WHITE PAPER

The Future is Now: Teledyne e2v's Quad Core ARM® Cortex®-A72 Radiation Tolerant Microprocessor Revolutionizes Heavy Computing for Space Systems & Satellite Projects

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TELEDYNE e2v | Semiconductors
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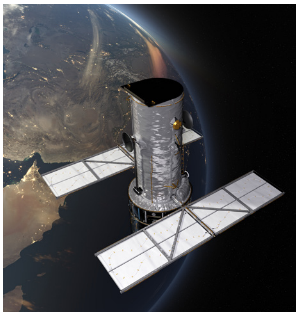
ABSTRACT

Space flight systems have experienced **rapid generational development** over the last sixty years. From military, to weather, to earth observation, and telecommunications (particularly as 5G networks globally advance), one technological problem has been consistent throughout--selecting and implementing a **fast** and **reliable space qualified microprocessor**. This fundamental requirement **must have the computing power/speed, size, weight, power dissipation**, and cost that will meet the **challenges and adaptability** necessary for **radiation tolerant space/satellite developments**. Now, as the future of state-of-the-art heavy computing ***requires*** next generation COTS (commercially available off-the-shelf) space qualified radiation tolerant processors, **Teledyne e2v's "LS1046-Space" Quad Core ARM® Cortex®-A72** microprocessor revolutionizes the heavy computing requirements for space/satellite developments in the upcoming decades. Utilizing GHz class high performance data processing from NXP QorIQ® LS1046 Microprocessor (**30K DMIPS @ 1.8 GHz**): its natural **high speed interfaces**, combined with convenient software programming (and reconfigurable capabilities), along with Teledyne e2v's **proven tolerance and mitigation techniques against radiation**; makes Teledyne e2v's LS1046-Space microprocessor the most suitable device enabling intelligent compute intensive space/satellite platforms.

TRADITIONAL & NEW SPACE: BOTH THE FINAL FRONTIERS OF PERFORMANCE VERSUS PRACTICALITY

"New Space" refers to the recent commercialization of ongoing space developments. As a result, space/satellite development teams must select and implement radiation tolerant electronic devices in conjunction with the latest state-of-the-art COTS technologies that balance the tradeoffs between performance versus practically. Before the massive expansion in consumer electronic products (gaming, cellphones, wearables, and IOT); government/military electronics accounted for a significant percentage of the semiconductor industry's output. This resulted in military and space agencies having significant influence over the types of new products and manufacturing processes that were being developed. Presently, this is no longer the case as the military and aerospace markets are not of significant size (compared to commercial markets) in order to justify such investments by semiconductor suppliers. This has led to the necessity for space/satellite development teams to use components that were previously developed as COTS integrated circuits and also qualified and screened for use in space.

Space/satellite developments reside within two basic design methodologies:



1. Traditional: Which has a very low failure rate and pays high prices for radiation-hardened (rad-hard), built-for-purpose semiconductors that are typically considered to be far from state-of-the-art; and
2. New Space: Which is more focused on mission assurance and is willing to use radiation-tolerant (rad-tol) COTS devices that utilize the latest technologies offering disruptive performance.

Given that the vast majority of new space satellites are used in Low Earth Orbit (LEO), where the radiation environment is less extreme, the risk of catastrophic radiation-induced failure is also lower (LEO's are between 300 km to 1,000 km from Earth). Therefore, both design methodologies (Traditional and New Space) are beginning to converge (by necessity) and resulting in the acceptance of radiation-tolerant, non-hermetic, organic packages versus traditional radiation-hardened hermetically sealed ceramic packages for space/satellite developments.

Over the last decades, there have been a number of developments that have been the driving force behind the higher cost of traditional radiation-hardened components:

1. Rad-hard by design (including SOI processing, etc.),
2. Spot Shielding,
3. Error Correction Codes (ECC) Memory,
4. Triple Mode Redundancy (TMR), etc.

In recent years, there has also been a push to reduce the high cost of using traditional radiation-hardened components by utilizing innovative hardening techniques that take advantage of high-volume commercial wafer foundries, and the use of commercial technology such as ARM (Advanced RISC Machine) microprocessors (the new LS1046-Space for example). These can now be utilized in heavy computing radiation-tolerant platform systems. As a result, while state-of-the-art computing power is now available, along with radiation tolerant reliability, all of these measures are facilitating the convergence of both traditional and new space developers (see Figure 1 tradeoffs below).

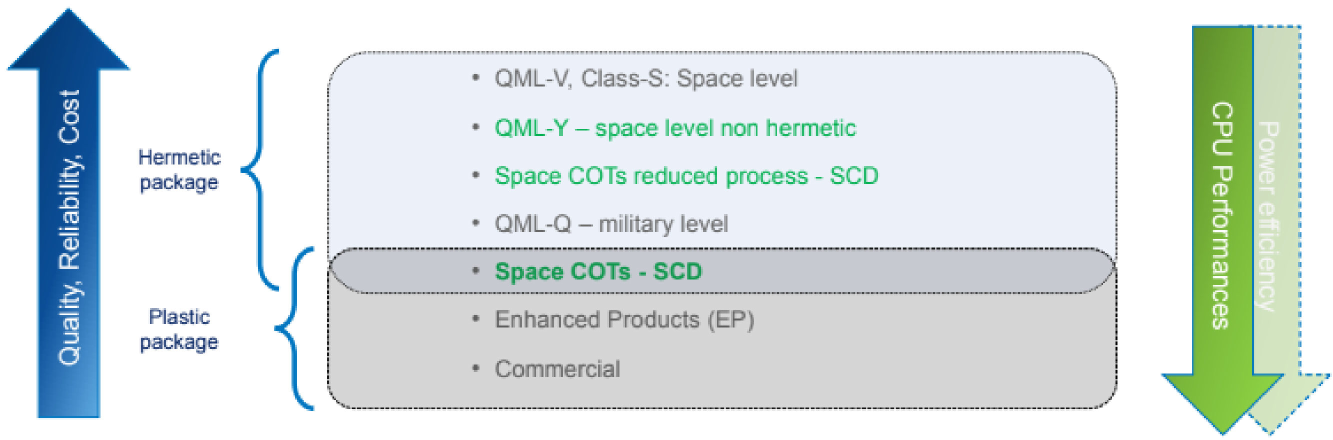


Figure 1 - As Quality and Reliability requirements increase along with Cost (from plastic to hermetic packaging), the CPU Performance noticeably decreases. The intersection is Space COTS- SCD.

Of course, another major factor in the overall cost and reliability of space electronic systems is the software. Having access to the latest commercial software development tools is a major benefit in the creation of a space/satellite platforms. When reliable software modules have been created and proven, it is also a significant benefit to be able to reuse them. The new space community, in particular, has shown a tendency towards using software-programmable architectures that can be developed, tweaked, and reused very quickly. This reduces product development time and improves reliability by reusing known good software modules.

Satellite developments can also be categorized as either small or large. As technology advances, smaller satellites provide a low-cost framework for space services and applications that facilitate the launch process with smaller weight payloads, using lower cost designs and allowing mission disaggregation. They are built within short timeframes utilizing state-of-the-art COTS technologies to achieve complex functionality, while at the same time minimizing dependence on complex mechanisms and deployable structures.

The commercialization of space is evident in the growth of the CubeSat. Its main purpose is to define a standard mechanical interface and deployment system for small satellites. The basic structure of a CubeSat (1U) is a 10cm wide cube with a mass of up to 1.3Kg, which is designed to work autonomously. The concept of multiplying CubeSats (2U, 3U, 6U, and 12U, etc.), with dimensions of 10x10x20cm, 10x10x30cm, 10x20x30cm, and 20x20x30cm is therefore inherently realized. These small satellite developments are realized at costs that are low enough to attract a growing number of customers that range from space agencies to new space private industries and institutions.

Currently, new space design methodology trends towards CubeSats to be used for low-cost space services and missions. The range of missions that CubeSats can perform relative to payload accommodation is significant. CubeSats have strict limitations in terms of mass and volume. Therefore, the challenge is to adapt classical payloads so that they can be integrated within a CubeSat. Two key factors must be taken into account when talking about payload adaptation for CubeSats:

1. Electronics Miniaturization: A single microprocessor must provide the whole computing system with very low power consumption, weight, and volume,
2. Cost: Building and launching multiple CubeSats is cheaper than building a single payload Large Space Structure (LSS) with required redundant platforms.

IMPLEMENTING HEAVY COMPUTING SPACE/SATELLITE PLATFORMS AND SERVICES

Today's globally driven, economic and environmental market requirements for heavy computing space/satellite platforms and services are demanding higher levels of autonomy, as well as greater navigational precision. These require radiation-tolerant heavy computing microprocessors versus radiation hardened microcontrollers (see Figure 2) along with available artificial intelligence (AI) and machine language (ML) software. In addition, high-precision space navigation to small comets and asteroids; entry, descent and landing (EDL) on moons and planets; and, rendezvous and proximity operations (RPO) with both cooperative and uncooperative targets all require sensing and perception capabilities provided by vision-based software and hardware systems. As previously mentioned, these types of technologies were almost exclusively "traditionally" developed. But presently, the New Space/private sector is also actively driving the advanced developments in vision-based technologies such as autonomous satellite servicing, lunar landing, and vision-based AI and Machine Learning.

Figure 2 -Heavy computational applications (telecom, data processing, etc.) trend towards rad-tol microprocessors vs. lower computational applications utilizing rad-hard microcontrollers

As artificial intelligence (AI) and machine language (ML) software continues to become more readily available, fundamentally, reliable space tolerant microprocessors (LS1046-Space) that can handle the necessary heavy computing load requirements become essential. Individual intelligent heavy computing satellite platforms can also become a component within a new space constellation (or satellite swarm and/or cluster development). Traditional and New Space design methodologies are continually proposing distributed architectures creating a tremendous shift within the space industry.

Distributed Space Systems (DSS) realized in satellite swarms and clusters, will provide improved re-configurability, flexibility, upgrade-ability, responsiveness, and adaptability to structural and functional changes. Large satellite swarms, based on small spacecraft, can also enlarge the autonomy of the mission by upgrading or replacing defective units while the mission remains under operation. Clusters and swarms are an implementation of DSS consisting of an array of autonomous satellites which share the same mission goals, and require communication and cooperation to achieve those goals. In clusters, the satellites fly in close formation, and require an accurate observability and controllability of the satellite positions and attitudes in order to coordinate their operations.

In addition to satellite network automation (swarm and cluster constellations), upcoming integrated 5G-satellite networks will also dramatically increase in size and complexity due to the world-wide adoption of mobile devices and wireless access. In most cases, optimal solutions for terrestrial-satellite network management can be difficult to model due to the complex environment and the presence of too many uncertainties. Developing fast and high-quality analytical models is not always a viable option for such developments either. As a result, with the growing complexity and reliability requirements for "traditional" test-and-verification methods for network management; it will be challenging, time consuming, and extremely costly. Network operators are increasingly uncomfortable deploying complicated satellite telecommunication networks on untested/unoptimized configurations. Therefore, the necessity of developing intelligent satellites with heavy computing capabilities that have the ability to self-optimize and self-organize, utilizing AI and ML technology, are highly suited for such complex applications.

TELECOMMUNICATIONS, DATA COLLECTION/SERVERS & EARTH OBSERVATION

Satellite telecommunications are undergoing innovative developments which are accelerating in the areas of new constellation types, on-board processing capabilities, non-terrestrial networks and space-based data collection/processing. Some of the most promising applications that are under development: 5G Integration, Space Communications, Earth Observation, Aeronautical and Maritime Tracking and Communication. In addition, internet-based applications that require developments to refocus space-level system designs for data services (including broadband) are under way. Data collection and servers are required for:

1. The rapid adoption of media streaming instead of linear media broadcasting, and
2. The urgent need to extend broadband coverage to underserved areas (i.e. developing countries, aero/maritime, rural, etc.).

Furthermore, a major milestone in regards to 5G integration is the convergence of diverse wired and wireless technologies. In this context, satellite telecommunications developments are enabling seamless integration targeting specific applications which can take advantage of intelligent/adaptive satellite core heavy computing microprocessors.

New constellation configurations (traditionally Geostationary (GEO) satellites) have been mainly used for satellite telecommunication since they avoid fast movement between the terminals and the satellite transceiver, and they allow for wide coverage using a single satellite. Multibeam satellite systems have been specifically developed to allow efficient frequency reuse and high-throughput broadband rates across the coverage area, similar to terrestrial cellular networks. In addition, new constellation configurations are currently being developed, driven by advanced communication technologies and cheaper launch costs. In this direction, there has recently been a tremendous interest in developing large Low Earth Orbit (LEO) constellations that can deliver high-throughput broadband services with low latency.

On-board processing capabilities have been the limiting factor for advanced satellite telecommunication strategies. The majority of satellites operate as relays which essentially convert, amplify, and forward the communication signal and thus the on-board microprocessor requires high speed DMIPS processing capabilities. The on-board microprocessor and corresponding technologies have to be fast, ultra-reliable, and radiation-tolerant due to the inability to repair or replace after the satellite is put into orbit. Nevertheless, recent advances in the efficiency of power generation and digital processing components (i.e. Teledyne e2v's LS1046-Space Quad Core ARM® Cortex®-A72 microprocessor) have allowed for enhanced on-board processing which can enable innovative communication technologies, such as flexible routing/channelization, beamforming, free-space optics and even signal regeneration. The LS1046-Space Quad Core architecture utilizes a 3-way decode out-of-order, speculative issue, superscalar pipeline technology. Furthermore, together with ARM software modules available, the LS1046-Space is fully capable to enable on-board telecommunication-specific processing which can also be upgraded during the satellite lifetime.

In regards to terrestrial IOT machine-level/sensory communications, even though the technology utilizes low cost and complexity sensors/actuators; the sheer number of sensors worldwide will generate communications traffic that will have a significant impact on future space communication networks. Therefore, future satellites will need to offload the terrestrial IOT network through backhauling, or provide service continuity in cases where a terrestrial network cannot reach. This particular application can be categorized on what a satellite can support, and how the IOT sensors are distributed on earth. For example, "wide area" IOT services are distributed over an expansive area and report information controlled by a central server. Typical applications where the satellite can play a "wide area" role include:

1. Energy: Critical surveillance of oil/gas infrastructures (e.g. pipeline status),
2. Transport: Fleet management, asset tracking, digital signage, remote road alerts,
3. Agriculture: Livestock management, farming,
4. Local area IOT services: The IOT devices in these kinds of applications are used to collect local data and report to the central server. Some typical applications can be a smart grid sub-system (advanced metering) or services to on-board moving platforms (e.g. container on board a vessel, a truck or a train),
5. Aeronautical and Maritime Tracking and Communication: These systems usually share similarities with other kinds of Device-to-Device (D2D) communications and the IOT. Such similarities include low data rates, the sporadic nature of the communications, and the simplicity of the protocols.

DEFENSE IN SPACE & CYBERSECURITY

Worldwide defense departments, agencies, and foreign countries are benefitting from traditional and new space commercial satellite developments in regards to their shared capabilities. These entities have found that using commercial satellites to "host" their sensors and/or communications packages can achieve in-orbit capability faster and more affordably. Cost savings can result from sharing development, launch, and ground system costs with the commercial host company. Using hosted payloads may also help facilitate a "proliferation of payloads" in orbit, making it more difficult for an adversary to defeat a capability. With access to rapidly expanding numbers of commercially available telecommunications satellites, defense entities are able to develop internet tactical networking for terrestrial air defense applications in the air, and at sea.

The idea behind "hosting" is to simply capitalize on commercial communications satellite constellations under development in order to reduce defense costs, as well as enhance reliability and data throughput. For example, of the many core projects in this area, defense entities are developing the ability to move and share data seamlessly among a wide variety of fixed and mobile operating locations using constantly available, high-bandwidth, beyond-line-of-sight communications. This new capability is called "path-agnostic communications" because it enables military users to communicate reliably to any location in the world without specifically identifying which nodes of a communication network are in use. Developing path-agnostic communications is possible due to the growing commercial space internet, based on commercial satellites. As mentioned before, commercial space/satellite companies plan to establish space internet constellations consisting of hundreds to thousands of satellites, each to create global internet services. As technological and cost barriers, in regards to space developments, continue to decrease; this enables more defense entities and commercial firms to cooperate in satellite construction, space launch, space exploration, and human spaceflight. Although these advancements are creating new opportunities, new risks for space-enabled services have also emerged. Having realized the benefits of space-enabled operations, some defense entities are developing capabilities that threaten others' ability to use space. This capability supports both space operations and counterspace systems such as developing jamming and cyberspace capabilities, etc.

In regards to defense and cybersecurity, one example from the NSA is the Commercial Solutions for Classified initiative. CSfC allows developers more flexibility on how they design and organize classified/sensitive data, while still maintaining high IT security standards. Rather than mandating the use of government off-the-shelf (GOTS) equipment, CSfC enables developers to construct alternative solutions utilizing commercial off-the-shelf (COTS) products and microprocessors that offer greater technological flexibility particularly for cybersecurity purposes (i.e. Teledyne e2v's LS-1046-Space Quad Core ARM® Cortex®-A72 microprocessor). CSfC solutions must comply with a stringent set of security requirements; for example, users who want to send and receive mobile data, including voice and video calls, need to encrypt this data by using a double VPN tunnel. Building a double VPN tunnel via CSfC will create solutions quickly along with other benefits such as higher computing power and reliability.

ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING FOR SPACE LEVEL APPLICATIONS

As space/satellite networks continue to evolve towards automation and autonomy due to ever increasing complexities, variations, and the need to adapt to changing system requirements; the need for "intelligence" and "heavy computing" within the system also grows exponentially. The following are some basic terms in regards to the design and pursuit of system level intelligence:

1. AI: Artificial Intelligence. When a computer performs tasks considered to require human intelligence.
2. ML: Machine Learning. An application of AI that provides inputs in order to automatically teach and train the computer model how to function. Learning is typically supervised with the application of a "trained" model which is called "inferencing." Learning can also be unsupervised utilizing cluster analysis.
3. NN: Neural Network. A class of ML algorithms either CNN (Convolutional) or RNN (Recurrent).
4. DL: Deep Learning. ML using a large Neural Network.
5. CV: Computer Vision. Techniques used in computers in order to perceive images.

Given the definitions above, it is intuitively obvious of the hierarchical/layered structure that exists between AI and CV, and beyond. Heavy computing "parallel" processing, in conjunction with "layered" processing, are both required from the microprocessor and the software. The software algorithms that are required are developed and validated by testing and implementation on production hardware. This process is complicated by the need to optimize the on-board processing resources, which are often limited by the availability of heavy computing hardware that can survive the hostile radiation environment of space. As part of this optimization, it is common for portions of the algorithms to be distributed between FPGAs and various computer processors. Partitioning these functions increase both design complexity and the number of engineered "modules" that are required.

The space industry has taken note of these issues and while space-based deployment of artificial intelligence and machine learning for computer vision is in the developing stages, organizations are already adopting machine learning techniques in production systems on ground segments. The primary initial developments are ground-based spacecraft health monitoring and geospatial analytics. The use of machine learning for space vehicle health monitoring is driven by large satellite fleet operators desiring to reduce operational costs. These operators can monitor multiple satellites from a single control center, with engineering staff able to respond to faults and failures if needed. The engineers are responsible for monitoring and trending the health of the fleet (a task which is now aided by machine learning). Low risk levels are maintained by using machine learning models to complement, rather than replace engineers in the control center who maintain responsibility for acting on the new information provided. The algorithms are trained using spacecraft telemetry data that operators process in data centers, and in some cases are able to detect trends before humans can, reducing the need for human eyes on the real-time telemetry data. The applied techniques and accrued knowledge are improving the acceptance of machine learning within the space industry and will potentially also apply to future uses of machine learning on-board highly autonomous spacecraft.

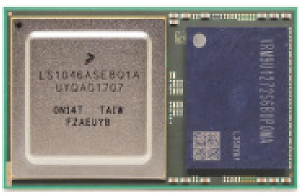
Geospatial analytics, or processing Earth-sensing data provided by imaging satellites, presents another opportunity for heavy computing and machine learning due to the usage of optical imagery technology. Machine learning in geospatial analytics enables on-board processing that reduces the required downlink bandwidth by selecting the relevant data to be transmitted to the ground. Downlink bandwidth reduction is a key advantage as available frequency bands are becoming increasingly crowded, and therefore, more expensive. Also, it is becoming prohibitively difficult to code algorithms by hand in order to perform the ever-expanding requirements of desired processing. From classifying agricultural landscapes, to planning crop yields, to detecting and classifying cars in mall parking lots; machine learning is well suited for these types of applications where large amounts of data are too complicated to process.

In regards to accomplishing the heavy computational loading that is required for space level AI, ML, and Data Processing (as stated above), the LS1046-Space microprocessor meets the requirements with integrated Quad Core 64-bit ARM® Cortex®-A72 cores with packet processing acceleration and high-speed peripherals.

The LS1046-Space utilizes a Layerscape (LS) architecture which is the latest evolution of the QorIQ family; which includes features provided by Data Path Acceleration Architecture (DPAA) and may be implemented in software or hardware. Layerscape architecture is a programmable data-plane engine networking architecture which also offers advanced, high-performance data path and network peripheral interfaces. The LS1046 features an encryption engine which can prove useful in secured communications and defense applications. With machine learning software, the LS1046-Space is able to learn, inference, and adapt in order to make decisions in real time with minimal latency and bandwidth challenges.

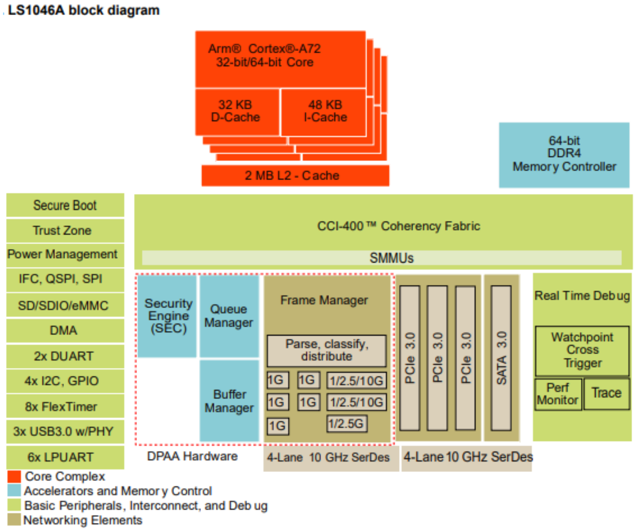
TELEDYNE LS1046-SPACE PERFORMANCE FEATURES AND QLS1046-4GB-SPACE

Teledyne e2v is space qualifying, space manufacturing, characterizing against radiations effects, and releasing a microprocessor called LS1046-Space. LS1046 is originally part of NXP's 64-bit ARM® Layerscape portfolio that implements a Quad Core Arm® Cortex® A72 design providing unparalleled performance in the smallest form factor possible, while enabling access to the vast ecosystem of software services, applications and tools compatible with Arm® technology. Teledyne e2v LS1046-Space is a 1.8GHz processor, integrating packet processing acceleration with high-speed peripherals and is recognized for its high-performance architecture and market-leading compute density. LS1046-Space offers more than 45,000 CoreMarks® of compute performance, paired with dual 10Gb Ethernet, PCIe Gen3, SATA Gen3 which is suitable for a range of high reliability space level applications. In addition, as part of Teledyne e2v's Semiconductor Lifecycle Management program, SLiM™, the lifetime of this device can be supported for 15+ years, avoiding common and costly obsolescence issues.



"We see a new trend developing in the Aerospace and Defense industry toward 64-bit Arm®-based products with the Teledyne e2v military qualified device from our Layerscape Series of commercial processors," commented Altaf Hussain, Marketing Manager for NXP. "We believe Teledyne e2v customers will not only leverage the advanced computing performance of the device but also the ecosystem that supports Arm®, creating new possibilities in system design." Teledyne e2v's portfolio also includes many PowerPC®-based qualified and supported processors from the NXP QorIQ® P- and T-Series, as well as the more traditional PowerQUICC® devices. Customers can continue using their Power Architecture-based software and applications, while Teledyne e2v continues to develop solutions on newer technologies such as ARM®-based solutions from NXP. Customers may either transition to ARM®-based solutions or start new developments with proven Power® Architecture-based solutions from NXP. The LS1046-Space is also able to be embedded into Teledyne e2v's latest Qormino® computing module (QLS1046-4GB-Space); which includes a 4GB radiation tolerant DDR4 memory (see above) and LS1046 Block Diagram (below).

LS1046A block diagram



CONCLUSION

Currently, space flight system designers are entering a crucial development phase due to the requirement for heavy computing microprocessors. With the growth and availability of artificial intelligence and machine language algorithms, and advanced internet-based applications and services; all have accelerated the developments for broadband, high-speed, ultra-reliable, low latency communications for: military, weather, earth observation, and telecommunications (particularly as 5G networks globally advance). At the core of each space/satellite design is the requirement for a stand-alone, reliable, space qualified, radiation tolerant microprocessor that has the heavy computing power, speed, reliability, size, weight, power, and cost that will meet the challenges and adaptability required for these "global" space/satellite developments. Teledyne e2v's LS1046-Space Quad Core ARM® Cortex®-A72 microprocessor revolutionizes intelligent heavy computing space/satellite developments for the upcoming decades. Utilizing GHz class high performance data processing (30K DMIPS @ 1.8 GHz), combined with convenient software programming (and reconfigurable capabilities), along with unparalleled radiation tolerant space qualification processing; Teledyne e2v's LS1046-Space microprocessor enables heavy computing space/satellite developments and real-time reconfiguring while deployed in orbit.

Note: Teledyne e2v LS1046-Space project is supported by CNES (French Space Agency) through an ESA ARTES program.

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