Institution: University of Strathclyde

Unit of Assessment: 13

Title of case study: Economic and environmental benefits of innovative sensor products for military and commercial applications

1. Summary of the impact

A significant body of research in ultrasonics at the University of Strathclyde led to the formation of Alba Ultrasound Limited in 2000. This successful UK engineering manufacturing company designs and manufactures high quality wideband ultrasonic array transducers for sonar applications to a worldwide client base, delivering benefits ranging from naval and maritime security through to safer ocean environments and informed exploitation of marine resources. Alba Ultrasound's unique array transducers constitute the sensor front-end in many leading sonar systems, and its innovative products are incorporated in a range of sonar devices used by the military and commercial companies. Through application of Strathclyde research, the company has experienced a significant period of growth during 2008-2013, with a three-fold increase in employees and turnover rising from £750k to £3.8M.

2. Underpinning research

Context: From 1993 Professor Gordon Hayward was based in the Centre for Ultrasonic Engineering (CUE) within the Department of Electronic and Electrical Engineering (EEE) where he undertook fundamental research into sonar transducers. The research was supported by a range of funded programmes, including EPSRC grants and research contracts from the US Office of Naval Research and the UK Ministry of Defence. In 2000, Hayward formed a start-up company Alba Ultrasound, while continuing as a full-time academic in the EEE Department. Hayward's research from 2000 focussed on demonstrating the transducer technology in underwater applications such as sonar systems in submarines and other vessels, where reliability in harsh marine environments, wideband operation, high power handling and cost-effectiveness are essential requirements.

Key Findings: A series of key research findings have informed the transducer design process at Alba Ultrasound. The breakthrough technology behind Alba's transducer arrays utilises a two-phase piezoelectric material, comprising a matrix of active piezoelectric ceramic pillars, embedded within a passive polymer phase [1] in a 1-3 composite structure. This structure has to then be encapsulated within a bespoke housing, incorporating additional backing and matching layers in order to optimize the transducer array's performance for a specific application. A detailed understanding of the multitude of resonance mechanisms associated with such a complex structure is critical in the design of truly wideband transducer arrays. In-depth knowledge of the interaction between the active and passive phases in 1-3 connectivity piezoelectric ceramic composite configurations ensures that no parasitic resonant modes appear in the desired operational frequency bandwidth of an array. Fundamental research undertaken during the period 1993-1999 provided significant advancement in the understanding of these complex interactions inherent in the composite transducer microstructure and included: design guidelines for the polymer passive phase in the 1-3 composite microstructure [1]; consideration of the complex interaction between the active and passive phases to maximise transducer efficiency [2]; and development of new polymer materials to minimise mechanical cross-talk in ultrasonic array devices, which is a source of image degradation in sonar systems [3]. Additional insight into the thermal behaviour of 1-3 composite transducers proposed the use of loaded polymers to extend the maximum operating temperature, which is important in high power sonar applications [4]. Moreover, when configured as an array transducer, these composite microstructures have a double periodicity through the composite matrix substrate and the array element configuration, further complicating the design process. Reference 5 is a two part paper that introduced a new understanding of the parasitic resonance modes in these structures and offered the potential to design truly wideband sonar arrays [5]. During this period, Alba and CUE collaborated on a KTP project which investigated the use of new, single-crystal piezoelectric materials in composite transducer designs, yielding enhancements in both sensitivity and bandwidth over composite devices incorporating conventional piezoceramic materials [6]. Thus the research, which has concentrated on understanding the fundamental resonance mechanisms between the two

constituent materials within the composite matrix substrate with control of the polymer phase [1,3,4] and the ceramic dimensions [2,5,6], is at the heart of Alba's efficient unimodal piezocomposite transducer designs. A key element in extending this piezoelectric technology into array structures was provided by the seminal work regarding the presence of Lamb waves due to periodicity in both the matrix substrate and array layout [5].

Key Researchers: Gordon Hayward, Professor in Department of Electronic and Electrical Engineering University of Strathclyde, at time of research from 1994 – 2006.

3. References to the research

References 1, 4, and 5 detailed below best exemplify the quality of the underpinning research.

[1] Hayward, G., Bennett, J. and Hamilton, R., 'A Theoretical Study on the Influence of Some Constituent Material Properties on the Behaviour of 1-3 Connectivity Composite Transducers', J. Acoust. Soc. Am., 1995, 98(4), pp 2187-2196.

[2] Hayward, G. and Bennett, J., 'Assessing the Influence of Pillar Aspect Ratio on the Behaviour of 1-3 Connectivity Composite Transducers', IEEE Trans. on UFFC, 1996, Vol 43(1), pp 98-108.

[3] O'Leary, R. and Hayward, G., 'Investigation into the Effects of Modification of the Passive Phase for Improved Manufacture of 1-3 Connectivity Piezocomposite Transducers', IEEE Trans. on UFFC, 1999, Vol 46(3), pp 511 – 516.

[4] Parr A.C.S., O'Leary R.L., Hayward G., 'Improving the thermal stability of 1-3 piezoelectric composite transducers', IEEE Trans. on UFFC, 2005, Vol 52(4), pp 550 – 563.

[5] Hayward G., and Hyslop J., 'Determination of Lamb wave dispersion data in lossy anisotropic plates using time domain finite element analysis', Parts I & II, IEEE Trans. on UFFC, 2006, Vol 53(2), pp 443 – 455.

[6] Robertson D., Hayward G., Gachagan A., and Murray V., 'Comparison of the frequency and physical nature of the lowest order parasitic mode in single crystal and ceramic 2-2 and 1-3 piezoelectric composite transducers', IEEE Trans. on UFFC, 2006, Vol 53(8), pp 1503 – 1512.

Other evidence for research quality

During the period 2000 – 2012, Strathclyde researchers were awarded two prestigious EPSRC Platform Grants (GR/N33430/01 and EP/F017421/1) which established collaborative research between the company and the Centre for Ultrasonic Engineering in the EEE Department at the University of Strathclyde, focussing on new perspectives for wideband transducer design through the use of novel materials [6] and an enhanced understanding of bio-acoustics. A collaborative KTP programme on array transducer design (KTP4501), won the KTP Partnership Award in 2007

4. Details of the impact

Process/Events from Research to Impact:

Hayward created the start-up company Alba Ultrasound in 2000, to pursue the commercial application of his research. From 2000 - 2005 the main focus of the company was to design and manufacture the sonar array suite for the UK mine hunting fleet, [text removed for publication]. This system was the world's first ever wideband sonar capable of performing location, identification and classification from a single system. Each sonar array comprises many, sometimes thousands, of individual transducer elements, arranged so that the sound beam can be moved around under control of the electronics in the sonar unit. Moving the sonar beam this way enables images of the underwater scene to be developed in real time. It was acclaimed as the best sonar system in the world (Defence Preview, April 2004).

The initial research was not only instrumental in establishing Alba's commercial relationship [text removed for publication], but has continued to contribute to the growth of the company. The collaboration between the company and the University of Strathclyde continued after 2000 through a KTP programme, collaborative grants and key scientific outputs (Source A). The recent expansion of the company also has its roots in the success of this long-term partnership. The

Managing Director of Alba Ultrasound has noted that '*The basic research at Strathclyde has been a key element in the uptake of piezocomposite technology and this is widely recognised by the worldwide community*' (Source B). The research undertaken at the University of Strathclyde has generated a platform of design tools and critical understanding to enable Alba to develop its range of world leading wide bandwidth sonar arrays. During 2005 – 2008, the research conducted by Hayward and CUE produced ground-breaking innovations in the company's product range which helped to realise a range of sensitivity-bandwidth properties which were previously unachievable.

Types of Impact

Expansion of Alba Ultrasound Ltd: Since 2008, Alba has undergone a significant expansion in business, primarily associated with diversification into commercial sonar markets, including underwater surveying, sea bed mapping, intruder detection systems and guidance of underwater vehicles. [Text removed for publication.]
In 2009, the company moved into new state-of-the-art customised premises in the North of Glasgow, which provided the environment to enable a step change in the production output. Subsequently, turnover has increased almost linearly from £0.75M in 2007 to £3.8M by the end of June 2013 and the business is growing rapidly, with an employee count of 45 in June 2013 – an increase of 200% from the start of 2008. The collaboration with the Centre for Ultrasonic Engineering has provided a conduit for 4 highly skilled researchers into Alba in both project management and senior engineer roles.

Sales and exports: Alba's key differentiator in the transducer manufacturing sector is the design of bespoke array transducers to match the wide range of applications associated with their worldwide customer base. Approximately 70% of Alba's products were exported in 2012. By July 2013 in the region of 15% of the company's sales were in the military/naval sector, and the remaining 85% of sales to other commercial sonar manufacturing companies. The company has strategic, long term relationships with a range of clients [text removed for publication].

Improved and innovative products: Sonar systems incorporating Alba's wideband array products enable higher resolution images to be realised which contribute to improved understanding of marine environments. Alba incorporated the outcomes of fundamental research undertaken at Strathclyde into their design process leading to products that are able to operate efficiently across extended bandwidths from a single device. This has revolutionised the mode of operation for sonar systems, as not only can a single device be driven at high power for enhanced propagation distances, but the ability to control the drive frequency provides the capability of switching from object detection (use of low frequencies, with low resolution) to object classification (using the higher resolution afforded by the smaller wavelengths associated with high frequency wave propagation). The application of advanced coded excitation waveforms within these sonar systems was a consequence of the uniform transducer behaviour achieved over extended bandwidths which, in turn, permitted the implementation of advanced signal and image processing techniques. The company received the Queen's Award for Innovation in 2012 (Source D).

Alba Ultrasound manufactures high end, bespoke transducer array products for the following applications; side scan and bathymetric sonar, mine hunting, high frequency imaging, intruder detection, autonomous underwater vehicles, remotely operated vehicles and hull mounted sonar systems (Source E). The clients who purchase Alba's arrays are companies who in turn manufacture the electronics and display systems for the complete sonar product, which is then sold on to the end-users. Each Alba 'product' is tailored to the requirements of an individual client and its particular sonar system.

Contribution to the commercial success of other companies: The research conducted in collaboration with the University of Strathclyde during 2008-13 has directly led to a range of Alba products which have had a beneficial effect on the global sonar market. In addition to the mine hunting arrays, Alba products [text removed for publication]…enabling underwater tasks to be carried out more safely and with minimal damage to the affected areas (Source G). This is achieved through the provision of highly detailed images in sub-sea surveying which permits more

accurate classification of structures such as shipwrecks, harbour installations and pipelines. [Text removed for publication.]

Minimising negative impact on marine environment: The advanced sonar imaging systems deployed by various commercial and military operators have been made possible by the research-based Alba products. Alba's transducer arrays are designed to operate well above the acoustic frequency range of Cetacean species, including whales and dolphins. The company has conducted in-house testing which has shown the effects of its sonar on marine mammals to be minimal.

5. Sources to corroborate the impact

A. http://www.ktpws.org.uk/Portals/58/KTP-alba-6092-high%20res.pdf

B. Statement from the Managing Director Alba Ultrasound Limited

C. [Text removed for publication.]

D. http://www.albaultrasound.com/downloads/queens_award.pdf

E. http://www.albaultrasound.co.uk/sonar.shtml applications for Alba Ultrasound products

F. [Text removed for publication.]

G. [Text removed for publication.]

H. [Text removed for publication.]

I. [Text removed for publication.]