MAGNETO-ELECTRIC NANO-COMPOSITE FOR ANALOG TUNABLE RADIO
FREQUENCY FILTERS

BY

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Abstract

The emerging field of magnetoelectric electronics opens significant opportunities for the next generation of sensors and wireless devices. A key feature of magneto-electric materials is the coupling between their magnetic and electronic properties that enables a voltage to be induced by a magnetic field, or a magnetic response to be induced by an electric field. This occurs in ferroelectric and ferromagnetic bi-layers. It also intrinsically occurs in multiferroics but obtaining a large room temperature magneto-electric effect with such materials can be challenging.

The National Isotope Centre, part of the Institute of Geological and Nuclear Sciences (GNS Science), has been working with Victoria University of Wellington (VUW) on a novel idea to use low energy ion implantation to create ferromagnetic nanoparticles on ferroelectric and multiferroic thin films to create a magneto-electric nanoparticle composite thin film. They demonstrated the viability of magneto-electric nano-composites in two early stage proofs-of-concept: a tunable radio frequency filter for wireless systems and a zero-power magnetometer measuring small electrical signals. The aim of this project is to assess the range of fields that this composite could have applications in, identifying the most promising of those fields and assessing the most promising applications in that field. Furthermore, this project also seeks out potential partners in New Zealand and a business case was subsequently prepared, which will be used to apply for government funding to pursue research on the technology, and to begin its commercialisation.

In this study nine fields were found to potentially benefit from the use of this technology. They were analysed and compared, using preliminary market validation, resulting in the decision to investigate further the tunable radio frequency (RF) filter market, which is projected at US\$13 billion by 2020. RF filters are designed using an original method patented

in the 1930s allowing a filter to address only one frequency. As a result, a device must integrate as many filters as frequencies it needs to use, which could be more than 50 for a recent smartphone. A tunable RF filter with a 20% tunability could disrupt this market by providing a huge gain of space, weight, and power efficiency. The RF market is also promising because of the wireless trend, which is occurring all over the world where everything is progressively connected to the what is called the ‘Internet of Things’ – the most important market for the next generation of interconnected electronics. During a year of literature review, interviews and participation at international fairs, the research team has built a value proposition case, a technology review, a market and competitive analysis, an intellectual property assessment and a commercialisation pathway, which are detailed in this project report.

The initial Smart Idea funding from the government has now ended and, if the project is to be kept alive, it needs to produce a quick-to-market application to unlock new credits. This report proposes a structured roadmap for several applications, starting with a tunable RF filter prototype for underwater communication. This has been progressed by GNS Science, embarking on a grant application during this writing. If granted, this funding could open the way to make New Zealand a champion in tunable RF filters and a research and development (R&D) hub for next generation nano-electronics.

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Chapter 1: Introduction

1.1 Background

GNS Science is one of seven Crown Research Institutes (CRIs) in New Zealand (Science New Zealand: Who we are, 2017). It is an institute dedicated to advancing ideas in strategic science and innovation, and delivering results that will benefit New Zealand economically. GNS Science is a public-good organisation supporting existing, and helping to generate new sectors. It aligns its science direction and core funding with government and industry priorities (Our Business - GNS Science, 2017). All its projects, including the one detailed in this report, are part of the mission of GNS to help New Zealand companies create high value devices and increase their exports. This mission has played an important part in the way the research has been oriented along its operation.

GNS has had a ‘Smart Ideas’ research programme (since 2014) led by Dr Jérôme Leveneur looking at developing intellectual property (IP) in materials and methods for electrostatically tunable inductors¹ and zero-power magnetic field nano-sensors using ferromagnetic² nanoparticles in ferroelectric³ and multiferroic⁴ films. ‘Smart Ideas’ is an investment mechanism from the Ministry of Business, Innovation and Employment (MBIE), funding high risk research programmes with high potential value to New Zealand. This grant, part of the newly-called ‘Endeavour Fund’, can allow up to NZ\$ 1 million over the term of a two to three year contract. In our case, NZ\$1 million has been granted, divided in two rounds

¹ An inductor is a coil of wire, or electromagnet, which can store energy in its magnetic field and resist any change in the amount of electrical current flowing through it (Brain, 2017). Teamed up with a capacitor, an inductor will allow to create an oscillator, used in many different types of electronics like radios or computers (Brain, 2017). In the case of an electrostatically tunable inductor, an electric current would modify the magnetic properties of the inductor.

² The strongest type of magnetic material that typically creates forces strong enough to be felt, and is responsible for the common form of magnetism in magnets encountered in everyday life (“Ferromagnetism”, 1998).

³ Material composed of crystals that exhibit spontaneous electric polarization that can be reversed in direction by the application of an appropriate electric field.

⁴ Material that exhibits ferromagnetism and ferroelectricity.

of NZ\$500,000 for a duration of two years. In terms of human resources, it corresponds to two full-time equivalent (FTE) people dedicated to the research programme per year⁵.

The main body of IP currently existing in the research area of magneto-electric devices is centred on thin film based magnetic sensors and magnetic Random Access Memory^{6,7}. There is a range of patents relating to the manufacturing techniques used to fabricate multiferroic thin films associated with these devices. These fabrication patents typically address technical challenges that arise when coupling the magnetic and ferroelectric order of magneto-electric materials.

GNS Science's novel approach to understanding and resolving the magneto-electric effect involves the use of low energy ion implantation into multiferroic and ferroelectric films. These films are then electron beam annealed to create nanoparticles to a depth of up to 40 nm, resulting in magneto-electric nano-composites. GNS Science has surveyed the literature and is not aware of any other group taking this approach. They believe they can enhance their understanding of the magneto-electric effect and generate new IP.

GNS Science's preliminary patent search in 2014 on the fabrication of multiferroic nanoparticles has identified a gap in the IP landscape. This gap lies in the application of magneto-electric nano-electronics, in particular for wireless communication applications and magnetic field sensing. To date, there are no suitable materials or methods (based on the magneto-electric effects) that can lead to commercial applications. GNS Science claims that nanoparticles have strong potential to fill this gap.

One of the biggest challenges in the fabrication of magneto-electric materials is to demonstrate that the fabrication technique can be commercially viable at an industrial scale. GNS Science has an existing patent that covers an arc discharge fabrication, and a method that

⁵ Dr Leveneur's estimation of a FTE is NZ\$250,000 a year.

⁶ Seagate Technology PLC (2010). Magnetoresistive sensor memory with multiferroic material.

⁷ Northrop Grumman Systems Corporation (2013). Multiferroic nanoscale thin film materials, method of its facile syntheses and magneto-electric coupling at room temperature.

can successfully be used to create ferromagnetic nanoparticles in SiO₂ with a high magneto-resistance for high magnetic field sensors^{8,9}. This project will build on this existing IP to create a new range of magneto-electric nanoparticles, production processes and methods. The synthesis of nanoparticle materials using ion-beam technology, electron-beam annealing and arc-discharge requires unique GNS Science fabrication equipment and knowhow that is unlikely to be duplicated easily.

The research program has been led by early-career researcher, Dr Jérôme Leveneur (GNS Science). Dr Leveneur has used low energy ion implantation to produce ferromagnetic nanoparticles in materials and co-holds the intellectual property (IP). Dr John Kennedy (GNS Science) and Prof. Grant Williams (VUW) are mentoring Dr Leveneur and assisting with material synthesis and prototype design as well as data interpretation. Dr Shen Chong (VUW) has led the wet-chemical synthesis of nanoparticles and magneto-electric laminate composites as part of risk mitigation. John Futter (GNS Science), an experienced R&D electronic engineer, led the electronics and proof-of-concept development. The IP management, commercialisation and interaction with end users and potential industry partners has been led by Joe Manning, a business development manager at GNS Science with 20 years of experience. He has been assisted by Pierre Mousnier (VUW), through the Master of Innovation and Commercialisation programme, who has four years of prior experience in media content commercialisation and marketing.

The ‘Smart Ideas’ research programme was meant to validate the proof-of-concept for two devices:

- A small electrostatically tunable inductor for a radio frequency filter in a wireless system, where an applied voltage will change the resonance frequency of the filter;

⁸ Kennedy, J., Markwitz, A. (2011). Patent No. US8872615 B2. New Zealand.

⁹ Kennedy, J., Leveneur, J., Williams, G., & Futter, J. (2013). Patent No. WO2013154440 A1. New Zealand.

- A zero-power nano-sensor for measuring small electrical currents and magnetic fields.

When the project started in February 2016, the team had no proof-of-concept for these two devices, but their work on the nano-structured components allowed them to identify new opportunities to use it in a range of applications. The first step is therefore to explore these opportunities.

1.2 Opportunity

Magneto-electric materials are used in most electronic devices which surround us. Not all these devices would necessarily benefit from a nano-structured magneto-electric component whose main advantages are its capacity to tune its magnetic properties and to generate electricity from a magnetic excitation. Here are all the applications that have emerged from this year's research:

- Zero power nano-sensor: for measuring small electrical currents and magnetic fields, opening up new innovative opportunities in the field of magneto-electric devices.
- Energy harvesting: powering a device with a small amount of electric current when it is in stand-by mode to increase its autonomy.
- Magnetic Random Access Memory (MRAM): could theoretically replace the current RAM technology used in computer memory with better performance due to the use of electromagnetism to memorize the data instead of electrical charges.
- System-on-Chip (SoC) powering: putting directly the power source on the chip itself with all the component of the computer, making a gain in space in all portable devices, which is one of the newest evolutions in electronics after the miniaturization of the components.
- Antennas: the component could be used to create a new generation of antennas, much smaller than those manufactured with copper.

- Wireless Power Transfer (WPT): the component has applications in mechatronics. It could power an entire small device without using wires, allowing 360 degrees of mobility.
- Radio frequency identification (RFID): RFID chips are made for one frequency. With this technology, a chip could read several frequencies, including a combination of frequencies that could allow encryption of the communication that will increase the security for some applications like contactless payment with credit cards.
- Army surveillance: measuring small amounts of electric current with high precision could lead to devices that can read the data transferred in a wire in close proximity.
- Tunable radio frequency filter: RF filters are used in wireless communication devices to isolate a signal in the RF spectrum. They are used in radios, smartphones, sensors, GPS, etc. The filtration is determined by the design of the filter, meaning that its sensitivity to a specific signal cannot be changed after it is manufactured. A magneto-electric composite allows one to modify the magnetic properties of the device, and equally its resonant frequency. We thus refer to this as a tunable RF filter.

All these applications represent the many opportunities that have been identified and assessed in collaboration with the research programme team. From two applications in 2014, the number of outputs had reached nine segments in late 2016. The next logical step is to sort them into the correct segments and decide which one should be delved into more deeply for the rest of the project's timeline.

1.3 Objectives of the project

The main objectives of the project is to help GNS Science's research programme team to validate the initial line of research, then pivot and explore new application opportunities. The latter will help GNS secure new funding to pursue their research innovation endeavour.

The initial objectives of the “Smart Ideas” programmes were framed very close to a basic research and development framework rather than a business development activity. The main difficulty in this situation is the absence of prototypes or specifications to showcase during the market validation process, and furthermore the product validation. Consequently, GNS Science’s objectives were not to build a business case on the commercialisation of a technology, but to assess the feasibility of a scientific material to be developed for applications in a promising market. Depending on the results of the research, the possibility to apply for specific funding would be evaluated with this scheme:

$$\text{Application for government funding} = \frac{\text{Potential market} + \text{Feasability}}{\text{Partnership with a NZ company}}$$

Potential market: The process of assessing the potential of a market is a mix of data and assumptions. Most of the applications listed above are under the radar of investment agencies, which publish regular reports on size and growth of the market. However, some indicators must be assessed to challenge these figures (Adams, 2010). For example, what is the maturity of the market? Is the market opportunity big enough to support another player? What kind of penetration is needed to support the business (the less percentage penetration required, the higher the relative attractiveness of the opportunity)? All these questions have to be asked, not just in New Zealand, but on a worldwide scale by means of comparing the compound annual growth rate (CAGR) of a market to the GDP growth of the country.

Feasibility: Feasibility here is taken in a production sense. The first assessment would be to determine if the advancement on the technology would lead the research programme team to believe in a short-term realisation of a proof-of-concept or, better, a prototype. The second assessment is in comparing the equipment and expertise needed to produce such a prototype with the manufacturing assets used in the industry which this market belongs to. Indeed, if the industrialisation process of the prototype is too heavy, there is logically less chance for the innovation to find a credible investor.

Partnership with a New Zealand company: This is a particularity of this project, due to the nature of GNS Science as a Crown Research Institute (CRI). One of GNS Science's mission as a CRI is to benefit New Zealand's economy. In other words, every project led by this institute must be motivated by a direct potential impact on this country's industry. This would include for example innovations that improve the productivity of a sector by enhancing a process, or creates a unique value proposition which would give a competitive advantage to New Zealand companies. After having proven the link between the technology and one or several companies, it is necessary to validate the interest of the potential partner(s) and agree on a future collaboration if the project is funded through a memorandum of understanding (MoU) by the government. One would assume that a company in New Zealand would not decline an investment which does not necessitate money or human resources, especially where the R&D investment by private companies in this country was below 1.2% of GDP in 2014 (Research and development in New Zealand: 2014, 2015).

In summary, the objective of this project is to assess the best leverage across all these parameters. For reasons detailed in this report, the tunable RF filter is identified as the most promising application for the magneto-electric nano-materials which GNS has developed.

1.4 Development strategy and business model

The RF filter market is divided into a range of segments as many industries have a need for its use. The diagram below shows the supply chain for a tunable RF filter and the main benefits for each player in adopting the technology:

Figure 1. Supply chain for a tunable RF filter.

To better understand the drivers across this chain, we have interviewed a series of key stakeholders and scientists with interests in telecommunication hardware and signal processing across New Zealand and overseas. In total, ten interviews were undertaken with senior staff (professors, CEOs, MDs or other senior managers) from several companies, government agencies and universities. An overview of the proposed GNS technology was presented to assess the potential interest for developing New Zealand businesses. Specific areas of feedback were sought from each interview. Below is a brief summary of the different requirements from the different segments listed in Figure 1.

- Filter manufacturers.** The GNS tunable filter is attractive to filter manufacturers as it disrupts an existing market with a new technology. It is still based on using a conventional manufacturing process and can potentially open up new market segments related to, and accessible through their existing telecommunication business. In addition, this is a global opportunity that can be accessed through an existing distribution network. From our interviews with Taiyo-Yuden and Murata Incorporation, there is an interest to license the technology if a prototype is able to prove a performance of 20% tunability in the mobile communication bands.

- **Module manufacturers** implement filters in RF front-end modules and are, most of the time, filter manufacturers themselves. They are in direct contact with device manufacturers looking for full-ready modules to be implemented into handset devices. They are the most promising target for licensing the tunable RF filter as they are currently in an evolving market where size and performance are key factors for the business.
- **Communication device manufacturers** will be the purchasers of the RF front-end modules. By purchasing and implementing the product, they provide customers with better performance and lighter design (through getting lighter, smaller components). They also benefit from the highest savings in terms of cost of materials and reducing the number of components in the final device.
- **Carriers** are striving to give the best user experience to their clients while keeping the operational cost to a minimum. Regulated bands are rented by carriers following two possibilities: either (1) the carrier possesses a monopoly of unlimited use on a band, or (2) only acquires a certain amount of data. The more bands a carrier is providing to its users, the more expensive it is to them. In that sense, exploring the possibility to transmit on unregulated bands is not only justified by not saturating the regulated bands, but also on the potential savings in terms of band renting.

From these data, the recommendation for a commercial strategy is to focus on the telecommunication manufacturers in the first step, as they are more flexible to reconfiguring their resources to innovate. As soon as this is realised, the next step is to reach out to the filter manufacturing market.

The current preferred commercialisation approach by GNS is to license any IP to third parties. A licensing approach is generally better if codified IP in the form of patents can be secured. The commercial strategy of the project is depicted in Figure 2.

Figure 2. An example of GNS’s commercial strategy for licensing IP in the telecommunication industry.

To reach these goals, a roadmap detailing the steps from the beachhead market¹⁰ to the main goal of commercialisation has been proposed and validated by the board of GNS Science. All along the journey, five development milestones have been identified:

Figure 3. Milestones for the proposed project. VC denotes a Venture Capital fund.

¹⁰ The notion of beachhead market (Moore, 2006) could be defined as a specific segment of a market which characteristics make it an optimal first target for a new product, based on best compatibility between the product, the market and the resources available for the company.

To reach these milestones, the project's recommendation is to split the research programme into two parts corresponding to two fundings. The first axis is based on Kiwinet 'PreSeed' funding and focuses on reaching a beachhead market among the RF filter market's segments, that is, underwater communication devices. The second is built around a MBIE 'Research Programme' funding, which does not require a quick-to-market product, but encourages 'high risk-high value' technology at an early stage. This second axis will allow the team to explore a wide tunability in high frequencies for the handset market.

Following the proposed prototype testing for underwater communication, the recommendation is to extend the market. This will follow the spectrum of other applications to reach the market of the Internet of Things (IoT) and handsets. The IP secured will reside in the filter design and the use of the nano-structured component licensed to several manufacturers with an exclusivity in its field of activity. New IP will be protected through trade-secrets, and where applicable, patent protection. GNS Science plans to license the IP to their New Zealand manufacturing partners to be used in their product offering. Subsequently, more applications' IPs will be assessed and secured with further product development, some for example in conjunction with Callaghan Innovation regarding in the area of Cognitive Radio.

1.5 Structure of the report and next steps

This strategy is the result of a ten-month project, with interviews conducted with the scientific community, telecommunication related players and manufacturers in New Zealand and Japan.

The data presented herein have been collected following a rigorous methodology that will be presented in the next section. I will describe the collection process of publicly available data, and the assumptions used during the collection. The data analysis and their transformation

into recommendations will also be described to show how the research has been conducted, how it has evolved during these ten months, and what challenges and limitations have been encountered.

In the second part of this report, I will list the different findings by separating those related to the different possibilities from those concerning the final application which has the greatest potential for the next stage of GNS's roadmap. An in-depth discussion regarding how the most promising application was chosen will be presented in the discussion section together with the most beneficial market implementation.

All these elements have been curated and integrated into a business case, which will be used in the different funding applications in the months following the writing of this report.

Chapter 2: Methodology

Chapter 2 provides the reader with information so they can assess how reliable the research methodology is. It describes the assumptions that were made in the development and business model, and the methodology used to collect and analyse the data. It outlines the decision making process for the research design and what key factors influence these decisions. Furthermore, it introduces the different research participants and the methods that were used to collect data. Finally, it describes the iterative processes of reflection and recommendations used, including how these processes made the research methodology evolve during the course of this project.

2.1 Assumptions that were made

Most of the innovation literature focuses on demand-oriented innovation, starting from identifying a user problem and trying to solve it with a new product. One can find a lot of resources on methods to help entrepreneurs to successfully tailor a product to a market. If we take for example ‘*The Lean Startup*’ method (Ries, 2011), probably the most popular method used by innovators presently, we can see how the whole purpose is to start from a user-defined problem and not the product itself. The question is which method suits the best science discoveries?

Science innovation aims to use scientific knowledge to develop new products or processes to solve market’s problems. User’s issues are not the original trigger for an institute like GNS Science. When the trigger is the product itself, there might be a process, a property or a material that can prove to be efficient in substituting an existing product or creating a new field of application. If any of these ideas are found to be novel and clear of patent or research from another institute, GNS Science would start to gather data on the range of applications. GNS science would then explore the benefits of this technology and meet with local industries

to evaluate their interest in partnering to get public funding and build a research programme team. This report aims to give leads and recommendations on the applications of GNS Science's magneto-electric materials, and their benefits to potential partners.

The first step is to assess the features of the technology is to link them to the market's needs. These include:

- Magneto-electric tunability: magnetic properties (and so resonant frequencies) of the component can be changed by electrical excitation.
- Energy harvester: a small amount of electricity can be produced by a magnetic field excitation.
- Size, Weight and Power¹¹ (SWaP): being nano-structured, the component can be used in magneto-electronic devices to enhance the performance of existing electronics, allowing reductions in size, weight or power consumption.

The second step is to list the different industries that could benefit from using the component in existing or future devices based on these three features:

Feature	Industry	Potential benefits
Magneto-electric tunability	- Magnetic Random Access Memory (MRAM)	An analogue tunability which needs only a small electrical current to change the magnetic orientation and the resonant frequency for uplink and downlink in wireless communication.
	- Radio Frequency Identification (RFID)	
	- Tunable radio frequency filter	

¹¹ Size, Weight and Power is defined in EE Times journal as a 'key concern' for 'high-end consumer and military SDR equipment and cognitive radio' by Paul Dillien (Dillien, 2014)

Energy harvester	<ul style="list-style-type: none"> - Zero power nano-sensor - Electronics empowerment - System-on-Chip (SoC) powering - Wireless Power Transfer (WPT) - Army surveillance 	Can be used to wirelessly power an off-grid device with no battery.
Size, Weight and Power (SWaP)	- Antennas	The magnetic sensitivity of the component is higher than those used in regular antennas.

Table 1. Potential applications of GNS Science's magneto-electric materials.

Potential benefit assumptions were made to decide which benefits are more likely to be needed by each industry, as well as what performance would be realistically provided by the technology. The following markets were selected following this evaluation to confirm these assumptions:

- Radio frequency identification (RFID)
- Tunable radio frequency filter
- Wireless Power Transfer (WPT)
- Antennas

As GNS Science's mission is to benefit New Zealand industry, priority has been given to New Zealand companies during the research process as described in section 2.4: "Research participants and methods to collect data from them".

2.2 Methodology to collect and analyse data

To collect and analyse data, this project has adopted the methodology described in *If you build it, will they come?* (Adams, 2010) – more precisely the ‘Ready’ stage which focuses on market analysis in a way that allows an application to be developed without a product. For example, a method like ‘*The Lean Startup*’ method created by Eric Ries (Ries, 2011) is closely linked to the product (‘minimum viable product’) and does not describe a lot of the previous stage on how to determine the viability of the market opportunity.

According to Adams, the first stage of market analysis should focus on five aspects to assess quickly the potential of a market to absorb a new product: domain knowledge, market size and growth rate, lifecycles and trends, competitive analysis, and outside data sources. First, the entrepreneur should start to gather a minimum comprehension of the domain knowledge by scanning the literature around the field he is entering. This can be done by internet-based research. Market studies can be accessed by regular agencies specialized in market size and growth rate evaluation. A good tip at this stage is to compare the market growth rate with one of the countries/regions’ gross domestic product (GDP) where the product will be launched. These agencies normally provide good overviews of life cycles and trends; factors which are useful to assess the potential of the product in a dynamic market. With this data in mind, the entrepreneur can then build a competitive analysis, listing the main players in the field and assessing the barriers to entering the market. Further than an internet research, Adams’ advice is to call directly the author of the study to start getting insights from a specialist on the potential of a new product. After all, these specialists are keen to know about future new players in their field of study.

The second aspect of the ‘Ready’ stage is to research scientific challenges and technology trends and to compare them with potential solutions which could be provided by the product-to-be. This part requires a search of scientific literature published by the

international community, including any existing patents (approved or under provision). As far as this project is concerned, this research has been comprehensively carried out by GNS Science, which has a core orientation on publication and patents. The scientific team is also aware of the scientific challenges in most of the related fields. This project was also able to include the participation of engineers and scientists from Callaghan Innovation, which has a close tie with GNS Science. Callaghan Innovation's mission is to provide experts from a range of fields to boost technology and product development in New Zealand by providing expertise, innovation skills and R&D fundings. Engineers from this entity are adaptive to staying up to date with technology trends, as well as connecting to New Zealand companies.

Finally, the last factor for market analysis was to align to GNS Science's core mission: to benefit the New Zealand economy. After assessing the global market size and growth it was mandatory to do the same at the scale of New Zealand's economy. The competitive environment of one or several national companies in this country was also determined as well as their position on the global market.

2.3 Decision making process

From this point, it was easy to create a template with a systematic approach to allow an optimal decision making process. Nevertheless, market analysis was not the only factor in deciding which way the research programme was to be pursued. The research team had to decide the different applications to be assessed based on the scheme below.

Figure 4. Key decision making guidelines to assess the potential applications identified.

As we have just seen, the market opportunity was evaluated by the market size and growth, the scientific challenges, and the technology trends. Regarding the search for a manufacturer, it was surprisingly complex to find any official directory from the government websites. Most of the task was then focused on searching with associated terms or to consult with specialists to obtain the appropriate contacts. Prototyping and the time to industrialise was estimated by the research team, as well as the potential to get funding from the government. Eventually, the freedom to operate was assessed by an external agency specialized in IP (A. J. Parks).

This scheme (Figure 4) was followed each time an application was put on the table to quickly move to the next stage when a “box-along scheme” was achieved. Consequently, an idea that could have led to a prototype was disqualified if no potential manufacturer is to be found in New Zealand. We will discuss the issues of this operation later in this report.

If an application would go through all these key points, it would be submitted to GNS Science’s research programme manager, Joe Manning, for the evaluation of the business aspects, and John Kennedy for the scientific and funding evaluation. With their agreement, the

project would be presented to the GNS Science board and included in the institute's funding applications in the following year, thus allowing the necessary resources to build a strong application and to gather a project team.

2.4 Research participants and methods to collect data from them

Primary market research was used in this project to gather essential data, including whom to interview. But before going to industrial scientists and manufacturers, it was decided to first obtain data from academics to obtain a wider picture.

2.4.1 Professors

Victoria University's School of Engineering and Computer Science was an ideal place to interview professors specialized in communication engineering and signal processing. The idea was to collect feedback from these experts regarding the technology itself and try to extend the range of applications to assess. To do that, the professors were first contacted by email and then, if agreed, they were interviewed for 15 to 30 minutes.

For the interviewing process we followed the Kvale recommendations described in *Interviews, An introduction to Qualitative Research Interviewing* (Kvale,1996), to conduct unstructured interviews where the interviewee and the interviewer have a conversation. This allowed the professors to speak freely and only use an aide memoir to keep the interview going fluidly. The choice of an unstructured interview was logical as these academics tend to work on a wide range of problems but are rarely on product development, even if they have the knowledge to understand the purpose when talking about 'magneto-electric components' or 'resonant frequency tunability', for instance. It was often necessary to deviate to more general topics to let the interviewee think and express ideas about the main subject.

The following is a list of the professors who were interviewed:

- Dr Pawel Dmochowski, Senior Lecturer, School of Engineering and Computer Science: Signals and Systems, Communication Engineering, Advanced Communications Engineering.

- Dr Bastiaan Kleijn, Professor, School of Engineering and Computer Science: Signals and Systems, Advanced Signal Processing.

- Dr Paul Teal, Associate Professor, School of Engineering and Computer Science: Advanced Signal Processing.

- Dr Grant Williams, Professorial Research Fellow, School of Chemical and Physical Sciences: Advanced Materials and Nanotechnology.

2.4.2 Scientists

Here ‘scientists’ are referred to all applied scientists and engineers from institutes like Callaghan Innovation and the Robinson Research Institute to distinguish them from lecturing academics from universities, as they are more closely linked to the applicative world.

This group was approached to challenge the potential applications of the nano-structured magneto-electric components, and not to get feedback on the fundamentals of the component itself as this had been covered in the professors’ interviews. This was for two reasons: first, these specialists are interested in what added value one is putting into their field of activity, rather than the progression science from the invention. Secondly, talking about applications with scientists/engineers who are most of the time working closely with the private sector allowed us access to contacts in companies which could be in demand for such an application.

For this segment, the method was to conduct semi-structured interviews which covered a range of key points using similar questions but allowing the interviewee to respond as they like.

The following scientists/engineers were interviewed:

- Shen Chong, Scientist, Robinson Research Institute.
- Andrea Bubendorfer, Senior Research Scientist, Callaghan Innovation.
- Andrew Best, Microfab Manager, Callaghan Innovation.
- Derek Richardson, Senior Research Engineer, Callaghan Innovation.
- Sudhir Singh, Senior Research Engineer, Callaghan Innovation.
- Neil Scott, Principal Research Engineer, Callaghan Innovation.

2.4.3 **Manufacturers**

Manufacturers are key for both research process and business development. At the same time, they are also the best source of data for market validation and potential partners to license and manufacture the product itself. Because of these two aspects, interviews were conducted following the recommendations of Eric Ries in *The Lean Startup* (Ries, 2011). In summary, this involved refraining from only talking about our solutions, but instead trying to understand our interlocutor's problem. To do that, we constructed guidelines¹² to conduct the interviews without telling too much about the technology or putting the manufacturers in a defensive attitude toward what they could consider confidential topics.

The guidelines were vigorously followed, but the interviewing process stayed semi-formal to open the door for the interviewees to lead the discussion to a point where they would find important aspects that matched their needs. After a quick presentation of the project which included the role that GNS plays, the interviewee was asked to talk about their company (history, size, clients, field of activity, local or international market). They were then asked to describe their products, what had been working for them, what had not, and the opportunities they foresaw. At this stage the interviewer would start to ask about any identified issue and

¹² Appendix 1, page 112-113.

what had been done about it. This stage of the interview could potentially be confidential. Following the guidelines, we would eventually switch the interview onto market description to keep it flowing: its evolution, its state in three to five years, and what main factors would guide the market in the future according to the interviewee. Finally, if the interview had reached its conclusion, the interviewer would go through the research and development questions to assess for future collaboration: Did they plan to invest in R&D? What were the main issues encountered to innovate? What were the priorities for product development between size, costs, performance or security? All these questions could lead the GNS team to go further and talk about a partnership.

In some instances, these guidelines were not appropriate especially in situations like conferences or fairs, and it was often necessary to adjust the questions to get the point through in the time available. The following manufacturers had been interviewed and agreed to give feedbacks:

- Times-7: RFID antennas. Unknown revenue. Number of employees: 5 employees (Times-7 website).
- Rakon: Frequency control, Quartz crystal, Electronics, GPS, Wireless. Revenue: NZ\$ 112.7 million in 2016 (FY2017 Rakon Investor Presentation, 2017). Over 2000 employees including joint ventures (Rakon website, 2012).
- PowerbyProxi: Wireless powering. Revenue: US\$ 11.5 million in 2015 ("PowerbyProxi Company Profile", 2015). More than 50 employees (Crunchbase Inc., 2017).
- Murata Manufacturing: Passive electronic components, including capacitors, resonators, filters and inductors. Revenue: NZ\$ 16.46 billion in 2015 ("Murata Manufacturing", 2015). Close to 60,000 employees (Murata website, 2017).

- Taiyo-Yuden: Electronics and semiconductors, including capacitors, inductors and filters. Revenue: NZ\$ 2.86 billion in 2012 ("Taiyo Yuden", 2012). Around 18,753 employees worldwide (Bloomberg: Taiyo Yuden, 2017).
- Omron: Electronics and electrical equipment. Revenue: NZ\$ 11.85 billion in 2015 ("Omron", 2015). Around 36,842 employees (Forbes: Omron, 2017).
- Navico: Marine electronics. Revenue: NZ\$ 458 million in 2006 ("Navico", 2006). Approximately 1,500 employees globally (NZMarines: Navico, 2013).
- Electronic Navigation: Marine electronics. Unknown revenue. 45 to 65 employees ("Electronic Navigation", 2016).
- 4RF: RF electronics manufacturer. Revenue: US\$ 35 million ("4RF Ltd. Company profile" - Zoominfo, 2017). Number of employees: 70 (Rigzone: 4RF Communications Limited, 2017).
- Vodafone Xone NZ: Innovation lab and partner. Unknown revenue. Number of employees: 20 (Vodafone Xone NZ website, 2017).
- Kotahi Net: Internet of Things solution provider. Revenue: NZ\$ 1 million per annual in 2016 ("Kotahi.net | NZ Startup of the Week", 2016). Unknown number of employees.
- Avnet: Technology distributor. Revenue: NZ\$ 37.45 billion in 2016 ("Avnet", 2016). Around 17,700 employees (Forbes: Avnet, 2017).

2.5 Data analysis and recommendations

The objectives of the research programme were clear: to assess the most promising applications for the technology and the most promising segment within its market. To do so, the best pathway of implementation is to have an iteration process and creative thinking with the GNS team. This was implemented through several workshops where the data collected were

compared, challenged and assessed. The idea was to expand the knowledge in all the possibilities for the component, to search data for their markets, to collect feedback from experts and then to compare the inputs with other applications. This process ended with recommendations, but we did not stop the workshops after one cycle. They were kept going until the final stage of the project and the discovery of the final and most promising application. See Figure 5 below to visualise the process:

Figure 5. A schematic diagram showing the process or steps taken to arrive at a final recommendation.

This process was followed until the proof-of-concept reached the stage of early performance in the lab, whereby a lot of applications were dismissed due to unrealistic perspective. This was carried out until the component showed convincing results in the application. From this stage, the project team centred their priorities on two axes:

- Get a market-oriented product out quickly to apply for short-term commercialisation funding; and
- Collect product specifications to re-orient the research and cite a long-term objective which could apply for high-risk high-value funding.

The recommendation was then to focus the development on the most feasible product which could be quickly prototyped and demonstrated to manufacturers to apply for the Pre-seed funding provided by Kiwinet. This funding, which aims at quick-to-market products (one year) investment, would have several impacts. It would allow the project team to keep on working on the technology even after the initial Smart Ideas funding had ended (October 2016) by allocating resources to engineering tasks and business development missions. It would prove that the technology could be licensed to a company (or at least generate a MoU), eventually being able to commercialise a product. In parallel to this short-term funding, GNS could also apply for long-term commercialisation funding, which would enhance the performance of the component, and open new applications for further licensing strategies. This part of the project would be suitable in the MBIE Research Programme funding. As all these fundings are subject to a partnership with a New Zealand company, the lab was recommended to work on a prototype to demonstrate this technology as soon as possible.

2.6 Research methodology evolution, limitations and challenges

It is now clear that the research process was not a linear journey and multiple factors had modified the work along the year. Firstly, it was the last year of funding from MBIE for the research team and, before even talking about the next stage and the potential applications, the immediate goals were to justify that the objectives penned in the Smart Ideas funding were achieved. Yet, in February 2016, only the proof-of-concept for a working magneto-electric composite was realised, where electrical signals were detected when the material was subject to a magnetic field stimuli. During this period the research process was still theoretically grounded and all the potential applications had not been subject to preliminary market validation. Moreover, the interview stage was not even launched. The idea to get paid directly from manufacturers without knowing if a solution can be provided by the technology was a

real challenge, but at least it allowed the team to cross out or add new features that were identified as important (or not) by market players. Eventually the team was able to produce a proof-of-concept for a tunable component which changed its resonant frequency when excited by an electric current, and the work already done on preliminary market validation allowed us to identify a promising candidate in the area of a tunable radio frequency filter. The next questions were: which one of the various market segments should we target, and what features are necessary to disrupt them?

In principle, it is much easier to establish all these when you know what your product will be. However, this does not mean that it was easy to find people to answer the questions which this project was seeking. From a scientific point of view, most of the professors from Victoria University of Wellington and the scientists who were interviewed, admitted that they are not working on this topic and that they were not aware of groups or other universities which specialised in RF hardware. The solution to this could only come from the manufacturers' R&D departments. Moreover, this was a huge limitation because there was no RF filter manufacturer in New Zealand. This led us to embarking on a trip to Tokyo to get data from Japanese manufacturers, which was a challenge in itself. These manufacturers are billion-dollar companies, but highly hermetic and with only a handful of English speaking employees. On the other hand, as the project was to be financed by the government, GNS was limited to partnering with a national company, thus constraining the team to meet with an antenna manufacturer like Rakon. Fortunately, Rakon's new strategic pathway was to go on the Internet of Things market and accepted to talk about a filter project with GNS. In the meantime, a prototype for a tunable RF filter was produced, but the performance was in the low frequency region, which was not suitable for either of these two applications. In November 2016, after many interviews with engineers and having changed the product roadmap several times, an

application started to emerge in the area of RF tunability. Furthermore, the operating frequency was close to that already obtained: in the field of underwater communication.

And so, from this chaotic journey, the project team was able to identify a beachhead market for a tunable RF filter, with a potential partner in New Zealand and with a prototype that could lead to fast commercialisation. But the other data were not abandoned, and the roadmap took into account further research on the component that could improve their performance in the higher frequency range. This would make them suitable for technologies used for the IoT market and even the handset market. This is the part of the work that will be studied in the next part of the report.

Chapter 3: Findings and analysis

The purpose of Chapter 3 is to present the results from the data collection and the interpretation of what it means for this project. It describes the findings in relation with the key assumptions around product development and the market opportunities. During the research various data were collected from two main trends. First, we will detail the preliminary market validation for the technology developed by GNS, categorised by feature (or potential added value) and industry¹³. Then, because it was assessed as the most promising application and market, we will detail the data regarding the radio frequency filter market and its segments.

3.1 Findings and assumptions on the technology's applications

3.1.1 Size, Weight and Power (SWaP)

3.1.1.1 *Antenna manufacturing*

- *Technology*

Antennas are used to emit and receive radio waves. Radio waves are a type of electromagnetic radiation which has frequencies as high as 300 GHz to as low as 3 kHz (Radio wave, 2017). For our purpose, we have to distinguish two types of antennas: the 'station' antenna type which works as the network provider (e.g. AM/FM radio stations, telecommunication radio stations, satellites, etc.) and the 'device' antenna which uses the network (radios, smartphones, GPS, etc.). Indeed, SWaP requirements are assumed to be different as well as the means to provide them, and some applications do not require the reduction of neither of these parameters.

Antennas are made of an arrangement of metallic conductors, usually copper due to its high conductivity. These conductors are electrically connected through a transmission line to a

¹³ See Table 1. *Assumptions for applications*, page 22-23.

receiver or transmitter. In transmission mode, the transmitter supplies an oscillating current of electrons forced through the antenna, radiating the energy from the current as electromagnetic waves (or radio waves). The level of electric current will determine the radio frequency of the signal. In reception mode, the electrons in the antenna are excited by the oscillating electric and magnetic field of a radio wave, creating electric currents in the antenna. Antennas are holistic devices as they are sensitive to all the frequencies of the RF spectrum they can address¹⁴. This spectrum is determined by the design of the antenna.

- *Industry portrait*

The global antenna market is projected to reach US\$11.31 billion by 2020 with a compound annual growth rate (CAGR) of 9.27% (Global Antenna Market | Global Antenna Market Report – Analysis, Trends, Future, Growth, Potential, 2017). This fast increase is linked with a growing demand for wireless systems and wireless communications. Analysts segment the market into two types of antennas: radio antennas (the conventional type) and smart antennas, which are sending several copies of a signal on several frequencies so that every part has a greater chance of reaching the receiver. The latter have grown immensely due to advancements in technology and the capacity to use smart signal processing algorithms to identify a spatial signal signature, which are useful for cellular networks or smart TVs. Antennas have many applications including RADAR, satellite communication, cellular communication, Wi-Fi systems, Bluetooth devices, RFID tags or IoT sensors.

Leading companies in the market are Intel Corp, Qualcomm Inc., Motorola Inc., Rakon Ltd, Accel Networks, Linx technologies, Array com LLC, Ruckuss Wireless, CommScope, Airgo Networks Inc., and Broadcom Corp. In New Zealand, there are companies that produce various types of antennas. They include Rakon Ltd, Navico, Tait Communication, Electronic Navigation and Times-7.

¹⁴ As we will see later, that is the reason electronics use RF filters.

- *Key assumptions for the product*

In this application, the magneto-electric nano-structured component developed by GNS could be an alternative to a metallic conductor-based antenna. Dr Leveneur believes that in terms of design and performance, the component could be more efficient, meaning better performance for an equivalent size or the same performance for a smaller design.

- *Market insights*

From the interviews conducted it appeared that the market restraints were mainly cost and design. Times-7¹⁵, a RFID antenna manufacturer, states that in their field, clients are seeking antennas for warehouses or other big spaces, so the device's size or power consumption are not the primary motivations. In its segment, the manufacturer predicts that most of the producers have the same price and that design (in terms of aspect and not engineering) will be the asset which will make a difference. Asked about investment in smaller antennas or smart RFID chips, the manufacturer had some difficulties projecting itself and thinks that focusing on its current production is a priority before thinking about developing a new range of products.

On the other hand, a world-class manufacturer like Rakon¹⁶, which produces oscillators/transmitters for cellular networks, seemed more interested in the RF tunability feature than coil design for a potential partnership with GNS. This manufacturer is actually working on its strategy to invest in the IoT market, identified as a more promising market. Asked about the SWaP paradigm, they declared that power consumption could be a selling point for years to come.

The research team, regarding a potential collaboration with Rakon, decided to focus on a tunable RF filter for an IoT application for the following reasons: (1) no proof-of-concept for a boosted antenna had ever been produced, and (2) their performance rate need to be further

¹⁵ Interview conducted in March 2016.

¹⁶ Interview conducted in July 2016.

improved to meet Rakon's criteria. The team decided to tackle these issues before meeting the manufacturer again.

3.1.2 Energy harvesting

3.1.2.1 *Zero power magnetic field nano-sensor*

- *Technology*

MEMS is an abbreviation for microelectromechanical systems, designating the main trend in microelectronic devices, which have been enabled by the use of micro- and nano-engineering. There are magnetic field sensors, at a small scale, based on this technology termed MEMS-based magnetic field sensors. At a larger scale, a magnetic field sensor such as a magnetometer is highly sensitive to changes in voltage or resonant frequency, and can be used to measure earth's magnetic field. By integrating this into a MEMS-based "magnetometer" this new magnetic field sensor can detect a small change in voltage, resonant frequency or even a mechanical displacement at various positions of an instrument. They are currently used in automotive engineering (engine position, rotary position, timing and displacement applications) but also in battery monitoring to detect a variation in the charge, and even in submarine detection ("MEMS magnetic field sensor", 2017).

- *Industry portrait*

The magnetic field sensors market is projected to be worth US\$4.16 billion by 2022, at a CAGR of 8.87% between 2016 and 2022 (Magnetic Field Sensors Market by Type Hall Effect – 2022, MarketsandMarkets, 2016). The market trend is the use of MEMS-based sensors in the automotive industry, the rising demand for high-quality sensing devices, the growth in consumer electronics applications and the medical sector's demand in biosensors. They are

also important in applications like displacement sensing, rotational reference or proximity detection.

The following is a list of the leading companies, among others, involved in the development of MEMS-based magnetometers: Analog Devices, NXP Semiconductors, Honeywell International Inc., MEMSIC Inc., Asahi Kasei Corporation, Sanken Electric Co., Ltd, Infineon Technologies AG, Robert Bosch GmbH, and Bartington Instruments.

There is no company specialising in this industry in New Zealand.

- *Key assumptions for the product*

Normal magnetic field sensors have to be powered by an external power source to stay ready to measure. Here the research team proposed to produce a proof-of-concept small-scale sensor self-powered by the energy it is monitoring. In this hypothesis, the sensor would be on ‘standby’ most of the time, under a constant oscillating current, and would monitor any changes in the oscillating frequency of the current or voltage without any external power source, making the device battery-less (or zero power).

Moreover, the component is not only sensitive to a change in magnetic field, it can also be configured to create an electrical current. Such a device would add value in terms of better life expectancy, and advantages in size and sensitivity to a manufacturer.

- *Market insights*

As there is no MEMS-based magnetic field sensor manufacturer in New Zealand, and it was very complicated to get insights from the market. The only source of feedback was from Callaghan Innovation which has a MEMS department and could give some insights from what was done at the time. It appeared that the field was well investigated by the industry players and Andrew Best asked about the performance of the prototype to assess GNS’s potential in the matter. However, the lack of a prototype during this early research stage paralysed the data

collection. Coupled to the absence of a manufacturer in New Zealand, this application possessed too many constraints to be investigated further.

3.1.2.2 *Electronics empowerment*

- *Technology*

The same way the component can empower a magnetic field sensor, it can use the electricity generated from magnetic waves and fields to power batteries or other electronics. The concept of energy harvesting relates to the process of using ambient energies (light, heat, vibration, magnetic fields, radio frequencies), which is converted primarily into electrical energy to power small and autonomous electronic devices. It could be an inexpensive and compact way to power portable electrical devices that in many cases rely on batteries. It has domestic and industrial applications for products that need to be disconnected from electrical outlets.

Energy harvesting and the IoT are closely linked and applications for these technologies are huge: personal electronics (laptops, smartphones), biomedicine (implanted devices for breathing, blood flow or muscle work), smart cities and smart homes (sensors), etc.

- *Industry portrait*

Market projections for energy harvesting include all the technologies able to collect ambient energy. However, there is no data about RF Energy harvesting alone. Nevertheless, the trend from the global market is a good indicator of the potential of this component. In April 2016, the global market in this industry was expecting to grow from US\$268.6 million in 2015 to US\$974.4 million in 2022, at a CAGR of 19.6% (Energy Harvesting System Market by Technology – 2022, MarketsandMarkets, 2016). The leading segment, building and home automation, is predicted to dominate the market as the demand for smart home and wireless sensor networks is increasing to reduce the energy consumption. Industrial and environmental

monitoring is the second leading the market, followed by transportation (cars, aircrafts, trains). In terms of the type of energy being harvested, light harvesting is and will continue to be the main source of energy. This is justified by the abundance of solar energy and the technology improvement for ambient light harvesting.

Even if there is an increasing demand for safe and durable power solutions, reduced carbon emissions and maintenance-free systems, the penetration of this technology is restricted by a high initial cost, which could explain their low adoption in developed countries without political actions. Like the IoT uptake, the difficulties in standardizing the communication protocol are also limiting the interoperability of the devices.

Following is a list of the major industry players working in this energy-harvesting field: EnOcean GmbH, Texas Instruments, Fujitsu, Murata Manufacturing Co., Linear Technology, Cypress Semiconductor Corp., Mide Technology Corporation, Lord Microstrain, Laird Plc., IXYS Corporation, STMicroelectronics and Cymbet Corporation. There is a rising player in this market in New Zealand: PowerbyProxi.

- *Key assumptions for the product*

The assumption was to find an application where the amount of energy which is harvested could be enough to power or charge a device. However, the amount of electricity being harvested is estimated to be very small as predicted by the research team. Therefore, a decision was taken to focus on a wireless power transfer application for small devices like a microelectronic ‘hand-held’ for biomedicine applications.

- *Market insights*

Initial feedback from a company working in the field of fruit picking. However, the mechanics plus the insufficient amount of electricity being generated has dampened our market research in this area and it was not further pursued.

3.1.2.3 *System-on-Chip (SoC) powering*

- *Technology*

The mobile computing market evolution is constantly reducing the size of the components to create smaller and lighter devices. Due to this trend, and the famous Moore's Law which stated that the number of components per integrated circuit is "doubling every two years" ('1965: "Moore's Law" Predicts the Future of Integrated Circuits', 2017), we are now seeing the arrival of system-on-chip (SoC) devices. More precisely, a SoC refers to a single chip substrate which carries an entire electronic system. SoC are characterized by their micro/nano structures, a small size with a low power consumption. If smartphones are the main consumer of SoC, you can find other applications like ones in biomedicine with Lab-on-Chip (LoC) directly injected into the blood to monitor and cure certain illnesses. At that scale, design and size optimisation have a huge impact on the final product and, as the market is very competitive, every nanometre counts.

- *Industry portrait*

The SoC market was estimated at US\$35.9 billion in 2014 and is projected to be US\$71.9 billion in 2021 with a CAGRO of 10.5% (System on Chip Market – Global Industry Analysis and Forecast 2021, 2015), which is impressive at this size. Demand for power efficient electronic devices is pulling the market forward, additionally with the decrease of costs and the increasing demand for multi-core technologies and embedded graphics systems. After smartphones and wireless communication equipment, the secondary applications are automotive body electronics and electrocardiogram telemetry devices.

The following is a list of the leading companies in this market: Apple Inc., Intel Corporation, Qualcomm, Inc., Samsung, Broadcom Corporation, Freescale Semiconductor, Inc., STMicroelectronics N.V., and Toshiba Corporation.

There is no manufacturer specialising in system-on-chip in New Zealand but some companies are working in the semiconductor field which is part of the global market supply chain. They include Festo, Intrepid Semiconductor and Precision Microcircuits Ltd.

- *Key assumptions for the product*

The idea was to propose an energy harvester material which would be used in SoC design to replace existing ones, arguing that the new component using magneto-electric properties would generate its own energy. It could be for example a micro-antenna made from the material, or a substrate for the chip which would generate electricity from the magnetic field generated by the device it is embedded in.

This hypothesis stood on several key assumptions:

- The manufacturers would be struggling with power-efficiency and size problems.
- Moore's Law would be reaching its limits to reduce semiconductor component size.
- It could be possible to license a single material without a full component proposition.

- *Market insights*

Without a concrete component or prototype to work on, market insights research was unproductive and the New Zealand manufacturers did not follow up interview requests. In the perspective of a funding application, it would have been complicated to build a convincing business case without a potential partner and a clear application for the technology with an identified market gain. These factors led to the decision to not take the topic any further.

3.1.3 Magneto-electric tunability

3.1.3.1 *Magneto-resistive Random Access Memory (MRAM)*

- *Technology*

Before presenting MRAM technology, it is essential to give a brief introduction to Random Access Memory (RAM). RAM is a volatile type of computer data storage which is dedicated to short-term memory instructions frequently used by programs in the system. It is different from non-volatile data storage like a hard disk, which writes data on a specific location of its surface. RAM uses electric charge (positive or negative in a binary scheme) to store data, that is way faster than a hard disk using a physical process to write and read data. In a RAM circuitry, the location of the data does not have an impact on the speed to process it. The issue with RAM is that when power is removed the stored data is lost as electric charges dissipate without energy (Random-access memory, 2017).

The idea behind magneto-resistive RAM is to combine the speed of volatile data storage with the advantage of keeping the data safe even without power. To do this, the MRAM uses magnetic orientation (as the binary) instead of electrical charges. According to Dr Leveneur, this technology has been in development since the 1990s but without a revolutionary process which could disrupt the RAM market. Nevertheless, devices are produced and sold, and the market is waiting for the big players to release new products soon.

- *Industry portrait*

The non-volatile data storage industry is an emerging market which was estimated at US\$53 million in 2015 (Emerging Non-Volatile Memory 2016, 2016). In comparison, RAM was at US\$80 billion the same year. It is projected at US\$4.6 billion by 2021, with an impressive CAGR of 110%. The need for this new technology is pulled by enterprise and client storage but also by the growing low-power IoT and wearable electronics. As for a lot of emerging technologies, market data are rare.

Everspin Technologies Inc. dominates the MRAM market at the moment with a share of 64% of the global market (Magnetoresistive RAM (MRAM) Market – Global Industry Analysis, Size, Share, Forecast up to 2024, 2016), but other players are developing solutions to gain a share of this promising market like Avalanche Technology, Honeywell International and Toshiba.

There is no company working on this technology in New Zealand.

- *Key assumptions for the product*

The magneto-electric component developed by GNS has the properties to be electrically excited to change its magnetic orientation and stay in that state. However, its performance will need to be tested and compared to the other components currently used for MRAM, and would need to suit an industrialisation process.

- *Market insights*

This application is without doubt the most complex one in terms of product development. From the beginning a red alert was given by Dr Leveneur regarding the capacity for GNS or any other lab in New Zealand to work on a realistic prototype, due to the lack of expertise on this technology in the country. Moreover, it has been decades since the big players in the market (IBM, Intel, etc.) were struggling to launch a competitive product. It was not until 2016 when MRAM achieved its milestone with Everspin launching new products with competitive potential, Samsung announcing a soon-to-be-ready working MRAM, and above all IBM demonstrated a proof-of-concept for a switching MRAM cell for devices with diameters ranging from 50 to down to 11 nanometres in only 10 nanoseconds, using only 7.5 microamperes (The best of 2016 - top MRAM stories | MRAM-Info, 2016). Facing these features, the research team admitted that their component was far away from these performances and that they were now clearly too late to compete in this sector.

3.1.3.2 *Radio frequency identification (RFID)*

- *Technology*

Though this has been around for a while, the RFID technology explosion is quite recent due to cost reduction and new types of tags replacing the original inductively coupled tag (Bonsor & Fenlon, 2017). RFID tags can now be activated, semi-activated or passive. Furthermore, in some case the tag can be powered by a battery to send a signal to the RFID reader, and in another mode the tag uses power harvested from the reader's electromagnetic field to emit radio waves back. Commonly passive tags are just composed of a microchip and an antenna enclosed within plastic or silicon. The antenna is the biggest part of the tag, and is made mostly from copper, with the restraints we have already listed. The key factors for this market are cost, data storage capability, tags interference and emission range.

- *Industry portrait*

In 2015 the global RFID market totalled US\$10.1 billion (tags, reader and solutions) and is projected by IDTechEx to reach US\$13.2 billion by 2020, with a CAGR of 5.5% (Das & Harrop, 2017). The market is dominated by retail (4.6 billion tags in 2016), followed by transit tickets (800 million tags) and the tagging of animals (420 million tags). Ultra-high frequency (UHF) tags are the most commonly used because they are cheap and disposable. High frequency (HF) tags will be in high demand as well because of their use in security for payments (near field communication, NFC) or security access.

The following is a list of the leading tag manufacturers: Avery, SMARTRAC, Alien, Arizon, SAG, Century, Invengo, Honeywell, Shenzhen Chuangxinjia and UBIQUE.

In New Zealand, there is no tag manufacturer but Times-7 is an international player in designing UHF RFID antennas and Tracient Technologies specialises in wireless mobile RFID readers for mobile devices.

- *Key assumptions for the product*

The key assumptions for an RFID application are that the market is in demand for a technology to reduce the size of the tags and optimise the energy harvesting as well. On a different axis, the research team imagined a tag that would tune its resonant frequency to code its emissions using an encryption key to secure the communication between the reader and the tag, assuming that security was also a need for the manufacturers.

- *Market insights*

Times-7 was one of the first manufacturers to be interviewed during the preliminary market validation and their insights on the tag market showed an interest in cheaper material, a demand being driven by costs. That is why the company focuses on antennas and is not interested in entering the tag market which is mature with a lot of barriers to entry. Nevertheless, they identified an opportunity in readable tags for containers, as there is a need to read the content of a cargo during transit but the metal casing blocks all RF signals. If GNS technology was not able to solve this problem, it at least gives a lead for further research to the research team.

3.1.3.3 Tunable radio frequency filter

- *Technology*

As presented in the antenna case, an antenna can receive or emit on the full RF spectrum. The communication with a single antenna would be subject to interference by all other communications at a given time. To avoid this problem, the RF spectrum is divided into regulated frequencies, or bands, where only certain players can emit. The simplest example being the AM/FM bands where only public radio stations can broadcast. To reject the interference from unwanted frequencies, the antenna's signal is 'filtered' by one or several radio frequency filters designed to let a particular frequency to pass: this type is called a pass-

band filter. RF filters are used in all communication devices, in radio stations, smartphones, GPS, walky-talkies, and wireless sensors. From the moment an antenna is used, at least one filter is needed. Moreover, the number of filters depends on the number of frequencies which are being addressed. Indeed, a filter can only be designed for one frequency. Consequently, multi-frequency device uses several filters; a figure that can reach uncharted proportions like smartphones (such as iPhone 7 or Samsung Galaxy S7 (Resonant Inc., 2017)), which can address more than 50 frequencies.

- *Industry portrait*

The RF filter market is monitored in the global RF front-end market, projected at US\$19 billion by 2020, with filters representing around US\$13 billion in Mobile Experts' LLC study ('RF Front Ends for Mobile Devices 2015', 2015). Filters are indeed leading the increase in the market because of multi-band and multi-mode mobile devices which supply the demand of consumers for a range of wireless communication systems (WiFi, Bluetooth, NFC, GPS, Long-Term Evolution (LTE) 4G and more). Smartphone manufacturers use two factors to pull the market. Their product combines all standards¹⁷ and the demand for data transmission is higher every year. Secondly, the GPS segment is on a rise as receivers are implemented into electronic devices like smartphones, tablets, wearable electronic devices or cars. Tablet manufacturers are progressively enhancing their products with 4G LTE features. At a smaller scale the filter market sees the increase of other segments such as e-readers or smart TVs with internet capabilities, but the next big thing for filters is in the emerging market of the IoT for which the global expenses for the next five years are projected at US\$6 trillion (Greenough, 2016).

The following is a list of the main manufacturers in the sector: Murata Manufacturing, Avago Technologies, Qorvo, TDK, NXP Semiconductors and Taiyo-Yuden.

¹⁷ Here standards are defined as the frequencies set by international consortiums like the Institute of Electrical and Electronics Engineers (IEEE).

There is no RF filter or RF front-end manufacturer in New Zealand.

- *Key assumptions for the product*

The Smart Idea funding was based on the project to produce two prototypes, including a tunable RF filter. It does not include a market validation since MBIE is focusing on the proof-of-concept for the magneto-electric nano-structured component and its properties. However, assumptions were made regarding the interest for an electronics manufacturer to use a tunable component for their communication devices. The critical risk factors at the time were to produce a tunable filter fitted for an industrial use (at a small size), with disruptive performances. A pre-validation scan of the literature confirmed that no one was working on the same concept.

- *Market insights*

At the preliminary market validation stage, the market insights were entirely picked from online sources, as there was no company specialising in this field and the interviewees from Victoria University were not working on wireless communication hardware. The size of the existing market and its dynamic were obvious, as well as the future potential new segments likely to be the IoT. But it was the technology challenge which made a difference. The topic of a ‘tunable RF filter’ being studied in multiple articles¹⁸, stated that this ‘holy grail’ had been sought for a long time without a convincing product being found.

With proof-of-concept and a prototype on the way, the tunable RF filter was confirmed to be a promising application, but with a challenge. The challenge was to find and convince a New Zealand company to build a partnership with GNS to raise funds and work on a market-ready product. Taking note from all the previous preliminary market validations, the GNS board and the research team decided to explore further this application and laid out a roadmap

¹⁸ EE Times | Electronic Engineering Times | Connecting the Global Electronics Community, 2015; Liu, 2015; Zedníček, 2016; Aigner, 2008; Blyler, 2012.

where an international partnership would be a more realistic and practical final goal, but with the first milestone achieved in New Zealand. It was proposed that from May 2017, the project will focus on finding applications and potential manufacturers for a tunable RF filter.

3.2 Findings and assumptions on the RF filter markets

3.2.1 Technology description

3.2.1.1 *Electronic filter types*

Here we are going to describe in more detail the different electronic filters and why their proliferation is projected to become a problem in years to come.

The fast increase in mobile wireless data has created a continuous need for new spectrum bands to support their transmissions. Whereas 3G networks only use around 5 bands, long-term evolution (LTE) 4G occupies 20 bands¹⁹. This standard can reach 40 bands at its maximum. These bands are regulated by government, and can operate at different frequencies depending on the existing spectrum they are launched at. Consequently, some bands could be located at different frequencies depending whether they are in New Zealand or in Europe for example. Feature-rich smart phone models, designed for international use, may need to deal with transmission and emission for mobile communication, as well as WiFi, Bluetooth and GPS signals. The most complex devices on the market (launched in 2016) could integrate more than 50 filters (Resonant Inc., 2017).

¹⁹ It is important to note that a band is divided in two frequencies (uplink and downlink) due to the frequency division duplexing (FDD) model. These bands are physically separated in frequency to prevent interference. This separation is called a 'duplex gap'. As a consequence, a filter is needed for the uplink frequency and another one is needed for the downlink. In this respect, 40 bands mean 80 frequencies, and as many filters in the smartphone for voice and data transmission.

Figure 6. Evolution of the number of filters (figure adapted from Resonant Inc., 2017).

There are four types of filters (Miller, 2015) defined as:

- Low pass: Allows all frequencies below a certain frequency to pass.
- High pass: Allows all frequencies above a certain frequency to pass.
- Band pass: Allows all frequencies between two frequencies to pass.
- Band stop: Rejects all frequencies between two frequencies while letting all others to pass.

There are many filter constructions from discrete inductor-capacitor filters to multilayer ceramic filters. The one which interests us is the acoustic construction, which has been used by GNS to test their new composite. This construction has the capability to meet both low and high frequencies up to 6 GHz. This construction type is used for mobile devices because it allows smaller designs with excellent performance and lower cost for complex filter requirements.

A range of criteria measures the performance of a filter but three are fundamentally required:

- Attenuation: An amplitude loss, usually measured in decibels (dB), incurred by a signal after passing through an RF filter.
- Insertion loss: Loss of signal power resulting from the insertion of a component.

- Q-factor: The ‘quality’ factor is a measure of the selectivity of a resonant circuit described as the ratio of stored versus lost energy per oscillation cycle.

3.2.1.2 *Surface acoustic filters and bulk acoustic filters*

The competitive environment has pushed the manufacturers to invest in new manufacturing process and acoustic filter technologies to meet today’s toughest mobile device filtering problems that challenge the global transition to 4G networks. This technology is divided into two major constructions, SAW and BAW filters, but some new types are emerging.

SAW filters are made on wafers, combining the advantages of implementable on a single chip and can be produced in large scale, and at low cost. In a basic SAW filter, the electrical current is converted to an acoustic wave by interleaved metal interdigital transducers created on a piezoelectric²⁰ substrate, as illustrated in Figure 7 below.

Figure 7. The basic configuration and mechanism of a SAW filter (Miller, 2015).

The performance of SAW filters can meet standard filter applications up to 1.9 GHz (GSM, CDMA, 3G and some LTE 4G bands operate under this frequency). However, it starts to decline in terms of selectivity above 1 GHz, which is why BAW filters are preferred for high frequencies. However, Resonant Inc., a new player in filter manufacturing, has made its

²⁰ A material that can create a voltage from vibrations, pressure or strain.

specialty to design SAW filters meeting the performance of BAW filters on certain bands (Resonant, 2017).

To complement SAW filters at higher frequencies, RF manufacturers use BAW filters which can address frequencies from 1.5 GHz to 6 GHz. Most of the LTE 4G bands operate in this range as well as WiFi. BAW filters, which are built vertically, deliver better Q-factor with lower insertion loss than SAW filters, but are more expensive and less simple to implement than SAW filters. A BAW resonator uses crystal as the substrate, and metal patches on the top and bottom sides of the quartz to excite the acoustic waves, which bounce from the top to the bottom surface to form a standing acoustic wave. Figure 8 shows how a basic BAW filter works.

Figure 8. The basic configuration and mechanism of a BAW filter (Miller, 2015).

Because the spectrum is saturated, government opens new bands but mainly in the high frequency range, giving BAW construction the most promising future.

To understand completely how the GNS prototype works, Figure 9 shows a SAW²¹ tunable filter from their Smart Ideas proposal:

²¹ The team has also produced bulk materials which could be used for prototyping a BAW filter.

Figure 9. Schematic diagram of a prototype tunable RF SAW filter designed by GNS (Dr Leveneur).

The nano-composite film allows the modification of the impedance of the substrate, which impacts the passage of the electrical current and changes the resonant frequency of the filter. To operate, the filter is linked to a CPU by a conductor sending an alternative current signal to vary the excitation of the nanoparticles of the composite. Current filters are designed with fixed impedance, hence they can address only one featured frequency. As the resonant properties of the filter can be modified in our proposal, we refer this as analogic tunability.

3.2.1.3 *Tunable RF filter patent research report*

The patent search focused on two applications: the magneto-electric material and the tunable RF filter. Three magneto-electric concepts have been developed by GNS (coupling of magnetic and piezoelectric nanoparticles in resin, multi-layered composite, and multi-layered composite with magnetic nanoparticles) and two concepts of variable inductors for a tunable RF filter (one with a solenoid coil and the other with a planar coil). The search was for variable inductors as well as tunable RF filters, considering some potential non-RF applications for variable inductors.

It appeared that the concept of a tunable RF filter using multiferroic material as the core of a variable inductor was not likely to be patentable. Indeed, one document (Sun, 2014) was

found to describe the use of a variable inductor with a magneto-electric core that directly modifies the inductance of a coil as the basis for a tunable RF filter. Several documents described variable inductors with composite cores comprising ferromagnetic and piezoelectric layers. However, there was no document that described a variable inductor utilising a nano-composite material with both magnetic and piezoelectric nanoparticles. This latter concept is patentable.

In conclusion, the concept for a tunable RF filter using a nano-composite material that shows coupling between magnetic and piezoelectric nanoparticles as the core of a variable inductor is the only one which is likely to be patentable.

3.2.1.4 How is the market solving the problem?

Band proliferation is an emerging issue which has been exploited by the LTE 4G network with the addition of 40 bands for voice and data transmission. As manufacturers want to provide the best experience for their customers, they progressively implement these bands in their devices' features to boost the capabilities in terms of speed and performance. Moreover, announcements from Qualcomm and Intel for a 5G-ready modem (Tilley, 2016) give an insight of the increase in performance to come, with download speeds reaching 5 gigabits per second. Regarding the frequencies, 5G would operate in the millimetre wave spectrum and more precisely all the frequencies between 24 GHz and 100 GHz (Tracy, 2016). From the manufacturer point of view, it means more BAW filters, or a new type of filter, including overcoming issues such as size and cost for the all RF front-end filters. To solve the problem, the market is currently investigating three different routes.

3.2.1.5 *Enhancement of BAW and SAW filters*

As previously described, many improvements have been made by manufacturers to reduce the size of the filters while improving their performance (insertion loss, temperature resistance, etc.). These improvements, though are part of the global movement of size reduction (see Moore's Law), are also confronted with the limitations of physical possibilities. This evolution can be clearly seen in the last few years if we take the example of discrete filter technologies: a CSSPlus model filter is $2.0 \text{ mm} \times 1.6 \text{ mm}$ ($= 3.2 \text{ mm}^2$); the next model, CSSP3, is 52% smaller with dimensions of $1.4 \text{ mm} \times 1.1 \text{ mm}$ ($= 1.54 \text{ mm}^2$). This was further reduced by 36% in 2016, to $1.1 \text{ mm} \times 0.9 \text{ mm}$ ($= 0.99 \text{ mm}^2$) (*Radically Reducing the Cost and Size of Cellphone RF Filters to Fuel the Mobile Revolution*, citing data from EPCOS, Resonant Inc., 2015).

3.2.1.6 *New RF architecture*

An alternate way to address more frequencies in a filter is to have several filters operating together. Resonant Inc., a US-based company specialising in RF architecture since 2012, has developed 'multi-band techniques' that allow two or three filters to share the same die, using vibrating resonators in a SAW design (Johnson, 2015). In other words, they can reduce the size of the RF filter front-end, but also the bill of materials and the manufacturing process. The company is still young and the first model of filters were implemented in smartphones in 2016, and they have since announced more than 100 pending and issued patents plus 26 devices under contract development (Resonant Inc., 2017). It is interesting to note that they previously announced in 2014 that they will achieve a tunable RF filter by the end of that year, but kept postponing the release of the prototype.

3.2.1.7 *RF agile transceiver for software defined radio*

On a more concrete basis, software defined radio (SDR) could be seen as the most equivalent technology to GNS's composite as it provides a single chip able to address all the frequencies from 70 MHz to 6 GHz (e.g. the chip AD9361 Analog Device), which is a high performing 10 mm × 10 mm chip (Taranovich, 2015). The RF transceiver for SDR is a combination of a RF front-end, flexible mixed-signal baseband section, frequency synthesizer, analogue-to-digital converter and direct conversion receiver. In simple terms, the signal is digitally treated to isolate the targeted frequency, enabling radio applications operating at a wide range of schemes and specifications. These devices are conceived to address complex issues in defence electronics, instrumentation equipment and communication infrastructures. Consequently they are complex to produce, complex to use and extremely expensive: US\$300 versus US\$0.28 to 0.62 for a conventional filter (Resonant Inc., 2016).

3.2.2 **Product validation**

The product validation process was more near to what Adams (*If you build it will they come?*, 2010) called the 'Aim' stage, collecting feedback from experts to understand what the product needs to do to solve a problem. For the first time, without any company specialised in this field, this research had to focus on finding engineers who could validate the technology and provide expert advice on the capabilities an RF tunable filter should possess to add value to the market.

After a cascade of referrals, the team met with Derek Richardson, Senior Research Engineer at Callaghan Innovation, who was the first to explain to us the implications of the use of an analogic tunability. He also emphasised that apart from disrupting the filter market itself, such a technology could even enhance the SDR architecture by adding a tunable filter between the antenna and the radio. Presently, the transceivers have to deal with the whole spectrum. By

reducing the range using a filter, the performance would be improved in terms of interference and even expand the spectrum that could be scanned²². However, Richardson did not have any advice from his expert point of view regarding the tunability range to reach. Nonetheless, he referred us to Sudhir Singh, who also works in this field at Callaghan Innovation.

Singh's team at CI has generated intellectual property (IP) from their work on cognitive radio technology. A cognitive radio is a radio system operating in unregulated frequencies (in opposition to regulated frequencies, or bands, rented from the government to a mobile operator for example), where everyone can emit without rules with the major consequence that the emitted signal will be absorbed by so many interferences it will never be received. To protect the signal from interference, a cognitive radio scans the RF spectrum and determines in real-time blanks where to emit. It then transfers the chosen frequency to the other cognitive radio before sending the data. This technique is also called 'frequency-hopping'. According to Singh, the adjunction of a tunable filter in a cognitive radio would indeed increase its efficiency²³ as shown in Figure 10 below.

Figure 10. Schematic diagram showing a wider bandwidth being accessed by the addition of a tunable filter to a cognitive radio.

²² Interview with Derek Richardson was conducted in August 2016.

²³ Interview with Sudhir Singh was conducted in September 2016.

This improvement would radically change the way radio works. A SDR is currently used to scan the whole RF spectrum to find frequency blanks, thus limiting the performance of the device which has to treat way more signals than it can handle to sort a single frequency range. By adding a tunable filter, which would follow spectrum scanning, the resources needed to treat the signal decrease, the speed in finding blanks increases and the usable bandwidth is wider as well. The wider a bandwidth is, the more data one can transmit on it.

As the first prototype was produced, the data regarding the tunability was proven and allowed the research team to start testing the operating frequency of their magneto-electric material. The first results operated in low frequencies showed a 6% tunability at 600 kHz with a possibility to go lower. This was surprising as all publications listed values in high frequency, but GNS believed the performance of their prototype can be improved. Nevertheless, the research team decided to assess potential uses at these frequencies and discovered underwater communication operates between 80 and 160 kHz, or even lower frequencies (30-300 Hz)²⁴.

From this point, the data collected was to consolidate a roadmap regarding each application and how to build a convincing project for the GNS board. In addition to these engineering insights, a decision was made to collect market feedback for each targeted segment.

3.2.3 Segmentation by market for a RF tunable filter

3.2.3.1 Handset

The market for RF front-end for mobile devices is projected to reach US\$19 billion by 2019 (RF Front End Market to Reach \$19B by 2020, 2015), thanks to the popularity of high-end smartphones. It is also important to keep in mind the evolution of connected tablets and,

²⁴ Interview with Neil Scott was conducted in November 2016.

above all, wearable electronics which are still a promising application which is projected at US\$31.27 billion by 2020 with a CAGR of 17.8 % (Wearable Technology Market worth 51.60 Billion USD by 2022, 2017). The common issue for these devices is the size reduction coupled with improved capabilities, and this for all the components they integrate to. As we have seen previously in section 3.2.1.5 *Enhancement of BAW and SAW filters* (page 56-57), this continuous size reduction has a foreseeable limit and manufacturers are investigating new ways to challenge this limit. The issue is the same for RF components, especially even more so when band proliferation is about to create further challenges.

To validate these assumptions and get a tunable frequency range targeting the handset application, the research team attended the Tokyo Japan IT week in October 2016. The aim was to meet with world leading manufacturers in that field. Three goals were established for the trip:

- Meet with Japanese electronic filter manufacturers
- Assess the interest for a tunable filter
- Gauge the connections between those in operations and development from the exhibitors

To overcome the language barrier, a leaflet²⁵ was printed and distributed, targeting engineers and decision-makers who would not be present on certain booths but could be interested in GNS's product. Two main players in RF electronics were interviewed²⁶: Murata Manufacturing and Taiyo-Yuden. Although both manufacturers showed great interest in our product, only Murata Manufacturing gave an indication of the desired tunability percentage which would justify a partnership: 10% minimum, with a huge interest for a 20% tunability in the LTE 4G frequencies.

²⁵ Appendix 2, page 114-115.

²⁶ JITW being a fair there was no time to sit and discuss with interviewees but precious data were collected during the event.

On a different perspective, in parallel to band proliferation, we had to take into account in the longer term the issue of band saturation. As manufacturers are more flexible than governments, their improvements to boost their capabilities in terms of data transfer are now limited even in the new bands opened by LTE 4G. Consequently, a new standard was created, called LTE-U (for unlicensed), allowing mobile carriers to use WiFi networks (WiFi being unlicensed by definition) for smartphone communication (Snyder, 2015). We will detail this trend in the Cognitive Radio segment.

3.2.3.2 *Internet of Things (IoT)*

As previously mentioned, the IoT market is the next multi-billion dollar market but is still considered as an emerging market to a lot of applications, especially for smart homes and smart cities. The main obstacle for its development is setting a predefined standard currently being debated among the manufacturers: ZigBee, Bluetooth Low Energy, SigFox, LoRa, Ingenu, Telensa, Weightless-P, EC-GSM-IoT, NB-IoT, and eMTC. Consortiums and manufacturers try to impose their standard because they consider the technology platform market to be more interesting than the hardware market.

This notion was validated at a meeting with Rakon in July 2016 with their Executive Director and Business Development Manager. The company, specialising in cellular communication, satellite positioning, 4G- to 5G networks and other communication fields, has identified the IoT as their next opportunity (Rakon internal document, 2016). They have launched Thinxtra expected to connect more than 27 million networks by 2022. The strategy is to be well positioned as a major infrastructure provider for data management. But to do that, they are keen to offer innovative products for the IoT, and a tunable filter would fit their objectives. They are targeting a filter-on-chip technology, small and power efficient, operating in 923 MHz to 933 MHz or at a lower frequency of 200 MHz.

3.2.3.3 *Cognitive radio*

The Cognitive Radio market is not studied by market agencies but can be put alongside the projections for the software defined radio (SDR) market, as a part of a future feature of this technology: US\$29.12 billion by 2021 with a CAGR of 12.39% from 2016 (Software Defined Radio Market by Application - 2021 | MarketsandMarkets, 2016).

As a cognitive radio needs to scan many frequencies in the RF spectrum, the use of classical filters is not possible. What is currently being done to address this issue is called Software Defined Radio (SDR). This is a system-on-chip technology which uses a digital solution (when classic filters are just analogue devices) to sort out some frequencies from the full spectrum. This digital solution has its advantages in terms of performance parameters such as low insertion loss and excellent out-of-band rejection, but with high power handling.

A tunable filter for a cognitive radio would increase the efficiency of devices in several ways:

- Rural broadband optimisation (unused licenced bands can be used by other devices than the ones which own the frequency; e.g. TV white space radio)
- Offloading cellular traffic into unlicensed bands
- Military telecommunication
- Detection and mitigation of hostile interference (for the safety of your signal if an unauthorised device is using your band to transmit data)
- Back haul point-to-point for cellular and internet stations

The present issue in cognitive radio lies in the frequency (2.4 GHz) used by Singh's team in collaboration with the manufacturer 4RF. Nevertheless, after seeing the potential of GNS's technology, Dr Singh advised the research team to get in touch with Neil Robinson regarding the applicability of tunable filters for underwater communication.

3.2.3.4 *Underwater communication*

Underwater communication is divided into two sub-segments. First, the global military communications market, which is estimated to grow from US\$23.02 billion in 2015 to US\$40.82 billion by 2020, at a CAGR of 12.1% (Military Communications Market by Communication, 2015). There is always a prerequisite for confidential, secure and fast communication flow to meet the needs of communication and technological advancements, which are growing at a fast rate. It is important to note that this projection includes several applications: airborne, shipborne, underwater, air-ground and ground-based communications. The second is underwater sensors and instrumentation. These have been developed for a broad range of activities including mapping of the seafloor, communicating underwater, locating underwater objects and observing underwater animals and plants. They are carried out by government, industry and the scientific research community. The world's exports of navigational and survey instruments nearly doubled from 2001 to 2011, from US\$7.5 billion to US\$16 billion. In 2011, surveying, hydrographic, oceanographic, hydrological, meteorological or geophysical instruments and appliances accounted for 63% of exports, or US\$10.1 billion, while navigational instruments represented 37%, or US\$5.8 billion (Lee, Turnipseed & Brun, 2012). If the increase in the market is sustainable, it could reach more than US\$20 billion in 2016.

Applications of these are heading toward ocean sampling networks, pollution and environmental monitoring, and distributed tactical surveillance. This implies miniaturization and power efficiency to be paramount, but also trends toward the development of shallow-water applications and devices with better resolution. Our research showed a need to deploy underwater networks enabling real time monitoring in remote configuration and interaction with onshore human operators. Many challenges have to be overcome in order to optimise these

operations. First, the properties of the water medium are complex: temperature, salinity and density vary depending on the place. This causes dampening of the RF signals. Second, a signal can interfere with itself by reverberation on the ocean surface and bottom. Third, natural and man-made noises pollute the emissions. These are just the main environmental challenges. In terms of the technical challenges, a tunable filter would be a promising lead with power optimisation, optimisation of the operating bandwidth and correction of high bit error rates (The Many Challenges of Underwater Communication - Schmidt Ocean Institute, 2015; Akyildiz, Pompili & Melodia, 2004).

Chapter 4: Discussion

Chapter 4 discusses the major findings and what it means for the project. It provides a reflection on the feasibility of the project, the opportunities and barriers that were presented by assessing the best application for the technology. A beachhead market was recommended and the proposed roadmap for the next steps of the project detailing the different milestones are outlined in the later part of this chapter.

4.1 Assessing the best application

In our case, the ‘best’ application would be the one fitting the GNS strategy to get the next funding, and less on a disruptive product. However, this does not mean the institute is not keeping track of the potential for other applications in the future. In fact, both were closely linked according to MBIE’s strategic investment funding (*Strategic Science Investment Fund*, 2016). The main constraint that was encountered throughout this research was the lack of a potential industrial partner to work alongside GNS. In fact, there was no primary RF filter manufacturer in New Zealand. Moreover, the existing companies that use RF filters in their products were reluctant to invest time and money to support R&D work, even if a fully funding project was available.

It is also true to say that the time-span impacted the final decision, as the Smart Ideas funding was approaching the end of its life cycle when this research was initiated. Furthermore, the GNS research team also took a long time to produce proofs-of-concept and prototypes which impacted on the final outcome of this project. Based on the immediate potential of the magneto-electric composite, which they had studied so far, two options had emerged: a zero power magnetometer and a tunable RF filter. For the reasons previously discussed, the research team chose the latter even though there was no clear potential partner identified at the time.

This leap of faith was a risk but it could open up many opportunities for the technology as presented above.

4.2 Assessing the beachhead market

Until the last day of the research, new market segments (see Glossary) continued to be discovered in the RF filter market. Since RF filters are found in every wireless device, there are many potential segments for a tunable RF filter to be used. It is probable that some segments have been missed, but we are confident that the best segments have been identified from the data collected in this research.

From the preliminary market validation, the handset market was the prime focus for the RF filter as the innovation is still heading towards optimising the size, weight and power. It was very encouraging to have a lot of indications from the literature showing great interest in tunability, adding to the fact that GNS's method has not been explored. The handset segment was then qualified as the main goal for the project, but because of the absence of such a manufacturer in New Zealand, a new beachhead market had to be identified.

For a time, the 'prototyping' market was desirable. Considering a magneto-electric laminated composite was fabricated and displayed tunability, the hypothesis was that there was a market for rough composite which could be bought by RF engineers in their day-to-day activity for prototyping new devices. The hypothesis was, instead of having to produce a new prototype device for each frequency they wanted to address, they could change the resonant frequencies of their device using our composite with just a small electrical current and a CPU to control it. This lead was quickly discarded, as engineers prefer to work with plug-and-play devices when it comes to prototyping. Nonetheless, it was during the research in this lead that we met Derek Richardson, an engineer who works with RF filter-based devices. Through this

contact, we were introduced to the field of field-programmable radio frequency device (FPRF) and SDR, which led to cognitive radio and eventually to underwater communication.

In parallel to all the market validation and interviews, the lab work was ongoing where the market validation feedback was used to optimise desired features. Questions that were relayed back to the GNS research team included: Can we produce a tunable RF filter prototype? Can we reach tunability in high frequencies? What are the frequencies that the composite can reach? What is the tunability in the very low frequencies? All these steps were achieved by the research team which had advanced the project to a stage where enough convincing proof was gathered to make the commercialisation process a realistic outcome. Furthermore, this would support future funding from the government for further technology development.

Based on these different factors, different roadmaps were produced to demonstrate a clear vision for the development strategy, streamlining of technical objectives, and a feasible commercialisation plan.

4.3 Building a roadmap covering three applications

Condensing all the required features into one roadmap²⁷ gives a global view on how a CRI such as GNS works, reorganising the different projects under a strategy built to create the conditions for success backed by a credible funding structure. The revised goal was therefore to combine two different grants from MBIE and Kiwinet. The former can be used to target a long-term project while the latter aims to quickly fund the setting up of a team. Five critical milestones were identified in these proposed projects:

- Setting up a team

Even though two objectives had been proposed here due to the different funding mechanisms, the technology at the root is the same. Here we proposed that in the first instance,

²⁷ See Appendix 3, page 115.

GNS would apply for a Research Programme (RP) funded by MBIE. This grant would permit more research to be carried out on tunability at higher frequencies where more time and money could be invested. A RP grant of NZ\$2 million for four years should be requested and it should commence at the end of 2017.

GNS should also apply for a Tier One PreSeed fund granted by Kiwinet, which normally consists of short-term-to-market projects where there is a prototype and a partner at hand. The application for this grant would operate on the basis of a RF tunable filter coupled with a cognitive radio for underwater communication, bringing together GNS, Callaghan Innovation and 4RF²⁸. This grant is worth NZ\$30k to 60k at this level one, but can be boosted to the second level to fund one full-time employee (FTE) in 2017 who would be a mix of a business developer with a strong engineering background.

- Reaching the beachhead market: underwater communication

If a prototype is finalised in level 1 in 2017, the end of level 2 should be the time for a market-ready device and at least an implementation pathway penned out (in the best case the licensing to 4RF would begin). The PreSeed funding is expected to last for one year. The next stage of the project would then benefit from the RP funding.

- Industrialising the filter with Rakon

If the project managed to be funded by MBIE, the beginning of the grant should be before the end of 2017. From this, NZ\$500k will be allocated each year, funding two FTEs in parallel: one at GNS and one at Rakon. Benefiting from the progress of the tunable filter for underwater communication, the team will work on the composite to improve its performances in higher frequencies and produce a proof-of-concept for tunability between 923 and 933 MHz²⁹ between 2017 and 2018. Both the FTEs are expected to be engineers, and we would

²⁸ Callaghan Innovation and 4RF are already working on a cognitive radio product.

²⁹ Following the features given by Rakon.

achieve our milestone if a prototype was produced and could be industrialised as a product for the IoT market.

- First venture capitalist funding round

A fourth milestone will consist of launching a venture capital (VC) funding round (depending on the results with the industrialisation process with Rakon) by 2019. A VC fund consists of approaching capital risk investors to get an important investment allocated to scale-up a product quickly. This type of funding requires several key points to be met: having clients ready to buy the product, being at a medium-stage in terms of funding (around US\$1 million) and proving the team is well built and is working on the very next promising product³⁰. In this avenue, a VC-like Power House Venture could invest in the project in a series A round (US\$10 million).

- Explore other markets with overseas partners

The last milestone of the project would consist of licensing the technology to a range of manufacturers with a licencing agreement for each application. With enough funding the team would be able to recruit a business development and marketing team to reach the main goal which is the mobile devices market (smartphones, tablets, wearables, GPS, etc.).

³⁰ Source: Tijs Robinson, Power House Venture.

Chapter 5: Recommendation - Business case

The purpose of Chapter 5 is to consolidate the findings and recommendations of the research into one concise report designed for an investor audience. The GNS board has asked the research team to submit an application to the Tier One PreSeed funding from Kiwinet. This chapter thus gathers what has been produced for this funding application while providing key points in terms of the project development.

5.1 Business model design

5.1.1 The project and its objectives

GNS has developed a nanostructured composite exhibiting coupled magnetic and piezoelectric property. This composite can tune its impedance through magnetic or electrical excitation. Accordingly, linked to a central processing unit (CPU), it is possible to change its resonant frequency with a simple electrical current. As the magnetic and ferroelectric properties are changed during the process, we refer this as analogic tunability.

Implemented as a radio frequency (RF) filter, the nanostructured composite developed by GNS has the potential to modify the resonant frequency through either magnetic or electric field stimuli thus making the filter tunable. Put in a smartphone, for example, it would be able theoretically to switch from 824 to 849 MHz (frequency for Long Term Evolution (LTE) 4G band 5 uplink) band-pass to 869 to 894 MHz (band 5 downlink). The improved performance would mean the higher the percentage of tunability of the composite and the more bands it would be able to address in a range of devices including smartphones or Internet of Things (IoT) sensors.

The GNS tunable filter will be commercialised via licensing to manufacturers in the telecommunication industry. We have identified several applications which would benefit from such a technology and will be focusing at the early stage on the underwater communication

area (as the targeted beachhead market) as our first prototype operates in the acoustic frequency range. However, several improvements have been identified which need further research for tunability into higher frequencies where other types of communication devices are operating. These improvements would open the doors for three bigger markets: the IoT sensors, mobile devices, and cognitive radio.

The project has assessed all the different applications for this magneto-electric composite and gives recommendations on which one to address for the next stage of the project, given that it has been funded by the MBIE as a Smart Ideas project. As this funding has ended, GNS needs to build new funding applications to pursue its research and start the commercialisation phase with potential partners. To do this, the fastest market to reach, or beachhead market, is the underwater communication field, because it operates in frequencies which are close to those measured in the lab on the first filter prototypes. It is also an important activity in New Zealand as two companies are among the leaders in that field: Navico and Electronic Navigation.

5.1.2 Opportunities and constraints for the product development

Current radio frequency filters are based on a patent from 1931 (10-K form, Resonant Inc., 2015), which allows a filter to address one band only on the RF spectrum. Since then the design has changed but this rule is still true. Consequently RF devices use as many filters as the frequencies they need to address. With the increasing need for wireless data transfer (LTE 4G, 5G, and IoT) the market is experiencing band proliferation (more than 30 bands for 4G), resulting in a multiplication of filters needed in communication devices. Taking the example of a smartphone between 2011 and 2014, the number of filters in the handset has gone from 8 in 2011 to 35 in 2014. It is reported that a handset like the iPhone 5 is equipped with more than 50 filters.

This increase is explained by the will of the handset industry to boost the performance of the devices regarding data transfer, which led to the implementation of new bands allocated to voice and data communications with LTE 4G. Governments all over the world have linked these new bands with precise frequencies, with some differences between state's regulations and between continents. As a result, handsets are sometimes equipped to deal with LTE 4G bands of different continents, leading to the addition of new filters for devices with an international market.

The last decades have been characterised by a regular reduction of the components through the computer industry. Filters are no exception, with some components reduced annually from 3.2 mm^2 to 1.54 mm^2 and then 0.99 mm^2 according to EPCOS (as cited in Resonant Inc., 2015). To reduce the size of individual filters, both the design and packaging must be optimised while maintaining the performance of the device. This "solution" is not efficient on the long term, the miniaturisation process being increasingly limited for all manufacturers among all the computer industries. In parallel to the space issue, the rise of the number of filters has an impact on the weight, cost and power consumption of the handset when all these components are activated. There is therefore a need for a tunable component which can reduce the number of filters, allowing RF front end to be smaller, lighter, more power efficient and cheaper.

As the band allocation is a slow process, band saturation (allocated frequencies reaching their maximum capacity of data transfer) is the next problem that pushes manufacturers to investigate an optimisation of regulated bands (2G, 3G, 4G) and to try to use unregulated bands like WiFi (2.5 GHz). On a regulated band, a carrier aggregator like Vodafone rents a precise frequency range which is dedicated to its communications. No one is authorized to use this range on the territory except from the devices of this carrier aggregator. On unregulated bands, everyone is allowed to send and receive data, creating a lot of potential interference. These

bands can be used by a smart cognitive radio which scans in nanoseconds the radio frequency spectrum and detects the blanks where no data is transmitted, to send and receive its data.

This kind of technology is still at an early stage, but researchers at Callaghan Innovation have managed to secure some IP for a cognitive radio system and have licensed it to 4RF, a company based in New Zealand. They are using a software-defined radio (SDR) which uses a digital method to address the full radio frequency spectrum. Dr Sudhir Singh, who is in charge of the project, could see the advantage of adding a tunable filter to this SDR. This kind of device is still sensitive to limitations and interference. However, a tunable filter would allow the expansion of the RF spectrum the SDR can address, and the reduction of interference during scanning by allowing a focus on small successive parts instead of the full spectrum at once, as shown in Figure 10.

State-of-the-art field-programmable radio frequency (FPRF) devices, using SDR, offer unlimited reconfiguration across the full range of wireless parameters, including multiple frequency treatment, but are very expensive (more than US\$100) and highly technical to manipulate. These chips are mainly used in RF engineering for military communication.

Most handsets currently available are equipped with regular RF filters priced from US\$0.28 to US\$0.62³¹, which cost will multiply by the increasing number of bands to address. In addition, the accumulation of filters produces bigger, heavier and more power consuming RF front-ends.

The GNS tunable filter is novel and preferable in that it allows a multi-frequency treatment, while being comparatively low in cost and easier to configure than a FPRF device. Furthermore, it can be produced using the same manufacturing process as traditional filters.

Further novelty in the GNS tunable filter resident in the use of an analogue process instead of a digital one, drastically simplifying the operation of the device compared to SDR.

³¹ Source: Resonant Inc. Investors presentation.

By reducing the number of regular filters while maintaining a similar manufacturing process, this tunable filter allows gains in terms of space, weight, power efficiency and bill for materials. This provides a unique selling proposition for filter and handset manufacturers. In addition, the concept of combining a cognitive radio with a tunable filter appears to be novel. The novelty and inventiveness of these concepts were highlighted by a preliminary freedom to operate (FTO) assessment.

5.1.3 Market pain

To validate the assumptions that were made regarding the potential markets, a range of interviews were conducted to get feedback from manufacturers and engineers. These insights are segmented into four applications for a tunable RF filter.

- Telecommunication market: a mature market looking for innovation.

Figure 11. RF component revenue for antennas, tuning elements, switches, filters and power amplifiers from 2014 to 2020, Mobile Experts (Resonant Inc. White paper, 2016, page 7).

According to Mobile Experts, the most significant revenue for RF front-end is concentrated on the filters, growing approximately from US\$3 billion in 2014 to US\$13 billion in 2020. Tunable filters would add value in all the devices that need to address multiple frequencies: WiFi, Bluetooth, ZigBee, 3G/4G/LTE cellular technologies, and custom RF-transceiver technologies. They will help reduce power consumption by decreasing the number

of inactive yet current-drawing discrete components. More power will be available to drive the antenna with less power being wasted as heat.

To confirm the interest of the international market, the team set up a trip to the Japan IT week in Tokyo (October 2016) to collect data from Japanese manufacturers of RF filters for smartphones and IoT. Good feedbacks were obtained from Taiyo Yuden (US\$2 billion revenue) and Murata Inc. (US\$11.5 billion revenue), though a performing prototype is needed to engage a dialogue with any engineer. Considering the data collected from the manufacturers, our goal is to reach a 10-20% tunability in the 4G LTE frequencies, i.e. 30 bands in the spectrum 698 to 3600 MHz.

- Internet of Things (IoT): a US\$883.55 billion market by 2022.

Mobile devices for the telecommunication market are the most mature. The next big thing in this sector is the IoT demonstration for businesses and individuals. All the filter manufacturers we met in Tokyo were presenting their solution for this industry.

GNS has already been in discussion with Rakon, which has also decided to expand its business along this path, to work on a prototype for a tunable filter developed for an application in the area of IoT. For this potential partner, GNS would work on the following frequencies: 200 and 923 to 933 MHz.

- Cognitive radio: the next answer to band proliferation.

On a long-term basis, the need for data transmission is projected to outrace the ability of governments to allocate new frequencies to all players. Cognitive radio is the most promising answer to optimise the spectrum utilisation and has already proved to be efficient in some fields of activity, including in New Zealand where 4RF is using a solution developed in collaboration with Callaghan Innovation.

From previous meetings with Callaghan Innovation, GNS is optimistic about the added value to its tunable filter for an application in Cognitive Radio. This application is also the most realistic in terms of potential benefits to a New Zealand's industry.

- Underwater communication

Applied to underwater communication, where interference and the transmission environment are pressing issues, the technology could find partners in two New Zealand companies: Navico and Electronic Navigation. Two segments have been identified under this underwater communication application:

- Segment 1: military communications

The global military communications market is estimated to grow from US\$23.02 billion in 2015 to US\$40.82 billion by 2020, at a CAGR of 12.1% from 2015 to 2020 (MarketsandMarkets, 2016). There is always a need for confidential, secure and fast communication flow to meet the needs of communication and technological advancements, which are growing at a fast rate.

- Segment 2: sensors and instrumentation (beachhead market)

The world's exports of navigational and survey instruments more than doubled between 2001 and 2011, from US\$7.5 billion to US\$16 billion (Marine Technology, 2012). In 2011, 63% of exports or US\$10.1 billion, were accounted for by surveying, hydrographic, oceanographic, hydrological, meteorological or geophysical instruments and appliances, while navigational instruments represented 37%, or US\$5.8 billion.

If the market increase is maintained at the same pace it should reach more than US\$20 billion in 2016. Most of the research challenges in this area could be addressed by GNS's tunable filter, especially coupled with a cognitive radio system.

5.1.4 Recommendations for a business model

Two business models have been assessed for the commercialisation of the GNS tunable RF filter. The first one, ‘low risk, low value’, is to license the developed technology to a manufacturer, earning royalties per unit produced. The second, ‘high risk, high value’, consists of building a fabrication-less (fabless) manufacturer in New Zealand which would design and sell filters while outsourcing the fabrication to a foundry.

GNS Science, as a Crown Research Institute, has the mission to ‘address New Zealand’s most pressing issues and achieve economic growth by improving sectors productivity’ (Crown Research Institutes | Ministry of Business, Innovation and Employment, 2017). Traditionally, the common approach to achieve this mission is to find a national partner who will agree to initiate, follow, and potentially commercialise the project’s results. Moreover, all the funding applications encourage all the applicants to prove that they have a project partner to support their application. In our case that would mean a reduction of the potential for the device to only three applications: IoT sensors with Rakon, cognitive radio with 4RF, and a sub-segment with Navico or Electronic Navigation for cognitive radio in underwater communication. The recommendation at this stage is to go for a licensing model though with limitations in terms of application, but can leave the door open for the mobile devices market in the future.

The plan is not to license first to an international market though this would benefit GNS financially and not to New Zealand industry, but to create a hybrid model. On one hand the licensing model would unlock the credits to set up a team and continue the work on the technology. On the other hand, the next step would be to use the achieved work and sales from the licensing to obtain further funding from Venture Capital (VC) funds and build a fabless company dedicated to the mobile device filter designs and sales. The collected data show that this market is the one pulling the whole sector, and most interested in solutions to address band proliferation and saturation. Benefiting New Zealand industry, in this view, would be achieved

by creating a new company in this territory, specialising in high value technologies with an international potential. This will lead to jobs creation, high skilled migrant attraction, raising investment and a range of research challenges for the country. In this model, all the dismissed applications of the technology (which lack a national potential partner) would eventually be assessed again for further developments.

5.2 Market validation and development

5.2.1 Commercial environment and channel-to-market

To better understand the drivers across this chain, we interviewed a series of key stakeholders and scientists with interests in telecommunication hardware and signal processing across New Zealand and from overseas. Ten interviews were undertaken with senior staff (professors, CEOs, MDs or other senior managers) from several companies, government agencies and universities. An overview of the proposed GNS technology was presented to assess the potential interest for developing a New Zealand business. Specific areas of feedback were sought from each interview. Figure 12 shows the channel of value in the RF devices market:

Figure 12. Supply chain for a tunable RF filter based on the interview conducted.

Filter manufacturers. The GNS tunable filter is attractive to filter manufacturers as it disrupts an existing market with a new technology using a conventional manufacturing process and opens up potentially new market segments related to and accessible through their existing telecommunication business. In addition, this is a global opportunity that can be accessed through an existing distribution network.

From our interviews with Taiyo-Yuden and Murata Incorporation, we found an interest to talk about licensing the technology if the prototype is able to prove a performance of 20% tunability in the mobile communication bands.

Module manufacturers implement filters in RF front-end modules and are mostly filter manufacturers themselves. They are in direct contact with device manufacturers looking for full-ready modules to be implemented into handset devices. They are the most promising target for licensing the tunable RF filter as they are evolving in a concurrent market where size and performance are key factors for the business.

Communication device manufacturers will be the purchasers of the RF front-end modules, and by purchasing and implementing the product will be better able to provide customers more performance and lighter design (through getting lighter and smaller components). They will benefit from the highest saving in materials bill and reducing the number of components in the final device. There are specific advantages for each market studied:

- Underwater communication:
 - Water is a very complex environment for communication because of movement, temperature, density and frequency reflection on the surface. In other words, a device can create interference with its own signal because of the rebound of its emission. Having frequency tunability could mitigate this issue and reduce the rate of data loss.
 - For submarine communication and defence underwater networks, tunability could be used as an encrypted signal using different frequencies.
- Internet of Things (IoT)
 - The main challenges in the IoT business are size, security and standards.

- Tunable filters are the best way to reduce the size of devices that send and receive data from the network. Moreover, tunability could extend the bandwidth which the device can access, multiplying the usable quantity of data (the wider the bandwidth, the more data a device can transfer). Rakon has indicated an interest in such prototype.
- Security could be improved using an encrypted mix of frequencies.
- Regarding standards, as the IoT market is an emerging one, a lot of manufacturers are launching their own standards (ZigBee, Bluetooth Low Energy, SigFox, LoRa, Ingenu, Telensa, Weightless-P, EC-GSM-IoT, NB-IoT, eMTC, etc.). On this matter a tunable filter would allow a device to switch between different standards; each standard being susceptible to change slightly between continents due to band regulation. The tunability could also be used at the manufacturing stage to configure devices depending on their market destination.
- Mobile devices
 - Gain of performance, space, weight and power consumption.
- Cognitive radio
 - Allows the cognitive radio to address a larger spectrum and then uses the wider bandwidth to transfer an optimised amount of data.
 - When the bandwidth is defined by the cognitive radio, the tunable filter isolates it to reduce the interference, enhancing the quality of the transmission and minimize the risk of data loss.

Carriers are interested in giving the best user experience to their clients while looking for ways to reduce their operating cost. Regulated bands are rented by carriers following two possibilities: either the carrier possesses a monopoly of unlimited use on a band, or only a certain amount of data. The more a carrier needs to provide bands to its users, the more expensive it is. Therefore, exploring the possibility to transmit on unregulated bands is not only justified by the saturation of the bands, but also on the potential savings in terms of band renting.

5.2.2 How the market's problem is currently being solved

As we have seen, the market pain is various and, depending on the application, different strategies are employed. Regarding analogue filters, filter manufacturers rely on their ability to reduce the size of the filters while improving their capacity. The market demand for smaller devices with higher performance is expected to last, contrary to the technology's capacity to adapt the existing analogic filters. The 'end of Moore's law'³² is also true for filter designing and it is getting harder and harder to fit more RF filters into smaller space. All the market leaders (Qorvo, Murata Inc., TDK Epcos, etc.) promote a proprietary technology to increase the performance of their filters (better Q factor, loss insertion, temperature resistance, etc.) but there is no track of research on tunability and development concept.

On the digital technology, software defined radio (SDR) is a possible solution to reconfigure the radio to address several frequencies. As the technology is mainly used for engineering purposes, the issue for this solution is low demand on the industrial RF market. Improvements are needed in terms of design for small devices and an increase in terms of power supply. Consequently the devices developed are promoted as a prototyping revolution or high-end engineering solution, far away from a mainstream manufacturing solution.

During this research, only one player was identified as a potential competitor to this project. An American company called Resonant, which aims to solve this market pain and is growing fast. Resonant has developed a new way of designing RF filter structures that outperform traditional designs. Their Infinite Synthesized Networks (ISN) method uses interaction between all the filters to address more frequencies than a classic set of filters. The Resonant ISN model allows a reduction in development time and cost. They have also managed to

³² In July 2016, the International Technology Roadmap for Semiconductors (a joint report from chip manufacturers) predicted that the transistors miniaturization could stop by 2021 as it would no longer be 'economically viable' to make them smaller (Worstell, 2016). The expression 'end of Moore's law' reflects this trend.

produce SAW filters showing performance of BAW filters for LTE 4G band. They have claimed for several years to be in the process of developing a multi-state, reconfigurable tunable filter which shares acoustic resonators to generate multiple pass bands. An announcement was expected by the end of 2015 on this product, but the company has kept on postponing the launching of such a device.

To keep the project confidential, there was no contact between the research team and Resonant. Nevertheless, it could be beneficial to keep them as a potential partner for future collaborative work as they would be interested to hear about any technology that could help them to achieve better tunability.

5.2.3 The barriers to change the market's existing behaviours.

The RF filter market is an oligopoly, with a few big manufacturers sharing most of the market and with few competitors³³. The maturity and the scale of these players (billion-dollar companies) is a big barrier for a new manufacturer to enter the market. Moreover, the cost to create a manufacturer is extremely high, estimated at between US\$30 million to US\$100 million by Andreas Olofsson (Olofsson, 2012). For this reason, the fabless manufacturing model is preferred when it comes to semiconductor manufacturing at the moment, with all the investments absorbed by engineering and not infrastructure, pulling down the cost to as low as US\$2 million according to A. Olofsson.

The Resonant case study³⁴ is very useful to get the barriers to changing the market's behaviour as they chose the fabless model and built their business model on licensing their designs to RF manufacturers or foundries working with them. Founded in 2012, the company had to wait four years, one initial public offering (IPO) and three memorandums of

³³ We built an interactive map to list them, see "RF supply chain map":
<https://www.google.fr/maps/@1.2633792,143.6719718,3z/data=!3m1!4b1!4m2!6m1!1s1bE9Ah-pC4JOJeqVfnqWfgeaLy8k?hl=en>

³⁴ Appendix 4, page 116.

understanding (MoU), before being able to license its technology. They managed to raise US\$ 6.2 million in 2014 but the study of their 10-K report (a mandatory audit of the company published for potential investors) show that they used most of this fund in R&D. A second fund-raising of US\$5.2 million in 2016 seems to indicate the difficulty the company has in maintaining its activity without any licensed products for more than two years after the IPO. It is a complex environment for a fabless manufacturer to convince its potential clients, as Resonant can be seen as a potential competitor for the manufacturers they are targeting. Their product needs to show better performances to convince a manufacturer to give up its own designs (and the work of its R&D department) and take Resonant's instead, which includes a licencing fee. To get to this point, the company, in 2016, reached the milestone of 100 patents, positioning itself as a strong player in this field, a strategy that is starting to be effective as they now have two licensed products on the market. These are licensed to TC-SAW and Taiyo-Yuden.

Added together, these barriers to entry are in favour of a strategic bias to find a niche beachhead market to implement GNS technology before even considering stepping into the international filter market. A strong patent strategy is therefore needed in addition to the commercialisation of products for smaller applications as the first milestone, before embarking on the path for taking a more global strategy.

5.2.4 The market's reaction to the proposed product and how the product could be positioned in the market and distributed

As written in the 'Market feedback' part, the research team collected positive interest for their technology, with several features identified depending on the application. From the hypothesis of reaching these specifications, GNS could project a commercialisation plan based on a licensing business model.

Following a proposed prototype testing for underwater communication (designated as the beachhead market for the technology), GNS aims to extend the market to other applications. These include entering the market of IoT and handsets, and to license the IP that resides in the filter design and the use of the nanostructured component to several manufacturers with exclusivity in its field of activity.

We have identified that the market can be segmented into three axes (see Figure 13 below).

Figure 13. Commercialisation plan based on a licensing business model with three different applications licenced to three manufacturers for specific uses.

The objective is to license the IP to several partners throughout New Zealand and overseas who will complete the development on the final product prior to commercialising the technology. The GNS tunable filter provides a handset manufacturer two key advantages in terms of designing its products. The space gain can result either in reducing the size of the device (i.e. smartphones, tablets, GPS) or boosting the capacity of devices which are too small to be fully equipped with all the filters needed (i.e. wearables, smart TVs, IoT sensors).

Besides that, the GNS tunable filter provides a new lead for an enhanced smart cognitive radio by combining the performance of a software defined radio system with an analogue RF tunability. This will result in a more accurate and better performing device with potential applications in rural broadband optimisation, cellular traffic offloading, hostile interference detection and mitigation, and backhaul point-to-point for cellular and internet stations. The GNS tunable filter also has the ability to improve speed and flexibility of the device it equips and to significantly drive costs down.

5.3 Product validation and development

5.3.1 Will the product works as intended

At this stage of the project only a prototype exists for a tunable RF filter operating in the 600 kHz frequency range with a tunability of 6%. This first prototype is an important milestone for the project as it converts an in-lab proof-of-concept to a concrete device which can be used for demonstration to industrial partners. The GNS team is optimistic about its capability to produce a larger tunability as well as exploring other range of frequencies. To this end, they have the specification for each application:

- For a mobile device filter: 10-20% tunability in the 4G LTE frequencies (30 bands in the spectrum 698 to 3600 MHz).
- For an IoT sensor filter: tunability at 200 MHz and from 923 to 933 MHz.
- For an underwater communication device: tunability between 80 and 160 kHz or lower range in ultra-low frequencies (30 to 300 Hz).

5.3.2 The development, testing and regulatory process.

The objectives are: (1) prototyping the tunable RF filter to (2) implement it in an underwater communication device, and (3) to provide technical evidence for performance and

manufacturability. In the long-term, GNS intends to (4) enhance the performance of the nanostructured component to reach a tunability in the higher frequencies and therefore (5) implement the tunable filter in an IoT sensor and then (6) in a handset device.

The performance will be assessed against other RF technologies (e.g. software defined radio) and through regular measurements of frequency switches. Manufacturability and ease of retrofitting will be measured against the actual costs at each step and hurdle identified during the course of the project.

A prototype of the technology was fabricated and their tunability assessed. The filter response was benchmarked against precise measurement systems. The tunability in the acoustic frequencies (600 kHz) was demonstrated in lab conditions with a modification of the resonant frequency of 6%. This prototype will be shown to underwater communication manufacturers (Navico and Electronic Navigation) as theirs also operate in acoustic frequencies.

The tests have highlighted the need for using different materials to investigate potential tunability in higher frequencies. A set of specifications (frequencies, insertion loss, isolation, and quality factor) was provided by data collection to develop the next prototype for further applications.

5.3.3 Can the product be manufactured and at what cost?

Current RF filters are manufactured using two main designs: surface or bulk acoustic wafer (SAW or BAW). SAW filters are made on wafers, combining the advantages to be implementable on a single chip and can be produced in a large scale at low cost. However, SAW filters can also be used at low and medium frequencies. For high frequencies, manufacturers prefer BAW filters, even if they are more expensive and less simple to implement than SAW filters because BAW filters are built vertically. As we have seen in the

Resonant Inc.'s case study, there is a demand for SAW filters operating at higher frequencies, motivated by cost and size optimisation.

GNS has worked on both designs without modifying the regular manufacturing process. All the concepts which have been produced could be implemented in an industrial manufacturing process. The only difference being the implementation of the magneto-electric substrate and the tunability controller (a simple CPU using voltage to modify the resonant frequency). This is important because it means that a manufacturer does not have to make important adaptations to its production line to start producing the tunable RF filters. It also means that the return on investment (ROI) from this product is fast as it can be written off the books quickly.

The question of the magneto-electric composite supply remains unanswered at the moment. On one hand, GNS has the capability to produce the composite but not in an industrial quantities. On the other hand, the investment for a manufacturer in expensive equipment would impact the ROI and the production cost. To address this issue GNS still needs to assess two hypotheses. The first would be to develop an independent structure dedicated to the production of meta-materials. Apart from this project, the National Isotope Centre, a department of GNS, have developed a lot of composites and, if justified by an important demand, it could be interested to investigate the possibility to fund such a structure. In a second hypothesis, the GNS team could replicate their equipment in a simpler form for the exclusive production of the composite at the manufacturer's facility.

A certain number of cost projections need to be made, depending on several factors, which would make it difficult to make an accurate estimation of the cost. The following is our best estimate. As a filter costs between US\$0.28 and US\$0.62, depending on if it is a SAW or a BAW. A tunable filter made by GNS cannot cost beyond this price range. A study from Barclays projected RF content to increase to around US\$22 by 2017 in a smartphone with 55

filters³⁵, thus making an average cost of US\$0.40 per filter. To make a competitive product, the cost of a tunable filter must be less than the total filters it is replacing. For example, a tunability allowing the replacement of 10 filters by one must stick to a maximum price of US\$4 ($10 \times \text{US\$0.40}$). And to be really attractive, even if the gain of space and power is multiply by 10, the final cost should be even lower than the regular cost to compensate the manufacturer's investment.

5.3.4 Can the IP be protected?

To be patentable, the magneto-electric materials or tunable RF filter devices must be novel and inventive over what is already known. One document (US 2014/0253272 – Sun) was found, which explicitly describes using a variable inductor with a magneto-electric core that directly modifies the inductance of a coil as the basis for a tunable RF filter. Based on this, it is likely, according to A.J. Park, that an examiner in most countries would object that using a variable inductor similar to one that is already known in a tunable RF filter is not inventive.

The research did not find any documents that disclose a variable inductor using a nano-composite material with both magnetic and piezoelectric nanoparticles. This concept may be novel and patentable. However, several documents that described variable inductors with composite cores comprising ferromagnetic and piezoelectric layers were found (CN 106033691 – Liu, JP 03485280 - Ishigaki). Some of the documents described the use of ferromagnetic nanoparticles (JP 05667422 - Kamiunten, JP 2013/120761 - Kamiunten). In light of these documents, only one of the concepts developed by GNS would be considered inventive by an examiner.

The current preferred commercialisation approach by GNS is to license any IP to third parties. A licensing approach is generally better if codified IP in the form of patents can be

³⁵ Barclays, study for Resonant Inc.

secured. It is then necessary, in light of these results, to undertake a revised patentability search and assessment, focusing this time on the inventive concept based on the use of a variable inductor utilising a nano-composite material with both magnetic and piezoelectric nanoparticles. The use of this concept in a tunable RF filter is unlikely to be patentable, but the core technology for a device could be patented.

The next step would be to file a patent on this overarching concept as a provisional specification in New Zealand to establish a priority date. Subject to a successful prototype, GNS will look to establish an up-to-date freedom-to-operate (FTO) position to confirm that no other patent would be published in the meantime with a prior date of filing. If cleared, GNS would move rapidly to file a complete New Zealand and Patent Cooperation Treaty (PCT) specification to ensure access to global protection if required, but also fast track examination in New Zealand to allow for licensing.

5.3.5 The features that the product needs

The general feedback is a need for smaller devices with high power savings. Nevertheless, with band saturation and the growing issue of interference, we can add the need for devices able to operate on very short bandwidths with minimal data loss rate as another desirable feature.

5.4 Resource requirements and returns

At this stage of the project, the resource requirements are based on a preliminary estimation by the GNS research team. This is based on the first step of the roadmap going through prototyping and manufacturing a tunable RF filter for an application in underwater communication.

5.4.1 The skills that are required in the team

As a precondition for raising governmental funds, the partnership with a New Zealand company implies a minimum collaboration from them in terms of orientation for the prototyping features and manufacturing specifications. This means that one specific interlocutor would be nominated among the partner's human resources to be the link with GNS. Their tasks would include feedback on GNS's questions and propositions, information transmission to the partner shareholders and sampling prototypes using their industrial equipment.

Regarding the project management, skills in the business case for funding applications would be necessary to follow up the present report. At this stage, considering the links that have been created between GNS and potential partners, the need for business development skills is a low priority and most of the resources should be allocated to research and development. Moreover, the partnership being based on an understanding of a commercial value for the partner, the commercialisation process would be at the partner's charge since they would license the technology.

Finally, to create a prototype and reach a manufacturing process, it is estimated that one full-time engineer would be needed on the GNS side. This engineer would be under the supervision of Dr Leveneur who would still be in charge of the coordination of the project.

5.4.2 The development and manufacturing process and equipment that is required

The implementation pathway to produce a tunable RF filter for underwater communication has been decided as follows:

- 1- Modifying and adapting the prototype to the underwater communication environment, by updating the current prototype to the frequency specifications given by the project partner. This can be realised in the lab at the GNS facility.

- 2- Building the tunable filter from the prototype by adapting its design to the manufacturing constraints of the project partner in terms of size, components, materials, costs, etc. This step is to be realised by the project partner, as GNS is not equipped with the appropriate equipment to produce industrial devices.
- 3- Installing the tunable filter in one of the project partner's products and assessing the enhancement of its performance in the lab.
- 4- Monitoring the device behaviour in real conditions to collect data regarding its behaviour, degradation and potential issues that may be encountered at this stage.
- 5- Pursuing the research on the nanostructure component to reach higher frequencies and tunability.

Most of these steps can be reached with the existing equipment from GNS and its project partner.

5.4.3 The funding that is needed and why and how it can be obtained

The next stage of the project aims to reach the beachhead market identified by the market validation research. As the funding from the Smart Ideas grant has reached the end of its life cycle, the priority for GNS is to apply for a new funding to maintain the core team and keep on working to improve the technology. The funding strategy is then built on two different funds which can be sourced by Kiwinet and MBIE contestable fundings.

Kiwinet grants the PreSeed fund to publicly fund research organisations like CRIs. This grant is dedicated to short-term investment and aims to convert science discoveries into commercially viable products and services on a fast-to-market timetable. Accordingly, a project is eligible for PreSeed funding if it can justify the commercial benefits to New Zealand

based on previously funded research, and give a proof-of-interest from private sector partners. At Tier One, PreSeed will reimburse up to 50% of a project's eligible costs up to NZ\$25k (NZ\$50k in total). PreSeed will also give resources for market validation, business case preparation, securing IP and technical development for a proof-of-concept. If the project's application is approved, a Tier Two of the same amount is unlocked for projects with a budget less than NZ\$200k, but a Tier Three is possible for projects with a higher budget (*KiwiNet Pooling Process Guide*, 2013). Applications for PreSeed can be submitted all year round and are reviewed within six weeks from the submission date.

This project is well suited to the objectives of the PreSeed accelerator fund to commercialise publicly funded research for the benefit of New Zealand. Commercialisation of the GNS tunable filter technology through the PreSeed project will de-risk the proposition to an 'investor-ready' point whereby Navico or Electronic Navigation (both New Zealand companies) would license the technology to complete the commercialisation. These companies could expect to generate significant export earnings from the tunable filter, while creating jobs in the wider economy. The PreSeed investment will enable GNS to increase the value of the tunable filter IP, to strengthen the licensing value of the technology and to de-risk it for potential investment.

In parallel with a PreSeed application, GNS could apply for the Research Programme funding provided by MBIE, which will call for proposals in September 2017. Contrary to a PreSeed, this investment mechanism aims to support well defined research ideas which are not at an early-market stage, but have credible and high potential. The Research Programme can invest from NZ\$0.5 million per year, for a term of three to five years, to over NZ\$2.5 million (2017 Endeavour Round | Ministry of Business, Innovation and Employment, 2017) for the entire project life-cycle.

In conclusion, the whole project could be supported by two investment mechanisms which are well known to GNS Science and would allow the magneto-electric component to reach its beachhead market and to positively benefit New Zealand industry by making it a pioneer in the next generation of nano-electronics.

5.4.4 The timeline for all activities

The roadmap gathering all activities and milestones is available in Appendix 3 page 115.

Chapter 6: Conclusion

When it comes to converting a scientific discovery to its application, the journey from the idea to the product could be long. Launched in 2014, the project is still at an intermediate stage and it will take several years before it reaches its maximum impact. Initially funded by MBIE the project's goal was to imagine how the next generation electronics could be produced using nano-technology. It was a high risk/high value investment, meaning that the chances of success were low but the potential benefits very high and impactful. To continue their work on this technology, GNS Science was in need of market data in order to apply for new funding. This report tries to create the link between the proof-of-concept stage and the best applications for what have been produced.

From the novel idea to use low-energy ion implantation to create ferromagnetic nanoparticles on ferroelectric and multiferroic thin films, thus creating a magneto-electric nanoparticle composite thin film, we have established a list of potential fields of application, opening the door for further development and projects. Following a preliminary market validation, the research team gathered and decided to explore the added value of tunability in the field of wireless communication and focused their research on an analogic tunable RF filter. Interviews were conducted with scientists, engineers and manufacturers, and the collected data show enough favourable leads to convince GNS to push this project into the next application endeavour. Tunability is indeed a promising solution and a challenge the RF-filter field is currently facing. First, there is the band proliferation. Due to the multiplication of bands allocated to communication in the RF spectrum with new standards for mobile communication and the internet-of-things (IoT), the number of filters needed in communication devices is expected to become a real issue in years to come. Second, as a direct consequence of band proliferation, band saturation is the next challenge for wireless communication management, when devices will have to go into unregulated bands if they want to keep on increasing their

capabilities without having to wait for new bands to be regulated. This report identifies tunability has the potential to provide many gains in terms of space, weight, power efficiency, signal optimisation, and reduction of signal interference.

This report has also identified alternative range of applications to open up further opportunities for GNS's technology. Since the first prototype cannot be used in most of the mainstream applications, which represent the majority of the current RF market, operating in the acoustic frequencies was found to be favoured. However, to be fully competitive, the tunable RF filter must evolve to address higher frequencies in LTE 4G bands, future 5G, WiFi, Bluetooth, and IoT standards which are emerging with this new market. These improvements necessitate time and research and, the most urgent of all, further funding.

After two years of Smart Ideas investment from MBIE, GNS must show results and perspective for what have been developed. To ensure the long term viability of the project, it was decided that a beachhead market needs to be identified, which would support the requirement to apply for a short-term investment such as a PreSeed from Kiwinet. More precisely, this market would need to suit the current capabilities of the prototyped tunable RF filter (acoustic frequencies) with potential partners in New Zealand interested in participating in the project to commercialise an innovative product. We have identified the underwater communication market as the beachhead market, as it operates in reachable frequencies for the current prototype and has two New Zealand companies operating in this field: Navico and Electronic Navigation. It is also a market which encounters issues with power efficiency, signal interference and optimisation, which promises a lot of benefits from the use of a tunable RF filter.

The incoming months are going to be crucial for GNS as they build a case for a PreSeed fund application based on the recommendations of this report. If this milestone is reached, GNS would be able to launch into the next step of the project, which consists of building a team and

designing manufacturing processes to meet industry standards to produce the first tunable RF filter for underwater communications. In addition, this report also recommends an application for a long-term investment mechanism, such as the Research Program from MBIE, to secure longer term funding for the project for several years, allowing GNS's team to enhance the composite and make it market-ready for mobile devices and IoT sensors.

The *National Statement of Science Investment - 2015-2025* states the vision for the place of Science in New Zealand economics in these terms: "A highly dynamic science system that enriches New Zealand, making a more visible, measurable contribution to our productivity and wellbeing through excellent science." (MBIE, 2015). This statement insists on the result-driven politics for science investment and, by that, encourages public institutes such as GNS to go out and work more closely with New Zealand companies in order to understand their needs and try to solve their problems through innovative ideas. We believe this project is a good example of a bridge to interface the world of science and business, putting scientific applications and the business opportunities at the centre of the research process with a real influence on what should be investigated and developed. Starting with a proof-of-concept, the research team managed to orient its work according to the collected data from the field. It is now a tangible, with a well laid-out roadmap, which combines the technical and business aspects that opens up opportunities to make New Zealand a potential champion in tunable RF filters and a R&D hub for next generation nano-electronics.

Glossary

Word/acronym/abbreviation	Full description
10-K report	A mandatory audit of the company published for potential investors.
BAW filter	Bulk Acoustic Waffle filter: A type of electronic filter using crystal as the substrate, and metal patches on the top and bottom sides of the quartz to excite the acoustic waves, which bounce from the top to the bottom surface to form a standing acoustic wave.
Beachhead market	The notion of beachhead market (Moore, 2006) can be defined as a specific segment of a market which characteristics make it an optimal first target for a new product.
CRI	Crown Research Institute: A public owned institute dedicated to advancing ideas in strategic science and innovation, and delivering results that will benefit New Zealand economically.
End of Moore's law	In July 2016, the International Technology Roadmap for Semiconductors (a joint report from chip manufacturers) predicted that the transistors miniaturization could stop by 2021 as it would no longer be 'economically viable' to make them smaller (Worstell, 2016). The expression 'end of Moore's law' reflects this trend.
FPRF	Field Programmable Radio Frequency device: A communication device using software defined radio and offering unlimited reconfiguration across the full range of wireless parameters, including multiple frequency treatment.

FTO	Freedom to operate: An assessment of potential existing patents linked to the developed technology.
IPO	Initial Public Offering: The first time that shares from a private company is offered to the public to raise funds and accelerate the development of the company.
IoT	Internet of Things: A name given to the most important market for the next generation of interconnected electronics where objects themselves are connected online to provide a better user experience.
Kiwinet	The Kiwi Innovation Network (KiwiNet) is New Zealand's network of public research organisations, working together to transform scientific discoveries into market-ready products and services.
LoC	Lab-on-Chip: A system-on-chip used in biomedicine.
Market pain	The issue the market is experiencing and which has to be resolved.
Market segment	Specific part of a market which unique characteristics.
MBIE	Ministry for Business, Innovation and Employment of New Zealand.
MoU	Memorandum of Understanding: An agreement between two parties to work on a specific project with a potential of partnership if successful.
MRAM	Magnetic Random Access Memory: This new technology could theoretically replace the current RAM technology used in computer memory with better performance due to the use of

	“magnetic charges” or “spins” to memorize the data instead of electrical charges.
Moore’s Law	Moore’s Law which states that every year the number of components per integrated circuit is doubling.
PCT specification	Patent Cooperation Treaty specification: A process to ensure access to global protection for a patent.
PreSeed	A Kiwinet grant which is dedicated to short-term investment and aims to convert science discoveries into commercially viable products and services on a fast-to-market timetable.
RF	Radio frequency.
RFID	Radio Frequency Identification: A technology uses a near-field communication between a beacon and a small tag made of a chip and an antenna.
ROI	Return on Investment: indicator which measures the time needed to make profit from an investment.
SAW filter	Surface Acoustic Wafer filter: A type of electronic filter converting the electrical current into an acoustic wave by interleaved metal interdigital transducers created on a piezoelectric substrate.
SDR	Software Defined Radio: A system-on-chip technology which uses a digital solution (where classic filters are just analogue devices) to sort out some frequencies from the full spectrum.
Smart antennas	Analysts segment the market into two types of antennas: radio antennas (the conventional type) and smart antennas, which are

	sending several copies of a signal on several frequencies so that every part has a greater chance of reaching the receiver.
SoC	System-on-Chip: Describes a chip containing integrated components of a computer or other electronic systems packaged on a single substrate.
SWaP	Size, Weight and Power is defined in Electronic Engineering (EE) Times as a 'key concern' for 'high-end consumer and military Software Defined Radio (SDR) equipment and cognitive radio' by Paul Dillien (Dillien, 2014).
WPT	Wireless Power Transfer: The transmission of electrical energy without using conducting wires and allowing 360 degrees of mobility.

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Appendix

1 - Guidelines for interviews

<p>Introduction (5 minutes)</p> <ul style="list-style-type: none"> - Student at Victoria University: Masters of Innovation and Commercialisation - Working with GNS on an audit about the RFID Industry / RF industry / etc. to get a global picture of the needs and issues of the NZ companies in these industries. GNS Science is looking for industry input to refine their research focus and market validation for some of the concepts they are working on. 	
<p>The company (10 minutes)</p> <ul style="list-style-type: none"> - Could you tell me a bit about the company's history? - What is the size of your workforce? - Who are your clients? - What are their fields of activity? - Is your market local, international or both? 	
<p>The product (15 minutes)</p> <ul style="list-style-type: none"> - What is your product? - What is working for it? What is not? - Did you identify a need or a problem? Is it important? Do you have an idea to solve the problem? Are you doing something about it? - Who else should we talk to about these? 	
<p>The market (5 minutes)</p> <ul style="list-style-type: none"> - Can you describe your market: how it was 5 years ago, how it is now? - Where do you think it will be in 3 to 5 next years? - According to you, what are the main factors that will guide the market in these next years? 	
<p>The R&D (5 minutes)</p> <ul style="list-style-type: none"> - Do you plan to invest to stay ahead on your market? - What is your main concern between these factors for your products: size, cost, performance and security? Why? - Could you tell me what are the main issues you encounter to innovate in your field? - Are you interested in + particular features to determine with J.L. for each company. 	

<ul style="list-style-type: none">- Would you agree to meet with GNS for further discussions? Can I get in touch with you for any other questions I may have?	
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2 - Leaflet front

licensing technologies

GNS aims to benefit New Zealand economy by creating high value technologies which can be transferred overseas to foreign partners.

We work with companies from all over the world which benefit from our expertise in various applications.

we are looking for partners

Make sure your brand is a future leader in mobile phone technology.

More information on www.gns.cri.nz

about us

We are New Zealand's leading provider of Earth, geoscience and isotope research and consultancy services. We apply our scientific knowledge from the atomic to the planetary scale to create wealth, protect the environment, and improve the safety of people.

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Introducing the future of RF filters:

the analog tunable filter

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2 - Leaflet back

3 – Roadmap

4 - Resonant case study using press releases and Resonant's website