MULTIBAND MULTISTANDARD DELTA-SIGMA-BASED RF TRANSMITTERS

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ABSTRACT

This paper proposes a new approach for implementing RF Delta-Sigma (DS)-based transmitters by considerably reducing the speed requirements of the digital processing block. The novelty relies in using a specific wave modulation in combination with a lowpass DS modulator to produce high frequency digital-like signals which can be used to drive highly-efficient switching-mode PAs. This allows obtaining reconfigurable all-digital multistandard and multiband wireless transmitters with increased flexibility, efficiency and linearity.

1. INTRODUCTION

Before today's high speed RF application, DSMs were widespread in data conversion applications because of its superior performance. For example, DSMs are able to convert an analogue signal to a two-level signal which can be amplified with switched mode power amplifier. Such a technique in RF power amplification has two advantages. Firstly, a two-level signal quality can not be affected by nonlinearity of amplifier and secondly the switched power amplifiers are highly power efficient.

The band pass DSM has been highly interested to modulate the RF analogue signal into two-level signal. However, oversampling and complex circuit behavior has actually made them useless for today's high frequency applications in wireless communications and signal processing. In order to centrate an analogue signal at the centre frequency f_c, the sampling frequency of signal, fs, must be 4fc. For instance for Wimax signal with frequency 2 GHz, the sampling frequency has to be 8 GHz and the delta band pass DSM should process at 8 GHz. But with today's digital technology, such a digital implementation is not feasible.

However, some researchers introduced the delta-Sigma modulators for RF applications [1], [2]. By modifying the transmitter architecture, some other researchers strived to alleviate the necessity for high frequency computation in delta-sigma modulator [3], but these works usually suffer from lower Signal to Noise Ration (SNR).

This paper presents a high frequency all-digital delta sigma modulator which can be used in RF transmitters while reduces the high frequency digital processing. Next section reviews a delta sigma modulator. Section 3 explains the proposed RF DS modulator. Section 4 reports the simulation and experimental results. The paper is concluded in Section 5.

2. DELTA-SIGMA MODULATION PRINCIPLE

The $\Delta\Sigma$ modulation technique consists in transforming amplitude and phase-modulated signals in digital two-level streams by quantifying the modulated signal using a two-level quantifier. This operation introduces an important level of quantization noise in the modulated signal. In order to overcome this problem high order interpolation is applied to the signal before quantization to push any quantization noise outside the useful band of the signal keeping only the useful information within the signal bandwidth. Filtering after power amplification of such signals results in a linearly amplified replica of the original input. Due to the properties of pulse-shaped modulated RF signal, highly efficient nonlinear amplifiers can be used throughout the transmitter chain to maintain very high efficiency even at microwave frequencies [4].

After converting the digital signal to analogue format through a 1-bit DAC, highly-efficient nonlinear switching-mode PAs can be used to amplify the analogue two-level signal without introducing any signal distortion. Prior transmission, the analogue amplitude modulated RF signal is recovered through simple passive bandpass filtering.

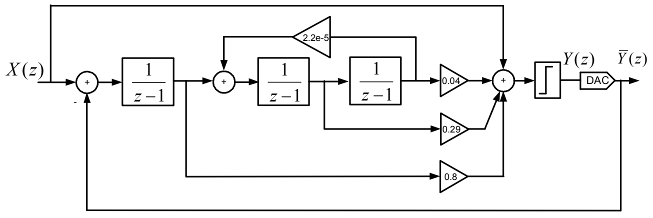

Fig. 1 Z-domain representation of a third-order low-pass DS modulator

Fig. 1 shows a block diagram of the used digital third-order LPΔΣ modulator. The noise transfer function (NTF) implements a bandstop noise shaping function guarantying a high signal-to-noise ratio (SNR) for signals whose energy is restricted to frequencies near DC. However, the width of the noise-free band is very small compared to the signal bandwidth due to the limited order of the NTF. In literatures, an order in the range of 2 to 4 is generally utilized for implementing the NTF of the ΔΣ-modulator as it gives a good trade-off between implementation complexity and computation requirements. Oversampling the signal more than the Nyquist rate is another technique to confine the energy of the signal within a small band compared to the signal double sided bandwidth BW while maintaining high signal quality. The oversampling ratio (OSR)

$$OSR = \frac{f_S}{BW}$$

defines how many times faster the signal is sampled compared to a Nyquist-rate converter.

3. PROPOSED DELTA SIGMA TRANSMITTER

Bandpass DS is an architecture which is utilized to make a DS output at a bandpass frequency. However, in the band pass sigma delta, input signal is sampled with $f_s = 4f_c$ and signal is concentrated in the f_c. In this way, the DS processor has to work at four times of desired frequency center. But with today's digital technology, it is not easy to implement an RF bandpass DS modulator.

The proposed topology is shown in Fig. 2. A lowpass DS modulator converts the digital or analogue baseband input signal into a bi-level pulse stream. The digital-like signal is then translated to higher frequencies by shaping it with an arbitrary waveform. The frequency of signal shaper is N times of sampling frequency of lowpass DS modulator. Depending on the shape of this waveform, higher harmonic replicas of the input signal are generated in the signal shaping process. A suitable output replica is then filtered and fed to a power amplification stage to boost its level. Before sending the signal over the antenna, a bandpass filter is used to suppress all out-of-band distortions and to recover the analogue signal.

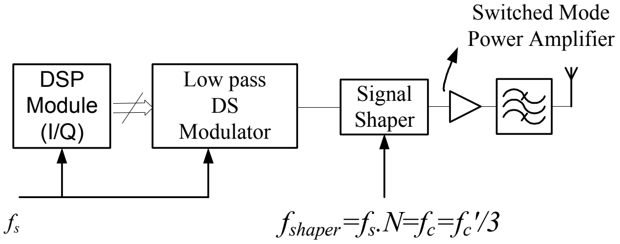

Fig. 2: Block diagram of the proposed DS-based transmitter architecture

4. SIMULATION AND EXPERIMENTAL RESULTS

The proposed approach has been implemented in Matlab for different signal such as multi-tone, OFDM, and CDMA for DS modulator order one to eight. Fig. 3 shows the simulated output spectrum using a fifth-order DS modulator modulated by a shaper, at frequencies f_c and $f'_c = 3fc$. Simulation has shown that the original signal can be reconstructed by filtering.

The principle has also been verified through implementation on a Stratix FPGA with N=8, 4 and f_s=20 MHz. A modulated signal with BW=30 kHz was passed through a fifth-order lowpass DS modulator. Fig. 4 shows the output spectrum for N=8 at $Nf_s/2$.

An OFDM signal with BW = 430 kHz was passed through the DS digital transmitter implemented on the FPGA. The clock frequency for DS modulators was f_s=50 MHz. Fig. 5 shows the output of FPGA before filtering. The minimum pulse length is 5 ns. Fig. 6 shows the time domain comparison of original signal (red) and DS signal after filtering (blue). The resulted Signal to Noise and Distortion Ratio (SNDR) is 41 dB, where is defined as:

$$SNDR = 20\log\frac{MSE(Signal)}{MSE(Signal - \mathrm{Re}\,constructed\ Signal)}$$

The frequency domain comparison is shown in Fig. 7. Fig. 8 shows the output spectrum of FPGA at $f' = 3f_c$=300 MHz, with SNR 41.9 dB.

5. CONCLUSION

This paper proposes a new multiband multistandard bandpass delta sigma modulator for RF applications. The methodology has been validated using an FPGA development board. The proposed architecture reduces the digital signal processing speed by a factor of $4N$, for the same carrier frequency, in comparison with regular band-pass DS modulators, where the clock frequency of signal shaper is *N* times of clock frequency of delta sigma processor. This topology paves the way to the penetration of DS based modulator in designing GHz range RF all-digital transmitters.

6. REFERENCES

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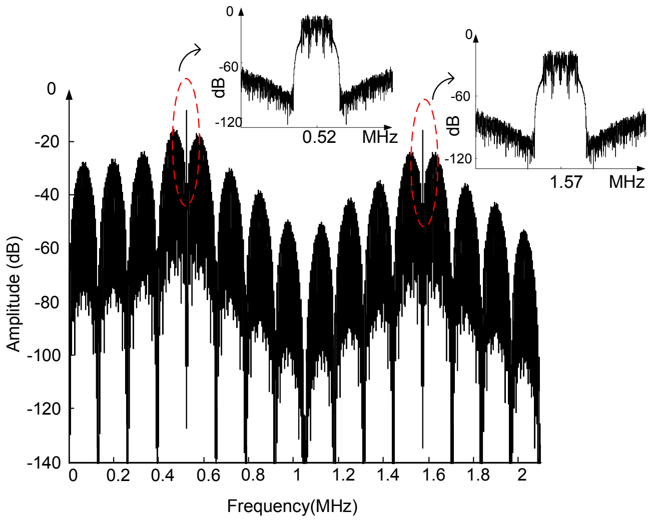

Fig. 3: Spectrum of a 1 kHz, bandwidth signal at the output of the signal shaper (f_s=0.13 kHz, N=8, f_c=0.52 MHz and f'_c=1.57 MHz)

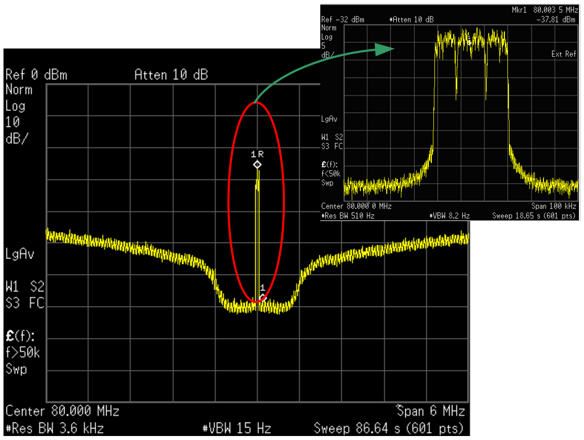

Fig. 4: Measured output of the experimental implementation on an FPGA

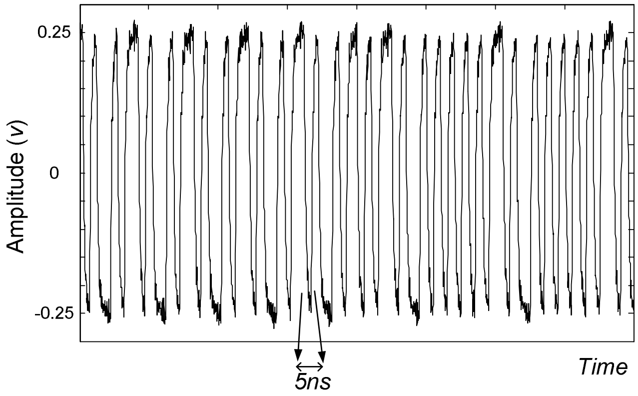

Fig. 5: Time domain output of FPGA measured with oscilloscope before filtering

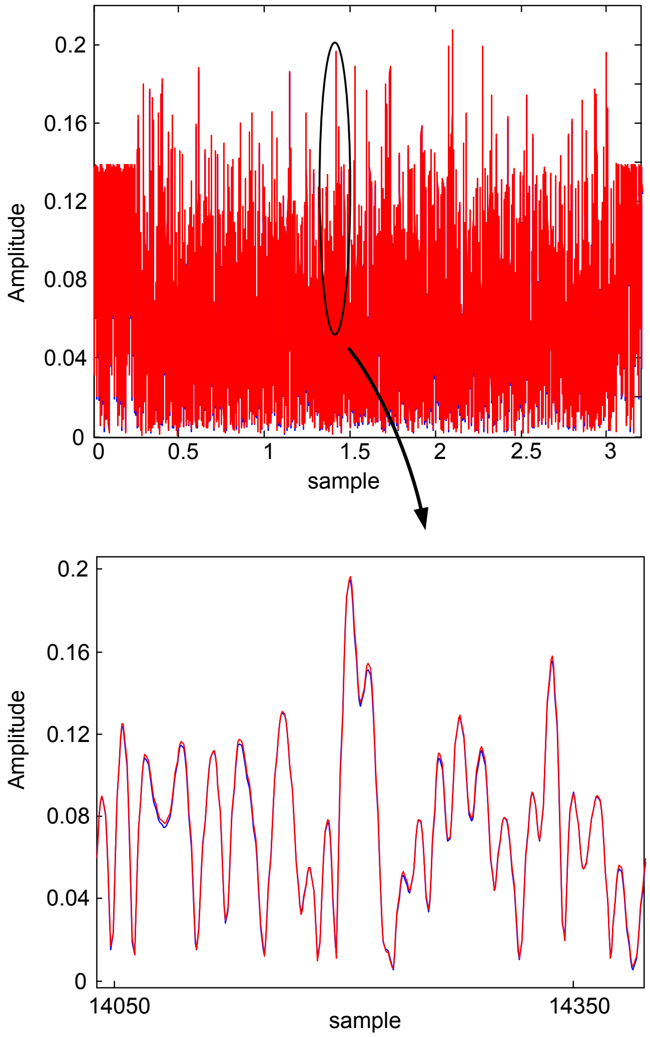

Fig. 6: Time domain comparison of original signal OFDM (red) and DS signal after filtering (blue), 430 kHz bandwidth signal at the output of the signal shaper with OSR=100, SNDR=41 dB (f_s=50 MHz, f_c=100 MHz and $3f_c$=300 MHz)

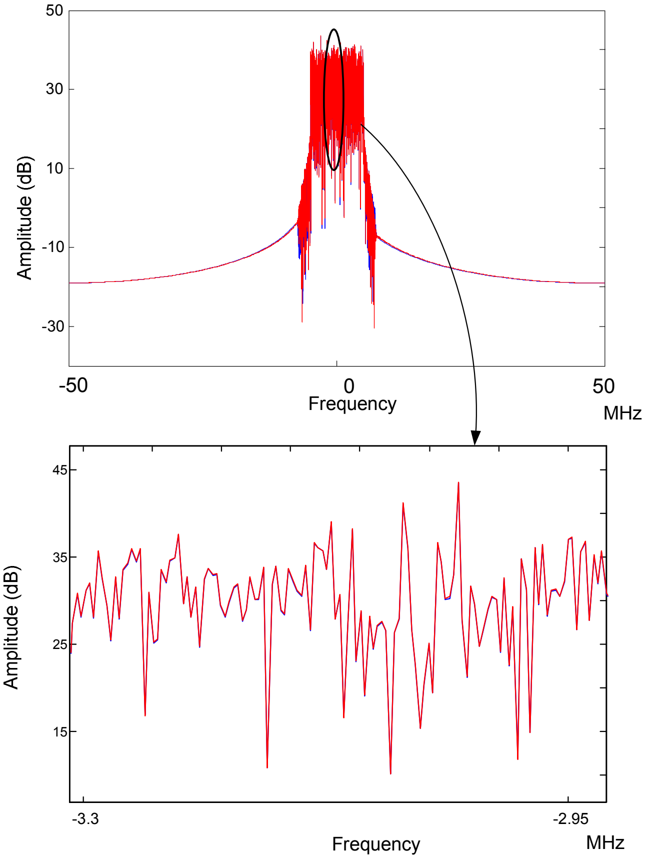

Fig.7: Frequency domain comparison of the OFDM signal

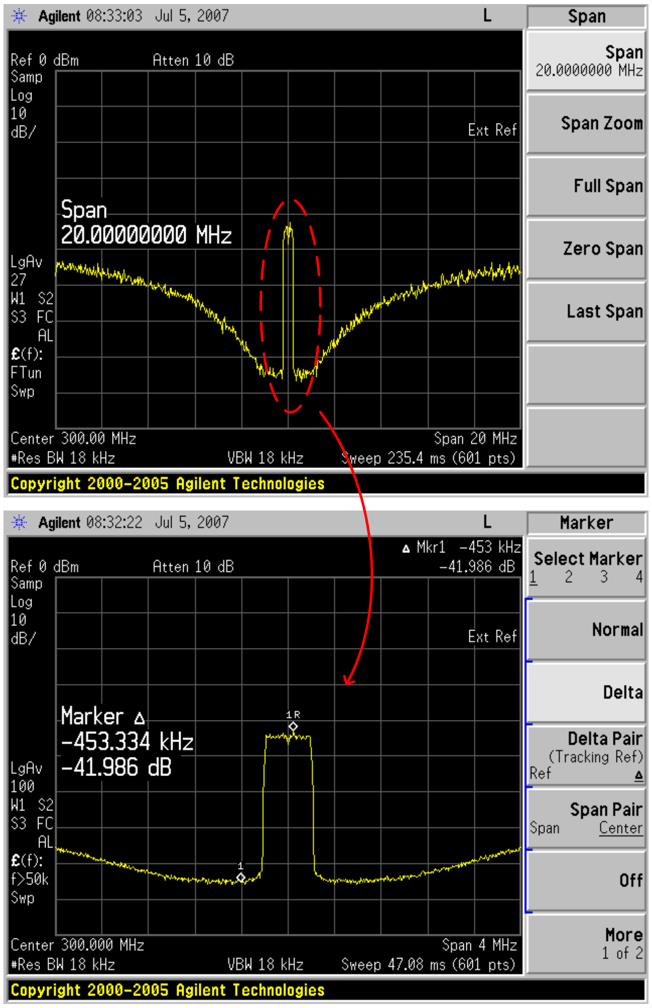

Fig. 8: The output spectrum of FPGA for OFDM signal at $f'_c = 3f_c$=300 MHz

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