COMMERCIAL APPLICATION OF EYESAT

Dr. Dino Lorenzini* and Doug Loughmiller †

With the continued growth in geosynchronous satellite communications transponders today, why could anyone consider using a low earth orbit, low data rate, limited availability satellite? Several factors have proven to be important as our experience with small, low earth orbit satellites increases: user priority, simple access, low investment cost, portability, global reach, and flexibility in meeting specialized requirements.

The purpose of this paper is to describe some of the potential commercial applications of the AMSAT Microsatellite. Four of these spacecrafts are currently in sun-synchronous orbit, being tested and used by amateur radio operators around the world. Interferometrics Inc. of Vienna, VA has been licensed by AMSAT to commercialize the Microsat technology. Several system concepts using the basic Microsat bus have been developed to meet user requirements. The combination of a small, proven, inexpensive satellite; affordable launch costs; portable, user-friendly ground terminals; and simple, on-orbit operations make these concepts extremely attractive to a number of potential customers.

Eyesat, Interferometrics' commercialized version of AMSAT's Microsatellite technology, has been adapted to a number of new applications. These include: (1) transmission of fax messages to and from countries with an underdeveloped telephone infrastructure; (2) spacecraft with an onboard TV camera that can gather global images for making environmental assessments (weather patterns, oil spills, waterway pollution, etc.); (3) command and data relay of inexpensive remote sensors and transmitters for monitoring local parameters on a continuous basis (temperature and pressures, water level and condition, wind velocity and direction, equipment status, etc.); and (4) standard spacecraft test bed for qualifying compact flight computers, electronics, and small sensors at low cost in a real space environment.

The low risk, low cost, and short schedule associated with meeting these market needs makes the use of Eyesat technology particularly attractive at this time. However, the crowding of the radio frequency spectrum below two gigahertz makes the implementation of these concepts extremely difficult. In the near term, limited space flight experiments can be expected, but widespread proliferation of Eyesat-type services must await complex decisions by the FCC and international regulatory agencies.

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* Executive Vice President, Interferometrics Inc.
† President and General Manager, Radio Amateur Satellite Corp.

INTRODUCTION

Eyesat is the commercial version of the Radio Amateur Satellite Corporation (AMSAT) Microsats that on 22 January 1990 were launched into an 850 km sun-synchronous polar orbit on an Ariane 4 from Kourou, French Guyana. Thanks to a new modular design for AMSAT's four Microsats, it took only 24 months of work by a team of volunteers to design, build and launch them.

These Microsats are now being used as electronic mailboxes for voice and digital a synchronous packet-switched messages by amateur radio operators around the globe. They also provide real-time communications within the 4000 km diameter footprint of each spacecraft. One, the WeberSat, has a number of on board experiments including a color CCD camera that can beam back video images of the Earth to its builders at Weber State University in Utah. Another, DOVE, (Digitized Orbital Voice Encoder) is a mailbox for voice messages. The PACSAT transmits computer files, while LUSAT includes a Morse code beacon. Their sun-synchronous orbits ensure that each Microsat passes over any ground communicator location at least six times each day, making it easy to schedule communications.

AMSAT volunteers have a long history of successful satellite development and operation. They have built and launched 16 other operational satellites since 1969. Recent AMSAT spacecrafts have demonstrated an average orbital lifetime in excess of five years. Eight amateur satellites are still operational.

Given the AMSAT track record, their spacecrafts have become a tempting opportunity for commercialization. On date Feb 1, 1989 AMSAT licensed Interferometrics Inc. of Vienna, Virginia, the exclusive worldwide rights to commercialize their Microsat as the Eyesat.

Although the Eyesat is not as capable as today's large geosynchronous communications satellites, it nevertheless has a place in space communications. The Eyesat cuts manufacturing and launch costs dramatically through its small size, simplicity, use of personal computer technology and a modular design.

EYESAT SYSTEM

An Eyesat global satellite communications or sensor system consists of four elements: the spacecraft, the user equipment, the control station, and launch operations (See Figure 1). A limited deployment would be composed of 6 satellites, two master control stations, 20 or more fixed or mobile ground stations, launch and operation of the satellites. The approximate cost of this system would be about $10 million including the launch. The system would be constructed in 18 months or less, although emplacement of the satellites in orbit would depend on the availability of the launch vehicle. To achieve this low cost and schedule, the customer must be able to obtain the necessary frequency allocations and, if required, an export license.

A constellation of six satellites would offer store-and-forward digital messaging with periodic real time links. It could transmit voice, data, fax, and single frame TV images, with software available to provide encryption. Expected system lifetime is approximately five years depending on the satellite's initial orbit.

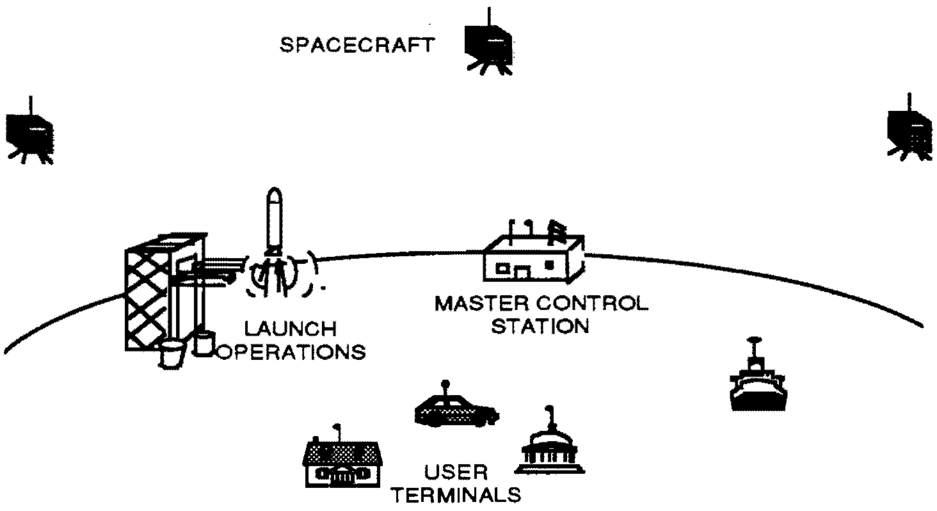

Figure 1. Eyesat System Configuration

The Spacecraft

The Eyesat satellite (Figure 2) is one of the smallest communication satellites ever launched. It measures 9 in. (23 cm) by 9 in. (23 cm) by 8 3/8 in. (21.3 cm) exclusive of antennas. It weighs approximately 21 lbs (9.6 kg), depending on payload options. It possesses 10 MB RAM, of which about 6 MB (depending on applications software) are available for storing the users' communications. The heart of the satellite is an IBM PC-compatible processor, the CMOS V-40, operating in a multitasking environment. It runs 5 receivers operating at 1200 to 9600 baud in UHF or L-Band frequencies, with 2 transmitters operating at 4800 to 9600 baud and able to use VHF, UHF, L-Band or S-band frequencies. The satellite electronic modules are tied together by a local area network.

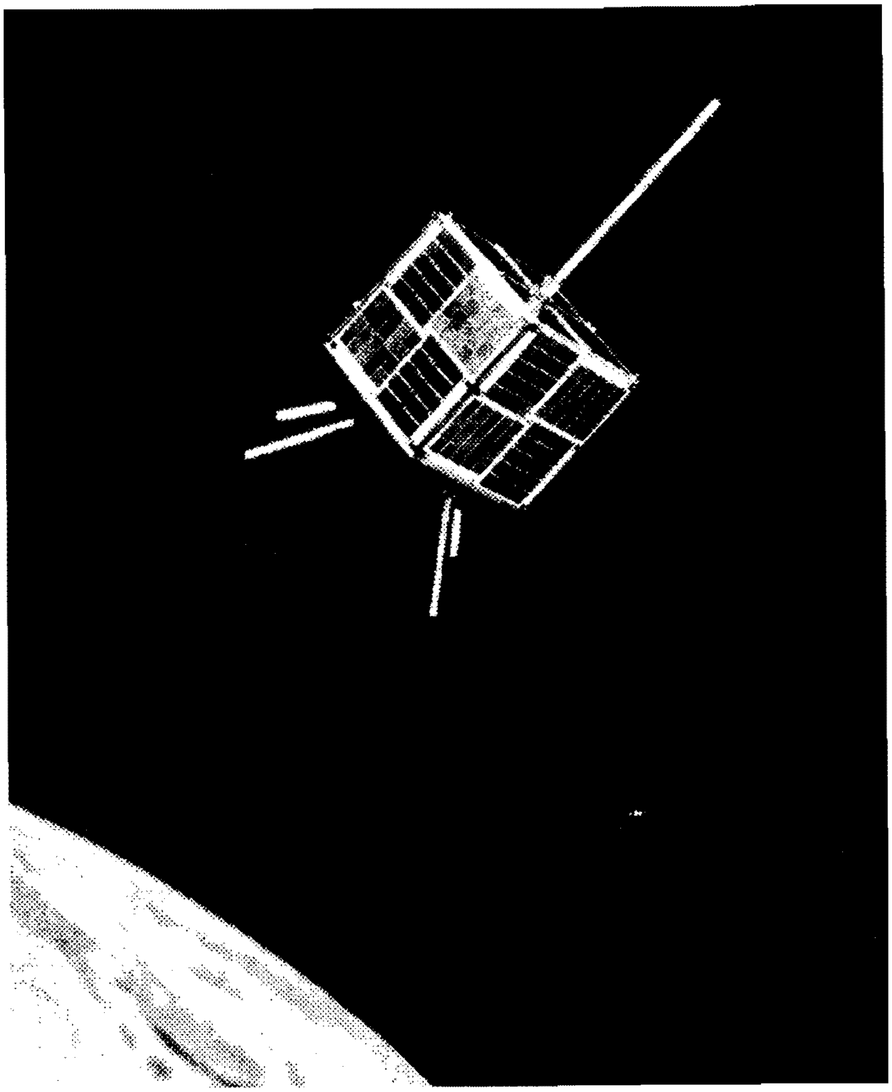

Figure 2. Eyesat

This basic spacecraft operates as a transponder within its approximately 4000 km footprint (depending on the altitude of the orbit), while for more distant links it stores transmissions on a bulletin board for later downloading. The Eyesat uses the AX.25 packet radio protocol to avoid errors without aborting transmissions (an erroneous packet is resent until it arrives successfully).

The basic version of the satellite consists of five modules. (Figure 3) The four standard modules include the receiver module, the computer module, the power module and the transmitter module. The fifth module holds optional equipment such as sensors transmitters, or experimental payloads. This modular construction enables production at affordable cost.

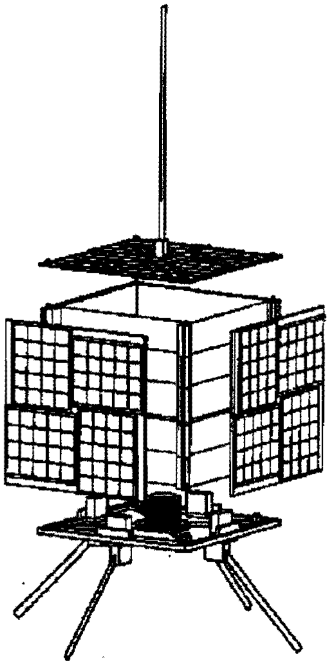

Figure 3. Eyesat Modular Stack

The Eyesat can be modified, both through software alterations, and by adding modules which plug into the power and data busses. Communications links can be modified to handle up to 56,000 baud. Data sent to the satellite can be compressed or preprocessed by its on-board computer before being re-transmitted to the ground. Software modifications in the satellite's mission applications program may be made after launch and uploaded to the satellite, making it possible to modify the Eyesat system while in orbit.

The electrical power system delivers over 100 watt hours of power per day to the payload, allowing continuous radio transmissions at 4 watts. Satellite stabilization is passive magnetic with solar spin at 0.4 rpm.

The User Equipment

Because of the low orbits used by the Eyesats, it is possible to communicate through them using inexpensive ground terminals. VHF and UHF frequencies are optimum because there is a thriving market for transceivers at these frequencies, meaning that their production is well along the learning curve. However, if Eyesat users are unable to obtain allocations in this popular frequency range, the terminals would be more expensive. This suggests that the Eyesat system should be most economical for use in countries in which the VHF and UHF spectrum is not crowded. (Television and FM radio operate in this range.)

Figure 4 is a block diagram of a user terminal operating with VHF uplink and UHF downlink. In these bandwidths a fixed-site terminal may consist entirely of commercially available equipment.

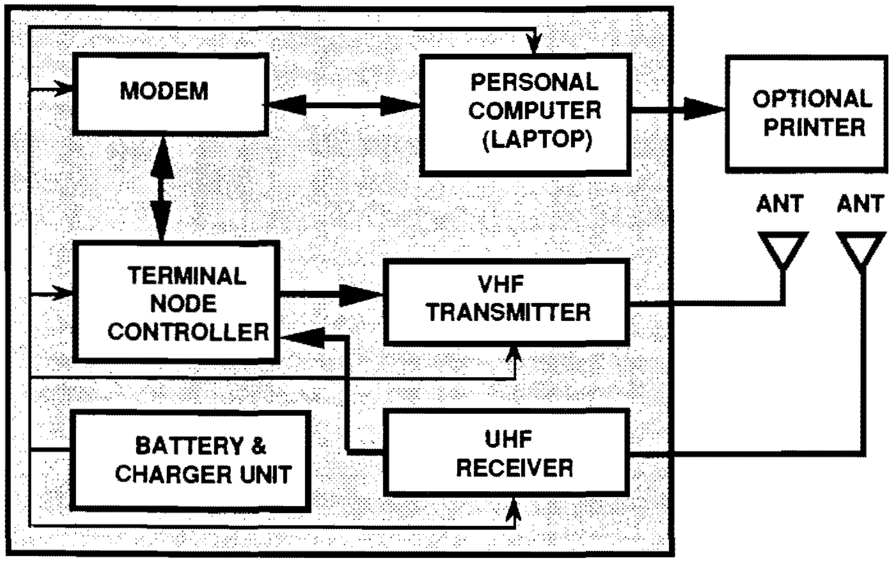

Figure 4. Block Diagram of Portable User Terminal

Interferometrics has developed a portable user terminal that combines a transceiver with a laptop computer and batteries. This terminal fits inside a briefcase and weighs approximately 20 lbs. Its transmitter uses only 10 watts on power and can transmit up to a megabyte of information (the size of a small book) per satellite contact. Setup is easy because the transmission is omnidirectional, which means the user doesn't have to point the antenna at the satellite. The components of this mobile terminal are commercially available, which makes possible a selling price of less than $10,000 each.

Because the Eyesat satellites are not interlinked, the user must wait for the particular satellite with a given message to come into range to retrieve its message. In order to not miss messages, a receiver can be automated so that it queries every passing satellite and downloads any messages addressed to that user. How long must a user wait to send a message? If there is only one satellite in orbit, then depending on the user's location, it could take as much as six hours. With six satellites in properly spaced orbits, a user could expect to access a satellite in less than one hour.

The Control Station

A ground control station may be built entirely from commercially available components. This would include: An omni UHF receiver antenna (linearly polarized), a low noise preamplifier, a UHF Receiver (with product detector), a demodulator (binary phase shift keying), a terminal node controller (TNC), an IBM-compatible computer with RS-232 serial port, a modulator, a narrow band FM VHF transmitter (10 watts or more power) and an omni VHF transmitter antenna.

Optional ground station equipment, also commercially available, include a high gain directional antenna, hard disk for data formatting and storage, applications software and a printer.

The Launch Operations

Because of its small size, the Eyesat is eligible to fly cheaply as a piggyback payload. For example, the four AMSAT versions of the satellites hitched a ride along with the large SPOT Earth resources satellite and two other small satellites for approximately $25,000 per satellite. This was the incremental cost charged by ArianeSpace because of the nonprofit, public service nature of AMSAT. Interferometrics anticipates a launch cost of $100,000 to $500,000 per satellite, depending on the launch vehicle.

Because four of these satellites have already been launched on the Ariane 4, the interface documents, installation and safety procedures and launch countdown activities have already been approved for use on this vehicle. Thus, risk and cost should be reduced for Ariane launches. Other possible vehicles for the Eyesat include the Orbital Sciences *Pegasus*, Microsatellite Launch Systems *Orbital Express*, LTV *Scout*, McDonnell Douglas *Delta II*, Peoples Republic of China *Long March 1*, the Soviet *Proton*, or Japanese *H1*.

The Eyesats are designed for low Earth orbits, which are much less expensive to reach than the geosynchronous orbit favored by the large communications satellites. However, unlike geosynchronous satellites, it takes a larger number of satellites to provide continuous coverage of a given area. For global coverage, a minimum of 32 satellites are needed. The optimum constellation geometry depends on the user's needs and mission requirements. An Eyesat constellation at 1000 km altitude with four orbital planes having 55 degree inclination would have eight equally-spaced satellites per plane. For more restricted geographic areas, a different constellation can be used to achieve better coverage.

One shotgun-style launch could orbit 16 or more Eyesats simultaneously. Orbital Sciences Corp has developed a scheme that takes advantages of perturbations of elliptical orbits to do most of the work of separating satellites into different orbital planes. Four pallets with four Eyesats per pallet and an integral propulsion system can be used to distribute a constellation of satellites into different orbits with a single launch. However, this points out the problem that satellites, once in space, drift from their initial orbits. Eyesat would need to be outfitted with an on-board propulsion option and attitude reference sensor to enable it to perform station-keeping maneuvers. The proper choice of orbit can help to minimize satellite drift.

APPLICATIONS OF EYESAT

Among the many possible uses of a standard or modified Eyesat spacecraft bus, four have been selected for discussion in this paper. These are: (1) Communications relay, (2) Earth imaging, (3) Remote data relay, and (4) Spaceborne test bed.

Communications Relay

Communications is the heart of the Eyesat system, but why would a user prefer the Eyesat system to a transponder on a traditional geosynchronous satellite? Some satellite communications users are concerned about access to geosynchronous transponders. When traffic exceeds capacity, some customers must be bumped. Those most likely to lose out are small-volume users. Those who are bumped tend to also lack a sophisticated telephone infrastructure in their region. Consequently, failed access to satellite communications can mean no communications at all.

Politically-motivated denial of geosynchronous satellite access is another concern of some international users. Furthermore, the history of satellite launch suggests that a user cannot count on enough geosynchronous capacity. Because it actually takes more propulsion to enter geosynchronous orbit than to escape the Earth/Moon system, and because traditional communications satellites mass a ton or more, only a handful of launchers are powerful enough to emplace them.

By contrast, the Eyesat can be launched on the smallest of vehicles, or could hitch a ride with other payloads on most large rockets. Eyesat can not be held hostage to situations such as 1987-88, when the space shuttle, Ariane and Titan were simultaneously grounded.

Another factor that favors the Eyesat is that geosynchronous satellites are too low on the horizon for good communication in the polar regions. For example, amateur radio satellites have been used to aid medical people operating in Siberia.

Perhaps the most significant advantage of the Eyesat is the portability and low cost of its user terminals. Eyesat receivers are much smaller, more portable and cheaper than those used with the far more distant geosynchronous communications satellites. Because geosynchronous satellites orbit some 22,000 miles (37,000 km) above the users, large dish antennas are required to receive signals, and comparatively high power transmitters to reach them. Even though satellite dishes are mass produced, for two-way communications they are still quite expensive. Portable use is impractical because of the size, cost and complexity involved in setting up a mobile unit.

By using to low orbit the customer can employ low power, lightweight transceivers such as those routinely used by radio amateurs. Thus economics and convenience are also drivers for Eyesat use. A similar strategy is planned by Motorola for its Iridium mobile satellite phone system. Motorola's planners recognize that for light weight, low-cost terminals, geosynchronous satellites are out of the question. Consequently the company plans a constellation of 77 small satellites in low Earth orbits.

Using the 20 pound Interferometrics portable terminal, the Eyesat system could serve traveling salespeople in areas where ground communications are unreliable or non-existent. Huge regions of the world fit this category: some of Eastern Europe, much of the Soviet Union, all most all of the People's Republic of China, much of Africa and South America. The bulk of the world's population lives in places where one can not simply phone in orders from a motel telephone.

The Eyesat system may be useful for two-way transmission of educational materials among a school system spread across a region with poor communications. In this application fixed terminals could automatically send and receive information.

Even in the developed world Eyesat communications may be desirable. One possibility is for communications in the aftermath of a major earthquake. According to a study performed by Morrison-Knudsen Engineers of San Francisco for the California Office of Emergency Services, during major earthquakes satellite communications may be the only reliable technique. And because mobile terminals are crucial to getting the capacity to where it is needed, the study identified a need for mobile terminals with the ability to receive and transmit at least 600 baud.[1] The problem is that after an earthquake, phone lines may be downed, cables are often broken, and microwave transmissions driven out of alignment. For example, in 1971 a 6.4 Richter earthquake in Sylmar, CA shifted the ground enough to misalign microwave transmission towers. [2]

The California study recommended a Very-Small Aperture Terminal (VSAT) system using existing commercial satellite transponders. These terminals are small enough to be transportable, yet still access geosynchronous transponders. However, these VSATs, configured to handle 56 kbits/sec, are estimated to cost $45,800 each and require a minimum of a 1.8 meter satellite dish with structural enhancements to keep it from getting damaged when moved. The overall system acquisition cost was estimated at $10,857,600, including two hub site terminals and 84 remote sites. [3]

Although a constellation of less than 32 Eyesats could not continually offer real-time communications, and although each Eyesat terminal does not offer the communications horsepower of the proposed VSAT-based system, it may actually be closer to the ballpark identified by the California study. An Eyesat constellation could be shared by many regions, as disasters tend to be localized both in time and space. The terminals could be carried by hand rather than lugged about in pickup trucks, without fear of putting dents in dishes. The Eyesat communications throughput is well above the 600 baud minimum identified by Morrison-Knudsen.

Earth Imaging

Besides relaying information from sensors, the Eyesat can also carry its own on-board sensors and cameras. One commercial application is to track oil spills, tropical storms, or other global events. Another application is for lower resolution, but also less expensive, Earth resources data.

Small satellite sensor applications are being evaluated by the National Oceanographic and Atmospheric Administration. Uses under evaluation by OAO Corp of Greenbelt, MD include mapping ozone concentrations, measuring the Earth's radiation exchange and for search and rescue.

Another area in which interest in small sensor satellites is rising is the Mission to Planet Earth program. The current plan to gang a large number of experiments onto the giant Earth Observer Satellite (EOS) is coming under fire from Congress in the wake of the Hubble debacle. The Marshall Institute of Washington, DC, famed for its critiques of the nuclear winter hypothesis, is currently analyzing the alternative of using small satellites for the EOS mission.

In 1988 the Jet Propulsion Laboratory held a workshop on "Micro Spacecraft for Space Science." Applications identified for platforms weighing less than 5 kg included mapping of the Earth's magnetosphere, radio science, particle, gamma ray and submillimeter wave detection, and imaging science. [4]

Remote Data Relay

Another application of the Eyesat system is for relaying data from remote monitoring sites to a central station. Examples include sensing of oil wells and water reservoir levels, pollution sensors, weather or ocean conditions.

Interferometrics is currently developing a Remote Sensing and Transmitter Unit that can sense environmental conditions and automatically transmit the data to an Eyesat and can also transmit commands from a central station to the remote units. These compact, low cost, solar powered units have a self-contained microprocessor and data storage. They can be deployed on land , oceans or coastal waterways.

Spaceborne Testbed

The Eyesat payload modules can be used as testbeds for space qualification of hardware and experiments. Because these can be carried as hitchhikers on the basic communications function, it may be possible to compete in price with the government-subsidized Getaway Specials that fly on the space shuttle. Even if price competition is not possible, the availability of the Getaway Specials is so limited that the program is not a serious competitor.

The Eyesat configuration may be ideal for the space qualifications of the family of microelectronics and space computers that are now being developed for future small satellite systems. For example, the DARPA Advanced Satellite Technology Program is seeking to space-qualify the Rockwell miniaturized GPS receiver, which is the size of a pack of cigarettes. The Brilliant Pebbles program, now the centerpiece of the Strategic Defense Initiative, also is developing miniaturized, space-qualified components such as a star tracker and computer.

CONCLUSIONS

Having by far the lowest mass of today's operational satellite communications systems, the Eyesat may become to the satellite communications industry what the Apple I was to the computer industry. Rather than attempting to equal the services offered by geosynchronous platforms, Eyesat seeks to address a new market. This market may include communications in arctic regions; in areas with poor telephone infrastructure where mobile, lightweight communications are desired; for nations concerned about reliable access to satellite communications, including politically-motivated denial; and earthquake-resistant emergency communications.

As a sensor platform, the Eyesat may be useful for research in Earth orbit on the magnetosphere, radio science, for particle, gamma ray and submillimeter wave detection, and imaging science. It might enable tracking of oil spills and other large area pollution events, and offer a low cost alternative for users of Earth resources data. It may provide economical weather data as well.

The Eyesat also promises to become a testbed for space qualification of components of the host of miniaturized space systems now gestating. It may, in fact, become the midwife of the age of lightweight satellites.

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