Injection Efficiency of DI and CTIA Readout Integrated Circuit

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***Abstract*—Advanced hybrid infrared focal plane arrays (IRFPA) consist of a semiconductor photodetector chip which is bump-bonded to a silicon CMOS readout integrated circuit (ROIC) chip generally containing a reset integrator preamp to accumulate detector photon-induced current over a fixed integration time. A number of readout structures have been developed for different system applications and concerns, among which the direct injection (DI) and the capacitor feedback transimpedance amplifier (CTIA) are popularly used. The structures and performances, especially injection efficiency, of DI and CTIA are respectively discussed and compared. The DI enables an ultralow power consumption and has a high injection efficiency at large background photocurrent, while the CTIA has a comparatively higher power dissipation and higher injection efficiency at low background photocurrent.**

Keywords-IRFPA; DI; CTIA; Injection Efficiency

I. INTRODUCTION

In general, the hybrid infrared focal plane arrays (IRFPA) can be divided into two major parts, namely the detector array and the readout integrated circuit (ROIC) chip, whose primary function is to provide infrared detector signal conversion and amplification, along with time multiplexing of data from many detectors to just a minimum number of outputs. ROICs are most often implemented in complementary metal oxide semiconductor (CMOS) technology, allowing for higher resolution and greater sensitivity in today's sensors. Most ROICs utilize preamplifiers that accumulate detector photon-induced current over a fixed integration time. Among a different types of preamplifiers, direct injection (DI) and capacitor feedback transimpedance amplifier (CTIA) are widely used and will be discussed in this paper.

II. DI AND CTIA READOUT STRUCTURE

A. DI Readout

The DI readout has a small unit cell and has been used for large IR hybrid staring focal plane arrays that require good image resolution. Fig.1 shows schematic structure of DI and its small-signal model analog equivalent circuit. Photon current in DI circuits is injected, via the source of the input transistor, onto an integration capacitor that has been reset prior to the beginning of the frame[1][2]. As the photon current integrates, it charges the capacitor throughout the frame. Figure 1 shows the schematic structure of DI readout and its small-signal response equivalent circuit.

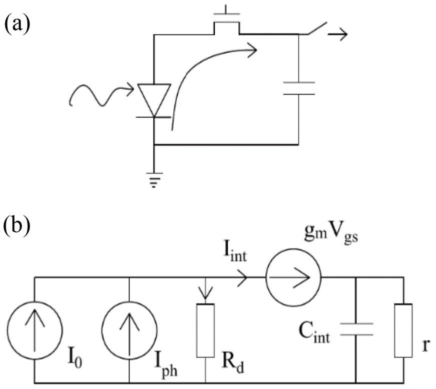

Figure 1. (a) schematic structure of DI readout and (b) its small-signal response equivalent circuit

As can be seen in Figure 1(b), I_0 is constant current, including dc dark current and background photocurrent. I_{ph} is the small signal photocurrent. C_{int} and r are integration capacitance and its leakage resistance respectively. The gate voltage of MOSFET remains constant to ensure that the drain current operates in the low-power subthreshold (weak inversion) mode, in which transconductance g_m satisfies

$$g_m = \frac{\partial I_{ds}}{\partial V_{gs}} = \frac{qI_{int}}{nk_BT}$$

where I_{int} is injection current, V_{gs} is gate-source voltage, n is subthreshold slope parameter and k_BT is the product of Boltzman constant and temperature. The photodiode detector is typically operated in reverse bias in order to avoid higher detector noise and nonlinear photo response. When a small-signal photocurrent is incident, a proportion of it injects into MOSFET and another proportion of it is shunted through R_d, the dynamic reverse bias detector resistance, and thus result in a non-unity injection efficiency, which is defined as[3]

$$\eta = \frac{I_{int}}{I_{ph}}$$

According to Figure 1(b), by using the definition the injection efficiency η can easily be derived as

$$\eta = \frac{R_d g_m}{1 + R_d g_m} = \frac{1}{1 + 1/R_d g_m}$$

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where the parallel connection relation R_d and g_m is used. considering the above equation, it is clearly seen that injection efficiency of DI is closely related to g_m, and g_m is influenced by drain current of MOSFET, i.e., background current and dc dark current. If the DI operates at a high background photocurrent, which result in a large value of g_m, eventually a high injection efficiency is attained and vice versa.

B. CTIA readout

The CTIA readout configuration contains an integration capacitor which is placed on the feedback loop of an operational amplifier with open-loop gain in the hundreds to tens of thousands[4][5]. Figure 2 shows the schematic structure of CTIA readout and its small-signal response equivalent circuit. Due to the Miller effect on the integration capacitor, its capacitance can be made extremely small to obtain low-noise and high-sensitivity performance.

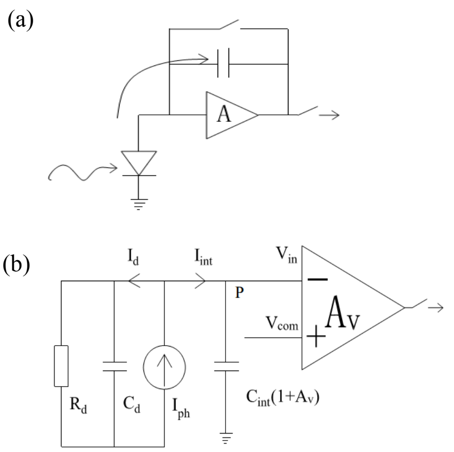

Figure 2. (a) schematic structure of DI readout and (b) its small-signal response equivalent circuit

As can be seen in Figure 2, C_{int} and C_d are integration capacitance respectively, I_{ph} is the small signal photocurrent which is much more smaller than background photocurrent, R_d is the dynamic reverse bias detector resistance, and A_V is open loop gain of the operational amplifier. Acoording to the temporal Kirchhoff current equation of node P

$$I_{ph} = (1 + A_V + C_d\,)C_{int}\frac{dV_{in}}{dt} + \frac{V_{in}}{R_d}$$

where the detector is assumed ground connection and V_{in} is input voltage of operational amplifier, using the initial condition of $V_{in}(0) = V_{com}$ and solving the above differential equation, we obtain

$$V_{in}(t) = I_{ph}\,R_d + (V_{com} - I_{ph}\,R_d)e^{-t/\{R_d[(1+A_V)C_{int}+C_d]\}}$$

Combining above two equations and the integration current

$$I_{int} = (1 + A_V)C_{int}\frac{dV_{in}}{dt}$$

as well as precisely defined injection efficiency

$$\eta = \frac{\Delta I_{int}}{\Delta I_{ph}}$$

we obtain the injection efficiency of CTIA

$$\eta \approx 1 - \frac{t}{R_d[(1 + A_V)C_{int} + C_d]}$$

where Taylor's expansion approximation is used and t is the integration time. It can be seen that the injection efficiency of CTIA is influenced by the features of readout such as integeration time t, open loop gain of operational amplifier A_V and integration capacitance C_d. Because t and C_d have a lot of limitation during readout circuit designing, the most effective way of raising injection efficiency of CITA is increasing the A_V.

III CONCLUSION

Based on above discussion, it can be seen that DI readout is suitable operating at high photo flux with high injection efficiceny and has simple structure and ultralow power dissipation as a result of subthreshold mode of MOSFET, while CTIA has a more complex structure power consumption than DI and a high injection efficiency regardless of photo flux and thus is suitable to operate at low photo flux. The choice between DI and CITA depends on different situations and conerns.

REFERENCES

[1] J. F. Johnson, "Hybrid Infrared Focal Plane Signal and Noise Model", IEEE TRANSACTIONS ON ELECTRON DEVICES, Vol. 46, pp. 96-108, JANUARY 1999

[2] J. F. Johnson, "Direct Injection Readout Circuit Model", SPIE, Vol. 2226, pp. 120-129, 1994

[3] L. Vampola, "Readout electronics for infrared sensors," in "Electrooptical components," W. D. Rogatto, Ed., inInfrared and Electro-optical Environ. Res. Inst. Michigan; also Bellingham, WA: SPIE Opt. Eng. Press, 1993, vol. 3, ch. 5.

[4] C. Hsieh, C. Wu, "Focal-Plane-Arrays and CMOS Readout Techniques of Infrared Imaging Systems", IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS FOR VIDEO TECHNOLOGY, Vol. 7, pp. 594-605, AUGUST 1997

[5] J. W. Beletic, R. Blank, D. Gulbransen, D. Lee, M Loose, E. C. Piquette, T. Sprafke, W. E. Tennant, M. Zandian, and J. Z. Nicole, "Teledyne Imaging Sensors: Infrared imaging technologies for Astronomy & Civil Space", SPIE, Vol. 7021(702110H), pp. 1-14, 2008

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