

Hello

I have heard that it should not be too difficult (big ) to calculate the circuit and values for a 2nd or 3rd order discrete delta-sigma A/D converter and would like to try it out.

However, although I have a generalist engineering background, I know myself well enough to realize that I'll be needing hands-on examples on how to do it, at least in the beginning. That is, something where I can try out the calculations and go on from there.

So, I hope someone here in this forum, maybe Bruno , knows where I can find a hands-on description on how to calculate these values in terms of other circuit parameters like input & output impedances, amplification factors, capacitances, etc.

If it's my lucky day maybe even a simple circuit topology (simple & preferably single-ended) that I can work out from ... Or an internet link.

I do not have access to e.g. Matlab, or the like. I am familiar with LTSpice, though, and can do some simulations here.

Could it be that somebody here knows of such a hands-on source?

Help is much appreciated!

Greetings,

Jesper

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Re: Hands-on delta-sigma A/D converter design examples? [message #490791 [is a reply to message #490240](#) ]

Mon, 26 July 2010  
02:18

[bruno putzeys](#)

**Messages:** 1061

Platinum Member

**Registered:** November 2006

**Location:** Rotselaar (BE)

About the loop filter:

For an n-th order modulator you'll be making a loop filter with n poles and n-1 zeros. Life is easiest if you start with all poles at DC, so just a chain of integrators. The n-1 zeros mean that at low frequencies the filter gain drops off at n\*20dB/dec, and at high frequencies only 20dB/dec (first order). Somewhere between these extremes there be zeros.

You'll be placing those in such a way that you get an orderly transition from nth order to 1st order around a frequency  $f_c$ . In a one-bit modulator this frequency determines the tradeoff between modulation headroom and stability. You might use numerical algorithms to optimize all zeros individually to but for a first experiment this is too complicated. What you can do for a good first shot is simply place the n-1 zeros like the poles of an n-1'th Butterworth filter (i.e. in a half circle).

The constant factor (gain) of the filter is, in theory, unimportant because the quantizer is

nothing but a sign function which means the result does not depend on constant gain factors.

The frequency  $f_c$  will typically be around 2.5% of sampling rate for a 6th order loop or 4% for a third order loop.

OK now you've got the loop transfer. Next you need to work out actual circuit values. First choose how you'll implement the circuit. The first main variety is a string of integrators with input & feedback summed once before the first integrator and a summing network taking inputs from every integrator to make the output. The second is a string of integrators with the feedback signal summed at each integrator's input, either with the input signal (at the first) or the output of the previous integrator. I call the first circuit the "state variable" implementation and the second "nested loop". Not having studied electronics much I could have the terminology wrong.

Once you've made your choice of circuit, write down its transfer function in terms of circuit values. Rewrite both this function and the calculated loop function in the exact same form (e.g. a ratio of polynomials). Now, match up the terms. Each pair of terms gives you an equation. You'll then find you've got more variables than equations. No problem, simply assume some to be "known" because you'll want to change them later in function of your simulation or hardware results and update the rest automatically. For the state variable loop, consider the integration capacitors, the resistors between integrators, the input resistor, the feedback resistor and one output summing resistor as known. That leaves you with the remaining  $n-1$  summing resistors. That's good because you have  $n-1$  zeros as well. Solve the numerators for these  $n-1$  resistors.

About the comparator:

The comparator should have a response time well below a quarter of a sample because you want the remainder of the time to put out the new value. There are mathematical tricks to work around any delay of less than a full sample but that would take us too far. Make your life easy and get a comparator with a latched output.

About the DAC:

Sample the (already latched) comparator output into a fast CMOS flip-flop. You'd be amazed at how good a DAC this makes.

Next step. Simulate the circuit with ideal op amps. It should work straight off the bat, but now is when you start changing the remaining variables.

For the state-variable circuit:

The first op amp sees the most HF. Change the integration cap so the slew rate remains at least 10 times below the rated slew rate of the part you're actually planning to use. The last 2 op amps see the most signal-dependent level. The last carries noise plus the signal, the one before carries noise + first derivative of the signal. Drive the circuit with the highest audio frequency/amplitude you plan to handle (say 50% modulation and 20kHz) and check the peak-peak amplitudes on all op amps bar the first (because that one was slew limited). Now scale the integrating caps so you stay below clip but not too far away. Recalculate the resistors, run again and see if it all looks good.

For a nested loop you'll find all integrators carry large slew rates, which explains why I never

use that topology in AD circuits.

Then build the circuit and that's where the fun begins. At least, the above should quickly give you a circuit that remains stable after overload (or on startup...) which is what holds most people up longest.

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*Warp Drive. Tractor Beam. Room Correction. Whatever.*

Affiliations: [Hypex](#), [Grimm Audio](#).

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Re: Hands-on delta-sigma A/D converter design examples? [message #491603 [is a reply to message #490791](#) ] Tue, 03 August 2010 02:48

[gentlevoice](#)

**Messages:** 7

Member

**Registered:** April 2008

**Location:** Denmark

Hi Bruno - Wow - thanks you so much for outlining this approach for designing a DS A/D converter

First, let me also say that my sort of late reply is because I was expecting a notification mail when there was a reply to the post (it is set up like that in my settings), however, for some reason haven't received any... So I read your reply saturday evening when visiting prosoundweb, and have now taken a couple of days to get an idea about what the implications may be in terms of designing such a converter.

I also guess you must be joking about this one "Not having studied electronics much I could have the terminology wrong."

To revert to the converter I'm a bit wary of what to do. What you write is a bit beyond my current knowledge and I also have a feeling that it may take some time to arrive at a (very) good solution which is what I eventually will aim at. So right now I will consider if I can find a solution (e.g. an engineering student who can help) or if I should let it be for now.

I will, however, like to thank you for taking the time to describe an approach about which I have the impression that it could get me past many of the challenges of making such a converter.

I have also sent you a PM.

My best regards,

Jesper

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Re: Hands-on delta-sigma A/D converter design examples? [message #491606 [is a reply to message #491603](#) ] Tue, 03 August 2010 06:34

[bruno putzeys](#)

**Messages:** 1061

Platinum Member

**Registered:** November 2006

**Location:** Rotselaar (BE)

I was only half joking about the study thing. I followed a B.Sc.E.E. and everything else I know is self-taught. I often have difficulty communicating with academics because I don't always know the established terminology and because I have a completely different way of attacking problems.

*Warp Drive. Tractor Beam. Room Correction. Whatever.*

Affiliations: [Hypex](#), [Grimm Audio](#).

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Re: Hands-on delta-sigma A/D converter design examples? [message #491725 [is a reply to message #490240](#) ] Wed, 04 August 2010 01:26

[Larrchild](#)

**Messages:** 4020

Platinum Member

**Registered:** June 2005

**Location:** Fort Lauderdale, Florida

Problems must hate you.

Larry Janus

<http://2ubes.net>

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Re: Hands-on delta-sigma A/D converter design examples? [message #491728 [is a reply to message #491725](#) ] Wed, 04 August 2010 02:03

[bruno putzeys](#)

**Messages:** 1061

Platinum Member

**Registered:** November 2006

**Location:** Rotselaar (BE)

They just call in their bigger brothers to bother me.

*Warp Drive. Tractor Beam. Room Correction. Whatever.*

Affiliations: [Hypex](#), [Grimm Audio](#).

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Re: Hands-on delta-sigma A/D converter design examples? [message #491823 [is a reply to message #490240](#) ] Wed, 04 August 2010 17:08

[Larrchild](#)

**Messages:** 4020

Platinum Member

**Registered:** June 2005

**Location:** Fort Lauderdale, Florida

When Bruce Lee disapproved of something, they would crash-zoom to close-up and he would make this smirk of disapproval. I envision that expression as the electrons challenge

Bruno to a match.

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Larry Janus

<http://2ubes.net>

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Re: Hands-on delta-sigma A/D converter design examples? [message #506396 is a reply to message #490240 ] Sat, 13 November 2010 14:44

[gentlevoice](#)

**Messages:** 7

Member

**Registered:** April 2008

**Location:** Denmark

Hi Bruno ...

Maybe you remember this thread? The A/D converter project is still buzzing in the back of my mind so may be moving on with it. A couple of practical questions, though, which I hope you can help with:

About the comparator: It needs to be adequately fast but I guess that it also needs to sound outstanding (?). Are there any specifications that are important besides speed? (amplification, noise, input impedance, something else?)

With regards to comparators I've taken a look at Analog Devices' "ADCMP567: Dual Ultrafast Voltage Comparator" but don't know if it's ideal for this purpose. More information can be found here:

<http://www.analog.com/en/amplifiers-and-comparators/comparators/adcmp567/products/product.html>

Or maybe the AD8611 is a better choice?

[http://www.analog.com/static/imported-files/data\\_sheets/AD8611\\_8612.pdf](http://www.analog.com/static/imported-files/data_sheets/AD8611_8612.pdf)

What might surprise you is that I'll be supplying a single-ended signal to the comparator so basically need a comparator that works well in this way (looks as if it could be the AD790 although it's too slow).

Might I also ask you about a tip for a CMOS flip-flop which has an "inherently good sound" (guess it might be flattered ) and is indeed very fast?

Greetings from Denmark,

Jesper Mønsted

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Re: Hands-on delta-sigma A/D converter design examples? [message #506469 is a reply to message #506396 ] Sun, 14 November 2010 09:00

[bruno putzeys](#)

**Messages:** 1061

Platinum Member

**Registered:** November 2006

**Location:** Rotselaar (BE)

The noise performance of the comparator isn't important since its noise is swamped by several orders of magnitude by the quantisation noise. It needs to be fast enough to be able to sample close to the end of a clock period. I use the LT1016.

The requirements of the DAC (CMOS flip-flop) vary with the exact circuit implementation but practice shows it's not a bad idea to have very little variation in on resistance across all outputs. Having low on resistance helps in this regards, which automatically points toward very fast chips.

In this game there is no such thing as "inherent sound quality", only objectively measurable performance counts.

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*Warp Drive. Tractor Beam. Room Correction. Whatever.*

Affiliations: [Hypex](#), [Grimm Audio](#).

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Re: Hands-on delta-sigma A/D converter design examples? [message Sun, 14 November #506479 [is a reply to message #490240](#) ] 2010 09:53

[John Roberts {JR}](#)

**Messages:** 251

Active Member

**Registered:** April 2004

**Location:** MS

IIRC Bob Adams (dBx) wrote an AES paper on that subject back 30 years ago or so.

I don't know if his was discrete, and he probably wrapped companding around it for more dynamic range.

JR

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Resotune at <http://circularscience.com/>

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Re: Hands-on delta-sigma A/D converter design examples? [message Sun, 14 November #506486 [is a reply to message #506479](#) ] 2010 12:08

[bruno putzeys](#)

**Messages:** 1061

Platinum Member

**Registered:** November 2006

**Location:** Rotselaar (BE)

I presume the OP is referring to mine: [http://www.grimmaudio.com/whitepapers/discrete\\_ad\\_converter.pdf](http://www.grimmaudio.com/whitepapers/discrete_ad_converter.pdf)

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*Warp Drive. Tractor Beam. Room Correction. Whatever.*

Affiliations: [Hypex](#), [Grimm Audio](#).

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Re: Hands-on delta-sigma A/D converter design examples? [message Sun, 14 November  
#506492 [is a reply to message #506486](#) ] 2010 12:51

[John Roberts {JR}](#)

**Messages:** 251

Active Member

**Registered:** April 2004

**Location:** MS

my bad.. that's what I get for not reading the AES journal for the last decade or two...

As usual good work..

JR

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Resotune at <http://circularscience.com/>

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Re: Hands-on delta-sigma A/D converter design examples? [message Wed, 17 November  
#506816 [is a reply to message #506492](#) ] 2010 13:24

[gentlevoice](#)

**Messages:** 7

Member

**Registered:** April 2008

**Location:** Denmark

Hi Bruno & John,

& thanks for replying. I'm just considering what/how to do so in the first round this short note. But thanks Bruno for the insight on the LT1016.

Will be back later..

Kind regards,

Jesper