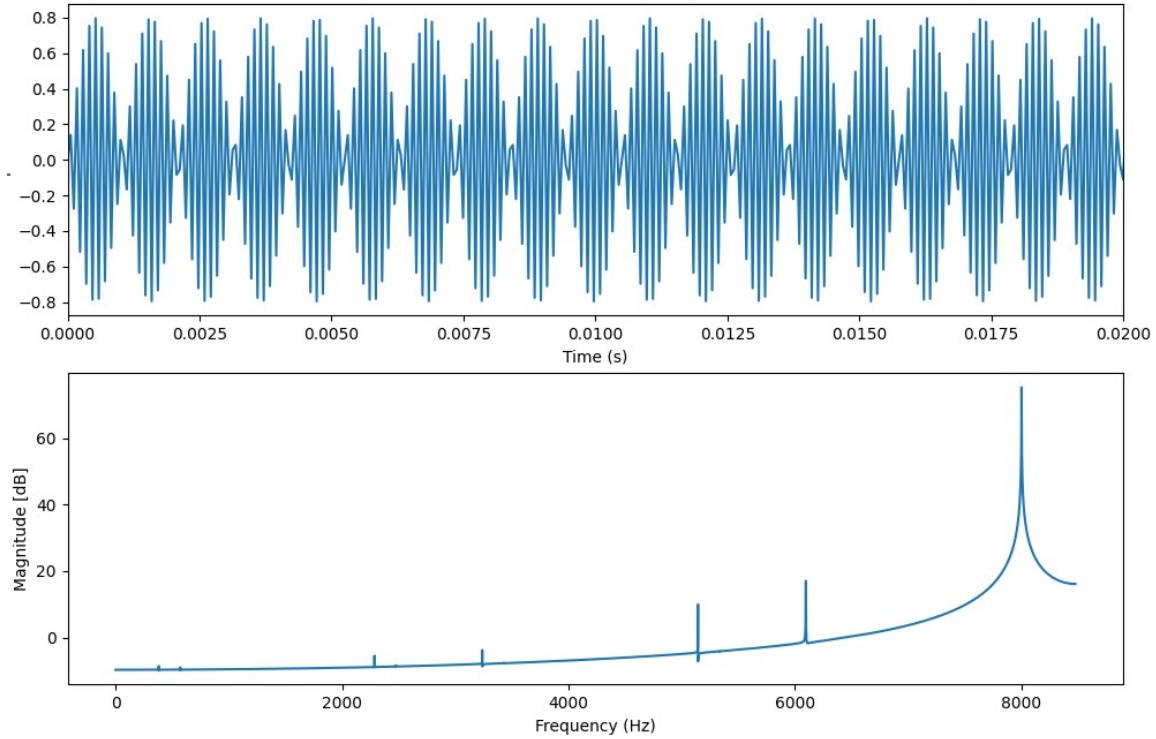
linear interp 16953Hz

Time margin [0, 0.02]



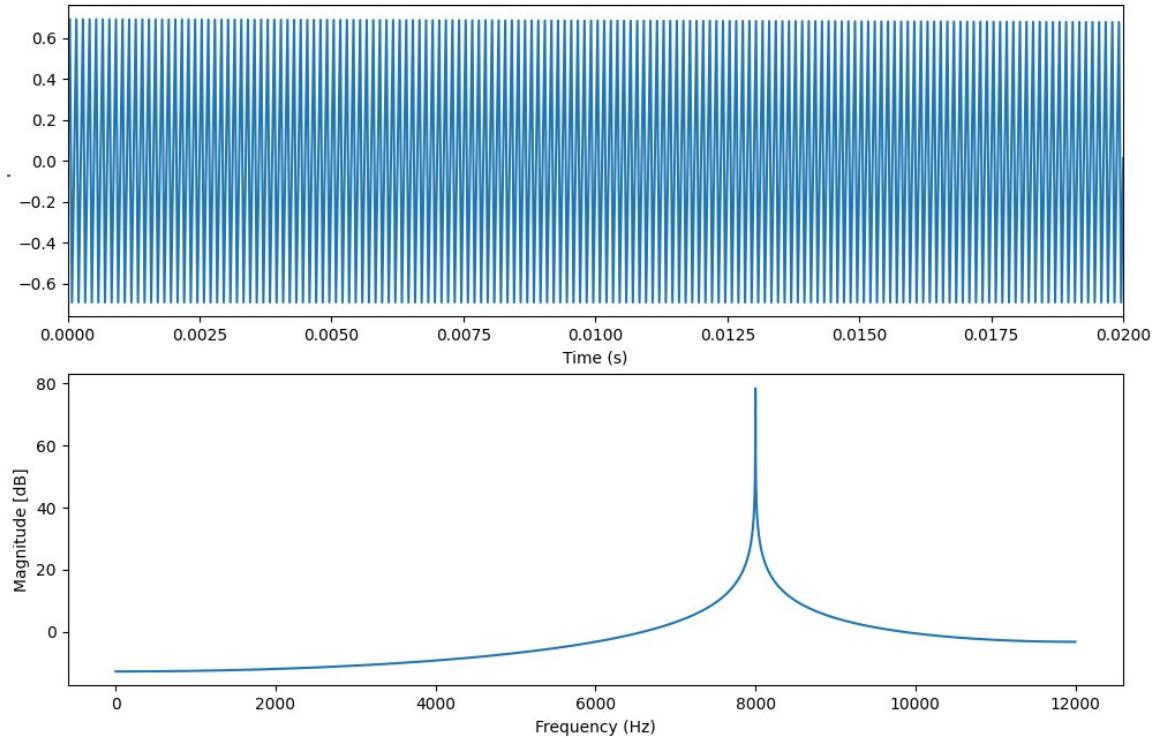
cubic interp 16953Hz

Time margin [0, 0.02]



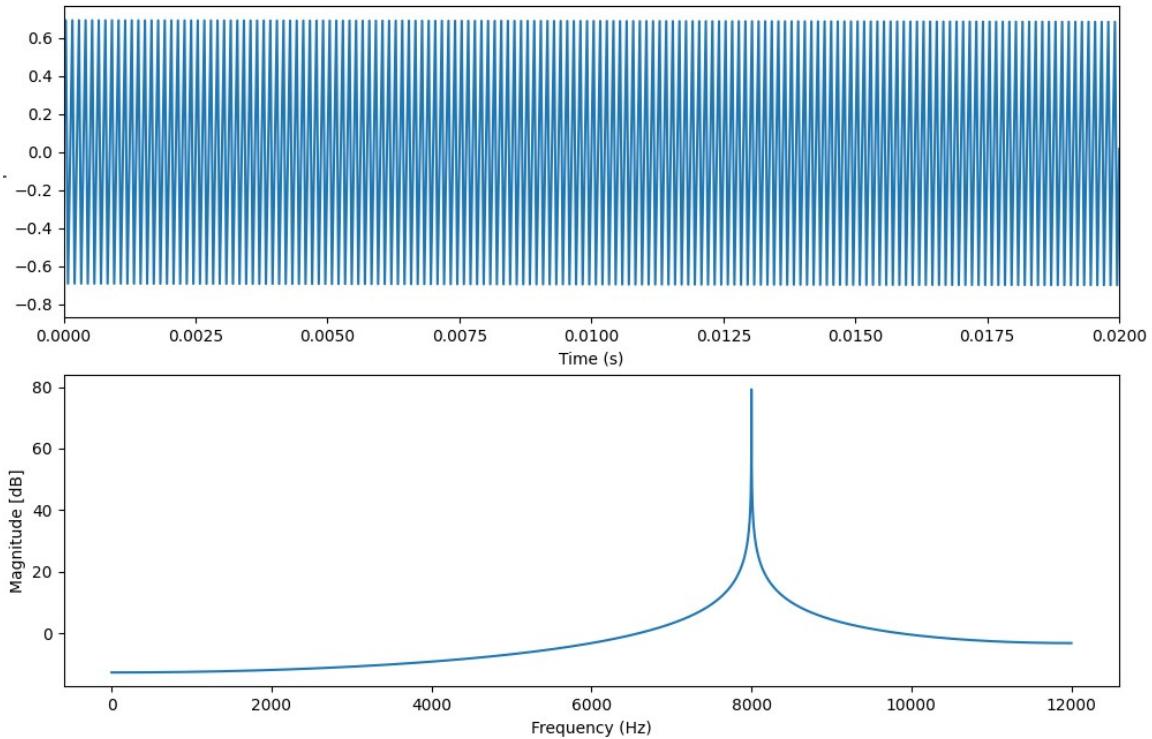
linear interp 24000Hz

Time margin [0, 0.02]



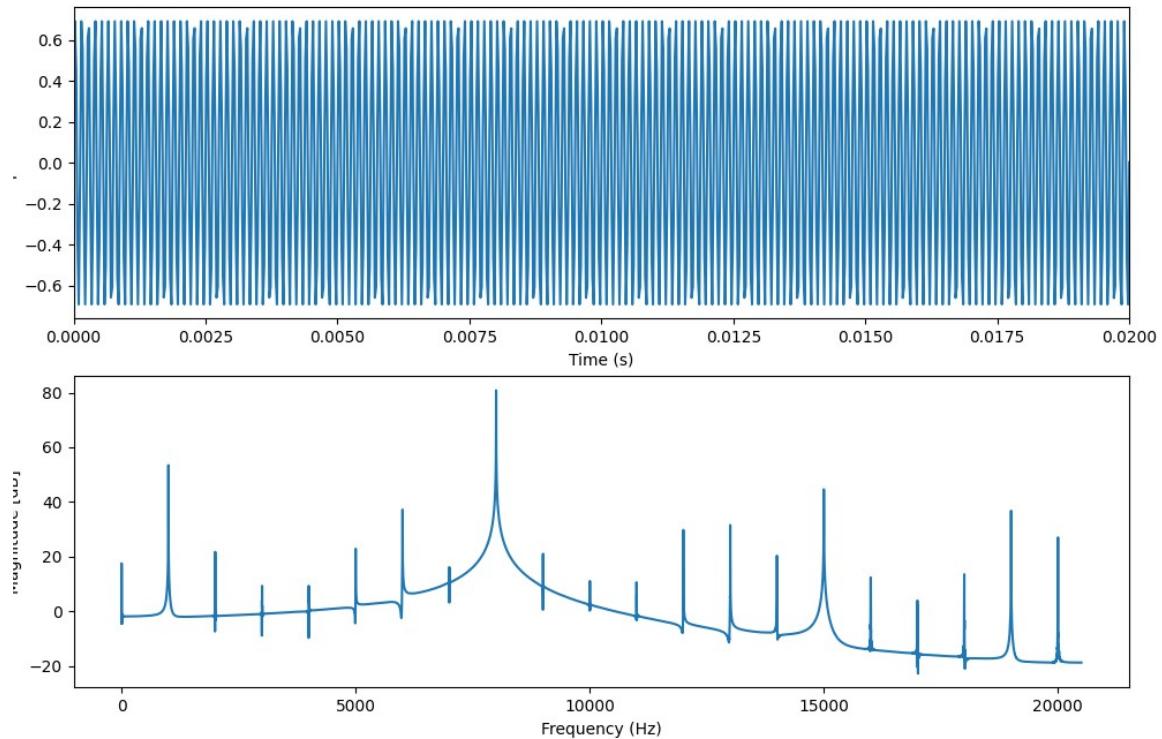
cubic interp 24000Hz

Time margin [0, 0.02]



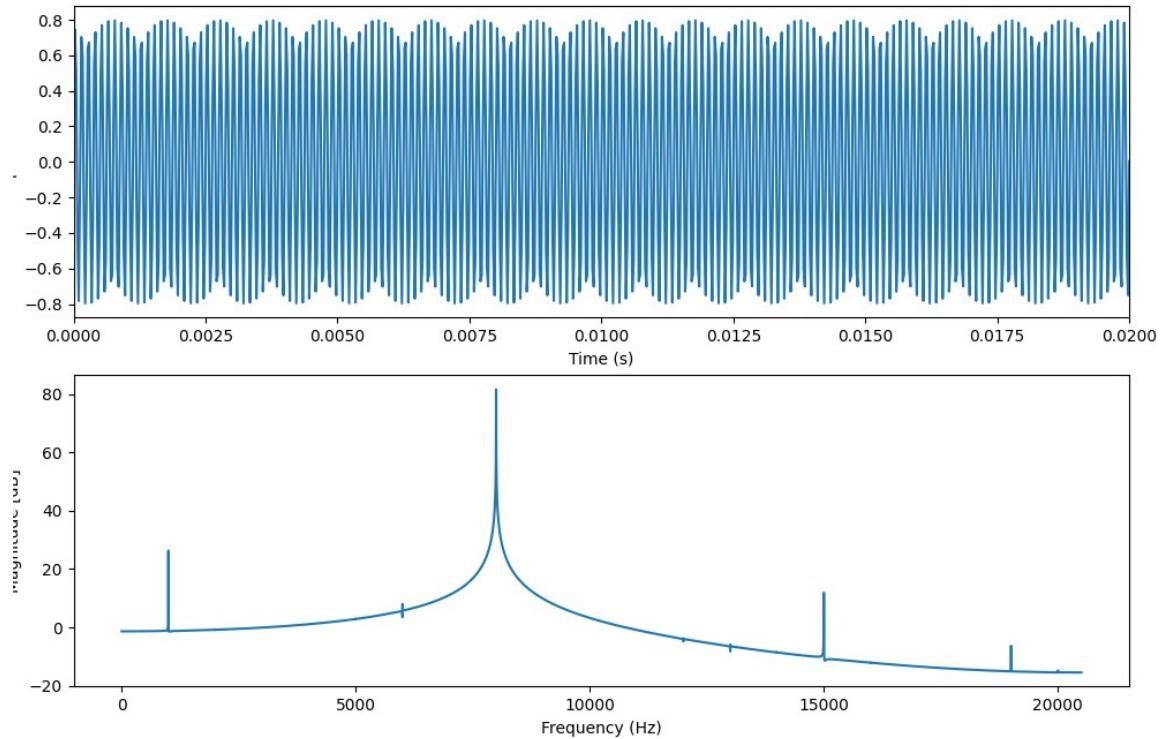
linear interp 41000Hz

Time margin [0, 0.02]



cubic interp 41000Hz

Time margin [0, 0.02]



File: sin_combined.wav

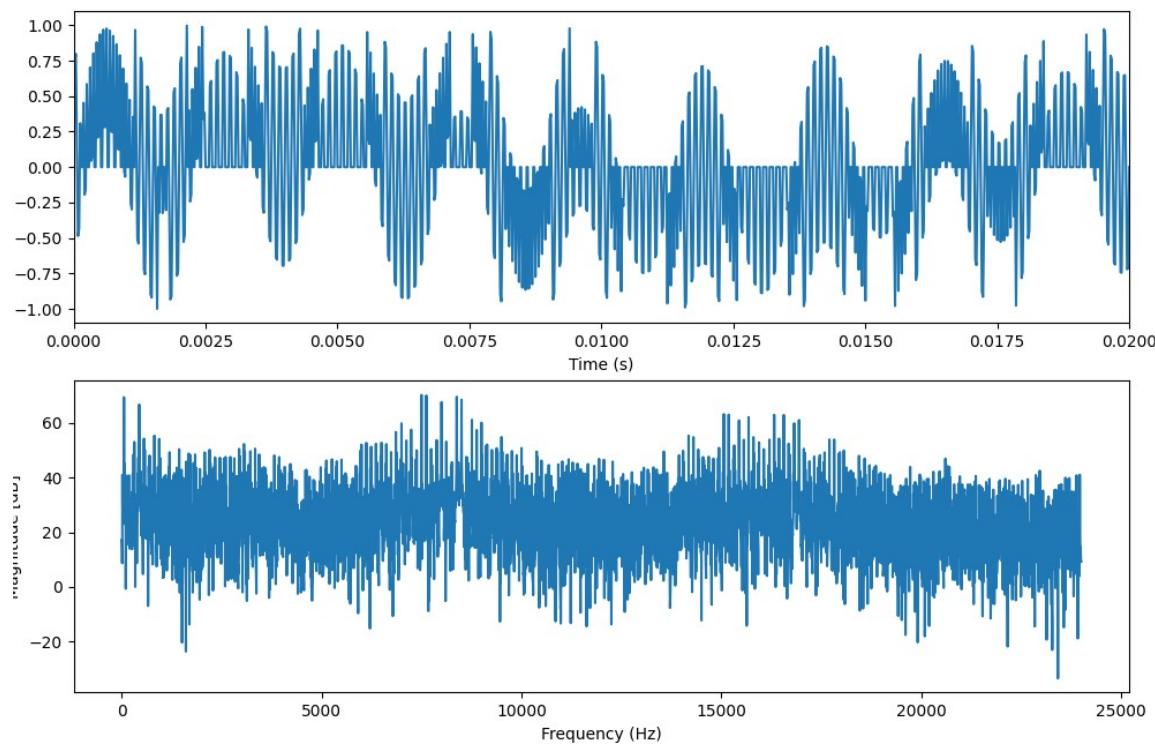
Modification	Max Frequency (Hz)	Max Amplitude (dB)
Original	7500.46	70.23
4-bit quant	7500.46	70.20
8-bit quant	7500.46	70.24
16-bit quant	7500.46	70.23
24-bit quant	7500.46	70.23
Decimation 2	7620.64	67.82
Decimation 4	4380.73	62.26
Decimation 6	60.02	59.64
Decimation 10	1980.83	54.61
Decimation 24	820.82	48.98
linear interp 2000Hz	384.38	45.57
cubic interp 2000Hz	384.38	46.40
linear interp 4000Hz	382.19	51.57
cubic interp 4000Hz	382.19	52.44
linear interp 8000Hz	381.10	57.70
cubic interp 8000Hz	381.10	58.57
linear interp 11999Hz	60.02	60.66
cubic interp 11999Hz	60.02	60.66
linear interp 16000Hz	7620.95	66.35
cubic interp 16000Hz	7620.95	67.18

linear interp 16953Hz	60.01	63.69
cubic interp 16953Hz	60.01	63.69
linear interp 24000Hz	60.01	66.69
cubic interp 24000Hz	8380.70	67.31
linear interp 41000Hz	60.06	69.36
cubic interp 41000Hz	7620.40	70.05

Visualizations

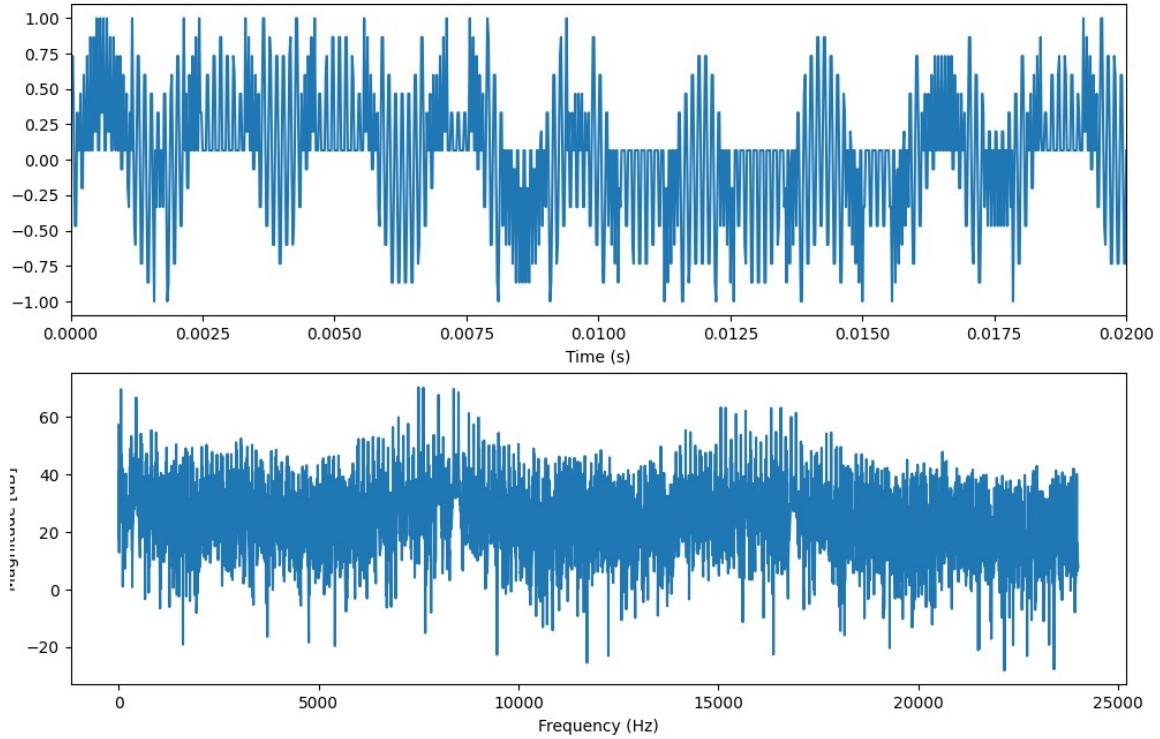
Original

Time margin [0, 0.02]



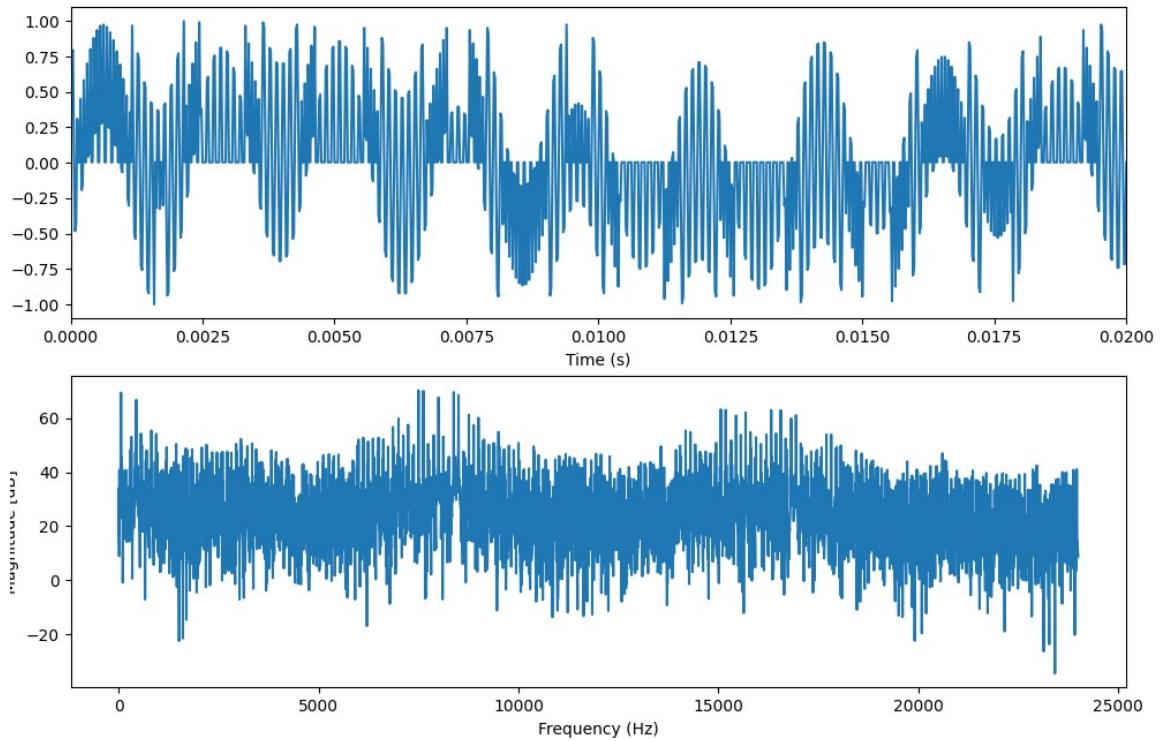
4-bit quant

Time margin [0, 0.02]



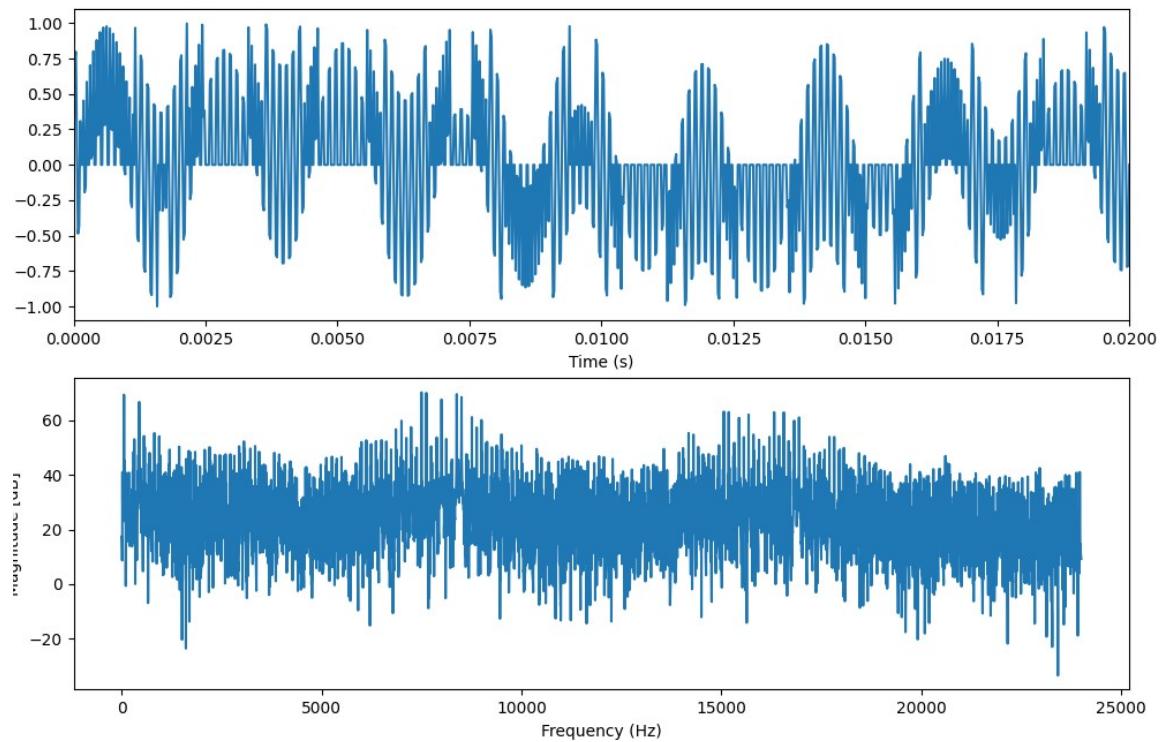
8-bit quant

Time margin [0, 0.02]



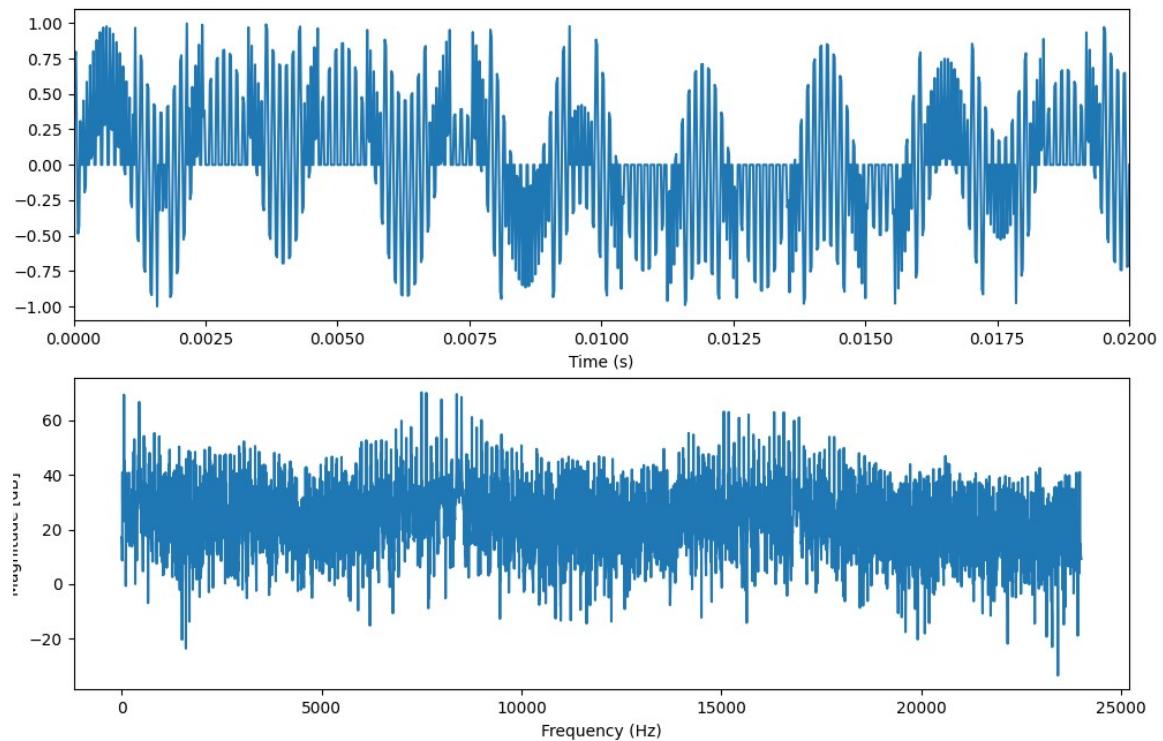
16-bit quant

Time margin [0, 0.02]



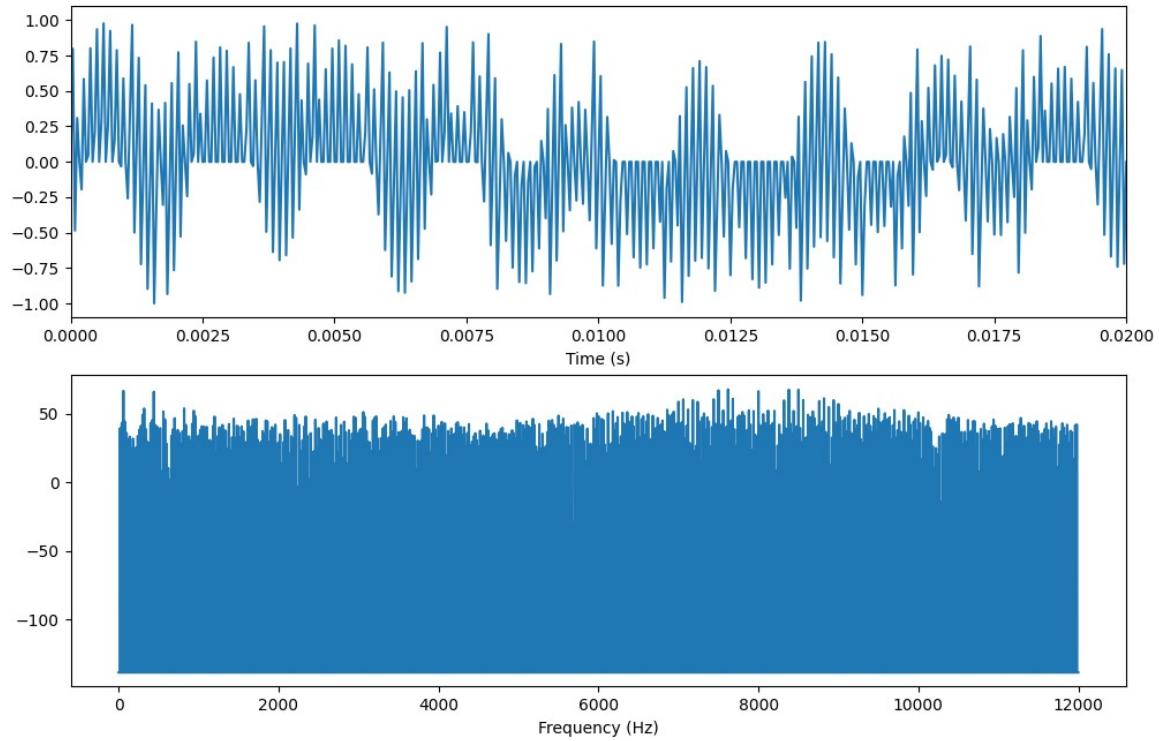
24-bit quant

Time margin [0, 0.02]



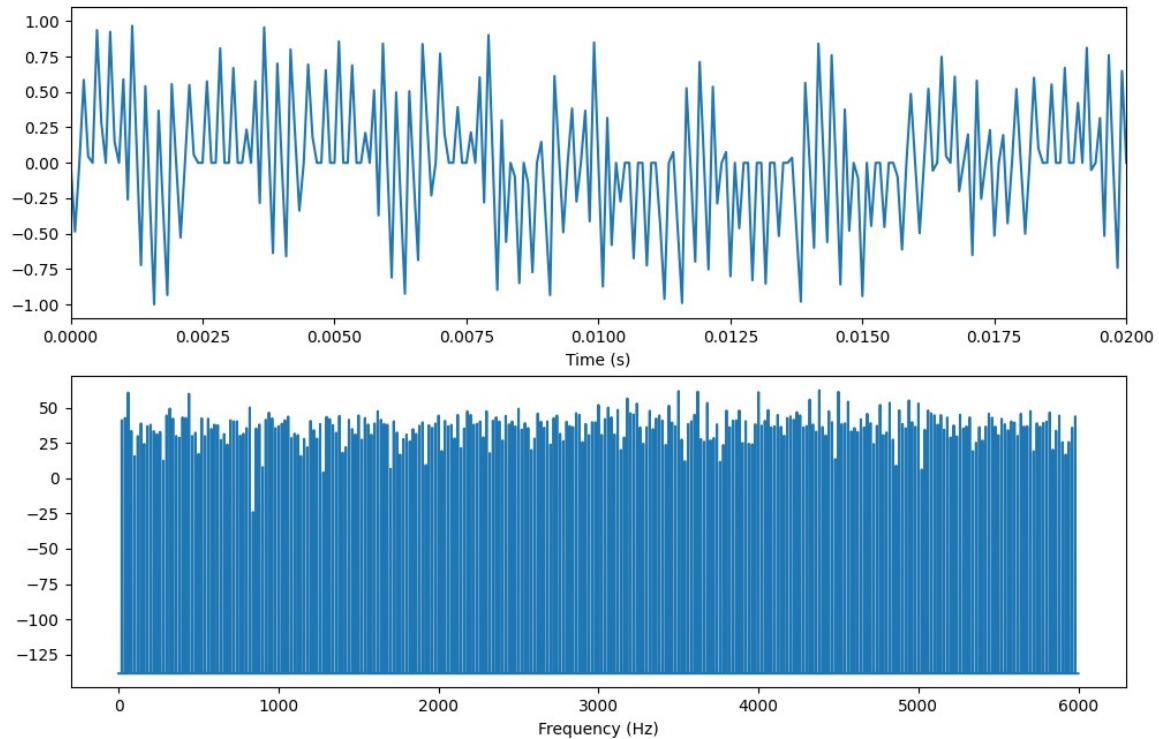
Decimation 2

Time margin [0, 0.02]



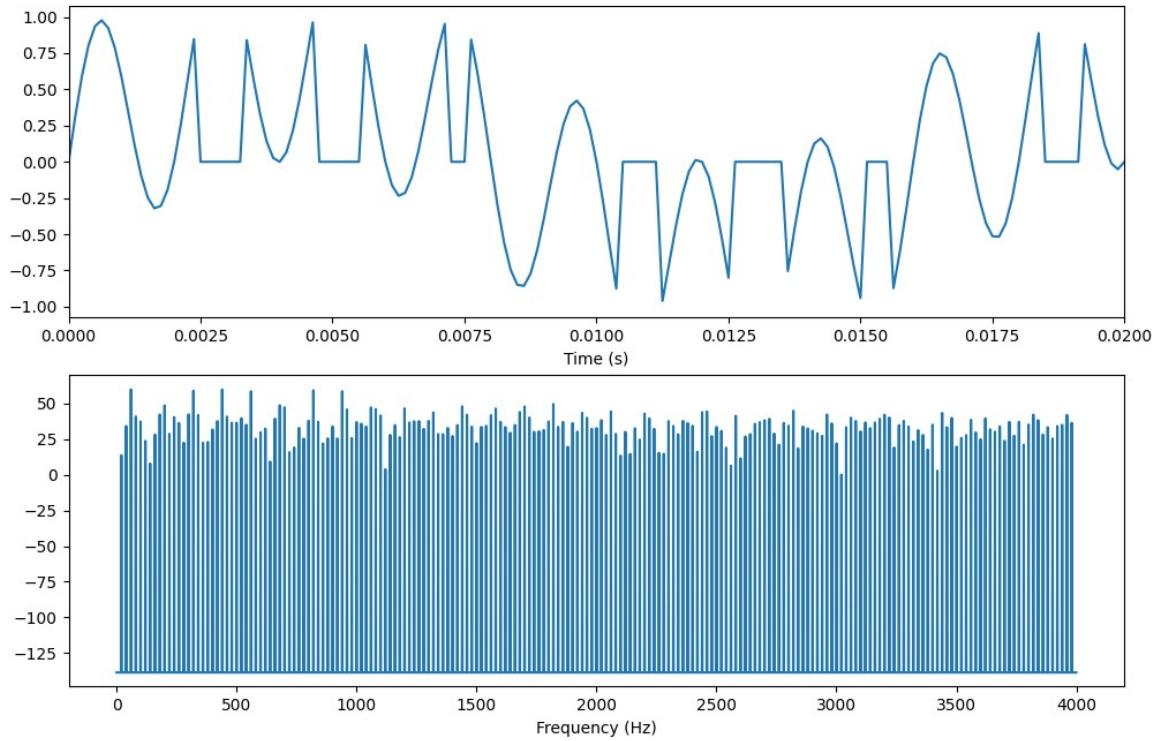
Decimation 4

Time margin [0, 0.02]



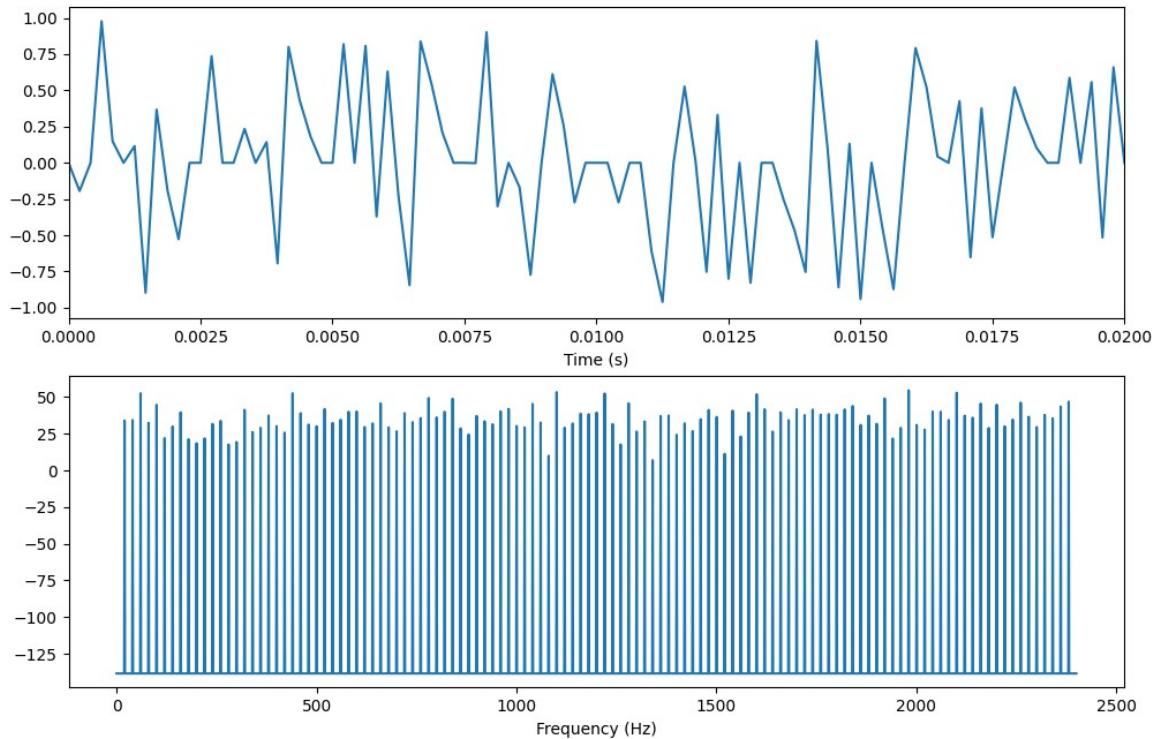
Decimation 6

Time margin [0, 0.02]



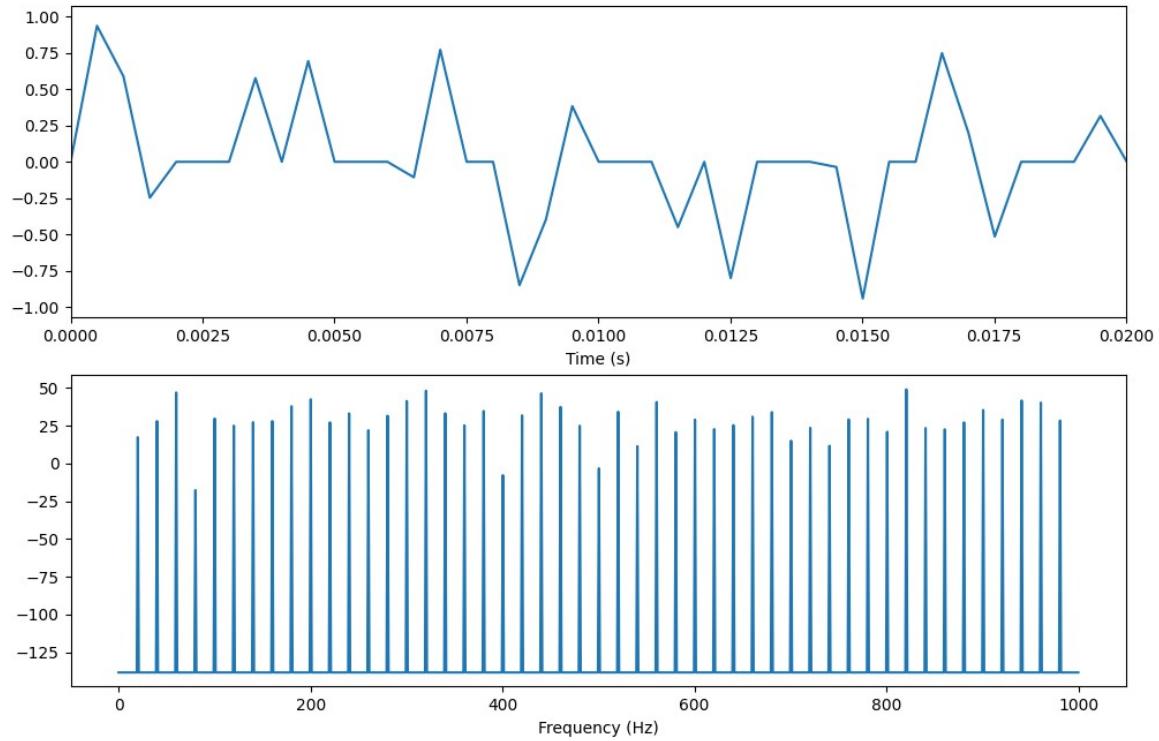
Decimation 10

Time margin [0, 0.02]



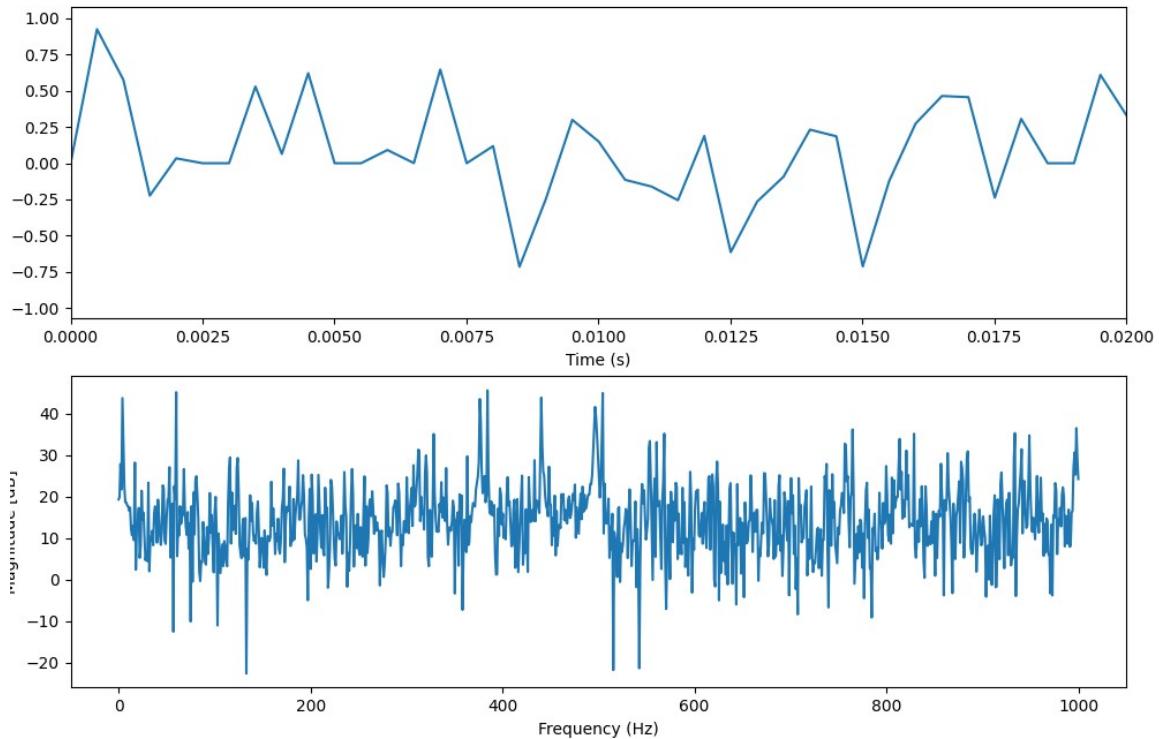
Decimation 24

Time margin [0, 0.02]



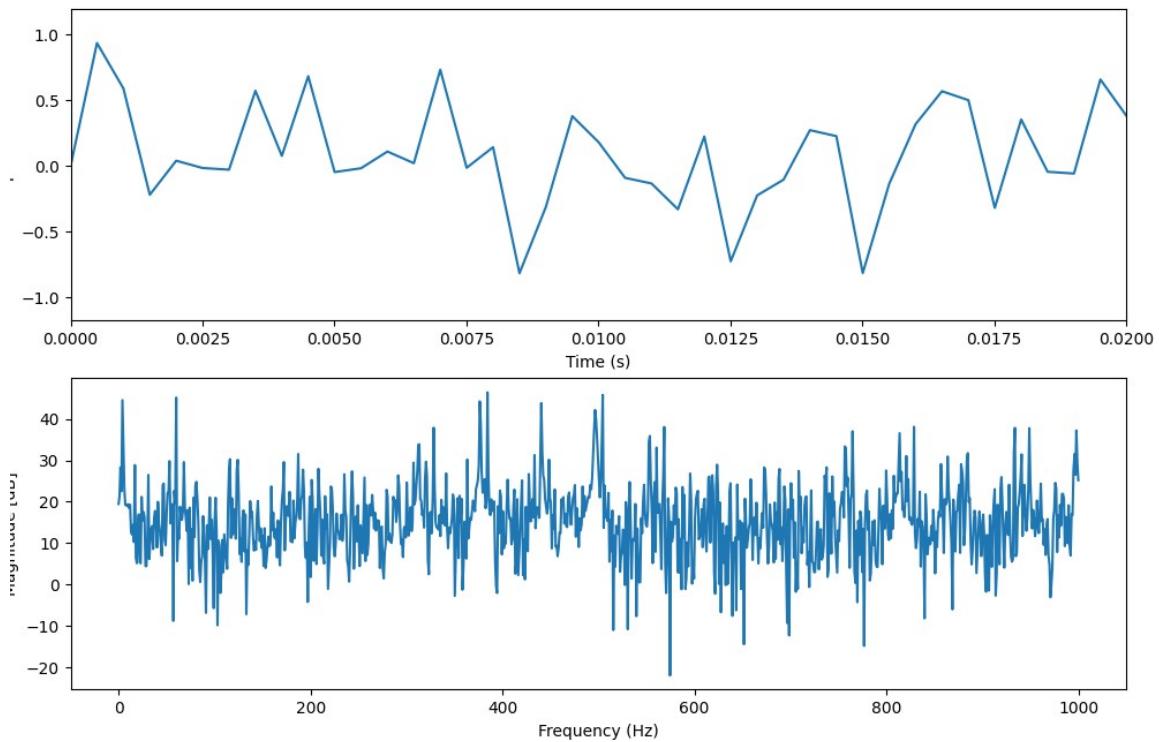
linear interp 2000Hz

Time margin [0, 0.02]



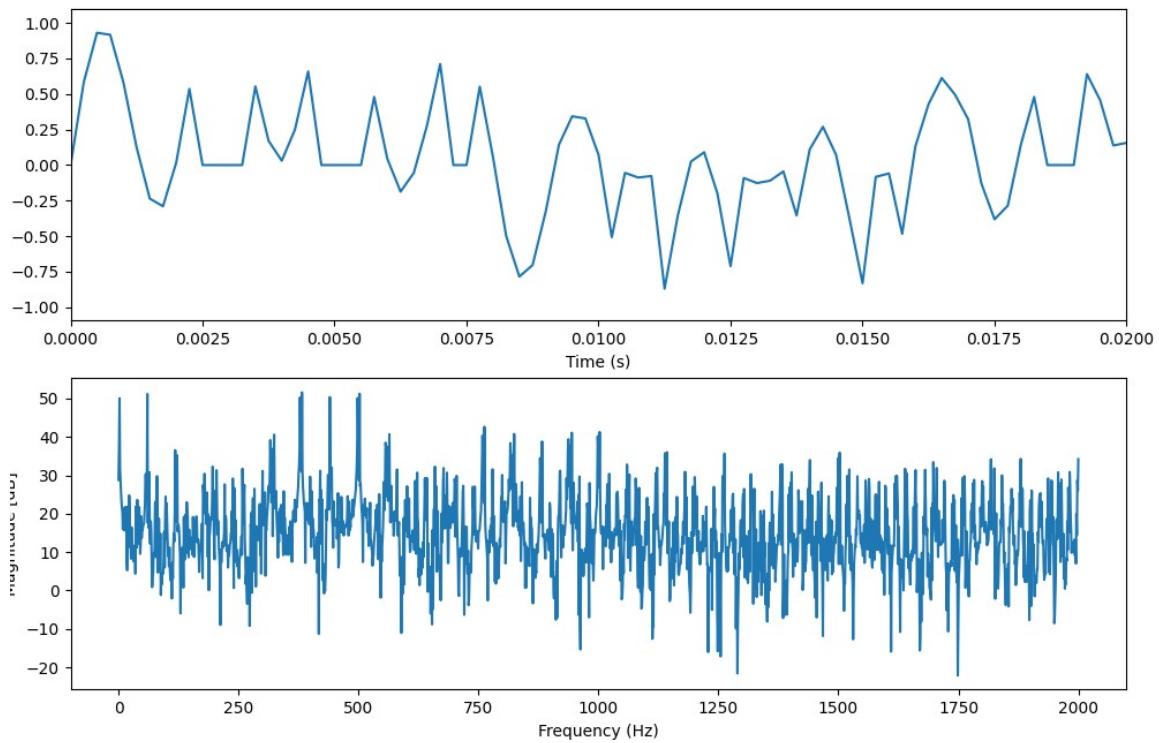
cubic interp 2000Hz

Time margin [0, 0.02]



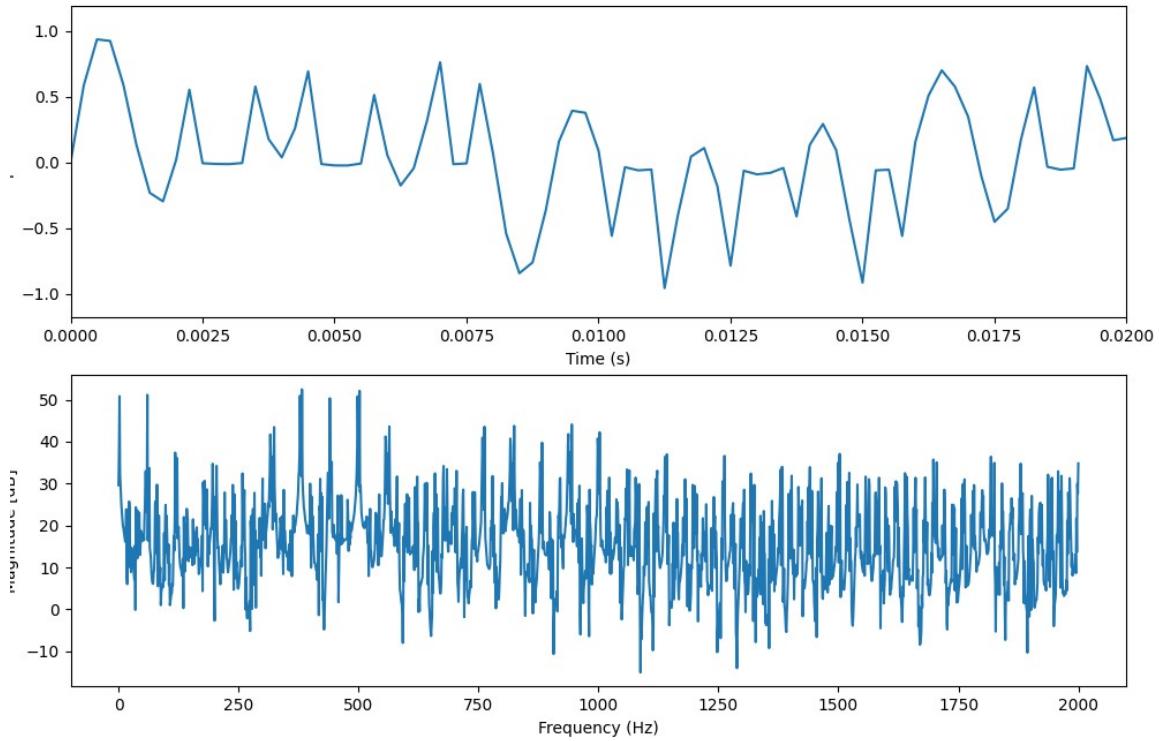
linear interp 4000Hz

Time margin [0, 0.02]



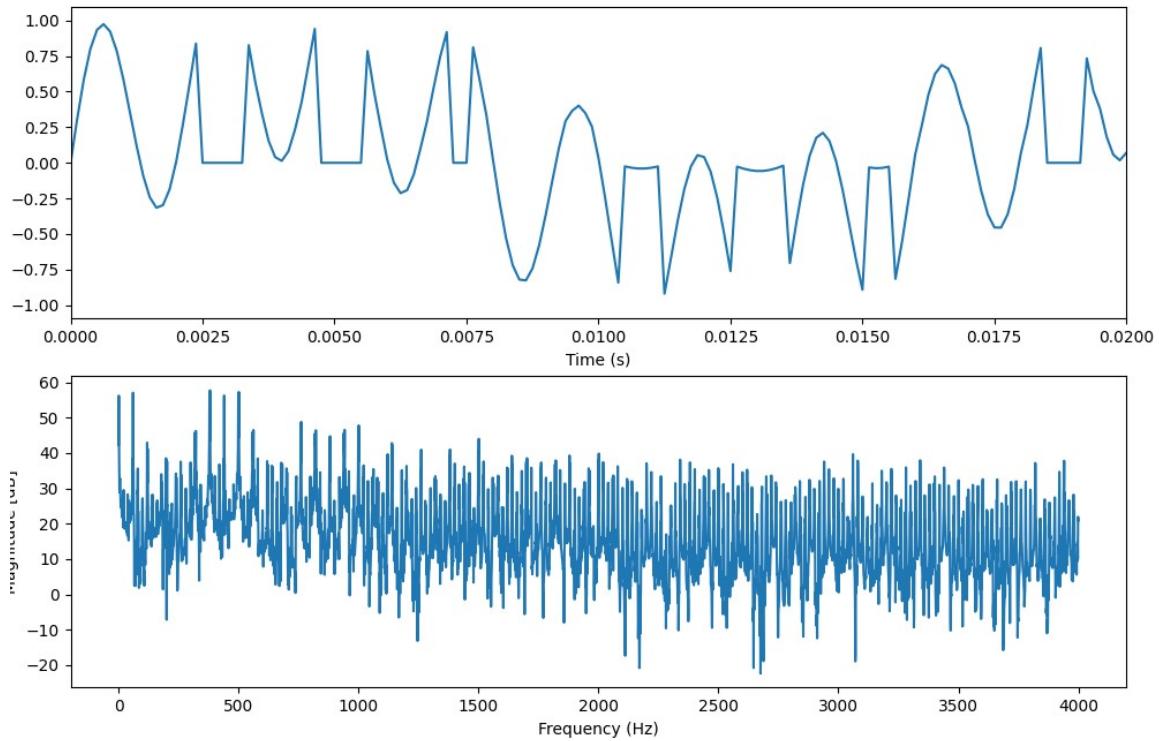
cubic interp 4000Hz

Time margin [0, 0.02]



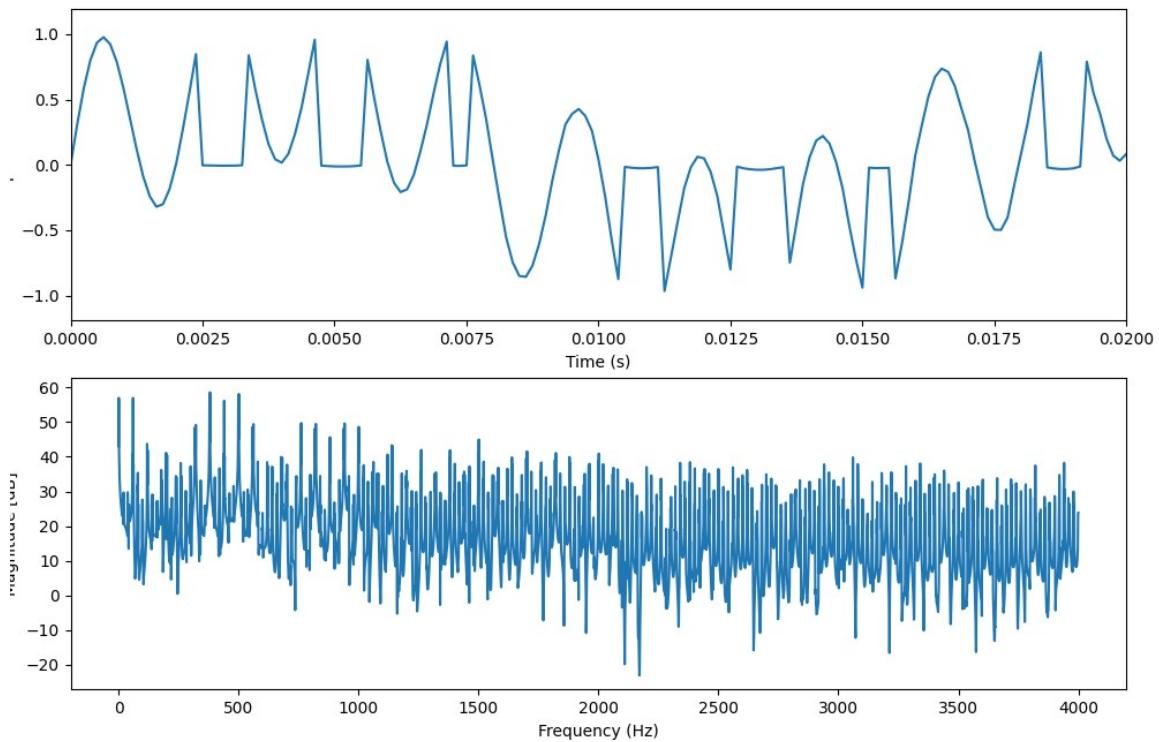
linear interp 8000Hz

Time margin [0, 0.02]



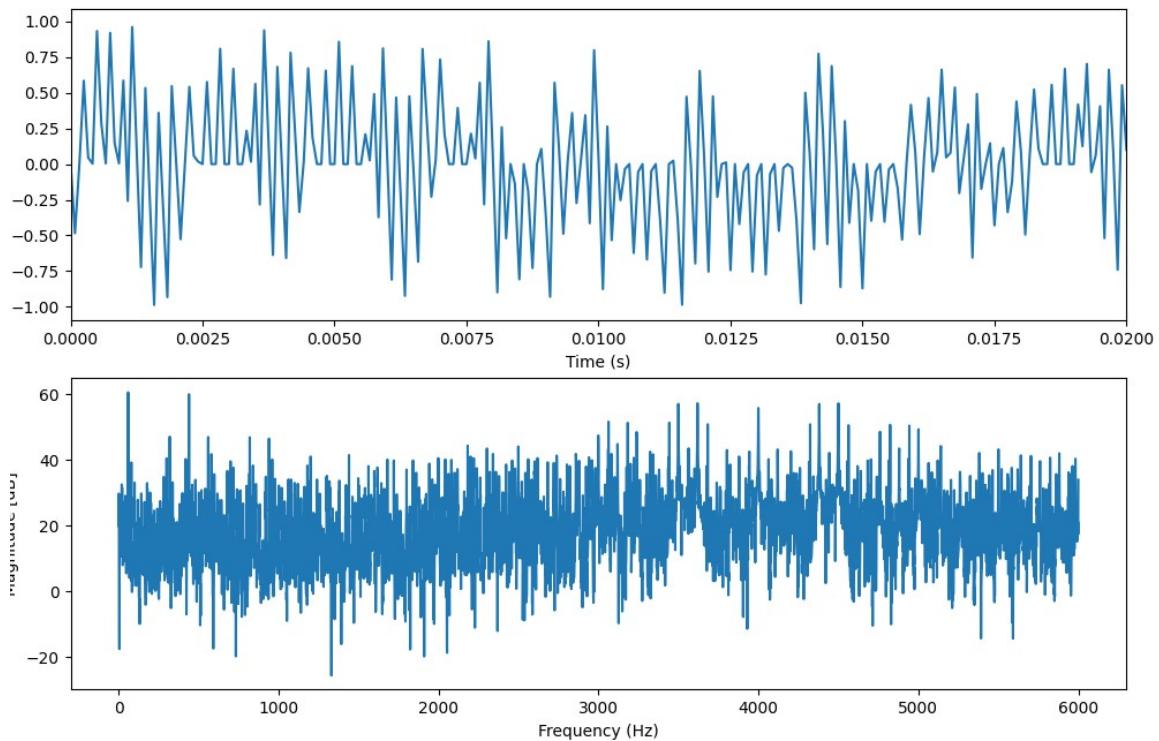
cubic interp 8000Hz

Time margin [0, 0.02]



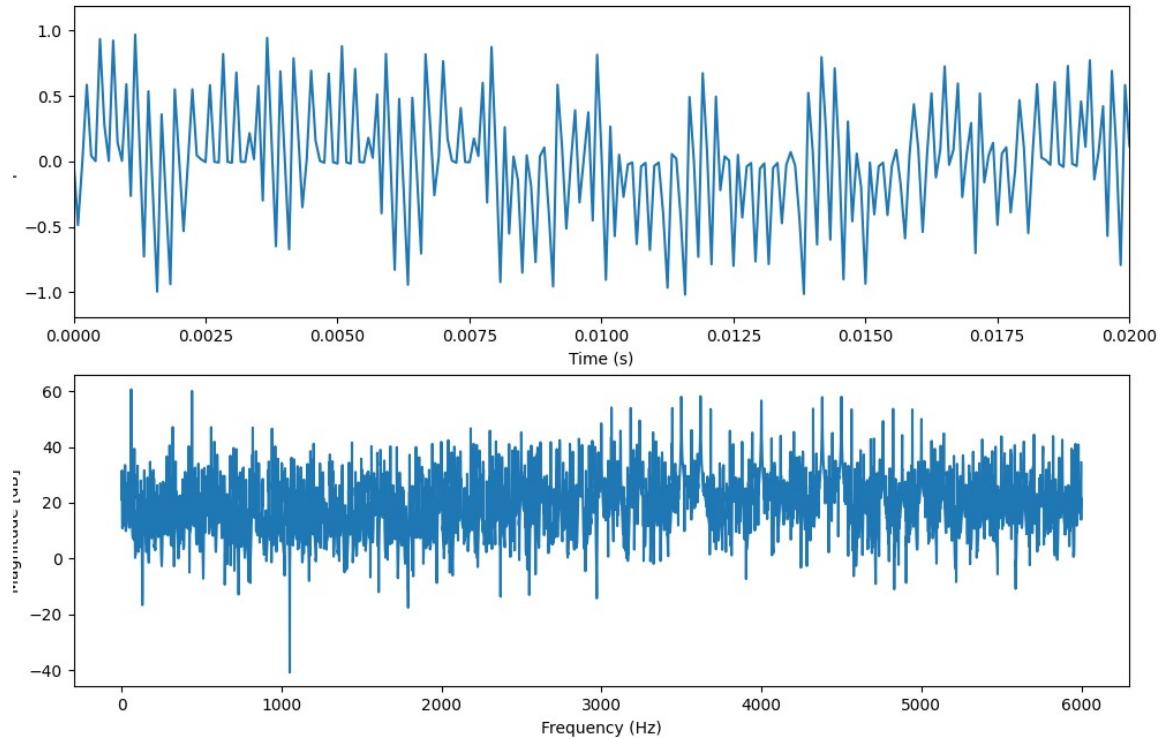
linear interp 11999Hz

Time margin [0, 0.02]



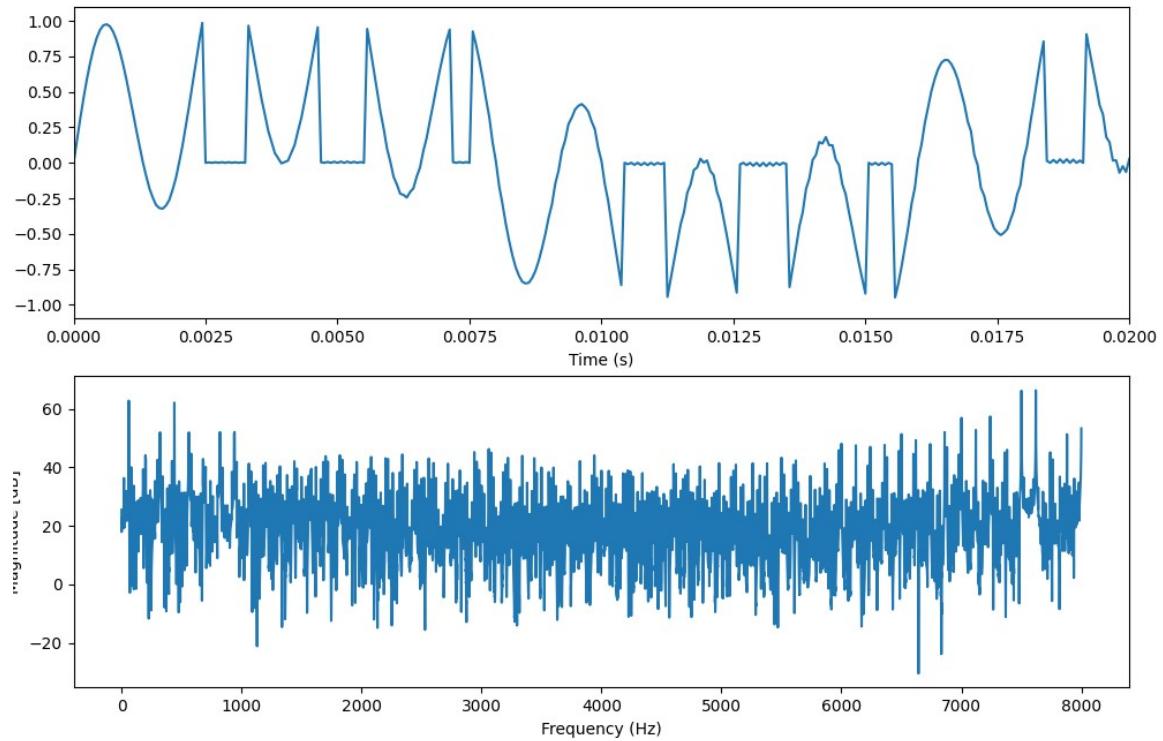
cubic interp 11999Hz

Time margin [0, 0.02]



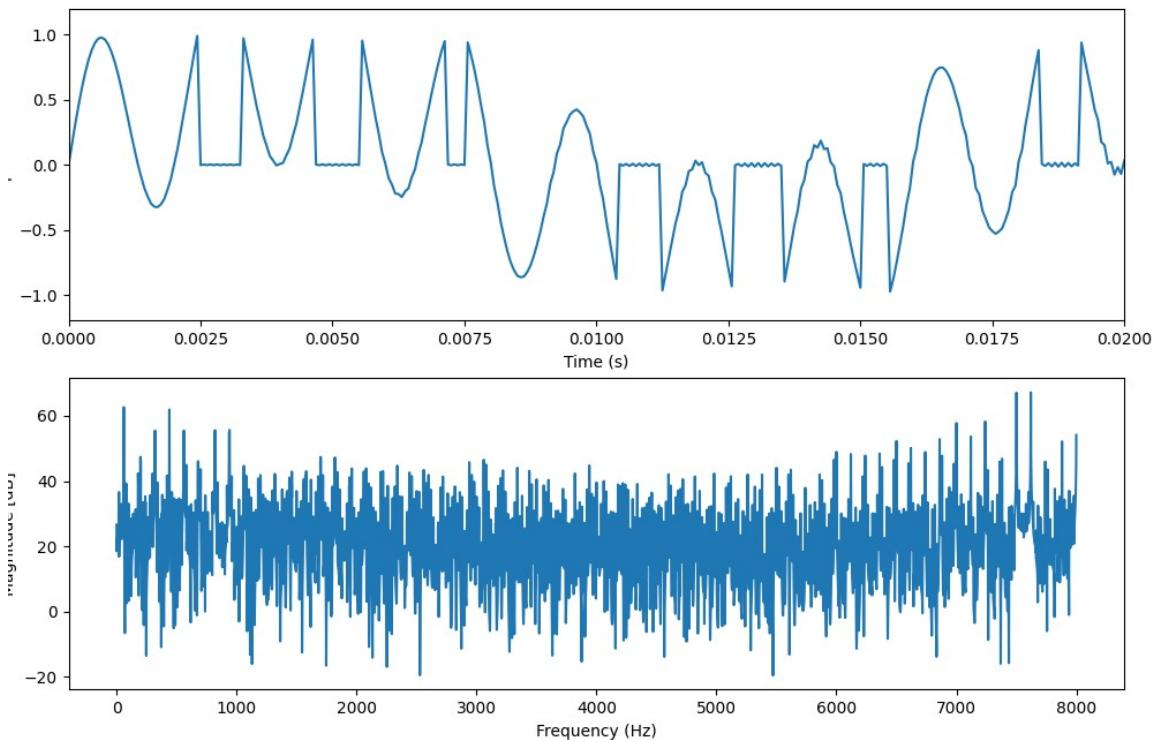
linear interp 16000Hz

Time margin [0, 0.02]



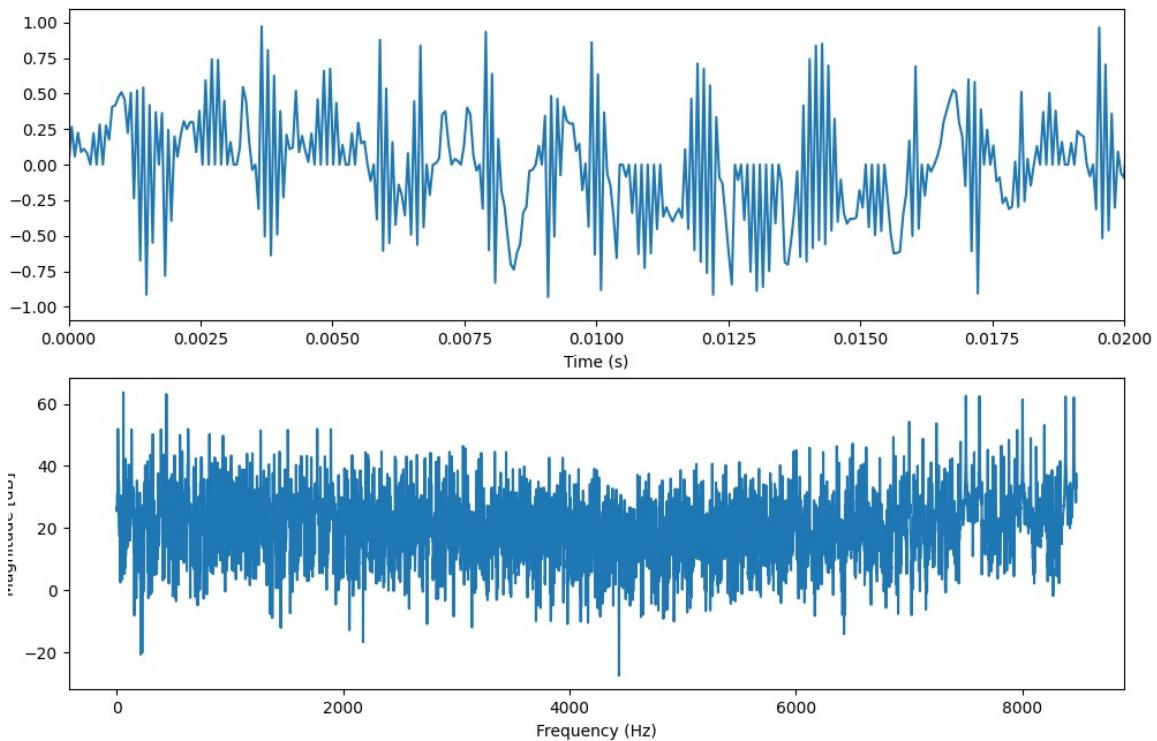
cubic interp 16000Hz

Time margin [0, 0.02]



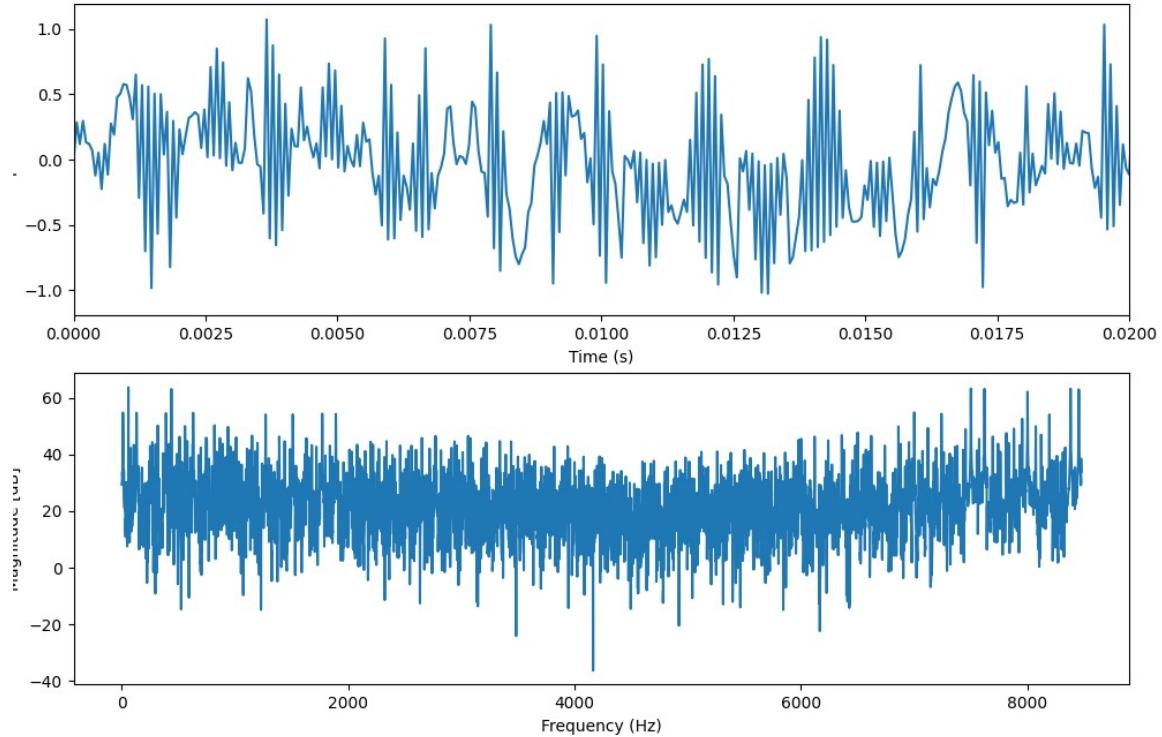
linear interp 16953Hz

Time margin [0, 0.02]



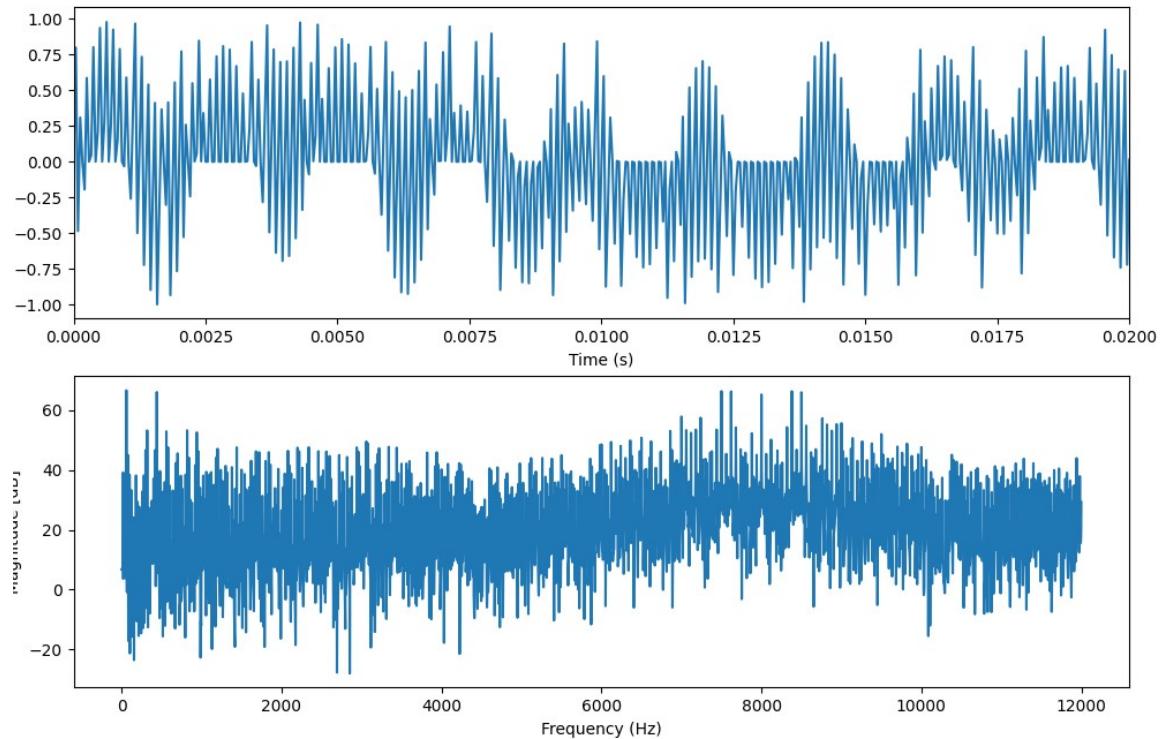
cubic interp 16953Hz

Time margin [0, 0.02]



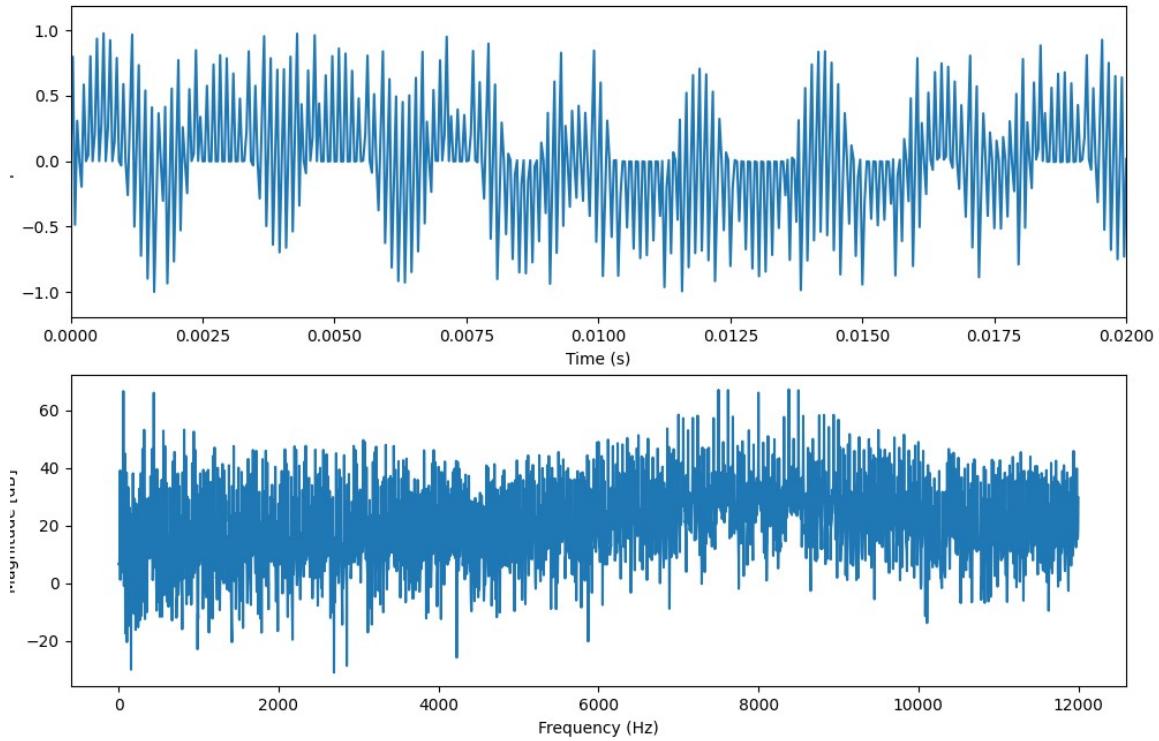
linear interp 24000Hz

Time margin [0, 0.02]



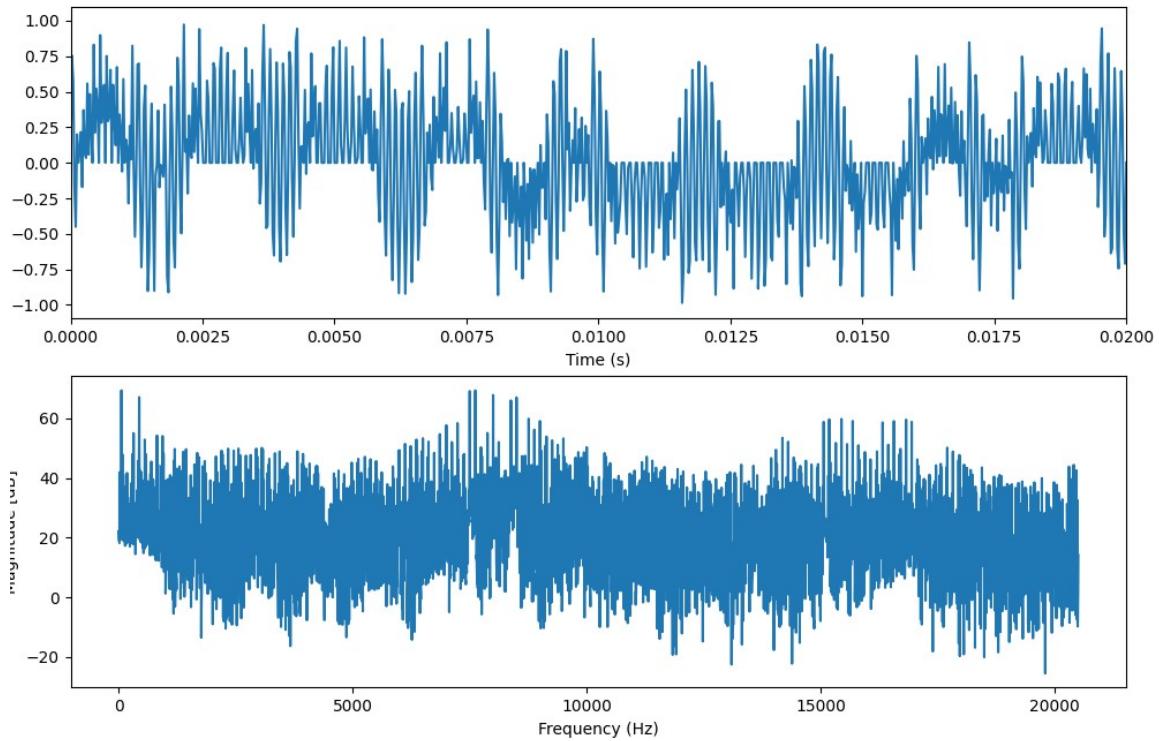
cubic interp 24000Hz

Time margin [0, 0.02]



linear interp 41000Hz

Time margin [0, 0.02]



cubic interp 41000Hz

Time margin [0, 0.02]

