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Crossover Audio RT-DSP Project

Introduction

This project consists on developing a crossover audio system using BeagleBone Black (BBB) with Xenomai kernel. We used BELA, a BBB environment focused on real time applications.

A crossover system filter uses two filters, a low and a high pass, around a common cutoff frequency. With that, you can split the signal in two channels, one with the low frequencies and another with the high. As audio drivers works better at specific frequencies, the system pass the low frequency signal to a woofer, for example, and the high ones for a tweeter. The system can be chained with more crossover filters, making even more specific outputs.

This project just implement a one cutoff frequency system, with two types of filters: Butterworth 2th degree and a Linkwitz 4th order.

Development and Implementation

Butterworth Implementation

The design was based on s domain expressions, so to use it on the project we need to put it to the z domain. Using the below expression:

$$H(s) = \frac{wo^2}{s^2 + (wo/Q)*s + wo^2}$$

(where wo is 2*pi*cutoff-frequency and Q is the quality factor)

Where Q is 1/sqrt(2) - fixed for Butterworth Filters, and applying the bilinear relation

$$\left(\frac{2}{T}\right) * \left(\frac{1-z^{-1}}{1+z^{1}}\right)$$

(where 1/T = 44100 Hz)

We have

$$H(z) = \frac{wo^2*z^{-2}+2*wo^2*z^{-1}+wo^2}{(c^2-d*wo^2+wo^2)*z^{-2}+(-2*c^2+2*wo^2)*z^{-1}+(c^2+d*wo+wo^2)}$$

(with c = 2/T & d = 1.41*c)

With the H(z) we can obtain the a and b parameters, showed on the table below:

b2	b1	b0	a2	a1	a0
wo^2	$2*wo^2$	wo^2	c^2 - $d*wo + wo^2$	$-2*c^2 + 2*wo^2$	$c^2+d*wo+wo^2$

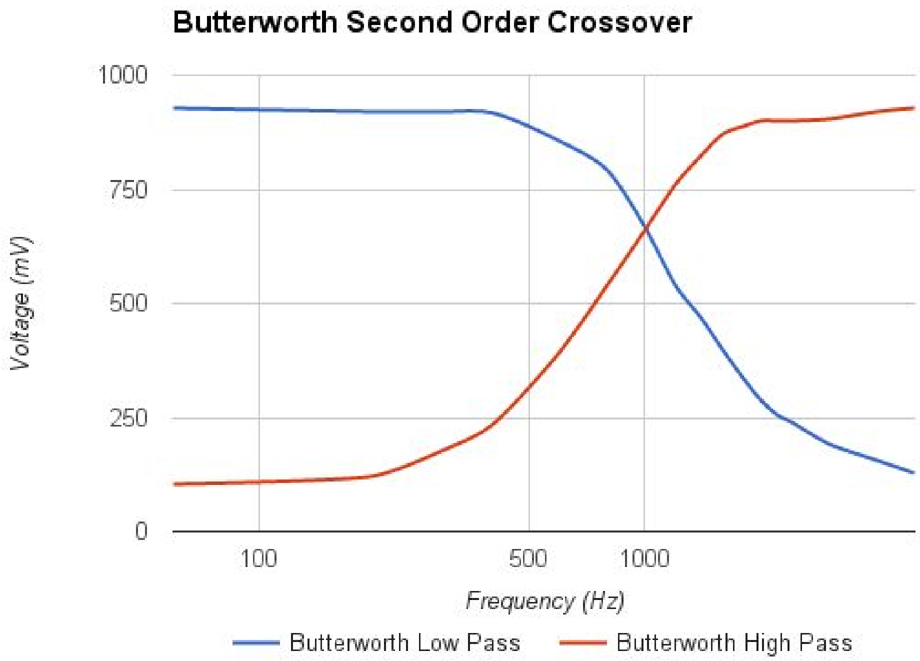
Low Pass Butterworth Filter parameters

To obtain the high pass filter, the process is the same but the equation have two zeros at 0 (dividend: s^2). With that, we obtain the same a parameters, but we have different b's. The table below show the high pass parameters.

b2	b1	b0	a2	a1	a0
$c*wo^2$	$-2*c*wo^2$	$c*wo^2$	$c^2 - d*wo + wo^2$	$-2*c^2 + 2*wo^2$	$c^2+d*wo+wo^2$

Low Pass Butterworth Filter parameters

With this parameters, and using the differences equation, the butterworth crossover could be implemented. The following plot shows the system working for a 1000 Hz cut-off frequency.



Linkwitz Implementation

The linkwitz is defined by two butterworth filters connected in series. So, using the same H(z) and powering it to 2, we get the linkwitz transfer function. The tables below show the filters parameters, referencing the butterworth parameters

b5l	b4l	b3l	b2l	b1l	b0l
$b2^2$	$2*b1*b2$	$b1^2$	$2*b0*b2$	$2*b0*b1$	$b0^2$

(Linkwitz Low Pass Filter Parameters (b))

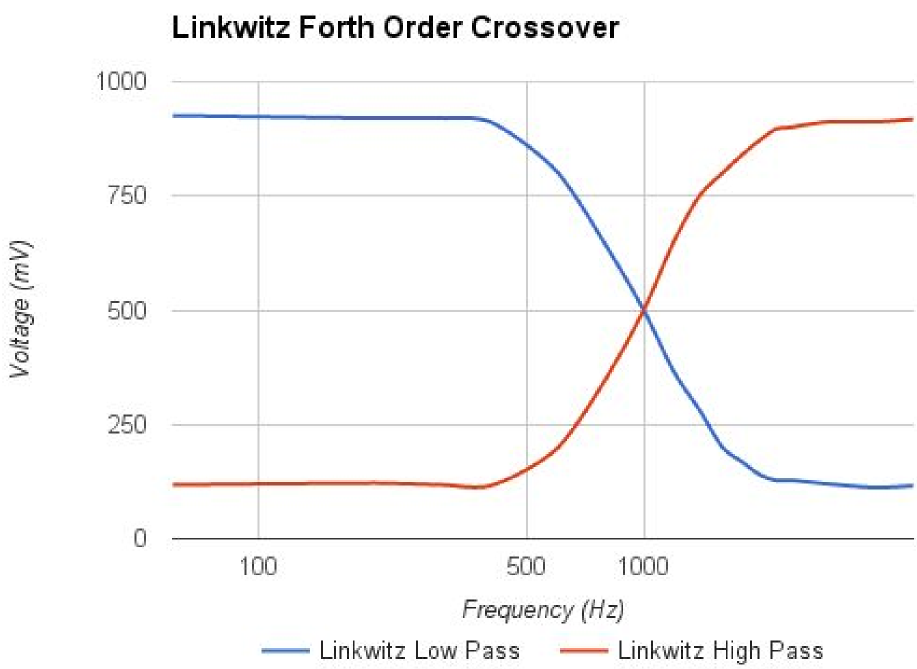
a5l	a4l	a3l	a2l	a1l	a0l

$a2^2$	2*a1*a2	$a1^2$	2*a0*a2	2*a0*a1	$a0^2$

(Linkwitz Low Pass Filter Parameters (a))

The parameters for the high pass filter use the same process, but instead of using the a and b's from the butterworh low pass filters, it uses the high pass ones.

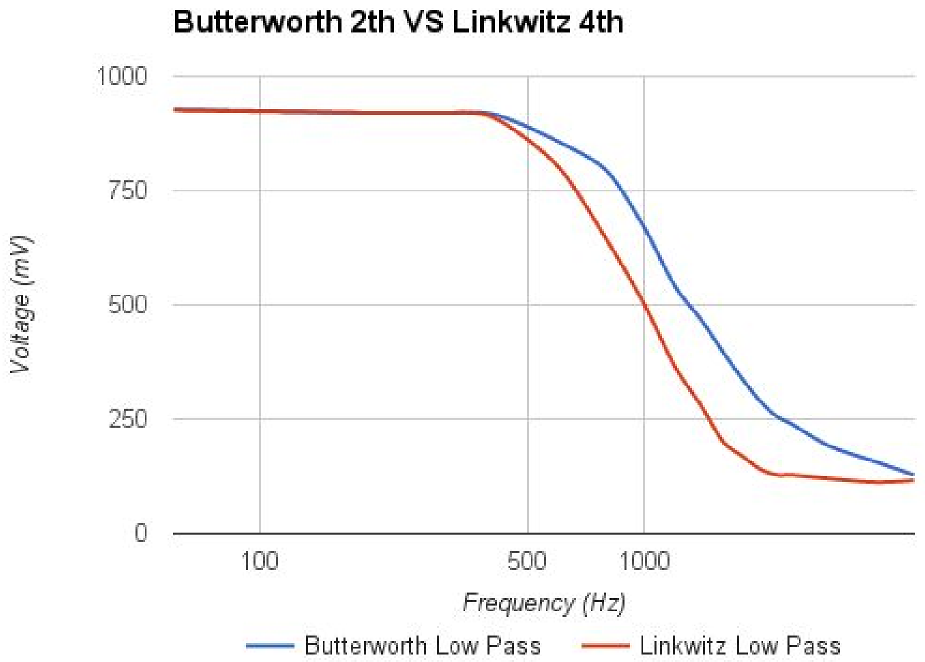
The graph below shows the frequency response of the implemented filter for a cut-off of 1000Hz.



Butterworth vs Linkwitz Implementation

As the Linkwitz of 4th order is two Butterworth 2th order filters in series, it is supposed to have a better performance when compared to the butterworth 2th order. Getting both low pass filters frequency responses plots and comparing them, we can observe that the linkwitz performance is better, cutting more quickly the signal.

The plot below shows this comparison:


Butterworth 2th VS Linkwitz 4th
1000
750
500
250
0
Voltage (mV)
100
500
1000
Frequency (Hz)
Butterworth Low Pass
Linkwitz Low Pass