Software-defined radio

— the solution for multi-standard multimedia in the mobile environment

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Consumers now demand the ability to consume a vast variety of multimedia content (music, video, photos, games, data services etc.) on a range of platforms – while on the move. Such content can be delivered using both broadcast and point-to-point means and, increasingly, the consumers require instant access. Indeed, entertainment on the move is becoming a must-have in today's mobile world.

A variety of standardized delivery mechanisms are available, using Digital Radio, Mobile TV and mobile-phone technologies – DAB, DRM, DMB and DVB-H as well as the 2.5 and 3G mobile-phone standards. Additionally, our mobile content might include MP2, MP3, MPEG-4 and IP-based audio and video services.

To cope with this plethora of multimedia services, consumed on a variety of mobile devices, an extremely flexible platform is increasingly required. One solution, from RadioScape in the UK, is described in this article.

Digital television and radio was pioneered by the DVB and DAB standards in the 1980s with rollout beginning in the 1990s. Since then we have witnessed an explosion in digital broadcasting with the advent of other terrestrial digital radio systems, such as Digital Radio Mondiale and HD-Radio, and satellite systems such as XM, Sirius and WorldSpace.

In addition there is increasing emphasis on the delivery of multimedia and video to users on the move in the form of the Mobile TV (MTV) phenomena. Here terrestrial systems include DAB-IP, T-DMB, DVB-H, ISDB-T and MediaFLO, as well as satellite-based systems such as S-DMB.

The vast majority of these standards use COFDM in some form.

There has been a plethora of articles prophesising the rapid expansion of the Mobile TV and digital radio markets with volumes that are typically as shown in *Fig. 1*. Importantly, it

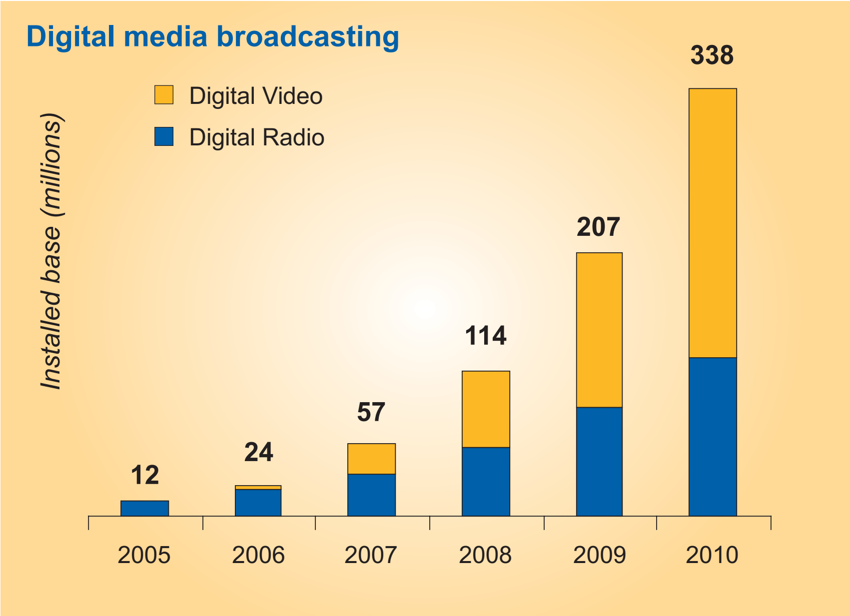

Figure 1
Digital Radio and Video receivers – installed base

is becoming clear that multiple standards will exist in many territories. *Table 1* shows the broadcasting standards which are likely to exist by geography with an indication of the timing of introduction. Those dates with a "?" at the end are estimates given current industry indications.

Table 1
Terrestrial broadcast standards usage by geography

Territory	Likely Standards	Timing	Adopters
Europe	DAB DAB-IP T-DMB DVB-H DRM	From 1996 2006 2006 2006 2007	Europe (including UK, Denmark, Switzerland, Germany, Norway, Sweden) UK, Ireland? Germany Italy, Finland Germany, France, UK, Benelux initially
Asia	DAB DAB T-DMB S-DMB ISDB-T DVB-H MediaFLO T-MMB / CMMB DRM	2006 2008 2006 2005 2005 2009 2007? 2007/8 Interest	Korea, China, Taiwan, Singapore Australia Korea Korea Japan Australia Japan? China Australia, China, India, SE Asia
North America	DAB DMB DVB-H MediaFLO DRM HD-Radio	2000 2007? 2007 2007 Interest 2005	Canada Canada? USA Canada, USA USA USA
Central and South America	ISDB-T DAB / DMB DVB-H	2007? Interest Interest	Brazil Mexico, Jamaica
Africa	DAB DMB DVB-H	2007? Interest 2006	South Africa South Africa

Not only will individual countries have multiple standards, there will likely be variations in those standards between countries. For example the UK will likely have DAB, DAB-IP, DRM and DVB-H while Germany is likely to have DAB, T-DMB, DRM and DVB-H. So for products to be able to operate with all services in both the UK and Germany, they will need to be able to receive and decode all five standards. Also it is likely that there will be a range of Digital Rights Management (DRM) and Conditional Access (CA) mechanisms used for the distribution of the content.

We note that Digital Radio Mondiale will exist in all geographies due to the long-throw nature of the transmissions. When DRM is operated in the HF band, transmissions can propagate for several thousand kilometres.

One of the most important aspects of the evolution of digital broadcasting is the allocation of spectrum. This is an ongoing process and indeed it is now clear that existing analogue broadcasting services will be replaced with digital alternatives. For example, the UK will completely turn off the analogue TV transmissions by the end of 2012. Other countries have various time frames but most will have completed the transition to DTV by 2012. AM radio transmissions are now also being targeted for switch-off, given the availability of DAB and DRM digital radio systems, and it is inevitable that FM will follow.

As MTV is a relatively new phenomenon, the standards which are being established, in particular DMB and DVB-H, will have some minor variations over the forthcoming years. While the updates will reduce with time, we now see these standards adopting an evolutionary approach. This approach includes backward compatibility where possible or appropriate.

The wide range of standard variations, as well as the variations and changes over time, leads us to consider receiver implementations which are both multi-standard and flexible. Traditionally, such flexibility has had a considerable price tag which generally forced such solutions out of the high-volume consumer mainstream. The use of flexible RF and Software Defined Radio implementations has now changed that situation, allowing consumer products to have wide functional coverage and giving benefits to the consumer and the manufacturer alike.

Software Defined Radio structures

Software Defined Radio (SDR) is a term which is used for a range of different radio implementations in software. In the context of this article, the term SDR is used as the name for the use of software which performs all the signal processing and control functions for the received radio signals as well as the applications processing. The hardware/software partition point in this case is the low-IF or baseband I/Q sampled received signals prior to the demodulation stage *(see Fig. 2).* Hence all demodulation, and quite often the front-end filtering for adjacent-channel rejection purposes is all done in software. Such a structure has many constraints with which it must deal, including the synchronization, detection, demodulation and decoding functions required for digital communications receivers as well as the system control, user interface and the scheduling of data transfer both within and to/from external sources. On top of this, we require a software system solution which is reliable but which can offer the ability to update software, add new features and progress to new models with a minimum of cost.

Clearly these requirements are difficult to meet. However, we add an additional dimension to this problem in the form of also undertaking the real-time decoding of the source data, whether it is video, audio or both. Indeed we may also need to decode multiple channels! Consequently we need to define a software structure which is not only flexible but can also cope with multiple simultaneous hard real-time constraints in a robust manner.

We have one more requirements of the software structure – it must be platform-independent! But platform independence comes at a price, that usually being *performance optimization*, i.e. the minimization of the number of instructions or MHz required to perform the required functions. Indeed no system can be completely platform-independent – as all software must run on a processor – but we

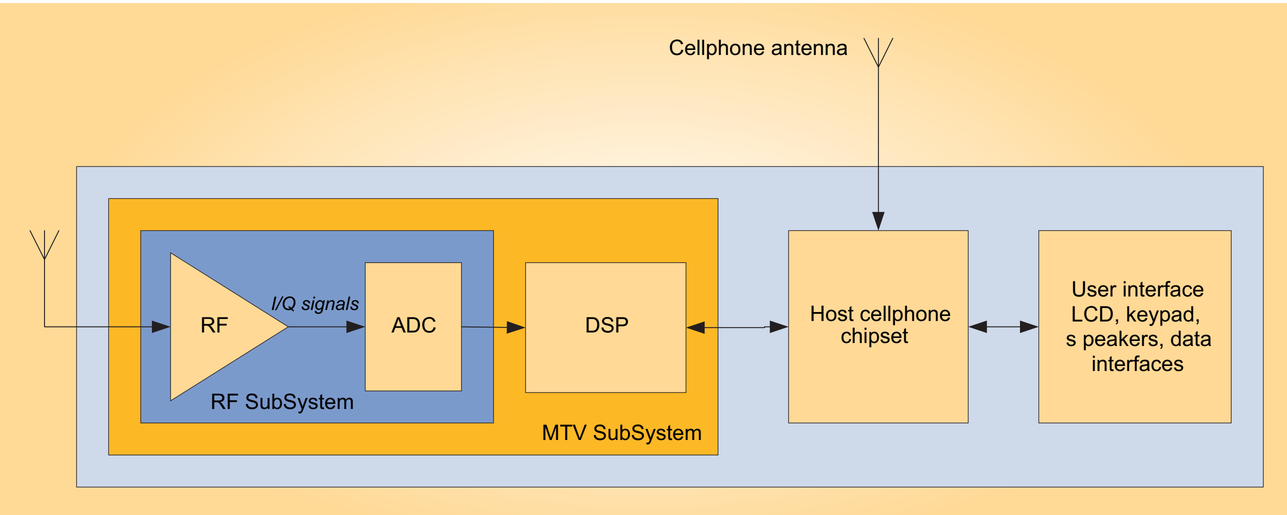

Figure 2
Example block diagram of a cellphone solution

can make the software as independent as possible. This gives us the benefit of being able to use the software system on multiple different platforms or processors with a minimum of additional effort. This allows the software solution to easily migrate to new markets (e.g. from consumer to automotive where the processors have much more stringent temperature and reliability specifications as well as higher cost) as well as allowing the use of new and emerging processors which provide the opportunity to remain competitive in terms of performance, cost and power consumption.

An example software structure is shown in *Fig. 3*. Here the system is based on a Real-Time Operating Systems (RTOS) which provides a number of services including hard real-time scheduling and memory management. Such RTOSs also usually have a number of associated service applications such as a TCP/IP stack, browser functionality and file system capabilities. In this case, those hard real-time requirements come from the need to receive and process the sampled RF data that is generated by the ADC in the RF system as well as audio and video output signals. Typically the RF samples enter the processor at a rapid rate, e.g. 8.192 million samples per second for DAB and DAB-derived MTV standards such as DAB-IP and T-DMB.

The software structure shown consists of five primary layers. The software and hardware ***Kernel*** layer includes the RTOS and hardware drivers. While the RTOS may be generalised for multiple platforms, it will be customised for each platform due to the specific features of that platform including instruction set, DMA, interrupts and system timers.

Above the kernel layer is the ***Abstraction*** layer. This is somewhat sandwiched between the Kernel layer and the ***Framework*** layer. When using an RTOS, a number of framework facilities will often be provided by that RTOS. These are usually enhanced by system-specific framework features to ensure that the overall system has the required capabilities. These features may be data-transfer capabilities to assure the real-time data flow between the functional objects, or the provision of timing functions to support synchronized stream applications such as DAB SlideShow. Above the Framework layer is the ***Applications*** layer. This in itself may have a number of internal layers as shown in *Fig. 3*. Typically in a multi-standard solution there will be three layers, the *demodulation* layer which supports the real-time demodulation of the various transmission standards, a *transport* layer which supports the different transport formats and conditional access methods used and which

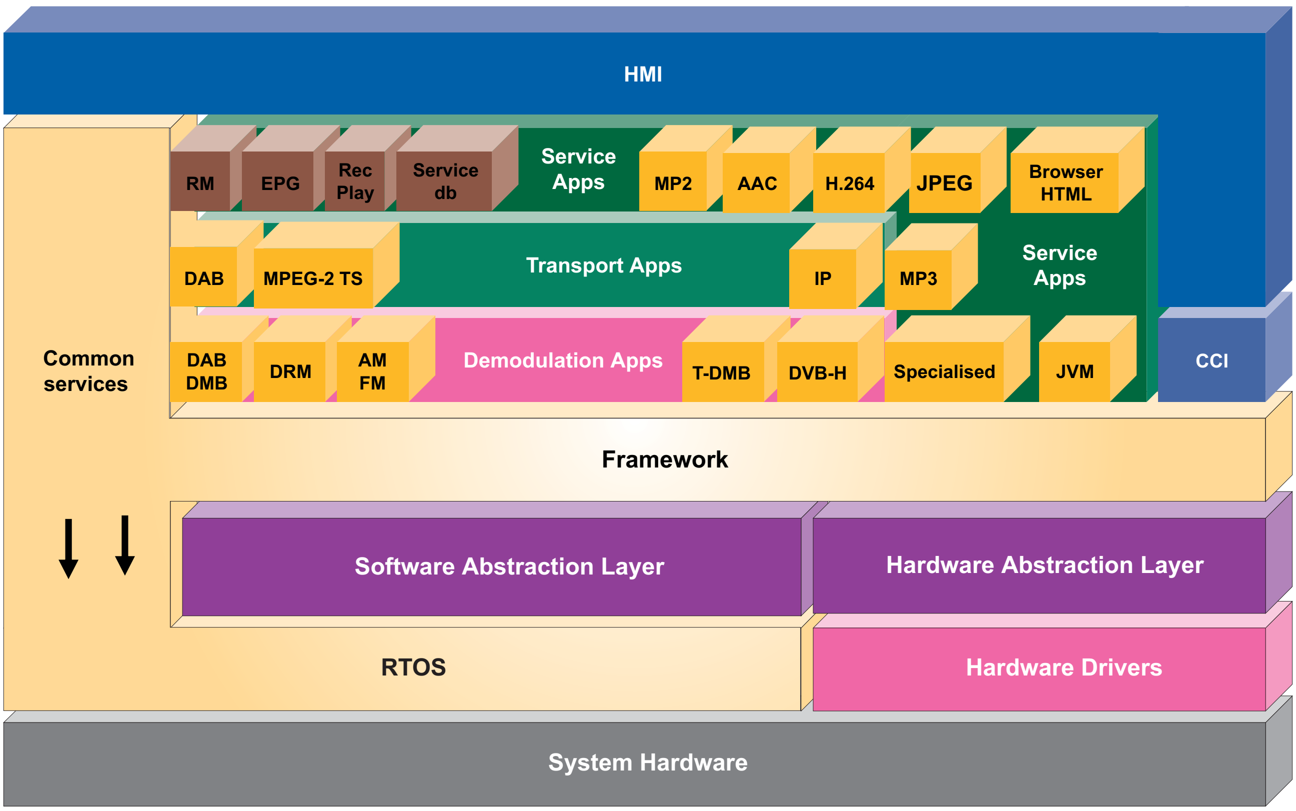

Figure 3
SDR block diagram

Abbreviations

ADC	Analogue-to-Digital Converter
AFS	Alternative Frequency Switching
AM	Amplitude Modulation
AMSS	AM Signalling System
API	Application Programming Interface
ASIC	Application-Specific Integrated Circuit
ASM	Assembly
BGA	Ball Grid Array
CCI	Common Client Interface
COFDM	Coded Orthogonal Frequency Division Multiplex
DAB	Digital Audio Broadcasting (Eureka-147) http://www.worlddab.org/
DAB-IP	DAB - Internet Protocol
DMA	Direct Memory Access
DMB	Digital Multimedia Broadcasting http://www.t-dmb.org/
DRM	Digital Radio Mondiale http://www.drm.org/
DRM	Digital Rights Management
DSP	Digital Signal Processor / Processing
DTV	Digital Television
DVB	Digital Video Broadcasting http://www.dvb.org/
DVB-H	DVB - Handheld
EPG	Electronic Programme Guide
FM	Frequency Modulation
HF	High-Frequency
HMI	Human-Machine Interface
I/Q	In-phase/Quadrature
IF	Intermediate-Frequency
ISDB	Integrated Services Digital Broadcasting http://en.wikipedia.org/wiki/ISDB
ISDB-T	ISDB – Terrestrial
JVM	Java Virtual Machine
LCD	Liquid Crystal Display
LW	Long-Wave
MIPS	Million Instructions Per Second
MTV	Mobile Television
MW	Medium-Wave
RF	Radio-Frequency
RISC	Reduced Instruction-Set Computer
RM	Radio Manager
RTOS	Real-Time Operating System
S-DMB	Satellite - Digital Multimedia Broadcasting
SDR	Software Defined Radio
SW	Short-Wave
T-DMB	Terrestrial - DMB
TCP/IP	Transmission Control Protocol / Internet Protocol
TTM	Time To Market

routes the *extracted data* to the audio, video and data applications which do the final processing of the received information and present the data to the user through the highest layer, the ***Human Machine Interface*** (HMI). The HMI is responsible for both the presentation of the received information but also system control, where it receives commands from the user and then instructs the software system to perform the appropriate instructions to realize those user commands.

The software structure described above supports a plug-and-play approach to system implementation. In this case, the system may be minimal for low-cost or even data-pump solutions or it can be fully-featured including a range of audio and/or video functionality. Each customer will have different requirements. The beauty of the SDR approach is its flexibility to provide customised solutions which fulfil the customer's needs in the most cost-effective way.

In this architecture, the Framework acts as a connection machine to ensure that data and control information is communicated in an appropriate fashion. All the signal-processing functions are performed in the applications. These applications can be either statically bound at code-link time or dynamically bound during normal system operation. This allows new applications to replace old applications and the reuse of those resources (MIPS, memory, DMA data bandwidth) that were previously occupied. For example, if the user decides to receive DRM instead of DAB, then the DAB stack is unloaded and all the resources it used are released. The DRM stack is then instantiated and it will use part or all of the resources which were previously used for the DAB stack. This flexibility ensures maximum reuse of the system hardware which in turn promotes minimum cost.

The plug-and-play approach allows the simple addition of new functionality as well as the updating of existing functionality. Indeed the structure and hardware abstraction of the code allows it to be deployed on a wide range of hardware platforms. Changes are generally limited to the Abstraction layer and platform-specific optimization using ASM code which is required for speed purposes as the majority of the code is written in C/C++ and is platform-agnostic and hence may be deployed on a range of DSP and RISC (e.g. ARM) platforms.

The approach outlined above may be used for basic digital radio systems such as DAB-only or for more highly complex systems such as Mobile TV SubSystems (MTV-SS) which are multi-standard capable.

ASIC versus DSP-based solutions

There is often debate regarding the relative merits of ASIC and general-purpose DSP-based solutions. There are many aspects to this comparison as outlined in *Table 2*.

Table 2
SDR / ASIC comparison

Aspect	SDR using a general-purpose DSP	ASIC
Cost	Low cost due to very high volumes and use in multiple application fields. The high volumes often allow the DSP vendor to be competitive in specific fields to ensure that price does not lock their product out of the mainstream market.	Sometimes lowest cost due to minimum chip size. However, sometimes the ASIC is designed for worst-case data rates which are unnecessary and hence the ASIC may be larger than required, particularly with respect to memory.
Functionality	Cutting-edge technology is available if necessary to provide a maximum feature set.	Technology usually lags slightly unless the ASIC developer is a major semiconductor provider.
Flexibility	With high flexibility, SDR offers the maximum ability to customise the feature configurations. This is particularly useful for feature upgrades and bug fixes.	With little or no flexibility in hardware, some flexibility is provided if a RISC processor is used for control functionality.
Size	General purpose DSPs are often available in minimum-size packages such as fine spaced BGA due to their use in handheld products. Size minimization options exist for solutions through the use of System-In-Package (SIP) technologies.	Often of the smallest size due to the direct targeting and inclusion of all or most of the required functionality in a single package. SIP technology is often used if different technologies need to be integrated or variable memory size parts are required.
Power	The use of cutting-edge technology can allow a DSP to have lower power than the equivalent ASIC at the same time due to the ASIC using older technology. Also, the DSP can usually be controlled to minimize clock speeds when the processing load allows.	The power in an ASIC is minimized by ensuring that the signal-processing operations are dimensioned correctly, particularly in terms of the bit widths being processed. This ensures that the minimum power is expended given the used technology. This generally allows ASICs to have lower power for equivalent technology.
Time To Market (TTM)	Time To Market is generally less for initial products depending on the software complexity. However, for derivative products, the TTM is generally much less than ASIC.	When a new feature or set of features is required to be added or modified with an existing ASIC, the full mask set will often need to be changed/updated. This is a time-consuming and costly process, particularly for products using the latest semiconductor technology.

In general, if the SDR-based solution has a consistent hardware basis and roadmap, then it will have the lowest cost of ownership over time. This does require careful planning of the product roadmap. However, if hardware interfaces can be kept consistent and software APIs be extended rather than modified, then the impact on the host system is minimized in terms of the number of changes and hence the effort to update the host software and hardware will be minimized. Indeed it must be remembered that for ASIC solutions, if there are any requirements for the addition of major functionality – e.g. a new audio or video codec, or a variation in the transport signal structure – then the chip will need a respin with the associated mask costs and delays. Conversely, with the SDR-based solution, it is simply a matter of integrating the new functionality in a plug-and-play fashion. Hence the SDR approach minimizes the Time To Market (TTM) for major functionality updates. This TTM minimization also applies for minor updates, which may be for model customisations, and to provide a range of features for different product models. For example, the use of a consistent software structure and interface allows the cellphone host software to be structured in a consistent way and hence minimize the effort required for such variants.

A multi-standard example: The RadioScape RS500

The RadioScape RS500 *(illustrated on the left)* is the first example of a multi-band, multi-standard module. In this case the RTOS used is ***RadiOS*** which is a RadioScape framework which sits above a kernel provided by the DSP supplier. This award-winning module provides reception for DAB (Band-III & L-Band), DRM (LW, MW & SW), FM-RDS (Band II) and AM (LW, MW & SW bands) including AMSS, as well as providing a number of features including automatic alternative frequency switching (AFS), EPG (DAB), MMC/SD card recording (DAB/DRM) and the playback of MP3/WMA files.

From the inception of this new product development, RadioScape has ensured that DRM integrates seamlessly with DAB. Users will not have to be concerned with having to know which technology or frequency to tune to ... they simply select the station name just as they do for DAB today. The RS500-powered radio displays a list of all the stations available on DAB, DRM, FM and AM.

There are two main points provided by this example:

- Firstly, consumers do not care so much about the technology used, they want to be able to access the services which they prefer, when they want, in a consistent and easy manner;
- Secondly, the use of an SDR approach has allowed the integration of these four standards along with other multimedia functionality while only minor software changes are required to provide the look and feel that is required by the customer with a minimum Time To Market.

The first multi-standard radio, based on the RS500, is available to customers in France, Portugal, Spain, Holland, Germany, Belgium and the UK. It is the Morphy Richards 27024 *(illustrated on the right)*, priced at around 199 Euros. Many other multi-standard radios from different manufacturers, also based on the RS500 module, will shortly be coming to market in Europe and elsewhere.

Conclusions

In the long-term, portable and mobile devices will be required to handle all the various broadcast standards – both for multiple programme and service access – so that users can freely move from country to country. Consumer receiver devices, whether they are based on mobile phones or personal media players, will need to be able to handle multiple transport standards in a unifying framework in order to extract content from the delivery mechanism and then handle a variety of content-protection mechanisms.

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He was born in Australia and received a B.Eng. from the South Australian Institute of Technology in 1980 and a Ph.D. from the University of South Australia in 1994. He has worked in the Telecommunications and Broadcasting industries for over 20 Years including spells with Lucent Technologies, Telstra, the Defence Science and Technology Organisation and at the University of South Australia.

Dr. Sabel has authored six Journal publications and over 35 Conference papers. He has four Patents and several patent applications. He has been a member of the IEEE Communications and Signal Processing Societies since 1987.

The users just want to be able to easily access content without having to worry about the delivery mechanism. This is an ideal application for Software Defined Radio solutions. This approach also minimizes the total cost of ownership for the manufacturer, as products for multiple different target geographies can be based on the same hardware with different software to provide the functionality which is appropriate for the targeted product type and market.

RadiOS is a trademark of RadioScape.