SOFTWARE DEFINED RADIO: THE TRANSITION FROM DEFENSE TO COMMERCIAL MARKETS

Aditya Kaul (Pioneer Consulting, Woburn, MA, USA; a.kaul@pioneerconsulting.com)

ABSTRACT

Software Defined Radio (SDR) until now has been seen as a military technology with a limited market for commercial applications. The commercial use of SDR has been restricted to providing 'partial software upgradeability' within a given family of wireless standards. This has been due to technological bottlenecks at the RF front end and its inability to be reconfigurable. However, with recent innovations in enabling wideband RF front ends and soft transceivers, SDR can move beyond 'partial reconfigurability' to 'multiprotocol multiband reconfigurability'. SDR in its new commercial avatar can allow for a smaller hardware footprint leading to lower costs and a shorter time to market. This paper looks at the innovations that are driving this transition and analyzes the critical factors and market dynamics needed to ensure its commercial market success. The paper also provides a realistic discussion around the ability of SDR to initiate disruptive changes in the wireless business model.

1. INTRODUCTION

One of the biggest markets for commercial SDR is the wireless infrastructure and devices market. However, SDR has been lacking the enthusiasm and interest from top-tier commercial wireless vendors, who truly drive the market. The inability to provide software reconfigurability and wideband capability at the RF front end has been a major reason for this lack of interest. Due to the technological bottlenecks, SDR has been viewed as a technology that simply enables 'partial software upgradeability'. Although the concepts of SDR have been used in commercial wireless base stations, the wider commercial market has failed to look beyond 'partial software upgradeability'. Another reason behind the lackluster commercial interest for SDR has been the lack of effort to categorize SDR platforms into the various tiers as defined by the SDR Forum, allowing for a differentiation and a clearer understanding of SDR and its capabilities.

However, innovations at the RF front end and improvements in the baseband processing capabilities are now beginning to bring about a change in the perception of SDR. SDR is now being viewed as an enabler for Multiprotocol Multiband (MPMB) support. Although the key drivers for developing a common SDR platform are reducing development cost and shortening time to market, MPMB SDR is being seen as the holy grail of an ever increasing complex world of rival standards like GSM, CDMA and OFDMA, which are being promoted by competing vendor factions.

However, the path towards full-fledged commercial SDR is not going to be easy. Apart from technological innovation, the market dynamics that guide a commercial technology are significantly different from that of a defense technology. Although there have been many successful defense to commercial technology conversions, there are many technologies that were unable to make the required transition into the commercial space. One of these includes the programming language ADA that started off as a military programming language but was unable to break the mould as a commercial programming language. This was due to a mismatch between the original defense requirements and the commercial requirements. However, more critical was the failure to understand the dynamics of commercial technology adoption. [1]. Therefore it becomes important for SDR to learn from the mistakes of the past. Both military and commercial stakeholders must ensure that commercial adoption is guided not only by technological advancement, but also by the desire to understand the drivers behind commercial technology adoption.

Apart from covering the technological innovations that are enabling MPMB support, this paper also covers the current initiatives behind development of a commercial version of the defense-oriented SCA (Software Communication Architecture) implementation architecture and the larger issues around the dynamics of commercial technology adoption versus defense adoption. The paper also goes on to suggest that SDR has the ability to bring in radical changes in the current wireless business model, characterized by time consuming and costly equipment replacements, to a common platform driven, efficient and cost effective, MPMB software upgradeable model.

2. 'PARTIAL UPGRADEABILITY' VS ' MULTIPROTOCOL MULTIBAND (MPMB) RECONFIGURABILITY'

Software Defined Radio in the commercial world has been largely restricted to software upgradeable base stations. The option to upgrade a base station platform without having to replace hardware has been an attractive proposition for cellular operators since the late 1990's. During that time the first flexible base stations were introduced. Some examples include OneBTS from Lucent, Evolium from Alcatel and RBS 2000 from Ericsson. Reconfigurability was aimed at a limited set of functionalities in the base station and was primarily achieved using FPGAs and DSPs, also known as firmware. This 'seamless upgrade' functionality was introduced when the initial hype around 3G was starting to take shape. However, surprisingly the role of SDR in base stations was not acknowledged until 2004 when a Boston startup, Vanu Inc. introduced the concept of using COTS (Commercial Off The Shelf) servers to run base station software.

Although reconfigurability and SDR go hand in hand, commercial SDR has still to achieve the economies of scale that would facilitate a large enough market for SDR commercial vendors and SDR third party software providers. This paper suggests that the reconfigurability offered in the past could best be termed as 'partial software upgradeability'. The reasons for this not being considered 'true SDR' are as follows:

1. Reconfigurability has been limited to a particular family of standards and does not allow 'cross-standard' upgrades. This usually means upgrading from GSM to GPRS to EDGE to UMTS or from IS95 to CDMA 2000 to EVDO, but not from GSM to CDMA or vice versa.
2. The cost of enabling 'partial software upgradeability' has been high especially at the RF front end due to the need for separate 'RF chains' to support different protocols and frequency bands.
3. The time to develop a software upgradeable base station has been high due to lengthy hardware design cycles. This has had a direct impact on the time to market, a critical factor in the commercial world.
4. The economies of scale that the SDR market needs can only come from handsets. SDR has been unable to make inroads into the wireless handset market. Until now multimode handsets have been using 'hard-coded' ASICs with partitions and separate RF chains, which lead to lengthy and complicated design cycles and high development costs. The absence of soft transceivers and reconfigurable baseband modems for multimode handsets has been due to particular technological bottlenecks in SDR.

The limitations and bottlenecks of 'partial software upgradeability' are now being overcome with the provision of Multiprotocol Multiband (MPMB) reconfigurability. This essentially means supporting multiple protocols and multiple frequency bands on a single common platform, thus minimizing the hardware silicon area, as well as reducing development time and cost. MPMB SDR is possible due to recent advances in technology at the RF front end as well as the baseband processing unit. MPMB allows SDR to be perceived as a strong commercial technology rather than a niche military grade application. The reasons why MPMB is expected to drive commercial SDR are the following:

1. A single Common RF Head/RF Chain reduces hardware components and lowers cost of equipment for supporting MPMB.
2. A common reconfigurable platform for multiband along with multiprotocol reduces the development time, and shortens time to market. This advantage holds true in both infrastructure products like base stations as well as devices like handsets and handhelds.
3. Supporting multiple protocols in different bands is the major advantage for the end user, whether it is a cellular operator or a handset user. Cellular operators can use a single platform and upgrade across different protocols, eliminating the need to choose a specific wireless standard. It also allows a handset manufacturer and the end user to use a single handset and enable operability in different regions with disparate protocols and frequencies.
4. Simultaneous protocol support is only possible with MPMB. This allows for rural operators to take advantage of roaming revenues using a MPMB base station and also allows a handset to simultaneously provide support for cellular protocols like GSM, CDMA and wireless broadband protocols like WiFi and WiMAX. This functionality can be provided using a single modem chip and a common RF front end. This drastically reduces the BOM (Bill of Material) cost and development costs for multimode handsets when compared to current hardware approaches.

The difference between partial software upgradeability and MPMB reconfigurability can be understood from the tiers defined by the SDR Forum. These tiers can also be explained using the boundary that lies between the software and hardware portions. These tiers are as follows:

- Tier 0 (Hardware Radio): Boundary is non-existent
- Tier 1 (Software Controlled Radio): No Clear Boundary defined. Limited functions are software-controllable like power levels, interconnects
- Tier 2 (Software Defined Radio): Boundary exists at the Coding Level between the ADC and Baseband Units. Typically baseband processing and part of the ADC/DAC functions are controlled and performed in software. However, the RF front end is still hardware based.
- Tier 3 (Ideal Software Radio): No IF (Intermediate Frequency) component required. Boundary extended closer to Antenna. Typically boundary lies after Antenna. RF front end is reconfigurable.

Based on the description of these tiers, 'partial software upgradeability' can be categorized as Tier 2, while MPMB can be categorized as Tier 3.

3. MPMB SDR INNOVATION

With technological innovation being key to determining the success of commercial SDR, it is important to firstly understand the bottlenecks. As has been discussed previously, the main bottleneck lies at the RF front end. However, the baseband processing unit has seen different approaches being applied over the past few years. The different approaches to baseband processing are crucial, especially when looking at commercial markets, as they determine the cost and time to develop a SDR platform. Additionally, reconfigurable baseband processing has not transitioned to small form factor devices like handsets.

3.1 Baseband Processing Unit

The most common approach for a reconfigurable baseband unit is to use FPGAs and DSPs, also known as the firmware approach. However, the COTS server approach was introduced by Vanu to reduce development time and costs of SDR systems. Vanu's solution uses high-level programming code like C/C++ to represent the waveform. Vanu's waveform code does not depend on any particular hardware unlike the firmware approach, which means that the code is not particularly optimized for performance over a particular hardware. In the firmware approach, the waveform code is written in low-level programming language like VHDL, which allows optimizing performance for a particular hardware, thus improving performance. On the other hand, this limits the range of hardware platforms that the code can be ported onto. Another limitation of the firmware approach is that development tools are more complicated and time consuming than the COTS server approach. Therefore the COTS server approach has a tradeoff of cost over performance, while the firmware approach has higher performance for a higher cost. Apart from the COTS server and firmware approach, a new technology called picoarrays takes advantage of the low costs of the COTS server approach and the performance benefits of the firmware approach. Picoarrays is a proprietary technology from a UK-based company called Picochip, who have been able to achieve significant performance enhancements even when compared to firmware approaches.

As seen in Table 1, Picochip is better than the COTS server and firmware solution, both in terms of cost and performance. However in terms of development time, although it beats the firmware approach, it is unable to match the COTS server approach. The difference between the firmware and picoChip approach is that Picochip uses C to program the waveforms unlike the firmware approach where VHDL is used [2]. Picochip essentially brings an object-oriented programming approach to DSPs.

Table 1.: Relative Cost vs Performance for Baseband Processing Solutions

	Firmware (DSP)	**COTS server (Vanu)**	**Other (Picochip)**
Cost	$50	$100	$1
Performance	5X	1X	10X
Development Time	5-10X	1X	3-5X

Although there are multiple approaches being introduced in the reconfigurable baseband, all of these approaches are not yet suitable for small form-factor devices like handsets. The current baseband approaches fit well with infrastructure products like base stations, as the size and power consumption are not as important as they are in handsets. However, there is some promise from companies like Freescale Semiconductor innovating with FPGA platforms on handsets [3] and Morpho Technologies providing a reconfigurable DSP for handsets [4]. Icera, a UK-based vendor has introduced a soft baseband modem chip specifically for handsets and datacards. Their proprietary technology implements the baseband modem in software allowing for multimode support. However, they are still in the startup phase and have yet to deliver any products for commercial handsets or datacards.

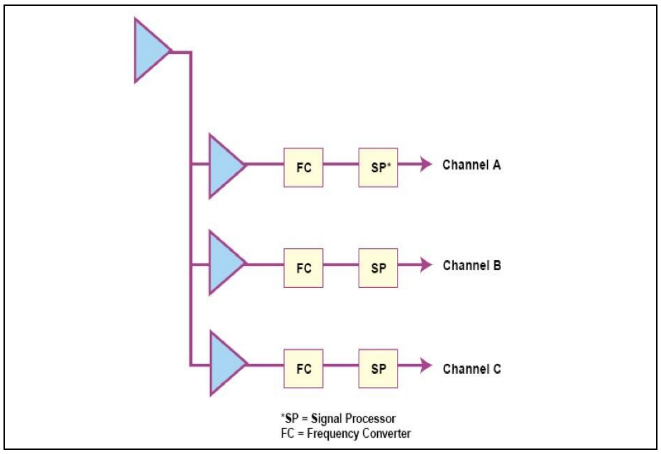
3.2 RF front end and Converters

The requirements for a RF front end that can provide MPMB depends on its ability to provide wideband support and be software reconfigurable.

3.2.1 Wideband Support

Until now, for a RF front end to support multiple frequency bands, it has followed the 'stovepipe' approach with parallel Tx/Rx (Transmit and Receive) chains supporting different frequency bands. The stovepipe approach is shown in Exhibit 1. This is a costly and time consuming approach. The alternative is a 'wideband' approach, which gets rid of the multiple stacks of Tx/Rx chains and supports multiple bands with a common Tx/Rx chain. Using a wideband RF front end, one should ideally be able to support frequencies from as low as 100 KHz to 6 GHz using the same Tx/Rx chain. This also means that the channel bandwidths or tunable bandwidths being fed to the filters and ADC can vary from 1-30 MHz or higher. A wideband-capable RF front end requires a high-resolution converter to convert the analog waveform into digital bits. The key metrics are the bit resolution, the SFDR (Spurious Free Dynamic Range) and the sampling rate. Typically converters have been able to provide 8 bits of resolution with 40-50 dB SFDR and 100 MSPS sampling rate. These converters can work with specific bandwidths of 5-10 MHz. However, for wideband signals that can vary from 1 MHz to 30 MHz or greater and support a higher resolution, these converters are not suitable. Advances in converter technology include a 14-bit Delta Sigma Converter from Terocelo that has a SFDR of 100 dB [5]. Texas Instruments has produced an ADC with 14-bit resolution, 400 MSPS sampling speed, and a SFDR of 85 dB [6].

Figure 1: 'Stovepipe' Approach



The RF front end, also known as the transceiver, needs to support high linearity and deal with phase and channel imbalances that are associated with wide bandwidths. In wideband operation, linearity is an issue because of in-band and out-band interference. Therefore interference in wideband operation is much more unpredictable than in narrowband operation [7].

The LNA (Low Noise Amplifier) is one of the major hurdles in controlling distortion and linearity. There is a tradeoff between the power that is being fed into the LNA and the SNR and the noise limit that increases with power. Some approaches to solve this include using adaptive cancellation and selective filtering before the LNA. Sigma Delta converters are also being used to take care of the non-linearities introduced by the LNA.

However, the most effective approach to tackle linearity and distortion is to remove the Intermediate Frequency (IF) conversions. This approach is also known as the 'Zero IF' approach where the signal is converted directly from the antenna and fed into the ADC, instead of passing it through filters. This approach is being used by Terocelo in their reconfigurable RF Head as well as by Alcatel in their Multiband transceiver. The Zero IF approach is now becoming commonplace in RF Heads that need to be multimode. The main reason is that a Zero IF transceiver does not need to convert a wideband signal into multiple intermediate frequencies, but converts it directly to the baseband frequency that is fed to the ADC. With this approach one eliminates costly development time, reduces silicon area, and ultimately lowers costs.

Other innovations at the RF Head have come in the Power Amplifier (PA) which amplifies the signal on the transmit end. New materials like GaN-HEMT and SiC-MESFET allow for high linearity, high output power and high efficiency as compared to the traditional LMDOS and GaAs power amplifiers [8]. These new materials possess a high band gap voltage allowing them to demonstrate properties that make them suitable for MPMB operation. Another approach to solving the power issue for PAs is using MEMS. However, MEMS has still not been able to overcome issues in a large-scale manufacturing environment [9]. There are other approaches being used. Sequoia Communications is a vendor which uses a polar modulation technique to feed amplitude back to the PA. This technique helps to linearize the PA at its input.

Other components like wideband synthesizers, multiband duplexers and wide-frequency mixers are just beginning to appear on the market but these components are too expensive and need further innovation to improve performance and also reduce cost [8].

3.2.2 Reconfigurable RF Head

Although wideband support is a crucial step towards a MPMB support, the need for a fully reconfigurable RF front end enhances the value of SDR in the commercial world. With the feature of soft reconfigurability, the handset or base station vendor can switch between frequency bands, enjoy variable gain, and use dynamic range. More importantly, however, soft reconfigurability allows the vendor to take advantage of the trade-off between bandwidth and power consumption and optimize the system for a particular customer scenario and application.

In MPMB solutions, wideband support and reconfigurability at the RF front end can be achieved independently of each other. Wideband support brings high power consumption at the ADC, which is a major issue in handsets. Vendors like Bitwave can provide reconfigurable RF front ends without wideband capability. However, if wideband support is provided at a smaller geometry e.g. 45 nm, then the power issue becomes less of a problem at the ADC.

The majority of soft transceiver chips are being marketed to small form factor, high volume device manufacturers, like mobile handset providers. . Multimode base stations, although useful in the field, are low volume and do not represent as high a risk in terms of design schedules.

4. COMMERCIAL VENDORS ENABLING MPMB SDR

Most commercial base station vendors provide 'partial software upgradeability' and are therefore categorized as Tier 2. Vendors that provide the end product or the essential components to enable a MPMB SDR platform can be characterized as Tier 3 vendors. The list of Tier 3 vendors and their components or products is given in Table 2.

Table 2: SDR Tier 3 Commercial Vendors, Products and Components

Vendor	Component/Product
Alcatel Lucent	MBFE (Multiband front end) in prototype stage
Vanu	Anywave Base Station
Bitwave	Soft Transceiver RFIC
ASICAhead	WiMAX Wideband Transceiver
Terocelo	Lycon Transceiver Chipset
Sequoia Communications	7 Band HEDGE Transceiver
IMEC	SCALDIO wideband transceiver

There is a growing list of RF components manufacturers who have introduced different versions of reconfigurable RF front ends. The differentiating factors include the degree of reconfigurability, the number of frequency bands and protocols supported, and other technical features such as silicon die area. There is also differentiation in the level of integration offered, with some vendors like Sequoia and Bitwave offering a complete integrated solution with LNA and filters included in the package. On the other hand, Terocelo's Lycon does not include an LNA.

Some vendors, such as ASICAhead, are focusing specifically on the WiMAX market, others like Sequoia are looking at the WCDMA market. Bitwave is aiming to support cellular handsets without restricting itself to specific protocols. Other vendors like Terocelo take a more holistic approach to support a wide range of markets from cellular to automobile to public safety. However, most of these vendors are still the process of sampling their silicon and are expected to proceed to production by early 2008.

On the other hand, base station manufacturers have managed sufficient innovation in soft transceiver architectures. Alcatel Lucent are one of the few base station vendors in the market who possess a lab prototype of a reconfigurable RF Head for base stations. They call this lab prototype a MultiBand RF front end (MBFE). However, it might be late 2008 before Alcatel Lucent can produce a cost effective version of the lab prototype for manufacturing.

In terms of end products, Vanu is the only base station vendor with a product that can be categorized as being close to Tier 3 architecture. Vanu's Anywave RF Head provides the ability to select frequencies and carriers to simultaneously support GSM and CDMA in the same band on the same RF Head, as well as providing just enough wideband capability (~25 MHz) [10].

Although it is too early to predict whether simultaneous support will become a differentiating factor especially in the SDR base station market, vendors such as Alcatel Lucent are confident of providing that support in future releases of their base stations. With regards to simultaneous protocol support in handsets, none of the soft transceiver component vendors or even handset manufacturers have shown any interest until now. Therefore, although simultaneous support in SDR platforms is technically achievable, usage cases and market demand for simultaneous functionality will determine whether or not it becomes a differentiating factor.

4. THE MARKET FOR COMMERCIAL MPMB SDR

With software becoming the key component in MPMB products and with hardware equipment being treated as a 'naked platform' upon which various waveforms can be ported, a new business model and disruptive value chain is likely to emerge. There is the possibility of a new entrant in the value chain, known as the third party software provider, who will provide the functional software, which is key to any SDR platform [11]. However, the emergence of third party software providers is intrinsically linked to the availability of a commercial implementation architecture that is ultimately adopted by SDR vendors in the market. Apart from the implementation architecture, the other key elements that are needed to initiate a commercial market for SDR include the business model and the end applications upon which MPMB SDR will operate.

4.1 Implementation Architecture

Although the military driven SCA was made with the intention to allow for platform independence, it has not been able to achieve that. In addition, the SCA also carries multiple overheads like the use of CORBA, XML and IDL, which can lead to long development cycles in the commercial world. The limitations with the SCA are linked to the fact that it was developed for the military sector. The dynamics of a military market are significantly different from the commercial market. These differences are listed out in Table 3 below.

The stakeholders in the SDR commercial space have understood these differences to some extent and have developed a solution. The OMG (Object Management Group) standards body has been able to develop a commercial version of the SCA called the OMG SWRADIO specification. This is now complete and mature for commercial use. The OMG SWRADIO is much more flexible than SCA. It provides the platform independence required for third party software providers and reduces the overheads that were present in SCA.

Table 3: Defense vs Commercial Implementation Architecture

Defense	Commercial
Architecture must ensure long life for the system without too many revisions	Architecture not geared towards ensuring long life
Low maintenance costs	Low development costs
Architecture must ensure error free operation	Errors should be minimized
Modular/Distributed Processor architecture	Centralized Processor architecture
Architecture supports rigid interfaces without concern for development time or cost	Architecture needs to support flexible interfaces to minimize development time and costs

However, although the specification is ready for use, it needs to be embraced by the commercial SDR market. In other words, it needs 'evangelists' to sell the advantages of the new software specification, and essentially create a large vendor community of third party software providers that collectively drives the specification forward [1].

4.2 Business Model

With MPMB and the opening up of the SDR handset market, there are bound to be changes in the business models that operate in the wireless space. This includes the possibility of a 'handset service upgrade' model which is capable of replacing the current 'handset replacement' model. This essentially means that the end user can benefit by purchasing a 'naked handset' and upload the necessary protocols that would suit his particular needs. In this case, the wireless operator would also need to adapt the current 'subsidized handset' model and suit it to providing 'protocols' and 'services' rather than locking the end user to a particular phone or wireless protocol.

However, as expected, there is a large amount of opposition from OEMs and wireless operators in adopting this 'replacement software' model, which directly affects handset volumes, which in turn drives the current 'replacement hardware' model. However it is quite likely that wireless operators will play a prominent role in provisioning of the software due to the security and piracy concerns associated with software. Therefore, in the long run it is more likely that the third party software providers will get consolidated in the value chain rather than remain as independent entities. With wireless operators visualizing themselves at the centre of this transformation, the inflection point of SDR moving from defense to commercial will most likely come when a single major wireless operator makes the decision to switch from the current 'handset replacement model' to a 'handset service provider' model.

4.2 Applications for MPMB SDR

The volume of demand for MPMB depends heavily on convincing high-volume market players, such as handset manufacturers, to adopt the technology thereby leveraging economies of scale. Although the wireless handset market is the largest in terms of volumes, there are other smaller but significant markets that are being considered by MPMB component and product vendors. The other markets include femtocells, handheld devices, laptops, automobiles, home entertainment devices, medical devices and public safety markets.

All of these markets are being driven by the need for a common platform that can support multiple protocols and frequencies either simultaneously or non-simultaneously. The key to determining the size of each market is directly related to the unit volumes generated. Out of all the applications, automobiles and femtocells both emerge as serious 'sweet spots' for SDR chipsets. Both applications have better economies of scale than base stations. Moreover, automobiles simultaneously need navigation, communication and entertainment systems, all of which operate on different wireless frequencies and all of which could be included on a single reconfigurable chipset. As far as femtocells are concerned, the need for indoor cellular coverage is becoming a necessity rather than a need because 3G mobile technologies are becoming more commonplace despite its poor ability to penetrate indoors. Multiple vendors entering the femtocell market presents soft transceiver component manufacturers, as well as soft baseband modem vendors, with an ideal target market.

6. CONCLUSION

The introduction of MPMB functionality is going to help SDR transition from a niche military grade technology, with commercial application limited to 'partial software upgradeability' in base stations to a full-fledged commercial technology with applications ranging from wireless handsets to automobiles and femtocell products. The inflection point from defense to commercial is most probably going to be driven by the decision of one major wireless operator to adopt the 'handset service upgrade' model and move away from the current 'handset replacement' model. The savings in overall cost and development time will allow SDR commercial vendors to efficiently service a market that has to contend with the shrinking lifecycles of rapidly evolving wireless standards. The end user could benefit from a value chain that is more 'service-oriented' rather than 'device-oriented'. A crucial element in ensuring a sustainable market for SDR lies in the successful adoption of the commercial version of the SCA implementation architecture and a sincere effort on the part of the commercial vendors to evangelize about this architecture amongst the SDR vendor community.

7. ACKNOWLEDGEMENT

The author would like to acknowledge the contribution of Julian Rawle and Howard Kidorf of Pioneer Consulting.

8. REFERENCES

[1] J. Chapin, "The Future of JTRS and its SCA: Lessons from ADA" *COTS Journal,* September 2004
[2] Picochip Product Brief, November 2004
[3] V. Mudagal, "Methods for Upgrading Reconfigurable Hardware Used in Mobile Phones", *Freescale Semiconductor White Paper,* GSPx 2006, Oct 30-Nov 2, 2006, Santa Clara, CA.
[4] N. Bagherzadeh, T. Eichenberg, "Mobile Software Defined Radio Solution Using High-Performance, Low-Power Reconfigurable DSP Architecture", SDR 2005 Conference
[5] R. Hickling, O. Panfilov, T. Turgeon, M.Yagi, "Software Defined Radio – Myths and Realities", *Terocelo Pape*r, 2007
[6] Texas Instruments ADC Product Datasheet
[7] O. Panfilov, R. Hickling, T. Turgeon, K. Mclelan, "Addressing Challenges of Software Radio", *Terocelo Paper* 2007
[8] W. Koenig, B. Haberland, A. Pascht, D.Wiegner, K. Nolte, "New Architectures and Technologies for Software-Defined Radio Base Stations", *Alcatel Technology White Paper*, April 2006
[9] R. Allan, "Mainstream MEMS: Monolithic or Hybrid", *SmallTimes Magazine*, January 2007 Issue
[10] "The Vanu Anywave Base Station Subsystem", *Vanu White Paper*, April 2006
[11] "Software Defined Radio – Altering the Wireless Value Chain", *Pioneer Consulting Market Research Report*, February 2005