A Study of a Complex Multi-Band Pass ΔΣ D/A Modulator for I,Q signal generation

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Outline

• Background & motivation
• Approach
• Complex bandpass $\Delta \Sigma$ modulator
• Complex multi-bandpass $\Delta \Sigma$ modulator
• Simulation result
• Conclusion
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- Conclusion & Future work
Background & Motivation

Communication devices
- cellular, wireless LAN, blue-tooth, low IF transmitter/receiver (use I,Q signal)

I,Q signal generator is desired
- communication IC testing (receiver)

High quality + low cost
I,Q Signal Generator
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Approach: I,Q Signal Generation Architecture

① DSP + Nyquist
- 2 Nyquist DACs
- 2 analog filters

② DSP + Real $\Delta\Sigma$
- 2 real BP $\Delta\Sigma$ DACs
- 2 analog filters

③ DSP + Complex $\Delta\Sigma$
- 1 complex BP $\Delta\Sigma$ DACs
- 1 analog complex filter

Digital rich
Why Delta-Sigma (ΔΣ) Modulator?

• **Only simple analog circuit**
• **Easy to design in digital**
  – High speed
  – Low power consumption
  – Low cost
• **Easy to configure**
  – programmable
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What is complex number?

Real number
- \( I_{in}(n), Q_{in}(n) \rightarrow I_{out}(n), Q_{out}(n) \)

Complex number
- \( I_{in}(n) + jQ_{in}(n) \rightarrow I_{out}(n) + jQ_{out}(n) \)

I - In phase (real), Q - In Quadrature (imaginary)
Filtering

more filtering stage ↔ less filtering stage
Real & Complex

Power

In band signal

Real

Cost

Digital input

DAC

Analog

Real band pass $\Delta \Sigma$

Power consumption

DAC

Analog band pass filter

Digital input

DAC

Analog band pass filter

Complex

Digital input

Analog complex band pass filter

Analog output

Analog output

Quantization noise

$-\frac{f_s}{2}$

$\frac{f_s}{2}$

$f$

bandwidth
Complex Band pass Filter

Transfer function

\[ H(z) = \frac{1}{z - (\beta + j\alpha)} \]

Frequency response

\[ |H(z)| \]

\[ F_s/4 \]
**Frequency Response**

**Case: negative**
\[
\begin{align*}
I_{in}(t) &= \cos(2\pi f_o t) \\
Q_{in}(t) &= -\sin(2\pi f_o t)
\end{align*}
\rightarrow e^{-j2\pi f_o t}
\]

**Case: positive**
\[
\begin{align*}
I_{in}(t) &= \cos(2\pi f_o t) \\
Q_{in}(t) &= \sin(2\pi f_o t)
\end{align*}
\rightarrow e^{j2\pi f_o t}
\]
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1st order Complex Band Pass
ΔΣ DA Modulator

\[ Y(z) = \frac{H(z)}{1 + H(z)} X(z) + \frac{1}{1 + H(z)} E(z) \]

\[ H(z) \rightarrow \infty, \text{STF} = 1 \quad H(z) \rightarrow \infty, \text{NTF} = 0 \]

① Oversampling
② Noise-shaping
1st order Complex Bandpass $\Delta \Sigma$
Output Spectrum

In band signal

Output

Level, dB

Fin/Fs

Positive

In band signal
2\textsuperscript{nd} order Complex Band Pass
\(\Delta \Sigma\) DA Modulator

No I,Q mismatch in modulation
2nd order Complex Bandpass $\Delta \Sigma$ Output Spectrum
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Complex Multi-Band pass Filter

Transfer function

\[ H(z) = \frac{1}{z^n - (\beta + j\alpha)} \]

Frequency response

n = 2

n = 4
Frequency Response

Case: n=2

\[
\begin{align*}
I_{in}(t) &= \cos(2\pi f_o t) + \cos(2\pi f_1 t) \\
Q_{in}(t) &= \sin(2\pi f_o t) + \sin(2\pi f_1 t)
\end{align*}
\]

\[A_0 e^{j2\pi f_o t} + A_1 e^{j2\pi f_1 t}\]

n-stages

\[
\begin{align*}
I_{in}(t) &= \cos(2\pi f_o t) + \cos(2\pi f_1 t) + \cos(2\pi f_2 t) + \ldots + \cos(2\pi f_n t) \\
Q_{in}(t) &= \sin(2\pi f_o t) + \sin(2\pi f_1 t) + \sin(2\pi f_2 t) + \ldots + \sin(2\pi f_n t)
\end{align*}
\]

\[A_0 e^{j2\pi f_o t} + A_1 e^{j2\pi f_1 t} + A_2 e^{j2\pi f_2 t} + \ldots + A_n e^{j2\pi f_n t}\]
2nd order Complex Multi-Band Pass
ΔΣ DA Modulator

DIGITAL INPUT

ANALOG OUTPUT

I_{in} → I_{out}

Q_{in} → Q_{out}

ΔΣ DA Modulator diagram with symbols and components labeled.
Complex Multi-Bandpass(1)

In band signal

Output

Level, dB

Fin/Fs

N=2

N=4

In band signal

Output

Level, dB

Fin/Fs
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Positive & Negative

Graph showing the comparison of Positive and Negative IF frequencies.
Real versus Complex

In band signal

Real BP

Complex BP

Level, dB

0 0.1 0.2 0.3 0.4 0.5

Fin/Fs

BW
Real versus Complex(2)

In band signal

SNR Decrement

>10 dB

Complex BP  
Real BP

OSR ($2^n$)

SNR Level, dB

Level, dB

Fin/Fs

-140  -120  -100  -80  -60  -40  -20  0  20

0  0.1  0.2  0.3  0.4  0.5
Complex Multi-Bandpass (2)

- **n = 1**
- **n = 2**
- **n = 4**

**SNR Decrement**

- Greater than 10 dB

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**SNR level (dB)** vs **OSR (2n)**

- **n = 1**
- **n = 2**
- **n = 4**

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Conclusion

• **Real & complex $\Delta \Sigma$ modulator**
  - Digital rich
  - **SNR $\rightarrow$ Complex BP $\Delta \Sigma >$ Real BP $\Delta \Sigma$**

  Suitable for a high quality, low cost for I,Q signals generation

• **Complex multi-bandpass $\Delta \Sigma$ modulator**
  - lower SNR compare to single tone

  Suitable for a high quality, low cost multi-tone I,Q signals generation
Thank you very much