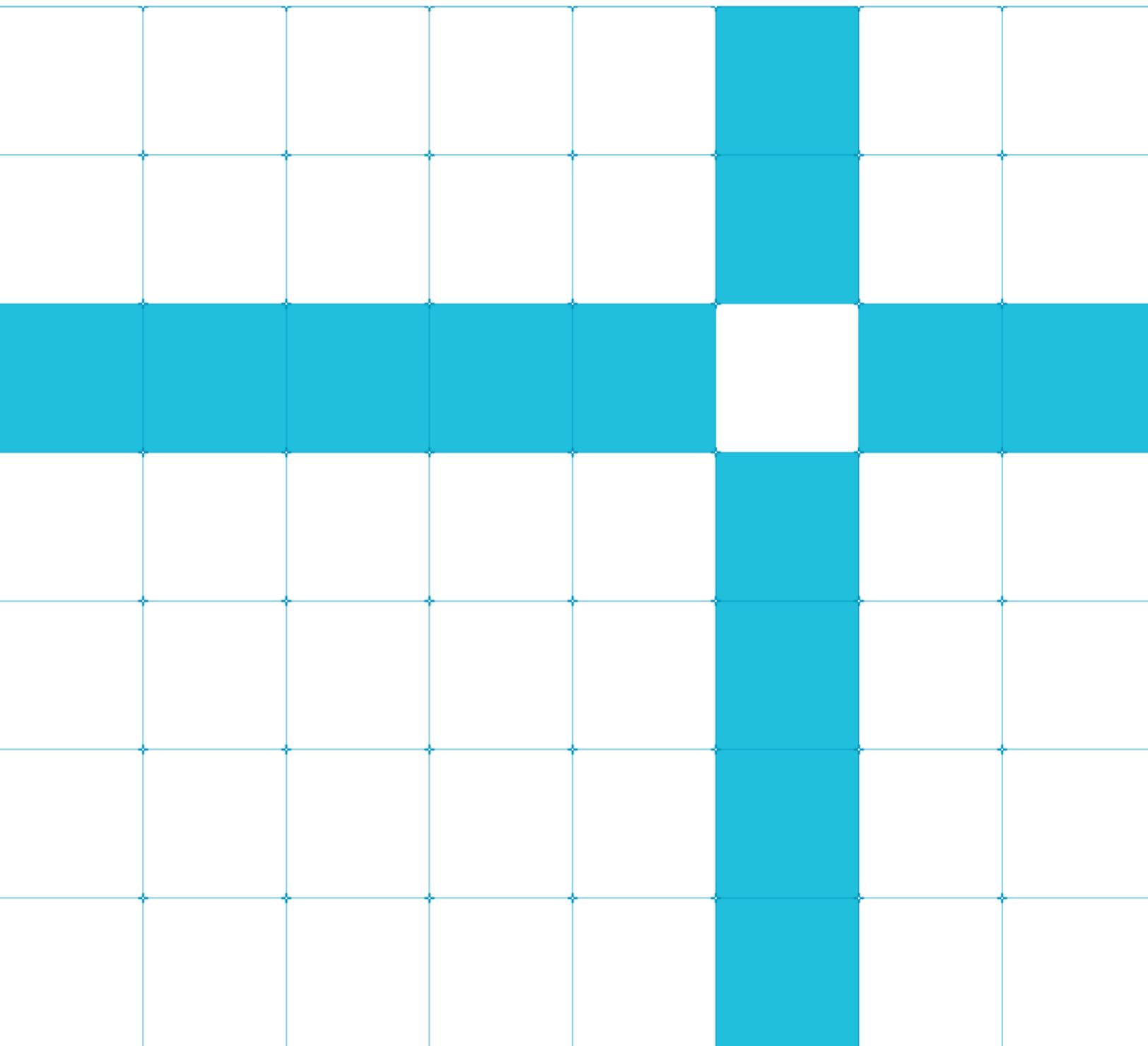




Guide: How to use the Python wrapper for CMSIS-DSP with biquads as an example

Version 1.0



Guide: How to use the Python wrapper for CMSIS-DSP with biquads as an example

Copyright © 2019 Arm Limited (or its affiliates). All rights reserved.

Non-Confidential Proprietary Notice

This document is protected by copyright and other related rights and the practice or implementation of the information contained in this document may be protected by one or more patents or pending patent applications. No part of this document may be reproduced in any form by any means without the express prior written permission of Arm. **No license, express or implied, by estoppel or otherwise to any intellectual property rights is granted by this document unless specifically stated.**

Your access to the information in this document is conditional upon your acceptance that you will not use or permit others to use the information for the purposes of determining whether implementations infringe any third party patents.

THIS DOCUMENT IS PROVIDED "AS IS". ARM PROVIDES NO REPRESENTATIONS AND NO WARRANTIES, EXPRESS, IMPLIED OR STATUTORY, INCLUDING, WITHOUT LIMITATION, THE IMPLIED WARRANTIES OF MERCHANTABILITY, SATISFACTORY QUALITY, NON-INFRINGEMENT OR FITNESS FOR A PARTICULAR PURPOSE WITH RESPECT TO THE DOCUMENT. For the avoidance of doubt, Arm makes no representation with respect to, and has undertaken no analysis to identify or understand the scope and content of, patents, copyrights, trade secrets, or other rights.

This document may include technical inaccuracies or typographical errors.

TO THE EXTENT NOT PROHIBITED BY LAW, IN NO EVENT WILL ARM BE LIABLE FOR ANY DAMAGES, INCLUDING WITHOUT LIMITATION ANY DIRECT, INDIRECT, SPECIAL, INCIDENTAL, PUNITIVE, OR CONSEQUENTIAL DAMAGES, HOWEVER CAUSED AND REGARDLESS OF THE THEORY OF LIABILITY, ARISING OUT OF ANY USE OF THIS DOCUMENT, EVEN IF ARM HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

This document consists solely of commercial items. You shall be responsible for ensuring that any use, duplication or disclosure of this document complies fully with any relevant export laws and regulations to assure that this document or any portion thereof is not exported, directly or indirectly, in violation of such export laws. Use of the word "partner" in reference to Arm's customers is not intended to create or refer to any partnership relationship with any other company. Arm may make changes to this document at any time and without notice.

If any of the provisions contained in these terms conflict with any of the provisions of any click through or signed written agreement covering this document with Arm, then the click through or signed written agreement prevails over and supersedes the conflicting provisions of these terms. This document may be translated into other languages for convenience, and you agree that if there is any conflict between the English version of this document and any translation, the terms of the English version of the Agreement shall prevail.

The Arm corporate logo and words marked with ® or ™ are registered trademarks or trademarks of Arm Limited (or its subsidiaries) in the US and/or elsewhere. All rights reserved. Other brands and names mentioned in this document may be the trademarks of their respective owners. Please follow Arm's trademark usage guidelines at <http://www.arm.com/company/policies/trademarks>.

Copyright © 2017 Arm Limited (or its affiliates). All rights reserved.

Arm Limited. Company 02557590 registered in England.

110 Fulbourn Road, Cambridge, England CB1 9NJ.

LES-PRE-20349

Confidentiality Status

This document is Non-Confidential. The right to use, copy and disclose this document may be subject to license restrictions in accordance with the terms of the agreement entered into by Arm and the party that Arm delivered this document to.

Unrestricted Access is an Arm internal classification.

Product Status

The information in this document is Final, that is for a developed product.

Web Address

<http://www.arm.com>.

Contents

1 About this document	5
1.1. Terms and Abbreviations	5
1.2. References	5
1.3. Scope	5
2 Overview	6
The source code for this guide can be found In the CMSIS-DSP PythonWrapper : https://github.com/ARM-software/CMSIS_5/blob/develop/CMSIS/DSP/PythonWrapper/example.py	6
3 Before you begin	7
4 How to implement biquads to filter an Electrocardiography signal	8
In this guide, we will see how to filter an Electrocardiography (ECG) signal using a biquad filter using SciPy and using the CMSIS-DSP from Python. We will check that we get the same results with both methods. The biquad filter will remove the high frequency noise. This guide won't explain how to design such a biquad filter.	8
5 Related information	13
6 Next steps	13

1 About this document

This document contains a guide explaining how to use the Python wrapper for CMSIS-DSP. Filtering on an ECG signal using biquads is used as an example.

1.1. Terms and Abbreviations

This document uses the following terms and abbreviations.

Term	Meaning
DSP	Digital Signal Processing
CMSIS-DSP	Cortex Microcontroller Software Interface Standard for Digital Signal Processing

1.2. References

The ECG data was taken from the PhysioNet database:

Goldberger AL, Amaral LAN, Glass L, Hausdorff JM, Ivanov PCh, Mark RG, Mietus JE, Moody GB, Peng C-K, Stanley HE. PhysioBank, PhysioToolkit, and PhysioNet: Components of a New Research Resource for Complex Physiologic Signals. *Circulation* 101(23):e215-e220 [Circulation Electronic Pages; <http://circ.ahajournals.org/cgi/content/full/101/23/e215>]; 2000 (June 13).

And was created for the master thesis:

Lugovaya T.S. Biometric human identification based on electrocardiogram. [Master's thesis] Faculty of Computing Technologies and Informatics, Electrotechnical University "LETI", Saint-Petersburg, Russian Federation; June 2005.

1.3. Scope

This guide explains how to use the Python wrapper for CMSIS-DSP. Filtering on an ECG signal using biquads is used as an example.

2 Overview

This guide provides a simple example of how to use the CMSIS-DSP Python wrapper and how a CMSIS-DSP API is represented in Python.

Signal processing algorithms on embedded systems are often implemented with a library of optimized functions using a reference developed in a scientific computing environment. Popular environments include the open source Python library, SciPy, or MathWorks MATLAB software.

There are always differences between a scientific environment and a library of optimized functions.

Those differences may exist for different reasons, depending on:

- What conventions are used, for example different normalization factors
- What memory layout is used for the parameters of functions, for example the order of filter coefficients
- Whether fixed-point arithmetic is used in the embedded system and floating-point arithmetic is used in the reference environment

These differences mean that translating the theoretical signal processing chain from the scientific environment to the embedded system does not happen immediately. The differences must be understood and under control.

To help, the Arm Digital Signal Processing (DSP) software team has introduced a Python wrapper for the CMSIS-DSP library that is compatible with NumPy. The [CMSIS-DSP](#) library is a rich collection of DSP functions that Arm has optimized for the various [Arm Cortex-M processors](#). CMSIS-DSP is widely used in the industry, and also enables optimized C code generation from various third-party tools.

With this Python wrapper, you can design your signal processing algorithm with SciPy and progressively replace part of it with CMSIS-DSP functions that are callable from Python. Once your algorithm has been validated with the CMSIS-DSP functions, you can port the algorithm to your embedded system. This is because the Python API follows the C API of CMSIS-DSP as closely as possible.

The wrapper makes it easy to experiment and ensure that your final implementation will behave as intended.

This guide will show how to use the CMSIS-DSP Python API. At the end of this guide you'll be able to use the CMSIS-DSP Biquad filter to filter a signal defined in Python, plot the result and compare with the SciPy version.

The source code for this guide can be found in the CMSIS-DSP PythonWrapper : https://github.com/ARM-software/CMSIS_5/blob/develop/CMSIS/DSP/PythonWrapper/example.py

This guide will explain the steps related to CMSIS-DSP only. The example.py file contains Python code to load the data and build the SciPy filter.

3 Before you begin

In order to complete this guide, you need to be familiar with CMSIS-DSP and Python. Our blog [Signal processing capabilities of Cortex-M devices](#) provides some useful background information.

Before you begin, you will need to access the wrapper. You can do this using the [:Guide to using Python wrapper for CMSIS-DSP](#). https://github.com/ARM-software/CMSIS_5/tree/develop/CMSIS/DSP/PythonWrapper

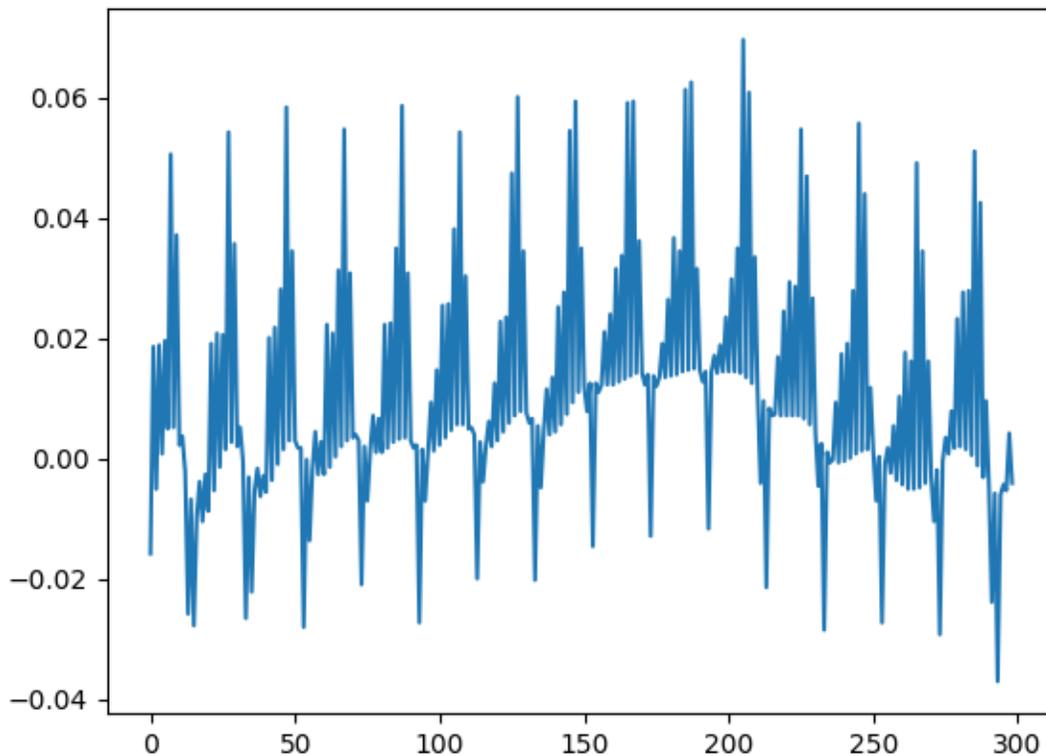
In GitHub, click on the README link (I think we should add a link to this README : https://github.com/ARM-software/CMSIS_5/tree/develop/CMSIS/DSP/PythonWrapper) for more information, and follow the Instructions to build and install the wrapper.

The signal used as example in this guide is coming from the PhyioNet databased that is mentioned in the Overview. (mentioned in 'About this document which we need to fold in somehow)

4 How to implement biquads to filter an Electrocardiography signal

In this guide, we will see how to filter an Electrocardiography (ECG) signal using a biquad filter using SciPy and using the CMSIS-DSP from Python. We will check that we get the same results with both methods. The biquad filter will remove the high frequency noise. This guide won't explain how to design such a biquad filter.

You can see a sample ECG signal in the following image (generated with Python) :



We want to remove the high frequency noise from the signal.

First, let's import some libraries that we will need for our example:

```
import cmsisdsp as dsp
import numpy as np
from scipy import signal
from pylab import figure, plot, show
```

Here is an implementation of the filter in SciPy, which shows three biquad filters in sequence. The biquads are described with their poles and zeros.

```
p0 = np.exp(1j*0.05) * 0.98
p1 = np.exp(1j*0.25) * 0.9
p2 = np.exp(1j*0.45) * 0.97

z0 = np.exp(1j*0.02)
z1 = np.exp(1j*0.65)
z2 = np.exp(1j*1.0)
g = 0.02
```

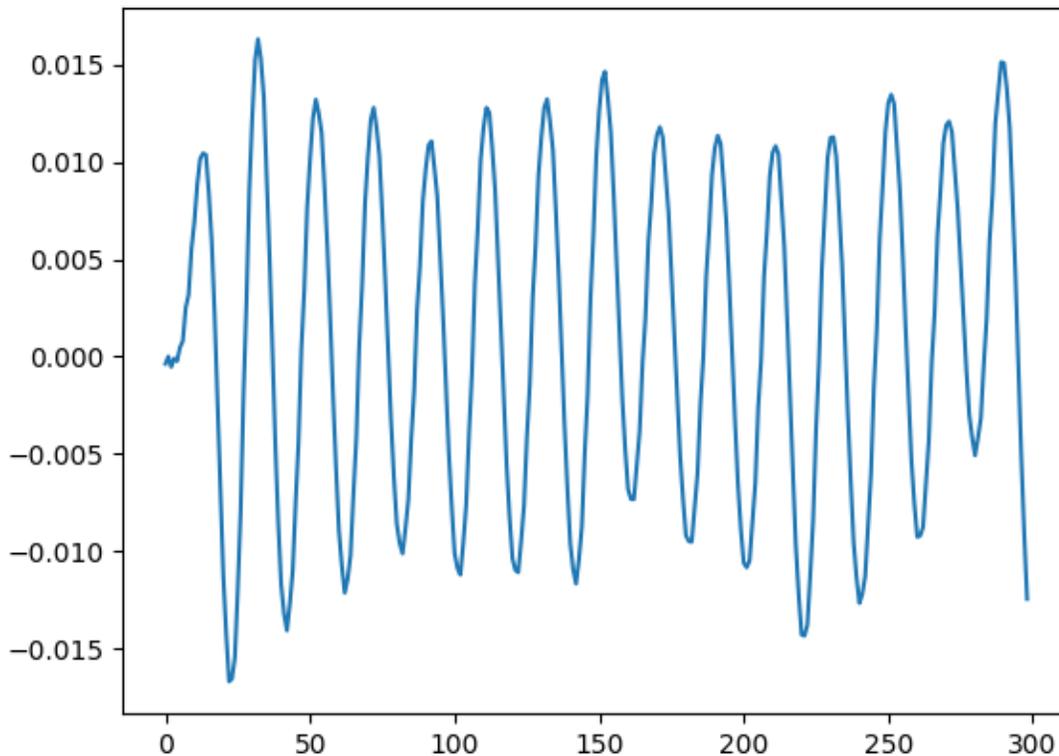
With those poles and zeros, the filter can be created with:

```
sos = signal.zpk2sos(
    [z0,np.conj(z0),z1,np.conj(z1),z2,np.conj(z2)]
    ,[p0, np.conj(p0),p1, np.conj(p1),p2, np.conj(p2)]
    ,g)
```

Now, we filter the signal with the biquad filter and display the first 300 samples of the result (**nb** is equal to 300).

```
res=signal.sosfilt(sos,sig)
figure()
plot(res[1:nb])
```

The high frequency noise has now been removed, as you can see in the following image:



Let's replace this filter with a Q31 implementation using CMSIS-DSP and check that we get the same result at the end.

First, we need to create an instance object. In CMSIS-DSP, an instance object corresponds to a C struct which must be allocated, and which contains the filter coefficients and the filter state. The name of the Python function is the name of the C type in CMSIS-DSP.

```
biquadQ31 = dsp.arm_biquad_casd_df1_inst_q31()
```

To initialize this instance with the CMSIS-DSP initialization function, we need a state array.

The state array must be big enough. According to the CMSIS-DSP documentation, (link to https://arm-software.github.io/CMSIS_5/DSP/html/index.html) we need four samples for each biquad. Our example includes three biquad

```
numStages=3  
state=np.zeros(numStages*4)
```

To initialize the instance object, we also need a coefficient array that contains the filter coefficients.

SciPy and CMSIS-DSP do not save the coefficients in the same way in memory. In CMSIS-DSP, the a0 coefficient is assumed to be 1 and is not saved in memory. Also, In CMSIS-DSP the "a" coefficients are negative compared to the SciPy conventions.

So, to use the coefficients with CMSIS-DSP we need to convert them.

Finally, to avoid saturations in the Q31 implementation we need to scale down the coefficients by 4. The following Python lines are doing the conversions:

```
coefs=np.reshape(np.hstack((sos[:,3],-sos[:,4:])),15)
coefs = coefs / 4.0
```

And of course, the coefficients need to be converted to Q31 format. The `toQ31` is a simple Python function that we wrote to convert the float into an integer using Q31 format.

```
coefsQ31 = toQ31(coefs)
```

Now that we have our coefficients, we can initialize our filter instance. Since the coefficients were scaled down by 4, we need to set the `postshift` to 2 in the filter as explained in the CMSIS-DSP documentation. (link to https://arm-software.github.io/CMSIS_5/DSP/html/index.html)

The API `arm_biquad_cascade_df1_init_q31` is a direct copy of the C version and would be used in the same way in the C implementation.

```
postshift = 2
dsp.arm_biquad_cascade_df1_init_q31(biquadQ31,numStages,coefsQ31,state,postshift)
```

Now that the filter instance has been initialized, we are nearly ready to filter our signal. But before testing the filter, we also need to convert the input signal to Q31 format:

```
sigQ31=toQ31(sig)
```

Now we can filter our Q31 signal using the CMSIS-DSP biquad function. Here we limit the signal to only the first 300 samples (`nb` is equal to 300).

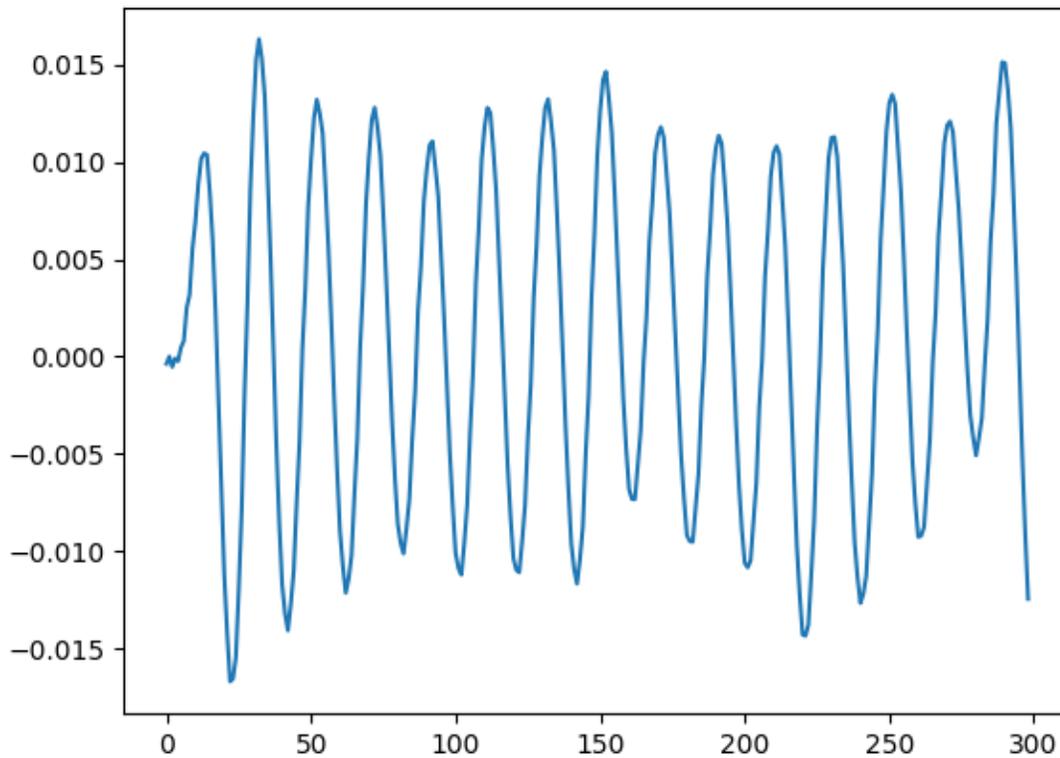
The API `arm_biquad_cascade_df1_q31` is a near copy of the C one. The only difference is that the `blockSize` parameter is inferred from the signal array to make the API a bit easier to use from Python. Also, the CMSIS-DSP `pDst` parameter is transformed into a return value, so that the API is easier to use. Apart from these differences, the API is a copy of the C API.

```
res2=dsp.arm_biquad_cascade_df1_q31(biquadQ31,sigQ31[1:nb])
```

The result `res2` from the function must be converted back to float before being displayed. This is because `res2` is a Q31 signal. Once done, the float version can be displayed to check that the filter is behaving as intended with no saturation issues.

```
figure()
plot(res2[1:nb])
show()
```

And we see on the picture that we get the Intended result:



Without this Python API, testing this example would have required much more work, including:

- A C implementation
- Generation of test patterns
- A test framework to load the input test pattern and read the output from the execution environment. It could be a board or simulator.

5 Related information

Here are some resources related to material in this guide:

- For more information about the signal processing capabilities of Arm Cortex-M processors and the CMSIS-DSP library, click the link below.
[DSP for Cortex-M](#)
- Ask development questions, and find articles and blogs on specific topics from Arm experts at the Arm community. *Hyperlink to* <https://community.arm.com/>
- Arm architecture and reference manuals *Hyperlink to* <https://developer.arm.com/docs>

6 Next steps

This guide has explained you how to use the CMSIS-DSP with Biquad as examples. Now you can design your signal processing chain in SciPy and then convert it for use in CMSIS-DSP in Python. Once you get something working, you are ready to write the C version which will be very close to the Python code you have written.

After reading this guide, you are ready to read the more detailed README file in the CMSIS-DSP folder (https://github.com/ARM-software/CMSIS_5/tree/develop/CMSIS/DSP/PythonWrapper).

This README will explain you how other CMSIS-DSP APIs are represented in Python. For most of them, it is similar to what has been explained in this guide. For a few APIs, like the Matrix ones, there are a few differences to make the API easier to use from Python.

Thank you for reading our guide on using the CMSIS-DSP Python wrapper. We look forward to seeing all the cool stuff you will create with this [Python wrapper and the CMSIS-DSP library](#).

If you have any questions when using the Python wrapper for CMSIS-DSP, please create a GitHub issue.