REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
01-07-2006	Paper PREPRINT	2006

4. TITLE AND SUBTITLE
Multiple Usage of Existing Satellite Sensors (PREPRINT)

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
James T. Keeney

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Air Force Research Laboratory
Space Vehicles
3550 Aberdeen Ave SE
Kirtland AFB, NM 87117-5776

8. PERFORMING ORGANIZATION REPORT NUMBER

AFRL-VS-PS-JA-2006-1014

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
AFRL/VSSS

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited. (Clearance # VS06-0305)

Government Purpose Rights

13. SUPPLEMENTARY NOTES
Submitted for publication in the IEEE Journal of Sensors

14. ABSTRACT
Satellites in orbit are subjected to severe environmental extremes and an ever increasing risk of collision with resident space objects. Sensors are becoming necessary to observe and measure the proximity of a satellite to determine the risks posed from kinetically approaching manmade and natural hazards. Space offers a near-perfect vacuum to operate a passive or active sensor. Volume, mass and power on satellites is limited and risk management approaches tended to remove such sensors from satellite systems. However, with newer system engineering approaches, the traditional sensors used for navigation and measurement can be used to sense the environment for hazards. A few examples are developed to illustrate the approach to "multiple usage sensors" and the potential for obtaining more information from previously single function device.

15. SUBJECT TERMS
Active Sensors, Detectors, Multiple Usage Sensors, Passive Sensors

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
					Dr James Keeney
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**	Unlimited	6	**19b. TELEPHONE NUMBER** *(include area code)*
Unclassified	Unclassified	Unclassified			505-853-1942

Multiple Usage of Existing Satellite Sensors (JULY 2006)

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***Abstract*—Satellites in orbit are subjected to severe environmental extremes and an ever increasing risk of collision with resident space objects. Sensors are becoming necessary to observe and measure the proximity of a satellite to determine the risks posed from kinetically approaching manmade and natural hazards. Space offers a near-perfect vacuum to operate a passive or active sensor. Volume, mass and power on satellites is limited and risk management approaches tended to remove such sensors from satellite systems. However, with newer system engineering approaches, the traditional sensors used for navigation and measurement can be used to sense the environment for hazards. A few examples are developed to illustrate the approach to "multiple usage sensors" and the potential for obtaining more information from previously single function device.**

***Index Terms*— Active Sensors, Detectors, Multiple Usage Sensors, Passive Sensors**

I. Introduction

THE traditional approach to satellite systems was highly specialized subsystems that performed extremely important functions. In some cases multiple redundancy of sensors are used to ensure a highly reliable performance of desired measurements for satellite navigation or detecting environmental conditions. Among these devices were sun, star, horizon, and partial or mass density sensors.

Since volume, mass and power is limited on satellites, a newer systems' engineering approach is to design multiple functioning sensors to perform the traditional functions with the added measurement or processing to extend performance to proximity detection. Many of these historical receiver and transmission systems operate in designated frequency bands that can be traced to their heritage of single function and spectral separation to prevent electromagnetic interference, improve electromagnetic compatibility and minimize atmospheric transmissions losses in communicating to and from orbit and the ground stations. [1]

Manuscript received July 19, 2006. This work was supported in part by the U.S. Air Force, Air Force Research Laboratory.
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Now with detection becoming an operational mission for the Department of Defense, several of these subsystems, outlined in Table 1, can have their functional performance expanded to include detection, identification, characterization and tracking through programmable electronic circuitry or designed-in multiple functionality. For example, if the telemetry antenna continued to perform only its original operations (primarily health-and-status and payload data), it would be dormant, or in a stand-by mode, for extended periods of time.[1, 2] If the receiver/transmitter

TABLE I
TYPICAL SATELLITE SUBSYSTEMS

Sensor Name	Current Functionality	Multiple or Additional Functions
Sun Sensor	Navigation	Detection of objects in field of view
Star Tracker	Navigation	Detection of objects in field of view or extended view using additional optic's
Telemetry transmitter/ receiver	Communication – Typically an S-Band link to/from ground station for commanding, etc.	Receiver/transmitter (using a changed frequency in band) could performed a localized area scan, detection of objects or additional space object identification – optional usage of same signal processing and additional antennas for greater field of view
Communication Antenna – L, C, Ku and Ka bands	Satellites Communications – voice/data relay between satellites or ground station receivers'	Receiver/transmitter (using a changed frequency in band) could performed a localized area scan, detection of objects or additional space object identification – but limited to the field of view due to placement of antenna
Telescopes	Space Objects Identification and research	Satellite maneuver, multiple optics and/or robust steering to image space objects in desired orbits
UV and IR Sensors	Research	UV and IR are expanding spectral regions open to multiple function sensor design
Space Weather	Astrophysics, environmental monitoring, research	Detection of changes in local magnetic fields, particle type, energy and density could be used to alert objects are present in the local region

changed frequency and performed a localized area scan, detection of objects or additional space object identification could be performed with minimum impact on satellite volume, mass or power.

II. Background

Satellite passive sensors are most commonly used for navigation and environmental monitoring. The receivers and transmitters are primarily for communication with ground stations. A system engineering design was applied to a passive sensor and active transmitter to demonstrate multiple functions are possible with a designed in multiple function approach.

A. Passive Sensor

Passive sensors measure levels of energy that are emitted, reflected, or transmitted by an object. The main differences between the active and passive sensors are that the object is not directly illuminated by the sensor. The passive sensor must be capable of detecting whatever is being emitted from the object of interest. Hence, the passive sensor is capable of detecting radiation in several different portions of the electromagnetic spectrum and uses a combination of several channels in order to collect and process faint emissions. These spectrally separated energy bursts could be time sequenced, phase shifted, amplitude varying and exhibit patterns that are unique to an object's materials or its electrical switching and computer processing system.

If the selected range of wavelengths emitted was know, the design of the passive sensor system could be maximized for performing detection, characterizing and identification. Since electronics have specified bus speeds, microprocessor operating rates and known crystal oscillators used in commercial products, these were specifically analyzed.

B. Active Sensor

Active sensors provide their own energy source directing a burst of radiation at the target and use sensors to measure how the target interacts with the energy. The sensor detects the reflection of the energy, measuring the angle, amount of time it took for the energy to return, and doppler shifting of the return energy pulses. This provides estimates of range, range rate or velocity, and the angle or direction of the target. Active sensors provide the capability to obtain measurements but require generation of large amount of energy to adequately illuminate targets and are not directly measuring the reactive emissions of the materials which could be faint and in other spectral bands.

Some active sensors are used to detect various forms of energy and take measurements of the density of the materials and provide detailed data about a wide variety of phenomena including material composition. These sensors radiate in bands, using specified wavelengths, and measure the returned energy in other bands to determine if absorbed energy is re-emitted: the sun's energy is either reflected, as it is for visible wavelengths, or absorbed and then red-emitted, as it is for thermal infrared wavelengths.

C. Detected Signal Strength

The basic principle of both sensors is received power. In equation (1), the power received, Pr, is dependent upon reflected or transmitted power, Pt, and the ability to collect and measure the signal strength and spectral characteristics.[1, 5] The proportionality factor, K, accounts for gains and losses in transmission through a system and medium, which for space the losses are minimal. Further analysis involving wavelength, timing, system losses and signal processing can be used to determine range, range rate, angle, and other signal properties of interest.

$$\mathrm{Pr} = K \cdot Pt \tag{1}$$

In a sensor system, Pt is highly dependent upon wavelength and cross section reflectivity of the object of interest. Therefore the minimum level of signal becomes the dominate factor. This Signal-to-Noise Ratio (SNR) is therefore one of the most important system design factors and can be very complex. Equations (2) and (3) are two forms of an SNR relationship which shows the relationships between several design factors that must be accounted for in a system design.[5, 6.7,8, 9] The difference is the design gains and losses associated with system designs. A single function sensor could maximize design performance, however, multiple functional designs will need to make design decisions to reach acceptable performance across several requirements. Lists of candidate parameters are in Table II.

$$SNR = \frac{Pt \cdot GA \cdot Ae \cdot \sigma}{4\pi^2 \cdot rs^4 \cdot Lmedium \cdot Lsystem \cdot k \cdot T \cdot FN \cdot B} \tag{2}$$

$$SNR = \frac{Pt \cdot GA \cdot Ae \cdot \sigma \cdot Gr \cdot Ga}{4\pi^2 \cdot rs^4 \cdot Lmedium \cdot Lsystem \cdot Lsignal \cdot k \cdot T \cdot FN \cdot B} \tag{3}$$

III. Engineering Examples

A. *Star Tracker – Passive Sensor*

Star Trackers detect stellar backgrounds, usually in the 5 to 6 magnitude "brightness" range, and compare this measurement to star mapping data to determine present position. The brightness of a star is usually expressed as a magnitude. [2, 3] The magnitude scale is logarithmic and, by convention, defined so that brighter stars have smaller magnitude values. Thus a first magnitude star is very bright; while a sixth magnitude star is at the limit of normal vision.

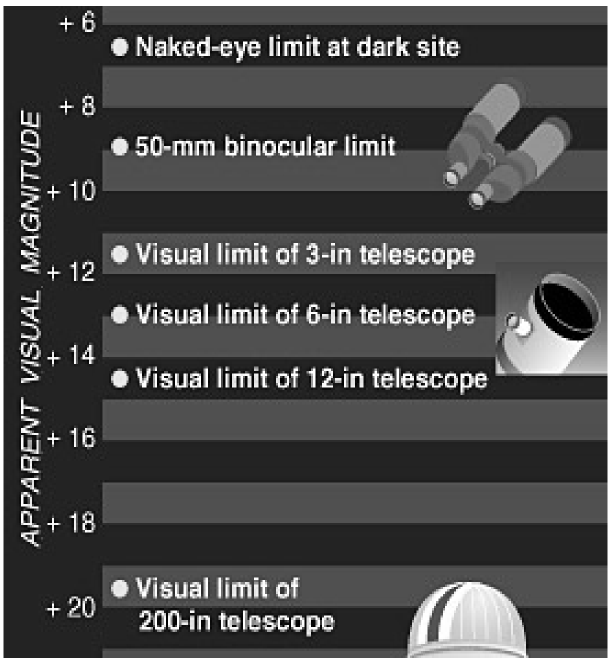

Figure 1: Visual Magnitude [3]

The Star Tracker normally measures this visibly dim illumination for navigational information, but can be adjusted to passively detect scattered or reflected energy from an object in proximity of this sensor. If a scanning or steering mechanism is used, the sensor could perform as a detector. The re-design would need to include the ability to detect stellar magnitudes of much dimmer objects. These objects could be in the apparent visual magnitude range of 15 to 20. As shown in Figure 1, the optical telescopes requirements are demanding. If the requirement is simply to detect, then dim objects in the proximity of a satellite could be sensed and notification sent to a ground station.

In most cases, a visible wavelength sensor will have difficulty filtering out the brighter magnitude 6 stars from the magnitude 15 dim objects. An extensive redesign of the telescope and optical components are required to first perform the navigation function and then increase sensitivity to a much dimmer range or selected wavelengths of interest. This research topic will be examined further in a follow-on publication.

TABLE II
Units for Sensor Parameters

Symbol	Quantity	Units
P_r	received signal power	watts
P_t	transmitter signal power	watts
G_A	transmitter gain factor	unit less
A_e	Receiver/sensor effective area	square meters
σ	target RADAR Cross Section	square meters
rs	range vector from target to sensor	meters
L_{mediun}	loss factor due to the propagating wave in a medium	Dimension-less ratio
L_{system}	transmission loss factor due to miscellaneous sources	Dimension-less ratio
N_r	received noise power	watts
k	Boltzmann's constant	= 1.38 x 10^{-23} Joules/degree Kelvin
T	Temperature	degree Kelvin
FN	system noise factor for the receiver, usually an approximate	Dimension-less ratio
B	noise bandwidth at the sensor	hertz
G_r	SNR gain due to range processing/pulse compression	Dimension-less ratio
G_a	SNR gain due to coherent pulse integration	Dimension-less ratio
L_{signal}	SNR loss due to signal processing	Dimension-less ratio

B. *Telemetry Sub-system – Active Sensor*

The S-Band (2-4 GHz) telemetry is used to provide a data command and control link to the satellite. [10, 11] This sub-system is in high usage, but is a good example of an active sensor that can be converted to a simple detector, or high performance radio amplification detection and ranging (RADAR) system.

Space qualified telemetry units are used for geostationary orbital satellites that transmit at ranges of about 42,000 kilometers to their ground stations. Modification to the design would include waveform, pulse width, data processing and scanning methods. The changes would measure and provide basic detection or range, range rate and angular data used to describe relative positional location.

A typical antenna is rigidly mounted "pointed towards the earth" and would only provide limited field of view. A conformal antenna molded into the satellite surface structure would provide full coverage. Figure 2 illustrates the typical flat panel array antenna and Figure 3 illustrates an S-Band candidate conformal "skin" sensor array used in missile testing.

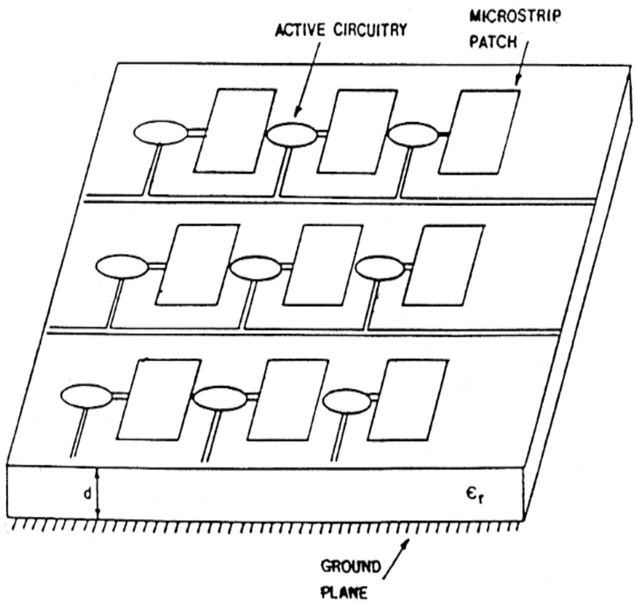

Figure 2: Typical Phased Array with active circuitry and Microstrip Patches

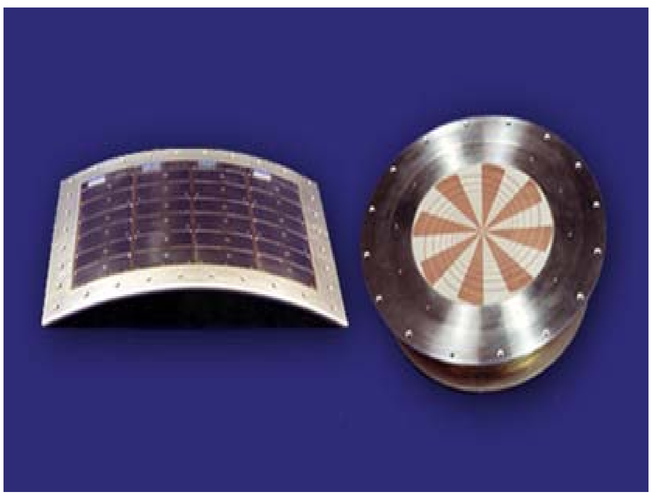

Figure 3: S-Band Conformal Antenna Array (courtesy of Northrop Grumman)

In both the passive and active cases, the original navigation and communications functions could be preformed. [11] The added complexity of multiple functions could be integrated into the existing designs and through time sharing of digital processing and common components, minimal impact could be realized upon volume, mass and power.

IV. Comparison of Passive and Active

The initial studies for star sensors have shown potential to perform multiple functions, while retaining their navigation role. The probability of detecting an object is dependent upon a major design change allowing for detecting both faint and comparatively bright signals from magnitude 6 stars and orbital objects. This fundamental design approach is currently being investigated by government, academic, and industrial teams and their results are pending.

The active sensor offers a clear advantage in detection range, probability to detect, and positional measurements. It will require complexity changes to currently simple designs with demands on power and field of view. As technology advances (and the need to perform proximity detection of objects increases) these obstacles can be easily overcome with current state of the art hardware and software systems after modifications for space environment.

V. Conclusion

The Air Force Research Laboratory is continuing its investigation in multiple usage sensors for space applications. The Star Sensor effort is under investigation and laboratory demonstrations will be performed in 2007.

Active Sensors are currently being tested in millimeter and sub-millimeter wavelengths for space applications. Their potential functions will be investigated for communication cross links, proximity detection, RADAR, and telemetry operations. In particular, phase array structures, conformal and 2-dimentional planar arrays will be investigated providing multiple beams patterns for diverse functional missions.

Both approaches will be reported in future publications as data and analysis proceed.

Acknowledgment

Dr. Keeney thanks Northrop Grumman for permission to present their antenna component as an illustration and the Air Force Research Laboratory for financial support.

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He has been with the Department of Navy and Department of Air Force in continuous service since 1983. He began his career working for the Navy at the Pacific Missile Test Center (PMTC) in the microwave laboratory of their electronic warfare department. He has since served at Naval Air Warfare Center and Office of Naval Intelligence in Washington D.C., and HQ Air Force Operational Test and Evaluation Center. He has served in four Major Commands of the military and jointed the Air Force Research Laboratory at Kirtland AFB, New Mexico in 2004. He is currently the lead for the satellite awareness and protection group.

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