REAL-TIME TELEVISION QUALITY FULL MOTION VIDEO FOR MARS MISSIONS

John F. McGowan III, NASA Ames Research Center, MS 233-18, Moffett Field, CA 94035-10000

ABSTRACT

Neither manned landings nor short-range robotic probes such as Mars Pathfinder can explore the surface of Mars, 144 million square kilometers comprising as much surface area as all the continents and islands on Earth. Complete exploration of Mars to find or conclusively rule out important discoveries such as past or present life will require high speed low-altitude or ground-based probes such as airplanes, balloons, or high speed rovers. These devices will need high frame-rate imaging, such as digital video, to explore the planet and for remote operation either by astronauts on Mars or mission control on Earth. A variety of uses for video on Mars are presented. Previous results including the size, weight, power, bit rate, and bit error rate requirements for a video system using commercial off the shelf International Organization for Standardization (ISO) MPEG-1 or MPEG-2 digital video compression standard technology are reviewed. A significant concern unique to Mars and space missions is that radiation, especially single event latchup, may require fabrication of video encoder chips in radiation hardened semiconductor processes. In this paper, the feasibility of fabricating an MPEG-1 or MPEG-2 video encoder in a current radiation hardened Complementary Metal Oxide Semiconductor (CMOS) semiconductor process technology is demonstrated. The near Earth uses of these compact, light-weight, low power digital video systems are also discussed.

INTRODUCTION

A desirable goal for missions to Mars is real-time or near real-time video coverage of the missions. Video coverage of robotic or manned missions will help build and maintain public support for missions to Mars and other space missions. This probably represents the most important and best recognized use of video for space missions. In addition, video can help achieve and may even be essential for a large number of scientific and engineering goals during missions.

Video may prove essential for life detection by robotic missions. Experience has shown that unambiguous detection of past or present life where it is not expected is difficult. For example, the Viking Lander Labeled Release experiments produced positive signals at both landing sites[1]. However, these results were eventually interpreted by most planetary scientists as the results of inorganic oxidants in the Martian soil. Similarly the current controversies over the Martian meteorites and the past controversies over biomarkers in carbonaceous chondrites such as the Murchison meteorite illustrate the difficulty of unambiguously identifying life. In the case of microbial life, even a detailed still image of a single-celled organism might be interpreted as an inorganic structure of some kind. A microscope with a video camera could observe microscopic organisms dividing or making copies of themselves in real-time. A video camera could also observe microscopic organisms swimming or crawling about in culture. A video of microscopic organisms reproducing would probably be accepted as unequivocal evidence of life. Video could also reveal exotic life based on biochemistry substantially different from terrestrial biochemistry.

Video may also be helpful for engineering goals such as failure analysis and failure prevention. Video of the risky final approach and landing of probes should be helpful in understanding failures. A camera or cameras mounted on a lander could unambiguously determine the cause of a failed landing such as the Mars Polar Lander. Cameras mounted on the interior or exterior of a probe could perform frequent inspections of the probe during the long journey from Earth to Mars. A camera could determine the relative location of the edge of Mars and the fixed stars during the final approach to the planet. The probe or mission control might be able to use this to determine if the probe is coming in too low as in the loss of the Mars Climate Orbiter (MCO) or too high.

Neither manned landings nor short-range robotic probes such as Mars Pathfinder can explore the surface of Mars, 144 million square kilometers comprising as much surface area as all the continents and islands on Earth[2]. Complete exploration of Mars to find or conclusively rule out important discoveries such as past or present life will require high speed low-altitude or ground-based probes such as airplanes, balloons, or high speed rovers. These devices will benefit from high frame-rate imaging, such as digital video, to explore the planet and for remote operation either by astronauts on Mars or mission control on Earth.

Video is better suited than a series of slightly overlapping still images to detect and observe transient phenomena such as dust storms, lightning, releases of sub-surface gases or liquids, and so forth. Video provides multiple successive images from differing viewing and lighting angles which should assist in understanding ambiguous surface features.

Ideally, the exploration of Mars or other planets should seek "something interesting" such as past or present life, geology relevant to terrestrial concerns, or unusual physical phenomena. Some features would be obvious even in a series of slightly overlapping still images. Seepage or venting of fluids or gases from beneath the surface seems like the most likely discovery on Mars and might be difficult to detect or study in still images.

On Mars, video should be useful in detecting and studying transient or dynamic phenomena such as dust storms, dust devils, and lightning in the atmosphere. Seeps of subsurface gases or liquids may occur on Mars. Mars contains substantial evidence of past volcanic activity including several apparently extinct volcanoes. Current volcanic or seismic activity may produce various releases of gases or liquids and other dynamic processes. Evidence of geologically recent seepage of groundwater has been reported[3]. If Mars possesses subsurface water or ice, surface seepage or eruptions of water or steam, even geysers or hot springs in volcanic regions, are possible. Geysers and hot springs have been proposed as possible sites for the origin of life on Earth.

The subsurface lithoautotrophic microbial ecosystem (SLiME) in the Columbia River Basalt Group is frequently suggested as a model of current subsurface life on Mars[4]. This ecosystem produces significant amounts of methane. Natural gas was produced commercially at the Columbia River Basalt Group early in the twentieth century. A sub-surface ecosystem similar to the Columbia River Basalt Group is likely to produce seepage of methane at the surface. In general, the most likely signature of subsurface life at the Martian surface would be surface seeps of gases or possibly liquids.

Conventional theory holds that the largest, by mass and volume, identifiable trace of past life on Earth are subsurface deposits of oil, natural gas, and other hydrocarbons. Oil is attributed to simple single-celled organisms trapped in sediments and pressure cooked over several million years[5,6]. If Mars was once warm and wet, supporting lakes and oceans with primitive microorganisms, Mars may possess subsurface deposits of oil and natural gas. These would cause seepage of oil and gas, especially methane at the surface of Mars. While trace gas detectors probably offer the greatest chance of detecting seeps of subsurface gases, video can assist in detecting and studying these dynamic phenomena[7]. Many gases of interest such as methane are transparent to visible light and could only be detected indirectly in the visible spectrum. An infrared video camera may be able to detect and observe releases of gas or fluids that would be invisible to a visible light camera, especially since gases or liquids from deep within the planet are likely to be warmer than the surface of the planet.

Although current animal life on Mars seems extremely unlikely, video would be better able to detect and identify animals than still images, especially if the animals are well camouflaged or small. Similarly, video will be better suited for detecting a variety of unanticipated transient phenomena on Mars or other planets. These exotic possibilities include new physical phenomena and mobile probes from extraterrestrial civilizations.

Video technologies for Mars pose a challenge because of the limited power, volume, and total weight of systems that can be transported to Mars, especially for robotic missions, the possible vulnerability of video systems to the harsh space environment, the large bit rate requirements of digital video, and the high bit error rates of deep space communication links. Video systems in Earth orbit share many of these challenges.

Video technologies for Mars have been previously studied for a proposed mission to Mars to fly a small airplane down the Valles Marineris canyon. This study concluded that a video system based on the

International Organization for Standardization (ISO)'s MPEG digital video compression standard could be built with a total weight of 2 Kg including heavy shielding, a size of about 800 cm^3, and a power dissipation of 20 Watts or less[8]. MPEG (Motion Pictures Experts Group) digital video at 352 pixels by 240 pixels, 30 frames per second, requires a bit rate of one megabit per second[9]. The bit error rate requirement is 10^{-6}. A video system of this type typically causes a peak signal to noise ratio (PSNR) of about 30 dB between the compressed image and the original uncompressed 352 by 240 pixel frame. The proposed video system consisted of a camera lens or lenses, a CCD or other imaging array, and a video processing system to compress the digital video for transmission back to Earth.

Table 1. Mars Video System Parameters

Parameter	**Value**
Size	800 cm^3
Weight	2 KG
Power	20 Watts
Bit Rate	1,000,000 bits per second
Bit Error Rate	10^{-6}
Compression	MPEG-1 or MPEG-2
Width	352 pixels
Height	240 pixels
Frame Rate	30 frames per second
Peak Signal to Noise Ratio	30 dB (approximate)

MPEG digital video at 352 by 240 pixels, 30 frames per second, with a bit rate of one megabit per second is about the lowest subjective video quality that viewers find acceptable. The 352 by 240 pixel, 30 frames per second, video format is known as SIF for Source Input Format. Video with dimensions of 176 by 120 is known as Quarter SIF or QSIF. MPEG-1 SIF digital video is sometimes referred to as "VCR quality". MPEG-2 digital video at 720 by 480 pixels and 30 frames per second requires about 6-8 megabits per second[10]. This is good digital video quality and is used routinely in DVD's (Digital Versatile Discs) and other consumer digital video products. This is sometimes referred to as "Studio" or "Broadcast" quality. An MPEG-2 digital video system for Mars would have the same size, weight, and power requirements as the MPEG-1 system if commercial off the shelf (COTS) components can be used. The bit rate requirement would be 6-8 megabits per second.

The principal obstacle to video for Mars missions appears to be the low bit rates currently possible over communications links between Mars and Earth. These have been less than 100 kilobits per second when the satellites have line of sight from Mars to Earth. This may be resolved by establishment of communications relay satellites in Mars orbit. The NASA Jet Propulsion Laboratory is considering a variety of communication relay satellite networks in Mars orbits with projected bit rates of 1-10 megabits per second[11,12].

Although essential for thorough exploration of Mars, communication relays are infrastructure and do not provide an immediate tangible return on investment. Thus, generating support for funding communication relay systems can be difficult. It is much easier to justify a relay if it performs some other function such as planetary exploration. Indeed, to date all relays sent to Mars have been part of planetary exploration probes with still image cameras such as the Mars Global Surveyor. A high bandwidth relay satellite may carry the first video system to Mars to observe the Martian dust storms and seek other transient phenomena. In addition to entertainment value, this may be useful for formulating Global Circulation Models (GCM) of the Martian atmosphere.

Digital video on robotic missions to Mars may be significantly affected by the mechanical stability of the platforms. Digital video compression technologies such as MPEG digital video use compression methods such as motion estimation and frame differencing that may be degraded by jitter in the camera from frame to frame. An airplane or balloon may experience jitter due to turbulence in the Martian atmosphere and limitations of the aerobot's guidance and control systems. A rover will be traversing a rocky surface. Mobile probes must provide sufficient mechanical stability for digital video compression to work efficiently.

Missions to the Valles Marineris canyon on Mars, a popular proposed destination for Mars missions, may suffer from multipath interference effects. Signals sent by the probe back to a relay or directly to Earth will also bounce off the canyon walls or floor, interfering with the primary signal. This can cause serious problems for communications, especially compressed digital video signals which are highly susceptible to lost data.

The radiation issues for Mars missions including Mars orbiters are much less severe than Earth orbit. Mars lacks a significant magnetic field and has no radiation belts, unlike Earth. Typical total ionizing dose for Mars missions is 10-20 Krads. It is likely that shielding such as an aluminum case can protect against Total Ionizing Dose (TID) effects during Mars missions. The primary concern is single event effects from high energy Galactic Cosmic Rays (GCR) that can penetrate any shielding. Single event upsets (SEU) could be detected using embedded monitoring hardware or software that could reset the video encoder or other hardware as needed. Single event latchup, however, can permanently damage a video processing chip. This seems to be the largest radiation concern and could force the use of radiation hardened Complimentary Metal Oxide Semiconductor (CMOS) even for a Mars mission.

Commercial applications including the Internet, computing, entertainment, surveillance, and medical video are steadily driving video technologies toward lower power, lighter weight, and higher levels of integration on a single chip, higher quality, and higher compression ratios for the same perceived video quality. Mobile and other wireless applications must address many of the same noisy channel and mechanical robustness issues as space missions. However, radiation is not a significant issue on Earth. Radiation hardening and some other space-hardening issues such as extreme temperatures may require custom development of video encoders or cameras.

MPEG digital video is highly sensitive to uncorrected errors. MPEG makes heavy use of variable length codes to achieve high compression. A single-bit error can cause loss of synchronization between the encoder and the bitstream or the bitstream and the decoder. In the worst case, a single bit error can cause the loss of a half-second of MPEG digital video. This happens when a single bit error causes loss of synchronization early in the MPEG I frame, the key frame used by the motion estimation and compensation. All the frames until the next key frame are encoded or decoded improperly.

The synchronization problem due to the variable length codes is one of the main reasons that MPEG hardware encoder and decoder design is especially sensitive to timing errors such as clock skew. There is very limited tolerance for errors since the effects of errors are not localized spatially or temporally if synchronization is lost. Thus, porting a working commercial bulk CMOS MPEG chip design to radiation hardened CMOS, where the signal timing will be different, may be difficult.

The problems with variable length codes over noisy communications channels have been extensively studied for mobile and wireless video applications on Earth. Several methods exist to modify the variable length codes without adding significant overhead to avoid the loss of synchronization and reduce the impact of uncorrected errors. These methods are not incorporated in the MPEG-1 or MPEG-2 standards. One method, reversible variable length codes (RVLC), has been incorporated in the ISO MPEG-4 and ITU-T (International Telecommunications Union – Radio Sector) H.263+ digital video standards.

Thus, video technologies for Mars and other space missions may encounter some special conditions not reproduced in commercial applications on Earth. The most worrisome is that missions to Mars or other space missions may require a radiation hardened video encoder. Below it is demonstrated that MPEG video encoders can be fabricated in current radiation hardened CMOS technologies. No advances in radiation hardened CMOS semiconductor process technologies are required.

RADIATION HARDENED MPEG ENCODERS

Developing or porting a Very Large Scale Integration (VLSI) chip design for an MPEG digital video encoder is a difficult project with substantial schedule risk. It is not uncommon for MPEG digital video encoders to fail during the first chip fabrication requiring revision of the design and fabrication of a second generation chip. According to some experts, roughly half of all Application Specific Integrated Circuits (ASIC's) fail on the first attempt, in many cases requiring fabrication of a revised design[13] Since Mars missions have a narrow launch window to Mars, difficulties in fabricating a working radiation hardened chip can easily delay a mission by years if digital video is deemed essential for the mission. Consequently, the use of Commercial Off the Shelf (COTS) components, probably repackaged for space, is preferred. However, the radiation hazards, especially single event latchup, may force fabrication of an MPEG or other digital video encoder in radiation hardened CMOS.

Unfortunately, radiation hardened semiconductor processes consistently lag a few generations behind commercial bulk CMOS semiconductor processes in system clock rates, levels of integration, and power requirements. Thus, while many single chip MPEG-2 Main Profile at Main Level (720 by 480 pixels, 30 frames per second, 4:2:0 and even 4:2:2 video format) video encoders in commercial bulk CMOS exist, there does not appear to be a single radiation hardened MPEG or other digital video encoder chip. However, it appears that radiation hardened CMOS semiconductor processes have recently achieved the clocks speeds and levels of integration required for a compact, light-weight digital video system.

Table 2 lists the relevant parameters of a number of commercial video encoders. Unless otherwise noted, these are single chip encoders. The size of the design is given in transistors or logic gates as quoted in the product literature. The industry standard is that a single two input NAND logic gate uses four (4) transistors. Thus, a chip using one million transistors corresponds to 250,000 logic gates. Some caution should be applied in using two input NAND gates to convert between transistors and logic gates. MPEG-1 and MPEG-2 digital video encoders are not constructed from two-input NAND gates.

Most MPEG-1 and MPEG-2 video encoders process ITU-R 601 (formerly CCIR-601) uncompressed digital video which has a clock rate of 13.5 MHz. Thus, the clock speeds of video encoders are typically multiples of 13.5 such as 27 MHz, 54 MHz, and 81 MHz. A minimum clock speed of 13.5 MHz is required simply to keep up with the ITU-R 601 input signal.

Table 2 Commercial MPEG Video Encoders

Video Encoder	Video Compression	Video Format	Number of Transistors or Logic Gates	System Clock Rate	Process Technology
Zapex 2001 MPEG-2 Chip Set (ZENC2001 and ZMEC2001)[14]	MPEG-2	MPEG-2 Main Profile at Main Level (720 by 480 at 30 fps)	2.5 million transistors (ZENC2001) 3 million transistors (ZMEC2001)	54 MHz (ZENC2001) 54/108 MHz (ZMEC2001)	0.35 micron CMOS
Zapex Z1011C Real-Time MPEG-1 and Motion JPEG Video Encoder Core[15]	MPEG-1, Motion JPEG	MPEG-1 SIF and QSIF (352 by 240 at 30 fps)	250,000 logic gates	54 MHz	0.35 micron CMOS
Winbond W99200F MPEG-1 Video Encoder[16]	MPEG-1 and Motion JPEG	MPEG-1 SIF and QSIF (352 by 240 at 30 fps)	UNKNOWN	27 MHz	UNKNOWN
iCompression iTVC10	MPEG-2	MPEG-2 480 by 576 for	6 million transistors	100 MHz	UNKNOWN

MPEG-2 Encoder[17]		PAL and 480 by 480 for NTSC			
NTT Electronics SuperENC Encoder[18,19,20]	MPEG-2	MPEG-2 Main Profile at Main Level (720 by 480 at 30 fps); 4:2:2 Profile at Main Level	5.8 million transistors	External input 27 MHz Internal rate 81 MHz	0.25 micron CMOS, 4 Layer Interconnect
Panasonic Single Chip MPEG-2 Video Encoder MN85560[21]	MPEG-2, MPEG-1	MPEG-2 Main Profile at Main Level (720 by 480 at 30 fps)	UNKNOWN	External clock 27 MHz Internal rate 81 MHz and 27 MHz	UNKNOWN
NEC Single Chip MPEG-2 Video Encoder[22,23]	MPEG-2	MPEG-2 Main Profile at Main Level (720 by 480 at 30 fps)	3,100,000 transistors	13.5 MHz for data input/output 81 MHz and 54 MHz	0.5 micron CMOS, Three Layer Aluminum
Sony CXD192xQ[24]	MPEG-2	MPEG-2 Main Profile at Main Level (720 by 480 at 30 fps)	4.5 million transistors	UNKNOWN	0.35 micron CMOS
Sony Virtuoso CXD1922Q[25,26]	MPEG-2	MPEG-2 Main Profile at Main Level (720 by 480 at 30 fps)	4.5 million transistors	External 27 MHz, 33 MHz; Internal 67.5, 45, 27, 22.5 and 13.5 MHz	0.4 micron CMOS, Three Layer Metal
Stream Machine SM2210 MPEG-2 Video Codec[27,28]	MPEG-2	MPEG-2 Main Profile at Main Level (720 by 480 at 30 fps)	3.0 million transistors	81 MHz	0.35 micron CMOS, Four Layer Metal
Tiosys VICA2000[29]	MPEG-2	MPEG-2 Main Profile at Main Level (720 by 480 at 30 fps)	UNKNOWN	UNKNOWN	0.35 micron CMOS
Vision Tech Kfir[30]	MPEG-2	MPEG-2 Main Profile at Main Level (720 by 480 at 30 fps)	UNKNOWN	81 MHz	0.25 micron CMOS
Mitsubishi M65722 FP pixel processor, M65727FP motion estimator, M65721FP controller (10 chips)[31]	MPEG-2	MPEG-2 Main Profile at Main Level (720 by 480 at 30 fps)	UNKNOWN	40.5 MHz (three times 13.5 MHz)	0.5 micron CMOS
IBM MM30 (IBM Part Number	MPEG-2	MPEG-2 Main Profile at Main Level (720 by	UNKNOWN	54 MHz	0.5 micron CMOS, Four Layer Metal

IBM39 MPEGMM30 CCA 180C)[32,33]		480 at 30 fps)			
Philips SAA6750H Encoder for MPEG Image Recording (EMPIRE)[34]	MPEG-2	MPEG-2 Main Profile at Main Level (720 by 480 at 30 fps)	UNKNOWN	External video clock of 27 MHz (suspect internal 54 MHz)	0.25 micron CMOS
Philips I.McIC[35]	MPEG-2	MPEG-2 Simple Profile at Main Level (720 by 480 at 30 fps)	4.5 million transistors	27 MHz	0.5 micron CMOS process

It is possible to make an MPEG-2 Main Profile at Main Level (720 by 480 pixels at 30 fps) video encoder with an internal clock rate of 54 MHz and 3-5 million transistors. An MPEG-1 SIF (352 by 240 pixels at 30 fps) video encoder probably can be manufactured with an internal clock rate of 27 MHz and about one million transistors.

Table 3 lists the relevant parameters of leading radiation hardened CMOS processes. These numbers should be taken with caution. Numbers of usable gates for gate arrays are often optimistic. These numbers may be derived by dividing the number of available transistors by 4, the number of transistors in the standard two input NAND gate. However, MPEG and other digital video encoders are not arrays of NAND gates and may require more transistors per logic gate.

Table 3 Radiation Hardened CMOS Semiconductor Processes

Process	**Maximum Clock Rate**	**Gates**	**Single Event Latchup**
Honeywell RICMOS-V Silicon on Insulator (SOI)[36,3738]	400 MHz	The largest HX3000 ASIC is the HX3999 with 1.2 million usable gates.	RICMOS is immune to latchup.
UTMC UT 0.6 micron CRH Commercial RadHard Gate Array Family[3940]	400 MHz	600,000 usable equivalent gates	126 MeV/cm^2/mg (80 is often considered immune)
Lockheed Martin Federal Systems 5M (0.5 micron 3-5 metal layer CMOS)[41]	at least 33 MHz (clock speed for RAD6000 rad hard CPU)	1,100,000 usable gates	UNKNOWN (however, used successfully for RAD6000 CPU on Mars Pathfinder mission)
Lockheed Martin ASIC RAD-LITE 0.25 micron ASIC family	>500 MHz	up to 7,500,000 usable gates	latchup immune
Sandia National Laboratory 0.6 micron CMOS6R[42]	100 MHz	1,700,000 transistors	latchup immune, never observed in tests

It appears possible to fabricate an MPEG-2 or MPEG-1 digital video encoder in current radiation hardened CMOS processes. For example, it appears that an MPEG-2 Main Profile at Main Level video encoder could be fabricated using Honeywell's RICMOS-V SOI process in one or two chips. The power requirement would be about 5 watts. Chips can be integrated into multichip modules to reduce mass and volume requirements. Packages largely determine the mass and volume of chips. The worst case would probably be five (5) chips with a power requirement of 5 watts. This assumes that Honeywell's figures for usable gates are substantially over-optimistic for an MPEG digital video encoder.

Radiation-hardened CMOS semiconductor process technologies have recently achieved the system clock rates and levels of integration necessary to implement MPEG video encoders and other video components on a few chips or a single chip. It should be possible to build and fly compact, lightweight video systems to Mars and near Earth in the next few years even if radiation-hardened silicon is needed.

NEAR EARTH APPLICATIONS

Video technologies for Mars can be tried out first near Earth where a much larger potential market for video systems probably exists. In addition, bit rates are not a restriction. High quality digital video is routinely relayed through geosynchronous Earth orbit (GEO) satellites. Consequently, a video system in Earth orbit is highly feasible.

It remains difficult to service satellites in Earth orbit. The Space Shuttle and other manned vehicles appear to be the only practical means to service orbital systems. This limits the lifetime of most satellites. Robotic servicing systems have been proposed to extend the lifetime of satellites in Earth orbit. Video cameras on the robots would permit remote operation or supervision of the robots in real-time. The remotely operated robots could refuel, repair, and upgrade satellites in orbit.

Video systems in Earth orbit could be used to detect and monitor transient phenomena including the weather, fires, automobile traffic, ship movements, and so forth. Several possible scenarios exist. The simplest would be a single video camera with a telescope on a geosynchronous satellite. Gyroscopes could be used to orient the camera and track phenomena on the Earth's surface. A more complex system would be an array of video cameras and telescopes on a single geosynchronous satellite.

A more ambitious scenario would be a constellation of low Earth orbit (LEO) satellites providing global coverage. This would require a sophisticated system for pointing the cameras at a target, stabilizing the cameras, and switching from satellite to satellite as the moved in and out of observing range. One could envision hundreds of small satellites with a single camera or a small cluster of cameras in polar orbits providing continuous real-time coverage of the entire planet. LEO satellites would not require as powerful or bulky optics as the GEO satellites.

The Earth could be divided into hexagonal regions. A user would select a hexagon that they wanted to watch. Then the system would route the video from the satellite in the constellation above the hexagon. As a satellite entered the hexagon, it would orient its camera toward the selected target in the hexagon or provide a wide-angle view of the entire hexagon. An adjustable mirror might allow the satellite to target a region within the hexagon quickly without expending much energy or reorienting the entire satellite.

CONCLUSION

It is technically feasible to fabricate a single-chip or few chip MPEG digital video encoder using radiation hardened CMOS semiconductor processes. Thus, there is no fundamental obstacle to creating compact, lightweight, low power video systems for missions to Mars or other space missions.

Historically, full motion television in space has been restricted to special missions such as the manned landings on the Moon, other manned missions, some weather satellites, and probably some classified reconnaissance satellites[43]. The advances in chip technology discussed in this paper make possible universal television for space missions, including missions to Mars.

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