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Output signal change analysis of an uncooled microbolometer focal plane array with respect to varying control voltages and operating point temperature

Abstract

This paper presents results of output signal analysis of uncooled microbolometric focal plane array FPA. The analysis focuses on detectors manufactured by ULIS. The signal has been tested against varying control voltages, it is blind microbolometer biasing V_{SK} and active microbolometer biasing V_{FID} . The working point temperature of the environment was also altered in range from 5°C to 60°C. Such analysis can be used to check the results against current mathematical model of FPA's behavior and verify validity of the measurement method in varying working conditions. Later it could allow explore possibility to design corrective algorithms.

Keywords: Focal Plane Array, microbolometer.

1. Introduction

Microbolometer focal plane arrays (FPA) detectors are susceptible to non-uniformly distributed response behavior due to imperfect manufacturing process [1]. Direct consequence of it is so-called fixed pattern noise (FPN), different shift in responses' offset and non-uniform amplification change due to working point temperature drift throughout each individual detector. To counteract these shifts, a process called non-uniformity correction (NUC) is employed. However such correction is valid in certain temperature vicinity of temperature working point at the time of calibration. During operation working point temperature fluctuates at different rates depending on factors such as working environment's temperature, observed scene's net power, or mode of operation to name a few. Once the image by NUC calibration is corrected, the operation point temperature drift as small as few Kelvins might render image unreadable [2].

To counteract image's deterioration, another NUC calibration needs to be made. Most commonly it is done by closing shutter with known emissivity coefficient and calculating corrective values based on its uniform image. The disadvantage of this method is that the device's user loses sight of the observed scene, which depending on the application might be undesirable or even endangering. If the FPA's behavior was completely deterministic or somewhat predictable with high accuracy, detrimental signal change could be anticipated and corrected in real time. Thus a need of repeating NUC calibration is eliminated or at least interval time between recalibrations is significantly prolonged.

Detector manufacturers constantly stride to improve their products and each released generation's parameters become more uniformly distributed and linear in change. Main goal of our research is to design corrective algorithm that could counteract negative influence caused by the thermal drift of the FPA's working point. There are a lot of factors influencing the bias of the matrix, but the most decisive are:

- V_{FID} : Bias voltage applied to the Active pixel FET gate
- V_{SK} : Bias voltage applied to the Blind Microbolometer
- T_{SC} : Temperature of the observed scene
- T_{ENV} : Temperature of the environment
- C_{int} : Integration Capacitance
- t_{int} : Integration time

For clarity, synoptic of a readout architecture with capacitive transimpedance amplifier (CTIA) has been presented in Figure 1.

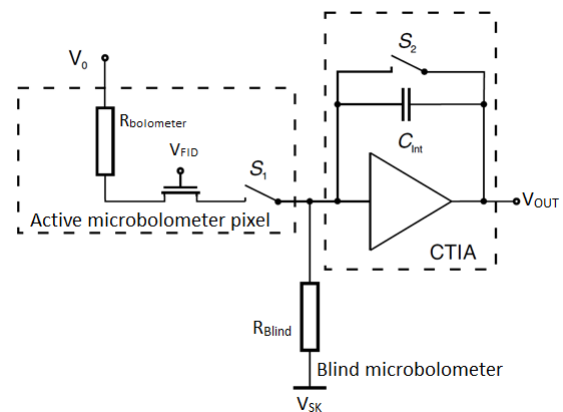


Fig. 1. Synoptic of the pixel readout architecture characteristic to ULIS detectors [3]

In order to invent such an algorithm, it is necessary to determine mathematical model of the FPA and verify its fidelity to reality. Manufacturer of the detectors provides mathematical formulas describing detectors' voltage response with respect to certain parameters. According to the formulas (1) (2), relationship between response and control voltages (V_{FID} and V_{SK}) should be linear in nature.

$$\frac{dV_{out}}{dV_{FID}} = \frac{t_{int}}{C_{int} R_{active}} \cdot 1, \quad (1)$$

$$\frac{dV_{out}}{dV_{SK}} = -\frac{t_{int}}{C_{int} R_{blind}} \cdot 1. \quad (2)$$

However some parameter values can be controlled (i.e. steering voltages or integration parameters), response is heavily influenced by independently varying operation temperature of the detector. Unfortunately, extent of the response's change is not a priori determinable, but it may be possible to derive it empirically. Hence our team decided to develop a method of examining FPA's responsivity change with respect to aforementioned varying parameters in order to determine whether theoretical model's linear behavior is reflected by empirical data. If collected data confirms theoretical behavior, it will simultaneously validate correctness of data acquisition method, which might enable to determine implicit temperature dependent behavior.

2. Measurement method

A measurement method of FPAs' response characteristic has been designed to be as universal as possible. The method has been developed around French company's detectors manufacturer ULIS. MICRO80 GEN2 microbolometer FPA has been chosen to be used in development. Specification of the detector has been presented in Table 1.

In order to accommodate the detector, a special interface PCB has been designed that would allow signal acquisition and processing down the measurement assembly chain. Detector interface board is serviced by Terasic DE10-Nano board with Cyclone V SoC FPGA.

Tab. 1. MICRO80 GEN2 specification

PARAMETER	SPECIFICATION
Pixel pitch	34 $\mu\text{m} \times 34 \mu\text{m}$
Active pixels (Full size configuration)	80 \times 80
Spectral response	LWIR (8-14 μm)
Frame rate	From 1Hz to 50 Hz full frame
Performance	(50 Hz, F/1, 300 K, GFID=2.7 V, integration time=75 μs , integration capacitance=6 pF)
NEDT	< 100 mK

The onboard FPGA has been programmed to control the FPA and read the digital level of the output signal from each of the 6400 detectors. The acquisition assembly has been presented in Figure 2. Custom designed acquisition modules were complemented by ready to use IP modules from MATLAB's and INTEL's digital signal processing (DSP) library. DSP modules allow communicate with a workstation PC via joint test action group (JTAG) interface. Hence both control and acquisition could be programmed and coordinated from MATLAB environment on PC workstation.



Fig. 2. The view of the Acquisition assembly consisting of interface PCB and DE10-Nano board

Various values of operation temperatures have been provided by laboratory grade bench-top type environmental chamber ESPEC SH-661. It was possible to control the chamber via RS-232 interface from workstation computer, which enabled partial automatization of the measurement. Technical black body SR 800R from ECI systems served as observation target. Because the measurements have been taking place from inside of the environmental chamber, while the target was on the outside, it had to be done through an opening in the chamber's side wall. To ensure that the chamber could reach and maintain target temperature, the opening's radius has been minimized and properly insulated. Additionally it reduced thermal influence of the outside environment on the detector, as only the outermost part of the lens had contact with the outside environment (Fig. 3).

In order to minimize the influence of chamber's inside radiation, a lens with relatively big focal length (13 mm) has been chosen. To verify behavioral fidelity of the mathematical model, a series of measurements have been taken with three controlled variables - V_{FID} , V_{SK} and T_{ENV} .

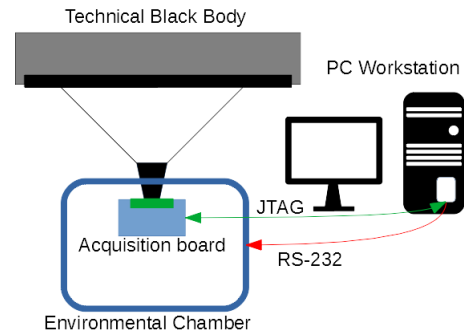


Fig. 3. Diagram of components comprising the measurement assembly

The integration time and integration capacitance have been maintained constant at 75 μs and 6 pF respectively throughout the acquisition. Temperature and even distribution of the scene radiation have been provided by the technical black body. It has been kept at constant 30°C. As for the detector's operating point temperature, it has been controlled indirectly through the temperature of the environment. The T_{ENV} has been restricted to range from 5°C to 60°C. The lower bound has been established above condensation point to avoid potential risk of water vapor condensing as droplets on optical components. For each measurement series, the temperature has been increased in 5°C increments. Before each acquisition series for a given temperature, environmental chamber has been set for desired condition. After reaching target temperature of the environment, the system waited for an hour to ensure that detector reached and stabilized at the ambient temperature. The V_{FID} range was from 0.7877 V up to 2.8073 V with increments of 0.0816 V. These values are dictated by the manufacturer as 0.7877 V is minimal V_{FID} value, 2.86 V is maximal value, and increment value is determined by the resolution of the 8-bit digital-to-analog converter. Analogically the value of V_{SK} is in range of 1.7315 V to 3.5021 V with increment of 0.0026 V.

Analyzing response characteristic of older microbolometric FPAs against varying control voltages' values showed expected behavior [4]. A full range, full resolution scan have been performed to ensure that any deviation from the expected behavior would have been detected. After learning the general behavior of the detector it has been possible to improve the measurement method by implementing binary search algorithm into acquisition program. Before implementing the algorithm, it was necessary to scan the whole measurement range in order to get to the behavioral characteristic's region of interest. As region of interest comprises relatively narrow range of variables' values, it was ineffective and taking undesirably long time. That in consequence could have been introducing fluctuation of measurement's conditions, hence greater uncertainty. The region of interest consists of the slope visible on characteristic presented in Figure 4. The rest of the values are either pulled down to the minimum value of 0 V or fall into saturation and maximum value of 5V. Therefore it was beneficial to first focus on acquiring data from the region of interest. Implementation of binary search algorithm enabled exactly that, hence reducing conditions' fluctuations during acquisition of critical data and reducing its uncertainty. Throughout the whole process, the detector was continuously working in order to maintain constant dissipation power. For every detector temperature, first V_{FID} was set and then scanned through V_{SK} values. Each measurement consisted of acquiring and saving 30 consecutive frames with values from each of 6400 detectors. After changing voltages during searches for the region of interest or if the change during acquisition was significantly big, there was 10 seconds interval in order to allow any transient states to stabilize and minimize measurement inaccuracies.

3. Results

Acquired data has been processed in order to extract desired behavioral information. The detector's response is in range from 0 V up to 5 V with readout integrated circuit that has a 14-bit analog-to-digital converter. Each series of frames have been averaged and made into a point on a graph. As one can see of Figure 4, the response characteristic is indeed displaying linear properties.

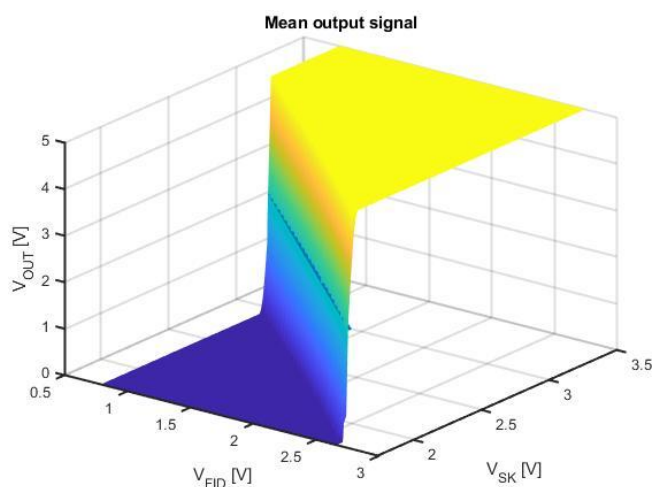


Fig. 4. Chart of mean output values in respect to varying control voltages with line marking midrange values at $T_{ENV} = 30^{\circ}C$

For any given V_{FID} value, there is an interval where detector's increase in signal response is proportional to increase of the bias voltage applied to the blind microbolometer. Furthermore the midrange response values also conform along a linear function of V_{FID} and V_{SK} pairs. With varying values of temperature, the linear function along which working point is in the middle of the FPA's dynamic range doesn't vary by a big factor. In fact there is reasonably limited amount of biasing voltage pairs that enable operation within the dynamic range. Visualization of these points for minimal and maximal temperature has been presented in Figure 5.

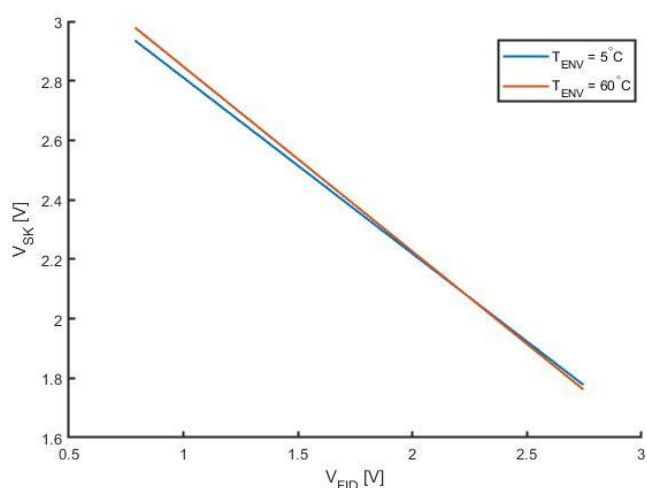


Fig. 5. Conformation of control voltages pairs for midrange values with respect to T_{ENV}

Within one temperature of operation, the slopes of detector's response rise with varying V_{SK} for given V_{FID} are nearly the same. Standard deviation to mean ratio value across the temperatures' values stays in narrow range of 0.04 to 0.05 (Table 2). This suggests that mathematical model given by the manufacturer closely represents reality and at the same time it confirms that the

measurement method is correct. This property makes the FPA's behavior more deterministic and might prove useful in designing corrective algorithms. Statistical data of variance in slope coefficients of dV_{out}/dV_{SK} for changing values of temperature has been presented in Table 2.

Tab. 2 Analytical mean values of slopes in varying temperature and its variance

Temperature $^{\circ}C$	Mean slope coefficient dV_{out}/dV_{SK}	standard deviation(std)	std to mean ratio
5	39.26	1.66	0.04
10	44.29	1.92	0.04
15	49.91	2.24	0.04
20	56.17	2.63	0.05
25	63.06	3.05	0.05
30	70.54	3.57	0.05
35	78.56	4.11	0.05
40	87.45	4.73	0.05
45	96.47	4.97	0.05
50	106.78	5.43	0.05
55	117.82	6.05	0.05
60	129.28	7.07	0.05

With varying temperatures however, the slopes' magnitude increases quite significantly, what in practice means that the detectors dynamic range is getting narrower with increasing temperature. What is worse, the skewing of the slopes is not happening around some determined points, but their translation appears to be more complex. Visualization of measured responses for V_{FID} set to 1.6853 V (middle of the range) has been presented in Figure 6.

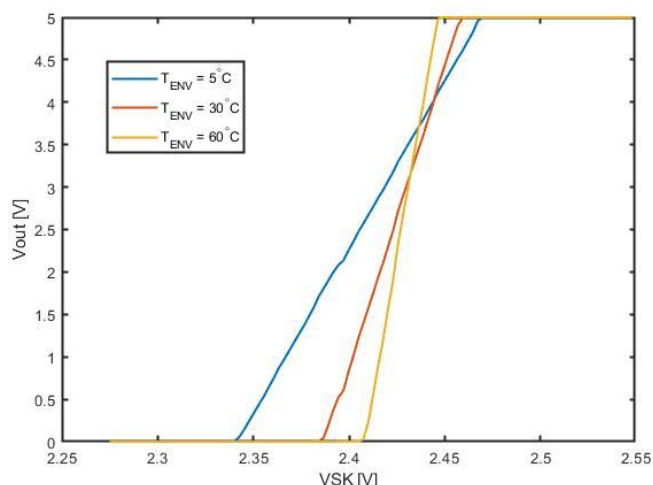


Fig. 6. V_{OUT} of dynamic range region in varying V_{SK} and T_{ENV} for constant $V_{FID} = 1.6853$ V

The amount of skewing with temperature change is proportional throughout the whole range of V_{FID} values with relation to each other. Hence it suggests that the thermal shift of the operating point is governed by a deterministic dependency.

While results of the measurements are consistent with theory and behavioral characteristic of older types of detectors, it is not sufficient to derive an unambiguous law governing the shift of the operating point. It is necessary to examine the influence of other parameters like C_{int} and t_{int} on the behavioral characteristic. Additionally it would be beneficial to alternate observed scene's temperature for each controlled parameter change to obtain data covering influence of all controllable variables. It would be used to find multivariable relation that might help predicting the thermal shift. It might be possible either by means of regression or use of newer tools like machine learning algorithms. As the

amount of data coming from every individual microbolometer is enormous, it is difficult to analyze the behavior of each individual detector and infer a general rule with a traditional approach. With aid of machine learning however, it might be possible to analyze behavior of each individual detector of the array and come up with an intrinsic relation that would be otherwise undetectable.

Also other arrays from ULIS need to be measured to determine whether any dependency is peculiar for an individual type of detector or is it more universal property. In order to do so, another PCB interface board has been designed, with detachable socket that can accommodate other types of FPAs. The detectors that are going to be cross-analyzed are ULIS detector types Atto320, Atto640 which are 12 μm detector types and Pico 386 gen2 which is a 17 μm type detector.

4. Conclusions

A method has been successfully developed to measure and gather data from different types of FPAs. The results have been presented and analyzed, what allowed visualize behavioral characteristic of FPA depending on varying control voltages and detector's temperature. Method's effectiveness has been validated and determined further direction of the research.

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