LARGE SCALE W-BAND FOCAL PLANE ARRAY FOR PASSIVE RADIOMETRIC IMAGING

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ABSTRACT

This paper discusses the development of a large scale W-band focal plane array (FPA) for passive radiometric imaging application. The goal is to develop a 40x26 (1040-pixels) FPA to cover 15°x10° instantaneous field-of- view. Each receiver consists of a single direct detection MMIC which is a W-band high gain, wide bandwidth switched LNA with integrated Schottky barrier diode detector. A 1x4 FPA module, employing linearly tapered slot antenna, is used as the basic building block for the FPA. Typical receiver temperature sensitivity is 0.4K with 10 ms integration time. For the first time, an automated assembly process is used to produce W-band MMIC modules in large volume.

INTRODUCTION

Passive millimeter-wave (PMMW) focal plane (FPA) camera are new sensors capable of imaging through fog, cloud and low visible conditions at video rate. In recent years, with the advancements make in millimeter-wave MMICs, array antenna, packaging and low cost automated module assembly, the development of a large scale FPA is close to being a reality. For the past few years, TRW has pioneered the development of a millimeter-wave MMIC direct detection radiometric receiver [1,2] which is suitable for the implementation of large-scale FPA. In 1994, we reported the first W-band direct detection 1x8 FPA [3]. Since then significant progress has been made to further improve the receiver performance. In addition, a FPA manufacturing infrastructure is being established at TRW. The key capabilities include MMIC wafer production, automated on-wafer chip screening, automated module assembly and test. This paper presents the design and fabrication of a large scale W-band FPA. Typical receiver temperature sensitivity is 0.4 K with 10 ms integration time. An automated assembly process is used to produce W-band MMIC modules in large volume.

PMMW DEMONSTRATION CAMERA

The camera is a W-band focal plane array imaging radiometer made from 1040 direct amplification and detection MMIC receivers packaged in a two-dimensional focal plane array configuration (40x26 receivers, or 80x52 imaging pixels). Its aperture size is 18", field-of-view is 15°x10°, effective spatial resolution is 6 milliradians. A perspective rendition of the demonstration camera is shown in Figure 1.

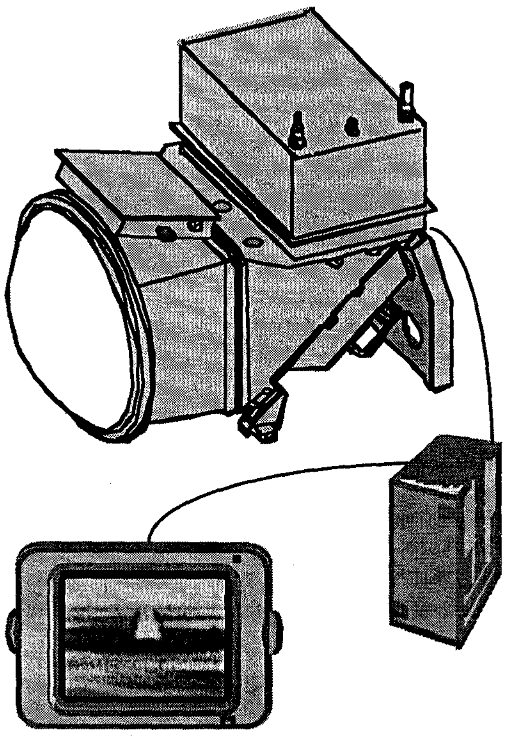

Figure 1. Passive Millimeter-Wave Demonstration Camera

Analogous to regular video or infrared cameras, a PMMW camera is made up of similar sub-systems: focusing optics, detectors at the focal plane, calibration, signal processing and display, and a housing for environmental protection. Figure 2 shows a block diagram of the camera's various sub-systems. In order to achieve a product beneficial to multiple users, each one of these sub-systems needs to be designed with functionality and low cost in mind. In this paper, we will focus the discussion on the FPA sub-system since it is the cost driver of the camera's system.

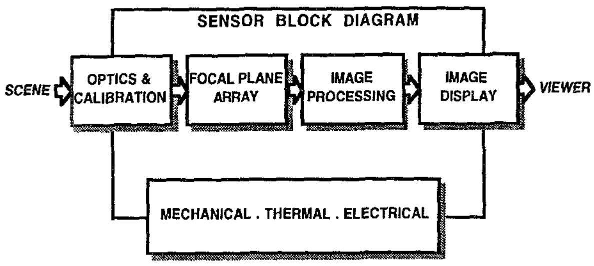

Figure 2. PMMW Camera Block Diagram

MMIC RECEIVER

The heart of the FPA receiver module is the W-band direct detection receiver MMIC. It is a high gain, wide bandwidth switched LNA with integrated Schottky barrier diode detector realized in TRW's production 0.1 µm InGaAs HEMT process. The design is similar to the one we reported earlier [4], but with further performance improvement. Figure 3 shows a photograph of the fabricated chip. It measured 7 mm x 2mm. The chip has a gain > 40dB over a bandwidth of 10 GHz, and a noise figure of 5.5dB. Adopting a novel receiver architecture, the chip achieved low system noise temperature and maintained good temperature stability. The direct amplification and detection switched receiver is a patented TRW design. Average temperature sensitivities of 0.4K with 10 ms integration time are achieved with the chips assembled on the 1x4 modules and with antenna in front of the chips.

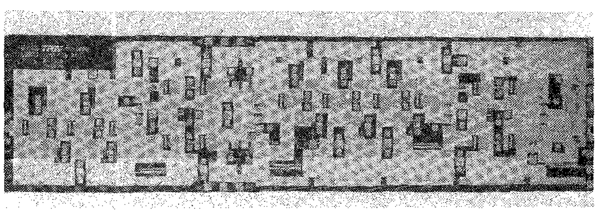

Figure 3. Photograph of the Direct Detection MMIC

The chips were on-wafer screened for ΔT performance. A powerful and unique automated W-band on-wafer ΔT test set was developed for this objective. Figure 3 shows the measured relative ΔT distribution from ~1000 MMICs. Correlation between on-wafer relative ΔT and receiver module ΔT has established that an on-wafer ΔT of 0.8K corresponds to a module level ΔT ~0.5K with 10 ms integration time.

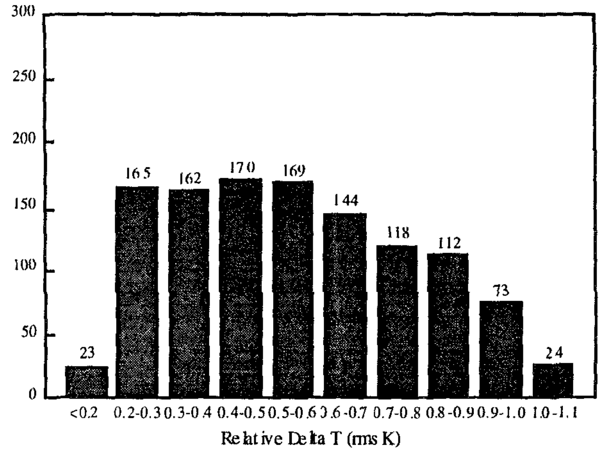

Figure 4. W-Band Direct Detection Receiver On-wafer Relative ΔT histogram

FPA 1x4 MODULE

The basic building block of the FPA is the W-band 1x4 receiver module. A picture of the fabricated 1x4 module is shown in Figure 5. It consists of the following elements:

- a W-band 1x4 linearly-tapered slot antenna
- 4 W-band MMICs
- 4 interconnecting substrates
- a multi-layer thick film board to house signal video signal conditioning and bias regulation
- I/O lead frame
- A40 carrier housing and cover

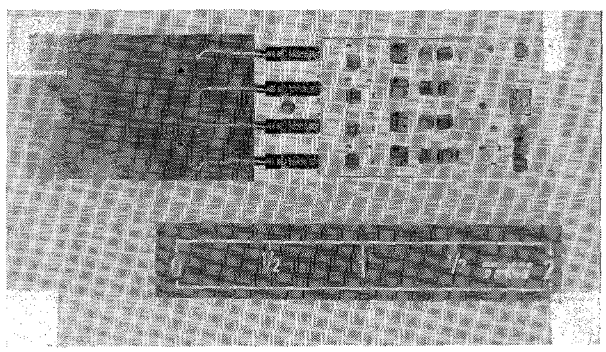

Figure 5. Fabricated FPA 1x4 Module

The manufacturing of these modules were done in TRW's Automated Assembly Line (AAL).

The AAL automates the following operations:

- die sorting, pick-and-place
- dispensing of adhesive and eutectic attachment
- epoxy cure
- plasma cleaning
- wedge bonding of ribbons and ball bonding of wires

It is important to recognize the performance advantage and economy of using an AAL approach to the manufacturing the of the modules. The placement accuracy for W-band MMIC is ±0.5 mils; the wire/ribbon accuracy is ±1 mil. Furthermore, with an automated process, yield will be improved, thereby reducing inspection and rework. Consequently, the throughput will also increase dramatically.

Figure 6 shows the measured ΔT performance from fourteen FPA 1x4 modules. Typical ΔT performance is 0.4K to 0.5K with 10 ms integration time. Currently, production is underway to produce the needed 260 modules for fianl FPA integration.

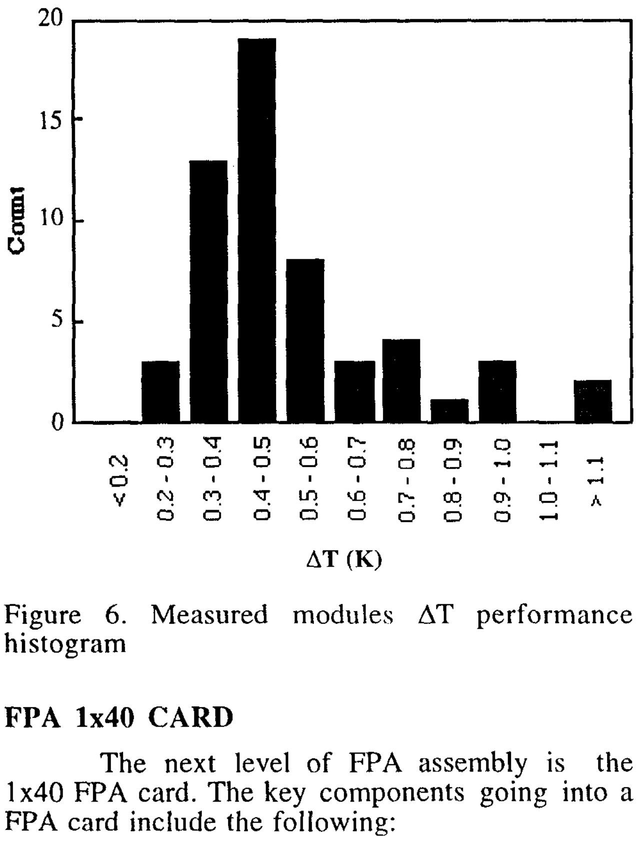

Figure 6. Measured modules ΔT performance histogram

FPA 1x40 CARD

The next level of FPA assembly is the 1x40 FPA card. The key components going into a FPA card include the following:

- ten 1x4 modules
- five signal processing hybrids for demodulation, amplification and digitization
- one printed-wire board
- one 1x40 card carrier
- one cable/connector assembly

A photograph of the 1x40 card is shown in Figure 7. The card itself is a linear focal plane array which can be used for various other imaging applications. Examples include cameras for airborne reconnaissance onboard aircraft or UAVs, automotive collision avoidance, airports and ground facilities traffic monitoring and sentry, etc.

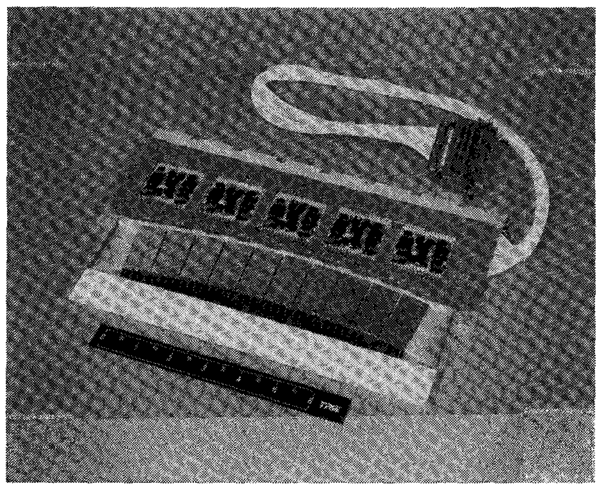

Figure 7. A completely assembled 1x40 FPA card

FPA ASSEMBLY

When the 26 (1x40) cards have been manufactured and tested, they are ready for FPA installation. The FPA housing has a backside cooling plate to remove heat efficiently from the cards. Cards will be mounted one by one into the FPA housing from the side. Cards are wedge-locked on the back-plate and screw-secured on both of the side-plates. In case of any need to remove a particular card for trouble-shooting and repair, the card can be easily removed without disturbing the adjacent cards.

The assembled FPA is placed at the focal plane (surface) in the camera housing for testing. Calibration of the entire FPA will be done by scanning through all 1040 pixels using a control computer. An external illumination source is turned on and off at two different power levels to simulate two different scene temperatures. During camera operation, this procedure is carried out periodically in order to provide a uniform reference illumination (calibration) to the 1040 receivers.

CONCLUSIONS

We have significantly advanced the state-of-the-art of passive millimeter-wave sensor design and manufacturing technologies. This is largely enabled by our ability to produce low noise, high gain, direct detection W-band MMIC receivers, and our ability to manufacture FPA receiver modules using an automated assembly line. The end product will be a passive millimeter-wave camera capable of providing an instantaneous, wide field-of-view, and which has many utilities for both military and commercial applications.

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