Quantum Well Infrared Photodetector Innovation Pathway

This case describes the development of quantum well infrared photodetectors (QWIPs). Following more than a decade of development, the QWIPs will fly aboard the Landsat Data Continuity Mission (LDCM) as part of the Thermal Infrared Sensor (TIRS). Over its history, Landsat data have enabled agricultural, forestry, air quality, and geological activity monitoring among other societal benefits. The new QWIPs technology will continue this legacy in the thermal infrared band, with improved sensitivity. The planned 2012 launch will mark the first implementation of a QWIPs-based sensor on a space-based platform, and one of the first applications of QWIPs principles in an infrared camera system in the relevant wavelength (8-12 µm) [DOC#12, INT#1]. The QWIP innovation has potential applications to a wide range of space and terrestrial missions [DOC#11].

Gestation Period (setting the initial conditions)

The QWIPs innovation pathway began in the late 1980s, when the potential for quantum wells to be used as far IR photo detectors was demonstrated through a unique collaboration between scientists at AT&T/Bell Labs and the NASA Goddard Space Flight Center (GSFC) [D16, I7]. During their year-long contract, funded on the order of $100K under the strategic defense initiative (SDI) [I7], they incorporated a QWIPs-based photodetector array into a camera system and used it to perform airborne imaging [D16]. However, despite the early promise showed by the new technology, the project essentially terminated with the contract, and the collaborating organizations went their separate ways. For Bell Labs, the termination resulted from a strategic determination that QWIPs detectors were not aligned with their commercial portfolio. For the GSFC technical team, their other flight project responsibilities won out, leaving the QWIPs detector arrays in the proverbial "sandbox." [D16, I7, I3]

Although Bell Labs as an organization ended the project, many of the young scientists involved maintained interest in the nascent technology [D16]. Recognizing the enhancements that QWIPs could offer to space-based imaging, the Jet Propulsion Laboratory (JPL), another NASA center, acquired both the technology and many of the original scientists in 1992 [D16, I3]. At JPL, they formed the Infrared Focal Planes & Photonics Technology Group, where they continue to push the scientific state-of-the-art in both space-based and earth IR imaging technology.[1]

Project Initiation (reuniting the old team)

In the late 1990s, the original collaborators were reunited for another reason. Believing that NASA as a whole would benefit from more collaboration among its centers, the GSFC and JPL groups were "encouraged" to find a basis for collaboration [I1, I3, I7]. Encouragement in this context meant that scarce R&D resources were earmarked for collaborative projects. So, the GSFC team spent a week on-site at JPL discussing potential common projects. It turns out that QWIPs detectors were the most promising area for collaboration between the groups, and the

[1] See http://scienceandtechnology.jpl.nasa.gov/people/s_gunapala/ for more details

outcome of that week was one of the concepts that is now, 10 years later, being developed for the TIRS instrument [I7].

Maturing the Concept

The team progressed under a sequence of back-to-back Earth Science Technology Office (ESTO) grants, supplemented by a short Director's Discretionary Fund (DDF) contract on the GSFC side [I1, I4, I7, D1-2]. The first tranche of funding included $700K over 3 years from 1999-2002 from ESTO's Advanced Technology Innovation Program (ATIP) and $80K for the first year of DDF [I7, D6, 9]. This allowed them to develop a hyperspectral QWIPs sensor array [D 6], useful for remote sounding of numerous geospatial quantities. This work showed sufficient promise to secure another three years of funding, again from ESTO, now under the Advanced Component Technology (ACT) bucket. In this round, they requested $1.2M over 3 years through 2005, and built a 1Kx1K detector array and the corresponding read-out circuit [I7, D2, 7]. As listed in the project report, the first contract matured the capability from TRL (technology readiness level) 2 to 5 [D6] and the second contract from TRL 2 to 6 [D7], illustrating the flexibilities of the definitions of TRL. These contracts enabled the technologies to be matured to the point that there was no new science left to be worked out; the remaining investment would target space qualification and engineering progress, tasks that fell under the purview of engineers and technologists.

Treading Water and Branching Out

However, this type of targeted technology funding is hard to come by. There is no clear path between ESTO development funding and project applications, and, for QWIPs, there was no immediate flight opportunity available within the space context. Nonetheless, after 7 years of significant progress, the technologists were motivated to find practical applications to further their work, including medical imaging and cave mapping, which served as partial bridge funding [I7].

A Chance Encounter

A new chance for space flight soon arose, when the Goddard technologist and the CEO of a small business began chatting at a domain specific technical conference [I1, 3, 7]. It turned out that the company had been doing some groundwork on manufacturing a QWIPs-based camera, but had been struggling to secure funding. In fact, they had already submitted three blind proposals to NASA's SBIR program (a congressionally mandated innovation funding mechanism) [I3], but despite success with the Army version of SBIR, all three NASA proposals had been rejected; the CEO was about ready to give up on NASA [I3].

Developing a Parallel Technology Branch

By the end of this informal chat, the two had come up with a proposal strategy with a well defined concept [I1]. Another *coincidence* further ensured the success of the company's fourth SBIR proposal. The relevant subtopic manager – the individual in charge of soliciting reviewers and technical contracting officers for the SBIRs – had an office down the hall from the Goddard technologist [I1, 7]. Thus, upon returning to Goddard, the technologist indicated to his friend, the subtopic manager, that there might be a QWIPs proposal coming in, and that he would be happy to review it. The subtopic manager agreed "*because it's really hard to find reviewers. So if someone volunteers it's very hard to say no…*" [I1] and assigned himself as the second reviewer

[I7]. Both technologists were suitably impressed; the contract was awarded in September of 2006 and the GSFC technologist became the contracting officer's technical representative (COTR) [D3].

Treading Water Again

The output of the phase I contract was a prototype QWIPs-based camera, an excellent result for the 6 month 100K contracting mechanism [I 1, 3]. Despite the success, the phase II bid was rejected for reasons that seemed baffling to the team [I1]. Outraged by what he saw as a clear failing of the system, the Goddard technologist made a series of phone calls to his colleagues in programmatic roles [I1]. As told from his perspective, within a few weeks, the funding managers realized their mistake and righted the wrong by securing enough funding (~$300K) to "*keep us both [him and the small business] alive for another 18 months, which turned out to be enough.*" [I1, 7] The funding came from a partial SBIR phase II and a partial ESTO grant – redistributed at the discretion of the program office [I 4]. In this case, the role of technology portfolio management for the SBIR phase II awards, and ESTO program manager were held by the same individual, a colleague of the Goddard technologist [I1, 4].

As recounted by the ESTO fund manager, the initial phase II rejection should not have been surprising at all [I5]. The way the transition from phase I to phase II SBIR awards is structured, center-level boards rank their own center's finishing phase Is, and that ranking forms the basis for NASA-wide SBIR portfolio planning for phase II [I5, 11]. In the case of QWIPs, the Goddard ranking was quite low, so it would have been inappropriate, from a process point of view, for the ESTO fund manager to recommend that it receive follow-on funding. In his view, the low ranking was because of a lack of advocacy in the review meeting by the Goddard technologist/project COTR [I5]. While advocacy is not explicitly necessary, a short presentation by the COTR is the primary basis for the committee's decision and, all else being equal, enthusiasm about the recommendation plays an important role.

The Goddard technologist had not appreciated the importance of his advocacy role; he believed that the capability's obvious importance as an enabler of future missions should speak for itself [I7]. This was not the first funding proposal on this innovation pathway that had been turned down for lack of advocacy. A previous Internal Research and Development (IRAD) proposal had been rejected because the link to future missions had not been effectively communicated [I8]; similarly, the earlier SBIR phase Is had not shown clear flight project ties. However, at this time, the Goddard technologist felt strongly enough about the efforts of the company to 'play the game' [I1, 7]. Retroactively, he was able to convince the funding manager and secure the follow-on funding. At the same time, he supplemented the SBIR/ESTO combination with Goddard's internal R&D funding (IRAD) [I1, 4, 7, 8].

Changing Contexts

However, even before the IRAD could be completed, the original SBIR team was drawn into a project-specific development contract to develop a QWIPs-based TIRS (Thermal Infrared Sensor) instrument for the Landsat Data Continuity Mission (LDCM) [I1, 7]. The politically charged LDCM mission was facing major technical difficulties with its baselined TIRS instrument [D12 -15]. To understand the context of this decision requires a brief history of the Landsat project, and LDCM in particular.

The Landsat Data Continuity Mission (LDCM) is a joint NASA-US Geological Survey mission that will continue a 30+ year legacy of geospatial data [D11]. Over its history, data from Landsat(from a seven satellite sequence of missions) have enabled agricultural, forestry, air quality, and geological activity monitoring, among other societal benefits. In 1992, the Land Remote Sensing Act guaranteed a data continuity mission to follow Landsat 7. This Act would include continuity of the thermal band imaging provided by Landsat 4, 5 and 7. However, since these measurements are difficult (i.e., expensive), and interesting only to a small community of specialists, their continuity has never been popular in Washington.

From the perspective of TIRS, LDCM has undergone several major reformulations. In the mid 90s, LDCM was investigated as a series of industry studies, with TIRS as an optional extra; they came up with huge cost estimates based on heritage microbolometers. None of the studies were selected and, following a National Security Council-led interagency review, the LDCM functionality was relegated as one of the many NPOESS instruments.[2] That program ran into difficulties. In 2005, OSTP released a memo directing NASA to reinstate LDCM as a free-flying mission. Thus, NASA released a request for proposals, which included the possibility of a TIRS instrument. By that time, scientists in Idaho had found a way to use Landsat thermal data to resolve water resource disputes, an important and expensive issue in the U.S. Midwest, and had established a powerful lobby in support of thermal imaging.

In 2007, NASA conducted an in-house concept study of a TIRS instrument. Believing that coming up with a reasonable cost estimate was the most important factor for TIRS inclusion, they turned to commercially available microbolometers. However a closer look revealed that microbolometers were not an adequate technical solution and the TIRS instrument was de-manifested to preserve schedule. Then, in 2008 at the Systems Requirements Review (SRR), the project was projected to be at least 6 months behind schedule. This created a new opportunity for a TIRS instrument to be manifested. HQ asked Goddard, the systems integrator, if a new instrument could be furnished. As recalls the LDCM project scientist, Goddard responded with an ultimatum: "*yes, but only if we can use QWIPs and develop it in-house.*" HQ conceded and QWIPs was baselined. [I10, D13]

The decision for an operational satellite program to infuse an unproven (read: risky) new technology is never taken lightly. Although the above quote emphasizes the Goddard's power to "strong-arm" HQ, this power is highly context specific and in this case was derived from the confluence of two sequences of events, joined by a timely problem. The first event was the application of significant and unprecedented political pressure: In addition to the 30,000+ publications that have resulted from Landsat science data, the turbulent launch history of the previous 7 Landsat missions brought together a cohesive Landsat lobby. It was the lobby that ensured that an LDCM would fly in the first place, and the decision to de-manifest TIRS sparked another round of heated debate [D14, D15]. In the end, the FY2009 Appropriations Act explicitly included $10M for a TIRS, officially legitimizing the risk [D16]. The FY2010 Appropriations Act provided another $150M for the TIRS instrument, to ensure the schedule was met. The second event was fortuitous technology readiness: Whereas in the original TIRS

[2] The National Polar-Orbiting Operational Environmental Satellite System has experienced its share of starts and stops (c.f. http://www.spaceref.com/news/viewpr.html?pid=25719)

technology trade studies in 2000 and 2007, QWIPs were not mature enough to even be considered [D12, I7], a year later, following significant investment through ESTO, SBIR and IRAD, the technology was now considered the least programmatically risky choice. Further, while the incumbent had made limited progress during the intervening 8 years, Goddard had developed the in-house capability of manufacturing QWIPs devices, thereby eliminating the need for time consuming procurement and making the extremely aggressive two year timeline realistic.

Parallel Development as Part of a Project

Currently in the TIRS baseline, the original QWIPs team and additional engineers have been pulled into the LDCM project and are operating under a stable, legislatively guaranteed ~$10M, project-specific funding with a clear, near-term mission objective. The Goddard technologist believes that an important difference between the ESTO product, which did not convince the TIRS team, and the SBIR output, which did, was the involvement of a commercial company [I1]. From the project perspective, though, the difference was as much a matter of evolving priorities as technical maturity. By 2008, schedule was the primary consideration and the fact that QWIPs could be manufactured in-house was a significant time-saving argument.

The schedule pressure also drove the decision to pursue two parallel development paths simultaneously; the idea being that at least one was likely to succeed. The first was a collaboration between Goddard and the US Army Research Laboratory (ARL) which sought to design and fabricate a corrugated QWIP array based on the concepts proven in the ESTO contracts. The second was a team consisting of the SBIR small business, with support from GSFC/ARL, to develop a grating based QWIP array [D11]. In the end, both technical approaches met all of the TIRS requirements. The SBIR approach was eventually selected based on a second order uniformity measure. The Goddard group sees the infusion as a win nonetheless, because now that QWIP technology has been flown once, it is now a "mature" technology that will be much easier to justify for use on future missions [I12]. At the time of this writing (November 2010) the TIRS QWIP-based flight focal plane assembly had been built, space-qualified, fully tested and was waiting to be installed on the TIRS instrument. The LDCM mission is scheduled for launch in 2012 [D11].