WHITE PAPER

Direct microwave conversion capabilities now made possible deep into the Ka-band

Dec 2023

EXECUTIVE SUMMARY

Analog to digital converters (ADCs) are the critical downlink bridge between the electromagnetic world and that of advanced digital signal processing. Extending sampling frequencies and bandwidth capabilities of these system critical components into the higher microwave frequencies opens a myriad of opportunities for future communication engineers to advance the state-of-the-art and to deliver greater flexibility in spectral usage. Teledyne e2v of Grenoble, France continues to leverage a strong history in microwave engineering to advance front-end radio capabilities to support ever increasing data throughput and system performance.

The latest ADC, the EV10AS940, is a single channel 10-bit resolution, time-interleaved ADC, with a 33GHz -3dB bandwidth that extends direct conversion performance deep into the Ka-band. Remarkably, this latest advance, lowers power consumption by a factor of five to a mere 2.5W/ch whilst achieving broadband operation and providing complex digital frequency management controls. The main innovations on display here include:

1. novel single-ended clock and signal inputs (that help eliminate baluns) simultaneously help extend sampling bandwidth & reduce system real estate
2. advanced integrated digital assets including a digital down converter (DDC) and
3. multiple numeric controlled oscillators (NCOs) facilitate fast frequency hopping (FFH) and eliminate the need for external mixers
4. a small form factor promotes the use of the device co-located with the antenna to facilitate smart antenna arrays and beam steering approaches

Each of these key advances will be discussed here.

What lies within?

This article discusses the development of a novel Ka-band capable, direct digital sampler – the EV10AS940 from Teledyne e2v. You will discover:

- A device capable of sampling a > 5GHz bandwidth up to 33GHz
- Exceptionally low power of 195 mW/Gsps
  - o Rated at just 2.5W @ fclk =12.8GHz
- A radical new design approach to achieving high-end performance
- Integration is enhanced by on-chip digital assist technology including a digital down converter (DDC) and multiple numerically controlled oscillators (NCOs)
- Envisioned applications demand a small form factor, single channel design

Anticipated applications

- HTS satcom systems
- Earth observation Radar including SAR
- Telemetry, tracking and command (TT&C) systems

INTRODUCTION

In pushing the performance envelope of direct conversion microwave in the pursuit of a software defined microwave radio (SDMW) or antenna-to-bits concept, Teledyne e2v has made substantial advances. It first signaled the pursuit of a broadband sampler describing a proof-of-concept design in this journal a few years back using an experimental device, the EV12PS640[1]. This work was further enhanced by a feasibility study of a fully digital, multi-band SAR radar[2] presented at the 7th Workshop on RF and Microwave Systems, Instruments & Sub-systems + 5th Ka-band Workshop 10-12 May 2022.

The result is a faster, more capable device than originally anticipated. This is perhaps unsurprising as several performance elements remained in the realms of theoretical, until a commitment to silicon was made. Several aspects of the novel design were reliant on changes to core technologies selected.

[1] *Discover Teledyne e2v ADC Proof of Concept - Capable of Sampling Directly from P- to Ka-Band, Nov. 2022*
[2] *Feasibility Study of a Fully-Digital Multi-Band SAR System operating at L, C, X and Ku Bands*

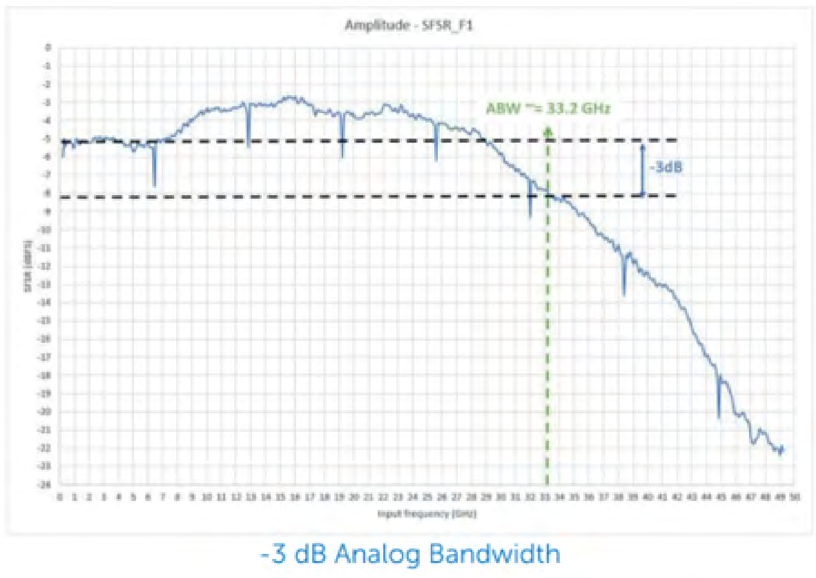

Figure 1 - EV10AS940 broadband input bandwidth

NEXT GENERATION DESIGN OBJECTIVES DEMANDED A FRESH APPROACH

This is a combination of a new architecture, new process technology together with substantial system innovations. Since the last ADC release – the EV12AQ600 this new part demonstrates a lot has changed in microwave engineering. Changes to front-end input design extends the bandwidth whilst increasing design flexibility. Power consumption is trending significantly downwards, whilst integration of digital frequency control capabilities massively enhances the value of this sampler and simultaneously gives a space saving edge.

SINGLE-ENDED INPUTS

Take for example, the advanced front-end design and the consequent appearance of single-ended signal and clock signals. This is a major departure from balanced differential input signals commonplace in contemporary RF designs. Consider the obvious benefits arising.

Invariably, modern RF designs require baluns to connect signals to data converters. This creates several challenges. Firstly, there's the inherent bandwidth limitation and thus baluns may significantly impact signal frequency response for a given design. Baluns complicate frequency planning, as only so many options are easily sourced. Moreover, baluns clearly add weight, space constraints and cost to a design. The balun free design of this device provides a broadband input stage with 33 GHz -3 dB bandwidth (see figure x) enhanced with integral DC blocking and 50-ohm effective impedance. That's a major enhancement to the front end, enabling a denser design layout.

EXTENDED BANDWIDTH

A novel broadband front-end was conceived for the new sampler designed to serve the Ka-band. With a 33GHz -3dB bandwidth that looks like mission accomplished. The device squeezes out enough spurious free performance to deliver useful signal sampling well into the Q-band (33 to 50GHz) domain – see insert for key dynamic specifications.
Further modifications to the front-end include the transition to single-ended signal approach and the inclusion of on-chip DC blocking and 50-ohm impedance matching.

Snapshot of key EV10AS940 dynamic characteristics

33GHz (-3dB) analog bandwidth
SFDR with Fs = 12.8GHz, POUT = - 6dBFS
Fin = 4.1GHz -> -54.5dBc
Fin = 14.1GHz -> -50.2dBc
Fin = 17.4GHz -> -50.4dBc
Fin = 28.4GHz -> - 50.5dBc
Fin = 40.5GHz -> -32.1dBc

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SIGNAL FREQUENCY MANAGEMENT

This sophisticated mixed signal product provides comprehensive digital signal frequency controls targeted especially at multi-band and beam steering applications. Integrated, digital signal down mixing is assisted by a quadruple bank of fine control, phase coherent NCOs that support four independent frequency bands selectable from across the device's 33 GHz (L-Band to Ka-Band) input range.

Coherent Fast Frequency Hopping (FFH) is achieved thanks to dedicated phase accumulators on each fine control NCO channel (see figure 2); which are then coupled to deterministic and dedicated frequency hopping trigger signals. This provides four independent configuration channels supporting multi-band systems. Phase continuity is achieved across all four channels. A 4-bit fine phase control is implemented in each NCO channel enabling a wide degree of flexibility in managing cross channel phase delays. A fifth NCO channel delivers coarse phase setting that gates the fine control outputs of the quad NCOs to handle the relative phase offsets between separate RF channels in a large array antenna environment. FFH is further supported by three programmable modes. These are return-to-zero (RTZ), phase continuous and coherent modes.

Determinism is one of the value advantages of this integrated sampler. An advantage derived from a frequently applied feature of other portfolio devices, namely the synchronization or sync chain (see side box). It is a robust approach to enable sample synchronization across a large, distributed array of devices. The sync signal is ordinarily a slow clock edge derived externally by the signal processing master. The sync signal is used to avoid metastable or uncertain clock edge events occurring across the sampling system. Individual samplers use the sync signal as a local sampling gate signal. A syncout signal is derived for each device in the sync chain and the output is adjusted to account for the latency of sync signal passthrough time (journey time through a single sampler). Retiming sync as syncout means that once a system has performed a start-up calibration, synchronous sampling is guaranteed across the extended system over a wide operating temperature range. This ensures deterministic sampling together with precision signal phase relationships are maintained across all bands.

The Sync-chain – enables massive channel parallelization for beam forming

As sample clock frequencies increase, it has become imperative, especially in beam forming systems, that the signal sample clock edge is deterministically applied across the system – thus establishing the spatial accuracy limit of the system. Sample phase accuracy places significant demands on clock system precision, especially in synthetic aperture Earth Observation (EO) radars.

Easing the sample clock phase requirement, Teledyne e2v has developed its novel Sync-chain capability. This sees each individual ADC in a phased array banish the digital metastability problem since each device on the chain 'retimes' its received Sync signal to be subsequently shared by all ADCs further along the timing chain. It is a genius method ensuring each device samples at a precise instant in time. As a result, massive channel parallelization is made possible, significantly easing the headache of channel phase alignment.

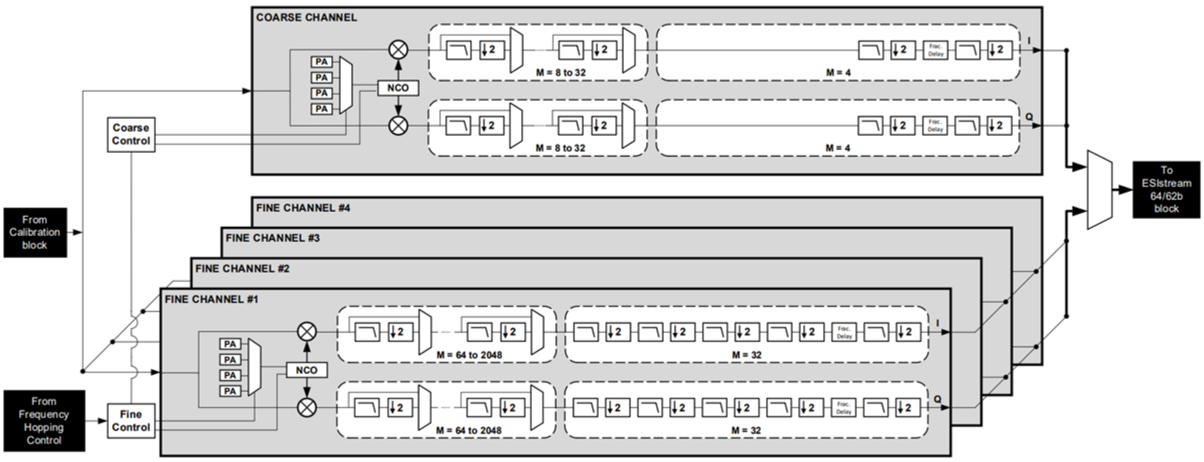

Figure 2 Digital coarse and fine phase control NCOs support multi-band FFH

You might deduce, the EV10AS940 is specifically designed to work in multi-channel systems. Digital, per channel fractional delays ensure rock solid phase sync in the RF front end ensuring this part has excellent credentials in digital beamforming phased arrays. Down conversion or frequency mixing derives from the integrated digital down converter that provides data decimation ratios from two to 1024.

Once decimated, sample data is output over dedicated ESIstream high speed serial links (HSSL) at 12.8 Gbsps. ESIstream is Teledyne e2v's license free data protocol. This latest expanded variant of the protocol features enhanced data transfer efficiency of 96.9 % using 62B/64B encoding. The main benefits of ESIstream are a deterministic latency and low hardware overhead easing the FPGA implementation of the link protocol. Furthermore, ESIstream embeds DC cable balancing within the coding scheme, ensuring maximum run lengths of 64-bits. It also enables active link synchronization monitoring.

HEAT, POWER AND SPACE

Lower heat, power and space are a trio of considerations in any broadband design and equally they are key factors that influence system design in challenging environments; particularly space bound, high-reliability missions. With high attention on continuous improvement in SWaP[3] performance of modern designs, this part delivers a step factor enhancement. A significant advancement in power consumption is demonstrated by this sampler design. Unlike the earlier proof-of-concept the EV12PS940, which consumed ~ 15W, this integrated device delivers a sample speed increase whilst lowering power consumption to just 2.5W/channel; a five times power reduction.

Such substantial reduction helps simplify the design layout, whilst simultaneously lowering demand on thermal management. Temperature monitoring of the device may be carried out by reading the on-chip thermal monitor. This digital sensor provides both instantaneous and average readings, which can be interrogated via internal device registers. In this way, thermal performance across an antenna array may be remotely monitored with no additional sensor provisioning.

The new device is packaged on an organic substrate helping limit parasitic performance degradations. The substrate is formed into a 350 ball, 0.8 mm pitch, 16 x 17.6mm flip-chip ball grid array (or FCBGA) package. This package has received approval for high-reliability applications including for space missions.

CONTINUOUS CALIBRATION

The EV10AS940 uses time interleaved ADCs which introduce offset and gain mismatches if left uncorrected and calibrated. An on-chip calibration system estimates and compensates the two mismatch sources. Note that timing mismatch and bandwidth imbalance of the interleaved ADCs, are mitigated within the analog front-end. Two types of calibration are provided:

- **Background calibration** is based on a continuous calculation that runs during active signal sampling. For each of the interleaved ADCs, the average and RMS values of the output are estimated on a sliding time window. Values are compared against the global average (for offset) and RMS (for gain), and deviations are extracted in real-time by subtraction and division respectively.
- **Default factory calibration.** In some applications, the background calibration function cannot be used, for power-saving reasons for example. In this case, calibration coefficients stored in the one-time programmable memory during factory calibration may be applied to the front-end.

CONCLUSION

The new EV10AS940 broadband microwave sampler demonstrates substantial device innovations. Notable in this first-of-kind sampler are the broadband, single-ended inputs which facilitate a balun-free design helping to maximize system bandwidth whilst limiting PCB area.

[3] SWaP -Size, weight and power factors.

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A duo of novel integrated and programmable digital frequency control features – the DDC and multi-band NCO subsystem make this an ideal beam forming solution for phased array designs. This device is certain to be welcomed by customers especially seeking to deliver mixed mission space payloads, those looking to enhance the performance of earth observation synthetic aperture radar (SAR) or even advanced electronic counter measure (ECM & ECCM) systems.

Moreover, the ability to perform triple mode FFH as well as to deliver deterministic phase sampling at high sample rates cement this device's position as a highly capable microwave technology demonstrator. Teledyne e2v are staying locked to their vision of multi-band software defined microwave radio systems. The EV10AS940 is yet another example of a continuous commitment to progress microwave state-of-the-art semiconductor engineering and migrating digital converters out of baseband operating mode (first and second Nyquist zones) and migrating performance ever closer to the RF antenna.

REFERENCES

- Discover Teledyne e2v ADC Proof of Concept - Capable of Sampling Directly from P- to Ka-Band EV12PS640 | Microwave Journal
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- State-of-the-art microwave ADC: A demonstration of the EV10AS940 FMC board

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For further information, please contact:
Nicolas Chantier,
Marketing Director
Signal and Data Processing Solutions
nicolas.chantier@teledyne.com

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For further information, please contact:
Heline Barneoud
Applications Engineer
Signal Processing Solutions
Heline.BARNEOUD@Teledyne.com