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Fast Fourier Transform

Application Note 148

This document describes the usage of the *Triamec Option Module FF*. It converts time domain signals into the frequency domain, implementing the Fast Fourier Transform (FFT). The module has one ADC channel input and processes the signal through a Xilinx FFT IP core. The spectrum lines can be recorded and scoped with a rate of 100kHz with the Tam System Explorer. The spectrum is updated every 1kHz. The scoped data may be processed by a user application.

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1 Specifications

Hardware limits:

- Analog Input 1.366Vpp max.
- Analog Input filter bandwidth 10MHz
- ADC built-in filtering 2.5MHz

Hardware calculation limits:

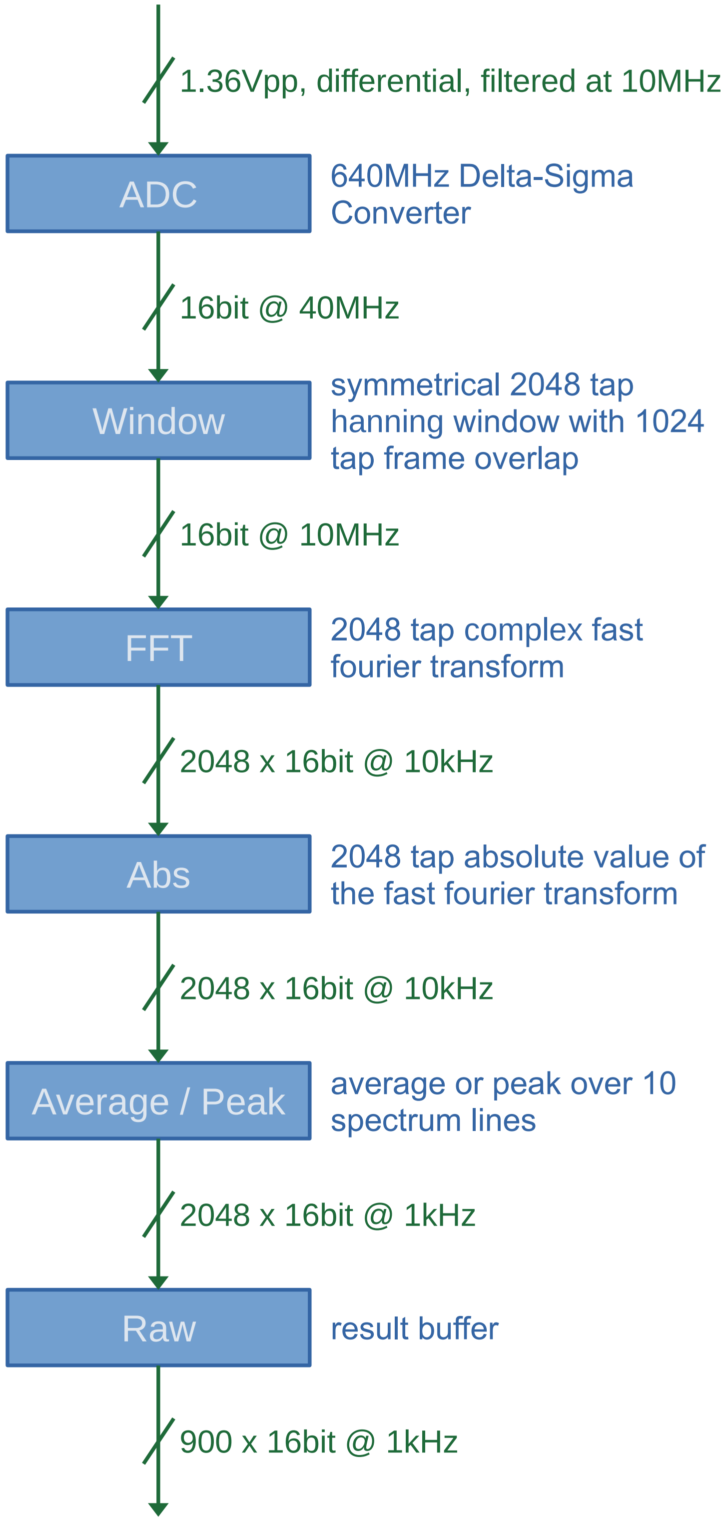
- FFT sampling 10MHz
- FFT samples 2048
- Frequency Steps 10MHz / 2048 = 4882.8125Hz
- Analog resolution 16bit

Signal scaling:

- FFT tap to analog signal 0.1334mVpp / Incr
- Analog signal to FFT tap 7496 Incr / Vpp

For the pin-out of the connector see the option module manual [1].

2 Signal Flow



Drawing 1: Signal Flow Diagram

2.1 Analog to Digital Converter

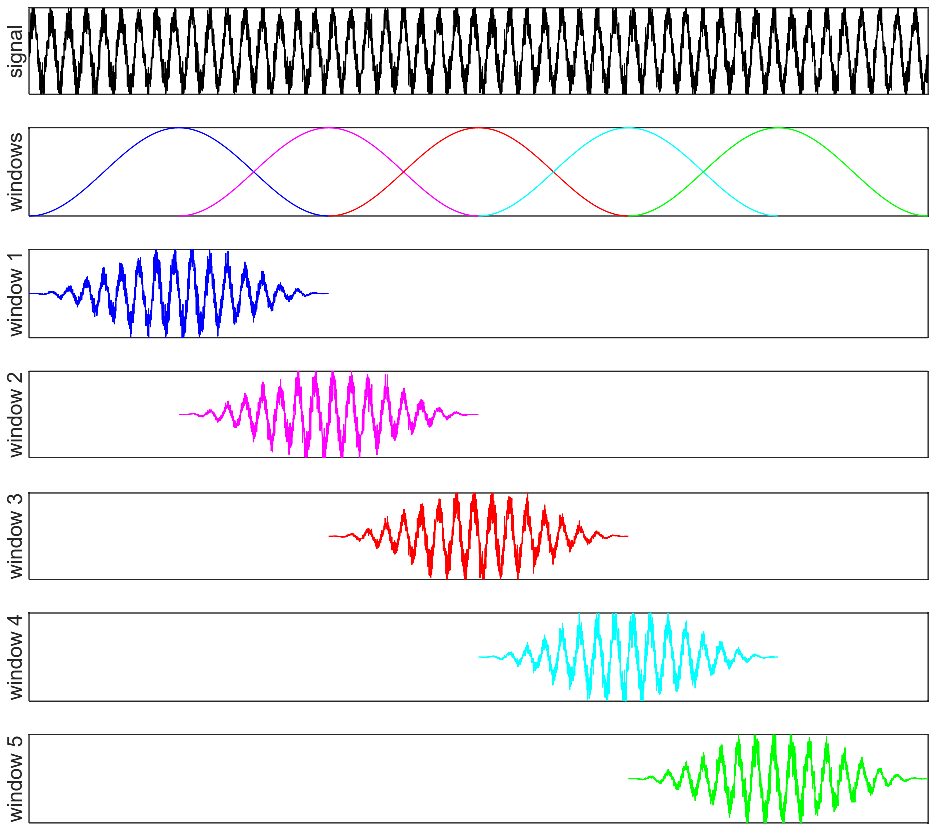
ADC properties

- 16 bit resolution
- 640 MSPS analog input sampling
- 40 MSPS digital output data
- Built-in 2.5MHz bandwidth filter

The FF uses a continuous time Sigma-Delta ADC. The input signal first passes an analog LC-Filter of 3rd order and with a bandwidth of 10MHz. The ADC filtering finally limits the bandwidth to 2.5MHz.

2.2 Windowing

In order to avoid boundary effects, the input signal needs to be windowed. This means that every data frame is scaled like in the figure below. The frames are overlapping, so no data is missing. The input data first passes a 4 tap averaging filter with data reduction of 1 to 4. The window data rate is 10 MSPS.



The window function is calculated every 10kHz. The FF has a 2048 tap window with an overlap of 1048 = 2048 - 1000 taps.

2.3 Fast Fourier Transform (FFT)

The Fast Fourier Transform (FFT) converts time signals into complex frequency signals. A detailed description of the FFT IP core xfft 9.0 can be found on the Xilinx / AMD website. The output data rate is set to 2048 complex frequency points every 10kHz. The spectrum resolution is 2x 16bit.

2.4 Absolute Values

The absolute values are calculated by the formula $Z = Sqrt(X^2 + Y^2)$ with X representing the real part and Y the imaginary part of the spectrum. The output resolution is 16 bit for every spectral line.

2.5 Average / Peak

The average gain is 10/8=1.25. Since frames with 2048 x 16bit can't be transferred every 10kHz with the existing drive infrastructure, a further data reduction has to be done. The application can choose between average and peek mode.

- The average mode performs a 10 sample average for every spectral line.
- The peak mode performs a 10 sample peak detection for every spectral line.

The mode can be set by the Local Bus:

```
Local Bus Device 0x04

0x000200 RW [4]   : '0' -> mean calculation (default)
                    '1' -> peak calculation
```

2.6 Raw Data

The spectrum can be read repeatedly every 1kHz with the Tam System Explorer (manual mode) or with some user specific software using the Tam System Explorer API. With a plugged FF module, the Tam System Explorer offers the following registers under the appropriate axis:

- Axes[].Signals.OptionModule.Raw[0]
- Axes[].Signals.OptionModule.Raw[1]
- Axes[].Signals.OptionModule.Raw[2]
- Axes[].Signals.OptionModule.Raw[3]
- Axes[].Signals.OptionModule.Raw[4]

To get a 1kHz spectrum, the raw signals above must be logged with 100kHz. The data is converted with the following rules:

```
index      = Raw[0][15: 0]
Z[index]   = Raw[0][31:16]
Z[index+1] = Raw[1][15: 0]
Z[index+2] = Raw[1][31:16]
Z[index+3] = Raw[2][15: 0]
Z[index+4] = Raw[2][31:16]
Z[index+5] = Raw[3][15: 0]
```

```
Z[index+6] = Raw[3][31:16]
Z[index+7] = Raw[4][15: 0]
Z[index+8] = Raw[4][31:16]
```

The firmware is preset to transmit 100 x 5 raw data samples with 100 x 9 spectral lines. This gives in total 900 spectral lines representing a linear frequency range from 0Hz to 4.389MHz (10MHz / 2048 x 899) with a frequency spacing of 4882.8125Hz (10MHz / 2048). The related sample frequency is [index+n] x 4882.8125Hz with n=0..8.

3 Signal Properties

When applying a pure sine signal there are two types of effects which have to be considered:

1. The sine frequency is an integer multiple of the lowest FFT frequency.

   Example f = 48825.125Hz = 10 / 2048 x 10MHz
   The maximum spectral line is at tap 11 and will be 0.5 of the signal amplitude. The taps 10 and 12 will be the side lobs with an amplitude of approximately 0.25. The side lobes are an effect of the Hanning window.
2. The sine frequency is **not** an integer multiple of the lowest FFT frequency.

   Example f = 50292.969Hz = 10.3 / 2048 x 10MHz
   Now there are two main lobes at taps 11 and 12. The side lobes are a) visible at taps 10 and 13 and b) not visible because overlapped by the main lobes. The Hanning window sharpens the main lobes. Without the Hanning window the main lobes would be spread over a wide frequency range.

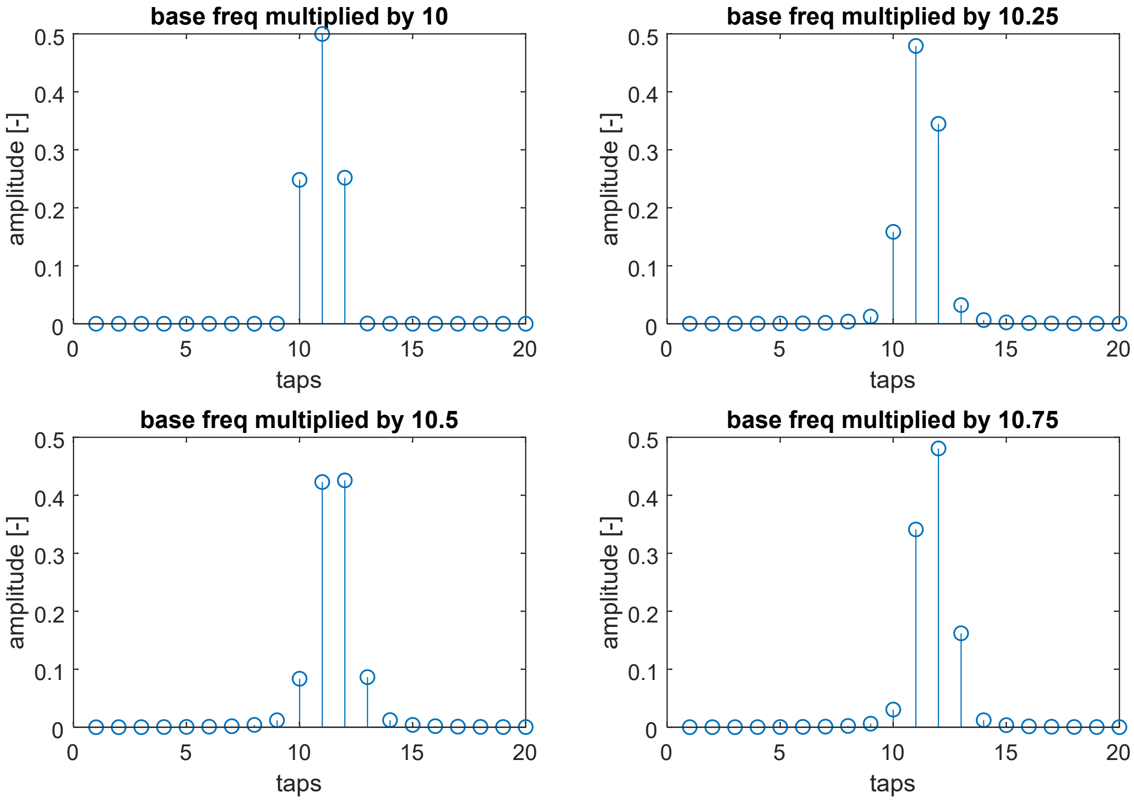


Figure 1: Base frequency multiples between 10 and 11

References

[1] "Option Modules Manual",
HWTO_OptionModulesManual_EP013.pdf, Triamec Motion AG, 2023.

Revision History

Version	Date	Editor	Comment
001	2022-11-15	lk	Document creation
002	2023-02-09	dg	Reviewed

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