WHITE PAPER

Teledyne e2v boosts radio softwarization efforts through its latest microwave data converter developments.

April 2020

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INTRODUCTION

The past few decades have seen an explosion in both radio technology standards, applications and a plethora of connected devices demanding ever increasing data bandwidth and throughput. Put quite simply, managing a demand curve that is currently growing at in excess of 25 %[1] annually, driven by 4.5 billion internet connected users combined with a burgeoning internet of things (IoT) revolution is a mighty challenge. With a recent turn towards home office working, key communication infrastructure both ground and space based is now, really being put to the test.

Simply put, critical radio frequency spectral space is in short supply and can not be made to scale with the present demands placed upon it. This means that modern communication network planning needs to find smart ways to keep the data flowing. Partitioning and re-using precious RF spectrum for maximum effect. And so, it is, that in the last few years the infrastructure backbones have started to be re-imagined for future readiness.

Internet traffic growth is currently in excess of 25 % (CAGR) and stands at over 200 EB/month (EB or Exabytes = 10^{18} bytes or 10^{6} TBs) in 2020 and growing further to 4.2 ZB/yr by 2022 (Source: Cisco 2019)

This short article will consider some of the key technologies shaping our near future electronic data exchanges; soft technology will have the biggest impact, as in software defined radios and networks (SDR/SDNs). Contemporary thinking proposes that best system efficiencies, optimal utilization and dynamic agility result from virtualizing system hardware and ultimately deploying artificial intelligence to orchestrate complex operations. Sounds like science fiction? Not really as this technology is just around the corner.

Wireless networks have become hugely complex. They are systems that cannot be optimized using traditional approaches such as design-time service planning and a simple one-size-fits-all configuration strategy pre-deployment. Instead, more intelligent and sophisticated techniques are needed: Cognitive radio (CR) for example – radios able to monitor dynamic network behaviour, sensing varying application demands, and then autonomously adapting their physical layer parameters to maximize network performance and quality of service (QoS). In many cases different applications share the same wireless channels and spectral bands making it really challenging to meet divergent QoS standards simultaneously. Basic control structures used today are inadequate to simultaneously balance extreme functional demands including latency, throughput, reliability and resiliency especially when mixed with diverging communication needs including: low and high data rates, time-critical and non-time critical signalling.

The solution will likely be found in softwarization approaches. Softwarization, relatively new terminology, refers to exploiting algorithmic approaches, where previously optimized hardware dominated communication problem solving. For this to happen, future systems will increasingly become virtualised and numerically controlled.

How does softwarization impact network design and planning. In the case of:

- SDRs, with cognitive radio technology, software increasingly establishes modulation, error correction and even carrier frequency and channel bandwidths to respond to dynamic operational profiles. SDR performance can be further enhanced through the deployment of beamforming and phased array antennas as well as rapid carrier frequency hopping.

- SDNs, control and data planes hardware are decoupled from each other with the control being centralised and infrastructure being abstracted from applications.

[1] According to Cisco Systems data

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THE DRIVE TOWARDS SOFTWARIZATION

The European Union's Horizon 2020 programme envisaged the challenges associated with next generation internet (NGI) leading to the Networld 2020 discussion document "Smart networks in the context of NGI[2]" released in late 2018. This detailed document addressed the manifold challenges of next generation networks built largely on the foundations of softwarization, particularly in respect to SDR and SDNs.

Research and development areas are outlined, and the paper provides a thorough grounding in the current state of network infrastructure. Unsurprisingly, many of today's challenges are well known by engineers and public alike: data security, and personal privacy stand out. Less obvious is orchestrating service scheduling, especially given the burgeoning range of network connected devices resulting from the impact of the internet of things (IoT) driving today's Industry 4.0 revolution.

A picture of extreme complexity emerges. Complexity of applications supported, shear data volume and traffic growth demanding capacity scaling, not to mention a diverse range of communication technologies (wireless standards, optical interconnects, Sat comms) and then the myriad array of actors and service providers which must be supported. No wonder that we now look towards artificial intelligence and machine learning solutions to hold it all together, orchestrating this advanced machine. It's a story that simultaneously leverages centralised and decentralised approaches to data as cloud, fog and edge computing resources operate symphonically.

What is radio frequency (RF) softwarization?

As partially implied by the question, softwarization means imbuing a radio communication channel or system with programmable or reconfigurable characteristics through the application of algorithms. Such radios are variously referred to as software defined (SDR) or even cognitive radios (CR); a category of radio capable of inspecting the local RF environment and then setting its own physical layer characteristics (carrier frequencies, modulation modes etc.) to make the best use of the available spectral capacity.

As digital electronic technologies have advanced over the last decade, increasingly complex, agile radio systems emerged with the best of what's possible for consumers exemplified by upcoming 5G mobile wireless terminals. But without extraordinary efforts, focused on network planning and control, it will be hard to orchestrate the smooth operation of our future communication infrastructure. Pressures on throughput and latency are set to increase as critical data needs to be exchanged in machine to machine (M2M) networks from the humble vending machine restocking call to the most dynamic of autonomous drive and traffic management systems.

MAKING RF AGILE

A speciality at Teledyne e2v, a company headquartered in Grenoble, France is microwave engineering. Teledyne e2v has been involved in the business since the early days of the first military RADAR deployments. It's a history built initially on travelling wave tube design and thyratrons, experience dating back more than 70 years.

The company's recent contributions to agile and scalable RF started in 1995 with the development of their first wideband data converters; analog to digital and digital to analog converter ICs (ADC & DACs).

[2] Smart Networks in the context of NGI, 2018.
The European technology platform Networld2020

These strategic devices take high frequency analog RF signals and down/up convert them in to/from the digital domain. These are the critical components enabling numerically controlled RF radio systems and provide the control flexibility to power next generation communication infrastructure.

THE ESSENCE OF SOFTWARIZATION OR NUMERICAL CONTROL

Radio communication systems rely on taking a carrier frequency, often viewed as a single pure 'tone' signal and modulating (or mixing) it with the data (or informational) signal. Data converters sample the signal frequency with an ADC providing a continuous stream of digital signal samples from which the informational content can be extracted within a digital signal processor (DSP). DACs are used in the transmit path to produce defined synthetic RF signal spectrum and can project signal power within and across specific channels.

In contemporary heterodyning radio designs, one or several intermediate frequency stages are required to project signal energy up or down the radio spectrum and into the baseband frequency range of the data converters. These intermediate frequencies require mixing circuits with local frequency oscillators that bring set-up and calibration challenges together with added cost and design complexity. Fortunately, with ever increasing advances to semiconductor device speed (i.e. transistor transition and maximum frequency), its increasingly economic to eliminate intermediate analog mixer stages and their varying local oscillator needs and digitize directly into or from the native RF signal band. Direct RF conversion using Nyquist sampling ADCs provides accurate, mixer free channel selection (or tuning) with the added benefit that a diverse range of data decoding and demodulation schemes can be instigated numerically within the digital signal processor.

The same is true on the transmit side of the system. Modern wideband DACs can project signal energy at microwave frequencies. Converters enable numerical control and brings programmability and flexibility to communication infrastructure. Such intelligent and flexible radios deliver a dynamically adjustable physical layer. It becomes possible to re-purpose the radio system either to handle short term capacity spikes or to enable a variety of different operating modes.

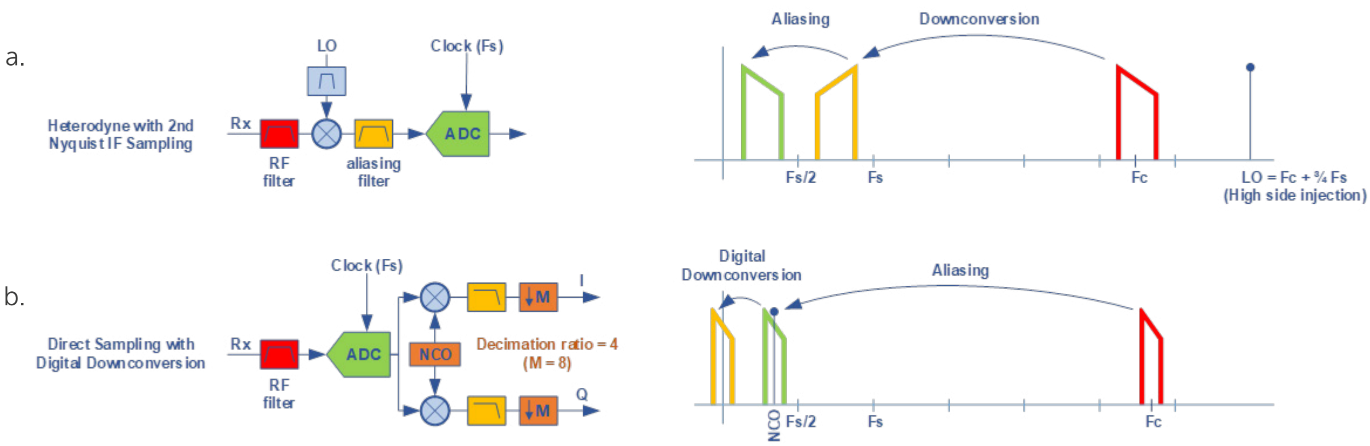

Figure 1 - Simplified Rx signal chains in a) traditional single stage heterodyne radio with mixer down conversion and b) a direct conversion system exploiting sampled signal aliasing within the ADC.

MATHEMATICS ENHANCES MODERN COMMUNICATION SYSTEM AGILITY AND FLEXIBILITY

Maths in the form of sampling theory, Fourier transforms and convolution has powered communication system design for many years. When deploying data converters in radio systems, some interesting behaviours and benefits emerge.

The impact of converters and digital signal processing on signal path design is clearly visible in figure 1 above. In contemporary heterodyne design (figure 1a) an analog mixer down converts the received signals into the second Nyquist zone of the ADC a first step towards an SDR. For the modified 'direct RF access' architecture (figure 1b), ADCs exploit signal aliasing for the first down conversion step. A final post-ADC down conversion uses different digital numerically controlled oscillators (NCOs) within the DSP to lock to specific carrier signals.

Ultimately, this scalable numeric approach lends itself to a highly flexible receive system capable of managing a huge number of channels each, defined by digital domain variables (figure 2). Thus there is a clear path to facilitate cognitive radios.

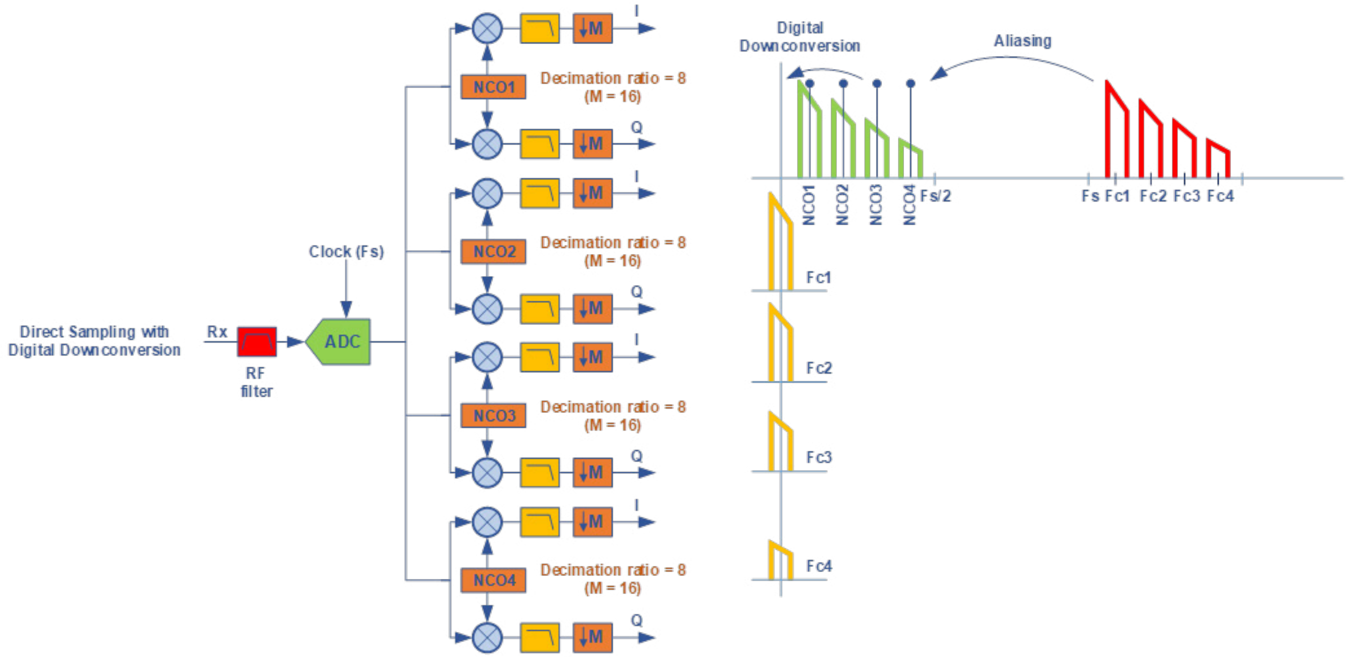

Figure 2 - In an enhanced SDR, numerical controlled oscillators can tune to any number of separate channels as shown.

RECEIVE PATH RF SUB-SAMPLING

In a sampled system, the Nyquist-Shannon sampling theorem indicates that an analog to digital converter sampling a bandlimited signal of bandwidth B at a rate 2B and can fully recreate that signal in the digital domain. Furthermore, with a bandpass filter applied, it is possible, using sub-sampling to down mix RF signals occurring in high Nyquist zones beyond the bandwidth 'reach' of the ADC directly into the its baseband spectral range (see figure 2). Sub-sampling exploits a track and hold amplifier (TH) applied ahead of the ADC.

The TH functions as a frequency converter 'folding' the applied RF signal, in this case sitting between 20 and 22.5 GHz into the baseband range of the ADC (in the first Nyquist zone (NZ_1), i.e. 0 to 2.5 GHz. This is a powerful simplification since it eliminates circuit stages associated with intermediate frequency generation (i.e. local oscillators and IFs) – substantially simplifying the analog signal path design (figure 3).

Figure 3 - Receive path TH (fs = 5 GHz) sub-sampling of 2.5 GHz bandwidth signal (on a 21.25 GHz carrier).

This is the foundational design step towards delivering numerically controlled radios. It is described in a previous paper[3] detailing the combination of the EV12AQ600, a 6 Gsps ADC partnered with a broadband TH are capable of sub-sampling signals in the K-band.

TRANSMIT PATH MULTI-NYQUIST ZONE FREQUENCY SYNTHESIS

On the transmit side, a traditional heterodyne radio's transmit DAC usually provides output signal power in the first Nyquist zone (NZ_1); any alias signal power being filtered out by a low pass filter. But what if the transmit DAC (TxDAC) provides enough bandwidth to project signal power into higher Nyquist zones? In this case, shown in figure 4, a band pass filter enables the target signal band to be selected.

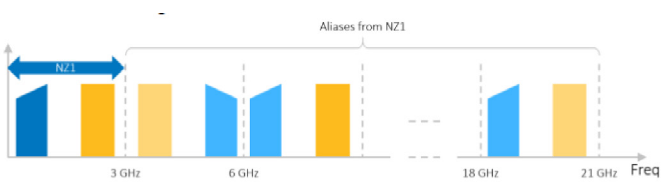

Figure 4 - Synthetic RF signal generated in NZ_1 and aliased into higher order Nyquist zones (fs = 6 GHz).

For example, the EV12DS480 TxDAC can project signal power all the way up to 26.5 GHz and samples at a rate of 8.5 Gsps.

ADC sub-sampling and DAC multi-Nyquist zone frequency synthesis are the crucial elements in RF numerical control and those leveraged at Teledyne e2v in pushing to further enhance next generation radio design.

IMPETUS FOR KA-BAND INNOVATION

The Interstellar program, a component project of the European Union's Horizon 2020 research effort, aims to develop new broadband data converters to simplify the RF signal chain and push direct conversion techniques towards the Ka-band. Within this vision, component aims include achieving greater system integration – i.e. increasing RF channel density, reduce power consumption, increase bandwidth, and improve dynamic performance; meanwhile strengthening Europe's space businesses. It is anticipated the project ultimately stimulates several far-reaching goals including access to improved telecommunication infrastructure and enhanced Earth observation (EO) capabilities to name just two.

Interstellar is driving Teledyne e2v's development of new data converters. Hand in hand with this, Teledyne e2v is prototyping an analog front end (AFE) demonstrator that dramatically expands microwave frequency sampling bandwidth, advancing the state-of-the-art in microwave direct digital down conversion and frequency synthesis.

Prototype Target Electricals

- High performance analog sampler with input bandwidth in the Ka-band
- High spurious free dynamic range (SFDR) in the Ka-band
- Single-ended input signal path (balun free design)
- High code efficiency, ESIstream serial digital interface
- Powerful clock management includes Sync chaining capability enabling easy, phased aligned, multi-channel scaling for beam forming applications

[3] Teledyne e2v Whitepaper, Dec. 2019: Advanced wide band sampling solution for direct digitization of the K-band – extending the boundaries of RF possibility

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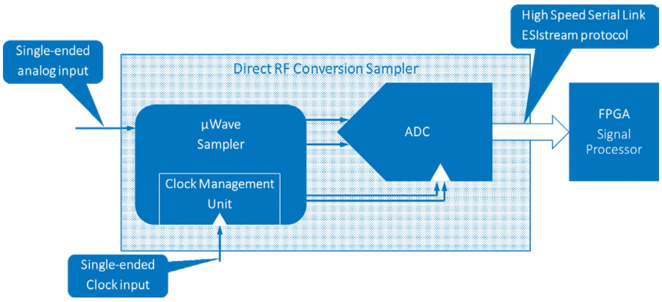

Figure 5 - Prototype direct conversion RF sampler.

The planned direct conversion RF sampler (figure 5), due to emerge towards the end of 2020, is expected to offer an analog input -3dB bandwidth in the microwave Ka-band (i.e. between 26.5 and 40 GHz). Beyond this unsurpassed bandwidth, this prototype will provide several unique features intended to make the device 'easily deployed' in real world systems. These features include:

- Single-ended analog input signal path eases printed circuit (PC) design and layout
- The elimination of the often [rather] expensive and space consuming HF baluns helping to simultaneously bring:
  - o improved economics of direct from microwave, digital sampling as well as
  - o minimizing signal distortion in the analog signal sampler
- A unique microwave sampler and low jitter clock management
- On the output side of this analog front end (AFE), the device eschews LVDS in favour of a high-speed serial interface system using the license free ESIstream protocol compatible with many off-the-shelf FPGAs (including Xilinx's KU60 series).

Interstellar motivates the next generation TxDAC development in the shape of the EV12DD700 featuring multi-Nyquist RF performance extending beyond K-band. The device delivers several user defined output data modes including a special 'dual RF' mode significantly stretching signal output capabilities beyond those of the existing EV12DS480. The latest converter is capable of sampling at frequencies beyond 8 Gsps and expands flexibility with a variety of digital numerical controls.

MODULARIZED, FULLY AGILE MICROWAVE SDRS REDUCE DESIGN PAIN POINTS

Input signal path simplification

Minimizing crosstalk and EMI sensitivity in complex microwave RF systems is no doubt a huge part of the design challenge. As a result, most high-end data converters use differential balanced signals to feed their signal and clock inputs. All well and good and pretty much today's standard practice. The downside to differential circuit design is two-fold:

- Each ADC input is normally a single-ended source such as an RF antenna signal transferred to the receiver via coax. Dealing with this signal adds a balun at each input (microwave sampler and ADC) and helps balance system impedance. Such components demand PCB real estate and prove rather costly, especially when designed for Ka-band operation.

- Handling fast clock edges in differential designs demands precise matching of PCB copper trace lengths, significantly complicating their design. With single-ended connection to the input stage minimizes or eliminates any signal phase error accumulation in those stages of the receiver.

Enhanced, compact data interconnects

In data converter interconnect, there has been a rapid transition in the data converter market over the last decade. A move away from multiple differential serial LVDS data lines with a separate data clock towards serial links using ultrafast transceivers with embedded clocks. Interfaces typified by the multiple generational implementations of JESD204 or the license free ESIstream alternative, both of which now support data rates up to greater than 12 Gbps.
Using serial protocols it is easy to see how copper can and has been replaced in some system implementations by an optical fibre physical layer further helping increase channel densities. In such cases, decimation and interpolation techniques help reduce the number of transmission lanes needed.

Maintaining signal phase information through sample clock precision

As sample clock frequencies have increased, it has become imperative, especially in beam forming microwave radio systems, that the sample edge is deterministically applied through-out the system. Signal sample phase precision is critical as it determines the spatial measurement accuracy of the overall system. It is a critical factor in precision synthetic aperture EO radar for example.

Teledyne e2v's unique sync chain[4,5] solves this challenge caused by SYNC signal metastability by using a relatively slow pulse edge to lock any number of converters to the same precise sample clock. Massive channel parallelization is now possible, significantly easing the headache of phase alignment across large distributed RF systems such as those found in phased array and MIMO applications.

CONCLUSION - HIGHER DENSITY MODULES MOVE EVER CLOSER TO THE ANTENNA

The objective of the project outlined here is to dramatically expand sampling bandwidth and extend technical capabilities of a wideband product portfolio driven by the Interstellar project vision and equally as a response to market need. Projecting direct conversion techniques into the microwave Ka-band is certainly a significant and challenging goal. However, previous developments already prove successful and result in economic implementations of direct to K-band approach using stand-alone components. It is also important to highlight this can be achieved for systems expected to meet the highest reliability levels for space operation including total ionizing dose radiation ruggedness.

As each engineering pain point is tackled, Teledyne e2v envisages a time in the near future when highly scalable, system in package (SiPs) data converter modules; those combining multi-input/output ADC/DACs paired with microwave samplers and associated clock management, are dense enough to migrate ever closer towards the antenna. At this point, ultra-wideband CRs will have become a reality and the challenge of highly agile radio infrastructure will, at least at the physical layer have been largely solved. SDRs will have become a critical part in flexible SDNs.

Whilst key technical details of this project remain 'under wraps', there is a lot to look forward to in 2020. Expect several major technical announcements in the final quarter of the year. Meanwhile, customers who have pressing problems to work on right now and are interested to get a more advanced insight into the elements of this development project should feel free to contact Teledyne e2v directly. Some preliminary data is already available covered by a non-disclosure agreement.

[4]Teledyne e2v Technical Note, Mar. 2019: SYNCHRONIZATION CHAINING, Simplifying Multi-channel Synchronization in Gigahertz Data Converters.
[5]Teledyne e2v Video: Learn about multi-ADC synchronization in only 7 minutes!

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