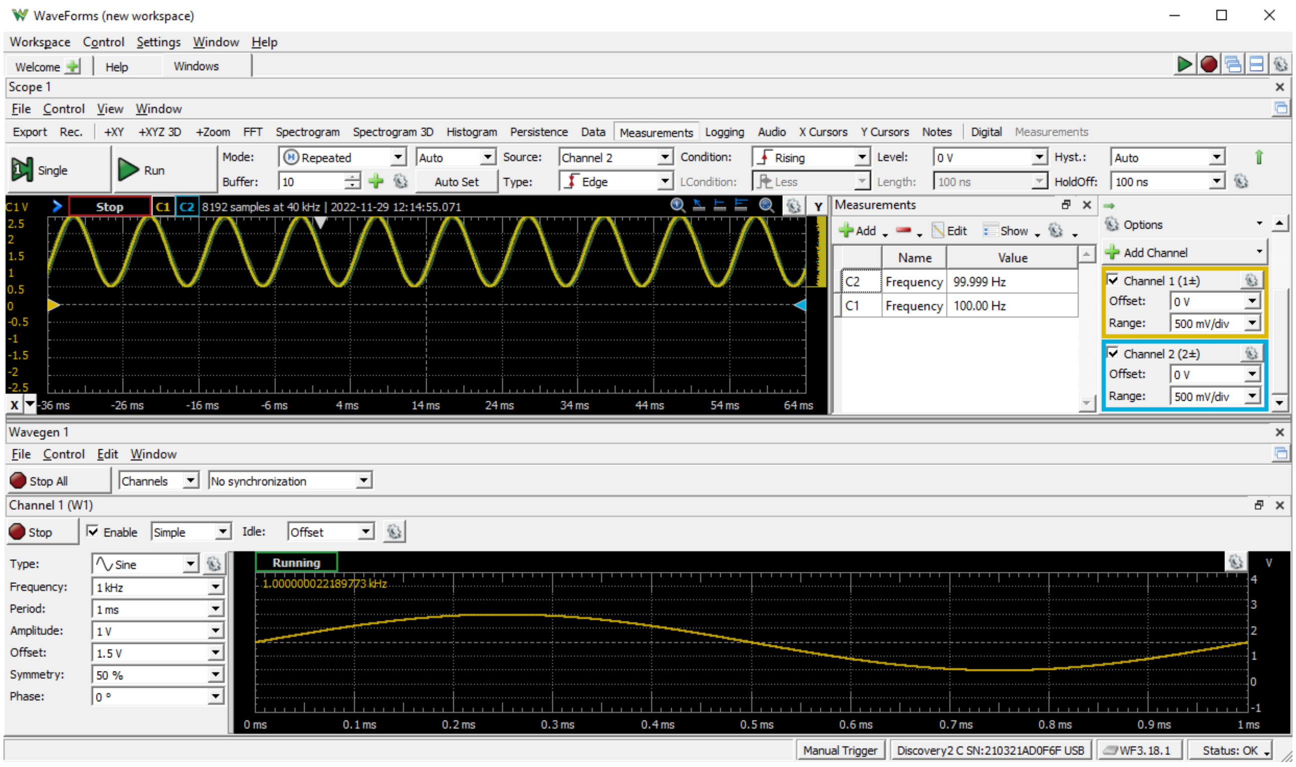
1. Introduction

The aim of the laboratory was to familiarize with the principles of DAC. Using Analog Discovery 2 as a sine wave generator, we had to read STM32 ADC input and feed it to DAC in the first part. Then instead of using signal from ADC, hardcoded generated values of sine were used. Lastly DDS algorithm was used to tweak the base frequency of signal. Additionally, RC filter was added.

2. Results

2.1. DAC driven by ADC with oversampling



WaveForms (new workspace)

Scope 1

Mode: Repeated, Auto; Buffer: 10; Source: Channel 2; Type: Edge; Condition: Rising; LCondition: Less; Level: 0 V; Length: 100 ns; Hyst.: Auto; HoldOff: 100 ns

Stop | C1 | C2 | 8192 samples at 40 kHz | 2022-11-29 12:14:55.071

Measurements

	Name	Value
C2	Frequency	99.999 Hz
C1	Frequency	100.00 Hz

Channel 1 (1±) — Offset: 0 V; Range: 500 mV/div

Channel 2 (2±) — Offset: 0 V; Range: 500 mV/div

Wavegen 1

Channels; No synchronization

Channel 1 (W1)

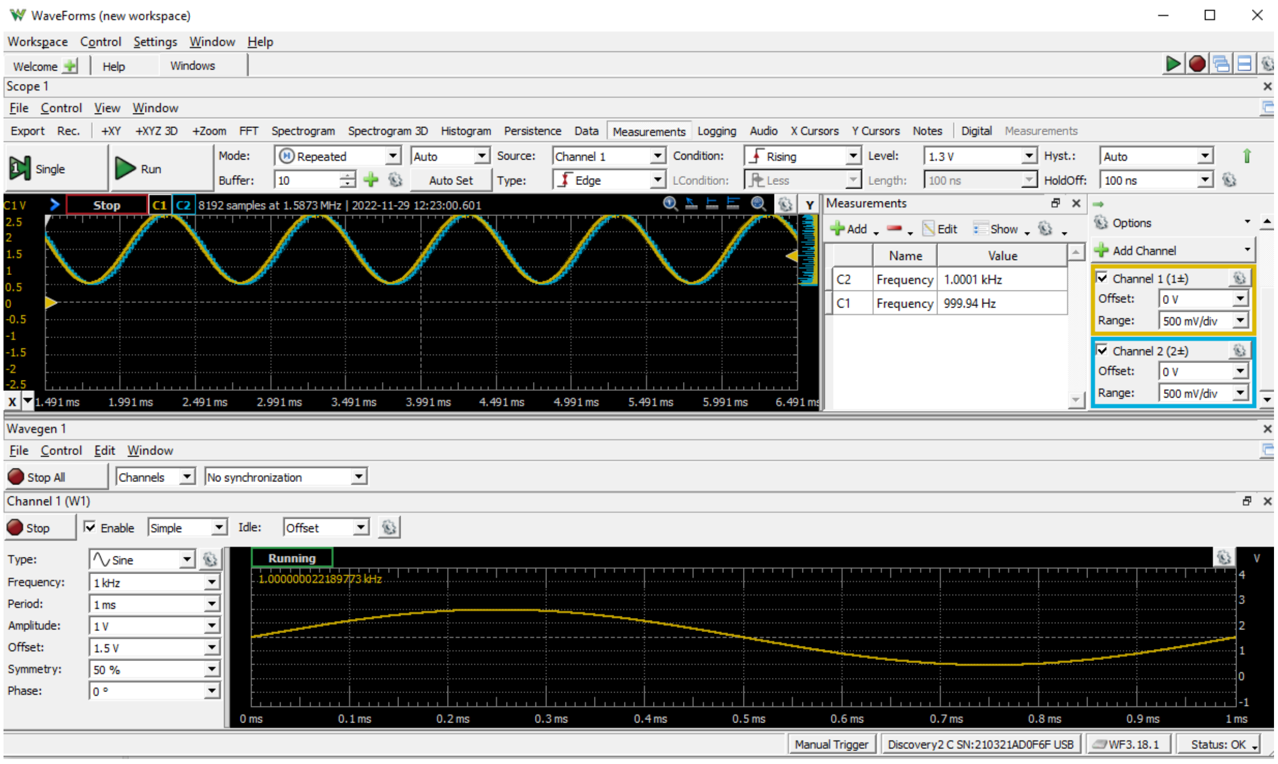
Enable; Simple; Idle: Offset

Type: Sine
Frequency: 1 kHz
Period: 1 ms
Amplitude: 1 V
Offset: 1.5 V
Symmetry: 50 %
Phase: 0 °

Running — 1.000000022189773 kHz

Manual Trigger | Discovery2 C SN:210321AD0F6F USB | WF3.18.1 | Status: OK

Figure 1 f = 100 Hz


WaveForms (new workspace)

Scope 1

Mode: Repeated | Auto | Source: Channel 1 | Condition: Rising | Level: 1.3 V | Hyst.: Auto

Buffer: 10 | Auto Set | Type: Edge | LCondition: Less | Length: 100 ns | HoldOff: 100 ns

Stop | C1 | C2 | 8192 samples at 1.5873 MHz | 2022-11-29 12:23:00.601

Measurements

	Name	Value
C2	Frequency	1.0001 kHz
C1	Frequency	999.94 Hz

Channel 1 (1±) Offset: 0 V Range: 500 mV/div

Channel 2 (2±) Offset: 0 V Range: 500 mV/div

Wavegen 1

Channel 1 (W1)

Enable | Simple | Idle: Offset

Type: Sine

Frequency: 1 kHz

Period: 1 ms

Amplitude: 1 V

Offset: 1.5 V

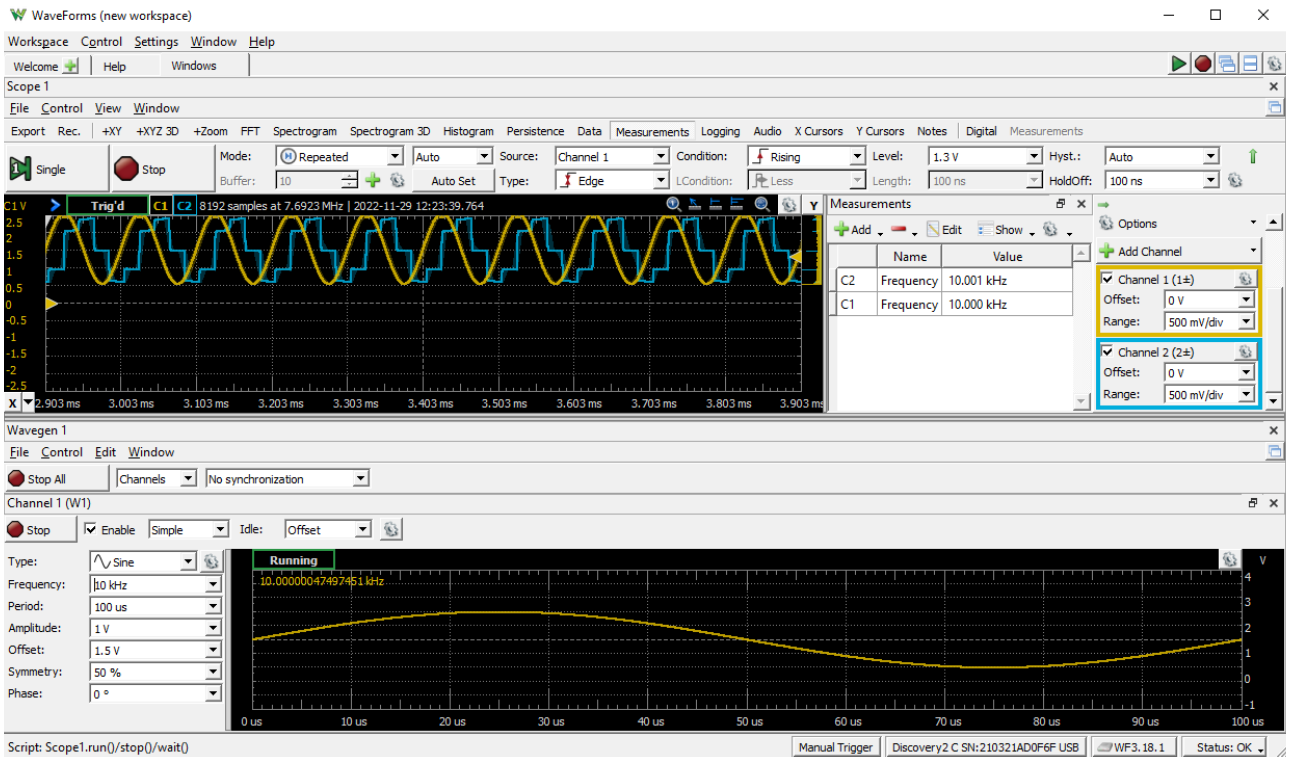
Symmetry: 50 %

Phase: 0 °

Running 1.000000022189773 kHz

Manual Trigger | Discovery2 C SN:210321AD0F6F USB | WF3.18.1 | Status: OK

Figure 2 f = 1 kHz


WaveForms (new workspace)

Scope 1

Mode: Repeated | Auto | Source: Channel 1 | Condition: Rising | Level: 1.3 V | Hyst.: Auto

Buffer: 10 | Auto Set | Type: Edge | LCondition: Less | Length: 100 ns | HoldOff: 100 ns

Trig'd | C1 | C2 | 8192 samples at 7.6923 MHz | 2022-11-29 12:23:39.764

Measurements

	Name	Value
C2	Frequency	10.001 kHz
C1	Frequency	10.000 kHz

Channel 1 (1±) Offset: 0 V Range: 500 mV/div

Channel 2 (2±) Offset: 0 V Range: 500 mV/div

Wavegen 1

Channel 1 (W1)

Enable | Simple | Idle: Offset

Type: Sine

Frequency: 10 kHz

Period: 100 us

Amplitude: 1 V

Offset: 1.5 V

Symmetry: 50 %

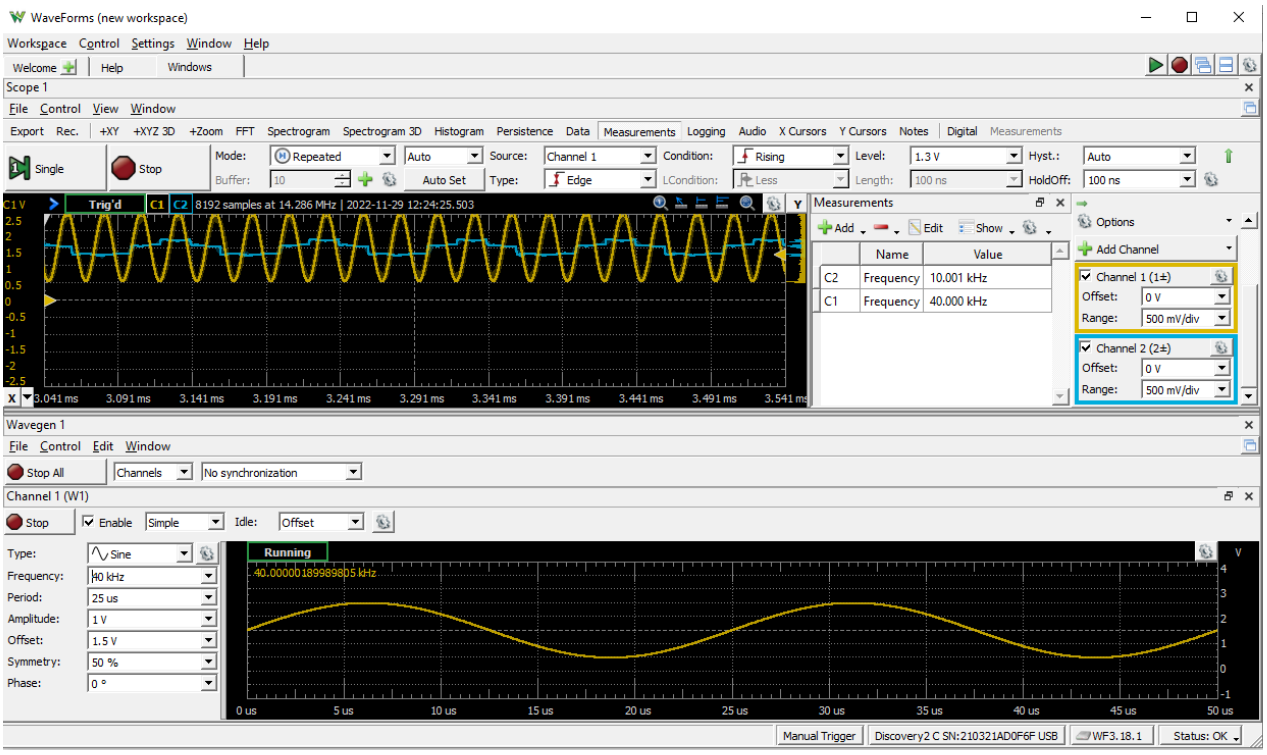
Phase: 0 °

Running 10.000000047497451 kHz

Script: Scope1.run()/stop()/wait()

Manual Trigger | Discovery2 C SN:210321AD0F6F USB | WF3.18.1 | Status: OK

Figure 3 f = 10 kHz


WaveForms (new workspace)
Workspace Control Settings Window Help
Welcome Help Windows
Scope 1
File Control View Window
Export Rec. +XY +XYZ 3D +Zoom FFT Spectrogram Spectrogram 3D Histogram Persistence Data Measurements Logging Audio X Cursors Y Cursors Notes Digital
Single Stop
Trig'd C1 C2
Wavegen 1
File Control Edit Window
Stop All
Channel 1 (W1)
Stop
Running
Manual Trigger
Status: OK

8192 samples at 14.286 MHz | 2022-11-29 12:24:25.503

Mode: Repeated, Auto; Buffer: 10; Source: Channel 1; Type: Edge; Condition: Rising; LCondition: Less; Level: 1.3 V; Length: 100 ns; Hyst.: Auto; HoldOff: 100 ns

Measurements

	Name	Value
C2	Frequency	10.001 kHz
C1	Frequency	40.000 kHz

Channel 1 (1±) Offset: 0 V Range: 500 mV/div

Channel 2 (2±) Offset: 0 V Range: 500 mV/div

Channels; No synchronization; Enable; Simple; Idle: Offset

Type: Sine
Frequency: 40 kHz
Period: 25 us
Amplitude: 1 V
Offset: 1.5 V
Symmetry: 50 %
Phase: 0 °

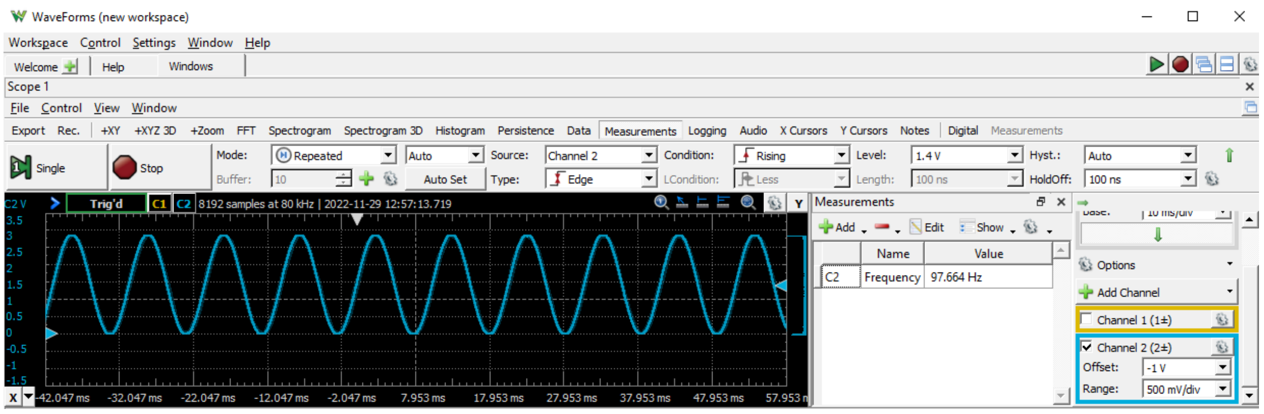
40.000018998805 kHz

Discovery2 C SN:210321AD0F6F USB WF3.18.1

Figure 4 f = 30 kHz

On the bottom part of each figure, we can see a signal as generated by Analog Discovery. Top part of them consists of signal outputted by DAC. DAC is fed by ADC converting first signal. Therefore it is limited by its sampling frequency equal to 50 kHz (parameters set as in the previous laboratory). We can see that 100 Hz and 1 kHz are nicely modelled with slight flaws. In the signal 10 kHz there are visible steps of sine, but the frequency is proper – there is no aliasing. The frequency is 5 times smaller than the sampling rate which can be seen as 5 visible steps for period. Last signal cannot be modelled properly because sampling is not twice larger. To avoid aliasing we should sample with at least 60 kHz.

2.2. Sine function generator


WaveForms (new workspace)
Workspace Control Settings Window Help
Welcome Help Windows
Scope 1
File Control View Window
Export Rec. +XY +XYZ 3D +Zoom FFT Spectrogram Spectrogram 3D Histogram Persistence Data Measurements Logging Audio X Cursors Y Cursors Notes Digital
Single Stop
Trig'd C1 C2

8192 samples at 80 kHz | 2022-11-29 12:57:13.719

Mode: Repeated, Auto; Buffer: 10; Source: Channel 2; Type: Edge; Condition: Rising; LCondition: Less; Level: 1.4 V; Length: 100 ns; Hyst.: Auto; HoldOff: 100 ns

Measurements

	Name	Value
C2	Frequency	97.664 Hz

Base: 10 ms/div

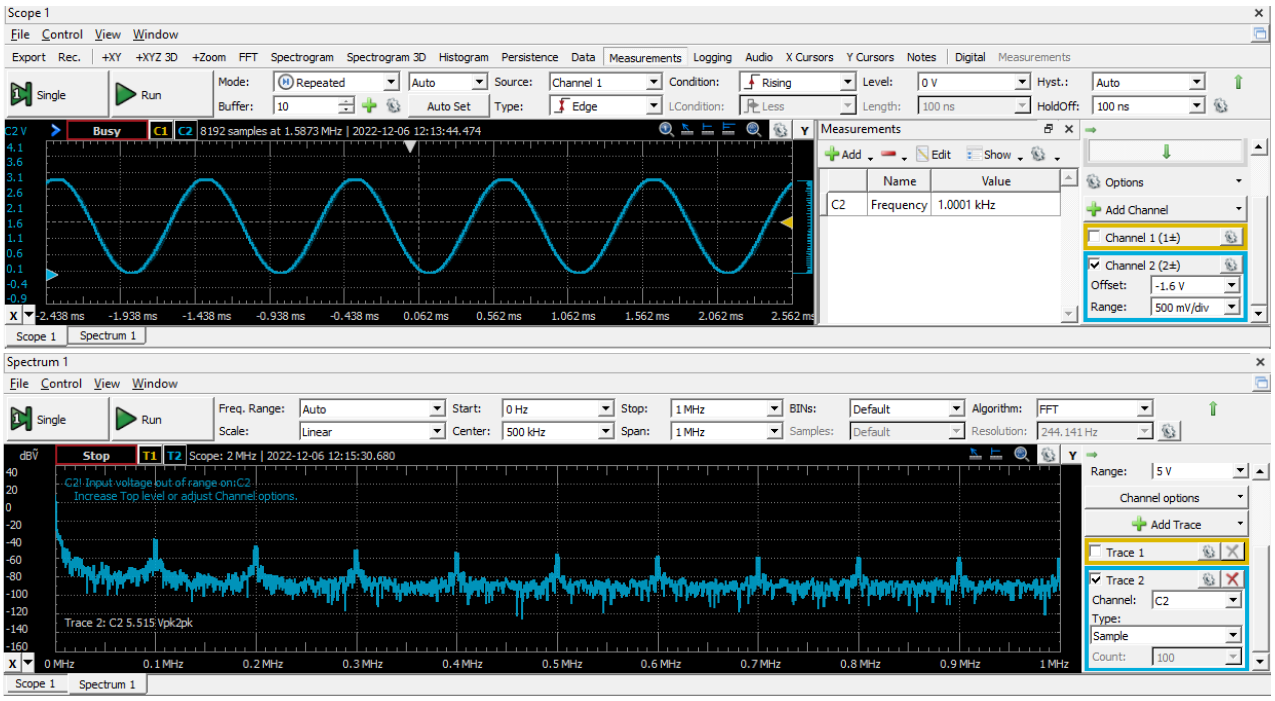
Channel 1 (1±)

Channel 2 (2±) Offset: -1 V Range: 500 mV/div

Figure 5 f = 100 Hz

In the next step, signal is no longer taken from ADC. Instead it was generated as 1024 table of sine values and then fed to DAC triggered by Timer 2. The achievable frequency is limited by the maximum frequency of timer, divided by 2 (to avoid aliasing).

2.3. DAC with DDS


Scope 1

Mode: Repeated | Auto | Source: Channel 1 | Condition: Rising | Level: 0 V | Hyst.: Auto

Buffer: 10 | Auto Set | Type: Edge | LCondition: Less | Length: 100 ns | HoldOff: 100 ns

Busy | C1 | C2 | 8192 samples at 1.5873 MHz | 2022-12-06 12:13:44.474

Measurements

	Name	Value
C2	Frequency	1.0001 kHz

Channel 2 (2±) — Offset: -1.6 V — Range: 500 mV/div

Spectrum 1

Freq. Range: Auto | Start: 0 Hz | Stop: 1 MHz | BINs: Default | Algorithm: FFT

Scale: Linear | Center: 500 kHz | Span: 1 MHz | Samples: Default | Resolution: 244.141 Hz

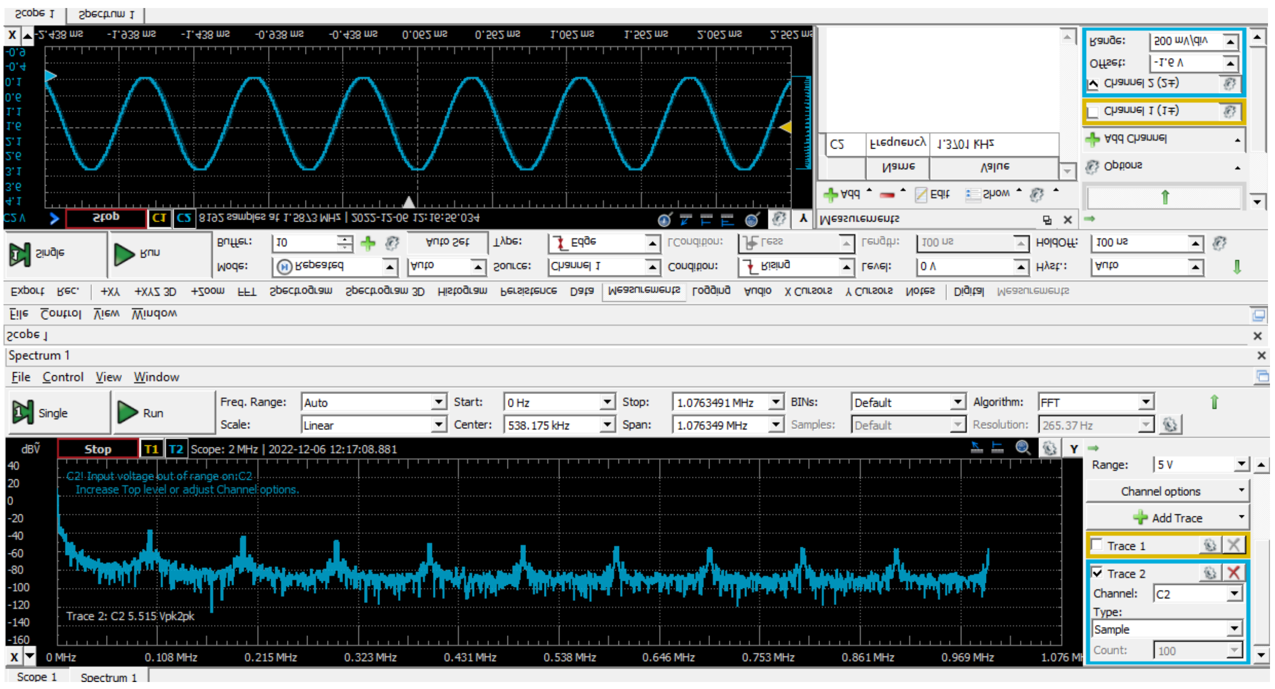
Stop | T1 | T2 | Scope: 2 MHz | 2022-12-06 12:15:30.680

C2! Input voltage out of range on C2
Increase Top level or adjust Channel options.

Trace 2: C2 5.515 Vpk2pk

Range: 5 V | Trace 2 — Channel: C2 — Type: Sample — Count: 100

Figure 6 f = 1 kHz


Scope 1

Mode: Repeated | Auto | Source: Channel 1 | Condition: Rising | Level: 0 V | Hyst.: Auto

Buffer: 10 | Auto Set | Type: Edge | LCondition: Less | Length: 100 ns | HoldOff: 100 ns

Stop | C1 | C2 | 8192 samples at 1.5873 MHz | 2022-12-06 12:16:58.034

Measurements

	Name	Value
C2	Frequency	1.3701 kHz

Channel 2 (2±) — Offset: -1.6 V — Range: 500 mV/div

Spectrum 1

Freq. Range: Auto | Start: 0 Hz | Stop: 1.0763491 MHz | BINs: Default | Algorithm: FFT

Scale: Linear | Center: 538.175 kHz | Span: 1.076349 MHz | Samples: Default | Resolution: 265.37 Hz

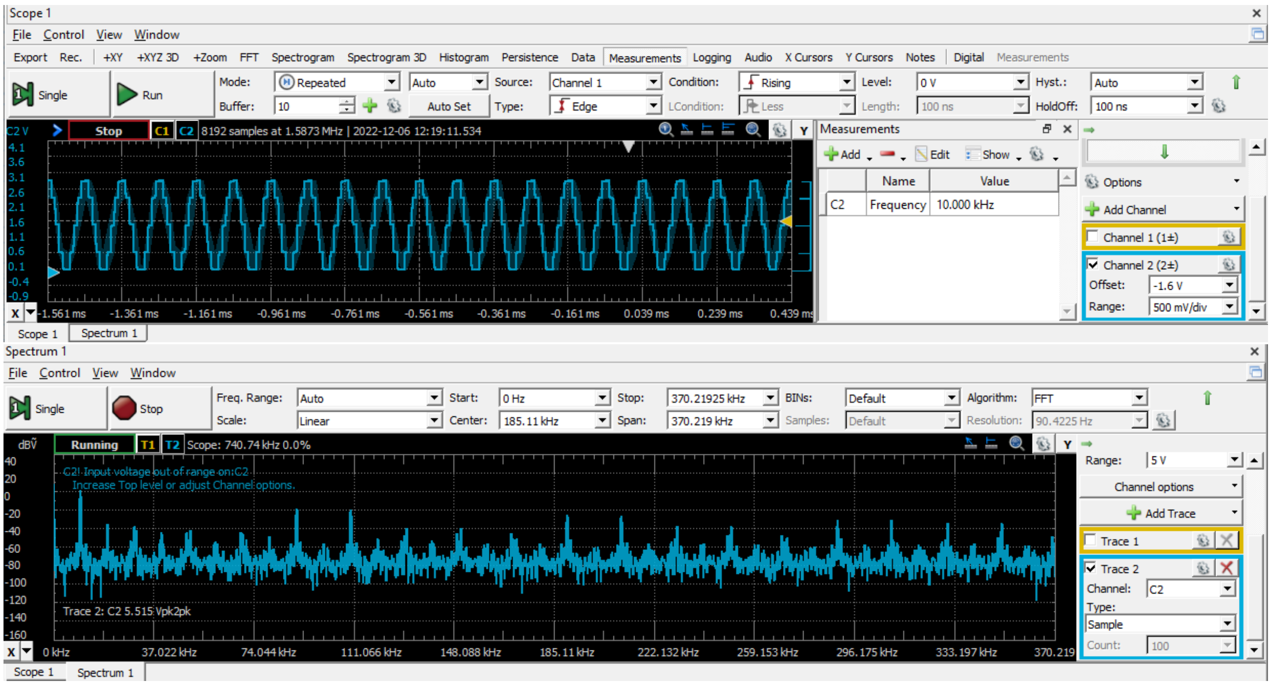
Stop | T1 | T2 | Scope: 2 MHz | 2022-12-06 12:17:08.881

C2! Input voltage out of range on C2
Increase Top level or adjust Channel options.

Trace 2: C2 5.515 Vpk2pk

Range: 5 V | Trace 2 — Channel: C2 — Type: Sample — Count: 100

Figure 7 f = 1,37 kHz


Scope 1

Mode: Repeated | Auto | Source: Channel 1 | Condition: Rising | Level: 0 V | Hyst.: Auto
Buffer: 10 | Auto Set | Type: Edge | LCondition: Less | Length: 100 ns | HoldOff: 100 ns

Stop | C1 | C2 | 8192 samples at 1.5873 MHz | 2022-12-06 12:19:11.534

Measurements

	Name	Value
C2	Frequency	10.000 kHz

Channel 1 (1±)
Channel 2 (2±) Offset: -1.6 V Range: 500 mV/div

Spectrum 1

Freq. Range: Auto | Start: 0 Hz | Stop: 370.21925 kHz | BINs: Default | Algorithm: FFT
Scale: Linear | Center: 185.11 kHz | Span: 370.219 kHz | Samples: Default | Resolution: 90.4225 Hz

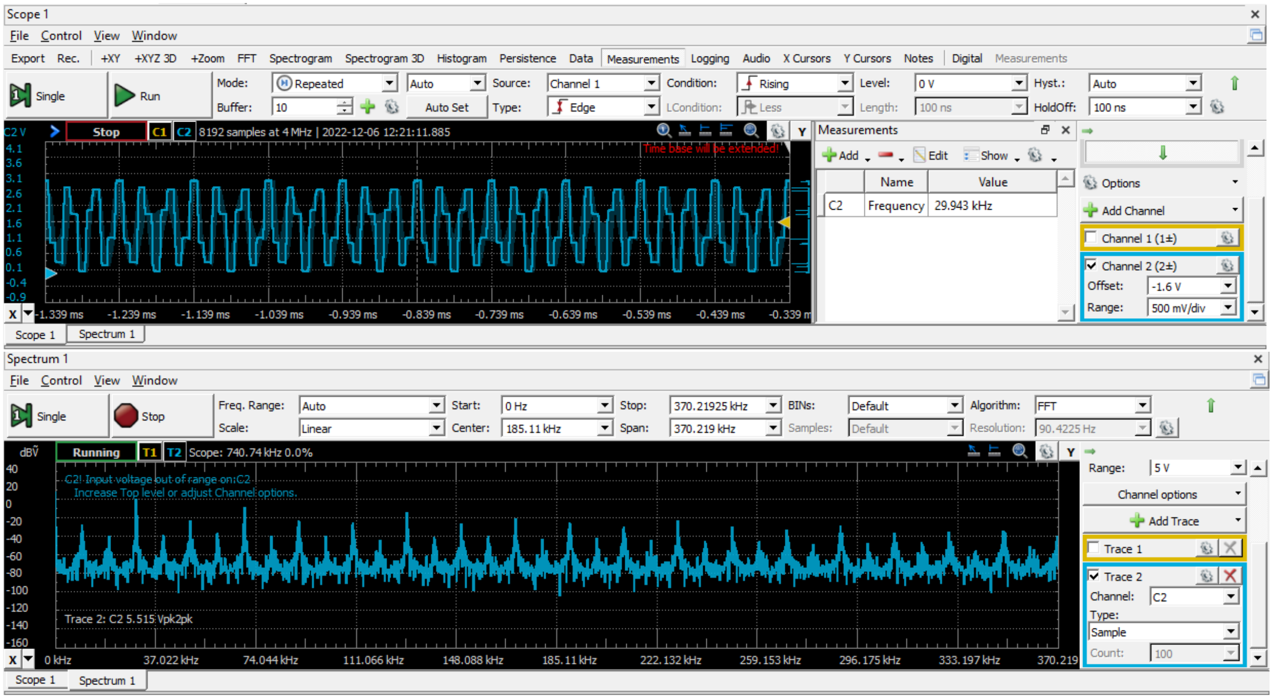
Running | T1 | T2 | Scope: 740.74 kHz 0.0%

C2! Input voltage out of range on:C2
Increase Top level or adjust Channel options.

Trace 2: C2 5.515 Vpk2pk

Range: 5 V
Trace 1
Trace 2 Channel: C2 Type: Sample Count: 100

Figure 8 f = 10 kHz


Scope 1

Mode: Repeated | Auto | Source: Channel 1 | Condition: Rising | Level: 0 V | Hyst.: Auto
Buffer: 10 | Auto Set | Type: Edge | LCondition: Less | Length: 100 ns | HoldOff: 100 ns

Stop | C1 | C2 | 8192 samples at 4 MHz | 2022-12-06 12:21:11.885

Time base will be extended!

Measurements

	Name	Value
C2	Frequency	29.943 kHz

Channel 1 (1±)
Channel 2 (2±) Offset: -1.6 V Range: 500 mV/div

Spectrum 1

Freq. Range: Auto | Start: 0 Hz | Stop: 370.21925 kHz | BINs: Default | Algorithm: FFT
Scale: Linear | Center: 185.11 kHz | Span: 370.219 kHz | Samples: Default | Resolution: 90.4225 Hz

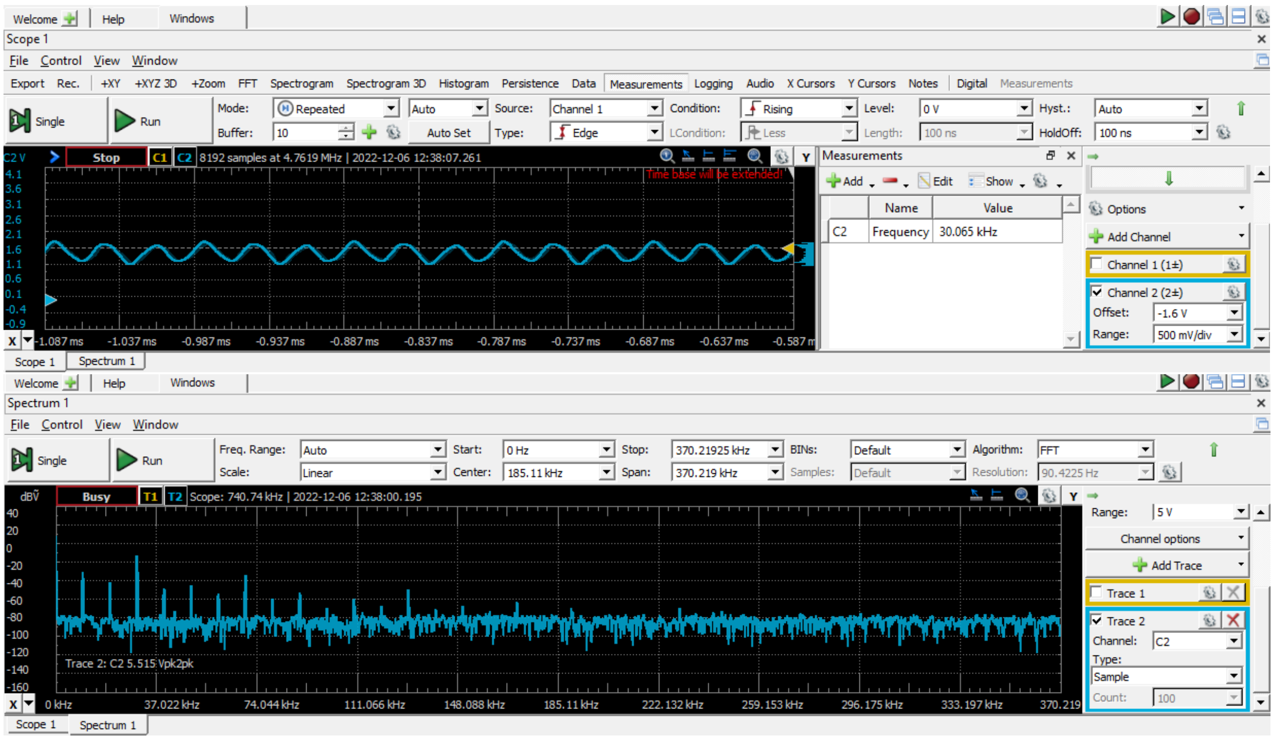
Running | T1 | T2 | Scope: 740.74 kHz 0.0%

C2! Input voltage out of range on:C2
Increase Top level or adjust Channel options.

Trace 2: C2 5.515 Vpk2pk

Range: 5 V
Trace 1
Trace 2 Channel: C2 Type: Sample Count: 100

Figure 9 f = 30 kHz


Scope 1
File Control View Window
Export Rec. +XY +XYZ 3D +Zoom FFT Spectrogram Spectrogram 3D Histogram Persistence Data Measurements Logging Audio X Cursors Y Cursors Notes Digital
Single Run
Stop
Time base will be extended!
Spectrum 1
Busy
Trace 2: C2 5.515 Vpk2pk

Mode: Repeated, Auto | Source: Channel 1 | Condition: Rising | Level: 0 V | Hyst.: Auto
Buffer: 10 | Auto Set | Type: Edge | LCondition: Less | Length: 100 ns | HoldOff: 100 ns

8192 samples at 4.7619 MHz | 2022-12-06 12:38:07.261

	Name	Value
C2	Frequency	30.065 kHz

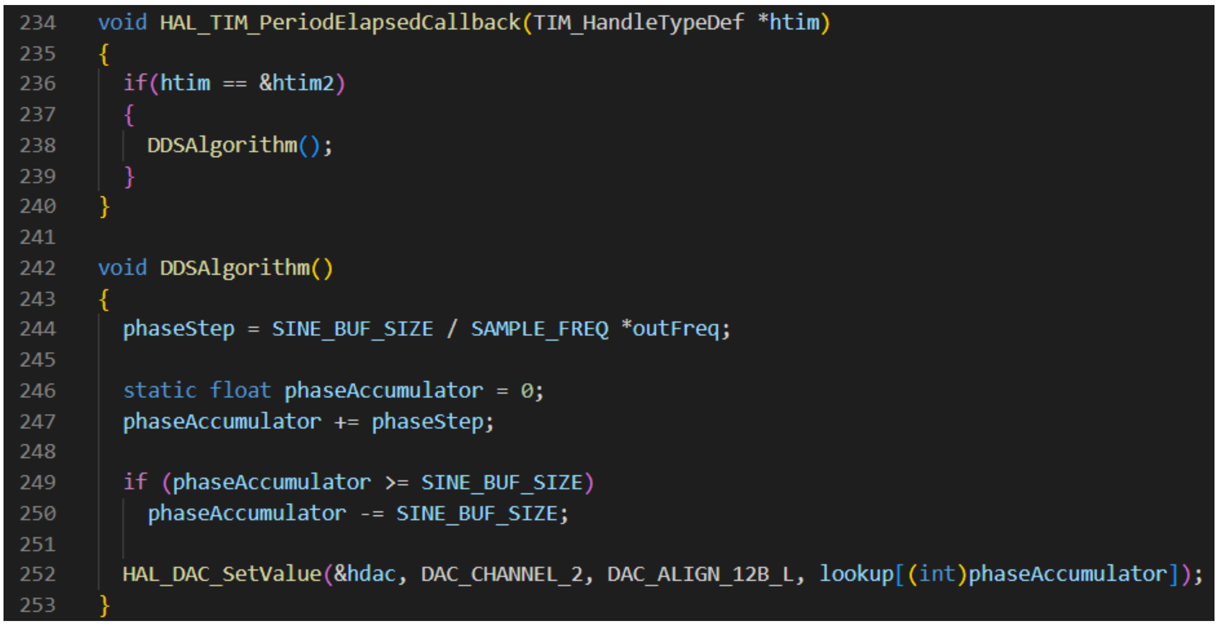
Channel 2 (2±) Offset: -1.6 V Range: 500 mV/div

Freq. Range: Auto | Start: 0 Hz | Stop: 370.21925 kHz | BINs: Default | Algorithm: FFT
Scale: Linear | Center: 185.11 kHz | Span: 370.219 kHz | Samples: Default | Resolution: 90.4225 Hz

Scope: 740.74 kHz | 2022-12-06 12:38:00.195

Range: 5 V | Trace 2 Channel: C2 Type: Sample Count: 100

Figure 10 f = 30 kHz with RC filter



```c
void HAL_TIM_PeriodElapsedCallback(TIM_HandleTypeDef *htim)
{
  if(htim == &htim2)
  {
    DDSAlgorithm();
  }
}

void DDSAlgorithm()
{
  phaseStep = SINE_BUF_SIZE / SAMPLE_FREQ *outFreq;

  static float phaseAccumulator = 0;
  phaseAccumulator += phaseStep;

  if (phaseAccumulator >= SINE_BUF_SIZE)
    phaseAccumulator -= SINE_BUF_SIZE;

  HAL_DAC_SetValue(&hdac, DAC_CHANNEL_2, DAC_ALIGN_12B_L, lookup[(int)phaseAccumulator]);
}
```

Figure 11 DDS algorithm

DDS main advantage is that it allows us to tweak base frequency purely in software. As seen above it is possible to implement it using DAC with DMA but of course there are some limitations. As shown, signals up to 10 kHz are modelled properly. It cannot be said about 30 kHz. Also, spectrum analyzer shows that generated signal has a lot of harmonics. The higher the frequency the worse is the quality of signal. However it can be helped with low-pass RC filter (figure 10). Such filter blocks signal of a frequency higher than cut-off frequency (by grounding them through capacitor) and allows those lower through a resistor. It lowered the amplitude of harmonics and smoothened the signal itself.