New array configuration for infrared remote sensing of forest fires.

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Abstract

A new array design where pixels present a bridge type configuration is proposed. This configuration improves the characteristics of standard infrared arrays for remote sensing, in particular of those used for forest fires detection (PbSe based). The consequences are of interest mainly in staring non-imaging, large range and large field of view, sensors. The design also accomplishes for low cost and low energy consumption.

Furthermore, non-uniformity effects in the focal plane as the azimuth angle increases can be properly minimised. Other important advantage is the FOV and fill factor enlargement maintaining the optics and connection complexity.

1. Introduction

IR sensors are commonly used in remote forest fire detection systems because of the high IR emission intensity of combustion gases (mainly carbon dioxide) in the 3-5 atmospheric window.

The development of a forest fire alarm system is the final goal of the research in course. The basic concepts of the sensor system and land coverage is described elsewhere. The proposed device is a staring non-imaging sensor that would detect the angular position for a determined forest fire. The global fire position would be obtained from two or more sensors or stations. One sensor includes one array and would cover a sector area of 7 km range by 20º azimuth.

In order to reduce costs and maintenance, only one fixed lens (no focusing device) and no mobile parts are permitted in the system.

Photoconductive PbSe is the ideal candidate to work at moderate low temperature, obtainable by Peltier devices, in the mid IR as it presents a pretty fair detectivity ($>10^8$cmHz$^{1/2}$/W). Also PbSe arrays can be obtained in a variety of linear formats. Otherwise, the high impedance of PbSe allows for to be interfaced with CMOS readout circuits. Linear array formats with CMOS readout are currently available in 64, 128 and 256 element standard configurations of square or rectangular pixel size[1].

Other important aspect to be taken into account in the system design is the non-uniformity in the signal response and the rapid deterioration of the spot shape as the azimuth angles increases [2]. Although there exist some algorithms for non-uniformity partial correction [3][4], a new method to improve it, using topologic design, is proposed in this work.

2. Bridge configuration and system characterization

Conventional designs (PbSe arrays) use a linear configuration with a single or a double row of elements. In this standard pixel configuration one of the two terminals (CP) of each pixel is common to all (see figure 1a). Each pixel is connected to a pin out, so the same number of pin outs that pixels is needed.

In the proposed design, bridge configuration, the pixels are grouped by pairs. Two pixels are connected to the same pin out, so the pin out number can divide by two the pixels number. This arrangement permits to maintain a simple technology with one interconnection level). There are in this case two common terminals, one (CP1) common to one half of the total pixels and the other (CP2) common to the other half, see figure 1b.

This arrangement can be defined as a bridge configuration, because of typical bridge detection techniques can be used in conditioning electronics. However, for a customary electronics, the activation of one of the common terminals is permitted too.

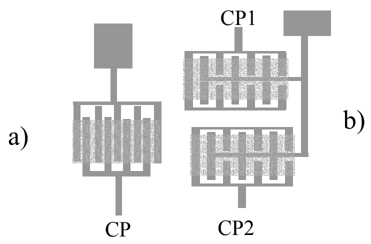

Figure 1 a. Standard Configuration b. Bridge Configuration.Shaded area means for PbSe material

The characterization of the bridge arrangement was accomplished using a physical simulator developed in order to evaluate different configurations.

The start point of the study was the evaluation of the IR emission of a forest fire. In order to obtain realistic values of the energy coming from a fire to be located 7 km apart from the sensor; experimental measurements of the irradiance of a controlled fire have been performed. A Fourier transform based spectroradiometer (model MIDAC-AM) has been used to carry out these measurements. Experimental spectra have been obtained at 400 m. Irradiance at 7 km has been calculated from experiment by using a simple model of energy transfer.

Simulation of atmospheric effects has been performed using PCMODTRAN2 code. This code is the PC version of the *Moderate Resolution Atmospheric Radiance and Transmittance Model* (MODTRAN), based on the 1996 HITRAN database. Values around 4.10^{-9} W/cm^2 for an incipient forest fire, have been obtained for IR irradiance in the 3-5 μm spectral region.

This irradiance level on the focal plane was obtained, inside the laboratory, from a calibrated black body properly located in front of the sensor. The measurements were carried out on PbSe detectors with an electronic arrangement to obtain the bridge configuration . Finally, an "embedded computer" card has been used for system control and data acquisition.

Bridge configuration characteristics

As the system must detect low irradiance, the relationship between the target spot size in the focal plane and the pixel size is an important aspect to achieve a high detection capability. In order to deliver more optical energy to the photodetector the designer would increase the collector aperture (Ac), but this decreases the FOV [5] rising the price.

For a constant number of pixels, the FOV can be increased enlarging the array size. This can be done by two ways, one increasing the spacing between adjacent pixels, but it increases dark zone also lowering the fill factor. The other way is to increase the pixel size but this leads to a loss of sensibility and resolution as relative variation of photodetector resistance ($\Delta R / R$), decreases.

Furthermore, the field of view can be enlarged increasing the array size simultaneously to the pixels number, this would be the solution for imaging sensors. In our case (non-imaging sensors) it would increase the energy consumption, the electrical noise, the circuit complexity and therefore the manufacturing and maintenance costs.

One of the fundamental advantages of this configuration is the feasibility of increasing the FOV with the same technology (one interconnection level) and the same pin out number.

Another property for this configuration is to have many degrees of freedom for the electronics circuitry. In all the cases studied the sensibility can be increased, therefore permitting the detection of smaller energies, increasing the system range.

As it is well known for all IR detectors, the photodetector resposivity and dark resistance are temperature dependent parameters. So it becomes necessary to implement some kind of temperature compensation.

Another important advantage of the proposed configuration is its capability for an automatic in-pixel temperature compensation. Furthermore, the differential signal obtained from the bridge arrangement permits the automatic compensation of every interference affecting simultaneously to the elements.

3. Geometrical Design

One of the main problems for large FOV optical systems is the distortion of the image at large incidence angles. For non-imaging systems as described here, with one sole lens, this distortion begins to be important for angles higher than 5º. [2]

This effect increases the non-uniformity behaviour and also the difference of the relative variation in the pixel resistance ($\Delta R / R$).

The proposed geometrical design optimizes the non-uniformity for large incidence angles as this pixel has a greater active zone in its center.

In figure 2, it can be seen two topologies. One of these (double pixel) increases the center of active zone and slightly increases the fill factor.

The resistance in the pixel corners can be used to compensate the spot distortion. This topology presents an equivalent length W greater than the simple topology. The difference between both lengths is:

$$\delta W = Na + (N-1)\Delta \qquad (1)$$

where a: width of the electrodes
N: number of sectors or fingers (should be pair)

$$\Delta = 2l((1/F.E) - 1) - a \qquad (2)$$

where l : distance between electrodes
F.E: corner factor (0,6 for a 90º corner)

This is only valid for Δ >0, in this case equivalent length W is greater than the simple topology.

As the pixel area is decreased, double pixel topology improves fill factor and homogeneity.

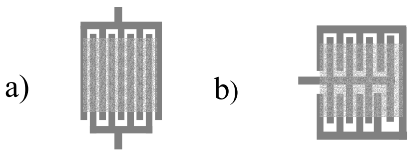

Figure 2. Pixel topology
a) simple b) double

A specific software was developed to study the effects of the spot size in order to optimize the pixel geometry.

In figure 3 these effects about fill factor in double and simple pixels, can be seen for 5 different areas (real area). This configuration is more advantageous when the pixel is shortened.

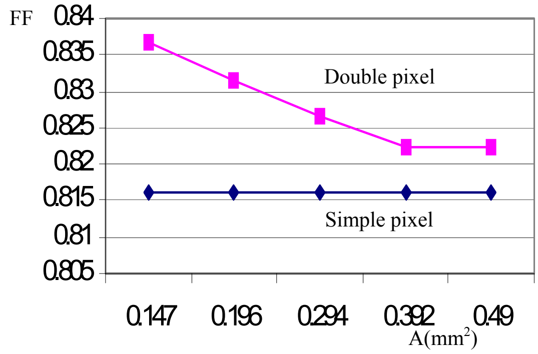

Figure 3. Fill factor simulation for five different areas as the pixel is shortened

In table 1, the sensibility ($\Delta R / R$) for two incidence angles (0º and 8º) can be seen. The non-uniformity is smaller in the double pixel topology. The PbSe total area is 0.176 mm^2 in both topologies.

When the azimuth is 0º (normal incidence) the sensibility is the same for both topologies but the evolution of the spot percentage inside the pixel with the incidence angle decreases and the sensibility too. In the double pixel topology the active area is greater than in the simple one, therefore the sensibility decreases less.

Azimuth	0º	8º
$\frac{Area(spot)}{Area(pixel)}$ (%)	100	62,5
$\Delta R / R$ % (Simple topology)	2,5	1,5
$\Delta R / R$ % (Double topology)	2,5	1,77

Table 1 Comparison of sensibility for two-incidence angles

In table 2 the comparison between some arrays with different configurations and different geometry can be seen. The magnitudes to be consider are the FOV and a new parameter NM to measure the non-uniformity in sensibility. NM parameter is defined as:

$$NM = \frac{R_{INA} - R_{EA}}{R_{INA}} \text{ x } 100 \qquad (3)$$

where R_{EA} is the resistance in the extreme of array and R_{INA} in the center.

ARRAY	Nº OF ELEMENT	FOV H/V	NM (%)
Standard simple	32x2 (bilinear)	13.35º 0.32º	24
Bridge double	32x4	13.35º 1.36º	19,5
Standard simple	64 (linear)	22.55º 0.28º	37
Bridge double	64x2 (Bilinear)	22.55º 1.32º	29

Table 2. Comparison between different arrays with different Field of view (FOV) and different non-uniformity factor (NM).

4. Conclusions

The bridge configuration and double topology presents the following advantages in the manufacture of low cost IR remote sensors.

- The proposed configuration allows for the addressing of up to four different rows with only one interconnection level.

- The FOV can be increased maintaining the number of pin outs so lowering the circuitry complexity.

- The bridge configuration greatly reduces the thermal and time drifts of the system.

- Topological design improves drastically non-uniformity in array signal response.

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