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<th>MEETING</th>
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<td>30 June - 21 July 2006</td>
<td>Women Engineers Pushing for Sustainability</td>
<td>Paris, France</td>
<td>G. Tischbier, +33 1 41 13 0371</td>
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<td>10-13 July 2006</td>
<td>2006 8th International Conference on Information Fusion (ICIF 2006)</td>
<td>Florence, Italy</td>
<td>P. Wolnax, (860) 466-2195</td>
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<td>18-21 September 2006</td>
<td>Antennacon 2006</td>
<td>Anaheim, CA</td>
<td>H. Baus, (619) 684-0232</td>
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<td><a href="mailto:hbaus@nrae.com">hbaus@nrae.com</a></td>
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<td>21-22 September 2006</td>
<td>Board of Governors</td>
<td>Washington, DC</td>
<td>J. Woywod, <a href="mailto:J.Woywod@usni.com">J.Woywod@usni.com</a></td>
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<td>16-19 October 2006</td>
<td>2006 IFI International Conference on Mobility Technology (IFI 2006)</td>
<td>Los Angeles, CA</td>
<td>N. Kramer, (818) 266-8372</td>
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<td>16-19 October 2006</td>
<td>Chinese International Conference on Lunar Science (CICS 2006)</td>
<td>Shanghai, China</td>
<td>J. Woywod, <a href="mailto:J.Woywod@usni.com">J.Woywod@usni.com</a></td>
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<td>3-10 March 2007</td>
<td>2007 IEEE Aerospace Conference</td>
<td>Big Sky, MT</td>
<td>J. Woywod, <a href="mailto:J.Woywod@usni.com">J.Woywod@usni.com</a></td>
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<td>17-20 April 2007</td>
<td>2007 IEE/IAA/USD Conference</td>
<td>Boston, MA</td>
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<td>13-15 October 2007</td>
<td>11th International OFDM Workshop 2006 (iOWo 06)</td>
<td>King of Prussia, PA</td>
<td>J. Woywod, <a href="mailto:J.Woywod@usni.com">J.Woywod@usni.com</a></td>
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## OTHER SOCIETY MEETINGS OF AESS INTEREST

- **June 16-17, 2006**
  - Electro-Magnetic Remote Sensing (EMRS) Defence Technology Centre (DTC) 2nd Annual Technical Conference
  - Edinburgh, UK
  - N. Whitehall, (0131) 543-6160
  - n.whitehall@emrs.com

- **12-14 July 2006**
  - Fourth IEEE Workshop on Sensor Array and Multi-Channel Processing
  - Waltham, MA
  - M. Rangaswamy, (781) 377-3446
  - m-rangaswamy@hanscom.af.mil
  - http://www.san2006.org

- **30-31 August 2006**
  - 11th International OFDM Workshop 2006 (iOWo 06)
  - Hamburg, Germany
  - H. Rohling, +49 (0) 40 42878 3228
  - rohling.hans@hsb.hamburg.de
  - http://iowof.hamburg.de
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In This Issue - Technically

LPI Radar: Fact or Fiction

LPI radar is a system that consists of a radar and ES system. Its performance depends on both components. An LPI Performance Factor is derived and applied to several examples. Operational LPI radars are described. A Digital LPI Radar Detector is described and test results presented.

A recent book on LPI radar received a number of somewhat critical reviews that were published in Systems magazine [1-5]. Although these reviews made a number of excellent points, several questioned the existence of LPI radar. The objectives of this article are to provide a sound technical basis for determining LPI properties of radar, examine several radars that have LPI qualities, and then to describe a Digital LPI Radar Detector designed and tested against the PILOT Mk2 Radar.

Lessons Learned - Using Software-Assisted Systems Engineering on Large Satellite Development Contracts

Over the years, the world's defense industries have become quite proficient at developing large, complex hardware and software systems. In recent years, the ubiquitous deployment of personal computers has changed the way we work. Additionally, tools designed to facilitate systems engineering have recently matured enough to start having a major impact on many major system development efforts. Finally, the government's faster-better-cheaper acquisition philosophy has started driving prime contractors to a concurrent engineering approach toward systems engineering.

Security, Internet Connectivity and Aircraft Data Networks

Internet connectivity which was in experimental stages only a few years ago is a reality today. Current implementations allow passengers to access Internet for pleasure and in some cases secure VPN access is provided to corporate networks. Several researchers are looking at the possibility of the existence of a total of three networks: passenger network (PN); crew network (CRN); and the control network (CON). Researchers envision an architecture where these three networks will co-exist in an airplane.

Navigating Towards the Future: Transitioning From Terrestrial Radio Navigation to Satellite Navigation and Airborne Surveillance

This paper presents a proposal for transitioning from terrestrial-based navigation aids to implementing satellite and airborne surveillance as the primary navigation means. The transition occurs through several steps. First, the installation and use of modern navigation and surveillance equipment is mandated by the regulatory organizations. The installations should take place in a sequenced fashion to allow time for companies to absorb the initial cost. Next, the existing network of terrestrial navigation aids is downsized leaving only the areas of heaviest use in service. At this point, the Global Positioning System (GPS) will be deemed the primary method of terrestrial and oceanic travel. Finally, terrestrial navigation stations will be available around airports and the remaining stations will be put in a standby condition for use in the event of a national emergency. This paper will discuss the security benefits and examples of cost savings through implementation of these steps.

A Hardware Signal Processing Platform for Sensor Systems

A Field Programmable Gate Array-based computing platform for high-speed sensors such as short-range radars is presented. The circuit performs necessary A/D conversions, raw data stream compression and target detection, and constructs a message structure suitable for external displays. In the prototype, USB is the connecting path to a laptop computer. An elementary pulse radar is utilized as an application example. An application interest would be in collision avoidance systems. Observed data transfer rates with real radar input signals were 36 Mbytes/s when typical target detection algorithms were applied.

Distance Estimation at 60 GHz

An FM-CW radar front-end was fabricated in an integrated manner at 60 GHz by using the NRD guide. Main emphasis was placed on compactness in size and high-precise operation in performance. The fabricated radar consists of an FM Gunn oscillator, a balanced mixer, and a planar antenna fed by leaky NRD guide with a mechanically beam-scanning performance. All circuit components and the antenna were contained in a compact housing of 170 × 140 mm in area and 25 mm in thickness, and thus, a thin type of millimeter-wave radar front-end was successfully developed. Moreover, an error of distance estimation was measured to be less than a distance of 0.7 m.

TerraSAR-X Active Radar Ground Calibrator System

In April 2006, the TerraSAR-X satellite will be launched. This paper describes the development of a novel and highly integrated, digitally-controlled active SAR system calibrator (DARC). It consists of both an active transponder path for absolute radiometric calibration and a calibrated receiver chain for antenna pattern evaluation of the satellite antenna. A total of 16 active transponder and receiver systems and 17 receiver-only systems will be fabricated for a calibration campaign in 2006.


The problems are considered of a modelling research of navigation features and improvement of the navigating filters algorithms used in the navigating devices of ground Mobile Vehicles (MV). It is supposed that the methods and approaches known as Real Time Kinematic (RTK) are incorporated in a basis of researched navigating devices and algorithms. Thus, the measurements from satellite navigating systems such as GLONASS/GPS, and also the measurements from other traditional measuring means (tactile sensors, steering wheel angle and/or inertial measuring instruments) are used in the navigating device of the MV. In the present report we solve the problems and describe the methods of a modeling research of the features of functional units algorithms of the MV navigating processor with account of a satellite navigation set integration with other measuring instruments.
LPI Radar: Fact or Fiction

D.C. Schleher
Naval Postgraduate School

ABSTRACT

LPI radar is a system that consists of a radar and ES system. Its performance depends on both components. An LPI Performance Factor is derived and applied to several examples. Operational LPI radars are described. A Digital LPI Radar Detector is described and test results presented.

A recent book on LPI radar received a number of somewhat critical reviews that were published in Systems magazine [1-5]. Although these reviews made a number of excellent points, several questioned the existence of LPI radar. The objectives of this article are to provide a sound technical basis for determining LPI properties of radar, examine several radars that have LPI qualities, and then to describe a Digital LPI Radar Detector designed and tested against the PILOT Mk2 Radar.

LPI Radar is a system that represents a confluence between Radar and Electronic Support (ES) technology. The objective of an LPI Radar is clear; that is, to escape detection by the ES receiver. However, the capability of the LPI Radar system depends upon the characteristics of both the Radar and ES receiver. To understand LPI radar one must first understand the nature of ES receivers. The functions performed by tactical ES receivers are immediate interception, identification, and location of both friendly and hostile emitters. Location requires interception in the emitter's sidelobes. Identification is performed by comparing the intercepted signature against the signatures contained within its threat library [6]. The metric that establishes the quality of interception is called the Probability of Intercept (POI) and is generally included in its specifications [6].

From the above discussion it is evident that radar might have LPI properties with respect to one type, but not to another type of ES system. This situation can be clarified if the claim of a radar being an LPI radar is accompanied by a description of the various types of ES systems for which this claim applies. However the LPI radar can never completely escape detection since there is always a minimum range ($R_{min}$) between the ES system and radar where the interception receiver detection threshold is exceeded.

LPI RADAR PERFORMANCE FACTOR

The scenario to be analyzed envisions a tactical platform, with radar cross-section ($\sigma_r$), that is equipped with an ES system whose function is to alert the platform that is being targeted by the LPI radar. Interception of the radar transmissions by the ES intercept receiver before the platform can be detected by the radar enables the platform to employ EA or other defense suppression actions thereby reducing its vulnerability to attack. Conversely, if the LPI radar can detect the platform before it is alerted by its ES system then the platform becomes vulnerable to missile attack and other offensive actions.

To illustrate the application of the LPI performance formula let us assume that the PILOT Mk2 radar is used in a Coastal Surveillance application to detect small 100 m² ships while it is to be intercepted by a conventional Radar Warning Receiver (RWR) on the ship. RWRs employ main beam detection to intercept immediate threats. They generally use four- to six-spiral antennas whose coverage is equally spaced over 360° in azimuth and have a gain of 0 dB. A common architecture utilizes a crystal video receiver (CVR) with a front-end LNA complemented by a scanning Superhetrodyne Receiver (SHR) to detect CW and high-duty-cycle Pulsed Doppler radars and an IFM receiver to accurately measure the emitter's frequency. The SHR is the best choice, since CVR and IFM receivers have limitations against FMCW-type signals. The normal maximum bandwidth of a SHR in practice is 20 MHz that would have to be increased to 50 MHz for this application. The SHR could then easily detect the PILOT MK2 signal that has a 30 MHz uncertainty about its nominal operating frequency of 9375 MHz.

A performance parameter for LPI radar is given in Figure 1. According to the computer program in Reference [6] the PILOT Mk2 has a noise limited detection range of 15
A performance parameter ($\alpha$) that quantifies the quality of an LPI radar is the ratio of the range ($R_{\text{SE}}$) at which an intercept receiver on board the platform can detect the LPI radar to the range ($R_{R}$) at which the platform can be detected by the LPI radar [7]. A ratio less than one ($\alpha < 1$) indicates that the radar has LPI properties while a ratio greater than one ($\alpha > 1$) indicates an advantage to the ES system.

$$\alpha = \frac{R_{\text{SE}}}{R_{R}} = \frac{G_{Ig}}{G_{Ig}}$$

where

$$\alpha = \frac{R_{\text{SE}}}{R_{R}} = R_{\text{SE}}(1 - \alpha), \quad \alpha \leq 1.$$  

The derivation of the above formula assumes that the radar and ES receivers have similar noise figures and detection single sample threshold sensitivities. The quiet range ($R_{\text{SE}}$) is a metric that identifies the range that the LPI radar can detect the target without interception from the ES system.

The first term indicates that radars with longer noise limited detection ranges ($R_{R}$) increase the detection range of the ES system. This follows from the one-way free space loss of the intercept receiver while the radar experiences a two-way free space loss. Further platforms with lower RCS ($\sigma_o$) increase the interception range ($R_{\text{SE}}$) of the ES system due to the increased power required by the radar. Since the ES system generally processes only one sample while the radar processes multiple returns the interception range is decreased relative to the detection range of the radar by the integration gain (IG) of the radar.

The second term involves the antenna gain of the radar ($G_{Ig}$), the antenna gain of the intercept receiver ($G_{Ig}$), and the antenna gain of the radar in the direction of the intercept receiver ($G_{Ig}$). For main beam intercepts this term reduces to $G_{Ig}$/$G_{Ig}$. Generally this term reduces the interception range ($R_{\text{SE}}$) of the ES system relative to the radar since the antenna gain of the radar is generally much greater than that of the ES system. For side lobe interception it is important to reduce $G_{Ig}$ to as small a magnitude as practicable pointing to the need for ultralow side lobe antennas in LPI radar designs.

The third term involves the ratio of the radar detection noise bandwidth ($B_{\text{SE}}$) to the ES receiver detection noise bandwidth ($B_{\text{SE}}$). This factor always reduces the interception range ($R_{\text{SE}}$) of the ES system relative to the radars range since the radar can employ a matched filter receiver while the ES receiver is generally severely mismatched to the many waveforms it must process. LPI radar waveform design focuses on reducing its noise bandwidth by using phase or frequency modulated CW waveforms such as FMCW to spread the frequency spectrum of the signal over a wideband while its matched filter compresses the spectrum into a narrow frequency band that generally corresponds to the reciprocal of the period of the waveform. The mechanism for LPI operation involves the difference in processing whereby the radar has available a stored coherent replica of its transmitted waveform while the ES receiver at best must synthesize the waveform to be intercepted. For example, the PILOT radar, in one of its modes, employs a simple FMCW waveform that linearly sweeps through 50 MHz in 1 ms resulting in a noise bandwidth of 1 kHz. If the intercept receiver employs some form of envelope detector its noise bandwidth must be a minimum of 30 MHz. The ratio of the relative noise bandwidths then favors the LPI radar by a factor of 47 dB.

The fourth term involves the ratio of the various losses attributed to the radar and ES detection processes. These losses translate the computed idealized range performance into that realized by a practical system and are diverse in nature and a function of the detailed structure of the radar and associated ES system [8]. As a working number it is convenient to assume that the losses associated with the ES and LPI radar systems are similar and the value of this term is one.

Fig. 1. LPI Radar Performance Factor

kilometers against a 100 m$^2$ Swerling 3 target and an integration gain of 3 38. The antenna rotates at 48 rpm and provides a gain of 30 dB and a beamwidth of 1.2$^\circ$. The losses of the ES system and radar are assumed equal although it is expected that a large radar loss might result from target fragmentation due to the 3 m resolution of the radar. Substituting these parameters into the LPI performance equation results in $\alpha = 0.409$ indicating that the PILOT Mk2
radar has LPI properties against the SHR-based RWR-type interception receiver. The resulting range of the ES system is 6135 m while the quiet range of the LPI radar is 8865 m.

As another example, consider an operational airborne ELINT intercept receiver utilizing a spinning dish antenna with 20 dB gain and a 50 MHz SHR [9, 10]. The platform has a 25 m² RCS and the Swerling 1 radar detection range is 8520 m.

Applying our formula for mainbeam interception results in $\alpha = 4.645$ and a $R_{50}$ of 39,575 m indicating that the PILOT Mk2 does not have LPI properties against this ELINT system. However the POI for this situation is extremely low for this classic beam-on-beam detection problem [6]. For sidelobe interception the radar has LPI properties since $\alpha = 0.104$. In general the PILOT Mk2 presents a difficult target for this operational ELINT system.

**OPERATIONAL LPI RADAR SYSTEMS**

The principal idea of LPI radar is to escape interception by mismatching its waveform to those waveforms for which an ES receiver is tuned. Since the majority of ES receivers are tuned to detect pulse, CW, and pulsed Doppler waveforms it is intuitively obvious that it should use some form of frequency or phase-coded high duty cycle signal. The wide bandwidth will negate the CW receiving channel and the high duty cycle with associated low peak power will make it difficult for the pulse channel to detect and identify the signal. The FMCW and phase-coded CW waveforms meet these criteria. The PILOT radar is an excellent example of LPI radar that is designed to be invisible to existing ES receivers. At the Naval Postgraduate School (NPS), we tested the PILOT against two sensitive ES and ELINT receivers and found the manufacturers claims to be substantially true [10, 11].

The operating principle of the FMCW PILOT Radar is best understood by referring to the waveform diagram depicted in Figure 1. The target return is displaced in time, but identical in shape, to the 50 MHz transmitted waveform. By mixing the target and transmitted waveforms in a homodyne receiver an approximately steady tone is produced whose frequency is proportional to the target’s range. However there is an end effect that is eliminated in the PILOT by the receiver’s 512 kHz IF bandwidth. The resulting beat frequency can be visualized as a one-millisecond rectangular pulse whose frequency is proportional to the range of the target. The matched filter for this pulse has a 1 kHz noise bandwidth. The matched filter is formed by a 512-point FFT filter bank where each filter’s bandwidth is 1 kHz and whose filter position represents the target range. Note that the 1 kHz noise bandwidth is determined by the period of the waveform and hence is independent of the frequency excursion of the linear sweep. The necessity for minimizing the end effect restricts the maximum range for each of the 6 range modes of the PILOT radar to a small percentage of the total unambiguous range that might be available from a sweep period of 1 ms.

The manufacturers of this radar claim that the radar is invisible to all currently available ES receivers. This claim is generally true since most currently designed ES receivers operate on the basis of a single sample and have little or no capability to detect internal signal modulation such as employed in FMCW radar. Under these circumstances, the FMCW signal is completely mismatched to the ES receiver signal processor, thereby preventing interception. However, since the FMCW radar’s characteristic is known at the ES receiver, it is relatively easy to synthesize a matched filter for the specific FMCW radar waveform used in the PILOT LPI radar. In this regard, the strategic problem faced by the ES receiver is to provide, not only a matched filter for this LPI radar waveform, but also for all conventional signals to be intercepted.

The recently introduced PILOT Mk3 operates with frequency agility (FA) over a band from 9.1-9.5 GHz and includes a Reflected Power Canceller (RPC) that enables it to operate with a single Transmit/Receive antenna [12]. The FA would require ES systems to use some form of Channelized receiver that is only available in the most modern RWRs (e.g., ALR-67(V)3).

Another operational LPI radar is the Ku-band APQ-181 used in the B-2 stealth aircraft [13]. The necessity of an LPI design for stealth platforms using radar is obvious since detection and location by an ES system would compromise its low observable properties. The radar employs a phased array antenna and a gridded TWT transmitter similar to those in the APG-63, 65, and 70 radars. The details of the LPI waveform are classified.

Many Radar Altimeters have LPI properties. These radars have special characteristics in that they process only a single target and their antenna’s mainbeam is directed away from
potential intercept receivers. Their transmitter signals are generally power managed.

**THE DIGITAL LPI RADAR DETECTOR**

An adaptive digital LPI radar detector was designed, built using COTS components, and tested at NPS against the PILOT Mk2 radar [14, 15]. The LPI detector was initially designed and tested using MATLAB simulation. Then the front-end consisting of an antenna, LNA, mixer, and LO was implemented using COTS hardware. The resulting baseband signal was amplified in a 50 MHz video amplifier and applied to a digital storage Gage card containing an 8-bit 250 MHz A/D converter, data storage and MATLAB interface embedded in a PC. Processing to detect and identify the LPI signal is then accomplished using the MATLAB program developed from the simulation design. The same procedure can be used to process any LPI waveform.

The philosophy of the design was that it is possible to adaptively form a matched filter using the general known PILOT signal structure. The processor adaptively tests the received PILOT signal using deramping techniques similar to those used in “Stretch Radar” to form a matched filter. The processor not only finds the correct mode (bandwidth) of the PILOT radar but also synchronizes to its sweep. The measured sensitivities achieved at the receiver terminals were –108 dBm for the 50 MHz bandwidth mode and –123 dBm for the 1.625 MHz bandwidth mode. For 1 W transmitter power and –25 dB sidelobes, the signal can be intercepted through its sidelobes and identified at a maximum range of 220 km with a spinning 20 dB antenna gain dish. For mainlobe intercepts with the high bandwidth 1 mW mode, as might occur in a power managed missile seeker, the maximum intercept range is 55 km. The processor was successfully tested, using simulation, against the interference from 500 pulse radars operating in the same frequency band as the PILOT radar.

**CONCLUSION**

LPI radar is a system that involves both a radar and ES system. Since there are many types of ES systems, the claim that a radar has LPI properties must include a description of the types of ES systems for which the claim applies. A metric that quantifies the quality of LPI radar against a particular ES system is the quiet range. Waveform design to achieve LPI operation relies on mismatching the radar signal to the signals for which the ES system is tuned. However, in general the signature of the LPI radar must be known at the ES receiver to accomplish its identification function. This signature is obtained through SIGINT and other intelligence methods. Knowledge of the signature allows the ES system to form a matched filter for the LPI radar signal that will generally negate the LPI properties of the radar but may not be economically practicable.

**REFERENCES**


Lessons Learned

Using Software-Assisted Systems Engineering on Large Satellite Development Contracts

Preston A. Cooper
Ingenuity Research Corporation

ABSTRACT

Over the years, the world’s defense industries have become quite proficient at developing large, complex hardware and software systems. In recent years, the ubiquitous deployment of personal computers has changed the way we work. Additionally, tools designed to facilitate systems engineering have recently matured enough to start having a major impact on many major systems development efforts. Finally, the government’s faster-better-cheaper acquisition philosophy has started driving prime contractors to a concurrent engineering approach toward systems engineering.

This confluence of events has had unexpected impacts on both the flexibility and rigor of requirements management processes. While the maturing requirements and design tools hold great promise in maintaining requirements traceability throughout the design process, the widespread use of desktop computing systems has inadvertently lulled many experienced systems engineers into sloppy processes because it now appears to be a simple matter to make a requirements change in a softcopy of a requirements document. Without strong process and management support, requirements changes inevitably start being derived in a broad spectrum of incompatible tools and formats.

This author is currently participating in the design phase of a major classified government satellite development effort. As an integral member of an extremely experienced requirements management team (boasting over 150 years of combined experience in the defense industry), this author has had the opportunity to watch the team navigate straight into many of the systems engineering potholes created when talented engineers implement concurrent engineering using a variety of tools without a consistent process framework.

This paper, therefore, specifically addresses process and implementation challenges that arose when establishing a software-assisted concurrent-engineering approach on a large satellite development contract.

INTRODUCTION

Having moved beyond the age of slide rules and paper-based configuration management, one of the questions that frequently occurs during today’s aerospace proposals is: “What tools will we use?” When it comes to selecting a systems engineering tool, asking this question during the proposal timeframe is often too late because tools are most effective when used from day one and when supported with systems engineering processes. Proposal time is therefore a difficult time to develop tool-expertise, specifications, and supporting processes.

Once the contract has been awarded, process-discipline becomes even more important because the engineers responsible for requirements management and design development have access to a wide variety of office productivity tools. The time constraints that drive contractors to concurrent-engineering processes frequently, and inadvertently, reward engineers for directly negotiating requirements changes at all levels and then documenting changes in the nearest available tool. While the requirements management group may be able to use their selected systems engineering tool to pull together a specification from these mixed-quality, mixed-source inputs, the resulting database will likely have poor internal uniformity, poor historical traceability, poor change descriptions, and poor requirements derivation.

In short, the lack of systems engineering process discipline can compromise many of the benefits that the tools are intended to provide.

This author’s recent experiences on a large government satellite development contract have turned out to be typical of many corporate endeavors. Since so many organizations are struggling with the same issues, this paper initially provides an
overview of software-assisted systems engineering. After the initial overview, this paper will provide some insights into how to develop a process, deploy a systems engineering tool, and manage expectations to improve the odds that projects will be able to successfully and efficiently use the tool.

SOFTWARE-ASSISTED SYSTEMS ENGINEERING

Traditional systems engineering entailed implementation of a manual system for controlling requirements (A-Specs, B-Specs, etc.) and for ensuring that the final products complied with the specifications. The rapid improvements in computing hardware and software in the 1980s saw the creation of comprehensive systems engineering tools that help guide and automate the systems engineering process from requirements management through system design and verification testing.

At its most basic, a systems engineering tool can be described as a software system comprised of a relational database, a graphical user interface, and tools for importing and exporting data. As an example, SDRC’s SLATE (System Level Automated Tool for Enterprises) supplies a relational database from Versant that is accessed using a unique graphical interface. SLATE is designed to provide engineers of all disciplines with a systems engineering environment that graphically helps them parse customer documents, derive lower-level requirements, and create system functional hierarchies. Working within the SLATE environment has the advantage of providing easy traceability, budgeting, metrics collection, and flow-control so that design problems can be discovered as the design is driven to greater and greater levels of detail. Similar systems engineering tools are available from other suppliers (e.g., Ascent Logic’s RDD-2000 and Telelogic’s DOORS).

Some of the typical steps involved in a software-based systems engineering process include:

- Importing a customer document into the tool
- Parsing the imported document into discrete requirement objects
- Recursively performing requirement decomposition
- Performing impact analysis as requirements change
- Performing reporting to find disconnects, collect metrics, follow traceability, etc.

The benefits of performing these tasks within a tool include having requirements, traceability, and history captured in a single place where they can easily be used to perform impact and consistency analyses.

Today’s systems engineering tools have finally reached a level of maturity, stability, and affordability that enables their widespread deployment across engineering departments. While this level of tool penetration is needed to efficiently capture system decomposition within the tool, merely making the tool available does not ensure its use. Development of a robust process, and instilling the discipline to use it, is required if a team wants to avoid having their engineers informally working requirements modifications using standard office productivity tools.

PROGRAM BACKGROUND

This paper is the result of this author’s recent system engineering experiences on a major satellite development effort, combined with 5 years of process improvement responsibilities for a prior employer. Details about the program cannot be released in a public forum but a highly generalized background can be provided.

The program’s current process challenges stem from decisions made in 1998. Back when the program’s RFP was released, the contractor team generated a high-level proposal A-Specification using a team member’s proprietary requirements management tool. While this tool was adequate for producing a proposal A-Spec, the team’s management proposal anticipated that a different systems engineering tool would be used during the actual contract. For this program, SDRC’s SLATE was made web-accessible to all program staff (including teammates) via a unique configuration involving Microsoft’s Advanced Terminal Server and Citrix web-browser plug-ins.

As part of the team’s pre-Authority-to-Proceed commitment, the requirements management team was sent to SLATE training. This cadre then imported the proposal A-Spec into the tool and spent a year massaging the imported data, creating a robust database schema, and developing processes for effectively using the tool. As shown below, it can be quite difficult to switch tools and establish processes after the project has started.

Process detractors will often be beyond an engineer’s control, but understanding the various events that can occur can help a team to both prepare and plan for problems. The remainder of this paper therefore provides both broad generalizations and specific examples to assist managers and engineers with establishing a viable systems engineering organization.

LESSONS LEARNED

A. Never Begin Vast Projects With Half-Vast Processes

It is best to have thought a problem completely through before starting. While no process will be perfect and remain unmodified, up-front analysis of the end-to-end process pays on-going dividends. Starting off with “half-vast” processes sets the program up for problems because extensive database retrofits must be done to ensure a consistent amount of analysis and data capture is performed on each requirement. Program startup is the most important time to efficiently use a software engineering tool, so deficient processes should be avoided.
One process factor to be considered is the desirability of establishing a common language and common toolset within the program. Extraordinary additional benefits can be reaped if commonality with existing corporate standards is maintained. Interoperability with an existing corporate standard can therefore be more important than picking the “optimal” tool because the program will have many more resources to draw from, a smaller learning curve as staff move between projects, and more efficient communication within the team due to the common language of the tool and processes.

Therefore, unless a project is a pathway for the company to beta-test the widespread deployment of a new corporate standard, it’s best to go into a proposal effort with an experienced staff, tested processes, and a pre-deployed toolset. Doing it right the first time helps avoid expensive requirements database rework downstream.

B. Don’t Perform Program-Wide Deployment of a Major New Tool At The Beginning Of A Major Program

As alluded to above, tools and processes can go hand-in-hand. It is just as important to maintain tool stability as it is process stability. In the case of a systems engineering environment like SLATE, using the tool during the proposal is the optimum way to start. Switching tools after the proposal creates extensive amounts of database-baggage that will be carried along for the duration of the program since customers become accustomed to seeing requirements in a certain format and with specific requirement-reference numbers.

An additional customer-relations problem can arise because customers dig into the details of a proposal A-Spec and will establish their own methods of traceability to ensure that their needs are being met. When a program subsequently switches tools, customer traceability is broken unless the team imports and carries forward the old tool’s unique requirement tags. While the database impact of carrying the additional data is minor, the more complicated report development process and the lack of a single, unambiguous requirement-referencing-scheme negatively impacts overall productivity.

C. Calendar Dates Are Closer Than They Appear

This is a truism whether a program is performing software-assisted systems engineering. While deploying a tool like SLATE can be very helpful for maintaining traceability and consistency, the initial tool deployment can bring out a host of other problems due to staff inexperience with the new tool and processes. This learning curve causes management to underestimate the time and effort required to complete tasks.

As already discussed, the beginning of a large new program can be a very poor time to deploy a new system, tool, and process. Inevitably, both expected issues (staffing) and unforeseen problems (power outages, database crashes, and system upgrades) will arise to cause schedule problems during the critical startup phase. This tendency has been exacerbated by the industry tendency to promise faster, better, and cheaper (FBC) in order to win contracts. All too often FBC translates into less schedule time, “scheduled” breakthroughs, and extreme resource constraints.

Additionally, organizational inertia and management inattention can destroy a schedule by allowing individual engineers’ penchant for certain tools to impede a tool-supported process. In the case of SLATE, progress is relatively smooth and straightforward as long as the entire team works within the tool. Once the boundary is crossed beyond performing relatively simple import/export events (parsing a customer requirements document or exporting a new version of an A-Spec for the configuration management group to control), then the amount of time and effort required to support data transfer goes up rapidly. Unless a program’s requirements engineers are prepared to become the data entry group for the rest of Systems Engineering, the program must not allow outside engineers to use non-systems-engineering tools like Word to redline the softcopies of specifications because those engineers will expect the requirements group to read through their document copies and transfer changes into the systems engineering environment. The program should either commit to properly using their tools or should abandon them because it is extremely time-consuming, error-prone, and demoralizing. A program’s retention rate, and award fee, will likely suffer as a result.

One additional scheduling concern that should be considered is the scheduling of contingency time. Unforeseeable events (such as an electrical crew deciding to replace an electrical panel without getting the attached computers properly shut down) can result in computer crashes and extensive rework. Had program schedules been written to plan for contingency time, deliveries affected by the last-minute power outage might have gone out on time.

D. Management Buy-In and Support of Process is Crucial

The best process in the world is useless unless actually implemented. In a multi-fiefdom environment, every player becomes most concerned with what is best for their home organization. Much-needed process supporters will unintentionally become process bottlenecks without strong middle management support, activist low-level managers, and empowered technical staff.

While accommodation and compromise between working groups is generally a positive thing, compromising on process tasks generally results in skipping steps to make a short-term delivery. Unfortunately, satisfying the short-term goal will often have far reaching impacts because parts of the foundation upon which the requirements database rests have not been established. Later retrofits and backfills to the database tend to need more rework, to be more costly to implement, and impede downstream progress and consistency.

E. Weekly Metrics Showing the Degradation of Process Status Do No Good if Not Read or Used by Management

Too often a project suffers from not having real metrics upon which to base management decisions. One of the major benefits to implementing an automated systems engineering process comes from the ability to regularly generate meaningful metrics. These metrics can identify process
bottlenecks, opportunities for high-payoff resource investments, and so forth. Since the opportunity to make decisions based on tangible data is so rare, it is important to ensure that management processes are designed to use metrics as required inputs to the decision-making process.

A specific example of this principle comes from the program described at the beginning of this section. After baselining the initial set of specification changes, the team established a robust change process that allowed engineers to capture changes within SLATE and shepherd them through the various approval steps. At the same time a metrics collection program was devised to keep managers apprised of the program-wide status of the requirements change process.

Metrics were collected on a weekly basis starting immediately after the process was briefed to the various stakeholders. After the metrics were collected they were analyzed to compare them to projected values. Briefings showing the metrics and their interpretation were then prepared and given to management. These weekly infusions of hard data started showing radical divergence from the plan after only 2 weeks. Despite repeating the message every week, the program continued to make almost no progress against the plan for another 2 months. In the end, a 3-month task was slipped two full months and nearly all the process steps designed to maintain a high-quality requirements baseline were bypassed to produce a highly suspect A-Spec (a situation which remained for at least 8 more months due to the management-directed inadequacy of recovery efforts). Clearly, proactive management processes should have used the hard data to make recovery decisions long before the schedule deviations became problems.

F. Avoid Changing Hardware or Software Baselines Shortly Before Major Deliveries

No matter how simple an upgrade is expected to be, it never works out simply. Even if upgrades are installed on time, these upgrades often have unexpected impacts on the project’s workflow. Accordingly, programs should avoid major changes to hardware or software configurations immediately before a major delivery.

This particular guideline was successfully adhered-to on the referenced program. The information management department’s initial plan to move from a standard SLATE client-server architecture to an untested, web-enabled, Citrix-based client-server architecture was scheduled to take place a week before completion of the first A-Spec update. It was delayed due to fears that the scheduled one-day downtime would not be adequate. These fears were well-founded because the eventual implementation resulted in nearly a week of downtime followed by months of decreased productivity due to system inefficiencies.

G. Do Not Inject Massive Database Changes Immediately Prior to a Major Delivery

Relatively simple changes, such as adding a new type of note to a requirement object, can have enormous impacts when replicated across an entire database. Unless the systems engineering team is vigilant, one or more deliveries can easily be impacted due to an unanticipated problem with a massive database change.

For example, to create an online requirements verification matrix, the Verification and Test team added a new requirements verification summary note to every high-level requirement object in the database. For example, on a moderately-sized database, a comprehensive summary note with about a dozen user-defined attributes can result in tens-of-thousands of new database objects. Unknown to the requirements team, the server’s optimization settings and hardware capabilities were exceeded by this database change. While the system tuning was accomplished relatively quickly, requisition and installation of new server capacity took weeks. In the meantime, the requirements team was required to work weekends to get enough tool-time to complete the next delivery.

H. Refer to Requirement Identification Numbers Rather Than Document Paragraph Numbers

Due to the widespread deployment of desktop computers many senior engineers and customers have come to use their new desktop tools (Microsoft Office applications) to help them track the evolution of their requirements. The starting point used is generally the proposal A-Spec and the tracking number used is the paragraph number. Not only is paragraph-number-referencing problematic when generating verification and traceability matrices (Word and Excel cannot sort legacy paragraph numbering schemes without writing custom sorting macros), but this is also problematic because the extreme flexibility of tools like SLATE allows systems engineers to easily relocate (and therefore renumber) the document.

When working within tools like SLATE, document reordering changes are transparent because the engineers use unique requirement numbers to find requirements anywhere within the database. However, people not using the tool tend to refer to requirements by the paragraph number in their version of the document. It is therefore imperative to train internal and external database users to reference each requirement by a unique and static designator like SLATE’s ROWN (Requirement Object Identification Number). Using a dynamic designator like a paragraph number becomes burdensome because the desired requirement’s designation will likely take on numerous values as the system evolves (during DID rewrites, between different versions of A-Specs, etc.). While having a team-wide agreement to use a dynamic designator at a specific point in time can help overcome some difficulties, it creates many new problems.

I. Use Multiple References to a Single Requirement When Duplicated Between CLINs

On some programs, separate CLINs are used to develop complementary products that use common resources. Developing separate-but-identical requirement objects for each CLIN becomes a configuration control and resource issue because it takes time and effort to ensure that both requirements change identically. Instead, the program should
strive to write single, generically-worded requirements and incorporate them by reference in the various documents.

J. Put All Output-Documentation Text into Requirement Objects to Ease Control Issues

Once a control process has been implemented to control the evolution of the requirements objects in the database, it can be a shock to realize that the program has no process established for controlling changes to “the rest” of the A-Spec text. Placing all A-spec text into requirements objects can solve this problem because the established process can be used to control the entire specification.

K. Manage Engineer and Customer Expectations

Systems engineering continues to evolve, but progressive systems engineering teams frequently have problems learning how to deal with senior staff members and customers who are used to traditional systems engineering processes.

As a systems engineering tool, SLATE is vastly superior to trying to create a workable system using Microsoft’s Office products. Despite passable workable import/export interfaces to Word and Excel, many of the Microsoft amenities that we’ve all become accustomed to are extremely difficult, or impossible, to replicate within SLATE. Examples include change marking (strikeouts and underlines), simple formatting, versioning, and retaining special characters. While tools like SLATE continue to mature, the program’s requirements group had to overcome many difficulties when trying to meet internal and external customers’ expectations.

But not everything is as gloomy as one might think. For example, SLATE’s unique display methodology and powerful report-writing capabilities made the “real” systems engineering work extremely straightforward. If a group can train users to work within the SLATE environment, then the majority of the problems encountered (essentially I/O problems caused by mapping Office expectations onto a SLATE environment) disappear.

An aside: program management staff also needs to manage customer expectations when the program chooses to use concurrent systems engineering rather than traditional systems engineering. While government managers are quite familiar with what to expect from traditional systems engineering, the expected “managed chaos” that is concurrent systems engineering can be quite alarming to customers expecting the traditional products and oversight. Since most customers are looking for end products in a shorter timeframe than ever before, the need to educate customers on what to expect from concurrent systems engineering is greater than ever before.

L. Pick a Role for the Requirements Engineers

When the systems engineers supporting the requirements management process become experts in the selected tool, they’re often relegated to a tool-support role rather than the intended requirements management role. If management processes determine that the requirements group will provide data entry support to the rest of the program, then many of the tool’s advantages are being circumvented and the requirements engineers turn into slaves of the tool as they perform the secretarial/data-entry function for the domain engineers who just want to see the latest version of the spec. While tools like SLATE are extremely powerful environments for systems engineering, they can be extremely inefficient word processors. If a team is going to wind up using the tool to replicate the functions of a word processor, extreme aggravation and disappointment are sure results.

M. Collocate Requirements Development and Support Team

Due to the extreme flexibility of systems engineering tools, it can be quite easy for different parts of the program to develop the database using divergent standards. Frequent interaction, most easily facilitated by team collocation, can be key to creating a workable, consistent database.

Additionally, many tools require the commitment of adequate support resources. Having a dedicated system administrator collocated with the team (as opposed to being in a centralized IM location) will ensure sensitivity to tool issues and will help drive optimization of the system. In the case of SLATE, having a dedicated Tool Control Language (TCL) expert dedicated to working issues is also imperative as your team works to automate system engineering processes.

N. Parse Governing Documents to Capture Customer Requirement in Separate Requirement Objects

Simply importing a customer requirements document can work if the customer documents are well-written. It is frequently the case, however, that traceability problems arise due to customer paragraphs containing multiple “shall” statements. Parsing each shall statement into a separate requirement object eliminates the traceability ambiguity that arises if each customer paragraph is kept intact.

O. The Blacker the Project, the More Important All This Becomes

The requirement for high-level security clearances further exacerbates every problem mentioned above because it severely restricts the quality and quantity of resources that can be applied to solve problems. This author’s program was extremely fortunate in that the teammates were able to supply numerous key individuals, but the clearance level of the project made it difficult to get new staff and timely technical support.

SUMMARY

This paper presented both general issues (that any systems engineering organization will experience) and specific issues that should be considered by any organization planning to run a major systems engineering effort using an automated systems engineering environment like SLATE. While automated systems engineering tools have evolved significantly in the past few years their incredible benefits come with limitations. These tools require the support of robust management and technical processes to realize their benefits.
Security, Internet Connectivity and Aircraft Data Networks

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ABSTRACT

Internet connectivity which was in experimental stages only a few years ago is a reality today. Current implementations allow passengers to access Internet for pleasure and in some cases secure VPN access is provided to corporate networks. Several researchers are looking at the possibility of the existence of a total of three networks: passenger network (PN); crew network (CRN); and the control network (CON). Researchers envision an architecture where these three networks will co-exist in an airplane. The available Internet connectivity can be utilized for transporting flight critical information like cockpit flight data recorder (CFDR) data, digital flight data recorder (DFDR) data, cockpit voice recorder (CVR) data, and controller pilot data link communication. In addition, the Internet connectivity could also be used for other safety mechanisms like video surveillance and remote control of the flight. Security is one of the major concerns that affect the successful deployment of Aircraft Data Networks (ADN) and other safety features. Several studies have been carried out to secure the network using firewalls and intrusion detection system but so far no study has focused on securing the communication channel (between the aircraft and the ground station) and its impact on the ADN. The scope of this research is to determine the viability and need of a security mechanism. The research will also focus on the performance of different security architectures and determine their usability in the framework of an ADN.

INTRODUCTION

Due to the recent technological advancements, deployment of Aircraft data networks (ADN) is on the rise. Many commercial airliners like Lufthansa, Scandinavian Airlines, China Airlines, and Singapore Airlines have already deployed ADN in their selected long haul flights. It is expected that, in the next 20 years, there will be 100,000 flights enabled with ADN flying across the world. With this volume of deployment, ADN security raises one of the major concerns for the authorities as well as airliners.

As pointed out by the authors of [1], aircraft data networks faces two kinds of security threats: internal and external. Internal security threats are originated from the passenger network where a malicious user can gain access to the control network and cause service impairments and/or attempt to take control of the flight. On the other hand, the external security threat is caused due to the security vulnerabilities of the satellite links.

Aircrafts equipped with ADN use satellite links to connect to the ground station. The advantages of satellite links lie in their ability to cover a large geographic area, distance insensitivity, and immunity to terrestrial hazards. Satellites are useful in providing broadband connectivity to remote locations which are harder to reach through terrestrial infrastructure. While satellite communication is advantageous, it has some peculiar characteristics like high delay-bandwidth product, low signal-to-noise ratio, long feedback loop, transmission error, variable Round Trip Time (RTT), and intermittent connectivity. These characteristics affect the communication, especially internet protocol (IP) based communication passing via the satellite network. A number of researchers have worked on improving the IP based communication performance over satellite networks. One of the solutions proposed in this area suggests using performance enhancing proxies (PEP) [3, 4] at strategic locations.

Apart from performance degradation, the satellite networks are also prone to security attacks. Due to their broadcast nature, satellite networks are prone to security threats like eavesdropping and flooding [5 - 7]. Usage of IPSec is one of the many solutions proposed to secure satellite communication. The versatility of IPSec lies in the fact that, unlike the other schemes which operate at the transport or application layer, IPSec operates at the Network layer thereby making it very easy to apply this security solution to different applications and with different transport layer protocols. Other
security mechanisms suggested for satellite communication include Transport Layer Security (SSL/TLS), Secure Shell (SSH), and Pretty Good Privacy (PGP), etc. However, the choice of security protocol depends upon the data type and the capacity of the encrypting device. In this paper, the authors analyze the ADN traffic pattern and look at various security options available for each data type. The main focus of the authors will be on the security mechanisms like IPSec and SSL/TLS.

The remainder of this paper is organized as follows: in the section that follows, the authors present a brief overview of IPSec and SSL/TLS security mechanisms. In the section entitled Aircraft Data Network Traffic Pattern, the authors present a discussion on the typical traffic pattern of ADN. In the section entitled Security Mechanisms and ADN, the authors discuss the advantages of each security mechanism with respect to ADN. In the Simulated Results section, the authors compare the performance of the two contending security mechanisms through simulation results. In the final section, the authors present their conclusions and suggest some future work.

OVERVIEW OF SECURITY MECHANISMS

Security is one of the major issues faced by most of the network administrators. Many schemes have been developed to address the security concerns of end users. It has been noticed that an enhancement in the security oftentimes adversely affects the application quality as perceived by the end users. Hence it is important for the end users/network administrators to choose the security mechanism that best suits their requirements.

In the case of an ADN, there are various types of traffic flow between the ground station and the aircraft. While some of this information may correspond to the flight control, others may be originated by the passengers. Typically, IPSec-based security mechanisms are used to protect sensitive information traversing the network. However, in the recent past, security mechanisms based on Secure Socket Layer (SSL) are also gaining importance due to their versatility.

Overview of IPSec

IPSec-based encryption is one of the means of providing security to confidential information. The versatility of IPSec lies in the fact that, unlike the other schemes which operate at the transport or application layer, IPSec operates at the Network layer. This makes it very easy to apply IPSec-based security mechanisms to different applications and different transport layer protocols.

IPSec offers authentication along with data encryption. IPSec achieves data security using three distinct components, each handling different aspects of security. Authentication header (AH) [9] is responsible for data authentication. Encapsulating security protocol (ESP) [8] is responsible for maintaining the data confidentiality. ESP defines the encryption mechanism, data format, etc. to ensure data confidentiality. Generally IPSec uses encryption algorithms such as data encryption standard (DES). Key exchange protocols are another important part of IPSec. Key exchange protocols such as internet key exchange (IKE) [10] ensure that the end points exchange the encryption and decryption keys securely.

IPSec operates in two different modes based on the security requirement. When operating in the transport mode, IPSec encrypts only the payload part of the IP packet. In tunnel mode, IPSec encrypts the entire IP packet and appends the encrypted IP packet with a new IP header specifying the address of the tunnel end point. The tunnel mode of IPSec offers maximum data security.

In order to provide enhanced security, IPSec induces some additional information (overhead) into the IP packet. IPSec overhead consists of IPSec header (24 to 57 bytes), authentication header (24 bytes in transport mode, 44 bytes in tunnel mode) and/or ESP header (30 - 37 bytes in transport mode and 50 - 57 bytes in Tunnel mode). In addition to the packet overhead, the IPSec encryption process also delays the entire packet delivery process and this delay depends upon the complexity of the encryption algorithm used by the IPSec process.

Overview of SSL/TLS

Compared to IPSec-based security mechanism, SSL/TLS is a newer security protocol (in terms of site-to-site access) developed initially by Netscape for web browsers. Unlike IPSec, SSL/TLS uses a layered approach. The record layer operates above the transport layer and provides encryption and authentication services. SSL/TLS uses symmetric key algorithms to protect user data. The keys to these algorithms are established by the handshake method which is handled by the handshake protocol. The handshake protocol uses public-key algorithms to create a master key between the SSL/TLS client and the server. The master key is used to generate cipher keys, initialization vectors, and message authentication code (MAC) keys. In addition to handshake protocol, there are other protocols like Change Cipher Spec (CCS) protocol, Alert protocol, and application data protocol which operate at the same level as handshake protocol. CCS protocol monitors the successful completion of handshake, whereas Alert protocol is responsible for notifying the protocol failures. The application data protocol is responsible for handling data to/from the higher layers.

Similar to IPSec, SSL/TLS accommodates a variety of encryption (DES, RC4), hashing (MD5, SHA), and key management (RSA, DH) algorithms. However, the standard specifies the usage of a specific combination of these security algorithms called cipher-suites in order to get a specific security effect.

Whenever a client wants to connect to a server, he/she first sends a hello message to the server. In response, the server sends a server hello message. This exchange of hello messages sets parameters like version, session ID, encryption method, and compression technique. Once this part is done, both client and server authenticate each other after which they exchange the session key. It has been observed that, with a Pentium Xeon
processor, this entire handshake process takes approximately 173 ms [17]. After the handshake process is complete, the client and server are ready to exchange application data. In addition to the handshake delay, typically SSL/TLS adds at least 23 bytes (depends upon the block cipher used and block size). However, there is no clear definition of the number of bytes added per packet in the case of SSL/TLS.

**AIRCRAFT DATA NETWORK TRAFFIC PATTERN**

As mentioned earlier, in addition to transporting passenger traffic, the available Internet connection could also be used to transmit certain flight parameters from the aircraft to the ground station. Currently, every aircraft stores approximately 15 minutes of cockpit voice information in the CVR. Every 15 minutes, this information is overwritten with the new data. As discussed in [16], with the recent technological advances, it is possible to store the flight information for the entire flight duration within the aircraft. In addition, using the Internet connection, this information could be transferred to the ground station in real-time, enabling the ground station crew to monitor the flight health and caution the flight crew in case of an emergency.

![Fig. 1A. Encrypted IP datagram in transport mode](image)

**SECURITY MECHANISM AND ADN**

In general, the perception is that the security mechanism deteriorates the application performance, which is partly true also. One of the main reasons for this is the complexity of the security mechanism itself. As the complexity of the security mechanism increases, the perceived security will also increase. On the other hand, with lower end systems, it affects the quality adversely.

In the case of ADN, the quality of aircraft traffic is affected by two factors: satellite link and security mechanism. The effect of the satellite links can be alleviated by using performance enhancement proxies (PEP). While PEP agents improve the TCP-based application performance, they do not work well in the presence of network layer encryption. When an end-to-end encryption mechanism like IPSec is used, the encryption scheme hides all the information including the transport layer header from the intermediate nodes. However, in order for PEP agents to work, they will need the transport layer information. This results in non-functioning of the PEP agents. Figure 1 shows the typical packet format of an encrypted IP datagram. As shown in the figure, the PEP agent could get just the IP header information but not the TCP header information.

The issue of IPSec and PEP coexistence was first identified by the authors of [15]. In their work, the authors explored many possible solutions to resolve the issue of security and performance enhancement working together. One of the possible solutions they proposed suggested that IPSec-based
encryption should be used selectively. They suggested that the traffic streams that need performance enhancement should not be encrypted. The major drawback of this approach is that it compromises the security of user traffic for better performance. In another suggestion, the same authors suggested establishing multiple IPSec associations. In their proposed approach, the authors suggested that the PEP agents should be used as IPSec end points. The end systems need to establish security association with the PEP agents. PEP agents will have certain IPSec-based security association between themselves, and they will transport user data across the satellite network after applying encryption. This method requires a distributed PEP implementation, and it also requires the end systems to know the presence of PEP agents. The major drawback of this approach is its complexity. This approach involves multiple encryption/decryption processes which increase the delay and reduce the throughput.

Another approach suggested by these authors was to use other encryption techniques like SSL/TLS instead of IPSec. SSL/TLS-based encryption provides almost the same level of security as IPSec but operates at the transport layer instead of the network layer. As discussed earlier, SSL/TLS supports almost all encryption standards similar to IPSec. However, since it is encrypting at the transport layer level, it will leave the transport layer information unencrypted thereby opening up the network for attack. On the other hand, it does not hinder the operations of the PEP agents, thereby improving the quality of the data transfer applications. Hence from application performance perspective, SSL/TLS is a better option compared to IPSec.

In the next section, the authors present some simulation results to support their argument of choosing SSL/TLS-based security mechanism for ADN.

**SIMULATION RESULTS**

In order to verify the advantages of SSL/TLS-based security mechanism over IPSec, the authors built a small test-bed as shown in Figure 2. The authors used a satellite link simulator (by Spirent Communications) to emulate the satellite link characteristics in the network. In addition, the authors also used performance enhancement proxies availed from SCPS.org. All the systems used in the test-bed were of the same configuration (P3i, 800 MHz, 256 MB RAM). The authors compared the throughput performance (using netperf) of the network under various conditions i.e. in a normal scenario, with satellite link simulator active and in the presence of performance enhancement proxies. Table 1 presents the results obtained under different test conditions.

From the results, it can be observed that the throughput of the network was almost similar for both IPSec and SSL/TLS-based security mechanisms. However, in the presence of PEP, only SSL/TLS-based security mechanisms were able to deliver the data across the network while packets encrypted using IPSec were dropped at the PEP gateways. This

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<td>Normal Scenario</td>
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<td>with Satellite</td>
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clearly indicates that SSL/TLS-based security mechanisms are
better in the presence of satellite links and performance
enhancement proxies.

CONCLUSIONS AND FUTURE WORK

In this research work, the authors focused on determining
the security mechanism best suited for aircraft data networks.
They compared the working of IPSec- and SSL/TLS-based
security mechanisms. While IPSec provides better security, it
fails to maintain the quality of service required by the
TCP-based applications. On the other hand, SSL/TLS-based
security mechanisms provide security almost equivalent to
IPSec without affecting the quality to a larger extent. Hence, in
the current conditions, the authors suggest using
SSL/TLS-based security mechanisms for aircraft data
networks.

One of the main drawbacks cited in the case of IPSec was its
inability to provide transport layer information to the PEP
agents. As a future work, the authors suggest making
modifications to the existing IPSec key exchange protocol
such that IPSec works along with PEP agents to improve the
application performance in satellite link environments.

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Navigating Towards the Future:
Transitioning From Terrestrial Radio Navigation to
Satellite Navigation and Airborne Surveillance

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ABSTRACT

This paper presents a proposal for transitioning from terrestrial-based navigation aids to implementing satellite and airborne surveillance as the primary navigation means. The transition occurs through several steps. First, the installation and use of modern navigation and surveillance equipment is mandated by the regulatory organizations. The installations should take place in a sequenced fashion to allow time for companies to absorb the initial cost. Next, the existing network of terrestrial navigation aids is down-sized leaving only the areas of heaviest use in service. At this point, the Global Positioning System (GPS) will be deemed the primary method of terrestrial and oceanic travel. Finally, terrestrial navigation stations will be available around airports and the remaining stations will be put in a standby condition for use in the event of a national emergency. This paper will discuss the security benefits and examples of cost savings through implementation of these steps.

INTRODUCTION

Terrestrial radio navigation has well served aviation for over 70 years. When first introduced, it significantly improved the safety and practicality of air travel. Today the system is becoming a hindrance both from a cost standpoint and the operational restrictions of the system. The launch of the first Global Positioning System (GPS) satellite in 1985 marked the beginning of a fundamental change in how the aviation community, as well as the rest of the world, travels. Improvements in airborne surveillance systems have improved safety and allowed more aircraft to use the skies. As with any new system, the initial cost of implementation is high. However, over the long term, the total cost of usage is much less than maintaining an outdated and inadequate system. The current system of radio navigation aids is a large complex network of transmitters that require extensive resources to operate and maintain. The new global threat of terrorism also poses a threat to these systems. Security for these facilities is minimal. A coordinated effort to take a number of the transmitters off-line could cause disruptions throughout the air travel system. Satellite and airborne surveillance systems provide a more secure system and increased operational safety. The benefits and cost of changing navigation means must be assessed on many different levels to fully grasp the scope of the project. This paper will examine the reliability, cost-benefit, security, and the proposed steps necessary to implement a new primary navigation and surveillance system.

AIRBORNE NAVIGATION TODAY

Aircraft operating in civilian airways today still rely on the same ground-based radio aids created over half a century ago. Pilots regularly use ground radio navigation signals to fly a prescribed course. The path moves the aircraft from one station to another. The stations are positioned to provide a good coverage area but generally do not allow the shortest course to be taken. During their service life the stations have proven reliable and shown their effectiveness. In a cost-saving move, the Federal Aviation Administration (FAA) has proposed shutting down of Non-Directional Beacon (NDB) stations in areas where there is coverage by other systems.

VOR and DME

The United States is home to approximately 2,000 VHF Omni-directional Range (VOR) and Distance Measuring Equipment (DME) transmitting stations [1]. This network was developed over the past 60 years. The network provides accurate information for traveling from one station to another. A major drawback to this system is that it does not provide a direct route from your departure point to final destination. Pilots must fly a series of straight line routes from station to station until finally reaching their destination airport. Also the reliance on ground based transmitters, as shown in Figure 1,
prohibits their use for oceanic and polar flights. A second system is required to accurately use those routes such as LORAN or GPS.

The VOR and DME stations provide information for a 360° coverage area. When traveling long distances, an aircraft follows a path from one station to another until reaching their final destination. Separation requirements based on the accuracy of the position indicators dictate how many aircraft can fit in the airspace between stations. This inevitably leads to congestion and delays throughout the major National Airspace System (NAS). The NAS is currently operating at maximum capacity in many areas and has “outgrown” the capabilities of the VOR and DME system.

Non-Directional Beacons

Non-Directional Beacons (NDB) were the first form of radio navigation for aircraft. The system is primitive by today’s standards providing only a signal for pilots to home in on. The NDB is susceptible to many types of interference including lightning, changes in the ionosphere, and terrain features (multi-path).

NDB has the advantage of being low-cost and having a higher useful range than a VOR station. This has helped promote its use in regions where it is economically impractical to set-up a VOR network. Areas such as Africa and Asia are using the NDB to establish an airspace system enabling access to more remote regions and promoting development.

In the United States, there are approximately 1,000 NDB stations operating even though an established VOR network has been in operation for over 40 years. Many NDB stations are used to supplement instrument approaches to airports; and are more of a redundancy than a necessity. In recognizing this, the FAA started a policy in 2005 of deactivating NDB stations that are viewed unnecessary. Small airports operating in the North East United States are primarily affected. This area has many high volume airports and contains an overabundance of radio navigation aids. One of the goals of inactivating the NDB is to free up funds to further develop GPS augmentation systems that provide better all-weather performance.

Small private aircraft will have to invest in a GPS system to continue to use these small airports in instrument flying conditions. The cost impact of this is minimal and the level of precision and safety offered by GPS will outweigh the inconvenience of moving to a new system.

Inactivation of less than ten percent of the NDB stations is a small change in the total NAS. It does mark an important step toward transitioning away from ground-based navigation aids. Many more of these small steps are necessary to change the NAS.

TRANSMISSION

Moving from ground-Based navigation to GPS and airborne surveillance will be one of the largest changes the aviation industry has ever seen. The transition will affect virtually everyone involved with aviation, and it will have a significant initial cost impact on the industry. The magnitude of this change requires that it be implemented in precise gradual steps to ensure compliance and prevent companies from going out of business because they cannot meet the financial requirements.

Mandating Navigation and Surveillance Equipment

The aviation community looks toward regulating bodies for direction on what equipment to use. These bodies are part of their respective governments and policies are often influenced by politics rather than the common benefit to the industry. Agencies such as the FAA must gain the support and have the internal commitment to see any changes through.

A set of new policies and mandates by the regulatory bodies will mark the start of the transition. The mandates must specifically call out who and what will be affected and give a specific timeline for the changes to take place. Following this the agencies must work to ensure the adherence to mandates. An example for this is the Reduced Vertical Separation Minimum (RVSM). This program requires the use of new equipment and its implementation was dictated by a deadline date. Users who could not meet the requirements are now required to operate in a restricted capacity. A similar policy should be required for those who cannot meet the transition deadlines.

Time for Implementation and Absorption of Cost:

- 0 Years: Start of Transition, Execution of FAA Mandates.
- 0-3 Years: Certification of GPS SPS signal as the primary domestic navigation means. Increase coverage area of ADS-B system to cover low volume air traffic areas.
- 3-6 Years: Require all commercial transport aircraft to certify or install an approved GPS navigation system. Increase ADS-B coverage to all areas except the area with the highest traffic area. Place low volume area NDB, VOR, and DME stations in an inactive mode.
• 6-8 Years: Require installation of ADS-B by all commercial transport aircraft. Complete ADS-B coverage area. Inactivate all NDB, VOR, and DME stations except those around major airports or route transitions.

• 8-10 Years: Inactivate remaining NDB, VOR, and DME stations; require all ATC users to have a certified GPS SPS system and ADS-B system.

• 10 Years: Transition Complete, NAS is Free-Flight Capable.

GPS: A PRIMARY MEANS OF NAVIGATION

The Global Positioning System (GPS) is one of the greatest advances in navigation since the development of the compass. GPS is a satellite-based system capable of providing position, altitude, and speed. The system is funded by the US Department of Defense and is primarily intended for military users. GPS satellites transmit two types of signals. One signal, known as Standard Positioning Service (SPS), is used by the civilian market to provide navigation information. When GPS first started broadcasting, a technique known as “Selective Availability” was used to reduce the precision of civilian receivers. This was done to prevent a hostile military force from using the system against the US military. In the year 2000, the amount of signal degradation from Selective Availability was set to zero. The second signal, known as Precise Positioning Service (PPS), is used with the SPS signal to give a very accurate position information to military users.

Use of GPS for primary navigation must comply with limitations of the system. GPS provides highly accurate information on a user’s location, but it is not 100% accurate even with the removal of intentional signal flaws. Random signal interference by the ionosphere and other natural phenomenon introduce error into the calculated position. This makes the unaugmented system unreliable for precision landing approaches in poor weather conditions. However position accuracy is good enough to meet current RVSM requirements. It is also acceptable for most Area Navigation (RNAV) flight criteria.

GPS has proven its effectiveness in civilian applications for over two decades. The system is used as a primary navigation for oceanic flights. The removal of signal degradation in the SPS signal gives civilian users a high level of position confidence. Improvements in the satellite constellation have made the likelihood of a complete system failure unlikely. Also, the introduction of signal error detection protocols for example Receiver Autonomous Integrity Monitoring, (RAIMS), has further increased system integrity. All of these made GPS more reliable and accurate than current terrestrial navigation means. The extensive amount of time the system has been used gives a history of performance.

The separation of using GPS for navigation versus precision lands is a key criterion for timely certification of GPS for the aviation industry. Technology for augmenting GPS signal and improving accuracy is under development. It will take some time before it is available is enough areas to warrant certification. A goal of transition is to use equipment readily available today. Navigation with GPS meets that goal.

Automatic Dependent Surveillance-Broadcast (ADS-B)

One of the major challenges in aviation service is tracking and identifying all airborne aircraft. This was partially solved through the use of transponders. Transponders are only able to communicate with ground stations. The more recently developed Traffic Alert and Collision Avoidance System (TCAS) enables aircraft to exchange information on their positions. This system comes at a significant cost that is beyond the resources of most General Aviation users. The ADS-B system provides the same position information as TCAS, as well as information on an aircraft’s intentions, at a fraction of the cost of TCAS. It should be understood that ADS-B is not intended as a collision avoidance system because it lacks the ability to coordinate maneuvers.

To use ADS-B, an aircraft will need a transmitter, display, and GPS. Under the transition plan proposed in this paper a GPS is required for users. Having GPS as the core feature for transition will lower end user cost and provide momentum for the acceptance and certification for both systems.

For the ADS-B system to operate a network of ground monitoring stations is needed. In addition, radar sites supplying traffic information known as Traffic Information Service-Broadcast (TIS-B) are needed. Existing locations at airports and FAA radar sites will serve as the ground sites. The FAA has already taken steps to establish this network on the East Coast of the United States as shown in Figure 2.

Similar networks are operating in Alaska and Australia. A scaled down version of the network is operating in the Central
Florida region. It is primarily used to track pilot training flights. The small scale networks are good models for a national network.

**Ground Station “Inactivation”**

After shutting down over 300 ground stations the next problem is: “What do we do with them?” The majority of the stations are quite old and built before current environmental protection laws were in place. The locations of these sites range from public airports to private land that is leased.

One option is to simply dismantle the stations and return any leased land to its owners. A major problem with this is the cost of clean-up and restoration of the land. The age of the facilities implies that toxins such as lead-based paint and asbestos were used during construction. The cost of removing and restoring the sites could jeopardize the transition program. In this time of terrorist concerns, it is also a waste of valuable assets.

A more promising option is to simply “inactivate” the stations and preserve them in a stand-by condition. The stations would require a periodic check for security and equipment condition. The cost of continuing to lease private land may be substantially less than a site clean-up and the stations remain available in the event of a major emergency.

![Fig. 3. GPS Ground Station Location (Credit US DoD)](image)

**SECURITY BENEFITS**

The threat of terrorism in the United States and world-wide is a primary concern for the aviation industry. Terrorists have placed a large burden on countries who must tie up precious resources for security. The attacks of September 11, 2001 put the focus of security on passengers and passenger safety. A secondary effect of the attack was the major disruption of air travel. Areas dependent on air travel for access found themselves virtually cut off with the suspension of flights. An example of this is the Hawaiian Islands. The ramifications of the lack of air service was a large decline in tourism revenue which harshly affected that state’s economy.

Terrorists can cause a major disruption to the NAS by damaging or destroying the navigation aids on which they rely. With most of the money spent on aviation security directed toward the passenger, little focus has been spent on the radio navigation ground stations. Navigation systems on airport property are often in remote portions of the facility and the electronics inside protected by a locked door and possibly a simple alarm. The Melbourne Florida International Airport VOR is a good example of a facility located on government land. Stations not located on government property have a fence surrounding the complex and other basic security features. These sites provide an easy target for potential attack.

The destruction or corruption of one station would have little to no influence to the NAS. However, a coordinated attack in several locations could jeopardize air service in that area causing a ripple of delays and cancellations throughout the system. If the attack were of a large enough scale to put in doubt the security of the system, we could see a stoppage of air travel. Once again we could suffer from hundreds of millions of dollars lost. The current NAS is simply not prepared to handle a future terrorist strike.

GPS was developed with the military as the primary user. Because of this, ground tracking stations were developed with security a higher priority. The loss of GPS is a major threat to national security and many steps are taken to prevent a breech of the system. The number of actual ground sites is much smaller than the number of VOR and DME stations, as shown in Figure 3. Error detection software and signal integrity monitoring minimize threats from local jamming attempts. Even in the event of complete loss of information from the controlling stations, the satellites can still deliver accurate information for almost six months.

The ADS-B system requires more ground stations than GPS, but is not essential to safe navigation. The actual equipment needed will fit into existing buildings and does not require the separate area that a VOR transmitter station requires. The loss of a ground station is overcome by the use of direct air traffic control. This does hamper the “Free Flight” system; however, aircraft will still be able to use the airspace.

**COST SAVINGS**

In a free market companies looking for a competitive edge drive technology to make products more practical and economical. When a new technology that gives a company an advantage is developed, it is first studied, and then copied. This minimizes the time one company has an advantage and maintains a competitive environment to help develop even better systems by all competitors.

The commercial aviation industry is a competitive market with companies ranging from large global airlines to single operator up-starts. The desire for new technology is the same as with any other market. However, the industry must wait on approval by the FAA before using any new technology in their
Table 1. 2003 FAA Operation & Maintenance (O & M) Budget DME, VOR, NDB [1]

<table>
<thead>
<tr>
<th>Facility Type</th>
<th>Number in NAS</th>
<th>Total O&amp;M Cost</th>
<th>% of Total O&amp;M Budget</th>
<th>Annual Facility Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>DME</td>
<td>822</td>
<td>$24,898,889</td>
<td>7.12%</td>
<td>$30,291</td>
</tr>
<tr>
<td>NDB</td>
<td>1,168</td>
<td>$16,370,539</td>
<td>4.68%</td>
<td>$14,016</td>
</tr>
<tr>
<td>VOR</td>
<td>1,037</td>
<td>$43,892,908</td>
<td>12.55%</td>
<td>$42,327</td>
</tr>
<tr>
<td>Total</td>
<td>3,027</td>
<td>$85,162,336</td>
<td>24.35%</td>
<td>$86,634</td>
</tr>
</tbody>
</table>

aircraft. This has put the FAA in the position of deciding what technology to use and when it must be used.

The FAA examines the cost-benefit analysis of any new policies before deciding to implement them. Unfortunately, political pressure is often the key factor with FAA doctrine. When a company has a large fleet of aircraft, the cost of installing new equipment can be very substantial and require a large investment in capital and funds. The company may find it is more cost effective to use political pressure to slow down the required use of new equipment.

A growing company acquiring new aircraft requires a smaller investment in the equipment since often the new equipment is already included with the aircraft. This gives a financial advantage to the newer companies. The companies desire mandates they know will put their larger competitors at a disadvantage. However, the newer companies lack the clout to help motivate key politicians.

For a transition to succeed, motivation for both large and small companies is needed. Using funds to help subsidize a change will motivate companies to change. The question is: "What source will provide enough money to make the transition financially acceptable?" The FAA annually spends over $85 million a year on the operation and maintenance of NDB, DME, and VOR stations, as shown in Table 1. During transition, as stations are inactivated, funds which were used to operate these facilities can be reallocated toward providing financial incentives in commercial and private users. Money can also be allocated to the certification of GPS and to the establishment of an ADS-B network within the United States. Assuming no change from the amount spent in 2003, almost one billion dollars of funding would be available for the program at no extra cost to the taxpayer and without taking money from other programs.

When the program is complete the FAA will decide how best to spend the money saved each year from inactivating ground stations. The stations will still need some minor maintenance and upkeep to maintain standby conditions. Improvements in other areas of the ground network should also be considered. Augmentation systems to replace the current Instrument Landing System (ILS) are needed. Funding for research and development of other systems is another viable option.

However the money is used, the savings and return on investment will be substantial.

CONCLUSION

For thousands of years humanity has traveled the Earth. Forward thinkers have continually sought ways to make traveling more efficient. Inventions such as the compass and the mariner's clock allowed ships to travel to new lands more safely and more quickly. Ground radio navigation aids have guided countless of aviators through our skies. But, just as the rest of the world has supplemented their compass with GPS, the aviation world must do the same.

The size of the aviation community imposes a large problem. How do you make this diverse group change its ways? Even though change will benefit users in cost savings and safety, it will still require a capital investment in the beginning. A similar challenge has occurred in the United States with the introduction of the one dollar coin. In the past 30 years the US has twice tried to replace the paper one dollar bill with a coin. Both attempts have failed. The reason for the failure is simple; there was no incentive or push by the government to change.

This paper has outlined a proactive plan for the transition from ground-based navigation aids to GPS and airborne surveillance. This plan provides a way to establish financial incentives and fund development without additional funding from the government. A period of ten years is set to give the community time to adjust with a minimum of impact. The end result of transition is a more efficient NAS that is safer from system failures and security threats and is capable of better serving its customers and positively contributing to the world economy.

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A Hardware Signal Processing Platform for Sensor Systems

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Signal Processing Laboratory
Jukka Ruoskanen
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ABSTRACT

A Field Programmable Gate Array-based computing platform for high-speed sensors such as short-range radars is presented. The circuit performs necessary A/D conversions, raw data stream compression and target detection, and constructs a message structure suitable for external displays. In the prototype, USB is the connecting path to a laptop computer. An elementary pulse radar is utilized as an application example. An application interest would be in collision avoidance systems. Observed data transfer rates with real radar input signals were 36 Mbytes/s when typical target detection algorithms were applied.

INTRODUCTION

Many modern sensors such as imaging systems and short range radars produce huge amounts of real-time raw data. This is partly due to the inherent nature of sensor information, for example, in infrared or visible-optics applications and partly based on the required reaction times of collision avoidance devices and weapon systems as can be deduced from [1]. In a typical pulse radar, for example, the pulse repetition frequency and scan rate must be such that the platform crew – or more often the onboard automated electronics – has enough time to initiate necessary counter-actions [2]. The pulse width, on the other hand, must be short enough to allow precise location of interesting objects. These high rates create signal bandwidths easily exceeding 50 MHz. Similar challenges are faced in infrared sensors when some form of pattern recognition is attempted “on-the-fly.” In both cases, one of the fundamental limitations is caused by the need to use data from previous scans or captures for the analysis of current information whereby memory capacity is easily exceeded. Alternatively, we have to be able to handle all the relevant bits and bytes fast enough. The difference in processing work between typical stationary air surveillance radars and short-range mobile platform systems is further illustrated in Table 1, which is based on data from [3, 4].

Due to the continuing miniaturization in electronics manufacturing technology, it is possible to implement modules and entire systems digitally. This trend is evident also in sensor technology, where traditional analog functions are being replaced by digital implementations, especially in radar control, baseband processing, and displays. An ideal digital implementation has the benefits of the speed of hardware and the flexibility of software. This can be accomplished by implementing as many functions as possible with Field Programmable Gate Arrays, in brief FPGAs. They are superior to processors in one particular respect: they give true parallelism for heavy computation. There are numerous published accounts on using FPGAs in radar signal processing, [5, 6], but mostly the previously presented solutions have tackled some limited portion of the processing chain only. This article highlights an approach where the entire processing part of a high-speed sensor relies on FPGA technology.

THE RADAR APPLICATION EXAMPLE

We use as an application example a basic short-range radar similar to that described in [7]. This radar has a high pulse repetition frequency (PRF) and its video bandwidth exceeds 25 MHz. Therefore, the sampling rate of each interesting channel must be of the order of 100 MHz or higher. As a first step forward from the classical A-scope display (actually realized with a low-cost digitizing oscilloscope) the test team tried to interface the existing radar hardware with a commercial off-the-shelf (COTS) data acquisition card to a host PC. However, despite the fact that the card was capable of receiving the
Table 1. Some performance figures for air surveillance and mobile short-range radars

<table>
<thead>
<tr>
<th></th>
<th>Surveillance radar</th>
<th>Short-range radar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scan time</td>
<td>10 . . . 20 s</td>
<td>0.5 . . . 1 s</td>
</tr>
<tr>
<td>PRF</td>
<td>100 Hz . . . 1 kHz</td>
<td>10 kHz . . . 100 kHz</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>1 . . . 5 MHz</td>
<td>10 . . . 100 MHz</td>
</tr>
<tr>
<td>Range Resolution</td>
<td>100 m . . . 1 km</td>
<td>1 . . . 30 m</td>
</tr>
<tr>
<td>Angular resolution</td>
<td>0.5 . . . 2.5°</td>
<td>0.3 . . . 1°</td>
</tr>
<tr>
<td>Reaction time</td>
<td>12 . . . 90 s</td>
<td>1 . . . 2 s</td>
</tr>
<tr>
<td>Raw data rate</td>
<td>200 kbit/s . . . 10 Mbit/s</td>
<td>500 . . . 1000 Mbit/s</td>
</tr>
</tbody>
</table>

necessary raw signals and performing the A/D conversions, the trials failed miserably. The uncompressed data rate of 800 Mbps quickly exhausted the host computer memory, thus making both real-time radar display generation and data stream recording for offline analysis practically impossible.

It is evident that the sampled data stream has to be compressed, and that some primary detection routines must stay outside the PC software. Figure 1 shows a simple visualization of a typical real-life V-band radar PRI, similar to that described in [7], and its large amount of useless “data.” An FPGA-based reconfigurable platform named SIG USB Card v2 [8], was developed and introduced for this purpose. The goal was to transfer as much computation as possible onto the FPGA-based platform. A generic signal flow diagram relevant for our example application is presented in Figure 2.

THE RECONFIGURABLE FPGA PLATFORM

The computing core card, now called SIG USB Card v2, houses two large FPGA chips of Altera’s Apex II device family [9], external connections, an SDRAM socket, 32 kilobytes of dual-port RAM, and an 8051 derivative with a Cypress CY7C68013 USB controller and transceiver as outlined in Figure 3. Both FPGA devices can be reconfigured on-the-fly, which shortens system development time. Two FPGAs give the additional benefit of numerous IO pins without a need for clumsy packaging (which would be mandatory if just one single chip was selected). The USB version 2.0 protocol was selected, as it is electrically simple with only four wires, has theoretically adequate transmission speed at maximum 480 Mbps [10], and is supported by laptop computers suitable for field tests. Choosing a laptop prevented using a higher speed PCI bus. Naturally, there must be constant bookkeeping by the 8051-based USB controller to prevent overlaps in reads by the host PC and writes by the FPGA.

The first target detection algorithm was written in VHDL and was based on a previous analog radar implementation. The incoming samples are compared to an on-the-fly adjustable threshold value, and the well-known n-out-of-m rule is applied for compression. The FPGA constructs a data structure with appropriate header bits and stuffing and writes detection results to the dual-port RAM. The data structure used for display generation is explained in Figure 4. There are four bits available for target echo amplitude, which was considered sufficient for human decisions. A limiting factor is the dual-port RAM size of only 32 kilobytes, and it was decided to encode an entire display frame into this amount of memory.

CONNECTIONS TO A/D CONVERTERS AND DISPLAYS

The SIG USB Card v2 is connected to two separate A/D converter boards using a flat cable. The first A/D converter is used for sampling the echo amplitude at 100 MHz with a resolution of 8 bits, and the second A/D converter samples echo phase for Doppler processing. A separate channel is provided for antenna bearing. At first sight, the granularity of
angle information at 1.4° (360°/256) may appear annoying, but in practice the laptop display quality did not improve with greater word lengths. Zooming in the display is not implemented. In addition to the two sampled bytes from A/D converters, a TTL pre-trigger pulse from the radar is transmitted to the FPGA devices (see Figure 2). Figure 5 depicts the real prototype card after assembly. Due to BGA-type IC packaging, the board has eight layers.

In our example application, the display software runs at the host PC in two operating modes: an A-scope mode and a PPI radar display mode. Depending on the mode selected by the user, the FPGA devices construct either the time-domain data stream or create an entire PPI display frame that fits exactly into the 32 kilobyte dual port RAM. In A-scope mode, the data stream can be saved to hard disk for offline inspection and algorithm development. The display software was developed with the OpenGL graphics library, which alleviated the load on the host processor by transferring the computation-intensive graphics algorithms to the display card. For example, implementing simulated after-glow is very efficient by simply decrementing a pixel value in the data structure. This is also in line with the applied design philosophy of transferring as much algorithmically demanding computation away from a general-purpose PC processor, which is most suitable for system-level bookkeeping and communications management.

**CONCLUDING REMARKS**

The main benefits of using our FPGA-based generic computing platform for sensor data processing are in their "on-the-fly" reconfigurability and high throughput. When designing entirely new systems, the relatively rapid design cycles with parallel hardware and software development threads is certainly appreciated. Only twelve-person-months were required by a three-man team having no previous experience in radar technology to implement the desired baseband and display modules for a fully functional test radar system.

Gate counts in modern FPGAs are sufficient for computationally demanding algorithms, and in our particular application, most of the logic remained unused as the target detection algorithm was very robust. USB 2.0 proved to be
much too slow for any future extensions and, depending on host PC circuit family, the real observed transfer rate was approximately 36 Mbytes/s. The specification would allow in bulk transfer mode roughly 53 Mbytes/s. Unfortunately, some IP blocks provided by the manufacturers are only usable in the very latest circuit versions. An obvious bottleneck in the first SIG USB v2 card is its dependence on the limited amount of DPRAM, and this will improve in the next version, together with an obvious upgrade in the FPGA generation. The design emphasis will shift to developing algorithms for increased range, range-rate, and angular accuracy, taking into account enhanced Doppler processing and implementing sliding-window techniques for detection. Connection to PC displays will be based on Gigabit Ethernet.

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Distance Estimation at 60 GHz

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ABSTRACT

An FM-CW radar front-end was fabricated in an integrated manner at 60 GHz by using the NRD guide. Main emphasis was placed on compactness in size and high-precision operation in performance. The fabricated radar consists of an FM Gunn oscillator, a balanced mixer, and a planar antenna fed by leaky NRD guide with a mechanically beam-scanning performance. All circuit components and the antenna were contained in a compact housing of $170 \times 140$ mm in area and 25 mm in thickness, and thus, a thin type of millimeter-wave radar front-end was successfully developed. Moreover, an error of distance estimation was measured to be less than a distance of 0.7 m.

INTRODUCTION

Millimeter-wave frequencies have attracted much attention for the construction of novel communication and sensing systems. Actually several types of millimeter-wave front-ends have been developed by many companies, institutions, and laboratories based on various printed transmission line techniques [1]. The printed transmission lines are suitable for applications in the centimeter frequencies, but they suffer from a lot of transmission losses in the millimeter-wave region.

Another candidate as a transmission medium is the NRD guide, which consists of dielectric strips inserted in a below cutoff parallel metal plate waveguide and features no radiation at curved sections and discontinuities. Indeed, many high performance millimeter-wave front-ends such as an ultra-high

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Based on a presentation at the IEEE Radar Conference 2005.

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Fig. 3. Side view of NRD guide FM-CW radar front-end

Fig. 4. Structure of NRD guide FM Gunn oscillator

Fig. 5. Measured performance of NRD guide FM Gunn oscillator

Fig. 6. Side view of leaky NRD guide

Fig. 7. Side view of coupling slit

Fig. 8. Plane view of coupling slit

speed LAN transceiver [2] and a broad-band transmitter and receiver [3] have been successfully fabricated.
Table 1. Performance of NRD guide pulse radar

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF Frequency</td>
<td>59.5 GHz</td>
</tr>
<tr>
<td>RF Power</td>
<td>6.3 mW</td>
</tr>
<tr>
<td>Modulation Bandwidth</td>
<td>75 MHz</td>
</tr>
<tr>
<td>Antenna Gain</td>
<td>33.5 dBi</td>
</tr>
<tr>
<td>Half Power Beam Width</td>
<td>2.7°</td>
</tr>
<tr>
<td>Parallel Plane to the Slot</td>
<td></td>
</tr>
<tr>
<td>Cross Plane to the Slot</td>
<td>2.3°</td>
</tr>
<tr>
<td>Beam Scanning Angle</td>
<td>15°</td>
</tr>
<tr>
<td>Detection Distance</td>
<td>5 – 120 m</td>
</tr>
<tr>
<td>Supply Voltage</td>
<td>12 V</td>
</tr>
<tr>
<td>Size</td>
<td>170 H X 120 W X 25 T mm</td>
</tr>
</tbody>
</table>

With this in mind, we developed an FM-CW radar front-end for distance estimation at 60 GHz band.

**NRD GUIDE FM-CW RADAR**

Figure 1 shows a structure of the NRD guide FM-CW radar, which has a double layered structure. The NRD guide circuit as shown in Figure 2, which consists of an FM Gunn oscillator, two 3-dB directional couplers, a circulator, and a balanced mixer, are installed in the lower layer. A modulated wave is introduced to a leaky NRD guide radiator through a coaxial transition. This leaky NRD guide is an uni-directional radiator because a reflector is set at right side. A leaky wave is introduced from the lower layer to the upper layer through a coupling slit. To scan a main beam, a short plate is mechanically rotated by a motor as shown in Figure 3.

**FM OSCILLATOR AND ANTENNA**

In this chapter, characteristics of key components for FM-CW radar are described. The metal plate separation of the NRD guide was set at 2.25 mm so as to be less than half a free space wavelength at 60 GHz. Teflon with a relative dielectric constant of 2.04 was chosen as a dielectric strip due to its low loss nature, and its cross sectional dimensions were 2.25 mm in height and 2.5 mm in width, respectively.

At first, a structure of an FM-Gunn oscillator is shown in Figure 4. A Gunn diode was transversely inserted in an H-shaped metal block, where a λ/4 choke circuit was installed in the metal block. A beam-lead type varactor diode mount was made by glass-Teflon substrate as shown in the inset of Figure 4, on which electrodes and bias chock circuits were etched. The diode mount was sandwiched by Teflon pieces and this was located behind the Gunn oscillator. Figure 5 shows the measured frequency deviation and output power of the FM Gunn oscillator. The oscillation frequency can be tuned at 300 MHz versus the bias voltage of 15 V, while the oscillation power is 80 mW on average.

Next consideration is concerned with a leaky NRD guide. The NRD guide has non-radiating nature, but radiation occurs in an asymmetrical structure for horizontal mid-plane of the NRD guide. A example of the an-symmetrical structure is shown in Figure 6, where the Teflon strip was embedded in a groove made on the metal plate. In this structure, a leaky wave is radiated to the left side due to installation of the reflector, and is introduced to the upper layer as shown in Figure 7.

Figure 8 shows a plane view of the coupling slit. When the short plane was leaned by the motor, the direction of the leaky wave was changed. The measured radiation patterns versus the leaning angle are shown in Figure 9. It is obvious that the direction of the main beam can be controlled at 150 without any degradation of the radiation pattern.

**PERFORMANCE OF NRD GUIDE FM-CW RADAR**

Figure 10 shows a photograph of the fabricated NRD guide FM-CW radar front-end. All circuits components and the antenna was contained in a compact housing of 170 x 140 mm
in area and 25 mm in thickness, and thus, a thin type of millimeter-wave radar front-end was successfully developed. The measured distance estimation performance is shown in Figure 11. The precise radar performance can be confirmed because the estimation error was less than 0.7 m for the distance to the target from 5 m to 120 m. The performance of this radar is summarized in Table 1.

CONCLUSION

An FM-CW radar front-end was fabricated based on the NRD guide technology at 60 GHz. The radar has a compact housing of 170 × 140 mm in area and 25 mm in thickness. Precise distance estimation was successfully performed. The NRD guide FM-CW radar is expected to play a key role in millimeter-wave sensing systems.

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TerraSAR-X Active Radar Ground Calibrator System

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University of Karlsruhe

ABSTRACT

In April 2006, the TerraSAR-X satellite will be launched. This paper describes the development of a novel and highly integrated, digitally-controlled active SAR system calibrator (DARC). It consists of both an active transponder path for absolute radiometric calibration and a calibrated receiver chain for antenna pattern evaluation of the satellite antenna. A total of 16 active transponder and receiver systems and 17 receiver-only systems will be fabricated for a calibration campaign in 2006.

INTRODUCTION

Within the first half of 2006, the TerraSAR-X satellite will be launched in a private/public partnership between the German Aerospace Center (DLR) and EADS Astrium GmbH. TerraSAR-X will provide SAR data both for the scientific and commercial communities with an extremely high accuracy. The SAR instrument is very versatile by multiple operation modes, adapted to various applications. The calibration of the SAR instrument is crucial to guarantee and verify data quality. This includes both internal and external calibration. The former is related to the instrument and control circuit design and is not the subject of this paper. The external calibration includes measuring the response of known targets. By comparing the ideal response with the measured signals, a correction scheme is derived.

Traditionally, the external calibration uses passive man-made and natural targets. However, active transponders are preferred for high accuracy applications requiring absolute radiometric calibration [1]. Additionally, this novel calibrator provides a calibrated receiver path for satellite antenna pattern evaluation. This paper presents the system concept and hardware realization of a Digitally controlled Active ground Calibration system (DARC) which will be used during the operation and validation phase of the TerraSAR-X mission in early 2006.

In total there will be 16 active transponder and receiver systems allowing both the analysis of the satellite antenna diagram in azimuth direction and a precise calibration signal. For the elevation direction, a number of receiver-only systems will be distributed along the corresponding longitude.

SYSTEM ARCHITECTURE

The calibrator system consists of a set of two antennas, a transmitter chain for the signal to be retransmitted to the satellite (transponder operation), and a detector (receiver path) as shown in Figure 1. Thus the system provides an active reference target for the SAR and simultaneously allows both analyzing the pulse signals transmitted by the satellite and monitoring the performance of the transponder itself.

In total, the DARC system is designed for:

- **Transponder**
  - active RCS setting
  - polarimetric and interferometric calibration
  - transponder gain monitoring, and
  - interpulse coding.

- **Detection**
  - azimuth satellite pattern (one transponder)
  - elevation pattern (several transponders), and
  - measure signal envelope distortion.

![Fig. 1. Block diagram of transponder](image)

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Based on a presentation at IEEE Radar 2005.
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**Fig. 2. Assembly of multi-layer substrate**

- **Additional Features Include:**
  - digital control through a web interface
  - synchronized to GPS clock
  - position through GPS
  - data compression & real-time pulse detection
  - data storage on flash ROM
  - dedicated control algorithms for heat up, and
  - power save modus.

The RF hardware is realized in a multi-layer architecture. The RF layer consists of a RF Duroid R04003 with a height of 0.2 mm. Then a DC layer is introduced which carries buried DC supply and control lines. FR4 is chosen for this purpose with a height of 1.2 mm. In order to guarantee a symmetric assembly, the bottom layer is again a Duroid substrate as shown in Figure 2. A grounded coplanar waveguide structure is chosen to feed the RF to the MMICs. It yields low losses and good grounding. The relative dielectric constant of the substrate is chosen to 3.38.

**SYSTEM OPERATION**

**System Overview**

The system bandwidth is 300 MHz, the midband frequency is 9.65 GHz. A dedicated filter suppresses distortion signals from outside the used bandwidth, e.g., the Astra TV-satellites. A good image rejection is also necessary, as the received signal shall also be downconverted to evaluate the pulse shape. The system is integrated in a metallic box to protect it from all kinds of distortion signals. Two optimum gain horn antennas serve as receive and transmit antenna. The arrangements of the antennas is such that the input and output signals are linearly, orthogonally polarized so that they are always aligned 45° to the incoming polarization. The transmitter gain can be adjusted within a range of 20 dB digitally by setting the attenuator of the RF path.

The phase of the retransmitted pulse can be coded digitally. The PN coding of the retransmitted signal allows us to identify each single transponder in the later SAR image [1]. The coding has a couple of benefits concerning the detection of the transponder in the later SAR image. Passive targets like corner reflectors cannot be removed from the later SAR image. Yet, if the retransmitted signal is coded digitally, one can either choose to suppress the surrounding and to focus on the calibration signal or to suppress the transponder and to focus on the environment. The coding is introduced by two single pole double through (SPDT) switches as shown in Figure 1. They introduce a true time delay of exactly 180° by a change of the transmission line length. The switches are controlled digitally.

**Automatic System Operation**

A digital, reconfigurable control unit realizes the signal detection and transmission process. It manages the data take from the satellite, controls the A/D converter, and applies an appropriate data compression algorithm to the incoming data. A temperature control will heat the system to work at the predetermined optimum temperature. The data can be accessed by an ethernet interface. Furthermore, the output signal power level is available which allows us to monitor the radar cross-section (RCS) of the transponder. The user has to feed the expected satellite pass-by-time.

**System Performance**

The input signal varies between –84 dBm and –39 dBm, covering a dynamic range of 45 dB. The maximum RCS is at 50 dBsm and the antenna gain is chosen to 21 dBi.

Concerning these figures, the electronic amplification can be determined with the maximum amplification to 55 dB. Additional losses have to be considered. The maximum output power is +16 dBm in the 45° configuration. Figure 3 shows the electronic amplification according to the RCS desired.

**System Measurements**

Systematic errors in the RF transmit path cannot be compensated for by calibration algorithms. The maximum
gain is plotted in Figure 4. Reflected power at the ports will introduce a ripple on the gain. Therefore, good input and output return losses are important. To achieve the high gain, five MMIC amplifiers are placed in series. Each amplifier has its own DC supply to prevent coupling of spurious RF through the DC supply lines which is crucial at high gain amplifiers. All amplifiers are separated by metal walls to prevent coupling through the air interface. For the RF-line, small holes are milled in the walls. These are designed so that higher modes cannot travel through them.

In order to ensure a very low ripple over the system bandwidth, the amplifiers must provide a flat gain. Therefore, high bandwidth MMIC amplifiers are chosen as seen in Figure 8. The first amplifier is a LNA which yields a gain of 13 dB and a noise figure of 2.1 dB. Several medium power amplifiers are placed in series. A digitally controllable attenuator and two switches are placed in between the amplifiers. The last amplifier is a high power amplifier which has optional gain control to adjust the desired maximum output power. A power sweep shows that the amplifier chain works within their linear range at the maximum amplification (Figure 5). Thus, the incoming signal will not be distorted by the calibration device and high linearity is guaranteed.

A very crucial point concerning signal quality with radar systems is signal coupling from the transmit antenna to the input antenna. The coupling was measured with a network analyzer an average of −100 dB. Thus no oscillation can occur. The following plot shows the results over the bandwidth. The dotted line shows the measured decoupling from the network analyzer alone and the solid line shows the measured decoupling in the operational configuration with two 21 dBi horn antennas.

The system performance must be guaranteed over a temperature range from −20°C to +50°C. Therefore, calibration data was taken for error correction to guarantee a high accuracy. The RF hardware shows a signal ripple of only ±0.3 dB rms over the experimental bandwidth of ± 150 MHz.

Fig. 4. S-Parameters at maximum amplification

Fig. 5. Power Sweep at f = 9.65 GHz

Fig. 6. Decoupling from output to input

A change in the amplification of the transponder with temperature can be compensated for by a change of attenuation. The final transponder will be kept at a constant working temperature during the data take by a dedicated heating system so that severe temperature effects will not occur. If there were temperature effects, they could be compensated for by a digital adjustment of the amplification as the behavior over temperature is known. Therefore, a calibration loop for the SAR calibration signal is not necessary. This keeps system complexity and production costs low. A picture of the transponder hardware is shown in Figure 8.

CONCLUSION

In this paper, a novel and a highly integrated digitally controlled active SAR system calibrator is presented. It consists both of an active transponder path for absolute radiometric calibration and a calibrated receiver chain for antenna pattern evaluation of satellites. The calibration device has to comply with very strict specifications in order to
Fig. 7. Amplitude accuracy over temperature

guarantee high accuracy. Up to now, a transponder prototype has been developed and is currently integrated to the complete system. First performance results are expected after the launch of the Terra SAR-X satellite during the calibration campaign in southern Germany in April 2006.

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ABSTRACT

The problems are considered of a modelling research of navigation features and improvement of the navigating filters algorithms used in the navigating devices of ground Mobile Vehicles (MV). It is supposed that the methods and approaches known as Real Time Kinematic (RTK) are incorporated in a basis of researched navigating devices and algorithms. Thus, the measurements from satellite navigating systems such as GLONASS/GPS, and also the measurements from other traditional measuring means (tactile sensors, steering wheel angle and/or inertial measuring instruments) are used in the navigating device of the MV. In the present report we solve the problems and describe the methods of a modeling research of the features of functional units algorithms of the MV navigating processor with account of a satellite navigation set integration with other measuring instruments. The improvement of these devices interaction is made by means of the computer complex “AutoMobil,” allowing us to simulate the certain conditions of these navigating tools operation. The imitation computer complex “AutoMobil” for researches of the MV navigation is developed within the frameworks of a programming environment “Delphi-7.”

Methods of modeling research of features and characteristics of similar navigating devices are illustrated in the details on an example of study of the navigating block operation in the case of 4-wheel vehicles (automobiles). The data processing algorithm in this device is of the Kalman filter type. Such a device allows us to trace geodetic coordinates of the MV precisely enough (including height above sea level), to watch the components of its velocity, orientation of a longitudinal axis of the automobile. Offered methods of modeling research of the navigating devices and navigating problems features may be applied also in sea navigation for navigating devices of sea ships at integration of the satellite GPS/GLONASS navigation equipment with traditional ship gauges – measuring instruments.

The special emphasis is made on a correct formulation of statistical model of the measuring and instrumental errors, the preventing parameters as bases for adequate display of real conditions of the integrated navigating device operation in the conditions of obstructions (interference) and the noises in receipt and indication channels, mechanic impacts, close to real. Separately the movement parameters (position-velocity) of the navigational S/C and errors of ephemeris-time maintenance of a satellite navigation signal for GLONASS and GPS systems are modelled. The receiver of a navigating signal from SRNS is considered in one-frequency and two-frequency variants (for two-frequency a correction of the ionosphere delays in pseudoranges measurements is applied on the basis of comparison of the measurements in different bands, for one-frequency the parametrical correction is used). The opportunity of work is stipulated at various User Equivalent Range Error (UERE) models for a satellite signal. Typical budgets of measuring errors for standard samples of the one-frequency and two-frequency user equipments have been considered and used.

Results are given on improvement of the algorithmic apparatus for the solution of a navigating coordinate-velocity maintenance problem and trajectory supports of the ground wheel vehicles using similar integrated equipment. The calculation formulas are specified necessary for transitions between various coordinates systems (reference frames) used in the navigating filter. The conclusion about conformity (fitness) of expected characteristics of the device to the requirements of the automobile navigation is made and also about good reciprocal combination in this case of information from satellite receiver and information from traditional tactile automobile sensors.

Results are illustrated by a graphic material. The statistical methods are used for an estimation of quality of the navigating device operation, the covariance analysis, procedures of the statistical analysis of the time data series, partially, a Monte Carlo method of statistical tests with use of random number
Fig. 1. The block diagram (a circuit) of the modeling complex “AutoMobil” for imitations of process of tracking-navigating support of the automobile movement with use of the GLONASS/GPS user equipment at its integration with other measuring means.

generators. The material of the report is intended for specialists in the field of design and exploitation of the integrated navigating systems for on-ground and sea vehicles, for experts in satellite navigation.

THE FEATURES OF FUNCTIONING OF A USER NAVIGATION EQUIPMENT EMPLOYED A SATELLITE SIGNAL FOR NAVIGATION OF THE AUTOMOBILE VEHICLES

The effective utilization of all opportunities on navigating service that the satellite navigating system may give potentially for ground transport users depends on the presence of the user’s measuring-navigating equipment of a good quality on a vehicle. It is desirable that this equipment was of low cost. For mobile transport consumers it is necessary to have the specific navigating equipment in which satellite measurements and a satellite signal are integrated with the certain traditional means or systems so that there was an opportunity of navigating maintenance steady at inexpensive serial cost of the complete set of the navigating device, reliable and acceptable on accuracy, and accompanying service opportunities.

Development of domestic automobile navigating devices effective and accessible at cost should base on results of preliminary scientific and technical researches. Such work includes also a stage of imitating tests with use of computer facilities which should precede more high on expenses and crucial stage of natural tests and operational development of the equipment samples.

With application of computer imitating modelling tests it is possible to investigate the problems of integration of a satellite signal receiver with traditional measuring instruments and inertial measuring systems. Also it is possible to simulate real external conditions at the receiver equipment operation, to take into account a structure of a navigating signal from SRNS and probable handicaps and distortions at its receive, in particular, effects from multipaths at the reflection of a signal from the big reflecting planes of city buildings. Also there is an opportunity on computer model to develop and optimize a structure of the dynamic navigating filter and to carry out imitating estimations of resulting accuracy of the mobile transport user navigation. Also it is important to estimate an opportunity of autonomous work at breaks in reception of a signal, influence of modes of movement and external conditions (buildings shadowing), etc. For solution of the given questions of satellite navigation on the base GPS and GLONASS the technology used is named in the foreign scientific and technical periodical press as Real Time Kinematic (RTK). As a rule, for essential improvement of the tracking accuracy the phase measurements (Integral
Doppler) on the current frequency are used and different ways of measurements smoothing and ambiguity resolution [25-41]. The use of adaptation Kalman filters adjoins also to this section. It is possible by means of a complex «AutoMobil» to investigate and to design the mechanisms of adaptation provided in the navigating device with the purpose of maintenance its best adjustment to concrete conditions of operation. A great attention is devoted to problem filters adaptation in scientific and technical publications concerning the given subjects [24-33].

Tracking support of the moving automobile on the basis of the integrated navigating device is carried out in circumstances of influence of various handicaps and presence of tool measuring errors of a various nature. During model experiment (at simulation process) all nuances of navigating algorithm behaviour are investigated at various values of real dispersions and covarizations of casual errors, regular deviations and preventing parameters, for different model characteristics of a trace line, shadowing of S/C by buildings, etc.). Computer modelling allows us to imitate the automobile movement on a district and on a trace with account of properties of spreading surface, dynamics of acceleration-deceleration at work of the car engine, influences of rotary mechanisms at realization of turns or movements on the circling line sites.

The received results of modelling may be used three ways:

A) for drawing up of certified passport characteristics on the concrete navigating device or navigating algorithm;

B) for improvement and adaptation of the navigating device algorithm and choice/check of the mechanism of adaptation; and

C) for revealing bottlenecks in a structure of measuring means and for choice of ways of their integration in the given navigating device with the purpose of its modernization and perfection.

The experimental variant of algorithmic software is considered in the report for usage in the navigation-measuring integrated equipment intended for mass use in civil sector on mobile (wheel automobile) vehicles. The given variant of the experimental navigating processor is developed and tested in Information-Analytical Center of Mission Control Center, Korolev, Moscow region.

In the navigating filter chosen as typical for demonstration of the constructive device of a developed modelling software complex, it is applied numerical polynomial extrapolator in order to forecast longitudinal acceleration referencing on five previous knots points of values MV position and velocity. With the help of computer imitation full suitability of such device for automobile navigation in city conditions is established at presence of the combined GPS/GLONASS receiver of a satellite signal or for full constellation.
GLONASS. The given navigating device functions on a basis (exploits) only the following information:

A) pseudoranges/pseudovelocities measurements performed on the base of a satellite navigating signal (GLONASS and/or GPS) reception,

B) indications from the traditional automobile tactile gauges (sensors) connected to wheels, and from the gauge of a steering corner (a corner of turn of a steering wheel).

METHODOLOGY AND RESULTS OF IMITATING COMPUTER TESTS OF NAVIGATION FEATURES OF ON-GROUND MOBILE VEHICLES

The main instrument for analysis and processing of model-imitation data, that is used in model software complex "AutoMobil" are methods of statistic analysis of data time series. These data series are the documented model deviations (differences) of the “virtual” navigation trajectory from the “real” (program-modelled) one of auto motion. With help of these methods, realized as software procedures, on the typical time intervals of model auto motion (about 10-60 min) on the base of accumulated recorded data of the pointed deviations the standard characteristics are defined, such as systematic biases, mean-square residuals of random deviations, MS errors of position-velocity definition, mean errors of the referencing to ITRF, and errors of attitude of auto longitudinal axis.

The resulting accuracy and reliability of navigation with use of measurements on a satellite radionavigating systems signal depends, first of all, on characteristics and features of satellite systems (completeness of an orbital grouping, structure of a navigational radio signal). The conditions of a signal reception and visibility of satellites constellation have essential importance (with account of a masking profile of the land relief or vicinity structures and so forth). For the planes flying at height of some km above the Earth surface, for sea ships at an open ocean the camouflage angle may be accepted equal 0°-5°.

It is necessary at navigation in city conditions, at presence of masking from buildings and culture structures (urban constructions), in mountain district to accept the camouflage (mask) angle = 25° and more.

The receiver-indicator of a satellite signal emitted from satellites navigating systems may be the equipment of uncombined type (is capable to accept a signal from only one of systems GLONASS, GPS, GALILEO), or combined type, in the latter case the conditions are improved for equipment operation in city conditions at presence of radio shadows from high buildings.

The program complex (software) "AutoMobil" allows us to realize several various models of a User Equivalent Range Error (UERE), inherent in modern and perspective satellite navigating systems. In such models the measurements errors of a single pseudo-range measurement from user up to the concrete navigating satellite depends on an angle of a view line inclination above horizon. The characteristic view of such curve accepted in the project of European satellite navigating system GALILEO, is shown in Figure 3.

The navigating automobile device (the integrated equipment) on the basis of the one-frequency receiver of a
satellite signal and usual automobile sensors of tactile type (an
odometer and a tachometer), and also with the gauge of a
steering angle, allows us to carry out the trajectory support
(navigation) of the automobile with satisfactory accuracy at
completely deployed grouping from 24 S/C GLONASS, in city
conditions of operation of the MV (at a mask angle about 25°–
30°). The maximal error of navigation of the MV at the real
data about accuracy of the specified sensors does not exceed
10-12 m in referencing to Terraneous Reference Frame on the
Earth surface.

At prediction of the automobile longitudinal acceleration in
the navigating filter at absence of data from inertial instruments or other sensors it is expedient to apply polynomial
extrapolator with reference on several (sliding set) previous
points of an estimated trajectory. Modelling tests have shown
that similar extrapolator operates satisfactorily on 5 values of
previous positions and speeds of the MV (a polynome of 9-th
degree is used). Such extrapolator overcomes the factor of
uncertainty (unpredictability of exact values in connection
with that the considered dynamic system contains the
determined control actions) of the future acceleration-deceleration of the automobile and uncertainty of
turn of its steering wheel.

Imitation researches with help of “AutoMobile” software
have shown that the measurements from standard tactile
automobile gauges of rather low accuracy and low cost are well
combined with measurements from the receiver of satellite
navigating signal GPS-GLONASS. The navigating device
does not only to reproduce a kinematic trajectory of the MV
with acceptable accuracy, but also to restore good the
orientation of its longitudinal axis (the last one is closely
related with a direction of a velocity vector of the MV).

Imitating researches by means of a complex “AutoMobil”
have shown, that the duration of an initial interval (an interval
of initial convergence) of a filtration process, i.e., time of
transient process of a virtual estimation approach to a real car
trajectory equals to 10 s for the above-stated navigating device,
at an error of initial basic approximation about 1 km in the plan
and 100 m on a height at presence of regular number (6-8 seen
satellites) of a full GPS and GLONASS orbital grouping on
this time interval at a masking angle = 25°.

It should be mentioned, that researches specially carried out
in IAC of MCC within the framework of typical covariation
analysis for the problems of positioning on SRNS signals [42]
have shown, that specificity of information properties of
pseudo-ranges measurements set (collection) is those, that at
absence of visibility of near horizon satellites seen of a local
point of the city user the working constellation of satellites may
appear close to a conic configuration (a worst degenerate
singular case from the point of view of the positioning problem
solution possibility). Nevertheless, such situation has more
effect in the form of critic increase of a vertical component of
positioning errors while HDOP remains at an acceptable level.
In these circumstances the aprioristic information about height
of a city surface (streets level) above sea level may be involved
in the navigating filter with success for increase of estimation
behaviour stability and increase of its horizontal accuracy.

Such aprioristic information may be collected at previous
operation phase of the device if the principles of adaptation
will be incorporated in the navigating filter design.

So, it is confirmed accordingly to the data of computer
modelling, that the accuracy characteristics of a trajectory
supports are equal 3-5 m on position for the navigating
automobile device of a considered kind with the satellite
equipment of the combined type on intervals of uniform
movement of the MV car on a straight line or on a circle.

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Digital Avionics Systems Conference

The 2005 Digital Avionics Systems Conference (24th DASC), with the theme “Avionics in a Changing Market Place – Safe and Secure?” was held in Washington, DC, on October 30 - November 3, 2005. DASC is the premier international conference for commercial, military and space avionics conference as well as for air traffic management. Co-sponsored yearly by the IEEE Aerospace and Electronic Systems Society (AESS) and the American Institute of Aeronautics and Astronautics (AIAA) it brings leading technical experts from around the globe to this prestigious conference. Conference Chair was George Andrews of Booz, Allen, and Hamilton (Figure 1).

More than 250 papers highlighting digital electronics and systems engineering for aviation and space were presented in 14 tracks. Tracks included: air traffic management (ATM), UAV/UCAV avionics, CNS technologies, flight critical systems, software engineering, human factors, open systems, and others. As usual, the technical program was preceded by two (2) days of tutorials with 25 sessions that included six (6) that were new.

2006 DASC SCHEDULED: OREGON IN OCTOBER

The next DASC (25th) with the theme “Network-Centric Environment and the Impact on Avionics and Systems” will be held in Portland, Oregon, October 15-18, 2006. Conference Chairman will be Paul Kostek with John Moore in charge of the Technical Program. For more information watch this magazine or access the DASC website at: www.dasconline.org

2005 DASC HIGHLIGHTS

Conference General Chair, George Andrews, of Booz, Allen, and Hamilton, welcomed attendees and encouraged them to take advantage of special programs that included a Net-Centric Operations Panel and a reception at the National Air and Space Museum. Technical program co-chairs were Paul Kostek, Boeing, and John Moore, Rockwell Collins. The Professional Education Chair was Alan Tribble, Rockwell Collins, and the Exhibits Chair was Glen Logan, American Systems Corp. Both are DASC regulars and will assume these DASC responsibilities again in 2006. The 2005 DASC tutorials covered the waterfront from introductory aviation and avionics to the latest system developments. Social programs included a successful Exhibitor Luncheon as well as evening receptions (Figure 2).

The trips to the Old Town Trolley and Mt. Vernon trip were especially popular with spouses and the other guests. Additional information and photos from the 2005 DASC, including viewgraphs from the plenary presentations, are available at: www.dasc online.org. The 23rd DASC (2005)
Proceedings are available from IEEE Publications, Piscataway, New Jersey; telephone: (800) 678-IEEE or via e-mail at: customer.services@ieee.org.

**PLENARY SESSION**

To kick off this conference, a plenary session that focused on the challenges of "Avionics in a Challenging Marketplace — Safety and Security," in avionics and aviation was held. **George Andrews**, Conference Chair, introduced the plenary speakers (Figure 3).

**John Walker** (Figure 4), Aviation Solutions, Inc., led off airspace in the summer of 2005. Recent interest in communications relay over major cities at 60K feet is one of the drivers for his initiative, but there is considerable concern regarding the safe integration of any UAS into the National Airspace System (NAS). The FAA has taken the lead by establishing an RTCA task force (SC 203) with industry to evaluate and develop safe solutions. Sense and avoid, as an initial approach, is currently the leading criteria for safe UAS integration into civil skies.

**Dr. Reza Eftekari** (Figure 5), MITRE CAASD, highlighted the operational considerations related to NAS safety. Air traffic is expected to expand 2-3 times by 2025 with regional transport and business aircraft the major growth areas. For information sharing, the next generation of Air Traffic System (ATS) must be network centric, similar to that of the DoD. A major problem is that by 2015 the spectrum for analog communications will be depleted and the current funds shortage makes it very difficult to see a systems level solution. Transition to a Next Generation ATS with improved digital communications and GPS could phase out some ground-based navigation and surveillance systems and reduce the plenary by focusing on safety. He pointed out that for safety reasons unmanned systems have been restricted to special use airspace. However that is changing and Unmanned Aerial Systems (UAS) were introduced into civil

**Fig. 6. Awards Head Table**
pressure on FAA budgets. It is obvious the overall problem will require a very innovative approach.

Richard Buenneke, Aerospace Corp., reemphasized the need for satellite-based communications (SATCOM). SATCOMs currently support both government and commercial systems with commercial SATCOMs providing 65% of DoD bandwidth. Unfortunately, availability and information integrity continue to be serious SATCOM threats. Other key issues include increased information sharing, analysis, and global network operations. Planning is underway to overcome obstacles and update the overall communications architecture by 2016.

David Sweet, Boeing ATM, focused on how to integrate and connect ATM with the necessary security systems. The challenge is how to implement a secure multi-layer information sharing system that provides interoperability and improves information exchange. This requires a network-centric approach the FAA has termed System-Wide Information Management (SWIM). The objective is to get the right information to the right people at the right time. However with today’s budget environment a systems level upgrade does not appear to be doable. The next steps are to refine operational concept and conduct user evaluations.

PRESENTATION OF AWARDS

Jim Diedonne, MITRE, introduced presenters and recipients at the DASC Awards Luncheon (Figure 6). Dr. Wilson Felder presented the AIAA Digital Avionics Award to Dr. David Corman. Nan Mattai accepted the AIAA DASC Distinguished Institution Award for Rockwell Collins. George Andrews received the 24th DASC Award from John Gonda (Figure 7), and Paul Kostek (Figure 8), General Chair for the 2006 DASC encouraged everyone to attend the special 25th anniversary meeting to be held in Portland, Oregon, October 15-18, 2006.
Society Administration

In accordance with AESS bylaws, each year the incoming President shall appoint, among others, a Vice President - Administration, to take office on 1 January. This Officer does not have to be an elected member of the Board of Governors. The Vice President - Administration may appoint, with the approval of the President, one or more Associates to aid the Officer in performing his duties. I currently serve as the AESS Vice President - Administration.

The Vice President - Administration is responsible for:

- Directing and coordinating the activities of the Standing Committees assigned to him. He shall generally assist the President in administrative matters, such as identifying new areas of activity, preparing and revising the organizational structure, and searching for appropriate personnel to fill various vacancies.

- Maintaining a copy of the current Constitution, Bylaws, and Procedures manual, and is responsible for the appropriate distribution, maintenance, and update of these documents.

- Initiating and maintaining appropriate means of electronic communication, such as IEEE e-mail and electronic bulletin boards, between members, officers, and other operating entities of the Society. He will maintain IEEE e-mail distribution lists for all AESS Officials and members of the BoG.

- Maintaining the AESS website, updating its content to reflect current and upcoming events of interest and information to AESS membership and visitors, hot-linked to the appropriate IEEE, Conference, and other organizational entities.

All AESS Officers, Governors, Standing Committee Heads, and Chapter Chairmen are expected to have e-mail addresses. In accordance with IEEE protocol, each officer will create an IEEE alias the connects to the company or personal Internet address of these officials. If an official is not able to have an Internet address, but has a fax number, the Vice President-Administration will obtain for him authority that connects to his Fax number. Systems Magazine regularly publishes the postal & e-mail addresses, and Fax & telephone numbers of the AESS leadership.

The Vice President - Administration creates and maintains IEEE bulk e-mail addresses (distribution lists), as required. Current AESS distribution lists include:

- BoG – aes-bog@ieee.org
- Officers – aes-off@ieee.org
- Publications – aes-pub@ieee.org
- Technical Panels – aes-tec@ieee.org

Bob Trebits
Vice President-Administration
AESS 2006
Warren Cooper: Vignettes

Warren was a regular visitor to my office while serving as Executive VP of this society, as, having presented the concept to our Board and receiving their approval, he worked with President Jack Harris and me in preparing the presentation to the IEEE Publications Board for the conversion of our then-Newsletter into a full-fledged IEEE magazine, giving us a wider scope and vastly more exposure. This “dream of change” was Warren’s, and followed his service as President of our sister society, Microwave Theory & Techniques. The presentation was successful, the Publications Board approved our change without dissent, and we assumed our present status and title with the January 1986 issue.

Warren felt deeply that the area of electronic systems had been downplayed within IEEE; there was a need for increased emphasis. When his term as President ended he immediately moved into the Editor-in-Chief slot for Systems as Lee Dickey stepped down for health reasons.

In his very first editorial, Warren wrote: “Systems . . . are the topics that distinguish AESS from the other IEEE Societies that are devoted mostly to technology and devices.” Continuing “We have also related (better) to our Transactions.” At that time, this small, but seemingly unimportant change was typical of Warren — always striving to improve upon whatever he was working.

Pearl Harbor’s anniversary was reason for Warren to pull out all the stops to get as many items into our pages that might otherwise be lost to history. These ranged from personal reminiscences through the original December 7, 1941, radar plot of the attackers to a Space Shuttle photograph of the Hawaiian Islands. It was a delight for me to help him on this quest, as I, also, remember vividly where I was that Sunday so many years before.

While serving as IEEE Director (1990-1991), Warren continued his drive to improve Systems; through changes in operations to changes in Headquarters interfaces.

Warren, born in Chicago, grew up in Wisconsin where he entered the University. His desire to get involved in World War II and “do more hands-on things” in the then-emerging field of electronics saw him voluntarily interrupt his education and enter the Signal Corps. Upon the completion of his basic and specialized training, he became “one of Uncle Sam’s guests taking a Liberty ship 30-day cruise into the unknown South Pacific.” Pausing at Melbourne for re-supply (and a very welcome leg-stretch for the “guests”) before continuing, the ship sailed — alone — on the final leg of its voyage. As they cleared the harbor they noticed a lot of excitement on a small craft chasing them. The ship was sailing directly into a minefield protecting the harbor! Learning only then that their destination was Kandy, Ceylon, they proceeded with no further interruptions. The group’s task at Kandy was the establishment of a major communications station for the OSS.

An interesting and typically Warren tidbit: While in Kandy he met and talked with an operative named Julia Something, who went on to later become known as Julia Childs of French Chef fame.

Returning in 1945, Warren continued his college days to obtain his Bachelor in EE at Las Cruces, New Mexico. He went on to Stanford University for his Masters in EE, studying under F.E. Terman. Graduation saw him start his industrial career at AIL — Airbone Instruments Laboratory. He moved to Litton (Maryland) in 1954 and Westinghouse Baltimore in 1958, where he remained until his retirement.

Warren was named an IEEE Fellow in 1970 “For contributions to antenna development, microwave integrated circuit development, and the application of microwave techniques to aircraft landing systems.” At various times he served as President of the Microwave Theory & Techniques Society; as an IEEE Director; as an IEEE-USA Director; on the Fellows Committee, the Technology Transfer Committee, the US Technology Policy Conference Committee, and the TAB New Technology Directions Committee, among others — all in addition to his service to AESS.

In my opinion, Warren was the dynamo in the powerhouse resulting in the establishment of the Historical Electronics Museum. He relished telling the story of the Army radar “rescued” from Central Canada and, refurbished, then put on display.

Warren and his wife, Marie, traveled widely. An ardent Rotary International member, he worked tirelessly to support their scholarships. This included the saga of the nonstop postal bus ride from Oslo to North Cape arriving just in time to attend the North Cape Rotary International meeting in Kistrand. I really think that he and Marie circumnavigated Cape Horn to make it possible for Warren to attend a Rotary International meeting in Punta Arenas, Chile.

I thoroughly enjoyed the privilege of knowing and working with Warren Cooper on our varied and numerous projects. He was a wonderful individual — eternally optimistic — who accomplished what he set out to do without ruffling feathers. Rest in peace, Warren.

Dave Dobson
FROM THE EDITOR-IN-CHIEF

Systems Brings You Three Bonuses This Year!

*Systems magazine* brings you three bonuses with your subscription in 2006:

**Bonus #1.**
*Tutorial III* will arrive with your June issue. It contains three more tutorials prepared by experts in their fields; it certainly maintains the quality level that you came to expect from *Tutorials I* and *Tutorials II*.

**Bonus #2.**
Later this summer you will receive, as part of a regular issue, a group of eight papers on Space Education that are being assembled by Sefer Kuniaz and Saj Durrani. Educational institutions in five countries are contributing. Look for it . . .

**Bonus #3.**
Early this fall we will issue, as Part 2 of a regular issue, the first printing of an unpublished radar manuscript written in 1961 that, according to all reviewers, should have been made public years ago. This quotation from the Preface give you the flavor:

"... to see what happened, why it happened, the sources of resistance, the things that slowed it down, the actions taken to overcome or circumvent obstacles and roadblocks, why it was turned down at first, arguments used ... to place it in development, and arguments used against it by its opponents . . . "

It is our pleasure to provide these bonuses to you. Please give us feedback after you read them. Thanks!

— Evelyn Hirt

University Airport Design Competition

The Federal Aviation Administration (FAA) has announced a National University Design Competition for Airports. The Competition will engage students as individuals or working in teams under the guidance of a faculty advisor to address a number of challenges that airport operators face today. The categories relate to airport operations and maintenance, runway safety/runway incursions, and environmental interactions of airport operations. The challenges provide opportunities for a range of engineering, science, and computer disciplines. Cash awards will be given to winners in each category and they will present their designs at the national meeting of the American Association of Airport Executives in Washington, DC in June 2007. The Competition runs through April 2006. For more information, contact:

Mary L. Sandy, Director
Virginia Space Grant Consortium
600 Butler Farm Road, Suite 200
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May 2006

Distinguished Lecturers Program

James R. Huddle, Chair

All AESS Chapters and IEEE Sections are encouraged to take advantage of the AESS Distinguished Lecturers Program for their regular or special meetings. We have selected an outstanding list of speakers who are experts in their fields. The AES Society will cover up to $500 of the speaker's expenses for travel in North America, with any remaining amount normally covered by the AES Chapter or Section or by the speaker's organization. For travel outside North America, the AES Society will cover half of the speaker's expenses per trip, up to a maximum of $1500. The procedure for obtaining a speaker is as follows: If a Chapter or Section has an interest in inviting one of the speakers, it should first contact the speaker directly in order to obtain his agreement to give the lecture on a particular date. After this is accomplished, and if the Chapter or Section wishes to request financial support from the AESS, it should contact James R. Huddle on (818) 715-3264, F (818) 715-3976, j.huddle@ieee.org at least 30 days before the planned meeting, in order to obtain approval for the financial support. The list of distinguished speakers who have expressed their willingness to speak to Chapters or Sections, along with their organization, topics, and telephone numbers, is given below.

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