Integration of Current-mode VSFD with Multi-valued Weighting Function

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Abstract: This paper describes a new type of the spatial filter detector (SFD) with variable and multi-valued weighting function. This SFD called variable spatial filter detector with multi-valued weighting function (VSFDwMWF) uses current-mode circuits for noise resistance and high-resolution weighting values. Total weighting values consist of 7bit, 6-signal bit and 1-sign bit. We fabricate VSFDwMWF chip using Rohm 0.35μm CMOS process. VSFDwMWF chip includes two-dimensional 10x13 photodiode array and current-mode weighting control circuit. Simulation shows the weighting values are varied and multi-valued by external switching operation. The layout of VSFDwMWF chip is shown.

Keywords: Variable Spatial Filter Detector with Multi-valued Weighting Function, Spatial Filtering Method, Spatial Filter Detector, Current-mode

1. Introduction

A sensor is a device that is able to sense the presence or absence of some phenomena and provide a reading of the intensity of those phenomena in a quantifiable form with the appropriate units of measure. Sensors take many forms depending on what they are designed to measure. However, the general sensor has only the simple function since it was developed and manufactured causing the material or the shape of sensor. For advance sensing system or developed measurement system, it is necessary to devise the shape of the sensor and the structure such as the mutual configuration of the sensor element. From this point of view, the interest in spatial filter detector (SFD) has been increasing because it can change the shape and configuration by varying its weighting function and process the signal at high speed by the spatial parallel processing. As the application cases of the conventional spatial filter detectors, many research results such as non-contact velocimetry and on-Line defect detection by the set of parallel slit have been proposed[1]~[4]. However, these spatial filter detectors have the demerits that are fixed weighting functions and limited weight values. Much more weighting values with continuously exchangeable setting have been demanded for high precision, active and adaptive measurement. To overcome these disadvantages, Ogawa proposed new type SFDs. Ogawa 's SFD has variable and multi-valued weighting function with 16x16 photodiode array[3]. Despite the system has discretely exchangeable 7-signal bits and 1-signal bit weighting values, the system are big size about 45cm x 35cm.

In this paper, we present a new type SFD with variable and multi-valued weighting function by current-amplification method using current mirrors. As the integration of this SFD, we design and fabricate variable spatial filter detector with multi-valued weighting function (VSFDwMWF) IC chip. In Section 2, we desribe the basic spatial filtering principle and the method for realizing two-dimensional SFD. In Section 3, we present the system configuration of VSFD-wMWF chip. In Section 4, we show the simulation results of multi-valued weight varying by switching using digital memories. Finally, Section 5 gives the conclusion.

The VLSI chip in this study has been fabricated in the chip fabrication program of VLSI Design and Education Center(VDEC), the University of Tokyo in collaboration with Rohm Corporation and Toppan Printing Corporation.

2. Spatial filtering method

2.1. Basic spatial filtering method

The spatial filtering method (SFM) is a spatial parallel signal processing technique which executes signal processing based on 2-D or 3-D spatial information. Features of the SFM in common are spatial parallel processing executed can be described by the space integral. If $f(x, y)$ is the spatial pattern at position (x, y), and $h(x, y)$ is the spatial weighting function, the spatial filtering method can be defined as equation

$$g(x, y) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x, y)h(x, y)dxdy \qquad (1)$$

Fig.1 shows the basic model of optical spatial filter for velocity measurement.

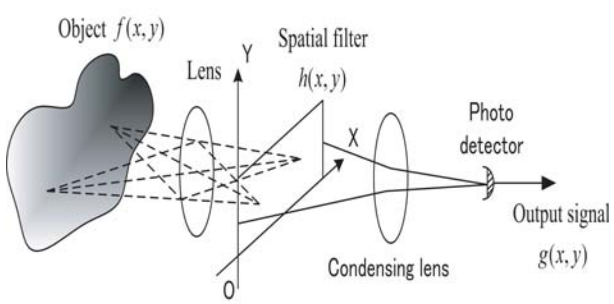


Fig. 1. Basic model of optical spatial filter velocimeter

2.2. Spatial filtering method to realize VSFDwMWF

2.2.1 Variation of weighting function

When realizing the spatial filter detector using a CMOS image sensor or photodiode array, we can think the spatial region is divided into small areas, a pixel, by the structure of the sensor. The spatial pattern $f(x, y)$ on a pixel of photodiode array is defined as Δxy. Fig.9 shows the structure of the VMSFD realized by using photodiode array structure. Here, a pixel is a square and has the width d with x, y axes.

$$\Delta xy = \begin{cases} h(X, Y) & (X \leq x \leq X + d, Y \leq y \leq Y + d\ ) \\ 0 & otherwise \end{cases} \quad (2)$$

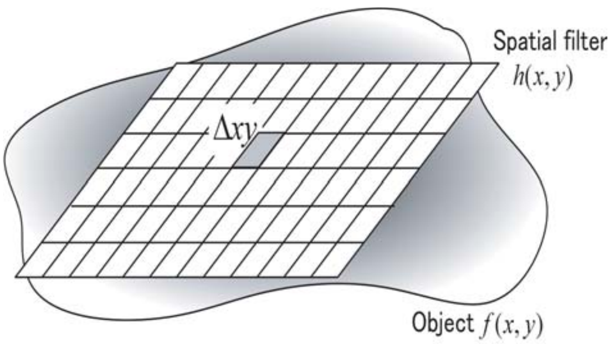


Fig. 2. Spatial filtering by the meshed spatial filter

In this case, the equation (1) can be written as

$$g = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} f(x, y)h(x, y)\, dx\, dy \quad (3)$$

$$= \sum_{X}\sum_{Y} g_{xy} \quad (4)$$

$$(where\ \ g_{xy} = \Delta xy \int_{X}^{X+d}\int_{Y}^{Y+d} f(x, y)dxdy) \quad (5)$$

By meshing the spatial region, the problem of the variable weighting function realization will be transformed to next two problems.

(a) From the problem of the multi-valued weighting function to the problem of the multi-valued weighting function of a small region Δxy

(b) From the variation problem of spatial pattern of the weighting function to the problem of the combination of small regions Δxy

2.2.2 the multi-valued weighting function of a small region Δxy

The small region Δxy is correspondent to the pixel on the image plane in case of the image processing. That is to say, the realization of variable and multi-valued weigting function is a pixel with multiple weight values which can be varied discretely in this case.

There are two methods to change the signal value. The first method uses the effect of the multiplication by the elements or the configuration with the amplifying function. The second method uses the effect of the addition with the superposition function like as the condensing lens and the time integral. We propose the structure which combined the structure of the product with the structure of the sum in order to realize the multi-valued weighting function of a small region .

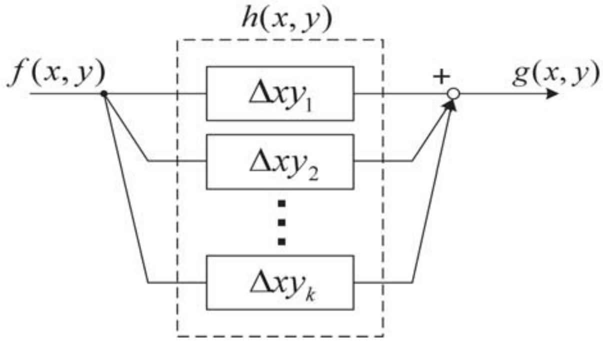


Fig. 3. Product-Sum structure

Fig.3 shows the product-sum structure. The total weighting function $h(x, y)$ is the sum of the weighted value.

Each Δxy_k has the structure of the product and the addition all of that is the structure of the sum. The methods to realize the structure of the product and the sum multi-valued can be considerable as follows:

[Structure of the product]

(a) Multiple sensor sensitivity itself

(b) Gradual adjustment of the input signal to the sensor

(c) Variable amplification of the amplifier

(d) Multiple division of the output signal of the sensor

[Structure of the sum]

(a) Time integration of signal

(b) Multiple summation of signal

(c) Combinative addition of the multiple signals

In the structure of the product, (a) is unrealizable because the sensor sensitivity is fixed. Since the spatial pattern of the input signal should not be converted, (b) is also difficult to be adopted. The possible methods are (c) and (d) as the structure of the product. At the viewpoint of the real-time processing, (c) of the structure of the sum is the most appropriate method. However, this method has the problem that the multi-valued weight must be discrete.

2.2.3 Combination of small regions Δxy_k

For setting the total weighting function of the small region variably, two-dimensional weight matrix table individual weighting value information to be an element is adopted. Two-dimensional weight matrix, M, which makes weighting value in the small region of spatial coordinate (x, y) to be the (X, Y) element is considered. On the spatial filter, the

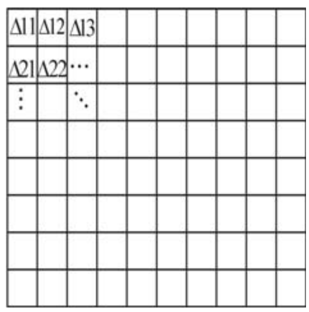


Fig. 4. Weight matrix table

variable weighting function will be realized by the (X, Y)

elements at each small region. If we can change (X, Y) elements, the variable and multi-valued weighting function can be realized. Fig.4 shows the weight matrix table.

3. VSFDwMWF chip fabrication

We fabricate VSFDwMWF chip using Rohm 0.35μm n-well double-poly three-metal CMOS fabrication process of offering from VDEC(VLSI design and education center) at the university of Tokyo. All desing are carried out in the full custom.

3.1. System configuration

VSFDwMWF chip includes 10x13 photodiode array, weight setting block, address decoding block and differential op-amp block. The power supply voltage is 3.3V. Fig.5 shows system configuration as block diagram. Metal 1 layer and 2 layers in

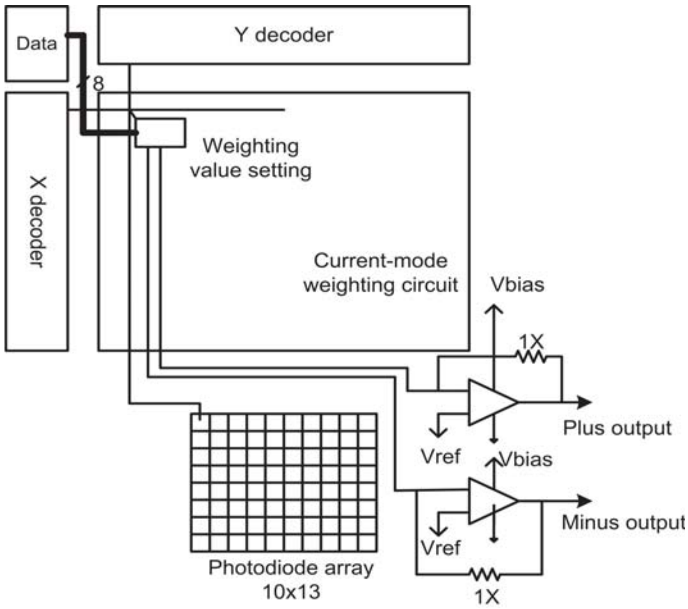


Fig. 5. System configuration of VSFDwMWF chip

three-metal process are used for the main routing. Metal 3 layer is used only for shading light except photodiode array region not to generate photocarriers and for routing between the current-mode weighting circuit and photodiode array. The chip takes the size of 2.4mm^2 and uses QFP 80 ceramic package.

3.2. Photodiode array

In this fabrication, the photodiode is used as the sensor of VSFDwMWF chip because it has simple structure and can be designed on CMOS standard process. There are 3 kinds of photodiode strurcture using CMOS standard process. These are n-active/p-sub, n-well/p-sub, and p-active/n-well structures. Out of three structure, we use n-well/p-sub structrue since that structure has high quantum efficiency and simplicity[5]. Fig.6 shows the layout of photodiode. The size of the photodiode is 20[μm^2]. The numerical aperture is about 8[%]. The anticipated photocurrent of photodiode is 0.5[nA] under 600[lx] as test result of reported photodiode IC[6]. Not to generate photocarrier, the region except photodiode region is shaded by metal 3 layer[8]. Guard ring around photodiode region is connected to ground in order to reduce the noise effect.

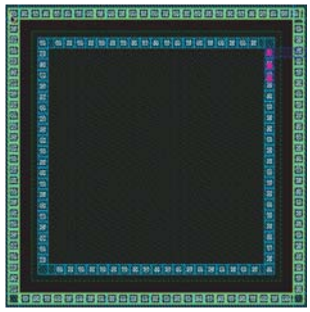


Fig. 6. Photodiode layout

3.3. Current-mode weighting circuit

In case of the spatial filter, the summation of the weighted singal is indispensable to finally obtain the effect of the spatial integral. The current is easier to use than the voltage in the summation of signals[9]. Additionaly, the current signal is expected to be also useful for improvement of reliability of measurement system, since to be strong for dielectricity noise. The output of the photodiode is, moreover, the current signal. Considering these point, the current exchange mechanism is adequate to realize the variable and multi-valued weighting function. To convert current value in this paper, multistage cascode current mirrors are used. We use the 7-stage cascode current mirror in our VSFDwMWF chip for 6 weight bits and a signal bit. The amplified current

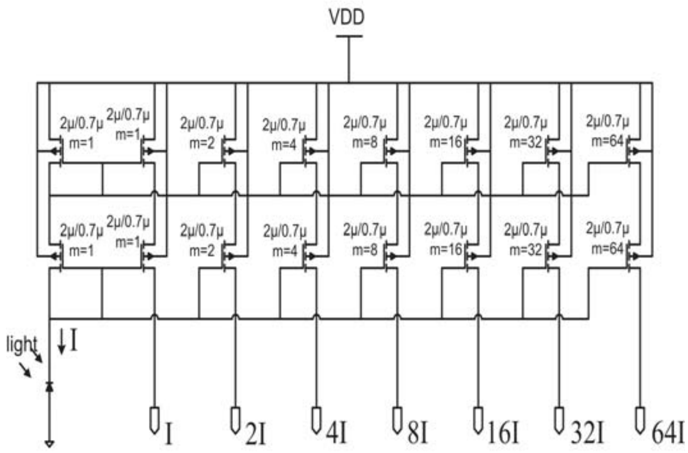


Fig. 7. Current-mode weighting circuit

by the cascode current mirror is added to be one signal and flows one line with a polarity, plus or minus, which can be controlled also to switching by the external weight data signal. Finally the output currents from all cells are converted the voltage signal by sense differential amplifiers. By the integration and memories internally, the processing speed will be faster. All of these operations achieve the equation of spatial filtering method between the spatial integration of input signal and the weighting function.

Switching is controlled by D flip-flop through data bus. The structure is shown fig.8.

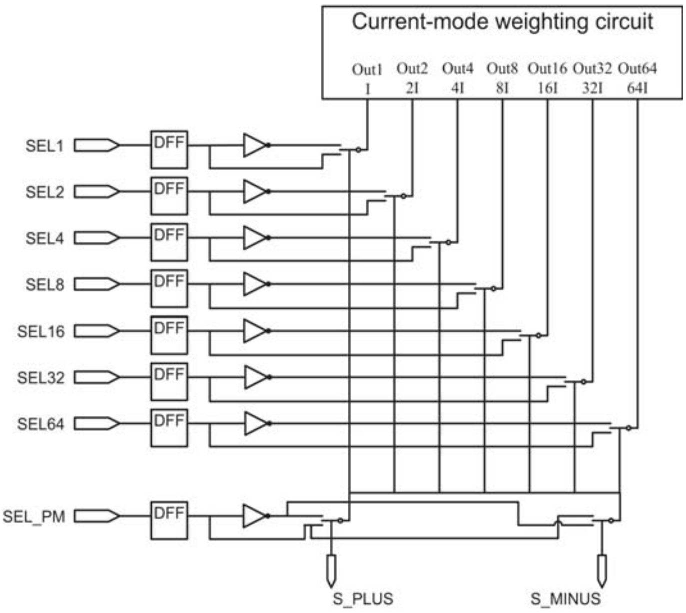


Fig. 8. Control circuits for weighting values

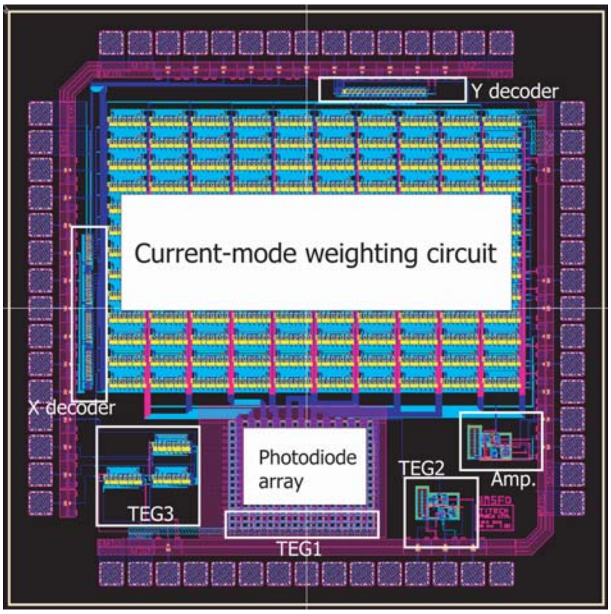


Fig. 10. Layout of VSFDwMWF chip

Fig.9 shows the layout of weighting control circuits. This part consists of analog weighting part and digital control part. In VSFDwMWF chip layout, the fingering method are used to draw current mirrors.

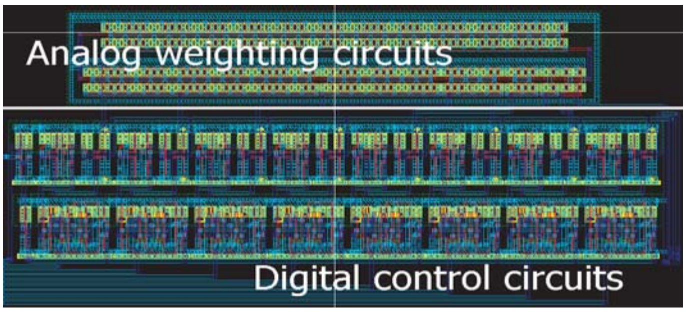


Fig. 9. Layout of weight control

3.4. Differential amplifier

The differential amplifiers are established at both sides of (+),(-) in order to amplify output signals. The gain of the amplifier is about 63dB, and phase margin is 62 degrees[7]. Using these amplifier with resistance carry out the current-voltage conversion. The circuit in which the bias circuit of amplifiers are insensitive for the temperature in order to decrese the effect of the rising temperature by the illumination.

3.5. TEG

In order to confirm the performance of designed circuits in VSFDwMWF chip, we design three TEGs(test element group) for photodiode, digital circuit, and analog amplification block.

3.6. Layout of VSFDwMWF

The design of VSFDwMWF uses Cadence^{TM}Virtuoso-XL layout editor and verifies Diva and Dracula tools[1]. The layout of VSFDwMWF chip is shown in fig.10.

4. Simulation

We report the simulation results which the amplified photocurrent through current mirrors from 1 to 64 times by switch on/off operations. Fig.11 shows the simulation results using Hspice. The error of the amplification is within 10[%]. As known from fig.11, the photocurrent from a photodiode can be amplified with various gain by switching the cascode current mirrors. This simulation uses Hspice[2]. Table4. and table4.show the simulation result with varying weight values when the feedback resistances of the differential amplifier are 1[MΩ] and 100[MΩ], respectively. Since the resolution is very low in the case of 1[MΩ] of the feedback resistance as we know from table of 1, it is necessary to use more amplifier attached outside in actual chip test. If moving the reference voltage of the amplifiers, the resolution will be high.

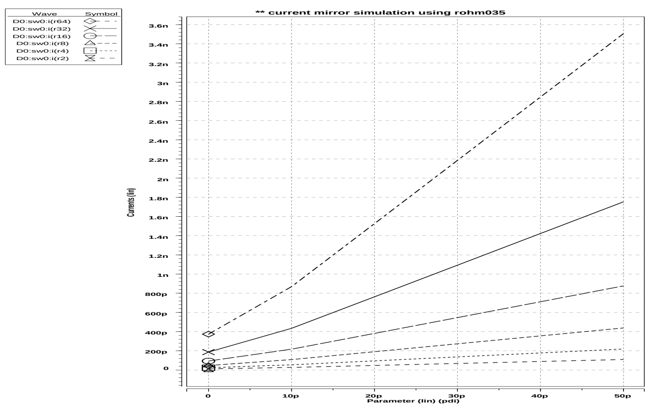


Fig. 11. Amplified currents by the cascode current mirrors

[1]"This work is supported by VLSI Design and Education Center(VDEC), the University of Tokyo in collaboration with Cadence Design Systems, Inc."

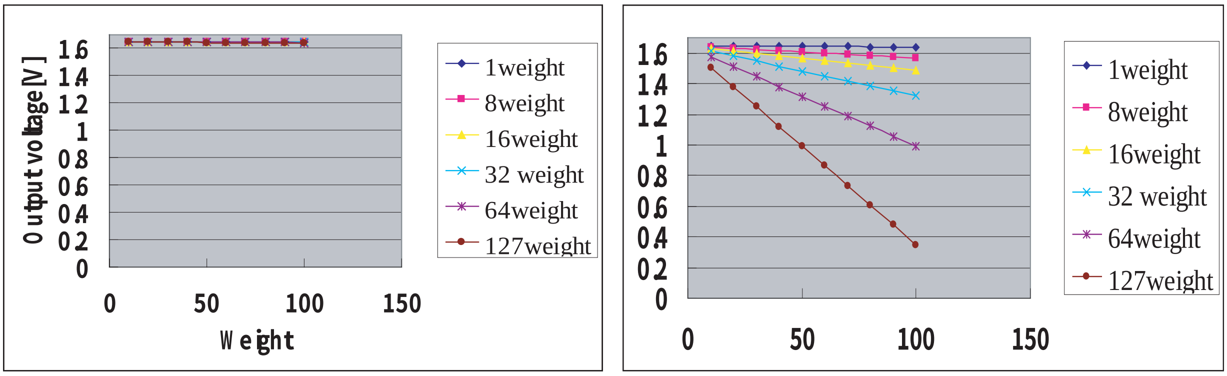
[2]"This work is supported by VLSI Design and Education Center(VDEC), the University of Tokyo in collaboration with Synopsys, Inc."

Table 1. Output simulation using $1M\Omega$ feedback resistance with varying weights

Use $1M\Omega$ feedback resistance						
$I_{pd}[pA]$	1weight	8weights	16weights	32 weights	64weights	127weights
10	1.65	1.650	1.650	1.650	1.649	1.648
20	1.65	1.650	1.650	1.649	1.649	1.647
30	1.65	1.650	1.649	1.649	1.648	1.646
40	1.65	1.650	1.649	1.649	1.647	1.645
50	1.65	1.649	1.649	1.648	1.647	1.643
60	1.65	1.649	1.649	1.648	1.646	1.642
70	1.65	1.649	1.649	1.648	1.645	1.641
80	1.65	1.649	1.649	1.647	1.645	1.639
90	1.65	1.649	1.648	1.647	1.644	1.638
100	1.65	1.649	1.648	1.647	1.643	1.637

Table 2. Output simulation using $100M\Omega$ feedback resistance with varying weights

Use $100M\Omega$ feedback resistance						
$I_{pd}[pA]$	1weight	8weights	16weights	32 weights	64weights	127weights
10	1.647	1.639	1.630	1.612	1.575	1.506
20	1.646	1.631	1.614	1.579	1.511	1.377
30	1.645	1.623	1.597	1.547	1.446	1.249
40	1.644	1.615	1.581	1.514	1.381	1.120
50	1.643	1.606	1.565	1.482	1.316	0.991
60	1.642	1.598	1.549	1.450	1.251	0.862
70	1.641	1.590	1.533	1.417	1.186	0.734
80	1.640	1.582	1.516	1.385	1.122	0.605
90	1.639	1.574	1.500	1.352	1.057	0.477
100	1.638	1.566	1.484	1.320	0.992	0.348



(a) Output simulation using 1[MΩ] feedback resistance with varying weights
(b) Output simulation using 100[MΩ] feedback resistance with varying weights

Fig. 12. Output simulation

5. Conclusion

In this paper, a new type of current-mode VSFDwMWF was proposed. Using the multistage cascode current mirrors, a pixel can have the weighting values of a pixel with 7bit resolution. In addition to this multi-valued weight, wecan exchange the weighing function as varying the weighting values, discretely. The simulation results prove VSFDwMWF chip can operate the spatial filtering method. We confirmed the various and multi-valued weighting function from the simulation results.
For realizing the integreted VSFDwMWF to miniaturization, we fabricated the chip using $0.35\mu m$ CMOS process. The size of this chip was $2.4[mm^2]$ and used the ceramic package. This chip consists of 10x13 pixel array, current-mode weighting circuit, address decoder,and the differential amplifiers. Although the resolution achieved of the designed VSFDwMWF chip is lower than expected, the obtained resolution can be useful to adopt the spatial filter applications like as non-contact velocity measurement, moment analysis, pattern matching etc., If the memory for saving the image is included in VSFDwMWF chip, more many applications as an image sensor are also considered such as a sensor for

the intruder monitoring with moving detection using the velocity measurement function. VSFDwMWF chip is valuable for adaptive and active measurement as a sensor with multifunction.

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