Collision Avoidance Device Using Passive Millimetre-Wave Array Based on Insect Vision

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A novel motion detector utilising a millimetre-wave array front-end, with signal processing that mimics insect vision, is described. The use of passive millimetre-wave detection enables a significant improvement over optical or infrared wavelengths, when a colliding object is obscured by rain, steam or other aerosols. This, for instance, used as a blind-spot detector, will enhance driver safety in poor weather conditions. As insect vision techniques do not attempt to process an image, but rely on tracking moving edges, the processing tasks are less hardware-intensive, resulting in a compact low-cost solution.

1 Introduction

Passive millimetre-wave radiometry is the art of sensing the low-spectral wavelength black-body radiation naturally occurring from typical everyday objects. A hardware configuration appropriate for passive millimetre-wave motion sensing, in industrial and vehicular applications where low resolution is acceptable, is described. Applications include collision avoidance and warning systems for automobiles and taxiing aircraft, close range all-weather object detection for ship docking and in-port navigation and industrial monitoring of manufacturing processes in obscured or dangerous environments. Operation in the frequency range 30 GHz to 100 GHz is aimed to take advantage of the characteristics of the millimetre-wave band that allow propagation over aerosol obscured paths. Commercial exploitation of systems operating in this band has in the past been constrained by the high cost of millimetre-wave systems and the substantial image processing required to process and resolve the information from the sensor.

With the availability of monolithic fabrication processes, it proves feasible to overcome the hardware constraints by the use of small, fully monolithic arrays. A single wafer supports a number of sensors comprising antenna elements, pre-detection amplifiers to enhance the signal-to-noise ratio and detectors or mixers to provide an output signal for data-acquisition and post-processing hardware.

The need to cost-effectively process images is solved by the use of techniques which extract primitive information from the sensors in a manner similar to that employed by insects. Such schemes are presently under investigation for optical systems [1-5] and can be adapted to process the video outputs of a passive millimetre wave sensor. Appropriate low-cost millimetre-wave hardware may therefore be incorporated with VLSI systems designed to minimise the processing requirements for specific applications such as motion detection and velocity estimation.

State-of-the-art systems, for collision avoidance, have concentrated on passive optical or IR techniques, or Doppler radar techniques. Passive millimetre-wave techniques offer the promise of improved all-weather performance, without the disadvantages of active systems – however, known mm-wave imaging techniques are far too expensive to compete. For the above applications, however, we propose a significant paradigm-shift by investigating the synergy between low-cost mm-wave techniques (with intentional sacrifice of performance) and low-cost insect vision processing techniques (that do not require high performance detectors). This investigation of artificial insect vision techniques augmented to the mm-wave domain is a unique world-first.

2 Discussion of the Array

A one-dimensional millimetre-wave antenna array, fabricated using hybrid technology, is used as a focal plane sensor in a lens based detection system capable of providing thresholded inputs to a processor based on insect vision algorithms. The short-range sensitivity and resolution, with a view to the design of monolithically fabricated arrays for use as front-end hardware in simplified object detection systems, is assessed.

The strategy was to develop a practical 37 GHz unit making use of the transmission window at this frequency and the availability of relatively low-cost fabrication techniques and components. The design is readily scalable to the 94 GHz band for monolithic fabrication. Integration of the millimetre-wave detector with post-processing electronics and appropriate algorithms for motion detection provides a functional system for many industrial and collision avoidance applications, and represents a significant advance in low-cost millimetre-wave hardware.

Preliminary test designs have been explored and tested at microwave frequencies. The antenna array comprises a number of substrate supported metal strip antennas of a design which is readily scalable for monolithic fabrication at millimetre wavelengths. The array has a bandwidth of 10% and has impedance and pattern characteristics that allow a field of view up to 90 degrees. It is shown from these characteristics that the millimetre-wave sensitivity is suitable for a test system operating at 37 GHz.

Since a one-dimensional array is used, a short focal length Rotman lens configuration was adopted for the beamforming. The entire system therefore has a planar geometry that is again compatible with printed and monolithic fabrication. Current work with the prototype array operating at 5 GHz has shown that care needs to be taken to avoid reflections that increase sidelobes in the element patterns. With F/D=1, it appears feasible at 37 GHz to construct a 15 element array with 15 beams, each having a beamwidth of 3 degrees, overlapping at 3dB points, and with sidelobes less that 10 dB. The resulting array aperture of 50mm at 37 GHz is readily achievable using hybrid fabrication techniques, and of 22 mm at 94 GHz is possible using wafer scale monolithic integration.

Passive millimetre-wave sensors have in the past involved detector diodes integrated with antennas. A lens is often used to create a focal plane system. In this work, the integrated antenna and low-loss beamforming network is followed by millimetre-wave mixers to downconvert the response of each beam. Low-noise mixers are fabricated with suitable beam lead Schottky diodes so as to maintain a reasonable noise figure without the need for expensive millimetre-wave amplification. This approach simplifies the required hardware and results in a single low-cost unit capable of integrated fabrication, while potentially retaining a satisfactory dynamic range and noise figure.

A 37 GHz array fabrication on an alumina substrate with a dielectric constant of 9.8 is described. Soft substrates such as RT-Duroid 6010 were found in our previous research to have unsatisfactory machining and fabrication characteristics resulting in unacceptable phase errors in the millimetre-wave system. Account is taken in the choice of the substrate thickness [6-9] and the finite array dimensions [10], in order to ensure that the measured performance is compatible with the performance achievable using monolithic fabrication at higher frequencies.

The principle mm-wave component required for implementation of the collision avoidance device is a radiometer capable of resolving approaching objects to the extent that the insect vision-based algorithms can identify moving edges. The layout of the circuit housing the antenna array, the beamforming network and the receiver is shown in Fig. 1. At the top edge are ten substrate supported metal strip folded dipole antennas. The feed lines from these antennas meander to the inputs of a Rotman lens beamformer to provide the appropriate phase inputs. Ten outputs from the Rotman lens are fed via impedance matching networks to ten Schottky barrier diodes that provide a direct conversion receiver. The dc level of the outputs provide a measure of the radiometric intensity of each beam , and are subsequently amplified for application to the processor. The measured beam patterns have approximately 10dB sidelobe levels, this level being mitigated somewhat by the flaring of the lens (dubbed 'batman') to eliminate reflections from the side ports of the lens. While tapers are used at the inputs to the lens, mismatches from the much

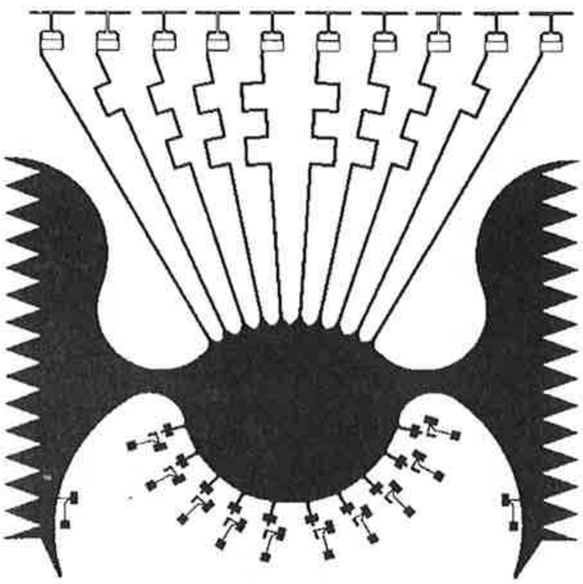

Figure 1: Circuit layout of Rotman lens array in a 'batman' configuration

smaller tapers at the outputs are tolerated due to the requirements for good beam definition between adjacent channels. This requirement is imposed by the differentiation and template generation procedure used in processing the outputs.

3 Conclusion

While millimetre-wave radiometric imaging has been the subject of investigation in the past, almost without exception the aim of such studies has been to produce images of sufficient resolution that they can be used as a substitute or backup to infrared or visual images, particularly where the propagation conditions are unfavourable to the latter systems. In this work, motion detection rather than imaging is of interest, particularly focussing on close range objects whose detailed structure is unimportant. Issues of both resolution and sensitivity are addressed in order to ascertain what features of the target are necessary for detection and how the resulting information can be used in systems such as those given as examples above. For example, in vehicle collision avoidance, the motion of an edge formed by the contrast change between the background and a vehicle may provide a basis for the detection of an approaching hazard.

In this paper we have reported preliminary radiometric measurements, on a small test array, demonstrating the feasibility of the 'batman' style layout. The next stage is to fabricate a larger 37 GHz array tailored to provide a proof-of-concept of the insect vision principle – this will require post-processing of the array outputs using insect vision algorithms. The main challenge will be to develop robust algorithms that can handle the noise, clutter, contrast, target features and ambiguity characteristics particular to mm-wave detection.

Further extension of this work will be to employ monolithic fabrication to construct a 94 GHz system for applications requiring more compact hardware or improved resolution.

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