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CMOS terahertz imaging pixel with a VCO-based ADC

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Abstract

We propose a Si–CMOS terahertz image sensor to solve the paucity of low-cost terahertz detectors. The imaging pixel consists of an on-chip antenna and an amplifier acting as envelope detector; which is connected to a VCO-based ADC for on-off keying. We fabricated the pixel circuit which is microstrip-patch type by using 0.18 -μm CMOS process. Our pixel circuit converts terahertz wave into frequencies and we confirm a responsivity of 46.8 kV@0.93 THz and a part of beam form by shifted imaging.

1. Introduction

Many of the THz detector technologies require additional process steps to make them compatible with CMOS technologies [1].

We propose an economical Si-CMOS detector, which evades those extra process steps. The Si-CMOS process technology is low-cost and highly-integratable with readout electronics and on-chip signal processors. We have been working on the Si-CMOS imaging chip, and find it to have good responsivity to THz waves [2]. For system implementation, monolithic integration of the pixel circuit with a ADC is convenient. In this paper, we will mainly report the imaging pixel with the voltage-controlled oscillator (VCO)-based ADC for on/off keying modulation (OOK) fabricated with 0.18-μm CMOS process and its measurement results.

2. Circuit configuration

Pixel circuit

Fig.1 shows the imaging pixel which consists of an on-chip antenna and cascode amplifier with a subthreshold-biased operational amplifier (subVth-OP amp). The output of the pixel circuit is connected to voltage-controlled-oscillator based ADC. Fig. 2 shows operating scheme of our pixel circuits. The detection is based on nonlinearity of the nMOSFET in the cascode amplifier biased, near the threshold voltage. Drain current with non-linearity leads as an envelope detector for carrier frequencies exceeding the cutoff frequency of the MOSFET. The subVth-OPamp operates very slowly, thus it responds to only DC components of the signal and the closed-loop works as DC servo to stabilize DC level of the output voltage. In this way, the cascode amp has low-pass filtering characteristics and negative feedback loop with subVth-OP amp operates like a high-pass filter for DC-cut operation.

Configuration of ADC

Fig. 3 shows the block diagram of our ADC configuration. It consists of two ramp wave generators, OP amps, a SR-FF, and a counter with a data buffer. When the ramp signal becomes over the Vctrl, reset signal is generated for another ramp generator resetting. Complementary resetting for two generators leads clock pulse generation with 50% duty cycle. Slope of the ramp signal changes along with the pixel value. Thus, value also controls clock frequency. This scheme works as VCO. In this study, we apply VCO based ADC architecture for tera hertz wave detection. Basically, VCO based ADCs works continuously and integrates the analog value for A/D conversion. Using lock in ADC scheme with on/off keying (OOK), we can easily estimate only "THz-ON" states and convert these estimated values to digital data.

3. Experimental results

Fig.4 and 5 shows chip micrograph/layout of our circuits and the experimental setup, respectively. An injection-seeded terahertz-wave parametric generator (is-TPG) was used as a frequency-tunable terahertz-wave source [3]. By changing the noncollinear phase-matching condition in MgO:LiNbO3 crystal, the terahertz-wave frequency was continuously tuned from 0.8 to 1.1 THz with a linewidth of approximately 4 GHz.

Fig. 6 and 7 shows the measurement results of our circuit. When the terahertz wave was detected, we confirmed changes in frequency while observing LSB of the ADC (in fig. 6). Our ADC has linear monotonically increasing characteristics, thus easy compensation can be applied (in fig. 7(a)). In our circuits, the analog part which consists of the VCO, which requires consumption current. However, we can reduce the current by the bias setting of the amplifiers (in fig. 7(c)). Measured noise and frequency characteristics were matched to post layout simulation (in Fig. 7 (c) and (d)). We also confirmed a responsivity of 46.8 kV @0.93 THz and a part of beam form by shifted imaging.

Acknowledgements

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References

[1] S. Eminoglu *et al*., J. Microelectromechanical Syst., **17**, no. 1, Feb. (2008) 20–30.

[2] K. Wakita et al., *2016 21st Int. Conf. Microwave, Radar Wirel. Commun. MIKON* (2016) 4–7.

[3] S. Hayashi et al., Scientific Reports, **4**, article number 5045, (2014).

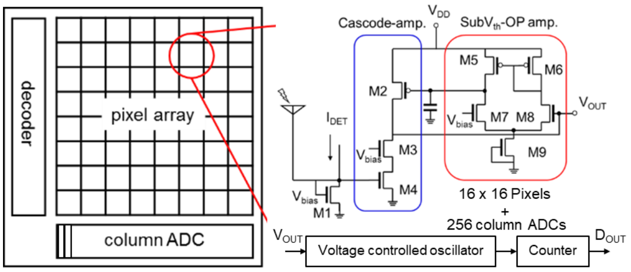

Fig. 1 Schematic of image sensor and imaging pixel. It consists of cascode amplifier with subthreshold operational amplifier which works DC servo.

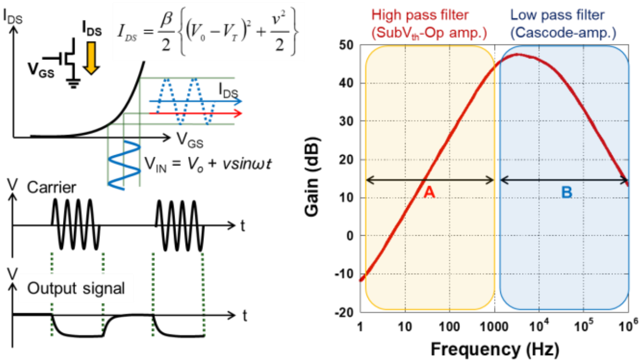

Fig. 2 Envelope detection of our pixel. (left) drain current of MOSFET over cut-off frequency. (right) bandpass characteristics of our amplifier with DC servo.

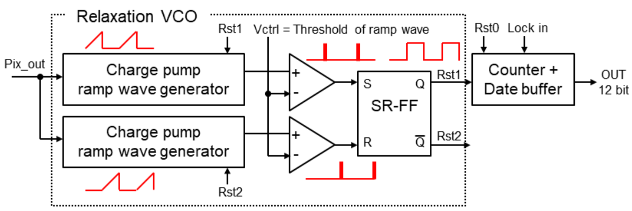

Fig. 3 Block diagram of our relaxation VCO based ADC.

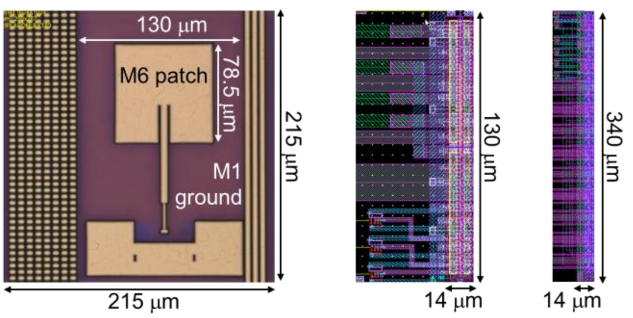

Fig. 4 Die photograph of fabricated imaging pixel. (left) a microstrip patch antenna-type, (middle) layout of VCO. (right) digital part.

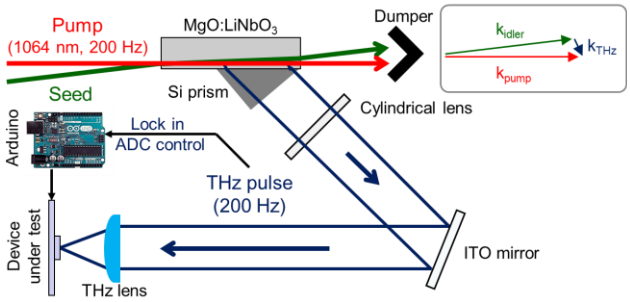

Fig. 5 Experimental set up with THz light source.

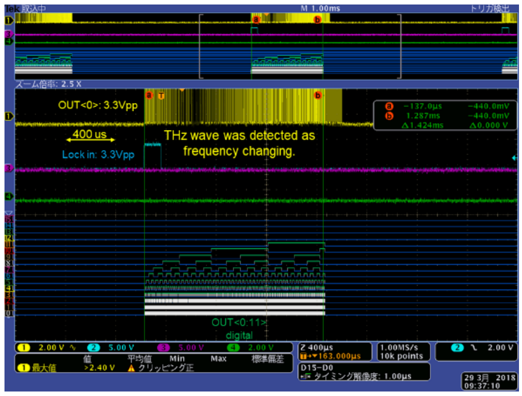

Fig. 6 Transient characteristics of ADC with pixel circuits.

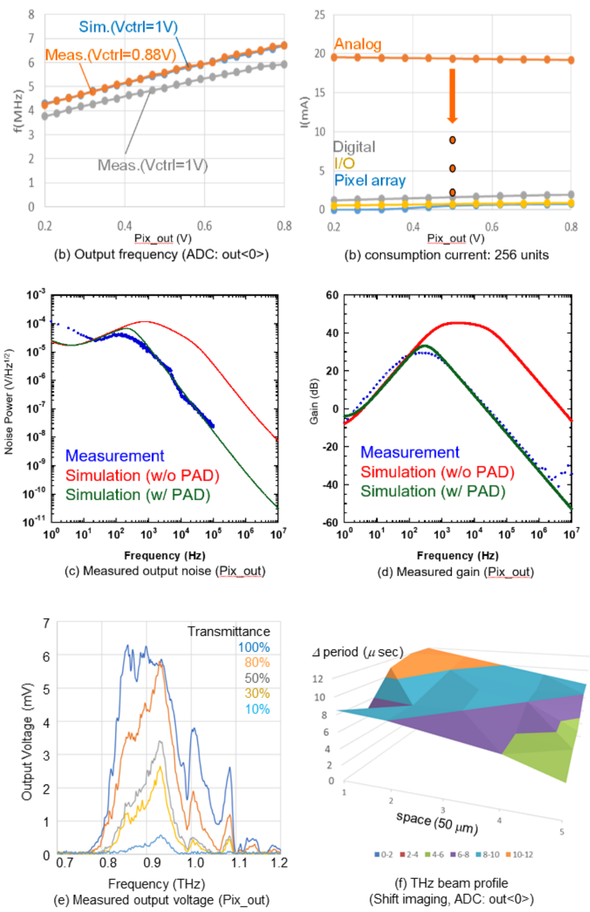

Fig. 7 Measured characteristics of Pix_out (c, d, e) and ADC_out (OUT<0> which is LSB of counter: a, b, f)