Infrared Physics & Technology 65 (2014) 9–16

Contents lists available at ScienceDirect

Infrared Physics & Technology

journal homepage: www.elsevier.com/locate/infrared

Readout circuit with dual switching mode design for infrared focal plane arrays

Tai-Ping Sun [a,b], Jia-Hao Li [a], Yi-Chuan Lu [a,*]

[a] Department of Electrical Engineering, National Chi Nan University, No. 1, University Rd, Puli, Nantou County 54561, Taiwan, ROC
[b] Department of Electronics Engineering, Nan Kai University of Technology, Nantou County, Taiwan, ROC

HIGHLIGHTS

- The amplifier of capacitive trans-impedance amplifier can share between two pixels.
- The readout circuit reduces the complexity design of circuit for dual band sensor.
- It has lower power and area which compared to traditional CTIA.

ARTICLE INFO

Article history:
Received 25 November 2013
Available online 25 March 2014

Keywords:
Readout circuit
Dual band
Trans-impedance amplifier
Direct injection
Pixel

ABSTRACT

The paper proposes a readout circuit architecture with adjustable integration time for dual-band infrared detectors. The readout circuit uses direct injection to be combined with a capacitive trans-impedance amplifier. The amplifier is sharing between two pixels to reduce the complexity of the readout circuit. The proposed device reduces power consumption and area overhead compared to traditional structures. An experimental chip was fabricated using the TSMC 0.35 μm 2P4 M 5 V process. The resulting unit pixel layout area is 40 μm × 40 μm with input photocurrent ranging from 0.11 pA to 50 nA. CTIA mode is applicable from 0.11 pA to 10 nA, while DI mode is applicable from 3.3 pA to 50 nA. The maximum operating frequency of the chip are 4 MHz. The CTIA output swing is 1.2 V, the DI output swing is 2 V. The signal to noise ratio of the readout circuit is 65 dB and power consumption is less than 9.6 mW.

1. Introduction

Dual-band infrared imaging technology has recently expanded into many areas including the military, medical imaging, scientific research, and the automotive industry [1–5]. Technological improvements are the main driving force in the steady decline in prices associated with infrared imaging. Low-cost imaging devices and optical technologies are being developed to reduce manufacturing costs and enable high-volume manufacturing. In infrared sensing systems, the front-end readout circuit serves as a bridge between analog and digital signals, required for the rendering of images. The back-end contains a proxy board including a buffer, filter, and analog to digital converter as well as a field-programmable gate array (FPGA) design board hosting the signal processor and display controller. Therefore, Readout Integrated Circuit (ROIC) plays a critical role in IR focal plane array (FPA) image system. ROIC signals are output sequentially using digital timing, which is externally fed back through the main clock circuit to complete the signal readout. This signal is transmitted to a display device showing a grayscale image.

Infrared sensors can be divided into two categories: thermal sensors and photon detectors. Thermal sensors change according to variations in temperature, which produce signals for detection. This type of sensor is inexpensive and operable at room temperature, albeit with lower sensitivity. Photon detectors absorb infrared energy, such that the electrons in the sensor leap to a higher energy level resulting in the creation of an electric current. These photo detectors provide high sensitivity and rapid response times; however, they require additional cooling or vacuum systems [6–8]. IR wavelength is proportional to light intensity and the response rate of infrared sensors varies according to wavelength. Longer wavelengths produce less energy; therefore, a small change in the signal can produce a miniscule sensing current. Different sensors respond to different IR wavelengths and must therefore deal with different energy levels. For example, devices based on QWIP and HgCdTe are able to detect long-wavelength (8–12 μm) light sources; however, the energy levels are very low. Covering a wide

* Corresponding author. Tel.: +886 492910960x4858; fax: +886 492917810.
E-mail address: chun999g@gmail.com (Y.-C. Lu).

http://dx.doi.org/10.1016/j.infrared.2014.03.003
1350-4495/

range of wavelengths requires a range of sensors, which in turn requires a readout circuitry capable of supporting a multi-wavelength IR detector system [9–15].

Conventional infrared sensors are only able to sense specific wavelengths. Dual-band detectors have high environmental tolerance, an enhanced signal, a wide dynamic tracking range, and the ability to differentiate between various wavelengths. In the early days, the development of dual-band sensors involved lying out an interlace array to generate two types of signal from light of different bands [7,8]. Thus, the readout circuit of a dual-band detector has greater practical value than a single-band readout circuit [16]. As a result, IR sensors have gradually shifted to a dual-band design [17–20].

The pixel circuit is a crucial component of an ROIC, susceptible to variations in resistance, photo-current, dark current, and capacitance. The distinctive parameters of various detectors have led to the development of a diverse range of circuits. Many previous studies have discussed readout circuit design, such as SFD, DI, BDI, CTIA, and GMI. A review of the literature indicates that the basic readout circuits found in most infrared detectors employ DI, BDI, or CTIA architectures [3–8,19–21]. The main performance standards by which pixel circuits are evaluated are power consumption, linearity, layout area, and noise. As a result, designers are tasked with developing devices with low-power consumption, low noise, and high-sensitivity within a limited area. Numerous combinations of bands could be assembled, such as the mid/long-wavelength IR (M/LWIR) and short/mid-wavelength IR (S/MWIR).

DI is often used in IR readout circuits due to its simple structure, small area overhead, and low power consumption. CTIA provides stable bias voltage, low input impedance, and low noise, making it suitable for short wavelength infrared (SWIR) sensors with small input current [8,15]. CTIA provides stability and adjustable bias voltage by controlling the positive input terminal of the amplifier. The equivalent internal resistance and capacitance of sensors influence the operational bandwidth of CTIA and the small sensing current extends integration time. Generally, when CTIA is used for small sensing signals, the problem of the integration capacitor being limited to the area, bandwidth, and power of the amplifier must be overcome.

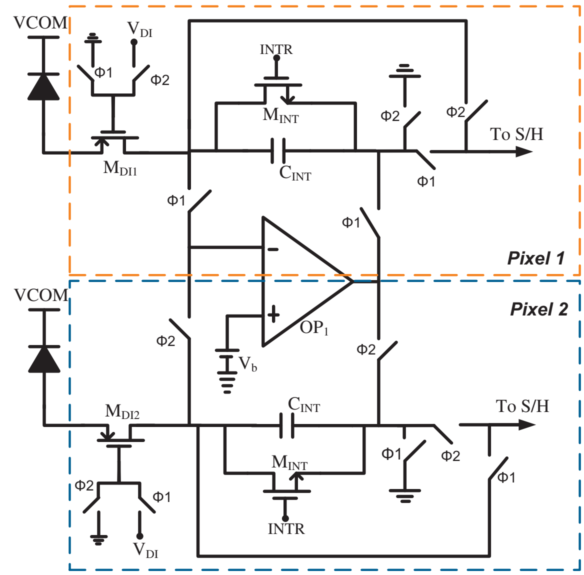

Fig. 2. Schematic of dual-mode pixel circuit.

The ROIC of dual-band IR usually requires a variety of architectures and tends to be limited with regard to pixel area. In order to reduce circuit complexity, this study integrated CTIA and DI architectures within a novel pixel circuit structure specifically designed for the ROIC of dual-band detectors. The two circuits are combined to select suitable ROIC of different sensors, which correspond to present sensing circuit design trends.

This study proposes a dual-mode pixel circuit with a CTIA circuit framework with switching device and DI circuit. A simple, low-power DI is used for MWIR or LWIR and CTIA with low background current and impedance is used in SWIR and visible light sensors. Amplifiers consume pixel area and power, thereby affecting the overall circuit performance; therefore, this study proposes the sharing of amplifiers by two pixels with both DI and CTIA functions. In this manner, we were able to reduce by half the overall power consumed by the circuit and the pixel area occupied by

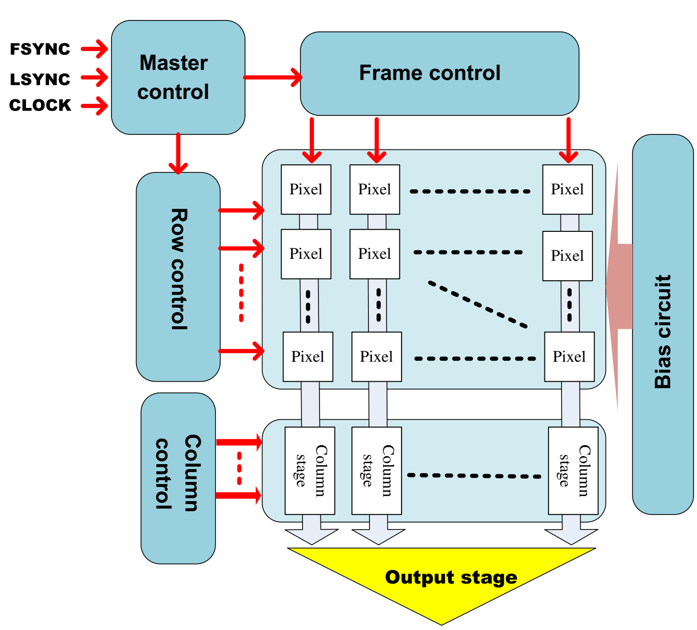

Fig. 1. Architecture of proposed readout chip.