A Novel Integrated Spatial Filtering Detector Chip with Variable Multi-valued Weighting Functions

H.M. GO$^1$, S. OHYAMA$^2$

$^1$ SAMSUNG TECHWIN CO., LTD., 145-3 Sandaewon 1-Dong, Sungnam, Kyunggi-Do, KOREA

$^2$ Tokyo Institute of Technology, 2-12-1 O-okayama, Meguro-ku, Tokyo, JAPAN

E-mail: hyunmin.go@samsung.com

Abstract. A novel integrated spatial filtering detector chip was introduced in this paper through the comparison with the conventional spatial filtering detectors. We designed and fabricated a novel integrated spatial filtering detector chip with variable multi-valued weighting function using CMOS 0.35μm process. This chip has 7-bit signed weight values and a weighting control circuit though the external interface with the PC. The multiplication of the frequencies is available from the dividing the weighting function of the chip. In order to confirm the validity of this chip, a simple velocity measurement was achieved. Experimental results show multiplied frequency ratio regarding to the reference frequency which are in proportion to the velocity of the measuring object.

1. Introduction

For the velocity measurement using the spatial filtering method(SFM), many papers have been proposed in the recent years[1, 2, 3, 4]. Besides the velocity measurement, many algorithms in the decade have been proposed such as a road surface recognition sensor[7], moment analysis[5] and so forth[6]. The SFM in these paper can be expressed using the spatial integral as

\[ g(x, y; t) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x, y; t) h(x, y) dx dy, \]  

(1)

where \( h(x, y) \) is the weighting function of the spatial filter and \( f(x, y; t) \) is the spatial pattern of the object. The spatial weighting function \( h(x, y) \) indicates the characteristics of the spatial filtering detector(SFD) by the functionality of itself. Adaptively designed the weighting function \( h(x, y) \) according to the optical pattern of the object, the SFD has the effective characteristics of the spatial pattern of the object appear as the output. Conclude that the weighting function is required to be changed in order to acquire the desired information, to eliminate the effect of the disturbance. The conventional SFDs, however, have disadvantages in that the weighting function \( h(x, y) \) is fixed and the weighting values are binary or ternary values as Table 1 shows. Besides establishing an accurate measurement system, programmable weighting functions are required for executing various applications; the arrow-feathers-type SFD for measuring the velocity vector[8], the radial-type SFD for detecting the rotational speed[9]. Introduced SFDs are fabricated with application specified hardware configuration, so that these structure were impossible to change and adjust to the measuring objective.
Table 1. Proposed methods to improve SFD function[10, 11, 13, 14, 15]

| SFD type                               | Shape          | Weight value(s)               | remark                                               |
|----------------------------------------|----------------|------------------------------|-----------------------------------------------------|
| Narrow bandpass SFD                    | parallel slits | fixed binary values: +1, 0 or -1, 1 | not optimized weight values to the objects          |
| Differential type SFD                  | parallel slits | fixed binary values: +1, 0 or -1, 1 | - Weight mask by optical film                        |
|                                        |                |                              | - Adjustment of incident light                       |
| SFD for measuring the rotational speed | radial slit arrays | fixed binary values: +1, 0 or -1, 1 |                                                     |
| SFD with variable multi-valued weighting function | 2-D photodiode array | variable weight values: 8 bits | selectable pixels and programmable weighting function |

In addition, many more weighting functions that is continuously changeable and easily set have been required to achieve the active and adaptive measurement system. As a solution of improving the conventional SFDs, we introduce a current-mode integrated SFD with variable multi-valued weighting function (ISFD-VMWF). This ISFD-VMWF is a device that can exchange programmably weighting functions and 7-bit signed weighting values. Furthermore, this integration produces advanced results that are the miniaturization of the size and low power consumption in comparison with the presented SFDs.

2. Construction of the Weighted-sum Structure

In order to design the structure for changing the weighting function in the integrated circuit, there are two ways to achieve the configuration: simply the voltage-mode circuitry and the current-mode one. In the VSFD we proposed, however, it is difficult that the weighted-sum structure using R-2R ladder circuitry is integrated by CMOS standard process. This is because the photo-current from a photodiode is not suitable so small as to construct the current-division method by R-2R circuitry on a chip. The on-resistance of the FET switch and the difference of R affect the current-division ratio and severely deteriorate the precision of the VSFD. In order to realize the weighted-sum structure in the integration technology, we adopt current-multiplication-type weighted-sum structure as described in the reference that explain more in detail[5]. In order to construct this structure in the circuitry, this paper use simple circuits as follows:

[Weight structure]
Current-mode MDAC
[Sum Structure]
Current-mode summation by the single-node connection of all pixel outputs

3. Integrated Spatial Filtering Detector with Variable Multi-valued Weighting Function

3.1. Configuration of ISFD-VMWF

Figure 1 shows the system configuration of the ISFD-VMWF chip. This chip consists of $32 \times 32$ photodiode array, weighting circuits with 7-bit signed weighting values using current-mode parallel multiplying digital to analog converter (MDAC), weight control circuit by D flip-flop and differential op-amps. The specification of the ISFD-VMWF chip is summarized in Table 2.
3.2. Weighted Pixel Element

When the light is incident upon the PD, the generated photocurrent is parallelly mirrored to the output signal line through the cascode current mirrors. The current ratio of the photocurrent to output current signals of current mirrors in the weighting circuit is determined by the dimension ratio of MOS devices. The circuit shown in Fig. 2 is a CMOS current-mode 6-bit MDAC. In this design, current gains are designed from 0 to 63 to achieve weighting the input signal and controlled by switching on/off through the external interface. The output of each MDAC is connected to one of two summing nodes, plus/minus signal nodes, according to the sign bit associated with the weighted signal. Figure 3 shows the schematic of the weighting control circuit. A layout of the overall circuit of the WPE is shown in Fig. 4. Metal 1 and 2 layers are used for routing circuit. Metal 3 layer is partially used for routing, but is mainly used for shielding light except the photodiode array region to prevent parasitic photo-carriers and partially for routing. Figure 5 shows a photograph of the fabricated ISFD-VMWF chip using CMOS 0.35 μm process with 2-poly 3-metal layers.
3.3. Basic characteristics of the Fabricated ISFD-VMWF

Figure 6 shows an experimental measurement system implementing an ISFD-VMWF chip. Output current signals of the system are converted to voltage signals amplified to $1\text{kV/A}$, $10\text{kV/A}$, $100\text{kV/A}$, and $1000\text{kV/A}$ gains by the external differential op-amp circuits within the ISFD-VMWF measurement system with the current-mode output. The gains, 1, 10, 100, and 1000 [kV/A] of the differential op-amp can be controlled by the control program through the ADC board.

Figure 7 shows output signals are linearly varied with exchanging weights on all pixels as a basic output characteristic of the ISFD-VMWF. The calculated errors due to shifting up a weight value at various gains are within 5%.

4. Experiments

4.1. An experiment on the velocity measurement

To confirm the validity of the ISFD-VMWF in the application, we manufacture a simple velocity measurement system as shown in Fig.9. The LED flasher are made of 16 lines moving along the x coordinate by impressing a clock frequency. With rising the speed of the LED flasher, a multiplied ratio according to given frequencies of the LED flasher is depicted in Fig. 10. Regardless of the same moving speed, the ISFD-VMWF can increase output frequencies with
Figure 6. Experimental measurement system

Figure 7. Basic characteristics of the ISFD-VMWF @ G=1,10,100 [kV/A]

1, 2 and 4 times by setting the weighting function as the same manner as like Fig. 8. In this case, the figure shows a case that the output frequency generates the same ratio of the given clock frequency. In this figure, in spite of the saturation of some waves caused by the fixed step gains of the external amplification stage, the results show that the output signal frequencies are in proportion to the moving speed of the LED flasher. From these results, the ISFD-VMWF is able to measure the velocity of over 0.5 [mm/sec], which corresponds to 2000 [frames/sec] of the digital imager.

5. Conclusion
In this paper, we have designed and fabricated a new current-mode integrated spatial filtering detector with variable multi-valued weighting function (ISFD-VMWF) using the current-mode weighted-sum structure. For configuring the weighted-sum with the electric circuitry, the current-mode parallel MDAC and digital memories were adopted. The fabricated ISFD-VMWF has 7-bit signed weighting values and various weighting function by the external interface. As a basic output characteristic of the ISFD-VMWF, the test result shows that output signals are linearly shifted with exchanging weights on all pixels. Furthermore, the velocity measurement result demonstrates the validity of the ISFD-VMWF as a simple application. As the next subject
of this research, A/D converter, address decoder, and frame memories will be integrated on the same chip that enable to increase internal scanning speed and expand application fields.

**References**

[1] E. Okada, H. Ehara, C. Oshio, E. Sekizuka, and H. Minamitani 1991 *Proc. of Industrial Electronics, Control and Instrumentation (IECON)* 3 2375–2378

[2] M. Nomura, M. Hori, J. Shimomura, and M. Terashima 1996 *IEEE Transactions on Industry Applications* 32 796–801

[3] K. C. Michel, O. F. Fiedler, A. Richter, K. Christofori, and S. Bergeler 1998 *IEEE Transactions on Instrumentation and Measurement* 47 299–303

[4] M. S. Uddin, H. Inaba, Y. Itakura, Y. Yoshida, and M. Kasahara 1999 *Applied Optics* 38 6714–6721

[5] H. M. Go, T. Ogawa, J. Takayama, S. Ohyama, A. Kobayashi 2004 *Sensors and Actuators A: Physical* 112 87–93

[6] K. Kitagawa, M. Hayashi 2000 39th *SICE Annual Conference* 201A-2

[7] Y. Shimoto, J. Takagi, K. Egawa, Y. Murata, and M. Takeuchi 1997 *Intelligent Transportation System (ITSC) IEEE Conference on* 1000–1004

[8] M. Nakayama, T. Yamaura, and A. Kobayashi 1982 *Transactions of SICE* 18 70–76

[9] A. Kobayashi, M. Nakayama, T. Yamaura, Y. Ohkami 1979 *Transactions of SICE* 15 89–96

[10] M. Nakayama 1982 *Doctor thesis, Tokyo Institute of Technology*

[11] Cao Li 1992 *Doctor thesis, Tokyo Institute of Technology*

[12] S. H. Jun, S. Ohyama, A. Kobayashi, and T. Yamaura 1994 *Transactions of the Society of Instrument and Control Engineers Japan* 30 276–284

[13] T. Ogawa 1994 *Master thesis, Tokyo Institute of Technology*

[14] A. Kobayashi 1980 *The Society of Instrument and Control Engineers (SICE) Transactions on* 19-4 409–417

[15] A. Kobayashi 1980 *The Society of Instrument and Control Engineers (SICE) Transactions on* 19-6 571–579