VOL. 11, NO. 14, JULY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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THE STUDY OF I-Q SIGNAL GENERATION USING COMPLEX FILTER BASED ΔΣ D/A MODULATOR FOR COMMUNICATION APPLICATION

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ABSTRACT

This paper describes the study of application of a complex bandpass ΔΣD/A modulator as Quadrature (I-Q) signal generation in communication system for communication Integrated Circuit (IC) testing as well as transmitter. The study shows that the complex bandpassΔΣD/A modulator is superior compared to two real-bandpassΔΣD/A modulators regarding to noise-shaping characteristics. Hence, the trade-off between bandwidth and sampling speed is better for the complex bandpassΔΣD/A modulator. This study also presents the theoretical analysis and simulation results of its extension and complex multi-bandpass modulator characteristics. From the result,

Keywords: complex filter, complex bandpass, multi-band, D/A modulator.

INTRODUCTION

Demands for low cost, low power and high performance of a digital-to-analog (D/A) (Figure-1) converter are significantly increased especially in communication applications. Since communication devices become inexpensive and more sophisticated, the D/A converter circuits in their transmitter parts (which often generate I-Q signals) become more complicated and challenging. Nevertheless, the Very Large Scale Integration (VLSI) fabrication cost reduces with the advancement of VLSI process technology. The successful market of the portable devices is also a factor that contributes o the high demands of low cost and high performance of D/A converter. Most of these devices also require for a low power D/A converter to allow them operate at operating voltage which mostly uses battery.

On the other hand, the testing cost of a IC device increases due to the circuit complexity and high specification requirements. The testing of the communication ICs requires high quality I-Q signal at low cost, and in many cases, D/A converters used to produce I-Q signal generation (Vasan *et al.*, 2012), (Abe *et al.*, 2014),(Byoungho and Abraham, 2014), (Khafaji *et al.*, 2014).

This paper discusses applicability of a complex bandpass ΔΣD/A modulator to generate I-Q signals rich configuration.

D/A CONVERTER FOR I-Q SIGNAL GENERATION

This section discusses advantages and drawbacks of the existing architectures for I-Q signal generation. The architectures can be classified as follow:

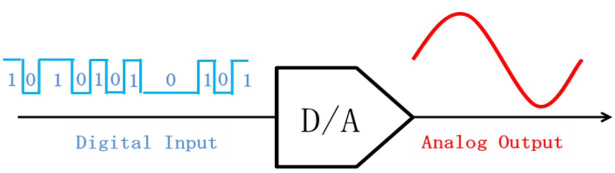


Figure-1. D/A converter with its input and output signals.

1) Analog method.

2) Digital method (DSP + D/A converters, or Direct Digital Synthesizer).

2-1) DSP + two Nyquist-rate D/A converters + two analog filters.

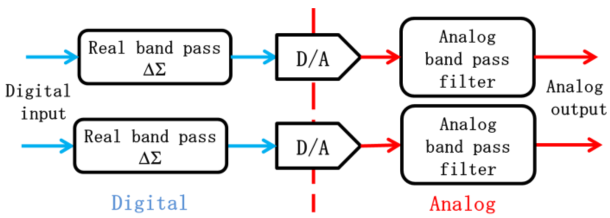
2-2) DSP + two real-bandpassΔΣD/A converters + two analog filters.

2-3) DSP + one complex–bandpassΔΣD/A converter + one analog complex filter.

As the VLSI technology progresses, digital method becomes much easier to design. The method 2-1) requires relatively large Nyquist-rate D/A converters and analog filters. The method 2-2) uses two digital ΔΣmodulators (whose circuits are negligible in fine Complementary Metal Oxide Semiconductor Large Scale Integration (CMOS LSI)) and two 1-bit D/A converters (which are also negligible), and also requirements for two analog filters can be relaxed due to the oversampling. The same arguments hold for the method 2-3) as those of the method 2-2).

Figure-2 shows block diagrams for the methods 2-2) and 2-3). Up-conversion mixers with local oscillators may follow the analog filters in the digital methods (Otsuki *et al.*, 2005).

COMPLEX BANDPASS ΔΣD/A MODULATOR FOR I-Q SIGNAL GENERATION



(a)

VOL. 11, NO. 14, JULY 2016 ISSN 1819-6608
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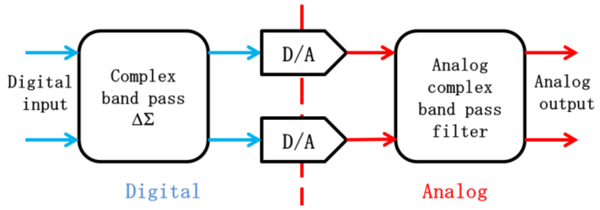


(b)

Figure-2. I-Q signal generation with ΔΣD/A modulation.(a) Two real-bandpass modulators (method (2-2)) and (b) One complex bandpass modulator (method (2-3)).

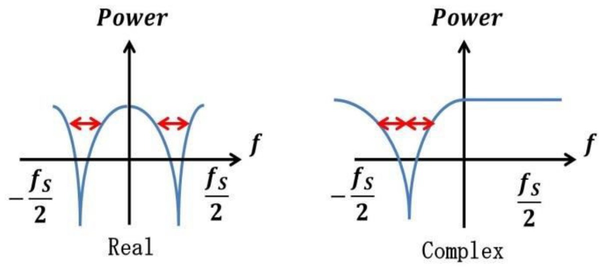


Figure-3. Noise-shaping characteristics. (Left) Real bandpass modulator. (Right) Complex bandpass modulator.

Now let us compare the methods 2-2) and 2-3). Suppose that the centre of the I-Q signal band is $-f_s/4$. Then asFigure-3 shows, the noise-shaping characteristics for the complex modulator around –fs/4 is better than that of the real bandpass modulators (in other words, the quantization noise in the signal band is lower in complex modulator case).

The complexity of two real analog filters and one analog complex filter would be comparable. Hence, the method 2-3) (which uses complex signal processing) would be better than the method 2-2).

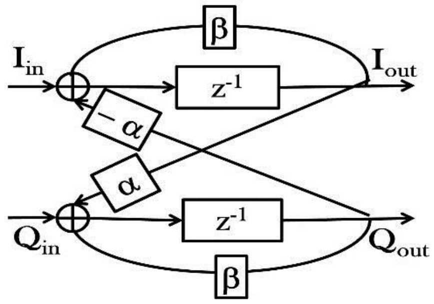
Remark: One might argue that better noise-shaping characteristics can obtain higher-order real bandpass modulators and digital modulators are free in fine CMOS LSI. However, higher-order modulators require higher-order analog filters following the modulators, and hence comparison of complex and real bandpass modulators with the same order would be fair.

COMPLEX BANDPASS ΔΣD/A MODULATOR

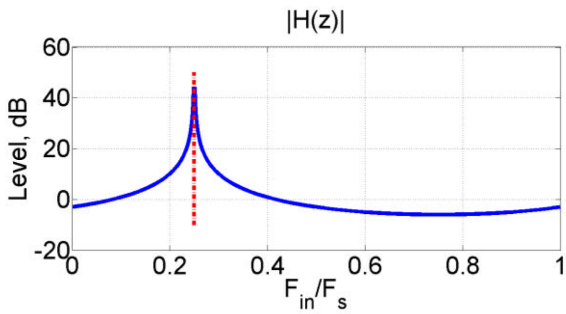
This section describes the complex bandpassΔΣD/Amodulator in details. Figure-2 and Figure-3 show the illustration of advantages of a complex bandpass ΔΣD/Amodulator compared to two real bandpass ΔΣD/A modulators. By using this type of modulator, larger bandwidth (or better Signal-to-Noise Ratio (SNR)) can be obtained due to its asymmetric behaviour with respect to $\omega_s = 0$. In contrast, the real bandpass modulator has a symmetric behaviour with respect to ω_s =0with 2 poles at two different points and it provides only a half bandwidth for each pole (Otsuki *et al.*, 2005), (Shreier and Temes, 2005), (San *et al.*, 2007), (Martins, 2004), (Kobayashi *et al.*, 2002).

Complex bandpass filter

Figure-4(a) shows the structure of a basic complex filter.



(a)



(b)

Figure-4. (a)Complex filter and (b) its gain characteristics.

From Figure-4(a), the gain of the system can be determined by obtaining their transfer function (Figure-4(b))? First, the equations derived from inputs to outputs as follows:

$$I_{out}(z) = I_{in}z^{-1} - \alpha Q_{out}z^{-1} + \beta I_{out}z^{-1} \quad (1)$$

$$Q_{out}(z) = Q_{in}z^{-1} + \alpha I_{out}z^{-1} + \beta Q_{out}z^{-1} \quad (2)$$

Next, complex input $V_{in}(n)$ and complex output $V_{out}(n)$ as follows:

$$V_{in}(z) = I_{in}(z) + jQ_{in}(z) \quad (3)$$

$$V_{out}(z) = I_{out}(z) + jQ_{out}(z) \quad (4)$$

Then, its transfer function, H(z) is defined as follows:

$$H(z) = \frac{V_{out}(z)}{V_{in}(z)} \quad (5)$$

Finally, the transfer function obtains as:

$$H(z) = \frac{1}{z - (\beta + j\alpha)} \quad (6)$$

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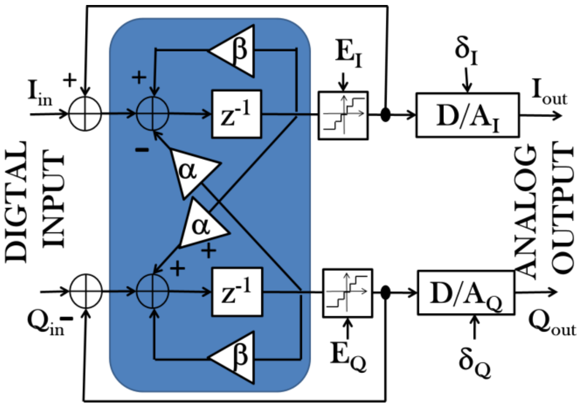
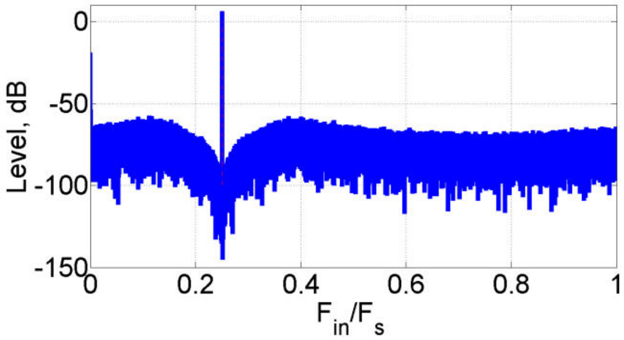
Complex bandpassΔΣD/A modulator

Figure-5(a) and Figure-6(a) show first-order and second-order complex bandpass ΔΣD/A modulators with the centre frequency $-f_s/4$ of the signal band. Figure-5(b) and Figure-6(b) show their output spectrum for the complex sinusoidal signal input around -fs/4, and it is shown that the quantization noise is shaped at -fs/4. Here, value of α=1, β=0 is used.

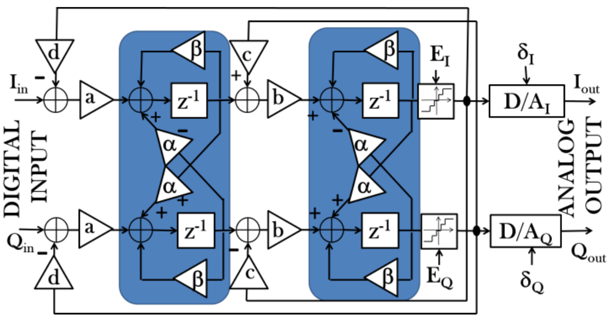


Block diagram.

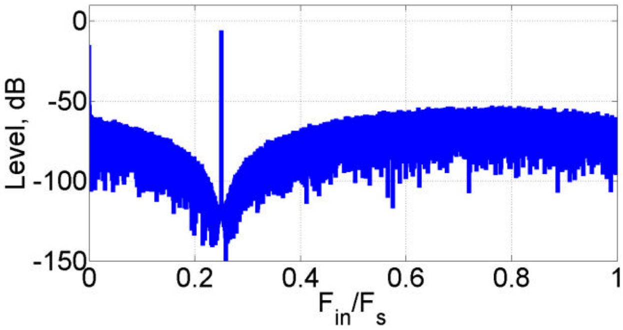


(b) Output power spectrum.

Figure-5. First-order complex bandpassΔΣD/Amodulator.



(a) Block diagram.



(b) Output power spectrum.

Figure-6. Second-order complex bandpassΔΣ D/A modulator.

COMPLEX MULTI-BANDPASS ΔΣD/A MODULATOR

This section describes complex multi-bandpassΔΣD/Amodulators for multi-tone I-Q signal generation (Motozawa *et al.*, 2007).

Complex multi-bandpass filter

Figure-7 shows a first-order complex multi-bandpass filter, and Figure-8 shows its gain characteristics for (a) n=2 and (b) n=4.

Its transfer function given as follows:

$$H(z) = \frac{1}{z^n - (\beta + j\alpha)} \quad (7)$$

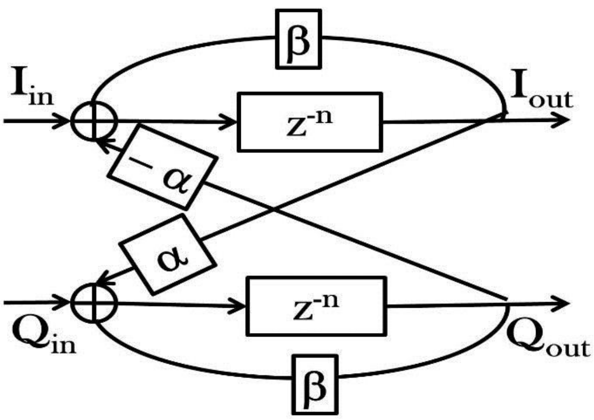


Figure-7. Complex multi-bandpass filter.

VOL. 11, NO. 14, JULY 2016 ISSN 1819-6608
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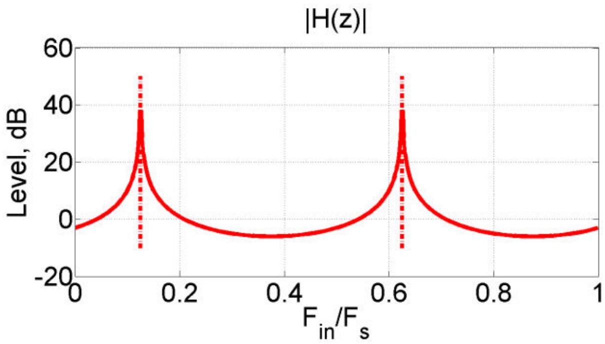
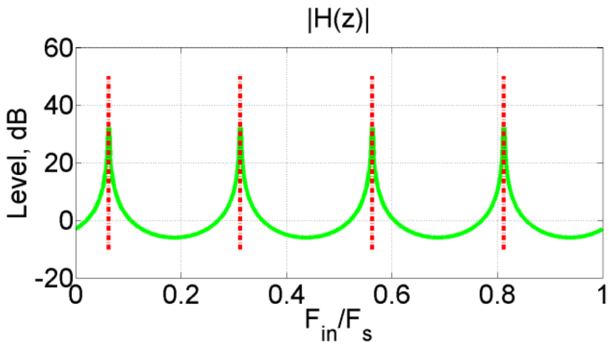


n=2. (α=1, β=0)



(b) n=4. (α=1, β=0)

Figure-8. Gain characteristics of multi-band complex filters.

Complex multi-bandpassΔΣD/A modulator

Figure-9 and Figure-10 show first-order and second-order complex multi-bandpassΔΣD/A modulators, and Figure-11shows the simulated output power spectrum for the second-order with (a) n = 2 and (b) n = 4. Figure-12 shows SNR versus OSR (oversampling ratio).

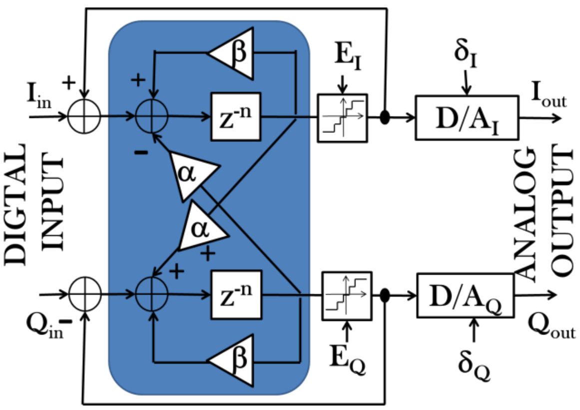


Figure-9. First-order complex multi-bandpassΔΣD/A modulator.

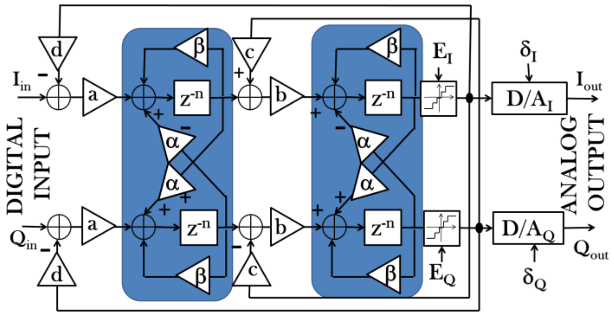
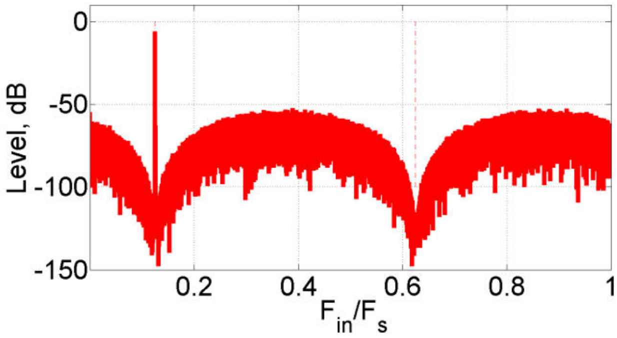
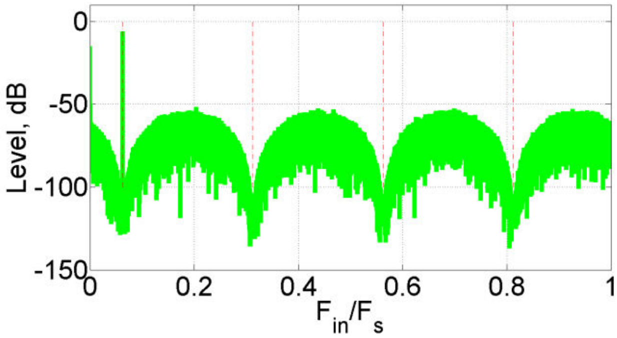


Figure-10. Second-order complex multi-bandpass ΔΣD/A modulator.



n=2.



n=4.

Figure-11. Second-order complex multi-bandpassΔΣD/A modulator output spectrum.

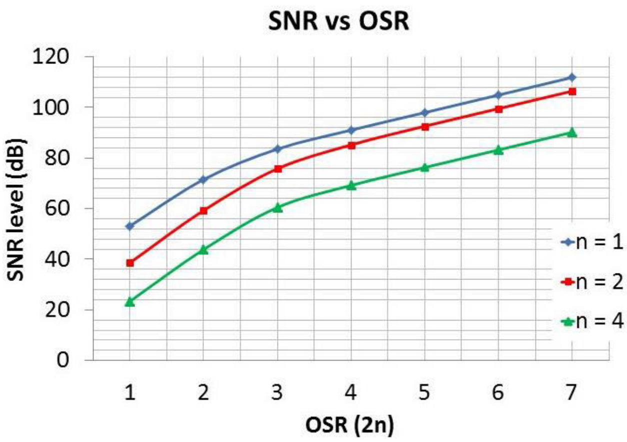


Figure-12. Simulated SNR versus OSR for second-order complex multi-bandpassΔΣD/A modulators.

SIMULATION RESULT

The performance of complex compared to real bandpass modulator is verified using MATLAB simulator. For comparison study, a second-order complex modulator in Figure-6, and a second-order real bandpass modulator in Figure-13 is simulated. The simulation results show their noise-shaping behaviours in Figure-14(a) and Figure-14(b) for both real and complex bandpass respectively, and their OSR versus SNR performance as shown in Figure-15. As a result, the second-order complex modulator has better SNR by 10dB compared to the second-order real bandpass modulator.

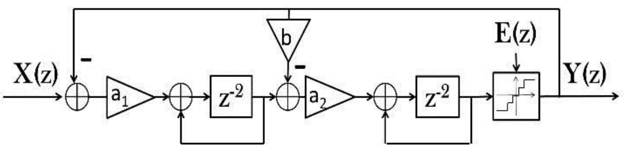


Figure-13. A second-order real bandpassΔΣD/A modulator used for simulation.

By set the value of a_1, a_2 and b as follow:

$$a_1 = 1, \quad a_2 = 1, \quad b = 2$$

The Signal Transfer Function (STF), STF(z) is defined as:

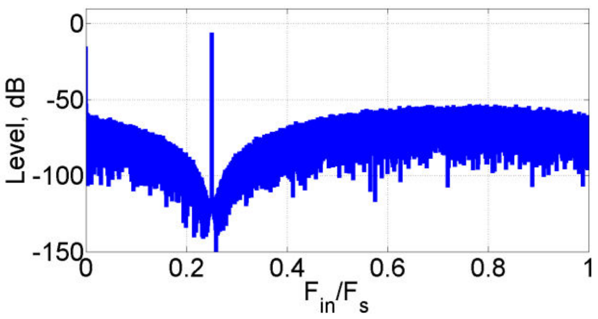
$$STF(z) = \frac{a_1 a_2 z^{-2}}{D(z)} \tag{8}$$

Then, the Noise Transfer Function (NTF), NTF(z) is defined as:

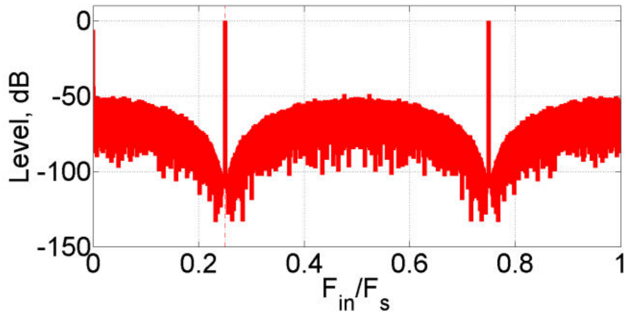
$$NTF(z) = \frac{(1-z^{-1})^2}{D(z)} \tag{9}$$

Finally, the denominator, D(z) can be expressed as:

$$D(z) = (1 - z^{-1})^2 + a_1 b z^{-1}(1 - z^{-1}) + a_1 a_2 z^{-2} \tag{10}$$



(a) The second-order complex bandpass modulator.



(b) The second-order real bandpass modulator.

Figure-14. Output spectrum comparison.

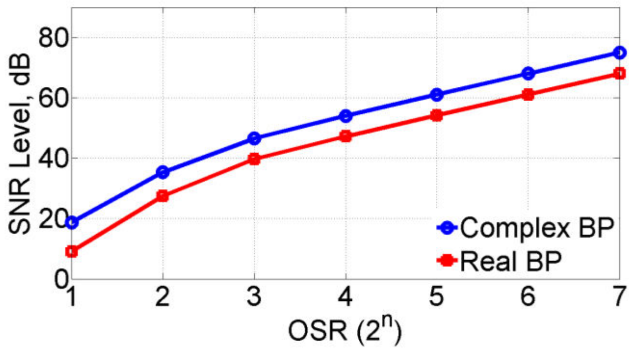


Figure-15. SNR versus OSR comparison between second-order complex and real bandpassΔΣD/A modulators.

CONCLUSIONS

From this study, it is found that:

- A first-order complex bandpassΔΣD/A modulator has one pole between $-f_s/2$ to $f_s/2$.
- A first-order real bandpassΔΣD/A modulator has two poles between $-f_s/2$ to $f_s/2$.
- A first-order complex multi- bandpass ΔΣD/Amodulator has $n$poles between $-f_s/2$ to $f_s/2$.

From the simulation results, it shows that a complex bandpassΔΣD/A modulators has better performance in terms of in-band noise and wide bandwidth compared to real bandpass ones. Thus, it proves that a complex bandpassΔΣD/A modulators would be a more suitable architecture for I-Q signal generation, while multi-bandpass is suitable for multi-tone I-Q signal generation.

Then for a given OSR, complex bandpass has the best SNR, followed by the real bandpass and lastly, n-bandpass one (n>2). Clarification of these relationships with analytical equations would be an interesting future work.

REFERENCES

Abe, F.; Kobayashi, Y.; Sawada, K.; Kato, K.; Kobayashi, O.; Kobayashi, H. 2014. Low-Distortion Signal Generation for ADC Testing, Test Conference (ITC), 2014 IEEE Int., pp. 1-10.

Byoungho Kim; Abraham, J.A. 2014. Dynamic Performance Characterization of EmbeddedSingle-Ended Mixed-Signal Circuits, Circuits and Syst. II: Exp. Briefs, IEEE Trans. on, vol. 61(5), pp. 329-333.

Khafaji, M.; Carta, C.; Tittelbach-Helmrich, K.; Micusik, D.; Fischer, G.; Scheytt, J.C.; Ellinger, F. 2014. A 32 GSps multiplexer with 1 kbit memoryfor arbitrary signal generation for testing digital-to-analogue converters, Circuits, Devices and Systems, IET, vol. 8(6), pp.459-468.

Kobayashi, H., Kang, J., Kitahara, T., Takigami, S., Sakamura, H. 2002. Explicit Transfer Function of RC Polyphase Filter for Wireless Transceiver Analog Front-End. ASICs, IEEE Asia-Pacific Conf. on, pp.137-140.

Martin,K. W. 200. Complex signal processing is not complex. IEEE Trans. On Circuits and Systems I, vol. 51(9), pp. 1823-1836.

Motozawa, A., Hagiwara, H., Yamada, Y., Kobayashi, H., Komuro,T., San, H. 2007. Multi-Bandpass ΔΣModulation Techniques and Their Applications. IEICE Trans. on Electronics, J90-C(2), pp. 143-158.

Otsuki, J., San, H., Kobayashi, H., Komuro, T., Yamada, Y. and Liu, A. 2005. Reducing Spurious Output of Balanced Modulators by Dynamic Matching of I-Q Quadrature Paths. IEICE Trans. On Electronics, E88-C (6), pp. 1290-1294.

Shreier, R., Temes, G. C. 2005. Understanding Delta-Sigma Data Converters, IEEE Press.

San, H., Jingu, Y., Wada, Y., Hagiwara, H., Hayakawa, A., Kobayashi, H., Matasuura, T., Yahagi, K., Kudoh, J., Nakane, H., Hotta, M., Tsukada, T., Mashiko, K. and Wada, A. 2007. A Second-Order Multi-bit Complex Bandpass ΔΣA/D Modulator with I-QDynamic Matching and DWA Algorithm. IEICE Trans. On Electronics, E90-C (6), pp. 1181-1188.

Vasan, B.K.; Sudani, S.K.; Chen, D.J.; Geiger, R.L. 2012. Sinusoidal Signal Generation for Production Testing and BIST Applications, Circuits and Syst. (ISCAS), 2012 IEEE Int. Symp. on, pp. 2601-2604.