Electronic Design

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Semiconductors: The Unsung Heroes in Space Exploration

From the very first Cold War Geiger counters that were Sputnik and Explorer-1, to the autonomous robots of Mars, asteroid missions, telescopes, and the Voyager craft now outside our solar system, semiconductors have played a key role in space exploration for over 60 years.

Semiconductor components help ensure reliability and performance in space's extreme environment. Over the past 60 years, microchips have played a pivotal role in more than 100 space missions, driving the success of some of the most historic milestones in space exploration. From the first successful U.S. space mission in 1958 to the ongoing Artemis missions, these components *(see table)* have consistently proven their value.

The Crucial Role of Semiconductor Components in Space Missions

Since the launch of the first US satellite, Explorer 1 onboard the Jupiter-C missile, semiconductors have had to demonstrate space qualifications, meeting stringent radiation and reliability standards while in outer space.

Semiconductor components in space missions began with frequency-control devices. Frequency control like quartz crystal oscillators, voltage-controlled SAW oscillators (VCSOs), or atomic clocks are critical in space-mission electronics, as it ensures the accurate transmission and reception of signals, maintaining communication stability, data integrity, and synchronization of systems.

These components were vital to the success of the first U.S. space mission in 1958 and laid the foundation for a legacy of reliability in space. The Apollo 11 lunar landing in 1969, one of humanity's greatest achievements, also relied on these technologies. Microchip provided critical communication support within the Apollo 11 Lunar Module (LM) on the surface of the moon as well as the critical logic components *(see figure)* used for the onboard guidance computer.

Rubidium, SAW, and quartz oscillators support more military communications, satellite ground stations, and test-and-measurement applications than any other precision frequency references in the world.

The Voyager 1 mission, now the farthest human-made object from Earth, further showcased the unmatched performance of semiconductors in space. Voyager 1's electronics featured a mix of TTL and CMOS logic ICs, analog components, memory chips, and custom semiconductors designed to handle the challenges of deep space.

Voyager 1's main computer used a custom-built central processing unit (CPU) called the SPS-8, which was designed for the spacecraft by NASA. TTL logic chips were a popular type of digital integrated circuit at the time; now most semi-

Part Number	Device Type	Space Program(s)	Function/Role
AT65609EHV	SRAM	ISS, Starlink, Ariane, Mars	Data storage, memory
AT60142H/HT	SRAM	ISS, Mars, Ariane	Data storage, memory
AT69170F	Serial EEPROM	ISS, Starlink	Data logging, configuration
AT28C010-12DK	Parallel EEPROM	ISS, Ariane	Data storage
AT17LV010-10DP	Serial EEPROM	ISS, Ariane	Data storage
Space System Manager (SSM)	Mixed-Signal IC	Mars Rovers, ISS	Power management, system monitoring
RT FPGAs (various)	FPGA	Chandrayaan-3, Mars, ISS	Reconfigurable logic, mission-specific tasks
Fairchild RTμL 9915	RTL NOR Gate IC	Apollo Guidance Computer	Logic circuits

The table lists some of the semiconductors that have been used in space missions.

conductor ICs are CMOS-based.

In more recent years, semiconductor technologies have been central to Mars exploration. The Curiosity and Perseverance rovers, which have provided invaluable insights into the Red Planet, depend on these components to operate in Mars' harsh environment.

The Mars rover, specifically the Perseverance rover, contains several components from Microchip Technology. These include a SPARC processor used for various control systems and data-processing tasks, as well as power-management ICs (PMICs) that are crucial for efficiently managing the power supply to different parts of the rover. All of these are radiation-hardened (rad-hard) components, thus ensuring the electronics can withstand the harsh space environment. Such components are essential for the rover's operation and help it perform scientific tasks on Mars.

For lunar exploration, the Chandrayaan-3 mission, India's third lunar exploration mission, utilized several semiconductor components. These components—e.g., radiation-tolerant (RT) antifuse FPGAs—are crucial for the mission's success, enabling communication, navigation, and scientific experiments on the lunar surface.

The ongoing Artemis missions, which aim to return humans to the Moon and eventually send them to Mars, also rely on the proven performance and reliability of semiconductor technologies.

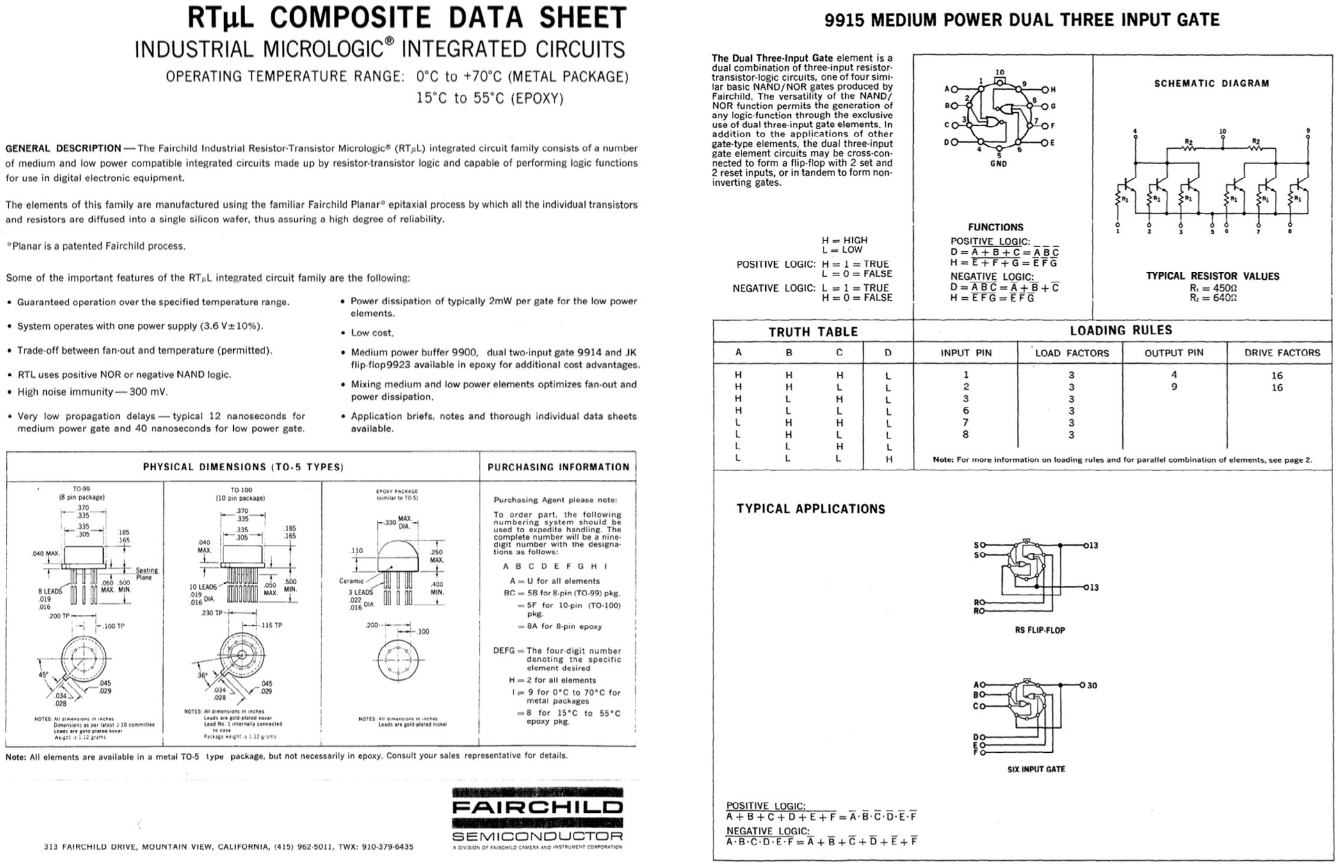
The Importance of Reliability and Performance in Space Programs

In the harsh environment of space, reliability and performance aren't just important—they're critical. Semiconductor components lie at the heart of modern space missions, powering everything from satellites and rovers to communication systems and space stations.

Given the extreme conditions of space—unforgiving temperatures, intense radiation, and the vacuum of space—components must perform flawlessly for extended periods. Even the smallest failure in a semiconductor could lead to mission failure, which highlights the significance of selecting highly reliable components.

The Challenge of Radiation in Space

Space is filled with high levels of radiation, which can be devastating to electronic components. Radiation can de-



RTµL COMPOSITE DATA SHEET

INDUSTRIAL MICROLOGIC® INTEGRATED CIRCUITS

OPERATING TEMPERATURE RANGE: 0°C to +70°C (METAL PACKAGE)
15°C to 55°C (EPOXY)

GENERAL DESCRIPTION — The Fairchild Industrial Resistor-Transistor Micrologic® (RTµL) integrated circuit family consists of a number of medium and low power compatible integrated circuits made up by resistor-transistor logic and capable of performing logic functions for use in digital electronic equipment.

The elements of this family are manufactured using the familiar Fairchild Planar* epitaxial process by which all the individual transistors and resistors are diffused into a single silicon wafer, thus assuring a high degree of reliability.

*Planar is a patented Fairchild process.

Some of the important features of the RTµL integrated circuit family are the following:

- Guaranteed operation over the specified temperature range.
- System operates with one power supply (3.6 V±10%).
- Trade-off between fan-out and temperature (permitted).
- RTL uses positive NOR or negative NAND logic.
- High noise immunity — 300 mV.
- Very low propagation delays — typical 12 nanoseconds for medium power gate and 40 nanoseconds for low power gate.
- Power dissipation of typically 2mW per gate for the low power elements.
- Low cost.
- Medium power buffer 9900, dual two-input gate 9914 and JK flip-flop9923 available in epoxy for additional cost advantages.
- Mixing medium and low power elements optimizes fan-out and power dissipation.
- Application briefs, notes and thorough individual data sheets available.

PHYSICAL DIMENSIONS (TO-5 TYPES)

NOTES: All dimensions in inches
Dimensions as per latest J-10 committee
Leads are gold-plated kovar
Weight is 1.12 grams

NOTES: All dimensions in inches
Leads are gold-plated kovar
Lead No. 1 internally connected to case
Package weight is 1.32 grams

NOTES: All dimensions in inches
Leads are gold-plated nickel

PURCHASING INFORMATION

Purchasing Agent please note:

To order part, the following numbering system should be used to expedite handling. The complete number will be a nine-digit number with the designations as follows:

A B C D E F G H I

A = U for all elements
BC = 5B for 8-pin (TO-99) pkg.
= 5F for 10-pin (TO-100) pkg.
= 8A for 8-pin epoxy
DEFG = The four-digit number denoting the specific element desired
H = 2 for all elements
I = 9 for 0°C to 70°C for metal packages
= 8 for 15°C to 55°C epoxy pkg.

Note: All elements are available in a metal TO-5 type package, but not necessarily in epoxy. Consult your sales representative for details.

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9915 MEDIUM POWER DUAL THREE INPUT GATE

The Dual Three-Input Gate element is a dual combination of three-input resistor-transistor-logic circuits, one of four similar basic NAND/NOR gates produced by Fairchild. The versatility of the NAND/NOR function permits the generation of any logic-function through the exclusive use of dual three-input gate elements. In addition to the applications of other gate-type elements, the dual three-input gate element circuits may be cross-connected to form a flip-flop with 2 set and 2 reset inputs, or in tandem to form non-inverting gates.

H = HIGH
L = LOW
POSITIVE LOGIC: H = 1 = TRUE
L = 0 = FALSE
NEGATIVE LOGIC: L = 1 = TRUE
H = 0 = FALSE

FUNCTIONS

POSITIVE LOGIC:
$D=\overline{A+B+C}=\overline{A}\,\overline{B}\,\overline{C}$
$H=\overline{E+F+G}=\overline{E}\,\overline{F}\,\overline{G}$

NEGATIVE LOGIC:
$D=\overline{A\,B\,C}=\overline{A}+\overline{B}+\overline{C}$
$H=\overline{E\,F\,G}=\overline{E}\,\overline{F}\,\overline{G}$

SCHEMATIC DIAGRAM

TYPICAL RESISTOR VALUES

$R_1 = 450\Omega$
$R_2 = 640\Omega$

TRUTH TABLE

A	B	C	D
H	H	H	L
H	H	L	L
H	L	H	L
H	L	L	L
L	H	H	L
L	H	L	L
L	L	H	L
L	L	L	H

LOADING RULES

INPUT PIN	LOAD FACTORS	OUTPUT PIN	DRIVE FACTORS
1	3	4	16
2	3	9	16
3	3		
6	3		
7	3		
8	3		

Note: For more information on loading rules and for parallel combination of elements, see page 2.

TYPICAL APPLICATIONS

POSITIVE LOGIC:
$\overline{A+B+C+D+E+F}=\overline{A}\cdot\overline{B}\cdot\overline{C}\cdot\overline{D}\cdot\overline{E}\cdot\overline{F}$

NEGATIVE LOGIC:
$\overline{A\cdot B\cdot C\cdot D\cdot E\cdot F}=\overline{A}+\overline{B}+\overline{C}+\overline{D}+\overline{E}+\overline{F}$

Fairchild's (now Microchip's) RTµL 9915 NOR gate was the basis of the Apollo Guidance Computer design.

grade materials, cause electrical failures, and corrupt the data being transmitted. For example, the solar radiation environment outside Earth's protective atmosphere can expose components to energetic particles that cause single-event upsets (SEUs) or total radiation dose damage.

To combat these challenges, advanced radiation-hardening techniques include the use of specialized materials like radiation-resistant semiconductors. These design modifications reduce vulnerability to radiation. For instance, space-grade microprocessors used in onboard computers are often radiation-hardened by design (RHBD) so that failure doesn't bring down the entire system.

Rugged Testing to Simulate Space Conditions

In addition to radiation hardening, companies with a legacy in space missions have pioneered rigorous testing and qualification processes that ensure the reliability and performance of their components. These tests go far beyond normal manufacturing quality control.

Space-grade semiconductors undergo extensive thermal-cycling tests, which simulate the wide temperature variations in space—from the intense heat of the Sun to the bitter cold of deep space. An example is NASA's testing of components for the Mars Perseverance rover, which experienced temperature swings from −55 to 125°C, demanding components that could withstand such extremes without failure.

Components also undergo vibration testing to simulate the stresses and vibrations experienced during launch. The intense forces generated during rocket launches are unlike anything seen on Earth; therefore, semiconductor components must be able to endure these conditions without compromising their integrity. For instance, during the Apollo 11 mission, critical electronics were subjected to vibration testing to ensure that they would survive the powerful launch forces, ultimately contributing to the success of the Moon landing.

Long-Term Reliability: Examples from Space History

Space missions require components that not only work during the mission, but also continue to perform reliably over time. The Voyager 1 spacecraft, launched in 1977, is a prime example of how reliability is crucial for long-duration missions. Over 40 years in space, the spacecraft continues to communicate back to Earth thanks to the rad-hard semiconductor components that have been rigorously tested to endure extreme conditions.

Another example is the International Space Station (ISS), which relies on a multitude of semiconductor-based systems to maintain life-support systems, conduct scientific experiments, and keep communication lines open. The ISS is constantly exposed to the harsh radiation environment of space, with temperatures ranging from +121°C (facing Sun) to -157°C (in the shade), alternating every 45 or so minutes. Nevertheless, the semiconductor components onboard must function reliably day after day.

Expanding Frontier: Evolution of the Space Market

A developing trend within the space industry is increased use of commercial off-the-shelf (COTS) devices, which provide a cost-effective solution for space missions due to their immediate availability. Starlink's low-Earth-orbit (LEO) satellite network capitalizes on COTS components to reduce costs and speed up production. Many of the onboard electronics, particularly for non-critical systems, rely on these components, which are both budget-friendly and carefully selected for their reliability in space environments.

A good example is the European launcher Ariane, developed by the ESA (European Space Agency) and CNES (French Space Agency). Ariane 5 (1985) was equipped with a hardened SPARC central processor in QML grade in a hermetic package and with a 1553 network for communication between all systems within the rocket.

The most recent version, Ariane 6 (2024), now embeds a COTS processor based on Arm architecture, housed in a plastic-based package. It uses the same Ethernet for communication that's a widely adopted industry standard, contrasting with the space/military-specific technology used in Ariane 5.

However, for high-reliability systems that must maintain strong performance in space-based communications, COTS devices need to be adapted and qualified, requiring specialized expertise. Companies seeking to enter new space markets or transition from new space to deep space are collaborating with semiconductor companies that have proven flight heritage, capable of upgrading COTS devices to meet the stringent demands of space missions.

In the short term, the future of semiconductors in space will be a blend of diverse strategies: upgrading COTS devices, leveraging our spaceflight experience with sub-QML versions of products to reduce screening requirements, lowering costs, shortening lead times, and customizing manufacturing processes to meet the unique requirements of specific mission profiles.

By combining these approaches, a robust and adaptable future for semiconductors in space is realized, while minimizing cost, complexity, and taking appropriate risks.

The Future of Semiconductor Components in Space

As the space industry continues to evolve with the rise of LEO constellations and growing space commercialization, so does the demand for reliable, high-performance semiconductor components. New space ventures require components that can meet the unique challenges, mixing high reliability, innovation, and profit-driven objectives.

Nicolas Ganry is the senior product marketing manager for Microchip Technology's aerospace and defense business unit. He joined the company in 2012 and is based in Nantes, France. Nicolas is responsible for leading A&D microprocessors, microcontrollers, memories, and the companionships product line and is driving business development activities in Europe. He works closely with the European Space agencies and prime industry leaders of the domain.

Nicolas joined Atmel in 2012, now Microchip since 2016, bringing with him 15 years of experience in system electronics, with a focus on hardware and software development for mobile phones. He has a master's degree in engineering from Polytech Nantes, the Graduate School of Engineering at the University of Nantes, and a master's degree in business unit management from Audencia International Business School Nantes.