SDR — a software-defined multi-radio platform for the auto industry

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Although Software-defined radio (SDR) concepts have been used in military applications for several years, it is only recently that designers of cost-sensitive products such as car radios and mobile phones have started developing SDR-based solutions. One important enabler has been Moore's Law, and the resulting ability of millions of transistors to support highly-computational signal processing chips. However, raw processing power alone is insufficient because, in the real world, radio performance is also judged by additional metrics such as power consumption, chip size and the flexibility of the processing core's architecture to accommodate new standards.

This article discusses the drivers, motivations and potential of SDR solutions for in-car entertainment applications

Thanks to the continuously growing performance of microprocessors, Software Defined Radio (SDR) can offer new solutions for vehicle OEMs. Migrating the radio functionality from hardware to software brings cost advantages for global car production, and also offers more flexibility on the manufacturing side for future radio features.

More than 80 years after the introduction of the first car radio receivers, the auto industry is confronted with larger challenges. Car radios must offer more than most other consumer products: very long lifetimes, high robustness and performance. Car radios today need to support not only the traditional analogue radio systems (AM and FM) but digital radio systems as well.

One of the main challenges to master is the worldwide diversity of broadcast standards for digital radio – ranging from DAB(+) to DRM(+) and HD Radio, to name just a few. Countries or regions have chosen different standards for a variety of reasons (commercial, political, financial, network considerations, etc). Truly challenging for radio design engineers is the integration of standards which are based on different broadcast technologies, error protection schemes and coding technologies, which are briefly introduced below.

Current digital radio standards

Digital Radio Mondiale (DRM)

DRM is a digital radio system for short-wave, medium-wave and long-wave radio at frequencies below 30 MHz. It delivers near-FM sound quality and the ease-of-use that comes with digital transmissions. The improvement over AM radio is immediately noticeable.

The DRM system uses Coded Orthogonal Frequency Division Multiplex (COFDM). All of the data produced from the digitally-encoded audio, and associated signalling data, are distributed for transmission across a large number of closely-spaced radio-frequency carriers.

All the carriers are contained within the transmission channel. Time and frequency interleaving is applied to mitigate fading from multipath disturbances. Various parameters of the OFDM and coding systems can be varied to allow DRM to operate successfully in many different propagation environments. The maximum bitrate for DRM is 72 kbit/s.

The DRM system uses MPEG-4 High Efficiency Advanced Audio Compression (HE-AAC+ v2) to provide high audio quality at low data rates. In addition, Code Excited Linear Prediction (CELP) and Harmonic Vector eXcitation Coding (HVXC) speech compression algorithms provide speech-only programming at even lower data rates.

DRM+

DRM+ denotes an ongoing development of DRM, and is a standard for digital radio transmissions in Band I (the old VHF TV band) and Band II (the VHF/FM radio band). Also here, OFDM provides a highly efficient usage of spectrum and offers undisturbed mobile reception with no interference. With its bandwidth of 95 kHz, DRM+ fits into the 100 kHz FM channel spacing used in Europe and can thus be transmitted within the respective gaps in Band II.

The maximum effective data rate is up to 186 kbit/s per multiplex. HE-AAC+ audio compression permits the integration of up to 4 different audio streams including additional data services or even video streams on one DRM+ multiplex. DRM+ integrates “smoothly” into DRM.

Digital Audio Broadcasting (DAB)

When the DAB system was designed in the late 1980s, it had five original objectives: (i) to provide CD-quality radio; (ii) to provide better in-car reception quality than on FM; (iii) to use the spectrum more efficiently; (iv) to allow tuning by the name of the station rather than by frequency; and (v) to allow data to be transmitted.

DAB+ and T-DMB, which both originated from DAB, use HE-AAC+ v2 audio compression and Reed-Solomon error correction coding with extra interleaving.

Abbreviations

AAC	Advanced Audio Coding
AM	Amplitude Modulation
AVC	(MPEG-4) Advanced Video Coding, part 10 (aka H.264)
BIFS	BInary Format for Scene description
BSAC	Bit Sliced Arithmetic Coding
CELP	Code-Excited Linear Prediction
CMOS	Complementary Metal-Oxide Semiconductor
COFDM	Coded Orthogonal Frequency Division Multiplex
CPU	Central Processing Unit
DAB	Digital Audio Broadcasting (Eureka-147) http://www.worlddab.org/
DAB+	DAB using the AAC codec
DMB	Digital Multimedia Broadcasting http://www.worlddab.org/
DRM	Digital Radio Mondiale http://www.drm.org/
DRM+	DRM for the higher frequency bands, up to 174MHz
DSP	Digital Signal Processor / Processing
DVB	Digital Video Broadcasting http://www.dvb.org/
EPG	Electronic Programme Guide
ETSI	European Telecommunication Standards Institute http://pda.etsi.org/pda/queryform.asp
FM	Frequency Modulation
HE-AAC	High Efficiency AAC
HVXC	(MPEG) Harmonic Vector eXcitation Coding
HW	Hardware
IC	Integrated Circuit
OEM	Original Equipment Manufacturer
OFDM	Orthogonal Frequency Division Multiplex
PS	Pseudo Stereo
R&D	Research & Development / Design
SBR	Spectral Band Replication
SDR	Software Defined Radio
SW	Software
T-DMB	Terrestrial - DMB

DAB+

The primary difference between DAB and DAB+ is that a DAB digital radio broadcast uses MPEG-2 Audio Layer II audio compression while DAB+ uses HE-AAC+ v2 audio compression.

HE-AAC+ v2 is a superset of the AAC core audio compression. This superset structure permits three options depending on the required bitrate: (i) plain AAC for high bitrates; (ii) AAC and Spectral Band Replication (SBR) i.e. HE-AAC for medium bitrates; or (iii) AAC, SBR and Pseudo Stereo (PS) i.e. HE-AAC+ v2 for low bitrates.

Each audio super frame is carried in five consecutive logical DAB frames which enable easy synchronization and management of reconfigurations.

T-DMB

T-DMB is also based on the conventional DAB transmission system according to the ETSI standard, EN 300 401. This means that the DAB transmission system can be used for T-DMB transmissions by adding a T-DMB video encoder to the existing DAB system. Since T-DMB and DAB are delivered via the same system, T-DMB devices can receive not only T-DMB multimedia services but also DAB audio services.

T-DMB uses Bit Sliced Arithmetic Coding (BSAC) or HE-AAC+ v2 audio coding for audio services, Advanced Video Coding (AVC) for video services and Binary Format for Scene (BIFS) for interactive data-related services.

HD Radio

HD Radio is a method of broadcasting digital radio signals on the same channel and at the same time as the conventional AM or FM signal (in-band, on-channel, or IBOC).

HD Radio is a proprietary transmission system which uses a COFDM system to create a set of digital sidebands on each side of the normal AM/FM signal.

The combined AM/FM and digital radio signal fits into the same spectral mask as specified for conventional AM/FM. The system allows for growth towards eventual full utilization of the spectrum by the digital signal in three steps: Hybrid, Extended Hybrid and Full Digital.

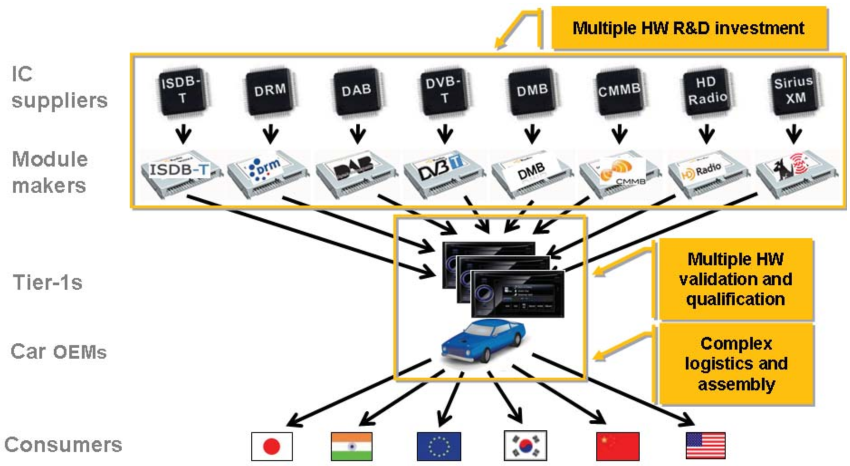

Figure 1
Production chain using dedicated single devices for each standard

Global market

Although car production is more-or-less global, the market for car radios is regional, due to digital radio standards being deployed on a regional basis. Thus, each market requires a dedicated digital radio solution *(Fig. 1)*. This diversity is expensive and time consuming since, for each market, different combinations of radio components need to be evaluated, tested and integrated.

More flexible

Hitting the sweet spot with the right combination of flexibility and cost efficiency can be accomplished with the right mixture of powerful embedded DSPs (= flexibility) and dedicated HW accelerators (= cost efficiency). Software Defined Radio is not a new idea as such but, so far, pure SW-based radio systems have been used mainly for academic purposes.

Key for a commercially-attractive digital radio system is a proper hardware/software partitioning, along with the following thoughts:

- Moving the digitization as close as possible to the antenna input (digital is more flexible);
- Processing steps which need fixed and regular number-crunching should be implemented in HW (e.g. digital filtering).

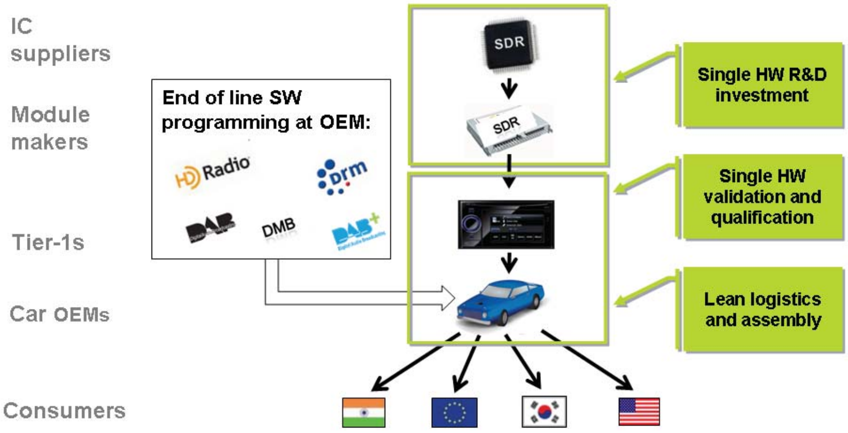

Figure 2
Leaner supply chain using SDR technology

The ever-growing computational performance of embedded processor technologies has changed quite a bit. That is true, also for SDR. Today it is still not possible to run pure SDR on a multipurpose processor. However, in the future, more and more processing elements can be mapped on processors, helping OEMs further to reduce HW costs and to increase the maturity of their products.

More economic

SDR technology provides a more economic way. Instead of developing a dedicated solution for each standard, customers can use a single chip which supports multiple standards. It will simplify the logistical effort and lower the R&D investment for chip development, SW validation and module manufacturing.

Figure 3
Multi-standard Digital Radio SAF356x for multiple markets

An example of such a solution is the Digital Radio Co-Processor, SAF356x, from NXP *(Fig. 3)* which supports standards such as HD Radio, DAB, DAB+,T-DMB as well as DRM and DRM+. The individual standards can be activated through programming at the end of the car production lines. You have to run only once through the costly integration process for the HW, regardless of where the radio will be used in the world.

The goal is not yet to run a complete radio on a general-purpose processor. Such a system would not be economical with today's technology. However, it is all about making the chip design in such a way that each function is executed by the processing unit which is technically and commercially the most suited, regardless if it is in HW or SW. Thus, a Multi-standard radio system is always composed of a component that carries the traditional AM/FM radio function and a second component which can, through SDR, realise all the digital radio standards that are required in the region.

More support during transition

There is another challenge and that is the combination of different technologies, customer support services and performance requirements.

One of the confusions in the car industry occurred when the codecs had to be changed with the introduction of DAB+. Although the installed base of in-car DAB radios wasn't that big when DAB+ was introduced, there were already quite a number of cars in the market with a DAB-only solution which could not be upgraded to DAB+. The switch to a new codec for DAB+ turned out to be a problem, simply because the radio-frequency and audio processing was not flexible enough to allow a reconfiguration. Furthermore, many solutions simply didn't offer a mechanism for upgrading the chipset with new SW, once installed in the car. Here, SDR solutions – in combination with efficient chip design – can help car manufacturers and providers of system solutions to react to challenges quickly. Furthermore, SDR can increase the adoption speed of new standards and features in the automotive world, because it provides faster inroads for e.g. consumer market features which have a higher evolution rate.

It does not help the adoption of new digital radio standards if the listening experience is hampered by audible effects, when the radio switches from analogue to digital reception (or vice versa) because of the delay in broadcasting between the same programmes on analogue (e.g. FM) and digital (e.g. DAB). That is why modern radio systems require to have functions like "DAB-FM blending" which enables a seamless roaming between analogue and digital reception without any interruption. The radio will always switch to the best reception available, based on reception quality parameters.

Being in the digital domain has yet another advantage. It is possible to create time-shift functions which allow the continuation of radio programmes, just from the point when the listener got interrupted, e.g. by an incoming telephone call. However, SDR technology can also bear risks for the supply chain of customers. For traditional radio systems there is usually a semiconductor company to provide help and services during integration. However, with a growing amount of SW components for various standards, the situation can become more complex, since the SW may come from different suppliers. It makes sense to ensure that there is a reliable supply and service network behind the silicon vendor.

More digitization and even more innovations to come

As long as Moore's Law [1] is valid, the value of SDR technology will continue to grow. SW-based innovation will be the driver for tomorrow's in-car entertainment innovations. There will be new ways to do things and shorter design cycles to introduce new features. Even updates over the air are possible as we already know from satellite receivers in the home. Software-defined radio technology will develop further in the field of vehicle electronics, bringing new applications, because SDR allows us to unify the chip technology development: we'll be able to migrate from application-specific signal processing to a broader more universal platform which encapsulates radio-standard-specific processing in SW.

Implementing a single digital radio standard such as DAB(+) or T-DMB may not be enough to address reception as well as geographical aspects for radio in the future. Some regions may decide to pursue a dual strategy such as using DAB in urban areas and DRM in rural areas, due to its larger coverage. The co-existence of different standards and services will be a further challenge for radio system designers in the future. For example, when coming from a rural area into a city with a different radio standard and different radio services, will require a seemless audio handover.

In this particular case, the radio has to continue audio service playback of the current radio standard while, in the background, extracting the service-linking information of an alternative channel which has the same audio content. Then, it needs to start a secondary radio reception to initiate decoding of the alternative radio service in the background and to determine the broadcast delay (which can be up to 5-10 seconds). In the final step, the radio performs a seamless handover between the two time-aligned audio services.

1. Moore's Law states that the CPU power doubles with each CMOS process node.

The result for the customer will be continuous listening to the selected audio services; the switch to a new reception standard may only be visible to the listener because of the availability of new services such as, for example, album cover art, weather maps, etc.

The described scenario can be seen as just one of many possible cases involving the co-existence of different radio standards, depending on the region. Many other possible combinations and scenarios are thinkable, not only limited to digital radio. Combinations of digital radio with digital TV standards, (DVB-T, DVB-T2, DVB-SH) could make sense when exchanging EPG (Electronic Programme Guide) data or linking to a TV or radio service.

However, such a use case can hardly be built using traditional radio technologies that process only single standards: the cost of such a radio would not be economical anymore. Instead, software-defined radio technology can help to reduce system diversity and costs for the auto industry.

Fig. 4 sketches a solution using SDR technology to overcome the problem of radio reception pipe diversity. The SAF356x follows this approach by implementing DAB, HD Radio and DRM baseband and audio decoding in a programmable architecture, in combination with a universal tuner which can cover all reception bands from AM up to L Band.

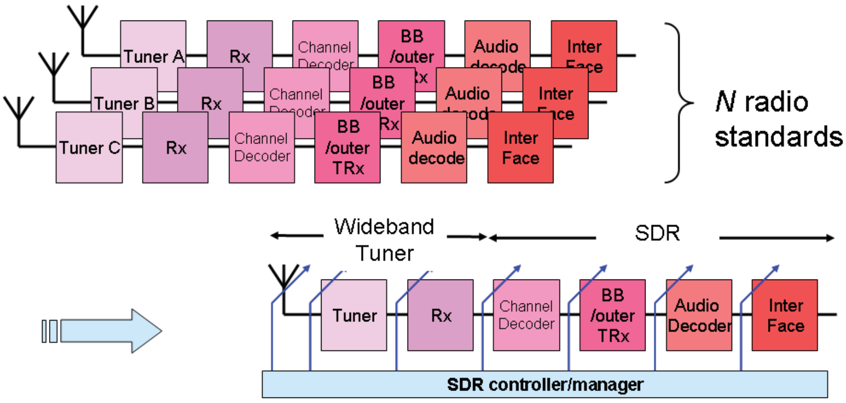

Figure 4
Reduction of Radio reception pipe diversity using SDR technology

Internet access

In addition to digital radio broadcasts, there is another important medium coming to the car – *internet access*, which will offer a vast variety of new services and opportunities to obtain music and other content, even on a personalized basis.

Internet access can be enabled via a GSM (e.g. 3G) connection or via a Wi-Fi connection (utilising stationary or mobile Wi-Fi as planned in Car2X concepts using the 802.11p standard). Regardless of how the content enters the car, there are many new options available, because most of the major radio services in Europe offer live or time-shifted audio streams to access over the Internet. Thus, new ways of combining broadcast radio and Internet radio are possible, which will make SDR technology even more valuable in the future.

Conclusions

The variety of new digital broadcast standards requires a refined approach for automotive applications. It must consider the needs for leaner supply chains of electronic components and systems. There is no uniform one-size-fits-all solution which can sufficiently cover all aspects of an appealing entertainment system, including:

- attractive cost;
- lean and global component design;
- feature and performance differentiation between markets and radio systems.

In a world where the lifetime of new features and performance benchmarks are measured in months – defined by the availability of new smartphones and tablets – Software-Defined Radio technology is set to offer a turnaround for automotive Broadcast Radio entertainment.

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Prior to this, Mr Steigemann held various positions in NXP dealing with product concept development, innovation and technology management in the consumer TV and 3D GFX business.

It has been shown that SDR can be used successfully to create momentum in a market which tries to be on a par with the latest consumer product features, while maintaining important additional requirements for the automotive environment, such as long life-time, high reliability and extreme robustness (temperature, humidity, mechanical stability, outstanding support).

The illustrated example of NXP’s Digital Radio processor solution (SAF356x) can handle the dynamics of new standards, still-emerging features, and market and product differentiation, by providing a platform which enables a lean supply chain for module makers and OEMs. The chosen HW/SW partitioning offers flexibility where needed and shields complicated real-time signal processing from the programmer’s interface.

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