Satellite Threat Warning and Attack Reporting

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

Abstract. The Air Force Research Laboratory's Satellite Threat Warning and Attack Reporting (STW/AR) program will provide technologies for advanced threat warning and reporting of radio frequency (RF) and laser threats. The STW/AR program objectives are:

a) develop cost-effective technologies to detect, identify, locate, characterize, and report attacks or interference against U. S. and Allied satellites.

b) demonstrate innovative, light-weight, low-power, laser and RF sensors.

The program focuses on the demonstration of RF and laser sensors. The RF sensor effort includes the investigation of interferometric antenna arrays, multi-arm spiral and butler matrix antennas, wideband receivers, adaptive processors, and improved processing algorithms. The laser sensor effort includes the investigation of alternative detectors, broadband grating and optical designs, active pixel sensing, and improved processing algorithms. An objective for both sensors is to miniaturize the sensor packages to reduce the weight and power requirements.

The most promising technologies will be demonstrated on two space experiments which will include the participation of Defense Department personnel involved with spacecraft operations. The ultimate goal is to deploy multiple STW/AR sensors as ride along payloads on high value spacecraft.

The RF space experiment will be flown on the Air Force Research Laboratory's MightySat II satellite in a low earth orbit around the year 2001. This light weight, low power, RF payload will monitor the 300 Mhz to 12 Ghz frequency range. The sensor will have the capability to geo-locate RF sources of interest. Due to the short physical span of the RF interferometers, the geo-location algorithm will utilize satellite motion to resolve ambiguities.

The laser technology program will demonstrate various laser sensors on the ground with eventual demonstration in space. Linear arrays, to detect and geo-locate both continuous wave and pulsed laser sources, are being investigated. A visible and infrared subassembly is used to cover the required wavelengths while maintaining the needed sensitivity and false alarm rejection. In addition,

algorithm development efforts are also underway to support the laser characterization and geo-location functions.

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1. Introduction

The Air Force Research Laboratory's Space Vehicles Directorate's Satellite Threat Warning and Attack Reporting (STW/AR) Technology Program supports a United States Air Force need to protect United States and Allied space systems. This paper highlights the Air Force need, presents a concept of operations, defines potential system concepts, and discusses related technology efforts.

The operational threats to a U. S. or Allied space system include natural and man-made radio frequency and optical interference. These threats can potentially damage or disrupt sensitive satellite subsystems and/or payloads, causing interference to the space system's mission.

The primary objective of the STW/AR program is to develop cost-effective technologies which detect, identify, locate, characterize, and report these threats. A secondary objective is to demonstrate light-weight, low-power, and cost-effective, radio-frequency and laser sensors. These objectives will be attained through two space experiments conducted by the Air Force Research Laboratory.

2. Background

Figure 1 presents the history of threat warning and attack reporting programs. In 1986, the Air Force documented a need for autonomous satellite threat reporting capability for its space systems. This need launched a development program called the Satellite On-Board Attack Reporting System (SOARS). SOARS was conceived as a demonstration program managed by the Ballistic Missile Defense Organization (BMDO), then called the Strategic Defense Initiative Office (SDIO), and later transferred to the Space and Missile Systems Center (SMC). SOARS was incorrectly labeled as a generic solution to attack warning. The program strategy did not include hardware redesign to fit the various host satellites. Also, the system performance requirements expanded beyond the original scope of the program. These developments eventually led to the opposition of several spacecraft System Program

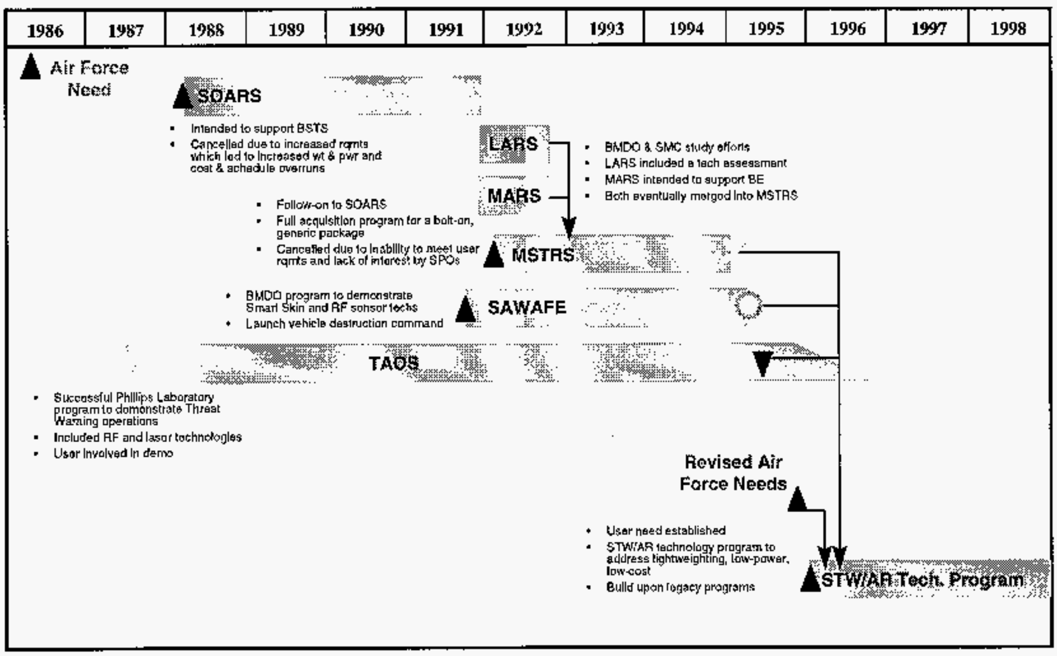


Figure 1. Satellite Threat Warning and Attack Reporting History.

Offices (SPO) to SOARS due to its growing weight and power needs. The program was terminated in fiscal year 1992.

After the termination of SOARS, two concept studies, called the Miniature Attack Reporting System (MARS) and the Light-weight Attack Reporting System (LARS), were initiated. The MARS concept was initially intended for integration into the Brilliant Eyes system, but was later merged into the Miniaturized Satellite Attack Reporting System (MSTRS). SMC performed the LARS study to look at the best combination of current or near-term technologies for performing the threat warning mission. The findings from the LARS study were also eventually merged into the MSTRS program.

SMC's MSTRS program was established to deliver a threat warning system having improved performance with a smaller footprint and with reduced weight and power requirements. MSTRS was later canceled because it did not show direct traceability to the user's needs or requirements and represented a generic system to be imposed on all host spacecraft. The program was terminated in the beginning of fiscal year 1995.

Technology for Autonomous Operations Satellite (TAOS) and Satellite Attack Warning and Assessment Flight Experiment (SAWAFE) experiments were Air Force and BMDO (respectively) sponsored experiments designed to test state of the art threat warning sensors against simulated threats in the intended environment.

The objective of SAWAFE was to prove the capabilities of smart skin technologies to deliver high performance sensors with very low weight and power. In addition, SAWAFE would have also explored the performance of threat warning RF and laser sensor technologies by exercising them against a range of potential threats. Similarly, the performance results from the successful TAOS threat warning sensor experiments were to be used to modify the experiment planning and emphasis for the SAWAFE sensor experiments. Unfortunately, SAWAFE was destroyed during launch in early 1995, however, many ground tests were conducted and the results can be obtained and utilized. On the other hand, TAOS is currently flying and limited tests are still on-going.

The current STW/AR technology program has learned from previous errors. A prime program goal is to include the satellite user in the program from the beginning to directly capture their needs. Reducing the power and weight demands upon host satellites by the RF and laser sensors is the primary design goal. The STW/AR technology program will include two, or more, space experiments to test these new technologies and measure their performance.

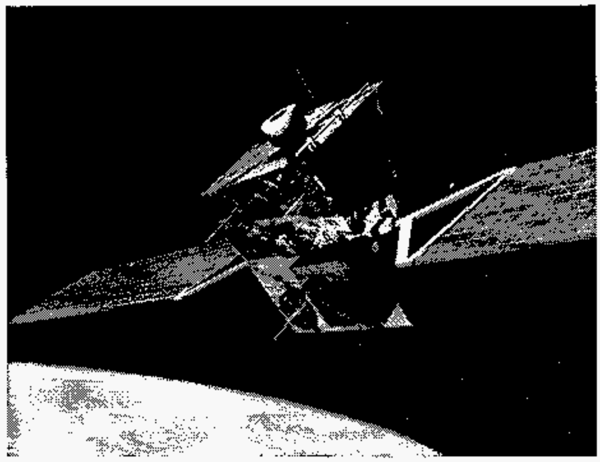


Figure 2. MightySat II with MSTRS-II Payload.

An upcoming RF space experiment, called Miniature Satellite Threat Reporting System (MSTRS-II) (see Figure 2), is being jointly built by Litton Amecom and the Los Alamos National Laboratory Non-Proliferation & International Security Division for the Air Force Research Laboratory. The experiment will be controlled and operated by the Air Force Research Laboratory at Kirtland AFB, New Mexico. The experiment will also involve the participation of Air Force satellite users. Their feedback will assist the Air Force Research Laboratory with focusing the STW/AR technology development efforts. At the same time, their participation will provide them with insight into the utility of a STW/AR system in their day-to-day operations.

The MSTRS-II experimental package will be one of several included on the MightySat II satellite. In addition to mission control personnel at the Air Force Research Laboratory, U. S. radar tracking sites at Ascension Island, Haystack, Massachusetts, and Kwajalein Island will likely participate.

3. CONCEPT OF OPERATIONS

The concept of operations document (CONOPS) is developed to satisfy Air Force needs. Once the CONOPS is defined, multiple system concepts and architectures can be developed. These potential concepts are validated against a set of measures of effectiveness (MOEs) and measures of performance (MOPs) suggested by the CONOPS, and from utility and feasibility analyses (see Table 1).

The STW/AR sensor must provide two types of information: incident information, and threat information. Incident information is an alert that a threatening event has taken place and includes, where and when the STW/AR sensor perceived the event. Threat information is used to determine what type of system delivered the attack and where it is based.

Incident information is generated when the STW/AR sensor first perceives any electromagnetic energy not part of the normal background environment. The normal background consists of both man-made and natural sources of a consistent nature. Likewise, incidents can be man-made or natural in origin. Examples of natural events include lightning, and solar radio energy. It is possible that some natural events will trigger an event report if it matches the characteristics of a threat. If a natural event can degrade spacecraft operations it should indeed be classified as a threat and reported. A STW/AR sensor must be able to differentiate between the radio frequency and laser threats. This will be accomplished by the use of dedicated sensors tuned to RF and laser threats.

It is important to note that a satellite may be subjected to RF or laser energy which may not be intentional but interferes with normal operations. These non-hostile threats must also be identified, as well as their location so that corrective measures can implemented to reduce or eliminate the interference. Indeed, this use of STW/AR may turn out to be a most valuable application, especially to commercial users.

From a military standpoint, pinpointing whether an incident signal is hostile and where it originates is most important but the process must also be consistent and accurate. Time of event and angle of arrival information is used to determine the probable source. Pulse format is also useful to identify the type of threat. Depending upon on-board resources, signal processing can be done on the satellite or data relayed to the ground for processing. Due to restrictions on the size of the interferometer array and, laser sensor spatial resolution limits, the location of an offending RF or laser source can only be identified to within a several hundred kilometer circular area.

Once a STW/AR sensor detects and characterizes an event, the sensor must report its findings. Obviously, the STW/AR sensor must be robust enough to survive an event to do this. A destroyed STW/AR sensor can still provide simple but useful data if it fails to respond to periodic ground interrogation. Frequent and periodic polling can facilitate pinpointing the time and place of an attack but may say nothing of the attack's origin or type.

A STW/AR sensor package onboard a host satellite will provide useful information in determining the cause of externally caused spacecraft anomalies, such as RF interference. Correlating the time of the anomaly with event reports from STW/AR may reveal the source of the anomaly. The resulting savings of operations dollars due to improved anomaly resolution may make up for the cost associated with weight and power allocation for a STW/AR sensor.

Detect
Probability of detection (POD)
False Alarm Rate (number in X years)
Locate
Angle of arrival (AOA), field of view (FOV)
Characterize
Wavelength, frequency band, power, pulse repetition frequency (PRF)
Level of Confidence (%)
Report
Time (X hours)
Probability of report being received (%)
Component miniaturization
Size dimension to minimize impact to host
Reduce weight and power
Reduce cost
Development costs
Recurring costs and operational costs
Cost of failure to detect threat/impact to host satellite

Table 1. MOEs and MOPs

The current CONOPS calls for STW/AR to use the host spacecraft's communications and power systems. In the future there may be a requirement for a dedicated or, emergency, STW/AR communications system.

Table 1 summarizes the MOEs and MOPs that have been established for STW/AR.

4. SYSTEM ARCHITECTURE

The STW/AR system consists of sensors, data collection and processing hardware and software, communication hardware, and associated support systems. Depending upon how it is deployed some of these subsystems could be provided by the host spacecraft. In return for electrical power and weight allocation, and communications support, STW/AR will provide assistance with anomaly resolution.

Although the most common deployment option for STW/AR is as a ride along payload, there are several alternatives. These options provide wide area coverage, or specific spacecraft protection for high value assets. As shown in Figure 3, the deployment options are: strap-on payload, add-in payload, mini-satellite with hover, and free-flyer mode.

STW/AR sensors deployed in a combination of options may provide a more robust warning network than a single option alone. Whatever option(s) is chosen, if the existence of STW/AR is made known to all nations the deterrence value of STW/AR will be enhanced. This is because the possibility that interference or an attack could be detected, and the source pinpointed, may serve as a deterrent to attack by itself.

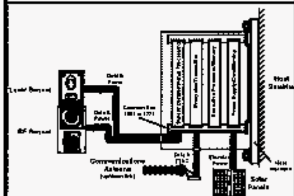
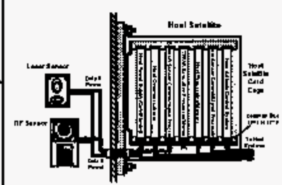
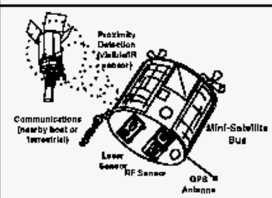
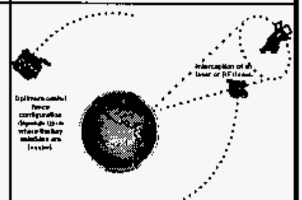
On Host Satellite		*Off Host Satellite*	
Strap-on Payload (independent)	**Integrated Payload**	**Mini-Sat in Hover Mode**	**Mini-Sat Constellation**
			
Features: • Fully autonomous / self-contained • Separate communications link to satellite user	Features: • Sensors and processing integrated with host • STW/AR data included with mission or telemetry streams	Features: • Separate miniature satellite • Flexible assignment to hosts, especially those already in orbit	Features: • Acts as a "picket fence" to RF and laser threats • Pre-determined constellation optimized for coverage of many key satellites
Advantages: • No intervention with host operations • Increased timeliness	Advantages: • Minimal requirements from host • Assists owner/operator with satellite anomaly resolution	Advantages: • Very little interaction with host owner/operator • One-to-one coverage • Possibly reassign to other on-orbit assets	Advantages: • No interaction with owner/operators • Low orbit constellation can be optimized to protect many high value satellites
Disadvantages: • Increased weight and volume requirements • Possible increased communicationcomplexity	Disadvantages: • Host must provide volume, weight, power, and communications • Increased training, ground operations	Disadvantages: • Possible interference due to proximity • Procurement of a satellite and launch capability	Disadvantages: • Requires a large constellation, especially for detecting laser threats • Procurement of a satellite and launch capability

Figure 3. STW/AR Deployment Architecture Options.

Strap-on Payload

The STW/AR sensor is deployed as an additional payload on a spacecraft but it is fully contained (non-distributed) and autonomous with its own power and communications subsystems. The host spacecraft provides only weight and volume margin to accommodate STW/AR. In return, the satellite user receives information about threats or attacks. Event reports are sent by the STW/AR sensor directly to the ground sites with no intervention by the host satellite. STW/AR communications links do not interfere with the host spacecraft's operations.

Add-in Payload

In this option the STW/AR sensor is an integral part of the payload. Power and communications are provided by the host spacecraft. The advantage is that the STW/AR sensor is simplified and weight and power requirements are minimized. The disadvantage is that satellite owners must be willing to support a payload not dedicated to the primary mission.

Miniature-Satellite in a Hover Mode

This deployment option calls for the STW/AR sensor to be deployed as a stand-alone, miniature satellite (mini-sat). STW/AR is launched at the same time as the host satellite and into the same orbit. Multiple mini-sats are deployed around high value satellites to provide a warning network. Using proximity detection, the STW/AR mini-satellites stay well clear of the monitored spacecraft while staying close enough to the host spacecraft that any electromagnetic energy directed at the host will also impinge upon the STW/AR satellites.

The advantage of this deployment option is that the STW/AR sensor does not have to be integrated with the monitored spacecraft. STW/AR mini-satellites can be produced in large numbers and stockpiled for future launches. The mini-satellite is self-contained providing its own power, navigation, and communications. Using a spherical design the mini-sat is covered with the appropriate sensors thereby eliminating the need to maintain a particular orientation. However, knowledge of the orientation, and position, at all times is required in order to determine the source of a threat or attack.

Miniature-Satellite as a Free-Flyer

In this option, the STW/AR mini-sats are deployed into their own orbits and are not associated with any specific host satellite. Over a period of time a network of STW/AR satellites is deployed to act as a picket line. These mini-satellites would be deployed in large enough numbers so that the diffraction spreading of a radar or laser beam directed at a satellite would 'spill over' and be detected by a STW/AR satellite as well. Ground processing would be required to correlate reports from one or more STW/AR satellites to determine the origin of the event. Although this deployment option would provide no direct indication of an event upon a specific satellite; status reports from satellite users would confirm or deny any impact of the event on their asset(s).

The advantage of this approach is that a global network would exist to detect threats against anyone's spacecraft. This may allow STW/AR to become a global utility just as the Global Positioning Satellite System. The cost to deploy and maintain such a system could be borne by many nations. The disadvantage to this deployment option is the large number of satellites which would be required, especially to provide a picket for laser attack. This is because of the small diffractive spreading of laser beams.

Communications

Timely receipt of event reports is the key to the effectiveness of the STW/AR sensor. There are four communication options:

host link direct to ground,

host link via relay satellite,

dedicated STW/AR link direct to ground, and

dedicated STW/AR link via relay satellite.

In the event that there is not a ground station in view, it is desirable for event reports to be relayed by NASA's Tracking and Data Relay Satellite System (TDRSS) or a similar system. Also, each STW/AR sensor could be equipped with a repeater which would pass-on any omni-directional broadcasted event reports that it intercepted from other STW/AR sensors. Confusion would be eliminated by attaching a unique STW/AR sensor identifier, belonging to the originating unit, to each event report. The presence of redundant transmission paths provided by this network presents obvious strategic and tactical advantages.

Data Flow

If STW/AR is an add-in or strap-on payload, event reports may be transmitted over the host spacecraft's communications link to the satellite user. Autonomous STW/AR sensors pass the event report directly to a ground station or via a relay to a ground station. The event report is then passed to the Air Force Cheyenne Mountain Complex for further processing and dissemination.

The location of the event relative to the earth's surface involves a straight forward coordinate translation of the spacecraft's coordinates. The nature of the event is determined by the power or intensity of the electromagnetic pulse, and the duration of the event. After consultation with the satellite user of the targeted spacecraft, an analysis is made to determine whether the event was intended to degrade or destroy any systems or whether the event was a probe or a tracking event. Using information about the event such as frequency, pulse format, power, intensity, and angle of arrival analysis will determine the probable device type and location and whether the event was hostile or an inadvertent friendly intrusion.

Design Issues

The false alarm rate must be very low.- If STW/AR is to become a mainstream operational space system, the reliability of its event reports must be very accurate. That is, a report of an attack or jamming must be true and all such events, directed at a particular spacecraft, must be

RF Band	Spectral Density
400 Mhz	2×10^{-14}
400 Mhz - 1 Ghz	1×10^{-13}
1 - 10 Ghz	9×10^{-12}

Table 2. RF Source Spectral Densities.

detected. Knowledge of the normal, RF or laser background is necessary. The earth background presents a large spatial and temporal signal variation to the sensor. This makes the job of discriminating a hostile signal,

Spacecraft Altitude (nadir - km)	FOV (full angle)	AOA (300 km resolution)
LEO 833	125°	20°
GPS 20,000	27°	1.7°
GEO 35,786	17.4°	1°

Table 3. FOV and AOA Requirements.

without error, more difficult. Additionally, the nature of the threat will probably change over the life of the host spacecraft and, perhaps sooner, in response to a STW/AR deployment. To maintain a low false alarm rate, STW/AR must be agile and the onboard computer must be re-programmable.

The RF background consists of terrestrial and astrophysical sources. Terrestrial sources include natural sources like lightning and man-made sources such as ground and air radars and communications systems. Astrophysical sources include galaxies, the cosmic background, stars, and our sun. The total spectral density (Watts / m^2 / Mhz) for all of these sources combined is shown in Table 2.

Locating the threat-The field of view of the sensor and the resolution of the angle of arrival measurement are a function of the host's altitude. To locate a threat source on the surface of the earth to within a 600 km circle the following Field of View (FOV) and angle of arrival (AOA) measurement resolution is required (see Table 3). The FOV is that required to see the full earth.

Spacecraft discharging-Spacecraft electrical discharge is a serious source of false alarms and is a problem at all spacecraft altitudes. As an example, some satellites routinely see 1500 volts creating broadband RF emissions that can damage the RF warning receiver or trigger a false alarm.

Host EMI - The range of possible host spacecraft presents a variety of electromagnetic interference environments which an RF warning receiver must be able to adapt to.

Host Configuration-The various host spacecraft present different antenna locations and frequencies. This increases the difficulty in designing a generic STW/AR sensor which can ride aboard any possible host with minimal redesign.

RF Sensor-Antennas for the RF sensor, comprising an interferometer, will be multi-arm spirals and dipoles. Borrowing from the electronic warfare community, the probable RF receivers are similar to that which would be proposed for any earth-based RF threat detection mission.

The superheterodyne receiver provides high sensitivity over a wide range of frequencies and excellent frequency selectivity. The superheterodyne mixes the input and the local oscillator signals producing output signals at the sum and difference frequencies. Only the difference signal is passed on and amplified. The stability of the local oscillator frequency is a major concern to the accuracy of the frequency measurements.

The superheterodyne receiver can scan the RF spectrum by sweeping the local oscillator frequency. Another method of monitoring a wide spectrum is to couple a superheterodyne with a wideband receiver which locates a signal and tells the superheterodyne where to tune.

The instantaneous frequency measurement receiver (IFM) can only process one signal at a time. If multiple, simultaneous, input pulses impinge upon the receiver the result may be an erroneous frequency measurement. An IFM splits an input signal and imparts a phase delay to one of these signals which is linearly proportional to the input's frequency. To measure the input frequency, the receiver measures this phase delay using phase correlators. The IFM covers a wide bandwidth with moderately high sensitivity and fine frequency response on short pulses. This approach allows the sensor to be made compact.

The micro-scan receiver is a scanning superheterodyne receiver which changes the local oscillator frequency in a sawtooth pattern. But, it scans too slowly to preserve high sensitivity. Compressive receivers (CR), a type of micro-scan receiver, are wideband receivers with fine frequency resolution which can process simultaneous signals. CRs have high probability of intercept and simultaneous signal capability.

The CR uses a linearly swept local oscillator, which is combined with the input RF signal to yield a linear frequency modulated (FM) or chirp signal. The chirp is sent through a dispersive delay line (DDL) whose time delay is the inverse of the FM pulse. The output of the DDL is a pulse compressed in time. The net result is that the input signal is converted to a short pulse. The position of the pulse in time is an indication of the frequency of the input signal. The width of the pulse is proportional to the intermediate frequency bandwidth.

Primary design issues are weight, power, size, reliability, and cost. The packaging goal is approximately 20 watts of electrical power and a weight of 10 pounds. The RF sensor must monitor the common communications and radar bands, 420 through 10,680 MHz, continuously. Pinpointing the threat location to within 'X' kilometers is probably the biggest mass and power driver. This is because a single antenna can meet all other RF requirements, but the geolocation requirement requires multiple antennas.

Laser Sensor Architecture-The laser sensor design is much less solidified at this time. As the launch date is not until 2001 this is not a problem. Sandia National Laboratory is looking at all possible laser sensor architectures to come up with the correct solution which meets or exceeds the performance requirements while minimizing weight and power, and demonstrating technology innovation.

The current effort is looking at several design issues:

- determine performance threshold and goals,
- evaluate optical concepts for maximum optimal performance,
- evaluate candidate detectors,
- investigate active pixel technologies,
- model the performance of optical and electronic elements,
- formulate efficient detection and signal characterization algorithms, and
- evaluate sensor packaging techniques.

During 1998 through 2001, Sandia National Laboratory will:

- fabricate and test detector chips, readout chips, and optics,
- assemble and evaluate a brassboard sensor,
- build an engineering model sensor, and
- build and qualify the flight system.

To protect the detector from damaging laser radiation, a fast acting shutter will be incorporated into the sensor. Previous flight units have weighed 21 to 44 pounds and consumed 13 watts and 32 watts, respectively. The goal for the laser detector is an approximate weight of 5 pounds, and electrical power consumption of 10 watts.

Linear arrays are expected to be the baseline. A slit coupled to a toric lens will focus the laser beam onto the array and serve as a one dimensional location sensor. The position of the first order peak on the linear array will pinpoint the angle of arrival of the laser beam in one angular coordinate axis.

5. PASSIVE DIRECTION FINDING AND GEOLOCATION

There are two general techniques to determine the angle of arrival of an RF signal, amplitude direction finding, and phase interferometry.

Amplitude DF

Rotating a highly directive antenna, until the received signal is maximized, is a simple, mechanical method of direction finding. This method has a low probability of intercept because the detection of multiple signals is difficult while one is scanning for the maximum strength of a single signal.

An alternative approach is to use four quadrant detectors and compare the amplitude of the four antenna signals. The best choice of antenna for this application is a spiral antenna which has a Gaussian gain function. Four crystal video or superheterodyne receivers monitor each antenna. The ratio of the received powers is proportional to the angle of arrival. A lookup table of power ratios quickly gives the angle of arrival in one plane. Channel imbalance is the primary error source of a 4 spiral antenna system. Other errors arise from variations in beamwidth, variations in crossover angle, and electrical noise.

Phase Interferometry

In this technique the received signal's phase difference as sensed by the elements of an array indicates the angle of arrival. If the phase of the received signal at each antenna, and the location of each antenna is known then the direction to the RF source can be calculated.

A linear array can only provide an estimate of one component of the source's location vector, that in the plane of the array. Therefore, a two dimensional array is necessary to pinpoint the RF source from space by determining the azimuth and elevation angles. A three dimensional array will also provide an estimate of the wavelength.

When the total length of the array is greater than half a wavelength phase ambiguities may result. Limiting the acceptance angle so that the maximum phase difference between extreme elements of the array is less than 2π will eliminate these ambiguities. The accuracy of interferometers range from 0.5 degrees (very expensive) to a few degrees. Generally, the wider the array the more accurate is the direction to the source.

6. RADIO FREQUENCY SENSOR DESIGN

Litton Amecom and Los Alamos National Laboratories are jointly designing the MSTRS-II RF sensor payload. The sensor consists of two antenna arrays, a wide band radar receiver, a tunable narrowband superheterodyne receiver, and signal and data processor. The RF bands of interest for the experiment are:

Band A: 0.3 - 1.2 GHz,

Band B: 1.0 - 6.0 GHz, and

Band C: 6.0 - 12.0 GHz.

The Band A interferometer consists of three crossed dipole antennas while the interferometer for Bands B & C are three spiral antennas.

The radar receiver consists of a wideband radar warning receiver (RWR) which continuously scans each of the three sub-bands and, when detecting a signal, tunes a narrow band superheterodyne receiver to the signal for data gathering and processing. The microwave receiver size is 8.1 in. x 11.6 in. x 1.25 in. The total RF sensor package, including receiver and processor consumes 36.6 watts and weighs 10.4 pounds. The design goal is 20 watts and 10 pounds. The payload will be radiation cooled.

The frequency of a detected signal is rapidly measured by an Instantaneous Frequency Measurement (IFM) receiver utilizing a delay discriminator line (DDL). The DDL converts the detected signal to a chirped output signal with a phase delay proportional to the input signal's frequency.

The total volume available for all Mightysat payloads is 20 in. x 20 in. x 14 in. The interferometer arrays will be mounted across three corners of the 20 in. x 20 in. payload area and therefore, range in size from just under 1/2 wavelength for 300 Mhz to several thousand wavelengths for 12 Ghz. The geo-location algorithm will resolve phase ambiguities by sampling the external RF signal continuously for several seconds as the spacecraft moves in its orbit.

The RWR has basically two modes of operation. The baseline mode is auto monitoring where the broadband receiver scans the three sub-bands while the narrow band receiver scans the sub-bands in 8 Mhz steps. In the enhanced mode a snapshot recording capability is activated whereby short samples of a detected RF signal are recorded and stored for later downlink.

The experimental data to be measured and downlinked include:

the phase difference between each antenna pair of the interferometer array,

SNR of each antenna's signal,

the frequency, modulation, time of arrival, and bandwidth of the signal,

latitude & longitude of the source, frequency, amplitude, time of arrival of the signal, and

snapshots of signal samples.

(watts/cm^2 vs seconds)

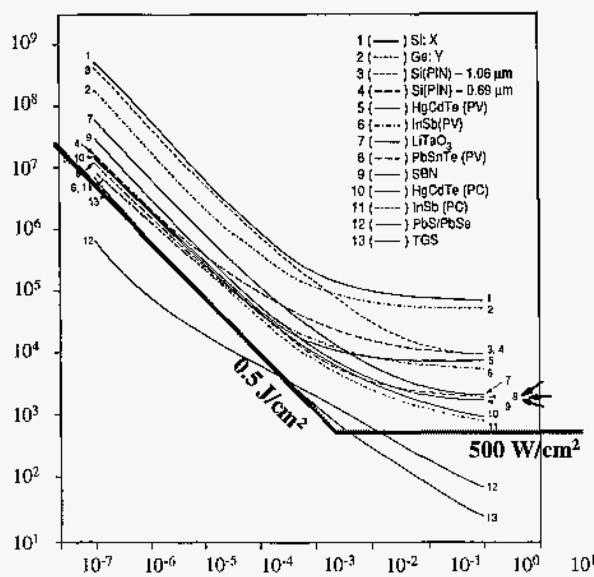


Figure 4 - Damage Level vs Time

7. LASER SENSOR DESIGN

Sandia National Laboratory's STW/AR efforts have focused on developing and evaluating conceptual designs for a next generation laser threat sensor. This sensor is intended to provide STW/AR capabilities to a wide variety of host satellites. Current ground-based lasers can threaten nearly any space sensor. Since the laser sensor is intended for nearly universal deployment the design goals place emphasis not only on sensor performance but on miniaturization, low mass, and low power consumption. Previous Sandia National Laboratory designed systems, although suitable for specific missions, are too large and massive for universal deployment. The present goals require a laser sensor that weighs approximately 5 pounds, and consumes approximately 10 watts of electrical power.

The mission of the sensor is to detect, locate, and characterize threats directed primarily at optical sensors. A laser sensor must be sensitive to energy levels many orders of magnitude lower than those which could damage. On the other hand, this same sensor should, ideally, be able to survive damaging levels as well.

Logically, initial efforts were aimed at defining laser sensor requirements. The growth in requirements can negatively impact the physical size and power consumption of the sensor. Therefore, diligence must be continually exercised to keep the requirements to only those which are truly necessary.

Damage studies on optical wavelength laser sensors, and optical sensor theory, provide a basic understanding of the performance capabilities and sensitivities for any particular choice of sensor. Figure 4 [1] illustrates laboratory determined sensor damage levels. At long exposure times the damage thresholds are measured in terms of watts per square centimeter deposited on the detector surface.

For short pulses the damage levels are expressed in units of joules per square centimeter. Examination of the data suggests that the approximate damage level appropriate for a generic detector is 1000 watts per square centimeter for continuous wave (CW) lasers and 1 joule per square centimeter for short laser pulses.

In order to conserve mass and power usage it was hoped that a single, uncooled detector would suffice for the entire waveband of interest. While a cooled detector could greatly enhance infrared detection performance, the cost in both power and weight would be unacceptable. The sensitivities of available uncooled detector arrays, as well as the need for increased sensitivity at visible wavelengths, requires the use of a dual band system.

The Sandia laser sensor will use an integrating detector sampled at likely a kilohertz. One detector will provide information on both pulsed and CW signals but two detector types are required to cover the infrared to visible waveband.

Infrared detectors respond to changes in material properties of the detector such at temperature. Therefore, an artificially pulsed input signal is usually provided utilizing a chopper wheel when detecting CW signals. A previous Sandia design used one chopped and one unchopped detector to sense both CW and pulsed infrared sources. To minimize weight we would like to use a single approach. However, using a single chopped system for detecting both CW and pulsed lasers is not acceptable since 50% of the time the sensor will be hidden from incoming pulses. The current plan is to use a proprietary electro-mechanical system to allow the continuous detection of both pulse and CW signals from each integrating, AC-responding detector.

The brightness of the earth's background from both reflected sunlight and infrared emission presents a problem in achieving extremely low detection levels. The use of electrical and optical background suppression techniques is required.

Both one- and two-dimensional arrays were considered. There is potentially more information available with two-dimensional arrays but there is a penalty in weight and power to support the large number of pixels and the processing required. The current sensor design uses a set of two or three linear arrays to detect and geo-locate both CW and pulsed sources.

Both a visible and an infrared set of arrays is needed to cover the spectral range. Each set will operate independently but their outputs are processed in a nearly identical fashion. Each array locates a laser threat on the earth in one linear dimension. Theoretically, only two arrays are needed for a complete geo-location with the third array providing additional solutions and/or accuracy. Prior experience with orbiting laser sensors indicates that a high-sensitivity system needs the third array if low false alarm rates are to be achieved. Therefore, in spite of the added weight and power, the final detection system will likely use a 3-array approach.

8. EXPERIMENT PLAN

The experiment objectives for the MSTRS-II experiment are:

a) Demonstrate detection, identification, location, and characterization of intentional and unintentional RF signals.

b) Demonstrate innovative, light weight, low power, miniature RF sensor technologies.

c) Demonstrate mission operations for gathering, analyzing, and interpreting the sensor data, generating and transmitting event reports.

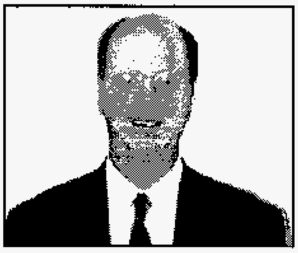
d) Measure the RF background in the .3 - 12 Ghz band from low earth orbit.

The MightSat II spacecraft will be launched into a circular low earth orbit in 2001. The mission duration is planned for 12 months. The Mightysat spacecraft will only be able to downlink 19 megabytes of data per pass to the Air Force Research Laboratory at Kirtland AFB. Therefore, attention is being given to designing efficient data formats.

The experiment plan is still being formulated but two types of experiment events are planned. The first is to detect and measure radar acquisition and tracking of MightySat from ground-based satellite tracking radars. The second event type is to detect and measure interference by ground-based RF sources.

Experiment type one will occur in co-operation with friendly radar sites at Ascension Island, Haystack, and Kwajalein. As MightySat passes within the field of view of these radars it will attempt to detect the radar performing its normal acquisition and tracking function, measure RF pulse characteristics and geo-locate the source. Event type two will involve undefined RF sources, perhaps these same ground-based radars, directing broadband RF energy at MightySat to see how this affects the scanning mode of the RF sensor.

The Air Force Research Laboratory will be responsible for payload planning and execution of the MSTRS-II experiments. Air Force Space Command will participate in the experiment by monitoring and assisting in operations of the MSTRS-II payload during the various experiments.



Downlink of data will occur only when MightySat passes within view of the Air Force Research Laboratory control center at Kirtland AFB. The Air Force Research Laboratory will perform the detailed sensor data analysis in concert with the Air Force Space Command participants.

9. CONCLUSION

The detection and geolocation of probings, jamming, and attack directed against U.S. spacecraft is a high priority mission for the Air Force Space Command. The Miniature Satellite Threat Reporting System (MSTRS) is an Air Force Research Laboratory technology development program whose objective is to develop, and demonstrate low cost, light weight, RF and laser threat sensors. Meeting the low weight and low power consumption design goals will make these sensors more acceptable as ride along payloads to satellite owners.

Two flight demonstrations will prove the hardware designs and will involve the end users. A hallmark of MSTRS is the early involvement of the ultimate end users of the threat warning system. Not only will the sensors become space qualified but the Air Force Space Command users will learn how to incorporate the threat reports into their day-to-day duties and how to use the data to improve satellite anomaly resolution.

Once deployed on high value spacecraft, the threat warning sensors will provide a level of protection from attack in that knowledge of the fact that the United States can detect attacks, and pinpoint the source will be a deterrent. Eventual deployment of these sensors onboard commercial spacecraft will provide insurance from attack as well as making it easier to resolve interference incidents.

REFERENCES

[1] *The Infrared & Electro-Optical Systems Handbook*, 1993, Vol. 7, p 333, Fig 5.4.

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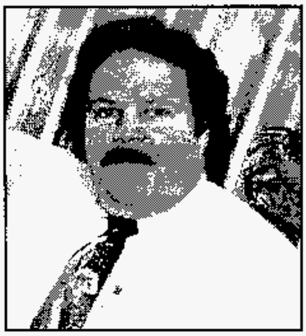

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Satellite Threat Warning and Attack Reporting

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Abstract. The Air Force Research Laboratory's Satellite Threat Warning and Attack Reporting (STW/AR) program will provide technologies for advanced threat warning and reporting of radio frequency (RF) and laser threats. The STW/AR program objectives are:

a) develop cost-effective technologies to detect, identify, locate, characterize, and report attacks or interference against U. S. and Allied satellites.

b) demonstrate innovative, light-weight, low-power, laser and RF sensors.

The program focuses on the demonstration of RF and laser sensors. The RF sensor effort includes the investigation of interferometric antenna arrays, multi-arm spiral and butler matrix antennas, wideband receivers, adaptive processors, and improved processing algorithms. The laser sensor effort includes the investigation of alternative detectors, broadband grating and optical designs, active pixel sensing, and improved processing algorithms. An objective for both sensors is to miniaturize the sensor packages to reduce the weight and power requirements.

The most promising technologies will be demonstrated on two space experiments which will include the participation of Defense Department personnel involved with spacecraft operations. The ultimate goal is to deploy multiple STW/AR sensors as ride along payloads on high value spacecraft.

The RF space experiment will be flown on the Air Force Research Laboratory's MightySat II satellite in a low earth orbit around the year 2001. This light weight, low power, RF payload will monitor the 300 Mhz to 12 Ghz frequency range. The sensor will have the capability to geo-locate RF sources of interest. Due to the short physical span of the RF interferometers, the geo-location algorithm will utilize satellite motion to resolve ambiguities.

The laser technology program will demonstrate various laser sensors on the ground with eventual demonstration in space. Linear arrays, to detect and geo-locate both continuous wave and pulsed laser sources, are being investigated. A visible and infrared subassembly is used to cover the required wavelengths while maintaining the needed sensitivity and false alarm rejection. In addition, algorithm development efforts are also underway to support the laser characterization and geo-location functions.

M98000556

Report Number (14) SAND--97-2545C
CONF-980319--

Publ. Date (11) 199710

Sponsor Code (18) DOE/CR, XF

UC Category (19) UC-900, DOE/ER

DOE