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Experimental Demonstration of Ideal Noise Shaping in Resonant Tunneling Delta-Sigma Modulator for High resolution, Wide Band A/D Converters

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Among various types of analog-digital converters (ADC), the ΔΣ ADC has a significant advantage; higher resolution can be easily obtained by increasing the sampling rate. It does not require high-accuracy analog components to achieve high resolution. Recently, we proposed a simple ΔΣ ADC using a resonant tunneling logic gate MOBILE (MOnostable-BIstable transition Logic Element)[1]. The MOBILE is an ultrahigh-speed functional logic gate, which is based on the monostable-bistable transition in the series-connected RTD circuit [2]. The MOBILE switches at the rising edge of the clock and the output remains in one of the two stable states while the clock is high. This indicates that the MOBILE works as an ideal 1-bit quantizer for high-speed ADCs. Owing to this feature, the ΔΣ modulator can be designed in a extremely simple form. However, the operation frequency and the resolution of our previous proposal was still restricted by the negative feedback loop in the circuit. In this paper, we will propose a novel resonant tunneling ΔΣ ADC, and compare its performance to the previous one.

The ΔΣ ADC consists of a ΔΣ modulator and a decimation filter. The input analog signal is first converted to the pulse density modulation signal, then it is converted to the Nyquist rate high-resolution (multi-bit) digital signal by a decimation filter. The key component of this is the ΔΣ modulator, which converts the analog signal to the pulse density digital signal. Here, we employ a novel ΔΣ modulation technique suitable to MOBILEs using a voltage controlled oscillator (VCO) [3]. The configuration of the novel ΔΣ modulator is shown in Fig. 1 together with the conventional one. This implementation is based on the fact that the phase of the frequency modulation (FM) signal from VCO, θ(*t*), is the integral of the input signal *x*(*t*) as

$$\theta(t) = 2\pi \int (f_C + k\,x(\tau))\,d\tau \quad ,$$

here, f_C represents the output frequency of the VCO when input is zero, and *k* the frequency sensitivity. Therefore the integrator in the conventional configuration can be removed. Moreover, the negative feedback is inherently embedded in the VCO, because the phase returns to zero when it reaches 2π. Owing to these features the feedback loop can be also removed. Using the 1-bit quantizer and the XOR the ideal pulse density signal can be obtained. However, it requires extremely high performance quantizer, having ultra

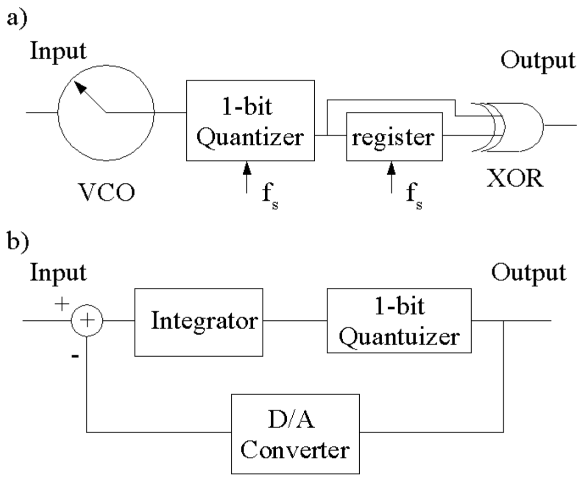

Fig. 1 Block diagram of ΔΣ modulators. a) No feedback type ΔΣ modulator using a VCO. b) Conventional ΔΣ modulator.

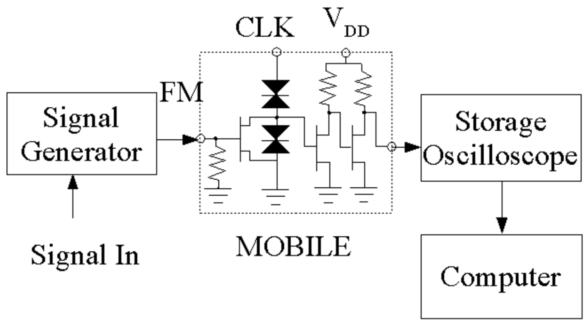

Fig. 2 Experimental setup of the demonstration of the no feedback ΔΣ modulator using a MOBILE.

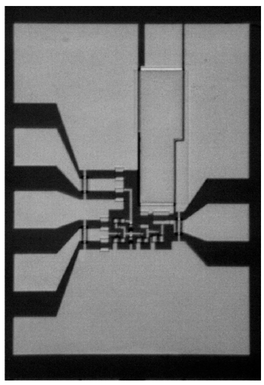

Fig. 3 MOBILE with an output buffer used in the experiment.

short aperture time and high sensitivity at high frequency, for fully developing this concept, so that this technique has been not widely used. Employing the MOBILE, this problem can be solved, and extremely high performance should be expected.

We tested this ΔΣ modulator concept using the MOBILE fabricated on an InP substrate. Figure 2 and 3 shows the experimental setup and the chip photomicrograph of the MOBILE used in the experiment. The HEMT has the gate length of 0.7 μm and a threshold voltage of about 0 V. The peak voltage, the peak current density and the peak-to-valley current ratio of the RTD are 0.35 V, 6.0x10^4 A/cm^2 and 10 at room temperature, respectively. The frequency modulation signal was synthesized by the signal generator and it was fed to the MOBILE. The output of the MOBILE was observed and stored in the storage oscilloscope, and then analyzed in a computer. Figure 4 shows an example of the output signal waveform. A relatively slow clock frequency of 4 GHz was limited by the storage oscilloscope used in the experiment. Figure 5 shows the output spectrum of the circuit. The input signal was 1 MHz, and the FM signal was 500 MHz with maximum modulation of 40 MHz. The input signal peak is clearly seen at 1 MHz. The quantization noise decreases when decreasing frequency with a gradient of 20 dB/dec. This is the result of the noise shaping effect of the ΔΣ modulator. One of the most significant features in this figure is that the noise linearly decreases more than 3 decades, and the remaining noise floor at 10 kHz is as small as -100 dB below the maximum noise amplitude. This is in contrast with the result of our previous circuit shown in Fig. 6, where the noise floor is high and the noise shaping is observed in a relatively narrow range. The ideal noise shaping feature observed in the novel circuit demonstrates the promise of the no feedback ΔΣ modulator. An extremely high clock frequency higher than 100 GHz is expected with a sophisticated circuit design. This should lead to ultrahigh performance ADC.

References

[1] Y. Yokoyama, et al., Jpn. J. Appl. Phys., **40** No. 10A, (2001) L1005-L1007.

[2] K. Maezawa, et al., IEEE Electron Device Lett. **19** (1998) 80.

[3] M. Hovin, et al., IEEE J. Solid-State Circ., 32, (1997) 13.

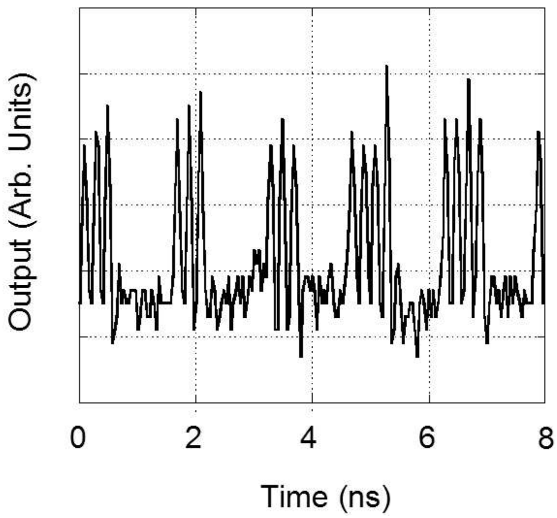

Fig. 4 Operation waveform of the MOBILE.

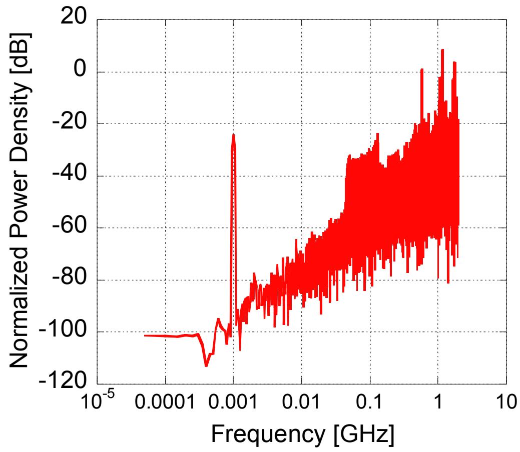

Fig. 5 Obtained output spectrum of the ΔΣ modulator using a MOBILE. The input signal was 1 MHz, and the FM signal was 500 MHz with maximum modulation of 40 MHz.

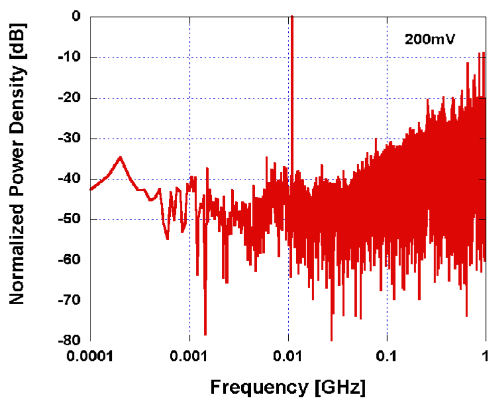

Fig. 6 Noise spectrum of the previous circuit proposed in [1]. The noise floor is much higher.