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Precise timing for aerospace and marine applications: a new low-power approach to high-performance oscillator design

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It is hard to imagine more challenging applications for radio-frequency equipment than space, or deep underwater. System designers have to take great care to specify components that will survive the rigours of these extreme environments, while keeping power consumption to a bare minimum to prolong operation on limited power supplies.

It is common for designers to devise an architecture for these applications around an FPGA because of its high-speed, parallel-processing capability. And downstream from the channel that digitises the radio signal, it is advisable to use a common frequency reference between the components responsible for digital sampling (based around an ADC) and those processing the raw data at the FPGA.

This raises two important questions at the outset of the design of a radio system for aerospace or under the sea:

- Can an FPGA technology provide the performance and the reliability required in these very harsh environments?
- How should the Local Oscillator (LO) for the frequency reference be specified, given the need for a combination of both stable, low-drift timing and low power consumption?

FPGA technologies suitable for aerospace applications

The choice of electronics components for use in aerospace must be capable of tolerating one special phenomenon: in flight, components are subject to a far greater number of particle impacts. Any one of these impacts can create a Single Event Upset (SEU) in an FPGA, which occurs when a particle passes through the component's packaging and circuitry and modifies a sub-micron configuration switch. An SEU can cause in-flight software configuration errors, with potentially catastrophic implications for the safety and operation of the craft and its occupants.

Different FPGAs, however, have different levels of vulnerability to particle impacts. Most FPGAs in use in electronics systems today have configuration switches made with volatile SRAM-based cells, an architecture which is vulnerable to SEUs, and which thus poses a risk to in-flight equipment.

On the other hand, FPGAs from Microsemi, now a Microchip company, have for many years been based on non-volatile technology which is proven to be highly resistant to SEUs over long service life in many aerospace applications. Radiation and reliability reports are available on the Microsemi website.

Microsemi evolved its product families of Flash-technology-based FPGAs through a series of process migrations. It most recently introduced the fifth-generation PolarFire FPGA family, which is built on an advanced 28nm fabrication process, as shown in Figure 1, and incorporates new non-volatile Silicon-Oxide-Nitride-Oxide-Silicon (SONOS) technology for the configuration switches. Products available today from across the three most recent generations of FPGAs can be found to fit the requirements of almost any application, such as aerospace, in which security and safety are of critical importance. In particular, the latest PolarFire FPGAs are an ideal cost-optimized, low-power, mid-range density solution.

Apart from its unbeatable performance in parallel data processing, the other important advantage of FPGAs lies in the fast and deterministic nature of their operation, supporting the safety certification of embedded products. Because of their architecture and construction, FPGAs do not have pre-defined instruction sets or data widths.

Features	SmartFusion, ProASIC3, IGLOO (3rd Gen. 130nm)	SmartFusion2, IGLOO (2nd Gen. 65nm)	PolarFire (5th Gen. 28nm)
Logic Elements	100 - 30K	5K - 150K	100K - 480K
Transceiver Rate	–	1Gbps - 5Gbps	250Mbps - 12.7Gbps
I/O Speeds	400Mbps LVDS	667Mbps DDR3 750Mbps LVDS	1600Mbps DDR4 1.6Gbps LVDS
DSP (18x18 Multipliers)	–	240	1480
Max RAM	144Kb	5Mb	33Mb

Fig. 1: the three most recent generations of FPGAs from Microsemi

FPGAs are therefore the best solution for the parallel processing of single or multiple data streams, as shown in Figure 2.

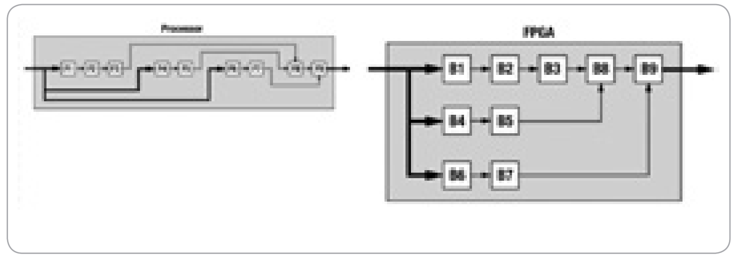

Fig. 2: Parallel processing in an FPGA (right) allows for faster execution of multiple sets of instructions which in a CPU must be performed in sequence (left)

A new processor architecture for the FPGA

Recently, Microsemi created a more integrated solution for FPGA-based designs, adding the option to implement the new RISC-V processor architecture in an FPGA. The implementation gives designers flexibility and cost optimization through the high levels of integration afforded by the presence of a microprocessor sub-system and FPGA on a single chip, helping to simplify circuit designs, reduce component count and save space.

The processor soft core developed by Microsemi for its FPGAs is based on the RISC-V open instruction-set architecture. The designer has access to the Register Transfer Level (RTL) source code for this RISC-V Intellectual Property (IP) core. This is an advantage in equipment designs that must attain safety certification.

The Microsemi RISC-V-based core is available now as soft IP which can run in an IGLOO2 or PolarFire device. Its performance is similar to that of an Arm® Cortex®-M7 microcontroller core.

Future Electronics also offers the 'Creative' Board developed in-house; it is a high-performance development kit featuring a PolarFire 300T device. It is supplied with a full set of software tools for developing RTL and C code.

LO stability over temperature: a key parameter in aerospace applications

RF equipment for aerospace applications, then, benefits from the parallel processing capability of an FPGA. A careful choice of FPGA ensures that it will be resistant to the impact of particles in space or the upper atmosphere.

RF equipment for use in aircraft or in space has to offer very high performance, because of the long range over which signals are transmitted and the many sources of noise which will interfere with these signals on their journey to the receiver. The RF system therefore requires precise, stable and accurate frequency control at both transmitter and receiver.

This means that aerospace designers have to carefully specify the LO's performance in terms of frequency stability and accuracy. At the same time, the power supply in a host device such as a satellite is highly constrained, so power consumption is also a critical parameter.

Choice of oscillator technologies

Faced with this challenge, the system designer has a choice of oscillator technologies which vary in performance, power consumption and price, as shown in Figure 3.

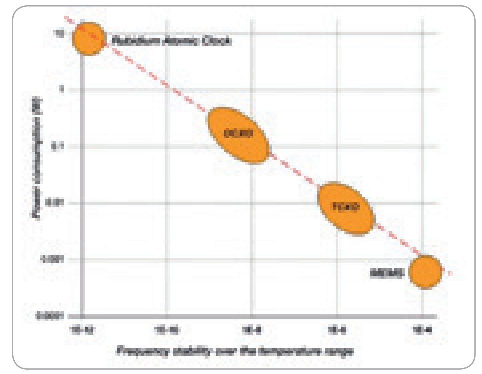

Fig. 3: Conventional oscillator technologies trade off power consumption against stability

Most consumer electronics products use basic oscillators, ranging in price from a few cents to a few euros. The choice in this range includes MEMS-based crystal oscillators (XOs) or in some cases Temperature-Compensated Crystal Oscillators (TCXOs).

In systems that require high frequency stability and low temperature sensitivity, Oven-Controlled Crystal Oscillators (OCXOs) provide the highest frequency stability among the various XO technologies. They are typically more stable than an entry-level XO by three to four orders of magnitude.

OCXOs are complex hybrid components. The frequency stability of an OCXO arises from its precise control of the temperature of the quartz resonator, regardless of the ambient temperature. The frequency of any quartz resonator drifts considerably as the temperature rises or falls. For a 10MHz resonator, the frequency drift between -40°C and 85°C is between ±250Hz and ±500Hz.

By maintaining the quartz at a precise temperature, an OCXO will reduce this drift to between ±0.05Hz and ±2.5Hz.

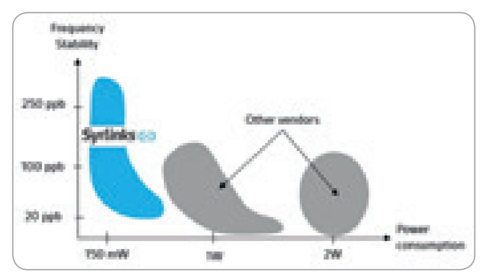

Fig. 4: The Syrlinks EWOS range of OCXOs combines good frequency stability with very low power consumption

OCXOs for battery-powered applications

Power consumption is the main disadvantage of an OCXO compared to a TCXO, because of the power supply to the heating element. Now however, Rennes, France-based Syrlinks has developed OCXOs which combine very small size, low weight and low power consumption while maintaining high frequency stability, as shown in Figure 4. This makes the Syrlinks OCXOs well suited to use in the radios that Syrlinks makes for small satellites, which have a highly constrained power supply.

For instance, the EWOS™ range of OCXOs covers frequencies between 10MHz and 40MHz; thermal sensitivity is between ±5ppb and ±250ppb, and power consumption between 65mW and 400mW at an ambient temperature of 25°C. This power consumption is around ten times lower than that of comparable OCXOs on the market.

EWOS OCXOs are used in all space radios made by Syrlinks, and also in other space applications such as space GNSS (satellite positioning system) receivers, which contain an FPGA. For example, the EWOS0525 is a 10MHz OCXO used in the G-Sphere-S GNSS receiver. It clocks simultaneously the RF digitization stage and FPGAs. The receiver achieves position measurement resolution of <10m at a high velocity of 7.7km/s.

This remarkable performance is achieved thanks to the very low phase noise of the OCXO, especially close to the carrier frequency. The performance of positioning or distance-measurement functions is directly linked to the short-term stability of the LO. This is why OCXOs are widely used in preference to TCXOs, since they provide better results in equipment in which position or distance are computed with a latency of <1μs.

The Syrlinks range of precision LOs also includes the EWOS83x family, which includes a Stress Compensated (SC) cut quartz resonator, as shown in Figure 5.

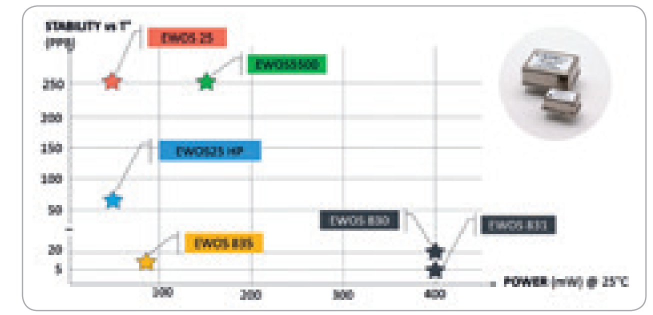

Fig. 5: The Syrlinks family of OCXOs offers a broad choice of characteristics to designers of timing-critical applications

This high-quality resonator type provides better phase noise performance and lower long-term frequency drift. This parameter is crucial for applications requiring precise timekeeping when a GNSS time source is unavailable: this is the case in environments in which GNSS signals are obstructed, and under water. Synchronization here depends solely on the performance of the LO.

The EWOS083x series offers an ageing rate of 0.3ppb/day. The low-power EWOS0835 is specified for underwater applications: it consumes 80mW at 25°C. In some cases it can be considered as a low-cost alternative to a chip-scale atomic clock.

For applications requiring the highest possible timing accuracy, Syrlinks offers its MMAC™ family of MEMS-based miniature atomic clocks, which offer long-term timing stability some 100 times better than that of OCXOs, while keeping power consumption very low: <200mW at -40°C.

Syrlinks also supplies the SGTM™ series of synchronization modules, as shown in Figure 6. In normal operation, the SGTM modules provide timing signals based on an input from a satellite GNSS signal or an external reference clock. When the GNSS signal or external reference become unavailable, the module continues to provide precise timing to the host system. The jitter between the input and output is approximately 12ns, and the time-domain holdover stability is around ±35μs/24h.

Fig. 6: The SGTM synchronization module from Syrlinks