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TITLE: Commissioning and Characterization of a Dedicated High-Resolution Breast PET Camera

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14. ABSTRACT
The high-resolution breast camera under development for this project consists of many detector modules formed by coupling pairs of high resolution scintillation crystal arrays to position sensitive avalanche photodiodes (PSAPDs). We finalized the design of these modules. We operated 16 of these simultaneously and no electrical shorts were observed. Software was written to analyze performance of many of these modules. We achieve an average energy resolution of 10%. In addition, progress has been made on constructing a block setup to analyze performance in terms of imaging capabilities. Redesign of the electronics was required to decrease noise in the setup. Currently tests are under way with the updated electronics.Reportable outcomes include 3 peer reviewed publications, one submitted, 4 abstracts submitted to the IEEE NSS-MIC conference, an accepted and presented abstract at the SNM Breast Cancer Imaging conference, and 3 conference proceedings articles.

15. SUBJECT TERMS
Breast Cancer imaging, high resolution, PET camera

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Contents

1 Introduction

The DOD funded project titled 'Commissioning and Characterization of a Dedicated High-Resolution Breast PET Camera' aims at enhancing the role of PET in breast cancer management by constructing a high resolution PET camera. PET is an imaging modality whereby lesions are visualized based on biochemical activity, rather than lesions' morphology, which is visualized by other imaging modalities such as mammography, MRI, and ultrasound. We will test this high-resolution PET system in the following indications: (1) resolving inconclusive screening mammograms which often show up for patients with dense breasts, (2) enhance staging accuracy, and (3) monitor the response to neo-adjuvent therapy. Dedicated high-resolution cameras can detect smaller lesions and thus enhance the precision of the images. Because of their high sensitivity these cameras can also reduce the injected patient dose. We aim to achieve 1 mm^3 resolution using a unique detector design that is able to measure annihilation radiation coming from the PET tracer in 3 dimensions, using many $1 \times 1 \times 1$ mm^3 scintillation crystals.

2 Body

2.1 research accomplishments as outlined in SOW

1. **Building a Block Setup**
   Goal of the first task in this project was to test camera detection concepts, obtain experience working with many channels and perform image reconstruction.

   Building a block setup was initiated during the first funding period. We used dual modules that each contain 2 position sensitive avalanche photodiodes (PSAPDs) coupled to 8×8 array of $1 \times 1 \times 1$ mm^3 LYSO crystals. The two PSAPDs are mounted on a thin flexible circuit and are multiplexed as mentioned in [1]. We experienced significant problems with electromagnetic interference in the setup causing signal deterioration due to noise. We solved this problem by carefully re-routing signals across a printed circuit board. Tests are currently under way with one half of the block setup. It is anticipated to finish this setup in the next 6 months at which point we will reach milestone one. Successful completion will provide significant experience working with many of these modules as well as the development of calibration and data acquisition software. Figure 1 shows a photograph of the setup. 4 dual modules are mounted in a dedicated support structure. An intermediate flex circuit connects the dual modules electrically to a routing board. Long flat-flexible circuits (FFCs) are used to transfer signals to a signal conditioning board ('discrete board') which itself is connected to a readout board housing the RENA chip. The latter chip has a preamplifier, shaper, and trigger circuitry.

2. **Acceptance test of the LSO-PSAPD modules**
   Significant high voltage problems caused a delay in ordering many of the LSO-PSAPD units needed in the camera. A prototype run initiated in the beginning of the funding period showed the need for better high voltage insulation. We experienced electrical shorts between adjacent modules and between modules and their aluminum holding structures. Optimizations have been made and a larger order of units is begin prepared. Electrical shorts between adjacent modules are circumvented by placing large amounts of insulating paste around the modules. Shorts between the aluminum registration card and the modules are prevented by splitting the registration card in two parts, one part being built out of electrically insulating alumina, and the other part being fabricated out of aluminum. We were able to bias 16 dual modules

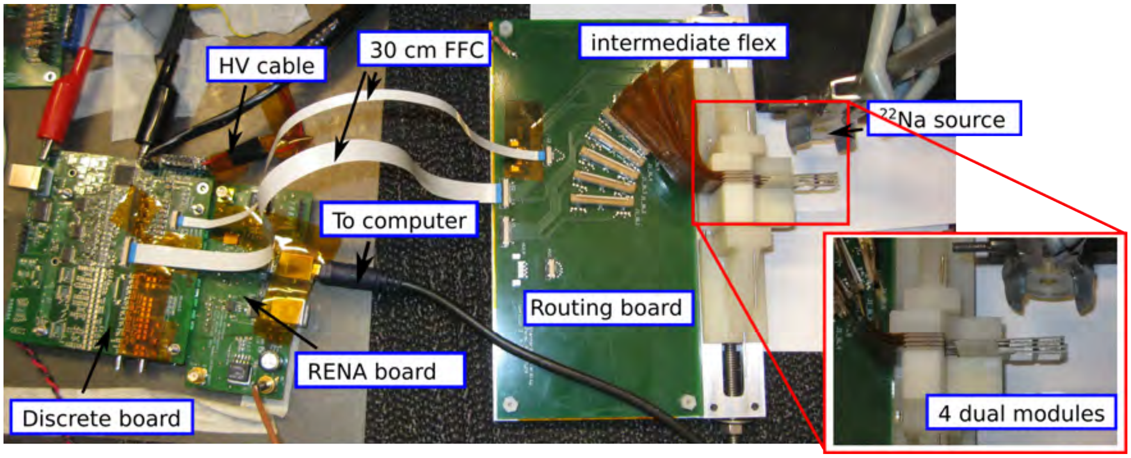

Figure 1: Photograph of the block setup being built. On the right four modules can be seen. Going from right to left a routing board, flat-flexible circuit (FFC), a discrete board and RENA board can be seen.

simultaneously in a registration card for several hours without observing any electrical shorts. A photograph of 16 dual modules in the registration card is displayed in Figure 2.

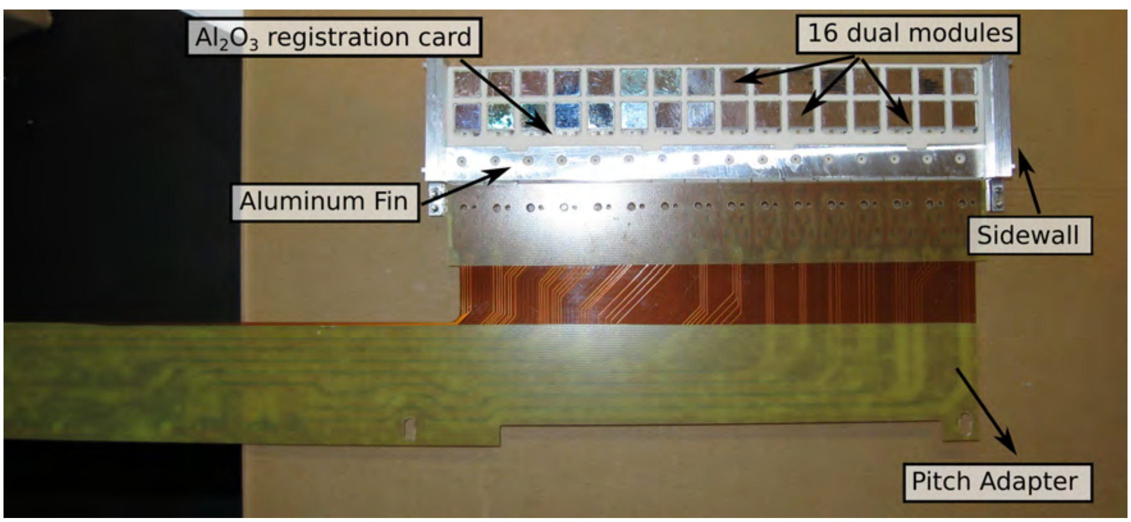

Figure 2: Photograph of 16 modules in a registration card. The latter has an aluminum fin for cooling as well as an alumina holding frame (white in the picture). 16 dual modules can be identified.

Software was written to test many modules. The software is able to analyze the manufacturer's test data and assign a score to each unit. Results of these tests are uploaded to a web server so they are accessible any time. Figure 3 shows an example of the analyzed data as obtained with the aforementioned software.

A mechanical setup was designed to test many of the modules. Preliminary tests are investigating the optimal bias voltage at which the modules should be operated. These tests are currently being performed.

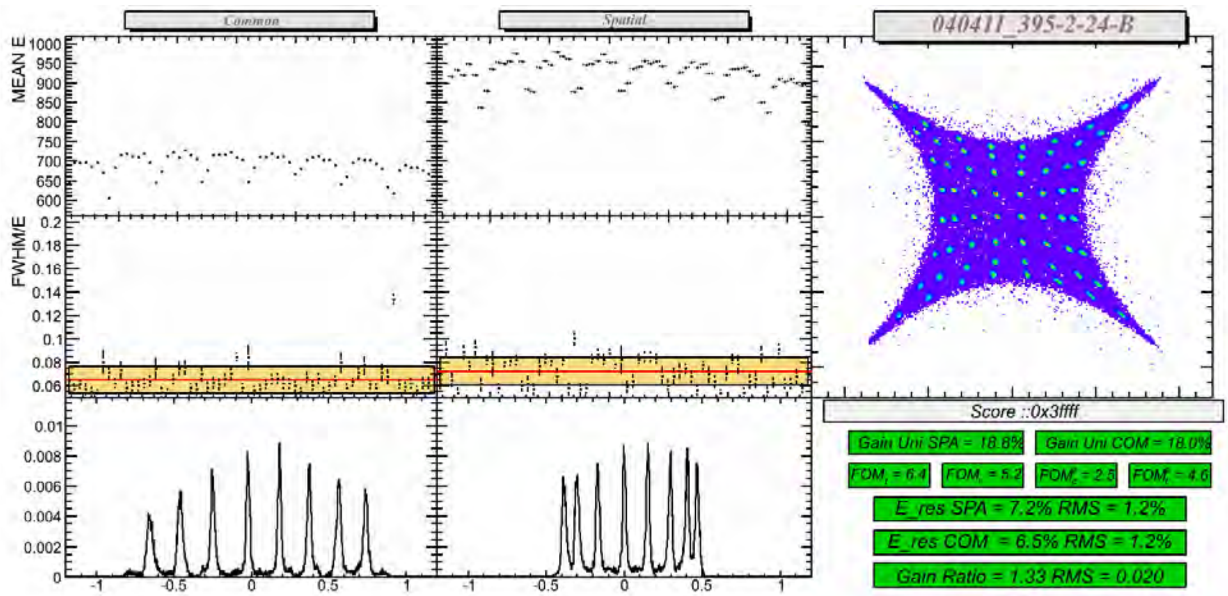

Figure 3: upper left frame shows the photopeak position for each crystal in the 8×8 array based on the spatial channels, center top frame, the photopeak position for the common channels. Center left and central panels show the energy resolution across the array for spatial and common channels respectively. The band indicates the average $\pm$ RMS. Bottom left and center show a profile through the flood histogram (upper right) for the top row and the 4th row respectively. Lower left frame shows the score for all aforementioned parameters.

3 Key Research Accomplishments

- Analysis of point source data yielded a point-spread-function of $837 \pm 46\ \mu m$, in agreement with the theoretically expected 793 μm [2]

- Simulation studies determined the amount of shielding required to reduce the amount of background radiation coming from highly vascular organs such as brain, heart and liver. These are reported in [3].

- Temperature and bias voltage dependence of module performance was studied and finalized in a paper that is currently under internal review.

- Significant HV problems were solved by applying a highly resistive paste around the modules

- Image reconstruction software was optimized for the two panel configuration. Reconstruction was performed on a graphics processing unit (GPU) instead of a standard CPU yielding significant speedup of the reconstruction.

- For the first time multiple modules were operated simultaneously.

4 Reportable Outcomes

4.1 Abstracts

- Abstracts submitted to the 2011 *IEEE Nuclear Science Symposium and Medical Imaging Conference*, to be held October 2011, Valencia, Spain:

    1. P.D. Reynolds, F.W.Y. Lau, A. Vandenbroucke, C.S. Levin: *Study of Readout for Groups of Position Sensitive Avalanche Photodiodes Used in a 1 mm3 Resolution Clinical PET System*
    2. F.W.Y. Lau, P.D. Reynolds, A. Vandenbroucke, C.S. Levin: *Signal Conditioning Technique for Position Sensitive Photodetectors to Manipulate Pixelated Crystal Identification Capabilities*
    3. A. Vandenbroucke, F.W.Y. Lau, P.D. Reynolds, C.S. Levin: *Measuring 511 keV Photon Interaction Locations in Three Dimensional Position Sensitive Scintillation Detectors*
    4. J. Zhai, A. Vandenbroucke, P.D. Reynolds, C.S. Levin: *Functionality Test of a Readout Circuit for a 1mm^3 Resolution Clinical PET System*

- Abstract submitted to *SNM Breast Cancer Imaging: State of the Art*, held April 21-22, NIH, Bethesda, MD

    1. A. Vandenbroucke, F.W.Y Lau, P.D. Reynolds, D. Innes, J. Zhai, C.S. Levin: *A high resolution, high sensitivity PET camera dedicated to breast imaging*

- Abstract submitted to *DOD Era of Hope Meeting*, to be held August 2-5, 2011, Orlando, FL

    1. A. Vandenbroucke: *Construction and Characterization of a high-sensitivity, 1 mm^3 Resolution PET Camera to aid Breast Cancer Management*

4.2 Publications

1. F.W.Y Lau, A. Vandenbroucke, P.D. Reynolds, P.D. Olcott, M.A. Horrowitz, C.S. Levin Analog signal multiplexing for PSAPD-based PET detectors: simulation and experimental validation *Phys. Med. Biol.* **55**, 7149.

2. A. Vandenbroucke, A.M.K. Foudray, P.D. Olcott, C.S. Levin Performance characterization of a new high resolution PET scintillation detector *Phys. Med. Biol.* **55**(19), 5895–5911.

3. V.C. Spanoudaki, F.W.Y Lau, A. Vandenbroucke, C.S. Levin, Physical effects of mechanical design parameters on photon sensitivity and spatial resolution performance of a breast-dedicated PET system *Med. Phys.* **37**, 5838-5849

4. A. Vandenbroucke, T.J. McLaughlin, C.S. Levin Performance evaluation of a large area position sensitive analanche photodiode coupled to an LSO crystal array as a function of temperature and bias voltage *Under internal review*

4.3 Conference Records

1. E. Gonzalez, P. D. Olcott, A. Vandenbroucke, C. S. Levin *Mixture Model for Fast Estimation of Positron Range*

2. P. D. Reynolds, F. W. Lau, A. Vandenbroucke, C. S. Levin *Readout Design and Validation for a 1 mm^3 Resolution Clinical PET System*

3. A. Vandenbroucke, D. Innes, C. S. Levin *Effects of External Shielding on the Performance of a 1 mm^3 Resolution Breast PET Camera*

5 Conclusions

Significant progress has been made during the first funding year towards the goal of commissioning and characterizing a high resolution breast PET camera. We have identified and solved key problems with the high-voltage. We have determined optimal shielding properties, and are preparing characterization of a large order of modules.

The reported results show that we are on our path to construct the breast dedicated PET camera described in the project. We have overcome significant technical problems. We plan to test the 1mm^3 resolution PET camera to assist in breast cancer management by resolving inconclusive mammograms, performing local staging and analyzing response to therapy.

References

[1] Lau F W Y, Vandenbroucke A, Reynolds P D, Olcott P D et al. 2010 Analog signal multiplexing for PSAPD-based PET detectors: simulation and experimental validation *Phys. Med. Biol.* **55**, 7149.

[2] Vandenbroucke A, Foudray A M K, Olcott P D, and Levin C S 2010 Performance characterization of a new high resolution PET scintillation detector *Phys. Med. Biol.* **55**(19), 5895–5911.

[3] Vandenbroucke A, Innes D, Levin C.S. Effects of External Shielding on the Performance of a 1 mm^3 resolution PET Breast Camera*NSS-MIC Conf. Rec* **2010**, 3644-3648