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A novel non-uniformity compensating method for microbolometric focal plane array

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ABSTRACT

This paper describes a non-uniformity compensating method for microbolometric focal plane array. Through the analysis of the basic principle of conventional non-uniformity compensating methods for microbolometric focal plane array, we have pointed out their common fatal limitation unable to compensate the nonlinear non-uniformity of microbolometer array. Based on our previous constant power optimized bias, a novel and simple nonlinear non-uniformity compensating method for microbolometric focal plane array is proposed in this paper. The proposed compensating method is simply configured and can easily and effectively be utilized to compensate the nonlinear non-uniformity of microbolometer array.

1. Introduction

With the development of fabricating technologies for microbolometric focal plane array, the characteristic performance of uncooled infrared image system based on microbolometric sensor has remarkably been improved. However, it is still a great challenge to design and fabricate microbolometers with uniform thermal and electronic performance. The normal microbolometric non-uniformity can cause offsets larger than the responding signal dynamic range [1,2]. If the microbolometric resistance non-uniformity is about 4% and the microbolometer temperature coefficient of resistance (TCR) is high about −2%, the offsets caused by the non-uniformity is then about two times larger than the signal dynamic range responding to a target at the temperature range from 0 °C to 100 °C with an optical aperture F/# = 1.0. Many researchers have focused on the increase of TCR and the decrease of non-uniformity to improve the performance of microbolometric array, and nearly have not achieved any progress in recent years [3,4]. So, the inevitable non-uniformity correction scheme for microbolometric focal plane array must be carefully investigated.

There are several typical conventional non-uniformity correction approaches for microbolometric focal plane array, of which the basic principle is based on a means of two-point correction method [5,6]. Two typical and similar kinds of more advanced non-uniformity correction ways are reported to trim the bias voltage across each microbolometer [7,8]. All these non-uniformity correction approaches are effective enough for the calibration of microbolometric linear non-uniformity. Unfortunately, microbolometer arrays are mainly based on vanadium oxide and amorphous silicon, and both of these two kinds of materials have obvious nonlinear semi-conductive thermoelectronic characteristics [9,10]. With the aggravation of microbolometric nonlinear non-uniformity, even these two advanced correction approaches in [7,8] will become useless.

In our previous work, we have proposed a constant power bias method and theoretically proved it feasible for microbolometer arrays based on semi-conductive materials [11]. In this paper, we have discussed the disadvantages of conventional compensating methods and propose a new kind of non-uniformity compensating correction technology for microbolometer array, which provides a common bias power to each microbolometer in microbolometer array through an internal ADC and a list of programmable 8-bit memories.

2. Conventional correction principle

If a microbolometric focal plane array is irradiated by the infrared radiation from a target, the resistance values of the microbolometers in this array are changed and all these microbolometric resistance changes can be transferred into responding current signals of the microbolometric focal plane array. The current responsivity of microbolometer can be expressed as

$$R_I = -\frac{V}{R(g + (V^2/R)\alpha)}\alpha, \tag{1}$$

where V is the bias voltage, α is the TCR, g is the thermal conductance, and R is the resistance of the microbolometer [11,12].

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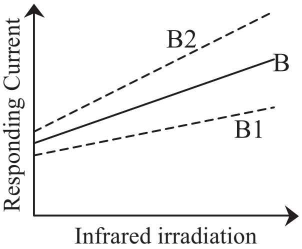

Fig. 1. The schematic two-point correction method.

Conventional non-uniformity correction approaches are based on the assumption that the bias voltage, TCR, thermal conductance and resistance of each microbolometer are constant, then the microbolometric non-uniformity mainly including resistance non-uniformity can be compensated by a method of two-point correction. The two-point correction principle can be explained as follows. Assuming the current responsivity curves B1 and B2 of two microbolometers are respectively shown in Fig. 1, the final responsivity curves of B1 and B2 should be compensated as the common responsivity curve B in Fig. 1. From Fig. 1, it can be found that the current responsivity curve is processed as linear. However, the TCR α and R in Eq. (1) are not constant and sure to be changed with the temperature change of the microbolometer [11], and that is to say that the responsivity curve of microbolometer is strict to be nonlinear. So, it can be concluded that the two-point correction method does not have a good correction effect for microbolometric focal plane array.

With consideration on the responsivity nonlinearity of microbolometer, the other two correction approaches in [7,8] are required to trim the bias voltage across each microbolometer. The different bias voltages for different microbolometers make all the microbolometers in an array operate at a common responsivity slope, which is illustrated in Fig. 2. If the responsivity curves of two different microbolometers are D1 and D2 respectively, two different appropriate bias voltages for these two microbolometers can prompt them to work at the responsivity slopes K1 and K2 and K1 and K2 have the same slope. Then, with a following fixed offset correction the resistance nonlinear non-uniformity can be corrected within a certain range. From above explanation, we can find that the responding nonlinear distortion can be effectively compensated if the infrared irradiating powers on microbolometers are very small. But almost every practical infrared image system is expected to be equipped with a microbolometric focal plane array to have a certain infrared responding range and a corresponding output signal dynamic range. Therefore, the nonlinearity compensating effect of these two correction approaches is not good enough and even becomes useless when the infrared input range of the microbolometric focal plane array is large.

From above analysis, it can be found that these referring correction approaches can not completely compensate the whole nonlinear non-uniformity of microbolometer array at present. Furthermore, more and more practical applications demand infrared image system to have low-noise output and small image distortion. Hence, the theory and technology based on nonlinear non-uniformity compensation of microbolometric focal plane array should be carefully investigated for future high-quality infrared image systems.

3. Nonlinear non-uniformity compensation

In order to overcome the responding nonlinear effect of microbolometer, a novel constant power bias method for microbolometer array is theoretically analyzed and proposed in our formerly published paper [11]. The semi-conductive sensing material of microbolometer in [11] is vanadium oxide and its resistance value is expressed as

$$R = R_0 e^{E_g/2KT}, \tag{2}$$

where R_0 is a constant, K is Boltzmann constant, E_g is the bandgap and T is the temperature of the semiconductor vanadium oxide. With the consideration that the TCR α of microbolometer is defined as

$$\alpha = \frac{dR}{RdT}, \tag{3}$$

the current responsivity of microbolometer from (1) then can be transferred into

$$R_I = \frac{K_1 E_g}{V\left[g - \frac{K_1 E_g}{2K(T_s+(K_1/g))^2}\right] 2K\left(T_s + \frac{K_1}{g}\right)^2}, \tag{4}$$

where the constant K_1 is the constant bias power V^2/R, and T_S is the substrate temperature of microbolometer. From (4), it can obviously be found that the microbolometric current responsivity is irrelevant to the resistance value of the microbolometer under a constant power bias, and that is to say that the constant power bias method can effectively eliminate the effect of microbolometric nonlinearity.

Only considering the resistance non-uniformity of microbolometers and assuming that the thermal g and the bandgap E_g of all microbolometers in an array are consistent, we can get that the microbolometric current responsivity is inversely proportional to the bias voltage V from (4). With a constant power bias method, different microbolometers in the focal plane array ordinarily have different bias voltages because of the microbolometric resistance non-uniformity and each microbolometer has its own current responsivity. Because the current responsivity is linearly dependent on the bias voltage with a constant bias power, the microbolometric linear non-uniformity of current responsivity can be compensated by conventional two-point correction method.

In accord with above analysis, the proposed nonlinear non-uniformity compensating method can be illustrated in Fig. 3. By first providing a constant bias power and then using the conventional two-point correction method for each microbolometer, the microbolometric output signal which has suffered from the

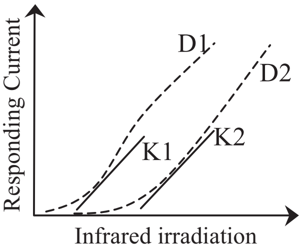

Fig. 2. The responsivity nonlinearity correction.

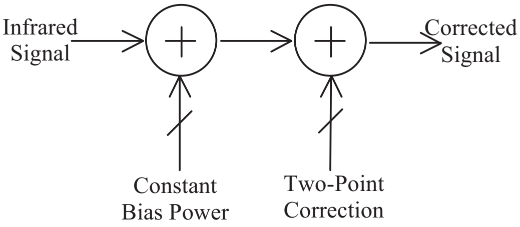

Fig. 3. The proposed nonlinear non-uniformity compensating method.