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Potential application of antenna-pair coupled micro-bolometers in whole complex field sensing

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ABSTRACT

This presentation explores potential application of *antenna-pair* coupled micro-bolometers in IR beam wavefront metrology. It describes an array configuration of such bolometers and a method for extracting a 1-D whole complex field information from its response. In addition, it discusses the requirements on the antenna-pair spacing and the spacing between the pair elements of the array configuration for extracting the complex field information. A numerical simulation based on the transmission line theory shows the effectiveness of such an array in recording the complex field spatial information of incident radiation; especially, it shows that the wavefront phase information can be extracted without the knowledge of the single antenna pattern. The discussions here should also be valid for antenna-pair coupled bolometers working at longer wavelengths.

1. Introduction

An antenna coupled square-law radiation detector (e.g. bolometer) array could potentially be important for astronomical imaging or other application fields at IR bands due to its fast response and excellent sensitivity to the radiation field compared to other detectors [1,2]. Since the square-law detectors are used however, sensors that are composed of single antenna-coupled detector array function like other regular radiation sensors and can not preserve the spatial phase information of the radiation field which is important in beam control and high-resolution imaging.

In order to retain the spatial phase information, detectors that are coupled with a pair of identical IR antennas have been examined recently [3–5]. In such a scheme, the radiation waves at two adjacent positions are collected by two antennas and then transmitted by coplanar strip-lines and combined at the bolometer. It is evident that the response of the bolometer would be associated with the interference of the two waves from the antenna pairs, a scheme similar to interferometers. The experimental measurements of the response of the such antenna-pair coupled element have demonstrated some of the features unique to the coherent interferences. For example, beam steering and beam narrowing effects in the response pattern have been observed in [4]; spatial coherence function measurement of an extended light source using such an antenna-pair coupled bolometer has been found in good agreement with the function predicted by the Van Cittert–Zernike theorem [3]. These observations indicate the coherent working abilities and the potential of preserving the phase information of the antenna-pairs. In this presentation, we look a step forward and explore the potential application of such antenna-pair coupled bolometer to construct an array for *direct* sensing the whole field that includes both of the phase and amplitude spatial information, which are important for imaging and beam quality monitoring, etc. It is shown through analysis and numerical simulation in 1-D case, the whole field spatial information can be retrieved by processing the readouts from a specially configured array.

The remainder of the this paper is organized as the following: In Section 2, a model of the micro-bolometer coupled antenna-pair and the response features will be summarized. In Section 3, the 1-D example of antenna-pair based array configuration and the corresponding one method for extracting the complex incident field information (both of the wavefront phase and amplitude) will be introduced, and a simulation example is given. In addition, the requirements on antenna-pair spacing and the spacing between the pair elements of the array configuration for correctly extracting the complex field information will be analyzed in this section. Conclusions are made in Section 4.

2. The antenna-pair coupled bolometer and its response to a local planar incident wave: a summary

The geometry of an antenna-pair coupled bolometer element is shown in Fig. 1. The bolometer is connected to a pair of identical antennas (shown as dipoles in the figure) via transmission lines. The bolometer is, in general, located some distance away from the center between the antenna-pairs and the shifted distance of

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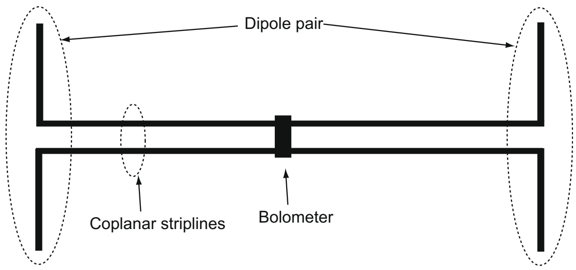

Fig. 1. Graphic illustration of dipole antenna-pair system.

bolometer from the center determines the property features of the overall angular response of the such element.

Considering a local plane wavefront is falling on such a device at angle of incidence θ, such a plane wave will stimulate electrical waves at the two antennas. Since the two antennas are identical, the stimulated open-circuit output voltage of the antenna must have the same form but with a phase difference ϕ with $\phi(\theta) = 2\pi \cdot d \cdot \sin(\theta)/\lambda$ where d is the spacing between the two antenna and λ is the wavelength of the IR wave. The stimulated waves undergo the propagation with attenuations along the transmission line, reflection and transmission at the bolometer and coupling into the antenna of its counterpart. The stable complex wave field distributed at the bolometer can be the resultant of sum of all the waves and described by the transmission line theory. The bolometer response to the radiation field can be estimated from the power generated on the bolometer. In general, the bolometer response is not only the function of angle of incidence of the radiation field, but also the function of shifted distance of the bolometer and all the electrical and geometrical properties of the configurations. The model for full description of the bolometer response can be found in Ref. [5] and it shows that the overall angular response $P(\theta)$ can be described as a single antenna response $\mathscr{P}(\theta)$ modulated by an oscillating term that can be characterized by the visibility κ and the induced phase shift Δ [5], which is

$$P^{\pm}(\theta) = \mathscr{P}(\theta) \cdot \{1 + \kappa \cdot \cos[\phi(\theta) \pm \Delta]\} \tag{1}$$

where $\kappa \leqslant 1$. κ and Δ are solely determined by the geometry of design and the electrical properties of the materials and the $\pm$ sign before the induced phase shift Δ is determined by the shifting direction of the bolometers from the center between the antenna-pair. Particularly, $\Delta = 0$ when the bolometer is located right at the center of the antenna-pair. In addition, it should be noted that the single antenna response $\mathscr{P}(\theta)$ can be viewed as the product of radiation power W_0 and the response pattern P_0 to the radiation of unit power, which means $\mathscr{P}(\theta) = W_0 \cdot P_0(\theta)$. The angular response pattern $P_0(\theta)$ for a single antenna could be complicated due to the complexity of the surface current distribution on the substrate–air interface and the multiple reflections of incident IR waves on the two surfaces of the substrate on which the element is fabricated, however it has been shown to be symmetric even function in general [4,6]. It is evident that the overall response would still be even symmetric when the bolometer is at the center and such a symmetry would be broken when the bolometer is shifted away from the center.

3. The array of antenna-pair coupled bolometers for whole field sensing: 1-D case

The induced phase shift Δ in Eq. (1) describes the beam steering effect, and it enables the local phase slope to be calculated from the power response measurements. For example, one can use two elements with $\Delta = \pm\pi/2$ to measure the response to the same field at the same location twice, respectively, and obtain response measurements of P^+ from the element with $\Delta = +\pi/2$ and P^- from the element with $\Delta = -\pi/2$, then the local wavefront phase difference ϕ, the slope of the local phase function ϕ/d and even the relative intensity can be estimated by solving the two equations: $P^+ = \mathscr{P} \cdot [1 - \kappa \cdot \sin(\phi)]$ and $P^- = \mathscr{P} \cdot [1 + \kappa \cdot \sin(\phi)]$, which have the solution

$$\phi(\theta) = \arcsin\left[\kappa^{-1} \cdot \frac{P^+(\theta) - P^-(\theta)}{P^+(\theta) + P^-(\theta)}\right], \tag{2}$$

$$\mathscr{P}(\theta) = \frac{P^+(\theta) + P^-(\theta)}{2} \tag{3}$$

Apparently the estimated local phase difference ϕ is *independent* to P_0 since it is a common factor in the numerator and denominator of Eq. (2).

Knowledge about the phase difference ϕ, or the slope of phase function ϕ/d over a spatial region would help to estimate the phase function of radiation field, which is very important to many fields. One way to obtain this knowledge is to apply directly the results of Eq. (2), which might require using an element to scan over the field twice at the same sampled locations by the element-flipping method described in [5]. However, here we examine using a specially designed array to get the field information in which only one measurement is required, and which should be easier and faster compared to the scanning scheme.

The array under discussion is shown in Fig. 2 and has N elements. These elements in the array have equal spacing h and are aligned along axis x with coordinates $x_1, x_2, \ldots, x_N$ in which the subscripts denote the sequence numbers. The elements with even sequence subscripts are designed to have $\Delta = +\pi/2$ while elements with odd sequence subscripts are designed to have $\Delta = -\pi/2$.

This array is illuminated by a field $\sqrt{W_0(x)} \cdot \exp[j \cdot \psi(x)]$ in which $W_0(x)$ is the spatially slow varying radiation intensity and

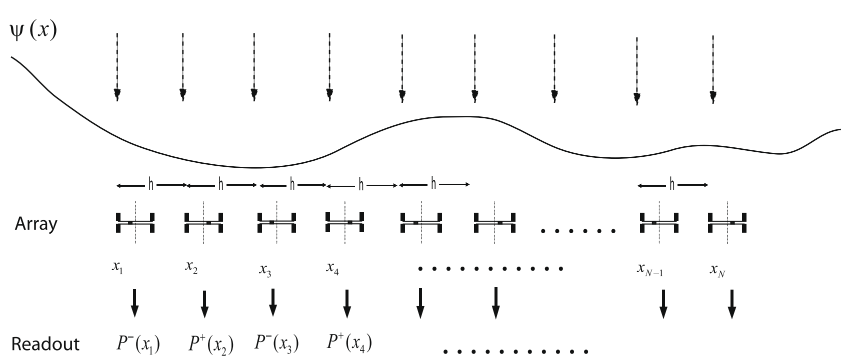

Fig. 2. Graphic illustration of the 1-D antenna-pair coupled bolometer array.